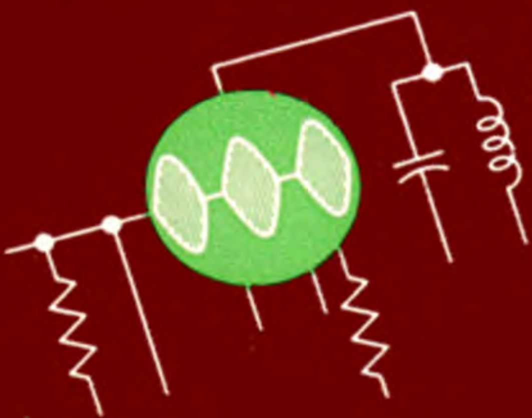
No. 146

obtaining and interpreting TEST SCOPE TRACES



by JOHN F. RIDER

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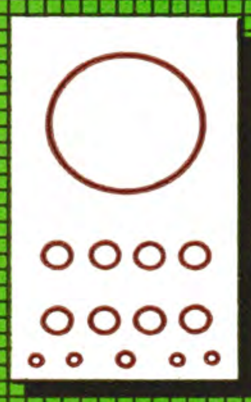

a RIDER publication

obtaining and interpreting

TEST SCOPE TRACES

by **JOHN F. RIDER**
Fellow, Radio Club of America

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FOREWORD

The cathode-ray oscilloscope is one of the important devices used for electronic maintenance and research. It affords a visual display of electrical phenomena of all kinds, including voltage and current amplitudes, waveforms, and phase relationships. In fact, it opens the door for the determination of component and equipment behavior under virtually all conditions of operation. Perhaps nothing else has been as informative to those who seek information in the world of electronics as the cathode-ray oscilloscope, more popularly identified by the single word "scope", which is used in references to it in this book.

Familiarity with the use of the scope is a distinct advantage to every service technician, every engineer, every student in radio, television or any other branch of electronics. There is nothing complex about the operation of the scope. If anything is confusing, it is the interpretation of what appears on its screen. In this respect it is hoped that the contents of this book will be of aid.

No attempt is made herein to cover every phase of scope application. Only those details which relate to field and manufacturing applications in the maintenance and production of electronic equipment have been included. In addition, a special effort has been made to plan the contents of this book to serve the civilian and military schools of instruction where electronics is taught.

A few words concerning the organization of this book are in order. Inasmuch as its main objective is the interpretation of waveforms seen on scope screens, it is felt that some background concerning the normal appearance of commonly seen voltage and current waveforms should be included. This need becomes particularly clear when it is realized that the recognition of what is wrong with an abnormal voltage waveform requires some understanding of the appearance of the normal version of that waveform. Otherwise it would be meaningless to refer to such things as "loss of high frequencies" when speaking about a degraded square waveform, and the "loss of response" of the portions of the system where such degradation can occur. Hence the first seven chapters of the book are devoted to a non-mathematical explanation of the shapes of commonly encountered waveforms and examples of their actual appearance. Each of these chapters is relatively short, and concentrates upon the common basic forms. Obviously it is impossible to dwell on every possible variety of waveform, there being so very many of them. It is felt that familiarity with the most frequently experienced waveforms will make it very much easier to recognize and understand the others.

After the ideal features of a number of waveforms have been dealt with, the scope controls are discussed. In this discussion it is assumed that the reader is familiar with the general uses to which the scope is put, and with its sections. But since the manipulation of the scope controls greatly affects the appearance and usefulness of waveforms, it was felt that important details of control operation should be reviewed. In this connection some space is devoted to the different names that identify each control, as used by the different makers of test scopes.

The largest single chapter in the book is devoted to the explanation of the causes underlying deteriorated voltage waveforms, with illustrations of each kind. The descriptions of these waveforms are respectively related to the individual chapters which deal with each type. A single cause of distortion in an equipment can affect any of a variety of waveforms of signals passing through the equipment. Therefore, distortion has not been discussed on an individual waveform basis in individual chapters since this would involve needless repetition. Since a variety of "distorted" waveforms of very many kinds are illustrated, the reader should have no difficulty in properly correlating cause with effect as it relates to the analysis of equipment defects, or the behavior of circuits being studied.

As far as equipment maintenance operations are concerned, no attempt is made to describe troubleshooting procedures; this book explains the "bad" waveforms seen on scopes and the probable causes for them. It is assumed that the reader inaugurates his own procedure for diagnosing faults in equipment. As far as the student is concerned, this book does not pretend to establish procedure in study; it simply explains what the student may see on his test scope under any of very many different conditions.

The last chapter of this book illustrates many "set-ups" for different kinds of scope observations, and indicates the points where scope connections can be made. Inasmuch as different readers will own and use different types of test equipment, discussions are not limited as to type, but are broad enough to be applicable to a general variety of scope models.

Before closing these few words of introduction, we emphasize that this is not a mathematical text, nor is it offered as a substitute for books which delve into the mathematical analysis of waveforms. This book was written for those individuals who have vital interest in waveforms, and either cannot interpret mathematical explanations, or may not desire to do so. It is hoped that it fills a void which the author feels has existed for a long time.

Acknowledgement is made to Mr. H. Dicker, who aided in the compilation of material for this book.

New York, N.Y.
June, 1954 *John F. Rider*

CONTENTS

Chapter 1

SINE AND COMPLEX WAVEFORMS

What is a Waveform?

A waveform is a graphical picture of how a quantity changes over a selected period of time. In radio, television and other electronic fields, we use a scope to observe waveforms of voltages and currents. Each such waveform, which is displayed on the oscilloscope screen, is a graph on which the horizontal, or "*X*" axis, represents time measured in seconds, milliseconds or microseconds, while the vertical, or "*y*" axis represents the amplitude or intensity of the voltage or current tested. The zero point on the horizontal time axis, where it intersects the vertical axis, is a reference; the horizontal scale indicates elapsed time after the reference. At any given time, or point on the horizontal axis, the distance measured vertically to the waveform indicates the relative amplitude of the voltage or current at that point. When the waveform line crosses to below the horizontal axis, the voltage or current is indicated as negative, or in direction opposite to that when the waveform line remains above the horizontal axis.

The Sine Waveform

A sine wave variation is basic. It describes the action of a simple swinging pendulum and a bouncing spring. It is also the kind of variation of current and voltage in a free resonant circuit shock excited into self-oscillation. Only when such action, motion or electron flow is affected by distortion-producing outside forces or conditions does the waveform change to a non-sinusoidal form. Although, after distortion, the waveform is changed to a different one, this difference can be traced to simply a combination of the original sine waveform with other basic components introduced by the distorting agency. Each of the distorting components has itself a sine waveform. Thus all waveforms which are non-sinusoidal can be reduced to a combination of components all of which *are* sinusoidal. On the other hand, a sine waveform quantity cannot be reduced to any components, because it is itself the only component present and is

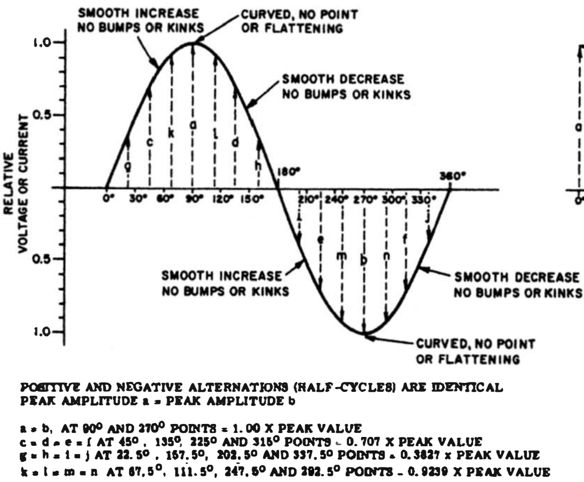

Fig. 1-1. Development and important ideal features of a sine waveform.

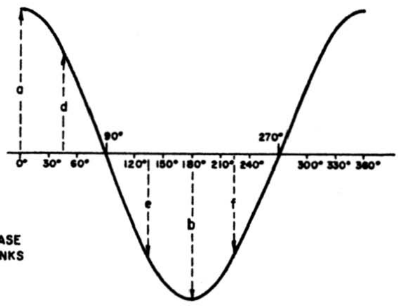

Fig. 1-2. The cosine waveform.

thus irreducible. The sine waveform is the graph of a current or voltage having only a single frequency component. No voltage or current having more than one frequency component has a sine waveform.

The features of a sine waveform are unique. It is not uncommon to hear some waves referred to as "distorted" sine waves. This is a figure of speech, rather than a rigid technical expression, because, as mentioned earlier, a waveform is either a sine waveform or it is something else. However because some waveforms do not differ too greatly from the sine waveform, hence they cannot be placed into other distinctive categories, it has become common practice to speak of them in this manner.

One objective of this book is to help the reader to recognize waveforms. Therefore a description of the features of the sine waveform is in order. This is done in part in Fig. 1-1. A single cycle of a sine waveform is shown on a time baseline which is divided into angular time intervals of 22.5 degrees—in

tinuous sine waveform quantity have this same shape. Reference is frequently seen to the cosine waveform. This is identical in shape to the sine waveform except that the waveform is advanced by 90 degrees with respect to the sine waveform. The cosine waveform is shown in Fig. 1-2 and is leading the sine waveform in Fig. 1-1 by 90 degrees.

A sine waveform can be drawn by the following method. First, assume a convenient horizontal distance to represent a cycle. Then, within this distance draw a predetermined number of equally-spaced vertical lines extending above and below the horizontal time axis. The total distance for one cycle corresponds to 360 degrees; thus each vertical line represents a proportionate fraction of the cycle. For example, the half-cycle point represents 180 degrees, the first quarter-cycle point 90 degrees, etc. Now, a point is plotted along each vertical line at a distance from the horizontal axis proportional to the sine of the angle represented. The distance is upward for positive values and downward for negative values. Then, a line drawn through all these points is the sine waveform.

For a very accurate development, many vertical lines are required, more than are used in Fig. 1-1 and 1-2. But it is not necessary to be so precise here because a waveform which has the relative amplitudes at the points shown in Fig. 1-1 is for all *practical* purposes an *acceptable* version of a sine waveform.

Recognition of the sine waveform appearing on a scope screen is a matter of familiarity with the *general features of the curve* rather than a point-by-point examination. It is seldom that the need for having a time baseline arises, or for the measurement of the amplitude at different points along the cycle. Such determinations produce quantitative data, and the familiarity we are attempting to create in this book is qualitative. When a time baseline is desired, it can be simulated by using one of the horizontal lines on the linear grid transparency which generally is furnished with scopes. This is a circular piece of clear sheet plastic on which cross-hatch lines are drawn, and which is placed over the front of the screen of the scope. Ample information can be developed without the baseline by simply looking for the features set forth in Fig. 1-1, such as the *identically* shaped positive and negative alternations; *equal* amplitudes for the half cycles; the *absence* of kinks, dips or bumps in the sides of the curve, and the *absence* of sharp points or *extreme rounding* or *flattening* of the peaks.

The actual rms or peak value of voltage or current has no bearing on the outline of the sine waveform. As long as the voltage or the current consists of but one frequency component, the shape of the curve will be the same regardless of how great or small is the voltage or current. But with a trace on the scope screen, it is conceivable that *improper propor-*

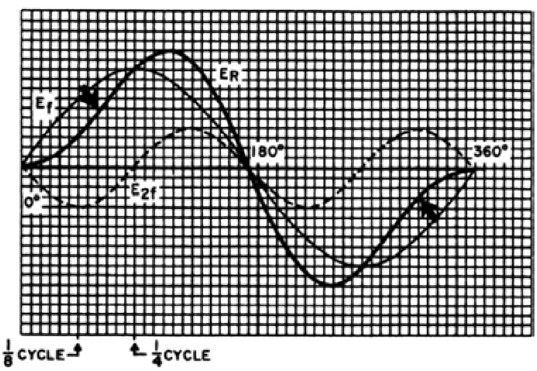

Fig. 1-3. Waveform resulting from presence of second harmonic component 180° out of phase with the fundamental.

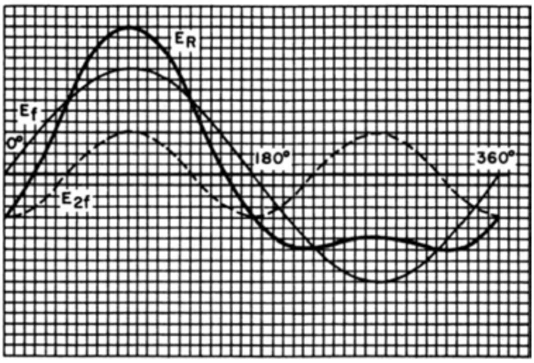

Fig. 1-4. Wave resulting from combination of fundamental and second harmonic 90° out of phase.

tioning will create a false impression and result in misleading conclusions. If the trace is too *narrow* relative to its height, the alternations will *appear* unduly *narrow* and the *peaks* will seem to be *pointed.* On the other hand, if the trace is too *wide* for its height, the alternations will be unduly *stretched* and the peaks will *seem* rounded-off to an extreme. But even so the true identity of the outline does not change. A point-by-point measurement would show the waveform to be sine no matter how incorrect its proportions appear.

Importance of the Sine Waveform

Why are we so concerned with the sine waveform? We have said that it is the basic or standard a-c waveform. But there are other and equally prominent reasons. Among them is that it is the input signal voltage used for many different kinds of tests at all frequencies. It is the kind of voltage encountered in resonant systems, and these are very common in electronic circuits. It is the kind of voltage which can be applied to all varieties of circuits without introducing complications which stem from nonsinusoidal voltages.

Still another extremely important reason is that, as has been previously explained, it is the *basis of all other waveforms. Signals of any other waveforms can be resolved into a number of sine waveform components.* Restated, all voltages of nonsinusoidal shape can be shown to be made up of two or more sine waveform voltages of different frequencies. These may be harmonically related or not. As a rule the great majority of nonsinusoidal voltages encountered in electronic circuits are *composed of harmonically-related* frequency components, the lowest frequency component *usually* being said to have the *fundamental* frequency and all higher frequency components being *harmonics* of the fundamental. There are *isolated* cases when a voltage contains only harmonic frequencies, the fundamental frequency having been removed.

The "Frequency Equivalence" Example

To illustrate the fact that the sine waveform voltage is the basis of other waveforms, reference is made to Fig. 1-3. A fundamental frequency sine waveform voltage E_f is shown being *added* to a second harmonic sine waveform voltage E_{2f}. The exact frequency of f is unimportant, because what is illustrated applies regardless. Let us assume the former to be 1000 cps, in which case the later is 2 x 1000 or 2000 cps.

The second harmonic is shown 180 degrees out of phase with the fundamental, indicated by the fact that the direction of advance of the second harmonic from the zero voltage starting point is negative whereas the fundamental frequency voltage is going positive. This is an arbitrary choice. The development of the resultant voltage waveform E_R shown by the thick line curve for the single cycle is simply a matter of *algebraically* adding the instantaneous amplitudes of the two components. The amplitudes are indicated by their instantaneous heights relative to the zero voltage baseline. Algebraic addition takes the polarities into account. The number of squares between a component voltage waveform at any one point and the horizontal axis represents the instantaneous amplitude at that point. The amplitudes of the two components measured along the same vertical line are added and the algebraic sum is the value of the resultant E_R along the same vertical line. If one is positive and the other is negative, the location of the resultant voltage point is determined as the difference of the amplitudes of the components. Thus at the ⅛ cycle point the resultant voltage E_R has an instantaneous amplitude of 3 units positive because the fundamental frequency voltage E_F is 7 units positive whereas the second harmonic frequency voltage is 4 units negative. The algebraic sum of these two is +3. At the ¼ cycle point the resultant voltage E_R is 10 units positive because the fundamental frequency voltage E_F is 10 units positive and the second harmonic frequency voltage E_{2F} is 0 units, etc.

Let us examine the resultant waveform E_R in Fig. 1-3 from another viewpoint. If for the moment we see only the "distorted" sine waveform (E_R) and not the component sine waveforms, and we recall the features of a sine waveform, the fact that E_R is not a sinusoidally varying voltage is evident immediately. As can be seen, it has its *equivalent* as a *mixture of two individual sine waveform voltages* which are related to each other by a frequency ratio of 2:1, the harmonic differs by a fixed phase relationship of 180 degrees and a relative peak amplitude ratio of 10:4 or 2.5:1, with the second harmonic the smaller of the two.

Any two signal components with frequencies of *this* ratio and with *these* relative amplitudes and in *this* relative phase will produce *this* resultant waveform. Changing the level of the second harmonic relative to the level of the fundamental frequency voltage will either increase or decrease the amount of *dip* at the points indicated by the arrow. If the second harmonic voltage level is decreased, the amount of dip at these points decreases and the resultant voltage approaches the sine waveform more closely. If it is increased, the dip increases until it becomes a kink with a distinct peak above and below the zero baseline.

Continuing with the same two voltages, but changing the phase relationship to 90 degrees, that is, the second harmonic lags the fundamental by this amount, changes the *appearance* of the resultant voltage completely. This is shown in Fig. 1-4. There can be no possibility of confusion between this resultant and a sine waveform, even though the positive alternation does bear a *resemblance* to the positive alternation of the sine waveform. Certainly the negative alternation does not!

The example in Fig. 1-4 illustrates that a nonsinusoidal waveform is equivalent to the sum of two or more frequency components. The number, amplitudes, and phase relations of the components determine the waveform of the resultant. This applies regardless of the complexities of the waveform. As stated before, every nonsinusoidal waveform can be resolved into a number of sine waveform components of certain relative amplitudes and certain relative phase relations.

The waveforms in Fig. 1-3 and 1-4 were shown for two additional reasons. They illustrate that if a sine waveform is somehow modified into any other shape, two of which are illustrated in these figures, it indicates the *creation* of one or more new frequency components which were not present in the original. Many times the frequency components created during signal processing are numerous and harmonically related to the original waveform frequency, which then becomes the *fundamental* frequency of the composite signal. New components which are created in this manner are voltages; they are present in the composite voltage active in the circuit and demonstrated by the shape of the composite waveform.

If necessary, the two frequency components present in the resultants in Fig. 1-3 and 1-4 can be separated by filtering. Either one can be removed and the other one will remain, and the one which remains then will exist as a sinusoidal waveform, just as if the one which had been removed had never existed. Sometimes filtering of this kind is done, but in most cases it is not practical; instead the effort is made to correct the circuit conditions responsible for the creation of the new frequency. In other words the conditions responsible for the *distortion* are corrected. Situations causing distortion of sine waveforms and the appearance of such waveforms during such conditions are discussed in a later chapter.

The second point we want to make is implied in what has been said. A "distorted" sine waveform like that shown in Fig. 1-3 can be changed to that appearing in Fig. 1-4 by *shifting the phase* of the second harmonic voltage relative to the fundamental. Both waveforms have the same frequencies and the same component amplitudes. If for the moment we visualize the voltage represented by the waveform in Fig. 1-3 fed into a circuit where the components are subject to such time delay as to retard the second harmonic frequency by 90 degrees, the result will be the waveform in Fig. 1-4. The shift in phase has changed the instantaneous amplitudes relative to time by changing the instants when the two component voltages add and subtract, and the degree to which these phenomena occur. Modification of a waveform in this fashion is known as "phase distortion."

It is easy to recognize phase distortion when it is presented in this fashion, but it is not a simple matter to recognize the action when it is taking place in a system. Only familiarity with the general appearance of waveforms can lead to recognition of unequal time delay by visual observation of the display on the scope screen. Moreover, a sinusoidal waveform suffers no waveshape change due to phase distortion, since only the fundamental is present and there are not two or more components to be shifted with respect to each other. Thus the phase shift of a sine waveform will *not be noticed* at all, unless the reference waveform also is on the scope screen when the phase-shifted waveform is displayed so the positions of the two can be compared. There is, however, a special method of using the scope to show phase shift. It is described in connection with Lissajous patterns.

The difficulty encountered in recognizing a shift in phase in a system processing such complex waveforms arises from the fact that other varieties of distortion also cause change of waveshape. Distinguishing one kind of distortion from the other then becomes somewhat confusing.

The change from a sine waveform to one which is nonsinusoidal, such as from Fig. 1-1 to Fig. 1-3 or 1-4 is "distortion," but this time it is the introduction of a harmonic, and it is known as "harmonic distortion." Distortion of this type is not limited to the addition of just one harmonic component, the creation of two or more harmonics and their addition to the original sine waveform is still identified in the same way. Now it is easy to recognize the change; the differences in outline of a nonsinusoidal wavform and the since waveform features described in Fig. 1-1 are easy to see. The nonsinusoidal waveform has the kinks, dips, flattened or pointed peaks, etc.—all of which are lacking in the sine waveform. More examples follow later.

It is important to mention that the complete contents of Fig. 1-3 and 1-4 should not be expected on a scope screen, unless the scope is very special. These illustrations show the construction of the resultant from two components; the usual scope will display the resultant waveform only. The reason for showing Fig. 1-3 and 1-4 was stated as being a demonstration of the frequency components. In addition, these figures display the effects of changes in phase relationship between the components of a composite waveform. These effects are not limited to two components; they occur when the composite wave consists of more than two components, and also when only one of several components is shifted in phase. Later on it will be shown that changes in *relative amplitudes* also influence the final waveform. These are more easily recognized than changes in phase.

Complex Waveforms

All waveforms which contain two or more frequency components are *complex* in character and are so identified. The resultants in Fig. 1-3 and 1-4 are examples of complex waveforms composed of the fundamental frequency component and second harmonic.

When applied to waveforms the word "complex" has extremely broad meaning. It embraces a great many different kinds of waveforms for it will be remembered that only one kind of waveform—the sine variation—consists of but one frequency component. The varieties of complex waveforms are so numerous that they have been classified in groups or families. Each of these has its own identification. Under the circumstances, we use the word "complex" only in a general sense. Wherever possible we apply a more definitive identification. As used here, the term "complex" refers to a waveform that is made up of a few frequency components. This is an arbitrary selection but one that is practical nevertheless.

Fundamental and Second Harmonic Waveforms

As mentioned earlier the resultants in Fig. 1-3 and 1-4 consisted of the fundamental frequency and the second harmonic. Additional examples are given in Fig. 1-5 and 1-6. They illustrate the effects of two variables—phase relationship and component amplitudes. In each case the second harmonic is shifted in phase and changed in amplitude. It is easy to see that each change creates an effect on the final composite waveform. Many of these waveforms, especially those that contain low amplitude second harmonic components will be encountered in electronic devices. These are the waveforms with 5% and 15% second harmonic, and with inphase relationships denoted as "0°" and opposite phase relationships as "180°".

In a sense all of these waveforms represent "distortion" of the sine waveform, but they are not shown here for that purpose. The discussion of distortion is held in abeyance until later on when the conditions *responsible* for distortion are discussed. At the moment these groups of waveforms are offered only as a means of creating familiarity with the features of nonsinusoidal waveforms consisting of these two components only. We have in mind the kinks, dips, bends, sharp peaks, tilts and rounded-off peaks which characterize these waveforms.

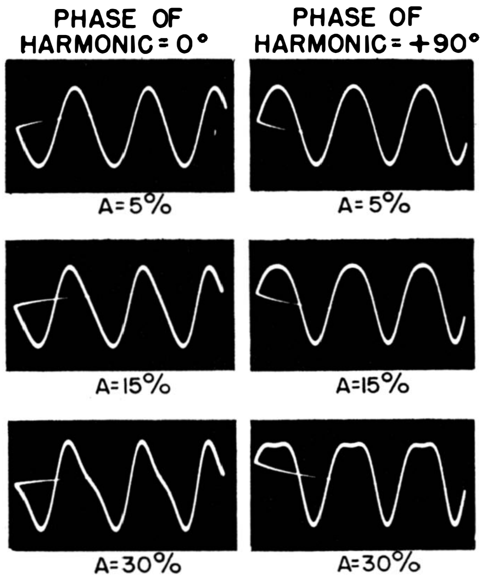

Fig. 1-5. Effect on fundamental sine waveform of addition of second harmonic in different amounts and 0° and +90° phases. *A* = per cent second harmonic.

Lack of Mirror Symmetry

Attention is called to a distinctive feature of waveforms composed of the fundamental and even-numbered harmonics. By even-numbered is meant the 2nd, 4th, 6th, 8th, 10th, etc., all odd-numbered harmonics beginning with the 3rd being absent. This feature is the *lack* of "mirror" symmetry. By mirror symmetry is meant that if either the positive or the negative alternation is "flopped over" so that both alternations are on the same side of the zero timebase line, they look alike. This does not occur when even-numbered harmonics are present in a waveform, as illustrated in Fig. 1-7.

Fundamental and Third Harmonic Waveforms

As the next step in the creation of familiarity with scope traces, Fig. 1-8 illustrates the construction of a composite waveform consisting of the *fundamental* and the *third* harmonic. The relative amplitudes are the same in all three cases; only the phase relationship has been changed. The process of combining the components so as to produce the resultant is algebraic as before. These waveforms comprise another group that is encountered in electronic equipments. Additional examples of these waveforms for still other phase relations and relative amplitudes are illustrated in Fig. 1-9. The waveforms in Fig. 1-8 are closely matched by some of those in Fig. 1-9.

An interesting characteristic can be noted by comparing Fig. 1-5 and 1-9. This is the more pronounced influence of the presence of the third harmonic of low amplitude as compared to the second harmonic of similar amplitude. When the fundamental and the third harmonic are in phase the amount of rounding-off of one of the peaks is very much more severe than when fundamental and the second harmonic are present. When the two components differ by 180 degrees, the resultant waveform containing the third harmonic is very *sharply peaked.* For +90 degree and −90 degree phase conditions, a pronounced *tilt* exists in the waveform. So while it is difficult to note the effects of low amplitude second harmonic, the same low amplitude third harmonic's effects are readily apparent.

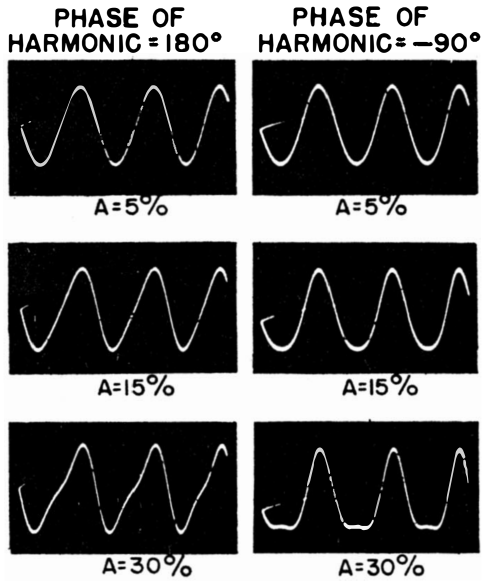

Fig. 1-6. Effect on fundamental sine waveform of addition of second harmonic in different amounts and 180° and −90° phases. A = per cent second harmonic.

Attention is called to the "flattened" positive and negative peaks when the third harmonic component approaches about 15% for the in-phase (0 degree) condition. One might say that this is the forerunner of the *square* waveform, and it is interesting to note that corresponding phase and amplitude conditions for the composite of the fundamental and second harmonic shows no such maximum amplitude plateaus.

Mirror Symmetry

The combination of the fundamental frequency and the third harmonic produces a waveform which has *mirror symmetry.* This can be seen in Fig. 1-9; if either the positive or negative alternation is "flopped over" the two alternations look alike. It is a characteristic of all waveforms which contain *only odd-numbered* harmonics, such as the 3rd, 5th, 7th, 9th, etc. in addition to the fundamental.

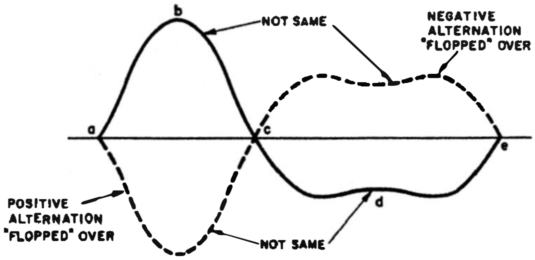

Fig. 1-7. Absence of "mirror" symmetry.

The Fundamental Plus the Second and the Third Harmonic

Another group of waveforms viewed as *distortions* of the sine variation are shown in Fig. 1-10. They consist of the fundamental frequency plus the *second* and the *third* harmonics. Those illustrated can be expected to appear on scope screens when defects exist in amplifying systems; also in detectors and generators. They are not offered here as keys to specific defects, because many different kinds of troubles will produce

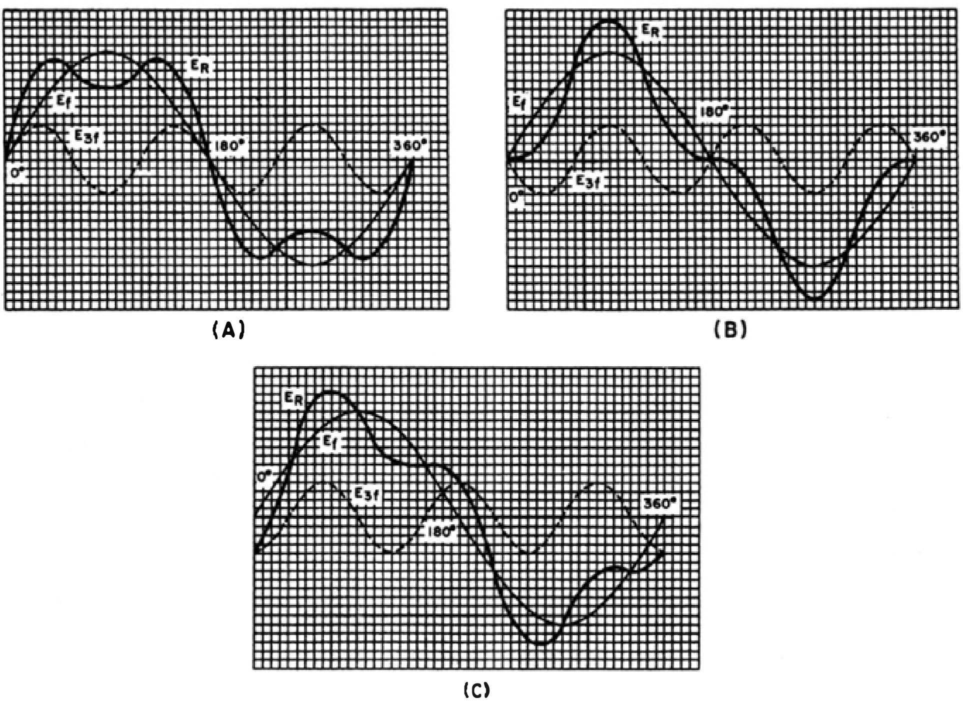

Fig. 1-8. Effect on sine waveform of addition of third harmonic (at amplitude = ⅓ of fundamental) at phases of (A) 0°, (B) 180°, and (C) 270°.

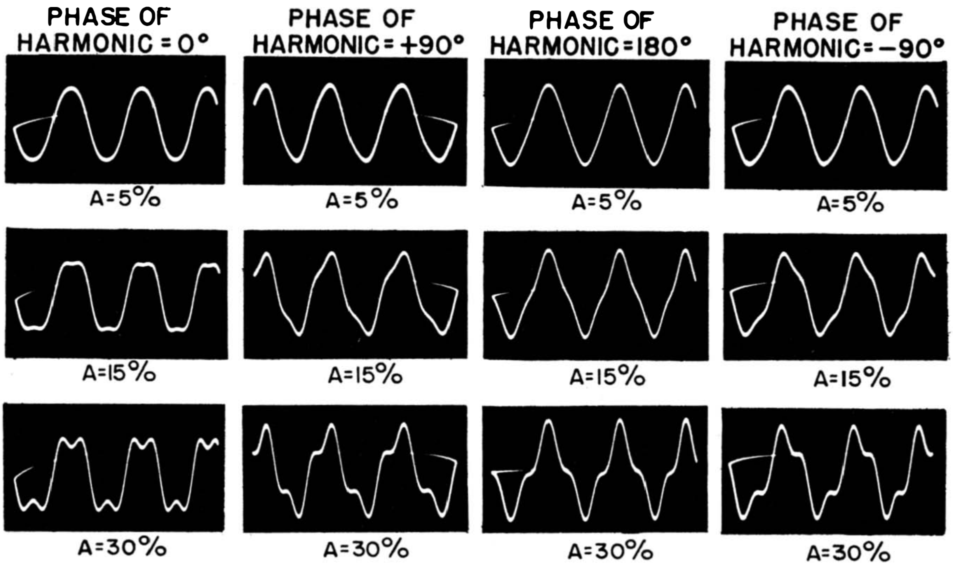

Fig. 1-9. Effect on sine waveform of third harmonic in different amounts and in four different phase relations. As before A = per cent harmonic.

similar waveforms. Improperly functioning vacuum tube circuits can modify a sine waveform input voltage to appear as one of those shown here. Explanations of such vacuum tube behavior appear later.

The Half-Sine Waveform

A variety of the sine waveform is the *half-sine* waveform. It is indicative of a voltage which consists of a series of unidirectional pulses, each of which resembles a half cycle of a sine waveform. The two versions of the half-sine waveform are shown in Fig. 1-11.

Functionally, the two examples of the half-sine waveform correspond to the output of a *half-wave* rectifier and a *full-wave* rectifier of ideal characteristics and while rectifying a sine waveform input voltage. By "ideal characteristics" is meant a linear rectifier and one which conducts only in one direction. This kind is typified by the *vacuum tube* diode. The voltage waveforms shown are those which appear across a non-inductive resistive load connected across the rectifier, and without any capacitance in the system.

Curve (A) is for the half-wave rectifier. Each cycle of input voltage appears in the output as a unidirectional half cycle with a corresponding interval of zero voltage between voltage pulses. The frequency composition of the output voltage waveform is a d-c component and the fundamental frequency and an infinite series of even-numbered harmonics of progressively decreasing amplitude. The half cycle of output voltage has a period equal to one-half of the input voltage cycle, but since it repeats itself once during each full cycle of input voltage, the fundamental frequency of the output waveform is the same as the frequency of the input voltage. Thus if the line frequency feeding a sine waveform voltage to a half-wave rectifier is 60 cps, the fundamental frequency of the output voltage is 60 cps.

The peak amplitude of each half cycle of output voltage is the same, and the time interval of the half cycle of output voltage is equal to that of the zero voltage interval.

In the case of the half-sine waveform for the full-wave rectifier shown as curve (B), the output voltage consists of a series of unidirectional pulses that follow each other without any zero voltage intervals between. In a properly balanced system each half cycle looks like the other; peak amplitude m equals peak amplitude n. The period of each half cycle is the same; period a equals period b, a' equals b', etc. Frequencywise the half-sine waveform for the full wave rectifier consists of a d-c component, a

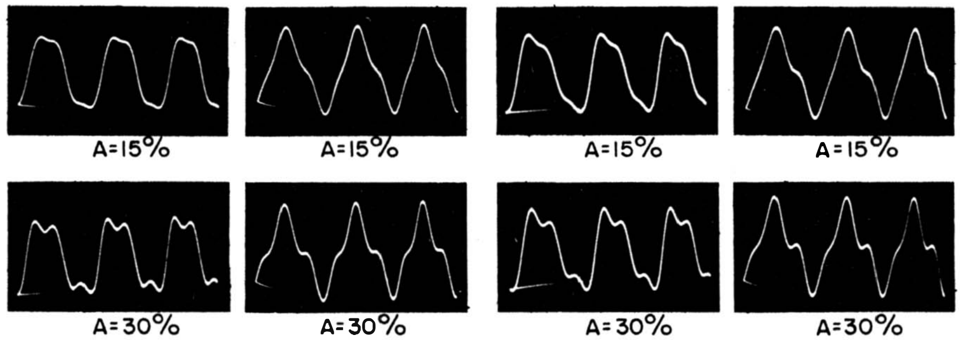

Fig. 1-10. Effect on sine waveform of addition of both second and third harmonics. In each case, either 5 or 15 per cent (as indicated) second harmonic at 0° phase is present. Then third harmonic is added in amount indicated as A and in phase indicated above each column.

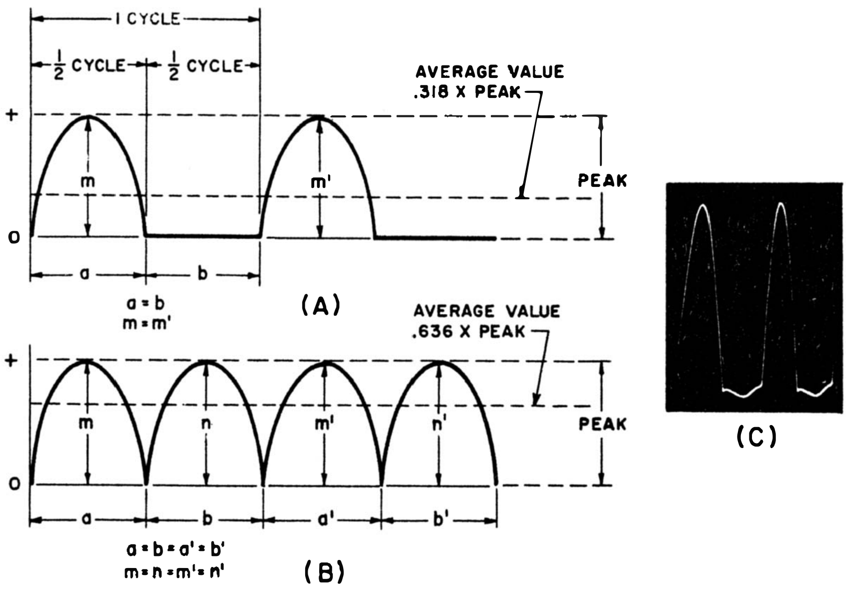

Fig. 1-11. Examples of half-sine waveforms resulting from rectification.

fundamental frequency component, and an infinite series of even-numbered harmonics of progressively decreasing amplitude. A unidirectional output pulse appears for each half cycle of the input voltage; the fundamental frequency of the output voltage is twice the input voltage frequency. In the most common case, the input voltage frequency is 60 cps and the fundamental frequency of the output unidirectional pulses is 120 cps.

The voltage of the half-sine waveform, from half-wave rectification has an average value of .318 times the peak value that resulting from full-wave rectification of the same variety of input voltage has an average value of .636 of the peak amplitude.

It is to be noted that the half-sine waveform is not the waveform of the ripple voltage encountered in conventional power supplies, unless the filters are removed. The action of the capacitors in these circuits modifies the waveform that exists across the output of the power supply.

It is of further interest to mention that metallic half-wave rectifiers do not produce half-sine waveform output voltages. The half-sine waveform appears during forward conduction in the rectifier, but a reverse current flows when the polarity of the voltage across the rectifier is negative. This waveform is shown in Fig. 1-11 (C). It is seen that the reverse current peak occurs concurrently with the peak of the input voltage. The high reverse resistance keeps conduction low during a substantial portion of the negative input voltage cycle. When full-wave rectification is used, the half-sine output waveform assumes the shape of Fig. 1-11 (B).

Chapter 2

THE SQUARE WAVEFORM

The Ideal Square Waveform

The *square* waveform illustrated in Fig. 2-1 occurs quite frequently in electronic equipment. It represents a *family* of waveforms but it is not considered basic because it can be broken down into a number of sine wave components. The application of a square waveform voltage to capacitance or inductance results in a *differently* shaped current variation and vice versa. It is only when the square waveform voltage is applied to a pure resistance that the current has the same square waveshape.

The square waveform voltage is one which rises abruptly from a zero value to a positive maximum, remains constant at that value for a time and then falls again to a negative maximum where it remains constant for the same time interval. This is illustrated in Fig. 2-1 (A) in idealized form. The square waveform voltage can fall through zero and alternate between positive and negative (a-c form) Fig. 2-1 (A). In another form it changes value but not polarity, the current or voltage remaining in one direction only from a reference level (pulsating d-c form) as shown in Fig. 2-1 (B) and (C). In (B) it rises from the reference level to a positive value, whereas in part (C) it increases from the reference level to a negative value. For a square waveform, the constant amplitude durations b and d must be alike.

The difference between parts (A) and parts (B) and (C) is that a d-c component is absent in (A), hence the voltage has positive and negative alternations. In part (B), the voltage has a positive d-c component which prevents it from swinging negative, and in part (C) it has a negative d-c component which keeps it from swinging positive. Thus (A) depicts an *alternating* current or voltage, while (B) and (C) depict *pulsating direct* current or voltage.

The features of the idealized square waveform are shown and labeled in Fig. 2-1 (A). The *rise* and *fall time* is assumed to be zero. The *leading* and *trailing* edges of the waveform are *perpendicular* to the zero time-

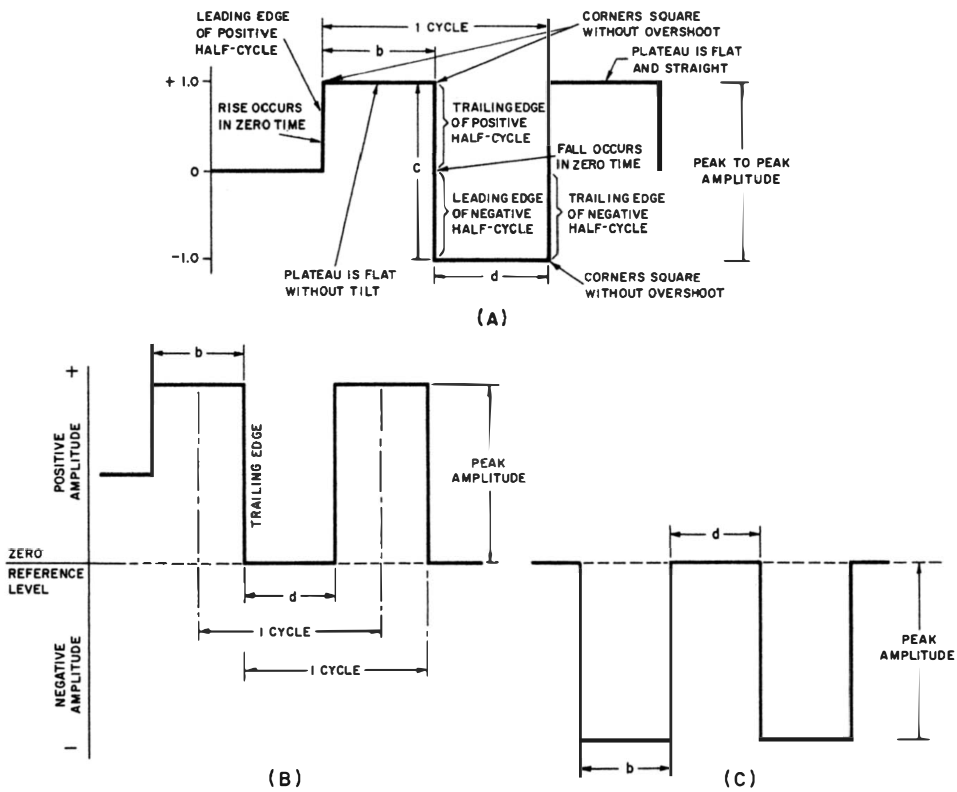

Fig. 2-1. A-c and unidirectional forms of the square wave.

base. It is seen that the alternating square waveform (A) has both positive and negative alternations; the *leading* edge is the side that rises from zero to maximum positive, and the *trailing* edge for the same alternation is the side that falls from the maximum positive plateau to zero; also that the negative alternation has its own leading and trailing edges, the former being the side that rises from zero to maximum negative, and the latter being the side that falls from maximum negative to zero. On the other hand, in the unidirectional voltages [(B) and (C) of the same figure] only one leading edge and one trailing edge appears in any complete cycle.

One of the features of an idealized square waveform is the fact that the maximum amplitude plateaus are *flat* without any *ripples, overshoots* or *oscillations* anywhere along their respective lengths. They are horizontal and parallel to the imaginary zero timebase, that is, they have no upward or downward *tilt*. The corners formed by the leading and trailing edges and the maximum amplitude plateaus are *sharp,* without any rounding off.

A cycle of any waveform is the largest portion of the continuing graph in which there is no repetition of variation pattern. A single cycle, taken at random, may start and end at any relative phase, so long as at the end of the cycle a complete repetition of the cycle again starts.

Thus, for example, a cycle of a square waveform may be bounded by either the midpoints of two like-polarity adjacent maximum-amplitude plateaus or by the leading edge of the positive alternation and the trailing edge of the next following negative alternation. These boundaries are shown in Fig. 2-1 (A). In the case of the unidirectional square waveforms, (B) and (C), the boundaries for the cycle are as shown. Of course a cycle could also be any section of the waveform bounded by any points one cyclic period apart.

The overall amplitude of the dual-alternation square waveform is expressed as the peak-to-peak amplitude, whereas the overall amplitude of the unilateral square waveform is expressed in terms of peak values because the reference level usually is zero amplitude.

Certain of the features of the ideal square waveform cannot be realizd in practice because generating equipment and scopes cannot be made perfect. For example, the zero rise and fall time cannot be achieved. While it is possible to attain very rapid rise and fall times, as short an interval as a small fraction of a microsecond, these times nevertheless must be finite. The practical rise time is the time elapsed for the voltage to rise from 10 percent of its maximum to 90 percent of its maximum value. The finite time required for the rise and fall of the voltage makes the leading and trailing edges tilt slightly. The longer the rise and fall time, the greater the amount of tilt. However, small amounts of tilt are not readily apparent in scope displays. Unless the tilt is substantial, the waveform seen on the test scope screen *appears* to have perpendicular sides. To see the tilt in the sides it is necessary to spread the trace horizontally. In fact the sides cannot always be seen; sometimes the rise and fall time is so short (for frequencies greater than a few kilocycles) that the rapidly-moving electron beam does not excite the scope screen material sufficiently to produce discernible glow.

The square corners are fairly well realized in practice, although there is usually some discernible rounding. Reasonable *flatness* of the maximum amplitude plateaus is also obtainable, although a definite tilt in the plateau will frequently be noticeable. The meanings of such deviations from ideal waveforms differ according to individual circumstances, as explained later in this chapter and in greater detail further along in the book.

Frequency Composition of Square Waveform

The frequency composition of the square waveform is shown in Fig. 2-2. It consists of a component of fundamental frequency (sometimes re-

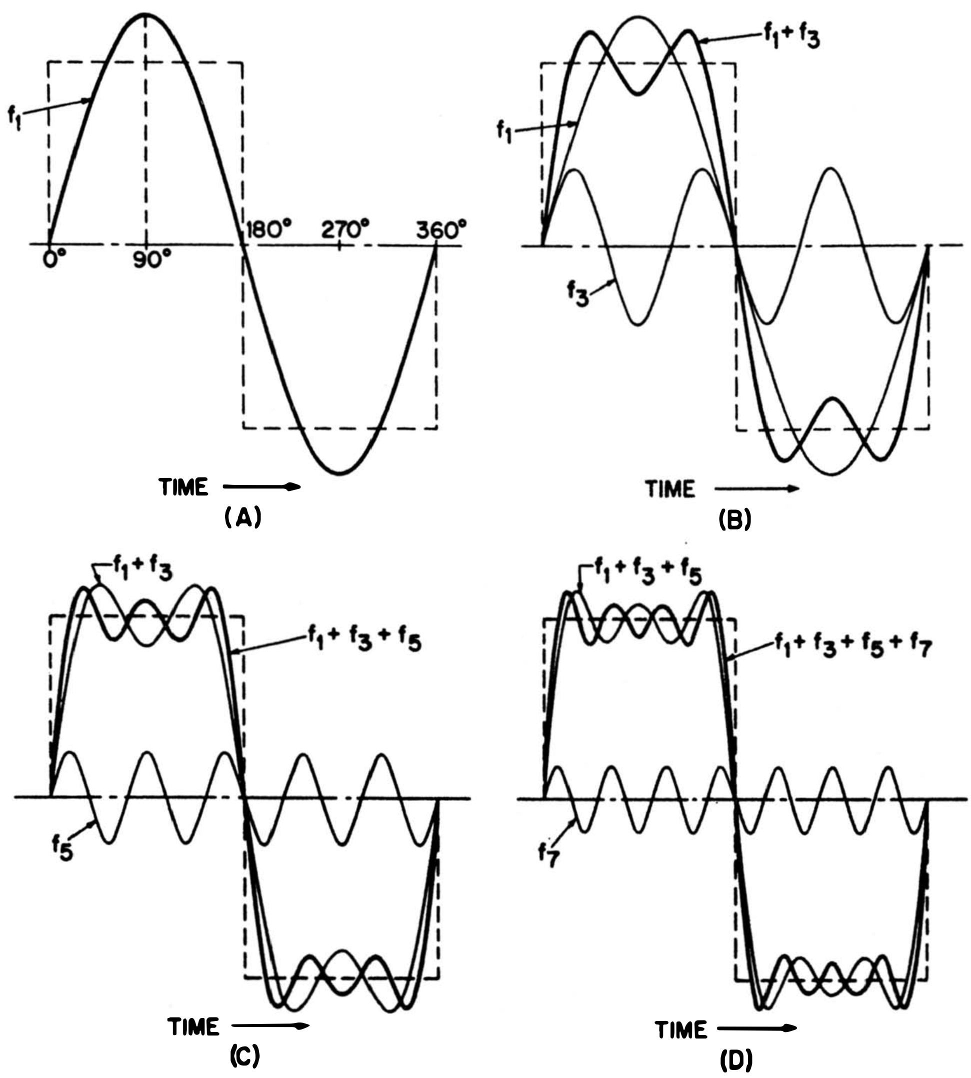

Fig. 2-2. Oscillograms showing the gradual change in waveform to a square wave as 3rd, 5th, and 7th harmonics are added to a sine waveform fundamental.

ferred to as the first harmonic) and an infinite number of *odd* harmonics of the fundamental frequency. Although only three odd harmonics of f are illustrated, these being f_3, f_5 and f_7, it is readily apparent that as the harmonics are added, the resultant waveform approaches the square waveform more and more. Given a sufficient number of *odd* harmonics, the ripples become *smaller and smaller* in amplitude, and the sides become *steeper and steeper*. (It is to be noted that *even-numbered* harmonics are not present in the square waveform.) As few as 10 odd numbered harmonics will produce a reasonable version of a square waveform, although it is better to have more frequency components present, say 100 odd harmonics. Oscillograms corresponding to the conditions shown graphically in Fig. 2-2 appear in Fig. 2-3.

The frequency f of any order odd harmonic can be developed from the equation

$$f_n = (2n + 1) \times f_1$$

where f_1 is the fundamental frequency
n is the order of the harmonic

For instance, if it is said that the presence of 100 odd numbered harmonics results in the development of a good version of a square waveform, and the voltage in question has a fundamental frequency of 1000 cps, the bandwidth required to accommodate harmonics up to the 100th odd, would extend from 1000 cps to f_n. The frequency of f_n for this fundamental is

$$f_n = [(2 \times 100) + 1] \times 1000$$
$$f_n = 201 \times 1000$$
$$f_n = 201{,}000 \text{ cps}$$

It follows from the above that for amplification of a square wave voltage without waveform change we must use an amplifier which has a frequency response including both the fundamental frequency and the frequency of the highest important harmonic. Thus in the above example, the amplifier must have a reasonably uniform response from 1000 cps to 201,000 cps.

Moreover, the response curve must not fall off rapidly at these limits, because such an abrupt drop interferes with phase response of the various frequency components. Most amplifiers of this range have somewhat gradual dropoff at the ends of the response range, so this is not a problem; however, if the dropoff in response is sharp, the response must be substantially greater than the range of frequency components to be amplified. For the example above, there should still be substantial response at as low as 100 cps and at least as high as 250,000 cps, to prevent poor output waveform due to phase distortion.

Using Fig. 2-2 as the reference, several important additional points must be mentioned. First, it is seen that the fundamental frequency and

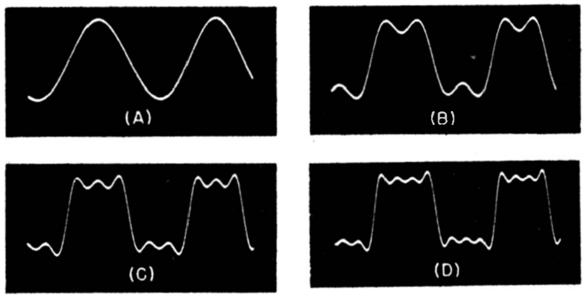

Fig. 2-3. Oscillograms corresponding to graphic illustration in Fig. 2-2.

the harmonic components are all in phase. This applies also to higher harmonics included in an ideal square wave voltage, but not shown in Fig. 2-2. Also notice that the amplitude of each successive harmonic *decreases* as the order of the harmonic increases, the decrease being proportional to the increase in order from one harmonic to the next. Thus the 3rd harmonic has an amplitude equal to 1/3 of the fundamental; the 5th harmonic has an amplitude equal to 1/5 of the fundamental; the 7th harmonic has an amplitude equal to 1/7 of the fundamental, and so on. This is not a chance relation, but one definitely and exactly determined by mathematical analysis.

A second important point to notice in Fig. 2-2 is that the phase of the frequency components is *fixed;* i.e., all frequency components are in phase with each other.

At this point one is apt to ask several questions. What happens if all the required frequency components are not present? . . . Or if the relative amplitudes are not correct? . . . Or if the original phase conditions are not retained? The introduction of any one of these deficiencies by a system that is processing a square waveform input will "distort" the waveform. Even more important, it will *distort* it in a particular manner. It will give the output waveform certain features that tend to indicate the kind of trouble present in the system doing the processing!

Square waveform voltages are not produced by generating a fundamental frequency and adding harmonics to it. Instead a waveform such as that of a sinusoidally varying voltage is clipped, or deliberately distorted by tube overloading. Having been thus produced, the square waveform voltage is then passed into a system for whatever functions or tests are required. The circuit of such a system must display certain capabilities frequency-wise and time-delay-wise if it is to pass this shaped voltage properly.

Proper transfer of a square waveform voltage through an amplifier requires that the amplifier pass a wide band of frequencies, amplify all frequency components substantially equally, and retain the proper fixed phase relationship between the components of the input voltage. The low frequency limit of the required passband is determined by the fundamental frequency of the voltage. The low limit of the passband should not be higher than one-fourth the fundamental frequency for reasons previously explained. The upper frequency limit of the passband is set by the frequency of the highest order harmonic necessary to provide an acceptable version of the square waveform. As previously explained, some extra response range is also required to prevent phase distortion due to sharp response dropoff.

If these requirements are not satisfied, the output voltage waveform will not be the same as the input voltage waveform. In essence the voltage will be "distorted." The conditions capable of causing distortion are numerous and they affect waveforms in various ways. Such conditions are discussed in detail in the next chapter.

The Practical Square Waveform

A "practical" square waveform is an ideal square waveform modified to take into account unavoidable differences from perfection in the generating, and indicating (scope) circuits. In other words, the waveform obtainable by connecting the square wave generator directly to the scope, without the tested equipment between, is the practical square waveform. Will the observed waveform be like the ideal in Fig. 2-1? The answer is in the affirmative within certain limits. First, we must assume that the *input* waveform is like the *ideal*. Second, we must set some arbitrary limits on the frequency passband of the scope which is being used. Since we are concerned with practical cases, that is, average cases, we shall assume that the low frequency limit of the vertical amplifier in the scope is between 20 and 30 cps. The high limit is between 500 kc and 1 or 2 mc.

With these scope constants as the premise, a cross-section of experience has shown that a *good* approach to the ideal will be achieved when the fundamental frequency of the square waveform is not below 100 cps and is not higher than 5 kc. An example of a 200-cps square wave observed under such conditions is shown as (A) in Fig. 2-4. Virtually all of the features of the ideal waveform are preserved. A variation appears in (B), which differs from (A) by the tiny "pip" at the junction between the leading edges and the maximum amplitude plateau. The pip is due to overcompensation of the high frequencies in the vertical amplifier of the scope. If the fundamental frequency is too low for the low frequency limit of the scope, traces like (C) and (D) are to be expected. The lower the fundamental frequency, the greater the tilt in the plateaus. Traces (C) and (D) can be expected if the low frequency limit of the scope vertical amplifier is higher than about one-fourth of the fundamental frequency of the square waveform.

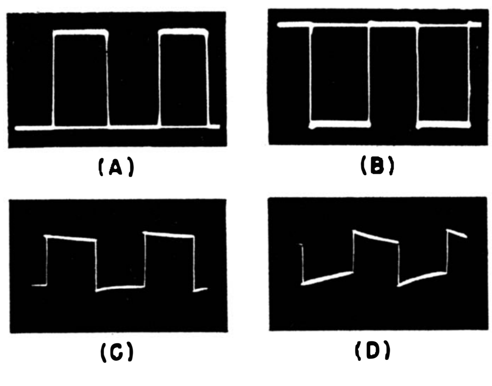

Fig. 2-4 (A) A 200-cps square wave showing good response. (B) Same wave showing overcompensation of high frequencies (C) and (D) Result of use of a scope with insufficient low frequency response.

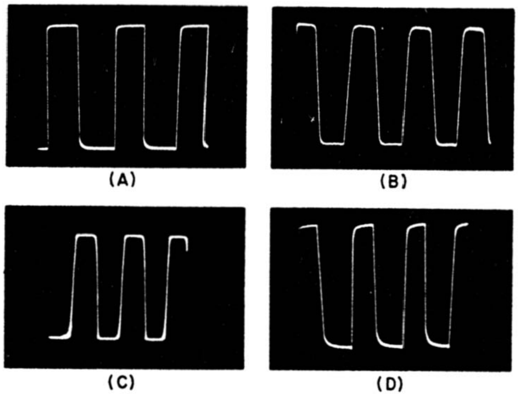

Fig. 2-5. Examples of square waves indicating insufficient high frequency response.

Working upwards in fundamental frequency, the observed *practical* square waveform will begin losing some of its *ideal* features, because raising the fundamental frequency raises the highest harmonics, pushing the latter beyond the range of the equipment and/or the scope. Examples (A) and (B) in Fig. 2-5 are for frequencies above 5 kc. The junction of the leading edges and the maximum amplitude plateaus now is rounded instead of being square. The rounding off is due to some loss of high frequency components. Conditions contributing to this behavior in equipment are discussed in a later chapter. It might be well to mention that examples of reference waveforms given in service data and elsewhere as criteria are not always the *ideal* versions—more often than not they resemble the practical case. As practical cases, these waveforms are just as completely acceptable as the ideal versions.

Two more practical versions of square waveforms are shown in (C) and (D) in Fig. 2-5. A definite tilt is seen in the sides of the waveform in (C). Many of the tests that can be developed with the ideal waveform can be achieved with waveform (C) even though it is not perfect. The example shown is an example of a 15-kc voltage derived from squaring a sine waveform voltage. The rise time is relatively low, but it is usable waveform for all but very critical applications. Waveform (D) is a typical practical square waveform voltage such as may be encountered in a wide variety of electronic equipments. It has a frequency of 15 kc and has suffered more than a small amount of high frequency attenuation. Also the positive and negative alternations are unequal in duration. The latter feature frequently originates in the equipment that produced the voltage originally; whether or not it interferes with the utility of the voltage is determined by the requirements of the equipment being tested. Nevertheless, it is a sample of a practical version of a square waveform.

The reasons underlying the differences between the features of the ideal square waveform and those of the practical waveform are explained in a later chapter, which also explains the means used to achieve a good version of a square waveform by control of its frequency components.

Chapter 3

RECTANGULAR WAVEFORMS

A rectangular waveform has all the features of a square waveform already described, except that the *durations* of the two main parts of the cycle are *unlike*. Identifying features of the idealized rectangular waveform appear in Fig. 3-1.

In (A) the pulse is bidirectional; it has a positive and a negative alternation. Here it is the fact that the negative maximum plateau lasts longer than the positive maximum plateau which distinguishes this wave from an a-c *square wave*. In (B) and (C) the waveforms are unidirectional. In (B) the amplitude rises to a maximum positive value, but never goes negative; in (C) it rises to a maximum negative value and never goes positive. In both (B) and (C), the amount of time the amplitude has its definite (maximum) value is less than the amount of time during which the amplitude is zero. Although duration *b* is shown here less than duration *c*, the situation could be the reverse with *b* greater than *c*. However, in order that the waveform be in the rectangular family, the two intervals must be *different*. If they are *equal*, the waveform is *square*.

The period of a rectangular waveform cycle is considered to be the time elapsed between the midpoints of two adjacent pulses as shown in Fig. 3-1 (A). If for the sake of explanation we assume *b* (and thus also *e*) equal to 100 microseconds, and *c* equal to 500 microseconds, then $b/2 + e/2 + c$ equals 600 microseconds, or 0.0006 second. This makes the frequency 1/0.0006 or 1667 cps in round numbers. The same answer is arrived at if the cycle is considered as the time elapsed between the leading edges of two adjacent pulses, or the time between any two corresponding points respectively located on two successive cycles.

