# tv...

# it's a cinch!

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# TV—IT'S A CINCH!

E. AISBERG

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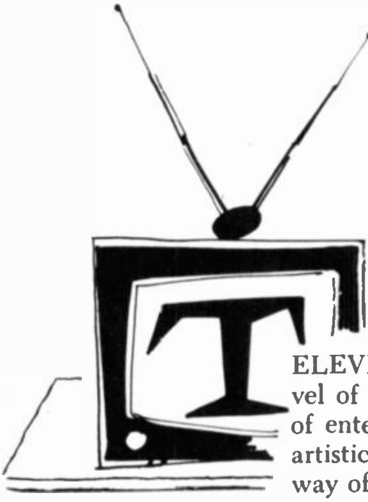
# introduction



TELEVISION is without doubt the great marvel of the 20th century. Incomparable source of entertainment, but also of intellectual and artistic enrichment, it is modifying our very way of life.

The object of this book is to analyze the anatomy and physiology of television transmitters and receivers. The author has tried to present, in an easily understood manner, the complex series of operations that —beginning at the studio and continuing through the cameras and the various stages of the transmitter, passing through space in the form of electromagnetic waves to the receiving antenna and the multiple stages of the receiver—finally form images on the kinescope screen before the eyes of the televiewer.

To understand the terms and to follow the explanations used here, it is very helpful to understand the fundamentals of radio, to know how vacuum tubes, amplifier, oscillator and detector circuits function. Every radio technician or experimenter who has these elementary prerequisites can gain, by a careful reading of this book, an excellent knowledge of television—a knowledge far more advanced than the appearance of this work might lead him to suppose.

The presentation is highly unorthodox in form—that of colloquial dialogue. Further, it is illustrated in the margins with imaginative sketches by Sol Ehrlich, based on the French originals by the late H. Guilac (to which have been added a number of humorous sketches by Willy Halle, taken from the German edition with the kind permission of our friend Walter Regelien).

Experience in teaching has proved that what one learns with a smile is easier and better assimilated. That is why, when explaining phenomena which may often be very complex, it is best *not* to adopt a solemn, academic tone. As the great French encyclopedist Montesquieu put it: "Solemnity is the delight of half-wits."

But let not the reader—tempted by the apparent lightness of the text—skip rapidly over these pages! To be effective, this material must be read slowly and attentively. It requires frequent repetitions and reviews. Note well that the most difficult conversation is probably the first one.

Written originally in French, this book has been translated and published in German, Spanish, Dutch, Italian, Finnish and Swedish. Yet for several reasons the appearance of this American edition has given me more pleasure than that of all the others. It is in the U.S.A. that television has attained its most prodigious development. Also, because the U.S.A. is the country of Lee de Forest, the veritable father of electronics, with whom all these things began. And it is also the country of my friend Hugo Gernsback, who after close to 50 years is still astounding the world with his scientific prophecies, which are continuing to be fulfilled with the same certainty as were those of Jules Verne.

Finally, I know of what dynamic enthusiasm the American youth is capable. And if this book—by helping numbers of them to select a vocation—becomes a factor in producing future engineers and research workers, I will be happy indeed.

Before ending, I cannot resist the pleasure of thanking Fred Shunaman, not for translating, but for brilliantly adapting my book into the American idiom, a task all the more delicate since the American and French television standards differ, and to express my appreciation to Martin Clifford, who so happily conceived and successfully carried out the presentation of this edition.

E. AISBERG

chapter 1

# Frequencies, v.h.f. and video

WILL—Ken, I need some advice for my Uncle Jack.

KEN—O.K.—something about his radio, I suppose?

WILL—Not exactly. He's interested in television now. He's had a rather bad foot injury, so he hasn't been able to get out of the house for a couple of months. You know what a movie fan he's always been. So now that he can't get out to see five pictures a week, he wants to get a TV set to bring the movies to him.

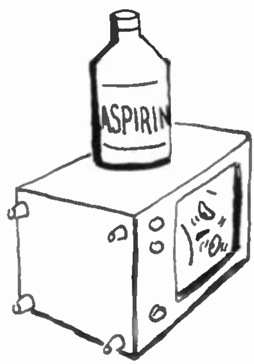
KEN—Good idea! I'll be glad to lend a hand. Let's drop over to your uncle's right now, and see where we can put up the antenna.

WILL—That's not going to be so easy. Didn't you know my uncle has been living in northern Maine for almost a year now?

KEN—Why didn't you tell me? You'd better just get your uncle a case of aspirin. He won't get television in northern Maine—at least not till we get a few more stations.

WILL—Why not? What about the programs from the Empire State Building?

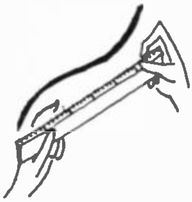
KEN—He can't even get programs from Massachusetts stations. Sixty miles is about as far as you can be sure of getting dependable TV reception. Sometimes you may pick up programs a lot farther away. But your uncle in northern Maine hasn't much chance of getting entertainment out of a TV set.




### The earth is round

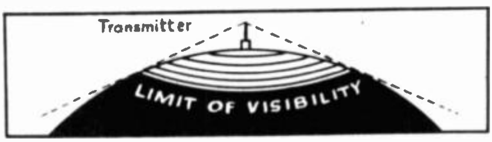
WILL—If TV stations don't get out any better than that, why don't they increase their power?

KEN—Because it wouldn't help—much. Most television is transmitted between 54 and 216 mc, in part of what they call the very-high-frequency band—between 30 and 300 megacycles; or on *ultra-high frequencies,* which means in the spectrum between 300 and 3,000 megacycles. The u.h.f. TV band runs from 470 megacycles to 890 megacycles. Now, the higher you go in frequency—or the shorter the waves get, if you like to put it that way—the more they act like light waves. Longer radio waves—like those in the broadcast band—can bend and follow the curve of the earth, but u.h.f. waves travel in straight lines and can't get around the bend in the earth's surface.



WILL—Does that mean that the receiving antenna must be in the sight of the transmitting antenna to pick up TV signals.

KEN—Well, not quite. Of course, what the engineers call "optical visibility" is best for reliable reception. But




*For consistently good reception the television receiver should be within 15 to 20 miles from the transmitting station.*

v.h.f. waves are a lot longer than light waves and are not quite so set on following a straight line. V.h.f. waves do reach a little beyond the visible horizon, and can curve around small obstacles.

WILL—Wait a minute! I think I get it. Because the earth is round, its curvature hides the transmitting antenna after a certain distance. The waves travel in straight lines, so they just keep on going over our heads and out into space?

KEN—You've just described in one sentence what has been called "The Tragedy of Television."

WILL—Why "tragedy"?

KEN—Because that's what makes it tough or impossible for large areas of the country to get good TV service. The transmitting range is so short that it would be too costly to put up enough stations to cover the whole country.

## Getting up in the air

WILL—Isn't there any way of getting around this "tragedy"? Maybe people who live too far from TV stations could find some way of hooking onto those waves that are going by way over their heads. Why couldn't they use kites or captive balloons to hold up their antennas?

KEN—I don't think any TV set owner has gone that far, but some communications companies use antennas on captive balloons (Kytoons) to test sites for antenna towers. Most TV stations try to get their antennas as high as they can, though. That's why you see television transmitting antennas on the Empire State Building, on Mount Wilson, and on other such high points.


WILL—So you see there is a way out! Why do they make such a good start and then stop short?

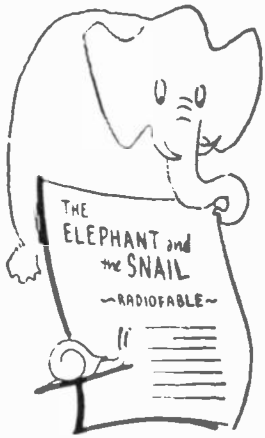
KEN—I don't get you.

WILL—Why don't they put the transmitter in an airplane, and get up even higher? A plane flying around in the stratosphere could cover a quarter of the country, and my uncle Jack could see his flickers!

KEN—Congratulations, Will! You've just invented *strato-vision*. That's what Westinghouse called just such a system some years ago. But they don't seem to have got it on a practical basis yet.

## Shedding a little light

WILL—Then why in blazes do they have to keep television on such short waves? Just because it's so new is no reason for putting it in the third sub-basement. Can't we reallocate or shut down three or four broadcast stations or commercial transmitters and put TV on the short or medium waves—where it really ought to be? Just think, if we only had one wavelength in the broadcast band we could put up three or four stations strong enough to cover the whole country. . . .




KEN—You're off the deep end that time, chum! Getting TV into the broadcast band would be about as easy as getting an elephant into a snailshell.

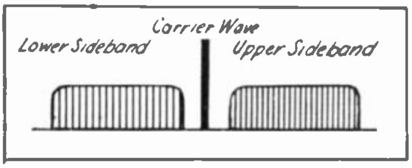
WILL—What's the connection between an elephant and television?

KEN—Easy, boy. Sit back and relax. Now think about the signals you get on your AM receiver. You have a carrier that sort of takes an audio signal along on its back. How wide a band does that need?

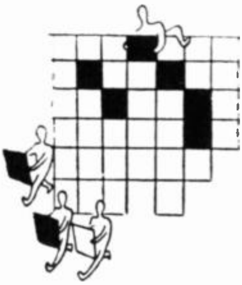
WILL—Well, the lowest audio notes are around 30 cycles and the highest about 15,000 cycles. I know for a fact, though, that most AM stations don't modulate much above 7,500 cycles.


KEN—In other words, when you remember that you have the audio signal on both sides of the carrier, most AM stations have a bandwidth of 15 kilocycles. Did you ever stop to figure out why an AM station should be limited to 15 kc?

WILL—I may not know all the reasons, but the most important one is to cut down interference on adjacent channels. You couldn't get much above 5,000 cycles with the equipment they had when broadcasting started, and frequency allocations were made on that basis. Now the official signpost is 7,500 cycles for each sideband. Lots of stations go beyond that today, if they can do it without causing too much interference on neighboring channels. What's all this got to do with TV?




*When a carrier wave is amplitude modulated (AM), two sidebands are produced. The sidebands contain the information and are "transported" to the receiver by the carrier.*



KEN—Plenty! But first, have you any idea of how television images are transmitted?

WILL—Of course! You can't transmit a whole picture at one time, so it's broken down into very tiny elements and then these elements are transmitted successively . . .

KEN—Whoa! You lost me there, chum! What's this with "elements" and how do you mean "transmitted" successively"?

WILL—Ever look real close at a picture in a newspaper?

KEN—Yes.

WILL—And it looked like what?

KEN—Like a bunch of dots—some light, some dark.

WILL—It's the same in TV. We take a picture and break it down into little bits, some light, some dark. Only we don't call 'em dots, we say *elements* (or sometimes points).

KEN—And this business about "transmitted successively"?

WILL—That's just the way the engineers say "one after another." The television transmitter changes each element into a voltage. Transmission is negative . . .

KEN—Hold it again! Just what is "negative transmission"?

WILL—It just means that the dark part of a picture produces more voltage than a light part. A black element produces the strongest voltage.

KEN—And a point that isn't so black?

WILL—Just that much less.

KEN—And what if you have just a white space?

WILL—You can't catch me on that one. A white space gives zero voltage.

KEN—Or at least a very low one. But how do we manage to pick out all the points of a picture and then transmit them one after another?

WILL—Easy. A scene is scanned exactly like you'd read the lines on the page of a book. You could think of each letter as an image element. All the lines on a page are scanned one after the other to form an image. When we've finished one page, we start scanning the next one . . .

KEN—Correct! And how fast is this "reading" done?

WILL—Well, the pictures have to follow each other fast enough so the eye sees one continuous moving picture. The movies use 24 pictures a second. In television they follow each other at the rate of 30 a second.

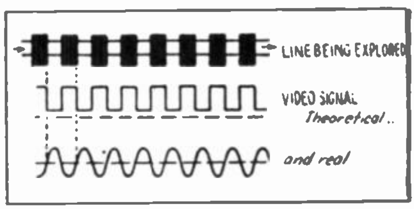
KEN—Or about half a minute to read "Gone with the Wind"! But we're getting away from why we don't have a TV station in the broadcast band.


WILL—Go ahead. I'm listening.

KEN—We've agreed that the voltage produced by any picture element depends on how dark it is. So when we transmit a signal that describes all the elements of a television scene, we're going to jump around from a very large voltage for a dark element to a very weak voltage for a bright one. And we're going to transmit all the elements of a complete picture in 1/30th of a second. Does that mean that the sidebands will be very wide?

WILL—Does it?

KEN—It certainly does! This signal that expresses the brightness of each element in a TV picture is called a *video-frequency* signal. It's really a wide band of frequencies—something like the audio frequencies in an AM receiver, only a much wider band, of course.




*Signals, ranging from black, through varying shades of gray, to white, can be represented by voltages. If black is maximum voltage, then white is zero. A black and white pattern would theoretically produce a rectangular voltage waveform.*

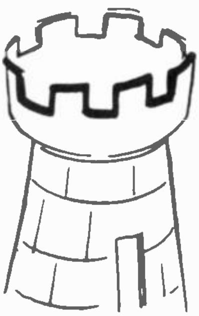
WILL—I suppose it can even be zero frequency sometimes. If you televise an all-white or all-black surface, all the little elements will be the same, and will produce the same voltage while the whole surface is being scanned.

KEN—That's true. But if the elements along the line being scanned are *not* all of the same brightness, the signal voltage varies. Now, when is that variation fastest, or in other words, when will we get the highest video frequency?

WILL—Probably when a lot of adjoining elements in a line differ in brightness.

KEN—Exactly. The frequency is maximum when we scan a line composed of elements which are black, white, black, white, successively. The highest frequency you could get would be with an image made of black vertical lines one element wide, separated by white intervals, also one element wide.

WILL—Then each element would give us one cycle of signal, and . . .



KEN—Easy, boy, easy! A white bar produces a very weak voltage and a black bar a very strong one. So scanning two adjoining elements—one black and the other white—produces a weak and a strong voltage. As we scan, the voltage alternates from weak to strong, back to weak, and so on. It takes the two bars, one black and one white, to make one cycle. And since one cycle can interpret two elements of the image, the total number of cycles . . .

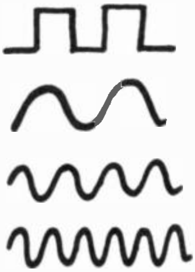
WILL—Is half the number of image elements!

KEN—This time you're right.

### Square wave or sine?

WILL—Funny looking, these video signals. Not much like the smooth-looking sine waves we have in radio. These are more like the top of an old castle.

KEN—Not as different as you might think! And for two reasons: first, these square waves can be broken down into a large number of sine waves. You can start out with a fundamental sine wave of the same frequency as your square wave, and add other frequencies 3, 5, 7, and more *odd* times as great and come out with a pretty respectable square wave. Frequencies which are multiples of a fundamental are called *harmonics*. They make it hard for our video signal to get through any amplifier. If the fundamental frequency is high, the harmonics must be even higher. And even an amplifier designed for a wide band of frequencies has to have a limit somewhere.

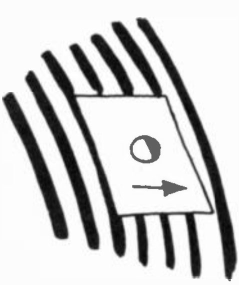


WILL—And the other reason?

KEN—Let's just make a little experiment. Take this piece of paper and punch a little round hole in it. Think of the hole as being exactly the size of one image element. Now rule a piece of paper with bars and spaces the same width as the hole, and move your little window in the paper across the black and white bars that make up our image.

WILL—We're analyzing the elements just like television!

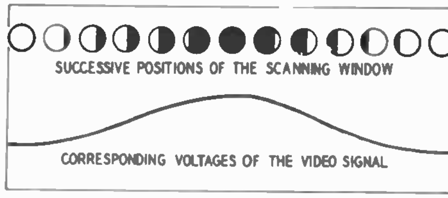
KEN—Exactly. Notice that as you sweep your window across the image, sometimes the window is exactly over a black bar or exactly over a white one. But we don't jump from one of those ideal positions right over to the other. We have to pass across all the intermediate positions where part of the area is white and the other part black. Suppose we get far enough away from the piece of paper so our eyes can't separate the black and white parts of the view under our little window. Now, as I move the paper, what do you see?



WILL—Well, there's a gray surface there, and when you move the paper it gets darker till it's black. Then it starts getting lighter again, going from black to a dark gray which keeps on getting lighter till it's white. Then it starts darkening till it gets all black again. I seem to be seeing the *average* shade of the area under the window.

KEN—Can you guess what kind of a voltage pattern these variations in light would produce?

*Scanning from left to right we have minimum voltage (corresponding to white) and maximum voltage at the center (black).*



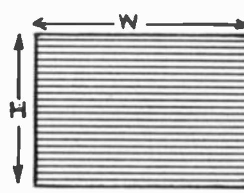

WILL—Unless I've forgotten all my radio training, it'll be our old friend the sine wave.


## A little arithmetic

KEN—Now I think we can figure out the maximum frequency of our sine waves. First of all, let's find out how many elements our picture is divided into. We'll call the height of the picture H and the width W. Now when we scan the picture we cover it with N horizontal lines and there are *n* images a second.

WILL—This begins to look like a problem in algebra.

KEN—It'll be a simple one. Now just think of each element as a little square. Now let's draw some lines down the picture anywhere and produce a number of squares. Now, how high is each square?



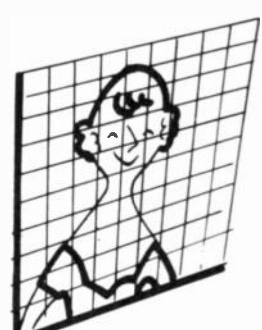

WILL—Well, it should be the total height of the picture divided by the number of horizontal lines.

KEN—Consequently, then, the height of each square is H/N. And since it is a square, it's just as wide as it's high, so the width of a square is H/N too. You can say that the total number of elements in a horizontal line is the width of the line divided by the width of a square, or:

$$\frac{W}{H/N} = \frac{WN}{H} \text{ elements in a single horizontal line.}$$

Now, the whole picture contains N lines, so the complete image contains the number of elements on one line multiplied by the number of lines in the picture or

$$\frac{WN}{H} \times N = \frac{WN^2}{H} \text{ elements.}$$



WILL—Yeah, that looks logical.

KEN—Now, since all the elements in an image have to be transmitted *n* times a second, we have $\frac{WN^2n}{H}$ elements a second. But since it takes two elements to make up a cycle, we can multiply our formula by one-half, and have

$$\frac{WN^2n}{2H} \text{ cycles a second.}$$

This is far from being an exact formula; it doesn't bother with the time taken to get back from the end of each line to the beginning of the next, and from the bottom back to the top—we'll talk about that another time. But it *is* good enough to give us the *maximum video frequency*.

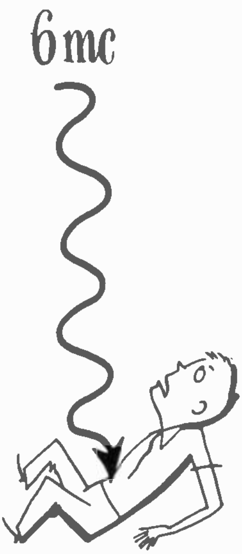
WILL—Each one of these little formulas looks reasonable while we're looking at it. But now that they're all down, the whole thing doesn't seem much. Can you put in some real figures instead of N and *n*—something that would show me the number of elements on my own TV screen for instance? Then I'd probably get it.

KEN—O.K. Suppose you do the figuring. The television screen is shaped so that, no matter what size it is, it is four units wide to three units high. Of course, you can put in the width and height of your own TV screen—if you know it—but it is easier to just let 4 stand for the width and 3 for the height. And it will be right for any screen. We scan it with $N = 525$ lines at the rate of $n = 30$ images per second. Take it away, Einstein!

WILL—Let's see, we have:

$$\frac{4 \times 525^2 \times 30}{2 \times 3} = 5{,}512{,}500 \text{ cycles per second.}$$

Wow! More than five and a half *megacycles!*




**Return of the elephant**

KEN—Now do you want to go ahead with your proposition to "make a little place" for television in the broadcast band?

WILL—H'm, the broadcast band runs from 540,000 to 1,600,000 cycles, or 540 to 1,600 kc. It's a little more than a million cycles wide. But, with two sidebands, our television transmission is going to be eleven million cycles wide! No, our elephant will never get into this particular snailshell!

KEN—It's not quite as bad as it seems. You'll learn later on that we can get rid of most of one sideband. And for practical purposes, the other one is limited to 4,500,000 cycles. So a TV channel is 6,000,000 cycles—or 6 megacycles—wide. But that's plenty wide. If we put one edge of a channel in the middle of the broadcast band, say at 1,000 kc or 1 mc, where would the other edge be?

WILL—At 7 megacycles, or around the 40-meter band. We'd use the whole spectrum from 40 to 300 meters just for one TV station! But with widths like that, how do they squeeze it in anywhere?

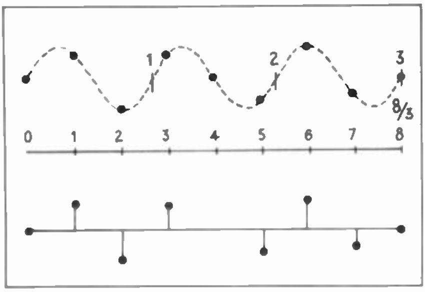
KEN—It's a lot easier on the higher frequencies. Take the two lower television bands. Channel 2 runs from 54 to 60 mc, or just a little more than five meters. Channel 11 runs from 198 to 204 megacycles, which is just over one meter.

WILL—Yeah! I can see now why TV has to be on the higher frequencies.

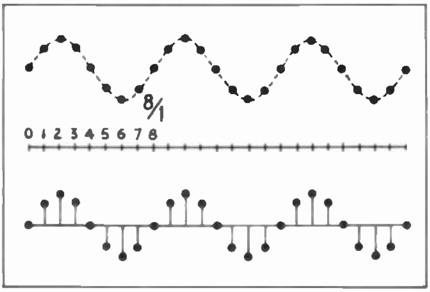
KEN—There's another reason. If we want good modulation, the carrier frequency has to be several times as high as the modulation frequency.

WILL—How come?

KEN—Well, we spoke earlier of the carrier wave sort of carrying the audio signal on its back. But there's a little more to it than that. Each wave carries its little piece of audio signal—takes a little sample as it were. And if your frequency isn't high enough to take a large number of samples, they may not represent the real shape and size of the audio waves. Suppose, for example, that there are eight cycles of the carrier to each 3 of the signal—that is, a ratio of 8:3 between them. The instantaneous values of audio signal we would transmit would be altogether too widely spaced, and you would never recognize the output as the signal you tried to modulate the carrier with. But if you choose a carrier whose frequency is, say, eight times




*The ratio of modulating signal frequency to carrier frequency is important. If the maximum modulation frequency is too close to the carrier frequency, reception will be garbled.*



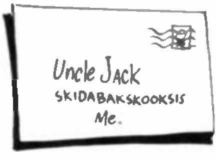

*With a higher ratio between modulation and carrier frequencies, enough instantaneous values are transmitted to give good reproduction at the receiver.*

that of the signal, you would transmit enough instantaneous values to make a fair copy of the signal.

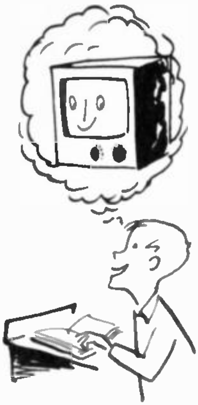
WILL—Something like those newspaper pictures again. If the dots get too far apart, you can't make out the fine detail in the picture.

KEN—Not a bad comparison at all!

## Too bad for uncle




WILL—Now let's see what I've learned: Television signals occupy a very wide band of frequencies. They can't be carried except by very-high-frequency waves. Those waves travel in straight lines, without doing much bending around the earth, so their range is strictly limited. And the



result of all this is . . . my Uncle Jack just isn't going to get television!

Ken—I'm sorry for Uncle Jack. But you've learned something of the principles of television transmission. . . .

Will—. . . which at first seemed to be complicated, but are turning out to be very simple. Television is a cinch!

Ken—Quite right. Learning television is not going to be difficult. But we will have certain technical problems.

Will—Such as?

Ken—Such as the best way in which to scan a picture.

Will—Quite easy, my boy, quite easy. As a matter of fact I can demonstrate this a lot easier than I can tell it. Just watch this. I know that it's going to seem very impractical to you, but I want to put across my idea as emphatically as possible.

## Our hero's dizzying adventure

Ken—Don't bother telling me what you're trying to do. Either you're practicing to become a whirling dervish, or TV has you going around in circles!

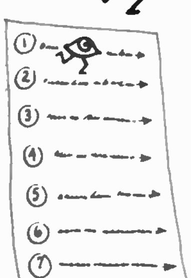
Will—Wrong on both counts, Ken! I'm just trying to read without having to jerk my eyes back from right to left at the end of each line.

Ken—I know I'll regret asking, but why?

Will—Because I've been thinking about the way a scene is scanned in TV. However, we just got through agreeing that television was like reading a book – line by line. But when you think of how fast the TV camera has to read, it seems there ought to be some way to save the waste of time getting back from the end of one line to the beginning of the next. So, when I finish one line, I spin rapidly round so my eyes fall on the beginning of the next one without having to snap back from the end of the last!

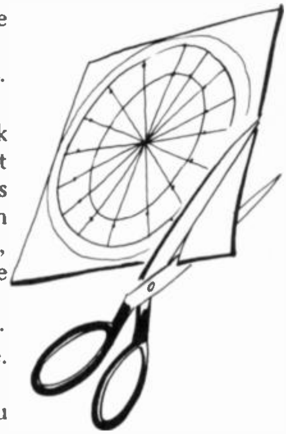

Ken—Bright idea, but I don't think you're going to save much time that way. You *can* get pretty dizzy, though! But you might be interested to know that your continuous-scanning method was the one they used in most of the early mechanical television systems.

## A little geometry




Will—I'd like to hear a little more about some system that really was used! All you've told me about "scanning" and "image analysis" so far has been pretty much up in the air. But just how do you "explore successively the elements of the image" in real live television?

Ken—I hadn't figured on telling you how mechanical television worked, because it's been abandoned entirely in favor of electronic methods. But maybe you'll be able to understand the more advanced systems better if we start in with the simplest—and the oldest—system: the Nipkow disc!

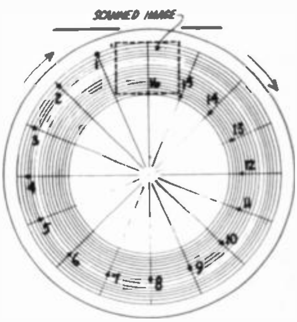


WILL—The Nipkow disc? I've heard about it somewhere. What is it?

KEN—We're going to make one right now! Take a look at this piece of thin Bristol board. We'll cut a circle about 16 inches across out of it. Now I'm going to lay out a series of concentric circles on it. The first will be 13 inches in diameter, and each one will be an eighth of an inch bigger, till we have 16 circles. Then we proceed to divide up the circumference of our disc into 16 equal parts. . . .

WILL—This is fine! We've been going through arithmetic and algebra—now we're getting a geometry exercise. When do we start integral calculus?

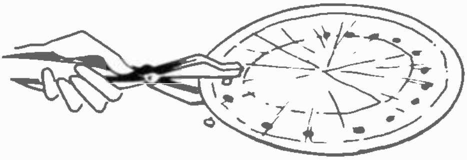
KEN—Never mind the calculus—I'll be satisfied if you learn television! Now let's get back to our disc. We have 16 radii, or arms, going to equally-spaced points on its circumference. I needed all these lines so I could lay out a spiral. I just mark the point where the first radius crosses the first circle, another point where the second radius crosses the second circle, and so on, going around the circle clockwise.




WILL—That gives you 16 points arranged in a spiral. What do you intend to do with them?

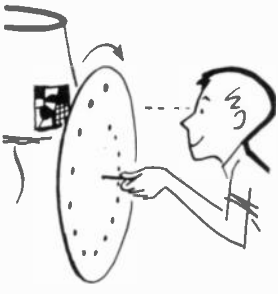
## Pinhole view of life

KEN—You'll see in a minute. First let's make—with a very small punch—a series of holes, one at each point on our spiral. And here is our Nipkow disc!



*Although a hand puncher is shown here, holes were drilled in Nipkow discs with machine precision. The price of inaccuracy was streaks and breaks in the final picture.*

WILL—And you really think you can use this for scanning television images?



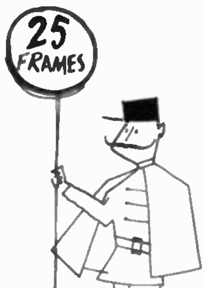
KEN—I do, and what's more, I'm going to prove it! Let's make a little design—something very simple in black and white—about two by three inches. Fasten it on the bottom of the lampshade here. Now put the disc on this knitting needle, hold it in front of the design, and spin it.

WILL—I see your design just as though the disc were transparent!

KEN—Now—just so we can see what's going on—let's turn the disc a little slower.

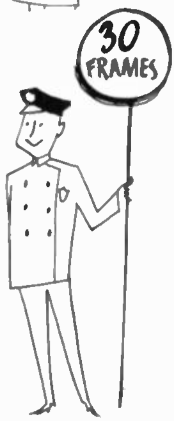
WILL—I get it! This is just a big improvement on the piece of paper with the window in it we had last time. When the disc turns, the first hole scans a line across the design. (Not exactly a straight line either, it's an arc of a circle, but that doesn't seem to make any difference.) Just as it finishes its line, the second hole starts across the picture and scans a line just below the first. And each hole follows (beginning at the outside of the circle or top of the design) and scans a line, till the whole design is covered.

KEN—And then the whole thing starts again with the second revolution of the disc. You see that if you turn the disc fast enough you apparently see the whole image, though really only one of its elements is visible at any one instant through one of the holes in the disc.




WILL—I see too that the disc reads in the whirling-dervish style, without having to make any backward movement to get to the beginning of each line. And I can see that it has to turn pretty fast before the eye blends all the elements into a single picture.

## Reading—the hard way



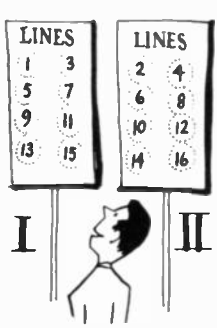

KEN—Yes, and when I let the disc slow down just a little, the image shimmies as if light and dark waves were going across it. That's because the sensation produced in the eye by the light from each hole doesn't last very long.

WILL—Just how fast does the disc have to turn to get rid of this flickering?

KEN—You know—to do a good job you need 30 complete images a second.

WILL—Yes, that's our television standard. You told me before the Europeans get by with fewer. But is 30 really enough? Wouldn't it be a good idea to scan even faster?

KEN—Don't forget that your video frequency is proportional to the number of images you transmit a second. It's not a good idea to do anything that will increase that frequency too much. Fortunately, there's a way you can kill the flicker without increasing the band of frequencies you have to transmit. It's called *interlacing*.




WILL—This TV business really has a language of its own! What's interlacing?

KEN—Instead of starting at line No. 1 and transmitting all the lines of the image one after the other, you transmit all the odd-numbered lines first: 1, 3, 5, etc.; then go back and transmit all the even ones. The whole scanning time is 1/30th of a second. That means that half the lines, covering the whole surface of the image, are transmitted in 1/60th second, and the rest of the lines are transmitted during the next sixtieth.

WILL—If I tried to read a book that way, I wouldn't get much out of it.

KEN—If it were an ordinary book, you wouldn't! But try this little sheet; you'll have to "interlace" to read it. Your eye will follow the exact course that would be followed by the scanning beam of a modern television camera.

> To read this text correctly, you must
> *ner in scanning: first the group (or*
> first peruse the odd lines, then the
> *field) of odd lines, then afterward*
> even ones. Interlaced sweep permits
> *the even ones. To sweep the image 30*
> "reading" the lines in the same man-
> *times a second, 60 fields are scanned.*

WILL—This is interesting, to say the least. Maybe it was turned out by a drunken compositor! But can you really scan that way in television? It sounds awfully complicated.

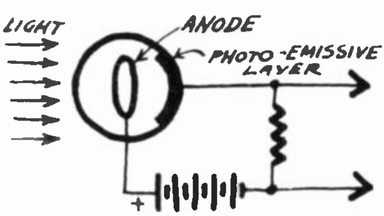
KEN—No problem at all! Suppose we make a Nipkow disc with two spirals, one on each half of the disc. We'll have lines 1, 3, 5, etc., on one spiral and lines 2, 4, 6, and the rest on the other.

WILL—Of course! It can't help but work! But now that we've proved that we can scan a picture—interlaced or otherwise—with a Nipkow disc, where do we go from here? How does it help to transmit a television program?

**Now a little chemistry**

KEN—Do you know anything about photocells?

WILL—Of course! I use an exposure meter when I take photographs. It's a photocell connected to a meter. The meter is calibrated to show how much light there is on the subject being photographed.




*Current flows in the photocell circuit when light shines on the tube.*

KEN—Then the photocell is a device for changing light energy into electrical energy. The current from the cell is proportional to the amount of light that falls on it. The photocells (or rather phototubes) used in television are the *photo-emissive* type. The simplest phototubes of that kind are little glass vacuum tubes with one inside wall covered with *photo-emissive* material.

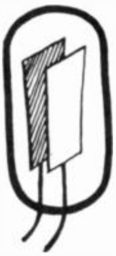
WILL—Is that material that emits light?

KEN—On the contrary. It's material that emits electrons when struck by light rays.

WILL—What kind of substances do that?


KEN—Most of the so-called alkaline metals: cesium, sodium, potassium, rubidium and lithium, as well as some of the rare earths, though they're not as commonly used.

WILL—I've got an idea! If all these metals give out electrons when you turn a light on them, you could use them for vacuum-tube cathodes! Then you could get along without filament supplies. In the daytime, just keep the tubes in the light. And at night, put your radio near a lamp!

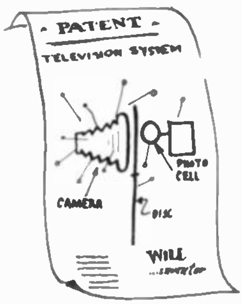


KEN—Believe it or not, the idea isn't absurd! Unfortunately, the number of electrons emitted wouldn't give you enough current to be of much practical value. But to get back to our television—if we are going to have current in our phototube, we need one thing more. The photoactive surface is the cathode. . . .

WILL—I see! We need an anode. We'll have to put a plate in our tube and put a positive voltage on it to attract the electrons.

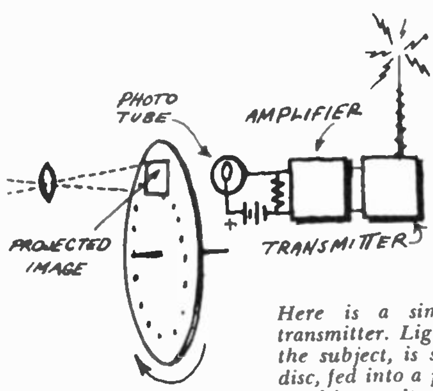
KEN—That's the idea, but a "plate" would block off the light. So our anode will be a wire ring or a fine grid.

### The image is scanned



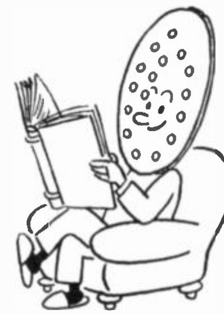

WILL—Now I think I see how to make a TV transmitter. I'll take my camera, but in place of the ground glass I'll put the outer part of our Nipkow disc. Then it'll be right where the lens forms its image. And behind the disc, I'll put a phototube. What do you think? Will it work?

KEN—Absolutely! You're practically reinventing tel-




*Here is a simple television transmitter. Light, reflected by the subject, is scanned by the disc, fed into a phototube. The resulting voltage is amplified and transmitted.*

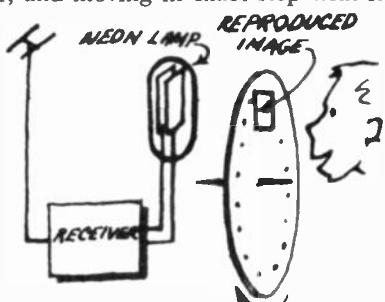
evision! Your phototube is now receiving—from instant to instant—the light from each successive element of the picture being scanned, and translating it into an electric current of proportional intensity. That gives us a video-frequency signal that can be amplified easily and used to modulate the v.h.f. or u.h.f. carrier that takes it out into space.



### The image is reproduced

WILL—How about the receiver?

KEN—It has to have a Nipkow disc like the one at the transmitter, and moving in exact step with it.




*The receiver action is exactly the reverse of that taking place at the transmitter.*

WILL—Is that what they call synchronization?

KEN—Right! And that's another word for your technical vocabulary.


WILL—But how do we get the variations in current back into light again?

KEN—Very simply—with a neon lamp. Do you know how it works?

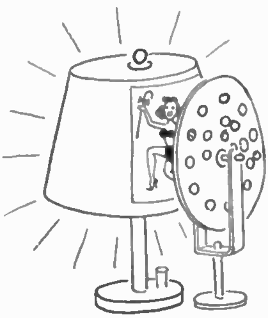
WILL—Oh, yes! I even engineered an accident to the one on the restaurant across the street when it began putting out more static than light.

KEN—I'm not interested in your criminal record. The lamps most commonly used in television in this country had two plates about the size and shape of the image to be reproduced. When you put enough voltage between the two electrodes, one of the plates glows over its whole surface. A large d.c. voltage makes a bright glow. . . .

WILL—And less d.c. means a weaker one, I suppose. But how . . . ?

KEN—Let me finish! If we add the varying voltage of the video signal onto the d.c. we started with, the brightness of the plate varies with the instantaneous signal voltages.

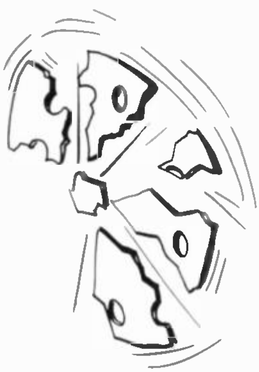
WILL—Yes, but how do we manage to light each point of the plate to the brightness of that exact spot in the televised scene?



KEN—You don't have to! Your Nipkow disc in front of the neon lamp will show you each point on the plate at the instant it has the right brightness.

WILL—Of course! At any instant the disc lets us see just one element of the surface of the plate. And at that same instant, the brightness is just right for that spot in the televised scene. For instance, when the first element of the picture is transmitted, the whole neon lamp is lighted to the brightness of that point. But we can see only that one spot through the hole in the disc. And when the hole passes to the next element the whole plate is just as bright as *that* spot ought to be, and so on. So we see all points of the scene in their proper places and with their proper brightnesses, and the whole image is reproduced!

KEN—Bravo! You have described exactly the system of television first outlined about the end of the 19th century and put into practice around 1924 by Jenkins, Baird, and others.



### Mechanics vs electronics

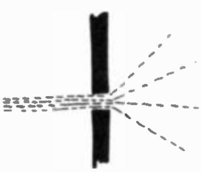
WILL—It looks like a very simple and practical system to me, and I doubt if it would be easy to improve it!

KEN—Pull in your hat-band, chum! They gave up that idea years ago! They couldn't get enough detail with it—180 lines was about the most you could get in a single image.

WILL—Couldn't they get more lines by using bigger discs with more holes?

KEN—No. At the speed the discs would have to turn, centrifugal force would tear them apart.

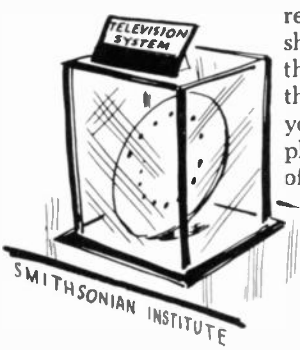
WILL—Couldn't you make the holes smaller?



KEN—Not very much smaller. You would cut down the amount of light that could get through, and after a certain point you'd be up against the very disagreeable phenomenon of diffraction.

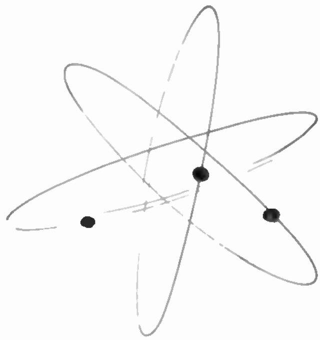
WILL—It seems I don't have any good ideas today!

KEN—No matter how good they might be, you wouldn't be able to save mechanical television. It had other bad faults. For example, the phototube at the transmitting end received the light from each point of the image for such a short time that they had to use very high illumination on the subject to get enough photoelectric current to use. And the efficiency at the receiving end was very low, because you can see only a very small part of the neon lamp's plate at any instant. And finally, we're living in the age of electronics now!



chapter 2

# The cathode-ray tube




Will—There's still one thing I can't get. When we were talking last time, you said mechanical TV systems had been abandoned in favor of electronic ones. Well, I think the Nipkow disc is electronic.

Ken—How did you get that idea?

Will—Aren't its atoms made of protons, electrons and neutrons? What could be more electronic?

Ken—When we say electronic, we are talking about electrons in the pure state, separated from the protons; that is, electrons all by their lonesome. Now, where would you find that kind of electron?

Will—Why, in vacuum tubes, of course; or at least in the part of the vacuum tube where the electrons make their jump from cathode to anode.

Ken—Correct! And—practically up to the invention of the transistor, every branch of the technique called *electronics* dealt with currents of electrons in vacuum tubes.

Will—Let's stick to television. Just how do they get the electrons that these modern systems use?

Ken—Just as they do in radio—by making them jump off a hot cathode.

Will—And then what do these electrons do?

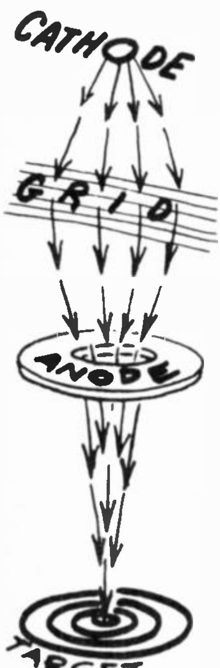
Ken—Plenty! It's those electrons that turn your image into an electrical signal at the transmitter, and then back to light at the receiver. Remember how we would scan a picture using the Nipkow disc? Well, in the electronic system, a *beam* of electrons scans the image, reading the elements line by line.

Will—I can understand electrons flowing from cathode to plate in an ordinary tube. But how can electrons be concentrated into a fine ray or beam, and then be moved across an image?

KEN—That's what we're going to find out right now. The *cathode-ray tube* is the device which takes the place of the Nipkow disc and makes all these things possible. And—if it will make you feel more at home—we can start our cathode-ray tube out in life as a triode, much like those in radio. It has its differences, of course. First, it uses a cathode with a very small emitting surface (a so-called "point cathode") to concentrate the electrons.

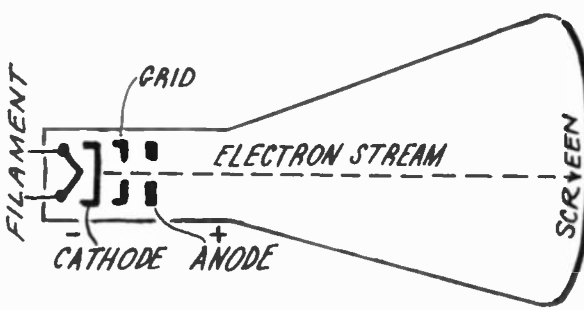
WILL—Get all your electrons together at the start, eh? Then they'll all follow the same path and stay in a tight beam.

KEN—My young friend, please remember that these electrons all carry the same (negative) charge, so they repel each other every step of the way. They're like those rugged individualists who won't co-operate to do useful labor unless they're compelled to. They try to get as far apart as possible unless some outside force makes them act sociable in spite of their own feelings.




**A peculiar tube**

WILL—Then where and how do you get these electrons together, if they keep spreading apart?




*The control grid and the anode of the picture tube are so constructed that they do not interfere with the passage of electrons on their way to the screen.*

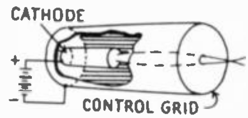
KEN—We usually start forcing them into a beam just after they've passed the anode.

WILL—Say, what kind of a tube is this? You mean the electrons keep on going after they pass the plate?

KEN—That's just what I said. This is a very unusual plate. It has a hole in its center, and is kept at a high positive voltage, so it speeds up the electrons quite a bit before they pass through the hole, to finish their course a lot farther on.


WILL—Funny kind of a tube!

KEN—Funnier than you imagine! If the electrons going through a hole in the plate looks funny to you, what would you say to a *grid* that's really a cylinder around the cathode?

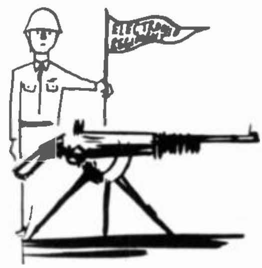



WILL—How could a grid like that work?

KEN—Same as any other grid. If it's very negative, it repels the electrons toward the cathode, so that a very few get by. When the control grid is made less negative, most of the electrons from the cathode can get through on their way to—and beyond—the plate.

WILL—Is this flow of electrons large?

KEN—No, the current in a television picture tube is a lot smaller than in a receiving triode. It can be in the order of a hundred microamperes. And the cathode-ray tube would be pretty useless as an amplifier, too. Its transconductance is only a few microamperes per volt, and its internal resistance is likely to be in the order of a hundred megohms!



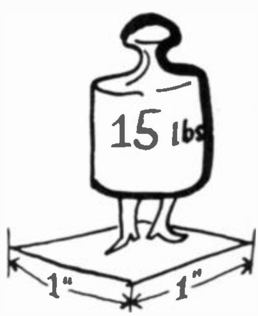
### Light artillery

WILL—So if it won't amplify, what *does* it do?

KEN—It acts like an electronic machine gun. Television needs a device that will produce quantities of electrons and—more important—regulate that quantity. So, in a receiving cathode-ray tube, or *kinescope*, you find this piece of electronic artillery (actually called an *electron gun)* at the rear of the tube, next to the socket.

WILL—I take it that these kinescopes are real vacuum tubes—there's no air in them?

KEN—Of course. Otherwise our electrons would collide with heavy molecules of air and lose their speed. You need a vacuum as nearly perfect as possible in a cathode-ray tube, on account of the long distance the electrons have to travel as compared with ordinary receiving tubes.

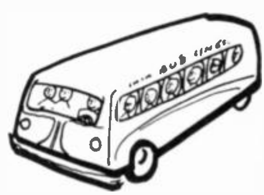



WILL—I'm like Nature; I "abhor a vacuum." But this one in the picture tube looks worse than most to me. Have you stopped to think that the surface of the tube has to support all the pressure of the atmosphere, or about 15 pounds per square inch?

KEN—I know. Now, surely you remember how to calculate the area of a circle? Suppose you tell me just what the pressure is on the face of, say, a 16-inch tube.

WILL—Let's see. . . . A little more than 200 square inches . . . ! Why, over a ton and a half!

KEN—And if you figure in the sides of the cone and the rest of the tube, you run up about another ton and a half. Altogether, you have the weight of about 40 people pressing in around your tube.



WILL—A bus-load of people! A tube like that must have to be fantastically strong!

KEN—Yes. Maybe you've noticed that the face of almost

every tube is curved slightly outward for greater strength. And the cone is often made of steel.

WILL—In spite of all that, I think I'll do my television experimenting up on a mountain.

KEN—A mountain . . . ? ?

WILL—To keep the tube from exploding. The higher up you go, the lower the air pressure.

KEN—That's true, but come back to earth long enough to correct a mistake. The word is "implode," not "explode." And implosions are rare, which is a good thing. It's dangerous to be around when a picture tube comes apart; besides, they cost money!

## The fluorescent screen

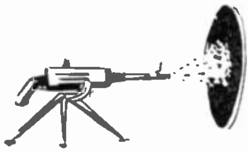
WILL—What happens to the electrons from the gun when they get to the end of the tube?


KEN—The inside of the tube face is covered with a translucent layer that glows where the electrons hit it.

WILL—Is that the same kind of stuff the hands of my watch are painted with?

KEN—No, that material is *luminescent*—a substance that glows by itself without being excited by light or some other radiation. A picture-tube screen is covered with *fluorescent* material—stuff that glows when it's excited by some other (usually invisible) radiation of a shorter wavelength than visible light.

WILL—Is that the principle behind fluorescent lighting?



KEN—Yes. In a fluorescent lamp, an electric discharge in the mercury vapor inside the tube produces invisible ultraviolet rays. When they strike the inside of the tube, which is covered with fluorescent material (called *phosphor*), it glows and produces visible light.

WILL—Your fluorescent tube is a sort of superheterodyne, then?

KEN—What?

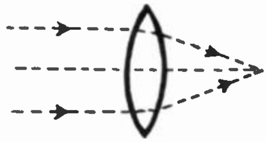
WILL—Doesn't it change the very high frequencies of ultraviolet light to the lower visible frequencies?

KEN—You're right, at that. But let's get back to the job. We have an electron gun that shoots its projectiles to the screen and makes it glow. But because the bullets spread out, we get a large bright spot on the screen. Trying to outline an image with a spot like that would be like trying to paint the fine details of a picture with a whitewash brush.

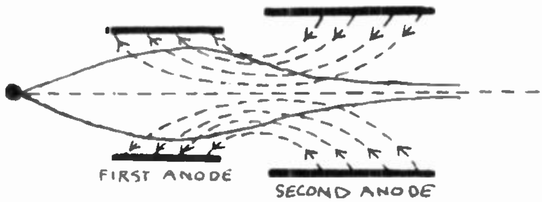
## The electronic lens

WILL—That brings us back to the problem of concentrating the beam. How are you going to get those electrons to stick together?

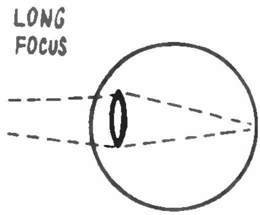
KEN—You do it with an *electron lens:* Electron beams act like light rays and obey electronic optical laws. Those are pretty much the same as the laws dealing with ordinary light that you learned of in physics.



WILL—Don't tell me that you can make an electron lens out of glass. The electrons couldn't get through it!




*If left to themselves, the electrons (having the same polarity) would repel each other and tend to diverge. The electrons are forced to converge by being sent through open-ended cylinders having a positive voltage.*

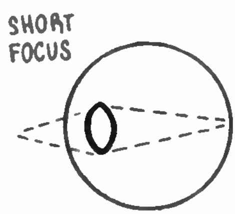



KEN—No, the electron lens isn't made of glass. There are a number of ways to bunch the electrons into a fine pencil-like beam. One of the oldest—and one still found in small tubes (and now being used in color television picture tubes)—is to add a second anode, at a higher voltage than the first. Each of these anodes has its own electric field, and their interaction causes the electrons to come to a point some distance ahead of the second anode. By regulating the voltages on one or both anodes, the paths of the electrons can be bent more or less. Thus you can alter the *focal length* of the lens so the beam comes to a sharp point right at the screen.

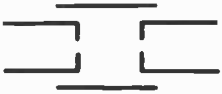
WILL—Adjustable, eh? This electron lens is better than an optical one.

KEN—Not at all. The lens of your eye—for example—can modify its focal length to accommodate to near or distant objects.

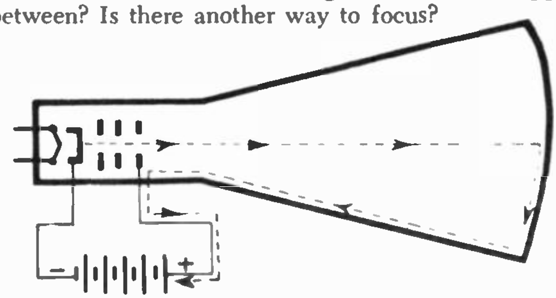
WILL—I suppose this is what they call electrostatic focusing. But our triode is now a tetrode!




KEN—I can even show you cathode-ray pentodes! But this is not exactly what they mean when they say electrostatic focusing today. In a modern electrostatic focusing tube, the anode cylinder is cut into two parts, separated a little from each other. Then another cylinder—a little bigger than the others—is slipped over and spaced very exactly from them. The latest types keep this cylinder at cathode voltage, though a few early ones had about 250 volts on the cylinder and some went up to 2,200. Again you have interaction of electric fields which acts as a lens, focusing the beam somewhere beyond the anode. This type of *automatic focusing* tube was developed in 1951 and is being manufactured in a number of types.

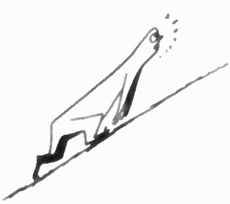


WILL—But you told me that the first focusing method was an old one, used in some small tubes. Now this is a new method (or a new variation of an old method) which seems to be used in a few large tubes. What happens in between? Is there another way to focus?



*The electron beam in a picture tube starts at the cathode but must find its way back to that point. The arrows and dashed lines show how the electrons return.*

KEN—I was wondering when you were going to ask that! Most of the tubes in sets today are focused in an entirely different way. But let's finish with our electrostatic tubes. Then next time we talk you will be in a better position to understand other focusing methods.



### Hard road for electrons

WILL—Now, what happens to the electrons after they reach the screen? They surely have to get back to the voltage supply they started out from?

KEN—That question never bothered the tube manufacturers very much. They let the electrons sort of shift for themselves. After the electrons have struck the screen at high velocity . . .

WILL—High velocity? About how high?


KEN—That depends on the voltage applied to the last anode—and to the *accelerating electrode*, which we will come to in a minute. It's proportional to the square root of those voltages. With 10,000 volts to speed them up, the electrons may reach a speed of 7 miles a second. But with 20,000 volts, they wouldn't travel at a speed greater than about 9½ miles per second.

WILL—Why should an electron have to get up speeds like that?

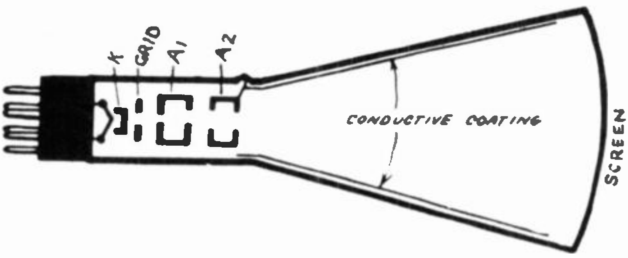
KEN—Because the harder the electrons hit the screen, the more light they make.

WILL—But we still haven't found out what happens to them *after* they hit the screen!

KEN—Since they move so fast, each electron kicks up several more electrons when it hits the screen, like raindrops falling into a puddle of water. Then these . . .

WILL—. . . secondary electrons . . .

KEN—I see you haven't forgotten our old talks on radio. These secondary electrons travel slowly and as best they can back toward the anode. In modern tubes, we make it easier for them by coating the inside of the cone with graphite. A connection to this coating is made with a flexible lead to a button on the side of the cone. The graphite coating is kept at a higher voltage than any other element in the tube, and is the *accelerating electrode* I mentioned a few minutes ago. It helps speed up the electrons after they pass what we have been calling the anode.

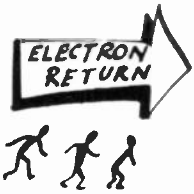


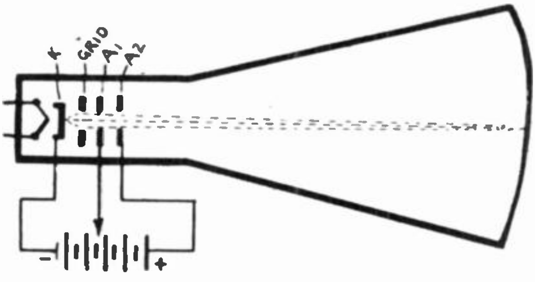

*The accelerating anode increases the velocity of the scanning beam. The dark gray coating on the inside of the tube is conductive and is known as Aquadag.*

WILL—Why the flexible lead? Sounds messy. Can't we just connect to one of the pins in the base?

KEN—No, the voltage is so high that it's more practical to keep the lead as far from the others as we can.

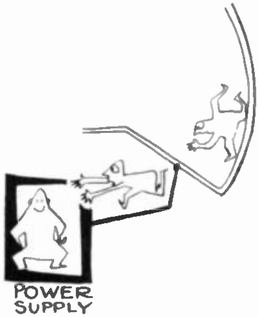
WILL—Now I think I can see the whole circuit. The electrons leave the cathode, go down the center of the



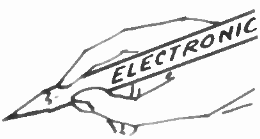

*The combination of cathode, control grid, first and second (accelerating) anodes is sometimes referred to as the gun. The electron beam is focused so that it produces a tiny dot of light on the screen.*

"grid" and through the hole in one or more anodes, and finally reach some part of the screen. Then they work their way back along the inside surface of the tube to the positive end of the high-voltage supply (and if you want to complete the circuit, through that to the cathode). I guess the hardest part of the journey is from the point that the beam strikes to the edge of the screen?




KEN—Yes. The fluorescent layer is far from being a good conductor. In some tubes there is a thin aluminum backing behind the layer. It's only about a molecule thick—too thin to bother the high-speed electrons coming from the gun. But it does stop the low-voltage secondary electrons and helps them to get to the edge of the tube. The real reason for this aluminum layer is to increase the image brightness. It reflects the light rays that start toward the inside of the tube and sends them back toward the viewer.

### The spot has its ups and downs

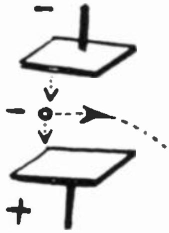



WILL—Now we have an electronic pencil to draw our picture on the screen. All we need is to control it! How do we pick up this pencil and move it around on the screen to make the picture?

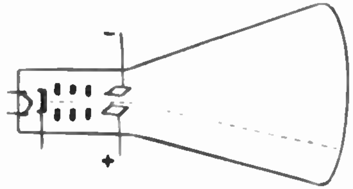
KEN—Think a little. When a real gun fires its bullets, do they travel in a straight line?

WILL—Of course not. They follow a curve—a parabola—because gravity pulls them down.

KEN—Then can you figure out how to apply a force to make the electron stream curve?




WILL—I get it! We can put a positive plate under the beam, to attract it the way the earth does the bullet. Then the electrons will be pulled downward.

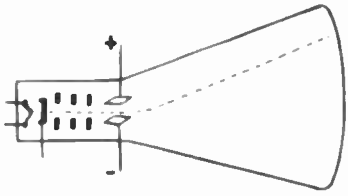



*As the electron beam passes the first pair of deflection plates, the positive and negative plates pull and push the beam down.*

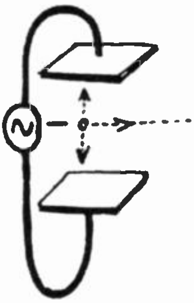
KEN—Good reasoning! And you'll do even better if you put a second plate—charged negative—*above* the beam.

WILL—I see. One plate pushes and the other pulls. But these two plates become a capacitor.

KEN—That's right. But we haven't any reason to apply a constant voltage or charge to our *deflection plates*. That would simply pull the spot up or down a little and leave it there. Now, what would happen if we put an *alternating* voltage across our plates?




*This action is exactly the opposite of that shown on page 30.*

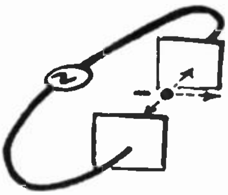


WILL—On one alternation the top plate will be positive and the lower negative, so the spot will go up. Then the bottom plate becomes positive and the top negative, and the spot goes down.

KEN—You see, the spot travels along the vertical diameter of the screen. Now if the frequency of the alternating voltage is 30 or more cycles a second . . .

WILL—. . . Then we'll see a bright vertical line, because all the positions of the spot will run together in the eye!

### A 90-degree twist

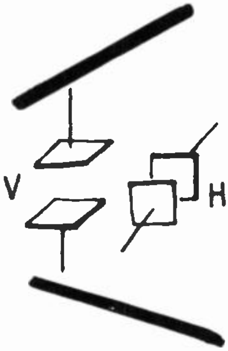


KEN—And now suppose you set another pair of plates along the path of the beam, but put them on the sides instead of above and below.

WILL—Then we can move the spot from left to right. And if we use ac on the plates, we make a horizontal line. There's only one funny thing: the *vertically* mounted plates give us the *horizontal* deflection, and the *horizontal* plates give us the *vertical* deflection.

KEN—That has made trouble. Some authors (and teachers) have tied students in knots by talking about "horizontal plates" when they meant "horizontal deflection plates," and *vice versa.*

### Drawing the picture




WILL—Now the spot can be moved both ways, but I still don't see how it can trace out a television image.

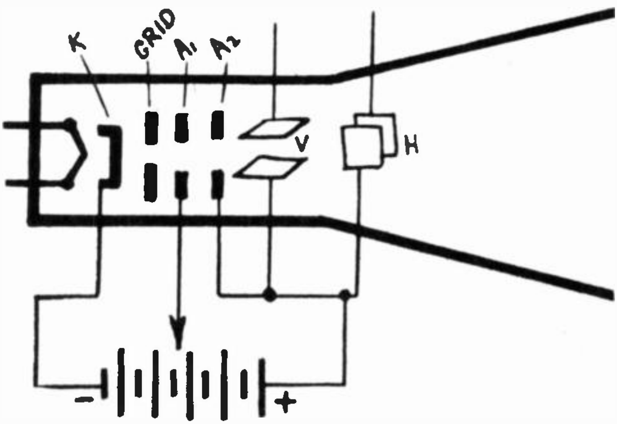
KEN—Let's not hurry this too much; I hope you'll be satisfied with just a rough idea for now. Suppose we apply a slow alternating voltage to the horizontal-deflection plates, so the spot will move at a uniform speed across the tube screen from left to right, and appear again at the left just as soon as it disappears at the right, and so on. Remember—when we say left to right we are looking at and facing the outside or front of the screen.

WILL—It would be just like reading the same line of a book over and over.

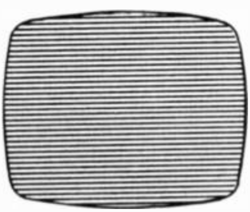
KEN—That's exactly what I was trying to get across! Now let's give the spot a much slower motion from top to bottom, by applying a lower-frequency voltage to the vertical-deflection plates.

WILL—So when we get to the end of one line, we won't come back to the beginning of the same line, but to a little lower point?

KEN—Exactly. And since the spot keeps moving downward at a uniform rate, the same thing will happen for all the lines. But when the spot has got down near the bottom of the tube, we'll reverse the voltage on the vertical-deflection plates very rapidly, so the spot will jump to the top of the screen and start on its slow trip down again.




*The vertical- and horizontal-deflection plates are connected to the positive end of the power supply. This prevents the plates from slowing the scanning beam.*



WILL—Just like finishing one page and turning to the next. That's all quite clear, but your spot still hasn't done anything but trace out a series of lines of equal brightness. They should give us a very evenly lighted rectangle. It's like a book in which all the letters are identical, or better, one full of glossy blank pages. Just where and how do we get our TV picture?

KEN—You are absolutely right about that evenly lighted rectangle. We call it a raster. But we surely must have forgotten some very important point! Suppose we vary the intensity of our beam so that each point on the image has just the proper brightness?

WILL—I don't see how you can do that.

KEN—Stop and think a little. Or can't you take any more today? What was it that we used to modulate our light beam so that it reproduced the successively scanned points of the image so faithfully in the Nipkow apparatus?


WILL—Why, the video signal, of course!

KEN—And to what element of the cathode-ray tube should we apply the video signal to make it modulate (or modify) the intensity of the scanning beam?

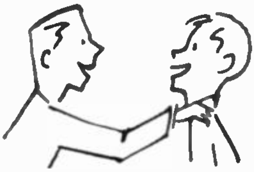
WILL—Of course! To the control grid! Then the brightness of our spot at any point will depend on the video signal. And the transmitted image can be reconstructed exactly, element by element, on the tube screen.

KEN—You seem to have absorbed this fairly well. Now the next topic on the agenda. . . . .

WILL—Wait! I want to make sure I can digest all you've given me so far. OK?

KEN—OK. You do the talking and I'll listen.

WILL—As I understand it, we want an all-electronic television system since mechanical setups do not work too well.



KEN—Right.

WILL—The heart of television is the picture tube. It has a filament which heats a cathode, just as a gas flame heats the bottom of a pot.

