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Video I. F. Amplifier Design

By the Engineering Department, Aerovox Corporation

IN modern radio communication and pulse ranging equipment, the necessity of transmitting and receiving a large amount of intelligence per unit time, or of handling wave forms which contain high frequency components, imposes difficult requirements upon the bandwidth of the circuits involved. In the radar system, for instance, the modulation of the transmitter by very short, rectangular pulses of energy, results in the r.f. output occupying a broad band or *spectrum* of frequencies. The width in megacycles of the band required for the transmission of such rectangular pulse signals is expressed, to a rough approximation, by:

(1)

$$\text{Bandwidth (mc.)} = \frac{2}{\text{Pulse length (Microseconds)}}$$

Thus, a radar transmitter being modulated by .5 microsecond pulses would occupy a band (exclusive of minor side bands) of 2 divided .5 or 4 megacycles. In television, the transmission of high-definition picture information consisting of several million elements per second, as well as synchronizing pulses and sound, requires the allocation of a 6 megacycle channel for each transmitter in operation.

In any such broad bandwidth system, if the receiver is to recover as much of the transmitted signal as possible, it must be capable of simultaneously accepting the entire band of frequencies transmitted and amplifying each equally. In the superheterodyne type of receiver, the satisfaction of this requirement greatly affects the design of the i. f. amplifier, since it is this channel of the receiver which determines the overall selectivity to a large extent.

Fortunately, the design of broadband or "video" intermediate-frequency amplifiers has been greatly simplified by war-time research work. As a result, the design of high gain amplifiers capable of essentially "flat" band-pass characteristics as wide as 10 megacycles is relatively uncomplicated.

The bandwidth of an i.f. amplifier is taken as the frequency difference between points 3 db. down from maximum amplitude on each side of the response curve and is symbolized by Δf. See Fig. 1. In the simplest form of amplifier stage, which is the single-tuned circuit shown in Fig. 2, the bandwidth in megacycles is given by:

(2)

$$\text{Bandwidth } (\Delta f) = \frac{1}{2\pi RC}$$

R = the total resistance shunting the tuned coil in ohms.

C = the total capacitance shunting the coil in mmf.

As this relation shows, the bandwidth of a single-tuned stage is inversly proportional to both the shunt capacity and the shunt resistance. In practice it is the resistance which is varied to control the shape of the response curve. The addition of "loading resistors" across the tuned circuits, common in television and other video i.f. circuits, broadens the response as is illustrated by the dotted curve in Fig. 1. Loading the resonant circuit lowers the circuit Q and thus reduces the maximum response or gain as is shown. The bandwidth at the new 3 db. point has been increased but the peak response has been sacrificed proportionately in favor of bandwidth. This demonstrates the important fact that the gain-bandwidth product of such an amplifier is a constant. This means that a stage giving a gain of 10 over a bandwidth of 1 megacycle may also be made to deliver a gain of 5 at a 2 megacycle band-pass, or any other combination whose gain-bandwidth product (G x B) is equal to ten. The gain-bandwidth product, which is the accepted "figure of merit" of an amplifier stage, depends on the transconductance (gm) of the tube type used and the *total* distributed shunt capacity in the following manner:

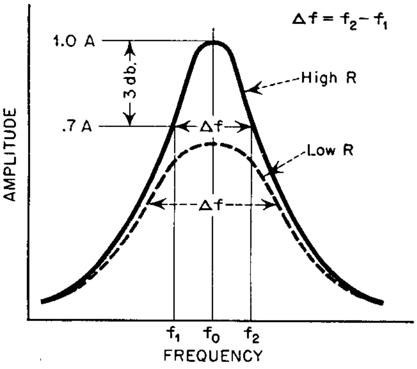

FIG. 1

Since the gain-bandwidth product is inversely proportional to C, which includes the distributed wiring capacity as well as the tube interelectrode capacitances appearing across L, it is very important in circuit lay-out to reduce stray capacity to a minimum. In practical circuits using modern tubes, the total C may be limited to

