RCA MANUFACTURING COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
Harrison, New Jersey

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PROPERTIES OF UNTUNED R-F AMPLIFIER STAGES

The design of an untuned (or resistance-coupled) r-f stage is facilitated by first reducing the usual tube and circuit relations to a group of characteristic curves which correlate transconductance, circuit values, frequency range, and stage gain. Such curves are directly useful as a guide in the preliminary steps of designing conventional r-f amplifiers, but are not intended for use in any special cases where the usual trial-and-error method of development may not be feasible.

Figures 1 and 2 show simplified r-f circuits for two conventional untuned r-f systems. In each case, the diagram shows two condensers of equal capacitance. One represents the output capacitance of the r-f amplifier tube plus wiring capacitance. The other represents the input capacitance of the following tube and the wiring capacitance. Making these two capacitances of equal value is a simplifying assumption which is permissible within the scope of this Note.

In each diagram, a current I is shown entering the circuit. I is the signal current in the plate circuit of the r-f stage. It is simply the product of transconductance and the signal voltage impressed on the grid of the amplifier tube. This relation presumes that the plate impedance (R_p) of the r-f tube is in shunt with the network shown. However, in any likely untuned r-f stage this presumption may be disregarded without material error, because of the relatively low values of load impedance employed for such stages. Fig. 2 shows a resistor across the grid end of the network. Were this resistor to be placed across the plate end, as might be done in some instances, the characteristic curves would remain unchanged. When this resistor is placed as shown, it is understood to represent the effective a-c resistance of the load resistor and the usual shunt grid leak.

The circuit of Fig. 2 is formed from the circuit of Fig. 1 by adding an inductor. This inductor is commonly known as a "peaking coil"; its inductance accounts for the immediately obvious differences between the curves of Figs. 1 and 2. The peaking coil is, of course, an element of a low-pass filter, but an appropriate concept of its effect may be established by disregarding the resistors and then noting that series resonance obtains at a frequency where the reactance of the peaking coil is numerically equal to the reactance of the two condensers in series. At this frequency, I flows into a high value of parallel resonant impedance, and therefore produces a voltage rise at the input end of the system. This voltage rise affects the output end, but is limited by the power dissipated in either or both of the resistors shown.

Explanation of Terminology

The ordinates of the curves for both figures are labeled "stage gain per 10^3 micromhos, per 10^3 ohms of X when m equals one." The abscissas are labeled "m". On Fig. 2, m is the ratio of the impressed frequency to the frequency where the inductance of the peaking coil is resonant with the two capacitances in series; i.e., m is equal to unity at the nominal peak frequency of the system. For a nominal frequency of 16 megacycles, a value of m of 0.7 would correspond to 0.7 x 16, or 11.2 megacycles.

The reactance of the paralleled capacitances at the nominal peak frequency is X. If the total capacitance of the paralleled capacitances is 20 μμf, then, for a nominal peak frequency of 16 megacycles, X is 500 ohms.

K is the ratio of the effective shunt resistance to the total parallel capacitive reactance when m equals unity. For example, with m equal to unity at 16 megacycles, a total parallel capacitance of 20 μμf, X equal to 500 ohms, and a shunt resistance of 2000 ohms, K is 2000/500, or 4.

P is the ratio of the resistance of the damping resistor across the peaking coil to the reactance of the peaking coil when m is unity. Suppose that a total capacitance of 20 μμf is made up of two 10 μμf capacitances. These in series have a capacitance of 5 μμf and a reactance of 2000 ohms at 16 megacycles. Therefore, the peaking coil should have a reactance of 2000 ohms for resonance at 16 megacycles. A damping resistor of 10000 ohms across the peaking coil means that P is 10000/2000, or 5.

Suppose some other value of total capacitance, such as 18 or 25 μμf, is used, or, some other value of nominal peak frequency, such as 15 or 18 megacycles. Then, m is taken as equal to unity at whatever value of nominal peak frequency is chosen, and X is calculated only at that frequency.