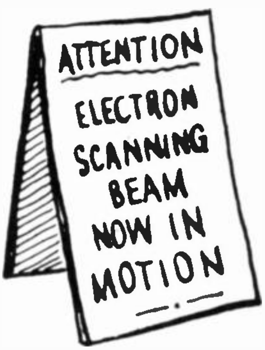
KEN—You're cooking on all burners.

WILL—I'll disregard that. We put a cylindrical anode with a high positive charge near the cathode. The negative electrons come tearing along. . . .

KEN—. . . . and are unable to stop.

WILL—Please don't interrupt. The electron velocity is such that they keep on going until they hit the screen. The impact produces a tiny dot of light.

KEN—Good. I hadn't expected you to remember that much.




WILL—We want to produce as sharp a dot as possible, so we use an electron lens.

KEN—We now have our dot of light. What next?

WILL—Since our electron beam consists of negative particles, we can move it back and forth, up and down, by making it pass two pairs of deflection plates.

KEN—Why two pairs?

WILL—One pair to make the beam move vertically, and the other to make it move horizontally.

KEN—And is this vertical and horizontal motion without reason?

WILL—Oh no! Let's imagine that we're facing the screen. The beam starts at the upper left corner, and moves from left to right.

KEN—So what!

WILL—So it produces a line of light.

KEN—And then what happens?

WILL—Our vertical-deflection plates move the beam down while the horizontal-deflection plates pull the beam back to the left-hand side.

KEN—In other words, you've got the electron beam in its proper position to sweep across the screen of the tube, producing another line of light.

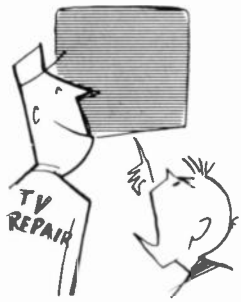
WILL—Exactly.

KEN—And is that all?

WILL—No, not quite. When we get to the bottom of the screen, our beam will have drawn hundreds of horizontal lines of light. These closely-spaced lines make a raster.

KEN—What happens when the electron scanning beam produces the bottom line of the raster.

WILL—That's easy. Our vertical-deflection plates just pull it up and put it into position for scanning the first line all over again.




KEN—And that's all?

WILL—Yup. That's all!

KEN—You have a beautiful raster, but no picture.

WILL—What did I leave out?

KEN—How do you get a picture out of all this?

WILL—Oh, I forgot. In the picture tube we have a control grid. We bring the picture signal into this grid. The signal modulates the scanning beam. As it moves across the screen, the beam will be stronger or weaker, depending on the signal strength. Sometimes the cathode is used as the signal electrode.

KEN—I never thought I'd get that much out of you.

WILL—And now that I know how television works, let's go on to something else.

KEN—Whoa! How does the picture at the receiver stay in step with that at the transmitter? And where do we get the high voltage for the picture tube?

WILL—I left out a few details, huh?

KEN—More than you realize. And just to make you happy, it's about time I told you that vertical and horizontal deflection plates are no longer used.

WILL—Then in heaven's name why. . . . . .?

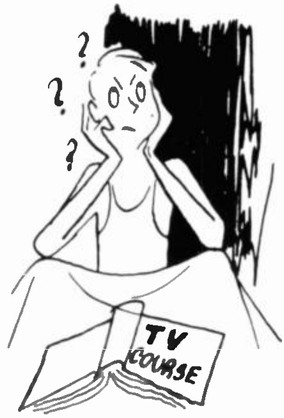
KEN—For the same reason we studied the Nipkow disc. You can't possibly understand television unless you have the proper background.

WILL—Hold it a minute! Now I have about a hundred questions to ask!

KEN—Let me ask *one* first: Why don't we call it a day and leave our problems till next time we get together?

chapter 3

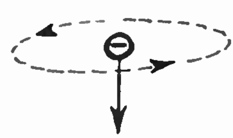
# Deflection and focusing




WILL—This confounded television is keeping me awake nights! There are about a hundred questions going around in my head: Just what kind of voltages do you put on the horizontal and vertical electrodes of your cathode-ray tube? How do you generate them? How big do they have to be? Why . . . ?

KEN—Hold it! Let's have your questions one at a time. Last time we talked about cathode-ray tubes that focused and deflected the beam with electrostatic fields. Those tubes are used only in oscilloscopes, or in antiquated 7-inch sets. Practically all sets bigger than that use *magnetic deflection.*

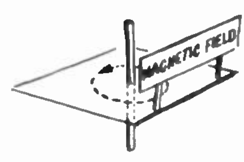
WILL—I can't see how. An electron has a negative charge, so a positively charged plate attracts it, and a negative charge on a plate repels it. But a magnetic field has no effect on an electrostatic charge.

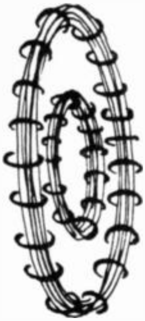


### From one field to another

KEN—If your electron was standing still, you'd be right; it would be just a negative charge and nothing else. But when it starts moving, it sets up its own magnetic field.

WILL—This isn't what you used to tell me. In other days, when I was learning about radio, you explained that an electric current creates a magnetic field around its conductor, and the field could be thought of as concentric lines of force with the conductor as a center.



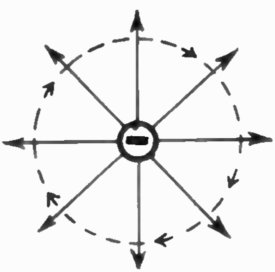


KEN—Your mental insomnia hasn't done you much good. Have you forgotten that an electric current is only a movement of electrons?

WILL—Naturally, I know that! Of course, it's not the conductor, but the moving electrons that have the field around them. If we have electrons in movement we must have magnetism.

KEN—Good! But sometimes we get so wrapped up in this electromagnetic field that accompanies the moving electron that we completely forget it has an electrostatic field, too. Now, what about that?

WILL—That's easy enough. We know the electron is a charged particle. This charge we talk about is an electrostatic charge. And when the electron starts moving, we have an electrosatic charge *and* an electromagnetic field.

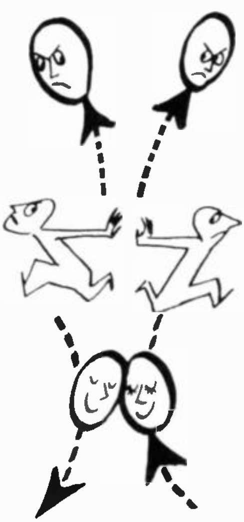


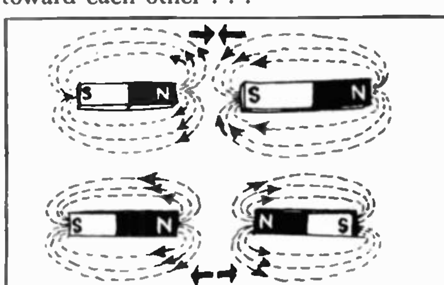
KEN—You've got it! And it's in this way that radio waves are bundles of magnetic lines, enveloped in electrostatic lines, and constantly growing. Now, have you noticed that the assumed lines of the electrostatic field radiate in a certain way from the electron, so they are always at right angles with the "lines of force" of the magnetic field? That is something worth remembering: *Lines of electrostatic and magnetic fields produced by the same cause are always at right angles.*

### Inside the magnetic field

WILL—Then what happens when you have two magnetic fields produced by two different causes?

KEN—Haven't you seen it happen? When you bring two magnets toward each other . . .






*The north and south poles of magnets are attracted. Similar poles (a pair of north poles or a pair of south poles) try to push away from each other.*

WILL—They attract each other—that is, if you have a north pole against a south pole. If two poles of the same kind are brought close together, they repel each other, the same as two electric fields of the same sign.

KEN—And we can also say that parallel magnetic lines going in the same direction repel each other, but when they go in opposite directions, they attract.

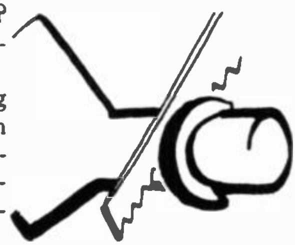
WILL—These magnetic lines of force are like a lot of people—the less you see of them the better. If you try to travel the same road with them, you just can't get along!

### The magnetic theater

KEN—Now you've got that straight, you won't have any trouble figuring out how magnetic deflection works.

WILL—Let me think. It would work all right to put a horseshoe magnet over the neck of the tube so the electrons would pass through its magnetic field.

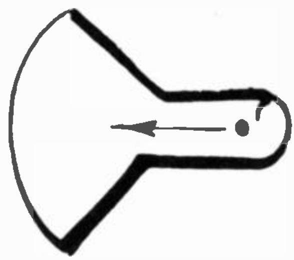
KEN—And which way would the electrons be deflected?



WILL—Why, they'd be attracted by one pole and repelled by the other, of course.

KEN—Oh, well, I suppose this is what you get for trying to use analogies on people without brains! But, Will, even you should know better than that. Have you been wandering off on a tangent ever since I pointed out that the electric and magnetic fields around an electron are perpendicular to each other at all points?

WILL—Are you trying to insinuate that the electrons are deviated at a right angle to the magnetic lines?



KEN—I'm not insinuating anything, I'm just trying to get you to think a little. Now, just to give us a better look at things, I'll draw a cathode-ray tube in a rather uncommon way. We'll cut the neck off just ahead of the magnet and show a cross-section. We won't bother drawing any electrodes, either. Now, imagine your eye in place of the fluorescent screen. The black dot at the center is an electron coming directly at you.

WILL—Quite a setup! Now that we've got all the scenery set and the actors in place, when does the show start?

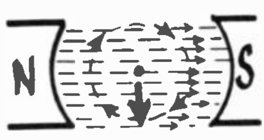
KEN—At once. We're going to stage a scene of conflict presented by two forces. One of them is the field of the magnet (the parallel lines) and the other is the magnetic field around the electron in motion. We'll represent that field by circles around the electron. Now, how will these two fields interact?


WILL—At each side the circle cuts the straight lines more or less at a right angle. So there'll be no interaction. But at the top the lines are going in opposite directions, so they'll attract each other. And on the bottom they're going in the same direction, so they'll repel.

KEN—So how is our play going to end?

WILL—The electron will have to go up. It's pulled from above and pushed from below.

KEN—Exactly. And if we reverse the magnet?




WILL—The electron will be deflected downward. But it bothers me a little to see a horizontal field deflecting the electron beam up and down.


KEN—It tangles up a lot of television students. But you shouldn't have any trouble if you keep in mind that an electron always moves *at right angles* to a magnetic field. And besides, remember the deflection plates in the electrostatic cathode-ray tube. Didn't the plates in the vertical plane produce the horizontal deflection, and the horizontal plates . . . ?

WILL—I remember. The horizontally mounted plates deflected the beam vertically. I guess the trouble is that I've just got to stop and think about it.

### Making magnetic fields

KEN—You'll have no trouble in seeing, Will, that if we want to keep our spot in continuous movement, we have to keep the value and the direction of the magnetic field changing continuously. And we can't do that by juggling with permanent magnets.

WILL—I suppose you could use electromagnets—coils carrying currents of the right size and direction to make the magnetic fields you need.

KEN—That's the way it's done! And, since we used two pairs of plates for electrostatic deflection, if we want to get horizontal and vertical movement of the beam with magnetic fields, we need . . .

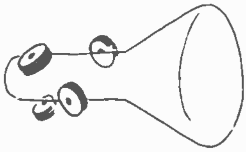
WILL—. . . two pairs of electromagnets; one pair mounted vertically to give the horizontal deflection and the other pair with a horizontal axis for the vertical deflection.

KEN—That's right, Will. The two coils are usually placed right where the neck of the tube joins the cone.

WILL—Are they iron- or air-cored coils?

KEN—They can be air-cored, but in modern sets these electron-beam deflecting coils are usually powdered-iron- or ferrite-cored. They are wound in rectangular form, then shaped to fit tight to the glass of the tube. In cases where iron-core coils are used, the pole pieces are usually shaped to keep them as close to the glass as possible.

WILL—So far we have just been talking about controlling the movement of our electron scanning beam. I suppose that with our pair of deflecting coils we can move our electron beam in any direction we want—horizontally or vertically.



KEN—Exactly. One pair of coils moves the scanning beam across the screen of our picture tube and the other pair moves it up and down. All four coils are housed in a single assembly known as a deflection yoke.

WILL—I guess that solves all our problems. We're just about ready for a picture, aren't we?

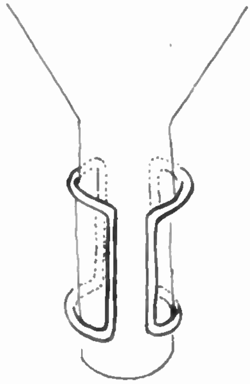
KEN—Not by a long shot. It's true that we can move the beam of electrons coming out of the gun just as we wish. But there is just one little item that is being overlooked.

WILL—And what is that?

KEN—We want our picture to be as sharp and clear as possible, so we must make sure that our beam produces a fine dot of light on the screen, and not a large, round, indistinct or fuzzy blob.

WILL—I see. It's just like a motion picture projector. We not only have to put lights on the screen, but we must do something about focusing the picture.

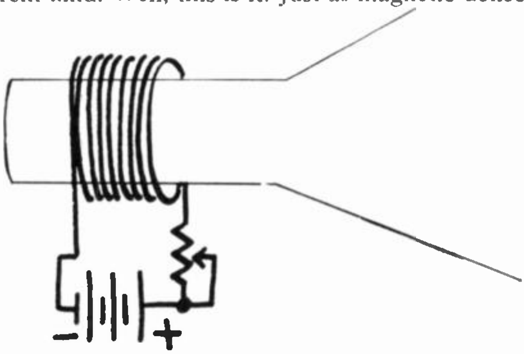
KEN—Right. Any suggestions on how we can go about focusing the scanning beam in a picture tube?



#### Magnetic focusing

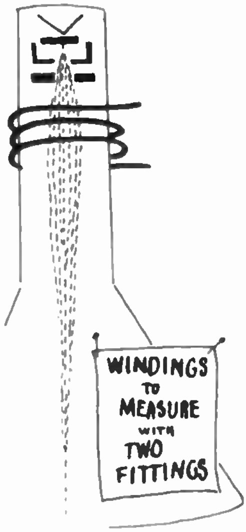
WILL—This may be dumb, but I've been wondering if the electrons couldn't be focused just as well by a magnetic field as by what you call "an electronic lens?"

KEN—Nothing dumb about that! When we were talking about electrostatic focusing, I told you that most tubes use a different kind. Well, this is it! Just as magnetic deflection



*The current flowing through the coil of wire is accompanied by a concentrating magnetic field. The battery supplies the voltage for pushing the current through the coil. The variable resistor helps control the amount of current.*

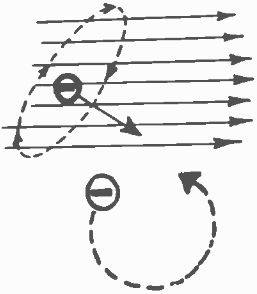
makes it possible to get rid of the two pairs of deflection plates and simplifies the construction of the picture tube, so does magnetic focusing permit us to get rid of the focusing electrodes. That makes life easier for the tube manufacturers.




WILL—H'm—if we keep on throwing out surplus electrodes, pretty soon we won't even be able to call it a tube. But how do we make a "magnetic lens"?

KEN—What's needed is a field in which the magnetic lines run along the tube in the same direction as the electrons. So all you have to do is put a simple coil around the neck of the tube.

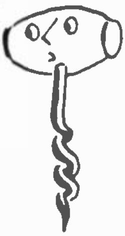
WILL—And I suppose you adjust the focus by varying the strength of the current through the coil?



Ken—Exactly! And, because this field has to be constant, the electromagnet can be replaced by a permanent magnet placed around the neck of the tube, or by much smaller ones, placed inside it.

### Dance of the electrons

Will—I sort of understand how—if we have a uniform magnetic field along the axis of the tube—the electrons would be concentrated in a beam along the same axis. Each electron that left the center of the tube would—if I have the idea right—be sort of taken by the hand and led gently back to the electronic path of virtue.



Ken—Your instinct does you credit. But what really happens is a lot more complex. Suppose an electron in a uniform field starts to move downward. We'll cut out this circle of paper and let the center represent an electron, and the edge will indicate its magnetic field. Then if the electron moves downward as well as forward, our circle leans ahead. If this bothers you, remember, the magnetic field must always be at right angles to the electron's motion. The upper and lower edges of our leaning field are still at right angles to the lines of force in the uniform field it's traveling in, but its sides are no longer at right angles to the lines in the uniform field. So, you have attraction on one side, repulsion on the other. Result . . .

Will—The electron is pushed sideways. Nothing ever happens the way you'd expect it in one of these magnetic fields! So, if our electron moves to the left . . .

Ken—The same reasoning shows it will be shoved upward.

Will—And then the field will push it to the right. And so on! Our electron is traveling in circles around the tube's axis. But how does all this end?

Ken—The circles just get smaller till the electron gets back to the axis and decides to follow it without making any more trouble. You can say the electron follows a spiral—or even better, a corkscrew—path.

Will—This magnetic focusing makes me think of a scalp dance.

Ken—Now, where did you get that . . .?

Will—Well, the Indians tied their prisoner to a stake, then danced around him in smaller and smaller circles, till . . .

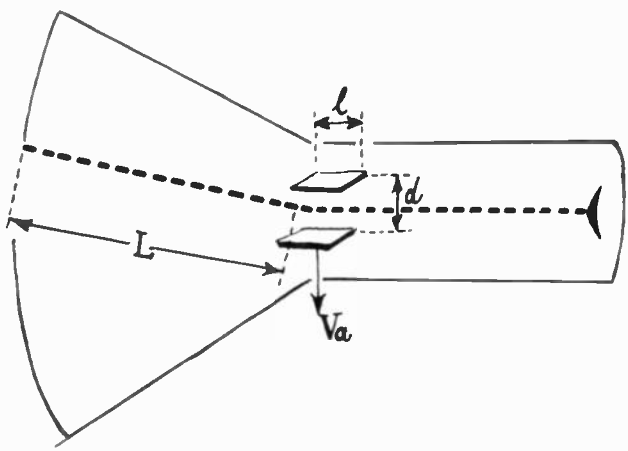
Ken—. . . at the last moment, some providential intervention saved the brave hero's scalp! I was brought up on The Last of the Mohicans, too!

### Question of sensitivity

Will—Now just how does magnetic focusing shape up against electrostatic focusing? Magnetic-focus tubes should be a lot easier to make. But it should be easier to deflect and focus electrostatic tubes, because all you have to do is apply simple voltages to the electrodes in the picture tube to set up your electric fields. With magnetic deflection and focusing, you have to pass currents through coils. That means loss of energy, so you must need some power, at least.

KEN—At first glance, all you say is absolutely right. But in practice, it applies only to small tubes—7-inchers or thereabouts. You just didn't think of the sensitivity factor.

WILL—What's a cathode-ray tube got to be sensitive about?




*In electrostatic deflection the scanning beam passes between pairs of metal plates. The amount of deflection depends on the voltage put on the plates, the length of the plates, and the distance that separates them.*

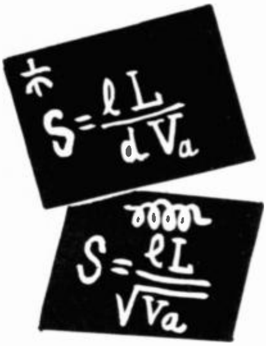
KEN—What I'm talking about is deflection sensitivity. It's a value you get—for any particular tube—by finding out how far the spot moves if you change the voltage on the deflection plates by 1 volt or change the strength of the magnetic field by 1 gauss.

WILL—If the spot moves further across the screen for a given voltage or current change, I suppose the tube is more sensitive?

KEN—That's the way it goes. Or you can say that the more sensitive a tube is, the smaller the voltage (or magnetic field strength) it takes to move the spot a given amount—say an inch.


WILL—And what does the sensitivity of an electrostatic tube depend on?

KEN—The longer the electrons are in the deflecting field, the greater is the deflection. So the longer the plates are, the greater is the sensitivity. At the same time the sensitivity increases as the plates are brought closer together, because that makes the field stronger.



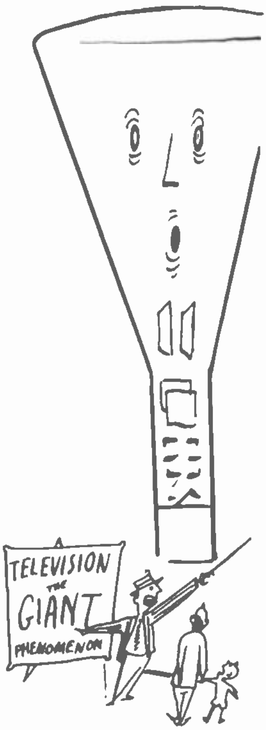

WILL—So you can make very high-sensitivity tubes by making the deflection plates very long and cutting the distance between them down to a minimum?

KEN—You can't get very far along that path. With narrow clearance and long plates, the least deviation will make the beam strike one of the plates, instead of going on to the screen. And—to complete the story—we have to remember that the deviation decreases as the electron speed increases.

WILL—That's reasonable. The faster a thing moves, the harder it is to deflect it from its path.

KEN—And you know that the electron speed depends on the final anode voltage. Increase that voltage, and the deflection *decreases* in proportion.

WILL—Why, I could make out a formula for the sensitivity of a tube. Sensitivity $S$ would be directly proportional to the length of the plates $l$ and inversely proportional to the distance $d$ between them and to the anode voltage $V_a$.




KEN—Colossal! The only thing you left out is the distance $L$ between the deflection plates and the screen. With the same angle of deviation, the actual displacement of the spot on the screen will increase with that distance.

WILL—Yes, anyone could see that. Now, how do you figure out the sensitivity of a magnetically deflected tube?

KEN—Much the same way. The sensitivity is again proportional to the length of the deflecting field and the distance between the deflection coils and the screen. The sensitivity decreases as the anode voltage increases, but not as fast with the electrostatic deflection. In a magnetic-deflection tube the sensitivity decreases according to the square root of the high voltage.

WILL—So, if you raise the high voltage four times, you cut the sensitivity in two?

KEN—If you keep this up, you'll be another Einstein yet!

WILL—But all this doesn't explain why it's the sensitivity that puts magnetic deflection ahead for large tubes.

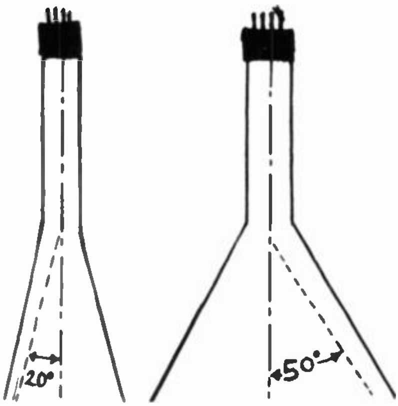
KEN—Let's take a concrete example. Suppose we have an electrostatic deflection tube with a 7-inch screen and a length of 21 inches. The voltage on the last anode is 2,500 and the sensitivity .015 inch per volt. For full deflection, we'll have to vary the voltage on the deflection electrodes by 7/.015, or a little less than 500 volts. A 7-inch screen is sort of small, of course. Let's apply the tube-stretcher, and double all the dimensions. Our tube now has a 14-inch face—which is good—and is 42 inches long . . .

WILL—. . . which is certainly not so good!

KEN—This is just an example. Don't take anything in it too literally. And we don't have to worry about cabinets in this problem. But do you see any other trouble?


WILL—No. the sensitivity seems to increase in the same proportion. The length of the plates is doubled, which increases the sensitivity, but their distance apart is also doubled, so those two ought to cancel each other. But the distance to the screen is doubled too, and that should give you twice the sensitivity. So, with the same 500 volts, we can deflect the spot all the way across the 14-inch screen.

KEN—Your figures are O.K., Will. Only trouble is, you've forgotten that in doubling the diameter of your screen, you've *quadrupled* its surface area. So it's only a quarter




*The larger of these two tubes requires a greater amount of scanning-beam deflection. Tubes with a screen diameter of more than 7 inches generally use electromagnetic deflection.*


as bright, for you're bombarding it with the same electronic machine gun and haven't speeded up the electrons. The amount of light is the same, so the brightness goes down when you spread it over our new bigger screen.

WILL—So what can we do?

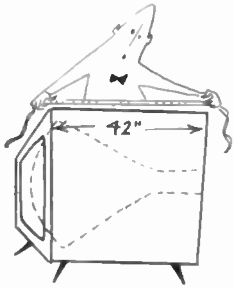
KEN—Run up the voltage! With 10,000 anode volts we'll get the same amount of illumination per square inch over our bigger screen.

WILL—But if you multiply the voltage on the last anode by 4, the sensitivity goes down four times!


KEN—That's exactly the point. It you want to sweep the screen now, you'll need all of 2,000 volts on your deflection plates.

WILL—Wow! But can you get by easier with magnetic deflection?

KEN—Quite a bit! We still have to multiply the accelerating voltage by 4 to get the same amount of illumination. But the sensitivity drops by a factor of only 2, so we can

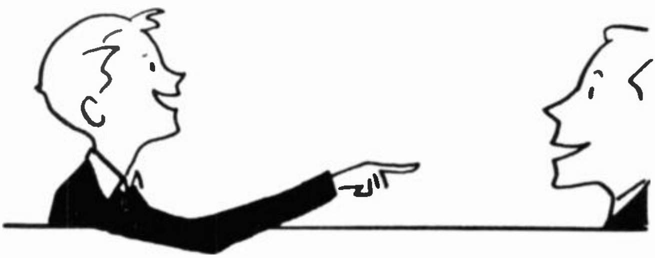



keep the power we need for deflection within more reasonable limits.

WILL—The magnetic deflection tube seems to be in, all right. But how about that 42 inches? I haven't seen any cabinets that deep. How did they get around that?

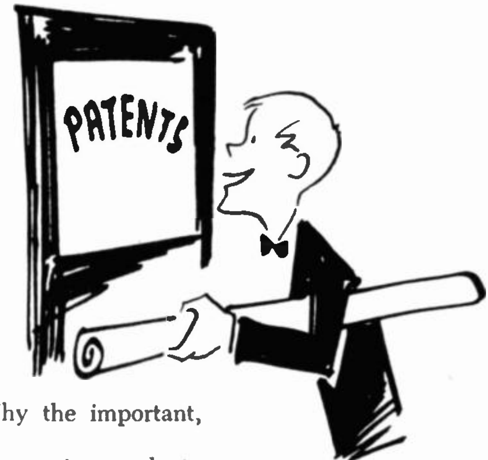
KEN—That's another point in favor of the magnetic tube. When you have to deflect the beam with a pair of closely spaced plates, the angle of deflection is limited to about 20 degrees, so the tube is very long for its diameter. But even the earliest magnetic deflection tubes had deflection angles of 50 degrees, Then came the 70-degree tube, and now we have 90-degree deflection tubes.

WILL—H'm, it won't be long before they go round the circle, and we'll have magnetic deflection 360-degree television crystal balls!



chapter
4

# Time bases




KEN—Just what's going on now? Why the important, secretive air?

WILL—Nothing in particular! I'm just getting ready to take out a patent, that's all . . .

KEN—A patent! I'd like to see the invention you'd turn out! May I ask just what scientific field you've selected to turn your genius loose in?

WILL—Television, of course. Ever since the last time we talked, it's been getting me more and more excited! You've been moving pretty slow with your explanations of how it works, so I've been digging into it myself. That's how I happened to invent my "rotating deflector."

KEN—Rotating deflector? That sure sounds like something new. I don't think I ever heard of anything like it.

WILL—I can trust you, Ken, so I'll tell you my idea. Strictly confidential, of course. Ever since we talked about electrostatic and magnetic deflection, I've been thinking hard about the way the spot is swept to make the lines of a frame . . .

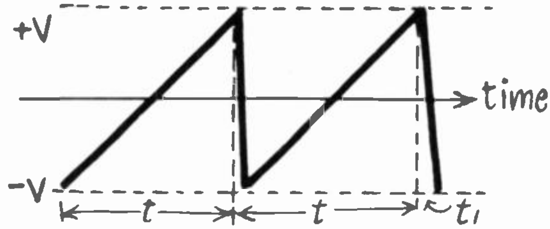
KEN—Yes, we did cover that question when we were studying the electrostatic deflection tube.

WILL—I remember it very well. You have to apply a voltage that starts negative and gets steadily more positive, to move the spot from left to right at a uniform speed. Then we have to get the spot back almost instantly, so we have to drop quickly back to the original negative value and start all over again.

KEN—Do you think you can draw a figure showing that kind of voltage?

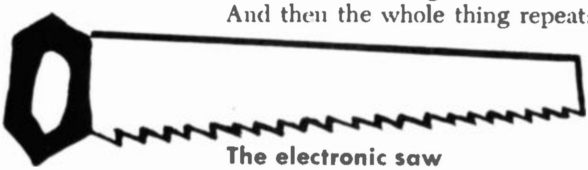
WILL—Sure! The passage from the negative voltage, $-V$, to the positive voltage, $+V$, is made at a constant


rate, so the spot will move steadily across the screen, without changing its speed. So, on this graph, we make a straight line rising progressively from –V to +V, in time *t*,

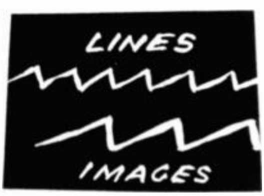



*The voltage increases linearly from –V to +V, the amount of time needed being indicated by the letter t. Note that very little time is needed for the voltage to decrease from +V to –V. The amount of time for the decrease is shown by $t_1$.*

which is the duration of one line on the screen. The straight vertical line represents the almost instant change back to the starting value that brings the spot back again. And then the whole thing repeats.



**The electronic saw**




Ken—Does the shape of that line you've just drawn remind you of anything?

Will—Yes, it's called a "sawtooth voltage," though I suppose on magnetic deflection tubes you'd have to use a sawtooth current?

Ken—Quite right.

Will—And the same type of voltage (or current) deflects the spot in the vertical direction. However, the frequency is much lower, for it determines the number of pictures (or in the interlaced system, the number of half-pictures) a second.

Ken—I can see you really *have* been thinking about this problem. But none of this explains your "rotating deflector."

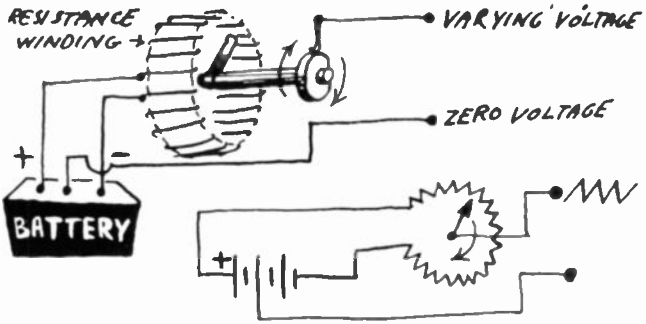

Will—We're getting to it. The device which I have the honor of presenting to you is a sawtooth generator for both horizontal and vertical spot deflection. It's composed essentially of a cylinder of insulating material on which is wound a toroid of resistance wire. A shaft is placed along the axis of the cylinder. As this shaft rotates, a contact finger attached to it makes contact with the resistance wire on the interior face (or one edge) of the cylinder.

Ken—Once you've stripped the Patent Office language off this device of yours, I can't see that we have anything more than an ordinary potentiometer, of the type used for volume controls in some old radios.

WILL—Exactly! The only difference between my potentiometer and any other is that it has no stops, so the contact can keep turning continuously in the same direction.

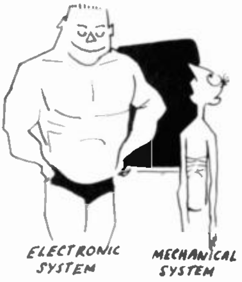
KEN—But just what is this remarkable invention going to do?

WILL—Haven't you already gathered, Ken, that I intend to put a battery or other voltage source across the ends of my potentiometer? Then, as the contact moves, it




*This arrangement uses a battery and the continuously rotating arm of a variable resistor to get a sawtooth wave. Electronic methods are much more practical than the mechanical system shown here.*

passes progressively from a high negative to a high positive voltage; and, as is passes the last wire, it snaps back instantly to the negative voltage, as required in a TV deflection system.




### Weakness of a mechanical system

KEN—Congratulations, Will. The idea (in itself) is good, and I've actually seen a demonstration apparatus in a radio school that worked exactly that way.

WILL—That's not all there is to the idea. I'm going to turn this potentiometer with a motor which will make exactly 60 turns per second, to give the correct vertical deflection voltage. Then, with a system of gears, another potentiometer will be turned to give the horizontal deflection.

KEN—Just what would your gear ratio have to be, and how fast would that make your second potentiometer turn?

WILL—That's not hard to figure out. With two fields in a frame, the ratio would have to be 525 to 2, or 262½ to 1. And the speed of the second pot would be 262½ times 60 or 15,750 turns . . .

KEN—. . . per second! Or a little less than one million rpm! Just what kind of a gear are you going to get that

will hold together at that speed? And wouldn't your resistance wire wear out a trifle fast?

WILL—Now, why didn't I think of that? Well, just another good idea gone wrong. So I guess we'll just have to toss mechanical methods on the junk pile and use some 100% electronic method . . .

KEN—When you bet on electronics, you win! Only an electron can move fast enough to do what's needed at TV sweep frequencies. Suppose you have a 16-inch tube—the line is just a little more than a foot long. The spot goes across the screen—and back—525 times a frame, or 1,050 times the length of the line. And there are 30 frames a second. Figure it out, and you'll find that the spot is moving a little faster than 6 miles a second. At that rate, it would travel around the earth at the equator in very little more than an hour!

### The electronic hourglass

WILL—Boy, when this army of 'odes—the pentodes, triodes, diodes, and all the rest—get under way, supersonic planes just don't move compared to them!

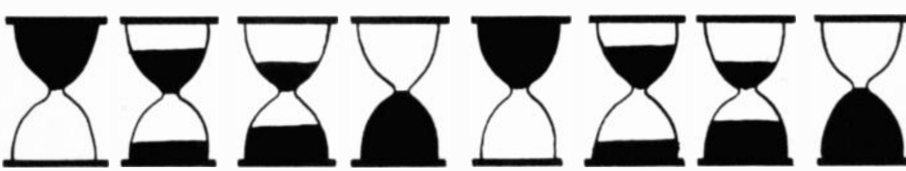
KEN—Actually, tubes play only a subordinate part in these time bases, sweep circuits, or sawtooth generators, as they are called.

WILL—What a flock of queer names! But why time-bases? Is that because the voltages increase proportionately with time?

KEN—Probably. But whatever you call them, we need voltages that increase linearly with time, like those you've just drawn.

WILL—This time-base, then, is a sort of hourglass where the grains of sand are replaced by electrons?

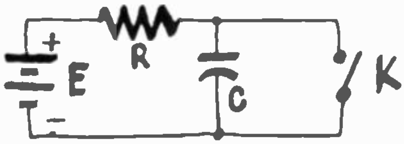
KEN—It's a good picture! Just as the amount of sand in the bottom half of the glass increases steadily till—just as



all the sand has run out—you turn the glass over and the bottom half is suddenly empty again, so in the time-base generator, the current charges a capacitor steadily till the moment of discharge. Then it also becomes suddenly "empty" and the cycle starts again.

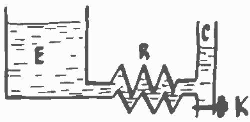
WILL—So, a time-base is mostly a capacitor, if I get you right. But why does it discharge faster than it charges?

KEN—Because you charge it through a resistor. Just picture a source of direct voltage E connected through a resistor R to a capacitor C. Here, I'll draw it. When you close the circuit, a current flows that starts to charge the capacitor to the same voltage as that of the source. But you don't get the full charge instantly, because the resistor limits the amount of current that can flow.


*Capacitor C becomes charged by battery E. Resistor R limits the flow of current.*

WILL—I guess you could compare that to a tank of water E connected through a thin pipe R to a smaller tank C at a lower level. When the valve is turned, C doesn't fill up immediately to the level of E because the pipe R prevents the water from rushing into it instantaneously.




KEN—Your comparisons are getting good today! And the bigger the tank E is in comparison with C, the better the analogy. In electrical terms, the job of charging the capacitor C shouldn't have any noticeable effect on the source voltage E.

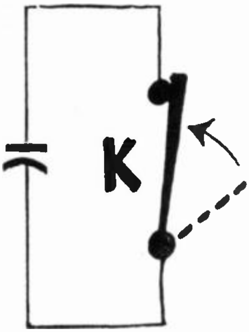
WILL—It seems to me that the charging time depends on the capacitance at C as well as the size of the resistor R. The bigger C is, the more electrons you have to put in to charge it. Just the same as if you make the water tank C bigger, it will take more time for the water to reach the same level as E.


KEN—That's exactly why the product of resistance and capacitance (RC) is called the *time-constant* of the circuit. If you express R in ohms and C in farads (or R in megohms and C in microfarads, as we usually do in electronic calculations), this time-constant will give you, in seconds, the time it will take for the capacitor C to reach roughly 2/3 the voltage of the source.

WILL—So, with a resistance of 10,000 ohms and a capacitor of 2 microfarads, we'd have a time-constant of 20,000 seconds?


KEN—Not bad for a first approximation; you're only about a million times off! Didn't we say *ohms* and *farads*, or *megohms* and *microfarads*? Ten thousand ohms is .01 megohm, so your time-constant is 2 × .01 or two-hundredths of a second!

WILL—Excuse the slight mistake! I see now that if we want our capacitor to discharge instantly, we have to have to place a very small resistance in parallel with it.




KEN—In actual practice, you close the key K, and put a dead short across the capacitor. This is equivalent to opening the outlet valve on tank C.

**Story without an end**

WILL—I'm still thinking about that time-constant. If it indicates the time in which the capacitor charges to two-thirds of full capacitance, then it should take half again as long to complete the charge. So our capacitor with the .02-second time-constant would take .03 second to charge completely?

KEN—Mistake! I've news for you, Will. The capacitor will *never* charge completely!

WILL—But that's nonsense! Why—after a reasonable time—shouldn't the voltage across the capacitor terminals rise to the voltage of the supply?

KEN—Don't you know, that in the Creation of the World of Electronics, first was the electron and the proton. Then after a few other labors, was created Ohm's law. And since then everything has been done according to that law.

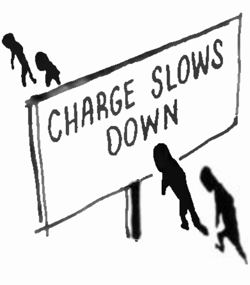

WILL—I know that the current that charges a capacitor has to follow Ohm's law. But what's that got to do. . . ?

KEN—Wait a minute! Is this current you're talking about constant or variable?

WILL—Since the voltage, the resistance and the capacitance are all fixed, there's no reason why the current should vary.

KEN—Yes, there is just one reason. The thing that attracts electrons from the supply terminal to the capacitor plate connected to it is the difference in potential between that plate and the (negative) terminal of the supply source. At the beginning of the charge, that difference is equal to the full voltage. But as the capacitor plate begins filling up with electrons, the difference decreases. And the longer the charging action lasts, the smaller that difference becomes. Now what happens to your rate of charge?

WILL—Obviously, the current will drop as the voltage does. The closer the capacitor is to full charge, the slower the charging will be.

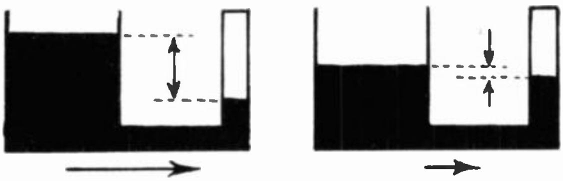



KEN—Now suppose our supply source is 100 volts. If the time constant is .02 second, at the end of that period the voltage across the capacitor plates is 65 volts roughly. In another .02 second, the voltage will have increased 2/3 the difference between 65 and 100 volts. So we'll find about 89 volts across the plates. Another two-hundredths of a second later, we'll measure 97 volts . . .

WILL—But this is never going to end! If each time you increase the voltage across the capacitor by only a fraction of what is needed to reach the supply voltage, it's mathematically impossible ever to reach it!

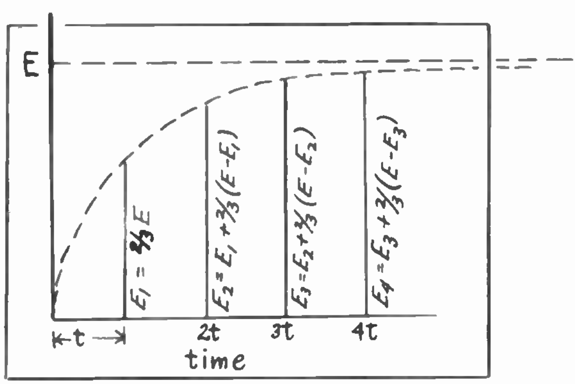
KEN—Correct, Will! The capacitor never gets to full charge. Oh, it would get pretty close to it in a few centuries, but . . .

WILL—But, by the same token, it's impossible for the tank of water C we were talking about yesterday to be filled to the level of tank E, because, if water is to flow into it, there must be a *difference* of level!



*Water will move from one tank to the next as long as a pressure difference exists between them.*

KEN—Exactly. And just to show how the charge drops off, here's the curve showing the law a charging capacitor follows. It's called an exponential curve, by the way. The curve of a discharging capacitor is exponential, too.




*This is the charge curve of a capacitor. Theoretically, the capacitor never reaches the charge voltage E.*

WILL—But then you couldn't use capacitors to control the spot deflection. You need a *linear* voltage variation, represented by a straight line, not this exponential kind of curve.

KEN—Theoretically, you're right. But practically, we can use these curves, as long as we just use a very small part of the curve. Such a small section can be treated like a straight line.

WILL—I see. Just the same as a small part of the earth looks flat, even thought it's part of a sphere.

KEN—And, if there *is* a little curvature, we can correct for it by introducing a little distortion which tends to curve it in the opposite direction.

### The electronic switch

WILL—I can see that a time-base is a very simple setup. A voltage source, a capacitor, and a resistor, are pretty standard equipment. But what bothers me is the switch. How are you going to get a switch that'll open (for almost no time) 15,750 times a second?

KEN—You're pretty sure it won't be a mechanical device . . . ?

WILL—I'll admit that beforehand. Electronics all the way! But what kind of a tube do you use to do that kind of a job?

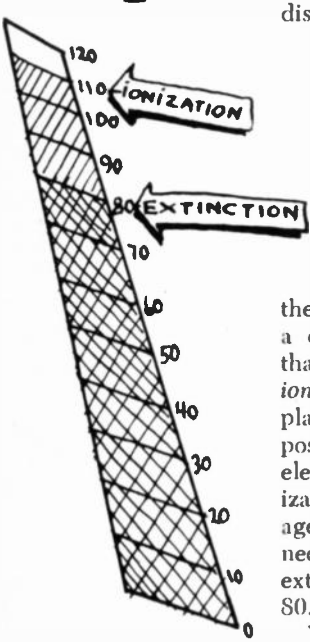
KEN—Believe it or not, you can use a gas tube. And you can make a sawtooth oscillator with an ordinary neon tube.

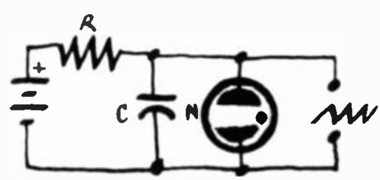
WILL—I know a neon tube can interfere with radio signals. Like the one that used to be on the cafe sign . . .

KEN—The tube we'll use belongs to the same family. But we need only a very small one—a little glass bulb, with two electrodes in the form of halves of a disc, or a spiral or cylinder, and filled with neon at low pressure.

WILL—No filament?

KEN—No more than any other neon lamp. You remember we discussed a neon TV lamp used with the Nipkow disc; it was a nonfilament type, too. Our lamp lights when




*The neon tube is an electronic switch. When the tube ionizes, the capacitor C discharges through it.*

the voltage between the two electrodes rises to more than a certain voltage called the "voltage of ionization." At that voltage the molecules of gas are disassociated or *ionized*. As the positive ions drift toward the negative plate, and the negative ions and free electrons toward the positive one, a current is set up. The space between the electrodes actually becomes a conductor. To stop the ionization (and the light) all you have to do is drop the voltage below a certain point. For example, some types of neon tube require a voltage of 110 to light, or "strike." To extinguish them, the voltage has to be dropped to about 80.

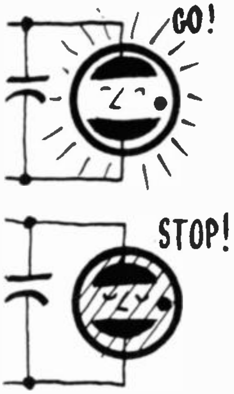
WILL—And how can you use it as an automatic switch?

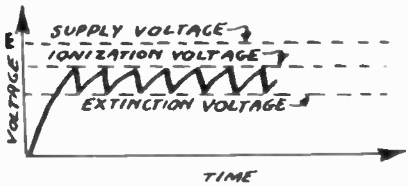
KEN—Easy—just put it across the capacitor C.

WILL—Why this dot in the symbol for the neon tube?

KEN—That just shows it's a gas tube.

WILL—I think I can see what happens. The voltage of the supply source has to be higher than the ionization voltage of the neon tube. So, as long as the voltage on the capacitor is below that value, it keeps on charging normally. But just as soon as the voltage across the capacitor is higher than the ionization voltage, the tube lights and the capacitor discharges through the gas tube almost as if it were short-circuited. Then, when the voltage drops far enough, the tube goes out, becomes a nonconductor, and the charge starts again.




*Here is the sawtooth waveform produced by the simple combination of dc voltage, R—C network, and a neon tube.*

KEN—Perfect! All you have to add is that—in our example—the voltage varies between the ionization voltage of 110 and the *extinction voltage* of 80. So we have an amplitude of 30 volts. And the frequency can be selected by choosing the right values for the resistor and capacitor.

WILL—I suppose that every television receiver uses two neon oscillators then—one for the horizontal, and one for the vertical deflection voltages?

KEN—Not at all, Will. Not a TV set being made today uses a neon oscillator.

WILL—That would make things too simple and easy, eh?

KEN—Please. No sarcasm. There are certain things . . .

WILL—I know. Now I'm going to learn that the neon tube oscillator really won't work.

KEN—Your lack of knowledge is exceeded only by your rudeness. Just be patient for a moment and let me explain.

WILL—Sorry. Go ahead.

KEN—There is nothing seriously wrong with the neon tube oscillator, except that it does have a few defects.

WILL—Such as?

KEN—Like all gas tubes, the neon type is noisy.

WILL—That's right. I should have known that.

KEN—Why?

WILL—Because we once used gas tubes as rectifiers in auto radios. Vacuum tubes were eventually substituted since they produced much less hash.


KEN—Hash?

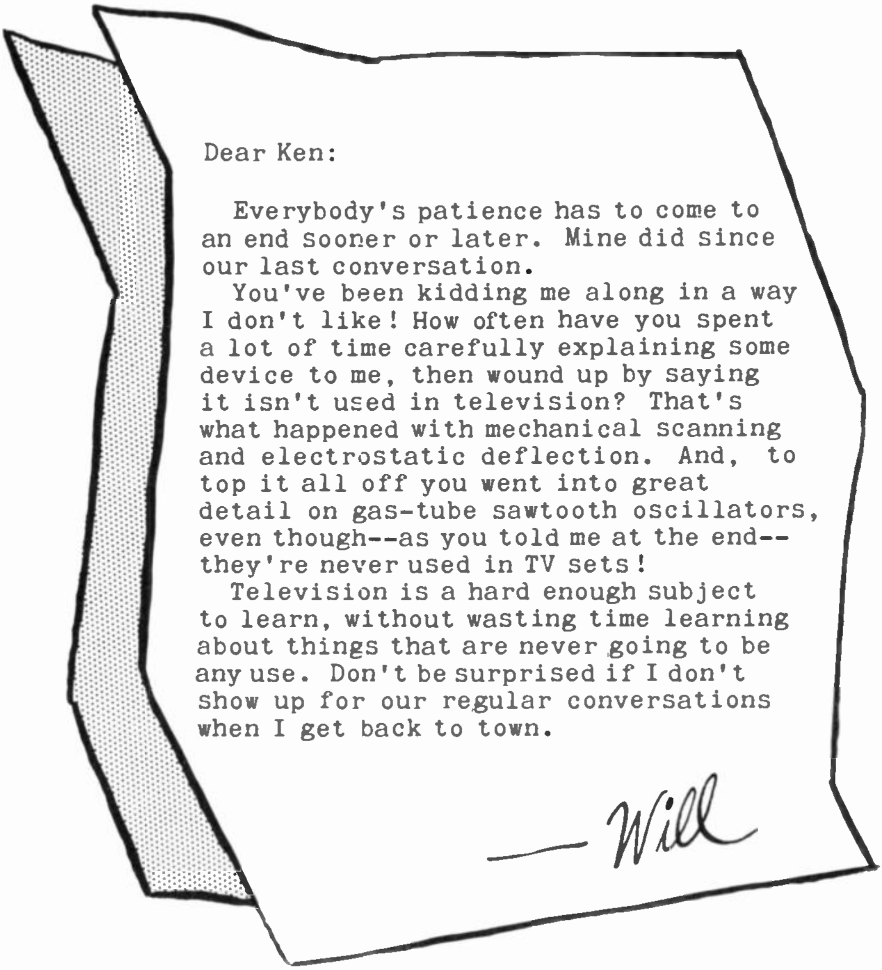
WILL—Yes. You know. Electrical noise.

KEN—Sometimes you surprise me. Now would you like to know about the time bases that are really used in TV sets?

WILL—You mean right now? Why don't we postpone it for a while? I want to think about what we've discussed and see if I can digest it thoroughly.

chapter 5

# Synchronization



Dear Ken:

Everybody's patience has to come to an end sooner or later. Mine did since our last conversation.

You've been kidding me along in a way I don't like! How often have you spent a lot of time carefully explaining some device to me, then wound up by saying it isn't used in television? That's what happened with mechanical scanning and electrostatic deflection. And, to top it all off you went into great detail on gas-tube sawtooth oscillators, even though--as you told me at the end--they're never used in TV sets!

Television is a hard enough subject to learn, without wasting time learning about things that are never going to be any use. Don't be surprised if I don't show up for our regular conversations when I get back to town.

—Will

Dear Will:

I can see why you're annoyed. But don't think I've been trying to kid you! I admit I've described to you in detail some things that are never used in television. But you haven't wasted your time. Learning how these simple things work has helped you understand more complicated methods a lot better.

There was a good reason for talking about the neon lamp. It isn't used in actual television--for several reasons. It's hard to regulate the amplitude of its sawtooth oscillations, they have too much curvature for us to linearize easily, and they're hard to synchronize. But by discussing the neon tube, we found ourselves able to dissect the fundamental principles of <u>all</u> time bases which use a charged capacitor in series with a resistor. You can say that all these devices are made up of three essential parts:

1. The charging circuit (the voltage supply, the resistor the charging current has to pass through, and the capacitor that accumulates the charge).

2. The switch that closes at just the right instant to release the charge built up in the capacitor (our neon tube, in this case).

3. And finally the discharge circuit (which, in the case we were talking about, was that same neon tube). Once ionized, its resistance is so low that the discharge can be very rapid, almost as if it were a mechanical switch.

Now that you have analyzed the simplest time base, you won't have any trouble figuring out the more complex ones. What would you say--for example--about a neon tube with a grid?

I'll be seeing you, I hope, as soon as you get back. With kindest personal regards,

—Ken

## The thyratron—a gas triode

KEN—Glad to see you back, Will. How's fishing?

WILL—You ought to know, after baiting your hook with that neon triode of yours! I suppose that's what you call it, isn't it?

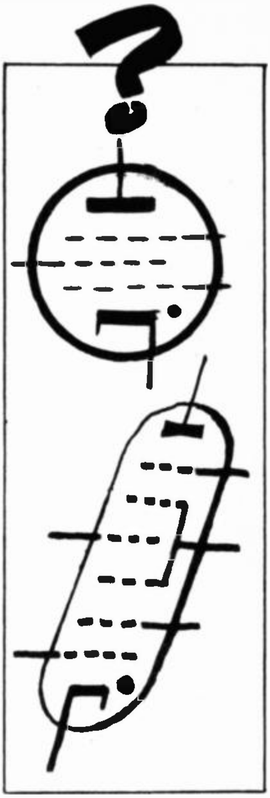
KEN—You can call it that if you like. But the ordinary name for a triode that contains gas (neon, argon or helium) at low pressure is a *thyratron*.

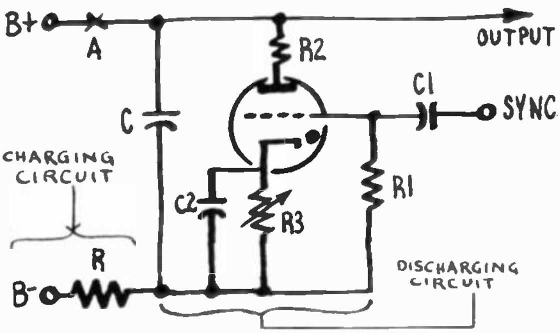
WILL—Don't tell me we've got to study gas tubes now—from the diode to the octode—same as we did ordinary high-vacuum tubes?

KEN—No danger! The three electrodes of the thyratron are plenty to make a fine switch and discharge circuit—just what you need for a good time-base. There are thyratron tetrodes, but we won't have to talk about them.

WILL—That's better! But how do you use this thyratron? You can't hook up a triode like a neon lamp.

KEN—Here's the complete diagram. You see it's quite a bit like the neon-tube circuit. First of all, here's the charging circuit—capacitor C and resistor R connected between B+ and B—.





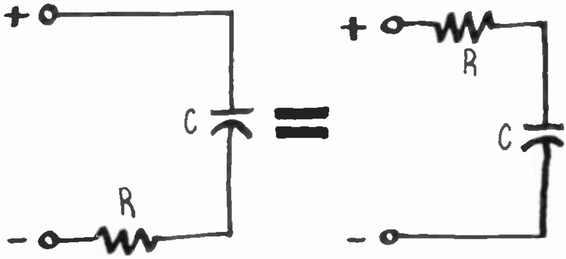

*The gas triode (thyratron) gives much more positive control over the sawtooth forming circuit. The output is taken from across capacitor C.*

WILL—But why's the resistor at the *negative* end instead of the positive end of the circuit?

KEN—It doesn't make any real difference. The resistor and capacitor are in series; it doesn't matter which comes first. But you can switch the resistor around to point A if it'll make you feel any better.

WILL—No need. I can see that in this case it doesn't make much difference which of the components the electrons run into first while they're making their trip around the circuit.

KEN—Now take a look at the discharge circuit. It's the cathode-anode space of our gas tube—again like the neon tube.



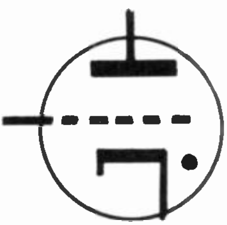

*In time-constant networks such as those shown at the left, it is immaterial whether the resistor or capacitor comes first. The charge-discharge action is the same.*

WILL—Not exactly. You have R2 and R3 in series with that space. Now the discharge circuit is *two resistors* and the tube resistance in series with capacitor C.

KEN—Yes, R2 does look like a plate load. Actually it's a small limiting resistor of just a few hundred ohms. The cathode-anode resistance of a thyratron is so small that when it discharges it can pass enough current to damage itself if it doesn't have some such protection.

WILL—And I take it that R3—between cathode and B minus—is a standard bias circuit?

KEN—You're right. R3—together with C2 across it—is the standard bias circuit. And will you please do me a favor and—for just a few minutes—forget about C1, which couples the grid to something called "synchronization"?



## The grid has something to say

WILL—This looks practically the same as a neon-lamp circuit. I suppose capacitor C charges till the voltage across it is high enough to ionize the gas in the tube. Then the tube's cathode-anode resistance falls to a very low value and the capacitor discharges till the voltage across it gets low enough to stop the ionization. At that point the tube stops conducting and the cycle starts all over again.

KEN—You have it exactly right.

WILL—But then why go to the trouble of using a thyratron, if it works just like a simple neon diode?

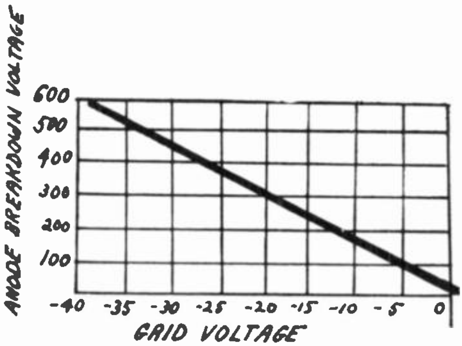
KEN—The grid is what makes the difference, Will. Its bias determines the anode voltage at which the tube will ionize. For example, if you have a high negative voltage on the grid, the plate voltage has to be much higher before the tube will break down than if the grid voltage were zero.


WILL—I think I see. Where the grid voltage in a high-vacuum tube controls the amount of current that will flow through the tube, in a thyratron it sets the ionization voltage.

KEN—Exactly! But the instant the anode voltage is high enough to give the electrons sufficient velocity to break down the molecules of gas they collide with . . .

WILL—. . . then, in the shock of those collisions, one or more electrons are likely to be knocked off each of the gas molecules that get in the way, and so the current of electrons moving toward the anode is increased correspondingly.

KEN—And what do you think happens to those wrecked molecules that the electrons have left along the road?




*The more negative you make the control grid of a thyratron, the higher must be the voltage on the plate to obtain ionization of the tube.*

WILL—Losing electrons leaves them positive. So they'll drift off looking for negative electrodes.

KEN—And which is the most negative electrode in the tube?

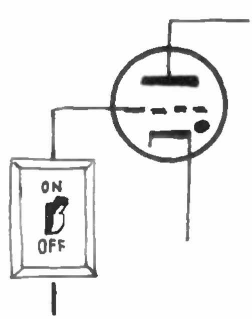
WILL—The grid, of course!

KEN—So the grid will be buried in a big cloud of positive ions as soon as the tube starts to conduct. But let's go back for a moment. In a neon tube, the anode voltage that starts ionization is always the same; but in a thyratron it depends on the grid voltage.

WILL—Sure! The more negative the *grid* is, the more positive the plate has to be to neutralize the grid's influence.

KEN—That's it! And, for each type of thyratron, there's a constant relation between the ionization voltage and the negative grid voltage. You can call it the *control ratio*. It usually runs between 10 and 40.

WILL—If I understand you, a thyratron with a control ratio of 20—for example—and with 15 volts negative on the grid, would need 15 × 20, or 300 volts, on the anode, before it would break down?

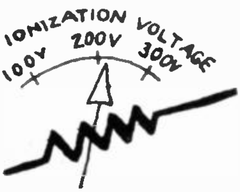



KEN—Your figures are absolutely correct, Will. Now you see that the ionization voltage can be fixed simply by adjusting the grid voltage. That's why R3 is made variable.

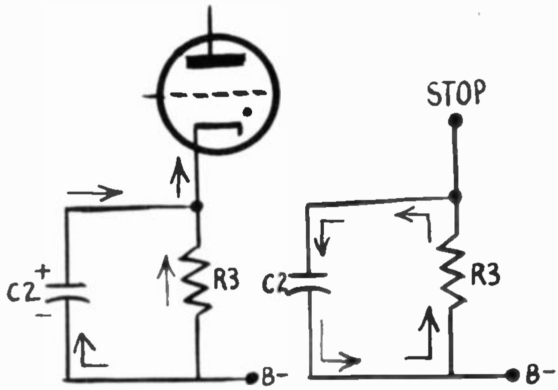
WILL—I suppose the grid voltage sets the extinction voltage of the tube, too?

KEN—You never were more wrong in your life! This grid of ours is so wrapped up in its cloud of positive ions that it's completely isolated from the rest of the tube and can have no effect on the electron flow whatever!

WILL—Then the grid lets us regulate the plate voltage that *starts* the discharge, but the voltage at which the discharge *finishes* is always the same. So, by adjusting the grid voltage, we can vary the size of our sawtooth waves, instead of having them fixed for us they were with the neon lamp.




KEN—That's right. And you can get oscillations several times bigger with a thyratron than you could with a neon tube.




*When the tube conducts, the capacitor charges. When the tube stops conducting, the capacitor discharges through the shunting resistor.*

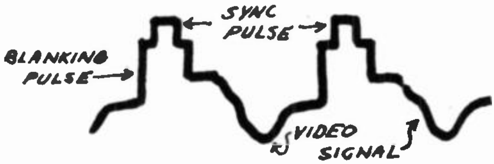
WILL—So I have to think of R3 as the sawtooth amplitude control. And I suppose that C2 is there to pass the ac component of the current?

KEN—Roughly, yes. To be more exact, it equalizes the large variations in the anode current so that the grid bias remains practically constant. At the instant of ionization, the heavy current charges it. Then—at the end of the discharge, when there's practically no current—it starts to discharge through R3. If C2 is big enough, the current through R3—and therefore the grid voltage—will stay pretty much the same throughout the whole cycle.

**Hey, you—keep in step!**

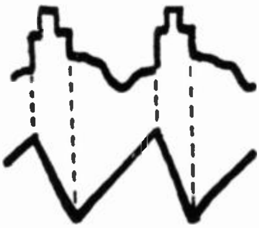
WILL—And now isn't it about time to take the wraps off that mysterious "synchronization"?

KEN—I think so. You know already that the line and frame sweeps at the receiver have to keep in exact step with those at the transmitter. The beginning of each line (and each frame) have to be *synchronized* rigorously at transmitter and receiver.

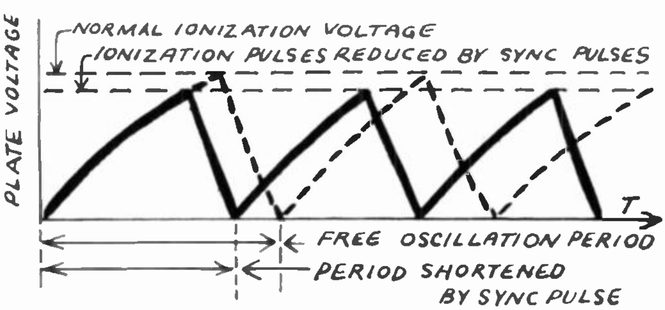



*The sync pulse sits right on top of the blanking pulse. These pulses represent the maximum voltage of the transmitted waveform.*

WILL—I can see that if they got out of step, you'd get a program something like a piece of music played by an orchestra with every instrument a few seconds behind the one beside it.



KEN—Well, let's not try to develop an optical analogy to your musical program. Actually, the transmitter sends out, along with the video signals, short signals (or pulses) to mark the end of each line, and a longer series of pulses to mark the end of each image.

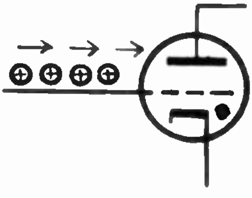



*Development of the synchronization of a time base. The arrival of the positive peaks on the grid lowers the normal ionization voltage. This starts the premature discharge at the same instant the peaks arrive.*

WILL—And it's these pulses you apply—through capacitor C1—to the thyratron grid?

KEN—Exactly. You have to arrange your circuits so these pulses are *positive* when they reach the grid—so that each one makes the grid *less negative* for a short instant.

WILL—I don't quite see what's going on. Does the tube amplify these pulses?



KEN—No, Will. You're just forgetting the effect of the grid on the anode breakdown voltage.

WILL—Of course! When a positive pulse arrives, the grid becomes less negative, and the ionization voltage drops.

Ken—So the normal oscillation period of the horizontal oscillator is made just a little *longer* than the time the transmitter takes to make one line (and the vertical oscillator's period a little longer than the time needed to make one field). In other words, the normal frequency is a little lower than the line or image frequency. Then, just before the anode voltage reaches the ionization point, a pulse comes and makes the grid less negative. So the tube discharges prematurely, *triggered* by the synchronizing pulse.

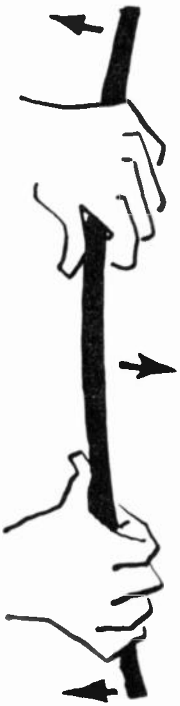
Will—I think I have it now. Say a thyratron has a control ratio of 20 and a grid bias of 15 volts negative. The ionization voltage would then be 300. If the synchronization pulse is 1 volt positive, the ionization voltage will be 280 instead of 300 volts, and the tube will discharge quicker than it would if there were no pulses.

Ken—You have it 100%.