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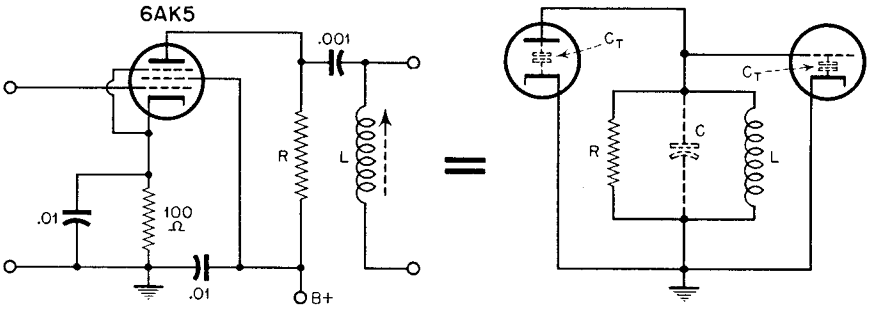


TYPICAL SINGLE-TUNED STAGE

A.C. EQUIVALENT

FIG. 2

(3) $$G \times B\ (\text{mc.}) = \frac{g_m}{2\pi C}$$

10 mmf. Table I shows the GxB products for some frequently used tubes, allowing 5 mmf. for distributed circuit capacity.

TUBE TYPE	Trans-conductance (Micromhos)	Tube Capacity +5 mmf.	Gain-Bandwidth Product (Megacycles)
6AC7	9000	21	68.7
6AU6	5200	15.5	53.6
6BA6	4400	15.5	45.3
6AG5	5000	13.3	59.5
6AK5	5000	11.4	69.4

TABLE I

Unfortunately, when single-tuned amplifier stages resonated to the same frequency (synchronously tuned) are cascaded, the overall band-pass does not remain that of the individual stages, but is reduced radically with the number of stages. Four stages, each 4 megacycles broad at the 3 db. point, when cascaded would thus have an overall band-pass of only 1.75 megacycles. This is evident from the fact that if the voltage gain at the center frequency (fo) is 10, the gain at the 3 db. points is only 7.07. Upon amplification by a second identical stage, the gain at fo is 10 x 10 or 100, while the gain at the former 3 db. points is now only 7.07 x 7.07 or 50, which is 6 db. down in voltage. The bandwidth at the 3 db. points has been reduced to 64% of that for the single stage. Further amplification by similar stages would result in the overall bandwidth being reduced to 51% for a third stage, 44% for a fourth stage, 39% for the fifth, etc.

In addition to the undesirable feature of rapidly decreasing pass-band for multiple stages, the synchronously single-tuned system does not satisfy the requirements of the television video i.f. since it is incapable of producing the flat-topped response curve required for picture reproduction. The shape of the video i.f. response which is accepted as the standard in television practice is shown in Fig. 3. An essentially "flat" band-pass of nearly 4 megacycles is required for high-definition picture reproduction on large-screen cathode-ray tubes, although sets using small tubes may get along with much less. The gradual, nearly linear decrease in the response at the picture-carrier end of the curve is intended to compensate for the presence in the transmitted signal of the first 1.25 mc. of the lower side-band. (The rest is suppressed at the transmitter). When the picture-carrier i.f. frequency is aligned to the mid-point of this slope, the small portion of the *vestigal* lower side-band which is under the response curve is compensated for by the omission of a similar area from the lower 1.25 mc. of the upper side-band. Therefore, the response to the lower video frequencies is made nearly equal to the higher ones, although derived partially from both upper and (vestigal) lower transmitted side-bands.