As to the frequency composition of rectangular pulses it is considered that the waveform is made up of a rectangular pulse of duration *b* which *repeats* itself at fixed intervals equal to the period of the cycle, in this case 600 microseconds. This corresponds to a frequency of 1667 cps, which is called the *repetition frequency*. The frequency content of the waveform consists of an infinite series of harmonics of the repetition

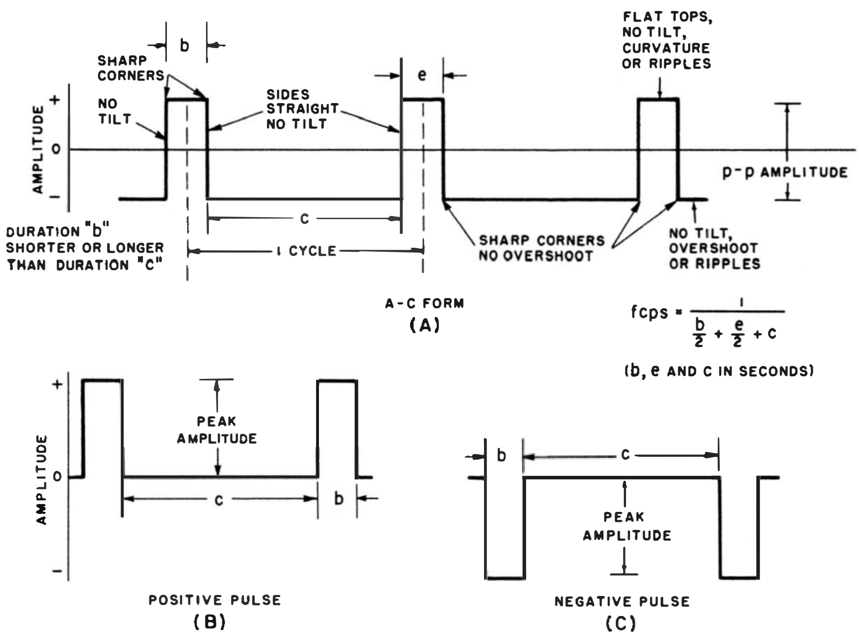

Fig. 3-1. Basic forms of the rectangular wave.

frequency, and the upper limit of the frequency band necessary to reproduce the pulse properly is determined by the reciprocal of the duration period b seconds or $1/b$ cycles per second (cps). A reasonable version of the pulse can be produced by between 10 and 20 harmonics of 1/b second. If $b = 5$ microseconds, $1/b = 200{,}000$ cps and the top frequency necessary for reproduction is from 2 to 4 mc.

The practical interpretation of the frequency content of the rectangular waveform is very much less complex than its description. For instance, the high frequency components are responsible for the steepness of the sides of the pulse. The shorter the duration of the pulse, the more rapidly must it rise to its maximum, hence the higher the frequency components which must be present. The longer the duration of the pulse, the narrower can be the passband of the circuit that is going to process the voltage, but the lower must be the low frequency limit. The lower portion of the frequency spectrum determines how nearly horizontal and straight are the constant amplitude regions b, c, and e of the pulse.

When the pulse has a d-c component as in (B) and (C) of Fig. 3-1 the amplifier must pass zero frequency or d-c, unless provision is made to restore the d-c component at some point after application.

Although the rectangular waveform voltage seldom is used as a test voltage, its features are capable of indicating operating conditions in the system that is processing the voltage. In this respect it behaves like the square waveform. Examples of deteriorated waveshapes, both rectangular and square, are discussed in a later chapter. The desired features of rectangular waveforms are illustrated by the waveshapes and the notes in Fig. 3-1 (A).

Practical Rectangular Pulses

As in the case of the square waveform, a rectangular waveform may be perfectly acceptable even though it lacks some of the ideal features. The degree of perfection required varies for different conditions of use. Accepted methods of display sometimes are shy of the capabilities necessary to reproduce the rectangular pulse properly. In such a case a less-than-ideal version may be given as the reference waveform for guidance. This is done to minimize confusion between test equipment characteristics and distortion added by the tested equipment. Examples of practical rectangular waveforms appear in Fig. 3-2.

For instance waveform (E) in Fig. 3-2 is a far cry from a rectangular pulse which can be viewed as being acceptable, yet it is a reference waveform for an agc (automatic gain control) pulse generated in a television receiver. The pulse originates in a winding on the horizontal output transformer, hence the transients present in this system appear on this pulse too. They have no effect however, because a filter circuit removes the transients before the voltage is applied. The filter circuit effects are not seen in this waveform because its location in the circuit was after the point of observation.

Rectangular Pulses on Top of Pulses

A variety of the rectangular pulse family is the formation featuring the coexistence of two rectangular pulses, one atop the other. This forma-

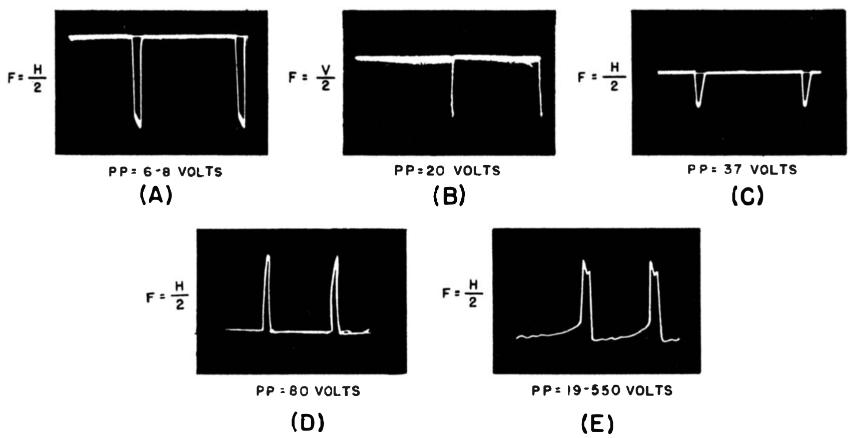

Fig. 3-2. Practical rectangular waveforms.

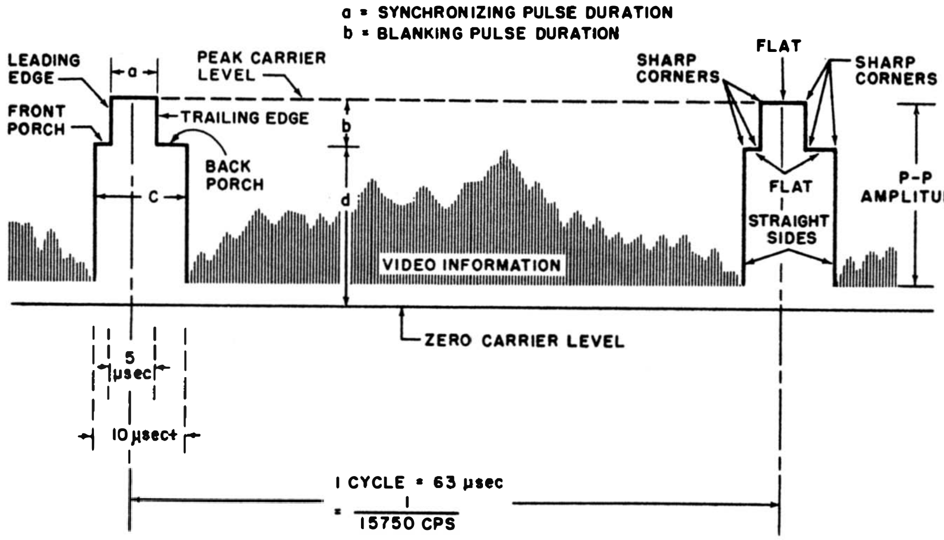

Fig. 3-3. Parts, proportions, and ideal features of rectangular wave used for tv sync.

tion appears in Fig. 3-3 and typifies a technique used in television transmission and reception.

In Fig. 3-3, the blanking pulse *c* is the lower one and furnishes the *pedestal* for the shorter duration horizontal synchronizing pulse *a*. Thus the shorter duration pulse is riding atop the longer duration pulse. The two pulses originate as two separate voltages in the transmitter, then they are combined and transmitted as amplitude modulation of a carrier. After demodulation at the receiver, the longer duration pulse sets a base voltage level *d* at which level it accomplishes electron beam blanking in the picture tube. Shortly after the initiation of the blanking action, the pulse voltage rises to a new level, that represented by the increase *b*, at which level it remains for duration *a*. Then it falls again to the original blanking level, where it remains for a fixed period. Since the blanking is already complete at level *d*, the increase in voltage during the synchronizing period has no further effect on the blanking action.

The form of this changing voltage is like that of the ordinary rectangular pulse, except for the *step* in the peak amplitude level. The duration of the pulse *c* is slightly more than 10 microseconds, whereas the interval between the end of this pulse *c* and the beginning of the next blanking pulse *c′* is about 53 microseconds. It is during this latter period that the video (picture) signal is transmitted. The period of the cycle is about 63 microseconds, equivalent to a pulse repetition rate or frequency of 15,750 cps. The duration *a* of the horizontal synchronizing pulse is slightly more than 5 microseconds. As far as frequency content is concerned, the pulses are formed of the harmonics of the 15,750 cps *repetition* frequency, but the highest frequency requirements are set by the *short duration* synchronizing pulse.

The appearance of the waveform in Fig. 3-3 is the ideal. Seldom except under the most favorable conditions of observation (with laboratory type scopes with adequate vertical amplifier passband) does the voltage take on this ideal outline. Usually the corners are rounded off and the constant amplitude plateaus are tilted. Such "distortion" does not necessarily indicate trouble. Frequently such deviations from the ideal are found in suggested reference waveforms. This does not necessarily mean that the outline shown is the true one in the receiver. More often than not observation is to be made with a service scope of limited passband, and deterioration of the outline due to limitation of scope, rather than the receiver, is responsible.

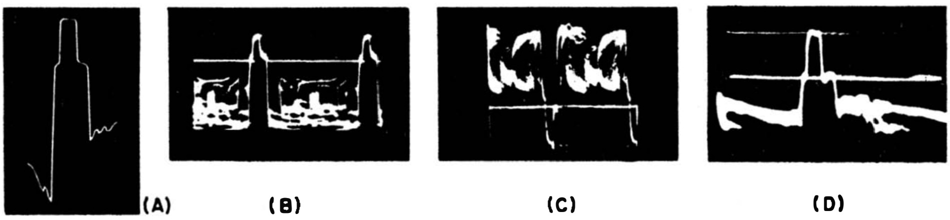

Fig. 3-4. Sync and blanking pulse waveforms in tv receivers.

Typical of what we are speaking about are the waveforms illustrated in Fig. 3-4. In (A) is shown an example of the pulse as transmitted. Examples (B) and (C) are two typical reference waveforms as encountered in *properly-functioning* receivers. They are *practical* versions. A more easily recognizable example is shown as trace (D). A point of interest in these television receiver pulses is that the normal height of the synchronizing pulse (amplitude *b* in Fig. 3-3) is approximately one-third the pedestal height (amplitude *d* in Fig. 3-3) above the zero carrier level. This point should be remembered because it is referred to in a later chapter in connection with one form of distortion of this dual pulse. The aforementioned amplitude relationship is evident in waveforms (B) and (C) of Fig. 3-4. The general information sought in such waveforms is obtainable from (B) and (C) even if the ideal features of the rectangular pulses are not evident. The peak-to-peak amplitude is measurable, as is the amplitude of the blanking pulse, and the synchronizing pulse. Examples of badly deteriorated pulses of this kind—sometimes indicative of distortion and trouble, and in other cases simply examples of reference patterns made under adverse conditions—are given later in this book.

Chapter 4

SAWTOOTH AND TRAPEZOIDAL WAVEFORMS

The Sawtooth Waveform

The sawtooth waveform has the shape shown in Fig. 4-1. The cycle consists of a *gradual* change in amplitude from a peak value of one polarity to a peak value of the opposite polarity, then a very rapid change in voltage back again to the original peak value of the first polarity. From this point on, the cycle of amplitude and polarity changes is repeated. The shape of the voltage graph resembles the teeth of a saw, hence its name.

Like all other nonsinusoidal types, the sawtooth waveform is complex in composition. If such a voltage is applied to a circuit consisting of inductance and resistance, or capacitance and resistance, the resultant current will not have the shape of the applied voltage. It is only when the sawtooth voltage is applied to a pure resistance that the resultant current has the same shape. Because it contains numerous basic sine-wave frequency components, the sawtooth waveform is not itself basic, although it does represent a *family* of waveforms.

The waveform in Fig. 4-1 (A) typifies the *ideal* state. The *rising* portion *a-b* of the cycle is a *straight line* without any *curvature* or *kinks.* Because the gradual rise in voltage takes place in the positive direction, that is, from peak negative to peak positive, it is known as *positive going.* Based on the manner in which these voltages (and currents) are generally used, the rising portion is generally referred to as the *forward trace* or simply *trace* portion. The remainder of the cycle—that part which changes very rapidly from the positive peak value to the negative peak value—is known by a variety of names. These are *return, retrace,* or *flyback.* In this book it is referred to as the *retrace.*

In the ideal example, the retrace portion of the sawtooth cycle is completed in *zero time.* Zero retrace time is impossible of accomplishment, although very rapid retrace is easily attained. As to the trace portion, it is shown as a straight line, therefore representing a *linear* change

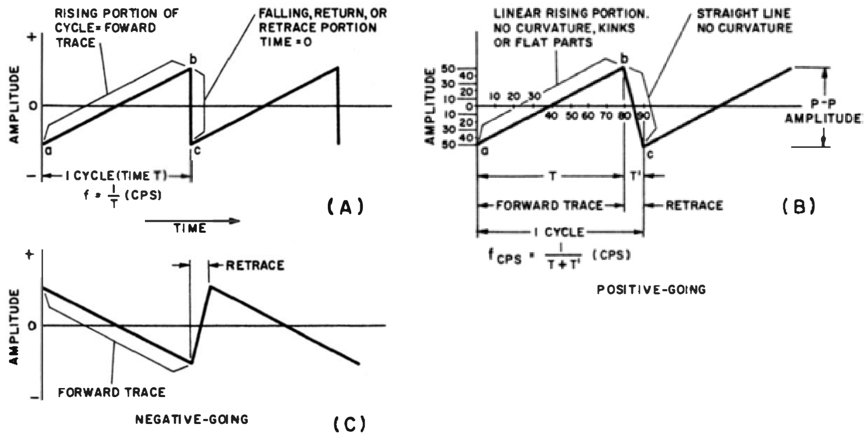

Fig. 4-1. Features of ideal sawtooth waveforms.

in voltage. This is achieved without too much difficulty, although the main problems associated with sawtooth waveforms arise from non-linearity of this part of the cycle.

Another variation of the sawtooth waveform is the *negative-going* type. In this case the slow change is from the positive peak to the negative peak, and the rapid change or return trace is from the negative peak to the positive peak. This is the equivalent of a flop-over of the trace and retrace portions of Fig. 4-1 (B) and is shown in Fig. 4-1 (C).

The Practical Sawtoth Waveform

The practical sawtooth waveform is shown in Fig. 4-1(B). It differs from the ideal in that the *retrace* portion of the cycle is completed in a *finite* amount of time. This produces a tilt in the retrace portion. The relative time intervals associated with the trace and retrace parts of the cycle are set by the design of the equipment which produces the sawtooth waveform, and by the needs of the equipment which uses it. As a rule the retrace part of the cycle occupies from a few per cent to perhaps 15 per cent of the total time of the cycle. An example is a sawtooth voltage of 60 cycles (16,666 microseconds) wherein the forward trace time is 16,000 microseconds and the retrace time is 666 microseconds. The retrace time therefore amounts to about 3.6 per cent of the time for the entire cycle, and about 4.1 per cent of the time of the forward trace.

The meaning of *linear sawtooth* is illustrated in Fig. 4-1 (B). It refers principally to the manner in which the voltage changes during the forward trace. If the change occurs at a *constant rate,* that is, the amount of change per *unit* time is the same throughout the forward trace, this portion of the waveform is *linear*. This is seen in (B) by the absence of any *curvature,* kinks, bends, or flattened sections in the trace part of the cycle. It is a straight line. The same is true of the retrace. The meaning of *constant rate* can be gathered from Fig. 4-1 (B) by correlating the voltage changes, the waveform and the time divisions marked off on the timebase line. Constancy of the slope, or tilt of the trace portion indicates constant voltage or current rise and linearity of the trace.

It is seen that the highest values or *peak amplitudes* of the voltage are 50 volts positive and 50 volts negative. Thus the total swing or *peak-to-peak* voltage is 100 volts. (Peak-to-peak voltage measurements on sawtooth waveforms are made in exactly the same manner as for any other waveform, assuming of course that the measuring device accepts this waveform.)

The *timebase line* is graduated in units of 10-microsecond intervals (Fig. 4-1(B)), an arbitrary choice for illustration purposes. It can be seen that the time lapse for the completion of the forward trace *a-b* is 80 microseconds, and for the retrace *b-c* it is 10 microseconds. In both instances the total swing in voltage is 100 volts, hence the *rate of change* for the trace portion is 100/80 or 1.25 volts per microsecond, and for the retrace it is 100/10 or 10 volts per microsecond. Simple arithmetical determination of the change in voltage per microsecond is possible only because the two portions of the waveform being considered are *straight* lines. If they were curved at any point along their lengths, the change in voltage would be *constant over the straight portions only,* and would vary over the curved parts. Such waveforms would be described by saying that they are *nonlinear sawtooths.* However, functional considerations determine the final decision as to whether a *nonlinear sawtooth is, or is not, usable.* Examples of such waveforms appear later, but it might be said here that when a substantial section of the trace portion of the sawtooth waveform has curvature, its usefulness is very limited, if not completely destroyed.

Because the voltage depicted has a change in value at a constant rate, the sawtooth waveform voltage is commonly used as the timebase deflection in test scopes. Also, sawtooth waveform current is used in television horizontal deflection windings.

Reference to Fig. 4-1 discloses that the sawtooth waveform has a negative and a positive peak value, and that it advances through zero. This is not normally evident when a sawtooth waveform is displayed on a scope screen because the timebase line usually is absent from the display. This in no way limits the interpretation of what is seen because the *appearance* of the waveform is sufficient to show if it is linear or nonlinear. Determination of the amount of nonlinearity seldom is necessary because the correction of a situation responsible for nonlinearity is qualitative rather than quantitative.

Frequency Composition of the Sawtooth Waveform

The frequency composition of a sawtooth waveform is not as important to interpretation in maintenance work and in waveform study as in the case of the square waveform. Many conditions of nonlinearity stem from the way in which the equipment that is processing the sawtooth waveform treats the component frequencies, but correction can be made on the basis of frequency composition as is discussed in a later chapter. Normal procedure is recognition of the display, comparison with the reference waveform, then correction of abnormal conditions until the waveform is that indicated by the reference. Both *even*-numbered and *odd*-numbered harmonics are present in the sawtooth waveform. Like the square waveform, the perfect shape is achieved when the number of harmonics is infinite. Starting with the fundamental frequency sine waveform voltage (or current) the change in waveform as harmonics are added is shown in Fig. 4-2. The reference f_1 means the fundamental frequency or first harmonic. A *positive-going* sawtooth waveform is illustrated. It can be seen that all components are in phase and starting in the *negative* direction. (Some equations of the sawtooth waveform establish the signs

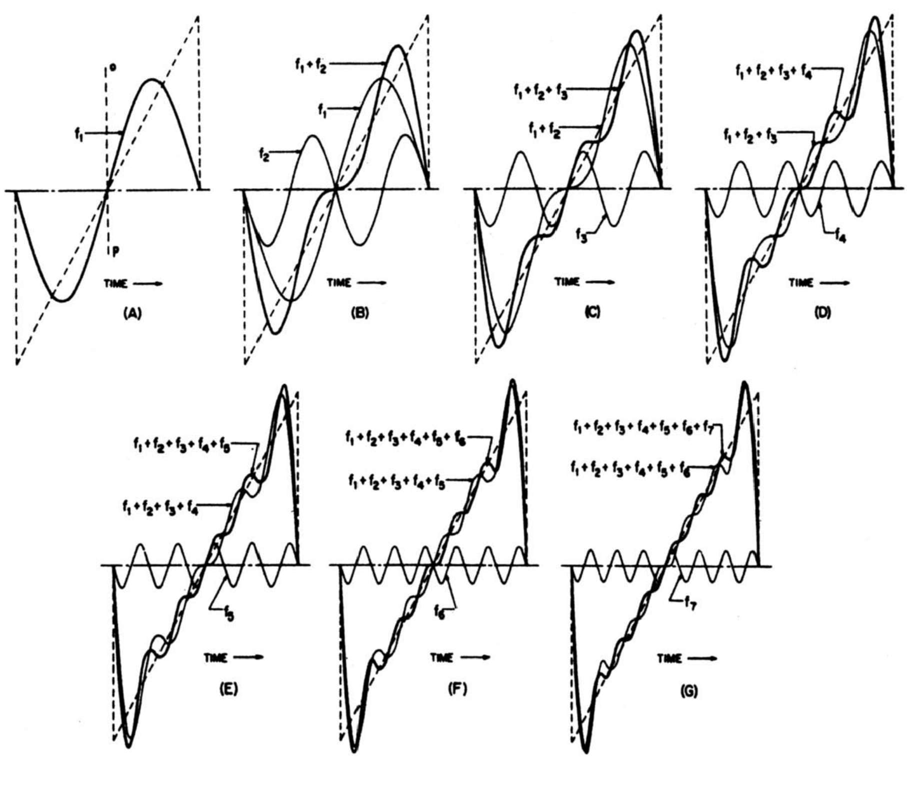

Fig. 4-2. Addition of frequency components to form sawtooth resultant.

of the components as alternating. This occurs if the starting reference phase is at the line *o-p* in Fig. 4-2(A).)

Only seven consecutive harmonics are illustrated but it is evident that the addition of higher and higher order harmonics removes more and more of the ripple in the rising portion of the cycle and steepens the retrace portion. The ideal is illustrated by the dotted line outline which appears in each part of Fig. 4-2. Each harmonic bears a definite predetermined amplitude and phase relation to the fundamental (f_1).

Typical Practical Sawtooth Waveforms

Some sawtooth waveforms typical of those encountered in properly-functioning electronic devices appear in Fig. 4-3. Traces in (A) and (B) typify sweep voltages used in test scopes, and other electrostatic cathode-ray tube deflection systems. Of these two waveforms, that in (A) is very close to the ideal case; the trace is linear throughout. Waveform (B) on the other hand, has a non-linear retrace portion, and a retrace time that is substantially longer than in (A). (A) is the type of waveform usually obtained at low scope sweep frequencies, say, from about 10 cps to 1000 cps in the average run of test scopes, and up to very much higher frequencies in the laboratory type scopes. Waveshape (B) is more representative of the display of the higher frequency voltages in the maintenance type of scope.

The disadvantages of the *nonlinear retrace* are not too great in the average run of applications, hence a sawtooth waveform of this kind is acceptable. There is no denying that a linear waveform throughout is preferable, but since the retrace portion is not usually active in any important way depending upon linearity, some nonlinearity is allowable. If the retrace is *blanked,* (sometimes the cathode-ray tube beam is cut off during retrace) nonlinearity during retrace means even less, provided that the forward trace is linear. Frequently, extreme settings of the positioning controls in test scopes affect the linearity of the sawtooth retrace.

Waveform (C) is an acceptable version of a sawtooth-shaped sweep *current* such as may be found in television receiver deflection coils. In this case, the waveform shown is that depicting the sweep current in the horizontal deflection winding. Waveform (D) is the sawtooth output of a

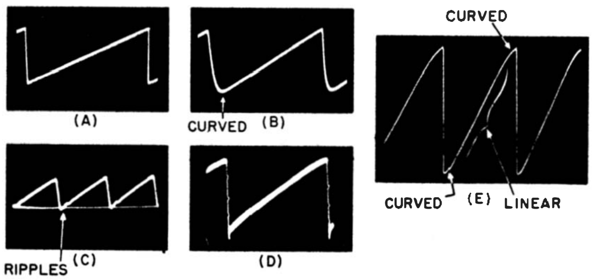

Fig. 4-3. Typical practical sawtooth waveforms.

blocking oscillator in a television receiver. Both are well-formed waveforms. A *small amount* of transient oscillation is seen at the start of the forward trace. (Bad cases of transients in these coils are discussed later.) While it would be much better if the trace were clean throughout, the effects of the transient at the start of the forward trace may not even be visible in the tv picture, first, because blanking exists for a short period before the start and after the completion of the retrace, second, because this region of the picture usually is behind the mask.

Another example of a sawtooth sweep current in a properly-functioning *vertical* deflection winding of a television receiver is shown as (D) in Fig. 4-3. This waveform is not wholly in accord with the ideal shape in Fig. 4-1 (B), but it is typical of *acceptable* versions. A slight amount of nonlinearity exists throughout the forward trace portion (the downward sweep in the picture tube). A critical examination of test pattern may show up its existence, but it would never be noted in the display of a televised scene. The nonlinearity is accentuated by the horizontal spreading of the trace on the test scope screen. More about such nonlinearity later.

A final example of an acceptable version of a nonlinear sawtooth voltage is the waveform shown as (E) in Fig. 4-3. Here a certain amount of curvature exists at the *start* and at the *end* of the forward trace but it is linear between. This waveform may not be satisfactory for critical uses, such as calibration or linear measurement along the horizontal dimension of a trace, but it is entirely satisfactory as a sweep voltage for the display of three or four cycles of a quantity. The small amount of expansion caused at one end of the trace and compression at the other end will not interfere with examination around the midpoint of the display.

Trapezoidal Waveforms

A variety of equipment functions require sawtooth-shaped *currents* in inductive components. Typical of these are deflection windings for cathode-ray tube devices such as television receivers and special test scopes, pulse transformers, generators which produce and shape these waveforms, and amplifiers that process them. A sawtooth-shaped current cannot be produced in an inductive component by a sawtooth-shaped voltage. It requires a specially-shaped voltage known as a *trapezoid.* A trapezoid waveform is a composite of a sawtooth and a rectangular waveform. It possesses the characteristics necessary to cause linearly-changing current through the resistive and inductive components of the coil.

Earlier references to the sawtooth waveform stated that while it was a complex waveform consisting of a great many harmonically related frequencies, the application of such a voltage to a pure resistance resulted in a similarly shaped current through the resistance. This is illustrated in Fig. 4-4 (A). The resistive element does not modify the phase or rela-

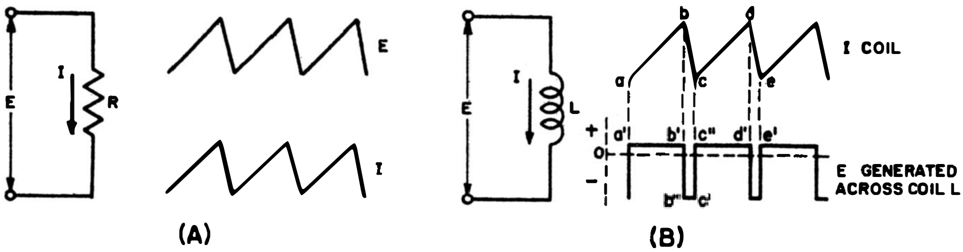

Fig. 4-4. Difference between current through a resistor (A) and an inductor (B) for applied sawtooth waveform.

tive amplitudes of the frequency components of the applied voltage, hence the current has the same shape as the applied voltage.

In the case of the pure inductance the situation is different. To make the explanation easiest to follow, let us examine the problem in a reverse manner. It is a fundamental fact that the voltage generated across a coil is proportional to the *rate of change* of the current through the coil and the inductance of the coil. A linearly-changing sawtooth current changes at a constant rate. Therefore if a *sawtooth* current is flowing through a coil, a *constant* voltage is generated across the winding.

When idealized graphically it appears as in Fig. 4-4 (B). With the current changing at a constant rate between *a* and *b*, a steady value of voltage indicated by the line *a'-b'* is generated across the coil. During the retrace portion of the current cycle, the rate of change is increased, hence the level of the voltage generated across the coil likewise is increased. This is indicated by the negative pulse *b'-b"-c'-c"*. The direction of this voltage is the reverse of what it was before because the direction of current flow during the retrace interval is the reverse of what it was during the trace interval. The *duration* of the voltage *a'-b'* corresponds to the duration of the trace portion of the sawtooth current, and the duration of the negative pulse *b'-b"-c'-c"* corresponds to the duration of the retrace *b-c*. Obviously the frequency of the voltage is the same as that of the current, and the shape of the generated voltage is rectangular.

If we now reverse what is seen in Fig. 4-4(B), it stands to reason that a *rectangular-shaped voltage will cause a sawtooth-shaped current* in a pure inductance. The constant *level* of *voltage* of one polarity indicated by the line *a'-b'* establishes a constant *rate* of *change* of *current* in one direction. When the voltage changes in value and polarity in the form of the pulse *b'-b"-c'*, a new level, *b"-c'*, of applied *voltage* is created and a new *rate of change* of current results (slope of *b-c*). This action is accompanied by a reversal of the direction of current change, to a *negative* direction, in harmony with the negative voltage *value b"-c'*. Finally, when the voltage returns to its positive level by rapid change *c'-c'*, the current *change* again becomes positive (*c-d*).

Knowing the voltage waveshapes required to cause a sawtooth-shaped current in a pure resistance and in a pure inductance, let us think about the needs of a practical inductor. The practical inductor has both resistance and inductance. The sawtooth-shaped voltage satisfies the needs of the resistive component and the rectangular-shaped voltage satisfies the needs of the reactive component. The two voltages must be combined into a composite voltage which will be applied to the winding. This is illustrated in Fig. 4-5.

As shown, the coil is composed of the resistance R and the reactive component X_L. The applied voltage E_3 is made up of the sawtooth E_1 with amplitude a and the rectangular waveform E_2 with amplitude b. The resultant voltage E_3 contains the features of both. Whereas E_1 has a peak-to-peak amplitude a, and E_2 has a peak-to-peak amplitude equal to b, the resultant voltage E_3 has a peak-to-peak amplitude equal to $a + b$. It is seen that the trace portion of the sawtooth is in effect added to the positive plateau of the rectangular voltage and the retrace part of the sawtooth is added to the negative plateau of the rectangular waveform.

Although E_1 arises from the resistance in the coil, and E_2 from its inductance, the resultant is applied to the winding as a single composite voltage. As a final thought it might be well to mention that the trapezoidal waveform E_3 shown in Fig. 4-5 need not necessarily be the voltage applied to a winding; it can just as readily be the waveform of a voltage

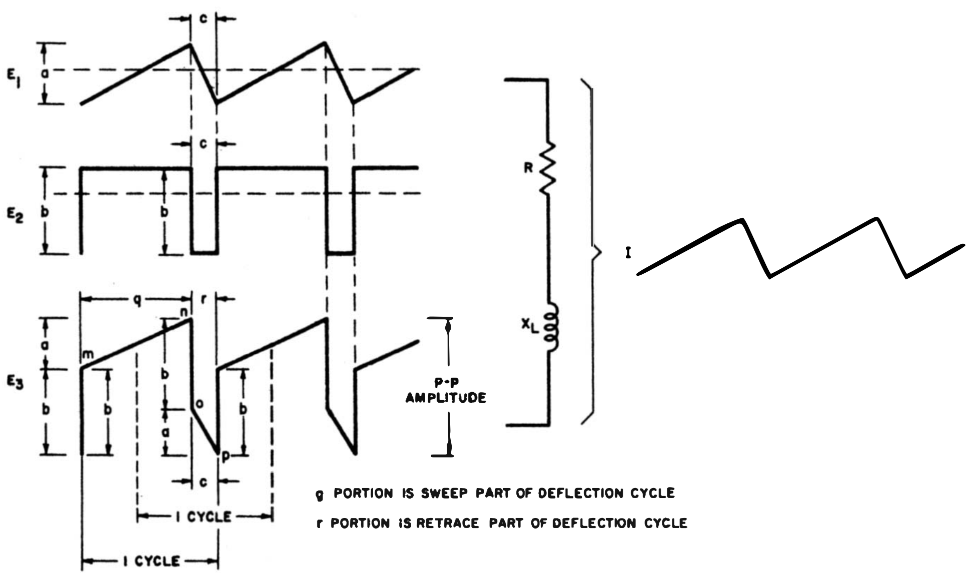

Fig. 4-5. How resistive voltage component E_1 and inductive voltage component E_2 combine in a practical inductor to form the trapezoidal resultant E_3.

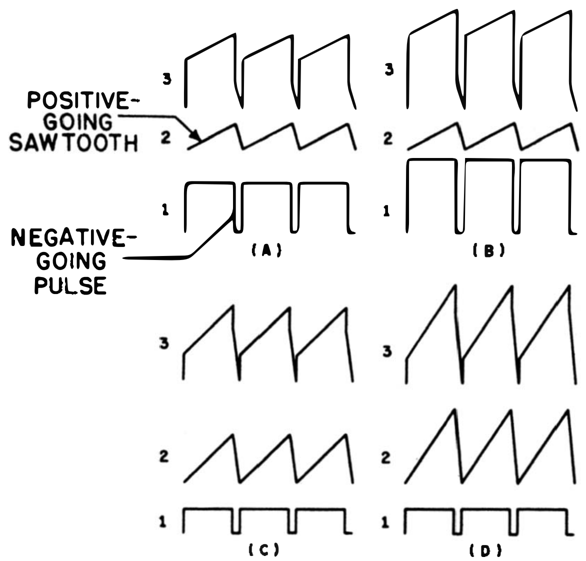

Fig. 4-6. Formation of trapezoidal waveform (3) by combining rectangular (1) and sawtooth (2) waveforms.

that is *generated* across a practical inductor as the consequence of a sawtooth-shaped current that is flowing through the winding. This is a very important point, because in some instances trapezoidal waveform voltages are applied to the windings, and in other cases they are observed there as the result of the sawtooth currents flowing in them. In still other cases, trapezoidal waveform voltages are applied to vacuum tube circuits in order to produce specially-shaped plate currents. All of these are explained in a later chapter.

Varieties of Trapezoidal Waveforms

The waveforms of Fig. 4-4 and Fig. 4-5 as applied in various practical cases, lead to numerous varieties of trapezoidal waveforms. All possible kinds cannot be shown here, but Fig. 4-6 illustrates a few which are commonly encountered. The rectangular voltage amplitudes and the sawtooth voltage amplitudes differ; in some the former exceeds the latter and in others it is the reverse. Each gives the resultant a particular characteristic, making the negative-going portion either a thin spike or a relatively wide pulse. Which it is, is determined by the relative amplitudes of the sawtooth and the rectangular voltages. These in turn reflect the preponderance of the resistive or the reactive components of the winding to which the voltage is applied. When applied to vacuum tubes they determine conduction intervals as explained later in this book.

Features of the Trapezoidal Waveform

There is no "ideal" case of the trapezoidal waveform. Each application sets its own proportions for the component voltages. It is, however, possible to say that in most instances the sawtooth component of the trapezoidal waveform is *expected to be linear*. An exception is the voltage input to the vertical deflection system of a cathode-ray tube which uses electromagnetic deflection, such as in a television receiver or a radar system. Some curvature is tolerated here as will be explained. No doubt there are other special equipments in which this is also true, but they are beyond the intended uses of this book.

Another reason for not being able to identify ideal features is the possible variation in retrace time of the sweep voltage, which in turn would have a great bearing on the shape of the negative-going pulse in the trapezoidal waveform. This can be seen in Fig. 4-6. Curvature in the retrace would modify the negative-going pulse even more.

As seen in Fig. 4-6, the resultant trapezoidal waveforms are clean of transients, that is, oscillations. Such might be viewed as the ideal case. In practice, trapezoidal waveforms vary in appearance according to the application involved and the test equipment used. In Fig. 4-7 are shown *practical* examples of trapezoidal waveforms representing *normal* operation in the systems where they are found. These are shown simply to illustrate that in some instances the waveform is clean of transients and in others the presence of transients is normal. Confusion is avoided in any given case because comparison is made with reference waveforms supplied for guidance to those who are making observations or studying behavior.

Note in Fig. 4-7 (A), (B) and (C) that some waveforms have negative-going pulses and others have positive-going pulses. The polarity in any given case is determined by the location of the point of observation in the system and the manner in which the test scope is connected. In one case the negative-going pulse has appreciable width, whereas in other cases it is simply a thin spike. The thin spike has width if the trace on the scope screen is *spread enough horizontally*, but of course the relation between positive-going and negative-going pulse widths does not change. Comparison of (B) and (C) shows a big difference in the tilt of the saw-

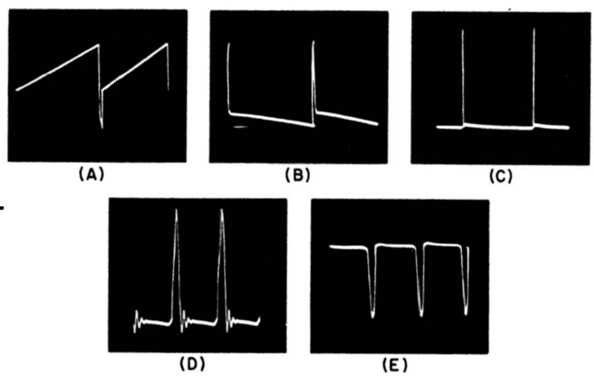

Fig. 4-7. Variations of trapezoidal waveforms.

tooth portion. This is the result of different reactance-to-resistance ratios in the circuits where these waveforms prevailed.

To illustrate still further the variety of trapezoidal waveforms which are normal according to circumstances, reference is made to (D) and (E) in Fig. 4-7. The transients seen in (D) do not appear in the construction of the trapezoidal waveform, but they are *unavoidable* in the *horizontal sweep output* systems which use flyback transformers. There is, however, a limit to their acceptable magnitude, as will be shown later. Another case is shown in waveform (E). Here only slight transients are visible. This waveform was taken across the horizontal deflection winding in a television receiver.

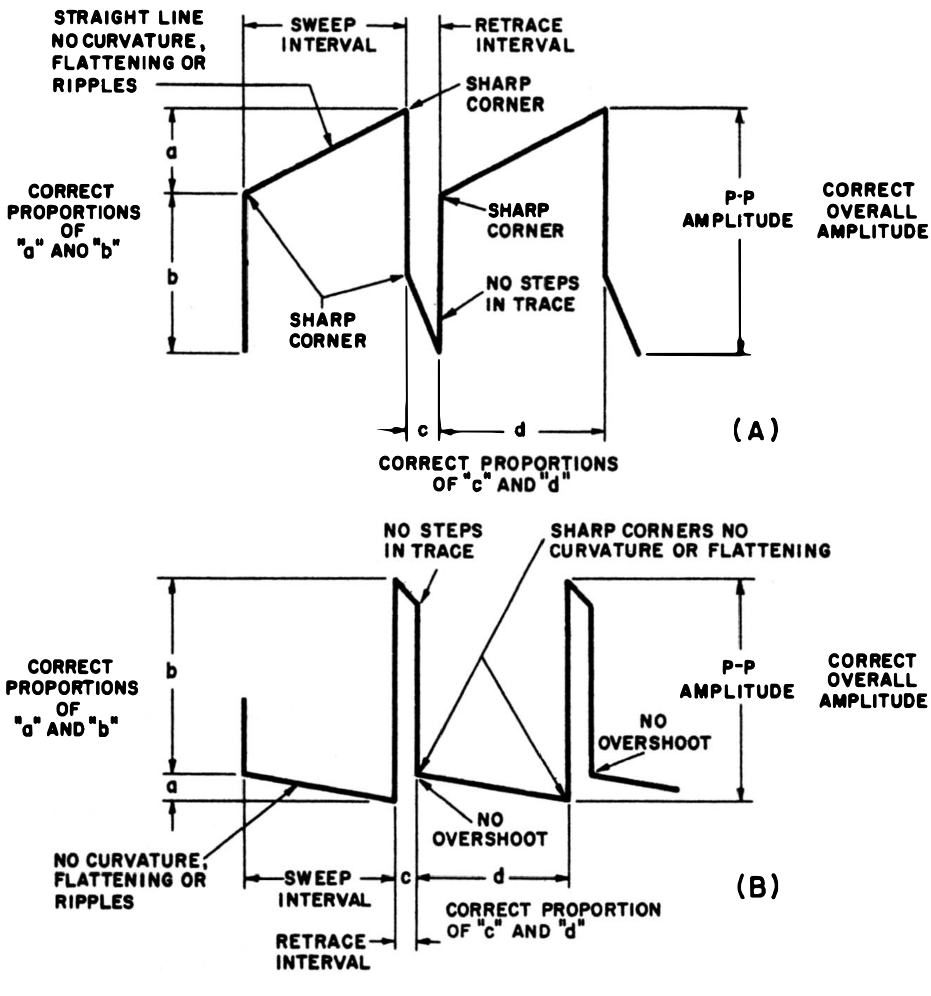

Fig. 4-8. Differences between trapezoidal waveforms in (A) sweep oscillator and shaping circuits and (B) sweep output circuits.

Problems relating to the trapezoidal-waveform voltage oftentimes are nothing more than inadequate peak-to-peak amplitude. Of course the possibility of distorted waveforms is also great. For an evaluation of what is desired in a trapezoidal waveform, reference is made to Fig. 4-8. In essence, both waveforms are alike, although they look different. The difference between them is an attempt at a realistic approach; namely to show the general appearance of the waveform (A) in the *sweep oscillator* and *waveshaping* circuits of a television receiver and the appearance of the waveform (B) in the vertical and horizontal *output systems* of these equipments. Distortions of these waveforms and reasons for them will be discussed in Chapter 9.

Chapter 5

DIFFERENTIATED AND INTERGRATED WAVEFORMS

Differentiated Voltage Waveforms

Some functions in electronic devices require voltage waveforms that are sharply peaked and have very short duration, and which also bear a time relation (frequency relation) to other voltages in the system. These peaked waveforms are frequently obtained by the process of *differentiation in short time constant circuits.* Both *R-C* (resistance and capacitance) and *R-L* (resistance and inductance) circuits are used for differentiating purposes, but the former are by far the most popular, hence our discussion revolves around them. The time constant in microseconds is the product *RC* wherein resistance (*R*) is stated in ohms and capacitance (C) in microfarads.[1]

By definition differentiation is the process of producing an output voltage that is *proportional* to the *rate of change* of the input voltage. If an available waveform has a part of its cycle in which there is a *rapid change,* this rapid change is differentiated as a sudden "pip" or short pulse, lasting only as long as the change in the original waveform. In other words, the height of the pip in the differentiated wave is proportional to the *rate of change* of the original wave; the nearer a changing portion of the original wave to the *vertical* the faster the change depicted, and the greater the pip in the differentiated wave. Changes nearest to the vertical are found in square and rectangular waveforms, therefore these are most frequently used for obtaining short sharp pulses through differentiation. The differentiation process is illustrated in Fig. 5-1.

The sine waveform seldom is differentiated, because all a differentiating circuit does to it is to produce a shift in phase between input and output voltages. The *phase-shifters* which are part of sweep generators and occasionally scopes, and which are used during circuit alignment

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[1] For a complete review of time constant, see "R-C and R-L Time Constant," by A. Schure, published by John F. Rider Publisher, Inc.

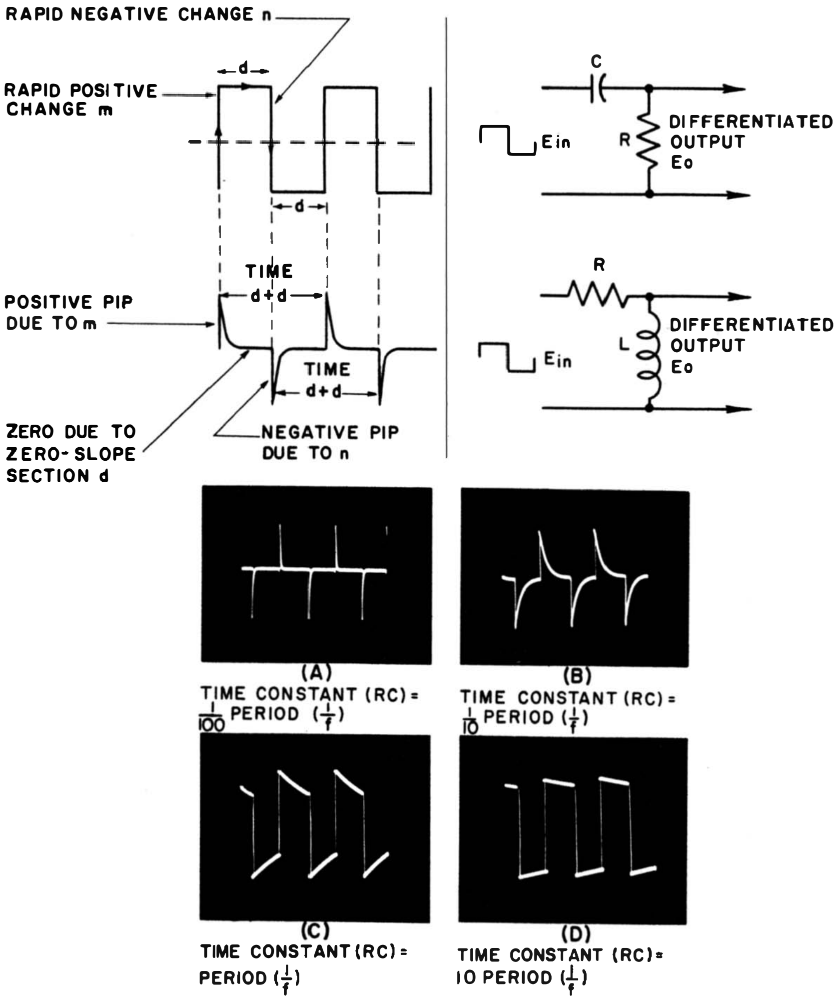


Fig. 5-1. Basic differentiating process and results of differentiation of a square wave when RC network has different time constants.

operations, are differentiating circuits with continuously-variable time constant. Examples appear later in this book.

Differentiated Square Voltages

Examples of output voltages derived from *R-C* differentiating circuits processing a square waveform input voltage appear in Fig. 5-1. The differences between the shapes of the different output voltage waveforms reflect the *differences in time constant* of these circuits. The shape of the output voltage is influenced by both the time constant, the duration (*d*), and the steepness of the leading and trailing edges of the input voltage waveform. In the examples shown, the total duration periods ($d + d$) of the input voltage were arbitrarily set at 2000 microseconds, corresponding to a frequency of 500 cps. It must be realized that the meaning of *short* and *long* time constant is relative to the frequencies involved. What is short time constant in one case may be a long time constant in another. Generally speaking, a *short time constant* circuit is one which has a time constant *not longer* than 1/10 of the time required for one cycle (period) of the input voltage. For the 500-cps (2000-microsecond) input voltage shown in Fig. 5-1, a short time constant differentiating circuit would have an *RC* or *RL* product of less than 200 microseconds. The differentiated voltage illustrated as (A) is produced by a circuit with a time constant of 20 microseconds or 1/100 the period of the input voltage. In (B) the time constant is 1/10 the period of the input voltage; in (C) it is equal to the period of the input voltage, and in (D) it is 10 times that period.

Concerning these examples, it is important to note that the output voltage consists of sharp pulses *only when the differentiating circuit has a short time constant,* and that one sharp pulse is produced during the *rise* and another is produced during the *fall* of the input voltage. This behavior explains the use of the name "peaker" for this variety of circuit.

The short time constant circuit allows the capacitor to charge fully and very rapidly during a small portion of the first half cycle of the input voltage, hence the sudden flow of charging current causes a momentary voltage to appear across the resistor. Since the charging current decreases as the voltage across the capacitor increases, the voltage across the resistor decreases. The shorter the time constant (A) the more rapidly does the voltage across the resistor fall to zero from its peak level, thus producing a sharply peaked output pulse during the rise, and another similar pulse during the fall, of the input voltage.

In Fig. 5-1 (C) and (D), as the time constant is made longer, the output voltage assumes the shape of the input voltage more and more, and differentiation takes place less and less. As a matter of fact, differentiation takes place only in short time constant circuits. Another interesting point which warrants comment is that in truth the capacitor never becomes fully charged in a practical operating circuit. The result is a tilt (slight though it may be in very long-time-constant circuits) in the maximum amplitude plateaus.

Differentiated Rectangular Voltages

Differentiation of rectangular pulses happens in the same way, and the same relationship between the time constant of the differentiating circuit and the period of the input voltage prevails. Unclipped output voltage waveforms for differentiated square and rectangular input voltages can be recognized by the distribution of the spike-shaped pulses in the output voltage. With the square waveform input voltage, the spikes are evenly spaced; with the rectangular input voltage, the spikes are grouped in pairs, the two spikes produced during each rectangular pulse

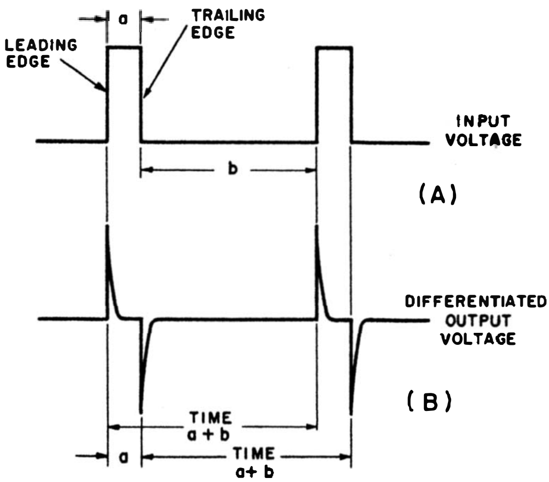


Fig. 5-2. Differentiation of rectangular wave.

being closer together than the paired spikes for the adjacent rectangular pulses. (How they are paired, of course, depends on whether the positive or negative alternation is longer.) This can be seen by comparing (A) and (B) in Fig. 5-1 with Fig. 5-2. But if the differentiated voltages are passed through a clipper system in order to remove either the positive or the negative pulses, the distribution of the remaining pulses will be the same for both square and rectangular voltage waveforms of like frequency. This can be seen by comparing Fig. 5-1 and 5-2 and visualizing the negative pulses in the differentiated outputs as having been removed. The result is the same whether the positive or the negative alternation is the longer.

A practical case of clipping a differentiated square waveform is shown in Fig. 5-3. In (A) both positive and negative polarity pulses are available. In (B) the negative pulses have been clipped, leaving only the positive pulses, each separated from adjacent pulses by a time interval corresponding to the fundamental frequency of the original square-waveform voltage. Clipping of the positive pulses shown in (A) is also possible, thus leaving the negative pulses. How clipping is done is shown in a later chapter.

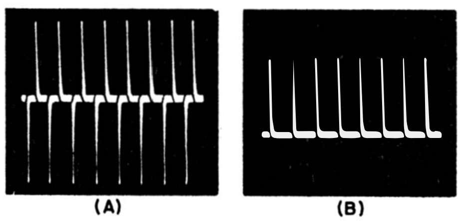


Fig. 5-3. Clipping a differentiated wave.

Differentiator As a Filter

A differentiating circuit behaves like a filter. Although its primary purpose is to provide peaked pulses, it must, by the same token, suppress low frequency components and pass high frequency components. It is thus a *high pass filter*. Comparison of Fig. 5-1 and 5-2 with some distorted square and rectangular waveforms discloses the similarity in outlines between the differentiated square and rectangular voltage waveforms and the square and rectangular voltage waveforms which are lacking low frequency components. The shorter the time constant the more the discrimination against the low frequency components.

The filtering action can be better understood by considering the differentiator circuit as a voltage divider. The output voltage E_o in Fig. 5-1 is a function of the ratio between the resistance R and the total impedance Z, formed by the resistance R in series with the capacitance C. Since the reactance of C increases as the frequency decreases, and resistance R does not change appreciably, the ratio of R to Z gets smaller. Thus for any one group of frequencies corresponding to the composition of a square (or rectangular) waveform the least output compared to input will be obtained at the fundamental frequency, and progressively greater proportionate output of higher frequency components will be obtained. This action explains the circuit's frequency discrimination. The voltage across the output (resistor) can never equal the input voltage because of the drop across the series arm C, although at relatively high frequencies this drop is effectively zero.

Differentiated Sawtooth Voltages

On occasion the sawtooth voltage is subject to differentiation. The results obtained with a short time constant circuit are shown in idealized fashion in Fig. 5-4(A). Both the forward trace *a-b* and the retrace *b-c*

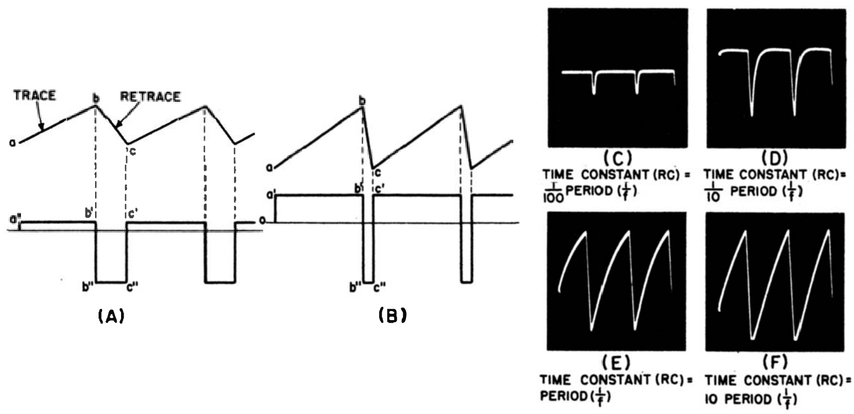


Fig. 5-4. (A) and (B) show basic ideal sawtooth waves and effect of differentiation. (C), (D) and (E) show actual waveforms as differentiated in circuits of progressively smaller time constant.

change at a constant rate, the latter at a higher rate than the former. If a constant-rate-of-change voltage is applied to a capacitor, the charging current will be constant; if the capacitor is part of a differentiating circuit, the current flowing through the resistor will be constant and a constant value of voltage will be developed across the resistor. This is seen in (A) of Fig. 5-4, by correlating *a-b* with *a'-b'* and b-c with *b'-c'*.

The steeper the slope of the input voltage, the greater is the rate of change of the voltage, and therefore the greater the value of current and output voltage during the time the slope has this value. This is symbolized in (B) of Fig. 5-4 where the sawtooth waveform has a greater slope (nearer vertical) than in (A) and the amplitude of the differentiated voltage is greater than in (A). Because of the very rapid retrace shown in (B), the duration of the negative-going pulse in the differentiated output is very short, having the same duration as the retrace. A differentiated waveform such as that shown in (B) would not normally show any horizontal dimension for the negative pulse when displayed on a scope screen, unless the image were spread sufficiently in the horizontal direction. For that matter, this is true for the waveform in (A) also.

The longer the time constant of the differentiating circuit, the more closely does the output voltage waveform resemble the input sawtooth voltage. Examples of sawtooth waveforms differentiated under different time constant conditions are shown in Fig. 5-4 (C), (D), (E) and (F).

The R-L Differentiator Waveform

Although the *R-C* differentiator is virtually standard in electronic devices, the *R-L* variety also finds use on occasion. The *R-L* circuit consists of a resistor and an inductor in series. The input voltage is applied across the series combination and *the differentiated voltage is taken off across the coil,* as shown in Fig. 5-1.

The time constant for the *R-C* circuit represents the time required for the capacitor to charge to 63 per cent of the applied voltage or to fall to 37 per cent voltage from fully charged condition. The *R-L* circuit time constant represents the time required for the *current* to increase to 63 per cent of its maximum value, and to decrease from maximum value to 37 per cent of that value. The formula for determining the time constant is $T = RC$ or $T = L/R$ with C in microfarads, L in microhenries, and R in ohms, the time constant in each case is in microseconds.

The shape of the voltage developed across the inductor in the *R-L* circuit is the same as for the voltage developed across the resistor in the *R-C* circuit; the shape of the current curve through the inductor is the same as for the voltage across the capacitor in the *R-C* circuit. Hence the details given earlier concerning differentiated waveforms for *R-C* circuits apply to the *R-L* differentiator too.

Integrated Voltage Waveforms

In contrast to differentiated voltage waveforms, there also exist *integrated* voltage waveforms. The *integrator* is a network which sums up instantaneous values; the output voltage depending upon the *duration* of the input voltage as well as its value. The integrator discriminates *against the high frequencies,* and the output consists of the low frequency components present in the input voltage; thus it is a *low pass filter.*

Circuit-wise the integrator network contains the same elements as the differentiator network; the difference between them is that in the *R-C* integrator the output voltage is taken off across the capacitor as shown in Fig. 5-5; in the *R-L* integrator the output voltage is taken off across the resistor. Hence the *voltage* developed *across the capacitor* of an *R-C* differentiator is the *integrated voltage,* and the *voltage* developed *across the resistor* in the *R-L* differentiator is the *integrated* voltage output.

Examples of square-waveform voltages integrated in *R-C* networks of different time constant are shown in Fig. 5-5. The shorter the time constant of the circuit, the more closely does the integrated voltage output resemble the waveform of the input voltage. The longer the time constant the closer does the output approach a back-to-back sawtooth waveform. It can be seen that the waveform of the integrated output displays those characteristics of the square waveform which indicate *attenuation* of the *high frequencies.*

The integrating action of a long time constant *R-C* network is more readily seen when the input voltage consists of rectangular pulses. In the case of the square waveform input the charge and discharge periods are alike, hence whatever voltage is built up across the capacitor during the positive half of the input voltage cycle is discharged during the negative half. When the rectangular input pulses have short-duration periods with

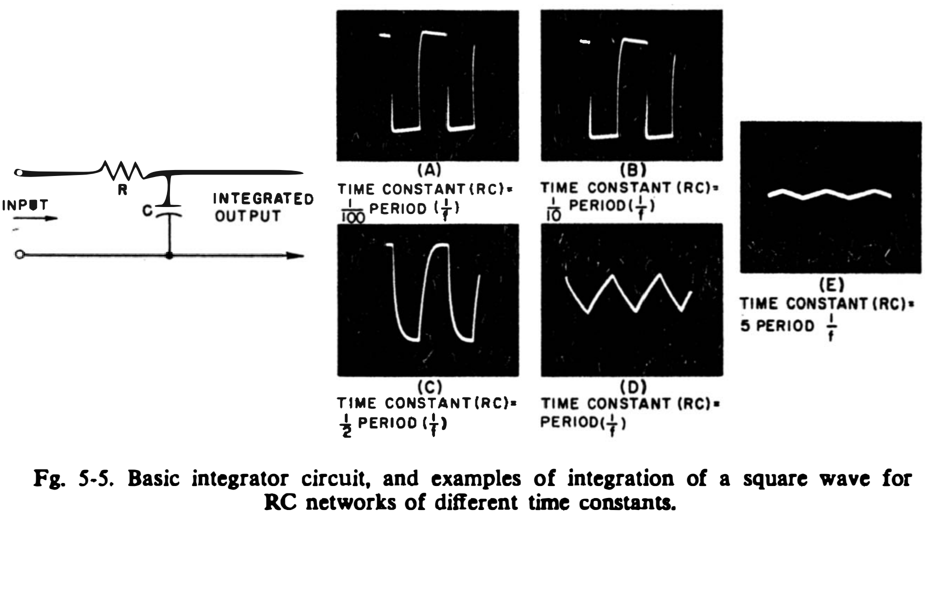


Fig. 5-5. Basic integrator circuit, and examples of integration of a square wave for RC networks of different time constants.

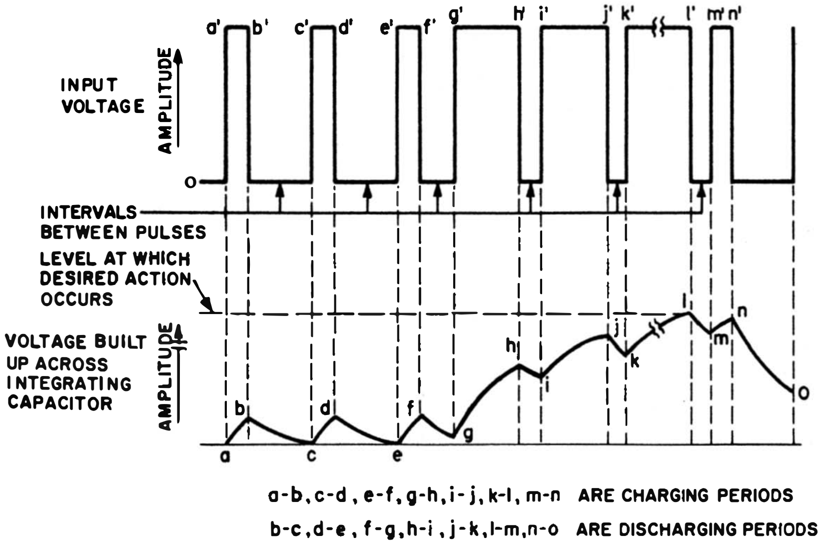


Fig. 5-6. How integration becomes cumulative to build up a single wide pulse from many narrower closely-spaced ones.

long intervals between pulses, the capacitor does not have opportunity to accumulate a charge beyond that set by the first cycle. The long duration between pulses affords the capacitor the opportunity to discharge almost completely. This cycle of events is repeated as long as pulses of this shape are applied, as indicated by *a-b-c, c-d-e, e-f-g* in Fig. 5-6. But when the duration of the input pulse exceeds the interval between pulses, the capacitor can accumulate a charge from each input pulse, each charge being additive to that remaining on the capacitor from the previous applied pulse, as shown by *g-h-i, i-j-k, k-l-m* in the same figure. This is indicated by the increasingly higher positions of *h, j* and *l*. This is continued until the voltage built up across the capacitor reaches a predetermined required level, at which time whatever other related action is desired is accomplished, such as the triggering, or timing of an oscillator.

In the instance shown, the last long-duration pulse is succeeded by a short-duration one with a long interval following, and the capacitor is given the opportunity to dissipate some of its charge as shown by the line *n-o*.