Will—It wasn't so hard! I had a good example to go by. While I was taking swimming lessons on my vacation, the instructor synchronized the divers.

Ken—Huh??

Will—When they got out to the end of the board and were ready to jump, most of them would hesitate. Then he'd just expedite them with a firm push on the back. And then they'd make beautiful parabolic curves!



## Saturated diodes to pentodes

Ken—Speaking of curves, this business of getting a sawtooth wave by charging and discharging a capacitor is fine, except that the sawtooth we end up with isn't quite linear—it has a curve to it. Now we've got to get back to the job of making that exponential curve as straight as possible.

Will—Can't we find some method of keeping the current that goes into capacitor C constant? Then the voltage would rise in exact proportion to time, and we'd have a linear sawtooth.

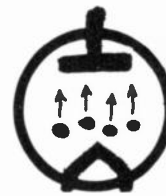
Ken—Maybe you could work out such a scheme. Can you figure out just how you'd limit the current?

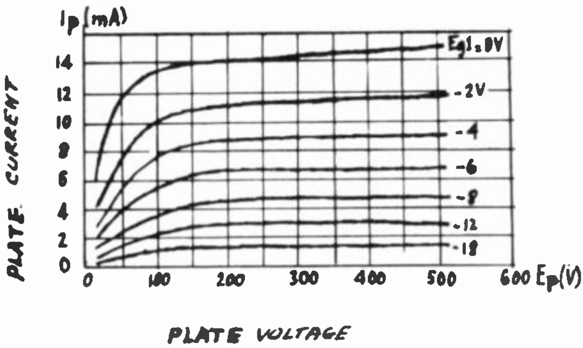
Will—You'd have to replace the charging resistor with something that wouldn't let more than a certain definite amount of current through. How about using a tube—or rather its plate-cathode resistance—for the job?

Ken—That would work, Will. For instance, you could use a diode (preferably a direct-heating type) working at saturation. All the electrons emitted by the filament reach the plate, and so any increase in plate voltage can't increase the current flow. You could regulate the amount of current flow within limits by adjusting the filament voltage.

WILL—But why do you want a direct-heating diode?

KEN—Because a direct heater saturates much more definitely and sharply than an indirectly heated cathode. But if you don't like filament heaters, you can use an ordinary cathode-type pentode.

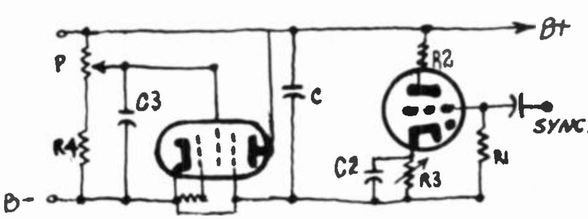





*This is a family of characteristic curves for a pentode. Beyond a certain point, the plate voltage has very little effect on the plate current.*

WILL—Do you work it at saturation, too?

KEN—The term wouldn't be correct, but the result is the same. You know how the plate-voltage/plate-current family of curves of a pentode looks. For any screen voltage, the plate current rises with plate voltage up to a certain point, then changes very little as the plate voltage goes on up. If you work the pentode on the flat part of the curve, it would charge a capacitor at a constant-current rate. Take a look at this schematic. The pentode

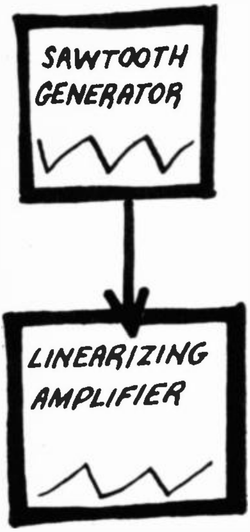



*The pentode replaces the charging resistor and permits charging the capacitor at a constant rate.*

replaces the charging resistor R. The screen voltage is regulated with a potentiometer P in series with a resistor R4 and C3 is a decoupling capacitor.

WILL—These saturated diodes and constant current pentodes remind me of the bed of that old Greek bandit who used to trim off travelers who were too long for it or stretch them out to size if they were shorter than the bed.

## The art of using curves

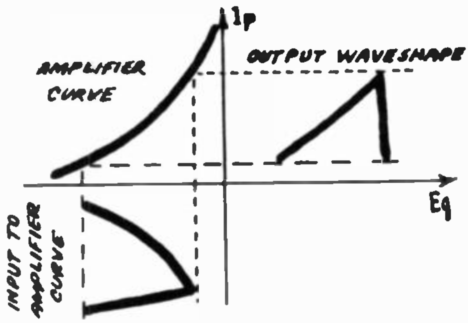



KEN—You're talking about Procrustes. Yes, it is a sort of inflexible way of doing things. As a matter of fact, it's more common to straighten out the curves *afterward*, in the amplifier tube that we need anyway, to bring our sawtooth waves up to the amplitude we want.

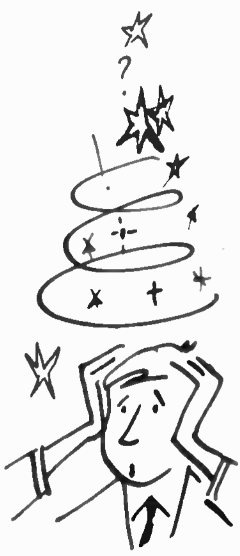
WILL—But how can an amplifier linearize a curved sawtooth wave?

KEN—It's easy. We make it distort a little, so it curves them in the opposite direction! Remember, Will, the most important thing in life is to be able to profit not only from the virtues and good points people or things may have, but also from their very faults and vices! What could be worse than a tube with such a crooked characteristic that it actually deforms the voltage it amplifies? But in this case that very fault becomes an advantage.

WILL—In other words, we have an amplifier tube with a curved grid-voltage/plate-current characteristic. And this




*A tube having a curved characteristic can be used to "linearize" the sawtooth waveform.*



curvature is exactly opposite to the curve of the sawtooth wave itself. If our sawtooth generator produces a wave that has a curve, all we have to do is feed this curved—or nonlinear—sawtooth into an amplifier that will bend the wave in the opposite direction. The result will be a practically straight sawtooth.

KEN—Here's a little drawing that will show that even better than you can describe it. The curves of the amplifier and those of the sawtooth oscillator may not balance each other exactly, but the compensation is good enough for any practical use.

WILL—Well, now that I've got all that down pretty pat, I suppose the moment has come to tell me that neither thyratron time-bases, constant-current tubes, nor linearizing amplifiers were ever used in television?

KEN—Not quite, Will. All of them have been used at one time or another, and some are still being used. Even if they weren't, I wouldn't have wasted your time, because the thyratron time-base is almost universal in oscilloscopes, and you'll use them a lot if you expect to do much with television receivers. But I must admit that there is a much more common type of time-base, and I can tell you now that it really is used in most TV sets. But we'll have to put that off till our next conversation.

## Out of chaos into order

WILL—Wait, Ken. Before leaving, I want to put my new furniture into place. The pieces are beautiful, but I haven't had the chance to examine them.

KEN—What are you trying to tell me? What's this business about furniture?

WILL—You see, since we started our talks on television, you've supplied quite a few new ideas. And I'm beginning to feel that my head is like a big, empty apartment which is gradually being stuffed. The only trouble is that the furniture movers have left everything in terrible disorder. For my head to be in order, all the intellectual furniture has to be put in place.

KEN—Don't let it worry you. I'll be glad to help. I think the best way would be to have a sort of rehash or resume of what we have talked about.

WILL—Good! We started our study of television by talking about the cathode-ray tube. In this tube a stream of electrons is emitted by a cathode. The intensity of this electron beam is controlled by a grid in the form of a cylinder. This grid, doing the same job as the control grid in an ordinary triode, is made negative with respect to the cathode. And, as in the triode, we find after that, an anode carrying a positive potential.

KEN—And what does this anode do?

WILL—It accelerates the movement of the electrons by attracting them. Most of the electrons, though, rush right on by and hit the screen. Where the beam strikes the screen a tiny dot of light is formed.

KEN—Pretty good. We'll make an engineer out of you yet. Let me remind you, though, that since the scanning beam is going to be used like a sharp pencil, we will have to . . .

WILL—Focus the beam. That's usually done by a permanent magnet sitting on the neck of the tube.

KEN—Not bad. Now what are we going to do with our electronic pencil?

WILL—We're going to draw pictures on the screen. The brilliance of each point of light will depend on the


strength of the scanning beam at that particular moment. And that strength will be varied according to the fluctuations of the video signal applied between the control grid and cathode.

Ken—Fine. Now put your scanning beam into motion.

Will—Easily done. We're going to put a pair of coils on the neck of the picture tube. The vertical coils will displace the beam horizontally, making it cover 525 lines of the picture in 1/30th of a second. Another pair of coils, perpendicular to the first, will move the beam vertically so that it will trace 60 fields of 262.5 lines per second. The fields are interleaved to form a frame or complete picture.

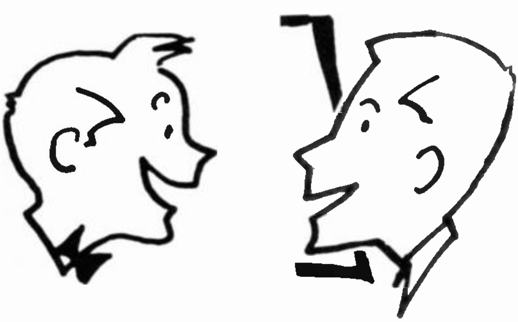
Ken—Congratulations. Most of your mental apartment is in order.

Will—The rest will go fast. To make the scanning spot move uniformly from left to right and then to snap back to the beginning of the next line we have to have sawtooth currents flowing through our deflection coils. Fundamentally, we get these currents through the charge and discharge of a capacitor.

Ken—Good! That wasn't so bad, was it?

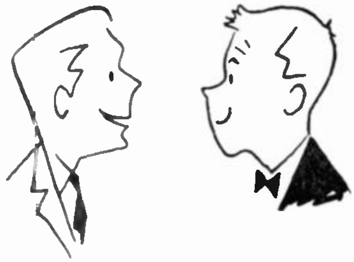
Will—I still get the feeling that we have much more to learn.

Ken—Of course. But it's getting quite late, so why not let it go for our next meeting.



chapter 6

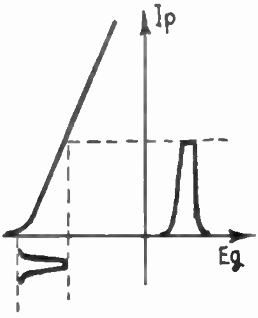
# Vacuum-tube time bases



## The "Will" time-base

WILL—You sort of broke a bad habit when you said at the end of our last conversation that thyratron time-bases are really used in modern TV receivers . . .

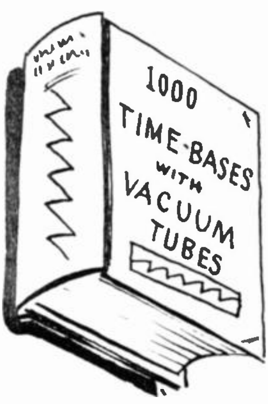
KEN—Well-l, I may have stretched things a little. They were used for a very short time, but I can't think of a manufacturer using them now. After all, gas tubes have a rather short life . . .




*A small amount of grid voltage can result in a large amount of plate current.*

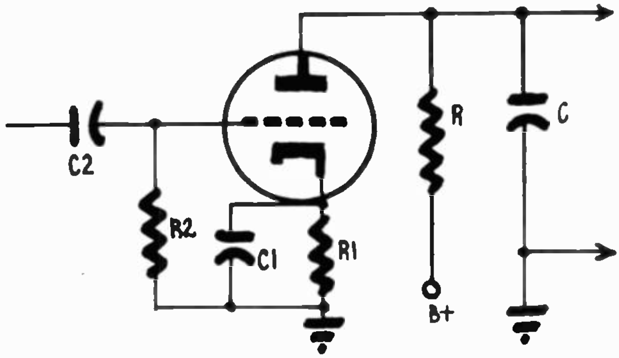
WILL—That's right! I can't see that using thyratrons is a good idea, anyway! Ordinary vacuum tubes would do the job just as well. I've worked out a very simple scheme that will make thyratron time-bases look silly!

KEN—Well, let's hear about it! But I warn you in advance that plenty of inventors have designed time-bases with high-vacuum tubes, long before you ever even thought of the idea!

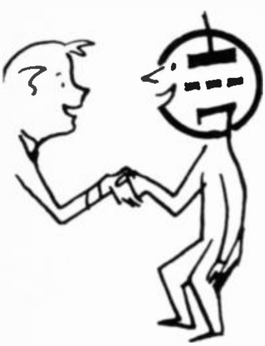



WILL—As usual! There's never anything left for me to invent. Why wasn't I born 50 years ago? But take a look at this time-base diagram. This is just the "Will" circuit—not the Williamson. It uses one vacuum tube—in this case a triode. It must be one with high mutual conductance and a sharp cutoff. Then we bias it to the point where the current is just cut off, so that a positive voltage pulse on the grid will produce a rather large plate current.

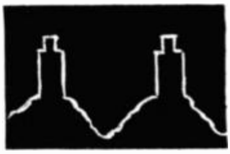
KEN—I can see what you are trying to do.




*Time-base circuit diagram. During the time that the tube is cutoff, capacitor C charges. A positive pulse coming in to the control grid through C2 produces a large flow of tube current and capacitor C discharges through the tube.*



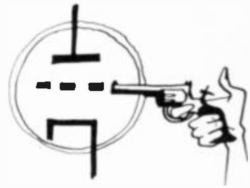
WILL—It isn't hard to understand. I have a charging circuit made up of resistor R and capacitor C, the same as in the thyratron circuit. The cathode-anode space of the tube is the discharge circuit. Normally the cathode resistor R1 (decoupled by C1) biases the tube just about to cutoff. During cutoff time capacitor C becomes charged, at a rate set by resistor R and capacitor C. Then I apply positive synchronizing pulses to the control grid through capacitor C2. As each pulse arrives, plate current is established, permitting capacitor C to discharge itself rapidly through the tube. What do you think of the idea? I'll be surprised if you haven't got at least a few objections!



KEN—No, Will, your lineup will work fine, *if* the sync pulses arrive at the receiver with roughly constant amplitude. It would work nicely with a receiver near a transmitting station. But in a fringe area, the synchronizing signals don't all arrive with the same strength and the discharges would be produced at a variable frequency, which would deform the picture. Another thing—when your station isn't transmitting, you get no sweep. Then the spot stays in the same place on the screen and destroys the phosphor there.

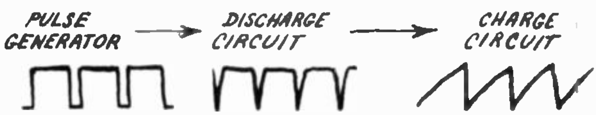
WILL—If I get you, my idea isn't worth too much?

KEN—No, I think your hookup is good. Only, instead of producing the discharges by applying the pulses directly to the grid, it's better to use locally generated pulses, with their frequency and amplitude both carefully regulated. Then you can control them with the sync pulses, and trigger your discharge tube reliably.



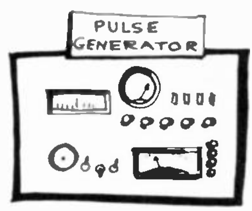
### Old idea in a new role

WILL—In other words, you want to introduce scientific organization by separating the functions. The resistance-capacitance charge circuit does its part of the work. The




*In effect, the time-base circuit changes the rectangular pulses of the generator to sawtooth waveforms.*

tube acts as the discharge circuit. Some mysterious device puts voltages on the grid to trigger the pulses. And finally, the sync pulses from the transmitter regulate the frequency of the pulses produced by the mysterious device?

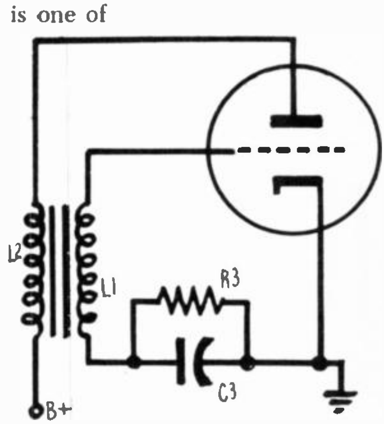



KEN—Everything really is just about the way you put it. And this device (you call it a "pulse generator") has its own natural frequency, so that even if we lose several sync pulses due to fading, the sweep frequency won't get too far out of the way. And it works whether or not a station is sending sync pulses.

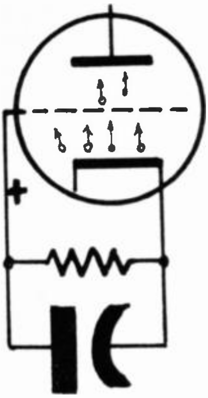
WILL—But how do you make these periodic pulses?

KEN—With the help of a blocking oscillator—or a squegger, as some of our would-be-learned friends would call it. Here's the hookup.

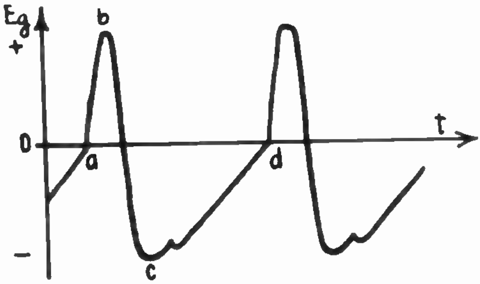
WILL—And *this* is television? Why, Ken, this is one of



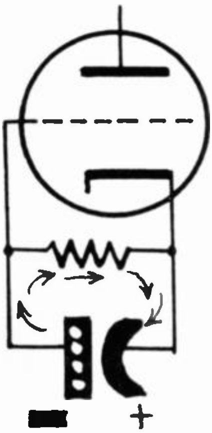

*Circuit diagram of a blocking oscillator. Initially, current flows from cathode to plate, through coil L2 and then back to the cathode (through the power supply.) A magnetic field around L2 induces a voltage across L1. This voltage will help drive the tube to cut-off or saturation. The tube is made to behave like an electronic switch, constantly opening and closing.*



my oldest friends! I built one of these when I belonged to the Boy Scouts, when I was learning the code. If it isn't the oldest oscillator in the world, it's not far from it. The grid leak and capacitor are on the wrong side of the grid coil, but that doesn't really change anything. But I do happen to know that this produces sine waves, not the pulses we've been talking about!



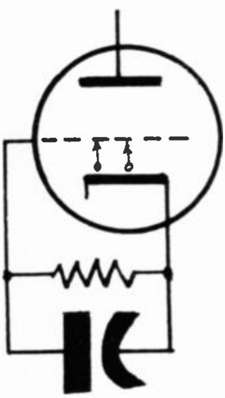

*Waveform of the voltage on the control grid of the blocking oscillator.*



KEN—That depends on the circuit constants. To make pulses, capacitor C3 and resistor R3 must have a considerably higher value than for a sine-wave oscillator. And the coupling between the grid and plate coils must be very close.

WILL—I still can't see why—even under those conditions—you get anything but good sine waves. When current starts in the plate circuit, the coupling between L2 and L1 makes the grid more positive. That can't help but still further increase the plate current . . .

KEN—Wait a minute! Stop right there! Your reasoning has been good so far, but it won't be if you go on much longer. Don't forget that the coupling between L1 and L2 is *very tight*. So the grid goes positive very rapidly. Because of that, it begins to attract electrons from the cathode.



WILL—Does it think it's an anode of some kind or another?

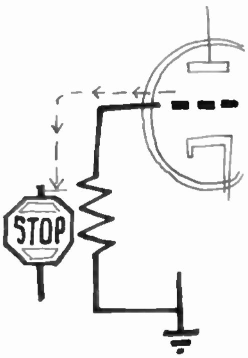
KEN—You could look at it that way. In any case, those electrons rush into C3 and charge it.

WILL—Don't they flow rapidly off toward the cathode? Isn't that what "grid current" is?

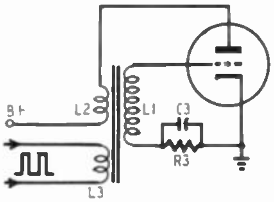
KEN—They do, but *slowly*, because of the high resistance of R3. So you can see that the grid voltage, after a rapid rise (from *a* to *b* in the curve) not only ceases to be positive, but becomes negative (as at *c*); this *grid-leak-bias* brings the tube down toward the cutoff point and we say that the tube is *blocked*. There is no noticeable plate current (or grid current either) for the moment.

WILL—But if there's no grid current, how can we have grid-leak bias?

KEN—Actually, this grid-leak bias comes in two parts. We get it at first because of current flowing from the cathode to the control grid inside the tube. This current flows through the grid-leak resistor, making the grid end more negative than the cathode end.




WILL—That I understand. But when the grid stops attracting electrons from the cathode, and there is no more flow, then where do we get our bias from?




*An extra winding permits injection of sync pulses to the blocking oscillator.*

KEN—See that capacitor C3? What is its relationship to R3?

WILL—I don't quite get what you mean?

KEN—Is it in series or parallel with it?

WILL—In parallel, of course, but . . .

KEN—That means, then, that the voltage developed across R3 will also be across C3.

WILL—Check.

KEN—Then C3 will charge. Now, when will it discharge?

WILL—I understand it now. We get the first part of the bias when the control grid attracts electrons and returns them home through R3. And the second part comes when C3 discharges through R3, which it does just as soon as the voltage across it is *greater* than the voltage developed by the grid current through R3. So these two currents, one direct from the grid and the other from electrons stored up in C3, keep the tube cut off till C3 is discharged.

KEN—Correct. And is that all?

WILL—No, that's not all. Everything starts all over again as soon as the grid voltage reaches a point where plate current can flow (*d* on the curve). We have another rapid positive thrust of the grid voltage, which makes another pulse, and a much longer negative period.

KEN—That's just about what I was trying to get across.

WILL—Simple! It's what I'd call a "police interrogation" circuit.

KEN—Do you mean to say you've found something in your favorite *True Detective* stories that you can use in your scientific life?

WILL—It's obvious. Standard third degree! A gangster is being questioned. He gets a heavy rap on the head, passes out; and as soon as he comes to, lets out a yelp. To keep him quiet, they give him another tap on the head. He comes to again, lets out another pulse—I mean another yell—gets another wallop, and so on.

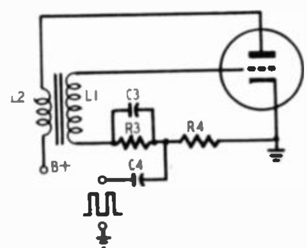
KEN—I only hope, Will, that we will be able to make you as great an authority on television as you seem to think you are on criminology!

### Simplifying simplifications

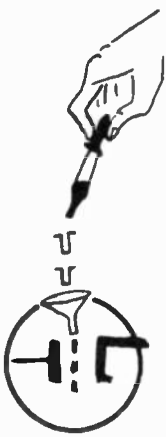
WILL—And how do you synchronize this blocked oscillator?

KEN—Simply by applying positive pulses to the grid, which trigger—at the right instant—the impulses which are being produced in the same direction.

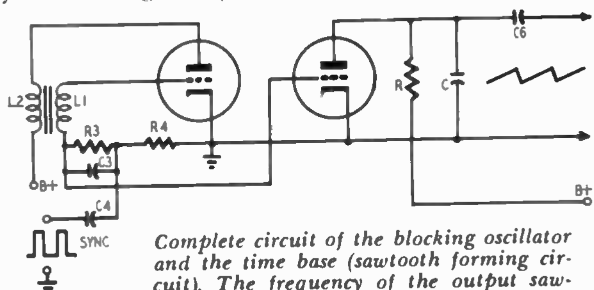
WILL—Third-degree methods again. When the gangster shows signs of coming to, it's correct to pour cold water on his face to speed up his return to consciousness.




*The sync pulses can be fed in through a capacitor.*

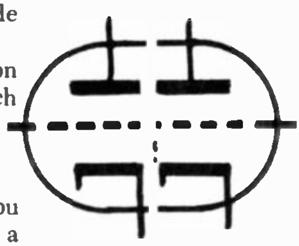


KEN—You'll excuse me if I think we can get along without gangster analogies! Now, we can use various methods of applying these synchronizing pulses to the grid of the blocked oscillator. You can use a third winding, L3, on your *blocking transformer* or you can bring them in




*Complete circuit of the blocking oscillator and the time base (sawtooth forming circuit). The frequency of the output sawtooth waveform is the same as that of the sync pulse.*

through a capacitor C4 which is connected at the hot side of a resistor R4 inserted into the grid circuit.

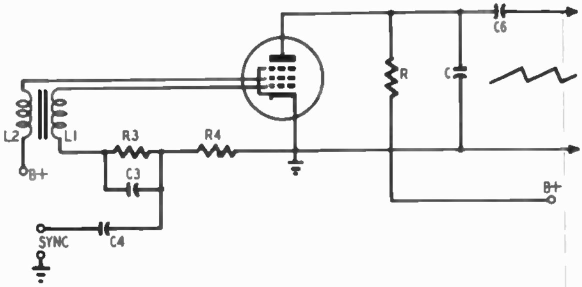


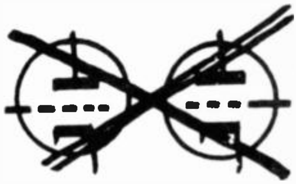
WILL—If we adopt that system, won't the combination of blocking oscillator and discharge tube look very much like the schematic I designed?

KEN—That's right.

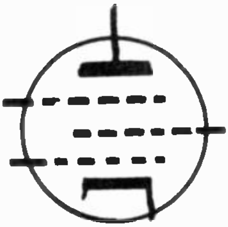
WILL—Only, it's no longer very simple.

KEN—That it isn't! In practical circuits, though, you can replace the two tubes with one; or at least use a double triode.



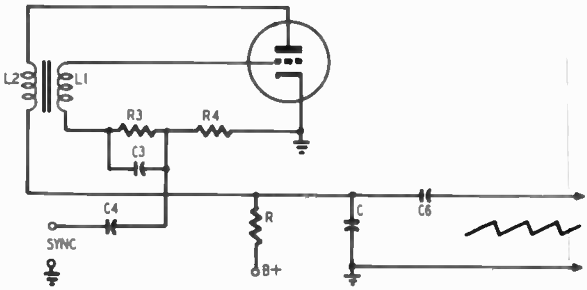



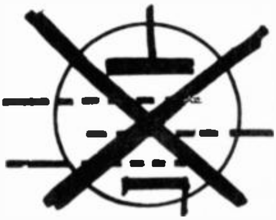
*A single pentode can be used as a combined blocking oscillator and sawtooth forming network. This circuit is not necessarily simpler than the double triode shown on page 72, since duo-triodes (two tubes in one envelope) are quite common.*



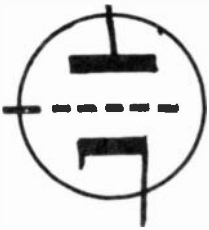
WILL—That doesn't simplify the hookup much.

KEN—Well, let's use a single pentode then. The blocking oscillator uses its screen as an anode. The cathode-anode space still serves as the discharge path for capacitor C. And this discharge is controlled by the rapid positive surges of voltages impressed on the grid at the sweep frequency.

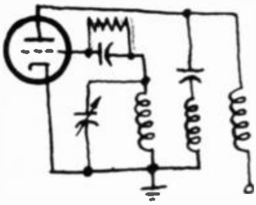


*A single triode makes the blocking oscillator and time base circuit as simple as possible.*



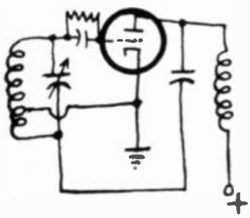
WILL—Couldn't we replace our pentode with an ordinary triode by connecting L2 to the plate and putting the charging circuit in series with it?



KEN—It has been done. But let's stop simplifying—before we wind up with a perfect sawtooth generator made out of a pilot lamp and a flashlight battery!

WILL—Isn't it possible to develop other pulse circuits than the one we've just been looking at? There are so many sine-wave generator circuits: Hartley, Reinartz, Colpitts . . .

### Input and output together

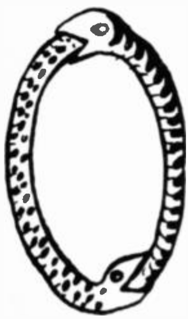


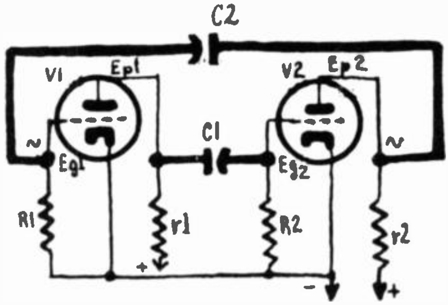
KEN—Sure, you *could* use such circuits, but they would only bring in unnecessary complications. But, you can abandon coils altogether and get the feedback you need for oscillations by using a second tube whose voltages will be opposite in phase from the first, then reinjecting these voltages back into the input to maintain the oscillations.

WILL—That explanation doesn't seem very clear.

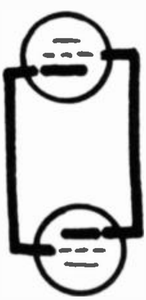
KEN—Let's try it another way. Imagine a two-tube, resistance-capacitance coupled amplifier. Connect the output back to the input. What do you get?

WILL—Something like two snakes eating each other up tail first!





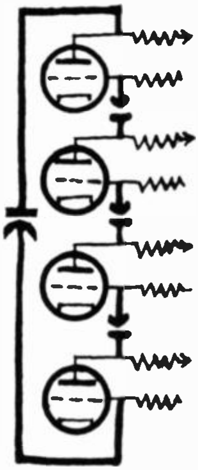

*The multivibrator circuit is very much like an ordinary resistance-coupled amplifier. Capacitor C2 provides feedback from the output to the input.*



KEN—We're not going to do too well with examples from the zoo so let's cut them out! Now, how about analyzing just what *does* happen in such a circuit?

WILL—Well, suppose I try to reason it out the way you'd do. Let the plate current of V1 be increasing. Then the voltage drop across plate resistance r1 increases, reducing the plate voltage Ep1 on the first tube. This—acting through coupling capacitor C1—reduces the voltage Eg2 on the grid of V2. As it becomes more negative, the plate current of V2 drops. Therefore, there is less voltage drop across r2, and the plate voltage Ep2 increases, increasing Eg1 through coupling capacitor C2. That, of course, makes V1 draw more current.

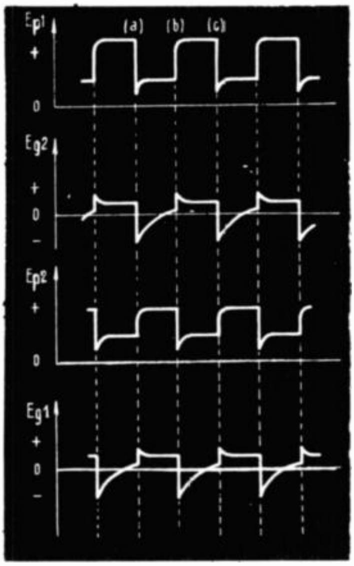
KEN—Of course, you understand that all these things are happening at the same time. What is important is to note that the voltage at the output is in such a direction that it *helps out* the things that are happening at the input. The output and input voltages are *in phase*. And we should expect it. You've learned long ago that a stage of amplification reverses the phase: when the grid becomes more positive the plate becomes less positive, and *vice versa*. So, with two stages, we get back into phase again.



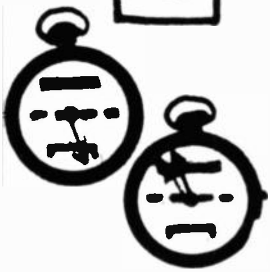
WILL—Then you could use four tubes? Or six? Or eight?

KEN—You could. But are you a tube manufacturer's agent?

WILL—It seems to me our explanation didn't finish. Can the current in V1 keep on increasing indefinitely?




*Grid and plate voltage waveforms of the multivibrator.*



KEN—Certainly not—the house fuses would blow sooner or later! The rapid increase of current in V1, by making the grid of V2 more negative, reduces its plate current to zero (instant *a* in the curves Ep1, Eg1, Ep2, Eg2). With no further increase in Ep2, there will be no increase in the voltage Eg1. So the plate current of V1 remains high and its plate voltage low. Now C1, which is charged negatively, begins to discharge through R2 (instant *a-b* on the curve Eg2).

WILL—I'm having trouble following so many things at the same time!

KEN—These curves should give you some help.


WILL—As capacitor C2 discharges, plate current flows in V2 and starts to increase.

KEN—That's right. And (at instant *b* on the curves) V2 finds itself in the same condition as V1 at instant *a*.

WILL—In other words, the voltage Ep2 drops; C2 passes that drop in voltage to the grid of V1, reducing its plate current and increasing its voltage. And that makes the grid of V2 still more positive.

KEN—You can stop now, Will, because the *multivibrator* will keep right on going. This oscillator with the long name produces regular voltages with an irregular shape. The two tubes repeat—every half-cycle—everything it has taken us so long to trace out with the curves' help.

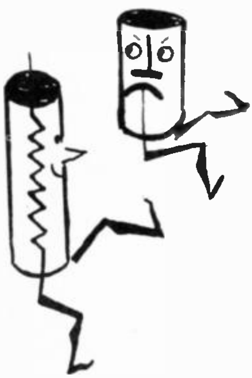
WILL—But this multivibrator won't give us sawtooth waves!

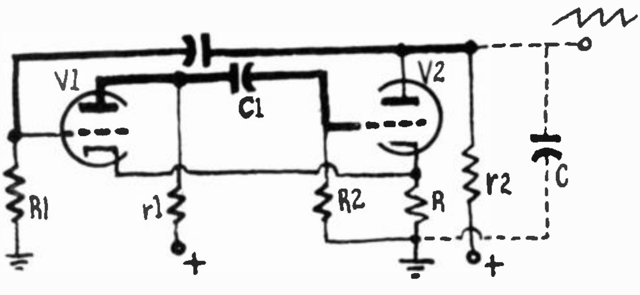
KEN—Well, no. Their plate circuits produce something more like square waves. These have plenty of applications in television—and in the whole field of electronics. The duration of their positive and negative alternations is identical if all the equivalent components in the two stages have the same values. But if they differ, we destroy the symmetry. By changing them intentionally we can get short impulses separated by relatively long periods. So we get our sync pulses.

## Return of the sawteeth

WILL—Couldn't we replace our two tubes with a double triode?

KEN—We can and we do. And further, if we have a single-cathode tube, or tie the two cathodes together, we



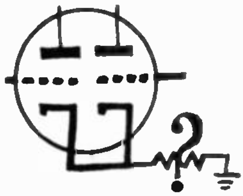



*Cathode-coupled multivibrator using a twin triode. C is the sawtooth forming capacitor.*

can use the coupling through the common resistance R to replace one of our coupling capacitors.

WILL—I don't see just how you can make a resistor replace a capacitor.

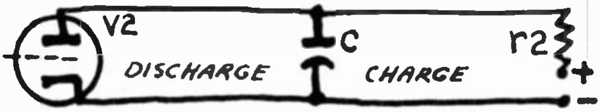
KEN—It's not hard to figure out. Remember that each increase of plate current through one of the triodes increases the current through R, which makes the grid of the other tube more negative, since the voltage drop across R makes the end to which the grids are tied negative as compared to the cathode end. The capacitor on the other multivibrator produced the same effect.




WILL—I see. And you apply your sync pulses through a capacitor to the grid of V1, in the usual style.

KEN—Yes, and I find it simple to synchronize the circuit because the multivibrator is a very easy circuit to pull into step with a synchronizing frequency.

WILL—The multivibrator seems to have a lot of virtues.




*This is the elementary charge-discharge circuit as it would appear if it were removed from the multivibrator.*

But since we are supposed to be talking about sawtooth generators, what good are they if it won't make a sawtooth wave?

KEN—If you must have sawteeth, we'll give you sawteeth! Just put the capacitor C (look at the dotted lines) between one of the plates and B minus. Then make the plate resistor (r2) of that tube considerably larger than that (r1) of the other tube. And you have sawtooth

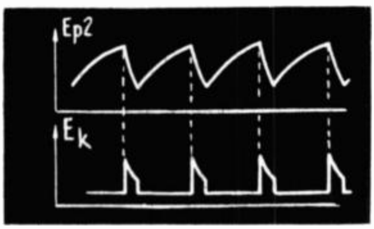



*Plate and cathode voltage waveforms of the cathode-coupled multivibrator when C is added (to the circuit on page 76) to produce sawteeth.*

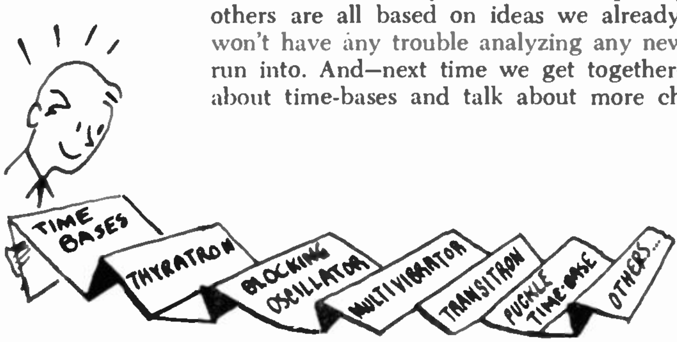
voltages across r2!


WILL—Is this our old charging circuit, with r2 playing the part of R? (page 49).

KEN—Exactly. Because of the high resistance of r2, we start with no current in V2. The voltage across C has to rise to a fairly high value before the capacitor starts to discharge across the anode-cathode space of the tube. But then we have an avalanche! For, as current starts in V2, the voltage across the cathode resistor rises, making the grid of V1 relatively more negative with regard to the cathode. Its current drops, and its plate voltage rises, charging V2's grid *more* positive through C1, accelerating the discharge. This quick discharge, followed by a slower charge limited by the constants of C and r2—when the current through V2 is cut off—gives us a typical sawtooth wave. Thus V2 plays the role of a discharge diode for capacitor C.

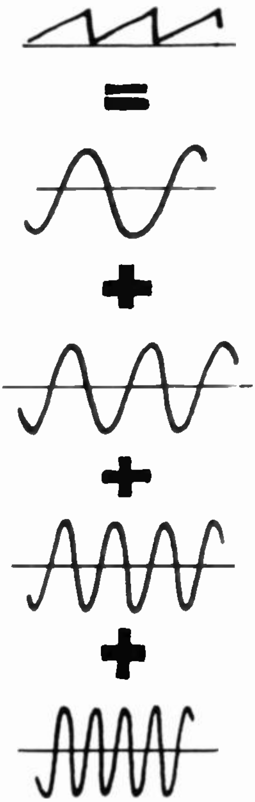
WILL—So now I know all the ways of making sawtooth waves!

KEN—Sorry to disillusion you, Will; there are plenty of others! But with the thyratron, the blocking oscillator and the multivibrator, you know the principal types. The others are all based on ideas we already know. So you won't have any trouble analyzing any new ones you may run into. And—next time we get together—we can forget about time-bases and talk about more cheerful subjects.



chapter 7

# Sawteeth in action



WILL—Last time, Ken, you promised that today we would have something better to talk about than sweep oscillators. I'm beginning to see them in my dreams! Right now, my trouble is that I don't just see *how* you get those sawtooth voltages onto the deflecting equipment—the deflection yokes, or—if you have an electrostatic set—plates.

KEN—Good! It's fine to have those voltages, but even better to know how to use them. First, we have to put them through an amplifier; they usually don't have enough amplitude to swing the bright spot all the way across the fluorescent screen.

WILL—That should be easy—the frequencies are fairly low.

KEN—Not so fast! The *fundamental* frequency of the time-bases is reasonably low. But they're not sinusoidal oscillations—far from it! So they're very rich in harmonics. You still remember what a harmonic is?

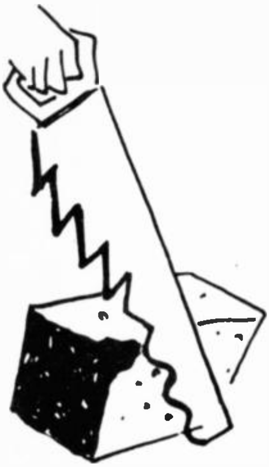
WILL—Of course! Harmonics are oscillations at multiples of the fundamental frequency!

KEN—Roger! Now, our harmonic-rich sawteeth need an amplifier that can pass a very wide band of frequencies. Otherwise we'd eliminate some of the higher frequencies, and deform our waves.

WILL—If I get you right, an amplifier that would cut off *all* the harmonics and leave only the fundamental would make sine waves out of our sawteeth?

KEN—Exactly—if you could get an amplifier that would cut off all the harmonics and still leave the fundamental! An amplifier usually attenuates only the higher frequencies, and just rounds the teeth off a little.

WILL—Oh! A worn-out saw!



KEN—Remember, quite often we use an amplifier that changes the form of the sawteeth *intentionally!* We can use one to make sections of an exponential curve into straight lines, for instance.

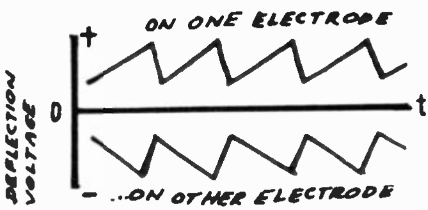
WILL—So I was in too much of a hurry when I decided that a time-base amplifier was simple!

KEN—At last you're right; It does a lot of jobs—it's an amplifier, it produces high-frequency harmonics, and it linearizes curved waveforms. But that's not all! In magnetic-deflection receivers, it has to deliver power . . .

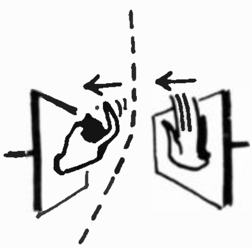
WILL— . . . like an ordinary audio-output stage that supplies power to the speaker. But in electrostatic-deflection receivers the amplifier supplies only voltages. There isn't any current to speak of, and so, practically no power.

### Port and starboard

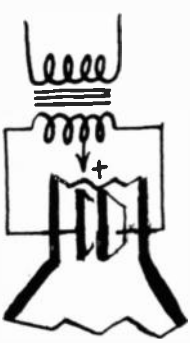
KEN—Yes, the electrostatic-deflection jobs are simpler. Let's find out how they work first, then go on to the magnetic systems, which are a little harder. Even electrostatic deflection has it problems. We have to apply a pair of voltages phased oppositely to the two deflection plates.




*The sawtooth voltages placed on the deflection plates are equal in amplitude but opposite in polarity.*



That is, while one plate becomes more positive, the other is becoming more negative. Then both plates have to drop back to zero simultaneously and practically instantly, so the whole thing can start over again.

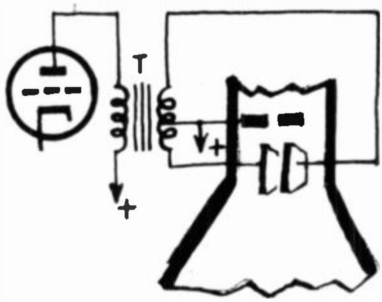


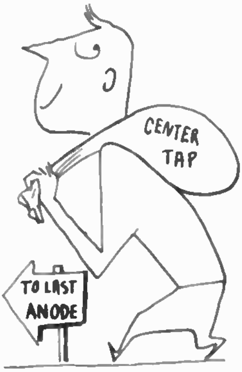

WILL—But how do we get these two oppositely phased voltages? Do we need a pair of sawtooth generators? What a mess!

KEN—Take it easy, Will! Remember when we were studying push-pull audio amplifiers? What did we find to be the easiest way to apply equal and opposite voltages to the output grids?

WILL—A center-tapped transformer was the simplest way out.

KEN—And so it is here! Take a look at this sketch. You put the primary in the plate circuit of the horizontal sweep amplifier, connect the ends of the secondary to the deflection plates, and bring the center-tap back to the last anode, so that the deflection plates and it will be at the same voltage.

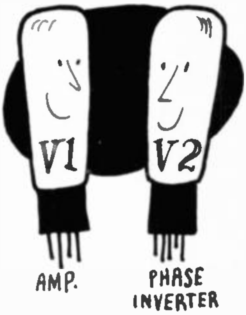


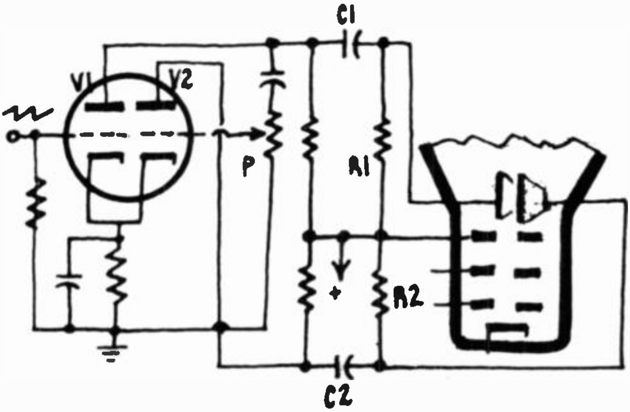




*The opposite ends of an output transformer make ideal connecting points for the deflection plates. The voltages at the ends of the transformer are equal in strength but opposite in polarity (with respect to the center tap).*

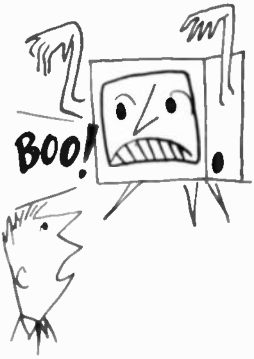
Will—And could you use a tube-type phase inverter with cathode-ray tubes?

Ken—Sure! Look at this. V1 is an amplifier; V2 a phase inverter. Potentiometer P controls V2 so its output is exactly the same as V1.




*A vacuum tube can be used as a phase inverter as shown in this circuit. The signal voltage on V1 plate is equal to that on V2. The two voltages, however, are 180° out of phase—that is, when one voltage is positive going, the other is negative going.*




**All seems simple**

Will—None of this looks very tough. When you really know radio, you don't run up against many surprises in television!

KEN—You'll find that out when you look at magnetic-deflection circuits, where you have to get power out of your amplifier, just like an audio-output circuit. The power is used to set up magnetic fields around the deflection coil. The field strength depends on the number of turns in the coil *and* the amount of current going through it.


WILL—I know, Ken! And you make me feel good by talking about ampere-turns that I can understand, instead of gausses, maxwells or oersteds, that don't mean a thing to me!

KEN—You know then that a coil of 1,000 turns with 0.12 ampere passing through it. . . .

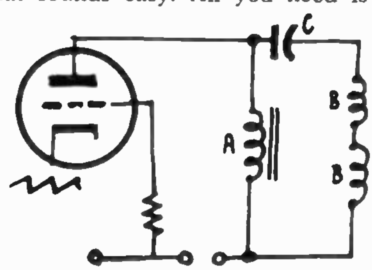
WILL—. . . sets up a field of 0.12 × 1,000 or 120 ampere-turns.


KEN—And that you could get the same field from a coil of 200 turns . . .

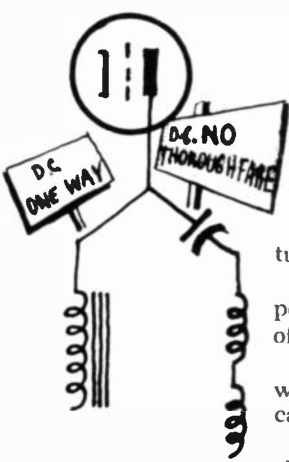
WILL—. . . and a current of 0.6 ampere.

KEN—Yes, and that happens to be just about the power needed to sweep a 10-inch tube screen. The field must rise from zero to 120 ampere-turns to sweep the spot once across the screen from left to right. That is, the current through our 1,000-turn coil must increase evenly to 0.12 ampere, then drop very rapidly to zero, and repeat.

WILL—That sounds easy. All you need is a good big




*The choke, A, is an inductive load for the tube. The two inductors marked B are deflection coils.*




tube. Insert the deflection coils in its plate circuit . . .

KEN—. . . and the dc through the coil would set up a permanent field that would keep the spot somewhere right off the screen!

WILL—So that won't work, eh? But how would this work? Connect the two deflection coils B through the capacitor C, with an inductance A to carry the current.

KEN—Fine, chum, fine! But what are you going to do about the well-known phenomenon of self-induction?

WILL—What's self-induction got to do with it?

## Deduction about induction

KEN—Well, now, we've a bit of wire in these coils—

about 1,000 turns each. The inductance is about 0.15 henry. Won't the rapid current variations produce some effects we'll have to take notice of?


WILL—Now I remember our old formula: "Induction equals contradiction." The induced current always opposes the current that produced it. If the current in a winding increases, it induces a current in the opposite direction. But if the current decreases, the induced current goes in the same direction, doing all it can to keep the inducing current up to its old value.

KEN—What a memory! All you need to add is that the induced current shows itself as a voltage at the ends of the winding. Can you guess what the value of that voltage depends on?


WILL—I suppose it's proportional to the variation in the inducing current and the amount of inductance in the winding?

KEN—Right! But there's just one other thing—the variation speed of our current—the time it takes to change. If the sawtooth current passing through our windings is quite linear, we can say that the voltage of self-induction increases as the duration *t* of the variation in current becomes shorter.

## Figures don't lie

WILL—I don't always like formulas, but I think if we call the voltage induced at the ends of the winding *e*, then:

$$e = \frac{L \times I}{t}$$

where I is the *variation* of the current.

KEN—Fine! Your formula is perfect! Now if L equals 0.15 h and I equals 0.12, can you figure out the voltage?

WILL—But what is *t* equal to? There are two chances here. The current rises and falls slowly or quickly. Is *t* the time of the long rise, or the quick drop?

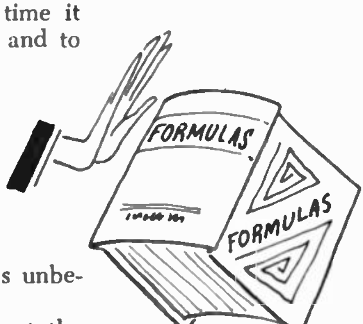
KEN—Let's take the line deflection. For 30 frames a second and 525 lines, we have 15,750 sawteeth a second. Then each one lasts only 63 microseconds. The time it takes to get across the screen is 55 microseconds, and to get back only 8!

WILL—The voltage *e* on the scan seems to be:

$$\frac{0.15 \times 0.12}{.000055} = 345 \text{ volts;}$$

and on the return

$$\frac{0.15 \times 0.12}{.000008} = 2{,}250 \text{ volts}$$

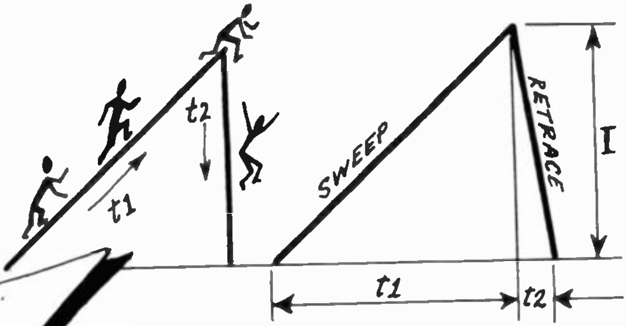



Two thousand, two hundred fifty volts! but this is unbelievable!

KEN—The most unbelievable thing about it is not the


amount of voltage, but that you got the figures right!

WILL—Now I know why you call them "surges!" I would never have believed that such small variations of current could build up voltages like that!





*T1 represents the time it takes for the cathode-ray beam to sweep across the face of the picture tube. T2 is the time that it takes for the beam to snap back into position for sweeping out the next line.*

KEN—With bigger tubes, you have to use heavier currents, and the surges reach several thousand volts. And your figures are too low, for the sweep does most of its dropping in less than the 8 microseconds we used, making the variation more rapid than we figured.

WILL—But isn't that dangerous?

KEN—Surges are one of the greatest dangers in electricity. You can get hurt—or killed by them. But our coils are in even greater danger. We have to keep them small, so we can't put safe, thick insulation on those thousands of turns of fine wire. With the relatively thin insulation we have to use, we run the risk that it won't be able to stand up under a particularly heavy surge.

WILL—M'mm. Bad! Can't we cut down the number of turns in the winding, then run the current up enough to keep the number of ampere-turns constant?

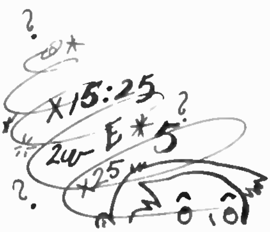
$$\frac{5}{25} = \frac{1}{5}$$

KEN—Sure we can. But what good will it do us?

WILL—Well, if you cut down the number of turns to one-fifth, the inductance will be reduced 25 times. Then, even though you have to increase the current five times, the surges will only be one-fifth as high. And you can use heavier insulation on the wire, because there are only 200 turns to go into the space.

KEN—You're doing well, keep on!

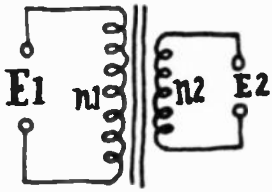
WILL—But there's one thing wrong. If we cut down the number of turns five times, and use five times the current, we'll have 0.12 × 5, or 0.6 ampere. What kind of a tube is going to pass a plate current like that?



KEN—There's a very easy way of getting around that. With only one-fifth the turns and 1/25 the self-induction, you can get a current five times as strong with only one-fifth the voltage. Catch?

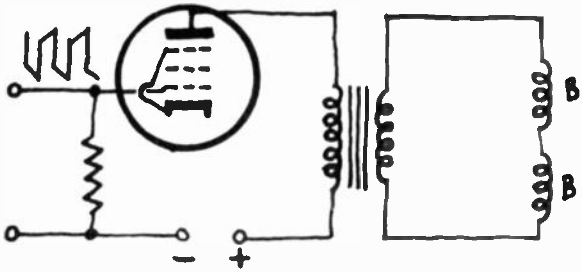
WILL—Wait a minute. This has me going in circles.

KEN—Think a little. The inductance of your winding, and therefore the inductive reactance that opposes a varying current—is 25 times less than before. So with the same voltage, you would get a current 25 times as strong. For one 5 times as strong you need only one-fifth the voltage.




WILL—So how does that help me?

KEN—Haven't you heard of that queer thing called a transformer?




*Transformer coupling is practically always used in television sets for obtaining both vertical and horizontal deflection.*

WILL—Of course! How dopey! I just use the same tube, same voltage, and put a 5-1 stepdown transformer in the plate circuit, and get the current I need for my lower-inpedance deflection coil!

$$\frac{E_2}{E_1}=\frac{n_2}{n_1}$$

KEN—Actually, transformer coupling—like this—is used in both vertical and horizontal deflection circuits. For vertical deflection you could also use resistance coupling, replacing the inductance A of your capacitor-coupled circuit with a resistor.

## Other surge troubles

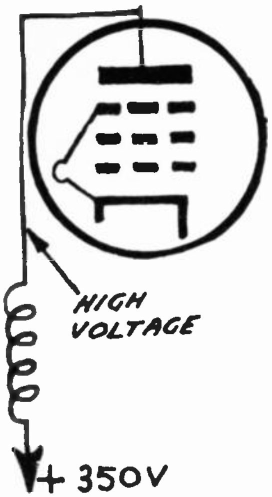
WILL—But don't we have to worry about surges in vertical deflection circuits?

KEN—No, for two reasons. First, we don't need quite as much variation in the magnetic field as for the horizontal sweep, because the spot doesn't have to travel so far vertically.


WILL—That shouldn't make much difference!

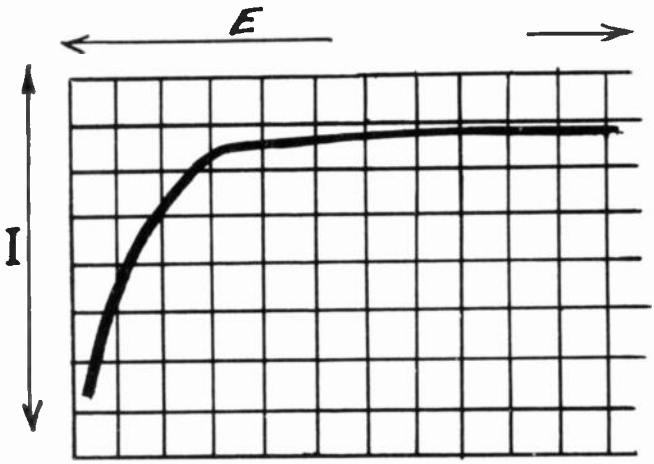
KEN—It doesn't! The main reason for the weaker surges is that the current varies at a slower rate. While the horizontal sweep is tracing out 525 lines, the vertical sweep makes only 2! So you can forget about the vertical sweep. But the surges in the horizontal deflection circuit complicate everything, even the functioning of the amplifier.

WILL—I don't see why.

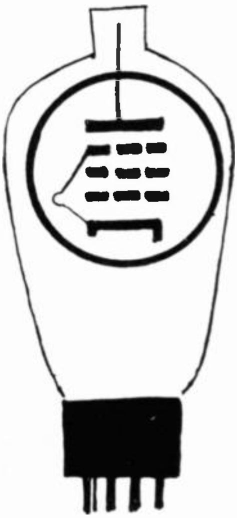



Ken—Don't you see that—no matter what type of output circuit we use—the deflection voltage is superimposed on the direct plate voltage, half the time in opposition to it and the other half adding to it? In an impedance coupled circuit—getting back to your hookup again—these surges pass through the capacitor C. In transformer-coupled hookups, they appear on the primary. Can you figure out the direction?

Will—While the current is pushing the spot across the screen, it's increasing. Then the induced current




*In a pentode, the current increases rapidly for a small increase in voltage and then levels off. The plate current then remains fairly constant even though the plate voltage increases.*



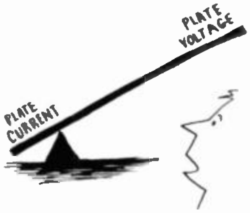
will be in the opposite direction to the plate current, to oppose the increase. So, plate current and voltage should decrease. In our example the deflection voltage was 250. So, if we're to have enough plate voltage left to work the tube—say 100 volts—we need a plate-voltage supply of at least 350 volts.

Ken—And then?

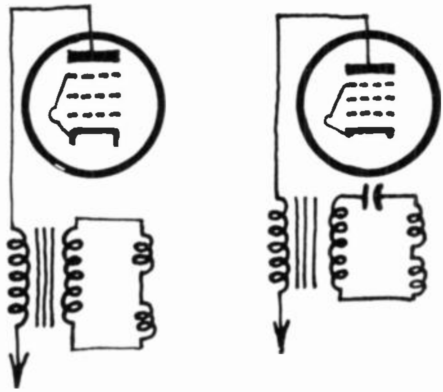
Will—The spot flies back to its starting point. The plate current drops, but fast! So self-induction produces a strong current in the same direction, increasing the number of electrons moving toward the plate by making the voltage more positive. The 2,250-volt surge adds itself to the 350-volt plate supply, and puts about 2,600 volts on the plate!

Ken—That's why you need special tubes in the horizontal - deflection circuit. Plate insulation has to be excellent, so many of the tubes have the plate connection at the top.

Will—One thing still bothers me. How does the tube manage to do its regular work while the plate voltage is shifting so much? There's enough variation to mess up the workings on any tube, no matter how rugged it is.




KEN—Not quite. The plate voltage variation won't produce any such serious effects if we use tubes whose plate current varies very little with large changes of voltage. What kind of tubes would they be?



*The inductive network at the secondary of the output transformer has enough stray capacitance to form a resonant circuit as shown at the right.*

WILL—Pentodes, of course! But to go on—if I get it right, we use a pentode amplifier for horizontal deflection, and connect it to the primary of a step-down transformer, insulating everything very carefully because of those surges?

KEN—You're not far out. But don't be too hard on the surges—you'll find out later that there's a very ingenious way of using them to obtain the high voltage for the cathode-ray tube!

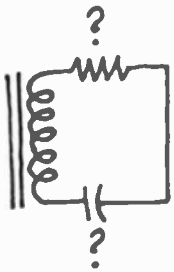
WILL—You mean we make a virtue out of a fault again?

KEN—Something like that! But now all we have to do to finish with this subject is to remember that, because the surges are a lot less serious in the vertical deflection circuits, a simple triode with inductance or resistance coupling is all we need in the vertical oscillator.

### Damped oscillations

WILL—Maybe this is stupid, but one thing I can't understand. With so much inductance in the circuit, how can the current vary fast enough to let the spot fly back in the short time it does?

KEN—A very sensible question. The surge we've just



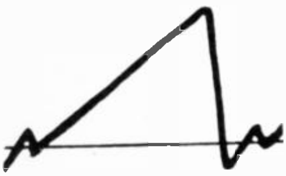
been talking about is the price we have to pay for that rapid flyback. We make the fast variation possible by designing our circuit so that we have a genuine oscillating circuit, complete with inductance, capacitance, and resistance.

WILL—But I don't see any resistors or capacitors!

KEN—We don't have to draw them on the diagram—they're there, even if you can't see them. For instance, can you imagine transformer windings without resistance and distributed capacitance?

WILL—Oh, I see! The deflection windings have resistance and distributed capacitance, just like transformer windings.

KEN—Exactly! Now, if the resistance isn't too high, we have a real oscillating circuit. And the rapid motion of the electrons as the spot returns is helped, because it's part of the circuit oscillation.



WILL—H'mm—good! And these oscillations stop immediately?

KEN—Unfortunately, no! That's the other side of the story! Once these electrons get going in an oscillating circuit, they don't stop till after several oscillations, which grow smaller and smaller, like the motion of a pendulum that has been set swinging by a sharp push.

WILL—But can we get along with these extra waves?

KEN—Not too well. The sawtooth finds itself with a little sinusoidal parasite which affects the spot as it starts at the left of the screen. Instead of starting from the left side and going across to the right in a single movement and with uniform speed, it starts out with a sort of hesitation-waltz—three steps to the right, two to the left, one-and-a-half to the right, one to the left—then at the end, one big leap to the right. These little to-and-fro motions show up as very disfiguring vertical fringes at the left side of the image.

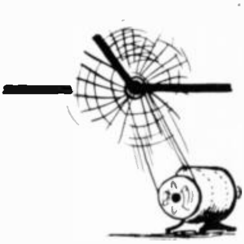
WILL—How do you get rid of these hangover oscillations?

KEN—Damp 'em out! Absorb enough energy so that the circuit will be able to oscillate, but won't be able to support parasites.

WILL—Well, about the only way to absorb the energy would be to put a resistance across the deflection windings.

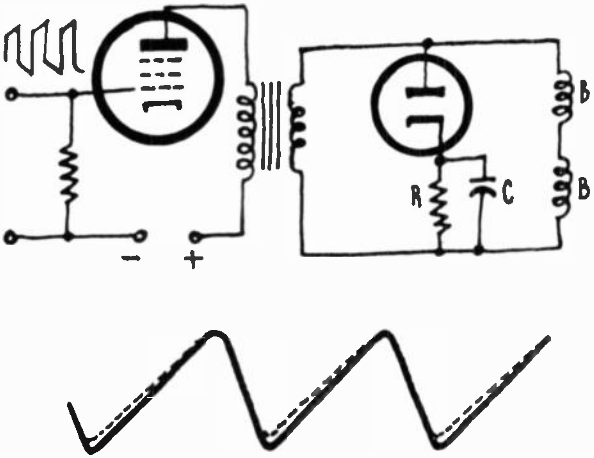
KEN—That is the easiest and cheapest way. We can keep cutting down the value of the resistance till we find a value just small enough to load the circuit so that it damps out parasitic oscillations.

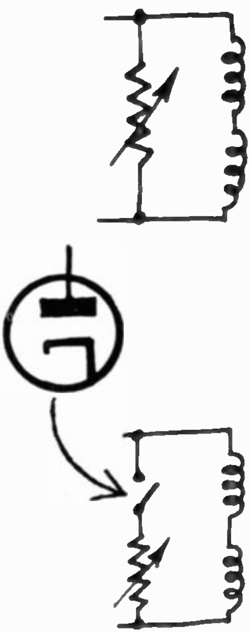
WILL—What a pity to absorb energy that could be used to pull the spot across the screen! It's a shame we couldn't have a very rapid switch that would connect our resistor only while it was needed to damp out the parasite, then disconnect it as the spot started to scan.



KEN—Nothing easier, Will! Just put a diode (hooked up in the right direction) in series with your resistor, so that it doesn't conduct during positive alternations of the current, but passes current during the negative alternations. Then it absorbs power just at the end of the return and the beginning of the scan, which is the danger point. This figure gives you the idea.

WILL—Ingenious! But what is this capacitor C across resistor R?