The circuit elements of the diagrams are labeled with their impedances. Each capacitance is labeled 2X/m. This caption agrees with the use of X as the reactance of the total parallel capacitance. The peaking coil is labeled with its reactance 4Xm, a value which agrees with the condition of resonance that m is equal to unity.

The terminology of Fig. 1 is the same as that of Fig. 2, except that m on Fig. 1 does not designate a peak frequency. The value of m may be taken as unity for any chosen frequency. At this frequency, the ordinate approaches unity as KX is made large in comparison with X. X is evaluated only at the frequency where m is equal to unity, as in the case of Fig. 2.

An expression for the stage gain of the system shown in Fig. 1 is

$$\frac{(g_m) X K}{\sqrt{1 + (Km)^2}} \qquad (1)$$

For Fig. 2, the stage gain is

$$(g_m) X K \sqrt{\frac{P^2 + m^2}{\left[P(1 - 2m^2) - Km^2\right]^2 + m^2\left[1 + KP(1 - m^2)\right]^2}} \qquad (2)$$

These expressions have been used in plotting the curves shown in Figs. 1 and 2, and may be used for plotting other curves based on other combinations of K and P. The transconductance, (g_m), is in mhos. X is in ohms.

Stage-Gain Characteristics

The curves of Fig. 1, labeled 1, 2, 3, and 4, have been calculated for the values of K given below.

Curve	K
1	20
2	10
3	5
4	3

Suppose that m be equal to unity at 16 megacycles, and assume a typical value of 20 μμf as the total capacitance. In this case, X is 500 ohms. When K is 3, curve 4 shows the stage gain at one megacycle to be 3 x $500/10^3$ x g_m(micromhos)/10^3. Hence, a transconductance of 2000 micromhos results in a stage gain of 3; 4000 micromhos gives a gain of 6. Moreover, it should be noted that curve 4 is essentially flat to an m of 0.1; i.e., the stage gain of this amplifier is uniform throughout the broadcast band. Consider curve 3, for K equal to 5. In this case, the assumed values of 20 μμf and 16 megacycles result in a stage gain of 4.6 at one megacycle when the transconductance is 2000 micromhos, and of 9.2 for 4000 micromhos.

When the other curves are considered in the same way, it becomes evident that variation of gain throughout the broadcast band is the chief difficulty in the use of high values of K in order to obtain high values of stage gain with low values of transconductance. However, since an untuned stage gain of more than 6 or 8 in the broadcast band is usually not desirable, and since a 2:1 variation of gain is usually tolerable, the development of an untuned r-f stage for the broadcast band is ordinarily a simple matter.

In many instances, an untuned r-f stage is called upon for amplification up to (say) 16 megacycles. When Fig. 1 is considered from this standpoint, it is noted that all of the curves merge as m is increased toward unity. Therefore, K may be disregarded. On the basis of 20 μμf as the total capacitance and m equal to unity at 16 megacycles, the stage gain is only 1 at this frequency, for a transconductance of 2000 micromhos, and 2 for 4000 micromhos. It is because of these low values of stage gain that a peaking coil is desirable.

The peaking coil has no appreciable effect at m-values less than 0.4. Consequently, the portions of curves 5, 6, 7, and 8 on Fig. 2 for low values of m are respectively the same as the corresponding portions of curves 1, 2, 3, and 4 on Fig. 1 when K has the same values on both figures. In general, K is the only controllable circuit property which can determine the stage gain at low values of m. Even though a value of K is chosen to determine the stage gain in the broadcast band, K also affects the gain at the high-frequency portion of the desired frequency range. This state of affairs is shown by making P so large that KX is essentially the only dissipative element in Fig. 2. Then, curves 5, 6, 7, and 8 have the same ordinate values when m is unity as when m is zero. Thus, it is apparent that K limits the high-frequency gain. Also, high values of K give rise to an obviously excessive sharpness of response at the peak frequency. Were a high value of K to be used, this sharpness could be removed by using a suitably low or moderate value of P. (This expedient would decrease the ordinate for m equal to unity.) However, it is seldom necessary to depend on P for this result, because K itself is likely to be low enough to prevent excessive sharpness when it is low enough for suitable gain in the broadcast band. Curves 7 and 8, based on K-values of 5 and 3, respectively, show a worthwhile degree of gain at the high-frequency end of the range, without excessive sharpness. These and all of the full-lined curves of Fig. 2 depend solely on K, P being infinite; i.e., in this example, the peaking coil dissipates no power in or across itself. P and the resistance of the peaking coil itself, are quite important from the standpoint of high-frequency gain.