The action shown in Fig. 5-6 illustrates one use of the integrating circuit. It is the ability to select between pulses of different duration when all are present in the same circuit, causing the build-up of voltage by the long-duration pulses only. The short-duration pulses have substantially no effect. The shorter the intervals between pulses relative to the duration of the pulse, the more effective is the buildup of the integrated pulse.

The usual display of integrated voltage waveforms does not show the step-by-step build-up of voltage across the capacitor. The practical

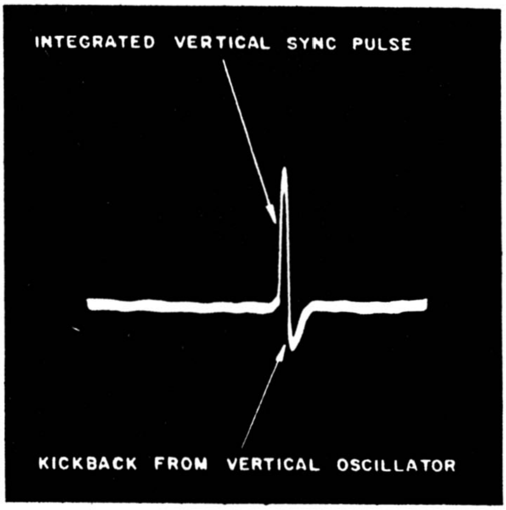


Fig. 5-7. Scope display of a typical integrator output pulse.

applications of integration of rectangular pulses as treated in this text deal with the accumulated voltage derived from a train of pulses. An example of an integrated pulse appears in Fig. 5-7. It is derived from a three-section integrating system in a television receiver. The similarity between this waveform and the outline of the rise and fall of the capacitor voltage in Fig. 5-6 is not very great, yet they represent the same kind of action. The time scales are different. Fig. 5-6 is spread, whereas Fig. 5-7 is compressed. The negative spike seen in Fig. 5-7 can be disregarded in this discussion. It exists in television receivers and is the result of signal leakage from the vertical sweep oscillator into the vertical integrating network.

Ideal and Practical Differentiated Waveforms

For all practical purposes there are no "ideal" examples of differentiated waveforms. The ideal and the practical are one and the same for any one set of operating circumstances. Each set of conditions produces its own "ideal" version for that particular set of operating parameters. Sometimes, because the constants of R and C, or R and L, are not what they should be, the required degree of differentiation does not take place. Then the effect on the performance of the equipment is determined by how the differentiated voltage is used. The differentiated voltage should be free of spurious voltages, such as might be induced into a differentiating circuit by neighboring voltage systems. An example of such a spurious voltage appears in Fig. 5-7.

That which is said above concerning differentiated waveforms applies equally well to integrated waveforms.

Chapter 6

AMPLITUDE MODULATED WAVE ENVELOPES

Nature of Amplitude Modulation

Amplitude modulation is a process of adding intelligence (modulation) to an r-f voltage (carrier). Typical of amplitude-modulated (a-m) carriers are the signals transmitted from a-m broadcasting stations, commercial, military, and other communication facilities, picture signals from television transmitters and the output of a-m r-f signal generators and test oscillators.

The result of the a-m process is a composite r-f voltage whose amplitude varies in accordance with the instantaneous variations of the modulating voltage. Graphic illustration of the combination of r-f and modulation voltages is shown in Fig. 6-1 (A). The upper curve is the sine waveform of an arbitrarily-selected modulating voltage. Region *A-B* indicates zero level, and curve *B-C-D-E-F* describes one cycle of the voltage.

The lower illustration shows the *unmodulated* carrier within the region *A'-B'*, and the a-m carrier bounded by *B'-C'-D'-E'-F'*. Although drawn in this figure as a series of straight lines for convenience, the unmodulated carrier cycles are in most cases assumed to be of sine waveform. The unmodulated carrier may, for any one of a number of reasons, contain harmonics. In this event the cycles of the unmodulated carrier would be nonsinusoidal.

Another item is that the amplitude of the *unmodulated* carrier cycles is *constant.* When amplitude modulation is applied (*B'-C'-D'-E'-F'*) *the* carrier cycles increase *above* the unmodulated level during the positive alternation of the modulating voltage and decreases *below* the unmodulated level during the negative alternation of the modulating voltage. The *positive peak* of modulation is called the *crest,* and the area around the *negative peak* of modulation is called the *trough.* These terms relate to the outline formed by connecting the peaks of all the cycles of the modulated carrier. This outline is known as the wave *envelope.* Both the positive and negative envelope lines of the modulated carrier conform exactly

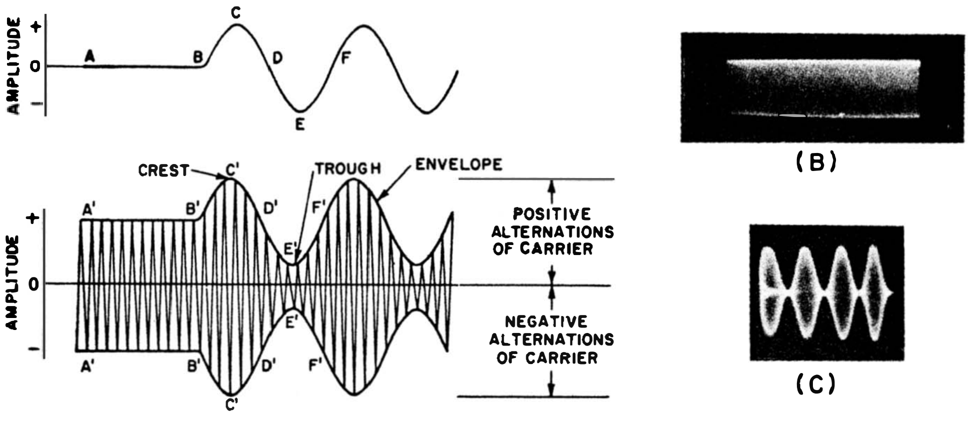


Fig. 6-1. Basic features of the amplitude-modulated waveform.

to the waveform of the modulating voltage, except that the negative outline is inverted. This is the ideal situation under correct modulating conditions. Variations from ideal conditions are described later in this chapter and in succeeding chapters.

The representation of the modulated carrier in Fig. 6-1 (A) is a simplification. While it is possible to see the individual cycles of the modulated r-f carrier in a normal scope display when the frequency of the carrier is low, they are not normally visible. As a rule, the sweep circuit in the scope is made an *integral submultiple* of the *modulating* voltage, in which case the r-f cycles are not visible on the screen. The usual appearance of a sine-waveform unmodulated carrier is shown in Fig. 6-1 (B), and a carrier that is amplitude-modulated by a sine waveform signal is shown in (C).

Frequency Composition of Amplitude-Modulated Carrier

An a-m carrier consists of one component of the carrier frequency, and two frequency components for each frequency component present in the modulating voltage. For instance, if a 1000-kc (1-mc) carrier is modulated by a 5000-cps voltage, the frequency components present are the 1000-kc carrier, a *lower sideband* component having a frequency equal to the difference between the carrier frequency and the modulating frequency ($1000 - 5 = 995$ kc) and the *upper sideband* component, having a frequency equal to the sum of the carrier and modulating frequencies ($1000 + 5 = 1005$ kc). The sideband frequency components arise from the modulation process. If the same carrier were modulated by three frequencies, say 1000 cps, 2500 cps and 5000 cps, the lower sideband frequencies would be 999 kc, 997.5 kc and 995 kc respectively, and the upper sideband frequencies would be 1001 kc, 1002.5 kc and 1005 kc respectively. Of course the carrier frequency component of 1000 kc is also present.

When the modulating voltage contains components having different frequencies, the modulated wave envelope has a nonsinusoidal waveform. It has that waveform which represents the composite of the modulating frequency components such as is illustrated in Fig. 6-2. If the scope pattern can be made to remain stationary the frequencies in the modulating voltage are harmonically related. If the pattern cannot be synchronized, the modulating component contains frequencies which are not harmonically related. A modulated wave envelope of the latter variety appears in Fig. 6-2 and represents the sound output from some musical instruments in an orchestra.

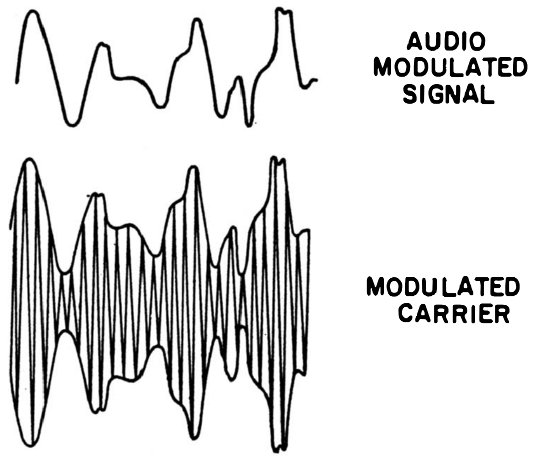


Fig. 6-2. R-F carrier modulated by a complex audio signal.

Percentage of Modulation

The intelligence in an a-m wave is in the modulation—in other words, in the sidebands. When an a-m carrier is detected or demodulated in a receiver, the negative half of the carrier is removed and the variation represented by the upward and downward swing of the amplitude of the positive half cycles of the carrier forms the useful modulation signal. Thus it would seem that the ideal thing to do is to apply the *maximum* amount of modulation to the carrier. This is normally done in a-m transmitters. The maximum amount of modulation feasible is set by the amplitude of the unmodulated carrier.

Two features of the modulated waveform are of particular interest. These are the *maximum* instantaneous carrier amplitude (crest) and the *minimum* instantaneous carrier amplitude (trough) both being illustrated in Fig. 6-3. The *average* amplitude corresponds to the peak-to-peak level of the *unmodulated* carrier. It is in relation to this amplitude that the maximum and the minimum amplitudes are examined. Under normal

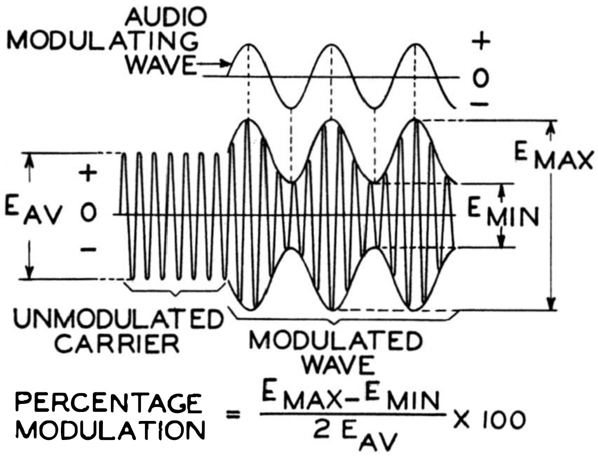


Fig. 6-3. Waveform of r-f wave amplitude-modulated 50 per cent.

conditions of amplitude modulation the *change* of the carrier level in the upward direction and the *change* in the downward direction *must be alike*. Hence over a complete cycle of modulation, the *average* voltage of the modulated carrier remains *constant* at the unmodulated level.

The greater the amount of modulating voltage added to the carrier, the more the difference between the maximum and minimum (E_{max} and E_{min}) amplitudes of the modulated r-f voltage. This ratio between amplitudes of the modulating voltage and the unmodulated carrier determines the *percentage of modulation* and gives the modulated waveform a characteristic appearance. The percentage of modulation is determinable from features of a scope display by using the equation

$$\text{Percentage modulation} = \frac{E_{max} - E_{min}}{2E_{av}} \times 100$$

Ordinary linear units of measurement can be applied to the modulated wave envelope pattern displayed on a scope screen in order to determine the maximum, minimum and average values. Measurement of the average value requires that the modulation be removed at the source. If the average value corresponds to a trace height of 1 inch, and the maximum value is a trace height of 1.5 inches, and the minimum value is a trace height of .5 inch, application of these units to the equation given above leads to an answer of 50 per cent modulation, which is the percentage depicted in Fig. 6-3.

Several examples of wave envelopes corresponding to different percentages of modulation are shown in Fig. 6-4. Sine-waveform modulation is used because it is the easiest to deal with in explanations, and also for tests of various kinds. This is also a practical illustration because all a-m signal generators are designed to deliver sine-waveform modulated signal output.

In Fig. 6-4, it is seen that increasing the modulation in the *upward* direction by increasing the amount of modulating voltages poses no problem; the composite signal amplitude simply gets higher and higher in the positive direction. It is in the *downward* or *negative* direction that the limit exists. If the modulating voltage is too high some part of the negative alternation of the modulating voltage *cuts off the carrier completely*. This gives rise to two undesirable conditions; the envelope of the modulated carrier no longer corresponds to the waveform of the modulating voltage, and this introduces distortion in the demodulated carrier. The second condition is the introduction of spurious signals and high harmonics by the sudden cut-off of the carrier in the modulating tube. Compare (D) and (E) in Fig. 6-4. The carrier is cut off for almost the entire negative half cycle of the modulating voltage.

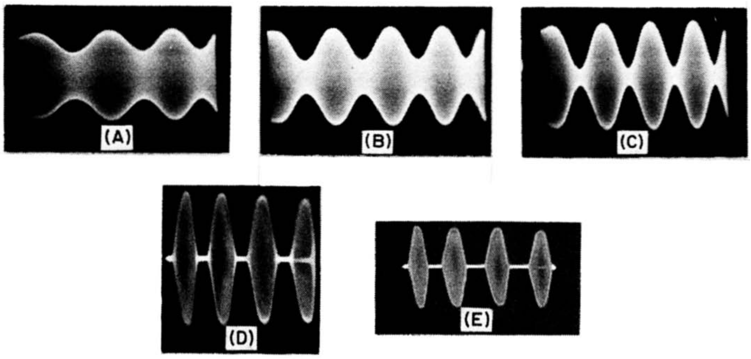


Fig. 6-4. Waveforms representing various percentages of amplitude modulation.

As mentioned earlier, all modulating voltages are not of sine waveform. An example of a square-waveform amplitude modulation is shown in Fig. 6-5.

The percentage of amplitude modulation employed differs for different applications. For testing receivers, 30 per cent modulation is a standard value, although it can be greater if desired. On the other hand, a-m broadcasting stations take advantage of the increased efficiency resulting from 100 per cent modulation and try to operate as close to this level as possible.

Incorrect conditions of modulation are numerous. Overmodulation shown in Fig. 6-4 (D) and (E) is just one of them. More on this later.

Amplitude-Modulated I-F Signals

Intermediate frequency amplifiers in a-m superheterodyne receivers process voltages that are a-m signals. Under normal circumstances of operation these voltages have the same characteristics as those delivered

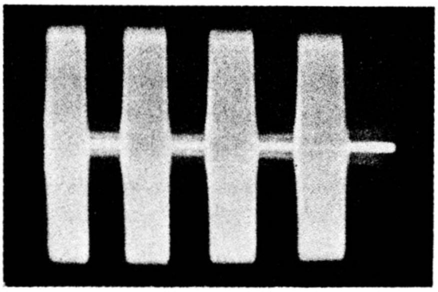
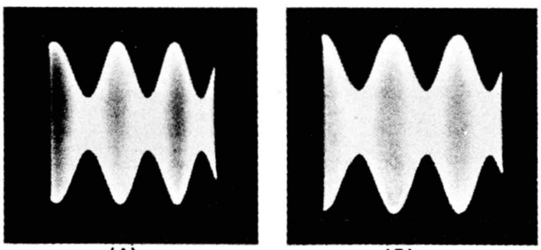


Fig. 6-5. Waveform of r-f wave modulated by a square wave.

to the input of the receiver, differing only in carrier frequency. As a result of the frequency-changing process in the superheterodyne receiver, the intermediate frequency replaces the carrier frequency, and the sideband frequencies are modified by this change. But as far as modulation characteristics are concerned, the i-f signal contains exactly the same modulation components as the originally received signal. Thus if a transmitter radiates an amplitude-modulated carrier of 1000 kc bearing 5000-cps modulation, the three signal components are 995 kc, 1000 kc and 1005 kc; if the composite r-f voltage is modified in a receiver mixer system for passage into an i-f amplifier rated at 455 kc, the frequencies present in the i-f system are 450 kc, 455 kc and 460 kc. In effect, the intermediate-frequency signal behaves like the r-f input signal. In both instances the signal occupies a channel 10 kc wide. Also, the envelope of the modulated i-f signal is exactly the same as that of the received modulated r-f signal, assuming of course that the operation of the i-f amplifier is proper. Examples are given in Fig. 6-6. The i-f signal waveform looks exactly like the r-f signal waveform[1].



(A) (B)

Fig. 6-6. Similarity between waveform of r-f input signal to a receiver (A) and the i-f signal resulting from it (B).

The features of the a-m i-f signal are supposed to remain constant (except for changes in overall amplitude as the signal progresses through

[1] It should be noted that, if the local oscillator frequency is higher than that of the received signal carrier, the sidebands reverse their position relative to the carrier when they are converted to the i-f signal. The high-frequency sideband in the r-f signal becomes the low frequency sideband in the i-f signal, and vice versa. This fact is important when a vestigial sideband signal is received, as in the case of television video reception.

the i-f system) up to the input of the detector or demodulator, where the demodulation takes place. The demodulated output has the same waveform as the envelope of the modulated i-f signal, this being the modulation component.

Ideal and Practical Amplitude-Modulated Wave Envelopes

Wave envelopes (A), (B), and (C) in Fig. 6-4 can be looked upon as "ideal" examples of a-m wave envelopes *corresponding to the stated percentages of modulation by single-frequency modulating voltages.* Whether or not an a-m wave envelope is representative of an "ideal" condition is determined by (1) the similarity between the envelope and the waveform of the modulating component, (2) by an indicated percentage of modulation that truly reflects the amplitude relationship between the modulating voltage and the unmodulated carrier voltage, and (3) by the sine waveform of the cycles of the unmodulated carrier. Obviously there is no one example of an "ideal" which fits all cases, if for no other reason than that the waveforms of the modulating component differ according to the nature of the intelligence that is to be added to the carrier voltage. Also because the percentage of modulation is a variable, depending on the requirements in any given case. Thus each set of circumstances produces its own "ideal" wave envelope.

It is only for a-m signal generators that any similarity in outline of the a-m wave envelope used in a large number of cases exists. The reason for this is that it is virtually standard practice to use a single modulating frequency (400 cps) and 30 per cent modulation. There is usually provision for increasing the modulation to 100 per cent when needed.

The "practical" versions of a-m wave envelopes approximate the ideal examples fairly closely. It is in the case of signal generators that the practical departs from the ideal in that the audio signal generated within the device and used for modulating the carrier is not always a sine waveform voltage. The result is that the a-m signal output from the generator does not have a sine waveform envelope. The audio voltage has a low amplitude second, and sometimes a third harmonic frequency content as well, resulting in wave envelope outlines similar to waveforms depicting such distortion, given earlier in this book.

Technically speaking, such envelope outlines constitute "distorted" audio, but when the distortion is not too severe (examples are given later) it is accepted as a "practical" version of sine waveform modulation. As far as use of the service type signal generator is concerned, distortion of this kind does not interfere with such operations as alignment, gain checking, signal tracing, etc. However, for distortion checks in a-f amplifiers, a more perfect sine wave must be used.

Observation of Amplitude-Modulated Wave Envelopes

There are certain limitations relative to viewing a-m wave envelopes on a scope screen. The ability to see the waveform of the modulated signal voltage depends on the ability of the vertical amplifier to pass the carrier frequency component (or the intermediate frequency component) which is modulated. Thus if a test scope is rated at a top frequency of 1 mc for its vertical amplifier, the highest a-m carrier frequency which can be displayed is 1 mc; if the scope rating is 5 mc, then the highest a-m carrier frequency which can be displayed in this manner is 5 mc. This is explained in somewhat more detail in a later chapter. There is a way of displaying a-m wave envelopes with carrier frequencies higher than the top frequency limit of the vertical amplifier. The modulated signal voltage is fed *directly* to the vertical deflection plates, and a small amount of the modulating signal component is applied to the scope synchronizing system for control of the sweep oscillator. For this method, the modulated carrier signal amplitude must be *at least* 30 to 40 volts peak-to-peak, and the modulating frequency must not be extremely high relative to the highest output frequency of the scope sweep generator.

Modulation of a Signal Voltage

There is another form of amplitude modulation wherein one signal is superimposed on another by simple addition with results that differ from normal amplitude modulation, in which a modulator must be used. This is typified in practice by "hum" modulation, wherein a 60-cps or a 120-cps voltage is superimposed on a higher frequency signal voltage. The upper and lower limits of the pattern then seem to have an outline which conforms with the waveform of the modulating voltage, but in this case, the bottom envelope line is *not* inverted. Examples of this are given in Fig. 6-7.

It is seen that the amplitude of the higher frequency cycles is *not* alternately increased and decreased as in normal amplitude modulation patterns in Fig. 6-1 through 6-6. The modulation of the higher frequency signal in Fig. 6-7 simply displaces the position of the cycles relative to what would be the normal zero reference axis position, in a manner corresponding to the waveform of the modulating voltage. Waveforms of this kind generally imply improper functioning of the equipment, so are somewhat out of place here. However, we include them because they bear

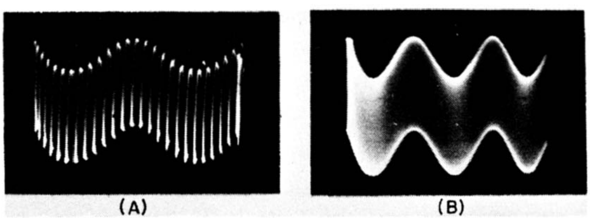


Fig. 6-7. Mixture of two signals in a linear system.

an association with another kind of amplitude modulation known as "intermodulation", a phenomenon closely allied to performance of audio amplifying equipment.

The production of a modulated pattern such as Fig. 6-7 occurs in a "linear" system wherein say, two voltages are simply added instant by instant and produce a resultant which contains only these two frequencies in their proper proportions and relative phases. Ability to do this is evidence of the fact that the system is linear hence "distortionless" within the boundaries established by the amplitudes of the two voltages.

If the system is not linear the combination of two such frequency components becomes amplitude modulation. The resultant signal contains sum and difference and harmonic frequency components which were not present in the original. Thus if 60-cps and 1000-cps voltages are combined in a nonlinear audio system, they combine to produce two new frequency components, one of 1060 cps (sum) and one of 940 cps (difference). The frequency components thus modulate each other; hence the term "intermodulation."

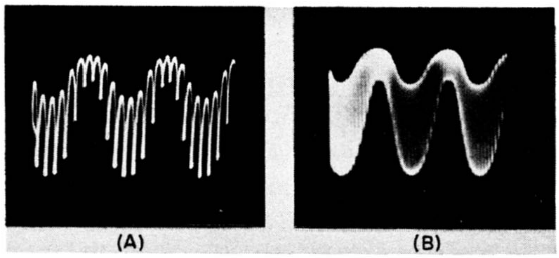
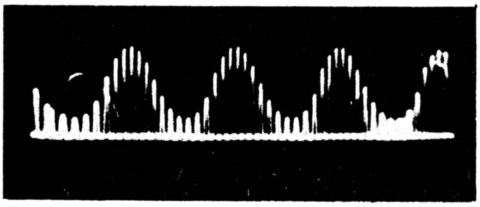


Fig. 6-8. Intermodulation waveforms.

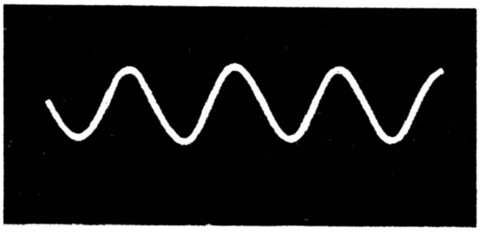
The a-m wave envelope corresponding to *intermodulation distortion* in audio systems is shown in Fig. 6-8. Two conditions should be noted in these waveforms. First, that the shape of the envelope corresponds to the waveform of the low frequency voltage; second, that the individual cycles of the resultant voltage vary in amplitude. A comparison of Fig. 6-7 and 6-8 discloses the difference between the resultant waveforms.

The Rectified Amplitude-Modulated Waveform

Rectification of an a-m waveform is necessary in order to extract the intelligence appearing as the modulation. This is known as *demodulation,* and consists of removing the negative half of the modulated wave envelope. The interesting aspect is that the demodulated waveform normally displayed on the scope is the modulation component and all signs of the carrier cycles generally are absent from the scope display. It is only when the carrier frequency is relatively low, or the scope sweep frequency is sufficiently high to show the carrier cycles, that the latter are seen in the display. An example of this is shown in Fig. 6-9(A). In this example the carrier frequency is 60 kc, hence easily displayed on the scope screen. By use of a high modulating frequency (5000 cps) showing a relatively



(A)



(B)

Fig. 6-9. Rectified waveform in which the individual r-f cycles are visible (A) and resulting demodulated a-f waveform (B).

high number of carrier cycles and removal of the charging capacitor in the diode circuit, the individual cycles of the carrier and the modulating voltage waveform are shown in the trace. The latter are evident in the outline of the positive alternations of the carrier cycles. The resultant audio waveform is shown in Fig. 6-9 (B).

The situation illustrated in Fig. 6-9 will be encountered for all types of modulation component waveforms when the carrier frequency conditions are as stated. Demodulated a-m wave envelopes resulting from improper operating situations are illustrated later in this book.

Chapter 7

RESPONSE AND "S" CURVES

Response Curves

A *response* curve is a graph of a voltage-frequency relationship. It indicates how the acceptance, amplification, or rejection of a signal by a component or a circuit varies as the frequency of a signal is varied over a desired range. The range of frequencies chosen is related directly to the functioning of the system under test.

The method of developing the response curve on the scope screen is as follows: an appropriate frequency-varying signal from a sweep generator is fed to the circuit under test; then the circuit's output signal voltage is rectified and applied to the vertical amplifier of the scope. The vertical dimensions of the trace correspond to the circuit's output voltage over the prescribed test frequency band. The frequency scale (horizontal dimension on the scope) is secured by applying the sweep voltage used in the sweep generator to change the frequency, or its equivalent, to the horizontal deflection system of the scope. Thus the horizontal dimension of the response curve represents the changes in frequency, or the frequency scale. Details concerning such set-ups appear elsewhere in this book. Unless otherwise stated, all response curves shown in this chapter were made with blanking on, so no signal is applied to the scope tube grid during retrace of the scope beam.

Circuit voltage response at any given frequency is indicated by the *separation* between the point on the response curve corresponding to that frequency and the *zero* voltage baseline.

Single-Peaked Response Curves

A typical response curve is illustrated in Fig. 7-1 (A) and (B). This is a simple single-peak response curve showing voltage-vs-frequency performance of a loosely-coupled narrow-passband tuned transformer in an a-m receiver. In (A) the response curve appears *above* the zero response baseline; in (B) it appears *below* the zero voltage baseline. Either one of these forms of presentation is used for all sorts of response curves. There

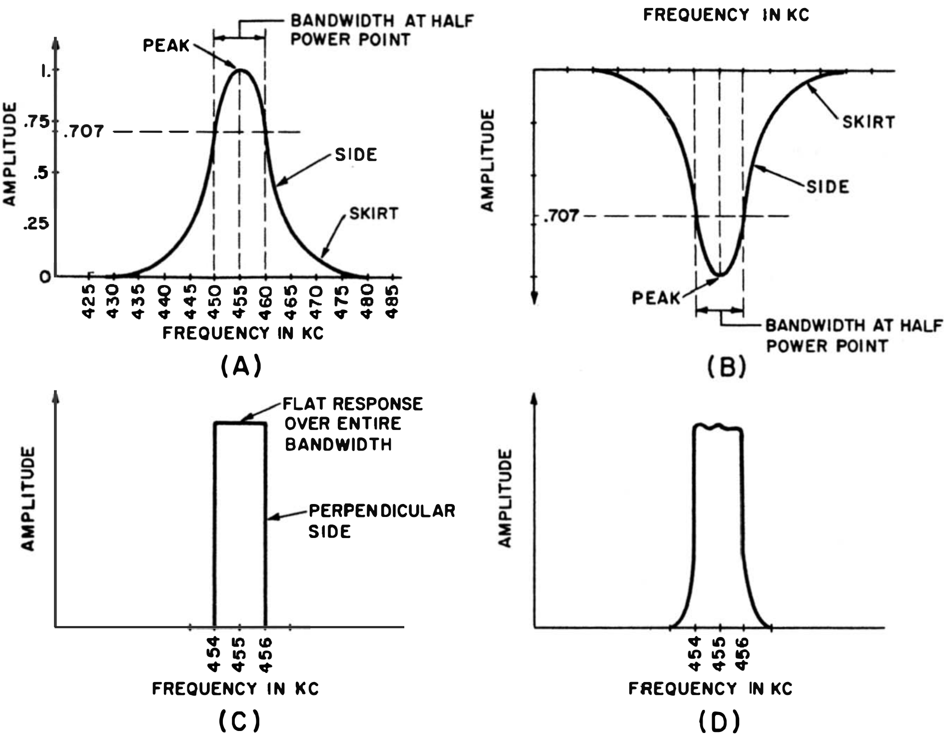


Fig. 7-1. (A) Basic features of response curve, (B) ideal response.

is *no* difference between them except for the direction in which the rectified signal voltage fed to the vertical amplifier deflects the beam in the test scope, or the number of amplifying stages in the scope's vertical amplifier. As a means of convenience, all further response curves in this book will be shown with the curve located above the zero voltage baseline, although they may be expected to appear either way in practice.

Several conditions seen in Fig. 7-1 (A) have similar meaning in most response curve displays. The *highest* point on the response curve represents *maximum* signal through the circuit, hence maximum gain or minimum attenuation. Maximum response is shown as being equal to unit level on the *amplitude* scale. The curve has but one point of maximum response, hence its name *single-peak curve.* In this example, the peak occurs at the 455-kc point. (Calibrated frequency scales do not appear on scope displays. The frequency corresponding to any given point is determined by means of *markers.* Or, if the band of frequencies being swept is accurately known, a frequency scale can be visualized as linearly laid out between the sweep extremes.)

Frequency is uniformly distributed along the frequency scale. This is true of most response curve traces, but not all. The frequency scale is uniform if the signal generator frequency and the scope sweep both follow the same variation pattern, or waveform. This is true in this case, and the total sweep width is 60 kc, from 425 kc to 485 kc. The response is seen to *fall* each side of the *peak* point. It is further seen that the sides slope outwards, hence the lower the observation point along the side, the wider is the band of frequencies accepted by the system under check. Eventually, at 435 kc and 475 kc, the sides of the curve approach the zero voltage line. Response from the circuit is zero at these frequencies and for lower and higher frequencies. The portions of the curve which approach the zero response condition are known as the *skirts.*

What is the frequency passband indicated by a curve of this kind? . . . Is it determined at the top of the curve, half-way down the sides, or at the bottom? The standard, widely-accepted point at which to measure the passband of a circuit is at the *half-power* point. This point corresponds to 0.707 of the *maximum* amplitude, or 3 db down from the maximum amplitude point. This range is shown bounded by dotted lines in curve (A), and in this instance is an *overall* bandwidth of 10 kc, 5 kc *each side* of the center or peak frequency.

Single-peak response curves represent circuits which are tuned to a *single* frequency, and which are intended to accept a relatively narrow band of frequencies. The curve of Fig. 7-1 (A) shows *fairly uniform* response for perhaps 1 kc *each side* of the *center* or *resonant* frequency. The *ideal* type of curve for a situation of this kind is a rectangular pattern like curve (C). The sides are perpendicular and the top is *flat over the required bandwidth.* Curves such as these *are not realized* in practice, although a fair approach to them is achieved in some communication receivers, as shown by curve (D).

A scope trace of a *sharply* tuned circuit response curve indicating resonance at one frequency and steep sides, is shown as (A) in Fig. 7-2. The skirts fall to zero voltage at about 5 kc each side of the resonant frequency and stay zero to the low side sweep limit of 445 kc and the high side sweep limit of 485 kc. A curve of this kind is not unusual in a radio broadcast receiver i-f system or in a communication receiver i-f amplifier.

An important point to be noted in the curve of (A) is that the *full width* of the entire curve trace *inclusive of the zero voltage* skirts corresponds to the complete range of frequencies swept through by the generator. The frequencies embraced by the overall sweep width are distributed uniformly along the entire base of the curve, inclusive of the zero voltage portions. This is true of all properly produced response curves.

Double-Peaked Response Curves

Frequently transformer-type circuit elements are so designed that, even though tuned to a single frequency, they produce a *double-peaked*

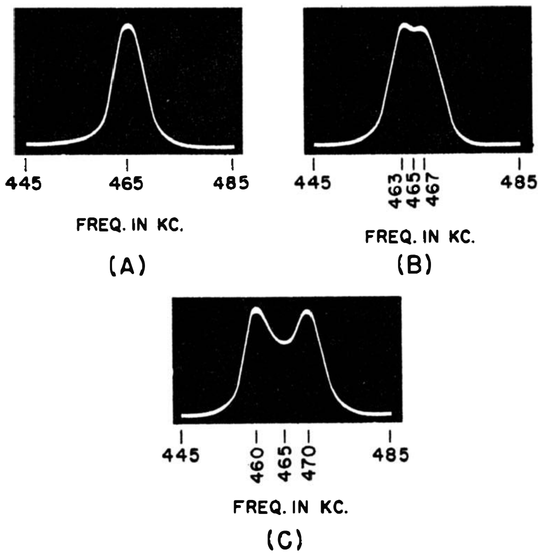


Fig. 7-2. Single and double peaked response.

response curve. Two examples of this type appear in (B) and (C) respectively of Fig. 7-2. The curves have two peaks with a *dip* or *valley* in between. One peak occurs *below* the resonant frequency and the other *above* the resonant frequency, with the dip centering at the resonant frequency. The wider the separation between the peaks the *greater the bandpass* of the transformer. The purpose of the double peak is to widen the acceptance band of the transformer.

It is to be noted that the top of curve (B) is fairly flat, affording substantially *uniform* amplification for about 3 kc each side of the resonant frequency. In this example, the resonant frequency is 465 kc and the two peaks occur at 463 kc and 467 kc respectively. At the half-power point, curve (B) is almost 10 kc wide whereas curve (A) is only about 3 kc wide. The base of curve (B) also is wider.

Curve (C) is an aggravated case of curve (B) (reflecting an increase in coupling between the primary and secondary windings). The transformer still is tuned to a single frequency, 465 kc, but now the two peaks are separated by 10 kc and the valley at the resonant frequency is quite deep. At the half-power point the bandpass is about 14 kc. The overall height of the curve is reduced, indicating less overall signal transfer. A curve such as (C) is not generally considered satisfactory for a system that is supposed to be flat-topped over, say, 10 kc. The valley is extreme for the overall height of the curve. Of course in the final analysis the determining factor is the shape of the response curve given for reference. The degree of coupling between primary and secondary considered in the design of a tuned transformer determines the separation between the peaks, or if there will be two peaks. Transformers intended to afford some sort of a flat-top peak over a band of frequencies use closer coupling than those which are intended to have a sharply-peaked response curve.

Curves (B) and (C) have *symmetry*. By symmetry is meant like variations each side of the resonant frequency. These occur when (1) regeneration is *absent* from the circuit and (2) both primary and secondary circuits are tuned to the *same* frequency. For that matter, symmetry is present in curve (A) also, and indicates the two conditions mentioned above.

Curves (A) and (B) in Fig. 7-2 are fairly typical of proper alignment of conventional a-m broadcast receivers; curve (B) being more likely to be found as the overall i-f response curve than (A). In this connection, it must be remembered that, with proper choice and adjustment of components, a curve such as (B) can just as readily represent a flat or *broad-band* response over a frequency band of 100 kc as it does 6 kc in this illustration. Also, a response curve like (B) can be the result of a series of response curves for several i-f transformers in a radio receiver. A set of three response curves, consisting of two like (A) and one like (C), will produce a resultant which looks like (B). This is symbolized in Fig. 7-3. The bandwidth of each of these curves contributes to produce the final overall curve. In one case this may be 10 kc. overall, in another it may be 25 kc, and in a third case it may be 100 kc. In other words, a response

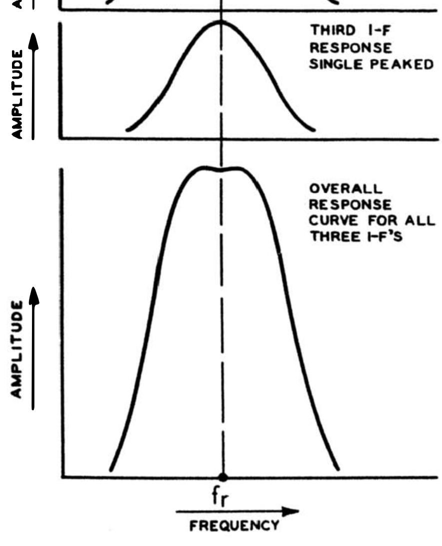


Fig. 7-3. Combination of separate responses to produce desired overall response.

curve shape is not restricted to use over any one particular frequency region.

Broad-Band Response Curves in F-M Receivers

Broad-banding in f-m i-f systems sometimes is done by stagger-tuning. The individual stage response curves may resemble (A) in Fig. 7-2, or more likely the first and third stages in Fig. 7-3, except that the three individual response curves show single peaks at *different* resonant frequencies. These may be 100 kc apart, producing a resultant curve which is substantially flat over a 300-350 kc band, or closer together or wider apart, being determined by the resultant desired. Examples are shown in Fig. 7-4.

Triple-Peaked Response Curves

The broad-band response curve shown in Fig. 7-4 can be viewed as a triple-peaked curve, but other variations of this may be encountered in high fidelity a-m radio receivers. Two examples are shown in Fig. 7-5. Neither (A) nor (B) is really flat-topped, but the valley in (A) and the peaks in (B) are not considered excessive relative to the remainder of the curve. The final amount of valley or peak allowable depends upon the kind of response curve given for reference, and the *curve shaping* which is suggested in the visual alignment notes.

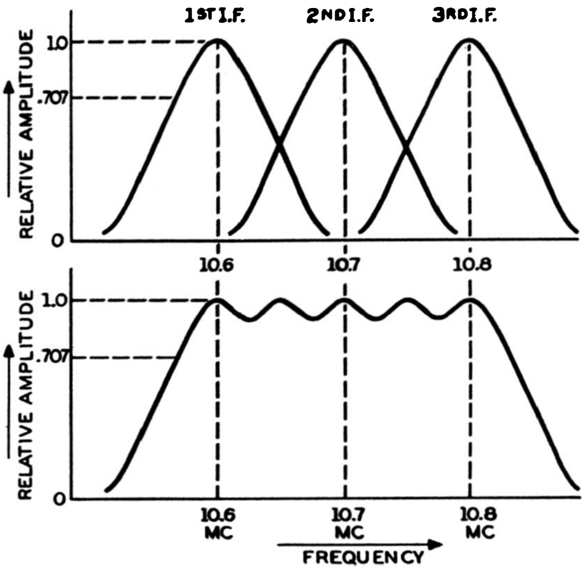


Fig. 7-4. Individual stage response curves for an f-m receiver and final overall i-f curve.

Reading I-F Response Curves

Reading the response curves illustrated in Fig. 7-1 through 7-5 is simple. Inasmuch as the degree of response is indicated by the height of any selected point along the curve above the zero voltage line, peaks indicate greater response than valleys. But an equally important consid-

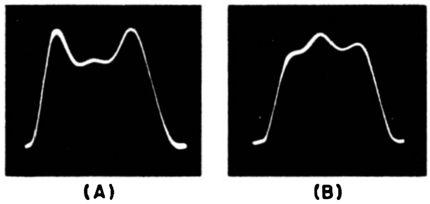


Fig. 7-5. Examples of triple-peaked response curves.

eration is the *equality* of response each side of the resonant frequency point in a-m systems. The distribution of the energy frequencywise in an amplitude-modulated signal is such that the lower modulating frequency components are closer to the carrier frequency (circuit resonant frequency) than the higher modulating frequency components. Frequency distribution for a carrier f_c, which is amplitude modulated at 1, 2, 3, 4, 5 and 7 kc is shown in Fig. 7-6. The highest modulating frequency component is seen farthest away from the carrier frequency f_c. When the circuit passband is flat over a frequency band, all the frequency components within that band receive equal treatment in the circuit or system. This is the case in Fig. 7-6 for 5 kc *each* side of the resonant frequency as shown by dotted line curve *a*. The response is uniform for all frequency components up to 5 kc within the lower and upper sidebands. The 7-kc modulating frequency component present in both sidebands is *rejected* completely by the square response curve.

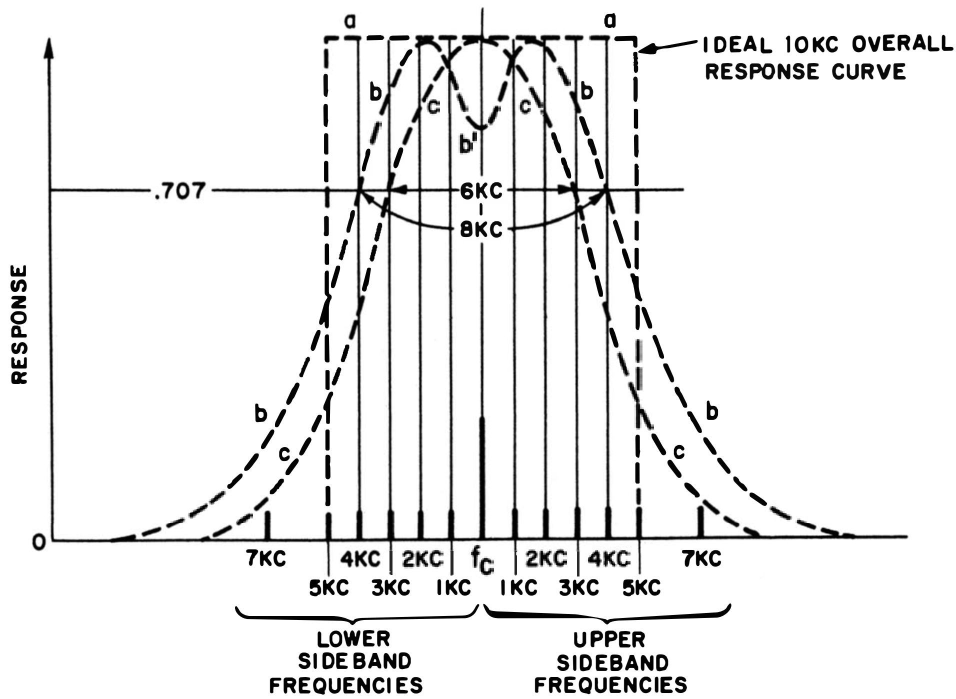


Fig. 7-6. Frequency distribution in an a-m signal with modulating tones of 1, 2, 3, 5 and 7 kc, and ideal and practical response curves.

Fig. 7-7. Examples of use of markers on response curves.

Two other conditions of response are shown by the dotted, double-peak curve *b* and the dotted single-peak curve *c*. Neglecting for the moment the gradually-increasing attenuation as the sides of both curves fall, frequencies located at peaks are accentuated in comparison with those that exist at the bottom of the valley. Hence the response at the resonant frequency f_c for the double-peaked curve occurs at the bottom of the valley *b'*, and is about 30 per cent less than at the peaks which occur about 1.5 kc each side of the resonant frequency. This much dip is just about the extreme and it should not be exceeded. Even so, this double-peaked curve does not represent a system that is affording good response over 5-kc sidebands, let alone 7-kc sidebands. The double-peaked curve *b* is about 8 kc wide overall at the half-power point and the single-peaked curve is about 6 kc wide.

The degree to which attenuation and accentuation cause distortion in the audio signal depends on individual circumstances, and its importance also is determined by the numerous factors which depend on the design and desired capabilities of receivers.

Determination of the frequency corresponding to any point along a response curve displayed on a scope screen is not possible from a simple visual examination. An estimate can be made from a lineal measurement when (1) the resonant frequency is known, (2) its location on the response curve is known, (3) the limits of the f-m signal fed into the circuit are known and (4) the output signal from the sweep frequency generator is linear. But a far more satisfactory and positive method is the use of frequency markers. These can be spotted anywhere along the curve and positive correlation between response and frequency is easy. Examples appear in Fig. 7-7. Markers at the center frequency, and on the skirts of the response curves are shown. Methods of injecting frequency markers are described elsewhere in this book.

Response curves encountered in television receivers[1] are, in a sense, in a special category. This is so because it is necessary to *shape* these curves

[1] It is impossible in a book of this kind to tell the complete story of sweep adjustment of television response curves. The highlights are treated here. It is seriously recommended that reference be made to "TV Sweep Alignment Techniques" by Art Liebscher and "TV Troubleshooting and Repair Guidebook" by R. G. Middleton, John F. Rider Publisher, Inc., N. Y. for full details.

to match a reference pattern, furnished as a part of the service information. Variations found in the different designs used by receiver manufacturers reflect the manner in which design engineers employ their own ideas.

The response curves can be grouped into three classes: (1) those relating to the front ends, (2) those for the i-f systems, and (3) those for the video systems. The sound discriminator in the television receiver is substantially the same as in any f-m receiver, hence comment is reserved until later when the discriminator is discussed. Also since the video system presents considerations which do not parallel the tuned r-f and i-f circuits in the television receiver, comment concerning this portion of the receiver also is reserved for later in this chapter.

The organization of the r-f response curves in television receivers is the same as in any other type of receiver, except for the fact that the bandwidth is very much greater. Similarity does exist between the response curves for the front ends in different VHF television receivers, that is, between the input to the antenna terminals and the grid circuit of the mixer. Typical examples appear in Fig. 7-8 for the twelve VHF channels. Many manufacturers show only two such typical tuner curves for all VHF channels, and then state or illustrate the permissible deviation

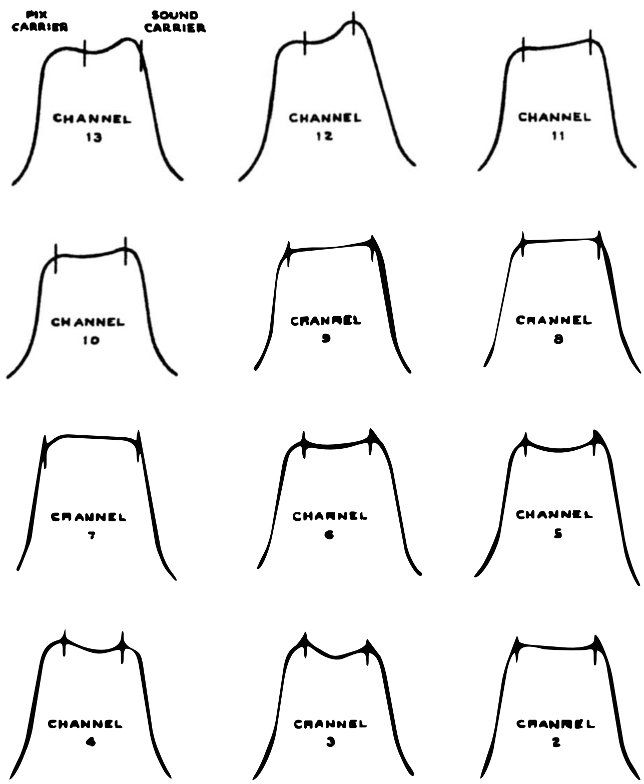


Fig. 7-8. Typical antenna-to-grid response curves for tv receivers. *Courtesy RCA.*

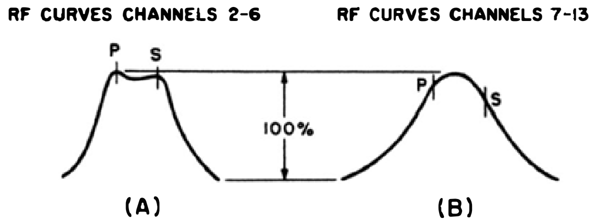


Fig. 7-9. Reference r-f response waveforms for (A) low-frequency, (B) high-frequency tv channels.
Courtesy GE.

from the substantially flat top of each of these curves and the location of the frequency markers. Examples of these single reference curves appear in Fig. 7-9. Curve (A) is for the low VHF channels and curve (B) is for the high VHF channels. As is readily evident, curve (A) resembles the curves shown in Fig. 7-8, but curve (B) is seen to have a single peak that is fairly broad. The normal markers appear as slight disturbances along the response curve. Whether the front-end tuner response curves for the different channels are like those in Fig. 7-8 or as in Fig. 7-9 is a matter of individual receiver design. Determining which shape applies in a given case is no problem because reference curves which must be matched by the receiver performance are invariably given for guidance.

The practical approach to the shape of the VHF front-end tuner response curve recognizes that the symmetry present in the double-peaked curves of Fig. 7-8 and 7-9 may not exist. Instead a decided tilt may be encountered; in the one peak being lower than the other. A difference of not more than 30 per cent in amplitude between these peaks is permissible, provided that the amplitudes of the picture and sound carrier locations along the curves are *above* the minimum amplitudes illustrated in Fig. 7-10 (A). For that matter, if the peaks are of similar amplitude the

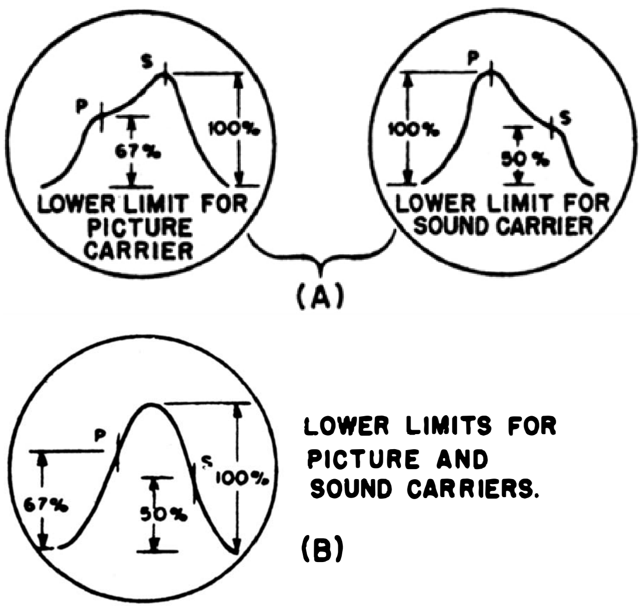


Fig. 7-10. Allowable deviations in the response curves of (A) low-frequency and (B) high-frequency channels.
Courtesy GE.

depth of the valley in between cannot exceed 30 per cent of the maximum amplitude.

In the case of the single-peaked response curve over the high VHF channels as shown in Fig. 7-9(B), the permissible deviation from the ideal should not exceed the limits shown in Fig. 7-10 (B). The sound carrier frequency location should not be below 50 per cent of the maximum amplitude of the curve, and the picture carrier frequency location should not be below 67 per cent of the maximum amplitude of the curve.

In a sense, the curves shown in Fig. 7-8 and 7-9 are the *ideal* shapes. These are obtained when both operating and testing conditions are correct.

UHF tuner response curves are organized like VHF tuner curves, but differ in outline and in the passband. Whereas the separation between the picture and sound carriers is 4.5 mc, the very much higher frequency of operation results in a circuit which has a wider bandpass than in the case of the VHF. This is because selectivity of a circuit is in terms of *percentage* of center frequency, and the same passband used for VHF channels would be too small a percentage of center frequency to be practical. Thus in practice the UHF tuner response width is between 30 and 40 mc near the bottom of the curve, although it is only about 5 or 6 mc at the half-power point. As a rule the UHF tuner response curves for each channel are single-peaked and the peak is fairly well rounded over the region where the sound and picture carriers are located. Examples of normal UHF tuner response curves for three widely-separated channels are shown in Fig. 7-11.

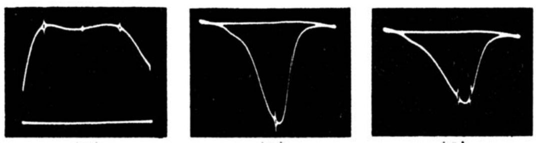

(A) (B) (C)

Fig. 7-11. Some normal UHF tuner response curves.

Reading VHF and UHF Tuner Response Curves

Tuner response curves are read in exactly the same manner as any other curves for resonant circuits. One other consideration is native to television receivers. Because of the broad-band condition of television receiver tuner systems it is conceivable for the shape of the curve to be correct yet the locations of the picture and sound carriers on the curve may not be correct. Television receivers oftentimes contain several interference traps in the input system, and incorrect adjustment of these can materially affect the shape of the curve. It might be well to mention here that the bias normally applied to the tuner tubes has a major effect on the shape of the tuner response curve; the bias applied during response

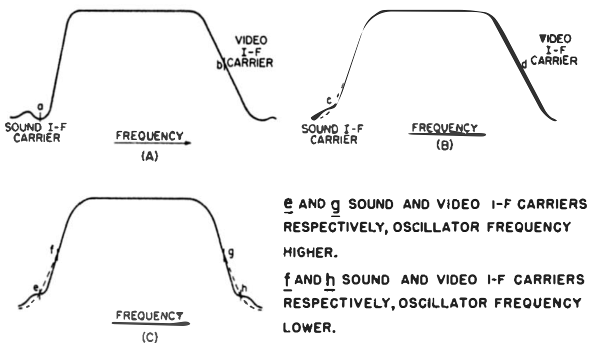


Fig. 7-12. Ideal overall video i-f response curve: (A) for the conventional type of receiver; (B) for the intercarrier type of receiver; and (C) for the intercarrier type which tunes above and below the incoming signal.

curve checks must be the same as used for normal operation of the system.

While it is true that the most important detail in tuner response curves are the locations of the picture and sound carriers on the curve, the bandwidth of tuner also is important. This is why it is necessary to determine the frequency limits of the tuner response by positioning markers near the zero voltage points and working upwards along the sides. When means are provided for altering the bandwidth, it will be noted that the locations of the picture and sound carrier points shift in amplitude with changes in passband. Excessive bandwith impairs tuner selectivity and may cause trouble from an adjacent channel.

Television Receiver I-F Response Curves

The organization of i-f response curves is like those already described. As far as shape is concerned, the television receiver video i-f amplifier response curve, (which includes the sound carrier in the intercarrier receiver) is not symmetrical. As a matter of fact, it may exist as any one of a variety of curves, depending upon the model of the receiver. The curve is broadband and when representative of the overall r-f and i-f response is typified by Fig. 7-12 (A) and (B). These are *ideal* curves for purposes of illustration and explanation. The practical curves for each receiver must be *shaped* to match the reference curves given in the receiver manufacturer's service literature.

Certain details are general. As a rule the sound carrier location along the curve is down very low on the curve, being never more than 10 per cent of maximum. The marker may be invisible unless the gain of the scope is high. The picture carrier on the other hand generally is located approximately 50 per cent down the slope. The bandwidth of the television receiver i-f response is not evaluated on the basis of the half-power point. It is strictly a matter of locating certain frequencies (picture and sound carrier and traps) at certain points and at certain levels along the curve. The frequencies of these signals differ in different receivers. All that is standard is the 4.5-mc separation between sound and picture carriers. Typical response curves of receivers having intermediate frequencies in the 20-mc region are shown in Fig. 7-13, while curves for receivers with 40-mc intermediate frequencies appear in Fig. 7-14.

Concerning the individual i-f stages, the response curves are even more singular in shape for each receiver than the overall curve. The contribution made by each stage to the final overall response is very special, hence few meaningful comments of general benefit can be made. It is imperative that shaping be done as required by the receiver manufacturer and stated in his service literature. The complete lack of symmetry in these curves is attributable to the presence of traps, different locations in the i-f strip circuit, different number of stages in different makes and models of receivers, different orders of gain in each stage, etc.

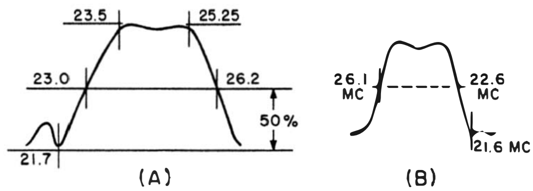


Fig. 7-13. Typical response curves for receivers with 20-mc intermediate frequencies.

A trap adjustment always produces a *dip* in the response curve. Its location along the frequency scale is determined by the frequency to which it is adjusted. Misadjustments due to vibration, aging, etc. can occur, hence it is not unusual for a trap to be active at a wrong frequency and so produce the dip at the wrong point along the frequency scale. The location of the picture carrier along the overall r-f/i-f curve strongly influences the quality of the picture and the general behavior of the receiver. This is so in all receivers. It can affect the waveform of the video voltages fed to the picture tube, as well as the synchronizing voltage waveforms, hence the synchronizing action in the receiver.

Discriminator "S" Curves

The discriminator used in f-m receivers and as the demodulator in television sound channels converts an f-m signal into a conventional a-f

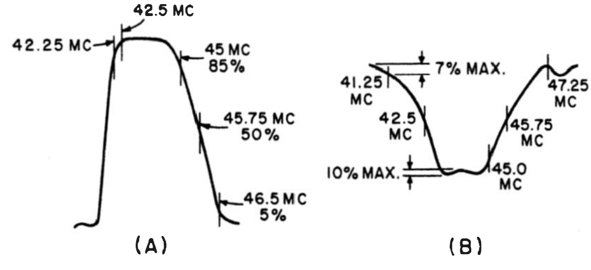


Fig. 7-14. Examples of i-f response curves in receivers with 40-mc intermediate frequencies. *(A) Courtesy RCA; (B) Courtesy GE.*

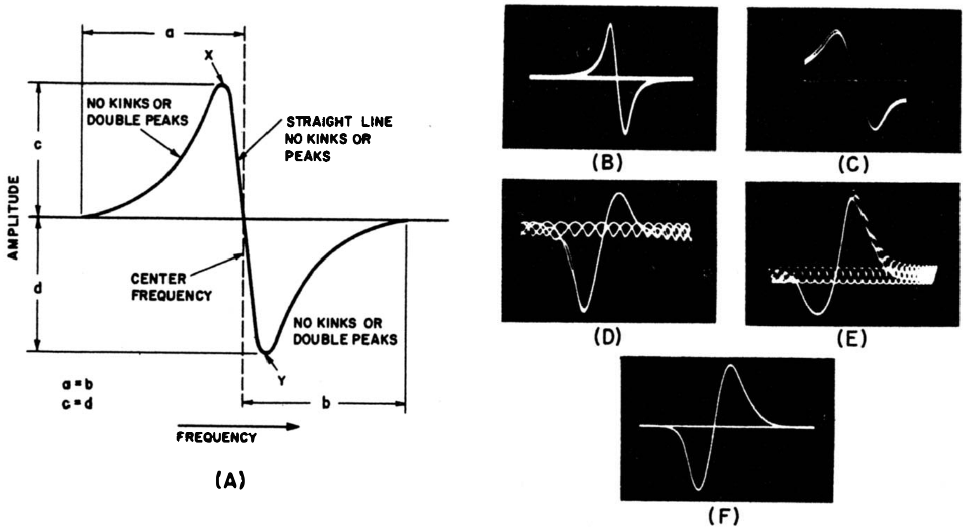


Fig. 7-15. Discriminator "S" curves.

signal. Adjustment of this system, or for that matter a check on the adjustment of the system, is made with a specially-shaped curve generally identified as an "S" curve as a reference standard. Its correct features are identified in Fig. 7-15(A). Variations from this correct version may be due to a variety of conditions, such as incorrect tuning of either the primary or secondary circuits of the discriminator transformer, or improper frequency adjustment of the i-f system ahead of it.

An "S" curve with the features indicated in Fig. 7-15 (A) is considered linear. There is very little difficulty identifying the important features with the exception of the frequency of the crossover point. Inasmuch as amplitude of response reads along the vertical dimension each side of the reference axis, the crossover point corresponds to zero voltage output, hence it is extremely difficult to see a marker at this point. (Some idealized drawings of "S" curves show a marker at the crossover point.)

Another item of interest relative to differences between the ideal and the practical is that the equality between *a* and *b* in Fig. 7-15 is only approximated in the practical. The same is true of the heights *c* and *d*, although care in adjustment of the i-f transformers ahead of the discriminator, and the discriminator as well as the manner of connecting the test equipment and the scope can produce a close approach to the ideal. An example is shown in Fig. 7-16 (B).

The peak-to-peak frequency difference of the discriminator system is determined by means of markers spotted at *x* and *y* shown in Fig. 7-15 (A). This difference corresponds to the sum of the maximum frequency deviation each side of the carrier that is permitted for the signal.

If the deviation in the test signal exceeds the overall passband of the i-f system feeding the discriminator or the latter, the sides of the curve will not rest on the zero axis and the curve will resemble *c* in Fig. 7-15. Interestingly enough this display shows the appearance of the "S" curve when a modulated 4.5-mc marker is used. The modulation reduces to zero in the vicinity of the crossover point when the location of the latter is correct.

If the sound i-f signal fed into a discriminator system bears audio modulation, the adjustment of the "S" curve is aided by noting the presence of the demodulated audio signal. Minimum audio signal appears on the scope screen when the "S" curve is correctly adjusted. Three conditions of adjustment appear, (D), (E) and (F) in Fig. 7-15. Curves (D) and (E) are for incorrectly-adjusted discriminator transformers, whereas (F) indicates correct adjustment. Note the presence of audio modulation in the curves (D) and (E) and the absence of modulation in (F).[2]

Numerous conditions may account for the inability to obtain an "S" curve with acceptable features. These are discussed later in this book.