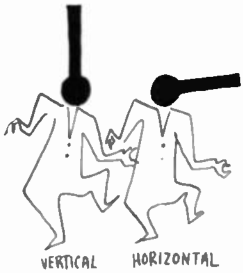
*A diode is usually placed in shunt with the secondary of the horizontal-output transformer to dampen the oscillations of this circuit.*

KEN—It charges during each passage of current, and by discharging through the resistor keeps the diode's plate biased a little. Then no current passes till the voltage on the winding is high enough to overcome the slight bias. The bias keeps the circuit undamped over a larger part of the cycle. Then the oscillation can go a little further negative on its return—just the difference between the dashed and solid lines here—and give you a higher-amplitude sweep. That uses the expendable energy more efficiently.

WILL—Actually, you are going to have a pair of deflection circuits. One of these will give us vertical sweep and the other will supply horizontal sweep.

KEN—Quite true. But why bring that up at this particular point?

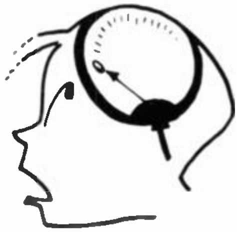
WILL—I want to be able to recognize these circuits when I look for them. From what we have discussed, I




know that the horizontal deflection circuit will have a diode used as a damping tube, while the vertical-deflection circuit will not.

KEN—Oh, you don't have to worry about that. When we get to our study of high-voltage power supplies you will see that there are many more differences in the two circuits than just the need for damping. Would you be interested in some sort of preliminary discussion?

WILL—Right now the efficiency of my brain has dropped to a very low value! I think it's being damped by all the ideas it had to absorb today. Suppose we let the rest go till the next time.



chapter 8

# The electron image

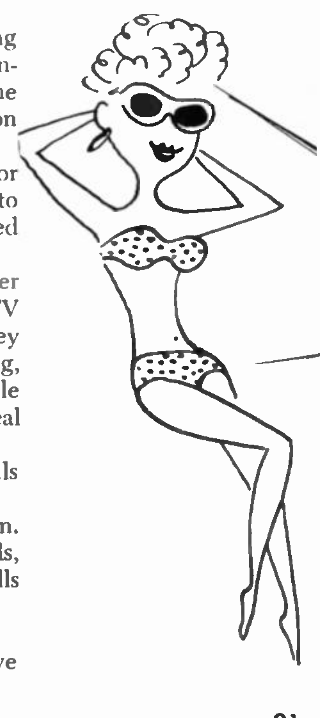
### In the land of the microseconds

Will—I've got news for you, Ken!

Ken—Go ahead!

Will—This talk about time bases and deflection circuits has got me fed right up to the neck. Can't we change the subject for a while?

Ken—It just happens I was thinking the same thing myself. We should now be able to attack the main principles of television—we've pretty well cleared up the preliminaries. How about starting to learn something on how images are transmitted as well as received?



Will—I do know a little about that already. For instance, I've just been reading how a TV studio has to be so brightly lighted that the actors get sunburned and . . .

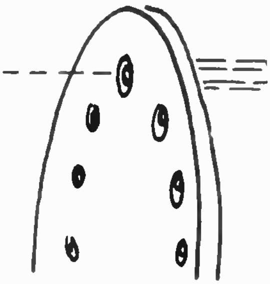
Ken—That's what you get for picking up back-number magazines! All that was out long ago! Nowadays TV camera tubes are as sensitive as the human eye, so they don't have to burn the skin off the actors with lighting, as they did in the early days. Color TV needs a little more illumination, of course, on account of the optical filters in front of the cameras.

Will—Then they've been making photoelectric cells more sensitive?

Ken—No, the progress wasn't made in that direction. What they've done is to learn to use more of the cells, and for more of the time. Instead of lighting the cells for short instants. . . .

Will—Huh?

Ken—Remember the mechanical Nipkow disc we



talked about a long time ago? And how each small element of the image could reflect its light onto the photocell only for the instant the hole in the disc was directly between the picture element and the tube? If you were to use a system like that for a standard 525-line scan, each of the picture elements would project its light on the cell only about a tenth of a microsecond.

WILL—That means that at 30 frames a second, each element would have a chance to get in front of the camera only about 3 microseconds out of each second. About 3-millionths of the time!

KEN—So you see that a system that could see *all the light* from the picture *all the time* would be much more sensitive—in theory at least.

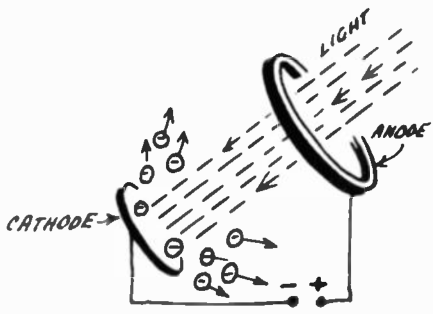

WILL—Yes, over 300,000 times as sensitive—as many times as 3 microseconds is contained in a second.

KEN—Well, you can't actually get anything like that in practice. But you could get something like 25,000 times more sensitivity.

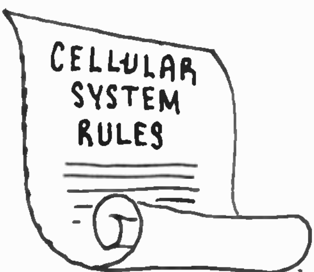
WILL—That ought to help a little! But how are you going to illuminate every part of your image—and get it picked up by a photocell—continuously?

KEN—Why use one photocell, Will? Why not use millions instead? Then each tiny image element would have half-a-dozen photocells for itself.

WILL—Now you're kidding! That's impossible, of course!



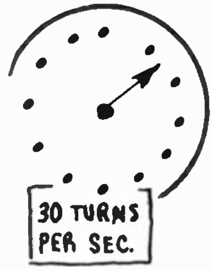

*Electrons are emitted by the light-sensitive cathode. The electrons are attracted to the positive plate (anode).*

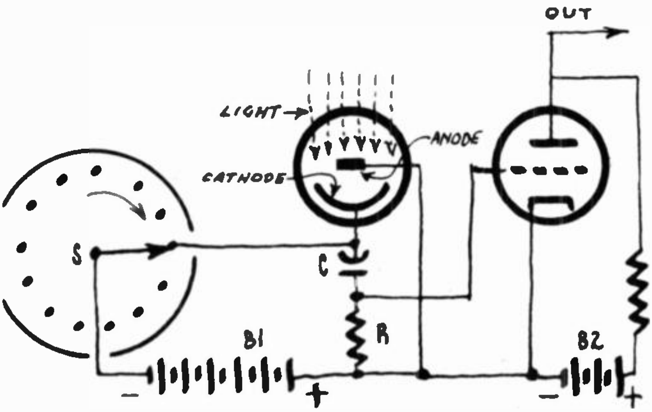



KEN—Nothing impossible about it at all! But before I show you how to use millions of photocells, let's take just one and see how it works. Look at this hookup. When light falls on the photosensitive cathode, it emits electrons. They are attracted by the positive anode, and from there go back to the battery, B1. Meanwhile, the upper plate of capacitor C, connected to the cathode, is charged . . .

WILL—. . . more or less positive, because of the negative electrons the cathode has lost.

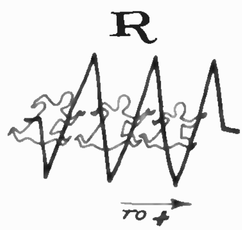
KEN—Now, switch S turns 30 times a second, and—for a very short instant—connects the negative terminal of the high-voltage supply to the cathode. What happens?



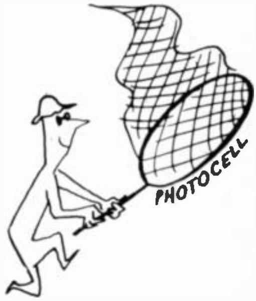

*Simple photocell circuit. The current through resistor R produces a voltage proportional to the amount of light falling on the photocell.*

WILL—Capacitor C's top plate gets back the lost electrons from the negative end of the high-voltage supply (battery B1).




KEN—Exactly! But, as the electrons from the battery neutralize the positive charge on capacitor C's upper plate, a corresponding negative charge is released from the lower plate. These electrons go to the positive pole of the battery through resistor R.

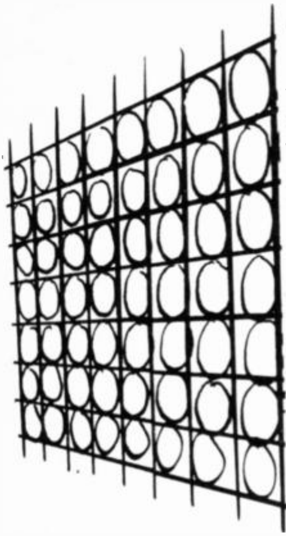
WILL—I see what happens. The current through resistor R is bigger or smaller according to the amount of light that falls on the photocell. And of course it produces a voltage drop across the resistor. So if we connect the control grid of the amplifier tube, as in the layout, its output will vary with the amount of illumination. But haven't you got a pretty heavy positive bias on that grid?




KEN—No. You're looking at the photocell battery. The amplifier is interested only in battery B2, its own supply. Both cathode and grid return are connected to B2's negative terminal. Standard hookup, no?

WILL—Sorry. I missed that one. But what I still can't see is how you're going to capture all those image elements with your photocell.

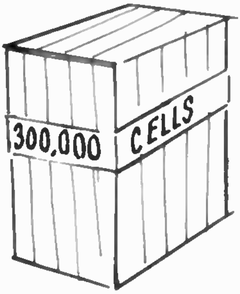
### Millions of cells? Impossible!



KEN—Try to imagine a surface completely covered with photocells like this one. Their cathodes are all connected to contacts. The switch passes over all these contacts 30 times a second. Each cathode is also connected to its capacitor C. The lower plates of all these capacitors could be connected together—or you could use a common lower plate, like they show in the diagram of a multiple-section electrolytic—and you would need only one resistor R for all the cells. Each cell now takes its turn putting its voltage on the amplifier grid. Now if we illuminate all these cells together . . .

WILL—. . . your system will work—in theory, that is! You're saying that there'll be a voltage on the amplifier grid—at any given instant—proportional to the light falling on the photocell connected to the switch at that instant.

KEN—Your mental pickup is good today! Now keep in mind that the light is falling on *all* the photocells *all* the time, so that the voltages are the results of an *accumulation of charge* for the thirtieth of a second between two discharges.

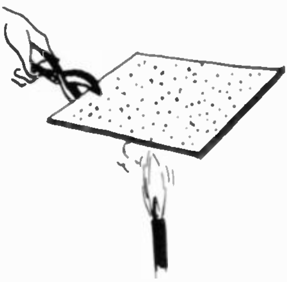



WILL—But all this is ridiculous! How are you going to assemble your panel of 300,000 photocells? And where are you going to get a switch that will make and break 9,000,000 contacts a second? It can't be done!

### Nothing is impossible

KEN—But it is done—on the photosensitive mosaic of the *iconoscope*, which is what I've been leading up to.

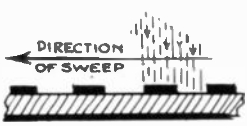
WILL—Photosensitive mosaic . . . ?



KEN—Yes. It's a thin layer of silver deposited on a sheet of mica. After the silver is deposited, the sheet is heated. That makes it expand and cracks the silver layer up into millions of little bits, each separated from the others by a gap of insulating mica. Then cesium vapor is deposited on them, making each of these little silver islands a photocell.

WILL—I know about heating paint on metal cabinets to get a crackle finish. But crackle-finish silver is a new one on me. So that's how you get your millions of photocells!

KEN—That's how. Or at least it's how we get the most important part of the cells—the cathodes. And you only need one anode for all of them, so that's no problem.



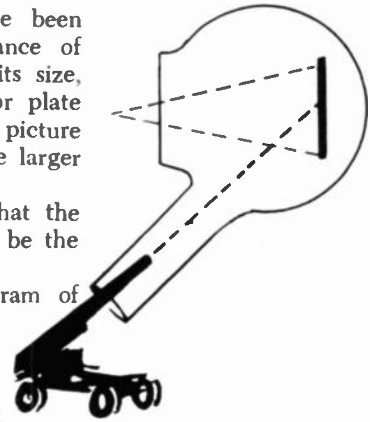

WILL—But how about the capacitors in the cathode circuits.

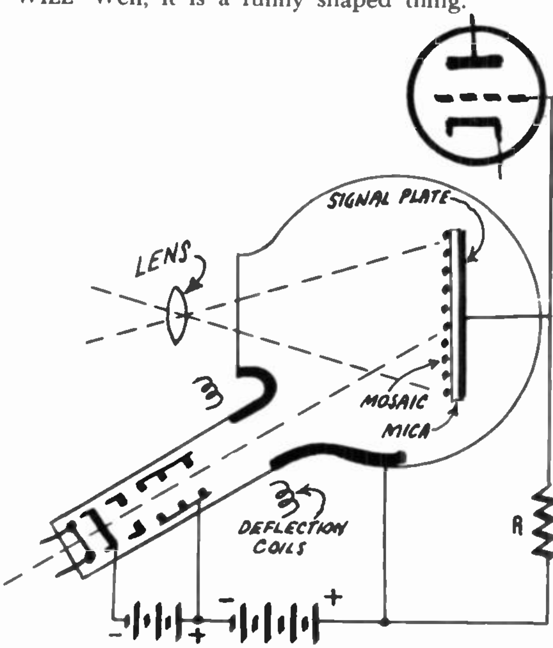
KEN—Very easy—just plate a thin layer of metal on the other side of the mica sheet. Then each cathode forms one plate of a capacitor and the metal on the other side of the mica becomes the common lower plate we've been talking about. You understand, of course, that the cathodes don't have to be regular or symmetrical, because there are several of them in the space we've been allotting to one picture element. The capacitance of each of these tiny capacitors is proportional to its size, so the voltage induced on the common capacitor plate is the same for the same amount of light on the picture element, whether it's represented by two or three larger islands or a half-dozen smaller ones.

WILL—Wonderful! And now I begin to see that the switch to contact each of these tubes is going to be the electron beam in a cathode-ray tube.

KEN—I suppose watching me draw this diagram of an iconoscope didn't help you any?

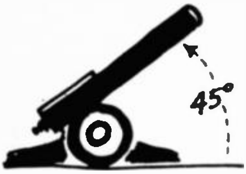
WILL—Well, it is a funny shaped thing.






*The iconoscope is somewhat similar to a cathode-ray tube, but uses a photo-sensitive mosaic instead of a screen. The mosaic receives the light from the object being televised.*

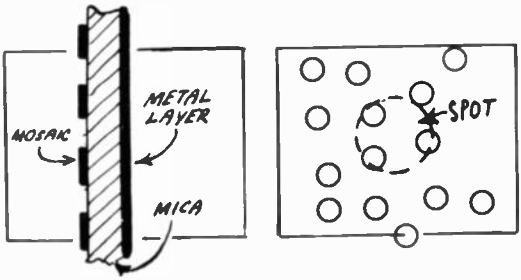
KEN—That shape is highly functional. You have to put the photomosaic where it can be swept by the electron beam and at the same time be exposed to the light from the scene you are televising. One face of the tube has to be flat so that a lens can form an image of the televised scene on the photomosaic. To keep it out of the way of



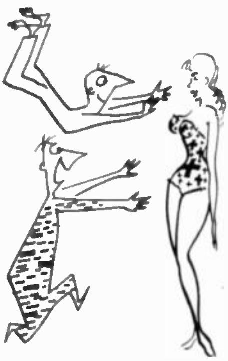

the light, the electron gun is mounted in a cylindrical tube at an angle of about 45° from the mosaic. And the common anode for all the cathode is a metallic film deposited over part of the inside of the glass.

WILL—It looks as though the beam is focused electrostatically and swept magnetically.

KEN—Doesn't matter. You could do it the opposite way and it would still be an iconoscope. What *is* important is that *all* the cells of the mosaic are *continuously*




*Cross-section of the mosaic. It resembles a capacitor since it consists of metallic materials separated by a dielectric. At the right, elements of the mosaic compared to the spot.*



being illuminated by the rays of light from the corresponding points on the televised scene. That is, the positive charges on each cell—due to loss of electrons as the light strikes it—keep on increasing as the light keeps on jarring more electrons loose.

WILL—And what happens to the electrons?

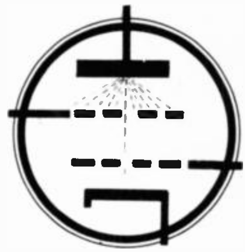
KEN—They are attracted by the anode. But we're more interested in the positive charges. As they accumulate on the mosaic they form a veritable *electronic image* of whatever you are televising. Then the electron beam sweeps over each cell 30 times a second; replaces the lost electrons and wipes out the image. Of course that releases the negative charges on the other side of the mica dielectric, and produces a current that travels through resistor R and sets up a voltage across it . . .

WILL—. . . which depends on the amount of light on the element of the image the beam is passing over at the instant! Why, the iconoscope is really very simple!

KEN—To tell you the truth, it's really very complicated. Such little things as secondary emission mess up that simplicity you think you see.

WILL—Secondary emission! You mean like in a tetrode, where an electron hits the plate at high speed, and knocks off a number of others, which go back to the screen grid?

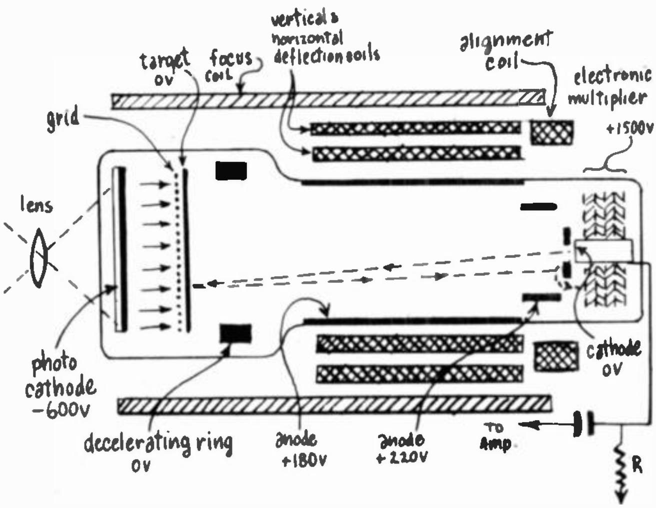
KEN—One of your good points is that if you ever learn something, you remember it! The iconoscope mosaic is bombarded with just such high-speed electrons, and they do knock off secondary electrons. Some of them get to the anode, but others just rain back on the mosaic, and make it slightly negative. So you can see that the action isn't quite as simple as you think.



WILL—You told me once that if you can make virtues out of the faults of people and things, you can really get somewhere. This secondary emission looks interesting. If one electron can set several into motion, why can't we use the effect to give us some amplification?

KEN—You were just born fifty years too late, Will! Your ideas would have made you the world's greatest inventor a half century ago!


WILL—And even today they're not so bad, either! I understand that this secondary emission *is* actually used for amplification.

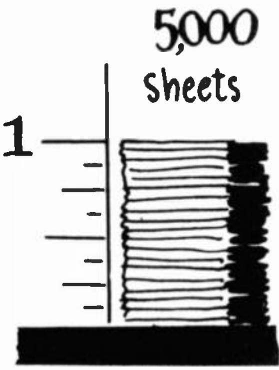



*The image orthicon is the pickup tube used in today's modern television cameras. It is much more sensitive than the iconoscope.*


KEN—Yes, and has been for some time, in a tube even more important to us than the iconoscope. It's the *image orthicon*, which is so much more sensitive than the iconoscope that it's the most widely used TV camera tube today. Here's a cross-section.

### A tube that looks simple . . .

WILL—Well, it doesn't look quite as funny as the iconoscope. But what is this *photocathode* just ahead of what I take to be the mosaic?




Ken—It's one of the things that makes the tube more sensitive. It's a thin translucent sheet with a sensitized inside surface. The light coming from the outside releases electrons from the inside surface.

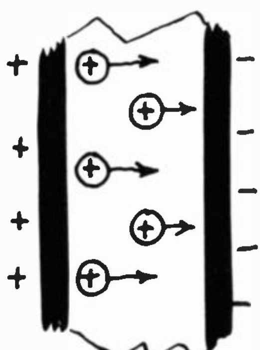
Will—Sort of mosaic in reverse, eh?

Ken—But it's not a mosaic. *All* the surface is conductive, with no waste space. So it's more sensitive than a mosaic. The electrons which leave it go to the *target*, which may be as much as 600 volts more positive than the photocathode, although at the same voltage as the regular cathode in the electron gun. The target is a very, very thin plate of glass.

Will—About how thin is very, very?

Ken—In this case, it means you would have to stack up about 5,000 of them to get a pile one inch high.

Will—And why would anyone want to go to the trouble of making glass that thin?



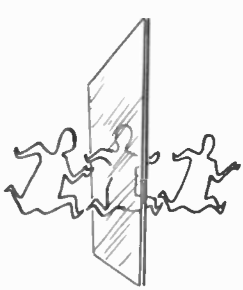
Ken—And real trouble it is, especially when you consider that this plate of glass has to stand up under the baking-out temperatures when the tube is evacuated! But it has to be done so that the charges which form on its opposite faces can leak through the glass in the time between successive scans—that is, in 1/30 second.

**. . . but whose action is complex**


Will—What charges?

Ken—Hold the questions for a few minutes, Will, and you'll get your answers quicker. Those electrons emitted from the photocathode where the light strikes it form an electronic image of the televised scene. As I just told you, they are attracted by the more positive target. They are kept in straight lines by the focusing coil, so the electron image is transferred to the target intact. Each electron striking the target produces a number of secondary electrons, which are captured by a fine-mesh grid placed very close to the target and kept 1 volt more positive than it.

Will—So we again have positive charges on the face of the target, and they are exactly proportional to the light that falls on each corresponding spot on the photocathode. Now what?



Ken—These charges move through the glass. That's why it has to be so thin, and of the right resistivity. If the charge can't all leak through the glass in 1/30 of a second, some of it may hang over to the next scan, and if it can travel too fast, it may spread out on the surface so that adjacent picture elements won't be sharply defined.

Will—Quite a critical proposition! But once the charges get through the glass in good order, they are scanned just as they are in the iconoscope, I presume?

KEN—Not just as in the ionoscope. For one thing, this tube works with *slow electrons*. For another, the electron stream itself carries the signal to the amplifier. Notice the low voltages on the *accelerating* electrodes—only 220 on the first and 180 on the second anode (which is our metallized layer on the inside of the glass tube). Then just before the electron beam reaches the target there is *decelerating ring* at zero volts. At the same time the electrons feel the pull of the 180-volt electrode behind them. The net result is that they are going to stop sooner or later, turn around, and go back down the tube again.


WILL—But they do scan the target first?

KEN—They do. The voltages are so adjusted that the beam just reaches the target—makes it a turnaround point. If there were no positive charges on the target, all the electrons in the beam would go back. But wherever the beam sweeps past a positive charge on the target, it loses just enough electrons to neutralize the charge. So *the returning beam varies with the amount and distribution of charge on the target*. You might say that every little bit of returning beam carries a message telling the amount of illumination on a given spot on the target. Or, you can say that the returning beam current varies much as did the current through resistor R in the iconoscope diagram.


WILL—Now the only thing to do is to get the video-frequency signals into an amplifier, I suppose.

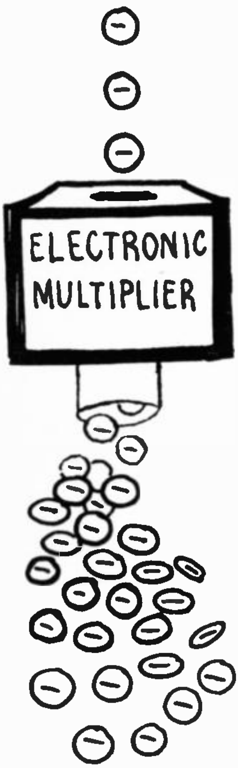
KEN—We're going to do quite a bit of amplifying before we even leave the tube. Here's where we use your secondary emission for the second time. As our electrons start back, they are kept going in a reasonably straight line by the same focusing coil that kept them together on the way out. But now the voltages on the accelerators are increasing, and by the time they get back to the area of the cathode they are traveling at a pretty fair clip. Then they strike the first *dynode* of the *electron multiplier* . . .

WILL—Hey! What's that?

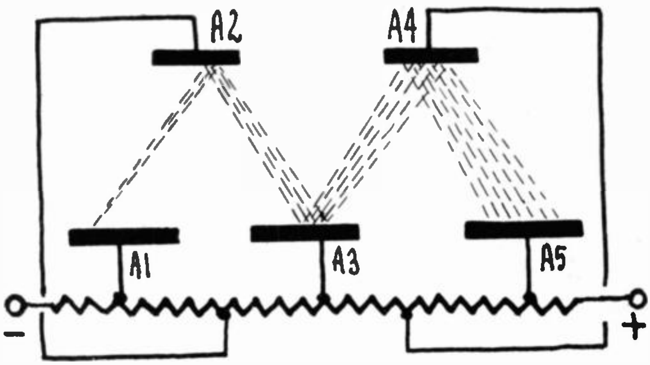
## A day at the races

KEN—Just another of those things you could have invented yourself, if someone hadn't done it before you were born.


WILL—That's the way it always is with me! But before you start on something new, let's get straight on what we've gone over already. Light falls on a *photocathode* and produces an *electronic image*, which is transported




to a *target*, where it produces *positive charges* by releasing *secondary electrons*. These charges are neutralized by being swept by an electron beam which leaves behind enough electrons to neutralize the charges. Because it has lost electrons in proportion to the size of the charges, it is *modulated* by them. The modulated beam

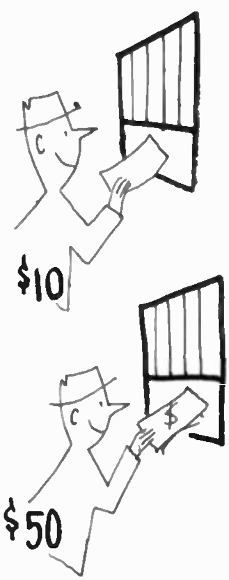



*The electron multiplier works on the principal of secondary emission. The small stream of electrons increases as it moves from one dynode to the next.*

now moves toward the *electron multiplier*. Is that right?

KEN—Spoken like an engineering instructor, Will! Now, about that electron multiplier . . . Have you ever played the horses, Will?

WILL—Hardly! If you can figure enough to use Ohm's law, you know better than to try to beat the odds at the races. But what has that to do with electrons?




KEN—You'd be surprised at the number of good mathematical minds who spend their time and money at the tracks. But I think I can give you an example without leading you astray. Suppose you go to the races with $10 to bet. You put it all on a horse in the first race. He wins, and brings you in $50. Let's suppose you're not wise enough to pocket your winnings, but put it all on another horse, and he wins, also at five to one. Now you have $250, and if you have the spirit of a true gambler, nothing in the world could keep you from trying to lose it all in the next race, and—since it's necessary for our example—suppose your horse comes in first, giving you a cool $1,250. And so it is also with the fourth and fifth races. You leave the course with $31,250 in your pocket.

WILL—I wouldn't leave. I'd phone for an armored car and wait right there for it! But I don't understand why you're wasting all this time. Don't you think I understand a straight geometric progression?

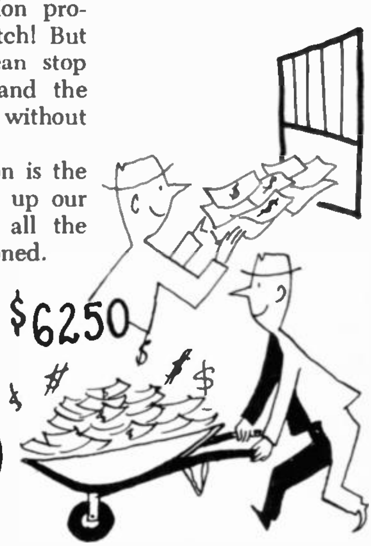
KEN—Don't get excited! I've been describing an electron multiplier. It is composed of a number of targets, or dynodes, each one operating at a higher voltage. When our modulated stream of electrons gets back to the first of these dynodes (shaped like a disc with a hole in the center to let the electron beam from the gun through), it knocks several electrons loose. The only thing around that isn't at a lower voltage than the first dynode is the second dynode, so most of the electrons are attracted to it, and are also speeded up by its higher voltage. So if your original electron caused 5 electrons to reach the second dynode, they might jar loose enough to send 25 to the third one. Actually you do get gains of 200 to 500 in the 5-stage multiplier of an image orthicon. It has 1,500 volts on the last stage. The intermediate stages are connected to taps on a voltage divider incorporated in the tube.

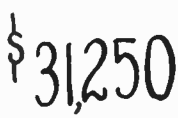


WILL—Now I can see why—with sensitivity like that—they don't need so much lighting in modern studios. Why, the image orthicon ought to work with ordinary room light!

KEN—It will. I've seen part of a demonstration program televised with the light from a kitchen match! But with a little better lighting, the camera men can stop down their lenses and increase the definition and the depth of focus. So they get a clearer picture without losing any brightness.

WILL—Well, you've said that the image orthicon is the most widely used tube today, so you can't finish up our conversation in the usual way, by saying that all the things we've been talking about are long abandoned.




KEN—No. You are definitely right about that. This is one time that I am not going to tell you that what we have studied is no longer being used.

WILL—Good! However, if we still have time, I have just had a wonderful idea.

KEN—Oh, no! Not again.

WILL—Could this be jealously on your part for my active and wonderful mind?

KEN—Very well, Mr. Edison. What have you invented now?

WILL—Single tube television.

KEN—I know I shouldn't ask, but just what do you mean by that?

WILL—A television set with an electron multiplier tube, The signal is carried along and is amplified as the electron stream goes from anode to anode. When the signal is strong enough we will take the current from the last anode, send it through a resistor. This will give us the varying voltage we need for the picture tube.


KEN—And have you worked out all the technical details and difficulties for this latest brainstorm?

WILL—As a matter of fact, no.

KEN—I hate to interrupt the thinking of a genius, but how would you like to go ahead with some discussion of the video signal.

WILL—I guess not. All of this heavy thinking has caused my mind to reach the saturation point. Let's postpone it for a while.

KEN—Just one more minute. We've used the words photocell and phototube, but these are not identical. A photocell is not a vacuum device. The electron emitting and receiving surfaces are close together. Your camera light meter is a good example.

WILL—And the phototube?

KEN—You can call it a light-sensitive tube, since that's what it is. The tube is either a vacuum type or gas filled. Electron emission is produced by light falling on a light-sensitive cathode. The anode is separated from the cathode.

WILL—I get the idea. Is that all?

KEN—Not entirely. TV camera tubes have been improved, and modified. In the Vidicon, for example . . .

WILL—Vidicon?

KEN—Yes. A small-sized camera tube used for closed-circuit and industrial TV.

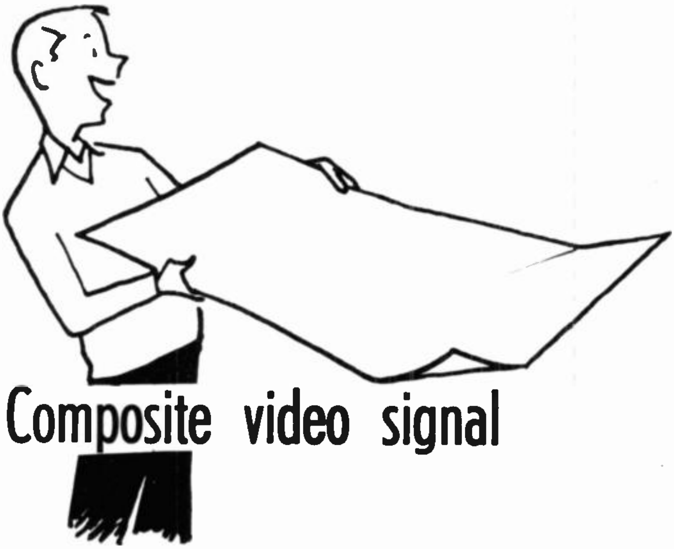
WILL—Would you explain just a bit more.

KEN—Sure. Not all TV is transmitted. You might want to use a TV camera to keep an eye on some industrial process, such as in a factory, and to send the picture to various monitors in the plant. The video signal is produced, but instead of being transmitted. it is sent directly along coaxial cable to receivers or monitors.

WILL—And I thought that TV just had entertainment value.

KEN—On the contrary. Closed circuit TV is being used by banks (to identify depositors), in freight yards, as commercial demonstrators, in hospitals and in factories. Think that over until our next meeting.

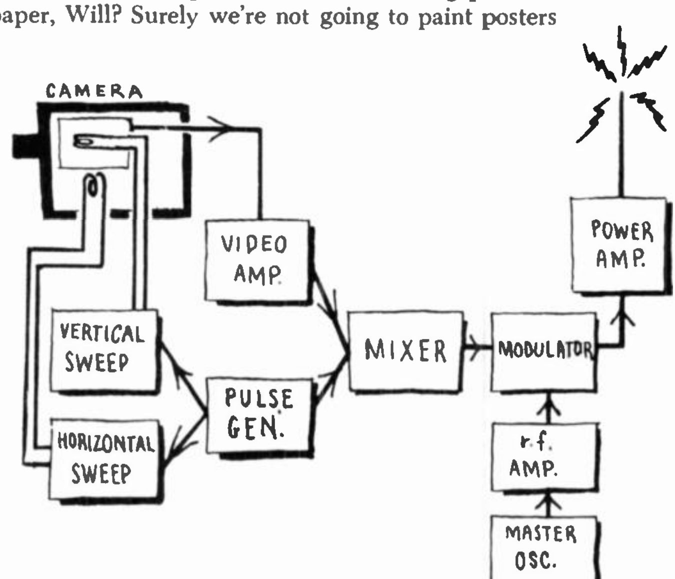
chapter 9



# Composite video signal

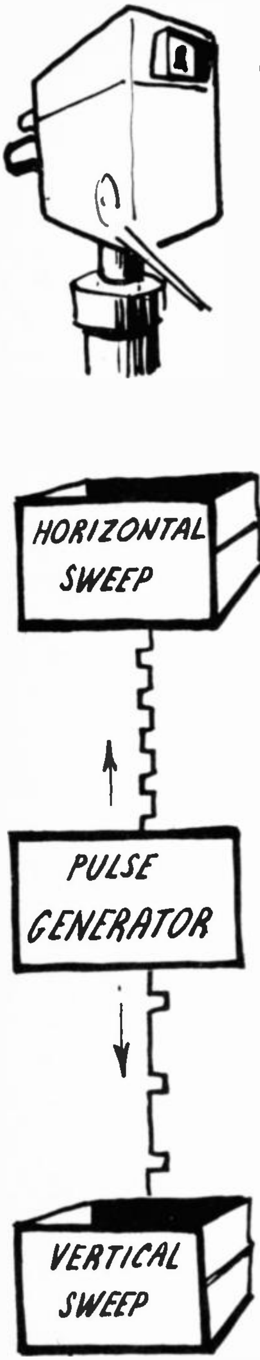
### A transmitter in boxes

KEN—What do you expect to do with that big piece of white paper, Will? Surely we're not going to paint posters today?




*Block diagram of a television transmitter. This is only the picture channel. The sound section has been omitted for the sake of simplicity.*

WILL—No, I'm looking ahead a bit, that's all. And I think we'll make a lot more progress if you draw me a complete schematic of a TV transmitter.




KEN—Thanks for the compliment, Will! But even if I *could* draw you a complete TV transmitter diagram right off the cuff, it would only confuse you. What you need to know is what kind of signals the transmitter puts out. Here, let me draw your diagram—in one corner of the paper. Is this schematic enough for you?

WILL—That's what I call an apple-box diagram. You have a complicated assembly hid in every one of those little boxes. But maybe a diagram like that *could* give a person an idea of a whole system and how its parts are tied together.

KEN—Well, this bunch of apple boxes *does* make up a television transmitter. It's a little simplified, I admit. I've left out all the power supplies, including the camera tube's. By the way, the camera is nearer to a true schematic than any other part of the diagram. But maybe I should have made it a pictorial, so we could show the electronic viewfinder.

WILL—And what would that be?

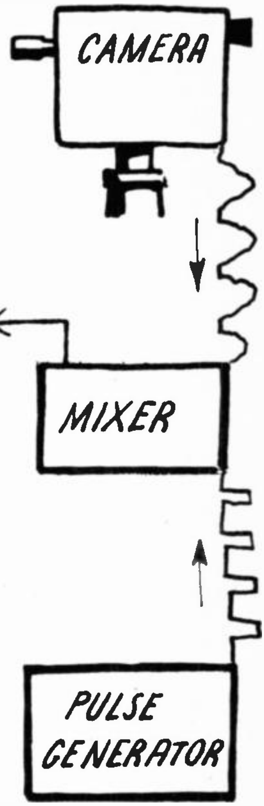
KEN—The TV equivalent of the optical viewfinder on your camera. It lets the operator of the TV camera frame and focus the scene correctly. Imagine a little TV receiver (with a 5-inch tube) minus front end and pix if amplifier sitting right on top of the camera, and you have it. The operator looks at the image on the picture tube of this sawed-off receiver, and can tell exactly how the televised scene is being viewed by millions of other spectators. So he frames his picture and varies the stop and focus to give the audience (and himself) the clearest picture.

WILL—I see that the vertical and horizontal sweep of the camera are connected to a pulse generator. Is that where we get the sync pulses?

KEN—Yes. They come from a pulse or sync generator. But don't get the idea that this generator is a simple little gadget. The pulses it produces are the very ones that keep the picture at the station and in your receiver in step with each other. It gives us the horizontal and vertical sync pulses and the *equalizing pulses* and *blanking signals* that are needed to make the complete television signal ready for transmission.

WILL—Both horizontal and vertical sync? I suppose it has to have two oscillators—one for each frequency?

KEN—Not generally. The most common method is to use one oscillator whose frequency is 31,500 cycles per second. Then this frequency is divided to get the horizontal pulses and also the much lower vertical sync frequency. That gives you a more stable system—you're sure the vertical and horizontal signals can't get out of step with each other.




WILL—H'm-m—that plain apple box marked "Pulse Generator" begins to look more like the "black box" full of tricks the engineers like to talk about!

KEN—Don't forget this is a very important generator. It supplies the whole synchronizing part of the transmitted television signal, and so keeps all the receivers synchronized with the transmitter.

*The pulse generator at the television station produces blanking and sync pulses. These are combined with the video signal in a mixer. The combination of pulses and video is known as the composite video signal.*

WILL—I suppose that this "mixer" you show just after the generator is the equipment that combines the synchronizing and video part into the complete TV signal?

KEN—Exactly. And it also includes an amplifier for the video signal, as well as a monitor receiver (which can be simpler than an ordinary TV receiver, because it has its video signal already detected for it). The monitor receiver is used to adjust the voltage of the sync pulses so that they're in proportion to the video signal. And after the signal gets through this mixer, we can handle it just like the audio frequency in a radiophone transmitter—feed it to a modulator stage. There, it varies the amplitude of the rf oscillations produced by a very stable master oscillator. Finally, after going through a power amplifier, the modulated rf currents are sent to the antenna and radiated into space.

**More light, less power**

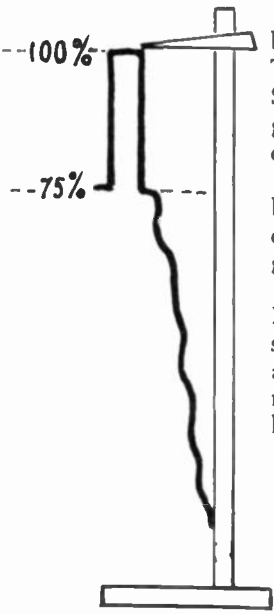
WILL—Suppose we follow that example! Let's leave the transmitter and go to the receiver. We're going to have to work with receivers rather than transmitters anyway, and I'd like to put in my time learning about them.

KEN—You'll be better off to hang around in space for a while—between the transmitting and receiving antennas—while we learn more about the *composite television signal* the waves are carrying.

WILL—Don't we already know that the signal is "composed of the modulation which interprets the light values of the successively scanned elements of the picture"?

KEN—That's the video signal. We have to include the sync signals in the complete, or *composite*, TV signal.

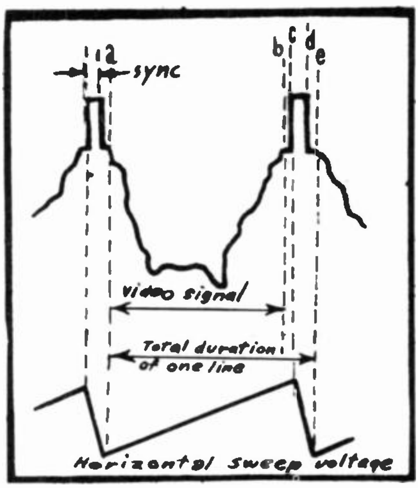
WILL—Of course! And I've been doing quite a lot of thinking about synchronization. But some things I can't figure out. For example, how can the receiver distinguish between video and sync signals? And, if it can do that, how does it know the difference between horizontal and vertical sync pulses?




KEN—The difference is a matter of amplitude. Voltages below 75% of the maximum are used for the video signal. The 75% level is *black;* white is the absence of signal. Signals between those two levels appear as halftones, or grays, on the picture tube of your receiver. Look at this drawing.

WILL—So we get these grays, as well as black and white, by detecting this video signal and applying it to the grid of the picture tube. But why should the strongest signal give you the weakest light, and *vice versa?*

KEN—Our *negative transmission* is a matter of choice. England and France use positive transmission, and their synchronizing region is between 30% of total amplitude and zero. But we think it's better to have the sync signals up near the maximum power level, so they are less likely to be interfered with than the weaker ones of posi-




*The cathode-ray beam sweeps across the face of the picture tube for the duration of the video signal.*

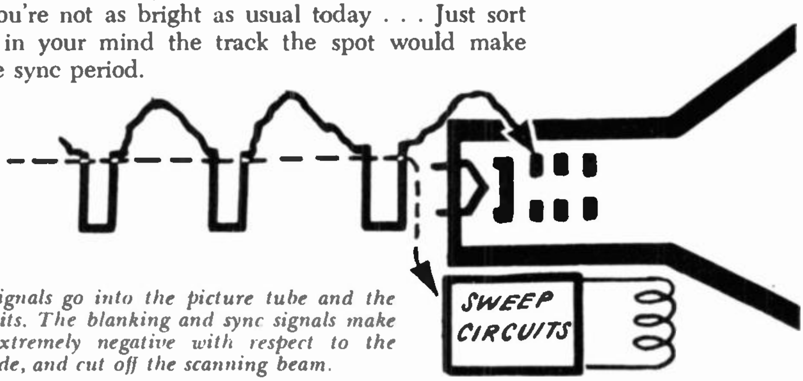
tive transmission system. Incidentally, the video signals don't have to be applied to the control grid of the receiver's picture tube. They are applied to the *cathode* in some receivers.

WILL—I hope those powerful sync signals don't get to the grid—or cathode—of the picture tube. They would drive the spot *beyond* zero light level—make it blacker than black, you might say.

KEN—"Blacker than black" is just what they do say! And I have bad news for you: The sync signals *are* applied to the control grid of the picture tube. What harm can you see in it? On the contrary, it's a great advantage to have the spot invisible while the sync signals are being received!

WILL—I don't see why.

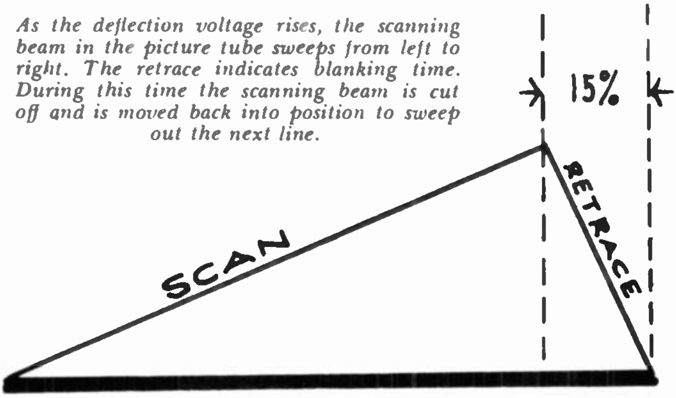
KEN—You're not as bright as usual today . . . Just sort of follow in your mind the track the spot would make during the sync period.




*The sync signals go into the picture tube and the sweep circuits. The blanking and sync signals make the grid extremely negative with respect to the cathode, and cut off the scanning beam.*

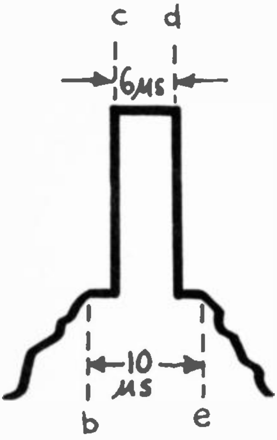
WILL—Let's see—the sync signals start the spot on its return journey, both at the ends of lines and the end of fields. . . . Oh, I see it now! Of course it's a great advantage to blank out the spot so the return movement won't be seen on the screen. So that's why they make the signals "blacker than black" and even follow them with a little step just at the black level, as you show in your little drawing.

*As the deflection voltage rises, the scanning beam in the picture tube sweeps from left to right. The retrace indicates blanking time. During this time the scanning beam is cut off and is moved back into position to sweep out the next line.*




KEN—That's not the only reason. The difference in strength makes it possible to separate the sync from the video signals and send them to the proper sweep circuits.

WILL—Now I'm beginning to see light in this blacker-than-black subject. The composite signal is applied to the grid (or whichever is the control element) of the picture tube to vary the brightness of the spot during the scanning time and to blank it out during its flyback periods. And the sync signals are separated from the others because they are stronger. Then they go their own way to keep the horizontal and vertical deflection voltages perfectly timed.




## Horizontal sync signals

WILL—Now, another important point. How much time do these sync signals take up?

KEN—Including the "pedestal" at the black level (b to c and d to e in the figure) they have to extend just a little beyond the time it takes for the spot to get back to the beginning of its trace, so that it will be blanked out during the whole trip. Under our standards, the horizontal sync signal takes up just a little less than 20% of the time it takes to trace a line. When we talk about a 525-line system, the time taken by each line (including the horizontal blanking pulse) is 63.5 microseconds. About 55 microseconds of that is the scanning trace and around 8 is spent on the return trip. And the whole time given to the sync signal (between its two black-level steps) is about 10 microseconds.

WILL—Then the horizontal sync signal is a pulse about 10 microseconds long?

KEN—Go easy, Will! The pulse itself is only about 6 microseconds long. But it has those two black-level steps we've been talking about—one ahead of it and one behind it.

WILL—Just a second! Give me a hand to get myself straight on this. I want to follow a line from beginning to end. During about 80% or more of the time we have the video signal (points *a* to *b* in the figure on page 106). This signal varies from a low level to about 75% of maximum signal. During this time, the horizontal sweep circuits of both the transmitter and receiver are producing the rising part of the sawtooth wave. Then for a microsecond or two (*b* to *c*) the signal stays at the black level (75%) with the spot still going from left to right toward the end of the line. Then the pulse itself comes along, and the transmitter signal rises to 100% of full output. This sudden jump (*c*) empties the sawtooth capacitor (as we learned a long time ago) and its sudden drop in voltage sends the spot back toward the left side of the screen. It gets there just about the time the pulse drops to the 75% level (*d*). Then we have a little safety zone (*d* to *e*) in which the spot remains invisible as it starts out to start tracing another line.

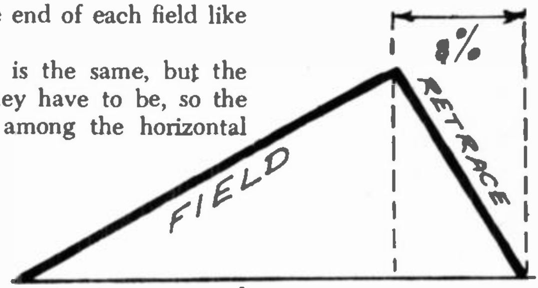

KEN—I see that you've got more help from my drawing than from my explanations!

WILL—And how is it at the transmitter? Do they apply the same type of signals to the TV cameras to blank out the spot during return traces?

KEN—Of course. Otherwise the scanning beam would set up charges on the photosensitive element during the return trace. That would mess up the picture—you'd have retrace lines in it.

WILL—And are the signals at the end of each field like the horizontal sync signals?

KEN—Yes and no. The principle is the same, but the pulses are quite a bit different. They have to be, so the receiver can pick them out from among the horizontal sync signals.



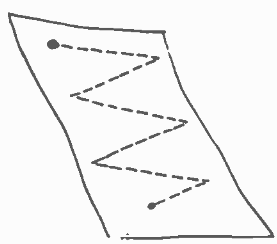

*A frame (or complete picture) consists of two fields.*

WILL—The vertical time-base has a lot longer period than the horizontal one, so I suppose the sync signals have to be longer, too?

KEN—It comes to that. We again have to blank out the spot during the whole time it is returning to the top of the picture. That time is about 20 lines, or more than 8% of the entire time spent in scanning the field.

WILL—What happens to the horizontal sync signals during that time. Are they blanked out, too?

KEN—Why should they be? You know already that the receiver is synchronized by a free-running oscillator and that the oscillator's frequency is controlled by the sync pulses. Starting and stopping it 60 times a second wouldn't help synchronization much! And there's nothing wrong in having the spot swing across the screen a few times on its way to the top (something like a souse coming home late at night) so long as the signal is up above the 75% level, so the spot stays blacked out.



WILL—But doesn't our free-running horizontal sync oscillator get out of step a little?

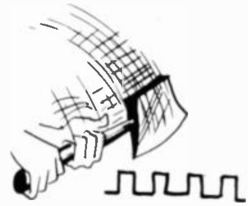
KEN—No. The vertical sync signal still has to keep the horizontal sweep circuit in sync. Otherwise it would oscillate at its own frequency, which—if you remember—is a little lower than the correct line frequency.

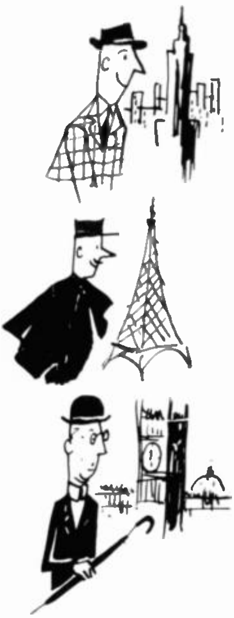
WILL—But how can you keep control?

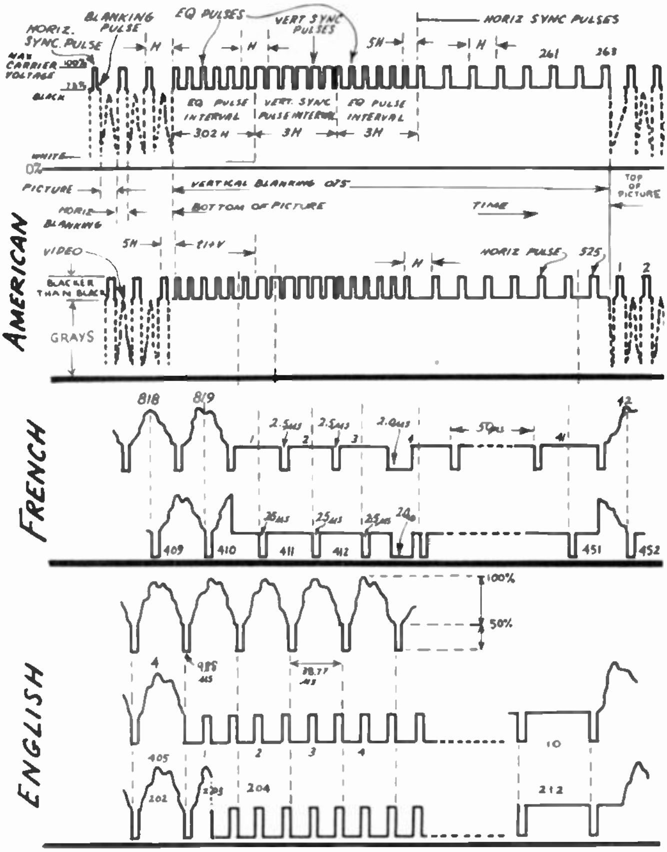
KEN—Can't you guess?

WILL—About the only way would be to keep on transmitting the horizontal sync signals during the vertical one.

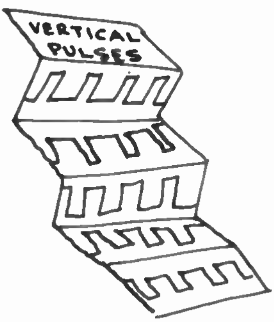
KEN—That's just what is done, at least in principle. The vertical sync pulse is split up into a great many smaller ones, some of which act as horizontal sync pulses. The complete vertical sync pulse looks just about like this sketch. You will see a couple of horizontal pulses after the video signal ends, followed by a number of *equalizing pulses*, then the broad pulses that trigger the vertical oscillator, another group of equalizing pulses, then a number of horizonal pulses before the video starts again. We'll find out more about equalizing pulses and just *how* the vertical pulses are applied to the vertical sync circuits of the receiver when you are a little more advanced.





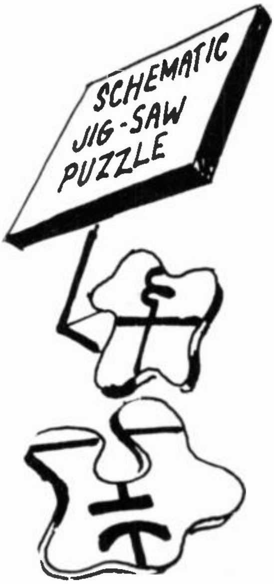



*Here we have a comparison of the American, French, and British composite video signals. The French system uses the greatest number of scanning lines. Note the polarity of the video signal and pulses in each form of transmission.*




Different TV systems use signals that look quite a bit different, but they all work on the same principle. (In color TV, for example, we're going to have a little burst of 8 or more pulses during the time after the line sync signal has ended and before the video signal starts—on the "back porch" of the synchronizing pulse.) You might as well take a look at these vertical signal patterns, used by the French and the British television systems, too. You can see that the horizontal pulses are much the same in all of them. And while you're looking, notice that the vertical sync signals have to provide for interlacing. One field starts at the upper left corner of the picture and ends at the middle of the bottom. The next one starts at the middle of the top and ends at the lower right corner.

## A "programmed" jigsaw puzzle



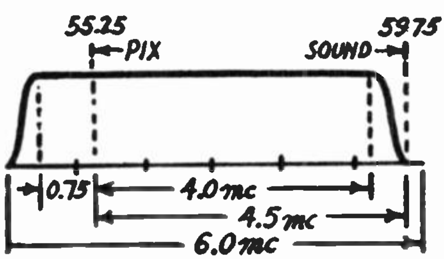

WILL—It's crazy, the number of things you can get together in this composite television signal. It reminds me of the jigsaw puzzles I used to play with as a boy. You had to get all those pieces together in just the right way to get a picture!

KEN—The TV signal is a lot more complete than your puzzles were! For not only does it carry all the pieces needed for a perfect picture—it also carries the complete instructions on how to put them together to get the perfect picture. The sync signals give those instructions. They remind me of the "taping" or programming of an electronic computer, that tells the machine what to do with the numbers fed to it to get the right result.

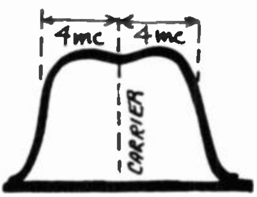
WILL—And this whole combination of complexities is packaged so that it can be shipped out on the high-frequency wave of a television carrier! I think you pointed out a long time ago that the video signal spreads itself out over such a large band of frequencies that it can be carried only by a very high-frequency wave?

KEN—That's right. You need a video signal of about 4 megacycles for a 525-line system. In higher-definition systems, like the French 819-line standard—the band is much wider.

WILL—I'm beginning to get dizzy. When I remember that a modulating signal creates *two* sidebands of its own width—one above and one below the carrier—I wonder how you can build equipment to send or receive such wide bands of signals.



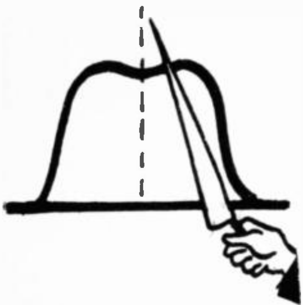

*A television signal, including picture and sound, requires a bandwidth of 6 megacycles.*




KEN—A TV signal certainly is wide if you compare it with an AM signal—or even with the entire broadcast band! But we don't have to go quite as far as two sidebands.

WILL—What? Can you do without one of the sidebands?

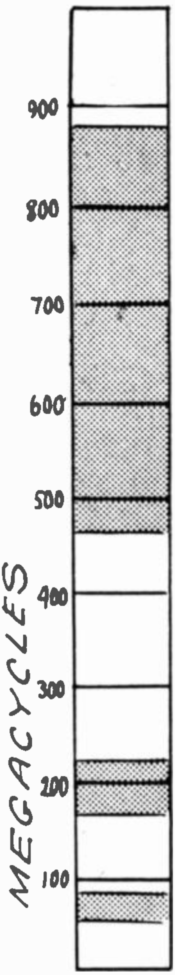
KEN—Not quite, unless you're willing to put up with a lot of distortion. But we can cut off the greater part of one



sideband. Have you ever heard of *vestigial sideband* transmission?

Will—Yes, but I never knew what it meant. So they trim off a lot of one sideband, and in this way reduce the frequency band you need to transmit the signal. But just what frequencies are used on TV? These channel numbers don't give you much of an idea about where the bands are or how much space a channel takes up.

Ken—In this country there are three TV bands. Two of them—from 54 to 88 mc and from 174 to 216 mc—are in the so-called very high frequencies, and one—from 470 to 890 mc—is in the ultra-high-frequency spectrum. Channels are 6 mc wide. The widest channel is the French high-definition 819-line system, which has a width of nearly 14 mc.




**And the word was given — —**

Will—Despite everything I've learned our images are still dumb. But I know they do speak on the real television screen. I suppose we add a narrow band of frequencies to our video signals to carry the sound.

Ken—There are some ways of carrying the sound on the same carrier as the video signals. But the practical way of doing it seems to be to use a separate transmitter for the sound.

Will—I suppose the sound is kept on a frequency well away from the video signals, to keep interference down?

Ken—On the contrary. The sound is as close to the composite TV signal as possible without letting the sound and video signals overlap. There is less than a megacycle between the two signals.

Will—Doesn't sound like a very healthy condition. Why do they have to be so close together?

Ken—There are several reasons. One is to keep the signals close enough together so that you can use one antenna for both sound and picture signals. And another reason is that our antennas are like tuned circuits.

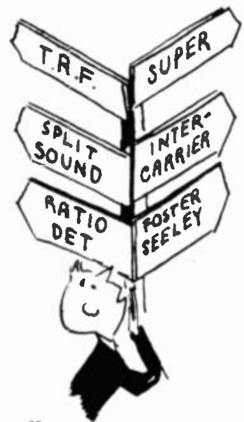
Will—And this sound signal—how wide is it? Do they keep it down to a theoretical 10,000 cycles or so, like an AM broadcast, or does it get a 200-kc channel like an FM signal?

Ken—In the first place, it *is* an FM signal—at least in American television. And it is permitted a deviation of 25 kc each side of the carrier.

Will—FM, eh? Then could you call television sound "high fidelity?"

Ken—Reasonably high—if the sound part of your reeiver is designed for high-fidelity reception and reproduction.

# Rf and if circuits




WILL—I'm glad to see you again, Ken; I've been walking around with an awful empty feeling . . .

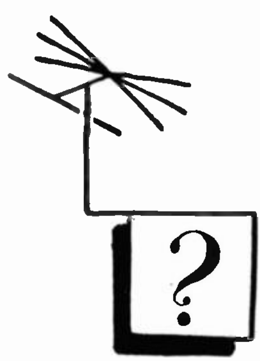
KEN—Why—what's the trouble?

WILL—Well, I feel something like a mother who abandons her child to run off to a bridge party. You remember, we left our waves carrying the TV image, sync signals and all that, floating around somewhere between heaven and earth . . .


KEN—. . . and now you want to bring all this high-frequency energy back down to earth . . .

WILL—. . . and use it to operate a TV receiver. Wasn't I supposed to be going to build one, as part of the job of learning how TV works?

KEN—And have you given your receiver any thought? Is it going to be a superheterodyne? Will it have a uhf range? Or are you sticking to the vhf for the present? Will . . .




WILL—Hold on a moment! I haven't had time to decide about all these things! Now this circuit question, for instance. You gave me the idea I could use a trf, but all the diagrams I remember looking at are supers.

KEN—I was kidding a little. You *could* use trf. They do this in some countries, where most sets are fixed-tuned, and get only one station. But the superhet is the universal circuit for TV reception today.

### The superheterodyne TV receiver

WILL—I see you're making another one of those *apple-box* diagrams.

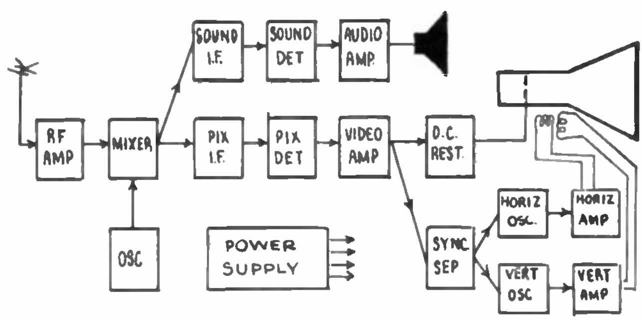
Ken—Will, you might as well learn to like these block diagrams! They're the best way to get a general idea of how assemblies are hooked together. Suppose I had a visitor who wanted to get acquainted with New York. Would I start in by taking him through all the picturesque lanes of Greenwich Village? Not at all; I'd take him to the top of the Empire State Building and give him a general view of the whole island. It's the same way with a TV receiver. If I were to draw a complete and detailed schematic for you at the start, all you'd get out of it would be a frustrated feeling!

Will—Oh, that's all right! Don't get me wrong— I don't object to apple boxes. But talking of frustration—I can't make anything out of this at all!

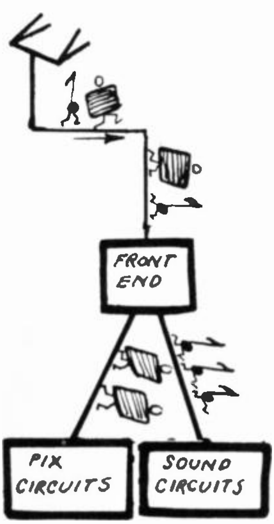
Ken—Get a grip on yourself and take a look at the sound part! How different is it from the radio receivers we studied together years ago?

Will—The sound part looks normal. But look—it and the video if both share the same oscillator and mixer. That ought to be very economical, but can you get it to work?

Ken—Very well indeed! First of all, the rf amplifier is wide enough to cover a whole channel—including both video and sound—without too much trouble.




*Block diagram of a television receiver. This is known as a split-sound type. The sound and picture have their own intermediate-frequency stages. This setup is not too widely used today.*




Will—But how do you separate video and sound after the converter stage?

Ken—Nothing magic about that, either! The oscillator beats with the different video and sound carrier frequencies and produces two intermediate frequencies that can be separated by tuned circuits without any trouble.

Will—I still don't understand it.

Ken—Let's suppose we're receiving channel 2, with the picture carrier at 55.25 mc and the sound at 59.75. Now, if we tune our oscillator to 101 mc, what will the sound and pix if's be?

WILL—For the sound we'll have:

$$101 - 59.75 = 41.25 \text{ mc}$$

and for the video:

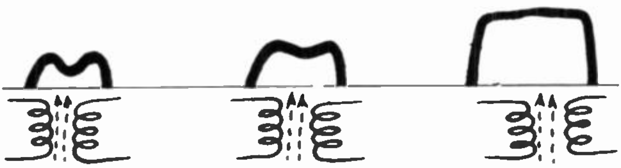
$$101 - 55.25 = 45.75 \text{ mc}$$


KEN—And if you tune your sound and pix if's to those frequencies, you shouldn't have any trouble. That is one reason the superhet is almost universally used. We need selectivity. The tuned circuits have to be wide enough to admit the whole band without attenuation, but the picture circuits have to keep the sound carrier and its sidebands out. So your selectivity curve must be flat and broad, yet have very steep sides. If not, you get sound mixed up with the picture. Then you really have trouble.

WILL—How? Does the picture-tube screen go into vibration?