Considerable improvement over the performance of synchronous single-tuned amplifiers may be obtained by the use of multiple-tuned circuits. In a double-tuned, transformer-coupled stage such as is shown in Fig. 4, the coefficient of coupling (k) and the primary and secondary circuit Q's may be adjusted so that the response curve is essentially flat topped. Such maximally flat or "transitional" coupling occurs when the circuit Q's and the coefficient of coupling are related as shown in Fig. 4. The term "transitional coupling" is derived from the fact that the coupling is adjusted to the point of *transition* between the single and double-humped response curve. It will be recalled that, as the coupling coefficient of the tuned transformer is increased from a very small value, the curve of secondary current versus frequency changes from a small sharp peak when the circuits are under-coupled, to a broad double-peaked response when the circuits are over-coupled. (Dotted lines, Fig. 4). The coefficient of coupling of the inter-stage transformer may be determined by measuring the capacity values necessary to resonate the primary to a given frequency when the secondary is alternately open- and short-circuited. (Co and Cs respectively.) Knowing the ratio of these capacities; At the value of k corresponding to critical coupling, the transfer of energy to the secondary is maximum and

(4) $$\text{Coefficient of coupling } (k) = \sqrt{1 - \frac{C_o}{C_s}}$$

the curve is flat-topped. The response characteristic obtained in this manner is more nearly that required by the television video i.f. Furthermore, because of the more uniform response over the pass-band, the overall bandwidth does not decrease as rapidly when identical stages are cascaded as in the case of synchronous single-tuned stages. When two double-tuned, transitionally-coupled amplifier stages are cascaded, the output bandwidth is reduced to 80% of the width of an individual stage. The corresponding figure for synchronous single-tuned stages is 64%.

Further improvement in gain-bandwidth performance may be obtained by the use of more complicated inter-stage coupling networks. These include; double-tuned stagger damped, triple-tuned transformer-coupled, single-tuned inverse-feedback and complex filter-coupled stages. Most of these types are difficult to design and troublesome to construct and align, so will not be discussed here in detail.

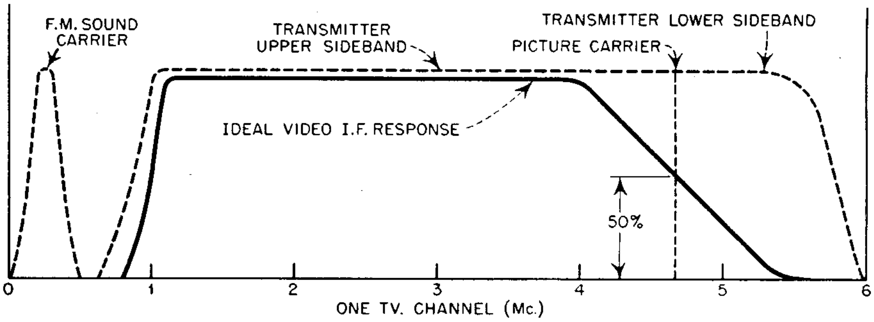


FIG. 3

• STAGGER – TUNING TABLE •

Δf = Required overall bandwidth, f_0 = Center frequency, $d = \frac{\Delta f}{f_0}$

NUMBER OF CIRCUITS	CIRCUIT FREQUENCY	CIRCUIT BANDWIDTH
Staggered - pair	$f_1 = f_0 + .35\,\Delta f$	$.71\,d\ (f_1)$
	$f_2 = f_0 - .35\,\Delta f$	$.71\,d\ (f_2)$
Staggered - triple	$f_1 = f_0$	Δf
	$f_2 = f_0 + .43\,\Delta f$	$.5\,d\ (f_2)$
	$f_3 = f_0 - .43\,\Delta f$	$.5\,d\ (f_3)$
Staggered - quadruple	$f_1 = f_0 + .46\,\Delta f$	$.38\,d\ (f_1)$
	$f_2 = f_0 - .46\,\Delta f$	$.38\,d\ (f_2)$
	$f_3 = f_0 + .19\,\Delta f$	$.92\,d\ (f_3)$
	$f_4 = f_0 - .19\,\Delta f$	$.92\,d\ (f_4)$
Staggered - quintuple	$f_1 = f_0$	Δf
	$f_2 = f_0 + .29\,\Delta f$	$.81\,d\ (f_2)$
	$f_3 = f_0 - .29\,\Delta f$	$.81\,d\ (f_3)$
	$f_4 = f_0 + .48\,\Delta f$	$.31\,d\ (f_4)$
	$f_5 = f_0 - .48\,\Delta f$	$.31\,d\ (f_5)$