Audio-Video Response Curves

Response curves representative of audio and video systems are similar in organization although they appear different when seen on a scope screen. These curves show a voltage-frequency relationship, with response being indicated in the vertical dimension and frequency in the horizontal dimension. The difference in operating frequency range in the two categories of curves accounts for the difference in appearance. Whereas the audio frequency curve is formed by the processing of voltages that are

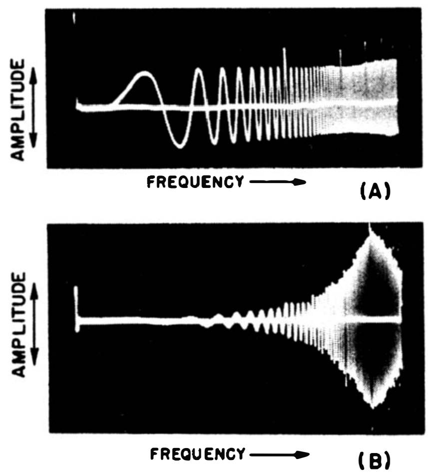


Fig. 7-16. Examples of visual a-f response curve, depicting (A) flat response and (B) circuit resonant at 3000 cps. *Courtesy Clarkstan Corp.*

[2] Very complete discussions of "S" curve development and cases of trouble are to be found in "TV Sweep Alignment Techniques" by Art Liebscher, and in "TV Troubleshooting and Repair Guidebook" by R. G. Middleton. Both books are published by John F. Rider Publisher Inc., N. Y., N. Y.

within the acceptance capabilities of the vertical amplifier of every scope, that is from about 16 cps to 20,000 cps, the video amplifier frequency range is very much greater. It starts at around 60 cps or lower and extends upward to an upper limit of from 3 to 4.5 mc. Obviously the frequency range used for video system checking exceeds the acceptance capabilities of many test scopes. Hence the development of these two kinds of response curves is accomplished by different methods.

Audio Frequency Response Curves

The usual scope display of an audio frequency response curve is developed by generating a test signal which is constant in amplitude but changes in frequency over a predetermined range. This is fed into the system under test, whose output audio voltage is fed directly to the vertical amplifier of the scope. The horizontal deflection or timebase voltage required for the scope display is secured from the sweep frequency audio generator. Thus the change in frequency taking place in the generator and the timebase voltage in the scope keep step throughout the range of frequencies supplied to the amplifier under test.

A typical response curve as seen on the test scope screen is shown in Fig. 7-16 (A). The overall range of frequency shown is from 40 to 10,000 cps. The uniform *height* of the cycles indicates that the amplifier response is substantially flat from the lowest frequency to the highest frequency. The "pips" which appear at different points on the positive peaks are frequency markers, in this case being located at 1, 3, 5, 7, 9 and 10 kc points. The baseline is useful for determining relative amplitudes of the output voltage. It corresponds to the zero voltage baseline in the ordinary response curve display, except that in this case, both the positive and negative cycles of the voltage are displayed, hence a pattern exists above and below the zero voltage baseline. This is not too important; what matters is the *pattern* of the outline relative to the zero voltage baseline, and in this respect, it is sufficient to examine the upper outline. The lower outline is exactly the same, except for being upside-down.

Uniform height throughout the trace indicates uniform amplification; *peaks* in the outline (excluding the frequency marker pips) indicate *accentuation* of the frequencies in the region of the peak, and *dips* or *valleys* indicate *attenuation* of the frequencies at those points. Thus it is possible to not only determine the voltage-frequency behavior of a system as a whole, but to display instantly the frequency characteristic of audio frequency filters or networks which are added to a system. For instance, Fig. 7-16 (B) illustrates voltage-frequency characteristic of an *LC* circuit that is resonant at 3000 cps, this being indicated by the peak at this frequency and the dropoff on both sides. Defective conditions are indicated by the difference between the observed outline and the proper outline as intended in the design of the device.

Scope observations of this kind differ from the use of a square waveform voltage for testing the behavior of an audio system. Whereas the latter test affords information concerning general frequency behavior and phase shift, the sweep frequency method is far more informative on an individual frequency basis, but also is more elaborate. However, it is much more limited in the frequency range that it can cover.

As to the desired outline of such presentations, there is no ideal; it is determined strictly by the response designed into the equipment. This is especially true when filters or corrective networks are being checked or when they are part of a system. The most common desired frequency characteristic is *flat* response throughout the frequency band normally handled by the amplifier. When it is something other than this characteristic, reference information is provided for comparison purposes.

Video Frequency System Response Curves

Video system frequency response curves are developed in a manner similar to that used for conventional tuned circuits, as for example during alignment operations. One difference is that the relative frequency band over which the response is determined, compared to center frequency, is wider than for the ordinary tuned circuits. Another is the low frequency limit. As a rule this is in the vicinity of about 60 cps and the high frequency limit is up in the megacycle range. Accordingly the method of developing the scope display is to feed into a system a frequency-changing signal that theoretically has a zero frequency low limit and the required high frequency limit. Then the output voltage from the system is rectified and fed to the vertical deflection plates of the scope. The sweep voltage for the scope is secured from the sweep generator. The final result is a trace typified by Fig. 7-17(A). Response is indicated in the vertical direction and the frequency is shown in the horizontal dimension. As in the case of the usual response curve, scope displays do not bear frequency designations, hence the frequency corresponding to any point along the response curve must be determined by the use of frequency markers which are injected into the system under test. Four markers are shown in curve (A).

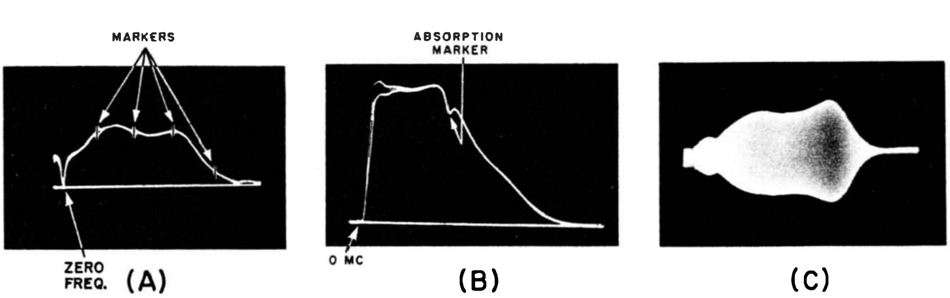


Fig. 7-17. Typical video response curves.

Two kinds of frequency markers are in use; one is a signal and this causes a disturbance along the outline of the response curve as shown in (A). The other kind of marker is a variable frequency tuned circuit which "sucks" energy from the circuit at the frequency to which the marker is tuned. It is called an "absorption" marker. Its effect on the response curve is shown in curve (B). As can be seen, the absorption marker behaves like a trap circuit and causes a *dip* in the response curve at the "marked" frequency. Too much "suck-out" impairs the usefulness of the technique.

A third form or video response curve is shown in (C) in Fig. 7-17. This is not commonplace but will occasionally be encountered. It differs from curves (A) and (B) in one significant fashion; the signal output from the system under test has *not* been demodulated, hence the individual cycles of the sweep frequency voltage are being fed to the scope and appear on the screen. The individual cycles cannot be seen because the horizontal dimension of the trace does not permit spreading it sufficiently to show the great many cycles present in a range of frequencies from say 0 to 3.5 mc. So the upper *outline* of the envelope relative to an imaginary baseline which divides the trace horizontally is used as the indicator of the response. Frequency markers can be injected in the usual fashion and they will cause a disturbance in the trace.

The display shown as (C) is not popular on two counts. First because it requires extended frequency response in the vertical amplifier of the scope. Whatever is the upper frequency limit of the band of voltages which are supposed to be passed by the video amplifier must be accepted by the vertical amplifier of the scope. Second, the location of frequency markers is very difficult to identify. On the other hand, the demodulated type of presentation is possible with vertical amplifiers of very limited frequency response, because the signal fed into the vertical amplifier varies at the *sweep* rate—usually only 60 cps times the number of significant variations across the response curve.[3]

What is an ideal video response curve? It all depends on the individual circumstances. However, several general comments can be made. For example, in intercarrier television receivers the upper frequency limit of the video response curve is generally not higher than between 3.75 mc and 4.0 mc. If anything, the limit is even lower than 3.75 mc because every attempt is made to keep the 4.5-mc sound signal out of the video amplifier, hence out of the picture.

The outline of the video response curve which affords the necessary frequency bandwidth in the amplifier also must minimize phase shift in

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[3] Extremely interesting techniques for developing video response curves are explained in "TV Sweep Alignmnt Techniques" by Art Liebscher, published by John F. Rider, Publisher, Inc., New York, N. Y.

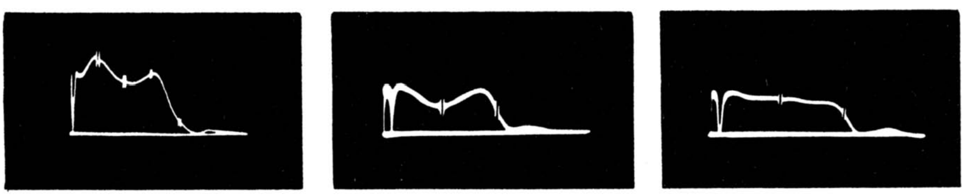
the signal frequency components. Thus two conditions must be satisfied. Just how they are satisfied is a function of the thinking of the receiver designer. He decides the frequency or frequencies at which the amplifier will be *peaked* so as to satisfy the required bandwidth. Because of the similar conditions of design which face different receiver designers, such peaking usually occurs at the upper end of the frequency band, hence some sort of rising characteristic appears in the response curve in the region between 2 and 3 mc—but not always.

An important point is that the dropoff of the curve is gradual rather than steep, at both the high-frequency and low-frequency ends, thus avoiding phase shift. It is fairly general practice not to peak the low end, although occasionally this is done.

Understandably all receivers that use a cathode tube display element are not used for television, hence the video amplifier response limits cannot be firmly established as being the bandwidth used for television. Regardless of the function of the receiver, the limitation of video frequency response and phase response limits detail in the picture.

Few video amplifiers are operated with very high peaks anywhere along the general outline of the response curve, especially when the remainder of the curve is fairly flat. The same is true about undue dips or valleys in the curve. Both of these features indicate improper response.

Excessively wide passband, as noted by the markers placed on the video response curve, also should be suspect. The conditions of peaking are subject to change in the event of component failure and it is not uncommon for the resonance peak to change to a higher frequency than originally planned for, and so introduce complications, such as 4.5-mc buzz voltages in the picture of a television receiver. Unfortunately failure of the peaking systems in video amplifiers does not necessarily manifest itself in a positive fashion in the cathode-ray tube displays, although it does affect the video amplifier response curve. But because there are no generalized and standardized video response curves to use as standards, it is difficult to evaluate what one sees on the test scope screen unless the response curve shape is completely bad, or unless a suitable reference curve is available. To illustrate the point being made, Fig. 7-18 contains



(A) (B) (C)

Fig. 7-18. Reference video amplifier response curves.

a variety of reference video amplifier response curves representative of conditions in several brands of television receivers. All of these are normal and offered by the manufacturers as reference curves for guidance of service technicians.

Sweep Generator Output Voltage Curves

The accuracy and usefulness of a response curve depend (among other things) upon the quality of the signal generator. The latter must deliver a signal whose amplitude is constant over the entire sweep range; otherwise variations in the response curve of a tested equipment cannot be identified solely with that equipment, but may arise from deficiencies of the generator output. For this reason, it is often desirable to check a sweep generator output voltage characteristic over its sweep range.

Although this subject relates to a device rather than to a response curve, the trace which illustrates the signal voltage vs. frequency output of a sweep generator has an appearance similar to a response curve, hence is discussed here.

The process of developing this scope display requires (1) termination of the generator output cable by the correct load resistance equal to the rated output impedance of the generator, (2) the use of a nonresonant demodulating system such as a crystal diode or a vacuum tube diode for rectifying the signal available from the generator. The rectified output then is fed to the vertical amplifier of the scope. The blanking voltage *is secured from the sweep generator,* the sweep voltage for the scope is secured from the generator or internally from the scope.

Two types of sweep-output-voltage-vs.-frequency characteristics are encountered in sweep generators. In one of these, the frequency of the signal varies both sides of a center frequency, the latter being the mid-frequency of the circuit being tested. The frequency range covered is determined by the sweep width control on the sweep generator. Mainly we are concerned with generators used for checking television receiver circuits. In these the sweep width is variable from several mc to about 20 or 30 mc.

At the moment, the exact frequency bandwidth of the signal is unimportant because the organization of the signal voltage-vs.-frequency curve is the same for all bandwidths. Inasmuch as the demodulator system is nonresonant whereas the sweep generator signal for any one sweep width and center frequency setting has a finite bandwidth, the resultant curve does not normally fall to zero, unless the output falls to zero. Hence the curve does not have skirts. The limits of the response curve trace join the zero voltage baseline (developed by the blanking voltage) by thin vertical lines.

Examples of such curves appear in Fig .7-19. The relative amplitude of the output voltage is indicated by the height of the curve above the

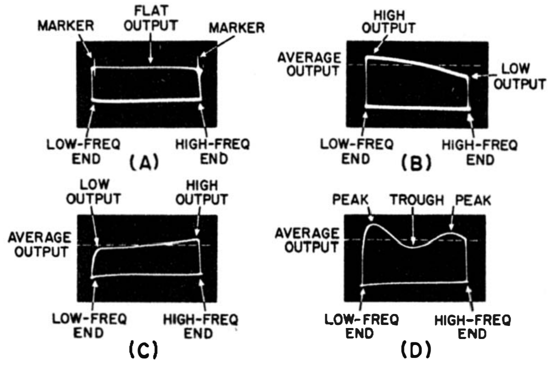


Fig. 7-19. Sweep generator voltage output curves.

baseline. The frequency scale is oriented in the horizontal direction with the limits of the sweep being indicated by the left and right limits of the trace. The frequency of any point along the curve must be determined by means of frequency markers. If markers are located at the two extremes of the curve, [see (A)] the overall sweep width is the frequency difference between them. As a general rule, the low frequency end of the swept band is located at the extreme left hand edge of the response curve and the high frequency limit is located at the extreme right hand edge of the response curve.

Four types of voltage-vs.-frequency curves are shown in Fig. 7-19. In (A) the curve is "flat", by which is meant that the output voltage is constant at all frequencies within the band being swept. In (B) the output *decreases* as the frequency *increases,* giving a downward tilt to the trace. In (C) the reverse of (B) exists—that is, the output *increases* as the frequency *increases.* In (D) the output is irregular with a pronounced peak over a region of frequencies.

The above four curves are symbolic and are not meant to apply to any one group of sweep generators. The important point is that the desired type of output curve is that in (A), that is, with a flat output. A slight amount of irregularity does little harm, although it must be remembered that if an attempt is made to locate the frequency markers amplitude-wise on equipment response curves by adjusting the curve amplitude, compensation in the location of the markers along the curve must be made so as to correct for the lack of "flatness" in the sweep generator output. The order of compensation is the inverse of the varience from flat output of the generator. If the output at any one frequency is "down" or "up" by 10 per cent relative to the average output, that frequency location on the equipment response curve must be raised or lowered accordingly by 10 per cent along the equipment response curve.

The second variety of sweep generator output-vs-frequency curve is shown in Fig. 7-20. The basic organization of the curve is the same as for

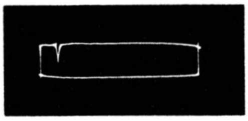


Fig. 7-20. Sweep generator output curve with zero-frequency gap at left.

Fig. 7-19, that is the output is indicated by the height of any position along the curve relative to the baseline. There is one major difference however. The low frequency limit of the bandwidth covered now is *zero* frequency, indicated by the abrupt dip in the curve to the zero value. The high frequency limit is set by the design of the sweep generator, usually 4.5 mc, but since the demodulator system is nonresonant the high end of the output curve does not fall to zero. It ends abruptly and joins the zero baseline by a thin vertical line, which sometimes is not seen in the scope display. The output curve should be flat except for the zero frequency point.

In the figure, the generator center frequency is adjusted to just below the center of the sweep range, so that when the scope retraces to the left side, the swept frequency has not quite reached its highest value. The generator sweep cycle is then completed near the left edge of the trace, after which the zero frequency "notch" occurs.

Voltage-vs-Frequency Curves for Demodulators

The technique used for determining the voltage-vs-frequency characteristics of a sweep generator is duplicated for determining the voltage-vs-frequency output characteristic of a demodulator, as for example a crystal probe. The only difference is the requirement that the generator output must be "flat" over the frequency range used for the tests. If this is so, then the voltage-vs-frequency characteristic curve displayed on the scope screen is the response curve of the demodulator. Inasmuch as the output circuitry between the sweep generator and the demodulator system is not resonated, the voltage fed to the diode contains all the components delivered to it by the generator. In other words, the voltage active on the diode is made up of the fundamental frequency to which the sweep generator may be momentarily tuned during the sweep in frequency, and whatever *harmonics* also may be present.

A word of caution is voiced here in conjunction with the use of a crystal probe. In view of the connections which are made to crystal diode probes, lead lengths, etc. it is conceivable that some order of resonance in the system can adversely affect the shape of the curve.

It should be noted that neither the generator nor the demodulator can be checked if the response of one is not known. If a given demodulator is to be used to check a generator, its characteristics must first be determined by independent means, such as check against another generator of known characteristic, or comparison with another demodulator of known response.

Response Curves of Lead-ins and Baluns

The response curves developed when checking the performance of lead-ins and "baluns" with a sweep generator and a crystal diode are organized in the same fashion as those shown in Fig. 7-19 and 7-20. The response at frequency points within the channel bandwidth is indicated by the height of the frequency point above the reference zero voltage baseline. Valleys and dips are undesired, the ideal condition is a straight horizontal line over the channel bandwidth.

If the voltage-vs-frequency response curve of an antenna lead-in system or balun, with or without receiver antenna input connection, shows a deep valley at some frequency point within the bandwidth of the television channels, or within a tuning band of a radio receiver, the response is greatly reduced over the frequency region spanned by the valley. This condition will be evident in the resultant i-f signal after mixing; that is, if the dip occurs at that frequency point which falls within the i-f signal bandwidth. In the absence of a signal at this frequency point, ahead of the mixer, there will occur a lack of signal, corresponding to that frequency in the i-f signal. Peaks in the curve accentuate signals corresponding to the peak frequencies and these same peaks are found in the resultant i-f signal.

Chapter 8

MANIPULATION OF SCOPE CONTROLS FOR DISPLAY

The ability to use the scope depends on three factors: (1) knowing where to connect the scope, (2) knowing how to manipulate the controls so as to develop the most useful display on the screen, and (3) knowing how to "read" the trace which appears on the scope screen. Satisfying these three requirements is the objective of this book.

In order to attain the goals set forth, we shall assume that the reader of this book is familiar with the general purposes of the cathode-ray test scope. Also that past experience plus information available in the instruction bulletins issued by the scope manufacturers has given the reader some background concerning the general organization of the scope, and has created some order of familiarity with the identity of the controls found on this variety of test instrument. In other words, we shall not give space to a basic explanation of how a scope operates.

We shall, however, devote a few pages to a review of certain features of scopes in general, mainly those which have a definite bearing on the *readability* of the trace on the screen. The ease of interpreting a scope display is influenced by how readily the features of the display are recognizable. This in turn is aided or hindered by familiarity with the correct manipulation of the controls or by the lack of it. This chapter is devoted to scope controls and their handling, to the names (sometimes more than one) assigned to each control, and to the adjustments required for best screen display. A variety of test scopes are shown in Fig. 8-1.

The Beam Intensity and Focusing Controls

The *beam intensity* and *focusing* controls are basic factors influencing the usefulness of the scope because they control the *brightness* of the spot on the screen, therefore the trace as a whole, and the *sharpness* of the display. By sharpness is meant that property of a scope trace or pattern which makes it appear as a well defined line so that its features and characteristics are readily seen. The trace must be formed from a thin, bright line, hence the *undeflected* spot of light must be a tiny, round,

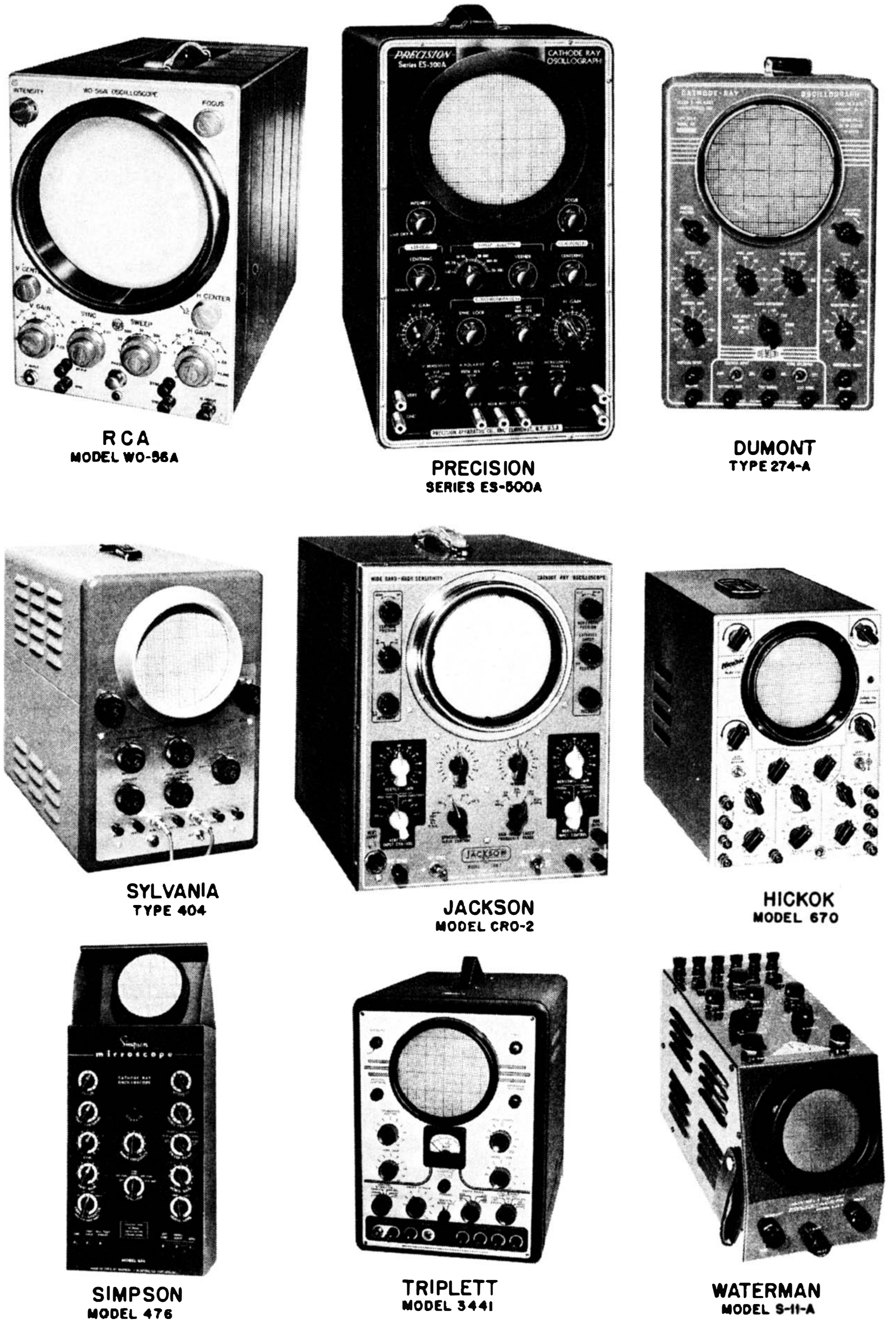
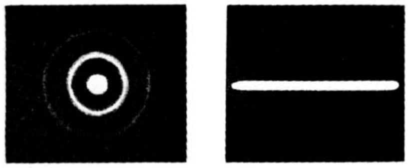


Fig. 8-1. Typical test scopes.
Photos are reproduced through the courtesies of the manufacturers named above.

(A) (B)

Fig. 8-2. Properly-focused dot (A) and horizontal line trace (B).



(A) (B)

Fig. 8-3. Result of excessively high brightness control adjustment.

bright dot. An example is shown in Fig. 8-2 (A). The same dot in motion and forming a horizontal line is shown in (B) of the same figure.

If the intensity control is advanced too far, the spot becomes very bright, and surrounded by a halo as shown in Fig. 8-3 (A). If this over-intense spot is caused to move across the screen by, say, the horizontal sweep voltage, the resultant line is thick with poorly defined boundaries. Any trace made with a spot of this kind would have many of its important features masked. In other words, the adjustment of the intensity control and the focusing control must be made with due regard to the requirements of the ultimate trace.

Poor focusing, even with properly-controlled brightness, causes a badly-shaped spot which will produce a line similar to Fig. 8-3 (B) and thus impair usefulness of the trace. Examples of incorrect focusing appear in Fig. 8-4 (A) and (B). The dot is large and fuzzy, or it may be elliptical and lying on its side or upright, or it may resemble a half-moon.

On rare occasions, the final result of intensity and focusing control adjustment is a misshapen dot, something which looks like a four-leaf clover, such as in Fig. 8-5 (A). It indicates hum inside the scope, usually in the power supply, or possibly in the vertical amplifier system. To prove the point, causing the spot to move by applying the horizontal sweep voltage will produce a trace like (B), that is, if hum is present inside the scope. If it is power supply hum, using the 60-cps line sweep will make the pattern stationary and show the frequency.

A scope subject to the difficulty shown in Fig. 8-5 is not usable until the trouble is cleared up.

(A) (B)

Fig. 8-4. Poorly focused beam spots.

(A) (B)

Fig. 8-5. Effects of hum from the scope, (A) on beam spot and (B) after sweep voltage is applied.

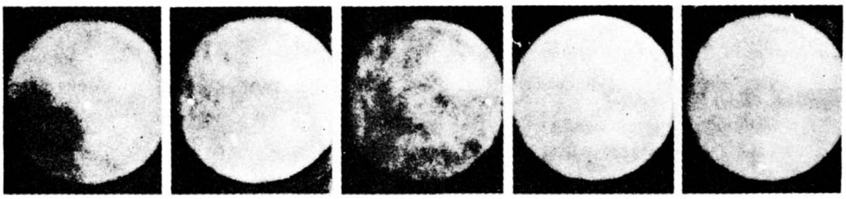
The intensity and focus controls react on each other. The adjustment of one usually calls for an adjustment of the other. Moreover, if the intensity has been adjusted for best undeflected spot, an increase in intensity may be required when the spot is placed into motion. The stationary electron beam excites the screen much more than the beam in motion because the energy in the latter is spread over a greater screen area. Maximum useful brightness is limited to that luminosity which is attainable with the properly-focused beam. Attempts to increase it beyond this amount will impair rather than aid readability.

The name assigned to the control which adjusts beam intensity is different in different scopes, and may be any one of three. These are *Intensity, Brilliance* and *Brightness.* The control which adjusts focus is always called *Focus.*

In some scopes, inability to obtain uniform focus when the electron beam is in motion can be overcome by adjustment of the *Astigmatism* control. As a rule this control, if provided, is located inside the scope.

The Beam Positioning Controls

These controls provide for positioning the electron beam in any desired part of the screen. Five examples of undeflected beam positioning are shown in Fig. 8-6. Spot position in (A) is the undeflected location at the center of the screen; (B) and (C) show changes of beam spot position due to adjustments of the *horizontal positioning* control, and (D) and (E) illustrate the same for adjustments of the *vertical positioning* control.



(A) (B) (C) (D) (E)

Fig. 8-6. Spot positions showing effects of adjustments of positioning controls.

Positioning of the undeflected beam is necessary in order that the display be properly distributed over the screen. Normally, the vertical and horizontal gain controls are set so that the entire display appears within the boundaries of the screen. But there are times when the size of the trace is adjusted so as to exceed the screen dimensions, so that one small part of the trace can be examined in detail. With such an expansion, the peaks of the display may be located near the upper or lower edges of the screen—beyond the curvature. The curvature of the screen tends to blur the trace. To clear the display, the vertical positioning control is used to raise or lower the whole trace, and so bring any desired portion into the unblurred position. Views of (A) the top portion of a

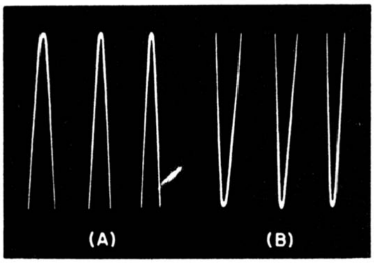


Fig. 8-7. Top (A) and bottom (B) portions of a single expanded sinewave trace. The portions can in this way be examined in greater detail than when one smaller trace including both is used.

trace and (B) the bottom portion are illustrated in Fig. 8-7, using a sine waveform voltage as the trace.

A variety of names are assigned to positioning controls. The vertical control is identified by a two-word expression. The first word is either *Vertical, Vert, V* or *Y;* the second word is either *"positioning"* or *"centering."*

Distortion of the trace may result if the positioning controls are advanced too far. The scope's sawtooth sweep waveform becomes nonlinear. Naturally any nonlinearity of the sweep will affect the display. Nonlinearity is discussed in detail in the chapter devoted to sawtooth waveforms.

The Vertical Deflection Amplifier Gain Controls

The vertical deflection amplifier gain controls determine the amount of signal applied to the first tube of the amplifier, and thus determine the amount of deflection voltage applied to the vertical plates.

Some scopes have a dual form of vertical gain control—a continuously variable control and a step attenuator; others have only the former. However controlled, the height of the pattern is optimum when it occupies between ½ and ⅝ of the total height of the screen. The reason for this limit is that the natural and convenient width of the trace is somewhat greater than its height. Thus to fill out the horizontal dimension of the screen and still maintain proportion, the height must be less than that of the screen limits.

Two examples appear in Fig. 8-8 and 8-9. In the former, the trace is vertical deflection only. In (A) the vertical deflection gain control is at zero; in (B) it is set too low, whereas in (D) it is advanced too far, thus driving the limits of the trace beyond the screen. The proper proportion for one complete view, as usually required, is shown as (C).

In Fig. 8-9 are shown different trace heights for a display that contains the horizontal deflection also. Although the horizontal dimension has not been discussed, it is evident that while trace (A) is readable, the proportion between height and width is not correct; a more appropriate height appears as trace (B), whereas excessive height is shown in (C). The features of the waveform are much more distinct in (B) than in (A). It is obvious that important characteristics of the display are not readily discernible in (C).

The ability to *measure* the amplitude of a waveform, for that matter even portions of a waveform, is dependent on the vertical dimensions. It would not be difficult to measure the peak-to-peak amplitude of the waveform (A) in Fig. 8-9, nor for that matter, the amplitude of the transient oscillations, but both measurements would be very much easier with trace (B) or (C). Thus the proportioning of a trace is in a way determined by what the objective is—amplitude measurement or just general examination of the display. In the case of the former, any proportion which locates the entire trace on the screen without extending into the curved portions is satisfactory.

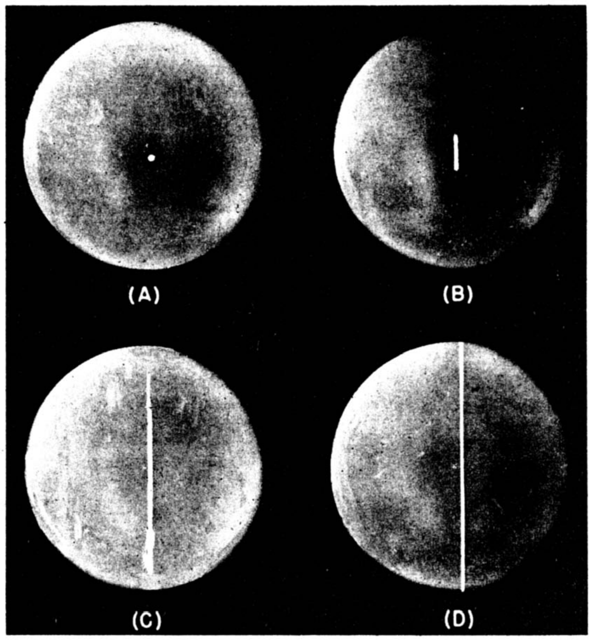


Fig. 8-8. Effect of adjustments of vertical gain control.

In this respect, it is essential to bear in mind that the vertical amplifier can be *overloaded,* in which event the usefulness of the scope as a device for examining the behavior of equipment in terms of waveforms is defeated. The gain controls are, as a rule, located at the input to the amplifier, and advancing the gain control is the equivalent of passing into the amplifier a signal of progressively increasing level. While it is true that most scopes are so designed that overloading does not take place while the display amplitude is within the confines of the screen (and in some cases substantially beyond the screen limits) it is nevertheless possible in certain others to overload the input stage or the one which follows it.

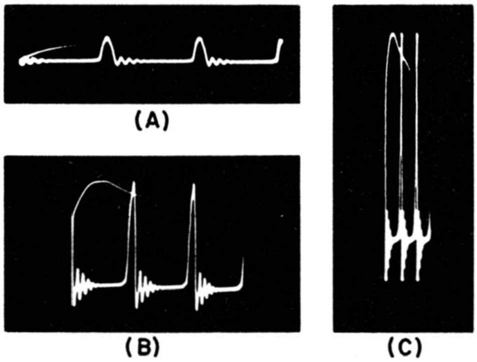


Fig. 8-9. Variations of waveform trace with adjustment of vertical gain control.

The visible effects of overloading cannot be described easily because they depend in a great measure on the kind of signal fed into the vertical amplifier. If only vertical deflection is being used, and the input is a single-frequency voltage resulting in a thin line display such as in Fig. 8-8, overloading might be indicated by *brightening of the top and bottom tips* of the line. The confirmation of the scope overload is a *reduction* in the intensity of the trace at these points when the vertical gain control is retarded.

Much more commonly experienced is the situation when a single-frequency voltage is fed into the vertical system and horizontal timebase deflection also exists. Overloading of the vertical amplifier in cases of this kind is indicated when the *shape* or waveform as well as the overall amplitude, changes with variation in the vertical amplifier gain control. However if the change in waveform accompanying a change in amplitude occurs over a wide range of input signal voltage the cause is probably not overloading, but rather a case of *frequency discrimination* in the vertical amplifier gain control system. Illustrations of this effect appear elsewhere in this book.

As to the labels that identify the two related vertical amplifier gain controls on scopes, they can be divided as follows: the step attenuator may be found labeled *Attenuator, Vertical Gain, Vertical Range, Amp Ratio, Attenuation, Signal Atten* or *V Sensitivity.*

The continuously variable control may be designated as *V Vernier, Y Amplitude, Vert Gain Control, Y Gain, V Gain, V Calibration, Gain, Attenuator, Vertical Amplifier, V Amplifier, Y Amplifier,* or *Vert Amplitude.*

The Horizontal Amplifier Gain Control

The horizontal amplifier gain control determines the voltage fed into the horizontal amplifier, thence to the horizontal deflection plates. By this means it controls the *width of the trace on the screen.* The nature of the control is the same regardless of the origin of the signal—whether it is the internally generated sawtooth timebase, the 60-cps sine wave timebase, or a voltage secured from an external source.

Assuming a signal from the sawtooth sweep oscillator, or for that matter from any other source, and no vertical deflection, four positions of the horizontal gain control result in displays like those in Fig. 8-10. In (A) the gain control setting is zero, in (B) it is low and the trace width is narrow. On the other hand in (D) it is extreme and the trace width is excessive. Trace (C) is normal, extending from about ½ to ⅔ of the diameter of the screen. It is to be noted that this dimension is greater than that suggested for the vertical trace, the reason being that an optimum height-to-width ratio of the trace is about 2:3.

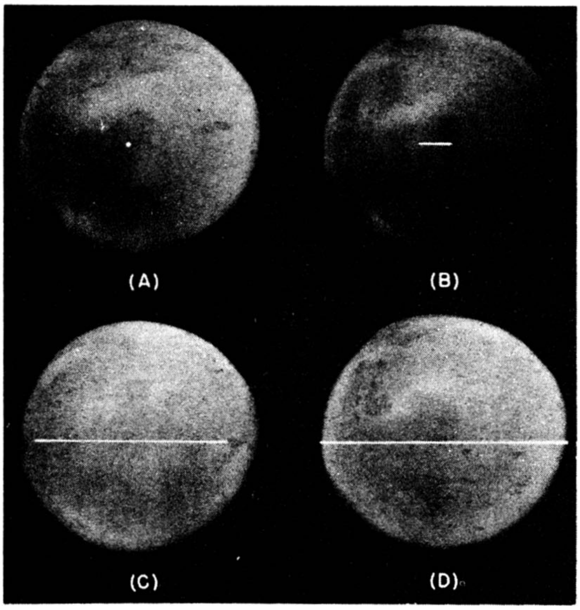


Fig. 8-10. Effect of four different settings of the horizontal gain control.

The necessity for a proper height-to-width ratio is indicated in Fig. 8-11 and 8-12. In both instances vertical and horizontal deflection voltages are applied, a single-frequency signal on the vertical plates and a sawtooth voltage of suitable frequency on the horizontal plates in Fig. 8-11. In Fig. 8-12, the signal voltage displayed is a complex one encountered in television receivers.

The point we want to make is that improper proportioning of the trace can easily lead to a wrong impression of the features of the waveform, or whatever may be the nature of the trace. As is explained elsewhere in this book, the features or the characteristics of voltage waveforms are excellent indicators of electronic equipment behavior. But in order that judgment be sound, the features of each trace must be readily

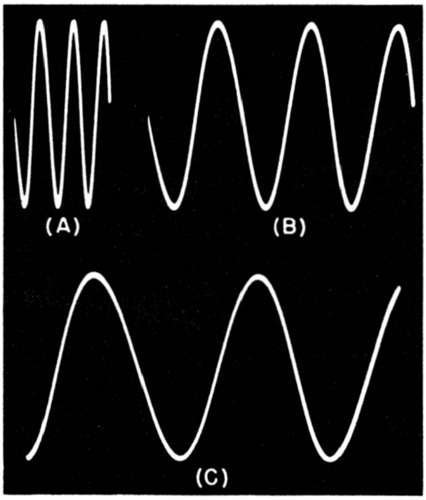


Fig. 8-11. Examples of effect on sine-waveform trace of adjustment of the horizontal gain control.

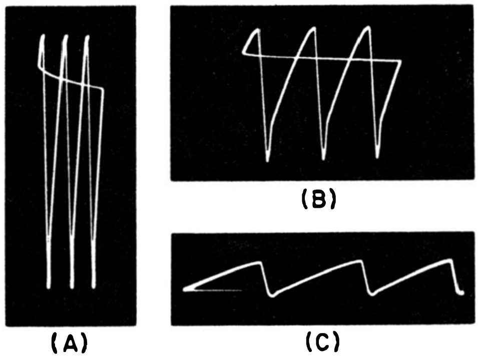


Fig. 8-12. How improper proportioning of the trace may cause loss of important detail.

identifiable. Critical examination, accompanied by quantitative measurement of a voltage waveform can establish exact conditions for almost any trace proportions. But it is not always convenient to make these measurements, moreover they are often unnecessary if the width of the trace is proper for its height.

Thus in Fig. 8-11, trace (A) is too narrow for its height, and the general appearance of the sine waveform is as if it had sharp peaks, which, as previously explained, are not characteristic of sine waveforms. Trace (C) on the other hand, is somewhat too wide for its height. Trace (B) is proper proportion for normal viewing.

The advantages of proper proportioning of the trace are much more clearly evident in Fig. 8-12. Although much remains to be said about the features of trapezoidal waveforms, it being discussed in a later chapter devoted to these shaped voltages, the misleading impression that can be gained from incorrect proportioning is evident in traces (A) and (C). The negative peak clearly seen in (B) is very small in (C) and can easily be overlooked in (A). For that matter, both (A) and (C) look like sawtooth waveforms rather than trapezoidal waveforms. If it were important to determine the relative amplitudes of the negative peak and the sawtooth portions of these traces, (C) would be useless for this purpose. Trace (A) could be used, but trace (B) certainly would be more convenient to work with.

Any one of these traces would be satisfactory for peak-to-peak amplitude measurement because such a measurement involves comparison with another voltage of comparable height. The width of the display is unimportant in these operations.

The names assigned to the horizontal amplifier gain control are like those assigned to the vertical gain control, except that the word *horizontal* or *Hor* or the letter *"X"* is used in place of the designation for vertical. It might be well to comment that some scopes have a dual gain control system for the horizontal amplifier. In addition to the continuously variable control a step attenuator also is used. It does not bear any special label except perhaps numerals indicative of the voltage ratio corresponding to the setting. Furthermore, the step attenuator is used only when the signal fed into the horizontal deflection amplifier is derived from an external source.

The Timebase Voltage Sources

We assume that the reader is familiar with the function of the timebase, but it might be well to make some comments concerning the bearing that the timebase voltage frequencies, as well as the two types of timebase waveforms, have on the display.

The ratio between the frequency of the signal voltage fed to the vertical deflection amplifier and the frequency of the timebase voltage determines the number of cycles of the signal voltage which appear on the screen. Recognizing that both sawtooth and 60-cps sine-waveform sweep voltages are available, the former is *generally* used for waveform display. Strangely enough, there are occasions when the 60-cps sine-waveform timebase is used for waveform display, but because it is irrelevant here, this matter is explained elsewhere in this book.

Examples of different sweep-to-vertical-signal frequency ratios, referred to above, are shown in Fig. 8-13. These are simple cases of sine

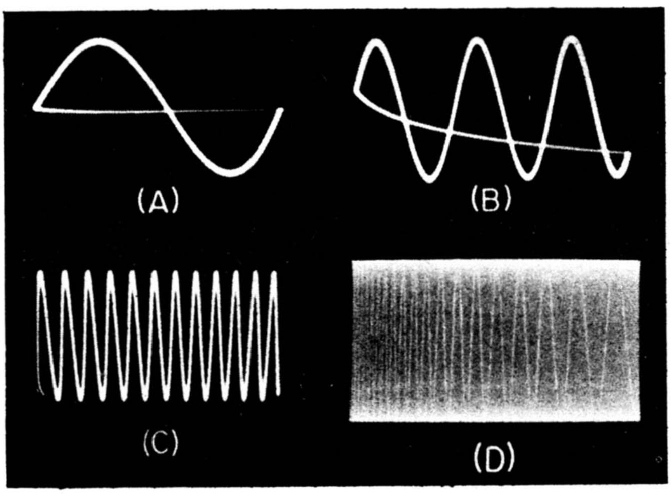
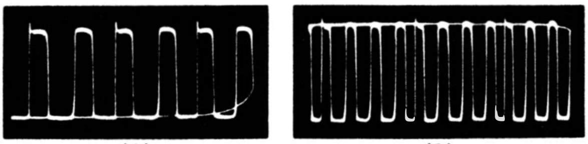


Fig. 8-13. Effect of signal-to-sweep frequency ratio.



(A) (B)

Fig. 8-14. Effect of signal-to-sweep frequency ratio on typical square waveforms.

waveform signals on the vertical plates, with signal-to-sweep frequency ratios of 1, 3 and 12 in traces (A), (B) and (C). In trace (D) the ratio is very high, hence only a rectangle of light comprises the trace. The waveform seen dimly in the background is composed of the cycles of the signal frequency that are developed during the retrace part of the sweep.

As a contrast in waveforms, but still illustrating two different signal-to-sawtooth-sweep frequency-ratios, reference is made to Fig. 8-14. Here the signal waveform is square with a synchronizing pulse on every other cycle in (A) and on every fourth cycle in (B). The signal-to-sweep frequency-ratios are 6:1 in (A) and 12:1 in (B).

In Fig. 8-13, note that the three-cycle trace (B) offers the greatest ease in inspection of the waveform. The first and the third cycles are slightly distorted because the retrace part of the sawtooth sweep cuts off a portion of each cycle, but the second or middle cycle of the waveform is complete and free from distortions attributable to the manner in which the waveform is developed on the scope screen. This is not so in (A); here the single-cycle trace is distorted by the location of the retrace line. Trace (C) has many complete and undistorted cycles, but they are too close together for study because too many cycles are shown. The entire trace can be spread in the horizontal direction by the horizontal gain control, even to the point that only four or five cycles are seen on the screen, in this way affording easier inspection. While there is nothing wrong with doing this, it is still better to form the habit of showing only a few cycles of the voltage (if possible). This is not a hard and fast rule; it is a suggestion which warrants attention.

Sweep Frequency Higher than Signal Frequency

A random adjustment of the sawtooth sweep oscillator may result in a frequency setting which is higher than the frequency of the signal applied to the vertical deflection amplifier. In this event the trace shown on the screen is useless for the examination of the waveform because the higher-frequency sweep breaks up the cycle of the signal into a series of segments which, in a way, lie beneath each other or overlap each other. For example, in Fig. 8-15, the sawtooth sweep frequency is twice that of the sinusoidal signal frequency. If the resultant trace is analyzed it is seen that each cycle of the sweep voltage displays a half cycle of the signal voltage. If the lower loop of trace (A) is moved towards the right so that *c* joins *b*, a cycle of the waveform of the signal voltage appears in normal manner. If the same thing is done in trace (B) the whole cycle of the signal is shown in normal fashion, with a phase relationship that is 90 degrees ahead of that shown as trace (A).

The higher the frequency of the sawtooth sweep the greater the number of segments into which a cycle of the signal voltage waveform is divided. This is illustrated in Fig. 8-16 and 8-17. In the former, the signal cycle is divided into three segments, *a-b, c-d,* and *e-f,* because the sweep frequency is equal to three times the signal frequency. In the latter figure the sweep frequency is four times the signal frequency, hence the cycle of the signal is divided into four segments, *a-b, c-d, e-f,* and *g-h.* To reform the original signal cycle in Fig. 8-16, it is necessary to visualize shifting of the segments so that *b* joins *c* and *d* joins *e.* In Fig. 8-17 *b* joins *c, d* joins *e,* and *f* joins *g.*

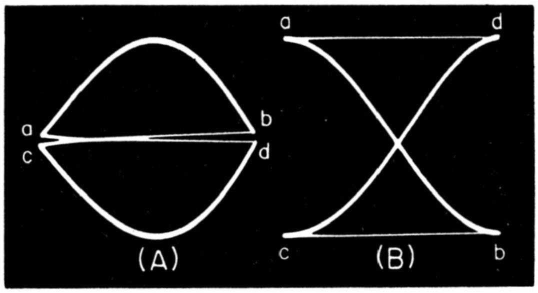


Fig. 8-15. Effect of use of sweep frequency twice sine-wave signal frequency.

Traces (B), (C) and (D) in Fig. 8-16 and trace (B) in Fig. 8-17 represent exactly the same frequency ratio between the signal and the sweep voltages as in (A) in each case. The difference in appearance is attributable to a change in the phase relationship between the signal and sweep voltages.

The control of sweep frequency is ordinarily accomplished jointly through two adjustments. One is a frequency range selector, which operates like the bandswitch on a communications receiver. It is a multiposition switch, each position of which corresponds to a portion of the total sweep frequency coverage. The other control adjusts sweep frequency continuously between the upper and lower limits of the frequency range to which the frequency selector is set.

The names assigned to the "coarse" *frequency selector* of the sawtooth voltage generator in different scopes are *Steps, Coarse Frequency, Frequency Range, Sweep Range, Range Switch, Sweep Frequency* and *Range.* Names used for the continuously-variable fine frequency adjustment are *Sweep Vernier, Fine Frequency, Vernier, Frequency Vernier, Frequency,* and *Fine.*

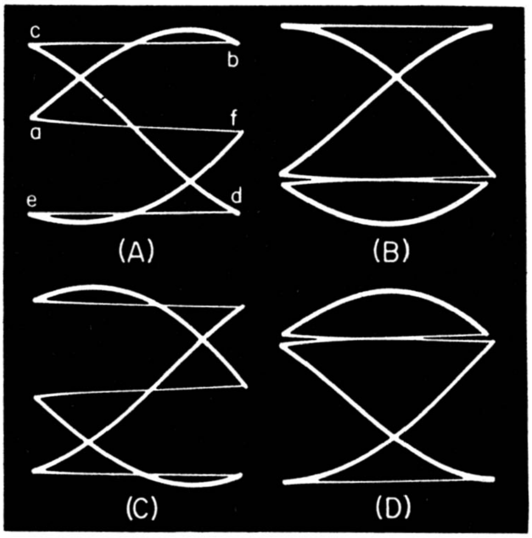


Fig. 8-16. Sine wave trace viewed with sawtooth sweep frequency three times sine-wave frequency, for four different sweep-to-signal phase relations.

60-cps or Line Sweep

The timebase section of the scope contains a 60-cps source of sine-wave voltage which also serves as a timebase sweep. Mostly it is used as the sweep voltage when observing response curves developed in conjunction with sweep generators. However, it is conceivable that by improper setting of the horizontal selector switch, the 60-cps or line sweep is chosen in place of the sawtooth timebase voltage. The error is indicated by the nature of the display, as shown below.

If the signal voltage applied to the vertical deflection plates is a sine-wave voltage, the resultant trace will be a Lissajous pattern, named after a French scientist.

If the signal also has a frequency of 60 cps, the pattern will be a figure which may change in shape from an oblique line, through a circle to an oval, as shown in Fig. 8-18. As will be seen later, these traces have value in frequency-comparison tests. In the event that either the signal or the 60-cps line sweep is distorted, the resultant Lissajous pattern may resemble one of those in Fig. 8-19. It is possible that the sine-waveform

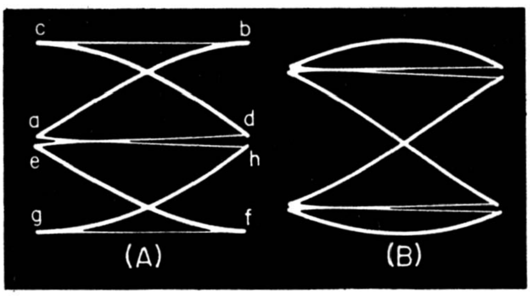


Fig. 8-17. Sine wave trace with sawtooth sweep four times signal frequency, for two phase relations.

signal-voltage frequency is substantially higher than the 60-cps line-frequency sweep, in which event a pattern similar to that shown in Fig. 8-20 may result. Depending on the ratio between the signal frequency and the 60-cps line sweep, the number of loops in the display may be many or few, and they may be in motion, because of a changing phase or frequency ratio. The smaller the ratio between the two frequencies the fewer the number of loops, and vice versa. The difference in appearance between (A) and (B) is due to a difference in phase relation between the vertical and horizontal voltages. These traces have a special meaning in connection with frequency comparison, as discussed later.

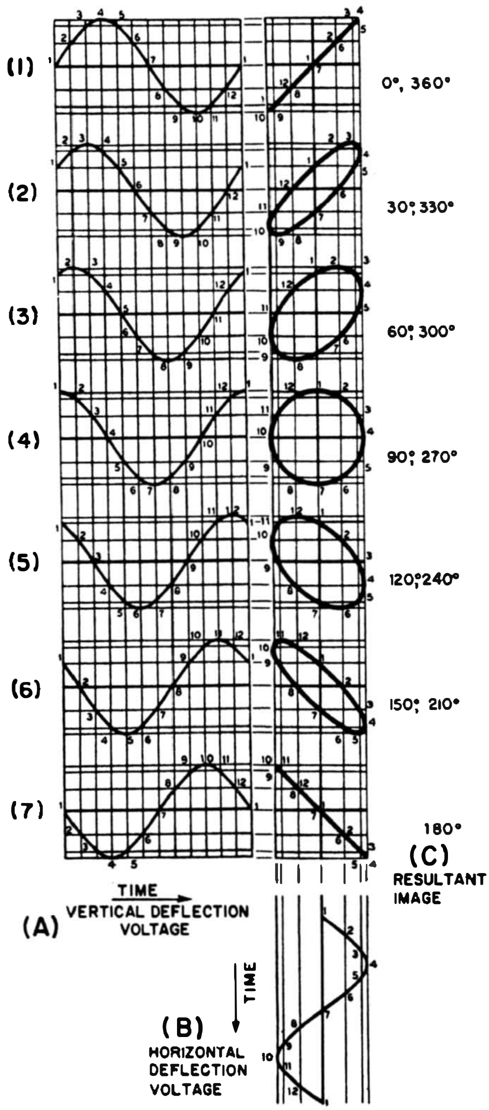


Fig. 8-18. Types of patterns when both horizontal sweep and signal (vertical) voltages have sine waveforms.

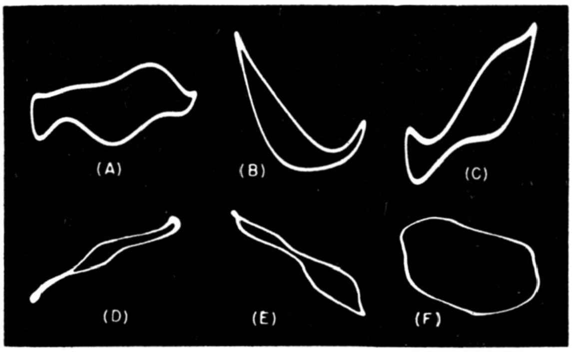


Fig. 8-19. Typical patterns resulting when signal and sweep voltages both have sine waveform, and one (or both) is distorted.

Inasmuch as the signal applied to the vertical plates may be any of a variety of waveforms other than sinusoidal, several other resultant traces are shown in Fig. 8-21 and 8-22 for identification. If the vertical signal voltage is a square waveform, patterns such as those in Fig. 8-21 may result. If the waveform is trapezoidal as in the input circuit of the vertical output tube of a tv receiver, patterns such as (A) and (B) in Fig. 8-22 may result. It stands to reason that variations of these can be expected and a few illustrations cannot conceivably portray more than just the general ideas. Innumerable combinations may be encountered. As can be readily seen, the usefulness of the 60-cps sine-waveform sweep for portraying the waveform of the voltage is extremely limited. On the other hand, the 60-cps sine wave sweep is just as effective as the sawtooth sweep of corresponding frequency for showing the features of the 60-cps vertical pulses in a video signal. As a matter of fact, the sine-wave sweep may be even more useful as it serves to spread out the center of the trace and make the waveform easier to examine. This is illustrated in Fig. 8-23. More will be said about this presentation later in this book.

Synchronization

The waveform patterns shown in this chapter were kept stationary on the screen during the photographing. This was made possible by proper *synchronization* of the sawtooth sweep oscillator by a portion of the signal voltage present in the vertical amplifier which was channeling the

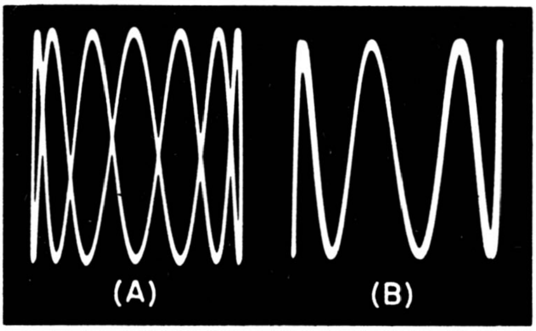


Fig. 8-20. Typical Lissajous patterns obtained when vertical voltage has a higher frequency than horizontal voltage, both being of sine waveform.

signal to the vertical deflection plates. This facility exists in every scope, but a stationary pattern will not be attained unless several conditions are satisfied.

As the starter for a simple waveform pattern formed out of a single line that is without multiple loops and crossovers, it is necessary that a whole number (integral) ratio exist between the signal frequency and the sawtooth sweep generator frequency. But this alone will not produce a stationary pattern. Even though the trace be readable it might have a tendency to *drift* across the screen. To make it stand still, a certain amount of *synchronizing* voltage must be injected. The synchronizing control adjusts the injection of sync voltage for best performance of this function.

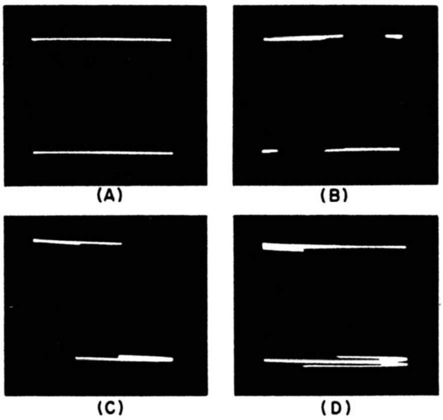


Fig. 8-21. Waveforms resulting from sinewave horizontal sweep and square wave vertical voltage. (A) Vertical and horizontal frequencies the same, (B) vertical frequency three times horizontal frequency, (C) vertical frequency lower than horizontal frequency, and (D) vertical frequency much lower than horizontal frequency.

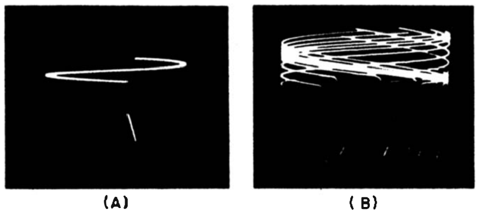


Fig. 8-22. Sawtooth waveform with peaking, as viewed with a sinewave horizontal sweep. (A) 1:1 frequency ratio; (B) non-integral frequency ratio.

But the freedom of adjustment of the synchronizing control is limited. Too much synchronizing voltage can have very bad effects. It can distort the waveform very badly. It can cause a dual-frequency presentation wherein two sets of waveforms appear on the screen, one being due to one frequency of the sweep and another waveform superimposed on the first being presented by another frequency of the sweep. In other words, the sweep generator is made erratic in its frequency-generating behavior. The third effect, although not as grievous as those mentioned, is that it can cause a reduction in the frequency of the sawtooth sweep generator.

Fig. 8-23. Presentation of 60-cycle vertical pulse in video signal with 60-cps sinewave sweep.

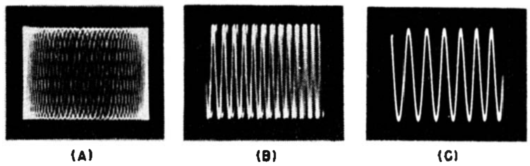


Fig. 8-24. Three stages of patterns as the fine frequency control is adjusted for synchronization.

In Fig. 8-24 are shown a series of stages of synchronization approaching a stable sine-waveform. In Fig. 8-25 the same condition is shown for a distorted sawtooth waveform pattern. In Fig. 8-26 (A) are shown three cycles of a sine waveform trace, and in (B) the distortion of that trace when the synchronizing control is advanced too far. In (C) of the same figure is shown the result of an unstable sweep system due to too much synchronizing signal. This waveform trace is double, due to a periodic change in frequency of the sweep generator. In (E) and (F) of the same figure are shown the effects of too much synchronizing voltage when the vertical signal is a square wave. The difference is the polarity of the synchronizing voltage. The normal waveform is shown as (D). Figure 8-27 illustrates the destruction of the waveform in a horizontal output tube plate circuit when the sync control is advanced too far. Trace (A) is the normal two-cycle waveform, while (B) is the result of incorrect sync.

Retrace Blanking

Some scopes provide means for preventing the retrace portion of the sawtooth sweep voltage from exciting the screen, so there is no display

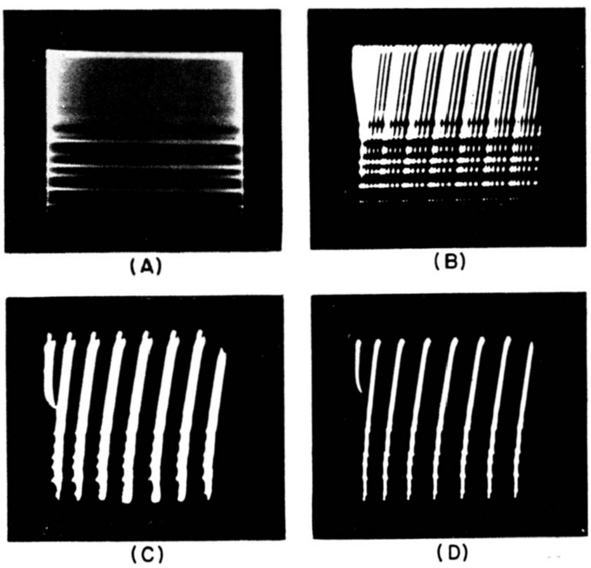


Fig. 8-25. Stages approaching synchronization of a sawtooth waveform.

during horizontal retrace. This is known as *retrace blanking*. Such blanking provides a waveform display that is clean of all traces developed during the *return* motion of the electron beam. Examples of blanked and unblanked traces have been shown in a number of figures given in this chapter. As a matter of convenience, Fig. 8-28 is included as a perfect example of (A) the unblanked, and (B) the blanked condition. It also illustrates another relatively important effect. Waveform (A) shows a sine-waveform voltage whose frequency is 14 times that of the sawtooth sweep voltage, and the retrace is *unblanked*. The fact that the signal frequency is 14 times the sweep frequency is established by the presence of 13 cycles in the normal display and one cycle of the voltage appearing on the return trace. A complete cycle of the sawtooth sweep voltage includes the forward trace and the retrace.