KEN—Not quite as bad as that, Will! When you get sound in your picture, you have black and gray horizontal bars over your picture.

WILL—That wouldn't be so good either. And you can keep the sound and picture apart without too much trouble?



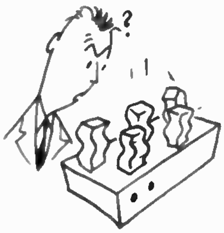
*By tuning each if transformer to a slightly different frequency, we can manage to pass a wide band.*

KEN—We-e-ll—not without trouble. . . . First, you must give your selectivity curve a shape that passes the whole video curve without letting the sound in. Since the if circuits are tuned to fixed frequencies, they can be adjusted very accurately. So you can produce that broad, flat-topped curve by tuning one (for example) to a point near 43 mc, the next to 45.5 and the next one to a point between them. That is called *stagger tuning*. Or you can tune them all to a point near the center of the video if band and couple them so close that the response at the center frequency drops and the curve spreads out, giving about the same effect. Second, you then use rejector circuits—called sound traps—to further reduce the sound signal.

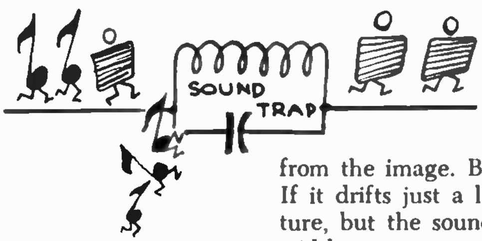
WILL—So it does look as if the super is best?

KEN—Except possibly where the set is fixed-tuned to one station, as is usually the case in Europe, for example. But the super has one disadvantage. By its very nature, it produces interference that shows up . . .

WILL— . . . as whistles!



Ken—In an AM broadcast receiver, yes. But in TV, the interference takes the form of stripes and bars, moire patterns and other visible figures instead of anything you can hear. But this disadvantage is balanced out by many other features of the super. It would be almost impossible to tune a multistage rf receiver to all the channels of the upper and lower vhf bands, to say nothing of the uhf. And we've seen that the fixed-frequency tuning of the if circuits makes it easier to get a curve broad enough for the pix signals, yet sharp enough to separate the sound




*Sound traps are used to keep the sound from modulating the input electrode (cathode or grid) of the picture tube. If the sound trap is not accurately tuned, bars will appear in the picture.*

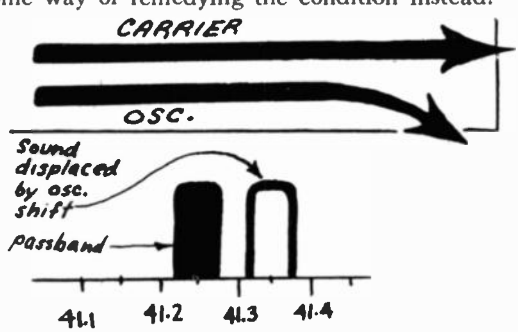
from the image. But a stable oscillator is very important. If it drifts just a little, it may have no effect on the picture, but the sound suffers because of its narrower bandwidth.

Will—Why should a narrow bandwidth be so disastrous?

Ken—Well, suppose the oscillator changed from 101 to 101.1 mc, or 1 part in 1,000. You probably couldn't see the effect on the picture. The sound if would move from 41.25 to 41.35 mc. Let's put it in kilocycles: The sound moves 100 kc, from 41,250 to 41,350. With a 25-kc deviation each side of the carrier, or a sound bandwidth of 50 kc, you can see that the new sound if is completely outside the sound if channel's passband. You wouldn't hear any sound at all.

Will—Considering some of the jokes and commercials, not to mention the sopranos—would that be bad?

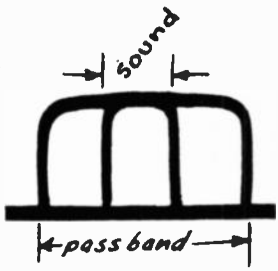
Ken—Making jokes about a thing is often an excuse for having no positive ideas in your head. Couldn't you think of some way of remedying the condition instead?

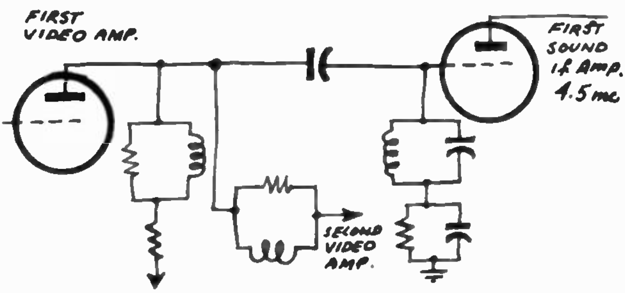



*A shift in the frequency of the oscillator can displace the sound.*

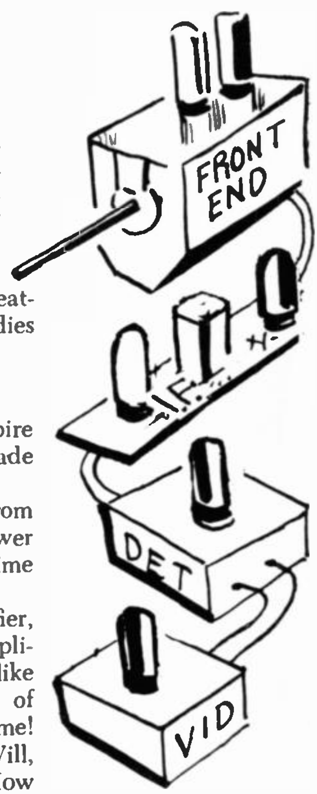
WILL—Just stabilize the oscillator better.

KEN—That's one way, and it works to a limited extent. Another is to make the passband of the sound if broader than the range of frequencies it has to amplify. Thus you have a safety margin if the oscillator varies a little. More popular is the *intercarrier* system. Both sound and pix signals are carried through the same composite if amplifier to the detector or video amplifier. Then the sound is picked off on an intermediate frequency of 4.5 mc produced by *the sound and picture carriers beating together.* This sound signal is amplified through one or possibly two stages at 4.5 mc and demodulated with an ordinary discriminator. The sound and pix signals then always stay the same distance apart, no matter whether the receiver oscillator drifts or not.




*In the intercarrier system, both sound and picture travel together through the intermediate frequency and detector stages. Separation of picture and sound takes place somewhere between the output of the detector and the input to the picture tube.*




WILL—Sounds simple, but I can't figure it out at all!

KEN—Probably your brain has taken too much of a beating already today. But I would like to continue our studies at this time.

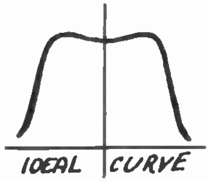
## The bad circuits are good

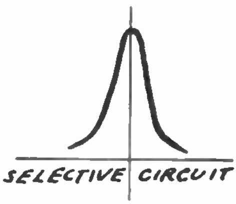
WILL—Very well. Now that we've taken your "Empire State Tower" view of how a television receiver is made up, how about getting right down to circuits?

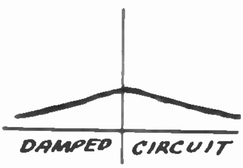
KEN—Fine! Suppose we follow the video signal from the antenna to the picture tube. We can forget the power supply, sync, and other auxiliary circuits for the time being.

WILL—In other words, we'll go through the rf amplifier, frequency changer, picture if, detector, and video-amplifier circuits. I didn't realize that TV was so much like radio—the only difference seems to be that instead of audio, we have video signals. All the rest is just the same!

KEN—You've been wrong plenty of times before, Will, but not often quite as dead wrong as you are now! How




many times have I tried to tell you that even the best broadcast radio transmission has a bandwidth of less than 20 kilocycles, while a single television video channel is 4 *megacycles* wide? That one thing makes each and every circuit different!

WILL—Different, but not difficult. For instance, you wouldn't have to make your circuits as selective as in radio. You get out of one difficulty right there!

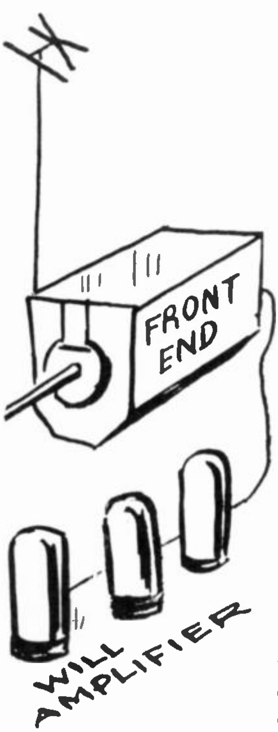
KEN—You mean you get into one! Just as in AM radio, you have to worry about trying to satisfy the opposite demands of selectivity and fidelity, so in television you are faced with the struggle between getting a broad enough band and getting enough gain.

WILL—You seem to have a few contradictions today yourself! Isn't it just the circuits that aren't selective that pass a wide band? When I remember how much trouble we used to have making our circuits selective enough, I don't think there can be much difficulty in cutting down the selectivity. All you have to do is use what in radio we called low-quality circuits.

KEN—This time you're right. Unfortunately, you can't get very much gain with "low-quality circuits." And you have to apply up to 50 video volts to the picture tube's control element, even though the signal on the antenna may be measured in microvolts. You need a voltage gain of several hundred thousand to do that!

WILL—So that's why a TV receiver has so many stages of different kinds of amplification?

KEN—That's the main reason. We'll go into some of the other reasons later.




**Why the rf stage?**

WILL—I've noticed that you can have a couple of rf stages, a number of if, and two or three video amplifier stages.

KEN—You don't see many sets like that! But sets with one rf, three if, and one or two video stages are becoming the common type. And notice, Will, that when you have your if's tuned up above 40 mc, you are already in the vhf range. So you can be studying vhf while you learn how the if's operate.

WILL—But if that's so, why bother dividing up the amplification between rf and if stages? Why not use just one 5-stage if amplifier?

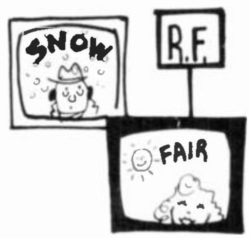
KEN—First of all, your amplifier is likely to oscillate if you cascade too many stages, even though the gain of each stage is pretty low. With two amplifiers working at different frequencies, you're going to have less regenerative feedback. But the rf amplifier has a far more important advantage. You can use it to cut down the amount of noise as compared with signal.


WILL—But why worry about *noise* in a picture receiver?

KEN—The word "noise" came from AM radio, but we give it a little different meaning in television. It means all those irregularities in current that result in the confused rushing noise you hear in an AM radio with no signal and the gain turned up. It's caused by several things: the current flowing through resistors, oscillating circuit irregularities, and unevenness in the cathode emission of the many tubes in the set.

WILL—But even then, noise is inaudible in a video channel!

KEN—Yeah, but it's not invisible! These irregularities of current—amplified through all the stages of a TV re-receiver—modulate the electron beam just as a video signal from a transmitter would. So the noise comes out on the screen as snow or a grainy image. I'm sure you've seen both, though maybe you didn't know you were looking at noise!



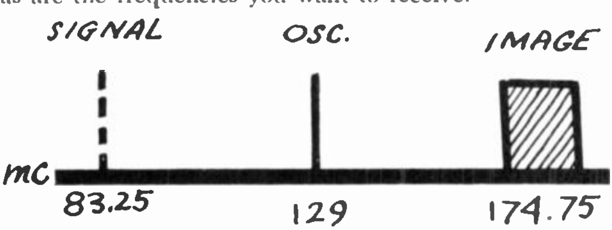

WILL—So rf amplification makes the pictures less snowy?

KEN—Exactly! In more technical terms, rf amplification improves the signal-to-noise ratio. And it has still another advantage. Even though TV rf stages are not particularly selective, they are a great help in cutting down interference from stations on neighboring channels.

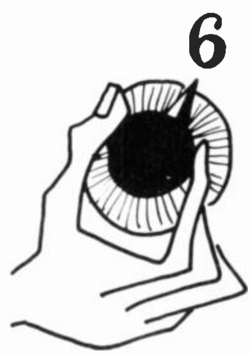
WILL—But I thought the FCC didn't allot adjacent channels in the same area.

KEN—It's supposed to work out that way, but there are places where there is adjacent-channel interference. And you have image frequencies to think about.

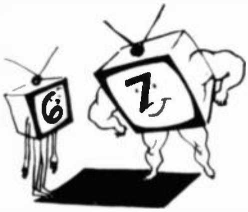
WILL—Oh, yes! If I remember right, they are frequencies that are the same distance away from your oscillator as are the frequencies you want to receive.




*An image signal can go through the receiver, since the image will produce the same intermediate frequency as the desired signal.*




KEN—Queerly put, but I think you have the idea. But to make sure, suppose you have a channel 6 video signal at 83.25 mc. With the oscillator at 129 mc, you have an if of 45.75 mc. A signal at 174.75 mc will give you the



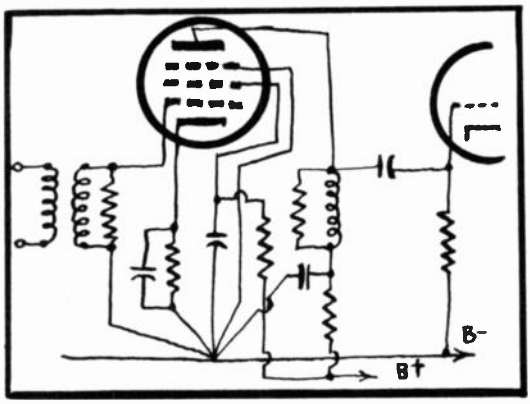

same if with the same 129 mc oscillator. The video carrier of channel 7 is at 175.25 mc, only a half megacycle away—well within the fine-tuning range of the usual receiver. Suppose you lived in a region where channel 7 was a strong station and channel 6 a weak one . . . ?

WILL—. . . maybe I could get two programs at once, without buying the expensive special receiver I read about not long ago!

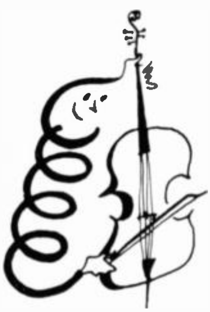
KEN—Except that you couldn't unscramble them with polarized glasses! But seriously, I think you've learned enough to know how useful rf amplification can be in a TV receiver.

### Schematic with invisible elements

WILL—So let's start with the rf stage. How about a diagram?




*Radio-frequency amplifier stage. The tuning coils are shunted by loading resistors. This reduces the gain but helps permit the full 6-mc signal to pass.*



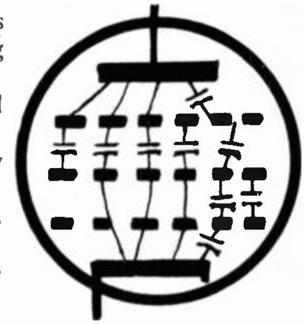
KEN—Here is it. You'll recognize an old friend—the tuned-plate circuit—in this schematic.

WILL—Are you kidding? Don't tell me that coil and resistor in the plate circuit are a tuned circuit!

KEN—Haven't we talked about invisible components before? If not, we'd better start now—they keep getting more important as the frequency goes up! The capacitor you can't see across the coil is really there! It's made up of all the capacitances shunted across the winding—its own distributed capacitance, stray wiring capacitances, and the interelectrode capacitances (between the plate and the other electrodes of the first tube and the grid and other electrodes of the second tube).

WILL—But why not use a variable capacitor, like a real self-respecting tuned circuit . . . ?

KEN—Because—to get any gain at all—we need as much inductance and as little capacitance as possible in our circuit. We even have to space the coil turns and keep leads as short as possible, to cut down distributed and wiring capacitances.

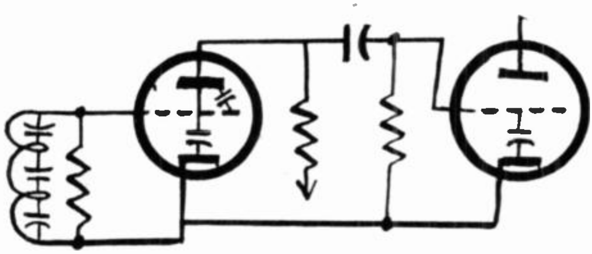


WILL—I suppose the first grid coil is also a tuned circuit?

KEN—Yes. And you'll note that it's also inductively coupled to the antenna coil.

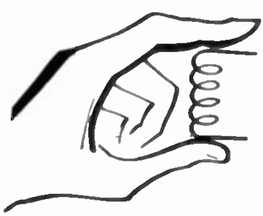
WILL—But I don't see any variable capacitors or cores. If these are *tuned* circuits, how do you tune them?

KEN—By changing the coil inductance. Most of these coils are made of a few turns of fairly stiff wire, so you



*Interelectrode capacitances cannot be seen but are just as real and as effective as capacitors you can see and touch.*

can tune them by squeezing the turns together or pulling them apart a little. But they use permeability-tuned coils occasionally at these frequencies, with cores of powdered iron or of copper.

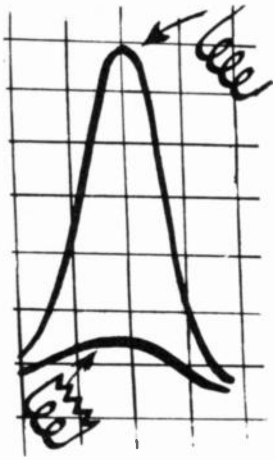


WILL—I understand the magnetic core all right. But how can a nonmagnetic core change the inductance of a coil?


*Either an iron core or one made of copper can be used to vary the inductance of a coil.*


KEN—The rf fields set up eddy currents in the conducting core. And these currents set up fields that oppose and weaken the field of the coil. The effect is to reduce its apparent inductance. You'll notice that conductive cores have an opposite effect to that of magnetic ones, which increase the inductance.

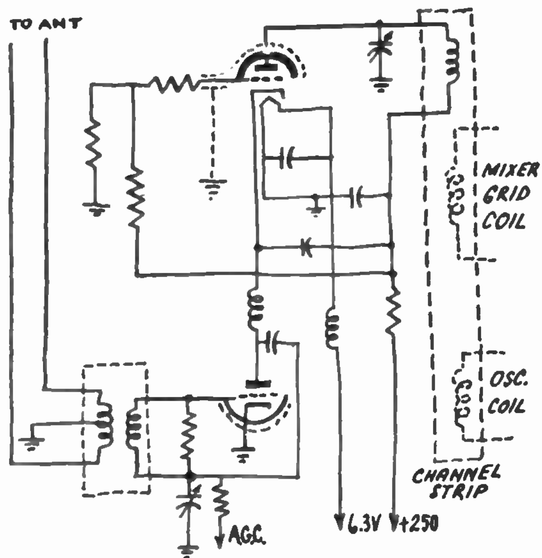
WILL—Then I see a practical difficulty. How are you going to adjust the cores? If you move them in and out of the coil by turning a screw, isn't the metal in the screw going to get into the argument?



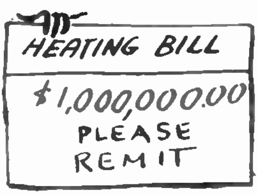
KEN—Quite correct. And that's the reason you'll often find the screws on this kind of coil made out of insulating material. And the screwdrivers too.

WILL—You see, I think of everything! But let's get back to our diagram. I see you have resistors shunted across your grid and plate coils. I hope they're high-resistance units! Otherwise they're going to absorb a lot of that high-frequency energy you've been trying to save.

KEN—I've bad news for you, Will! Their resistance is pretty low—may go down to 5,000 ohms or so. But you're quite right about their absorbing a lot of the energy in the circuits. That results in what the technicians call "damping." And it's just such damping or flattening of the selectivity curve that lets the circuit pass the necessary wide-frequency band.

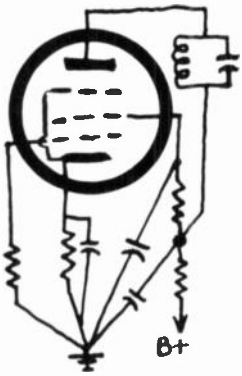

*Circuit showing the hookup of a cascode front end. This arrangement produces a much better signal-to-noise ratio than a tuner using a pentode.*



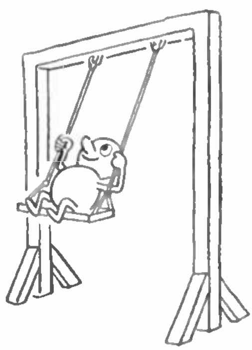

WILL—That's not my idea of a smart operation. Just to pass all the video modulation frequencies, you feed the tiny parcels of energy you get from the antenna into these damped circuits. There you dissipate them in heat, instead of amplifying them to help the signal. Isn't that the most expensive form of heating in the world?

KEN—You're absolutely right, but we can't get away from it! Now you understand why stage gain is low. But, to make up for it, you can use very high-gain tubes. Some pentodes with extremely high gain have been developed specially for TV rf amplifiers. But, unfortunately, the more elements you get in a tube, the more noise it produces. So some manufacturers prefer to stick to the triode, with its lower gain and better signal-to-noise ratio. Now practically all TV front ends have an rf amplifier that uses the famous *cascode* circuit, which consists of two triodes so hooked up that they give the gain of a pentode with the much lower noise level of two triodes.

WILL—There's something new and different in your diagram. Usually all the lines in a schematic come together in neat right angles. But here you have a spray of lines coming from a single point on the chassis. Why?




*A common tie point for all ground returns is advisable to minimize possibility of feedback.*

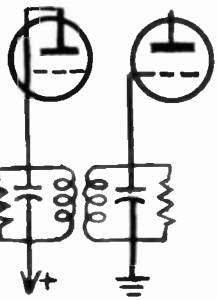


KEN—You'll see more of that kind of hookup. It simply means that all of the negative, or ground, connections are brought together at a single point on the chassis or ground bus. The old radio stunt of bringing ground leads to the most convenient point on the chassis is a sure way of producing oscillation (or sometimes heavy degeneration) when the frequencies begin to get high!

WILL—I see that the screen and plate are bypassed by capacitors that lead to the ground point on the chassis, and the cathode is bypassed by another capacitor across the cathode resistor. But aren't we trying to bypass plate and screen back to the cathode?

KEN—You're right. Decoupling might be a little better if the capacitors from the screen and the lower end of the plate coil were brought directly to the cathode. But it's easier to wire up a set with all these leads coming back to a common chassis point for each stage, and there doesn't seem to be much difference in practical results.

WILL—Are all televisers wired this way? I've seen plenty of TV schematics, but I don't remember ever seeing one that looked like this.

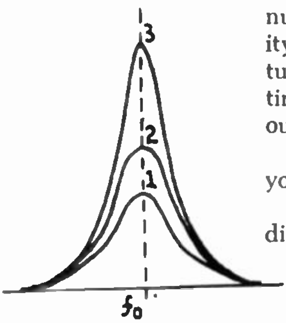



KEN—Once you understand the principle, it isn't necessary to show it in the diagram. For example, the drawing on page 122 is in standard schematic style.

WILL—Yes, this looks normal. Here's the good old inductively coupled circuit with tuned primary and secondary. This kind of a circuit should help to bring up your selectivity quite a bit.

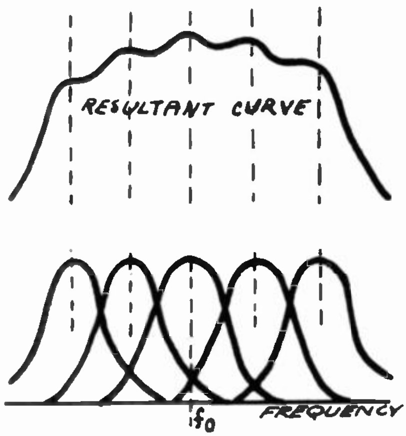
### The camel with many humps

KEN—Poor Will! You still insist on thinking and talking like a good broadcast technician. But comparing TV to broadcast radio is like comparing radio to electric power circuits! You've got to change your whole outlook on life! "Bringing up the selectivity," as you put it so innocently, would be a calamity! And the worst of it is, increasing the number of tuned circuits does lead just toward that calamity. For example, look at this selectivity curve of one tuned circuit, then of two and of three in cascade. Every time you add another stage you narrow the passband, and our video signals have less and less chance to get by!




WILL—But they do get by! You're holding out on me—you have a cure for this trouble. What is it?

KEN—It's simple! You just tune each circuit to a slightly different frequency!




*The bandpass curve is the resultant of the curves of the individual intermediate-frequency stages.*

WILL—What? Do you mean you intentionally misalign the circuits—throw your if amplifier out of adjustment?

KEN—Exactly. By selecting the frequencies of the various tuned circuits properly, you can get an over-all selectivity curve that approaches the ideal shape very closely.

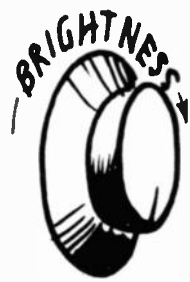
Of course, you pay for it in reduced gain—we still haven't found any way of getting something for nothing.

WILL—This curve of yours reminds me of the way we used to play camel when we were small kids. We'd get in a row and cover ourselves with a blanket. Our "camel" did have too many humps—I never saw anything just like it till you drew this flock of curves.

KEN—It's nice to know that a few of the experiences of your misspent youth are helping your understanding today!

**Sensitivity and contrast**

WILL—This may sound a little dopey—but is the gain of these TV amplifiers fixed, or do you have a gain control of some kind? I don't remember ever seeing any such controls—but I don't exactly know the meanings of all the terms on the screwdriver adjustments.




KEN—There is an adjustment all right, and it's right out on the panel—with a knob—where you can see it. It varies the gain the same way as gain controls work in radio—occasionally by varying the voltage on the screen grids, but mostly by varying the cathode bias.

WILL—And just what does a TV gain control do? Let's see—it would vary . . . Oh, of course! It's the brightness control! You said it was on the front panel . . .

KEN—But I didn't say it was the brightness control! The brightness is controlled by varying the picture tube's cathode bias, but we'll talk about that later. The gain con-

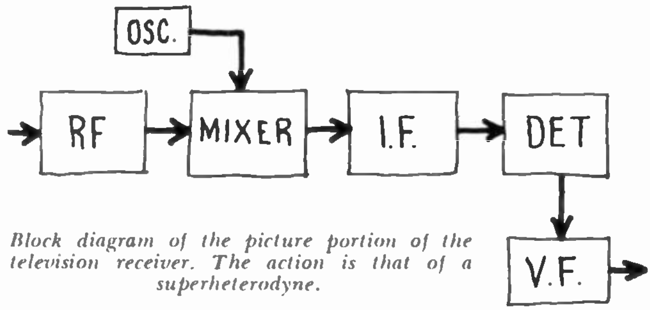
*The gain control in a television receiver corresponds to the volume control of a radio set. The gain control adjusts the strength of the video signal. With this control you should be able to cut off the picture completely or have a picture of adequate strength.*


trol varies the amount of video modulation applied to the control element (grid or cathode) of that tube. When the video signals are weak . . .

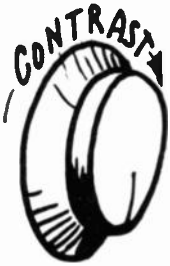
WILL— . . . of course, the brightness of the spot varies very little.

KEN—. . . and when the signals are strong, the spot goes through the whole gamut of brightness from dead black to intense white.

WILL—So—in the first case—you have a gray picture. In the second you have a picture with sharp blacks and whites. It's just like printing a photo negative on a soft

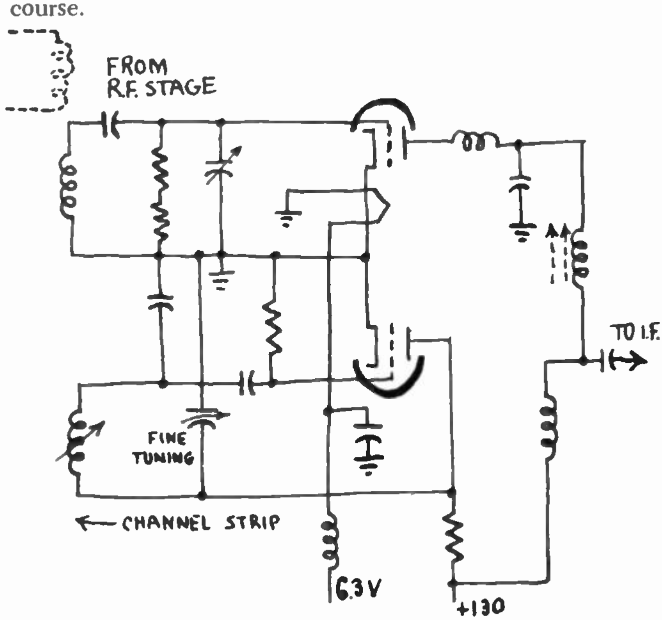



*Block diagram of the picture portion of the television receiver. The action is that of a superheterodyne.*




type of photographic printing paper and then on a contrast type of the same paper.

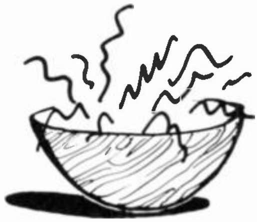
KEN—Exactly! And you have named the gain control without realizing it! It's the one you call "contrast" of course.




*Mixer circuit in the front end of a television receiver. The fine tuning control makes small changes in the frequency of the local oscillator.*

WILL—I guessed it! Now, does it control the rf tubes or the if tubes?

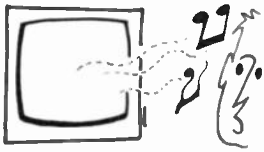
KEN—It has been used on both—and even on the mixer tube—but now it generally controls the cathode bias of the video tubes, and the if and rf stages have automatic gain control.

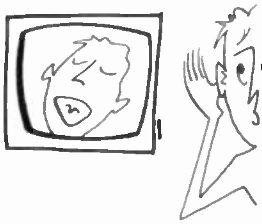


### One or two tubes ?

WILL—You spoke of a mixer tube. I notice that TV circuits generally show an oscillator and a mixer, instead of the one converter tube we always have in radio. Why?

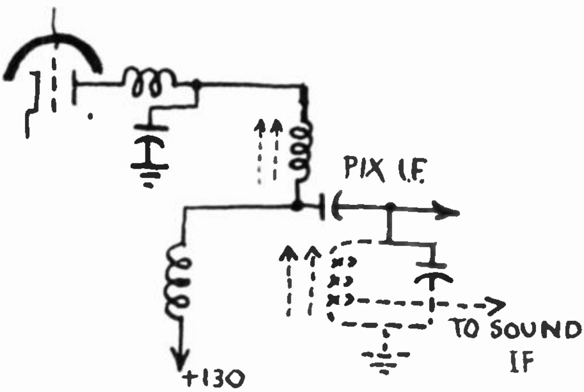
KEN—There are several advantages. You would get very much less gain with a converter tube at TV frequencies than on the broadcast band. It's better to use a pentode with a lot of gain and have a separate local oscillator. But both the converter tube and the pentode mixer have a bad fault—noise. The more elements you have in a tube, the noisier it is. So the majority of front ends now have a triode mixer and a triode oscillator—usually in the same tube—preceded by a cascode rf stage.





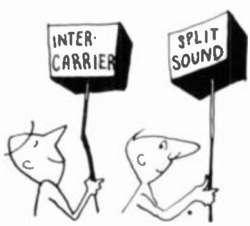
### Sound without picture and picture without sound

WILL—But I see only one output lead here. We know there are two if's, sound and pix. Do they both go through the same if amplifier?




*The sound can be extracted at any point from the output of the front end tuner to the input to the picture tube. A sound takeoff coil is used.*

KEN—In most cases, yes. That's what happens in all sets that use the *intercarrier* system. The *split-sound* receiver does have a separate sound if amplifier, and another little coil tuned to the sound if is placed in the output circuit of the tuner-converter to pick off the sound intermediate frequency. Perhaps I should have said "take off" the sound, because the coil is called a sound take-off. We'll draw it in dotted lines. Then there are a few sets that have one or two composite if stages like an intercarrier receiver, then send the sound if to a separate amplifier.



WILL—I suppose that the sound if goes to a grid-leak detector.

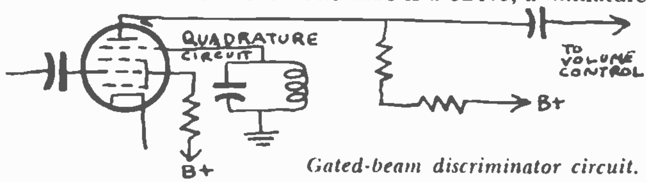
KEN—Aren't you forgetting that TV sound is FM?

WILL—That's right! So the detector would be just like that in my FM set—a limiter followed by a discriminator-type detector.

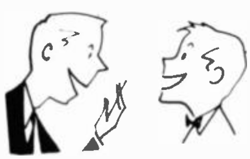
KEN—Your FM set must be old. Most TV sets today have a ratio detector. Properly operated, the ratio detector does away with the limiter. Another circuit, the gated-beam detector is becoming popular.

WILL—Gated-beam detector? Sounds interesting. Would you explain?

KEN—Here's the circuit. The tube is a 6BN6, a miniature




*Gated-beam discriminator circuit.*



type used as a combined limiter, discriminator and audio amplifier. Have you any idea why limiting action is required?

WILL—Sure. We're dealing with FM. We're not interested in amplitude variations, so we restrict them. And a discriminator is a detector that converts rf frequency deviations to audio with varying amplitude.

KEN—You certainly remember your FM theory. In the gated-beam detector, the if signal is brought into the control grid. With an input of about 1 volt the tube will go from cutoff to saturation.

WILL—I see. This is just the way the limiter works in my FM set.

KEN—Connected to one of the grids is a quadrature coil circuit. The electrons flowing from cathode to plate must pass the quadrature-coil grid. Electrons on this grid are repelled and set up a current flow in the quadrature coil.

WILL—Isn't that electrostatic induction?

KEN—Exactly. The quadrature coil, tuned to the if, will produce a voltage 90 degrees out of phase with the input signal.

WILL—Yes, but the incoming signal is changing in frequency.

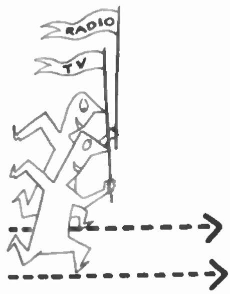
KEN—Right. And as a result we have a change in phase between the quadrature coil voltage and the input signal. You see, not only is the time of current flow through the tube determined by the control grid, but also by the quadrature grid. In other words, the average current flow is varied by the frequency deviation of the signal. Think of the input and quadrature grids as gates. The gates open and close and as a result the plate current changes with frequency. Actually, the 6BN6 was specially designed for its job.

chapter 11

# Detectors & video amplifiers


WILL—You know, every once in a while our talks remind me of a trip up a steep mountain trail.

KEN—I hope the road isn't getting too rough and rugged for you. We can take things a little easier—go into a little more detail, if you like.




WILL—No, that's not it! You know those hairpin roads that hang onto the side of a mountain, and give you the feeling that you're passing the same place over and over again, though you're really quite a little higher up each time? Well, every once in a while, I have the feeling that I'm going back through my course in radio, because the things we've just been learning are—if you don't mind me stealing a radio-TV term—"parallel" to things I've learned in radio. For example, haven't we just been talking about rf frequency changing, and if?

KEN—You've got a good comparison there. And you'll find as you go further and further up, the scenery is going to broaden out—get vaster and vaster. As you go through the various stages of a TV set, you're going to find the terrain a lot more rugged than in radio, because both the carrier and the modulating signal it carries are at much higher frequencies.

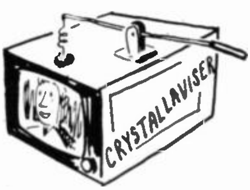

WILL—Well, I suppose we're just coming to the part of the trail where the signs they put up for tourists read: *Detection and Video Amplification.*

KEN—You're right! We'll begin with the problem of detection today. Now that we've amplified our signal at higher and lower radio frequencies (in the rf and if stages) the time comes when we have to get at the modulation it's carrying. After all, the rf is just a means of transportation for the signal. It gives us so many problems we sometimes forget that. It's a very rapid transport—but nothing more. Your carrier is like a truck. We load the video signal on it at the transmitter. Now we've got to unload it—get the video frequency out of this rf carrier.

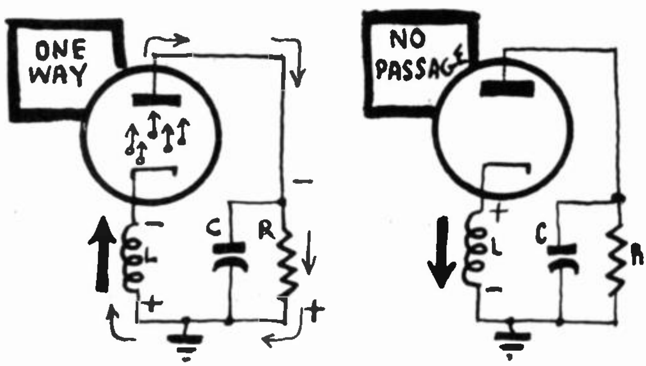
WILL—And when we detect our signal, we have to amplify it at audio frequency, I suppose?

KEN—You can hardly use the term "audio frequency" for the video signal. It covers a band that runs practically from zero to several million cycles per second. Let's give it its right name—video amplification!

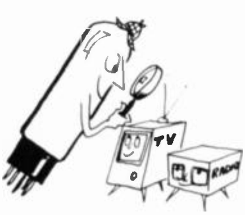
### A question of polarity




WILL—Beg pardon! I was just thinking of radio again. But let's not get ahead of ourselves. Suppose we cover detection before going on to amplification. I suppose we can use a crystal, diode, or triode to detect a TV signal, just the same as a radio signal, and either grid-leak or grid-bias detection—if we detect with a triode?



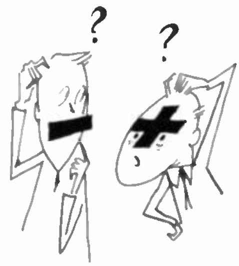

*A voltage can be induced across coil L so that the bottom of the coil is positive and the top of the coil is negative. When this happens electrons flow through the diode. Conduction stops when the polarity of the coil voltage is reversed.*




KEN—Yes, I guess you *could*. But in actual practice you'll find the diode most of the time, and grid-bias (or plate-bend) detection with a triode pretty rare. But the crystal is becoming very common. A crystal diode is less trouble than a tube and, because of its small capacitance, is better adapted to high-frequency work.

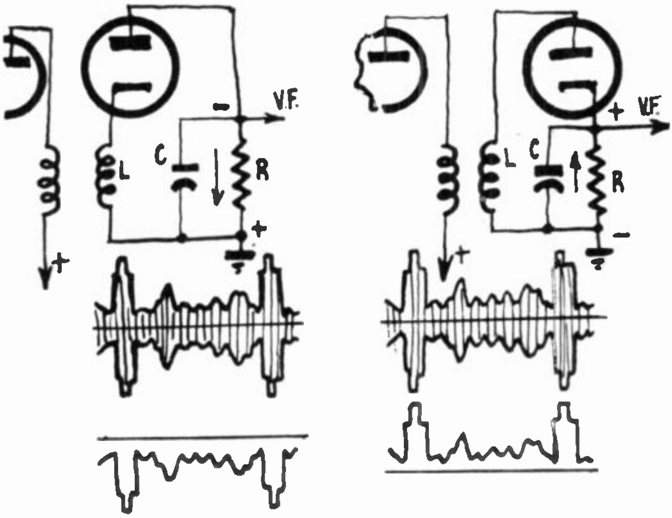
WILL—Is there any difference between a diode detector circuit in TV and radio?

KEN—Not a bit! Take a look. The rf (or if, if you like) voltages across coil L are applied to the diode (crystal or tube). It is connected in series with load resistor R, which has capacitor C across it. The alternation that makes the cathode positive cannot get through. But the next alternation, the one that makes the cathode negative, permits current to pass to the anode in the direction of the arrows. . . .



WILL—But why do you say that current flows when the cathode is negative? You have the plate marked negative here.

KEN—When the cathode is more negative than the anode, electrons can flow across the vacuum in the tube, or through the surface barrier in the crystal. You know that. These electrons are supplied by the voltage induced in L. Since the top end of L is the most negative point in the circuit, any current flow will make the bottom of the resistor more positive than the top. Electrons are being




*The diode rectifies the signal, passing either the bottom half of the waveform, or the top half. Capacitor C bypasses the higher-frequency carrier, so that in the output we have only the combined video and pulse signal.*

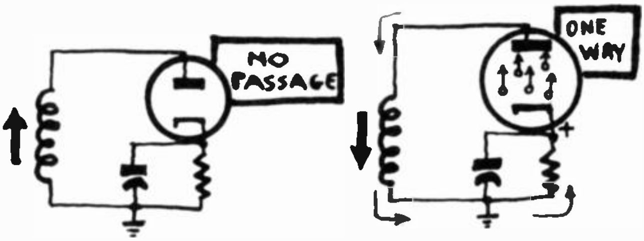
drawn away from it by the positive lower end of L, if you like. When the top end of L is positive and the bottom negative, no current can flow through the diode or R, so the polarity isn't changed.

WILL—Then if we represent our modulated rf signal in the usual way, as you have here below the circuit, the detector blots out everything above the horizontal zero axis and lets only the negative alternations go through, and even these rf alternations lose their identity and are combined to produce the video signal by the accumulative action of capacitor C.

KEN—I see you haven't forgotten much of what I taught you about radio not so many years ago. But notice now that instead of passing the negative alternations, we could

just as well use the positive ones. All you have to do is turn the diode around.

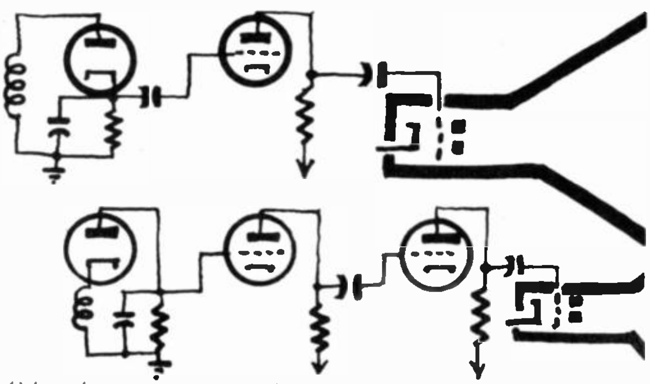
WILL—That would be silly! Then your maximum video signals would be produced by the most positive voltages.



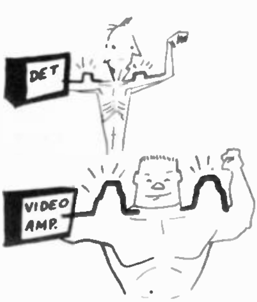

*The diode will conduct if the plate is made positive with respect to the cathode or if the cathode is made negative with respect to the plate.*

If you applied signals like that to the picture-tube grid, you'd get blacks where you should have whites—a negative image!

KEN—Perfect reasoning! And if you intend to use the signal from the detector directly on the picture-tube grid, you'll have to use negative polarity. But we usually have



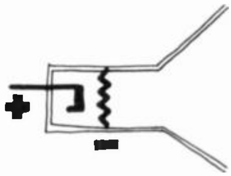
*Although two stages of video amplification can be used, most modern receivers use only one. The polarity of the signal at the video-amplifier output determines whether it is fed into the cathode or control grid of the picture tube.*




one or two stages of video amplification between the detector and the picture tube. The detector doesn't put out enough voltage to modulate the cathode-ray spot from a good white to a good black. Now, an amplifier stage reverses the phase of a signal applied to it—what comes in as a positive pulse to the grid becomes a negative one at the plate, and *vice versa*.

WILL—I can finish the story now. If you have one video amplifier stage, you need positive polarity. But if you have two, you need negative.

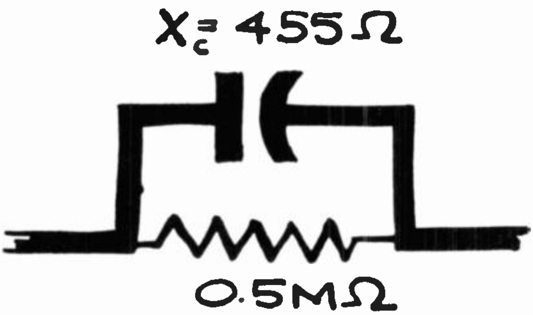
KEN—Exactly! But remember you can change your signal polarity another way. You can apply a *negative* voltage to the control grid of your cathode-ray tube, or a *positive* voltage to the cathode, which makes the grid relatively more negative. So, if you have the wrong polarity at the picture-tube grid, it may be easier to redesign your circuit to apply the signal to the cathode than to add another video stage.



WILL—Then we'd use negative detection for one stage and positive for two.

**Sudden drop of values**

KEN—You seem to have it, Will. Now let's try to figure out the values of capacitor C and resistor R in the detector circuit.




*Capacitive reactance varies inversely with frequency. If the frequency is high enough, the capacitor will act as a short across the shunting resistor.*

WILL—Well, I suppose we can still use our standard values of one hundred $\mu\mu$f and a half megohm, just as in radio?

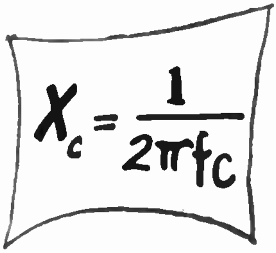
KEN—Oh, you think so? Well, now, just remember that the current you're detecting is alternating at a frequency not far from 50 megacycles a second. And the detected video voltages can run up to 4 mc. What reactance would your little one hundred-$\mu\mu$f capacitor offer to 3.5 mc, for example?

WILL—Let me calculate—why, only a little more than four hundred ohms! ! Is that possible?

KEN—It's probably correct. Now, how do your 400-odd ohms compare with the half-megohm resistor?

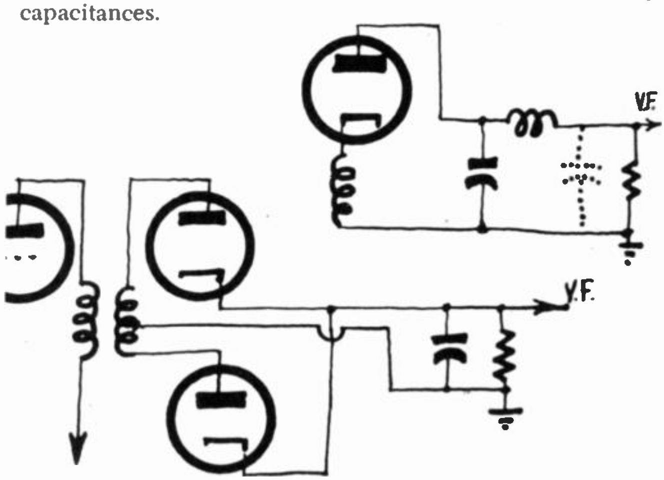
WILL—It would be practically shorted. You'd get practically no voltage across resistor R, and no signal into the video amplifier.

KEN—You're getting just a little too quick again! Certainly the lower video frequencies would get through with practically no attenuation. But the higher frequencies *would* be attenuated, and you'd get a picture with little or no fine detail.




WILL—Well, let's cut down the capacitor till it has enough reactance for the higher video frequencies.

KEN—That's just what has to be done. But you can't go too far in that direction either. The capacitance of C must remain considerably higher than the cathode-anode capacitance of the detector diode, if the greater part of the detected voltage is to appear across the terminals of C and R. So we use a capacitance of 10 to 20 $\mu\mu$f. Some sets omit it entirely, and leave the job to the various wiring capacitances.



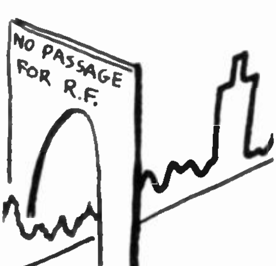

*Full-wave detection can be used, but the simpler half-wave diode (either tube or crystal) is very practical and is always used. An elementary filter helps eliminate the high frequency component from the detected signal.*

WILL—That would be economical, anyway. But it seems to me that the reactance would still be a little low compared to R.

KEN—Yes, you have to cut that down, too. Most sets use 3,300 or 3,900 ohms.

WILL—I suppose with a load resistor as small as that, the detection efficiency would take quite a drop, too?

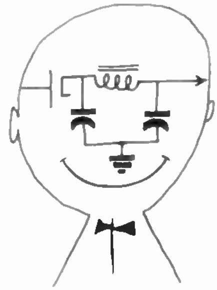
KEN—Well, even in radio we're a long way from getting 90% of the detected voltage. But by using special diodes designed for television, which have very low internal resistance as well as low cathode-to-anode capacitance, we can apply a good part of the detected voltage to our video amplifier.




WILL—So the circuit will be the same as in radio, but the values will be much smaller?

KEN—Well put! And you'll see a filter to bypass the residual rf much more often than in radio—present-day radio, at least.

WILL—Why, that filter looks just like the low-frequency filter in a power supply!



KEN—Nothing strange about that, Will. Both circuits are designed to get rid of a higher frequency than the one to be passed. So in both cases you use inductors to block the higher frequencies, and capacitors to give them an easy path to ground.

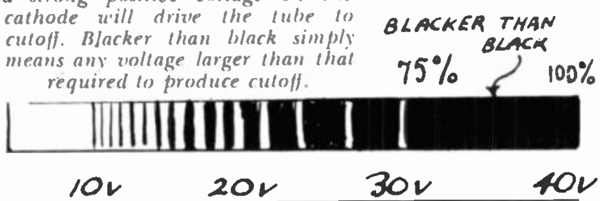
WILL—Well, since this filter looks so much like part of a power supply, couldn't we go even further and make our detector a double-diode affair, to give full-wave rectification?

KEN—Your idea would no doubt work perfectly, and—if you had a suitable balanced input transformer—the circuit would be more efficient than a single diode. Filtering would be easier, too, same as at 60 cycles.

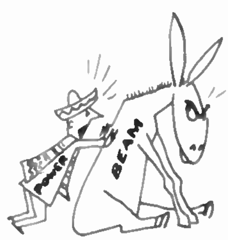
### Video is not audio

WILL—Now that we've finally got our video frequency clear of its carrier, all we have to do is amplify it. That shouldn't be too much different from amplifying the audio frequencies in a radio receiver, except for the wider frequency band you have to amplify. And with the frequencies 'way up in the megacycles, I suppose you have to be pretty careful of stray wiring capacitances?

*A strong negative voltage on the control grid of the picture tube or a strong positive voltage on the cathode will drive the tube to cutoff. Blacker than black simply means any voltage larger than that required to produce cutoff.*




KEN—That's for sure! But that's not the only difference between audio and video frequencies. Fortunately, some of the differences are in our favor and make our problems easier instead of harder. For instance, we need only a *voltage* to control the picture tube's electron beam at the output of our amplifier, rather than *power* to operate a speaker.

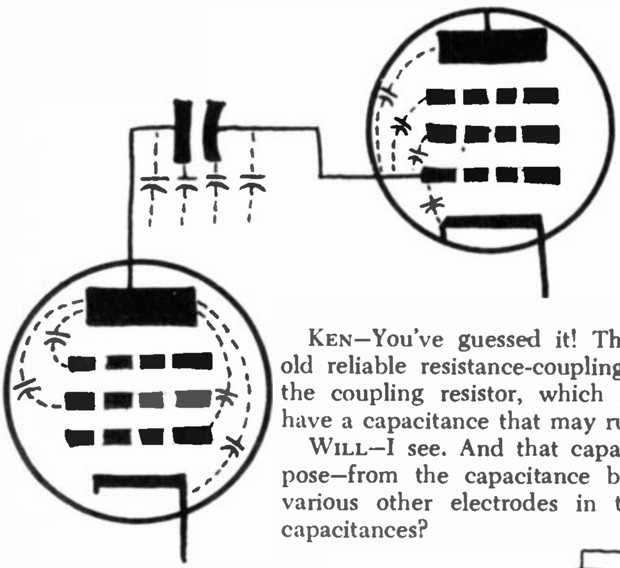



WILL—So we have to put out volts instead of watts? Fine—voltages are easier to calculate! And what are the other differences between af and vf?

KEN—Another important difference is that we don't need nearly as much gain as the average audio amplifier. To vary the brilliance of the spot from a good white to a good black needs only 20 to 30 volts. You usually get about a volt at the detector output. Therefore—in spite of the things that tend to cut down the gain in a video am-

plifier—one stage is enough in most cases. A few models do have two video stages, though.

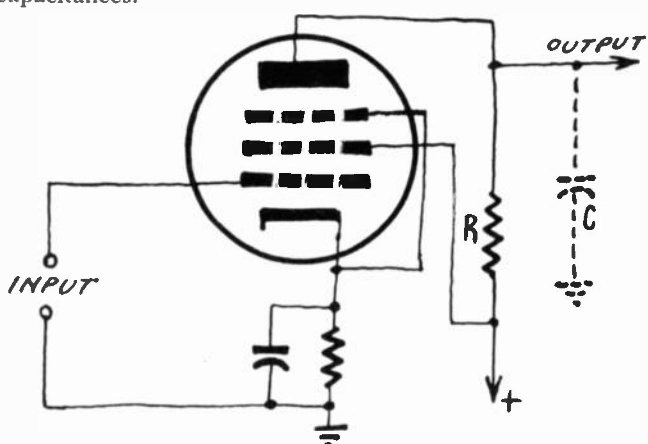
WILL—And the "things that tend to cut down the gain" are tied up with the high frequencies and problems of stray capacitances?



*Interelectrode and stray capacitances are everywhere. Sometimes these invisible capacitances can be put to work; at other times they are a definite nuisance. The use of miniature pentodes helps cut down on interelectrode capacitance.*

KEN—You've guessed it! The video amplifier uses the old reliable resistance-coupling system. And—right across the coupling resistor, which is R in this diagram—you have a capacitance that may run up to 30 $\mu\mu$f.

WILL—I see. And that capacitance is made up—I suppose—from the capacitance between the plate and the various other electrodes in the tube, plus the wiring capacitances?



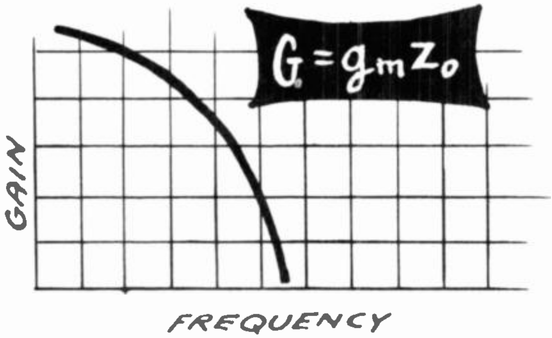

*It is sometimes easier to represent the sum of all the capacitances by capacitor C. The dashed lines indicate that it represents stray capacitance.*

KEN—Pretty good! All you've left out is the input capacitance of the following tube—between the grid and cathode of the picture tube, or (if you are feeding into the second of two video stages) the grid and cathode of the following amplifier.

WILL—H'm-m, with all these parasitic capacitances, the reactance at 4 mc would be less than a couple of thousand ohms. That means if we use a 100,000-ohm load resistor, same as in radio—all the higher frequencies would be shorted around it, and the high- frequency gain would be zero. So we lose all the highs—I mean detail—on our image.

KEN—Fine. You've analyzed the causes of the trouble, so you shouldn't have much difficulty supplying a remedy.

WILL—Well, I suppose we'll just have to throw away some more efficiency. So, we'll have to cut the load resistor down to a value that's comparable to the reactance of C at the highest frequencies the amplifier will have to handle. But—if we cut R down to 2,000 ohms or so the gain will be pretty low. With such a low resistance, we're going to need a lot of plate current to get any gain at all! So our tube will have to be a pretty powerful one. . . .




*As the frequency rises, the tube gain decreases.*

KEN—You're right all the way! As with the rf and if amplifiers, we need a tube with high transconductance. The gain is—under these conditions—practically equal to the product of the transconductance and output impedance of the amplifier.

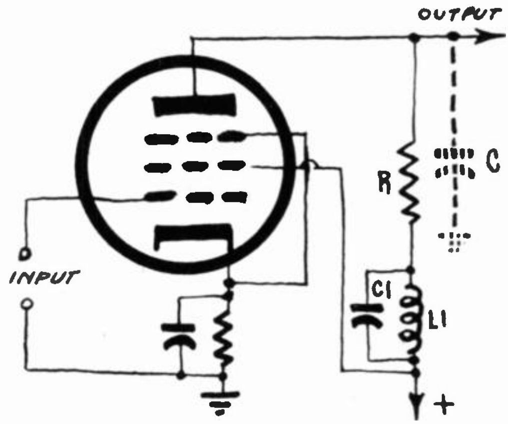
WILL—Then TV is based on waste all the way down the line! We invent special tubes that are remarkable and then use them at a fraction of their possible amplification, damp our tuned circuits, cut down our load resistors . . . ! What a life! !

KEN—Don't worry, Will. The main thing is to get enough signal at the output. In spite of all the inefficiency and low gain we usually manage to do that.

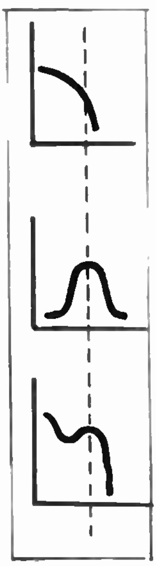
**Improving the response curve**

WILL—I'm thinking along radio lines, as usual. So I

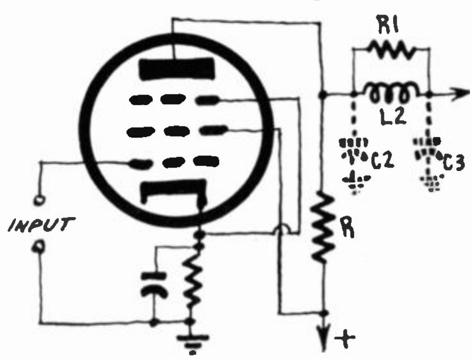
wonder why we can't help out our high-frequency response with some kind of "treble boost" that will accentuate the higher frequencies?




*The resonant arrangement of L1 and C1 (placed in parallel with the stray capacitance) helps boost the higher frequencies of the video signal. L1 is known as a peaking coil, and is most often wound directly on a resistor. C1 is generally not included. Here it represents the stray capacitance across coil L1.*



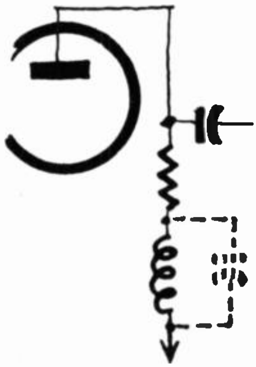
Ken—A good question! And the answer is—they *do* use such a "boost" on all receivers. The job is done with small inductors, placed either in series or parallel with the parasitic capacitance, or in both positions. In *parallel*



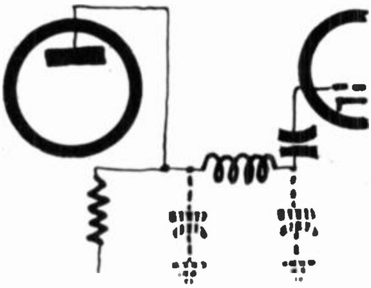

*Here we have another possible position for the peaking coil which is placed in parallel with the stray capacitance. In some sets both series and shunt peaking is used. See the drawing on the facing page.*

compensation, the winding L1 is placed in series with the load resistor R, as you see. When the value is correct, the response in the high-frequency direction is considerably improved.

Will—I suppose L1—together with the stray, or parasitic, capacitance—is tuned to the high frequencies you want to reinforce. Then its impedance increases a lot at those frequencies and is added to load resistance R, so the apparent plate load (and therefore the stage gain) will be higher over a small range of frequencies in the upper video range?

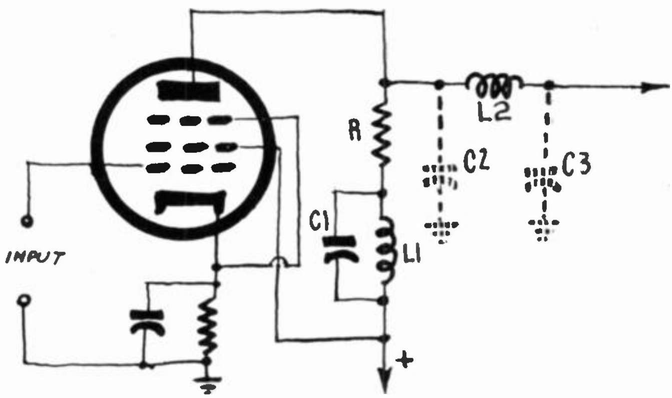


Ken—That's just about it. In fact, it's even a bit better,



*The peaking coil, shunted by stray capacitances, resembles the low-pass filter circuit of a power supply.*

for L1 neutralizes the effect of the parasitic capacitance and to some extent therefore increases the plate load over the whole range of frequencies. And we can get the same result—or even a little better one—by *series peaking*. A winding L2 is placed in the output circuit of




*Since L1 is in series with the plate load resistor R, it increases the effect of the plate load as the frequency rises.*

the stage in such a way as to divide into two parts (C2 and C3) the parasitic capacitance. In some cases L2 may be shunted across the resistor of the same order of resistance as R. The coil is often wound right on the resistor.

Will—The circuit looks like a low-pass filter.

Ken—That's just what it is, but it has a very high

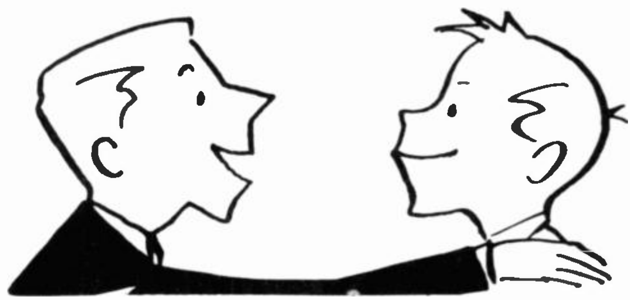

cutoff point. But to be really valuable as a filter, the capacitances C2 and C3 should be in a certain ratio. And of course—with these wild capacitances—it's pretty hard to be sure of anything. . . .

WILL—Didn't you say a while ago that we could combine both types of compensating circuits in a single video amplifier stage?

KEN—I did. And a combination of series and parallel peaking really does do the work! It gives you an excellent response curve, and permits an increase of gain by further increasing the value of R. But all the elements must be carefully calculated and precisely adjusted.

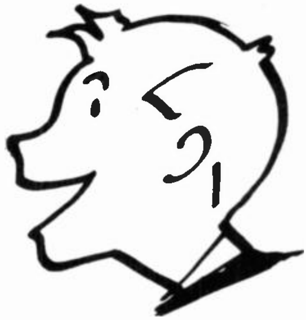
WILL—Effective, eh? Can you use these circuits on two-stage video amplifiers, too?

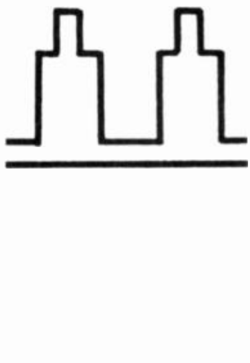
KEN—Of course. But isn't it getting a bit late? Suppose we continue our studies some other time.



chapter 12

# The dc component





Will—The other day, when we were talking about video frequency, you put in a lot of time on high-frequency problems. But don't you run into difficulties with the other end of the spectrum—the very low frequencies?

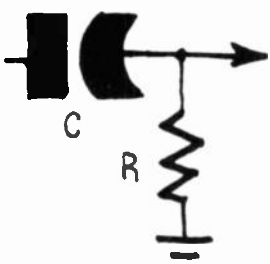
Ken—Maybe—but just how does all this come up?

Will—Well, I began by wondering if—in certain cases—the video signal didn't come down to a simple direct current. For example, suppose the picture has a large horizontal band of one shade. But you can't transmit dc through the interstage-coupling capacitors . . .

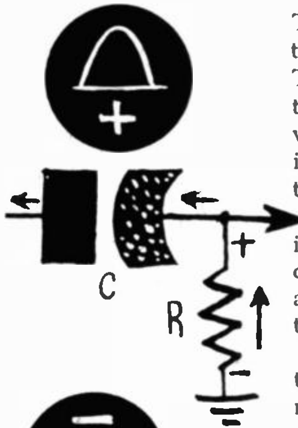
Ken—You might have a real difficulty there if you didn't have sync pulses at the end of each line. They make a very sudden change in the voltage and prevent it from becoming the simple dc you're thinking about. But—as you say—a capacitor can't transmit an unvarying direct current. And that poses some problems—only they're not the ones you're thinking about!

Will—Suppose you lay off the mystery and give me a line on some of those problems! Who knows—I might understand you!