Effect of P and Resistance of Peaking Coil

Peaking coils, as ordinarily found in commercial receivers, are by no means "low loss" inductors. The "coil form" is often the resistor which provides the shunt damping, and it is usually wound with small wire. For such a coil, Q should not be assumed to be greater than about 20, even though P (in Fig. 2) may be so high that the coil resistance itself is the limiting factor. Accordingly, were P to be taken as 20, the true meaning in practice is that the series and shunt resistance are as though P is 20 when the resistor is connected across a lossless coil. The highest value assigned to P in this Note is 20.

Consider curves 7 and 8 of Fig. 2. These curves are of interest in practice, but their ordinates at the high-frequency end of the range are based on a peaking coil having no series resistance and no shunt damping. Consequently, it is important to determine the effect on these curves when P has its highest likely value of 20. The result is shown by the dotted curves 10 and 9. These correspond respectively to curves 7 and 8. Fortunately, when P is 20, curves 7 and 8 are not affected severely.

Curves 5 and 6, based on K-values of 20 and 10, respectively, are included for reference use with low transconductance; e.g., 1000 micromhos, or less. From curve 6, which has a K-value of 10, the dotted curve 11 is obtained for P of 20. This same dotted curve 11 is also obtained from curve 5 for P of 10. Curve 11 may be regarded as roughly indicative of the maximum degree of sharpness which is acceptable in practice.

Stage Gain at Medium Values of m

All of the curves of Fig. 2 are substantially coincident between m-values of about 0.4 and 0.8. This condition means that any likely values of K and P have no material effect on the stage gain throughout the wide range of frequencies received by an all-wave receiver; for example, from roughly 6.5 to 12.5 megacycles when m is unity at 16 megacycles. The ordinates in Fig. 2 for these medium values of m have a minimum value of 2.4. This ordinate value is accepted as a natural property of the system. On this basis, the expected stage gain in practice can be increased only by increasing the transconductance, provided the circuit has its irreducible minimum value of capacitance. When this capacitance is 20 μμf, and when m is unity at 16 megacycles, X is 500 ohms, and the stage gain for medium values of m is taken as $2.4 \times 500/10^3 \times g_m(\text{micromhos})/10^3$, or, 1.2 per thousand micromhos of transconductance. Thus, 500 micromhos gives a stage gain of only 1.8, while 4000 micromhos gives a stage gain of 4.8. A high-transconductance tube is required for worthwhile stage gain in the range of frequencies corresponding to medium values of m.

Effect of Transconductance on Shape of Stage-Gain Characteristic

It is evident from curves 8-9 that substantially uniform gain is readily obtainable when a high-transconductance tube is used to provide a worthwhile amount of gain. On the other hand, low-transconductance tubes lead to a consideration of curves 7-10, 6-11, etc. Although these curves lack the uniformity of gain shown by curves 8-9, they show a worthwhile amount of gain for the broadcast band and at the high-frequency end of the chosen range. In these cases, the low order of gain at medium values of m is a natural property of the system. This condition is sometimes regarded with enforced complacence, because signals in the broadcast band and in the high-frequency portion of the range are ordinarily more important than signals at frequencies corresponding to medium values of m. However, a gain of less than 1 at these less important frequencies is difficult to accept. For this reason, it is reiterated that regardless of the chosen curves of Fig. 2 the expected gain for medium values of m is found to be only 1.2 per thousand micromhos, when m is unity at 16 megacycles and when the total capacitance is 20 μμf.