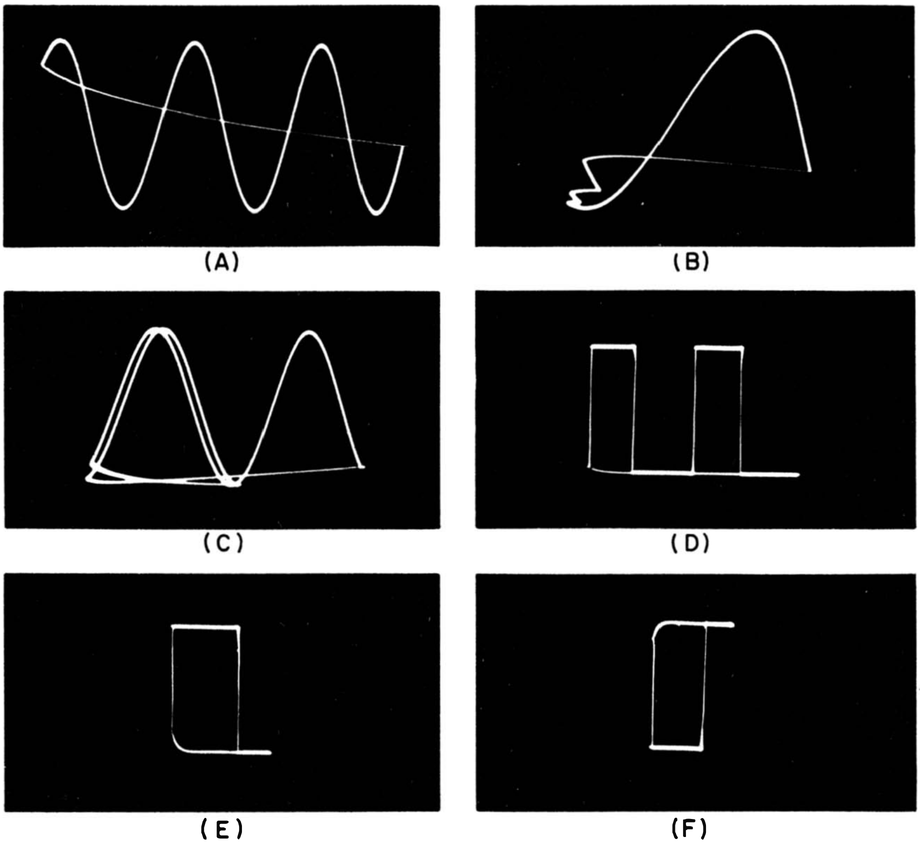


Fig. 8-26. Results of excessive sync voltage.

Waveform (B) in the same figure is exactly the same signal voltage, except that the sweep retrace has been *blanked*. Without question the display is easier to examine because the retrace line is absent. For all purposes of inspection or examination or peak-to-peak voltage measurement,

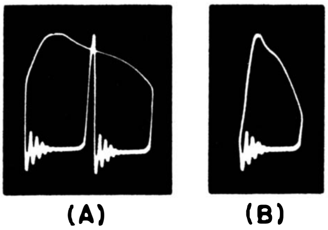


Fig. 8-27. Horizontal output voltage waveform (A), and distortion due to excessive scope sync voltage (B).

waveform (B) offers all the possibilities presented by (A), although (A) can nevertheless be used for all of these tests. But if the number of cycles shown in (B) is compared to the number in (A), it will be seen that one cycle less appears in the latter. Normally this result of blanking is unimportant; it becomes significant only if an attempt is made to determine the frequency of the signal relative to a known sweep frequency by examining the display. In this case the retrace time amounts to a cycle of the signal voltage, hence the blanked trace is shy one signal cycle. Also it is slightly narrower because of this effect. In many scopes the retrace time is very short and a reduction in the number of cycles in a display accompanying blanking does not occur until the frequency of the signal becomes relatively high.

It is not too often that signal frequency is determined in this manner, hence the effect of retrace blanking is not important. However, it might be said that measurement of this kind does afford an idea of the retrace time, that is, if it is deemed important for the applications on hand. Knowing the frequency of the signal makes the period of a cycle known. The retrace time then is equal to the period of the fraction of a cycle or of the number of cycles that appear on the retrace.

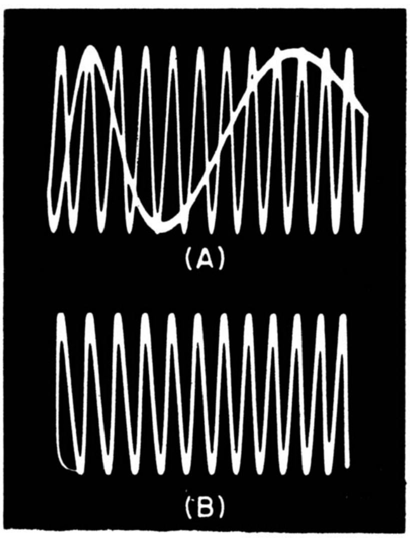


Fig. 8-28. (A) Unblanked and (B) blanked traces.

Amplitude Modulated Wave Envelope Display

Some displays of a-m waveform envelopes have been shown and others follow later. If the frequency capabilities of the vertical system of the scope and of the sawtooth sweep generator are such that the r-f carrier cycles are passed by the vertical system, and the sweep frequency range is high enough, the individual cycles of the modulated r-f carrier can be displayed by proper frequency setting of the sweep generator.

If the vertical amplifier of the scope passes the modulated carrier frequency, but the sweep frequency range is not high enough, then only the wave envelope can be displayed, in which case the sweep generator frequency is set to be an integral submultiple of the modulating frequency component of the a-m carrier.

The display in Fig. 8-29 illustrates the appearance of an a-m wave envelope when the sawtooth sweep frequency is not an integral submultiple of the modulating frequency.

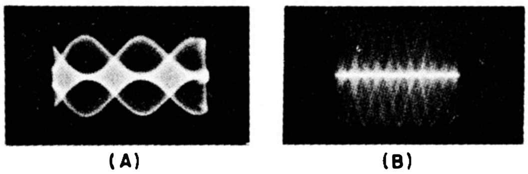


Fig. 8-29. Trace of a-m waveform when sawtooth sweep frequency is not an integral submultiple of the modulating frequency.

Response Curve Display

Adjustment of scope controls to display response curves of all kinds is simple. The 60-cps or line sweep is used in virtually all cases because almost all sweep oscillators are driven by 60-cps sine-waveform voltages. In the event that a voltage of a frequency other than 60 cps is used to drive the sweep oscillator mechanism, then it is necessary to procure the sweep voltage for the scope from the sweep generator source. (Sometimes it is better to do this anyway.)

Two general varieties of response curve traces are possible. In this connection, we are assuming perfect operation. (Imperfect performance is considered later.) Kinds of scope traces which function with return-trace blanking supplied by the generator have been previously considered. When the return portion of the sweep of the trace is blanked the display is a single-line image whose frequency changes continually in one direction. The lowest frequency in the band being displayed is ordinarily at the left hand edge of the image, if phasing and sweep width are proper. This left end should correspond to zero frequency in those traces where the sweep generator passes through zero frequency and sweeps upwards. (See Fig. 8-30.)

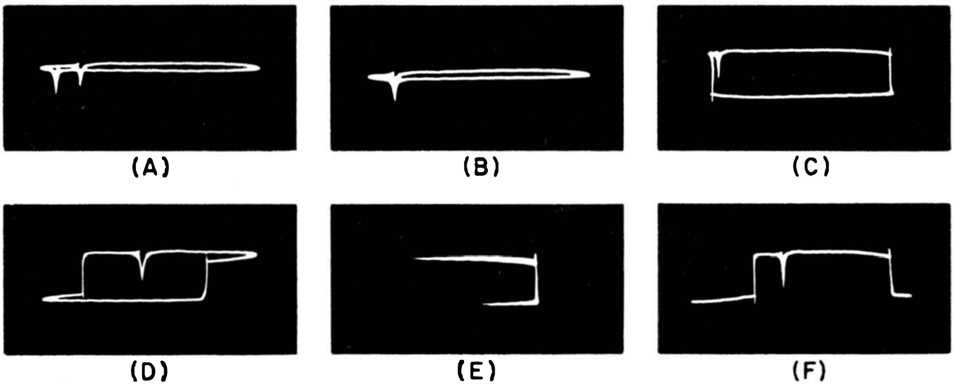


Fig. 8-30. Displays showing the importance of blanking.

When the sweep generator sweeps *both* sides of a *center* frequency, and the return trace is blanked, the change in frequency is in the upward direction from the left hand edge of the display. This is the lowest frequency as determined by the sweep width setting of the sweep generator.

When the return trace is not blanked in the generator, the generator signal-frequency sweeps forward from a low-frequency limit to the high-frequency limit of the range, and then back again through the same range from the high end to the low end of the band. Under the circumstances, a *dual-line* response curve appears on the screen; one trace corresponding to the forward sweep of the sweep generator and another which apparently doubles back on the first, and represents the downward sweep of the generator.

Video response curves, sweep generator voltage-vs-frequency output curves, demodulator curves, and others of similar nature require return-trace blanking in order to develop a usable display. Without blanking the trace may be difficult to examine. This is indicated in Fig. 8-30. Part (A) shows sweep generator output for video amplifier checking, with no blanking and phase control incorrectly set. Part (B) shows the result of the same setup as (A) with phase control properly set. Note the coincidence of zero points. Part (C) represents the same setup as (B) but with blanking applied. Note the appearance of the zero-voltage baseline. Part (D) is the same as part (C), but with the phase control incorrectly set, while (E) is the same as (D) with the retrace blanking in the scope turned "on." (F) is the same as (C) but with scope sweep 60 cps sawtooth instead of sine waveform.

In the event that return trace blanking is not available in the equipment being used, it can be simulated in effect by momentarily shorting the vertical input terminals of the scope. This will cause a baseline to position itself on the screen each time the input terminals are shorted. The curve developed on the screen when the vertical input terminals are not shorted can be inspected relative to the temporary baseline. This curve will be positioned above the momentarily-produced baseline.

Waveforms with D-C Components

An a-c coupled scope, that is, one which has a coupling (or isolating capacitor) in the input circuit of the vertical amplifier, or one which uses blocking capacitors in the vertical amplifier, will not pass d-c voltage. Hence a waveform which contains a d-c component will be treated as an a-c voltage. Assuming no leakage in the system, the a-c presentation will result in deflection in both directions from the undeflected position of the beam. The shape of the waveform will not be altered by the presence of the d-c component, providing the frequency response of the scope is adequate and there is proper frequency compensation in the vertical amplifier attenuator system. In all other respects the handling of the controls is just as if the input voltage were a purely a-c voltage.

If the scope is d-c coupled, that is, there are not blocking or isolating capacitors anywhere in the chain of signal voltage transfer in the vertical amplifier, the beam will move either upwards from the undeflected position, or downwards from that position—depending on the polarity of the d-c voltage in the input signal. The controls are handled in normal fashion for the display of a waveform. However, due to displacement up or down of the baseline by the d-c component, the vertical positioning controls may need readjustment each time a change is made from a pure a-c wave to one containing d-c and vice versa.

Summary

It is understandable that every type of scope trace cannot be shown as an example of what to expect during the manipulation of the controls. Many more varieties of displays appear later in this book, but in spite of the large number presented herein, it is natural that still others, not shown, will be encountered.

Another point which must be made is that the controls treated in this chapter are those found on the vast majority of scopes used for electronic maintenance and study purposes. Such features as expanded sweep, timing markers, calibrating pulses, intensity modulation and a host of other facilities exist in *laboratory* scopes but are not within the desired coverage of this book. However, if the basic facts given here are digested by the reader, the familiarity so created will make it rather easy to grasp the operational capabilities of such advanced features.

Chapter 9

INTERPRETATION OF SCOPE TRACES

As indicated in the first eight chapters of this book, scope traces fall into four major categories: (1) waveforms, (2) a-m wave envelopes, (3) response curves, and (4) Lissajous figures. They will be treated in that order in this chapter, except that now we shall deal with malformed or distorted examples of all but the Lissajous figure. The nature of the last named variety of scope traces is such that there are few distinctions between normal and abnormal varieties. Hence the examples of Lissajous figures given will illustrate both of these varieties.

Interpretation of Waveforms

The waveforms illustrated in this chapter are assumed to be representative of voltage. Current waveforms can be accurately duplicated by causing the current to develop a voltage drop across a non-inductive resistance of very low value connected in series with the circuit being checked. Do not disturb the circuit in which the current is flowing.

The word "distortion" or "distorted" as applied to a waveform is strictly relative. A "distorted" waveform is not necessarily an *incorrect* waveform—or one which represents a defect in equipment. It is not unusual that a waveform is declared to be "distorted" for one set of circumstances and so indicative of a fault or some incorrect operating state, and the same waveform is the "reference" or *proper* waveform for another set of circumstances. The term "distorted waveform" as used in this chapter indicates one which has undergone a *change* as the consequence of incorrect functioning of the equipment in which it appears.

We shall also be concerned with waveforms which differ from the ideal shape because a wide tolerance is allowed in the application. For example, service-type a-m signal generators are nominally designed for sine wave modulation of a sine wave carrier. However, because ordinary receiver service applications do not call for low distortion, the modulation is allowed to have a waveform which is appreciably nonsinusoidal. Thus the difference between distortion and allowable variations is decreed by the particular application, usually determined by the *reference waveform,* which shows the proper practical shape for that application.

The features of a waveform perform a dual function. They indicate the characteristics of the voltage (or current) that the waveform represents; and if the waveform is a *departure from normal* or the reference, its features are capable of indicating the reasons responsible for the *change.* When two voltage waveforms at two related test points are compared, or when an observed waveform is compared with the reference waveform, a difference in characteristics of features has meaning in terms of the equipment behavior.

No attempt to present the theory of electronic circuit functioning is made in this book. Whatever references are made to vacuum tube circuitry are limited principally to those details which demonstrate effects on the waveforms of signal voltages. Control voltages are deemed to be a part of the signal voltage category.

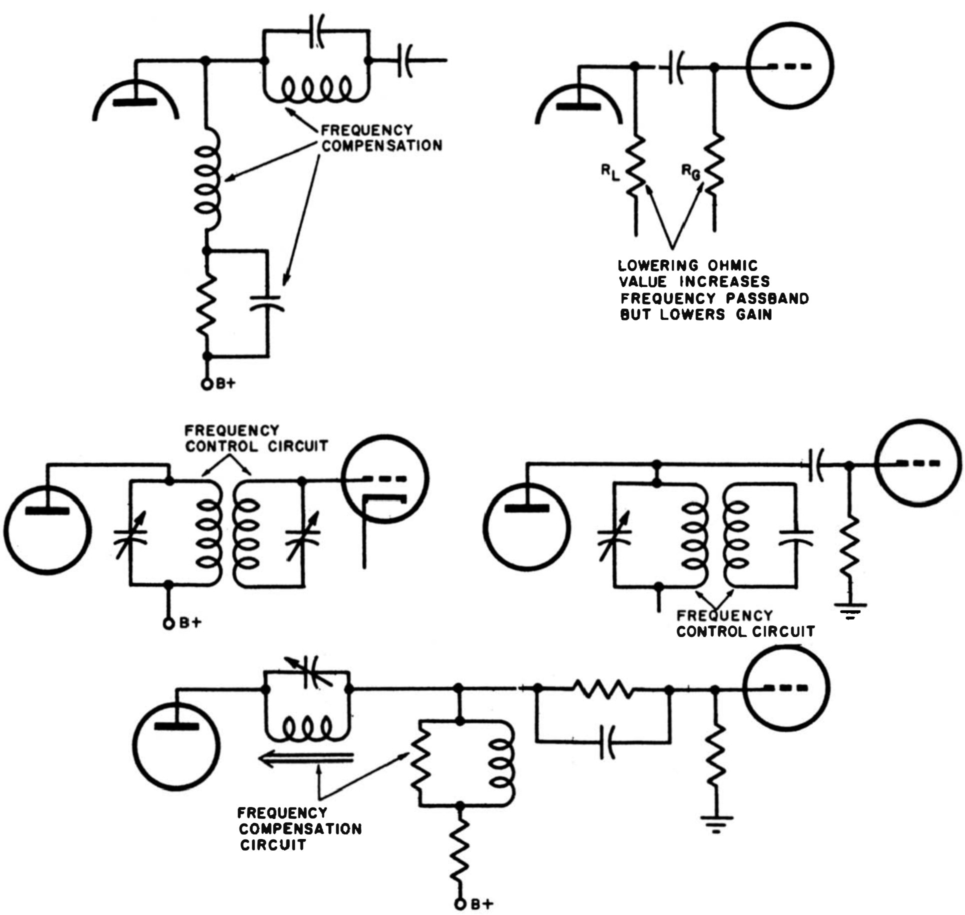


Fig. 9-1. Typical circuits in which signal can be distorted by improper action of resonant circuits.

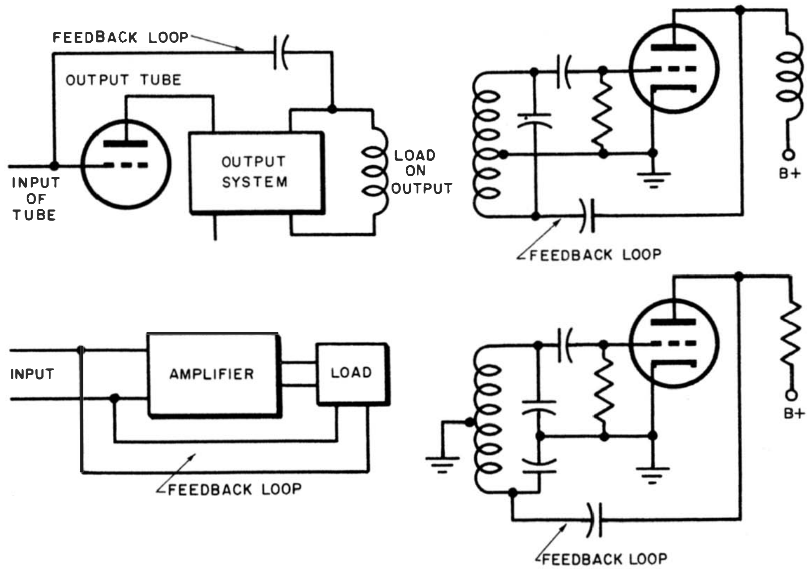


Fig. 9-2. Systems in which waveform may be distorted by improper feedback.

A change in amplitude of a signal is not by itself considered distortion. It is usually simply a matter of greater or less amplification than normal, although it may be caused by the same kinds of troubles as may produce distortion.

Following is a capsule review of conditions which can result in the deterioration of waveforms during the processing of a signal or control voltage. Due to space limitations, it is not complete. Nevertheless, it will prove helpful to the user of the test scope.

Conditions That Result in Distortion of A Waveform

Resonance. Incorrect resonance conditions can distort the waveform of a modulated voltage. Radio frequency, intermediate frequency, and video frequency amplifiers offer such possibilities. Any condition of resonance which unduly attenuates or accentuates frequency components in a broadband amplifier will distort a signal voltage waveform. See Fig. 9-1.

Feedback. Defective positive or negative feedback circuits in amplifiers are capable of distorting a waveform. See Fig. 9-2. These feedback circuits may also be found in a-f, i-f and r-f oscillators. Excessive positive feedback in an oscillator system usually generates voltages with high harmonic content. Feedback loops also are used in waveshaping circuits. Examples of these are vertical and horizontal sweep output systems in electromagnetically-deflected cathode-ray tube display devices.

Impedance matching. Incorrect matching between the driving source and the load usually affects the power transfer and impairs the waveform of the voltage being transferred or of the current that is caused to flow in the system. See Fig. 9-3. Mismatching with pentodes is more serious than with triodes. Such situations arise in systems that use resonant or non-resonant transformers for power transfer, low impedance circuits, systems joined by transmission lines, delay lines, transducer circuits, modulation systems, electromagnetic deflection circuits between generators and loads, and others.

Transients. Insufficient or excessive damping in systems subject to transient oscillations generally will result in abnormal waveforms of voltage. Oscillators of this variety are typified by blocking oscillators. Systems wherein voltage or current is generated by shock excitation are subject to transients. Horizontal output systems in television receivers are examples of such circuitry. Any vacuum-tube system subject to sharply changing voltages which cut off the plate current will contain transient oscillations unless damping means to prevent their growth are applied. See Fig. 9-4.

Parasitics. Undesired resonance can result in the generation of sustained oscillations which can distort a voltage, appearing as oscillations at certain points in a voltage waveform. See Fig. 9-5. Such oscillations are possible in all varieties of circuits, where amplification or signal level is high, or in systems subject to sudden peaks of energy, as in audio systems, transmitter amplifiers. Unwanted electrostatic (capacitive) or magnetic

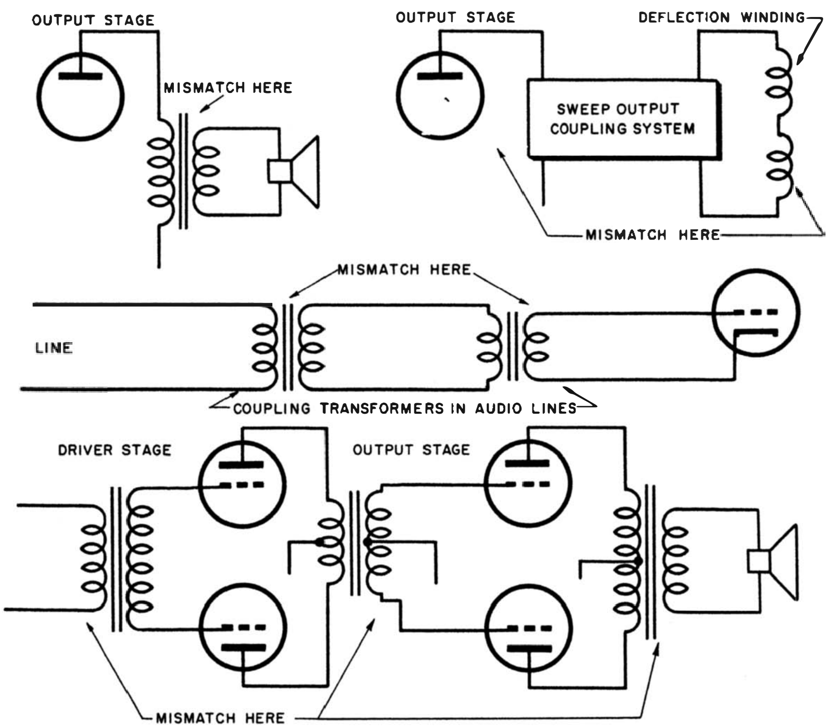


Fig. 9-3. Some systems in which mismatching of impedances can cause distorted waveform.

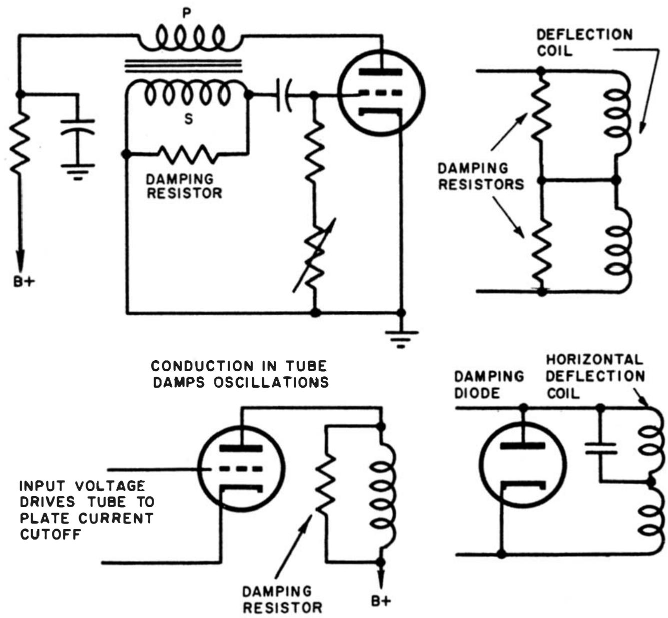


Fig. 9-4. Typical circuits in which damping action influences waveform.

coupling between input and output circuits of the same vacuum tube stage or adjacent stages can result in the generation of unwanted oscillations which modify the signal voltage waveform.

Reactive Loads. Waveform deformation occurs in reactive loads which are not designed for use with interrupted current waveforms, but which are subject to them. Examples of these are transformers used in the plate circuits of tubes driven to plate current cutoff. Audio transformers not designed for square-waveform response will distort a square-waveform voltage.

Time Constant. Incorrect *RC* and *RL* circuit component constants in voltage "shaping" circuits will alter the appearance of all but sine waveforms. See Fig. 9-6. Examples of these are *RC* coupling circuits in amplifiers of all types where nonsinusoidal waveforms are being processed. Differentiation can occur when it is not intended, or a differentiated waveform can be altered by an incorrect time constant. Examples of these are capacitive type test probes, capacitance-isolated input circuits in scopes, RC coupled amplifiers, etc.

Overload. Excessive signal levels at the input circuits of amplifying vacuum tubes will result in overloading—with consequent distortion of the voltage waveform.

Operating Voltages. Incorrect operating voltages will as a rule impair the signal voltage waveform. This happens in most instances, although it also is true that given the proper set of circumstances, especially in the presence of low level signals, the result of incorrect operating voltages is a reduction in signal voltage amplitude rather than a modification of the waveform. Defective components related to the grid circuits of vacuum tubes, especially coupling (or blocking) capacitors with reduced insulation resistance (leaky) can materially reduce, if not completely overcome, the bias voltages normal to the circuit, and so create a condition equivalent to incorrect operating voltage. See Fig. 9-7.

Defective Components. Defects in components will, as a rule, modify the waveforms of the voltages which they are processing. Depending on the type and function of the component, the waveform change may assume any of a variety of shapes. In the case of balanced-to-ground arrangements, capacitive unbalance to ground can result in unlike amplitudes, unlike voltage duration periods, introduction of noise, tilt in waveforms, hum voltages, etc. In the case of push-pull audio systems, unbalance in tubes, operating voltages, or transformer windings will introduce distortion.

Defects in resistors which carry tube currents will affect the voltage waveform in the same fashion as incorrect voltages derived from the voltage sources. When used in a-c circuits, defective resistors can alter the time constant, the degree of damping, the frequency passband, pulse amplitude, the duration of the voltage, the frequency of the voltage, the frequency composition of the voltage—depending on the manner in which

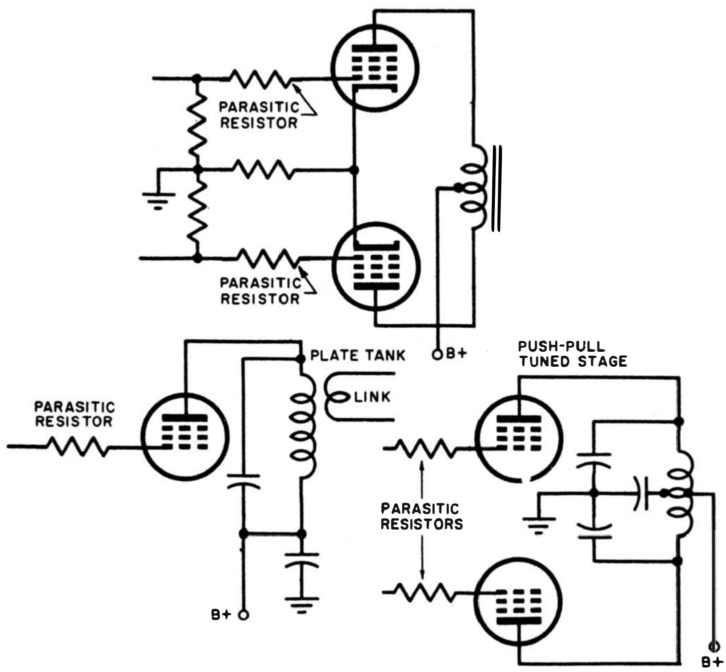


Fig. 9-5. Circuits in which parastic oscillations may occur to distort waveform, and location of suppressor resistors for eliminating them.

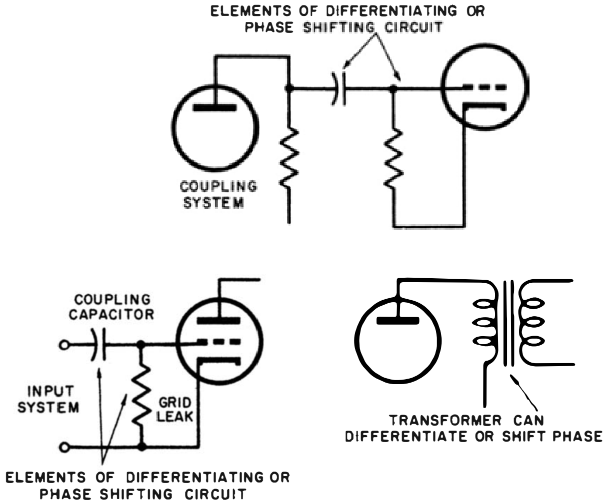


Fig. 9-6. Typical circuits in which RC and RL combinations can affect waveform.

the resistor is used. Noise voltage can reach substantial proportions in resistors, and so add spurious "grass" pulses to an otherwise normal voltage waveform.

Defective capacitors can change frequency, alter pulse amplitude, duration of a voltage, linearity, the degree of differentiation, time constant, symmetry in an a-m wave envelope, linearity of modulation, modify the sine waveform, change the amplitude of the frequency components in a complex voltage—modify the d-c voltage level in a circuit, distort charging current waveforms, or modify triggering time—depending on how the capacitor is used.

The ways in which defective tubes modify a voltage waveform are varied. Deactivated cathodes (or filaments) will interrupt operation or reduce voltage amplitude much more frequently than they change the waveform. On the other hand, the presence of gas in a tube will alter the operating voltage conditions and produce waveform deterioration like that due to incorrect operating voltages. Direct current paths between electrodes, especially between a-c operated cathodes and heaters, cathodes and control grids, heaters and control grids, will not only introduce spurious voltages on top of the signal voltage waveform at the control grid, but also will modify the operating voltages at the control grid and cause waveform alteration representative of incorrect grid voltages.

Obscure Faults. It stands to reason that some of the conditions responsible for waveform changes will be obscure. For example, a poor ground connection in a system can give rise to numerous varieties of waveform impairment. The same is true of imperfect bypassing or the lack of bypassing, yet it is not technically sound to state unconditionally that either of these circuit states will produce a particular, distinctive kind of effect. They may and they may not modify a waveform, depending on the circumstances. Neither can it be said that the same variety of fault will demonstrate the same effect in two different cases. Nevertheless it is necessary to bear in mind that these details and others, such as radiation from adjacent pulse circuits and modulation of d-c voltages in power supplies by induced signal voltages, can modify signal voltage waveforms.

Frequency Compensation. The matter of frequency compensation in either the devices under test or in the test scope is important. Over- and under-compensation—inadvertent or deliberate—can adversely affect the waveform. Frequency-compensated circuits generally are adjustable, and, given one adjustment to suit one test condition, such a circuit may not be suitable for other tests. Frequency-compensated circuits do not appear in conventional radio receivers or even communication receivers, but they are quite common in virtually all devices whose function involves the presence and amplification of "shaped" voltages.

Correlation Between Waveform and Operating State

It is not to be expected that every variety of waveform deformation can be shown, the possible variations are entirely too numerous. For that matter, the possible causes for the waveform shapes likewise are so numerous they cannot all be stated. But it is possible to show typical cases of "normal" and "distorted" waveforms and to state the general causes responsible for the distortion.

Attention is called to one limitation which exists in the portrayal of distorted waveforms on a broad scale. It relates to the conditions under which the "normal" waveform is used; it can either be the test signal injected into a stated circuit or it can be the waveform which is expected in a properly-functioning circuit under normal operating conditions. Even then variations between the observed "normal" and the "normal" shown may be encountered.

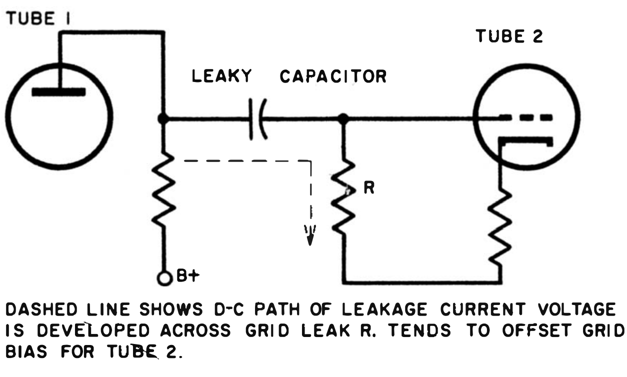


Fig. 9-7. Effect of leaky coupling capacitor.

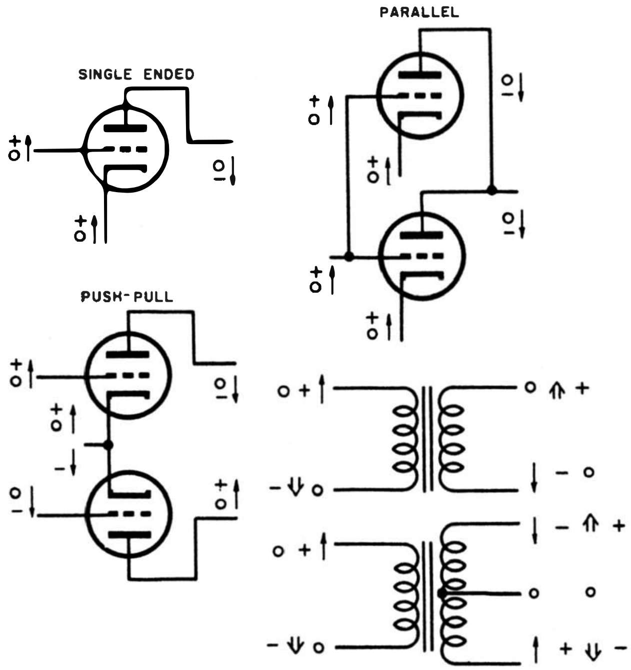


Fig. 9-8. Inversion of signal voltage in single-ended, push-pull and parallel tube systems.

Given one set of conditions, a "normal" waveform may be normal; given another set of conditions the "normal" waveform may be representative of distortion, because the true "normal" may be a close approximation of the ideal. On the other hand the general run of "distorted" waveforms shown herein will be found to be truly representative of defective states. These may issue from the test equipment or from the equipment under test.

Accordingly it is expected that the reader will decide whether the test equipment—say a generator, is producing the desired "normal" signal; or if the "normal" signal shown herein agrees with the reference waveform he may see in service literature. The "distorted" versions shown herein are related to the "normal" illustrated. In general it will be found that both the "normal" and the "distorted" examples given agree fairly well with what will be encountered in practice. Thus the causes for, and the locations of, distorted versions given herein will be found to apply to practical equipment encountered by the reader.

Polarity of the Scope Trace

Most effective correlation between the scope trace being displayed on the screen and the circuit conditions is accomplished if the polarity of the trace is known. The *upward* deflection in any waveform usually corresponds to *positive* deflection unless otherwise noted; and the positive alternation of the voltage at the point of test or observation.

The above may not be the case in every setup used by the reader—this is something which must be determined on an individual basis with each scope used. When a polarity reversal switch is a part of the test scope, there is no problem because it can be so set as to make the upward deflection correspond to positive.

Inversion Between Stages

A fundamental condition present in all vacuum tube amplifiers is the *inversion* of the signal between the input (control grid) and output (plate) circuits. See Fig. 9-8. This is not easy to see when the waveform is sinusoidal, unless both input and output waveforms are seen on the screen at the same time, which is not possible with the usual run of test scopes. But in the *presence of any noticeable amount of distortion,* the inversion of the trace is readily evident. The same inversion occurs when the signal is an a-m waveform, but it is difficult to note the inversion unless the modulation is non-symmetrical.

When working with push-pull systems it is to be remembered that the polarity is *opposite* on the two control grids, therefore is *opposite* on the two plates of the tubes in the stage, as shown in Fig. 9-8. In the case of paralleled tubes, the polarity of the input system is the same on both control grids, likewise is the same on both plates, although polarity inversion does occur between the input and output circuits.. Inversion occurs in transformers as shown in Fig. 9-8.

Inversion of the signal waveform does *not* occur between the control grid and the cathode of the same tube, but it *does* occur between the plate and the cathode of the same tube. This can be seen in Fig. 9-8.

SINE WAVEFORM SIGNAL WITH SPURIOUS OR HUM SIGNALS ON VERTICAL PLATES. Cases such as these arise from poor grounding or shielding, spurious signals in vertical amplifier, external signal coupling to vertical plates, or coupling between horizontal and vertical systems.

(A) (B) (C) (D) (E)

Fig. 9-9. Examples of scope trace when spurious or hum signal is present on vertical plates. Note amplitude modulation of signal cycles in (A). The trace in (C) appears to rotate around its horizontal axis. In (D) the spuriours signal has a lower frequency than the vertical input signal. In (E) the spurious signal has a higher frequency than the vertical input signal.

SINE WAVEFORM SIGNAL WITH SPURIOUS OR HUM SIGNAL ON HORIZONTAL PLATES. Cases such as these arise from hum or spurious signal entering horizontal deflection system.

Fig. 9-10. In (A) and (D) the spurious signal has a high frequency relative to that of the signal.

SINE WAVEFORM SIGNAL DISTORTED BY EXTERNAL FIELD. This distortion may result from a current carrying transformer, a choke, or soldering iron near scope.

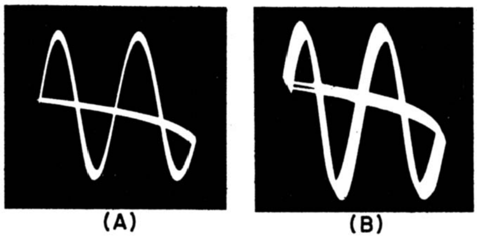


Fig. 9-11. Non-uniform spreading and tilt of trace due to the presence of external field in the vicinity of scope.

SINE WAVEFORM SIGNAL DISTORTED BY POWER SUPPLY HUM.

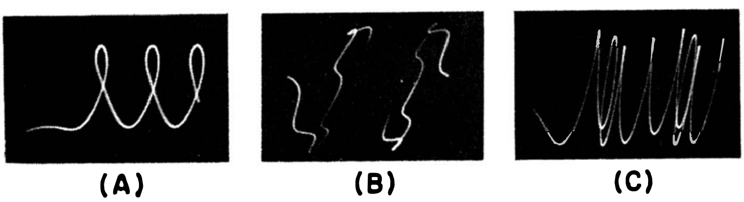


Fig. 9-12. Examples of traces when hum voltages (60 or 120 cps) are present in the scope's d-c operating voltages. The vertical amplifier is processing a sine waveform.

SINE WAVEFORM SIGNAL DISTORTION IN SINGLE-ENDED CLASS A AMPLIFIER. This distortion may result in Class A audio or other amplifiers due to improper operating voltages or signal amplitudes.

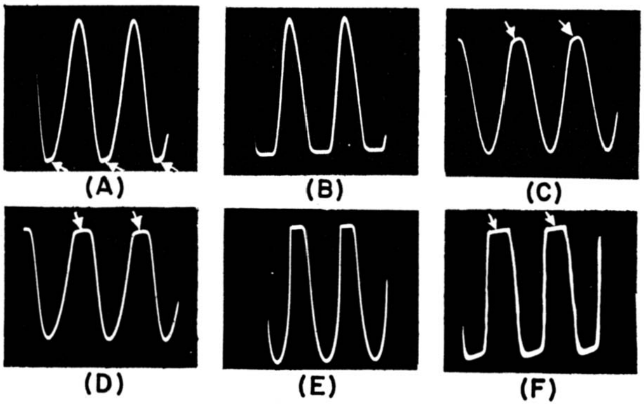


Fig. 9-13. Traces (A) and (B) show flattening of the negative peak of the *output* voltage because of insufficient grid bias, leaky coupling capacitor, grid current, grid limiting, high resistive load or unduly low plate or screen voltage. Traces (C) and (D) indicate flattening of positive peak of the *output* voltage waveform due to excessive grid bias, unduly low plate load resistance. Traces (E) and (F) show overloading by high level of signal input. Both positive and negative peaks of output voltage are affected.

SINE WAVEFORM SIGNAL DISTORTION CAUSED BY AUDIO TRANSFORMER.

(A) (B)

Fig. 9-14. Distortion of sine waveform when frequency is too low for transformer.

SINE WAVEFORM SIGNAL DISTORTION IN PUSH-PULL CLASS A AMPLIFIER. In a Class A push-pull amplifier, depending on the point of observation, certain forms of distortion of the signal voltage waveform are *normal*. Points of waveform observation are indicated in the caption.

(A) (B) (C) (D) (E)

Fig. 9-15. Traces (A) through (E) apply to a Class A push-pull amplifier stage under the following stated conditions. Trace (A) is an acceptable version of a sine waveform signal across an appropriate resistive load on the secondary of the output transformer. Trace (B) is the signal voltage between one plate and ground when grid bias for this tube is zero. Trace (C) is the distorted signal voltage across the output load resistor for this condition. Insufficient grid bias (B) rounds off the negative peak of output voltage, and amplifier output contains a substantial amount of second harmonic. Traces (D) and (E) are the equivalent of (B) and (C) for the other tube in the push-pull stage. Because the signals in the tubes of a push-pull pair are 180 degrees out of phase the waveforms of voltages in one tube are inverted with respect to waveforms in the other tube. Also see Fig. 9-16.

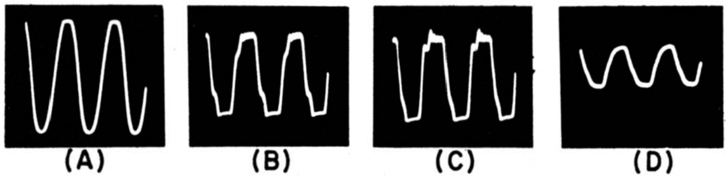


Fig. 9-16. Trace (A) is an example of the signal voltage between control grid and ground when the level is sufficient to overdrive each grid. The resistance of the grid leak is causing grid limiting as indicated by the flattened positive peak. Traces (B) and (C) show the signal voltage between the respective plates and ground of the two output tubes. Trace (D) is the resultant output voltage observed across a suitable resistive load on the output transformer. Transients present across each half of the primary winding have been smoothed out by the cancellation of even harmonics in the plate circuit system. However, the final output voltage is distorted nevertheless.

Exactly the same traces are not to be expected under all conditions of grid overdrive, although flattening of both positive and negative peaks of the signal in the individual plate circuits does usually occur. The design of the output transformer has a great bearing on the actual shapes of these voltage waveforms.

SINE WAVEFORM DISTORTION IN CLASS AB_1, AB_2 and B AMPLIFIERS. Distortion is normally present in the signal present in the plate circuits of Class AB_1, AB_2 and B amplifiers because these tubes are so biased that plate current does not flow during the full 360 degrees of the input signal cycle. These tubes always are used in push-pull.

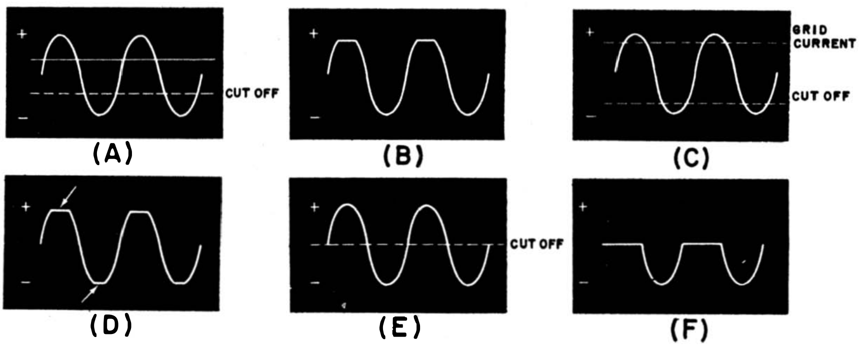


Fig. 9-17. Trace (A) is the sine-waveform voltage assumed fed into the class AB_1 audio amplifier. The dotted line indicates cutoff level. Trace (B) shows the waveforms of signal voltage between the plate and ground of the respective tubes used in push-pull. Note clipping on the positive peaks (negative peaks of the input signals). The output voltage traces for both tubes look alike because the scope shows both traces relative to a common ground, and positive peaks are similarly located on the scope screen.

Trace (C) is the sine-waveform input signal voltage for the class AB_2 amplifier. The dotted lines show the portion of the positive peaks which drive the control grids into the grid current region, and the portion of the negative peaks which make the control grid negative beyond plate current cutoff. The resultant distortion (clipping) of the signal voltage waveform between plate and ground of the output tubes in push-pull appears as trace (D). The amount of clipping of the positive peak is less than that of the negative peaks. It is very important that the grid circuit resistance be low; otherwise grid limiting will be excessive. Also, it is important that the amount of grid current permitted to flow be limited, otherwise excessive clipping will occur with consequent distortion.

Trace (E) is the sine waveform signal fed into the class B system. The horizontal dividing line indicates that the bias is such as to remove almost the entire negative alternation. The output voltage in each plate circuit consists of a series of negative half-cycles. The direction of the signal currents in the output transformer primary winding is such that the signal voltage available from the secondary winding has a waveform with positive and negative alternations.

Class B operation may be carried on with sufficient drive to cause grid current, in which case a certain amount of grid limiting will occur and the peak of the voltage waveform in the plate circuit may be flattened if the grid resistance is appreciable. Depending on the tubes used, some class B systems operate with zero bias, whereas others use a negative bias equal to one-half of the peak-to-peak value of the signal, or slightly less.

SINE WAVEFORM SIGNAL DISTORTION IN AUDIO AMPLIFIERS. This is in addition to items shown in Fig. 9-13 through 9-17.

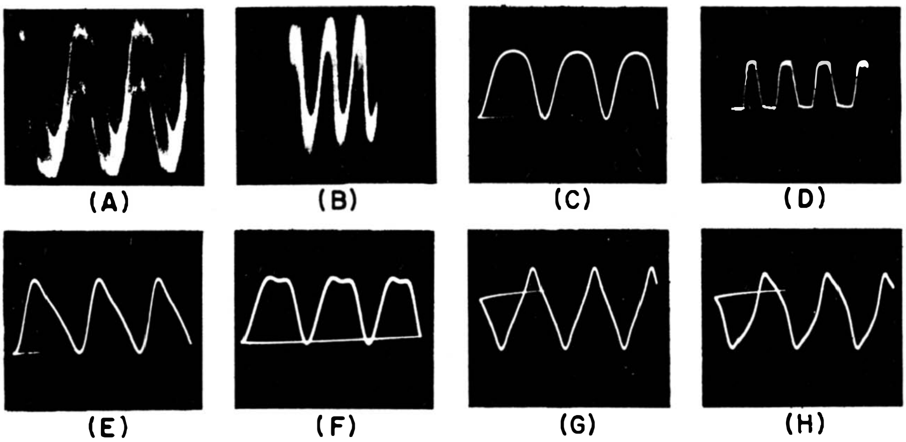
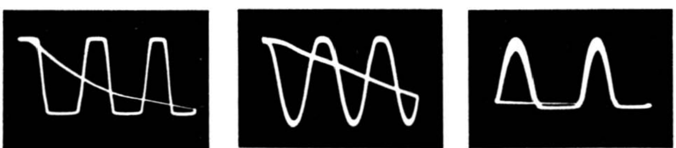


Fig. 9-18. Trace (A) shows the appearance of a sine voltage waveform when an oscillatory condition is present in the amplifier. Trace (B) illustrates the presence of noise in the signal. Traces (C) and (D) typify the distortion encountered when a mismatch exists between the amplifier tube(s) and its load. Since different conditions may prevail in the load circuit, the waveforms may differ appreciably from traces (C) and (D). Traces (E) through (H) typify distortion which may be encountered in audio amplifying equipment as the consequence of incorrect perfor-. mance. Examples are defects in transformers of push-pull systems, distortion due to reactive loads at low frequencies, etc.

For a given amplifier, distortion increases with power output. It increases when the load impedance is less than the impedance of the tube output circuit. All factors which determine operation, determine distortion—signal level, grid bias, plate and screen voltages, plate load impedance, bypassing, and either negative or positive feedback.

SINE WAVEFORM SIGNAL DISTORTION IN AUDIO SIGNAL GENERATORS. If at any time it is sufficient to be noticeable as a departure from a sine waveform, the generator is faulty and its use as an audio frequency signal source is very limited. See COMPLEX WAVEFORM SIGNAL FROM GENERATOR.

SINE WAVEFORM SIGNAL DISTORTION IN SQUARER OR CLIPPER.



(A) (B) (C)

Fig. 9-19.

Fig. 9-19. Trace (A) shows inadequate amplitude of sine waveform input to a balanced squarer (clipper) and poor balance to ground of input signal, indicated by unlike duration of intervals. Note sloping sides. Trace (B) illustrates insufficient sine waveform voltage amplitude into squarer, also unbalance as indicated by clipping of one peak only. The same type of trace can result when the input signal frequency is higher than originally planned in the design of the squarer. Trace (C) is another example of what can happen in a squarer when the system is unbalanced and the input signal voltage is too low. One half cycle of the input signal voltage has been clipped. A slight trace of hum pickup is present in the trace.

SINE WAVEFORM SIGNAL INTENSITY MODULATED IN SCOPE.

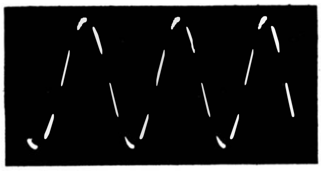


Fig. 9-20. This shows the appearance of a sine waveform when a higher frequency signal is applied to the intensity-modulating grid of the scope's cathode-ray tube. The intensity modulation separates the trace into segments. The higher the frequency of the intensity-modulating signal the greater the number of segments.

HALF SINE WAVEFORMS IN POWER SUPPLIES. Rectification of sine waveform voltages results in the production of half sine waveforms. But all rectifiers are not perfect, hence some permit the flow of some reverse current.

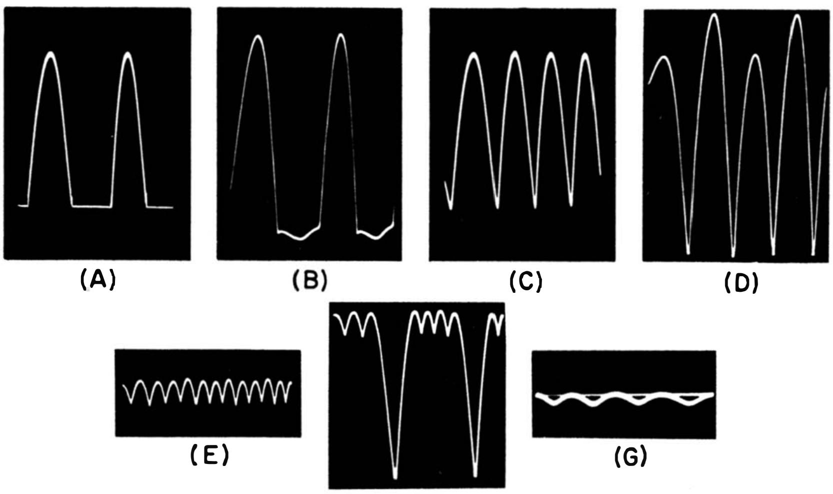


Fig. 9-21. Trace (A) is the waveform of the output of a vacuum tube half-wave rectifier as seen across a load resistor without filter chokes or filter capacitors in the circuit. Note the zero voltage output during half-cycle intervals of nonconduction. Trace (B) shows half-wave rectification, under similar conditions, by a metallic rectifier. Note the momentary reverse current which becomes prominent around the peak of the a-c input voltage. Trace (C) shows the waveform of the rectified output voltage from a vacuum tube full wave rectifier or a bridge circuit metallic rectifier.

An output voltage pulse exists for each half cycle of the input voltage. Compare this waveform with trace (A). Note that the height of the pulses is the same. Compare it also with trace (D) wherein the two half-wave rectifiers making up the full-wave system are not furnishing similar output voltages. This may be due to lack of electrical balance in the high-voltage winding of the transformer, unlike rectifier tubes, or a defect in one of the bridge circuit legs. Trace (E) illustrates the appearance of the half sine waveform voltage across the load of a three-phase bridge type full-wave rectifier using six elements, three per arm. Note two half cycles of output voltage for each cycle of input voltage per element or arm. If one arm of the circuit is open, rectification during one phase is lost, hence the trace appears as in (F). Two half cycles of output voltage are then missing and the voltage falls to zero during this phase. Trace (G) is representative of the low amplitude "ripple" voltage which appears across the load of a power supply which is operating properly. Its peak-to-peak amplitude should be less than 1 per cent of the maximum d-c voltage available from the power supply under normal operating load. High-level ripple reflects trouble in the filter capacitors or in the choke, excessive load on the power supply, or in the case of a full-wave rectifier, one of the legs of the rectifying system may be defective. For other difficulties, see SAWTOOTH WAVEFORMS IN POWER SUPPLIES. *Courtesy Radio Receptor Co.*

COMPLEX WAVEFORM TRACES DISTORTED BY HUM PICKUP IN THE SCOPE.

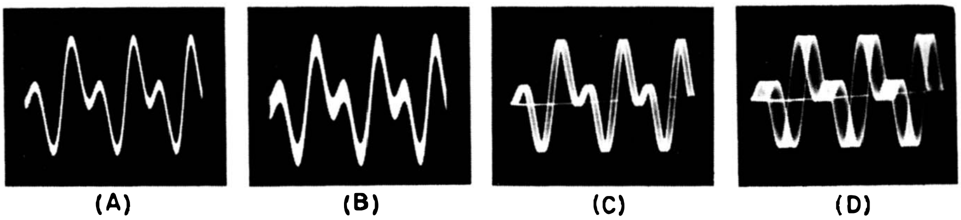


Fig. 9-22. Traces (A) and (B) show the distortion of a complex voltage waveform when hum is present on the vertical deflection plates. The hum affects the trace in the vertical direction. Traces (C) and (D) show the same complex waveform when hum is present on the horizontal deflection plates.

COMPLEX WAVEFORM SIGNAL BEHAVIOR IN AUDIO AMPLIFIERS. It is virtually impossible to use a complex waveform input test voltage for checking harmonic (amplitude distortion) in amplifiers. It is difficult to establish visually whether a change in waveform is due to harmonic distortion (the introduction of new frequency components) or if it is phase distortion (unequal time delay). Thus either sine-waveform or square-waveform voltages are used for testing amplifiers. If a complex waveform is processed by an amplifier without any changes in the appearance of the waveform except inversion and overall amplitude change, the amplifier is functioning properly and is free from distortion.

Fig. 9-23. Traces (A), (B) and (C), (D) are paired illustrations of the *inversion* of a complex waveform in an amplifier without noticeable distortion. Inversion can be recognized readily when the positive and negative half cycles are unlike, but if they are the same it may be difficult to note. This applies to both sine and square waveforms. Traces (F), (G) and (H) indicate the change in a complex waveform (E) by the addition of frequency components. This action is called *harmonic distortion.* In (F) the third harmonic was added to the fundamental and the second harmonic; in (G) the fourth harmonic was added to the first two, and in (H) the fourth harmonic has been increased in amplitude. Distortion as shown in

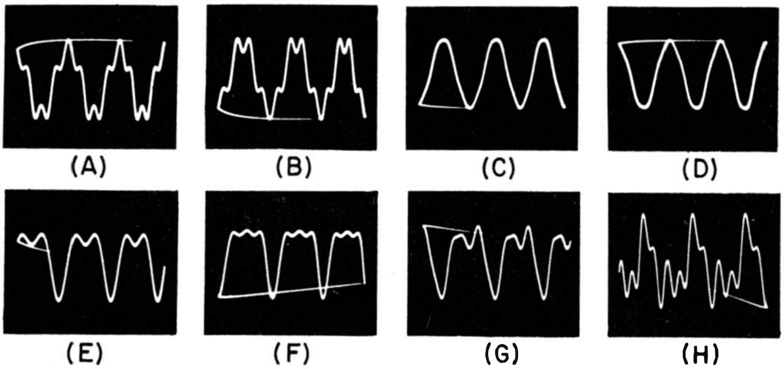


Fig. 9-23

traces (F), (G) and (H) is more frequently encountered in reactive loaded circircuits than resistive load tube circuits.

Nonlinearity will round off peaks, plate current saturation or grid current will tend to flatten the positive peaks of the input voltage. Grid clippers will clip off the positive peak(s) or more of the positive half cycle, as determined by the design, and so clip the negative half cycle of the output voltage. Plate current cutoff will limit the amplitude of the positive peaks of the input voltage.

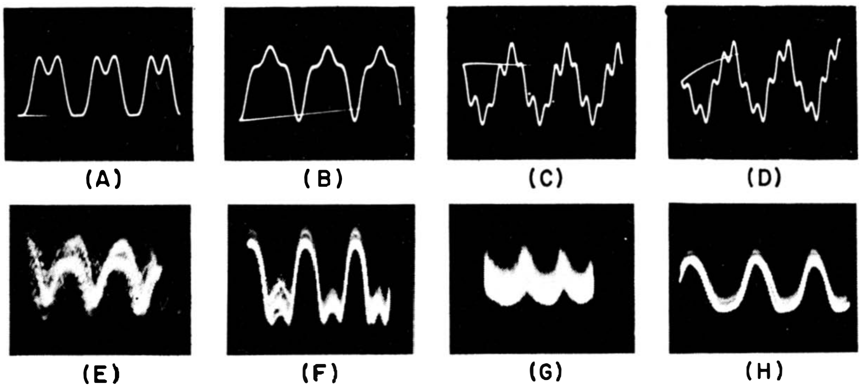


Fig. 9-24. (A), (B) and (C), (D) are paired illustrations of the change in appearance of the waveform because of a *change in phase difference* of the frequency components. This is known as *phase* distortion. The relative amplitude of the component frequencies in each pair are the same; the difference between the appearances of the traces in each pair is strictly a matter of relative phase between the component frequencies. For other methods of checking phase shift between components see PHASE MEASUREMENTS.

Traces (E), (F), (G) and (H) illustrate the presence of noise on a variety of complex waveforms. The noise impulses appear as "grass" on the trace and usually are in continuous motion.

Square Waveform Signal Distorted by Defects in the Test Scope. Because the test scope is used as the display element in the examination of waveforms, any of a variety of difficulties experienced in connection with, or within the scope, can adversely affect the features of waveforms other than sine waves and so lead to erroneous conclusions. Hence, it is imperative that the scope used be in perfect working order.

Fig. 9-25. Traces (A) and (B) illustrate the distortion of a good square waveform by the presence of a 60-cps hum field originating external of the scope in a current-carrying transformer, choke, or soldering iron, which is close to the scope.

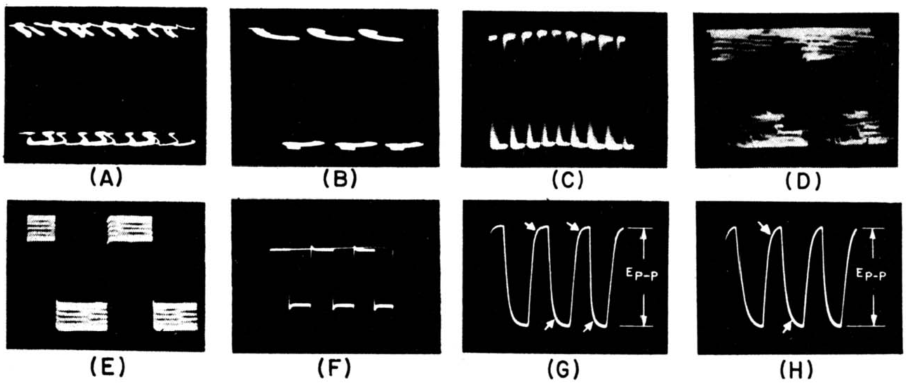


Fig. 9-26. Traces (A), (B) and (C) illustrate the effect of hum, present in the scope power supply, on the appearance of a square waveform trace. Traces (D) and (E) illustrate the effects of 60-cps hum voltages present in the vertical amplifier. Such conditions may arise from imperfect shielding, grounding, stray pickup. The trace on the screen bounces up and down. Trace (F) shows overcompensation of the high frequencies in either the vertical amplifier circuits or in the vertical gain control system. It is indicated by the sharp pips which appear on the leading edges of the waveform.

Trace (G) shows the distortion resulting from the loss of high frequency components at a low-amplitude setting of an uncompensated vertical gain control; the significant characteristic being the rounding-off of the leading edges, as pointed out by the arrows. A more aggravated case is illustrated in trace (H), being created by further advancing the gain control. It is to be noted that the peak-to-peak amplitude of even a distorted square waveform can be measured because the overall height of the voltage trace is not altered by the loss of high frequencies.

SQUARE WAVEFORM SIGNAL DISTORTION IN WIDE BAND (VIDEO) AMPLIFIERS. Distortion can appear in five different ways; attenuation or accentuation of high frequencies, attenuation or accentuation of low frequencies, and phase shift between the components. Each of these demonstrates its effects in a distinctive manner. It is assumed that the signal voltage fed into the system has satisfactory square waveform features.

Wide band frequency response in a wideband or video amplifier depends upon a particular set of resonant conditions. These are achieved by the use of series and shunt frequency compensating circuits in the plate and grid systems of the amplifier tubes. These circuits help keep the gain of the system at a prescribed level over a fixed range of frequencies. Plate load resistors and operating voltages must be kept within certain boundaries. Increases in either with the other constant will reduce the overall frequency passband and increase the gain.

Changing the resonant frequencies, or the amount of amplifier gain, over the different portions of the overall response or gain curve will affect the processing of the components of a square (or rectangular) waveform used to test the circuits and so affect the features of the output test voltage.

Signals having low frequencies are affected by the blocking capacitors and grid leaks. The offsetting frequency compensation usually is found in the plate circuit in the form of RC networks. The time constants of the RC networks formed by cathode bias and bypass capacitors, screen voltage dropping resistor and bypass capacitor, and plate circuit decoupling resistor and bypass capacitor affect the phase shift at low frequencies. When these have long time constants the low frequency response conditions generally are good.