Ken—Good! Suppose we start by thinking of the way an alternating voltage is transmitted through a coupling capacitor C with its leak resistor R.



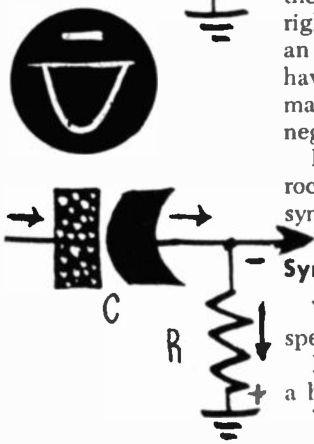

Will—We did that a long time ago, and nothing could be simpler. Let's say that an alternating voltage is applied to the left-hand plate of the capacitor. During the positive alternation it draws electrons away from that plate. Because the atoms on the left-hand plate are short of electrons, they try to attract a few from the other plate.




They can't get them across the dielectric, but a lot of electrons are dragged onto the right-hand plate. Where from? The only place they could come from is the ground, through resistor R. That current flow through R causes a voltage drop across it, and its top end becomes more positive than the bottom. So it's just as if the positive alternation had passed through the capacitor.

KEN—With this one important difference: If an alternating current is superimposed on a direct one (as in a plate circuit where you usually find your high alternating voltage), the dc won't be passed through the capacitor. But tell me, what goes on during the negative alternation?

WILL—Much the same thing. The electrons flow into the plate at the left, and of course chase others off the right-hand one, because there's nothing more repulsive to an electron than another electron. The displaced electrons have nowhere to go except to ground through R. That makes its top end negative. So again, it's just as if the negative voltage had gone through the capacitor.



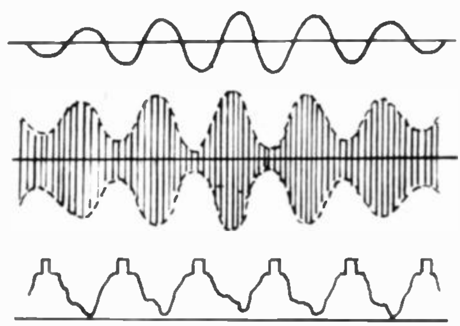

KEN—You're right all the way. The way these electrons rock back and forth balancing themselves so neatly and symmetrically reminds me of children on a seesaw.

## Symmetry and equilibrium

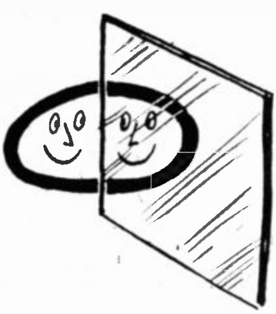
WILL—I knew all this a long time ago. Is there some special reason behind this refiesher course?

KEN—There is. And the reason is that things are just a bit different for the video signal.

WILL—How come?



*A modulating voltage is illustrated at the top. After being impressed on the carrier, it assumes the symmetrical appearance shown in the center drawing. After detection, the video signal (bottom) is all positive or all negative.*



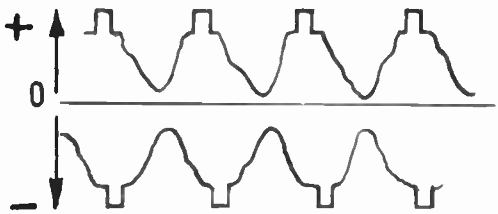
KEN—Because—unlike modulated rf or sound af—the video-frequency signal is not symmetrical. It isn't made up of equal positive and negative alternations that are exactly like each other—like an object and its reflection in the mirror.

WILL—I see! Once it's detected, our video signal is either all positive or all negative. Only the extreme whites even approach zero. We haven't got that *axis of symmetry* you can always draw on an ac waveform.

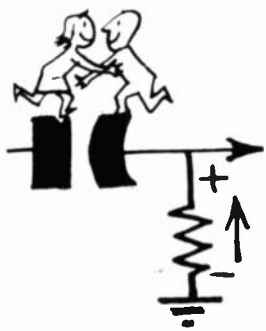
KEN—Let's take a look at the way those signals are transmitted through the coupling circuits.

WILL—Do you want positive or negative polarity?

KEN—Let's take the commonest case—a set with one video stage and the control voltage to the picture-tube grid. Then the detected signal would, of course, be . . .

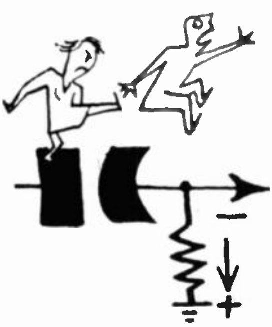



*The video signal can be positive (top) or negative (bottom). Every time the video signal goes through a video-amplifier tube, the polarity of the signal is inverted.*




WILL—. . . positive-going. Then we'd always have more or less of a shortage of electrons in the left plate of the capacitor, except during the odd periods when we have a "whiter than white" signal. So there'd be a greater or lesser number of electrons crowding into our right-hand capacitor plate.

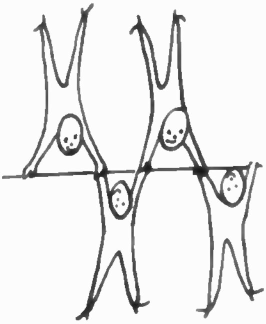
KEN—That's it. As the positive voltage reaches a peak (during the sync pulses) the largest number of electrons are being dragged from ground through R and to the right-hand plate. So the top of the resistor becomes more positive.




WILL—I think I see what you're driving at. As the signal becomes less positive—for instance during a white patch on the image—some of the electrons in the right-hand plate leave it and try to get back to ground through R. That would make the top of R negative . . . ?

KEN—You see, the signal we get on the right-hand side of the capacitor is a voltage of the same form as the one that came from the detector. But it's no longer entirely positive (or entirely negative if the detection was in that direction). The voltage on the grid of the video amplifier, while not entirely symmetrical, is composed of alternations which are negative and positive as compared to the ground potential, and equitably disposed around it.

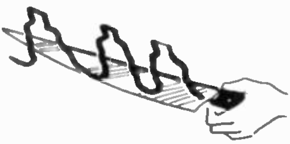
WILL—What do you mean "equitably"?

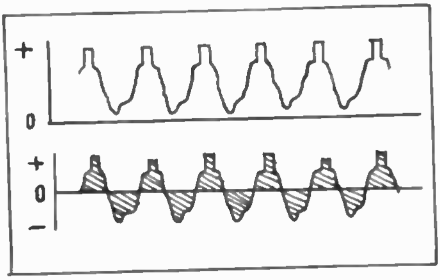


KEN—The number of electrons that leave the plate in a negative alternation is equal to the number that come back into it in a positive one. They're good accountants and always try to even up the receipts and expenses. I think you can realize—without going into integral calculus —that the quantities of electricity are proportional to surfaces inside these curves?

WILL—Then, to find the zero axis of a non-symmetrical voltage it's necessary to cut the image as shown on paper and to balance it on the blade of a knife. When equilibrium is reached, we can be sure that the surfaces are equal on both sides of the axis.

KEN—At least that would be a way of seeing if the curve is well drawn. . . . You see, in sending your video signal through the coupling capacitor, you have made it





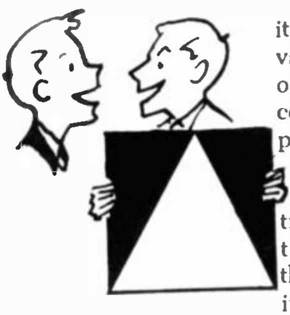

*After passing through a detector tube or crystal the video signal is all positive (or all negative). Sending the signal through a capacitor makes the signal symmetrical about the center line (equally positive and negative).*

alternating—have taken away its polarity. And above all, you have separated the sync pulses from the constant level as compared with zero volt.

## Misdoings of capacitance

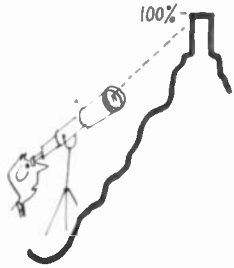
WILL—Is that bad?

KEN—It's not as catastrophic as was once thought, but it's not good! For instance, your sync pulses are going to vary in height according to the strength and modulation of the signal. That makes it harder to set the controls for correct synchronization. On top of that, the shade of the picture itself it likely to be altered.

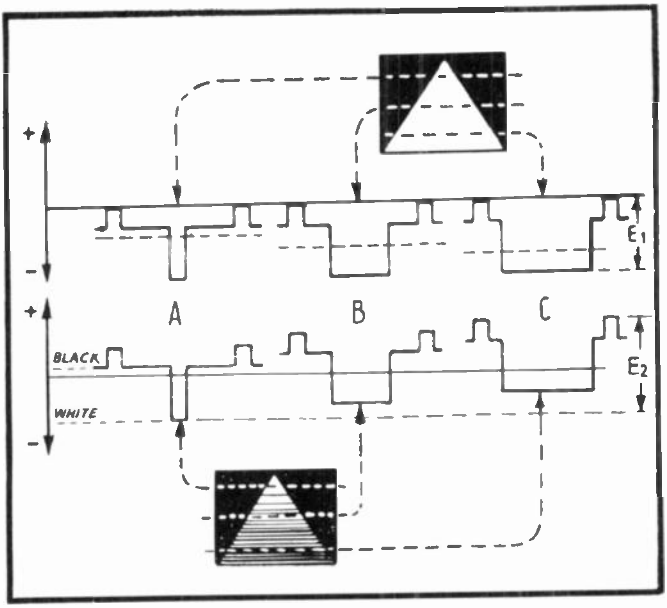


WILL—I don't get that!

KEN—Let's try a simple example to show what the situation really is. Suppose the image is a white equilateral triangle on an even black background. Now try to trace the form of a detected video signal (with negative polarity) for three of the scanning lines: one at the top, the next near the middle, and the third at the base of the triangle.



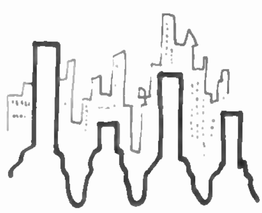

WILL—Easy! We have the sync pulse at 100% of maximum amplitude, then a black line at about 70%, with the exception of a short point where the amplitude drops down close to zero. The black lines occupy only about half the middle scan, and the white one lengthens out accordingly. And it keeps on lengthening out, till it occupies practically all the bottom line.




*Analysis of three lines of the picture (shown at the top) coming out of the detector and represented by voltages A, B and C (top). After going through a capacitor these voltages are as shown in the lower waveform. If suitable precautions are not taken, the screen will show the picture represented at the bottom.*

KEN—Perfect. Now can you draw me—in dotted lines—the zero axis for each of these signals as it would be situated after passing through a coupling capacitor?

WILL—Nothing simpler. Here are your axes!



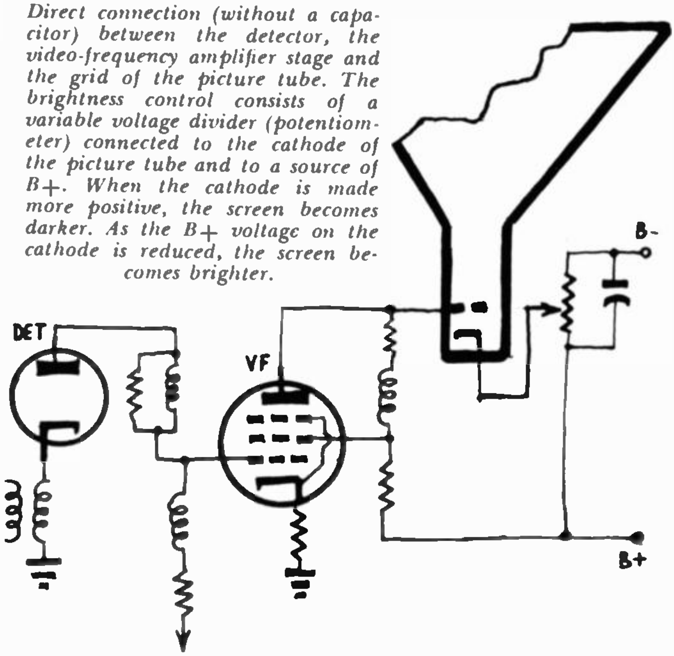
KEN—You see now that the sync pulses are all at different voltages. In fringe areas that would mess up synchronization. But that isn't all! If you were to apply signals exactly like these to a picture-tube grid and regulate the brilliancy so as to get a good white for the top line, it wouldn't stay the same for the other two. The middle one would be a decided gray and the bottom one

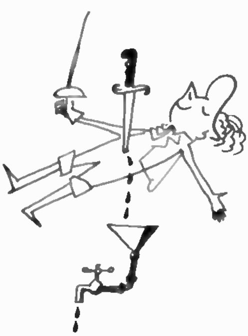
even darker. So our triangle, instead of being a uniform white, would get darker and darker toward the base.

WILL—I don't quite understand it! Then all capacitors —and even parasitic capacitances, I suppose—are practically fatal to a good picture. Suppose we throw them all out?

KEN—You're joking, I hope! But that's just what has been done—quite seriously—in "direct-coupling" hookups. Nothing prevents you from getting rid of the capacitor between the detector output and amplifier grid. Eliminating the capacitor between the video-amplifier plate and the picture tube's grid is a little harder. Without that capacitor, the grid finds itself at the high positive voltage of the video-amplifier plate circuit.

*Direct connection (without a capacitor) between the detector, the video-frequency amplifier stage and the grid of the picture tube. The brightness control consists of a variable voltage divider (potentiometer) connected to the cathode of the picture tube and to a source of B+. When the cathode is made more positive, the screen becomes darker. As the B+ voltage on the cathode is reduced, the screen becomes brighter.*



WILL—So of course that can't be done. We know that the picture-tube control grid has to be more negative than its cathode, just the same as the grid of a little receiving triode.

KEN—That's right. Yet there is a way of keeping the cathode at a higher voltage than the control grid. Take a look at this. All we have to do is tap it in on a bleeder across the low-voltage power supply. Use a potentiometer. Now we have this circuit, and you can see that we can put more or less B plus voltage on the grid by varying the pot. And it acts as the brightness control, too!

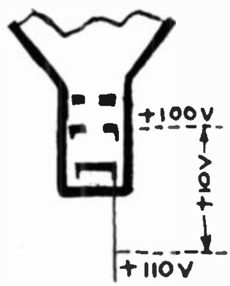
WILL—Wonderful! With no capacitors to make trouble, everything should be smooth scanning. I never thought the solution would be so easy!

KEN—Don't worry—it isn't! In fact, things get a little less simple—the circuit has its own defects and troubles. For one thing, you take a chance on the life of the picture tube.

WILL—I can't see any connection!

KEN—Suppose that—for one of the many reasons that make a picture tube conk out—the video tube goes dead. As soon as it stops drawing current, its plate voltage goes up because there's no longer a drop across its plate resistor. The voltage on the picture grid is now likely to go up almost as high as the cathode voltage.

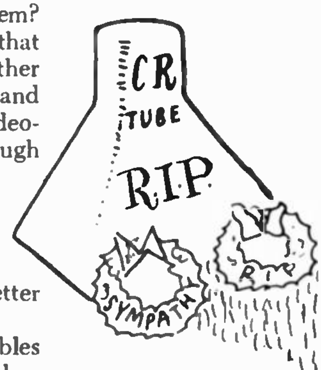
WILL—I see what would happen. The voltage on the control grid could go up to the low-voltage B plus. And the control grid—tapped to its bleeder—would be likely to be very little more positive. So the current goes way up,




*Although the grid and cathode are both positive, the grid is negative with respect to the cathode by 10 volts.*

and before long the tube is ready for the garbage can! So I suppose picture-tube manufacturers might like the circuit, if no one else! Is there any way around *that* problem?

KEN—There are complex direct-coupling circuits that safeguard the picture tube as well as eliminate some other defects of direct coupling. But there are other—and simpler—methods that work by bringing the video-frequency voltages back into place after they go through the coupling capacitor.

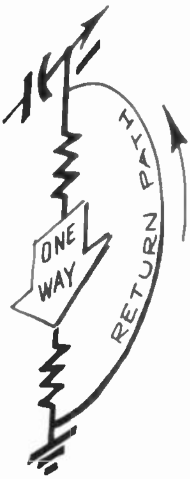



## A simple restoration

WILL—Let's hear about them—at least, if they're better than the improved direct-coupling circuits.

KEN—I take it that you've noticed that all our troubles with coupling capacitors come from the passage of electrons in both directions through R. It's the voltage drops these two-way currents produce that give us the alternately positive and negative voltages.

WILL—I suppose if we could bring our electrons back to the right-hand capacitor plate without having them go through a resistor, we could cut out the positive alternations. But I don't see any way of doing that.



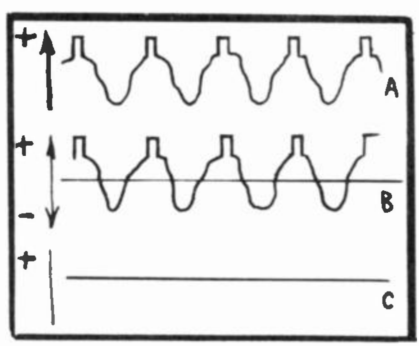

KEN—But there is a way, and it's not complicated. All you have to do is shunt R with a diode that has its cathode connected to ground.

WILL—Why couldn't I have thought of that! Now the electrons driven out of the right-hand plate can't get to ground except through the resistor, because they make the diode plate negative. But on the way back they simply go through the diode. Its resistance is so low in that direction that the voltage across it (and R) is very small.

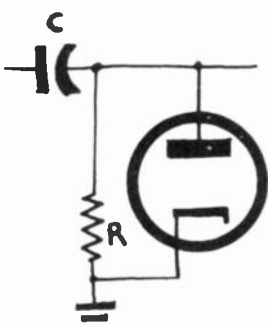
KEN—You make it sound very simple. In actual fact, the electrons that charge up capacitor C don't flow through R instantaneously. The job of the diode is to feed the right-hand plate of C enough electrons to keep the video signal always negative, so even the whitest whites don't approach zero voltage. So now the right-hand plate of C is varying in one direction from ground potential, instead of fluctuating around it as an average voltage.

WILL—Do electrons go through the diode on every scanning line?

KEN—Not necessarily. If the voltages on succeeding lines have practically the same form—or more exactly, if they put the same number of electrons into movement—the diode can just charge up the capacitor and sit back.




A= B+C




*A dc voltage (represented by the straight line C) can be added to the ac waveform (shown at B) to form a positive video signal (shown in A). The amount of dc is equal to that blocked by the capacitor.*

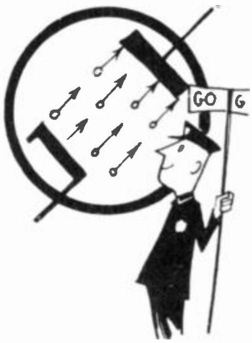
But if more electrons are put into circulation, the diode has to pass a large enough number to keep the charge up. And if the charges become weaker, the excess electrons flow out through R. So the restorer . . .

WILL—Is that what it's called?

KEN—Pardon me—I overlooked the introductions. The official title is dc restorer. And sometimes it's called a clamping tube, because it "clamps" the circuit to a given dc voltage.

WILL—And what is this dc we're restoring?

KEN—Well, it's a little bit abstract. The one-polarity voltage (either entirely positive or negative) we get after detection can be considered as the sum of two voltages. One of them is an alternating voltage of the form we find after the signal goes through a capacitor; the other a direct voltage (dc voltage, if you must!) with the right polarity and enough amplitude to put the alternating voltage entirely within the positive or negative region.



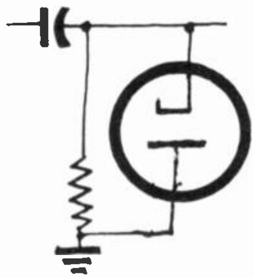

WILL—I suppose this voltage will be just equal to the one I drew in dots on the graph to divide the surface of the video frequency signal curve from our white triangle into two equal parts?

KEN—Once more you're right, Will.

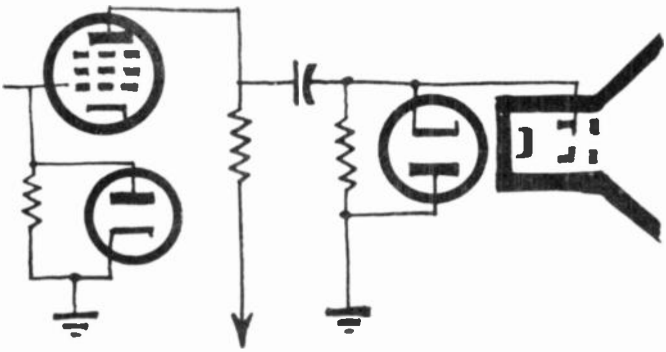
WILL—You've drawn your figure for negative polarity. Can you show what happens in the positive case?

KEN—Nothing easier. If you have positive-going signals, just turn your diode around—connect the plate to the ground and the cathode at the junction of C and R.

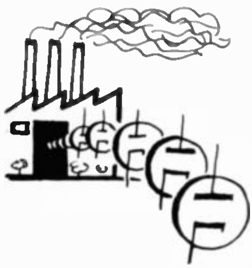

**Diode here, diode there**



WILL—Just where along the road do you have to put back this dc component? I suppose the best thing would be to put it at the output of the last stage, at the coupling to the grid or cathode of the picture tube?



*Although two restorer circuits are shown here, modern TV sets have eliminated the restorer entirely. The resultant effect on the picture is not noticeable. Color TV sets, however, do use restorer circuits.*



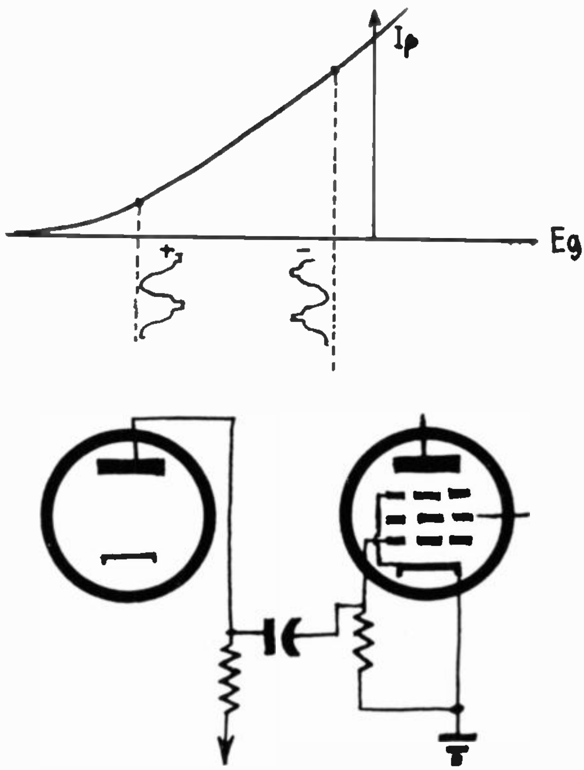
KEN—That's probably the best place to put it. Of course you have to take your sync voltages off first, but that's usual. You can also use several restorer diodes—one after the detector, one after the first video amplifier stage, and so on. . . .

WILL—You don't happen to own a piece of a tube factory that specializes in diodes, by any chance?

KEN—Not at all, worse luck! But do you remember the little triangle you drew, and the signals from it? Can't you see that—with no diode—the ac signal area was noticeably greater than that occupied by the signals from the detector, which (also because of a diode) were all of the same polarity?

WILL—But why should we worry if the signals stretch out a little further along the voltage scale?

KEN—Just because video amplifiers already have very unfavorable conditions to work under—as you learned not long ago—and there's no object in overloading their grids




*The operating point of a video-amplifier tube can be at the lower or upper end of the characteristic curve.*

if we can help it. But video signal variations are usually pretty small, so we can dispense with our flock of diodes. Some sets dispense with dc restoration altogether, and let brightness values vary. Blacks come out sort of grayish, but it's cheaper, and the viewers don't seem to mind.

WILL—I wonder how you should bias video-amplifier tubes to amplify these unsymmetrical "unipolar" signals?

KEN—An excellent question! There would certainly be very little sense in using "the center of the linear portion of the tube's characteristic curve" as your operating point. If you have negative-polarity signals, the operating point can be less than 1 volt negative. And if they're positive-going, the operating point should be at the extreme negative end of the linear part of the tube's curve.

WILL—To sum up, if I take the concrete case of a receiver with one video amplifier and with negative-going signals applied to the picture tube's control grid. one diode—across the pix-tube grid resistor—should be enough?

WILL—That gives me a wonderful idea!

KEN—Not again.

WILL—Definitely. But this time I'm reaching back into my storehouse of radio knowledge.

KEN—I can hardly wait. Please proceed.

WILL—You know, the control grid of a tube can act simultaneously as a diode plate and as a grid.

KEN—And your authority for this?

WILL—Any tube acting as a grid leak detector. The tube rectifies the signal and amplifies it as well. With the control grid behaving as a diode plate we get a small amount of grid current.

KEN—Enough to do you any good?

WILL—It doesn't take very much current. It takes only one microampere of current through a 1 megohm resistor to give us 1 volt.

KEN—Actually, your reasoning does you credit.

WILL—Then have I said enough to convince you?

KEN—More than enough, Will. If your signals are negative, the cathode-grid space of the picture tube can replace your diode. 'Way back in the days when we analyzed the grid-leak detector, you knew that the grid of a tube can—and does at times—act at the anode of a diode. In this case it's so connected with respect to the grid resistor and the signal polarity as to become its own dc restorer.

WILL—And I've just been accusing you of being an agent for diode manufacturers . . . !

KEN—That's quite all right.

WILL—This was quite a session, so I suppose we are just about coming down the home stretch.

KEN—What do you mean? I don't quite follow you.

WILL—We've just about covered every topic we could possibly discuss.

KEN—Not quite.

WILL—You mean there's more?

KEN—Let me answer that by asking a few questions. How do we separate the sync signals from the composite video signal? How do we get the low and the high voltages the television set needs? What kind of antennas can we use with our television receiver?

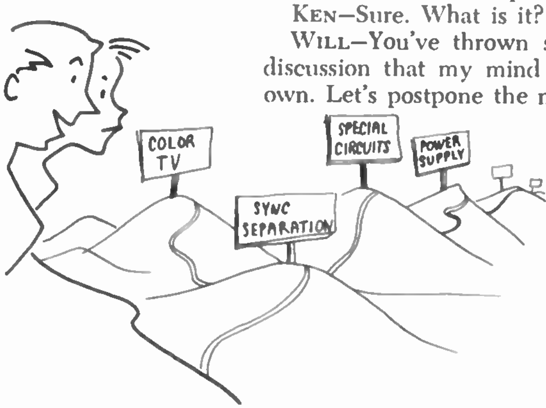
WILL—It does sound as though we still have some way to go.

KEN—We most definitely do. And I haven't even mentioned color television. I'm sure you'd want me to hit the high spots of that subject also.

WILL—OK. I give up. Let me ask just one favor.

KEN—Sure. What is it?

WILL—You've thrown so much material at me in this discussion that my mind needs a little restoration of its own. Let's postpone the next lesson for just a little while.



chapter 13

# Sync separation

WILL—Now I'm sure I know it all!

KEN—Your usual modest self, I see! But just what prompted that remark?

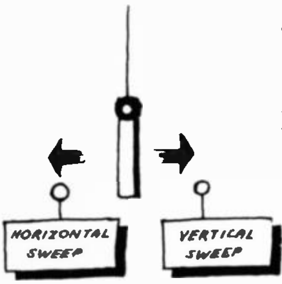
WILL—What I mean is—now I know the television receiver from end to end—from the first radio-frequency amplifier to the final video stage. And besides that, I haven't forgotten the time bases. So, I know all the circuitry of . . .

KEN—Don't get excited, Will! You've still plenty to learn! For example, how are you going to go about synchronizing those time bases?

WILL—Now that you mention it, I remember that the vertical and horizontal sweep circuits are synchronized by the sync pulses we studied a long time ago. But where's the problem? If you just apply the composite video signal to the sweep oscillators . . .


KEN—. . . you'd get into plenty of trouble! The mixture of video signals with the horizontal and vertical sync pulses would keep triggering the sweep circuits at the wrong times! When you figure your time in microseconds, everything has to be neat and clean. Each sweep oscillator has to receive its own sync pulses, free from any other signal whatever. Those sweep circuits can often be started into action by the least fluctuation of the voltage on the grid of the tube that triggers them.

WILL—I see what you're coming to: you have to separate the sync from the picture signals. Because I remember when you first drew a block diagram of a televiser, you had a block marked "sync separator."




KEN—I hope, then, that you'll have no trouble figuring out how such a circuit would work?

WILL—I suppose we'll have to have some kind of electronic switch that applies the signals to the right sweep circuit at the right time. For example, at the end of each line, the voltage is applied to the horizontal sweep, and . . .

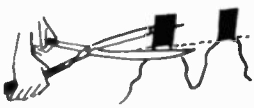
KEN—No, Will. First of all, how would you synchronize your electronic switch? Can't you see another way of capturing the pulses from the video signal—a method based on some fundamental difference between the two sorts of signals?

WILL—Well, the main difference is in their amplitudes . . .

KEN—You're on the right track. Keep going!

WILL—The sync pulses occupy the top 25% of the composite video signal. Voltages below that represent the video image, ranging from black to white. So all you have to do is cut off the top 25% and you then have only the pulses.

KEN—Excellent, Will! Only instead of cutting, it's called clipping.

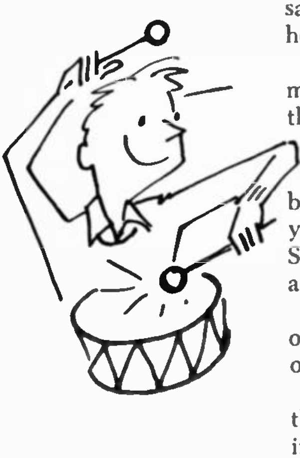


WILL—But just how can you clip the top off a wave?

## The limits of patience

KEN—It's easy. Just apply the signal to a tube that will function perfectly up to a given point, but absolutely refuses to pass that limit.

WILL—H'mm, something like my Uncle Jack. He never did like noise of any kind, so I was always a little worried when I was practicing as a Boy Scout bugler. He never said a word; but the day I started to train for a drummer, he blew his top! But what kind of tube acts like that?



KEN—You use pentodes, generally. But a triode could be made to work, and in many setups a simple diode does the job—fairly well at that.

WILL—And where do you put this separator?

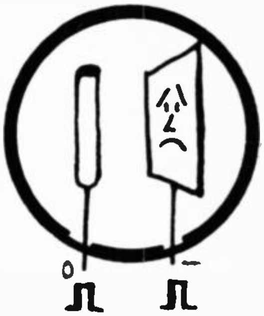
KEN—Theoretically, you could separate the sync signal before the detector, for the signal would be detected while you were clipping it. But it's an unreliable way in practice. So it's usually put at the output of the video amplifier, or at least after the first video stage.

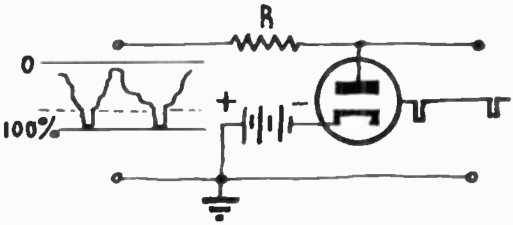
WILL—And of course the signal can be either positive or negative, according to whether you apply it to the grid or cathode of the separator.

KEN—You can have either polarity of signal, though there are several circuit tricks that are better than applying an input signal to the cathode.

WILL—Now suppose we have a positive signal, so the first 75% of the voltage is below the sync level. How is a diode going to clip off the top 25%?

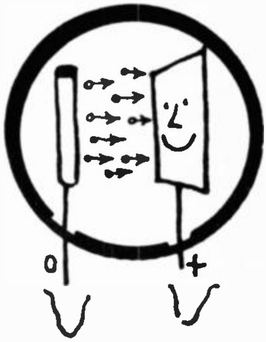
KEN—There's more than one way to do it. The easiest is to use a diode biased so that its cathode is more negative than the plate at all voltages below the point where you intend to begin clipping. You shunt your diode across a source of composite video signal. The diode short-circuits all voltages up to that which makes the cathode more positive than the plate. So the sync signals, which are more positive, stop the diode conducting and pass on to the output.

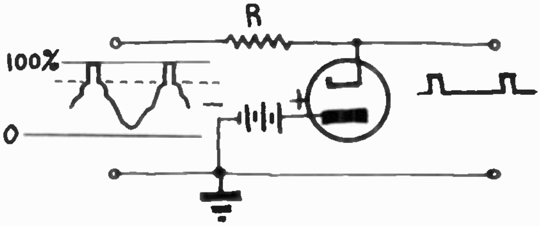


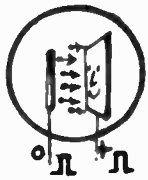

*The polarity of the sync pulses shown here is exactly the opposite of those in the illustration below.*

WILL—I can see that the diode should be biased so the plate is a little more positive than the highest video signal voltage—a little above the black or pedestal level, whatever you like to call it. Then you are sure to short all the picture signals through the tube. But what's this resistance R in your hookup?

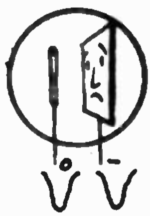



*The diode is so biased that only the top portion of the waveform (sync pulses) does not cause conduction through the tube.*




KEN—It keeps the diode from shorting the stage that supplies the signal. You are getting your signal from some point in the video circuits and you can't permit your sync separator to affect the signal going to the picture tube. The picture tube has to get all the picture signal without distortion, and also the sync signal to black out the return trace.

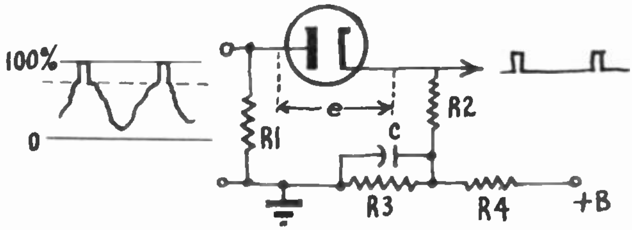



WILL—Of course—I just didn't think of it . . . But now can you draw me a circuit for negative-going signals?

KEN—Certainly. We just turn the diode around and


make the cathode more negative than the plate again. If you have the right bias, it remains more negative through the range of picture signals so the diode shorts them out. But the sync pulses drive the plate more negative than the cathode, conduction stops and the sync signal passes through. And that's how a shunt type separator works.

WILL—You give me the idea there must be a series type separator as well.

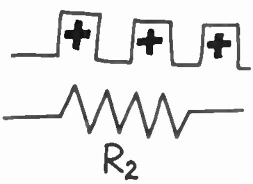



*Series-type sync separator. The cathode is so biased that only the sync pulses can drive the diode into conduction.*

KEN—There is. One circuit is like this. The cathode is connected into a voltage divider (R3, R4) that makes it a little more positive than the plate. If the bias is right, only sync pulses can pass through the tube. You take the output pulses off R2, and C passes any alternating component.

WILL—What's R1 for?

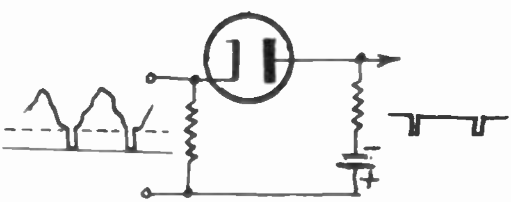
KEN—It's just to give you a closed diode circuit—makes it possible to connect to your signal supply source through a capacitor. It may have other uses, as you'll see later.




WILL—I think I see how this works. If the bias voltage is about the same as the video signal at the black level, no picture signals can get through. But when the sync pulses raise the voltage higher, the plate is more positive than the cathode, the circuit conducts and the pulses go through.

KEN—Good reasoning, Will. And the output of the circuit—the voltages across R2—consists of nothing but a series of positive pulses.

WILL—Would this work for negative pulses?

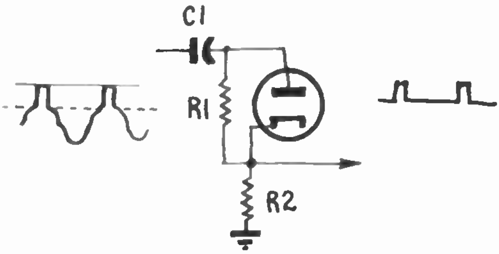



*A negative voltage is placed on the plate of the diode. When the cathode is made more negative than the plate (by the sync pulses) the tube conducts.*

KEN—Well, if you need to make a positive signal out of a negative one, you can always use a triode as a phase inverter. But this circuit will work with negative signals, if you reverse the diode like this. Your cathode is now more positive than the plate except when the very negative pulses come through. They drive it more negative and the pulses are passed.

WILL—One thing I don't like about these circuits—the batteries you keep throwing in. This is an all-electric age—can't you make them all work with voltage dividers to bias your diode elements?

KEN—I just used the batteries to simplify the drawing. They wouldn't be used in a television receiver. Take a look at this circuit. You apply the positive-going com-




*An R-C network can be substituted for the battery. This is much more convenient, and works just as well.*

posite video signal through C1. Each pulse attracts electrons from the cathode, which have to flow back through R1. That biases the diode so the plate is more negative than the cathode. By choosing the right values for C1, R1 and R2, you can adjust the bias so that the tube begins to conduct just at the black level. The sync pulses then appear as voltage pulses across R2. The great feature of this circuit is that it is self-adjusting to different signal strengths. If you get your components adjusted so the diode just triggers at the right level on a medium-strength signal, stronger signals will increase the bias and weaker ones decrease it, because of the change in current through R1. So both weak and strong signals will clip at the right point.

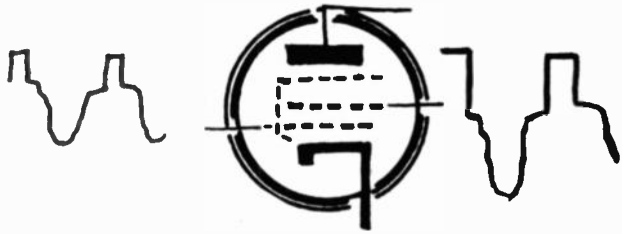
## With three grids or more

WILL—The bias batteries would never do that. One good thing about the diode—it doesn't change the polarity of the pulses. And the circuits are simple. I wonder why anyone would want to use pentodes?

KEN—Simplicity doesn't always mean perfection! Our diode separators are weak in many ways. The separation

*A diode does not invert the polarity of the sync pulses. There is no change in phase between input and output, but unfortunately there is capacitance between the cathode and anode.*

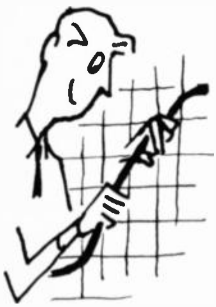
is imperfect, for the high-frequency picture signals—those that represent very rapid variations of intensity—work their way into the sweep circuit time bases through the interelectrode capacitance of the diode. That can give you sync trouble. Another thing, a diode doesn't give out with more signal than you put into it, and never quite all of that. So, it's only natural to take advantage of the pentode because it amplifies. Besides, its grid-anode capacitance is very small, so little or no high-frequency picture signal can get through.

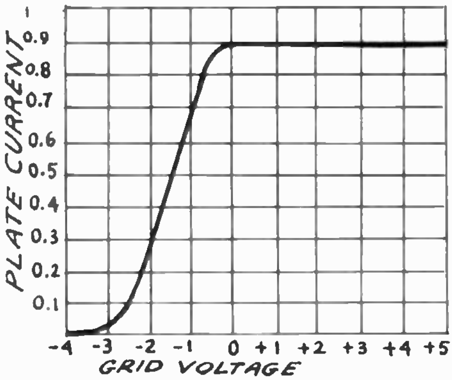


*The pentode sync separator is not as simple as the diode, but the pentode does amplify the pulses.*

WILL—But how do you limit the patience of a pentode?

KEN—Its patience—actually, its plate current—can be limited at either end. We can make our tube blow its top at the least provocation or we can push it so far it will



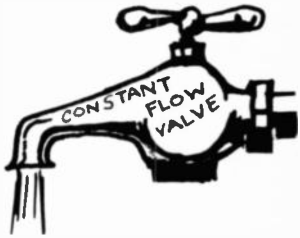



*The characteristic curve shows why we can make the pentode work as a sync separator. Once the saturation point is reached, an increase in grid voltage will have no effect on the plate current.*

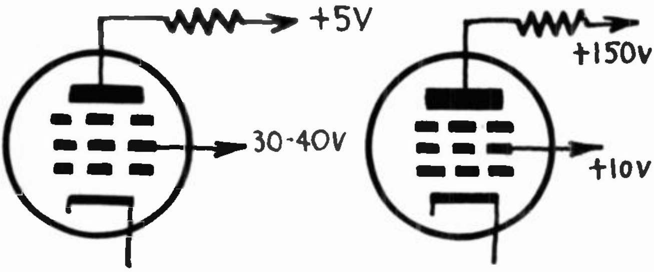
give up and tolerate anything. Take a look at this grid-voltage—plate-current characteristic curve. Right down here—in the negative-voltage region—you have a bend. And again—near zero volts—there's another very sharp bend followed by a long level stretch.

WILL—So that any increase of grid voltage from that point won't affect the plate current?

KEN—Exactly, and that applies to any reduction of grid voltage beyond the lower—or plate cutoff—bend. Since the plate current reaches zero at that point, it has to stay at zero if the grid goes more negative.

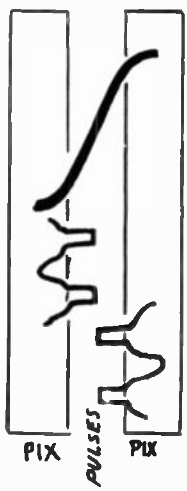


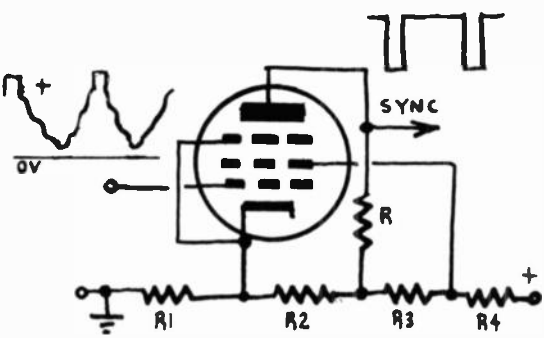

WILL—I'm beginning to see just how you could use those two limits of patience. But that curve doesn't look too standard to me. Just how do you model that kind of a grid-voltage—plate-current characteristic?




*A pentode can be made to saturate very easily by operating the plate or the screen at very low potentials.*

KEN—By applying the right voltages to the screen and plate. The idea is to prevent the plate from receiving more than a certain amount of current, however wide you may open that electron valve we call the grid. So you put a very low voltage on the plate and a higher one on the screen. Or you can tackle the problem from the opposite



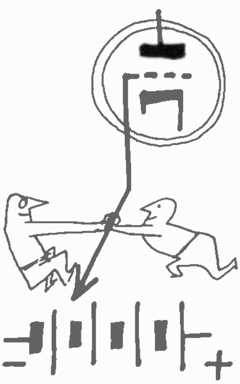




*Circuit of a pentode sync separator. Input is to the control grid; output is from the plate. Note that the incoming signal is positive.*

direction and put normal voltage on the plate but very low voltage on the screen.

Will—I suppose all pentode separators are hooked up so the sync pulses fall in the part where the current varies —the so-called rising part of the characteristic curve. Then the picture part of the composite video signal will disappear completely—it will be in the area of no plate current or that of the flat top. In either case a change of grid voltage would have no effect whatever on the plate current.

Ken—You've outlined the principles underlying sync separators completely! And I don't think you'll have any trouble analyzing the circuits in detail. Let's take a case of positive-going video signals. Here's a pentode hooked up across a voltage divider so the plate has a low voltage, the screen a higher one and the cathode is at a considerably higher voltage than the grid, due to the voltage drop across R1 in the diagram at the bottom of page 159. So the grid is biased negative.



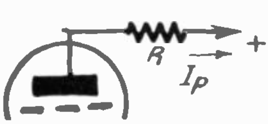

Will—I see. And this bias is to . . . ?

Ken—. . . bring the grid to the point where plate current just begins when the signal reaches the black level. Then the pulses extend out into the region where the tube amplifies (the rising part of the characteristic). It's a good idea to bias the grid far enough that the pulses start in the region of no plate current. Then you're sure all parts of the picture signal are cut off and only sync pulses are amplified.

Will—Wonderful! Now what's the hookup for a negative-going signal?

Ken—Exactly the same! Only the connections to the voltage divider are changed to make the grid a few volts more *positive* than the cathode, so that all the picture signal is buried in the region of maximum plate current, and only the sync pulses are negative enough to reach what from this end you might call the falling part of the tube's characteristic curve.

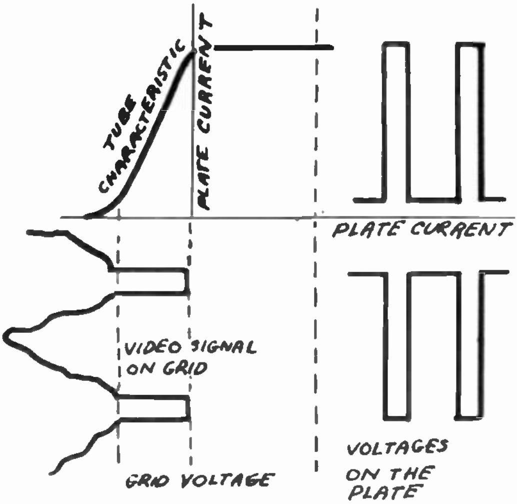
Will—It seems we'll get a positive output signal anyway. We're taking the signal off the plate; and since the drop in plate current means a lot less drop across the load resistor R, each pulse should drive the plate voltage up practically to the supply voltage as the plate current approaches zero. Consequently we get positive sync pulses from the output instead of the negative ones applied.




Ken—That shouldn't surprise you—in fact you mentioned not so long ago that the diode *didn't* invert the signal, as if you expected that any other tube would. And you may have noticed that I drew input and output pulses for the positive-going signal. But I've bad news for you again. The separator that we've just drawn can't possibly work right!

WILL—What, down a wrong trail again? What's wrong with the circuit? It looks almost foolproof!

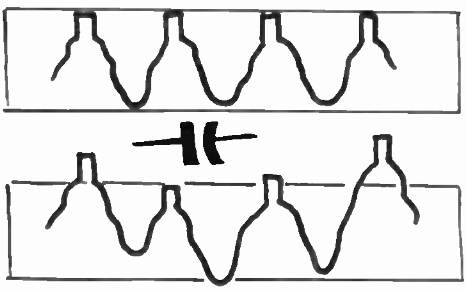
KEN—First of all, our separator is most likely to be connected to the stage which supplies its signal through a

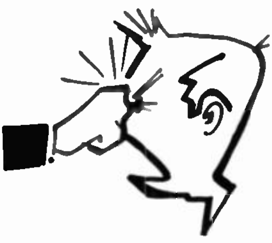

*The pentode sync separator works at one end of the characteristic curve. Only the sync pulse operates the tube. The video signal itself has no effect on the output waveform.*


coupling capacitor. And when you say "capacitor" you say good-by to the direct-current component of the signal.

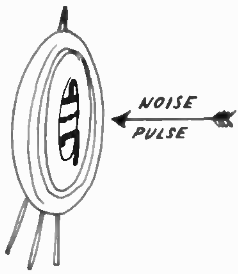
WILL—I think we've already had enough of that! But just how does it bother us in this case?



*The sync pulses will not line up if the composite video signal is sent through a capacitor.*



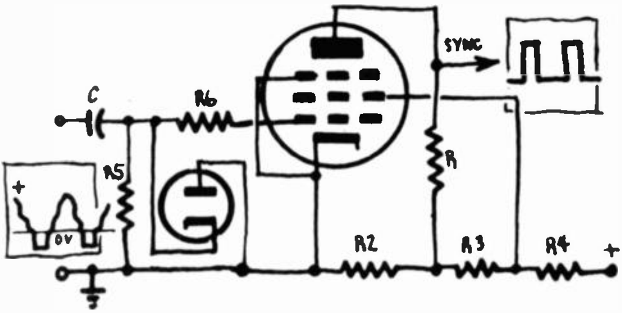
KEN—Doesn't it hit you right between the eyes? The whole operation of this separator depends on the black level being lined up properly with the grid voltage point where the plate starts to draw current. So, without the dc level, your pulse tops will look like a rough mountain range, each peak at a different height than the others.



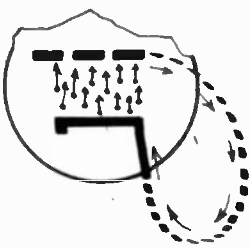

With this synthetic mountain range controlling the plate current, you can't expect correct syncing. Some of the pulses won't have enough effect. In other lines parts of the video signal or maybe noise pulses, would trigger your sync circuits.

WILL—Can't we save the situation again by putting in a grid resistor (R5 in this diagram) and putting a diode across it? This looks like a good dc restorer circuit now.

KEN—You have the solution. Now everything falls into order—or almost, for we still have disturbances due to grid current . . .

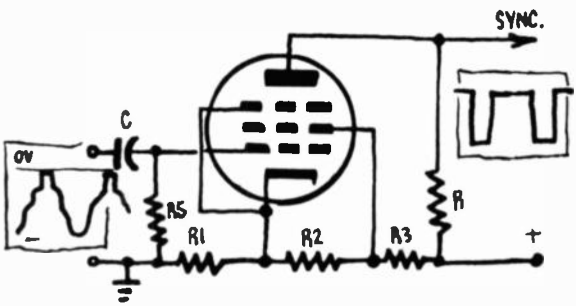



*In the case of negative-going signals the diode shown in the circuit diagram produces an effect opposite to that of the capacitor, restores the sync pulses to a uniform level.*



WILL—How bad is that?

KEN—Well, you can see that you're going to have some fairly high signal voltages on the grid, especially with negative-going signals, where the black level is roughly at zero volt and the picture signal takes the grid far positive. Under these conditions it becomes an anode and captures electrons, which have to follow the external path from grid

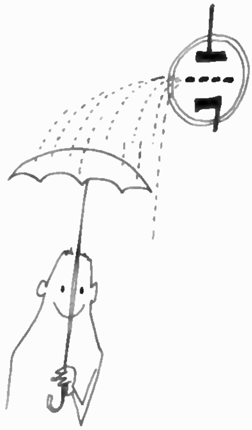



*For positive-going signals, the elimination of the diode makes the circuit simpler. The pentode now acts as a combined sync stripper (or sync separator) and amplifier.*

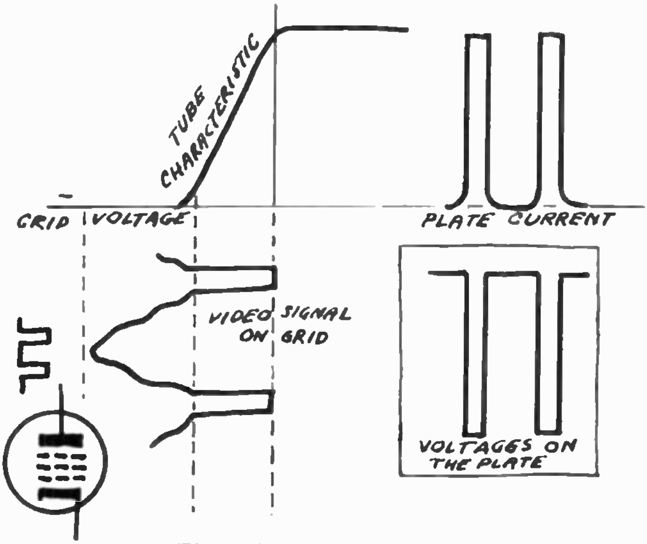
to cathode. You can help the situation by putting R6 in series with the grid. Now any grid current produces a voltage drop that keeps the grid a little negative and prevents it from reaching high positive potentials.

WILL—And from what you've just said, I suppose a positive-going signal gives a lot less trouble?

KEN—Yes. Everything happens in the region of negative grid voltage, so you don't have to worry about grid current.

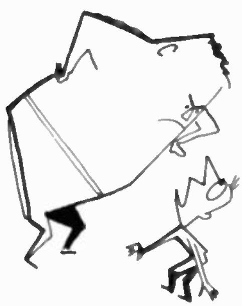


WILL—Now I'm beginning to get this for the first time. I can see that only the sync pulses can possibly affect the plate current and that picture signals will be rejected absolutely, since they are all in the region below plate current cutoff.




*The only portion of the composite video signal that has any effect on the plate current is the sync signal. The sync makes use of the entire length of the tube characteristic.*

KEN—Before you dismiss it from your mind, remember once again that the output signals are opposite in phase to those at the input. The sync signals produce increases in the plate current and because of the voltage drop across the load resistor, they are transformed into negative voltage pulses.



WILL—Just one more thing, Ken. You said something about noise pulses triggering the sync. Wouldn't electrical interference be strong enough in a lot of places to make trouble? And if so, what's the use of all our careful separating?

KEN—You're right, Will, and in many modern televisers the sync signal is "keyed" or "gated" which means that the sync separator is switched into the circuit only for a short interval around the time the sync signals are due to come in. Then it doesn't work during the rest of the scan.

### The jolly capacitor and the mean resistor

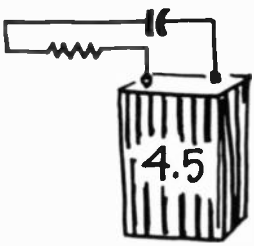

WILL—And now that we're able to extract good pulses with either diodes or pentodes, how are we going to pick out the vertical field pulses from the horizontal ones?

KEN—You know that one is much longer than the other. The principle of selection is to change duration into amplitude.

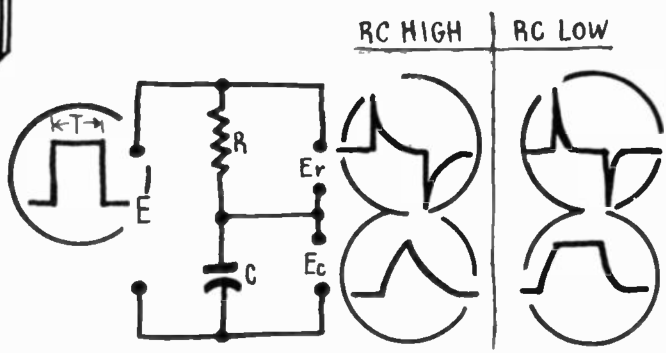
WILL—How perfectly clear! Almost like a political commentator before a close election!

KEN—It's really simple enough. The usual method is to use differentiation and integration.

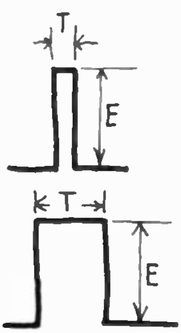
WILL—Better and better! Excuse me while I run out and take a couple of calculus courses before you go on with the explanation!




KEN—It won't be necessary! The terms that impress you so much refer to voltages in the most simple circuit you could design: a resistor and capacitor connected in series! Now suppose you figure out what happens if we suddenly apply a voltage E across this circuit, maintain the voltage for a given time T, then cut it off just as suddenly.



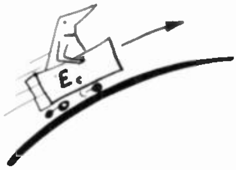

*After passing through the sync separator, the vertical and horizontal sync pulses must be separated from each other. This is done by R-C networks known as differentiating and integrating circuits.*



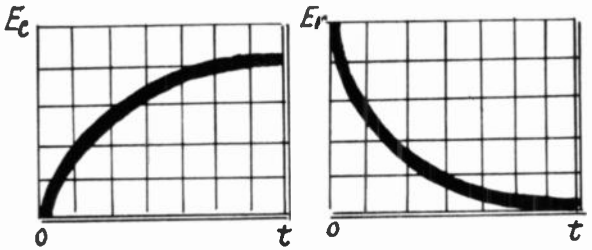

WILL—I've learned a lot of things in the time we've known each other, but nothing better than to know when you've a sneak ball coming. This voltage that we start and stop so suddenly, isn't it a horizontal or line sync pulse if T is short, and a vertical or field pulse if T is long?

KEN—You're getting good, Will! Now what we want to study is the form of voltages $E_r$ and $E_c$ that appear across the resistor and capacitor.

WILL—But we've already gone through this before when we discussed time bases. When you apply voltage E, you start to charge capacitor C through resistor R. Voltage $E_c$ rises along an exponential curve more or less according to the time constant of the circuit, the product $R \times C$, that is.

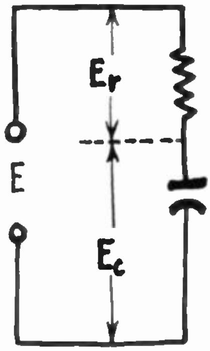



KEN—Your good memory makes things easier for me as well as yourself. Now, depending on whether R and C have high or low values (let's draw graphs for both), the capacitor will charge rapidly or slowly. Can you tell me what happens in resistor R during this time?



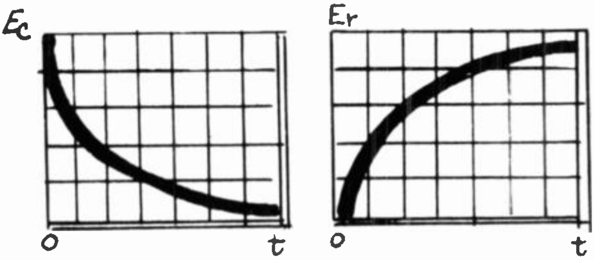

*During the charging time in an R-C network, as the voltage across the capacitor increases, the voltage across the resistor decreases.*

$E = E_r + E_c$




WILL—Certainly. At the beginning of the charge, it carries maximum current, which makes voltage drop $E_r$ large. As the charge continues the current diminishes, and with it voltage $E_r$, also according to an exponential curve.

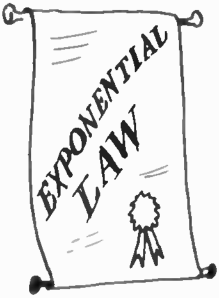
KEN—Has it occurred to you that the sum of the two voltages $E_r$ and $E_c$ would be equal to the total voltage E at each instant?




*When the capacitor in an R-C network discharges through the resistor, the voltage across the capacitor decreases but increases across the resistor.*

WILL—I took that for granted! Obviously, then, if you know how, you can calculate the form of curve $E_r$ from that of $E_c$ and *vice versa*, since their sum will give you E.

KEN—I've drawn the voltage curves for a rectangular pulse with a duration T for both a long and short time constant. In the first case, we can consider the charge practically completed during the time T. In the second, it finishes much more rapidly, so voltages $E_r$ and $E_c$ rise very quickly and are prolonged at level E, the voltage of the




flat top of the rectangular pulse. Now, what happens when the applied voltage drops to zero?

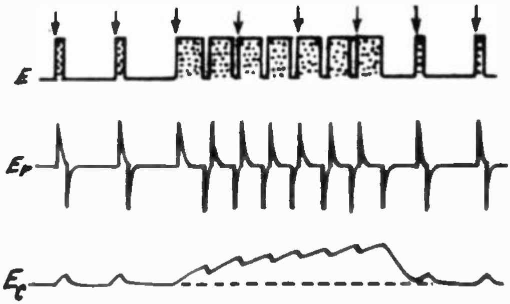
WILL—Capacitor C starts to discharge across the resistor and through the original voltage source. So $E_c$ starts to drop (I guess I don't have to say according to the exponential rule) with the same time constant. And if that is long enough, we find our old friend the sawtooth wave we got so well acquainted with when we were studying time bases.

KEN—Our present sawtooth is a little different from those earlier ones. Here charge and discharge follow the same law, while in the time base the discharge circuit had very little resistance and so had a very short time constant. Now what becomes of $E_r$, across our resistance?

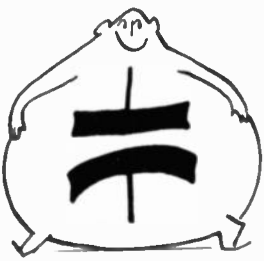
WILL—It reverses itself! We have a negative voltage drop across the resistor. And the current—and therefore the voltage—is high at the beginning of the discharge this time too, then diminishes according to that exponential rule which seems to be the supreme law of radio.

KEN—Don't be too surprised at the change in direction of the voltage on R. With a little thinking you'd have seen it already. Since $E_r$ plus $E_c$ equals E, and now that E has dropped to zero, $E_r$ will have to be negative if their sum is to be zero.

WILL—Sounds reasonable—but don't confuse me with mathematics. Can you drop the calculus and come out with a good physical explanation? That's what I understand.




*The rectangular pulse input to an R-C network is changed to the waveforms shown above. Arrows show moments when the line time base is driven.*



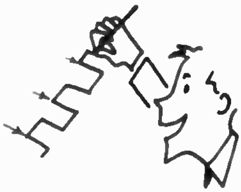
KEN—Don't get so scared! The voltage E is *integrated* when you take $E_c$ as your output. Its form is different from E—it's been rounded off—the sharp corners have been rubbed down. On the other hand, those changes are accentuated in the *differentiated* voltage $E_r$, you take from across the resistor.

WILL—In other words, the capacitor is a jolly fat fellow who takes everything in good humor, and the resistor is an acid old hag with a sour face, jerky movements and a sharp tongue.

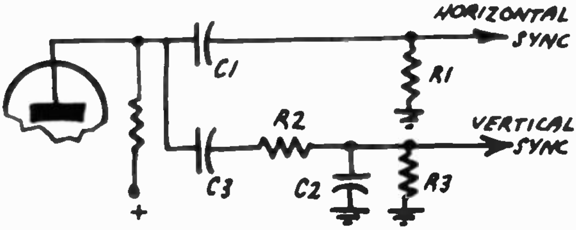
KEN—When worse comparisons are pulled, you'll pull 'em! Only remember what we've just said—that the same circuit can be a differentiator or integrator, depending on whether the voltage is taken across the resistor or the capacitor. In a differentiator circuit R and C should be fairly small, so their product—their time constant, in other words—won't be greater than about one-fifth the duration T of the pulse. But R and C should both be much larger in an integrator circuit, so the time constant is several times longer than T.

WILL—So, even if you do use just a resistor and a capacitor for either a differentiator or an integrator circuit, the circuits really are different, since you choose different values. But I still don't see just what you do with them.

KEN—You should by this time. Draw the form of a sync signal as it comes out of the separator.



WILL—Here's a nice row. First we have two horizontal pulses, then the wider vertical ones, then line pulses again.




*Differentiating and integrating networks as they appear at the output of a sync separator.*

KEN—Now let's mark the points where the horizontal sweep oscillator is triggered. Remember how we found that the horizontal sync had to be maintained throughout the vertical sync pulse? Now do you think you could show how those signals would look if they were differentiated?


WILL—According to what you've just said, the time constant should be very short—less than one-fifth the duration of the pulses—which pulses?

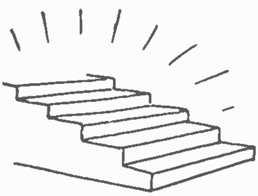
KEN—The narrowest ones—the horizontal pulses.

WILL—Well, we get very sharp, narrow differentiated pulses, positive or negative according to whether they are at the beginning or end of the pulse.

KEN—Those razor-blade signals are perfect for synchronizing the lines. Now try to draw the signals coming out of an integrator.

WILL—H'm, this circuit must have a time constant quite a bit longer than the duration of the pulse. But we won't get much of an output pulse from it! The capacitor just starts to charge when the voltage is removed and it starts to discharge again.

KEN—All the better, Will. If you can't find the horizontal pulses in the output of the integrator, you're doing well. Notice how the circuit reacts when the vertical pulses come along?



WILL—They last a little longer, so the capacitor has a chance to charge up a little more. But it discharges a little between the first and second pulses. Then during the second pulse it charges up some more. Then there is another little discharge, another bigger charge, and so on. Each charge ends up with a little more voltage on the capacitor, and the whole picture looks something like a set of steps.

KEN—With this difference: as the voltage rises, the steps become shorter.

WILL—That exponential law again! But everything has to come to an end. And when the train of vertical pulses stops, the capacitor discharges, giving you another perfect exponential curve.

KEN—Not quite perfect, Will, because it gets little jolts from the horizontal pulses following . . .

WILL . . . so because of our integrator circuit, the whole group of vertical pulses begins to look like a long sawtooth where the line pulses practically disappear, leaving only insignificant jags along its top. Now what are we going to do with this integrated voltage?