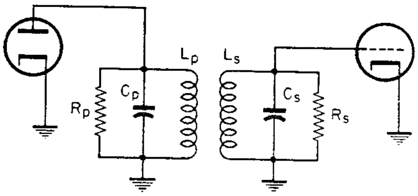
TABLE II

After Wallman

One type of band-pass amplifier which does retain the simplicity of design and alignment of the synchronous single-tuned type, and yet overcomes most of it's disadvantages, exists in the stagger-tuned amplifier. Wallman* and others have shown that if the successive stages of a simple single-tuned amplifier are adjusted to slightly different frequencies (staggered) throughout the desired pass-band, the composite response curve may be made flat-topped and the gain high. Furthermore, the design work requires only high school math and a few simple tables, the construction done with common tools and the alignment may be accomplished in a few minutes with the aid of a spot-frequency signal generator and an output meter. The double-tuned and other more complex types previously mentioned require the use of a swept-frequency signal generator and an oscilloscope. Stagger-tuned systems are being used extensively in commercial television practice.

Since the individual stages of the stagger-tuned amplifier are merely the single-tuned type shown in Fig. 2, the design equasions (2) and (3) which were presented in connection with the synchronously tuned amplifier may be used. These, used in conjunction with the table of stagger-tuning and bandwidth factors shown in Table II (after Wallman) and a method of cutting the coils to resonance, are all that are needed to complete the design.

To illustrate the method of procedure, suppose that a video i.f. amplifier using 6AK5 pentodes is to have a uniform gain of 75 d.b. over a bandwidth of 4 mc. centered at 24 mc. Referring to Table I it is seen that the 6AK5 has a gm of 5000 micromhos and the total interstage capacity may be limited to 11 mmf. The gain-bandwidth product (Eq. 3) then becomes 5000/6.28 x 11 or 72.4 megacycles. If this stage "figure of merit" is divided by the required overall bandwidth of the amplifier, the result (18.1 or about 25 db.) is the mean stage gain available using 6AK5's. Therefore, three stages, properly staggered should be capable of providing the specified 75 db. gain. Table II gives the value of frequency and bandwidth to which each of the four coupling networks associated with the three stages must be adjusted to form a flat staggered-quadruple. In this example, the factor d, which is equal to the bandwidth divided by the center frequency, is 4/24 — .166. Using this figure in Table II indicates the four circuits should be stagger-tuned to; 24.76, 23.24, 25.84 and 22.16 megacycles with the bandwidths adjusted to; 3.77, 3.56, 1.63 and 1.39 megacycles, respectively. Knowing the required bandwidths and the value of total C per stage, the values of the needed loading resistors may easily be found from the equation for the bandwidth of a single-tuned stage (Eq. 2). Solving for R in this equation yields values of 3845, 4060, 8900 and 10,400 ohms, in the order of decreasing bandwidth. In practice, the next higher standard values of resistance may be used, since other tube and circuit resistances are in parallel with the loading resistors and lower the total effective value somewhat. The inductances required to resonate with 11 mmf. distributed circuit capacitance at the above stagger-frequencies may be determined by the use of a reactance calculator, a "Q Meter" where available, or by emperical formulas. Since additional capacitance is very detrimental to the gain-bandwidth product of the stage, the coils should be self-resonant with the circuit capacity or tuned with high quality powered-iron slugs.