As to high frequency compensation, peaking coils may be found connected in series with the plate load and in series with the coupling capacitance. These peaking coils are resonated by their own distributed capacitance plus stray capacitance present in the circuit. Therefore, changing the position of the coil (lead dress) can impair the performance of the peaking coil, hence the frequency passband.

The plate load and the related frequency compensating circuits determine high frequency response. The amount of damping applied to the compensating circuits and the frequency at which the resonance occurs determine whether undercompensation or overcompensation results.

Every system with a fixed frequency passband sets a limit on the fundamental frequency of the square waveform voltage which it can process properly. If the fundamental frequency of the input test voltage is too low, a good output square waveform will be achieved but the signal is not a good test of the circuit behavior. If the fundamental frequency of the applied square waveform voltage is too high for the bandwidth of the system, the output waveform is misleading. All engineers do not agree on the point, but it is generally conceded that a reasonable determination of high frequency response can be achieved by using a fundamental frequency equal to the highest frequency of the rated passband (not down more than 3 db) divided by about 100. For low-frequency response examination, the fundamental frequency of the square waveform should not be higher than about 3 or 4 times the lowest frequency of the rated passband (not down more than 3 db).

Attenuation of high frequencies is attributable to peaking coils being completely open circuited, short circuited, or containing shorted turns, changes in ohmic value of damping resistors, open bypass capacitors, changes in values of resistive plate loads, and changes in the lead dress of inductive and capacitive components. Frequently peaking coils can be open-circuited and even short-circuited without interfering with the low-frequency and mid-frequency operation of the amplifier, although the high-frequency response will be impaired.

Accentuation of high frequencies is attributable to difficulties in the previously discussed lead dress components and changes in the frequency of resonance of the peaking systems. Reduced damping by an open in the peaking-coil damping resistor will sharpen the resonance and raise the amplitude of the signal voltage near the resonant frequency, modifying the appearance of a square-waveform of voltage processed by the system. For more information on the behavior of video amplifiers, see FREQUENCY RESPONSE CURVES FOR VIDEO AMPLIFIERS.

Low frequency response is determined by coupling capacitors and grid leaks, plate decoupling resistors and capacitors and screen bypassing. Low-frequency compensating circuits usually are located in the plate circuits of the amplifier tubes, but cathode bypassing *also must* be effective. Phase shift situations and the loss of low frequencies are not too easily distinguishable from each other, as is shown in the traces below.

Fig. 9-27. Trace (A) illustrates extreme high frequency response. It is tantamount to a strong high frequency transient, as indicated by the decaying cycles which succeed the initial high pulse. For comparison, trace (B) illustrates the pip which usually appears in the trace when high frequency compensation is somewhat excessive.

Excessive high frequency response in a television receiver video amplifier will affect a television picture by causing vertical black and white shading lines following a sharp change in contrast of the normal scene, that is, a sudden change from black to white or vice versa.

Slight overcompensation at the high frequencies can prounce a tiny pip as in trace (C). Correction usually results in a voltage waveform such as (D). Here a slight loss in high frequencies is indicated by the slight rounding off of the leading edge, but this much attenuation will not result in any harmful effects. Greater amounts of high frequency attenuation appear in traces (G) and (H) in Fig. 9-26. In between voltage waveforms such as (D) in Fig. 9-27 and (G) in Fig. 9-26 will be found many intermediate waveshapes.

Attenuation of the high frequencies in a television receiver video amplifier (indicated by square waveform response such as (G) and (H) in Fig. 9-26) will result in poor picture detail and general "fuzziness" when sharp changes in contrast exist in the same scene.

Attenuation and phase shift of the low frequencies gives the waveform a downward tilt from the maximum amplitude plateau. The fall from the maximum amplitude to zero is a function of the low frequency content. In trace (E) the circuit response to the fundamental frequency and below it is effectively zero. In trace (F) the fall in amplitude is much more gradual than in (E); this indicates that some response to the fundamental frequency is present.

A vastly improved situation appears in trace (G). A tilt in the waveform still exists, but a semblance of a maximum plateau is evident. The tilt downwards indicates that the response at the lowest frequency in the passband is less than at higher frequencies. Still less tilt, indicative of greater response at the lower frequencies, is seen in trace (H). The plateau is almost horizontal. Increasing downward tilt can be expected as the fundamental frequency component of the voltage is decreased, unless the system design is such that zero frequency is accepted, in which event the plateaus of low frequency voltages are horizontal, but higher frequency voltages will suffer some attenuation.

A television receiver video amplifier which gives output test waveforms such as traces (E), (F) and (G) will affect the shading of the picture vertically. A gradual change in shading will appear from top to bottom of the scene.

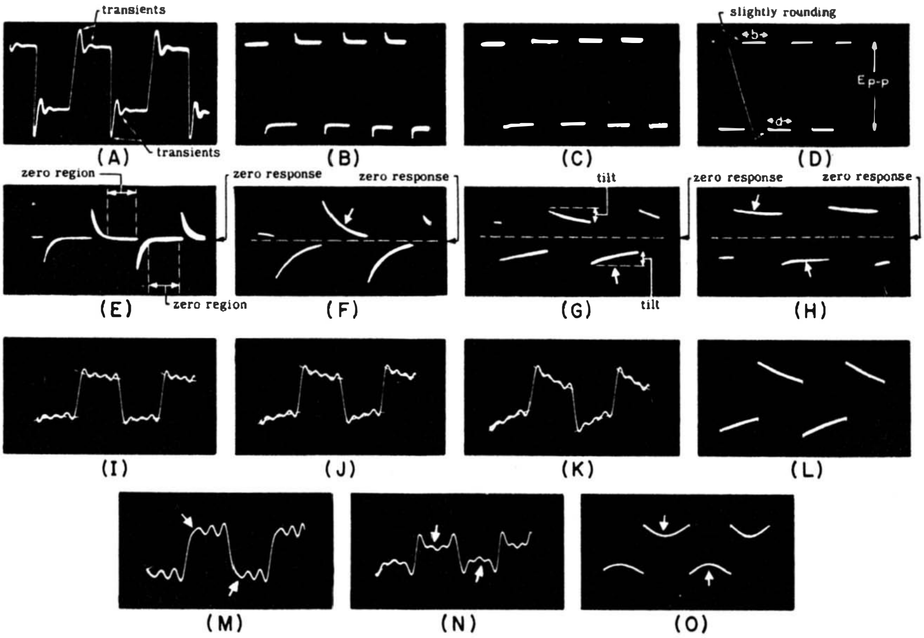


Fig. 9-27.

The effect of low-frequency phase shift (unequal time delay) in the amplifier processing the square waveform is illustrated in traces (I), (J), (K) and (L). Here are shown three approximations of a square waveform during the process of synthesis using the fundamental, 3rd, 5th and 7th harmonics, as traces (I), (J) and (K) respectively. In each succeeding trace, the low frequency components are made to lead more and more; it is seen that the outline of the waveform has a progressively increasing downward tilt, which is the same as for low frequency attenuation. The final shape of a square waveform which suffers phase shift of this kind appears in trace (L).

Phase shift at the higher frequencies demonstrates an effect similar to the attenuation of the higher frequency components. An illustration of this appears in trace (M). Here, the seventh odd harmonic is advanced in phase relative to the fundamental, also relative to the lower frequencies. Even this simple case containing but four odd frequency components is capable of illustrating that advancing the phase of the high frequency components modifies the waveform so that the leading edges become rounded. High frequency attenuation, rather than high frequency phase shift, is the more common problem.

One common cause of high frequency phase shift, as shown in trace (M), is a high peak toward the upper frequency limit of the response curve, and steep slope on the higher frequency side. Lowering the resonant frequency or increasing the damping reduces the effect. Thus it is apparent that the constants of the high frequency peaking circuits are involved.

A situation which results in a reduction in the amplitude of the fundamental frequency component and abnormally high neighboring harmonics modifies the square waveform in a distinctive fashion. Examples are shown in traces (N) and (O) respectively. Trace (N) illustrates the condition when only four odd harmonics are contained in the waveform, and waveform (O) illustrates the effect as noted in a practical square waveform containing the aforementioned shortcomings. Amplitude relationships of this kind may arise in amplifiers which have a rising characteristic from the lowest frequency, and the square wave has a low fundamental frequency.

Square Waveform Signal Behavior in Audio Amplifiers. While it can be said that square waveform signal is acted upon in the same fashion in different kinds of amplifiers, it is only so if the conditions of operation are the same. Whereas Fig. 9-27 illustrates situations which one might encounter in video amplifiers or wide band amplifiers, the use of square-waveform voltages for testing audio amplifiers results in patterns which are distinctly different because circuit conditions are generally different. Nevertheless, the fundamental situations which tend to modify a square waveform are encountered in both instances, but somewhat more severely in the audio amplifier. This is especially true when the amplifier contains frequency controlling elements such as treble, bass and "voice" tone controls, and positive or negative feedback.

As to the conditions which might alter the square waveform so that it becomes malformed, they are somewhat the same as in a wideband amplifier. Under the circumstances, reference is made to the description concerning square-waveform distortion in video amplifiers as described in this chapter. But because some audio amplifiers have a relatively limited bandwidth, and some use negative feedback, special examples of variations of the square waveform under these influences are shown here.

Concerning tone controls, it is necessary to mention that the waveforms shown are specific for a particular circuit, which if not duplicated, limits the usefulness of the distorted waveforms as far as interpretation is concerned. Each waveform has meaning but only in a general way. Also see Fig. 9-29.

Fig. 9-28. Traces (A) through (F) illustrate the manner in which a recording audio amplifier of substantial frequency passband processed square waveforms of a variety of fundamental frequencies in the *absence* of inverse feedback. The exact specifications of the amplifier are not important at the moment, because the point being made is simply the general order of improvement that is derived from the use of inverse feedback, as shown by waveforms (A′) through (F′); or conversely to illustrate the impairment of waveform which is to be expected when an inverse feedback system incorporated in the design of an audio amplifier fails to function properly.

When negative feedback is added, the output waveform is much improved at the low frequency limit of 40 cps and below. The higher frequency response has also been improved. Even the 5000-cps waveform in (D′) is a reasonable version.

The whole answer is not inverse feedback alone, as indicated in traces (G) and (H). Here is illustrated the effect of loading on the output transformer of an

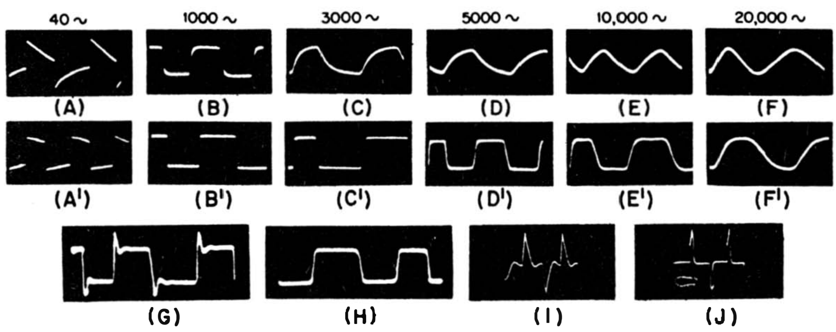


Fig. 9-28

amplifier. Inverse, or negative feedback in unloaded circuits can produce transients (G) as a result of the sudden changes in voltage. The frequency is 5000 cps. The addition of a suitable load on the output transformer results in the elimination of all transients, as illustrated by trace (H).

Audio transformers not intended for square wave checking can produce weird looking waveforms when subjected to such tests, especially at low frequencies. Two examples appear in traces (I) and (J). The input voltage is 60 cps square waveform. The transformer is of the variety used in conventional radio receivers. In (I) the transformer was loaded by the speaker; in (J) the transformer was unloaded. Trace (J) indicates behavior of the transformer as substantially a *differentiating* device. (Also see Fig. 9-29.) *Parts (A) through (H) courtesy Measurements Corp.*

SQUARE WAVEFORM DISTORTION IN AUDIO AMPLIFIERS AS THE RESULT OF TONE CONTROL. These data are related to Fig. 9-28, but are different in that they illustrate the manner in which distortion of a square waveform can be used to determine the behavior of tone controls. Obviously, only qualitative conclusions are possible from these data because the traces will differ with differences in fundamental frequency, composition of the test signal voltage and the design of the tone control circuits. The input gain controls were set for optimum square wave input to the tone control circuits.

The amplifier circuitry may appear normal when the input signal has a low fundamental frequency, say up to perhaps 500 cps, but at frequencies of 1000 cps and higher, some degrading will occur.

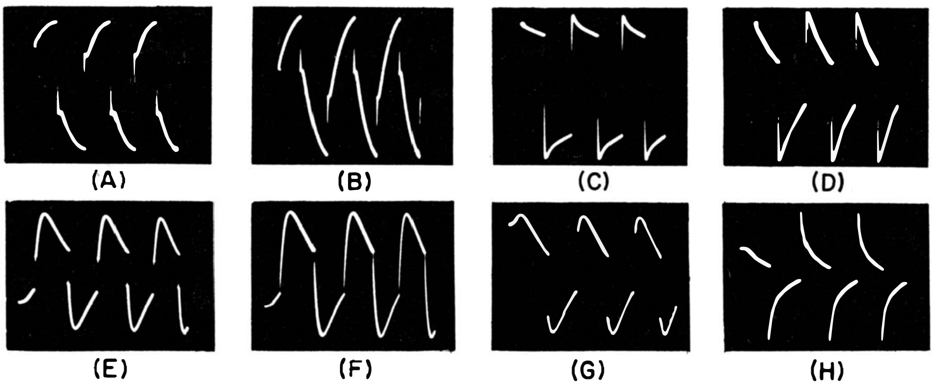
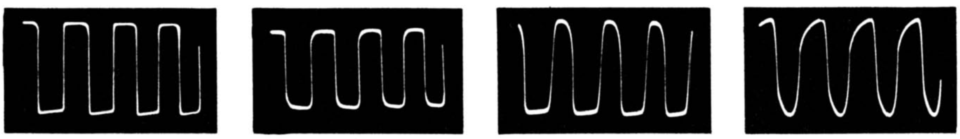


Fig. 9-29. Traces (A) and (B) illustrate the effects of the tone control at two settings which favor the "bass". The input test signal is a 400-cps fundamental frequency square waveform voltage. Note the progressive increase in high frequency attenuation. Traces (C) and (D) illustrate the effect when the tone control is set to "treble" for the same 400-cps voltage. Note the progressive increase in the high-frequency components of the square wave. Traces (E) and (F) illustrate the limited effect of the tone control set to "treble" when the input test signal is a 60-cps square waveform voltage. Traces (G) and (H) show the effect of the tone control set to "bass" with the 60-cps square waveform signal. Here there is an effect which is not unlike differentiation for, after all, limitations are being placed on frequency content.

SQUARE WAVEFORM CHANGES IN TUBE CIRCUITS. In view of the constant-amplitude peaks of square waveforms, numerous forms of incorrect tube and circuit behavior do not show up in the waveform. Grid clipping, plate saturation, or plate current cut-off will not modify the appearance of a truly square wave. But if the wave has tilted plateaus, transient peaks, or is deformed in some way which modifies the flatness of the maximum amplitude interval, nonlinearity of the amplifying tube will modify the shape of the voltage. Grid clipping or plate saturation will flatten or round off the negative half cycle, and plate current cutoff will flatten the positive half cycle of the output voltage in the plate circuit of amplifiers or clippers. It may even put a "step" into the waveform. A deformed square waveform may appear to be improved in appearance, and so lead to wrong conclusions.

Square Waveform Voltages in Multivibrators. Symmetrical multivibrators are sources of square waveform voltages which are sometimes changed to sawtooth shapes. Changes in grid resistance or in the feedback loop in the system can impair or improve the square waveform, depending on operating conditions. Virtually all the elements in the system will demonstrate an effect on the waveform. Circuits having like constants for similar tube electrode circuits will as a rule produce the best square waveform. There are exceptions to this general relationship, especially in cathode-coupled systems wherein the resistive elements in the grid circuits differ.

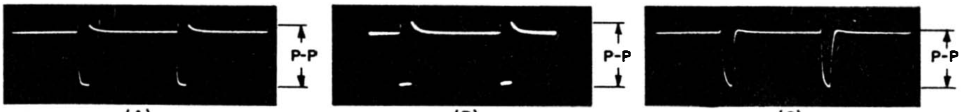


(A) (B) (C) (D)

Fig. 9-30. Traces (A) and (B) are the square waveforms obtained from the two plate circuits in a cathode-coupled symmetrical multivibrator. In traces (C) and (D) are shown the effects of changing the grid return resistor—lowering its value. The changes in waveform are not interpretable in terms of frequency composition, rather in the intervals of tube condition in the system.

Rectangular Waveform Distortion. In the applications dealt with in this book, such features as peak or peak-to-peak amplitude, duration and steepness of sides are the significant characteristics. Freedom from spurious signals also is important.

The appearance of the trace is determined by its frequency composition, but there are numerous instances of voltage (waveform) conditions when the frequency composition is of secondary interest. Examples of these are pulses that are used to synchronize generators of different kinds. Such pulses are sharply peaked. On the other hand, pulses that are intended to "gate" (open and close) amplifying systems for prescribed intervals, must have particular duration periods, and so must be formed in a particular manner. In these cases, the frequency composition is important.



(A) (B) (C)

Fig. 9-31. The voltage is a 50-microsecond pulse repeated 4000 times per second. Trace (A) is the output waveform after passage of this signal through a circuit with a 500-kc passband; (B) is the result with a 100-kc passband and (C) is the output for about a 40-kc passband. The overshoot is a consequence of charging the blocking capacitor in the circuit.

The peak-to-peak value of the pulse is measurable even under the most adverse high frequency conditions. The duration of the pulse at its peak is reduced as the frequency passband is decreased, but the importance of this is determined by the level at which the pulse is used.

Rectangular Waveforms as Blanking and Synchronizing Voltages in Television Receivers. Rectangular waveforms are common in television receivers. Well-known examples are the blanking, synchronizing and equalizing pulses which are a part of the composite video signal; also the voltage which is fed to the horizontal afc system and the agc input voltage.

In comparison with "ideal" characteristics, virtually all rectangular pulses encountered in television receivers are "distorted." But this does not make interpretation difficult, because the differences between proper performance and incorrect functioning of the equipment are readily identifiable. Whenever possible, and this is quite frequently, judgment should be based on comparison of the observed waveform with the reference information contained in the service literature. Another point which warrants emphasis is that inadequate amplitude, rather than distortion, oftentimes is the problem which requires correction.

Attention is called to the major role played by the r-f front end, the video i-f amplifier, and the video amplifier in the frequency composition of the signal which appears at the output of the video detector or which is used for synchronizing purposes. The features of the response curves in these systems determine the characteristics of these pulses.

Fig. 9-32. Trace (A) illustrates the organization of the composite video voltage waveform seen at the output of the video detector or in the video amplifier of a black and white television receiver when the scope sweep is synchronized at $H/2_f$. Two horizontal pulses are seen. Trace (G) is the same as (A) except for inversion. Waveforms such as (A) and (B) are referred to as showing two horizontal lines. Actually the trace contains vertical pulses as well, because the period of viewing permits a number of frames to be shown. Line *a* is formed of a great many vertical synchronizing and equalizing pulse tips that appear to join each other and form a line; the line *b* is formed of a great many vertical blanking pulse pedestals in the same manner. The front and back porches of the horizontal blanking pulse are indicated in (A), and are duplicated in (B). All elements of (A) appear in (B). Attention is called to the heights of the blanking pulse and the synchronizing pulse relative to the bottom of the trace in (A) which corresponds to maximum white, and is slightly higher than the zero carrier level. The height of the synchronizing pulse normally is about ⅓ the height of the blanking pulse and projects this much above the blanking pedestal. The video information has no standard appearance. We can

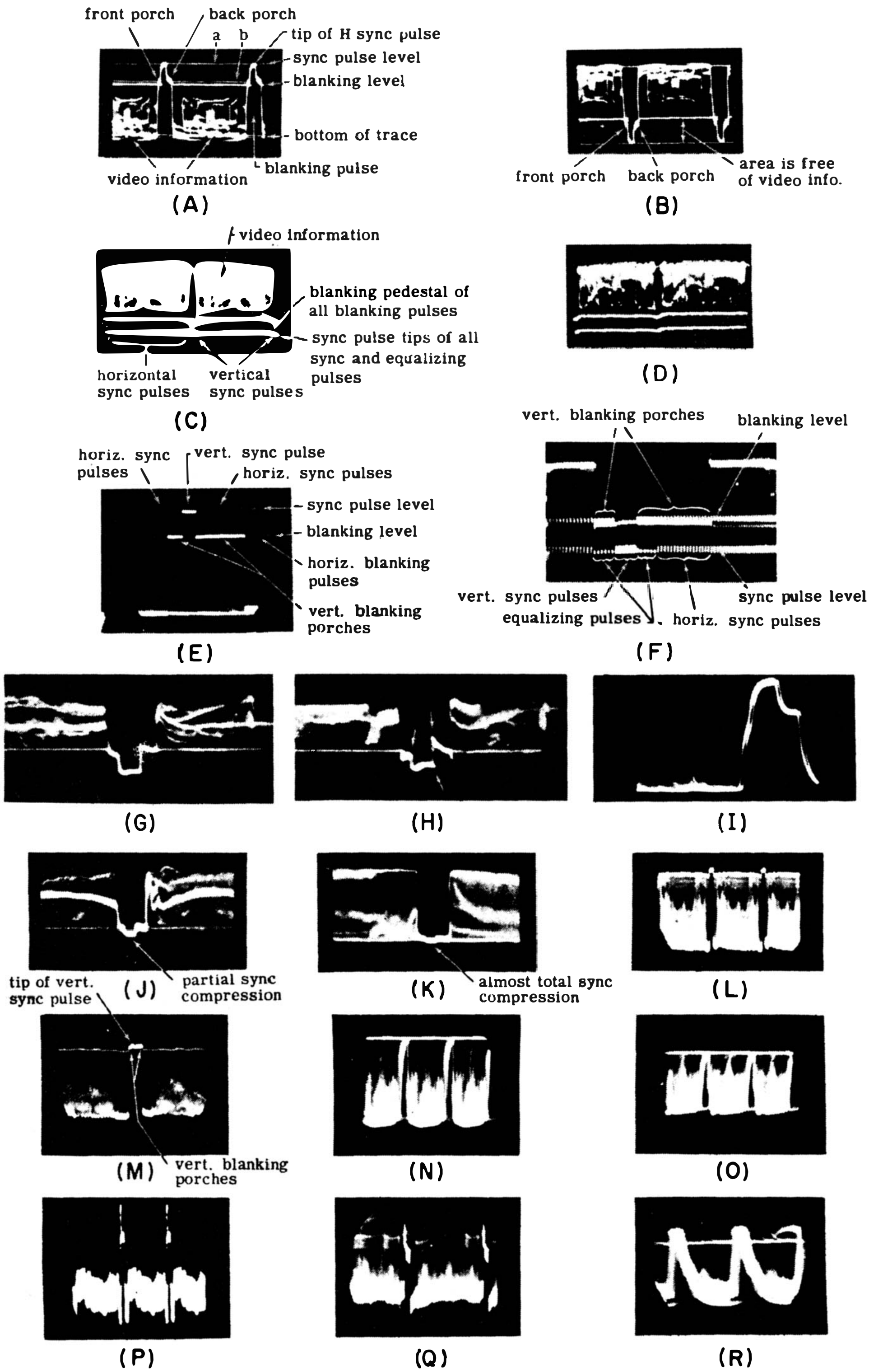

front porch
back porch
a
b
tip of H sync pulse
sync pulse level
blanking level
bottom of trace
blanking pulse
video information
(A)
front porch
back porch
area is free of video info.
(B)
video information
blanking pedestal of all blanking pulses
sync pulse tips of all sync and equalizing pulses
horizontal sync pulses
vertical sync pulses
(C)
(D)
horiz. sync pulses
vert. sync pulse
horiz. sync pulses
sync pulse level
blanking level
horiz. blanking pulses
vert. blanking porches
(E)
vert. blanking porches
blanking level
vert. sync pulses
equalizing pulses
horiz. sync pulses
sync pulse level
(F)
(G)
(H)
(I)
tip of vert. sync pulse
(J)
partial sync compression
(K)
almost total sync compression
(L)
(M)
vert. blanking porches
(N)
(O)
(P)
(Q)
(R)

Fig. 9-32

consider this portion of the trace as being made up of shaded lines in motion. During proper operation the video information extends upward from the bottom of the trace to just *below* the blanking level; also that video information is not present in the signal during the blanking periods.

Concerning the appearance of the synchronizing pulse and the blanking pulse pedestal, traces (A) and (B) are not ideal in features, yet they represent a properly operating receiver. Although the shapes of the pulses are not perfect, it is still possible to measure relative amplitudes. This is important.

Traces (C) and (D) illustrate the vertical pulses. The scope sweep can be either the sawtooth or 60-cps line sweep. In waveforms (C) and (D) the sweep is the sawtooth. In trace (E) it is the 60-cps line sweep with the horizontal gain full advanced so as to spread the image. The horizontal pulses and equalizing pulses can be seen in the trace. A more readable example of the vertical pulse is shown as trace (F) wherein video information is absent, and this makes the serrations of the equalizing and vertical synchronizing pulses discernible. The vertical pulses approach the ideal features very much more closely than the horizontal pulses, although they are not too readily seen on the usual scope screen which is being used to observe signals in the television receiver.

Traces (G) and (H) are two enlarged views of horizontal blanking and synchronizing pulses corresponding to different positions of the picture carrier on the video i-f response curve. Trace (G) is for a normal response curve; the pulse is well formed. In trace (H) the overshoot is very pronounced; it is the result of video i-f adjustment, or even r-f tuning, which raises the amplitude of the high frequency end of the response curve. Quite often the better picture is obtained with a trace such as (H) rather than (G)! It is sharper and more contrasty. Trace (I) is for reduced high frequency response, with a consequent loss of detail in the picture.

Traces (J) and (K) illustrate two different cases of horizontal synchronizing pulse compression, being almost complete in (K). Such conditions can be caused by incorrect bias or plate load or plate voltage conditions, or overloading in the video amplifier, although it can also occur in the video i-f amplifier or video detector. Traces (L) and (M) illustrate two conditions of vertical synchronizing pulse clipping in the video amplifier. (Traces taken at plate of video amplifier.)

Traces (N) and (O) illustrate clipping of horizontal synchronizing pulses in the video amplifier, video detector, or video i-f amplifier. Incorrect operating voltages or load resistor conditions can account for these defects and consequent horizontal instability.

Trace (P) illustrates the video i-f signal as seen at the last video i-f amplifier grid through a detector probe with an unduly long time constant. Note that the video information voltage amplitude is seriously reduced. This trace illustrates the importance of the correct time constant in the detector probe used with the scope. Trace (Q) is the equivalent of (P), except that demodulation occurs in the scope, using a direct probe. For all practical purposes, such a trace is useless.

Trace (R) is taken at the control grid of the last video i-f amplifier tube and is demodulated with an unsuitable demodulator probe. The probe presents a high value of capacitance across the circuit. Identification of the features of the waveform is impossible.

RECTANGULAR WAVEFORMS IN SYNC SYSTEMS OF TELEVISION RECEIVERS. In view of the wide variety of circuits used for sync systems and the names assigned to them, it is not possible to correlate generalized waveforms with specific portions of these circuits. But since the functions of the system are the same, although some receivers may use two tubes to accomplish it, and others may use four, it is possible to generalize by illustrating the desired results of different actions—good and bad. In the final analysis, conclusions are based on the evaluation of a comparison between the observed waveform and the reference waveform, hence a knowledge of what is desired in general can be helpful.

It is emphasized that incorrect action in the sync system results from incorrect biasing of the tubes, wrong plate voltages because of changes in plate and cathode resistors, and in general, defective tubes. The problem in general is not ideal features for the waveform, but rather its separation from video information and its adequate amplitude.

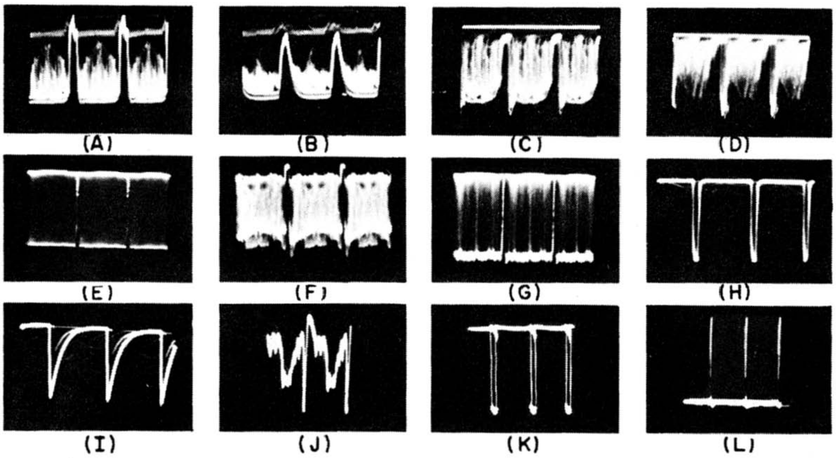


Fig. 9-33. Trace (A) is the rectified video voltage fed to a sync amplifier with the scope sweep set to H/3f. It is shown here with positive polarity, but it can be negative as determined by the particular system. The scope displaying this waveform has a 2-mc vertical passband. Trace (B) of Fig. 9-33 is the same as trace (A) but is seen on a scope deficient in vertical amplifier passband. Trace (C) is the rectified video signal after it has suffered removal of the sync pulse and lowering of the blanking level pedestal by grid bias cutoff clipping. The video signal and the pulse amplitude are alike. Trace (D) is a rectified video i-f signal which has been passed through a sync amplifier with incorrect operating bias and the video signal still present. Trace (E) is the normal appearance of the vertical sync pulse after proper clipping. Trace (F) is a rectified video i-f signal from which vertical sync pulse has been removed but the blanking pulse and video information is present. Trace (G) is the equivalent of (E) except that earlier clipping has reduced the amplitude of the sync pulse to the limits shown by *a* in (E).

Trace (H) is the correct appearance of the horizontal sync pulses. No video information is present and the pattern is square because of the fairly broad passband of the scope. The scope sweep is set to H/3f. Trace (I) is the same as (H), except seen on a scope deficient in vertical amplifier passband. Trace (J) is trace (F) at the output of a combination sync amplifier and clipper when the cathode circuit of one tube was defective.

Traces (K) and (L) are found at the plate and in the cathode circuits of phase splitters which serve dual input horizontal phase discriminators. The appearance of these horizontal sync pulses is the same except that one of them is inverted. The vertical pulse output to the integrator from the phase splitter resembles trace (E). The output voltage is taken off directly as the cathode of the tube.

Rectangular Waveform (Buzz) Pulse in Television Receivers. Usually the buzz pulse is spiked, but sometimes it is rectangular, hence the subject is treated here. Its causes are incorrect alignment, faulty ratio detector or discriminator transformer, excessive signal, operation of video i-f amplifiers over nonlinear region, cross-talk between vertical or horizontal oscillator systems and audio amplifier, coupling from horizontal oscillator into audio amplifier, nonlinear operation of video amplifier, excessive lead dress and coupling between sweep oscillator and antenna.

The methods used for observing the buzz signal are tuned detector probes to explore i-f coils, and conventional direct-coupled probes beyond the video detector. Tunable buzz can be related to the front end, the video i-f amplifier, or the sound i-f amplifier. Non-tunable buzz may be related to coupling between the sweep oscillators or output systems and the audio amplifier.

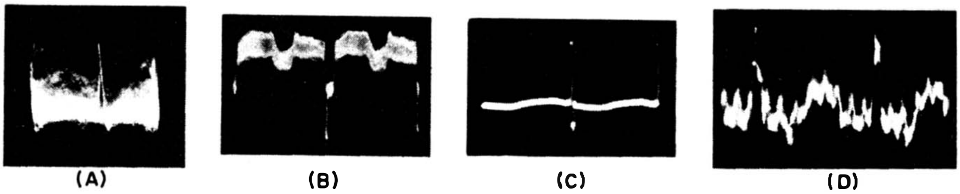


Fig. 9-34. Trace (A) is a buzz voltage waveform as seen in front-end tuned circuits. Trace (B) is a buzz waveform in i-f coils. Trace (C) is a buzz voltage seen in video amplifiers, and trace (D) is an example of a buzz waveform in audio amplifiers.

RECTANGULAR WAVEFORMS IN THE HORIZONTAL SWEEP OUTPUT SYSTEM OF A TELEVISION RECEIVER. These waveforms appear at various points within the system, such as the plate of the output tube, across the width coil, the damper tube, and across the horizontal deflection coil. This shaped voltage arises from the requirement for a linear sawtooth-shaped current through windings that are principally inductive with relatively low d-c resistance.

These rectangular pulses contain transient oscillations also as a part of the waveform. Normally they are of limited amplitude. The polarity of the voltage across the deflection yoke, damper tube and width coil is the opposite of that present between the output tube plate and ground in transformer-coupled systems, and is the same in autotransformer and direct-drive systems.

Defective states give rise to distortion of the voltage pulse, but frequently the nature of the trouble is such that only the amplitude of the voltage is low, whereas the waveform remains normal. Attention is called to the fact that difficulties in horizontal output systems do not create waveform symptoms at specific points only; frequently a fault at one point will distort the waveform at several points in the system. (See also Fig. 9-36)

Fig. 9-35. Correct and incorrect waveforms at the plate of the horizontal output tube. Waveforms are shown in pairs. Normal peak amplitudes of these voltages are from 4000 to 5000 volts positive in all but the direct drive systems, wherein the usual voltage range is from 3000 to 6000 volts positive. Obviously great care must be exercised when working with these pulses. Trace (A) is an example of a normal waveform. The transients that follow the sharp peak are due to the oscillations normal to the functioning of the system. Their amplitude is small relative to the peak amplitude of the pulse. The first negative pip (*a*) following the pulse drives the plate of the output tube negative (below the screen potential) by some amount depending on the amplitude of the voltage developed in the circuit. This

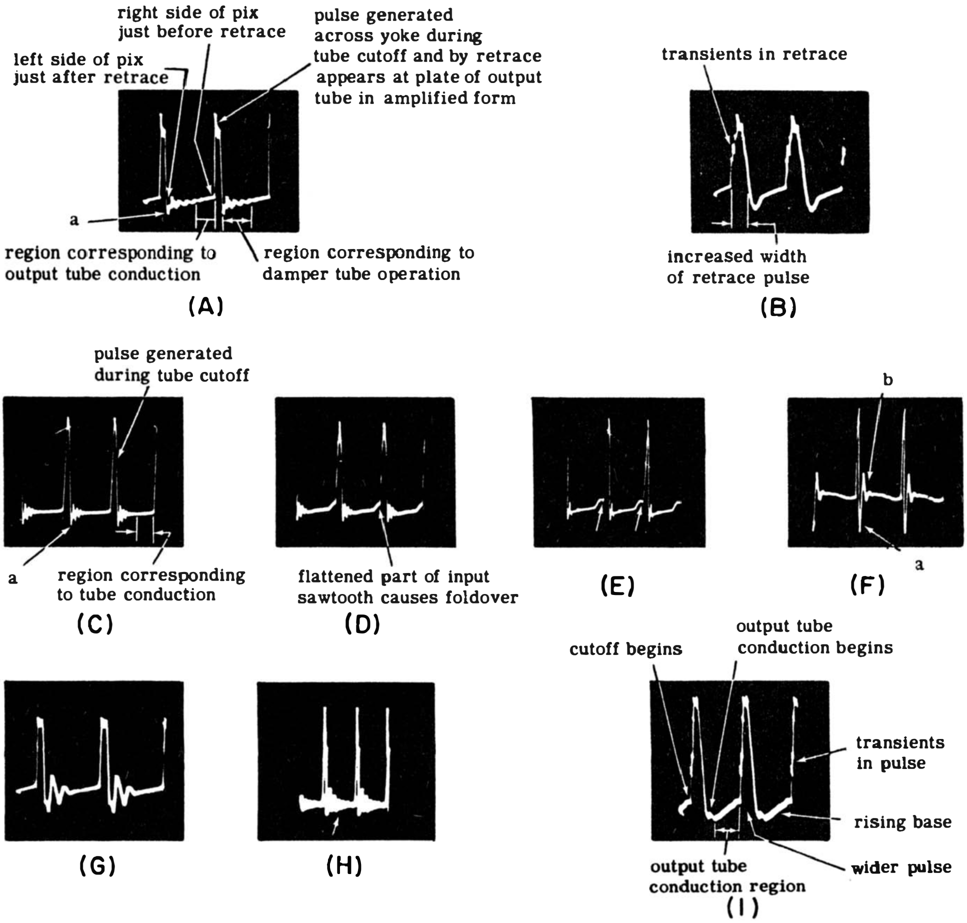


Fig. 9-35

momentary negative voltage is responsible for the Barkhousen oscillations that are generated in the output tube.

Still referring to trace (A), the base of the pulse does not as a rule have a tilt; usually it is a horizontal line as illustrated in subsequent examples of normal waveform at this point. Trace (B) is the companion to (A) but indicates a *defective* waveform caused by an open winding in the secondary of an auto-transformer type of horizontal output transformer. Stray capacitive coupling permitted the generation of a voltage.

Trace (C) is the typical waveform of the pulse at the horizontal output tube plate. Note the horizontal baseline and the short duration transients as well as their relatively low amplitude. Note the labels which indicate the portions of the pulse. Trace (D) corresponds to trace (C); the abruptly rising segment is caused by flattened sawtooth portion of trapezoidal driving voltage fed to the input circuit of the horizontal output tube. It accounts for horizontal foldover at the right side of the screen.

Trace (E) indicates a defective state at the point indicated by the arrow. This distortion accounts for horizontal foldover, again due to an incorrectly-shaped driving voltage fed to the horizontal output tube.

In trace (F) the negative pulse *a* is unduly high, while the positive pulse is unduly low by comparison. Note the increased transients shown by arrow *b* caused by a shorted width coil, which reduces voltage applied to the deflection coil, hence reduces the magnitude of the "kickback" voltage appearing at the plate of the output tube.

Trace (G) indicates the increased amplitude of transients present on the plate voltage pulse when one of the secondary windings in the output transformer is open-circuited, thus reducing the loading on the transformer. The open winding was shunted by the width coil. Ringing is evident in the picture tube pattern.

Trace (H) indicates the result of an incorrect impedance match between the horizontal output tube and the horizontal deflection winding because the deflection winding has incorrect constants. Note the transients through the conduction period. Ringing is evident in the raster as vertical shading lines.

Trace (I) is an example of what happens when the deflection winding is open. A transient pulse appears at the plate of the tube each time that the output tube plate current is cut off, but it is a low-amplitude pulse. Its amplitude amounts to several hundred volts rather than several thousand. The normally constant-amplitude portion between pulses now has a rising characteristic similar to the shape of the changing plate current.

RECTANGULAR WAVEFORMS ACROSS HORIZONTAL DEFLECTION WINDINGS AND DAMPER TUBES IN TELEVISION RECEIVERS. The voltage generated across a horizontal deflection winding consists of two parts: a constant amplitude portion which is generated by the linearly-changing sweep current present in the winding, and a relatively sharp pulse of between 1000 and 2000 volts that is generated across the coil when the horizontal output tube is cut off and the magnetic field around the deflection winding collapses. Troubles such as those illustrated show up on the picture tube screen as reduced width and ringing.

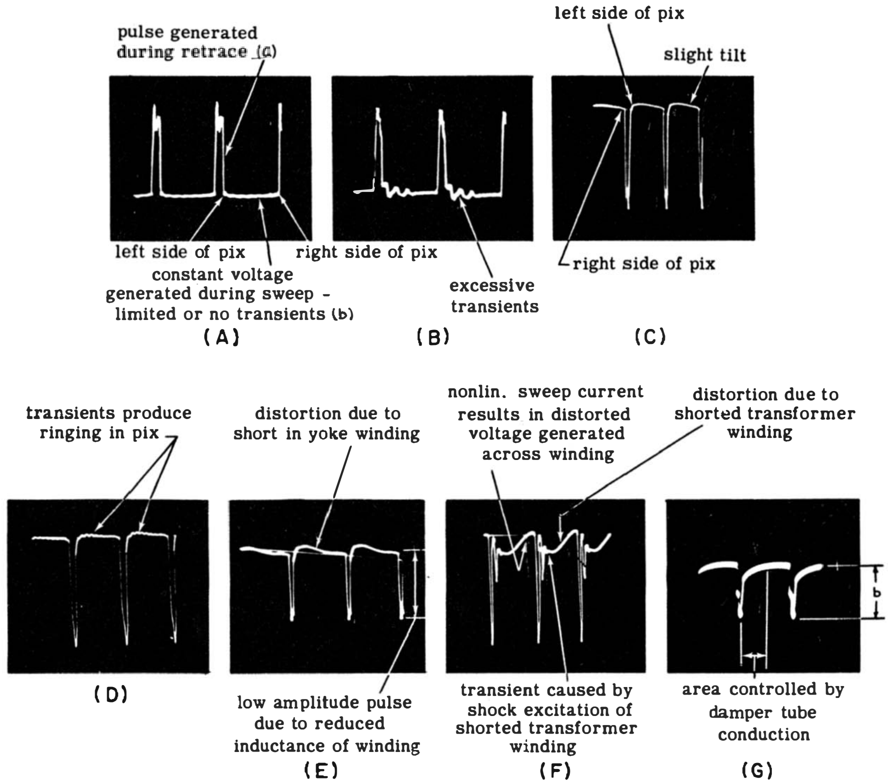


Fig. 9-36

Fig. 9-36. Trace (A) is an example of the rectangular voltage present across the horizontal deflection coil during normal operation. Trace (B) illustrates the transients which appear on this voltage when a width coil is shorted.

Trace (C) is another example of a normal voltage across the horizontal deflection coil. It has a slight downward tilt, indicating a higher resistive component for the deflection coil than in (A). Trace (D) shows the presence of transients when the balancing capacitor across the deflection coil is not correct.

Trace (E) shows a reduced amplitude pulse and distortion of the constant amplitude portion of (C) because of shorted windings in the deflection coil.

Trace (F) shows severe distortion and extreme transients. The transients are attributable to individual resonance in that winding of the output transformer which is shunted by the short-circuited width coil. It accounts for extreme foldover in the picture and greatly reduced picture width.

Trace (G) shows the effect of a defect in the horizontal linearity circuit. The overall peak-to-peak amplitude of the voltage is reduced (*b*) and the absence of a constant amplitude portion indicates that the sweep current was not a linear sawtooth.

Rectangular Waveform in Television Receiver High Voltage Power Supply. The high voltage required for the television power supply in most receivers is secured from the horizontal output system, by step-up transformation of the "kick-back" voltage present across the primary of the horizontal output transformer by the high voltage winding on this transformer. Accordingly the features of the high voltage pulse seen between the plate and ground of the output tube are present between the high voltage rectifier anode and ground. It is possible to determine the nature of this voltage (although not its amplitude) by arranging for stray capacitive coupling as the transfer means between the voltage source and the scope pick-up probe.

Fig. 9-37. Traces (A), (B) and (C) are examples of normal high voltage pulses observed between the anode of the high voltage rectifier and ground. The abnormal pulses do not appear much different except in amplitude. Traces (D) and (E) are the abnormal and normal conditions at the filament junction to the high voltage filter circuit in a system where the input filter capacitor is connected to the damper tube plate instead of ground. It is to be noted in (D) that the polarity of the pulse seen here is positive whereas the normal polarity, trace (E), is negative. The inversion is the consequence of the input filter capacitor being open instead of being joined to the damper tube plate. In this instance, the inversion of the pulse is the pertinent condition rather than the pulse waveform.

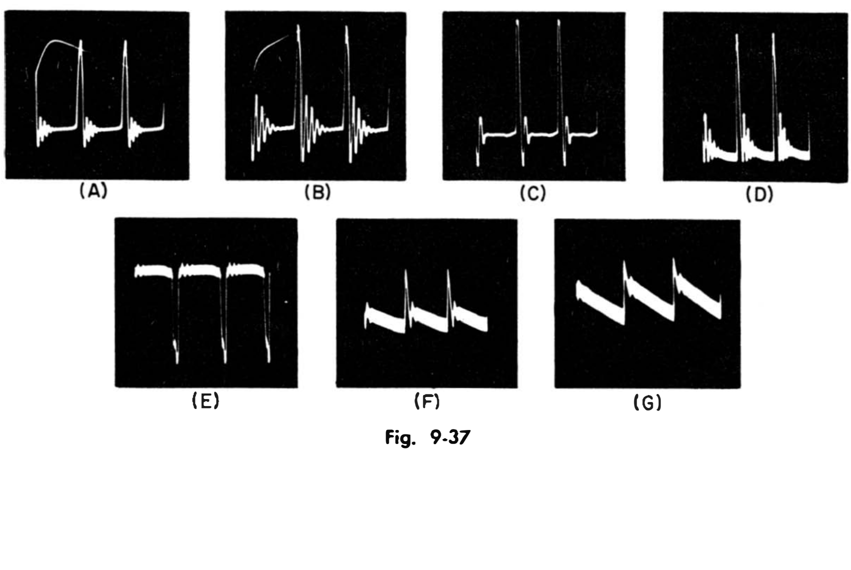
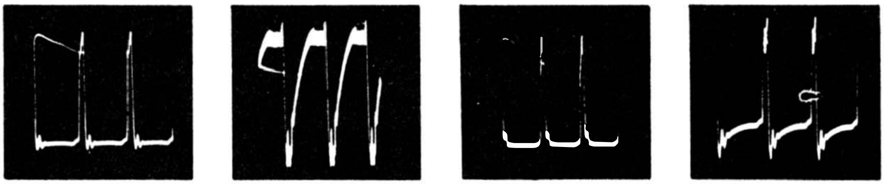


Fig. 9-37

Traces (F) and (G) are a pair. The point of observation is the filament connection to the input capacitor in the high voltage filter. In this instance the capacitor connects to ground. The normal condition appears in trace (F). Note that the pulse is positive, which is normal at this point of observation for the circuit conditions mentioned. Note the positive polarity of the pulse in the abnormal case, trace (G) and the severe tilt to the waveform. The situation causing trace (G) was a leaky input filter capacitor.



(A) (B) (C) (D)

Fig. 9-38. Traces (A), (B), (C) and (D) illustrate waveforms at the input to the filter system in a tripler type of high voltage power supply. Trace (A) is the normal waveform and (B) illustrates the effect of an open in the doubling capacitor. Trace (D) illustrates the waveform when the tripling capacitor is open. Trace (C) shows the effect of an open in one of the filament path capacitors.

Sawtooth Waveform Distortion. The principal method of producing sawtooth waveforms is by charging a capacitor through a resistor from a d-c source, then suddenly discharging the capacitor through a momentarily-shorted path. In order to develop a reasonably linear sawtooth, it is the practice to charge the capacitor from a high d-c voltage source, but only for a short period, then to discharge it rapidly. The discharge path generally is a vacuum tube, control of this tube being accomplished by a voltage source, hence there usually exists a basic charging voltage level and a discharge voltage level at which the tube behaves as a nonconducting path and as a conducting (shorting) path.

A situation in a circuit which will (1) prevent the capacitor from acquiring the charge rapidly, (2) prevent the charging of the capacitor at a constant rate, such as a changing voltage source, (3) tend to lower the charging voltage, (4) prevent the capacitor from storing the charge, (5) raise the voltage level at which the discharge action will begin, (6) prevent rapid discharge, all of these will tend to make the sawtooth waveform nonlinear, and will affect the retrace time.

Factors affecting triggering of charge and discharge actions are leaky capacitors, capacitors which have changed in value, resistors that have increased or decreased in value, substantial changes in operating voltages at their sources, gassy tubes, and improper damping in transformer-coupled oscillating systems. Substantial changes in the waveforms at the electrodes of the tubes in a multivibrator or in a blocking oscillator can materially affect the shape of the output sawtooth voltage, hence correcting the operating waveshapes will frequently correct the sawtooth output waveform.

It is to be noted that there are times when a nonlinear sawtooth voltage is deliberately fed into the input circuit of an amplifier tube and correction is accomplished in that tube by adjustment of the transfer characteristic. Overcorrection is possible and should be avoided. The only guidance in such a case is the reference waveform for the output of the sweep generator.

Correction for nonlinearity sometimes is a matter of frequency compensation in the system by the process of bypassing or removing the bypass capacitor across the cathode resistor.

Fig. 9-39. Traces (A), (B) and (C) illustrate the progressive increase in nonlinearity of a sawtooth waveform generated by a gaseous-tube-relaxation oscillator as the grid bias is made more negative, thus allowing the capacitor to charge to a higher level.

Traces (D), (E) and (F) show the progressive increase in distortion (marked by arrow *a*) of a sawtooth waveform generated by a cathode-coupled asymmetrical multivibrator as the amplitude of the synchronizing voltage injected into the grid circuit is increased.

Traces (G), (H) and (I) represent the distortion of a sawtooth sweep voltage generated in a scope by the settings of the positioning controls. Trace (G) is usable,

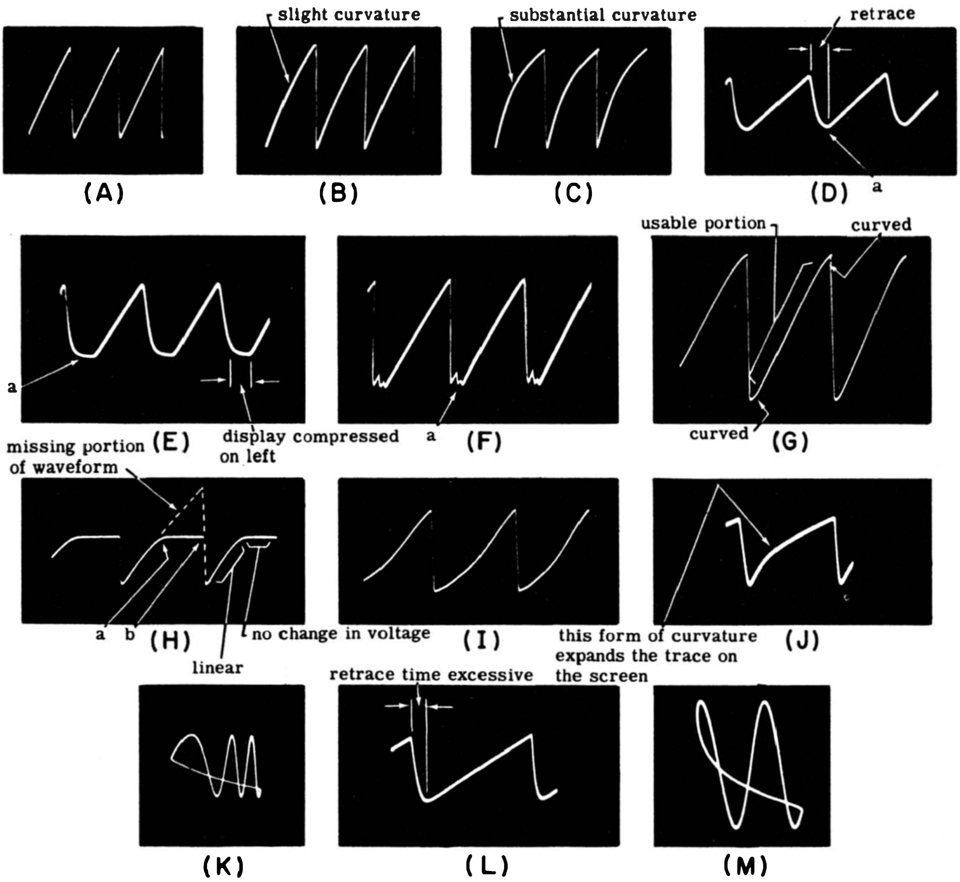


Fig. 9-39

especially when three or more cycles of a voltage appear on the screen. In the cases of (H) and (I), neither of these is usable. In (H) the lower half is linear whereas the upper half would result in extreme compression of the display (between *a* and *b*). Trace (I) is curvilinear in that one portion has a concave curvature and the other has a convex curvature, hence would distort the trace badly.

The distortion evident in traces (G), (H) and (I) can result from incorrect operating voltages applied to amplifier tubes that are processing a sawtooth voltage. Trace (H) is the product of overdriving an amplifier, or excessive bias, depending on where the waveform is observed—i.e., in the grid circuit or in the plate circuit of the amplifier. Bypassing, cathode bias resistor value, the plate load resistance and the B+ supply voltage are important operating details in linearization circuit performance. A trace like (H) oftentimes is caused by a leaky coupling or blocking capacitor.

It is to be noted that the curvature in (I) is the opposite of that in (J). Whereas trace (I) causes compression of the waveform display at the left side, the curvature in (J) causes expansion of the trace as shown by trace (K).

Excessive retrace time is indicated in trace (L). The result is a loss of a substantial portion of the signal cycle being displayed as shown by trace (M). If five or six cycles of the waveform under investigaton are displayed, the excessive retrace time in the sweep signal becomes unimportant.

Sawtooth Waveform Sweep Currents in Deflection Windings. The sawtooth sweep current in a deflection winding is a function of the shape of the voltage applied across the winding. A prominent factor of control is the impedance match between the deflection winding and the source of the sweep voltage. The current waveform is determinable by inserting a small amount of non-inductive resistance (1 to 3 ohms) in series with the low side of the deflection coil and observing the voltage developed across this resistor. Care must be exercised when connecting the grounded side of the scope input to the deflection circuit because some deflection circuits are above ground throughout.

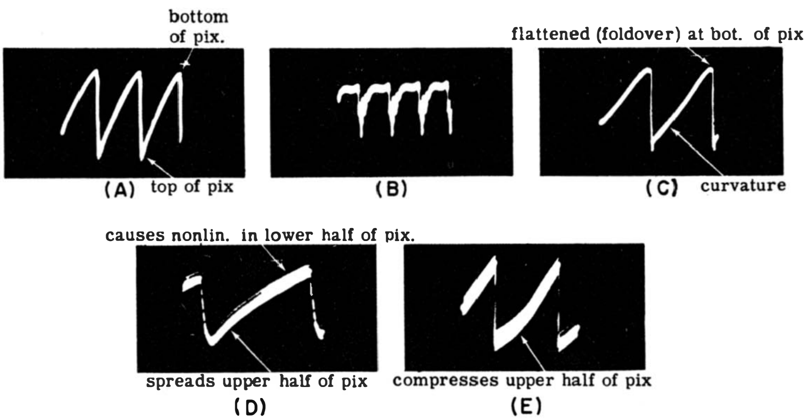
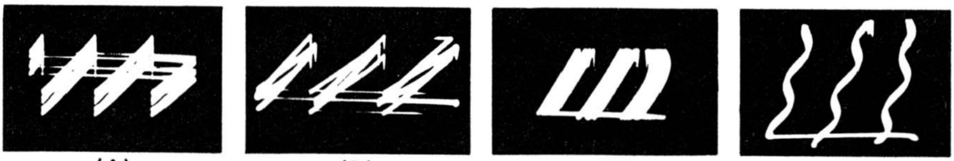


Fig. 9-40. Trace (A) is the normal waveform of the horizontal and vertical sweep Trace (B) is the kind of waveform encountered when the horizontal deflection coil inductance is very much higher than the proper value. Its amplitude is very low. Trace (C) is the result of using a vertical output transformer which has a primary impedance very much lower than planned for in the design of the equipment. Traces (D) and (E) are the results of improper impedance matching with the vertical output transformer.

SAWTOOTH WAVEFORM DISTORTION BY SPURIOUS SIGNALS IN SCOPE.

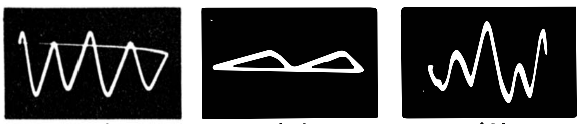


(A) (B) (C) (D)

Fig. 9-41. Traces (A) and (B) illustrate the effect on a sawtooth waveform when 60-cps hum voltage is present on the vertical deflection plates. Trace (C) shows 60-cps or 120-cps hum on the horizontal plates of the scope.

Trace (D) shows a spurious signal on the horizontal plates when the sawtooth signal frequency is lower than the spurious signal frequency.

SAWTOOTH WAVEFORMS IN POWER SUPPLIES. Waveforms resembling the sawtooth shape are encountered in power supplies. They appear as voltage variations across the input filter capacitors, or across the power supply output when either the amount of capacitance is insufficient, when the capacitor or the filter choke is defective, or the current drain is excessive.



(A) (B) (C)

Fig. 9-42. Trace (A) illustrates the sawtooth voltage waveform present across the input capacitor in a power supply when the input capacitor is too low in capacitance for the current drain; also when the output capacitor is open-circuited. The same waveform appears across the input of an inductance-input filter in a full wave rectifier with unbalance in the rectifier system. A reduced-amplitude sawtooth voltage [trace (B)] may be found across the output capacitor when unbalance exists in the rectifier system, or when the filter choke has short-circuited turns, or when the d-c current through the choke exceeds its rating. Sometimes this waveform assumes the shape shown in trace (C).

TRAPEZOIDAL WAVEFORM DISTORTION. Distortion in trapezoidal waveforms can appear in any of a number of ways. The *sawtooth* portion is the focal point of interest. Every variety of distortion which may exist in an ordinary sawtooth waveform or in a rectangular waveform may be encountered in the corresponding part of the trapezoidal waveform.

The causes underlying these features are the same as for the sawtooth waveform explained earlier in this chapter, both as to the generator circuitry and amplifier behavior. When the trapezoidal waveform is the basis of the sweep current in an electromagnetically-deflected cathode ray tube display system, nonlinear features of the sawtooth part of the trapezoidal voltage account for expansion or compression of the display, or *foldover*. Although not a form of distortion, the peak-to-peak amplitude of the trapezoidal voltage plays a very important role in indicating the performance of the equipment in which it is being processed.

In view of the manner in which a trapezoidal waveform is created, attention must be paid to the rectangular pulse portion. In general, this is known as the *negative spike* in the waveform. This portion of the waveform is produced by the *peaking* resistor in series with the capacitor across which the sawtooth voltage is developed in most of the trapezoidal-waveform generating systems. Proper functioning of the system under the influence of the trapezoidal waveform requires the correct relative amplitudes of the sawtooth and the rectangular pulse components. Specific proportions cannot be given because they differ according to the individual equipment design. Guidance is found in the reference information that invariably is a part of the service literature which accompanies the devices being examined.

If the negative-spike portion of the trapezoidal waveform voltage fed to the vertical output tube is excessive, the retrace pulse generated in the plate circuit of that tube will be excessive; it may damage the output transformer, and it may result in ringing following the retrace. If its amplitude is low relative to the remainder of the voltage, the vertical output tube will start conducting before the retrace is completed, and the retrace will be slowed down near the top of the picture.

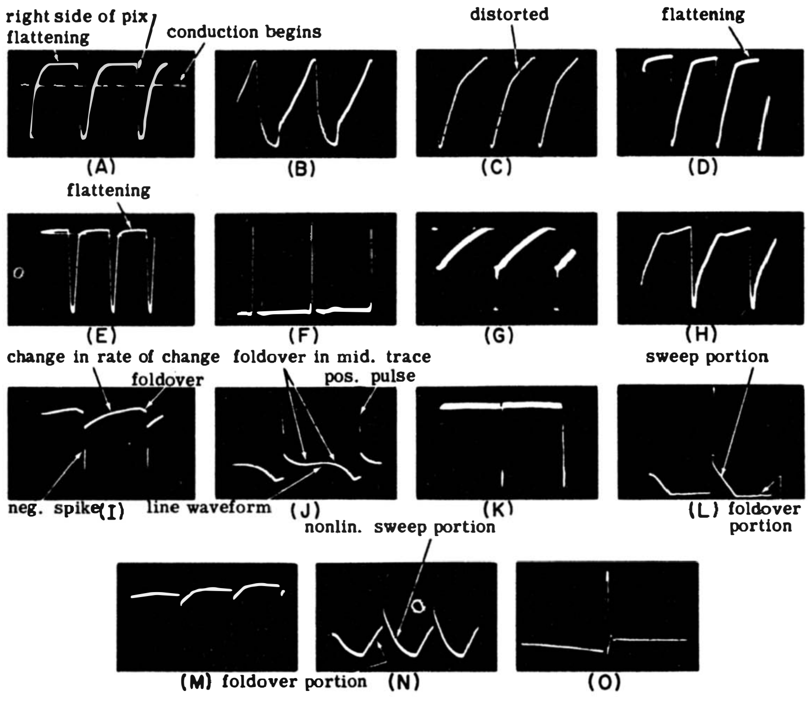


Fig. 9-43

Fig. 9-43. Trace (A) is a trapezoidal voltage which has suffered grid clipping at the horizontal output tube causing foldover at the right side of the picture. Trace (B) results when the differentiating capacitor in the waveshaping circuit feeding the horizontal discharge tube is inoperative. The end product is no raster.

Trace (C) is the distorted version of a trapezoidal waveform at the sweep output plate of an asymmetrical sawtooth generating multivibrator in a television receiver. The defect here is a bad capacitor in the feedback loop circuit between the deflection coil and the input to the output tube. Trace (D) is seen at the grid of the horizontal output tube. The cause is the same as for trace (C). Trace (E) is a variation of (C).