KEN—You apply it to the vertical time base and, if you have luck, these pulses will synchronize it perfectly. If you want to refine the circuit further, you can use a biased diode to smooth off the rough edges and pass only the voltage peaks. But that's not necessary. You can have a very simple selector circuit in which the voltage across the separator load resistor is applied to a differentiator circuit C1-R1 which goes to the horizontal circuits and also to an integrator circuit R2-C2 which is connected to the vertical oscillator. Look at page 167 for the circuit.

WILL—And how about C3 and R3?

KEN—C3 is a coupling capacitor that keeps B plus out of the time-base circuits. And R3 is a grid resistor.

WILL—But won't C3 and R3 constitute themselves a sort of differentiator that will disturb the integrator action?

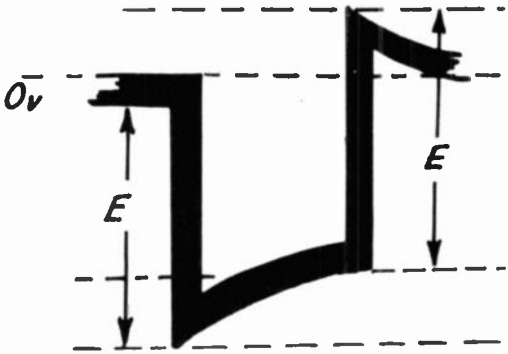
KEN—Don't worry—you can choose their values so they have an insignificant differentiating effect.

## Exponential ladder

WILL—Why did you say "if you have luck" when you spoke of synchronizing the vertical sweep circuit?

KEN—Oh, I have no love for those integrator circuits. The vertical signal isn't neat—it has no shape! Give me differentiators, where the signal appears at full amplitude the precise instant you need it!

WILL—Yes, but you can't use a differentiator to build up your vertical pulse!




*Start of the action in obtaining a vertical field pulse. This is a magnified view of one of the pulses ($E_r$) shown in more detailed form on page 170.*

KEN—Why not? Suppose I just use a capacitor and resistor large enough to give me a time constant a lot longer than that of the horizontal pulses?

WILL—I don't see how that would work. Can you help me out with a drawing again?

KEN—Sure. Let's take negative-going pulses this time. Can you draw the voltage across the resistor?

WILL—Let's see. At the instant the negative line pulse appears, the whole voltage is across the resistor. The charging current that produces it decreases slowly, because the time constant is long, and . . .

KEN—But, my young friend, the charge isn't going to have much time to decrease, because the horizontal pulse itself isn't going to last very long.

WILL—Exactly. After the commencement of the charge, the drop of voltage across the resistor diminishes slightly, then returns to zero at the end of the pulse.

KEN—Are you absolutely sure of that? When the applied signal drops back to zero, it rises E volts. But since after the beginning of the charge, the voltage on your capacitor has already risen a little toward zero, as you can see from the tips of the first two pulses, it reaches a slight positive value at the end of the pulse. Then the capacitor discharge starts bringing it back toward zero again.

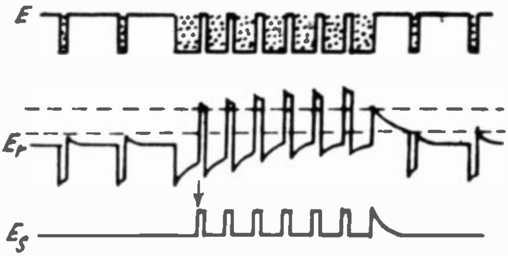
WILL—How complicated can this "most simple" circuit get?

KEN—It's a little simpler than it looks at first glance.

You can easily see how the action gets you your vertical field pulse.

WILL—The principle seems to be the same as for line pulses. But the charge lasts a little longer for each individual pulse. And at the end of each, in rising E volts, the voltage across the resistor becomes more and more positive because the capacitor hasn't had time to discharge in the short interval between two successive vertical pulses.

KEN—And the voltages again form a sort of steep stairway . . . ?




*Rectangular pulses integrated by a circuit having a relatively long time constant.*

WILL—Exponential, I'm sure! And this lasts till the end of the vertical pulses. Then the capacitor can heave a sigh of relief and start discharging.

KEN—Now you see how our long time constant circuit has succeeded in making the vertical pulses into a series of impulses that rise till they dominate the countryside, figuratively speaking. Now what do we have to do to use them?

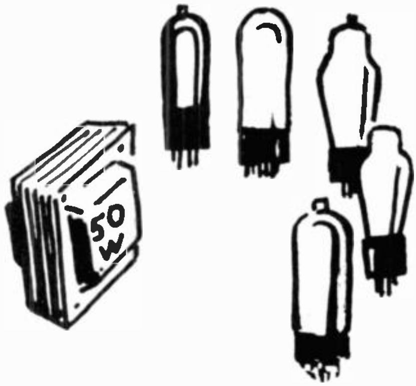
WILL—I guess that if you clipped off everything outside the two dashed lines, you'd get the voltage pulses you've marked $E_s$. Then you'd use them to synchronize the vertical oscillator.

KEN—Isn't that much neater than the integrator approach? The very first pulse—there, I've put the arrow—triggers the vertical time base precisely.

WILL—Ah, well, this time base I wear on my wrist indicates that it's time for me to go to bed and try to integrate your differential explanations!

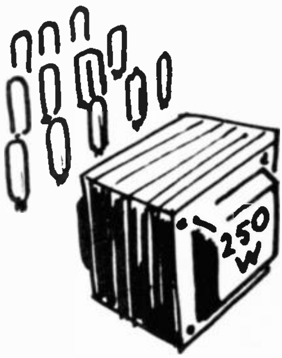
chapter 14

# Power supplies




WILL—Well, at last we've finished! We've studied every part of the television receiver!

KEN—You're right—up to a certain point. But if you build yourself a TV receiver with only the things we've talked about so far, you'll have much the same thing as a motor car without a gas tank.

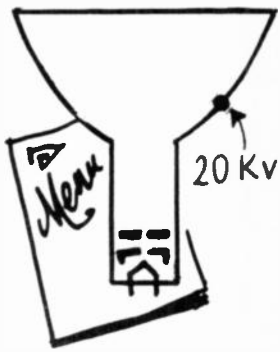



WILL—Of course! We never did bother to talk about a power supply! But there isn't anything in television that's so different from radio that I couldn't design a power supply for a TV set! Of course, a televiser of 20 to 30 tubes will take a lot more power than a five-tube superhet. But with a good, sturdy transformer—250 watts or heavier—and a heavy-duty rectifier, there shouldn't be any trouble.

KEN—Very fine as far as it goes, but the real difficulty seems to have escaped you.

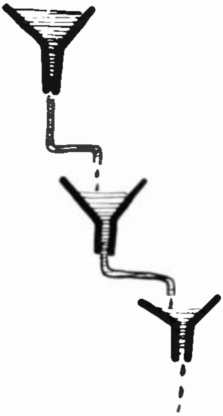
WILL—What's that?

KEN—The thousands of volts you need for the high-voltage anode (ultor, if you like) of the picture tube. But let's forget that for the moment. It's true that you can use a good big radio-receiver type power supply for the rest of the set. But you'll need a little extra filtering for the power to the sweep circuits. If not, the rapid voltage rises and drops of the sawtooth waves will kick back into the power supply and get into both your sound and video channels. The best approach is to have separate filter systems for the sweep circuits, the video and the sound.

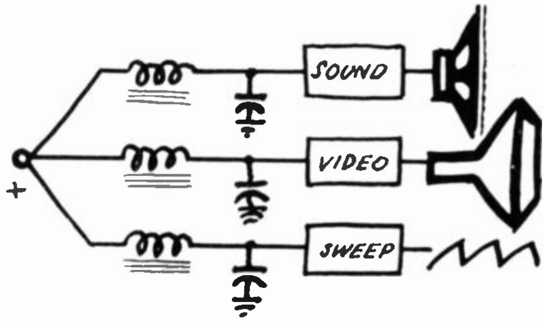



WILL—Nice stuff for the choke and capacitor manufacturers!

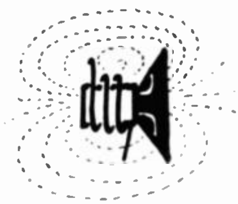
KEN—Doesn't help them too much. In practical circuits the extra filtering usually comes down to some extra



electrolytic capacitors and decoupling resistors. On some old sets you'll even see a focus coil pressed into use as a filter choke.




*In the television receiver, the sound, video, and sweep signals are separated by individual filters and follow their own paths.*

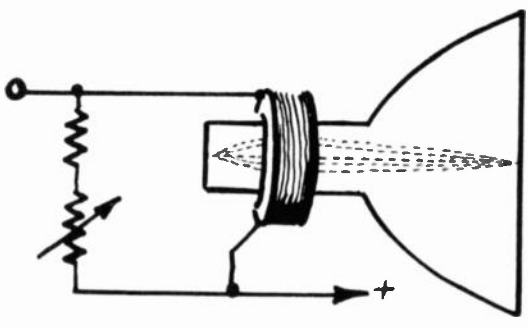


WILL—Just like the field coil on a radio speaker?

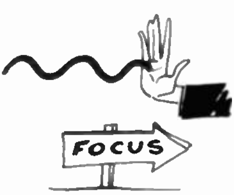
KEN—Exactly—though you'd look pretty hard to find a radio speaker with an electromagnetic field nowadays.

WILL—But in sets that use the focus coil as a filter choke, doesn't the focus need any adjustment?

KEN—It does! And you'll find that part of the current goes through a variable resistance in series with a fixed one, shunted across the focus coil. Then by varying the



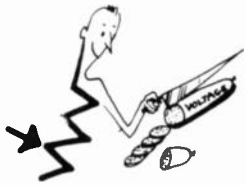

*Electromagnetic focusing is obtained when a current is sent through the focus coil. Nearly all modern receivers use permanent magnet focus units with variable slugs for adjusting the strength of the magnetic field. The operating principle is the same for both types of focus devices.*

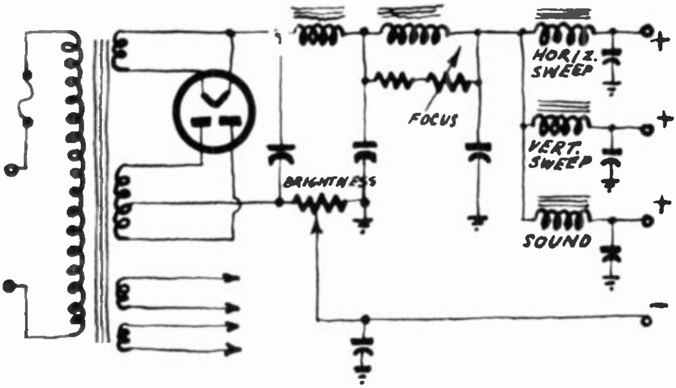



current through the resistance you can change the current through the coil, and thus the magnetic field it produces.

WILL—In this diagram you've drawn, the focus coil has another filter choke ahead of it. I suppose that's to keep ripple out of the focus circuits?

KEN—Correct. Too much ac in the focus coil might not be good. But notice also that I've indicated a potentiometer in the negative lead. The voltage drop across it makes that lead negative with respect to ground. By varying it we can make the control grid of the picture tube more negative than the cathode—in short, it's our brightness control. The potentiometer often forms part of a voltage divider across the whole power supply, and sometimes it's positive with respect to ground. Then, of course, the control grid returns to ground, and the cathode of the picture tube is connected to the moving arm of the pot.

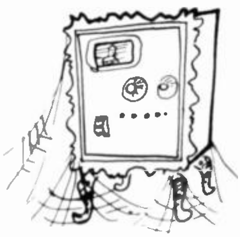





*The low-voltage supply uses a full-wave rectifier. Sometimes two rectifier tubes are used in parallel to pass the current required by the receiver. Modern receivers with permanent-magnet focusing do not use a focus potentiometer.*

WILL—I've seen such circuits. And you say that the three separate filter circuits following the second choke often consist of resistors and capacitors buried in various parts of the set? I see we also have an extra filament winding.

KEN—Yes, you'll find out the reason for that shortly. Some sets have a number of windings—they may have several filament circuits with the filaments in series in each circuit. And especially in older sets, you may find the picture tube filament on a separate winding. Pity the manufacturers abandoned it—it's a valuable precaution, especially if you bias that tube by the variable-cathode-voltage method instead of the variable-grid-bias method I've shown.



WILL—I'd like to get back for a moment to something you said about focus coils.

KEN—And what is that?

WILL—How can you have a focus unit but still not have it as part of the power supply?

KEN—I thought we had discussed that. All that the focus coil does is to supply a magnetic field. This magnetic field can be furnished by an electromagnet or a permanent magnet.

WILL—That's what bothers me. I can understand how the magnetic field around the electromagnet can be varied. All you do is to control the amount of current going through the focus coil. But how do you change the magnetic strength of a permanent magnet?

KEN—That's easy. The permanent focus unit is a circular type and sits on the neck of the picture tube right behind the deflection coils. The magnet has one or more brass slugs which can be made to move in or out of the magnet.

WILL—I see. The brass changes the reluctance of the path of the magnetic field, thereby changing the magnetic strength. I should have thought of that.

KEN—Why?

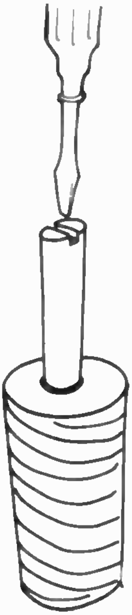
WILL—It's the same idea that has been used in radio. We have polyiron slugs in if transformers. These change the inductance of the coils and in this way vary the magnetic strength. But would you do one more thing for me?

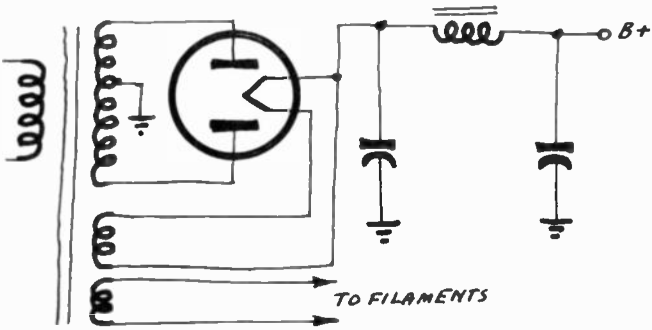
KEN—And what is that?

WILL—Draw a circuit for me showing a power supply as it really is.

KEN—You'll have to be more specific.

WILL—What does that mean?






*Full wave, vacuum-type power supply. This type of supply is quite commonly used.*

KEN—Every television set really has two power supplies. One for low voltage and the other for the picture tube.

WILL—Oh, I meant a low-voltage supply.

KEN—Actually, there are several types of low-voltage supply, but let's start with one that looks very much like the full-wave supply shown on page 173.

WILL—Why, that's the same supply that we use for console radios.

KEN—Of course it is. Some television sets use two rectifier tubes in parallel to meet the current demands of the receiver.

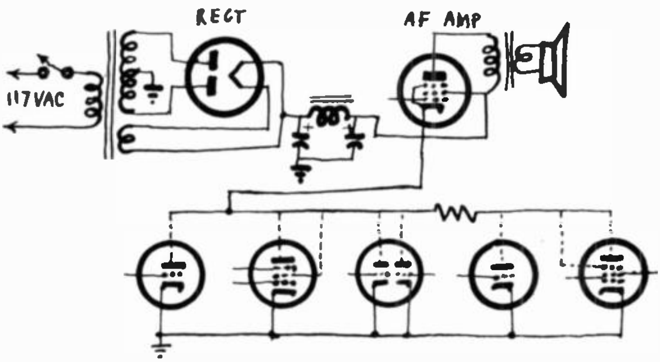
WILL—And the filter choke?

KEN—That can be a regular filter choke or, in some of the older sets, the field coil of the loudspeaker. Most sets use a regular choke. Just a few use the speaker field, focus coil, or an R-C filter after the rectifier.

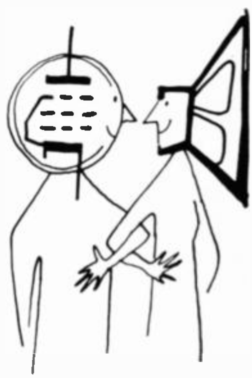
**Series feed**

WILL—Are there any variations in this supply?

KEN—Of course. Here. Take a look at this circuit.




*The audio-output tube is used as a voltage divider. The remainder of the tubes in the receiver are connected in parallel.*



WILL—I can recognize part of it . . . that is, the power supply portion. I suppose that the row of tubes along the bottom represents the tubes in the television set.

KEN—Exactly. Note that all the tubes are in parallel.

WILL—What about the tube marked AF ampl that we have connected to the speaker?

KEN—Now we're getting down to business. The audio output tube is in series with the other tubes in the receiver.

WILL—Sorry, but I just can't quite see the advantage. I suppose there is one.

KEN—Definitely. Nearly all the tubes in the television receiver require about 200 volts on the plate. A power tube, such as the audio-output tube, generally calls for about 300 volts. Now—and here's the big question—how do you go about furnishing two different voltages from one supply?

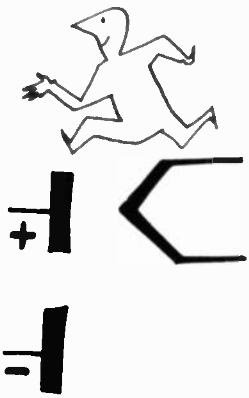

WILL—The best thing to do would be to use a voltage divider.

KEN—Are you sure that's the best way?

WILL—Of course. All you do is put a resistor across the filter output and just tap off the voltage you want. Simple, isn't it?

KEN—Sometimes I wonder why I bother. Have you given any thought to the size of the voltage divider resistor? And just what its power rating should be?

WILL—Why, no. Should I have?



KEN—Most definitely. Just trace the path of the current flow. If we start at the filament of the rectifier tube, the current flows . . .

WILL—To whichever plate is positive at the moment.

KEN—Right. And from the plate?

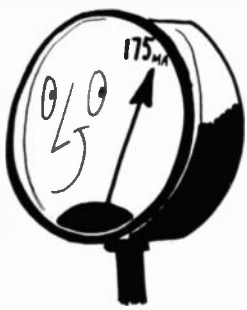
WILL—The current flows through the secondary winding of the power transformer to ground, or to the chassis.

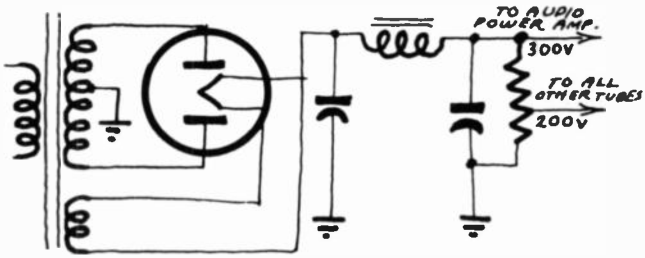
KEN—And from the chassis?

WILL—The current flows up through the voltage divider resistor.

KEN—And how much current would that be?

WILL—The amount called for by all the tubes connected in parallel. This would be the sum of all the plate and screen currents. It would vary from set to set. Shall we say about 175 milliamperes? I imagine that some of the newer portable type receivers would require less than this, but I think we'll be fairly safe if we assume 175 milliamperes as an average figure.



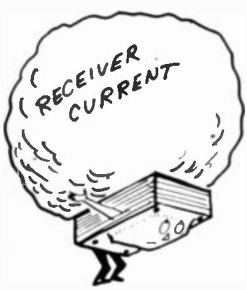

*The voltage divider is connected across the output of the filter.*

KEN—Very well. But don't forget that your voltage divider is right across the power supply, so that it will have a current demand of its own.

WILL—Ah-ha. Now I see that our voltage divider puts us on the horns of a dilemma. If we make its resistance value too low, the voltage divider will demand a heavy current of its own.

KEN—So what?

WILL—So it might overload the power transformer—that's what.




KEN—Then why not make the voltage divider with a large value of resistance?

WILL—Not so good either. Since the tube current must flow through the divider, we would have to have a resistor with a high wattage rating. In high resistance values these would be large and expensive. So what do we do now?

KEN—Let's get back to our series parallel circuit. If you will trace the circuit, you will see that B+ is connected to the screen and plate of the audio-amplifier tube and that ground is tied to the cathodes of the tubes in parallel.

WILL—So?

KEN—This means that the audio-amplifier tube is in series with all the other tubes, but this series combination is connected right across the output of the power supply.

WILL—Oh, now I get it. Your tubes are taking the place of the voltage divider.

KEN—Hallelujah. Finally.

WILL—But is this an unmixed blessing?

KEN—No. Just as we have to pay for everything in life, so too must we pay a premium here.

WILL—And that is?

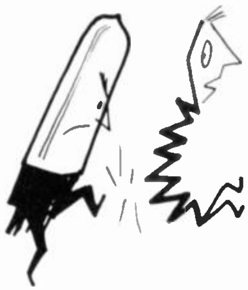
KEN—What if the audio-amplifier tube becomes defective. Your voltage distribution network becomes completely upset. For example, suppose you had a television receiver and the picture insisted on rolling vertically. What would you suspect?

WILL—The vertical oscillator?

KEN—Possibly. But if your receiver used the audio-amplifier tube as a voltage divider and if that tube became defective . . .

WILL—I see. The vertical oscillator might not get its correct plate voltage.

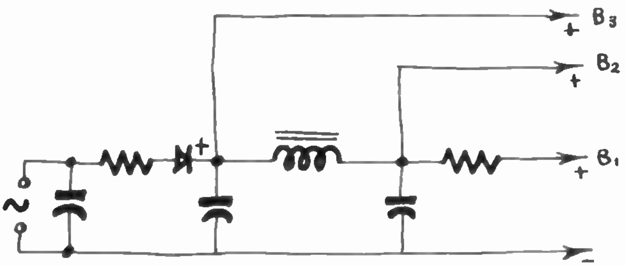
KEN—Exactly. Or the trouble might develop elsewhere in the set. That's why, with modern receivers, the audio-output tube is one of the first to be checked.



## Away with the transformer

WILL—It seems to me that quite a lot of what I've learned in radio has been carried over to television.

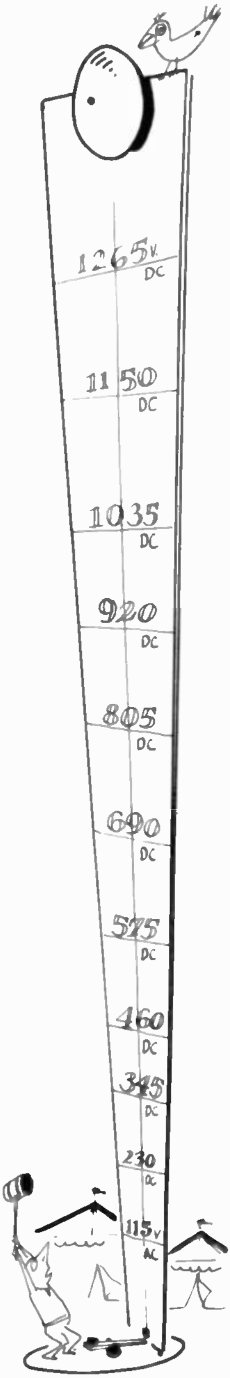
KEN—Quite true. I may even have mentioned this to you before. The knowledge you gained by studying radio theory and circuits is just like having money in the bank. You can draw on it any time that you want to do so.




*The choke and the resistor in the filter form a voltage-divider network.*

WILL—And yet we haven't even discussed one of the most important circuits used in radio.

KEN—Are we still talking about power supplies?




Will—Naturally. Now what about ac-dc supplies? I would imagine that they are needed even more in television than in radio.

Ken—As a matter of fact, transformerless supplies are quite commonly used in television. A few sets do use a single selenium power rectifier, but most transformerless sets use two selenium rectifiers in a voltage doubler circuit.

Will—Why don't we start with a simple half-wave rectifier type and work our way up.

Ken—Can do. Here's a typical arrangement.

Will—So you've been fooling me again.

Ken—How's that?

Will—I thought you said we had to have tubes in series or a resistor at the output of a power supply if we wanted voltage divider action. There's no voltage divider here.

Ken—Actually, there is. We use a filter choke and a resistor in series as part of the filter. We take advantage of the fact that there is a voltage drop across these units, and so in a sense, they also act as voltage dividers.

Will—Well, I suppose so. This circuit is so simple that I imagine all television sets use it.

Ken—It does have its disadvantages, though. The maximum voltage is only about 135. And filtering is not so easy because the ripple frequency is 60 cycles.

Will—OK. Now can we get started on the doubler? I've always been a little skeptical about such circuits.

Ken—What do you mean?

Will—After all, aren't we going to get something for nothing?

Ken—I'm sorry. I don't quite follow you.

Will—We're going to connect our voltage doubler to the 115-volt ac line. Right?

Ken—Right.

Will—And the output of our voltage doubler will be about 230 volts dc. Right?

Ken—Yes. You're right. But how did you know how much the output would be?

Will—That's simple. From the name of the circuit. Voltage doubler—get it?

Ken—At least that's one thing I won't have to teach you. But seriously, there is nothing mysterious about voltage doublers. But before we start, let me ask just one question.

Will—Shoot.

Ken—Suppose that I had two capacitors of equal rating and charged each of them to 100 volts.

Will—Well, the charge would gradually leak off, I suppose. . .

Ken—No, just wait a moment. Let's assume that we have perfect capacitors and that they will hold their charge.

Will—Very well. Now what?

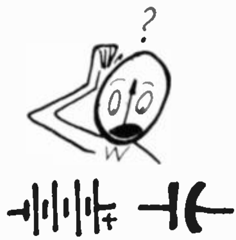
Ken—And now let's suppose that we connected these capacitors in series. What would be the sum total of the voltage we could measure?

Will—You mean, what would be the voltage across the two ends of the capacitors that had not been connected?

Ken—Yes.

Will—Well, now, I really don't see. . .

Ken—Suppose you had two 100-volt batteries in series. The sum voltage would be . . . ?




Will—200 volts.

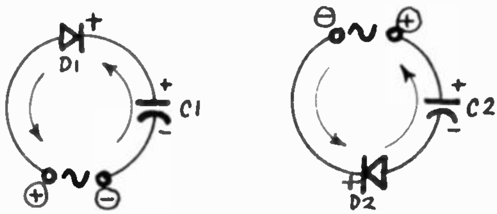
Ken—And do you really think that your voltmeter knows the difference between a battery and a capacitor?

Will—I guess not. But what has all this to do with voltage doublers?

Ken—Doesn't all this give your inventive mind some ideas?

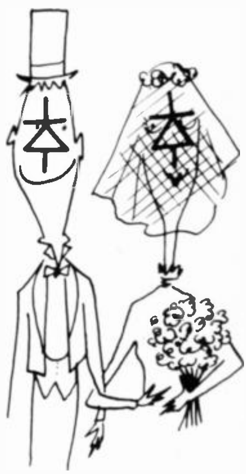
Will—Now that you mention it, I do have a few thoughts on the subject. We could make a voltage doubler by charging capacitors and then putting them in series. But how could we go about doing that?

Ken—Just take a look at these sketches.




*Capacitors C1 and C2 are charged in the same direction.*

Will—All I see are a pair of half-wave rectifiers.



Ken—Yes, but note the position of the rectifiers.

Will—I can see that your two rectifiers are placed in such a way that one of them works for one-half of the cycle and the other works during the next half of the cycle.

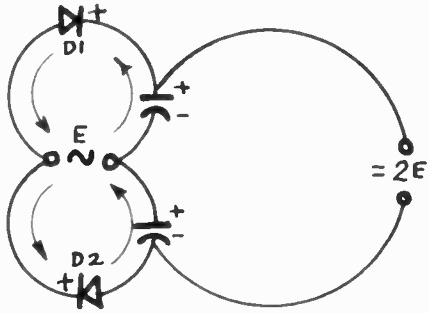
Ken—I'm sure you understand that this hasn't been arranged accidentally.

Will—Don't worry about that. I've known for a long time how you go about doing things. In a minute you're going to suggest that we combine our two rectifiers into one in such a way that we can rectify both halves of the cycle.

Ken—I see that I can hide nothing from you, so let's put the two rectifiers together.

Will—That's fine. I see what we're doing here. Not only are we going to rectify both halves of the ac cycle, but we have joined our two capacitors in series. The voltages


developed across each of them will add and this is how we get double our voltage. That's what you wanted to do, isn't it?



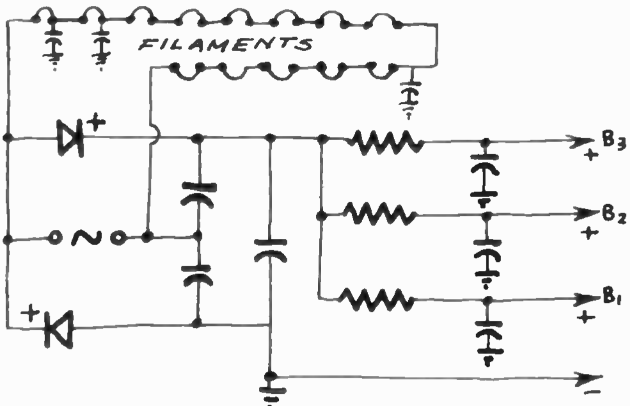

*Simple voltage-doubler circuit.*

KEN—That's exactly what I wanted to show. Shall we continue?

WILL—Definitely. But I wish you would clear something up for me first.

KEN—And what might that be?

WILL—I'd like some information on the filament circuits of television receivers. I know that in transformer type radio sets the filaments are wired in parallel and in ac-dc receivers the filaments are usually series connected. I suppose television follows the same practice?




*Filaments connected in series. Sometimes series-parallel combinations are used.*

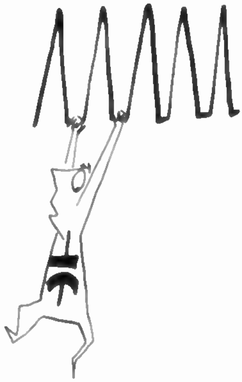
KEN—Yes, but of course we have some slight modifications.

WILL—I might have known it. Why can't life be simple?

KEN—A simple life is a boring one. But cheer up. All it needs is just a slight amount of mental effort on your part.

WILL—OK. Let's carry on.

KEN—Here's a diagram of the filament supply in a transformerless type of television receiver. Can you spot anything unusual?



WILL—Sure. The power supply is a voltage-doubler type.

KEN—No. I don't mean that. How about the filaments?

WILL—It looks like a series-parallel combination.

KEN—Look again. All those filaments are in series.

WILL—Well, what are those capacitors hanging off one end of the filament leads?

KEN—Those are rf bypass units.

WILL—Rf in the power supply? I thought the line frequency was 60 cycles.

KEN—And so it is. But the tubes must work at rf and it is entirely possible for some of it to get into the filament bus.

WILL—What would be the result of rf in the filament circuit?

KEN—Feedback. You might get enough to throw one of the tubes into oscillation.

WILL—And?

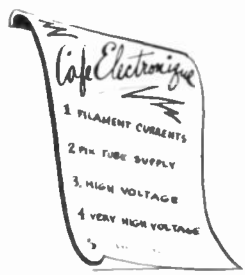
KEN—Do you want your tubes to work as oscillators, generating signals of their own—or as amplifiers?

WILL—I see. Is there anything else I should know about the filament circuit?

KEN—Some sets use rf chokes in addition to the rf bypass capacitors.

WILL—A complete filter network?

KEN—Definitely. As far as the filaments are concerned, transformerless sets usually have series string filaments, and sometimes series-parallel combinations.




WILL—What about transformer-type receivers?

KEN—For the most part these are operated in parallel from a filament winding on the main power transformer. In some transformer type receivers, though, the filaments are tied in series and are worked directly from the power line.

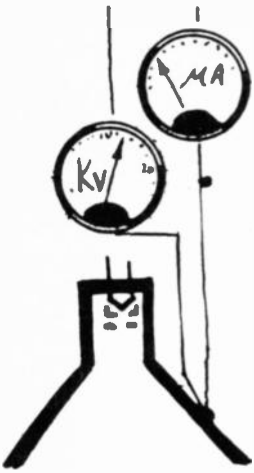
WILL—Well then, we've got the supply problem 90% solved, and all we need is to find out how to feed the second anode of the picture tube. What do we put on the menu for it?

## In the land of kilovolts

KEN—You'll find the picture tube no hog, but it does have rather refined tastes. TV picture tubes demand anything from 12,000 to 20,000 volts (less for some of the older, smaller tubes).

WILL—You'll blow the house meter if you go after voltages like that!

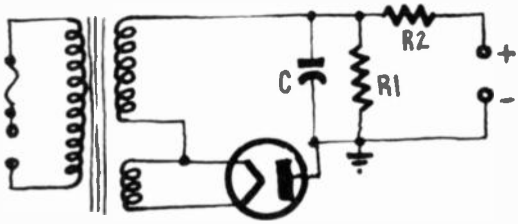
KEN—No danger—to the house meter least of all. You have kilovolts, but no kilowatts. The anode currents of



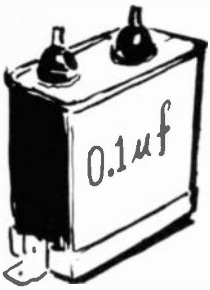

cathode-ray tubes are measured in microamperes. A tube with a voltage of 16,000 may have an anode current between 100 and 200 microamperes—that is, between 1.6 and 3.2 watts. A watt-hour meter would hardly notice such small amounts of power.

WILL—Well, then, we shouldn't have any trouble. Any circuit that will give you low B voltage will also work for high voltages, if we use higher-voltage transformers, I imagine.

KEN—They would, and 60-cycle TV power supplies were originally designed on that basis. Here is a very common older type. Since the current is so small, a single half-wave rectifier is all you need . . .




*Half-wave power supply used for high voltage in very early television receivers. Such supplies are dangerous.*




WILL—But the filter is pretty crude for half-wave rectification—only a capacitor and two resistors.

KEN—The capacitor alone would probably be enough. It's being charged 60 times a second and is discharging such a small current that it remains at practically the peak voltage of the power transformer's high-voltage secondary. A 0.25- or even 0.1-µf capacitor is big enough.

WILL—I suppose that R2 does improve the filtering quite a bit, though?

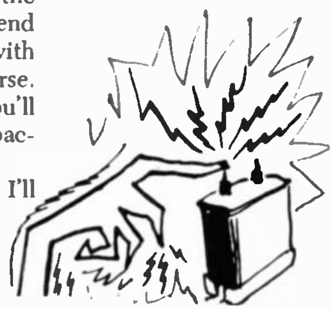
KEN—That's not what it's there for. It prevents overloading the rectifier or transformer in case of accidental short circuits. You need about 50,000 or 100,000 ohms.

WILL—And what is R1 for?

KEN—It's another protective resistor—this time for the repairman. That resistor—in the order of 20 megohms—discharges the capacitor when the set is turned off. In dry weather that capacitor will hold a charge for hours—even for days. And getting across even a 0.1-µf capacitor charged to 16,000 volts or more is no fun. At worst it can be fatal, and even at best it will create quite a commotion.

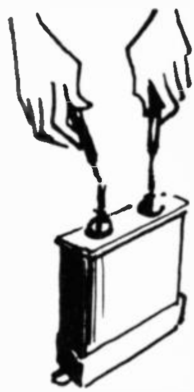
WILL—So, with R1 to discharge the capacitor, there isn't any risk . . .

KEN—When you're dealing with electrical circuits—from 100 volts up—*never* assume there isn't any risk! (And never touch any part of a high-voltage circuit with the juice on!) Even with the current turned off, don't depend on R1 for safety. *It may be open!* Short the capacitor with a screwdriver—one with an insulating handle of course. And if you hear a loud crack and see a big spark, you'll know you have to replace the resistor. Probably the capacitor too—a sudden discharge can destroy it.



WILL—Thanks, Ken. If I ever do see such a spark, I'll sure think of you!

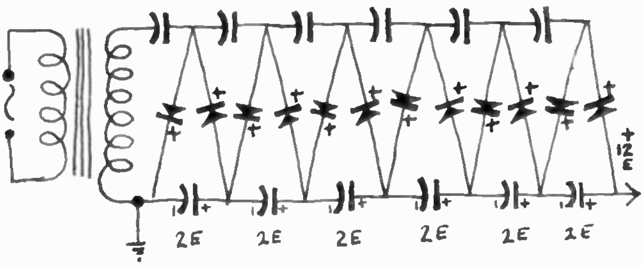
## High-voltage difficulties



KEN—There are other troubles and dangers—dangers to the equipment itself. The transformer and tube are subjected to very high voltages and insulation breaks down, especially in warm, humid weather.

WILL—I won't ask you how to avoid all those dangers, Ken, because I happen to know there isn't any high-voltage transformer in a television receiver. You're not leading me out on a limb again!

KEN—You're right, Will—at least, not in the sense in which you are using the term. But they were very common in the early days, and I can probably find you a few old receivers that are still holding out, high-voltage transformer and all! But before we look at other type of high-voltage power supplies, it will be interesting to see a circuit that has been used in Europe to get high voltage from a low-voltage 60-cycle transformer.




*Elaborate setup of a voltage-multiplier power supply.*

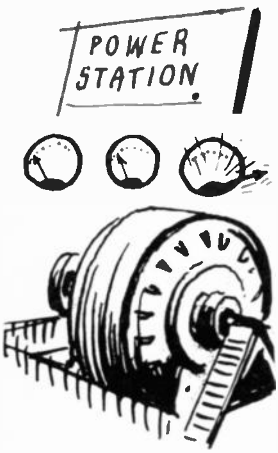
WILL—Looks screwy. But it's some kind of voltage multiplier.

KEN—Correct. It's an ordinary half-wave multiplier. During the first alternation, the current passes through the first diode and charges the top capacitor at the left to E, the voltage of the secondary. On the next alternation, the voltage on the secondary is added to that on the capacitor, charging the bottom capacitor (left) to 2E. At each succeeding alternation the action is passed down the line in true voltage-doubler fashion, so with 12 capacitors you get an output voltage 12 times that of the transformer.

Will—I don't remember seeing any sets that used a system like that.

Ken—I said they were used in Europe. The large number of rectifiers and capacitors make this kind of voltage supply expensive to construct and maintain. But it's one way to get high voltage with low-voltage components. The atom scientists cascade a whole series of voltage multipliers to get the millions of volts they need for those atom busting machines whose names end in "tron."

Will—I've heard of cyclotrons, synchrotrons and betatrons. But let's get back to the simple cathode-ray tube that ends in "scope" and just uses a few kilovolts instead of megavolts.

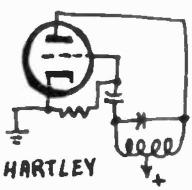



### Roll your own ac

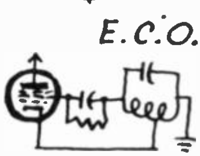
Ken—Well, I think we can abandon the 60-cycle transformer as a television high-voltage supply. They pretty well all went out with the 7-inch tube.

Will—Then what's wrong with finding out how high-voltage supplies really do work? If we don't step up the 60 cycles, what do we do? Use some other frequency, maybe?

Ken—You've said it—probably without intending to. One of the worst features of the old-fashioned system is the low frequency. Among other things, it needs big filter capacitors. A charge on even a 0.25-$\mu$f capacitor by a 16,000-volt, 60-cycle power supply can be fatal, as I've told you already. But if we had a 10,000-cycle current, for instance, we could use a proportionally smaller filter capacitor. And the capacitor discharge, while it wouldn't be exactly pleasant, wouldn't be dangerous to life.



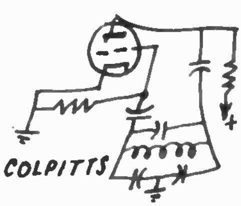

Will—Fine! Do you think we could call up the power station and ask them to speed up the generators to give you 10 kc?




Ken—Why bother? I can make it myself, from the low-voltage dc supply!

Will—Sounds like witchcraft. But go ahead.

Ken—It's easy enough. Simply use a good big tube, supplied with voltage from the receiver's own power supply. Hook it up as an oscillator at any frequency you want. It doesn't matter much what kind of circuit—tuned plate-tuned grid, Hartley or what have you. Once you get your ac, you treat it like any other ac supply.

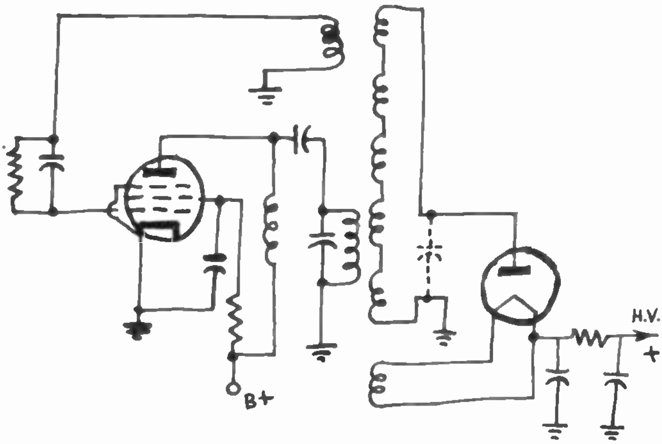



Will—You mean . . . ?

Ken—. . . step it up with a secondary, then rectify it with a simple half-wave high voltage rectifier tube or selenium rectifier.

WILL—In your schematic you show the heater winding on the rf transformer too. Are you heating the filament with radio frequency?

KEN—Why not? The tube is specially designed to use low filament power. And you can keep your high voltage well away from ground that way.




*The high voltage is generated by a tuned-plate oscillator. It is induced across the secondary winding, rectified and filtered.*

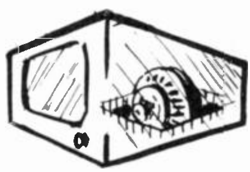
WILL—About what frequency would you use?

KEN—You could use anything from about 600 cycles up; but with lower frequencies you'd have to use iron-cored coils, and you'd have insulation problems again. It's much better to use air-cored coils and frequencies up in the radio range. Power supplies have been designed to work at various frequencies between 50 to about 300 kc.

WILL—And a radio-frequency power supply solves all the high-voltage insulation problems?

KEN—It makes them simpler. Remember, you still have big voltage differences between successive layers, even in air-cored coils. That's why they are usually wound in a number of well spaced pies, with not too many turns on each. Thus the voltage drop is distributed along the form, and no turns with large voltage differences are near each other.

WILL—I've seen these coils.

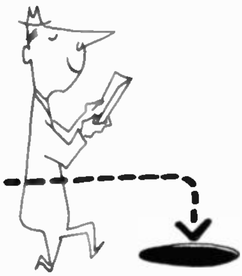


KEN—What you've seen was probably something quite a bit different—something that is used in all modern TV receivers. You see, we don't need to install an ac generator in our set—there's an efficient one there already.

**Virtues out of faults**

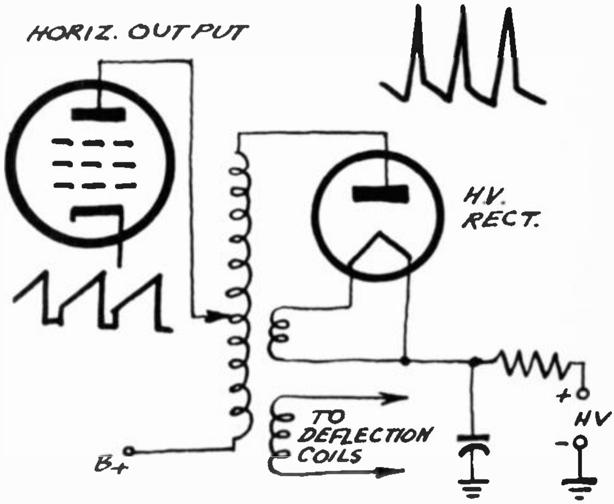
WILL—Surely you're not talking about the oscillator in the mixer circuit?

KEN—Not at all, though in some portable radios it has been used to supply cathode bias for the output tube. I'm thinking of something entirely different. Don't you remember when we were talking about horizontal scanning circuits we found we'd get surges of several thousand volts on the retrace?



WILL—I remember now. The sharp drop in current that produces the steep side of the sawtooth sets up dangerous voltages across the primary of the transformer connected to the anode of the pentode horizontal-output amplifier. And—if I remember right—even then you said we could turn a vice into a virtue by using the surges as a source of high voltage for the picture tube.

KEN—With a memory like yours, you may still go far, Will! You see then that we can use the high-voltage pulses produced by the horizontal-sweep circuits during the re-




*Autotransformer type of horizontal-output transformer. The ac on the plate of the high-voltage rectifier tube is in the form of pulses.*


trace period. And we can increase those voltages by adding another winding to our horizontal-deflection transformer primary, making an autotransformer out of it.

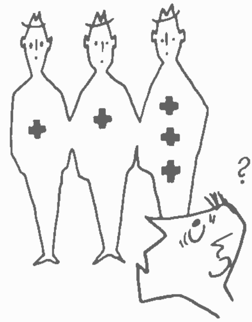
WILL—And then all you have to do is rectify the high voltage and filter it in the ordinary way. I notice again that you heat the rectifier filament with a little winding on the same transformer.

KEN—Yes, we have that advantage of the rf system, plus one that no other system has. If by accident the sweep circuits fail, the bright spot resting on one point of the tube face would soon destroy the screen around that point—make an electron burn rather than an ion burn. But with this high-voltage supply system, the high voltage goes off as soon as the sweep fails, and there is no bright spot to damage the tube.

Will—So this is efficient, economical and, on top of that, makes things safe for the picture tube. Practically a perfect system. But there's one thing that's been puzzling me. On some schematics I've seen B+, B++ and B+++. I can understand two B+ voltages, but what do you do with the middle one?

Ken—That's easy to explain. First, imagine a low-voltage power supply. Let's suppose that this voltage supply has a bleeder resistor across the output.

Will—I'm right with you.



Ken—Coming from a tap on the voltage divider or bleeder we will get a certain value of voltage. Just as an example, let us say that amounts to 200 volts. This we will call B+.

Will—Fine.

Ken—Now is this the maximum voltage we can get out of our power supply?

Will—No. The voltage gets higher and higher as we get to the top of the voltage divider until we get to the maximum voltage point.

Ken—Right. In a typical supply this might be 300 volts. We can call this B++.

Will—I see. And what about the B+++?

Ken—That's the boost voltage we get from the damper-tube circuit in the high voltage supply.

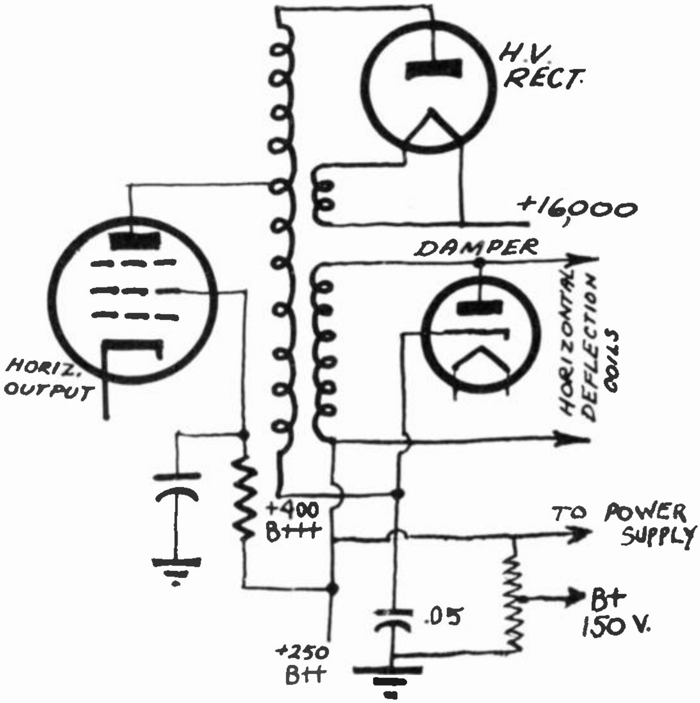
Will—Boost voltage? I thought that the advantage of the flyback system was just in the elimination of that lethal 60-cycle power transformer. But now I see that there is a little more to it.

Ken—That's still another advantage of this so-called flyback system of getting high voltage. High-voltage transformers get less efficient as you wind more wire on them and stretch them out over more space. So, to get high voltage on the big tubes, you have to use good sturdy horizontal-output tubes and put more voltage on them. And believe it or not—the horizontal-output tube itself supplies that extra voltage.

Will—Sounds impossible. But I do remember hearing of a bootstrap voltage boost. This must be it!

Ken—You're so right, Will! Here it is. This is a simplified drawing—I've left out everything not needed for the voltage boost. Most transformers are harder to figure out because the primary, deflection and high-voltage windings all form part of one autotransformer on most modern sets. I have shown a separate winding here. (The principle is the same, of course, but the diagram is less confusing and you'll find plenty of older sets with such transformers.) And in a schematic of a complete receiver you'd find a width and linearity coil mixed up in the circuit.

WILL—I can't figure this out. Looks almost as if the damper was being used as a high-voltage rectifier.




*The boost voltage is applied to the plate of the horizontal-output tube. Note that the boost voltage is substantially higher than the B++ voltage.*

KEN—Well, what is the purpose of a damper tube?

WILL—That's right! It does rectify, doesn't it? But it never occurred to me you could *use* the current that it rectifies.

KEN—And what is the source of this voltage that it rectifies?

WILL—That's simple enough, once you get the idea. The deflection winding is a half-wave secondary. And since its lower end is connected to the B++ supply, its voltage is added to the ordinary B++, so whenever the damper conducts, the voltage at its cathode is the rectified voltage across the deflection winding, plus the B++ voltage of the rest of the receiver.

KEN—Exactly. B+++. And one more point will make your story complete. The rectified current is filtered by the .05-$\mu$f capacitor you see in the diagram.

WILL—So now we have our B+++ voltage.

KEN—I would just like to add one or two words of caution about this B+ and B++ business.

WILL—Yes.

KEN—And that is to explain why some manufacturers use three different symbols. A television circuit can get to be pretty complicated. And so, if we just mark various leads as B+, B++ or B+++ we can cut down on the number of connecting lines needed. It really does make the diagram look much simpler and certainly much easier to follow.

WILL—That makes sense.

KEN—Yes, but unfortunately. . .

WILL—What now?

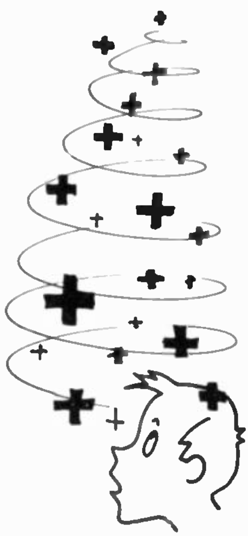
KEN—Not all manufacturers are in agreement on B+ symbols. Some manufacturers use the B+++ to indicate the high voltage for the picture tube.

WILL—This is getting kind of confusing.

KEN—It's not so bad. The only thing to watch for when reading circuit diagrams is not to approach them with preconceived notions.

WILL—What does that mean?

KEN—Don't take it for granted that B+++ is the boost voltage. The manufacturer may have had some ideas of his own along those lines. And the same goes for the other B voltages.



### Away with the voltage difficulties

WILL—What a pity!

KEN—OK. I know this is leading up to something. Maybe I shouldn't ask, but what is your problem now?

WILL—I was just thinking about how nice it would be to have a television set on the beach next summer.

KEN—And what might be stopping you?

WILL—Can you just imagine the length of line cord stretching all the way from the beach to the power outlet in my home.

KEN—So, my scientific young friend, we finally have a problem that has you stumped.

WILL—Only temporarily. Just give me some time to think about it.

KEN—Mind if I supply a few clues?

WILL—Sure. Go right ahead.

KEN—The problem has two parts. You'll need a low-voltage supply and also a high-voltage unit.

WILL—Right.

KEN—Why not work on the easiest part first?

WILL—Good idea. I'll start on the low-voltage supply at once.

KEN—The low-voltage supply? Isn't that more difficult?

WILL—Not at all. With enough batteries I'm sure I've got that problem licked immediately.

KEN—Possibly. But you'd better use miniature tubes or transistors. Otherwise you'll need a truck to carry the batteries and a big pocketful of cash to pay for them.

WILL—I'll tell you my idea if you'll promise not to reveal it.

KEN—You have my solemn word of honor.

WILL—I thought of using transistors and since we'll be on the beach anyway, using the power of the sun for a group of sun batteries.

KEN—Believe me. The idea isn't completely original. You've got your job cut out for you. Now how about the high-voltage supply?

WILL—How about a transistorized rf oscillator.

KEN—You mean along the ideas of the rf power supply we discussed?

WILL—Yes.

KEN—That's another possibility. But can I make a suggestion?

WILL—Sure.

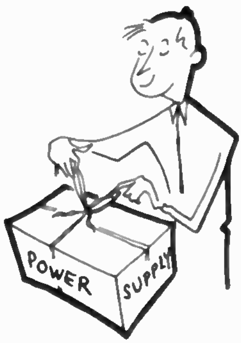
KEN—What you've outlined will take quite a bit of research and time. I hope you're going to have time for more of our talks.

WILL—Naturally. I still think I have a lot to learn.

KEN—We all do. See you next week.

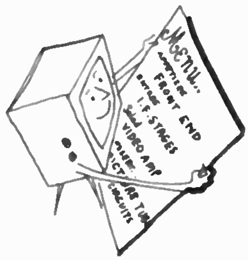
WILL—Doesn't that just about wrap up power supplies. Anything more on the schedule?

KEN—Nothing at all that we will have to bother about today, Will.



chapter 15

# Antennas



WILL—Well, we seem to be pretty well away! Now that we've learned to supply our television receiver with low, high and very high voltage . . .

KEN—Do you really think you've got the job done? Do you think the set will be satisfied with your menu?

WILL—Why, is it going to want a special dessert of some kind?

KEN—Have you forgotten what puts life on your screen —the video signals that are brought to your set by an rf carrier? How are you going to capture them?

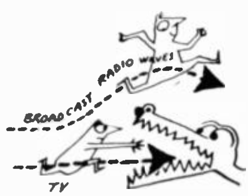
WILL—I didn't forget! It just isn't a problem. All I have to do is hook a piece of wire on the TV set, call it an antenna, and I'm off!

## Television antennas are important

KEN—Further than you think, Will, further than you think! Unless you're close enough to the transmitter to be in a very strong signal field, your piece of wire will be a pretty sorry collector of waves at television frequencies!

WILL—I can't see why TV should be so different from radio. After all, they're radio waves!

KEN—Don't forget that TV frequencies are far higher than the broadcast band and even higher than most of the short-wave radio you've been receiving. The TV waves are absorbed by conducting objects in their way and can't get around obstacles like broadcast waves. That's one reason the receiving range of TV is so much shorter, by the way.

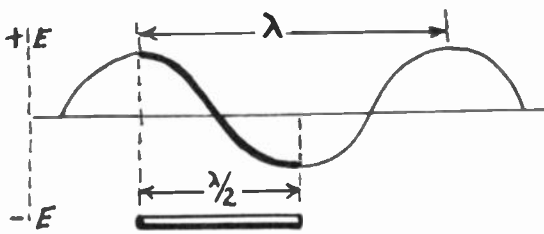



WILL—So we've got to take a lot more trouble with our TV antennas?

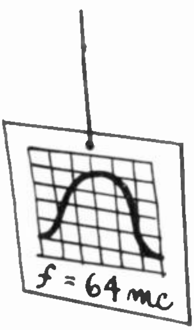
KEN—Will, the antenna is the most important part of the whole receiving installation. Well designed and well installed, your antenna is as good as one or two extra rf stages. In television the waves are short enough so that you can make your antenna length as long as a TV wavelength, unlike broadcast reception where the antenna must be a small fraction of the wavelength being received. You can make quite a profit out of that fundamental difference—because you can *tune* your TV antenna to the frequencies being received.

### What kind of a tuned circuit is that?

WILL—Wait a minute, Ken! Do you mean to tell me you can make a tuned circuit out of a piece of wire—no coil,




*One wavelength is the distance from peak to peak (or from start to finish) of a single waveform. The rod shown below the waveform has a length of one-half wave. That is the distance giving the maximum voltage between its ends.*

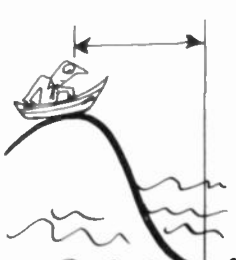



no capacitor, no nothin'? And it will have a resonant frequency and a resonance curve and everything?

KEN—Exactly, Will. And the resonance curve of a television antenna has to be pretty wide at times. Even an antenna intended for only one channel has to receive a band 6 mc wide, without attenuating either end. That's particularly important in color TV, for the color information is out near one end of the band received.

WILL—Well, if I didn't see TV antennas every day, I'd say they must be very complex, with tuning capacitors and damping resistors to widen the passband . . .

KEN—But you know they aren't. The facts are infinitely more simple, and even you can figure them out if you do a little reasoning. What are these radio-TV waves?



WILL—Well, they're electromagnetic fields, created at the transmitting antenna and moving through space at about 186,000 miles a second.

KEN—You seem to have the general idea, if not the exact terms. You understand that these waves produce electromotive forces—currents—in any conductors they find in their way? Can you tell me the minimum distance in a conductor in which a given wave can produce a maximum voltage?

WILL—The greatest voltage a wave could produce would be between the crest of a positive alternation and the trough of the following negative one. That would be a half-wave length.

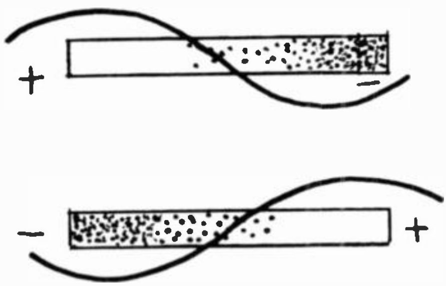
KEN—So, if I want an antenna that will get the most voltage possible from a signal of a given wavelength, I'll use a wire, strip or rod a half-wavelength long. Such a conductor is a *half-wave antenna*.


WILL—But how long a piece do you pick out for one of these all-wave antennas I've seen advertised?

KEN—We'll come to that. Meanwhile, let's stick to a single channel till we understand it.

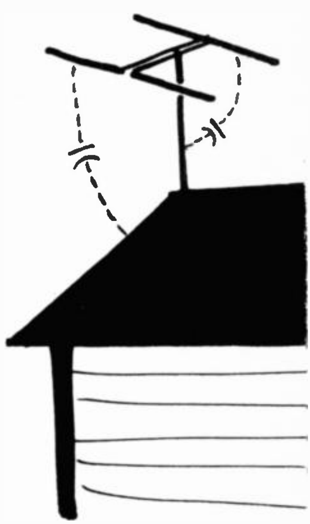
### A tuned rod

WILL—Let's see, it'll work about this way. The waves passing by your rod set up voltages or currents in it, de-




*The current flowing through a conductor depends upon the voltage induced across it by passing waves.*

pending on whether you're thinking about the electric or the magnetic field. So during one alternation the electrons sweep from one end of the antenna toward the other, and during the next alternation they come back and go toward the end they just left.



KEN—And that—of course—takes place in exactly one cycle of the transmitting frequency.

WILL—That's why you use a tuned antenna, I suppose.

KEN—Exactly. Even if they were disturbed by a single pulse, the electrons in our antenna would oscillate back and forth at its natural frequency. So if a wave of that frequency comes along, it's easy to build up big currents or voltages. But remember all this is a little theoretical. It would be exactly correct for a very fine wire suspended far from the earth or any other conductor. In real life, the mast, the ground or roof and any nearby conductors create capacitances that increase the wavelength of the antenna. We have to shorten it a little to compensate for this *end effect*—cut it down about 6%.

WILL—So if I were going to receive channel 4 pictures, at 67.25 mc, which is just about 4½ meters, I wouldn't cut my antenna 2¼ meters long, but a little less than 2¼?

KEN—Better get a chart where it's all figured out in inches for you, Will. But if you want to get the channel 4 sound at 71.75 mc equally well, you'll have to cut your antenna a little shorter. And if you want to get channel 6—up beyond 80 mc—as well as channel 4—you'll have to go still shorter.

### Increase that passband!

WILL—That's going to call for quite some passband! How are we going to get it?

KEN—One of the most effective ways to broaden the response curve of the antenna is to increase the diameter —or more precisely, the ratio of diameter to length. That's why TV antennas are usually made of tubing.

WILL—I suppose that if you wanted a really wide passband, you could go in for a cage, made of several wires in the form of a cylinder, like some old commercial and ship antennas?

KEN—Believe it or not, that's exactly what's done, though you can't recognize the cage. You know that they bring the wires of the cage together at a point to take off the lead-in. And that's at the center of a TV antenna. So your cage becomes a sort of double cone. Then it was found possible to leave out some of the wires. So a "conical" antenna now consists of two pairs of three rods each, radiating in opposite directions from the lead-in. In some cases there are only two rods, and it's then often called an "X" antenna.

WILL—But how about the channels from 7 to 13? They're up around 200 mc.

KEN—You'll notice that the whole upper section of the vhf TV spectrum is about three times the frequency of the lower part. That means that a half-wave antenna for channels 3 and 4 will be approximately three half-waves on channels 8 to 12.

WILL—And a three-half-wave antenna works like a half-wave one?

KEN—Much the same, though not quite so well. But a few tricks are used and compromises made that give us antennas that work fairly well over the whole vhf band. For example, the way the ends of a conical are tipped ahead is to help it on the upper part of the band.

WILL—And these double-V's are dipoles with a lot of tipahead?

KEN—No, they belong to a different group of antennas, the so-called "long-wire" type, and are even better on the upper than the lower section of the band. In fact, they can be used on uhf too, as well as the rhombic, another member of the long-wire family. But if you have to receive both uhf and vhf stations, it's usually best to have separate antennas. The most common are simple dipoles, fanned out into bowties to make their response curve broader.

WILL—Another thing. Why do the English stand their antennas up on end, while we lay ours flat?

KEN—That's because of the polarization of the electromagnetic field. The English use vertical transmitting antennas, which send out vertically polarized waves, and you have to use a vertical antenna to receive them. In the early days of TV it was thought there were certain advantages in vertical polarization. For instance, a vertical transmitting antenna sends out equally strong signals in all directions, but a horizontal one sends best in a direction broadside to the antenna and transmits very little in the direction of its ends. The pickup of receiving antennas follows the same pattern. But our horizontal polarization is—among other things—less susceptible to certain types of interference, and I believe the latest European systems —for instance, the French 819-line setup—also use horizontal polarization.

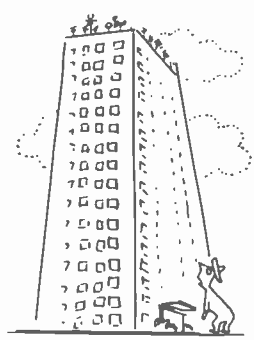
## Atom-age apartment house

WILL—Tell me, why does the lead-in come from the middle of a TV antenna? You have the greatest voltage at the ends. That's where you should be able to get the most signal.

KEN—You tell me—where is the stair carpet in your house worn the most?

WILL—Along the middle, naturally, but a stair carpet isn't a TV antenna! How does it get in on this?

KEN—Simply because it may give us the clearest explanation of the way current and voltages are distributed in our antenna. But let's go a little further. Let's imagine an atomic-age apartment house built with the thought of hydrogen-bomb attacks in mind. It has eight stories above ground and eight below. Each floor has approximately the same number of tenants. The place is a walkup—we can't depend on elevators in emergencies, or at least so the landlord says. Now, do you imagine all the stairs would be equally worn?



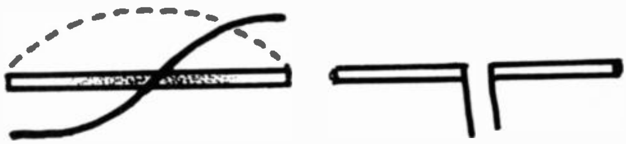
WILL—Of course not. You'll have only a few fresh-air lovers and safety-first enthusiasts on the very top and bottom floors. Their part of the stairs will get very little wear. But the first flight up and down from the entrance would be used by everyone in that half of the building.

KEN—Now you see the analogy between the tenants in our 16-story walkup and the electrons in our antenna?

WILL—I get it! There can be very little motion of electrons at the ends of the antenna—they have nowhere to go. But as you approach the middle, the number of electrons increases and the very maximum is right at the center.

KEN—So you see the example was useful if it did seem a little far-fetched at first. Now you know where the current is greatest, can you tell at what point the lead-in should come from?