EQUIVALENT DOUBLE-TUNED CIRCUIT

When: $Q_p = Q_s$

$K = \frac{1}{\sqrt{Q_p Q_s}}$ for transitional coupling

$\Delta f = \frac{\sqrt{2}}{2\pi RC}$ where. $C = \sqrt{C_p C_s}$, $R = \sqrt{R_p R_s}$

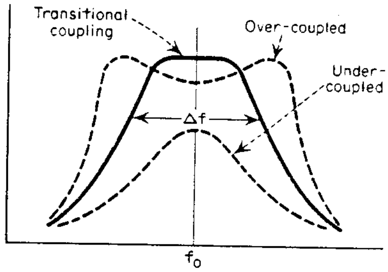


FIG.4

When resistors and inductors corresponding to the values determined for R and L are inserted in typical single-tuned stages such as that shown in Fig. 2, and these stages are connected in cascade, the resulting stagger-tuned amplifier is non-critical to adjust and will compare favorably with more complex types in performance. The overall gain-bandwidth product is better than a synchronously tuned amplifier of the same number of stages by a factor greater than two. Alignment is accomplished by connecting a standard AM signal generator to the input of the amplifier and an amplitude indicating device such as a voltmeter to the output. The signal generator may then be set to the recommended stagger frequencies in succession and the individual stage corresponding to that frequency peaked for maximum output response. Due to the isolating action of the tubes, there is virtually no interaction between stages while tuning. This is in sharp contrast to the procedure with double-tuned or triple-tuned circuits. In this case, a swept-frequency signal source and an oscilloscope must usually be connected to the input and output (respectively) of each stage in succession and the coupled circuits tuned and retuned until the desired response is observed on the 'scope. If adjacent-channel and sound carrier frequency "traps" such as are found in most television video i.f. amplifiers are incorporated in the single-tuned system, some slight tuning interaction may be noted.

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*Wallman, Henry. MIT Radiation Lab Report No. 524.

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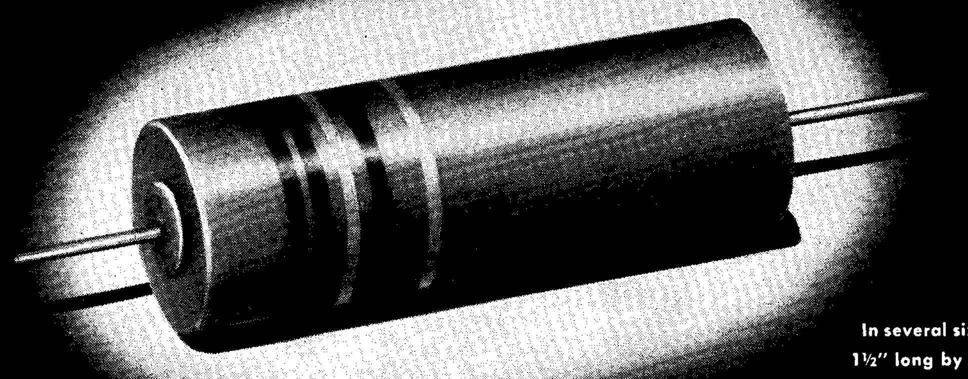

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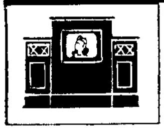

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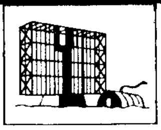

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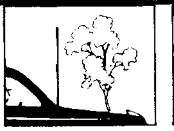

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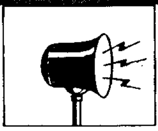

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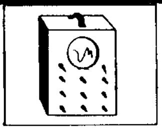

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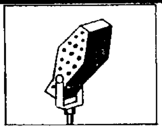

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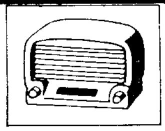

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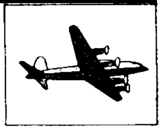

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