Trace (F) is the grid signal consisting of substantially short duration pulses at the horizontal discharge tube. The fault was a defective coupling capacitor in the horizontal discharge tube grid circuit. Trace (G) is another example of the horizontal output tube grid signal caused by a defect in the horizontal oscillator. The signal had a high negative spike and the overall peak-to-peak value of the voltage was very low. Trace (H) is still another example of the horizontal output tube grid signal caused by incorrect bias on the output tube. The coupling capacitor feeding the signal was leaky.

Trace (I) is the grid signal at the vertical output tube for a vertical foldover case. Trace (J) is the plate signal corresponding to (I). The trouble indicated is heater-to-cathode leakage in the vertical output tube. In the plate signal [trace (J)] the presence of a sine waveform is evident. The sweep voltage variation at the beginning and at the end of the sweep resembles portions of a sinusoidal waveform.

Traces (K) and (L) show grid voltage and plate voltage waveforms for a vertical output tube when the trouble is vertical foldover at the bottom of the tv picture. The defect was leakage between the control grid and the cathode at the socket. Traces (M) and (N) show grid and plate signal voltages at the vertical output tube when foldover occurs. The plate voltage trace (N) shows a peculiar condition; a nonlinear sweep for the upper half of the picture, then the foldover which is linear in sweep action, as indicated by the fairly straight diagonal line running upwards.

Trace (O) illustrates the effect of excessive negative peaking in the vertical sweep signal fed to the vertical output tube. The effect is not readily discernible in the input signal, but can be noted in the plate signal by the transient which follows the retrace.

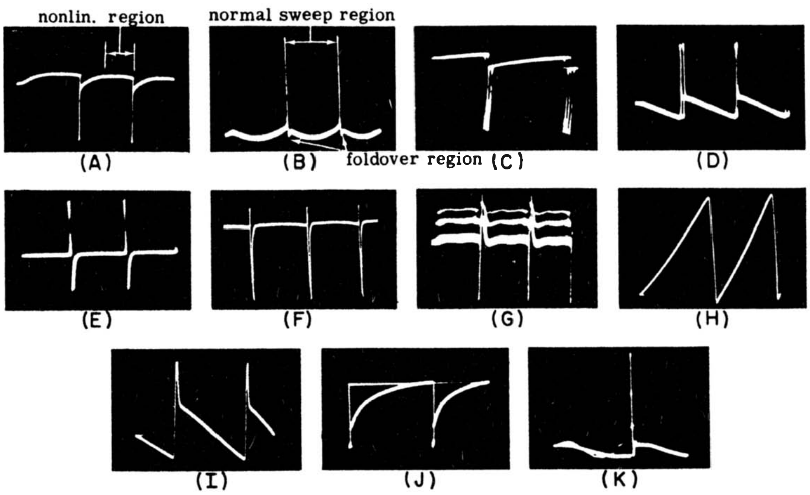


Fig. 9-44. Trace (A) shows improperly shaped trapezoidal voltage waveform at the control grid of the vertical output tube in a self-excited vertical sweep output system. A positive-going a-c pulse is fed from the output tube plate to the oscillator grid circuit. Trace (A) corresponds to reduced vertical height and severe nonlinearity over the lower half of the picture. This region of the voltage waveform is indicated by the arrow.

Trace (B) is the voltage as seen in the plate circuit for the grid signal of trace (A). The first half of the waveform is a reasonable approach to a linear sweep, but the second half is obviously a reduction in sweep voltage amplitude, hence foldover occurs. Its insulation resistance was very low. The difficulty was in the sawmaking capacitor in the output circuit of the vertical oscillator.

Traces (A) and (B) occur for a wide variety of defects in the oscillator grid circuit components in such self-excited vertical oscillator and output circuits. In addition to reduced picture height, one of the symptoms is loss of vertical sync. Similar symptoms issue from such defects in the feedback loop as might apply d-c from the output tube plate to the oscillator grid such as leakage in the feedback loop blocking capacitor. When this occurs, a jittery, double-imaged waveform higher in frequency than is correct, as in trace (C), may be seen at the plate of the vertical oscillator. The waveform is substantially normal, but the frequency is not. The vertical output tube plate voltage waveform appears as in trace (D), is higher in frequency than it should be, and lacks the negative pulse that is common in such self-excited oscillator circuits. The incorrect waveform generally seen under such circumstances at the low side of the vertical oscillator grid blocking capacitor is illustrated in trace (E). Note the high-amplitude positive pulse and the low-amplitude negative pulse. The correct waveform appears as trace (F). Note that the predominant pulse is negative.

Trace (G) is an example of the signal voltage waveform at the plate of the vertical oscillator tube in a self-excited vertical sweep system, when the vertical oscillator is not functioning and only the vertical sync signal is present at the plate.

Trace (H) shows the sawtooth rather than a trapezoidal waveform which develops across the waveshaping *RC* network in an asymmetrical cathode-coupled multivibrator when the peaking resistor is short-circuited. The plate circuit waveform in the television receiver vertical output tube fed from such a multivibrator signal source appears in trace (I). Note the very low amplitude positive pulse corresponding to the retrace portion of the sawtooth. The sawtooth portion of the plate signal has a greater amplitude than the positive pulse.

Trace (J) is the signal voltage at the plate of a vertical blocking oscillator used in a television receiver when the sawtooth making discharge capacitor is open. The exponential rise in voltage is evident, and this result is a nonlinear grid signal voltage being applied to the vertical output tube. The abnormal plate signal in the vertical output tube is seen in trace (K). The flattened part shortly after the completion of the positive (retrace) pulse creates a condition of foldover at the top of the picture tube display, and also appears as a bright horizontal area.

DIFFERENTIATED OR INTEGRATED WAVEFORM DISTORTION. This is in the main a matter of incorrect time constant for the circuit or signal in question, thus producing an output waveform which is not what it should be. In the event that the output of the circuit feeds the differentiated or integrated voltage to a vacuum tube for subsequent processing, incorrect operating conditions can modify the waveform in an inadequate fashion. Examples are given here.

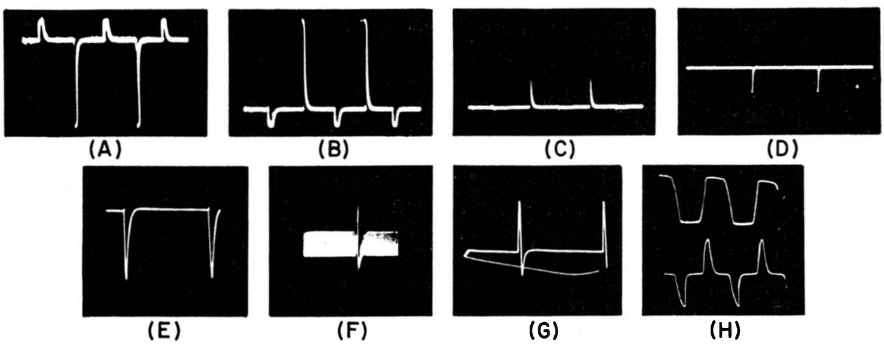


Fig. 9-45

Fig. 9-45. Trace (A) is a square waveform of voltage differentiated in a short time constant circuit with the positive pulses partly clipped by a clipper tube. Trace (B) illustrates partial removal of the negative pulses. Trace (C) illustrates removal of the negative pulses and also a portion of the positive pulses, leaving only the tips of the positive pulses. Trace (D) illustrates the removal of the entire positive pulse and a portion of the negative pulse also, leaving only the negative pulse tips.

Trace (E) is the output of the vertical integrator without the vertical oscillator kickback pulse. Trace (F) shows the vertical integrator output as a positive pulse and bearing the tiny negative pip corresponding to the kickback from the vertical oscillator. Trace (G) is the equivalent of (F) except that horizontal sync pulses are still present in the vertical sync pulse signal. They are the rectangular patterns formed by the fine lines on both sides of the vertical pulse. Trace (H) is an example of a differentiated square waveform voltage when the input waveform has tilted sides.

AMPLITUDE-MODULATED WAVEFORM DISTORTION. Overmodulation (described earlier) is one form. A wave envelope that has a different shape than the modulating voltage is another form of distortion. This action is known as *nonlinear modulation.* Unlike positive and negative halves of the a-m envelope is still another form of distortion. It is known as *nonsymmetrical modulation.*

Nonlinear amplification of an a-m waveform or overloading of an amplifier stage by an excessively strong a-m voltage produces distortion of the waveform. A distorted intelligence voltage can be combined with a carrier so as to produce an a-m waveform, but this is not the equivalent of a distorted a-m voltage. Whether or not such a voltage is usable depends upon individual circumstances.

If the signal issues from a transmitter and the distorted intelligence is speech, the signal may be unintelligible. Then again, a supposedly sine-wave-form a-m signal generator may furnish a modulated output signal in which the modulation is distorted, yet the signal can be used for test purposes without too much difficulty. The features of the a-m waveform are relatively unimportant when checking r-f and i-f systems, provided that the envelope of the waveform as seen at the input of the system is retained during the amplification process.

The distortion present in a demodulated voltage does not prevent its use as an audio test signal, provided that its features are known. If the same features are retained during the processing in the amplifier, the latter is free from distortion. Care must be exercised to avoid wrong conclusions in the event that phase distortion in the amplifier alters the features of the audio signal.

Conditions underlying distortion in an a-m waveform are numerous. Dealing for the moment with distorted output from an a-m signal generator, too much feedback in the audio oscillator is a common cause for distorted envelopes. Incorrect bias conditions, change in value of the oscillator grid leak, incorrect operating voltages, changes in *R* and *C* in phase shift oscillators, are common causes for high harmonic content in the audio modulating voltage. Imperfect modulation can be attributed to a mismatch in the modulating system, wrong bias, defective modulating transformer, low plate (and screen) voltage, too much audio signal, insufficient r-f signal voltage, imperfect tuning conditions between oscillator and output r-f amplifier.

In the case of low powered transmitters such as used by radio amateurs or for laboratory experimentation, all of the conditions generally associated with an audio amplifier can account for distortion of the audio signal, hence for the distortion in the wave envelope. The difficulties stated for the r-f portion of the signal generator also apply to the r-f portion of the transmitter. Add to this list such items as imperfect neutralization, poor regulation in the modulator B+ supply.

Demodulation of the a-m voltage can produce distortion of the modulating voltage if the time constant of the demodulating system is insufficient to accommodate the period of the modulating component.

The ability to display a-m waveforms on test scopes depends on the passband of the vertical amplifier. To show the a-m wave, the passband must accept the carrier frequency. If the amplitude of the carrier voltage is sufficient, the voltage can be fed directly to the vertical plates, and the sweep voltage fed to the horizontal amplifier. Only if the modulating voltage is made up of harmonically-related frequencies can the trace be made stationary.

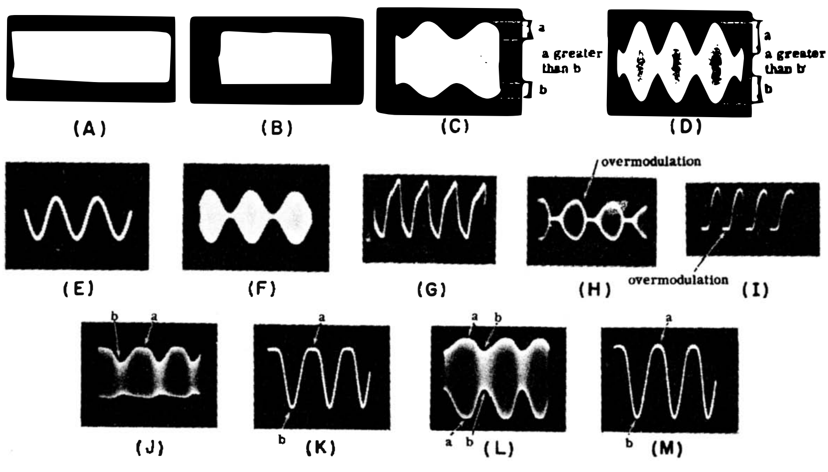


Fig. 9-46. Traces (A) and (B) show the unmodulated carrier (A) and the modulated carrier (B) as rectangular traces.

Traces (C) and (D) illustrate approximately 30 and 70 per cent sine waveform modulation respectively. The audio modulating signal, before being combined with the carrier voltage, and after demodulation of the modulated carrier is shown in trace (E). Attention is called to the nonsymmetrical modulation present in traces (C) and (D). While sine waveform envelopes exist, the amplitude of the positive envelope exceeds the amplitude of the negative envelope. The change in amplitude is not symmetrical around the unmodulated carrier level. This is not important because demodulation of either half of the waveform will produce a sine waveform signal. As a rule, the positive envelope is rectified and becomes the waveform of the demodulated signal, hence the correct positive envelope will result in the correct waveform for the extracted intelligence, that is, if the demodulating process is correct. Another example of a nonsymmetrical sine-waveform amplitude-modulation is shown in trace (F). Here the negative envelope bears a greater swing in voltage than the positive envelope. The percentage of modulation is 100.

Traces (G), (H) and (I) form a family illustrating the action in an a-m signal generator and pointing up an interesting condition. In trace (G) is shown the audio modulating waveform; in (H) is shown the a-m carrier, and in (I) is illustrated the demodulation extracted from the modulated carrier. The difference between (G) and (I) is evident); the modulating conditions are incorrect and the wave envelope does not conform to the waveform of the modulating signal. In fact, overmodulation occurred.

Trace (J) is the unsymmetrically-modulated output from an a-m signal generator, and trace (K) is the audio extracted from the modulated voltage. Note the similarity between the audio waveform and the envelope of the positive half cycle of the modulated waveform. The distortion present in the negative envelope is unimportant because the negative half cycle of the modulated carrier is ineffective at the demodulator. A similar condition appears in traces (L) and (M), except that here the positive and negative envelopes of the modulated carrier are alike even though the modulation is unsymmetrical. Although traces (K) and (M) indicate the presence of distortion by the flattening of the positive peaks of the extracted voltage, both of these modulated carriers are suitable for the testing of tuned circuits, and the extracted audio voltage is suitable for the testing of audio amplifiers. It is not as easy to work with as a sine waveform, but it is usable nevertheless.

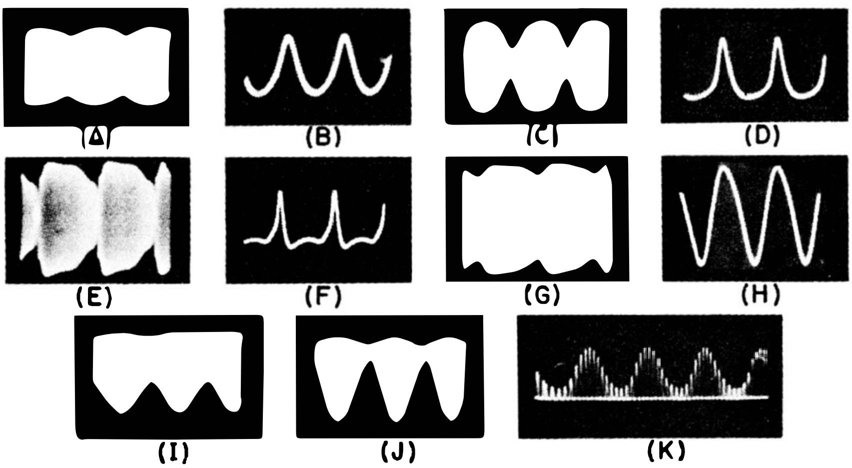


Fig. 9-47. Traces (A) (B), (C) (D), and (E) (F) form a family illustrating the effects of progressively increasing amounts of overloading of an i-f amplifier in a radio receiver by a sine waveform a-m signal voltage, and the waveform of the demodulated signal, as seen across the demodulator load. In each instance, the modulated wave envelope was observed at the plate of the third i-f amplifier.

Trace (G) is another example of distortion in the modulated wave envelope in the i-f system of a radio receiver by extreme overloading. Trace (H) is the demodulated trace as observed at the third i-f amplifier tube plate. The discrepancy in the envelope shape and the demodulated voltage waveform is attributable to the fact that the crystal demodulator probe did not have a time constant long enough to accept the modulation contained in the i-f signal. Thus it is evident that demodulator probes can create erroneous impressions if the operating constants are incorrect.

Traces (I) and (J) illustrate the normal appearance of the sine-waveform a-m signal across the demodulator load in the absence of any capacitance across the load resistor. Modulation is 30 per cent in (I) and about 70 per cent in (J). The polarity is a function of the scope connections. The i-f carrier signal is present because the load bypass capacitor is absent. The failure to remove the entire negative half-cycle of the input modulated carrier is attributable to the functioning of the diode, namely that it does not cut off exactly at the zero carrier amplitude level; also some stray capacitance feed-through to the scope. The individual cycles of the carrier are not visible in traces (I) and (J) because they are too numerous for the limited horizontal dimension of the trace and therefore blend into each other.

Individual carrier cycles of a low frequency a-m voltage after demodulation can be seen in trace (K). The rectifying conditions are ideal, and the individual carrier cycles can be seen in the absence of the bypass capacitor across the demodulator load.

Amplitude-Modulated Waveforms in Transmitters. Details given above Fig. 9-46 apply to transmitters also, but in view of the singular variety of scope display used for transmitter testing, namely the trapezoid, the following scope traces supplement those shown in Fig. 9-46. The method of securing the trapezoid trace is shown in Chapter 11. This trace is a plot of the instantaneous value of modulating voltage against the instantaneous value of the modulated carrier amplitude. It is effective in showing incorrect operation of the transmitter when the modulating frequencies are random.

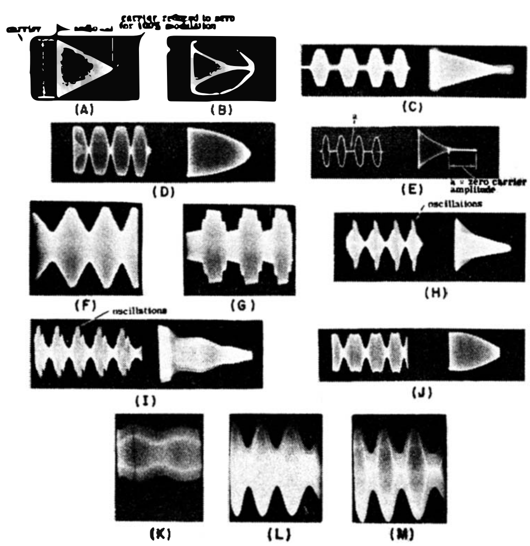


Fig. 9-48. Trace (A) shows linear modulation for 100 per cent modulation and zero-degree phase difference. Trace (B) compares with trace (A); it shows 100 per cent modulation except that the phase difference between the two components active in developing the trapezoid is not zero degrees.

Trace (B) can be changed to trace (A) by proper connection between the signal takeoff point in the modulator and the scope, assuming no phase shift in the vertical amplifier of the scope.

Traces (C) and (D) indicate excessive and insufficient r-f plate voltage respectively. Extreme overmodulation appears in trace (E). Note the region of zero carrier amplitude in the trapezoid.

Traces (F) and (G) illustrate the distortion which can result from mismatch between the modulator stage and the final.

Traces (H) and (I) illustrate the effects of imperfect neutralization; note the oscillations at the peak of modulation. The non-uniform density of the modulated wave envelope trace is a sign of oscillation also. Trace (J) illustrates the effect of slightly detuning the final. Note the dip in the crests of the envelope.

Traces (K), (L) and (M) illustrate the appearance of the modulated wave envelope trace when hum exists in the power supply for the r-f final.

RESPONSE CURVE DISTORTION. Distortion is a relative term when applied to response curves. Any departure from normal, or from the *reference* curve, is tantamount to distortion, and is so treated here.

Reasons for "distortion" in response curves are: regeneration due to feedback between input and output circuits; long leads between the signal generator and the input system; long leads between the indicator and the output system; improper bypassing; bad ground connections; insufficient sweep width; open circuited, short circuited or generally defective peaking coils; defective absorption traps; excessive signal strength; high-level marker signals; mismatch between generator and load; presence of spurious signals from other local oscillators; damping resistors open, shorted or changed value; hum in the d-c operating voltages; incorrect grid bias.

Bad ground connections, imperfect bypassing, feedback, and standing waves on the line manifest themselves by high sensitivity to body capacity with resultant changes in the response curve and great instability, also by the inability to overlay a dual-line response curve by means of the phasing control. Signal overload can cause the last-named effect. The degree of "distortion" is variable in a system subject to changes in frequency. Thus passband response curves for a television receiver front end will be found to vary with the channels; the same is true for balancing elements used in front of the antenna terminals as the operating channel is changed. Interference traps will demonstrate different effects on the response curve of a television receiver front end, as the channels are changed.

Different sweep generators will not produce identical response curves in a system unless the electrical and performance characteristics of the two generators are alike. The wider the bandwidth of a scope, the more severe is the need for limiting the amplitude of the marker signal to the absolute minimum; also the need for reducing the frequency content of the marker signal beat indication by either resistive isolation or shunt capacitance at the vertical terminals of the scope so as to minimize the disturbance along the response curve by the marker signal.

The frequency requirements of a circuit are specified by the reference information. Recognition of frequency passband, degree of response to any one or more frequencies, or the location of any frequency along the response curve, requires the use of marker signals.

The response curves shown in Fig. 9-49 and 9-50 are typical, rather than exact versions which will be encountered under conditions similar to those described.

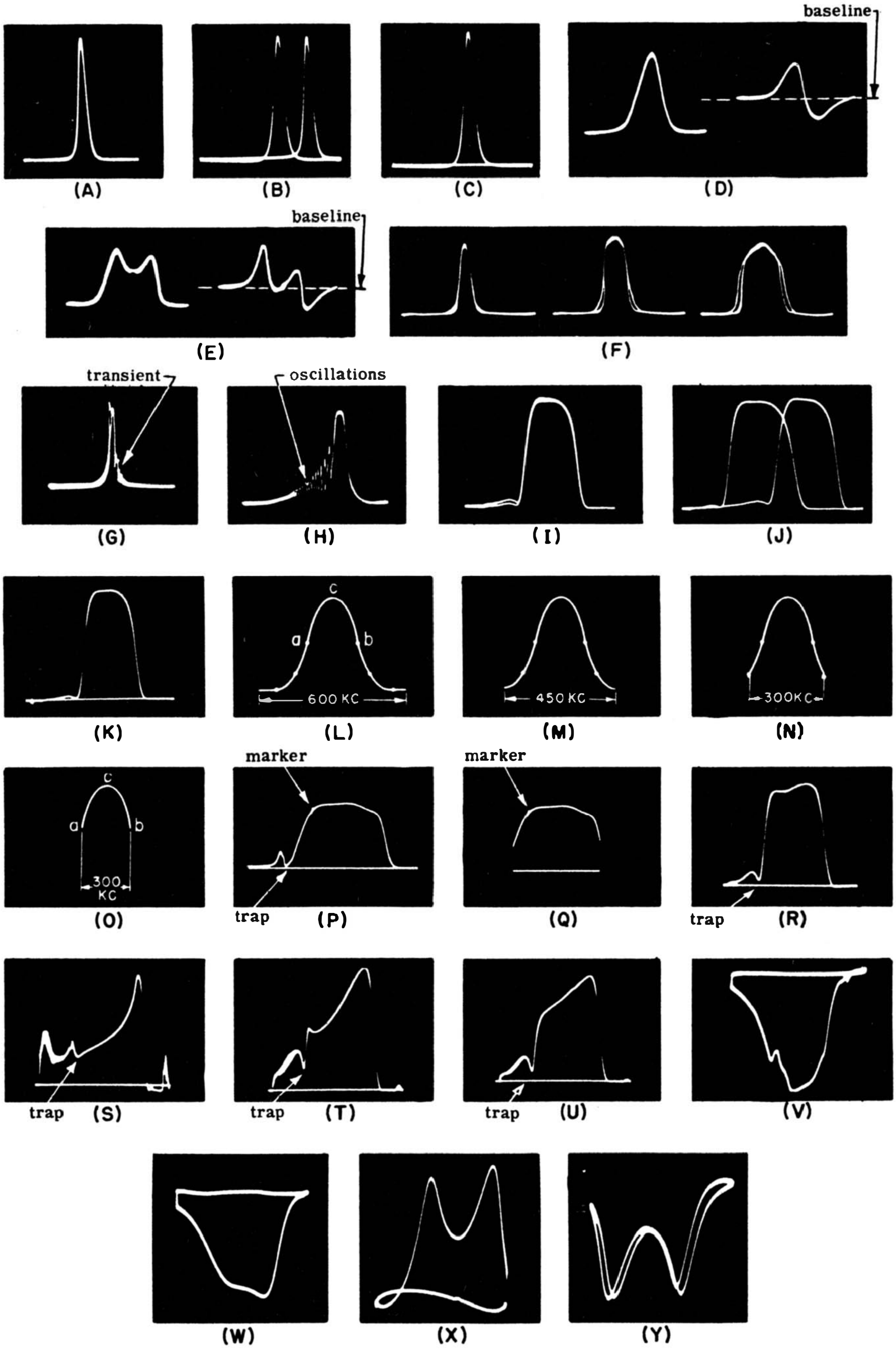

baseline
(A)
(B)
(C)
(D)
baseline
(E)
(F)
transient
oscillations
(G)
(H)
(I)
(J)
(K)
c
a
b
600 KC
(L)
450 KC
(M)
300KC
(N)
c
a
b
300 KC
(O)
marker
trap
(P)
marker
(Q)
trap
(R)
trap
(S)
trap
(T)
trap
(U)
(V)
(W)
(X)
(Y)

Fig. 9-49

Fig. 9-49. Trace (A) is a typical symmetrical single-peak response curve being displayed with blanking "off" and correct phasing. Trace (B) is the same as trace (A), with the phase control improperly set; trace (C) is the same as trace (A) with blanking "on". Note the presence of a baseline in (C), but its absence in (A) and (B). (B) appears to have a baseline, due to the extension of the zero portion of one trace under the response portion of the other, although each curve by itself lacks a baseline. Note the symmetry of the response curve, and almost perfect overlay of the two traces in (A). Markers are absent.

Trace (D) shows the distortion of a single-peak resonance curve because of phase distortion caused by insufficient coupling capacitance at the signal takeoff point. The normal display is (D) (1) and the distorted display is (D) (2). Trace (E) illustrates distortion due to insufficient coupling capacitance when the resonance curve is double-peaked. Trace (E) (1) is the normal display and (E) (2) is the distorted display. Blanking is "off."

Traces (F)(1), (2) and (3) show the gradual change in the resonance curve under conditions of increased amplifier tube overloading. The passband is increased, the selectivity is decreased, the gain is decreased, and the overlay of the two traces becomes less complete.

Trace (G) illustrates a single-peak response curve with regeneration occurring near the high frequency limit of the passband. The transients are seen along the lagging edge of the response curve. Trace (H) is a more aggravated case of high level oscillations near the low frequency limit of the passband.

Traces (A), (J) and (K) show three forms of display of a broadband response curve such as in the i-f system of a television receiver. In (I) the blanking is "off" and the phasing is correct; in (J) the blanking is "off" but the phasing is incorrect; and in (K) the phasing is correct and blanking is "on."

Traces (L), (M), (N) and (O) illustrate the change in appearance of a broadband response curve as the generator's sweep width is decreased until it is less than the passband of the circuit being checked. When the sweep width is less than the circuit bandpass the curve shows only that segment of the passband which is spanned by the signal bandwidth. The circuit response falls abruptly to zero each side of these limits. In the cases shown, a 600-kc wide signal develops the response of a 450-kc passband system in an f-m receiver i-f amplifier. The skirts are readily seen in (L) and partly in (M). In (O), only 100 kc each side of the center frequency is swept, hence the response curve seen is that which corresponds to response 100 kc each side of the center frequency. Compare *a-b-c* in trace (O) with *a-b-c* in trace (L).

Trace (P) illustrates a normal video i-f response curve for comparison with one which develops when the sweep signal does not have sufficient sweep width, as in trace (Q). Note that the marker location remains unchanged on both response curves because the frequency position along the curve is the same, but the action of the trap is not seen in the curve generated by the reduced sweep width signal.

Traces (R), (S), (T) and (U) comprise a family. A normal video i-f response curve is (R). Traces (S), (T) and (U) show the change in response curve waveform as the grid bias is made more and more negative, until the correct value is reached, this being trace (R). Note the progressive approach to curve (R) in traces (T) and (U). The point being made in traces (R) through (U) is the extreme importance of applying the correct grid bias when aligning r-f front ends and i-f systems. It is equally important to successful alignment to note whether reducing the signal input from the generator changes the shape of the response curve. Only the amplitude should change—not the shape. Excessive input signal will flatten peaks, give the response curve an ideal outline, and create the erroneous impression that alignment is satisfactory. Response curves should be shaped with minimum signal input and correct fixed bias.

Traces (V) through (Y) illustrate distortion of front end response curves as indicated by tilted baselines and ripples in baselines. The tilted baseline in (V) is due to reflections from the i-f system when the first video tube is removed. The ripples in the baseline of trace (W) are due to the presence of 120-cps ripple in the power supply output. The distortion of traces (X) and (Y) is due to hum. Blanking is used in (X) and blanking is "off" in (Y).

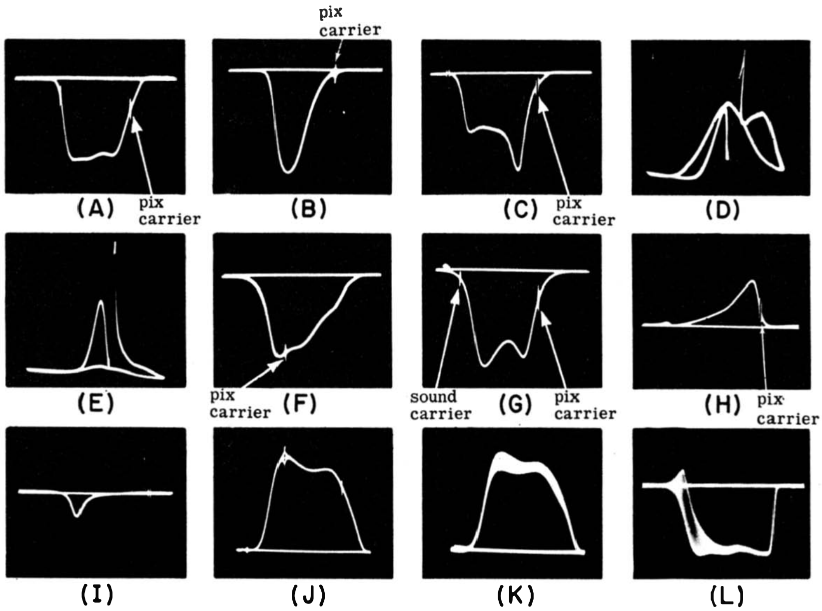


Fig. 9-50. Traces (A) and (B) show a normal and a defective video i-f response respectively. The greatly reduced bandpass as well as sharp peaking in (A) resulted in moving diagonal lines in the picture. The trouble was incorrect alignment of the first video i-f transformer. Trace (C) illustrates incorrect video i-f alignment and wrong location of picture carrier, as well as peaking in the high frequency region. The result is a smeared picture. The correct reference response curve is shown in trace (A).

Traces (D) and (E)illustrate the greatly distorted response curve experienced with a heater-to-cathode short in the first video i-f amplifier tube. The result is no picture.

Trace (F) illustrates an incorrect video i-f system response curve which resulted in a smeared picture. The video carrier marker is incorrectly positioned at the peak of the response curve. The sound carrier marker did not appear on the curve. The correct response curve appears as trace (G). Traces (H) and (I) illustrate low amplitude, badly distorted video i-f system response curve which results in no picture. The defects in each case were shorted grid-to-ground resistors, thus loading the associated i-f transformers very greatly.

Traces (J), (K) and (L) illustrate the effects of marker signal amplitude. The markers are of correct proportions in trace (J), but they are excessive in traces (K) and (L). High amplitude markers destroy the features of the response curve.

Response Curve Distortion in Video Amplifiers. Incorrect response curves in the video amplifiers of television receivers can give rise to a variety of defects. These can impair the picture tube display in many different ways, examples of which appear here. In the traces shown here, the markers are spaced at 1, 2, 3 and 4 mc from the zero frequency low limit of the response curve, thus enabling immediate identification of the frequency-voltage relationship.

Fig. 9-51. Trace (A) shows a video response curve which corresponds to poor horizontal sync stability and horizontal pulling. High frequency response decreases as the frequency increases. The response falls almost to zero at 3.5 mc. The cause is a defective peaking coil. The correct response curve appears in trace (B). Traces (C) through (E) illustrate incorrect video amplifier response curves which accom-

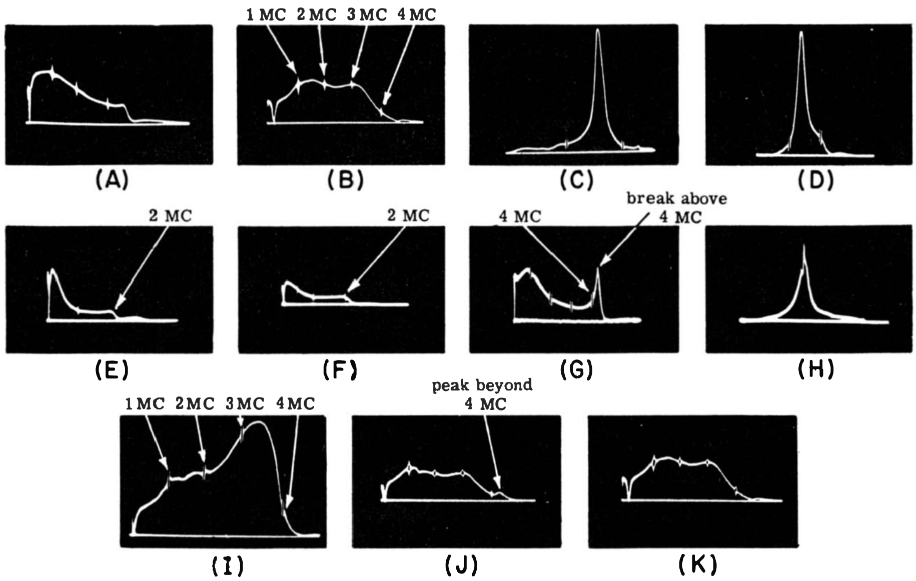


Fig. 9-51

panied picture with low contrast, signs of trailing reversal and signs of ringing. Note the sharp peaks and very low response points.

Traces (F) and (G) illustrate video amplifier response curves accompanying smeared picture tube displays. Note the accentuation of the low frequencies and the loss of high frequencies in the first case, and the accentuation of the low frequencies and also above 4 mc in the second instance.

Trace (H) is the video response curve accompanying a negative picture. Note the very sharp and narrow peak around 2 mc. It is occasioned by a short across a peaking coil assembly. Trace (I) accompanies a condition of extreme buzz. Note the rising response and the peak between 3 and 4 mc, also the response above 4 mc.

Trace (J) accompanies a condition of trailing reversal. Interestingly enough, there appears to be very little difference between the defective video response curve and the normal response curve shown as trace (K). The major difference is the peak above 4 mc in the defective curve (J), also that the ratio of response to the frequencies below 4 mc and at 4 mc and higher is greater in the normal condition [trace (K)] than in the abnormal case.

SWEEP GENERATOR OUTPUT TRACES. Inasmuch as sweep generators are used to determine the frequency response of many different kinds of resonant systems, it stands to reason that first-hand information concerning the frequency-versus-voltage output characteristic of the generator should be known in order to properly evaluate the performance of the resonant system. The scope traces that follow illustrate a variety of sweep generator characteristics which in one way or another are abnormal.

Fig. 9-52. Trace (A) occurs when blanking is off and the phasing is incorrect. Note absence of baseline. Forward and reverse traces are seen. Trace (B) occurs with 60-cps sawtooth sweep and sweep generator blanking turned off. This is not a practical trace because the baseline is missing. Trace (C) occurs with sawtooth sweep slightly different than 60-cps and blanking on. Trace is not usable.

Trace (D) occurred when linear sweep output was checked with a poor ground connection joining generator, demodulator probe and scope. This accounts for nonlinear output. Generator output cable termination is proper; sine waveform 60-cps sweep and blanking is on.

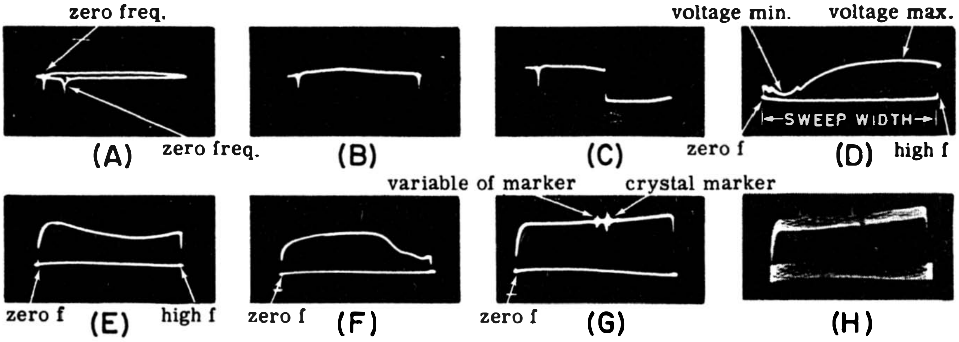


Fig. 9-52

Trace (E) is from an otherwise linear-output sweep generator, but in this case the termination is incorrect. 60-cps sine-waveform sweep and blanking is on. Phasing also is correct. Note abrupt fall-off towards high frequency end. Stranding waves are on line. Trace (F) shows a small amount of nonlinearity over the mid-frequency region of the swept band. 60-cps sine-waveform sweep is used, and proper phasing and blanking is on. This much nonlinearity is about the maximum that can be tolerated without correction.

Traces (G) and (H) show the beat effect between a crystal marker which is on the trace and a variable frequency marker. Conditions are 60-cps sine-waveform sweep, proper phasing, and blanking on. The crystal marker is stationary on the trace whereas the variable frequency marker moves along. Trace (G) shows the crystal marker on the right and the variable marker on the left. The trace shows a rising characteristic with frequency. In trace (H) the variable marker frequency is coincident with the crystal marker frequency and the low beat frequency signal is indicated by the weaving lines running through the pattern. These lines become fewer and spaces between them become greater as the markers approach zero beat.

Response Curves in Front Ends with Filters. The presence of f-m, high pass, or other kinds of filters at the input of television receiver front ends can impair the frequency response of the entire front end on the different channels by causing peaks and valleys in the response curve. This is especially true when the filters are added after the design of the receiver has been completed, as for example, after the receiver has been installed in the home. The ideal condition is the flat response over the passband of each channel. Each of the curves shown in Fig. 9-53 was developed by sweeping the channel over 4 mc.

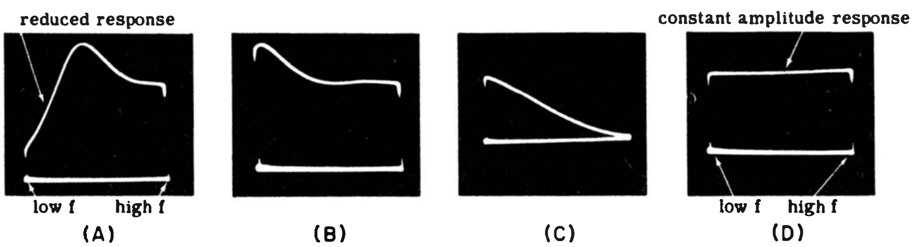


Fig. 9-53. Trace (A) shows severe attenuation over the lower third of the frequency passband, with a peak towards the center of the band. Trace (B) shows a peak at the low frequency end and gradual reduction to about the middle of the channel, then linear response. Trace (C) shows a marked reduction in signal transfer and a reduction to substantially zero response at the high end of the passband for the channel.

Trace (D) shows that the two filters used have no effect because of the very much higher frequency of the channel. The response of the channel is linear as shown by the flat response curve.

In all instances the scope sweep is 60-cps sine-waveform, the phasing is correct, and blanking is on, thus producing the reference baselines.

These traces illustrate how incorrect response curves can prevail for the front end of a televison receiver because of the appendages added in the effort to eliminate interference of various kinds.

"S" CURVE DISTORTION. The proper "S" curve used for the alignment of discriminator circuits is explained in another chapter. The examples given in Fig. 9-54 illustrate various conditions of distortion.

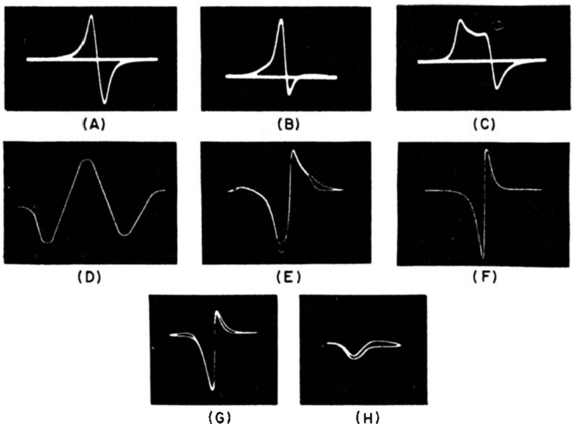


Fig. 9-54. Trace (A) is the normal shape of an "S" curve. Traces (B) and (C) are examples of incorrect alignment of the discriminator transformer. Misalignment of the primary usually results in a change in shape of the "S" curve, whereas misalignment of the secondary results in zero voltage being produced at some frequency other than the intermediate frequency.

Trace (D) shows the "S" curve for a ratio detector when the scope probe is connected to the quadrature coil without using an isolating probe. Phase distortion shifts the curve. The effect of the stabilizing capacitor across the load resistor is shown in trace (E); it accounts for the loops in the "S" curve. The curve with the stabilizing capacitor removed is shown in trace (F).

Trace (G) illustrates the normal "S" curve for the gated beam f-m detector. Note that normal appearance of the curve in this case means one leg of the curve being about twice the height of the other. An open quadrature coil produces trace (H) and the sound output is low.

PARABOLIC WAVEFORMS. A variety of voltage waveform which resembles the half sine waveform is parabolic in shape. It is the shape of the plate current in inductively-loaded amplifiers which are processing sawtooth and rectangular shaped voltages. The parabolic plate current generates a similarly-shaped voltage across the cathode resistor in the amplifier circuit. Such amplifiers are the vertical and horizontal output stages in television receivers. Similarly-shaped voltages appear between the damper diode and ground; also in the linearity circuits of these receivers.

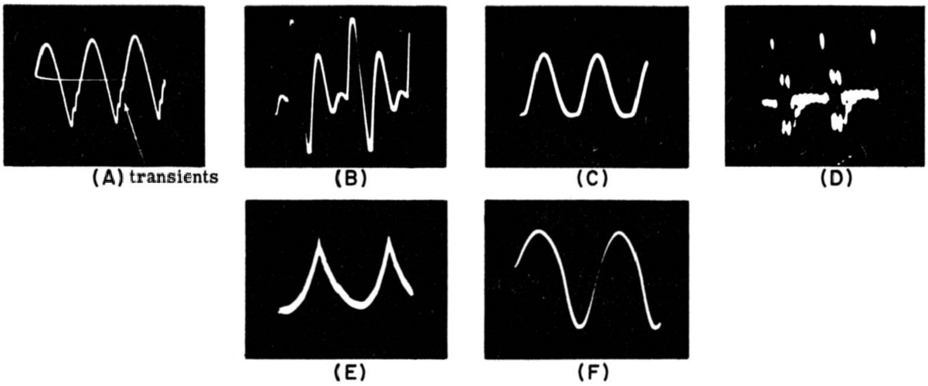


Fig. 9-55. Trace (A) is an example of a normal parabolic voltage waveform seen at the input to the linearity circuit of a horizontal sweep output system. Traces (B), (C) and (D) are three examples of distortion of (A) caused by difficulties in the boost capacitor or in the input capacitor to a "pi" type of linearity circuit. Trace (E) is an example of the normal parabolic waveform voltage seen across the cathode resistor of the vertical sweep output tube. Trace (F) is a distortion of (E) caused by heater-to-cathode leakage in that tube. Note the sine waveform appearance originating in the voltage applied to the heater. Traces (A) and (E) are to be seen between cathode and ground of horizontal output tubes as well, sometimes inverted and sometimes with higher-level transients than seen in (A).

Chapter 10

LISSAJOUS FIGURES

When two voltages of sine waveform are applied to the vertical and horizontal deflection plates of a scope respectively, a special variety of trace is formed on the scope screen. Its shape may be anything from a tilted line through a circle, or any of a series of ellipses of different width, a single figure eight or a number of them joined, or some other special shape illustrated in this chapter. The important point is that it is not a waveform, it is a special pattern known as a *Lissajous figure.*

Its shape is a function of the amplitude of the two voltages, their frequency content, and the instantaneous phase and frequency relationship between them. Thus it becomes possible to identify the phase relationship between two voltages by means of a Lissajous pattern; or to compare an unknown frequency with a known frequency thereby permitting the calibration of signal sources; or to note a change in the composition of a voltage during processing by noting the Lissajous figure formed by the input and output signals.

The frequencies that can be worked with are those which are within the capabilities of the scope amplifiers. The limiting determinant is the horizontal deflection amplifier. Of the two amplifiers in the scope, the horizontal amplifier is the one with the more limited frequency passband. When both vertical and horizontal deflection amplifiers have like frequency passbands, then the highest frequency which can be displayed by a Lissajous figure is the upper frequency limit of the rated passbands.

In general, most testing using Lissajous figures is done with sine waveforms. This does not preclude the possibility of frequency calibrating a nonsinusoidal signal generator, but evaluation of signal processing, phase shift and the like is done most easily by working with one or more individual selected sine waveform voltages of predetermined approximate frequency.

There are a number of methods used for developing Lissajous figures on a scope screen. The fundamental system only is shown here, being

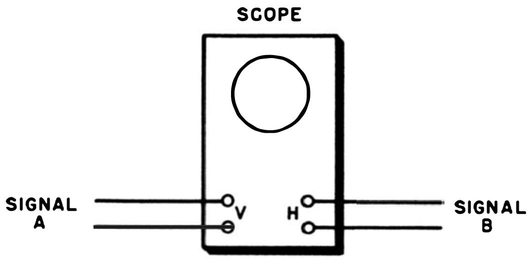


Fig. 10-1. Basic setup for deriving Lissajous figures.

illustrated in Fig. 10-1, where *a* and *b* are two signal voltages secured from appropriate sources or points as determined by the variety of test involved.

Two Sine Woveforms of Like Frequency

When the two signal voltages (*a* and *b* in Fig. 10-1) are of like frequency, and have been adjusted to have like amplitudes, a variety of Lissajous figures are possible, depending upon the instantaneous *phase* between the two voltages. Seven illustrations labeled *C1* through *C7* in Fig. 8-18 (see Chapter 8) illustrate the possibilities in trace shape when the phase difference between the two voltages differs in steps of 30 degrees. The same illustration shows how the resultant trace is developed by applying two sine waveform voltages of equal amplitude but different degrees of phase difference respectively to two sets of deflection plates. At each instant the two voltages are acting on the beam at right angles to each other. The phase difference between the two voltages simply sets the instantaneous relative amplitude and polarity of each voltage and thus determines the deflecting force it will exert on the beam. These instantaneous amplitudes and polarities are shown by the waveforms labeled (A). The reference waveform assumed to be constant, is (B) and the resultant is (C). Lissajous pattern *C1* is the resultant of *A1* and *B; C2* is the resultant of *A2* and *B; C3* is the resultant between *A3* and *B,* etc. The numerals on the (A) waveforms and on the (B) waveform are useful in developing the resultant whose numbers locate the instantaneous position of the beam.

The design of test scopes in use today is such that when two voltages of like frequency are *in phase,* the resultant Lissajous figure is a *straight* line tilted towards the right. This is illustrated by Fig. 8-18 (C1). For any repetitive waveform, zero electrical degrees represents the same relative

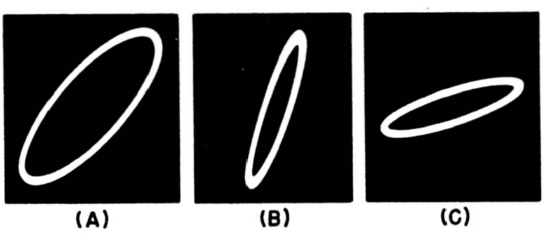


Fig. 10-2. Effect of relative amplitudes of component signals. (A), (B) and (C) represent 45 degrees.

position on the repeating wave shape as 360 electrical degrees. Thus a trace of this kind can mean either that the two signals have exactly the same phase or that they have shifted exactly 360 degrees. This is an important point in the event that (A) and (B) are of the same signal frequency and derived from two different points in a system processing a given signal. Then it means that there is no phase shift during the processing of the signal between the point where waveform (A) is derived and the point where waveform (B) exists. Or, if there is phase shift, it must be exactly 360 degrees, or a whole number multiple of 360 degrees.

A phase difference of 30 degrees or 330 degrees produces the tilted ellipse *C2*; a phase difference of 60 degrees or 300 degrees produces the tilted ellipse *C3*. It is seen that the height of *C2* is the same as *C3*; only the width is increased. The tilt in the ellipse *C3* is the same as the straight line *C1*, being a function of the relative amplitudes of the two component voltages. When the phase difference is 90 degrees or 270 degrees, the resultant pattern is a circle, *C4*. When the phase difference is 120 degrees, which is the same as 240 degrees, the resultant is trace *C5*.

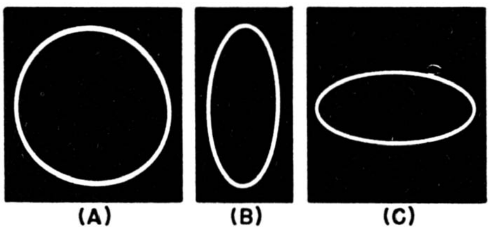


Fig. 10-3. (A) Circle resulting from equal frequencies and amplitudes. (B) Equal frequencies, vertical amplitude greater. (C) Equal frequencies but horizontal amplitude greater.

Note that the tilt now is towards the left. When the phase difference is 150 degrees or 210 degrees, the tilt is to the left, but the width of the ellipse has decreased. Eventually, at 180 degrees phase difference, the ellipse narrows to a single line tilted to the left.

It stands to reason that possible phase differences between two signals may be other than those illustrated in Fig. 8-18, which means that with the exception of the 0, 360 and 180-degree situations, traces corresponding to other phase differences and unlike vertical and horizontal voltage amplitudes will result in a variety of tilts to the ellipses and a variety of width and heights for these patterns. The reason for excluding the 0, 360 and 180-degree relationships is that while the tilt may differ as the consequence of the relative amplitudes of the two voltages, they will remain single lines nevertheless, as long as this same phase relationship prevails. What we mean is shown in Fig. 10-2. Traces (A), (B) and (C) indicate the same phase difference (45 or 315 degrees) but differ in amplitudes of the component voltages. In (A) the two voltages are equal in amplitude; in (B) the vertical voltage amplitude exceeds the hori-

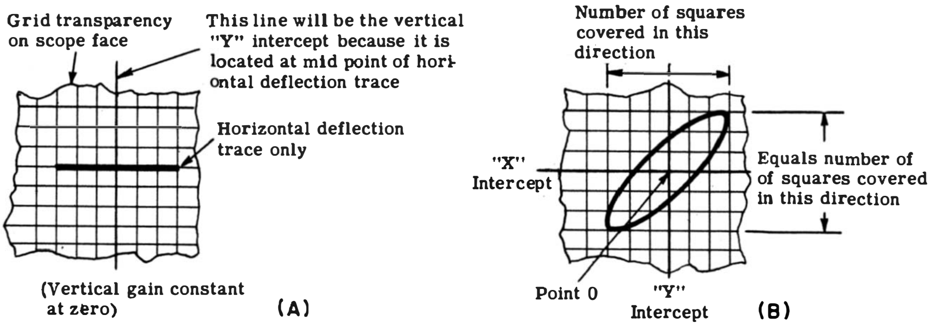


Fig. 10-4. How to set the scope for measurement of phase differences.

zontal, and in (C) the horizontal amplitude exceeds the vertical. Even the circle resulting from a 90 or 270-degree relation changes in shape when the two component voltages are of different amplitudes. This is shown in Fig. 10-3 (A), (B) and (C). As soon as one voltage is smaller than the other the circle changes into an ellipse, but it is to be noted that the figure has *no tilt.* The ellipse for a 90 or 270-degree phase difference has a major axis which is either vertical or horizontal. This distinguishes the ellipse due to unlike voltage amplitudes for a difference of 90 or 270 degrees from other ellipses due to other phase differences.

Concerning the patterns in Fig. 8-18, 10-2 and 10-3, each is a stationary pattern only when there is no continuous change in frequency or phase taking place. Naturally when the same signal is observed at two different points in a system, the resultant Lissajous pattern will remain stationary. On the other hand, if the vertical and horizontal voltage components are derived from two individual and separate signal sources that are *not locked to each other* in frequency and phase, the pattern will pass through a series of progressive changes which will include the full gamut of phase differences from 0 degrees through 360 degrees, hence through the steps shown in Fig. 8-18.

The average use of the phase difference Lissajous pattern is simply a case of determining if *any phase difference or phase shift exists.* The exact amount is seldom determined except in critical applications.

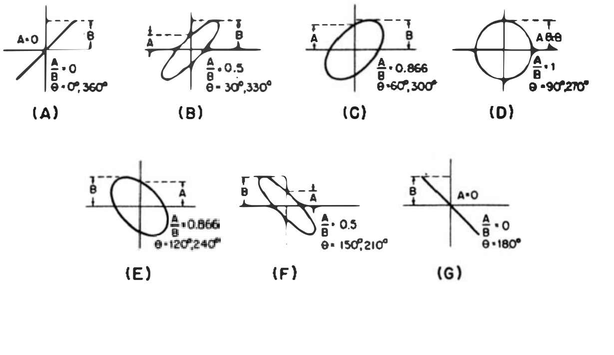


Fig. 10-5. Calculating phase angle from scope pattern.

Determining the phase difference indicated by a Lissajous pattern formed by two sine waveform voltages is relatively simple. It does, however, require the presence of "X" and "Y" axes which the pattern can intercept. Such axes are available on the usual grid transparencies that are supplied with most scopes. The pattern can be located on the grid by first selecting one of the lines on the grid to serve as the "X" axis of the pattern. The vertical amplitude of the trace is reduced to zero and the resulting horizontal line trace is arranged to fall on the grid line previously selected as the "X" axis. This is illustration (A) in Fig. 10-4. The horizontal gain control is adjusted for any desired length of the horizontal deflection trace. The vertical line on the grid transparency which coincides with the midpoint of the horizontal trace is noted. This line will be the "Y" axis of the trace. Then the vertical gain control is advanced until the height of the image is equal to its width as shown in (B) of Fig. 10-4. This can be established very easily by simply counting the number of squares that are encompassed by the dimension in each direction.

Having established the "X" and "Y" axes, the phase difference corresponding to any pattern is equal to

$$\sin \theta = \frac{A}{B}$$

as illustrated in Fig. 10-5. Here are shown a variety of patterns and the manner of calculating the phase difference. The ratio between distances

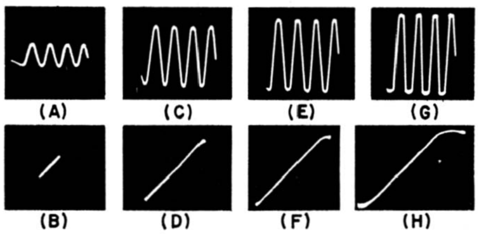


Fig. 10-6. Effect on Lissajous figure of increasing amplitude (A) to (D) and overload distortion (E) to (H).

A and B in Fig. 10-5 is simply the numerical ratio of the lineal dimensions A and B as measured on the grid transparency. The value of sin θ for the ratio A/B is determinable from any table of sines and cosines. Thus if A/B equals 0.7, the phase difference is 45 degrees or 315 degrees. Other typical values are indicated in Fig. 10-5.

1:1 Frequency Ratio Lissajous Figure Tests

The traces shown in Fig. 8-18, 10-2 and 10-3 are seen to be free from kinks and irregularities in the ellipses and in the circle; also the oblique lines are seen to be free from any curvature. This indicates absence of any distortion in the waveforms, hence that they are single-frequency signals, and if one of them is the input signal to a system and the other is the output signal from a system, the system functioning is free from dis-

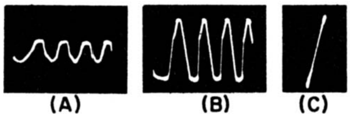


Fig. 10-7. (A) input, (B) output signal, and (C) Lissajous figure. Nonsinusoidal nature of waveform does not affect (C).

tortion, but introduces the particular phase difference condition which the pattern indicates. In these respects these illustrations are exaggera-ions.

A more practical approach is shown in Fig. 10-6. Here are shown a series of waveforms and the equivalent Lissajous patterns for input and output voltage relationships for different conditions of operation. Trace (A) is the single-frequency sine waveform signal present at both input and output circuit of an audio amplifier, and (B) is the resultant Lissajous figure indicating zero-degree phase difference between the input and output circuits, as well as the absence of any distortion. Traces (C) and (D) indicate the same conditions as for (A) and (B), except that the signal amplitudes are higher, hence the length of the Lissajous figure line is greater. It is straight, hence indicates a *linear* relationship between the input and output voltages.

In traces (E) and (F) are indicated a small amount of distortion. It is evident in the output waveform, and it can also be seen in the Lissajous pattern by the curvature at the top of the trace. Traces (G) and (H) indicate a condition of greater overloading in the amplifier.

The traces (B), (D), (F) and (H) show a simple means for indicating the nonlinearity of performance in an audio amplifier by using the input and output signals to develop a Lissajous figure on the scope screen.

Lissajous Figure Tests with Complex Waveforms

Lissajous figures resulting from voltages having a 1:1 frequency ratio and containing distortion appear in Fig. 8-19 (see Chapter 8). Either or both voltages contain distortion. It should be realized that the resultants shown in Fig. 8-19 represent signals derived from different sources. Under the circumstances these traces will not remain stationary unless a fixed frequency and phase relationship prevails between the component voltages.

In contrast to Fig. 8-19, there appears in Fig. 10-7 the Lissajous pattern resulting from an input-output signal combination when an amplifier is processing a complex waveform but its input-output relationship is linear. The fact that the input signal is complex does not affect the Lissajous figure indicating a linear relationship between the two component signals. Trace 10-7(A) is the input signal; (B) is the output signal, and trace (C) is the resulting Lissajous figure. If phase shift prevailed between the input and output circuits, trace (B) would not be an enlarged version of (A) and trace (C) would be some sort of

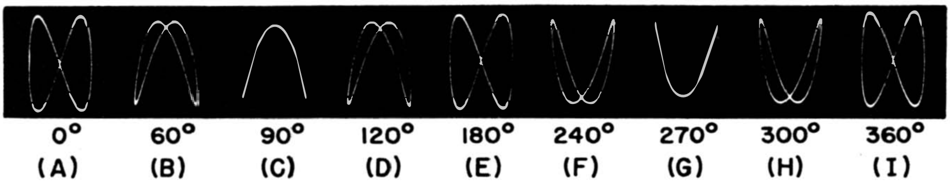


Fig. 10-8. Traces resulting when the signal to the vertical plates has twice the frequency of the signal on the horizontal plates.

an ellipse. Because the input and output signals are of the same frequency, trace (C) is a stationary pattern.

Comparison of Frequencies

The Lissajous figure permits a comparison between frequencies which are unlike. This function of the scope is not utilized too frequently, but it is useful to know about it just the same. Assume Fig. 10-1 as the basis of feeding the two signal voltages into the scope and assume signals *a* and *b* to be derived from different sources. The illustrations that follow show the variety of patterns which develop under different conditions of frequency and phase. It is to be understood that while the patterns appear stationary in these illustrations, it is conceivable that they will be in motion on the scope being viewed by the reader. But even so, if the two signals are very close to the frequency ratios stated, they will be recognized as producing the traces shown.

2:1 Frequency Ratios

In Fig. 10-8 are shown a variety of traces obtained when the two voltages have a 2:1 frequency ratio; both are sine waveforms, the higher frequency voltage is fed to the vertical plates and the phase difference between the two voltages differs as indicated. As a rule, neither the phase difference nor the two frequencies remain fixed during calibration, hence the trace may be seen varying through these different phases. Between these phases the trace consists of multiple lines. In Fig. 10-9 is shown the same frequency and phase relationship as in Fig. 10-8, except that now the higher frequency is fed to the horizontal plates. Note that the pattern has shifted through 90 degrees and seems to be lying on its side. It is seen that the difference between the traces is that during cer-

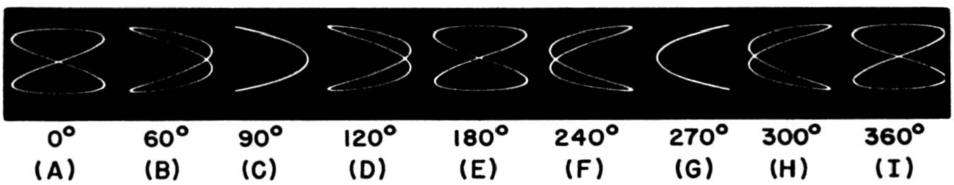


Fig. 10-9. Traces resulting when the signal to the horizontal plates has twice the frequency of the signal on the vertical plates.