WILL—I do know there are two wires in a piece of flat lead-in, and they are attached to the inner ends of a pair of straight aluminum tubes—in the simple antenna you've been talking about, that is. But how can these be half-wave antennas? They are really two antennas in line. Surely the currents can't jump the space between two antennas—especially if we are going to have the most current there. How do you go about attaching the lead-in to a *real* half-wave antenna?



*In a half-wave antenna, the voltage (continuous line) is maximum at the ends; current (dotted line) is minimum. The voltage is zero at the center where the current is maximum. However, the voltage has its maximum rate of change at the center. The lead-in comes from the center where the current is maximum.*

KEN—Don't worry, Will. The job you're talking about is a real half-wave antenna and is the most commonly used of all antennas, in some form or another. It is the *dipole*, made of two quarter-wave sections. The current has no problem, for as it flows toward the center of the antenna, the lead-in offers it the same impedance that the rod itself would if you had a straight dipole with no lead attached to it. So if you make a gap in the center just long enough that the impedance at the ends of it is about 72 ohms and attach a 72-ohm lead-in, the current acts just as if it were flowing on a straight rod. Of course, you have to remember to cut your antenna short enough to account for the end effect due to the mast and other things, as I explained a few minutes ago.

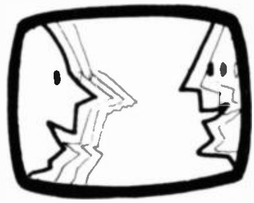
## Reflections on reflections

WILL—So it's all a matter of matching impedances again?

KEN—Even more than you think. On the uhf bands in particular, the lead-in is extremely important and its task a very delicate one. And it's especially important to avoid reflections due to poor matching.

WILL—Reflections?

KEN—If the lead-in is not properly matched to the antenna at one end and to the antenna circuit of the receiver at the other, it's likely that only a part of the signal will get into the receiver. The rest of it will be reflected to the antenna, which will send it back to the receiver again. The receiver will only take part of that reflected signal, and so on.



WILL—The signal goes round and round, eh? And it finally gets into the set in several deliveries, instead of all at once. So what are the practical consequences of this piecemeal pickup?

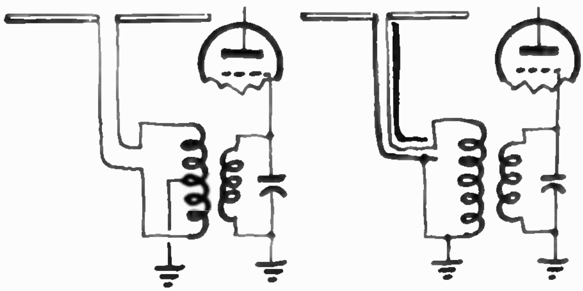
KEN—You've seen the consequences—multiple images on the screen. The main image, representing the heaviest delivery of energy to the receiver, appears farthest left and is followed by a number of successively lighter and fainter ghosts.

WILL—I've gotten an effect something like that by moving a photograph slowly under a small fluorescent lamp.

KEN—The effect might be cute as a parlor trick, but in television we've got to get rid of it at all costs. So it's necessary to make sure the impedance of the lead-in is equal to both the center impedance of the antenna and the impedance of the receiver input circuit.

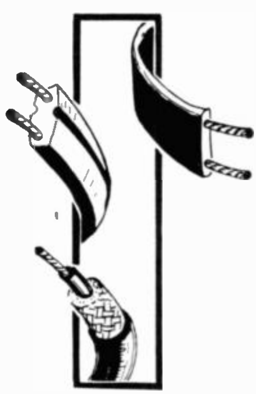
WILL—I've run into this "impedance" thing before, but I never could figure out how a piece of line could have the same impedance whether it's 5 or 50 feet long!

KEN—I could answer you very elegantly by telling you about "distributed constants" but that probably wouldn't



*Circuit at the left shows balanced 300-ohm transmission line. Unbalanced, 72-ohm line, is illustrated at the right.*

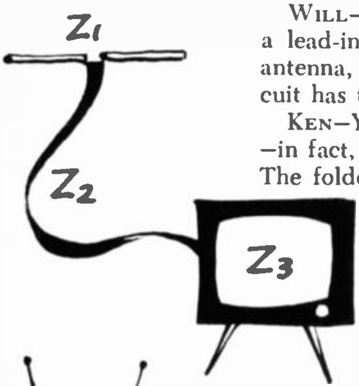
help you very much. It's probably better to say that all antennas have resistance, inductance and capacitance, and their resultant causes the antenna to have a certain impedance. In a dipole, the impedance near the center of the antenna is about 72 ohms. The lead-in also has L, C and R distributed along its length, and these also result in a



certain impedance. Now notice that, as you lengthen the line, the increased capacitance tends to reduce the impedance, while the increased inductance and resistance tend to increase it. Thus you have a balance, and the *characteristic impedance* of a given type of line remains the same for any length and over a wide range of frequencies. And the antenna input circuit of the receiver has a certain impedance, too.

WILL—If I get all this straight, it's necessary to have a lead-in with an impedance of 72 ohms to match the antenna, and the impedance of the receiver antenna circuit has to be 72 ohms, too?

KEN—You've got it all right! But you'll find that many—in fact, most—antennas don't have a 72-ohm impedance. The folded dipole and most of the more elaborate types




*The impedance of the antenna should match that of the transmission line. The impedance of the transmission line should match the input impedance of the receiver.*

have an impedance of nearly 300 ohms. That's the impedance of ribbon line. A 72-ohm line is coaxial (though you have a lot of higher-impedance coaxial, too). Practically all receivers have a 300-ohm input, though at least one big manufacturer confined himself to a 72-ohm input sets for a long time.

WILL—But how about these indoor antennas? Do you really have to have an outside job, up on the roof?

KEN—If you're in a really good location, a short distance from the transmitter, an indoor antenna may work well. Otherwise, a roof antenna is almost a necessity.

WILL—But we've been talking about tuned antennas. Those living-room dipoles certainly aren't big enough to resonate on the lower vhf band?

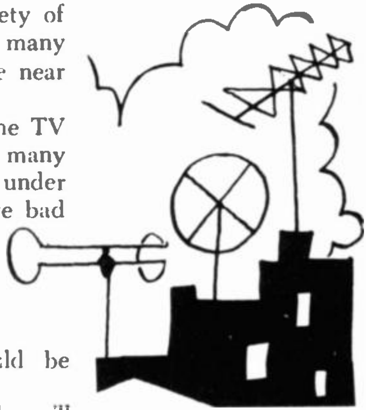
KEN—Some of them have special methods of tuning which make them electrically longer than they look. For instance, the common rabbit-ears type depends on interaction between the two arms to some extent. Other antennas have a loading coil in the middle, and still others have hairpin loops that give the same effect. Then some have switches which put inductance and capacitance units in series or parallel with the antenna.

WILL—And what do you do if you have a 300-ohm antenna and one of those 72-ohm sets you've been talking about? Can you use an impedance-matching transformer?

KEN—You most certainly can, and do. Of course, you can use the old straight dipole with a 72-ohm lead-in, and there are various types of arrays with low impedance.

WILL—But why do we see such a fantastic variety of antennas on the roofs? The fact that there are so many kinds seems to me to prove that none of them are near perfect.

KEN—The ideal is always just out of reach, in the TV antenna field as in most others. But there are many antennas that get a very good picture when used under the proper circumstances and where you don't have bad trouble with reflected images—ghosts.



## Ghostly history

WILL—I can't see why the TV screens should be haunted like lonely houses . . .

KEN—All you need is a little reflection, Will, and you'll get it. You know that conducting materials are able to reflect radio-TV waves?

WILL—Yes, or we wouldn't have radar. Of course, radar uses microwaves. But vhf waves are reflected by the ionosphere—at least when we get TV dx.

KEN—And I think you understand that vhf and uhf waves are reflected, not only by metallic objects, but also by surfaces that have a dielectric constant sharply different from that of the medium in which they have been traveling. Thus you can get reflections off a mountain—even one of poorly conducting rock—or off a building, though in most cases you will find the steel frame responsible. If you have enough reflections, your antenna may capture a half-dozen transmissions besides the one direct from the transmitter. And, of course, a signal that has arrived at the antenna after a reflection (or maybe two or three) has traveled farther than the one direct from the transmitter.

WILL—Let's see if I can follow this—it's practically the same thing as fading. When the waves follow paths of different lengths, they don't arrive at the antenna at the same time and in the same phase. If the reflected wave arrives out of phase, the signal is weakened. If it arrives in phase with the main signal, the two reinforce each other, and everything is fine.

KEN—Not in this case, Will! Even though the waves arrive in phase, the difference in time shows up on the screen as a second image—a ghost—positioned to the right of the main image in exact proportion to the difference in time of the wave travel.

WILL—Then I suppose if you measure the distance between the live image and the ghost, you can calculate the difference in the length of the signal paths?

KEN—Nothing easier! For example, if your picture is 16 inches wide, the spot travels almost exactly 3 inches in

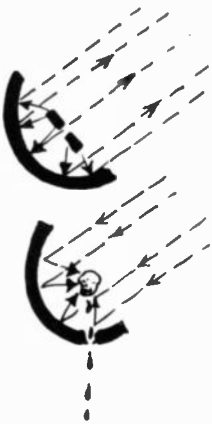
10 microseconds. So, if your ghost is exactly 0.2 inch to the right of the image, it arrived two-thirds of a microsecond after it. And, since radio waves travel about 300 meters per microsecond, the path of the ghost image must have been 200 meters longer than the direct wave. You could probably pick out the object that caused the reflection with the help of a map showing all prominent objects. You can even get a device called a *Microstick** that you can put on the screen to measure the distance directly in microseconds.


WILL—And if the reflecting object is a gas tank or metal tower, I suppose there's nothing for it but to use dynamite?

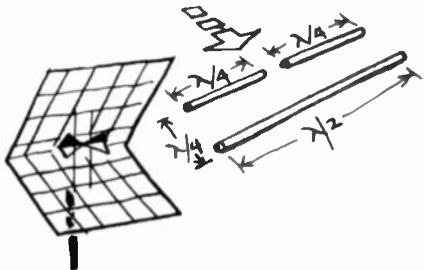
KEN—They have criminal laws covering that type of ghost elimination, Will. But you can often get the same result by using a highly directional antenna that discriminates against signals other than those coming directly from the transmitting antenna. Then reflected signals from the side or back are too weak to appear on the screen.

### Mirrors on the rooftops

WILL—I understand directional transmitting antennas. They use reflectors and transmit the waves in a beam much like the light beam projected by the parabolic mirror of a searchlight.



KEN—A good many things in nature work both ways, Will. Take your parabolic mirror for example. You can use it to receive rays from the sun, with such effect that a piece of iron placed in the focus of the parabola can be melted as if it were in a furnace!




*The reflector is one-half wavelength long and is spaced one-quarter wavelength behind the antenna.*

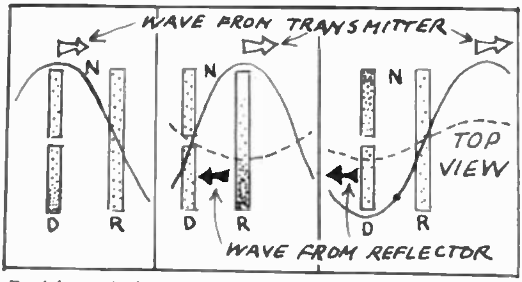
WILL—So, any directional antenna used for transmission will work just as well for reception? And all we have to do is use an antenna with a large number of wires to form a parabolic mirror, and we have no ghosts.

KEN—The idea works well, but it's a little expensive. They use something like it on uhf though—the corner

*Copyright RCA.

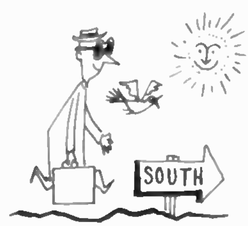
reflector. And you can make a parabolic-cylindrical mirror with four or five wires that will give fair results. Usually, you just put a single reflector—a wire 5% or so longer than the antenna—behind the dipole. The distance may be between 0.15 and 0.5 wavelength, depending on whether you want greatest sensitivity in a forward direction, greatest rejection from the rear, what impedance is desired and a few other things that vary simultaneously with change in spacing.

WILL—I can't follow you, Ken. But let's get back to our reflector. I can see that four or five wires could give you something vaguely like a parabola. But one!




*Position of the waves coming from the transmitter and from the reflector. The drawings show the movement of electrons in the dipole D and the reflector R at three successive instants.*

KEN—How about doing a little thinking? You can easily see that the reflector, like the dipole itself, picks up signals that cause currents to flow in it. And these currents set up waves that are sent to the dipole and reinforce the currents flowing there.




WILL—Yeah—I suppose so. But let's draw a diagram. I'll never get it otherwise. Now suppose a wave arrives at the dipole and drives the electrons toward the south end. It reaches the reflector a quarter-wave later—because they're spaced a quarter-wavelength apart. There it also drives the electrons toward the south end. According to the laws of induction—which always work in contradictions—this displacement of electrons will set up a field that would cause electrons to move in the *opposite* direction—from south to north. This wave reaches the dipole a quarter wave later. Then it chases the electrons from south to north, in the opposite direction from that the first wave did! Do you call that reinforcement? That's cancellation!

KEN—Your mathematics are perfect, but your results are 100% wrong. You just forgot that between the time the first wave passed the dipole and the reflected wave reached it, time passed—the time of one alternation, or one half-wave to be exact. And during that time the next alternation of the original signal reached the dipole. It was exactly opposite in phase to the previous alternation, and . . .

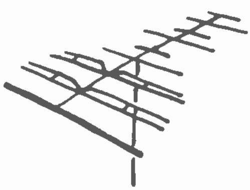
Will— . . . also drove the electrons from the south to the north end. I see it all now! Now I see how a reflector can increase the pickup of a dipole. And I see also why it makes the antenna more directive. It wouldn't have any effect on signals arriving from the sides.

Ken—Now you can see how the antenna with a single reflector, whether a straight or folded dipole, a conical (often with the reflector disguised as another conical) or some related type, is the most common of all antennas.

## How about a director?

Will—What a pity we don't have a lens—an objective—as well as a reflector, as we do in optics. Then we could turn a real electronic telescope on our signals!

Ken—Your craze for far-fetched analogies will get you in wrong sometime, Will. But this time you've fallen right into a good example. The objective—call it a director—does exist. In microwaves we even have two kinds of lenses which work by refracting the rays just like optical lenses. The *director* is an element a trifle shorter than the dipole and is put ahead of instead of behind it. It is used together with a reflector to increase the directivity and sensitivity. You can have an antenna with more than one director and reflector. This type is called a Yagi, after the Japanese physicist Hidetsugu Yagi, who invented it.



Will—But—except for a little difference in length—the director is the twin brother of the reflector. Why is its action exactly opposite?

Ken—That "little difference," as Marconi once pointed out, "is precisely the difference that makes it work!" The reflector is *longer* than the dipole and acts like an inductor. But the *shorter* director has a capacitive characteristic, so it has a very different action on the phase of the waves it reradiates. You can make up another of your diagrams and figure it out, if you like. But before you do, note down that the dimensions of these *parasitic* elements are critical, that their presence cuts down the impedance of the dipole and that the impedance decreases as the elements are spaced closer together.

Will—That just about does it Ken. And now—if you don't mind—I think my mental antenna has been overloaded— I can't receive any more!

chapter 16

# Special circuits


WILL—Thank goodness for that!

KEN—I suppose I shouldn't ask, but what are you so especially cheerful about today?

WILL—Why shouldn't I be happy? Haven't we gone through a complete course in television?

KEN—It all depends on what you mean by the word complete.

WILL—I must say you are in a very philosophical mood today. Complete means complete. What else could it be?

KEN—Finished?

WILL—That's it. Finished. Nothing more to learn. We've got all our circuits down pat.


KEN—And I suppose that the next thing to do would be to burn down the patent office or at least to throw the key away.

WILL—Not quite that. But, after all, television is here to stay. Most homes have at least one television set and I know that my own receiver works fairly well.

KEN—So what does that prove?

WILL—Television is perfected.

KEN—And the future holds out no hope whatsoever for your inventive genius?

WILL—Now you're being sarcastic. I suppose that some day I'll be making a few valuable contributions of my own.

KEN—Just a word of advice, my modest young friend. Don't wait too long. Television circuits are being improved constantly.

WILL—What! Do you mean to stand there and tell me that everything I've learned from you has to be tossed overboard? What a waste of time!

KEN—Not so fast, not so fast. Did you ever make any improvements in your home?

Will—Sure. We just put in a new washing machine.

Ken—And I suppose that you tore down your house just because you made this change?

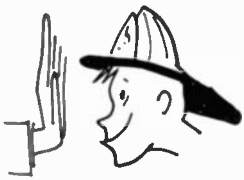
Will—Of course not. I see what you're driving at. We can keep making improvements in television, but in general, we'll still keep most of the techniques now being used.

Ken—Right. And isn't it better that way? Just because television is a working system does not mean that there is no room for change, no room for improvement.

Will—Somehow I have the feeling that all this is leading up to something.

Ken—I won't disappoint you. Why don't we go over some of the newer circuits?

Will—Swell! We'll start at the front end, work our way through the if stages, the picture detector, the video amplifier, the picture tube, the . . .



Ken—Whoa: Where's the fire? And what do you think you're trying to do?

Will—I'm organizing things. I'm sure you'll want to do this in a logical, organized fashion.

Ken—Coming from you that's strange indeed. But why this sudden passion for organization? Why not take a few sections of the receiver in which important changes are being made?

Will—Just a few? Do I detect just a slight trace of laziness?

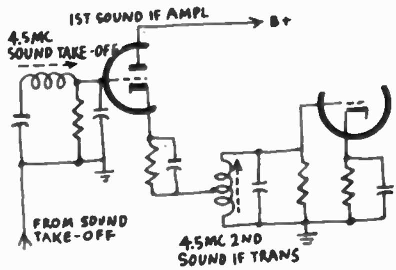
Ken—You're confusing laziness with caution and common sense. If we were to talk about each and every change we would never get finished. And I'm positive that after we've discussed a half-dozen or so circuit modifications you'll begin to see a pattern.

Will—Pattern? I don't understand.

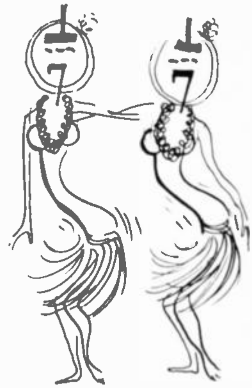
Ken—Get rid of the idea that circuit improvements are revolutionary, radical changes. They're nearly always based on the application of some very elementary theory.

Will—This I'll have to see for myself.

Ken—Very well. Let's start out in an easy way. Suppose you take a look at this circuit.




*Cathode-follower sound if amplifier.*



WILL—Hm-m-m-m. It's a sound if amplifier system.

KEN—Any unusual features?

WILL—It uses a double triode. Is that something special?

KEN—Definitely. Triodes like to oscillate. And they do so because. . . .

WILL—Because the large interelectrode capacitance keeps feeding energy back from the output to the input circuits.

KEN—Sometimes I have great hopes for you. In this case the manufacturer uses a double triode to cut down on the total number of tubes in the receiver. Any other unusual features you can spot?

WILL—Yes. The output signal of the first half of the triode seems to be taken from the cathode.

KEN—It not only seems to be. It is! A circuit in which the output is taken from the cathode instead of the plate is called. . . .

WILL—A cathode follower. But I always thought that a cathode follower had certain disadvantages.

KEN—Such as?

WILL—Don't you get a loss?

KEN—Loss?

WILL—Yes. Isn't the output of a cathode follower smaller than the input?

KEN—You're right about that.

WILL—So what's the sense of it? Instead of getting a gain through the first half of the tube we get a loss. If we keep this up we'll have a signal smaller than the one that came into the antenna.

KEN—Suppose you were to take a subway ride.

WILL—Subway ride? What's that got to do with what we're talking about?

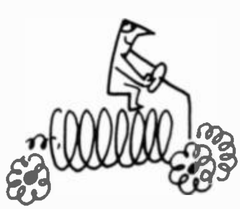
KEN—Don't argue so much. Could you get on the subway without paying a fare?

WILL—Of course not.

KEN—And isn't that fare really a loss? Haven't you got less money in your pocket?

WILL—That's true. But I'm getting something in exchange for what I've spent.

KEN—Very well. In this cathode follower we get a loss. But that's the price we have to pay to keep the triode from oscillating.



WILL—Wouldn't it be nice if we could get something for nothing.

KEN—That's exactly what we are going to do.

WILL—What! Do you mean to say . . . ?

KEN—Yes, I do mean to say. Look at that coil in the grid circuit of the second half of the triode.

WILL—So?

KEN—Ever hear of an autotransformer?

WILL—Sure. When we had our talks about high-voltage supplies.

KEN—No reason why we can't apply that kind of thinking here. The signal voltage from the cathode appears between the tap on the coil and ground. A much larger voltage is developed across the entire coil. And this is the voltage that is fed into the second half of the triode.

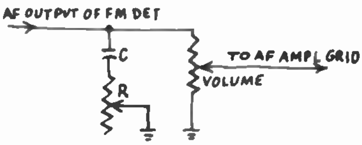
WILL—That's clever. Now why couldn't I have thought of it?

KEN—How odd! Just a few minutes ago you thought that television was finished.

WILL—Some day I'll learn to keep quiet. What's next?


## The weak become strong

KEN—Suppose you take a look at this circuit. Any comments?




*Noise-reducing volume control circuit.*

WILL—It looks like the usual volume control arrangement with a few added attractions. What's that R-C network ahead of the volume control?

KEN—Sometimes a television signal will be weak. For example, a person might be living in a fringe area and . . .

WILL—Oh, you don't have to go into too many details with me. Even where I live not all the channels come in with the same strength. But excuse me for interrupting. You were saying?

KEN—If the incoming signal is very weak, it may not be strong enough to overcome antenna and tv receiver circuit noises. As a result, you might hear a high-frequency hiss or frying sounds in the background.

WILL—And do you mean that this circuit will bring up the signal strength?

## Confusion compounded

KEN—Nothing of the sort. It will reduce the signal even further.

WILL—Absolutely, this is the most nonsensical thing I have ever heard. The signal is too weak, so to improve matters we knock the signal down even more.

KEN—Strange as it sounds, it is true. Most of the noise has a fairly high audio frequency. Capacitor C bypasses this noise to ground through resistor R. Of course, we do lose some of the higher audio frequencies as well, but the remaining sound is fairly clean.

Will—What a life. No rose without a thorn.

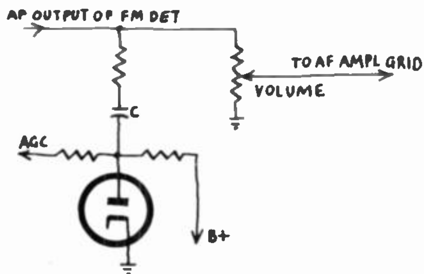
Ken—Philosophy? From you?

Will—There's a finer side to my nature you have never seen. But let's continue.

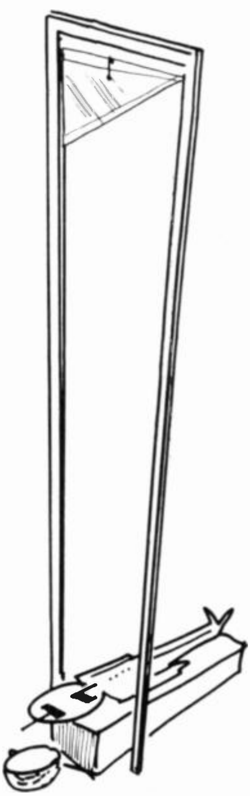
### The diode is a variable resistor

Ken—Suppose you take a look at this circuit.

Will—It's almost the same as the one we've just gone over, except this one has a diode.




*The diode substitutes for a variable resistor.*



Ken—That diode takes the place of the resistor in the circuit we just discussed.

Will—I don't think I'll ever get used to a vacuum tube substituting for a resistor.

Ken—Why not? Wherever you have a voltage and a current flow you have resistance. It's simple Ohm's law.

Will—I suppose so.

Ken—Note that the diode replaces a variable resistor. If we vary the current flow through the diode that's exactly what we have. The circuit values are adjusted so that the diode plate is slightly negative when the agc voltage is low and highly negative when signal strength and agc voltage are high.

Will—In other words, the diode doesn't conduct when signals are strong.

Ken—That's right. If the signal is strong, we don't have to worry about background noise or hiss.

Will—I see.

Ken—We usually consider a diode cut off when its plate voltage is zero or negative with respect to the cathode. Electron velocity from the cathode, however, is enough to land electrons even on a slightly negative plate.

Will—Live and learn.

Ken—In the absence of a signal, there is no agc voltage, and we have B+ on the diode plate. The diode conducts heavily.


WILL—And the effect is almost that of a short circuit. But since no signal is coming through, why worry?

KEN—We don't. But an agc voltage applied to the diode plate will reduce the amount of B+ voltage on the plate. Current through the diode will decrease.

WILL—That's just as though we were increasing the resistance.

KEN—Correct. And if the agc voltage is high enough, the diode stops conducting.

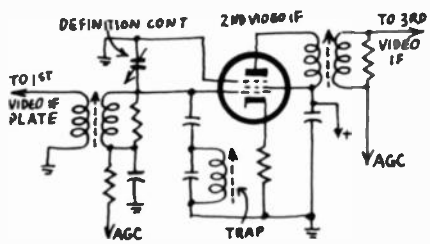
WILL—Now I see. We range from a short circuit to an open circuit condition, with all varying values of diode resistance, depending on the signal strength. What we really do is to let the signal control itself.

KEN—Why not? It eliminates a variable control, doesn't it?

WILL—That it does. And now that my appetite has been whetted, professor, what have you to offer now?

### Definition is a matter of taste

KEN—Here's a circuit that might tickle your palate. Note that the only change is the insertion of a variable capacitor called a definition control.




*Variable capacitor is used to change picture definition.*

WILL—That's an odd one. Why should we want to change the definition of the picture?

KEN—Why do we have tone controls in an audio amplifier?

WILL—So we can make the sound as pleasing as possible to our ears.

KEN—Why not carry that idea through to the picture. Some people like a very sharp, clearly defined picture. Others prefer a softer picture.

WILL—I see. This little trimmer varies the response of the if, hence controls picture definition. Very, very clever.

KEN—It's only the application of elementary principles to existing circuits.

WILL—Still, someone had to think of the idea.

KEN—That's true of every invention or improvement.

## Picture width

WILL—That reminds me. When we talked about high-voltage supplies you mentioned a width control very briefly. How come we didn't go into that in more detail?

KEN—Because the width control began to disappear from television sets.


WILL—Disappear?

KEN—Yes. Most old style width controls consisted of a variable coil placed across a small part of the secondary of the horizontal-output transformer.

WILL—And now?

KEN—Width controls seem to be coming back into style. You won't find them shown on any modern circuit diagram though.

WILL—How's that?

KEN—Some manufacturers are now using a mechanical width control known as a width sleeve. The control is a metal sleeve around the neck of the picture tube. The sleeve, an insulated cylinder of aluminum or copper foil is put around the neck of the tube under the deflection yoke.

WILL—I don't see how that could control the picture width.

KEN— Ever hear of eddy currents?

WILL—Sure. That's why we use laminated cores in transformers.

KEN—Again we get the application of known principles. The deflection currents circulating in the yoke induce eddy currents in the width sleeve.

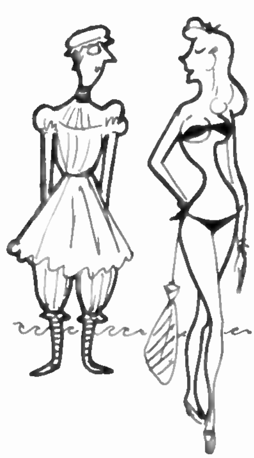
WILL—And?

KEN—These eddy currents have a magnetic field which opposes . . . . . .

WILL—I get it. The magnetic field of the eddy currents opposes the magnetic field of the horizontal-deflection coils and we get less width.

KEN—Right. And the width is controlled by pushing the width sleeve more or less under the deflection yoke.

## Series-connected if stages



WILL—I didn't realize how many changes could be made in circuit design.

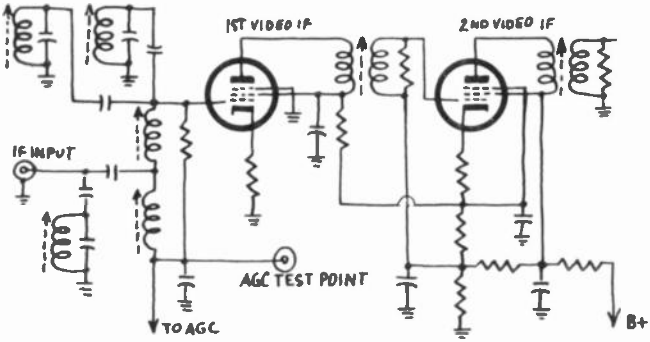
KEN—Hundreds and hundreds are suggested. Some are used and many fall by the wayside. We have styles in circuits just as we have in almost everything else. Now here's another circuit you might want to look at.

WILL—I don't see what's so different about this. It's only the first two stages of a typical if amplifier.

KEN—Look again. Where does the first if amplifier tube get its B+ voltage from?

WILL—Let's see. The plate and the screen of the first if tube are connected to the cathode circuit of the second if tube. But that's impossible. It can't work.

KEN—Why not? The first if tube's cathode is connected to ground or B minus. And the plate of the second if tube goes to B+. So what we really have are two if tubes connected in series across the B+ line.




*Series-feed if stages. This reduces the variation in load on the power supply.*


WILL—What do you know about that? But why—why complicate a perfectly good if system?

KEN—Would you say that two resistors in series are complicated?

WILL—No.

KEN—Then why do you consider two tubes in series to be difficult?

WILL—I see. We're using tubes as resistors again.

KEN—That's an easy way of looking at it, isn't it?

## Small circuit change—big improvement

WILL—I suppose so. I presume that you have some reason for this arrangement?

KEN—You presume correctly. The current required by if amplifier tubes will vary, depending on the signal strength.

WILL—I know that.

KEN—And if we go from a weak signal to a strong one we will get quite a variation in the amount of current needed by our if tubes.

WILL—So what?

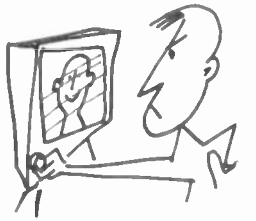
KEN—This means that we put a variable load on our power supply. If the voltage regulation of the supply isn't too good . . . .

WILL—I get it. The B+ voltage will go wandering all over the place and who knows what that might do to the picture and sound.

KEN—Exactly. But if we put our two tubes in series, the same total current flows through them.

WILL—Now I understand. It's as though we had cut our total current variation exactly in half. We could even think of the two tubes as one.

KEN—Precisely.



### Retrace blanking

WILL—I guess I'll have to take my hat off to the person who figured out the answer to that problem.

KEN—No doubt. But please take note, Will, of just what is happening. A problem exists but the solution makes use of everyday radio theory.

WILL—That's right. Nothing we've talked about so far has been in the nature of something completely new.

KEN—Very well. Let's try another one. Ever have any trouble with retrace lines on your set?

WILL—How do you mean?

KEN—When you sit down to watch a television picture, are you always satisfied with it?

WILL—Now that you mention it, no. In my area I have one weak station and . . .

KEN—And?

WILL—And I have trouble. I turn the contrast control to maximum.

KEN—Yes?

WILL—But when I try to adjust the brightness control I get retrace lines across the picture. It's pretty exasperating.

KEN—So what do you do about it?

WILL—Easy. I change to a different station.

KEN—Lucky for you that you have more than one station in your area. But instead of avoiding the problem, why not meet it face on?

### Begin at the beginning

WILL—I wouldn't even know how to start.

KEN—Let's analyze it a bit. The picture tube has an average brightness.

WILL—I know that. The brightness of the picture tube depends on the bias voltage between control grid and cathode.

KEN—And how is the brightness controlled?

WILL—That's really tough. By the brightness control, of course.

KEN—Fine. Now do you remember our discussion about the composite video signal.

WILL—I do. The video signal extends from zero to 75%. The 75% point is called the blanking level or the pedestal.

Ken—And what about the region extending from 75% to maximum amplitude, or 100%.

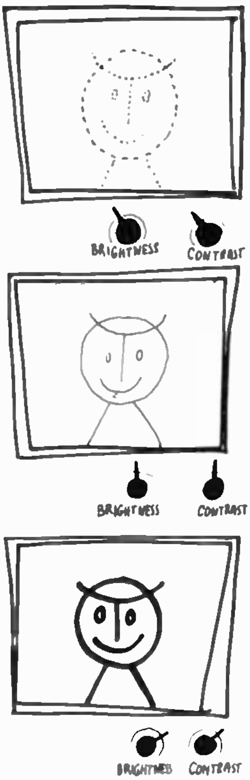
Will—Our sync pulses are in this region.

Ken—That's right. We sometimes call this the blacker-than-black region since our picture tube is supposed to be cut off during this period.

Will—In other words, starting at the 75% level of the composite video signal, the picture tube scanning beam is supposed to be cut off. Result—no light on the tube screen.

Ken—Correct. But the brightness control sets the amount of bias on the picture tube.

Will—So what?




Ken—Suppose that you adjust the brightness control so that you don't have enough bias on the picture tube.

Will—That's easy. Less bias, greater brightness.

Ken—That's right as far as it goes. But now, with your brightness control set in this way, the picture tube will not be cut off at the 75% blanking level.

Will—So what?

Ken—If the picture tube isn't cut off during retrace time the retrace lines will be visible.

Will—Now I get it. During blanking and retrace time the picture tube is supposed to be biased so strongly negative that there is no light on the screen. But if we don't set our brightness control properly . . . . .

Ken—The picture tube will remain lighted and we'll see the retrace lines.

Will—Honestly, now, I don't see how we can avoid it.

Ken—All we need to do is to increase the bias on the picture tube during retrace time.

Will—I know that. But if my signal is weak and I put more bias on the picture tube, then I'll get rid of the retrace lines—and the picture with it.

Ken—Then what we need is a gimmick that will automatically put more bias on the picture tube during retrace time but will automatically remove it when the picture is on.

## Tough problem and simple solution

Will—I understand the problem but I just can't quite see how we would go about solving it. I suppose we could develop some sort of automatic bias circuit with about three or four tubes. Goodbye now. See you in three or four weeks.

Ken—Wait. Why do you always look for a complicated solution when a simple one is looking right at you?

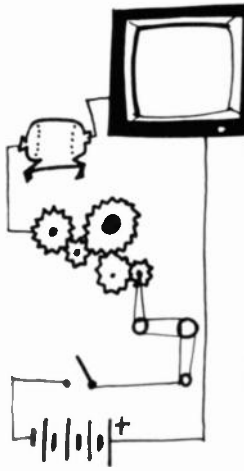
Will—I'm from Missouri. You'll have to show me.

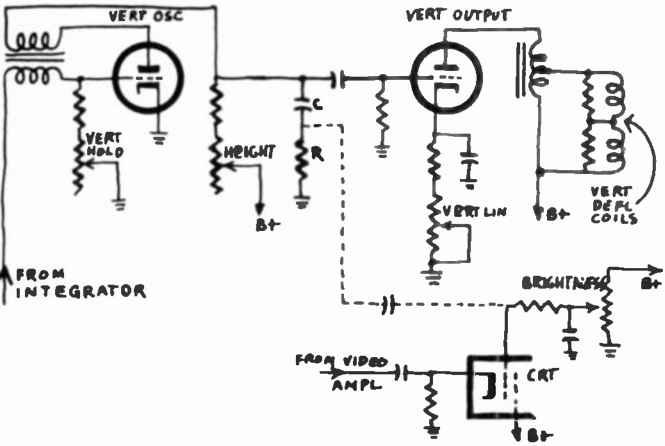
KEN—OK. Take a look at this circuit.

WILL—Let's see what we've got. We have our vertical sweep circuit and we also have the input circuit of our picture tube. There's something I don't quite understand.

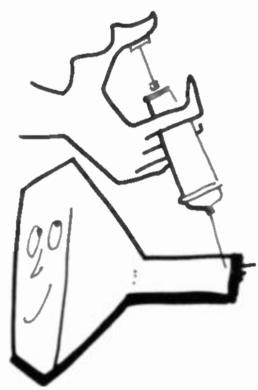
KEN—And what's that.

WILL—I sort of suspected that you were going to draw a diagram of the brightness circuit of the picture tube because that's where our problem starts. But why the vertical sweep circuit?






*Retrace-elimination circuit. C and R form a pulse-voltage divider network. The strong negative pulse is fed into the control grid, but the video signal goes into the cathode.*



KEN—What are we looking for?

WILL—An automatic bias circuit.

KEN—Right. We want to drive our picture tube off during retrace time.

WILL—And so?

KEN—And so the best way to do that would be to put a strongly negative pulse into the picture tube.

WILL—Why a pulse?

KEN—This is going to be an off—again on—again proposition. Now take a look at resistor R and capacitor C in the circuit diagram.

WILL—I see. They're connected in the output circuit of the vertical oscillator.

KEN—Do you get the idea of what we're trying to do?

WILL—Not quite. I don't see what you're going to get out of this arrangement.

KEN—When is the vertical oscillator supposed to be on the job?

WILL—Now I see. The vertical oscillator is triggered by the vertical sync pulses. But these are the pulses that start the vertical retrace action.

KEN—Exactly. And during the vertical retrace time a large negative pulse develops across R. This is applied to the control grid of the picture tube.

WILL—But this is as easy as can be.

KEN—Of course it is. Don't I keep telling you that TV is a cinch.

WILL—But are all improvements so simple? Aren't there any unusual changes.

KEN—I don't know if you could call them unusual. Do you remember automatic volume control from your radio studies?

WILL—Yes. It helps keep the audio level fairly constant for changes in input signal voltage.

KEN—Right. And in a TV set we have automatic volume control for sound *and* it is also automatic gain control (agc) for the picture.

WILL—But where do we get the picture agc voltage from?

KEN—From the video-detector diode. Sometimes a separate agc detector diode is used. It can also be taken from the pentode sync separator. And, as you probably suspect, we have different agc circuits. Some agc circuits are slow acting. Others, like a keyed agc, are faster.

WILL—I'm beginning to get the idea that special circuits in TV could be a study in itself.

KEN—Most definitely. Some sets use noise-immunity circuits. Others put a halo of light around the screen of the picture tube. And some sets have elaborate audio systems.

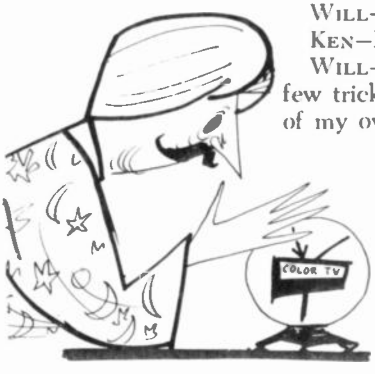
WILL—And I suppose we can expect changes other than circuit modifications?

KEN—Naturally, television will change. We're going to have transistors in our television sets, we'll have picture tubes that will have a depth of but a few inches. And in color tv . . . . .

WILL—Speaking of color tv, when do we start on that?

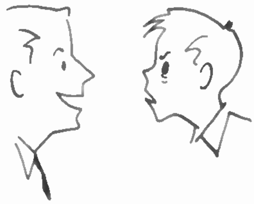
KEN—Now?

WILL—Not for me, thanks. Now, that I've learned a few tricks of the trade, I'm going to try a few new ideas of my own. See you in about a week, or so.



chapter 17

# Color tv



KEN—Well, why the disgusted look? Anything happen?

WILL—I've just been thinking that here I've spent all this time learning about television, and now in a year or two we'll have very little but color TV. So all the time I've spent on ordinary television is wasted. I'll have to start all over again.

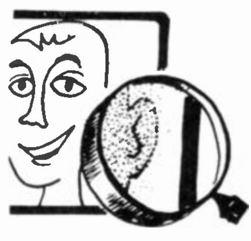

KEN—Don't let it bother you! Most of the circuits in a color television receiver are the old familiar ones we've been studying in black-and-white. Besides, black-and-white will be with us for some time yet. And the color circuits are not going to be too hard—they say!

WILL—Oh, yeah? And can you tell me in a few well chosen words just how they transmit and receive color?

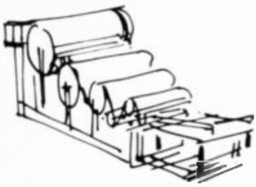
KEN—Well, several systems have been tried. All, of course, based on the trichromatic principle . . .

WILL—. . . in which all the hues are reproduced from three fundamental colors: red, yellowish green and greenish blue. By mixing them in the proper proportions, you can get all the shades and tints you like.

KEN—Wonderful; I didn't know you'd been studying the subject.



WILL—I learned that working in a print shop, where they printed pictures with red, blue and yellow inks. If you look at the pictures through a magnifying glass, you see the dots in those *primary* colors but at a short distance the eye mixes them up to make a solid picture. And, because I already knew a little about it, I was interested to find that the primary colors in TV are red, green and blue. That's because you're working with light and *add* the colors together. But when you print colors one on top of the

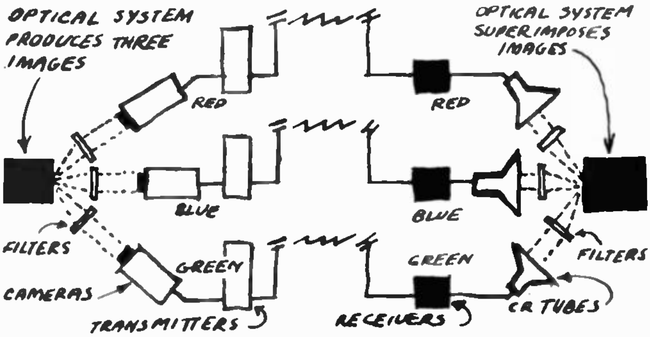


other, it's equivalent to subtraction, so you have to use different colors to get the same result.

KEN—Boy, you keep right on surprising me! I never thought of you as an artist or color expert.

WILL—Do you take me for an ignoramus altogether? But let's get back to TV. I suppose, to transmit an image in color, we must work the same as in printing. First, we have to *separate* our scene into the three primaries, then transmit them separately and superimpose them at the receiving end to build up our picture.

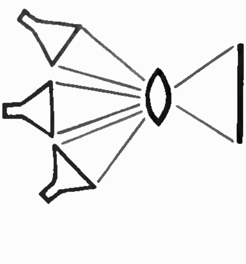
KEN—That's just about it. So we have to get three images—red, blue and green—from our multicolor scene. How do we do it?




*Basic setup of a color tv transmitting and receiving system. Three primary colors are used: red, blue and green.*

WILL—Easy. By using color filters. For example, if you photograph the scene through a red filter, you get a red image. The brightness of any surface element in it depends entirely on the amount of red light emitted by the corresponding area in the scene. So the red parts are brightest. And the blue and green parts, which emit no red light whatever, are black after they've gone through a good red filter.

KEN—That's right. Now we have three images: red, green and blue. What are we going to do with them?

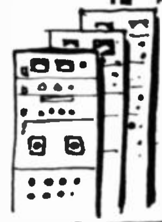


WILL—Transmit them like any other television signals, of course. Then, at the receiver, we'll bring in each image in black-and-white on a separate picture tube. But in front of the "red" tube I'll put a red color filter (a piece of red glass probably) and green and blue filters before the other tubes. Then all we have to do is superimpose the three images—it should be easy to do it by projection—to get the original image in true color. I can't see why the idea won't work!

KEN—Neither can I, Will. In fact, one of our big companies experimented with just that system about 10 years ago with some success. In spite of difficulty in registering the three images (as a printer you'd understand that!) they got very satisfactory pictures.

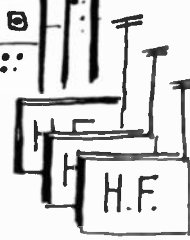
### Simultaneous or sequential ?

WILL—From the sound of your voice, there's a "but" in this somewhere!



KEN—And can't you see where? Three cameras, three transmitters, three channels, three receivers and three picture tubes?

WILL—I suppose it would cost a lot. And those three channels! No, with the spectrum as crowded as it is, you'd never get away with that! But what *is* the solution?



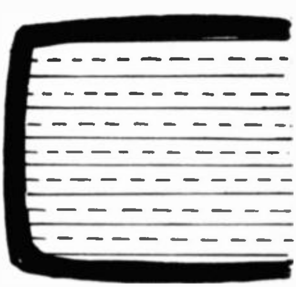

KEN—Remember the first things we learned in television? How, to get all points in a scene to the eye simultaneously . . .

WILL—. . . we transmitted them successively! I get it now! The solution is to send the red, blue and green images successively along a single channel. If they follow each other rapidly enough, the eye will blend them into a single picture!


KEN—That's the general idea. But don't think you can transmit the whole green image, then the red, then the blue. Unless you have a very large number of images a second you'll run into *flicker.*

WILL—Why?

KEN—Well, suppose part of your image is pure blue. Then that part would be transmitted only once during the time three images were going across space, for the red and green images wouldn't add a single quantum of brightness to the receiving screen. The eye would get the sensation of a light flicker over that part of the image because that part of the screen would be dark so long between the times the blue area would light up.



WILL—Can't we interlace the same as in black-and-white? First transmit the odd lines, then the even ones . . .

KEN—You're on the right track—you can use the same principle in color.

WILL—Fine! Now I suppose we could transmit a color picture if we vary the colors for every field?

### The color disc

KEN—Definitely. Here's a system that has actually been used. It has a revolving disc which passes red, green and blue filters successively ahead of the lens of the camera, and a similar disc ahead of the picture tube. The discs are kept in step by the sync signals.

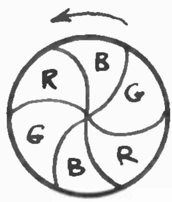
WILL—I see that each disc has *six* filters: red, blue, green; then red, blue, green again. Three filters ought to be enough.

KEN—They are. But if we use six, we can cut the speed in two, which is an excellent idea. You develop a lot of centrifugal force in those discs and, if you quadruple it by doubling the disc speed, you take a chance on the discs flying apart.

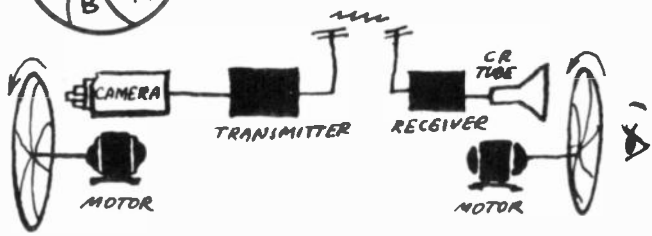
WILL—And so, while one color filter is passing ahead of the screen, you're not analyzing a complete color image, but only one color field—either the odd or even lines?

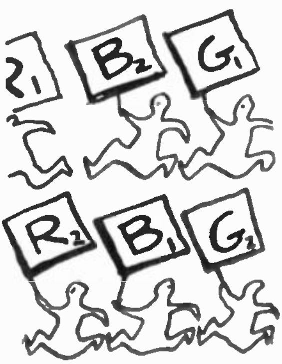
KEN—Exactly. Can you analyze the procedure?

WILL—Let's see. Suppose we start with the red odd lines. Then we have six fields:




*Mechanical system of color television makes use of tri-color rotating disc at the transmitter and at the receiver. This technique was tried but abandoned in favor of an all-electronic method.*



1. Red, odd lines / 2. Blue, even lines / 3. Green, odd lines / 4. Red, even lines / 5. Blue, odd lines / 6. Green, even lines and then it starts all over again.

KEN—And in one turn of the wheel, each image is analyzed in each of the three primary colors, both for odd and even lines, and the fields are interlaced.

WILL—But that's six fields for black-and-white's two. Looks like we still might get flicker. But why not stick to black-and-white standards of 15,750 lines and 60 fields a second?

KEN—You forget that you have to transmit three times as many points or surface elements. Even with higher line and frame frequencies, you can't squeeze them all in. But if you cut the number of lines per frame the eye is so satisfied with the sensation of life and depth that you get with color that the poorer definition doesn't bother it. The eye doesn't notice it, in fact.

### Saving the fine detail

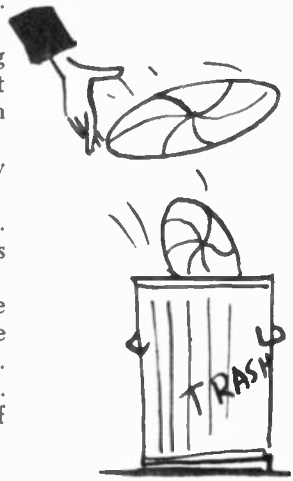
WILL—So a lot of faults are covered up with a good coloring job. Who was it said television is like a woman?

KEN—Well, there are ways of limiting the modulation bandwidth without losing too much detail. The most important one is to transmit the fine details in black-and-white and to save color for the relatively larger areas, which of course would not need as high a frequency for their transmission. The result is very satisfactory.

WILL—Of course. I knew that when I was a small child.

KEN—Huh?

WILL—Definitely. My parents used to give me coloring books and I smeared up big areas with water-colors. That never obscured the picture detail, which was printed in black-and-white.

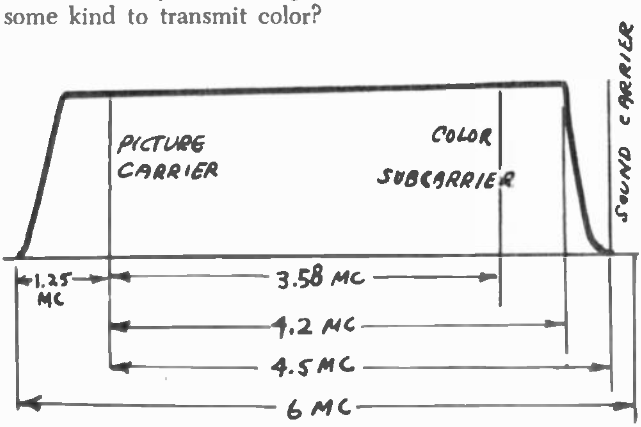



KEN—I can see that color television must look pretty simple to you!

WILL—Maybe. But let's get back on the job again. How's about giving a little on how television really is broadcast in color?

KEN—Well, you've been coming pretty close to it. If we keep our fine details in black-and-white, we find that we can send all our color on a band less than 1500 kc wide. That's quite a bit different from three television channels.

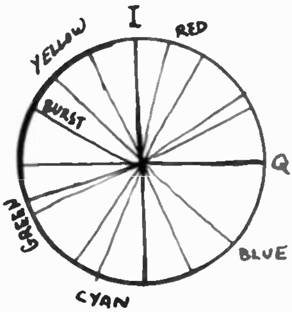
WILL—But you've still got to have an extra channel of some kind to transmit color?




*A 6-megacycle bandwidth is all that is required for a television signal that contains color information in addition to black and white signals.*

KEN—That problem has been solved too. The color signals modulate an oscillator at approximately 3.58 mc, in the video band. And this modulated *subcarrier* is part of the video signal that modulates the transmitter frequency. At the receiver, special circuits pick out the 3.58-mc signals, demodulate them, and . . .

WILL—Hold on! You are talking about one color signal, and we have to deal with three colors. Are they any other color subcarriers?




KEN—It's not quite as simple as that. *Two* color signals —I and Q—are sent on the color subcarrier—one at 90° phase difference from the other. These two signals are phase-modulated according to the colors being transmitted. They are detected at the receiver by a phase detector or demodulator, whose output is divided among the color tubes of the receiver so that the original colors are reproduced.

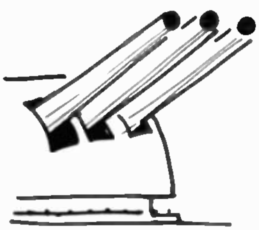
WILL—It's no use! You've been way over my head for the last 10 minutes. And now you're even talking about color *tubes* in the receiver. I thought there was only one.

KEN—You're right, Will—color is too tough a subject for a single conversation. If you're really interested, maybe we can get together sometime soon and go into it seriously.

WILL—Check. But what about the tube?

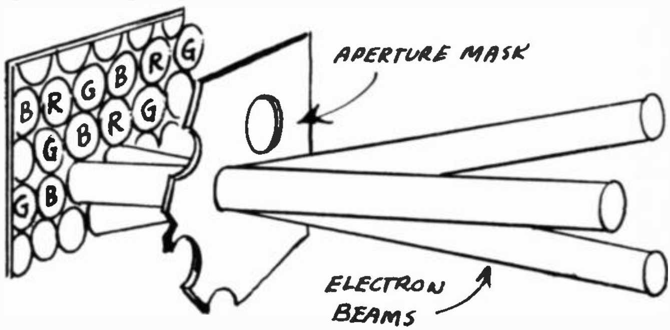
KEN— You're right about it, too. The one that's almost universally used today reminds one a little of the old three-tube system: it has three guns, one for each color. But there is also a single-gun tube, and some sets using that are now under construction.

WILL—Could you go over the receiving picture tube lightly? Just how does it work?



## A three-gun battery

KEN—In the three-gun tube, the screen is composed of a pattern of phosphor dots, each of which luminesces in one

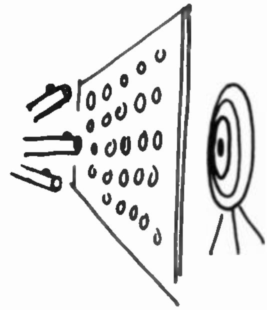


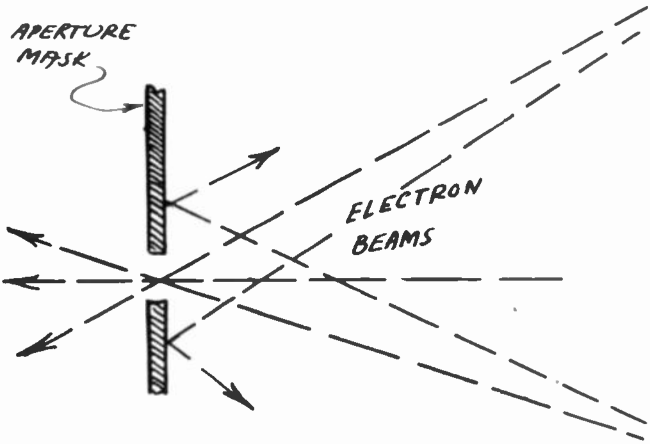

*The three scanning beams, when properly converged, will simultaneously pass through a single hole in the aperture mask. Each scanning beam will then strike its particular color dot in the triad group on the screen.*

of the three primary colors. Each of the three guns is triggered by one of the primaries and is so "aimed" that its beam contacts the dots of its own primary color.

WILL—That must be some aiming! The dots would be at least as small as those at my color printer's. And the beam is skipping along from one to the other at several miles a second. Just how is this miracle aiming done?

KEN—It's not so much a matter of good aiming at the desired spots as an ingenious method of keeping the beam from one gun off the other guns' territory. That's done by inserting a "mask" between the guns and the screen—close to the screen. It's a sort of partition pierced with thou-






*The aperture mask blocks the passage of electrons in the scanning beam not accurately directed at the color dots on the screen.*

sands of tiny holes. Each beam, after it goes through one of the holes, *must* fall on a spot of the correct color.

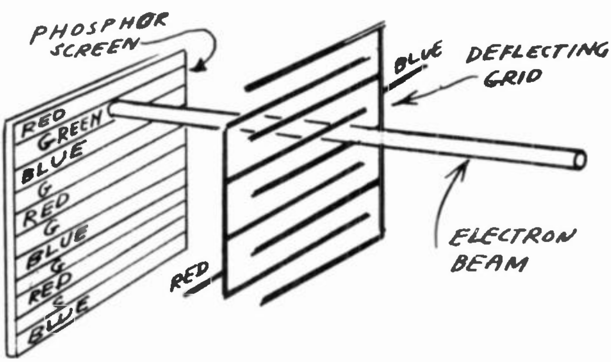
WILL—That *is* a bright idea. Ingenious is right!

KEN—Yes, and it also takes a lot of ingenuity to work out the idea, particularly in mass production!

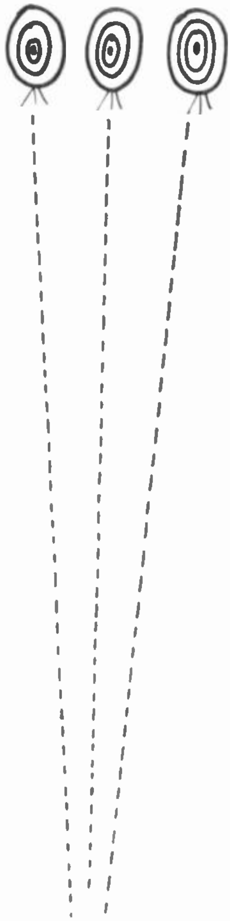
WILL—Is the one-gun tube simpler or easier to make?

**Three in one**

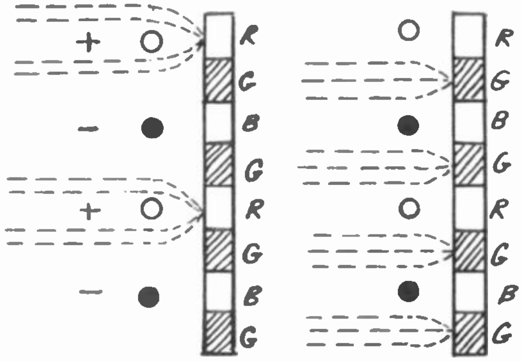
KEN—The one-gun tube is the invention of Dr. Lawrence of Cyclotron fame. Its screen is divided into color




*Chromatron tube uses horizontal color strips on the screen. Deflecting grids in front of the screen guide the scanning beam. This is a single-gun type tube.*

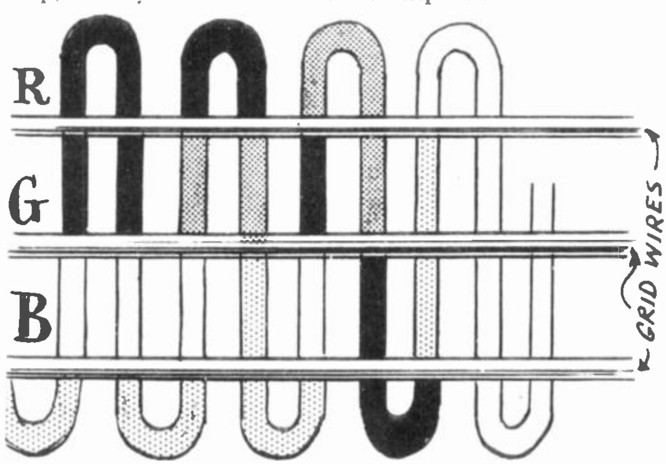


*stripes* instead of the dots of the color-mask tube. A little ahead of this striped screen is a grid of fine wires. I should say two grids, because half of the wires are connected

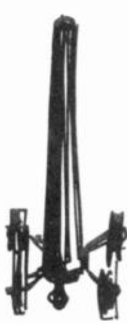



*Positive and nagative voltages on the grid wires will deflect the scanning beam at any particular moment so that it will strike the correct color.*

together and are directly behind the blue stripes in the screen. The other half—also connected in parallel—are behind the red stripes. If—say—the red grid is positive, electrons passing just above one of the red grid wires will be bent down and those passing just below will be bent up, so they'll both strike the red strip . . .




*When a single color strip is excited, it will produce a saturated color. Pastel shades are produced by using two or more color strips simultaneously.*



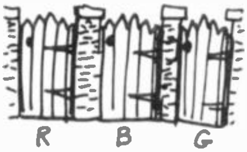
WILL—. . . and the same is true of the blue. But how about the green?

KEN—If the two grids are at the same potential, electrons passing halfway between go straight ahead to the green strip. And—because the screen is at a potential of several thousands volts higher than the grid, electrons passing near the red and blue grids are actually bent away from them and turned toward—or focused on—the green strip.

WILL—Aha! the post-deflection tube?

KEN—Exactly. Now the electrons are kept moving up and down at a frequency of 3.58 mc by a power amplifier coupled to a coil between the two grids. That coil and the grids form a resonant circuit at approximately 3.58 mc, making it easier to drive.

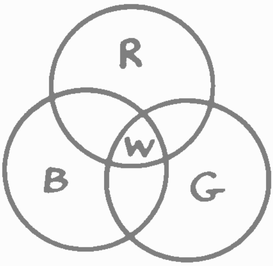
WILL—But wait a minute! According to that, the spot will be moving up and down all the time as it sweeps across the line. Your red and blue grids will simply be acting like a spot wobbler, whether the color is red, green or something else. Surely the beam will sweep along the red line only when there is a red signal . . .




KEN—No, Will, just the opposite. You get a red signal only when the beam is on the red line. The tube is *gated* so that the red signal comes in only when the beam is on the red strip. For example, if you were receiving a pure saturated blue, the beam would be cut off all the time it was on the red and green stripes and would be at maximum strength when it was on the blue.

WILL—But that fine detail you were telling me about?

KEN—Fine detail is black-and-white and is handled the same on both kinds of tubes. White is produced by all color signals working together. In other words, you get the fine detail by feeding it to all color areas—whether dots or stripes—at the same time in proportions which give a black-and-white picture. And if you want a *desaturated* color—a pink for instance—you simply feed some signal into the blue and green channels as well as the red. Part of the red then combines with the green and blue to make white. That dilutes or desaturates the red signal and you get pink.




WILL—Yeah, sounds plausible. I guess we *will* have to get together for another series of conversations on color. But, who knows, maybe something else will turn up before I learn all about color?

KEN—You can be almost certain something will, for TV is still a long way from its final form and studying it is a permanent job. That's one of its main attractions—it's anything but static. Television has now reached about the same degree of perfection as the movies. Like them, it has sound and color. Like the movies, too, it will have little trouble conquering the third dimension for some of the 3D techniques used in moving pictures work just as well on TV. TV is also like the movies in that it has much wider


fields of use than mere entertainment. It is being widely used in its closed-circuit form for instruction, conferences, inspection and control, and its capabilities along these and possibly other now unknown lines can't even be guessed at. There's plenty to be done. If you make a career of television, you won't be bothered by limits to your chosen field!

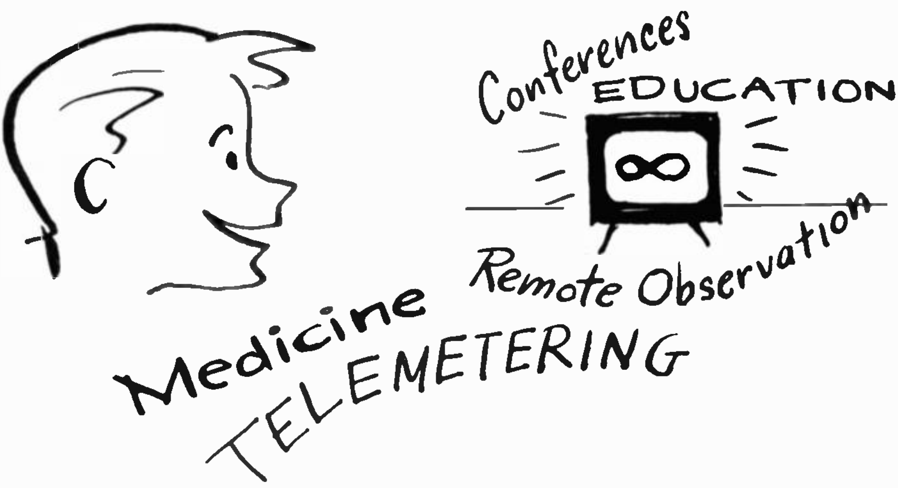
WILL—Do you really think that with what I've learned so far I could go in for a career of, say, television research?

KEN—Modesty was never one of your faults, Will! No, you certainly haven't got enough out of our conversations to make you a laboratory technician. I didn't try to show you all the circuits used in TV transmitters and receivers nor even teach you how to design or repair a receiver. But I think I did give you a fair idea of the various elements of a TV receiver and their functions as well as all those of a transmitter you need to know to understand how a receiver works. Today, no schematic—no matter how complex it may appear at first—can give you any trouble if you study it a little.

WILL—I think I know what you're trying to get across. You are advising me to decompose the diagram into a certain number of elementary circuits that I can compare with the ones we've talked about. Isn't that what they call the analytic method?

KEN—Exactly. And if you get the habit of analyzing and synthesizing, if you continue to follow the progress of television, if you keep reading the best books and the latest issues of the technical magazines, you'll find that television isn't unsurmountably difficult.

WILL—Difficult? TV—It's A Cinch!



This book is set in:
Caledonia (body)
Erbar Cnd (heads)
Futura (?) (crossheads)