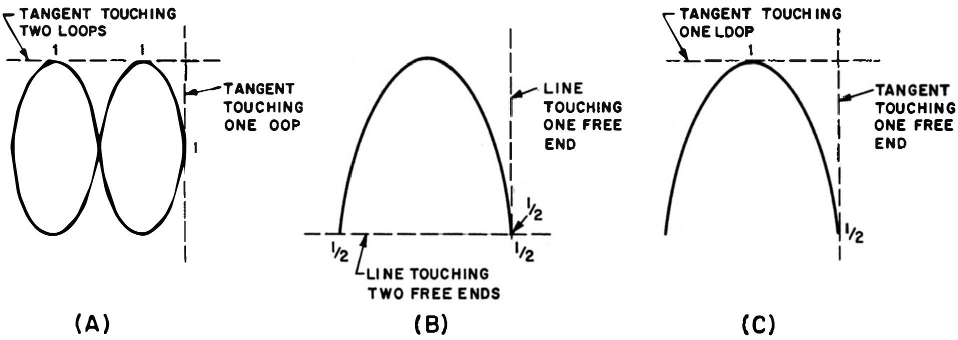


Fig. 10-10. Drawing tangents to check frequency ratio.

tain phase conditions the lines overlap each other, whereas under other phase conditions they separate and form completed loops that cross each other.

The method used to determine the frequency ratio is simple. Two tangents are drawn at right angles along two sides of the trace, as shown in Fig. 10-10. In (A) the pattern is made up of completed loops which cross each other. One tangent is seen to touch two loops and the other tangent is seen to touch one loop. The frequency ratio therefore is 2:1. If the higher frequency is applied to the vertical plates, the greater number of loops touching the tangent will be either at the bottom or the top of the trace. If the higher frequency is applied to the horizontal plates, the greater number of loops will touch the tangent located on either the right side or the left side of the trace.

If the pattern has overlayed lines which form a trace that has what seem to be free ends and half loops like (C) and (G) in Fig. 10-8 and 10-9, the tangents are used as shown in Fig. 10-10 (B). Each free end is considered as a ½ contact, hence, with the vertical frequency being indicated by two ½ contacts and the horizontal frequency being indicated by one ½ contact, the ratio is 2:1. Another way of determining the frequency ratio is shown in (C) of Fig. 10-10. The tangents contact one half loop and one free end. The half loop contact is considered as 1 and the free end contact as ½, hence the frequency ratio is 2:1.

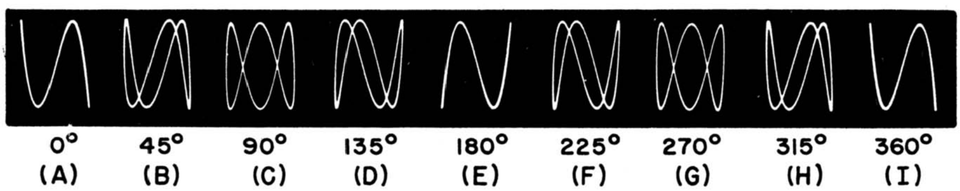


Fig. 10-11. Vertical signal frequency three times horizontal frequency.

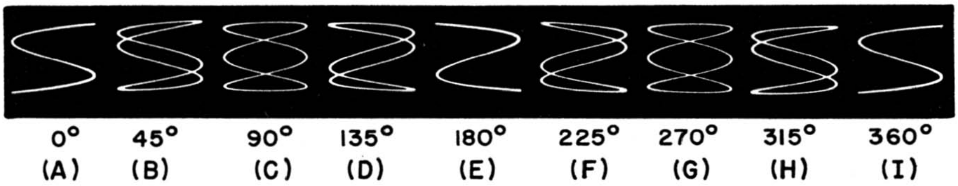


Fig. 10-12. Horizontal signal frequency three times vertical frequency.

3:1 Frequency Ratio

In Fig. 10-11 and 10-12 are shown two groups of Lissajous figures having 3:1 frequency ratios and various phase conditions. The two voltages have sine waveforms. The higher frequency voltage is applied to the *vertical* deflection plates in Fig. 10-11, and to the *horizontal* plates

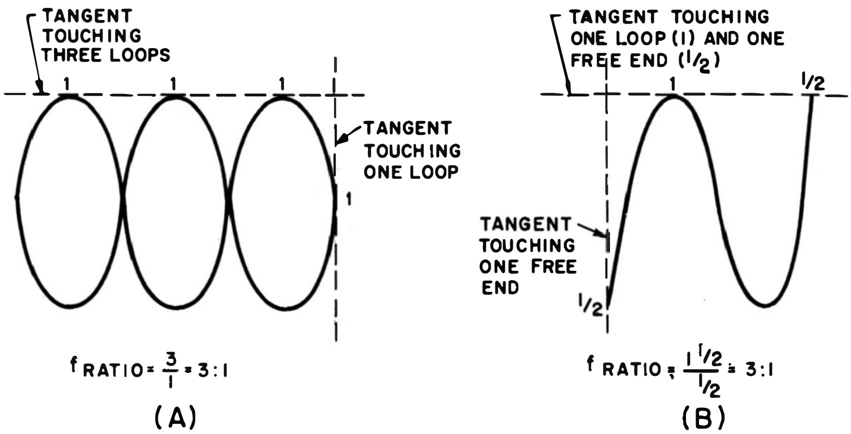
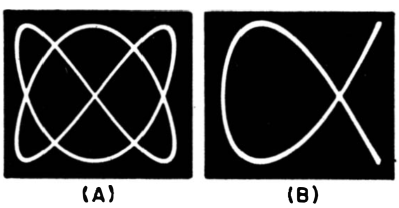


Fig. 10-13. How tangents are used to check 3:1 frequency difference.

in Fig. 10-12. The changing phase conditions modify the appearance of the figure from one which is made up of closed loops that cross each other to ones that are made up of lines that overlay each other forming a pattern of h alf loops and free ends. The method used for determining the frequency ratio is shown in Fig. 10-13. Again, it is a case of drawing "vertical" and "horizontal" tangents and counting the number of contacts with the trace. A closed loop or a half-loop contact counts as 1 and a free end contact counts as $\frac{1}{2}$, hence $1\frac{1}{2} : \frac{1}{2} = 3 : 1$. Fig. 10-14 shows a 3:2 frequency ratio.

Fig. 10-14. Lissajous pattern depicting a 3:2 frequency ratio.



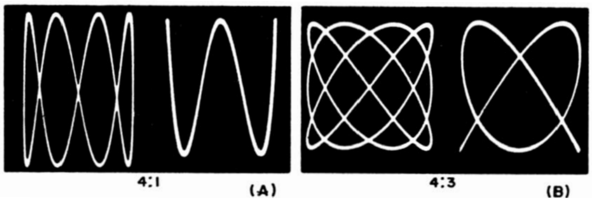


Fig. 10-15. (A) 4:1 frequency ratio, (B) 4:3 frequency ratio.

A Variety of Frequency Ratios

The frequency ratios useful for frequency comparison or calibration seldom have to exceed a maximum of 10:1. This is because normally a flexible standard is used; this standard can almost always be set to a frequency within a ratio of 10:1 with the unknown signal.

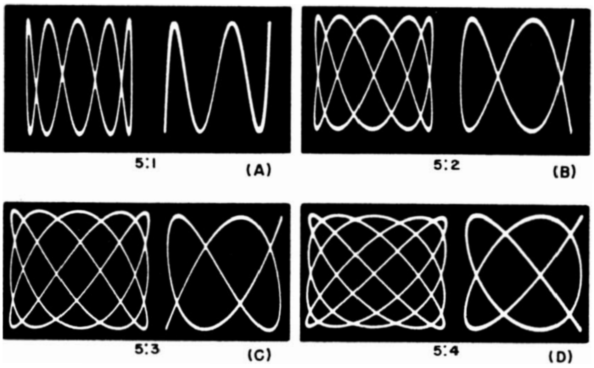


Fig. 10-16. (A) 5:1 frequency ratio, (B) 5:2 frequency ratio, (C) 5:3 frequency ratio, (D) 5:4 frequency ratio.

Group 4 Ratio—In Fig. 10-15 are shown traces corresponding to 4:1 and 4:3 frequency ratios.

Group 5 Ratio—In Fig. 10-16 are shown 5:1, 5:2, 5:3 and 5:4 frequency ratios.

Group 6 Ratio—In Fig. 10-17 are shown 6:1 and 6:5 frequency ratios. Ratios such as 6:4 appear as 3:2, and 6:2 appears as 3:1.

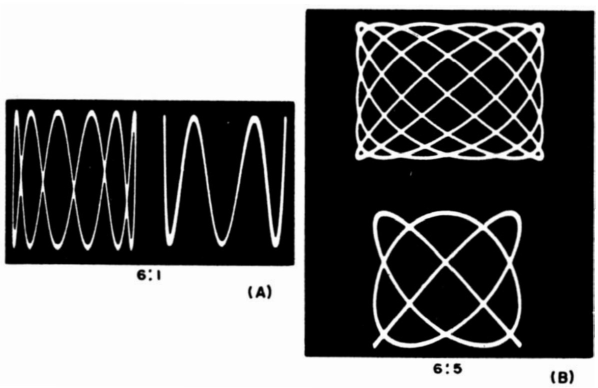


Fig. 10-17. (A) 6:1 frequency ratio, (B) 6:5 frequency ratio.

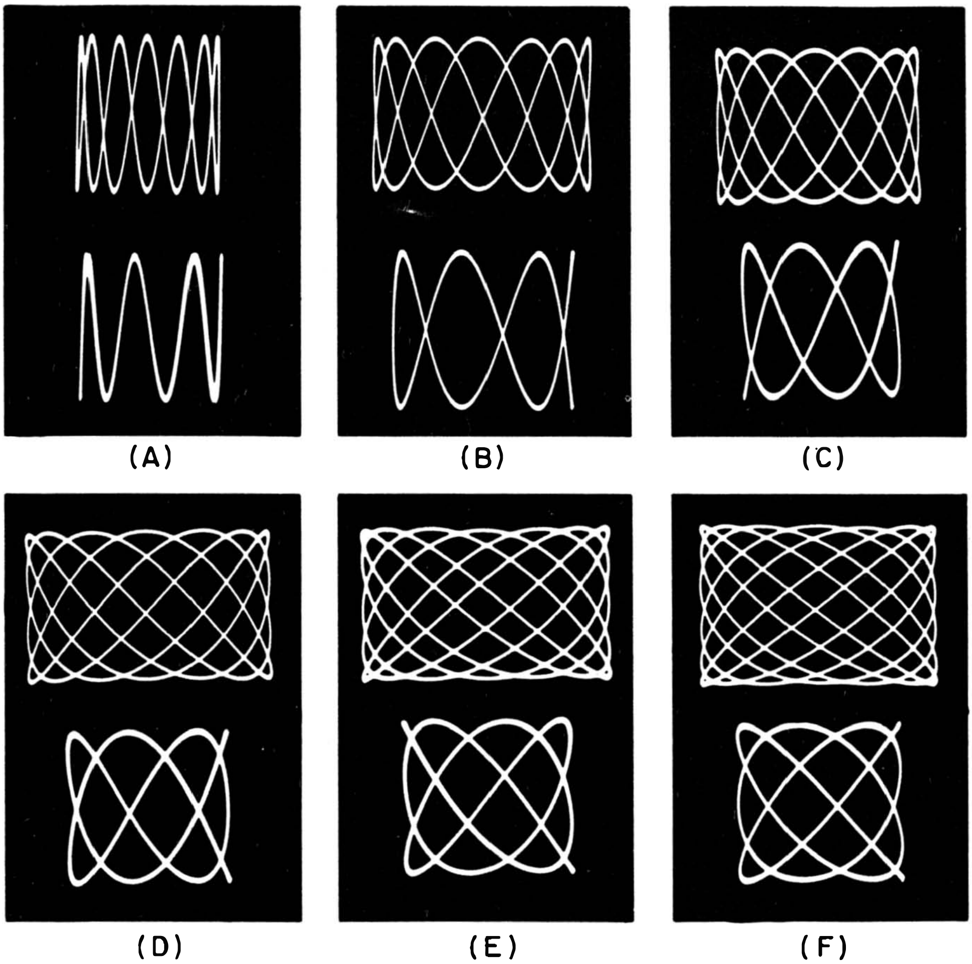


Fig. 10-18. (A) 7:1 frequency ratio, (B) 7:2 frequency ratio, (C) 7:3 frequency ratio, (D) 7:4 frequency ratio, (E) 7:5 frequency ratio, (F) 7:6 frequency ratio.

Group 7 Ratio—In Fig. 10-18 are shown 7:1, 7:2, 7:4, 7:5 and 7:6 frequency ratios.

Group 8 Ratio—In Fig. 10-19 are shown 8:1, 8:3, 8:5 and 8:7 frequency ratios.

Group 9 Ratio—In Fig. 10-20 are shown 9:1, 9:2, 9:4, 9:5, 9:7 and 9:8 frequency ratios.

Group 10 Ratio—In Fig. 10-21 are shown 10:1, 10:3, 10:7 and 10:9 frequency ratios.

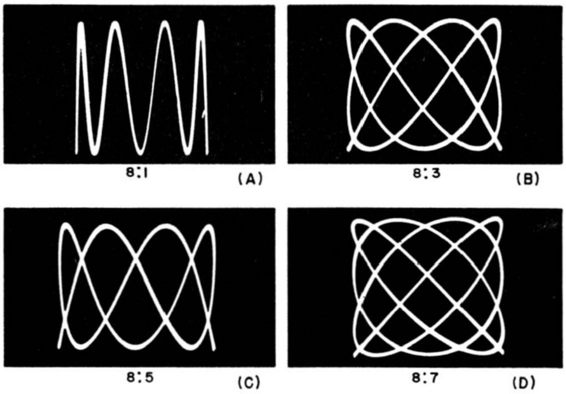


Fig. 10-19. (A) 8:1 frequency ratio, (B) 8:3 frequency ratio, (C) 8:5 frequency ratio, (D) 8:7 frequency ratio.

Completely closed loop traces are not shown for frequency ratios higher than 7:2 because they are not convenient to work with. When the loops and free-end contacts are counted, the ratios indicated are arrived at by multiplying by 2 to eliminate fractions. For instance, it is seen that

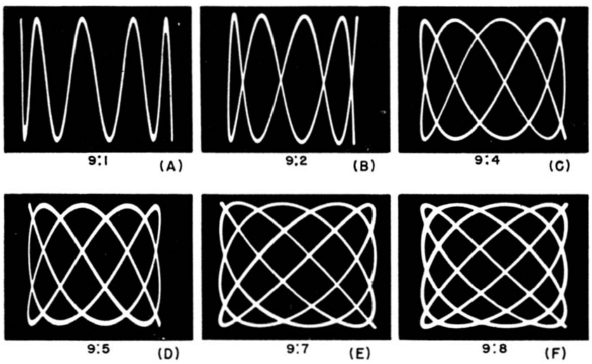


Fig. 10-20. (A) 9:1 frequency ratio, (B) 9:2 frequency ratio, (C) 9:4 frequency ratio, (D) 9:5 frequency ratio, (E) 9:7 frequency ratio, (F) 9:8 frequency ratio.

the pattern for the 10:9 ratio in Fig. 10-21 consists of 5 complete loops at the top and 4 complete loops and 1 free end on the side. Thus the ratio is $5:4\frac{1}{2}$, which if both sides are multiplied by 2, becomes 10:9. Similarly

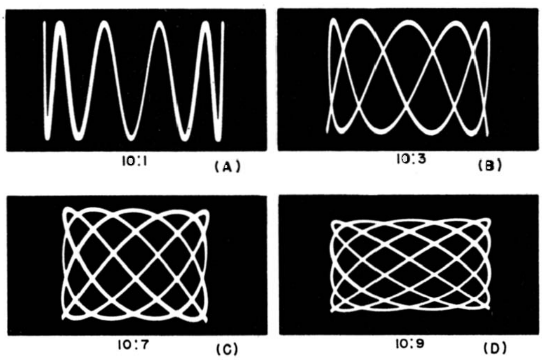


Fig. 10-21. (A) 10:1 frequency ratio, (B) 10:3 frequency ratio, (C) 10:7 frequency ratio, (D) 10:9 frequency ratio.

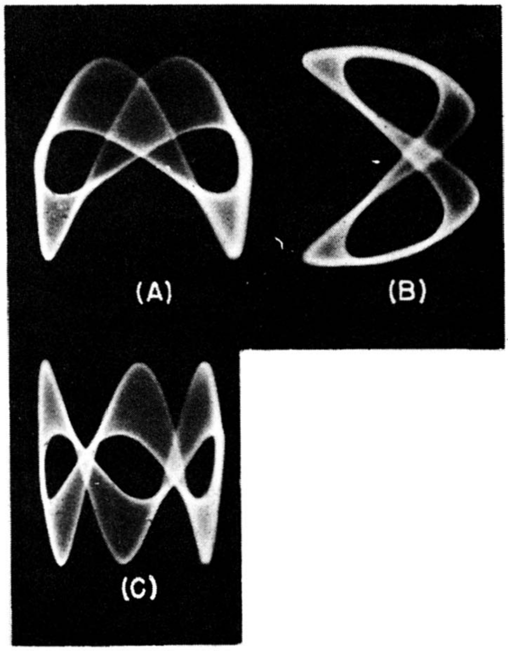


Fig. 10-22. Lissajous figures resulting when one of the component voltages contains amplitude modulation.

if the trace for 9:8 frequency ratio in Fig. 10-20 is examined, it will be found that it consists of 4 complete loops and 1 free end on top and 4 complete loops on one side and 3 complete loops and 2 free ends on the other. In one case it is $4\frac{1}{2}:4$ and in the other it is $4 : (3+\frac{1}{2}+\frac{1}{2})$ or again $4\frac{1}{2}:4$, which, if both sides are multiplied by 2, becomes 9:8.

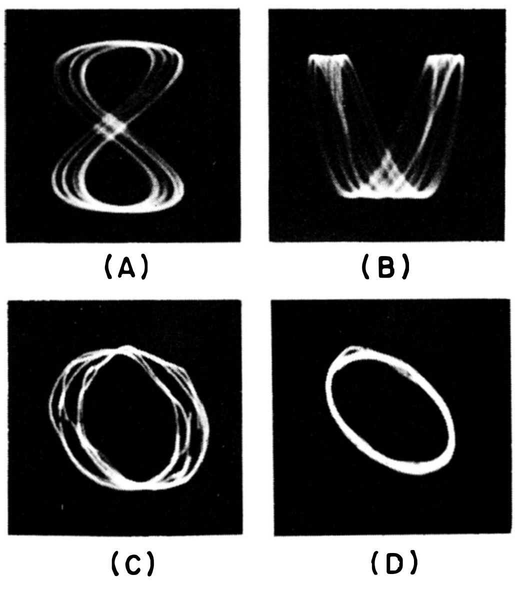


Fig. 10-23. Lissajous figures with spurious hum pickup.

Lissajous Figures with Spurious Signals

Occasionally Lissajous patterns used for frequency comparison are made confusing by the presence of spurious signals in one or both voltages. In Fig. 10-22 are shown a variety of low-frequency-ratio traces resulting when one of the voltages contains amplitude modulation. In Fig. 10-23 (A) and (B) a 500-cps and a 1000-cps voltage are compared and 60-cps hum pickup appears on the vertical plates. In trace (C) the voltages being compared have a frequency of 80 cps, but a 60-cps hum voltage exists on the horizontal plates. Trace (D) is for the same signal voltage conditions as (C) except that now the 60-cps hum appears on the vertical plates.

Chapter 11

TEST SETUPS FOR OBSERVATION WITH THE SCOPE

Waveform Observation

Waveform observation techniques using the scope do not require special test setups. The "high" scope terminal connection is the roving test lead. As a rule the ground terminal of the equipment under test is the junction for the ground terminal of the scope, but on occasion the low side of the circuit under test is above ground. This will not impair the scope display, unless the low side of the circuit being checked is at a substantial potential above ground and connecting the scope to the circuit impairs its action.

Commonly used waveform observation points are the signal processing electrodes of vacuum tubes, namely the control grid, plate, cathode and screen grid (if used). The plate and cathode of diodes are active signal-processing elements. Germanium and metallic rectifiers also are used for signal voltage processing, hence the terminals of these circuit elements are signal observation points.

Scope Probes

A factor in the success achieved in voltage waveform examination is knowledge concerning the kind of scope *probe* to use as the signal coupling link between the point of observation and the test scope. Four types of scope probes are in common use. These are (1) high voltage capacitor divider, (2) low capacitance-high impedance, (3) detector or demodulator, and (4) the direct probe. Depending on the situation, one of these types is the preferred probe; in some cases more than one type may be suitable. Which it is, is decided by the kind of signal being checked and the impedance of the circuit in question. The following is offered for guidance in this connection.

High Voltage Probe. This probe is suitable for use in the presence of high a-c voltages, usually 600 volts and more. Typical applications are in cathode ray tube deflection circuits, across deflection windings, at the horizontal output tube plate, at the high voltage rectifier anode, at the damper tube anode, etc. These examples are found in television receivers, but their parallels can be found in high voltage cathode ray display systems of other kinds, as in radar equipment, and in transmitters.

Low Capacitance-High Impedance Probe. Can be used for all waveform observations provided that the peak-to-peak amplitude of the signal voltage is sufficient. Seldom used where voltage exceeds 500 to 600 volts a-c. Ideal for high impedance circuits, and in frequency-sensitive circuits. Used where capacitance must be small, and impedance must be high. Preferred in *LC* and *RC* oscillator circuits, blocking oscillators, sweep generators, control grid and plate circuits of amplifiers of all kinds in transmitters and receivers, and at all frequencies. Suitable for observation of clipper and rectifier operation, phase inverters, sync amplifiers, etc. Preferred for the display of modulated waveforms. Ideal for use in r-f, mixer and i-f systems. Can be used in low impedance circuits. Substantial attenuation at power and low audio frequencies.

Detector Probes. Necessary for demodulation of modulated waves. Will develop modulation component from a-m wave; must have correct time constant for distortionless demodulation; will develop resonance curve from f-m voltage (sweep generator output), hence is used in the r-f, mixer and i-f circuits to view the modulation components of a-m radio and video carriers. Is used to develop response or resonance curves of systems being checked by signals from sweep generator; develops frequency-voltage output curves of sweep generators, response curves of demodulators, acts as mixer for comparison of frequencies, etc.

Direct Probes. The direct probe is a medium-capacitance medium-impedance coupling unit. Suitable for use in all low impedance circuits, video amplifier grid and plate circuits, audio amplifier plate circuits, transformer-coupled audio amplifiers, supersonic frequency amplifiers, phase and frequency measurements, hum measurements, for coupling to receiver demodulator when making response curves or doing alignment on r-f, mixer, video and sound i-f systems, in differentiating and integrating circuits. The use of a direct probe in circuits containing a-m waveforms may result in a demodulated trace. When this happens, the reason is nonlinearity in the amplifier being checked.

Test Signal Sources

The use of a signal generator as the source of test signals always is recommended. An alternative is a received signal. The demodulated a-m carrier from a signal generator can supply the test a-f signal if an audio oscillator is not available.

Tests on the r-f, mixer and i-f systems of f-m receivers are limited to the display of response curves rather than the modulated waveform.

Given an f-m signal generator wherein the frequency modulation contains the audio signal, demodulation of the carrier in the discriminator supplies the audio signal for testing the audio amplifier.

In the case of television receivers, or others of similar nature which process a-m carriers wherein the modulation component contains the equivalent of video information and control voltage pulses, the most practical approach is the use of a received signal. Television receiver carrier frequencies are so high as to be beyond the frequency range of acceptance by the vertical amplifiers in text scopes. Examination of r-f, mixer and i-f amplifier performance in television and similar receivers usually is done by analyzing the response curve and the demodulated carrier waveform.

Tests on audio or supersonic frequency amplifiers of all kinds are accomplished best by the use of either a variable sine-waveform signal generator of suitable frequency range, or with a square-waveform voltage of selected frequency available from a square-waveform generator.

Examinations made at a single frequency generally utilize a-m signal generators, whereas examinations made over a band of frequencies generally make use of sweep generators. Phase and frequency measurements or the comparison of frequencies require the services of stable sources of known frequencies.

Termination of Signal Generators

The successful application of signal generators as signal sources requires that the generator output cables be terminated by the correct load impedances. Sometimes the terminations are a part of the output cable construction. When this is not so, the terminating resistance must be added. The resistance should be non-inductive and of the type which remains constant over a wide range of frequency. Its value is determined by the output impedance rating of the generator. When the unit being checked has a balanced input, the generator output cable termination should be organized for balanced output. Instructions to accomplish this are contained in the instruction bulletins which accompany the generators, and should be followed.[1]

Polarity of Observed Signals

It is a well-known fact that signal inversion occurs between the control grid and plate of a vacuum tube. This will not be noted when examining modulated or other symmetrical voltage waveforms, or probe-demodulated voltages in r-f, mixer and i-f amplifiers. The polarity of the demodulated signal is a function of the connections to the demodulating element in the detector probe. Advancing from the control grid to the

[1] See also Chapter 7 of HOW TO USE SIGNAL AND SWEEP GENERATORS, by J. Richard Johnson, John F. Rider Publisher, N. Y., which contains a full and detailed discussion on this subject.

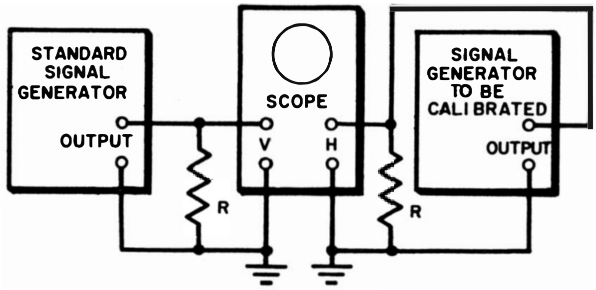


Fig. 11-1. Setup for comparing frequencies in calibration of a signal generator.

plate circuit of an r-f or i-f amplifier will not result in inversion of the demodulated signal because the demodulator output has constant polarity. Inversion of unsymmetrically distorted waveforms can be noted, however.

Audio Amplifiers

Three kinds of tests are applicable to audio amplifiers. They are (1) sine waveform tests for distortion, (2) square waveform tests, and (3) phase shift and overload tests. The square waveform test allows simultaneous examination of the frequency response and phase characteristics of the amplifier as a whole. Clipping will not be readily recognizable when a square waveform voltage is applied.

The sine waveform test is an individual frequency examination. It permits a stage by stage waveform check of performance.

The phase-shift test is the development of a Lissajous figure by feeding a sine waveform voltage to the input circuit and applying the input to the amplifier, and output voltages from the amplifier to the vertical and horizontal deflection plates respectively. This test shows the presence of clipping or overloading. It is an overall test, embracing the complete amplifier between input and output.

Frequency and Phase Measurements

Frequency and phase measurements with the scope are in two groups. One is the comparison of frequencies by means of Lissajous figures. A suitable signal generator supplies the *standard* frequency voltage to the *vertical amplifier* and the ***unknown*** frequency voltage source applies the signal voltage to the *horizontal amplifier*. Neither the sawtooth nor the 60-cps line sweep available within the scope is used.

The other is the determination of phase shift in a system by feeding the same signal voltage to both the vertical and horizontal deflection systems; the vertical amplifier receives the voltage that is fed into the *input* of the system under test, and the horizontal deflection amplifier receives its signal voltage from the *output* of the system under test.

Frequency Comparison

When comparing frequencies or when calibrating an uncalibrated signal generator with a calibrated signal generator, it is best if the frequency of the standard does not exceed the frequency of the unknown by more than a ratio of 10:1. This leads to an easy-to-read scope trace. The setup is shown in Fig. 11-1.

As a rule, comparison of frequencies using the scope is most convenient in the audio and supersonic frequency regions, although higher frequencies can be compared if the generators are stable and the scope amplifiers pass the frequencies.

The outputs from the two signal generators should be set for similar trace dimensions on the screen. The largest sized image possible on the screen should be used. Sine-waveform voltages are the most convenient to compare.

Because the two generators are not synchronized, it may be necessary to continually manipulate the uncalibrated generator in order to produce a readable Lissajous figure on the scope screen. This effort is made easier if the standard and the uncalibrated generators are made stable by allowing them to warm up for a prolonged period; also if the two generators are operated from regulated line voltage sources. But even without these refinements, it is possible to calibrate fairly accurately if care is exercised.

Phase Shift Measurements

The phase shift measurement setup is shown in Fig. 11-2. The signal fed into the system under test also is fed to the vertical deflection amplifier and the output signal from the system under test is fed to the horizontal amplifier. Neither the sawtooth sweep nor the 60-cps line sweep contained in the scope are used. The scope trace should be adjusted for equal vertical and horizontal signal amplitude, although this is not a must.

Resonant Frequency Determination

The resonant frequency of a tuned circuit, either series or parallel, can be determined by the methods shown in Fig. 11-3. Use the shortest

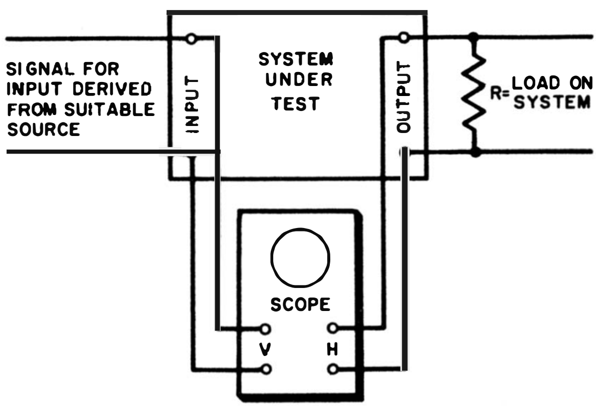


Fig. 11-2. Setup for checking phase shift.

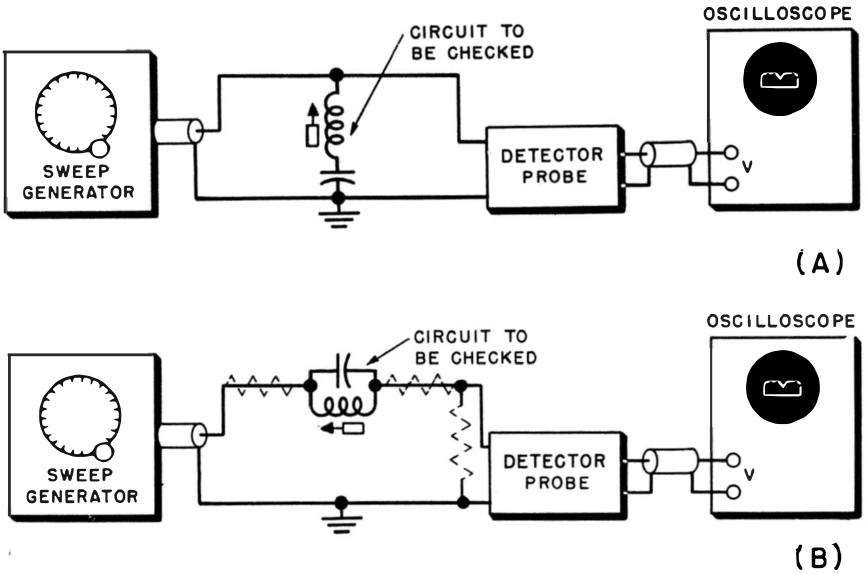


Fig. 11-3. Resonant frequency determination.

possible connecting leads. The resonant frequency of these circuits must be within the bandwidth of the sweep frequency generator.

The scope is adjusted to show the response curve of the terminated sweep generator, using the 60-cps line sweep. At resonance, the series circuit will cause a dip in the response curve. The parallel resonant circuit connected into one leg of the circuit to the detector probe, will also cause a dip in the response curve on the scope screen. If a sharp peak appears before the dip, it is attributable to cable resonances or lack of isolation between the instruments employed. This peak may be removed by inserting an isolating resistor (5,000-10,000 ohm) in any one of the three positions shown in the figure. To determine the resonant frequency of the circuit, a marker must be injected.

Phase Difference in Transformers and Phase Shifting Networks

The phase difference between the primary and secondary voltages of a transformer, or between the two halves of a center-tapped transformer, can be demonstrated by means of the setups shown in Fig. 11-4 (A) and (B). The variable change in phase between input and output voltages in an *R-C* phase shifting network can be demonstrated by the setup shown in Fig. 11-4 (C). If the input does not have a sine waveform, the phase shifter will behave like a differentiator and distort the waveform.

R-F Signal Generators

The limitation imposed on such tests is the frequency range of the generator relative to the frequency passband of the vertical amplifier.

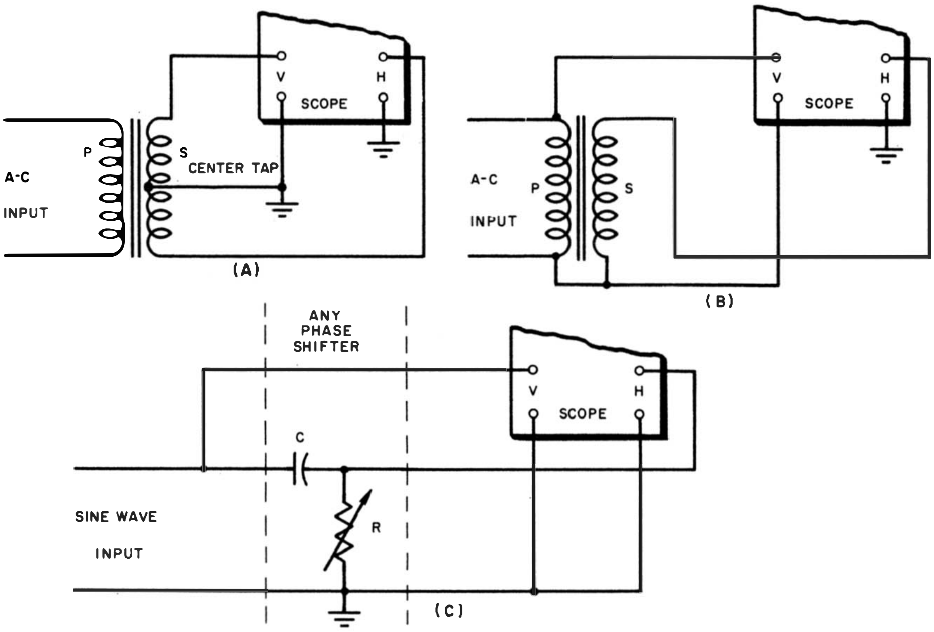


Fig. 11-4. Checking phase shift in transformers and phase-shifting network.

The tests shown here are limited to such frequencies as are accommodated by the vertical amplifier in the scope.

Signal output from r-f signal generators is either of two kinds, unmodulated or modulated. The setup for determining the modulated wave envelope is shown in Fig. 11-5. The scope sweep is the sawtooth voltage and its frequency is a whole-number *submultiple* of the *modulating* frequency used in the generator.

A satisfactory method of examining the modulated wave envelope of an r-f signal whose frequency exceeds the upper limit of the passband of the vertical amplifier of the scope is shown in Fig. 11-6. The modulated signal is fed into the antenna terminals of an a-m radio receiver known to be in perfect working order. The receiver is tuned to exact resonance with the r-f signal. The scope picks off the i-f signal at the plate of the first i-f amplifier tube. The receiver should not be overloaded. The setup used to observe the waveform of the modulation component of the a-m output from the r-f signal generator is the same as

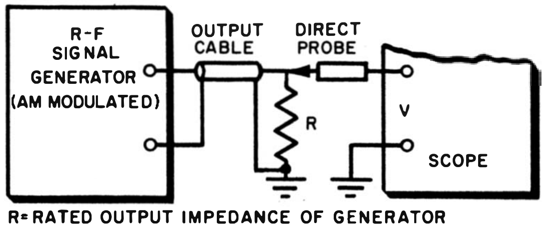


Fig. 11-5. Setup for determining modulated wave envelope shape.

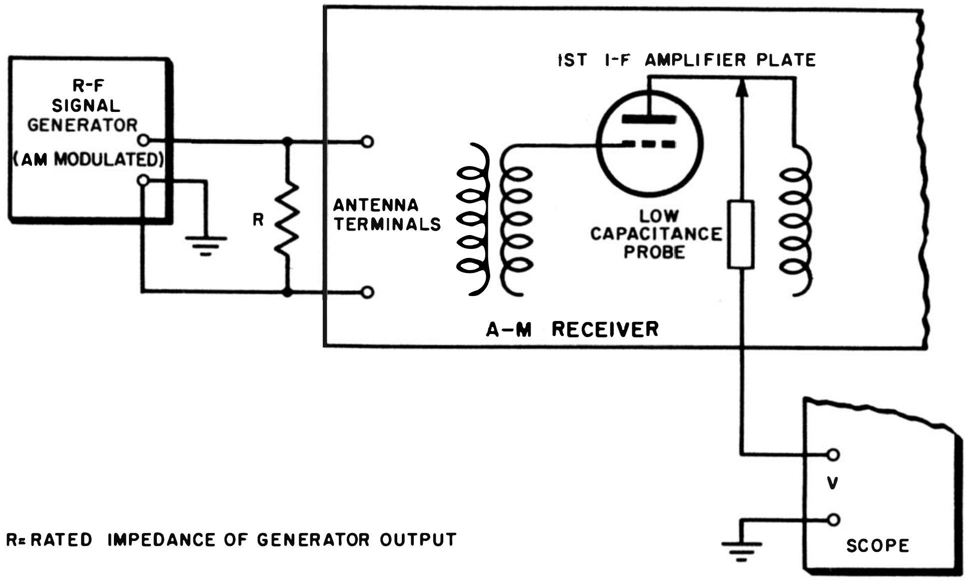


Fig. 11-6. Use of a-m receiver to examine modulated wave envelope when carrier frequency exceeds vertical amplifier passband.

Fig. 11-5 except that a demodulator probe is used. In order to examine the waveform of the audio modulating voltage generated within the r-f generator, the scope must be connected to the output of the audio generating system inside this generator. (Sometimes a convenient output terminal is provided on the generator for this voltage.) When making audio waveform tests of this kind, the demodulator probe is replaced by the direct probe.

A-F Signal Generators

For waveform tests on a-f signal generators, the test setup is as shown in Fig. 11-5, except that the generator is an a-f unit. Some a-f signal generators are designed to work into different load impedances. In this event the load impedance *R* should be changed to suit the impedance rating of the generator. The generator output should be tested at all output levels up to the maximum, and at all output impedances available with the device.

Uniformity of signal output from the generator over its frequency range can be checked by noting the amplitude of the vertical trace in the absence of any horizontal sweep voltage, while frequency is varied by tuning the generator.

Sweep Generators

Tests on sweep generators establish the linearity of output on the different frequency ranges. The test setup is shown in Fig. 11-7. The de-

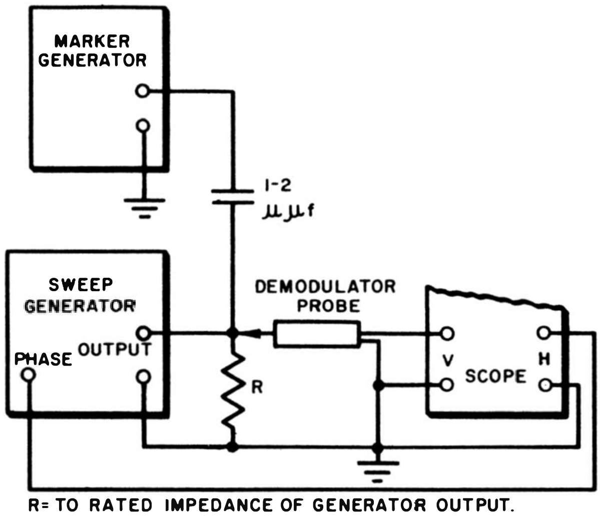


Fig. 11-7. Linearity-output test of sweep generator.

modulator probe is assumed to have a linear output for frequency changes within the range of the sweep generator being checked.

The scope sweep is set for the 60-cps line sweep. Blanking should be available in the sweep generator in order to afford a reference baseline in the scope trace.

Identification of frequency limits requires the application of suitable frequency markers from either a marker generator or from any other suitable r-f generator.

Marker Oscillator

The setup for checking the accuracy of the marker generator by zero beating against a crystal calibrator appears in Fig. 11-8. The signals from the two oscillators mix in the demodulator probe and produce a

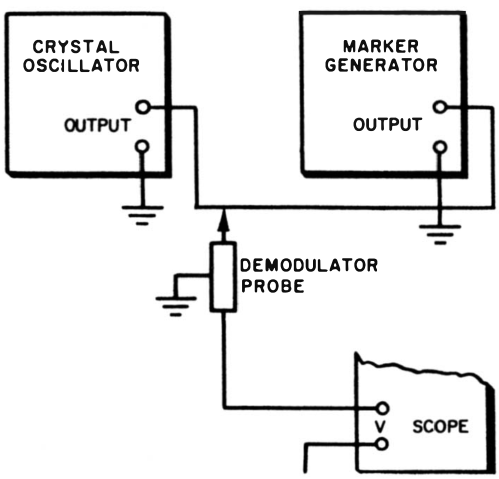


Fig. 11-8. Check of marker generator accuracy by beating against crystal oscillator harmonics.

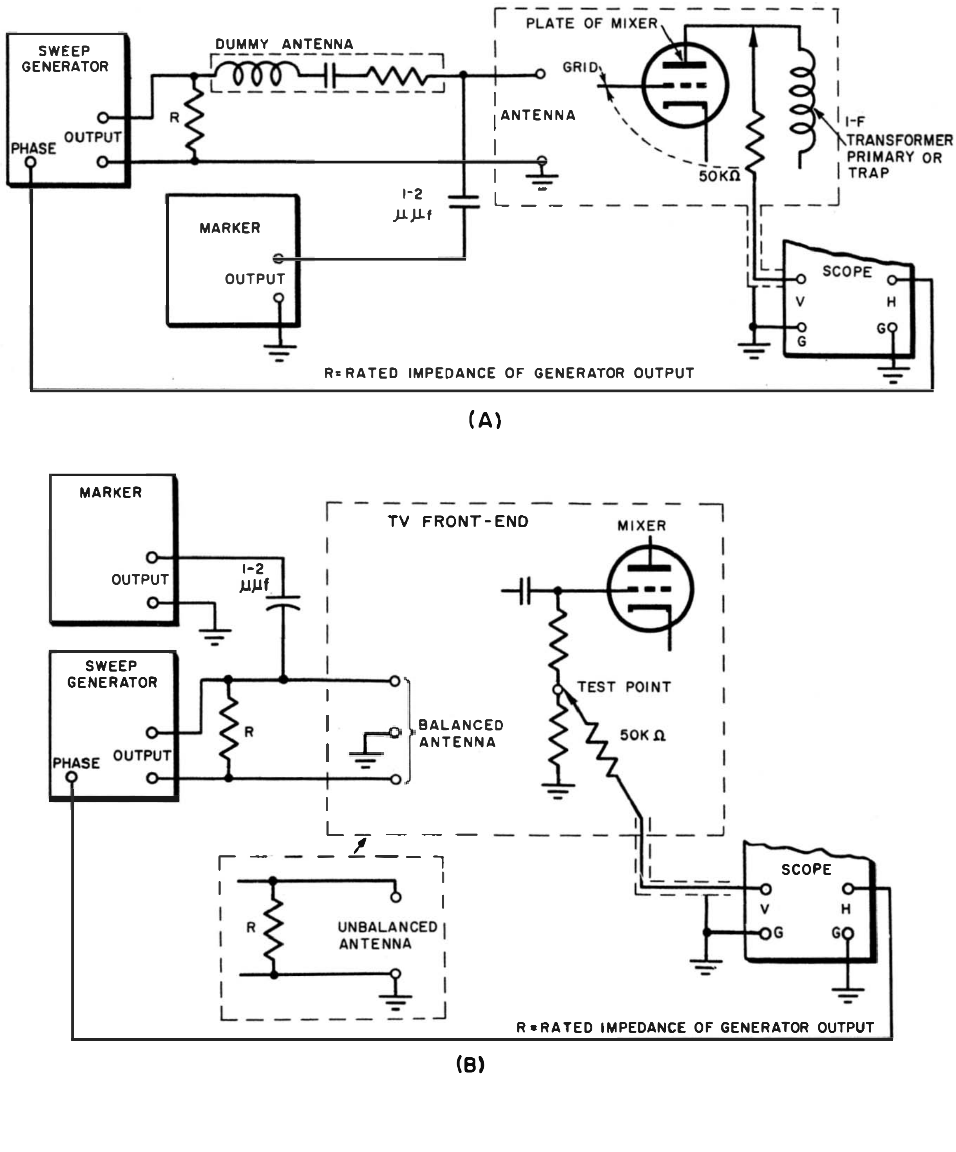


Fig. 11-9. R-F alignment setups, (A) a-m receiver, (B) tv receiver.

difference frequency voltage which becomes zero when the two frequencies are alike. The scope is set to show low frequency waveforms. Minimum beat signal amplitude will occur when the marker frequency is the same as the fundamental frequency of the crystal; also when it is the same as a harmonic of the crystal frequency.

It is conceivable that some hum or noise component may be present and this will prevent the signal from falling to zero vertical amplitude. If one signal is excessively strong, it can swamp the other and make the beat unrecognizable.

Visual Alignment

The fundamental principles of visual alignment of r-f, i-f and discriminator systems are the same, even though the shapes and passbands of the resulting resonance or response curves may differ. The sweep width required in the sweep generator is determined by the rated passband of the transformer or circuit which is being checked or adjusted. It should exceed the passband of the receiver circuits by about 50 per cent. The location of frequencies along the response curve is done by injecting marker frequencies as shown in the test setups.

The scope is adjusted to display waveforms, using the 60-cps line sweep. In the absence of blanking in the sweep generator, a double-line trace will appear on the screen. Assuming correct operating conditions (especially proper grounding), overlapping of these traces so as to form

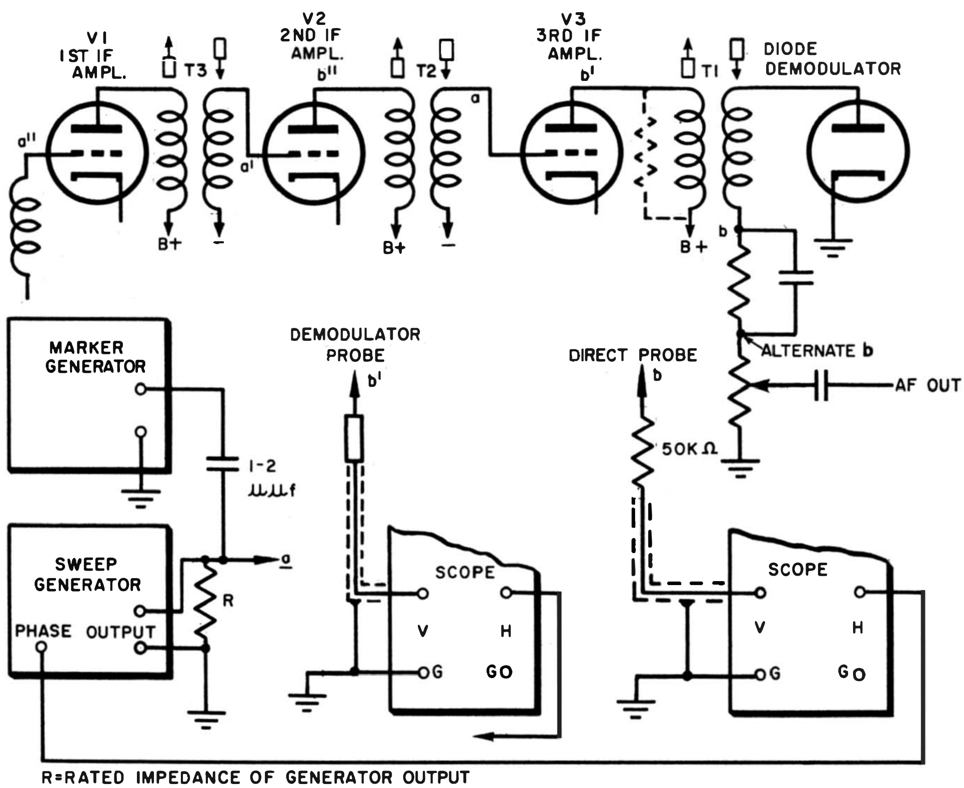


Fig. 11-10. I-F alignment setup combinations

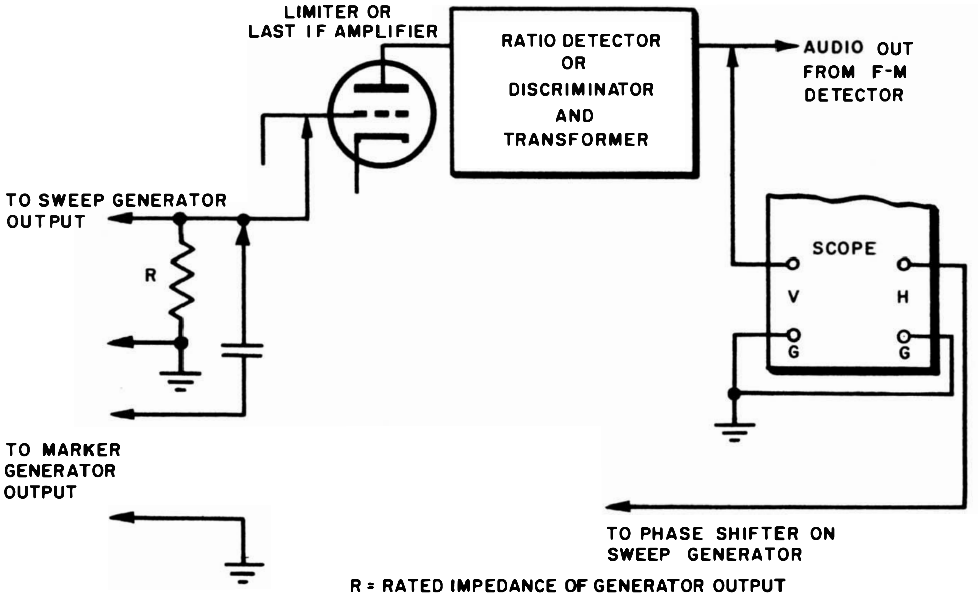


Fig. 11-11. Alignment of f-m detector transformer.

what is the equivalent of a single-line image is brought about by adjustment of the phasing control on the sweep generator. When blanking is available in the sweep generator, a zero voltage reference baseline will appear on the screen, and the response curve will rest above or below the baseline. In the case of "S" curves for discriminators, or their equivalent, one-half of the curve will lie above the zero baseline and the other half will lie below the reference line.

Required conditions of operation for the production of response curves are (1) correct grid bias and (2) minimum input signal consistent with a readable trace, and low level marker signal. It is best if the agc voltage is removed and a fixed bias applied instead.

R-F Alignment

The test setups in Fig. 11-9 are for r-f systems in radio and television receivers. In (A) the signal take-off point is the plate of the mixer tube, or it may be the control grid of the mixer tube. In (B) (a tv receiver) the signal take-off point is the "test" point generally provided for the purpose on the front-end of the receiver. Attention is called to the two possible antenna input systems, that is, balanced and unbalanced. In either case the generator output cable is terminated by the appropriate load resistance *R* and the connection to the receiver input terminals is made as short as possible.

I-F Alignment

The test setup for i-f alignment in a-m radio, tv and similar receivers, is shown in Fig. 11-10. Here are shown a variety of possibilities relative to the signal injection point and the signal take-off point. Intermediate frequency amplifier alignment can be done on a basis of a single stage at a time, two or more stages at a time, or a complete system, depending on the service instructions, and the objective of the alignment.

If the i-f stage feeding the demodulator (diode) is to be aligned or checked, the signal injection point is the control grid of the last i-f stage. This is indicated by the arrow *a* (corresponding to the labeling of the output from the sweep generator). The low impedance resistor *R* across the sweep generator cable loads the secondary winding of the i-f transformer *T2* in the grid circuit of IF-V3. The signal take-off point is the receiver demodulator load using scope *b*.

If, on the other hand, the second i-f transformer *T2* is to be checked or aligned by itself, the signal injection point is the control grid of the tube feeding that transformer. In this case it is IF-V2, and the signal injection points is labeled *a'*. Since only *T2* is to be checked, the receiver demodulator cannot rectify the output of the transformer, therefore the scope probe provides this facility. This means the use of scope *b'*. It is joined to the plate of the i-f amplifier tube being fed by the i-f transformer being checked. In this case, it is IF-V3. In order to assure that the primary of *T1* does not affect the response curve, the plate winding is temporarily shunted by a low value of resistance, say 200 ohms.

In similar manner, alignment of *T3* would call for signal injection at the control grid of IF-VI (*a''* is the schematic) and the demodulator probe would be connected to the plate of the amplifier tube fed by *T3*,

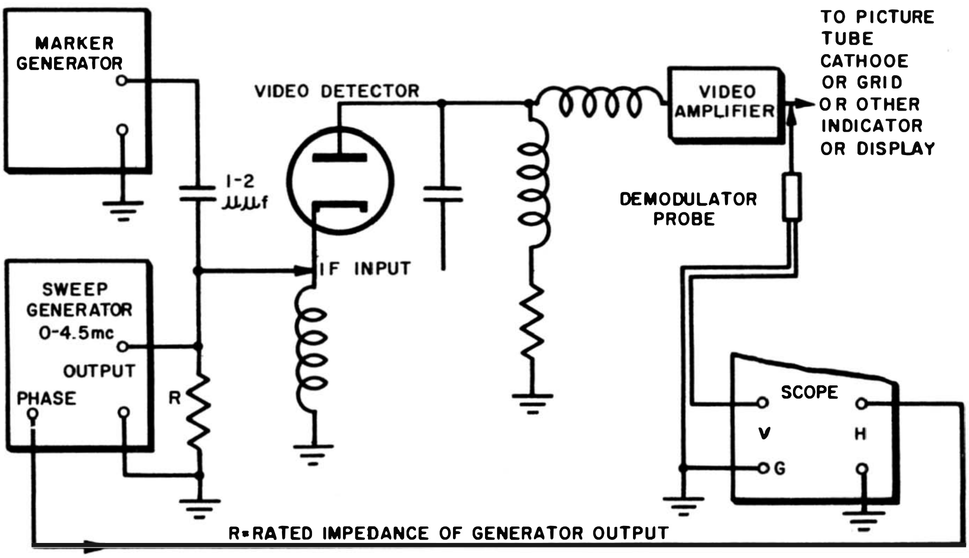


Fig. 11-12. Video response-checking setup.

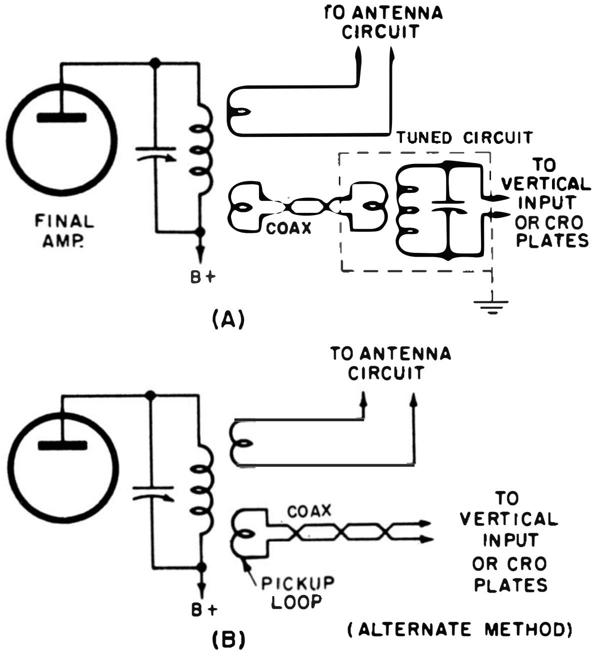


Fig. 11-13. Two methods of displaying modulated output from the transmitter.

namely IF-V2. This point is labeled *b''*, and like before, the plate winding of IF-V2 would be temporarily shunted by a low resistance.

To check all three i-f stages simultaneously, the signal injection point would be *a''* and the signal take-off point would be the demodulator diode load, point *b*.

F-M I-F Amplifier Alignment

The alignment of an f-m i-f amplifier in an f-m receiver, or the sound i-f amplifier in a television receiver is done like in an a-m receiver, except for the difference in the appearance of the response curve when the demodulator is the discriminator or the ratio detector, and for the passband of the i-f transformers or the i-f system as a whole. The setup is shown in Fig. 11-11. The signal injection point is the control grid of the tube ahead of the f-m detector transformer. This may be the last limiter or the last i-f stage depending on the design of the receiver.

If i-f transformers ahead of the limiter (when used) are to be aligned, the limiter may be used as the demodulator with the signal take-off point being the limiter control grid using a direct probe. If the i-f amplifier does not employ a limiter, then the signal take-off point is the plate of the last i-f stage and the scope probe contains the demodulator. The transformer loading is as described in connection with Fig. 11-10. The alignment of interstage i-f transformers in f-m i-f amplifiers which do not use a limiter can follow the procedures outlined in connection with Fig. 11-10.

Video Amplifier Response Curves

The setup for checking the response curve of the video amplifier in tv receivers and other equipment appears in Fig. 11-12. A 0-4.5-mc (or other suitable bandwidth) signal, obtained from a sweep generator, is fed into the video detector at the point where the video i-f signal normally is applied. The signal take-off point is the video output. A demodulator probe feeds the signal to the vertical amplifier of the scope. The marker generator allows identification of the frequency locations along the response curve.

A-F Amplifier Response Curve

The setup for determining the response curve of an a-f amplifier is basically the same as for a video amplifier. The sweep signal generator in this case has a bandwidth of from 0 to perhaps 20,000 or 30,000 cps (or higher as needed). Inasmuch as sweep generators of this kind include their own methods of marking the frequencies contained in the signal, no separate marker generator is used.

Square-Waveform Test on Amplifier Equipment

As a rule, two fundamental frequencies are used; a low frequency approximately 40 to 60 cps or lower, depending on the low frequency rating of the amplifier, and a frequency of between 1,000 and 2,000 cps. This is sufficient to show frequency response up to at least 20,000 cps. The impedance match should be correct; the capacitance of the cable feeding the voltage to the input of the amplifier should be minimum; the input signal voltage level should be ample but not enough to overload the amplifier and the proper load should be applied to the amplifier. The square waveform voltage is fed into the amplifier and the scope is connected across the amplifier load. The scope controls are set for waveform observation and the sawtooth sweep is used.

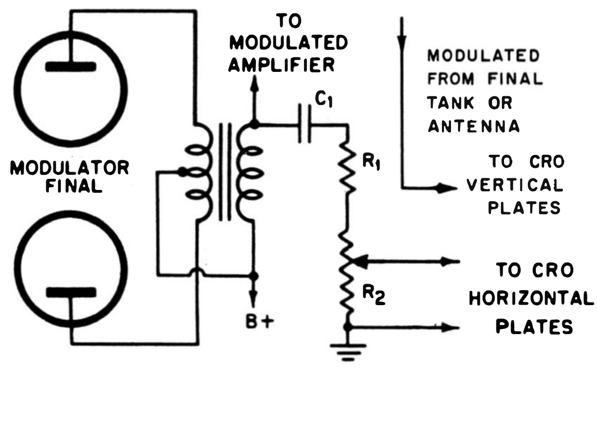


Fig. 11-14. Trapezoid-method for checking modulation percentage.

Tests on A-M Transmitters

The tests shown here concern the audio voltage used for modulation and the modulation process. The examination of the operation of the speech amplifier and the modulators is conventional waveform observation, assuming a signal input to the speech amplifier from a sine-waveform audio signal source. The test setups in Fig. 11-13 show two methods of displaying the modulated output from the transmitter. The scope is adjusted for waveform display. In (A) link coupling is used between the final tank coil or the antenna coil and a tuned circuit connected to the vertical amplifier or to the vertical deflection plates of the scope. (The signal is fed to the deflection plates when the carrier frequency is higher than the passband of the vertical amplifier.) The two link windings consist of several turns of insulated wire for each coil. The connection between them is made with a short length of coaxial cable.

The alternate method in (B) is a simple pickup coil coax-connected to the scope. The coupling between the final tank or antenna link and the scope pickup coil should be as loose as possible consistent with developing the trace on the scope screen. Physically speaking, the scope pickup link coil should be fastened so that it is rigidly in position and does not shift in location during operation.

The display of the trapezoid pattern of the a-m waveform, shown previously, is a simple means of examining the modulated output signal when the modulating signal is made up of a variety of frequencies which are not related harmonically, as for example speech signals. It is suitable for use with sine-waveform modulation also. The modulated output of the transmitter is fed to the vertical deflection system. At the same time, the audio modulating voltage is fed to the horizontal deflection amplifier. The internal scope sweep is not used.

The circuit arrangement in Fig. 11-14 shows how to derive the audio signal from the modulation transformer. High level plate modulation is shown. The values of *C1*, *R1*, and *R2* should be such that the total circuit impedance is from 10 to 20 times the impedance of the r-f final at the applied plate voltage. The amount of voltage required for the horizontal deflection system is very low, several volts are sufficient. Because the output voltage of the high-level modulator is very high, the voltage rating and insulation of the *C* and *R* elements must be adequate. The voltage rating of *C* should be twice the peak voltage generated in the circuit. The sum of *R1* and *R2* should be 2,000 ohms per volt of modulator output. *C1* can have a value of about 0.1 μf. (Note: The setup shown in Fig. 11-14 is suitable across any modulation transformer in any modulation system.)

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