Example--Calculation of Gain for 6SG7 Stage

Suppose that an amplifier stage having a gain of approximately 7 is required for the broadcast band, and that this order of gain is desirable at all frequencies up to 16 megacycles. Since the stage gain is to be substantially uniform, rather than low at medium values of m, a high-transconductance tube is essential. The 6SG7 is well suited to the purpose.

It has a transconductance of 4700 micromhos for a plate voltage of 250 volts, a screen voltage of 125 volts, and a grid bias of -1 volt. Its output capacitance of 7 μμf, the probable input capacitance of the following tube, and a reasonable allowance for circuit wiring, suggest that 10 μμf be assigned for each capacitance shown in Fig. 2; i.e., a total capacitance of 20 μμf, and a series capacitance to resonate with the inductance of the peaking coil at 16 megacycles, of 5 $\mu\mu f$. This latter value has a reactance of 2000 ohms at this frequency. The peaking coil, therefore, must have a reactance of 2000 ohms at 16 megacycles and hence, an inductance of 20 microhenries.

A choice of 3 as the value of K leads to curve 8 of Fig. 2 as the form of the stage-gain characteristic for low and medium values of m. The ordinate when m is 0.05 shows that the stage gain is approximately the desired value of 7 at 0.8 megacycle, for a transconductance of 4700 micromhos. Since curve 9 is suitable at the high-frequency end of the range, 20 is chosen as the value of P. Curve A of Fig. 3 shows the gain of the stage plotted against frequency. Curve B applies if K is 5, all other factors being the same as for curve A.

SIMPLIFIED CIRCUIT OF UNTUNED R-F STAGE WITHOUT PEAKING COIL

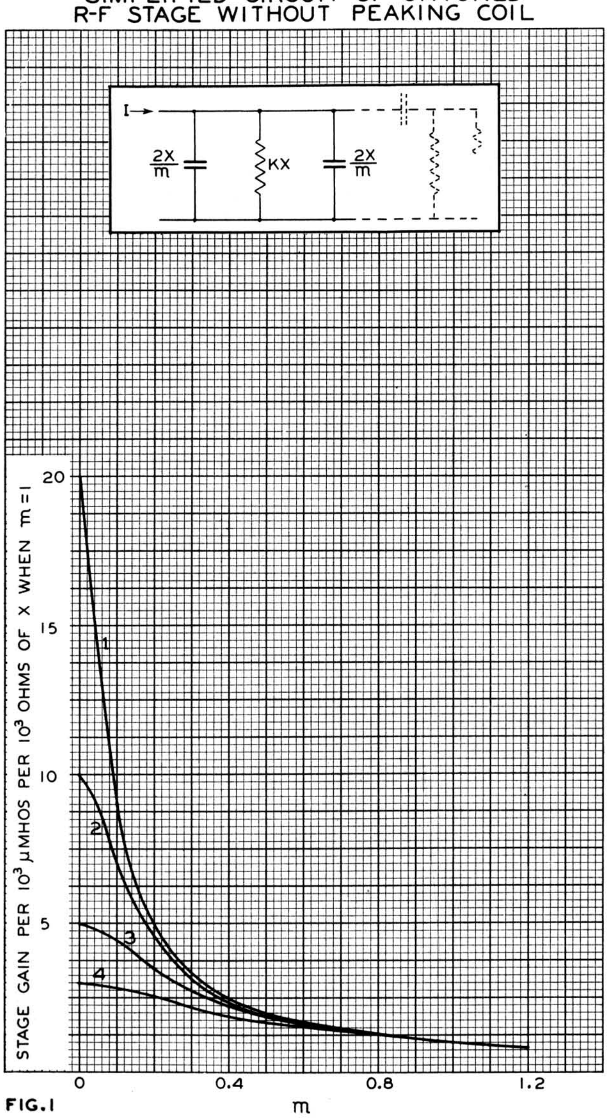

FIG.1

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SIMPLIFIED CIRCUIT OF UNTUNED R-F STAGE WITH PEAKING COIL

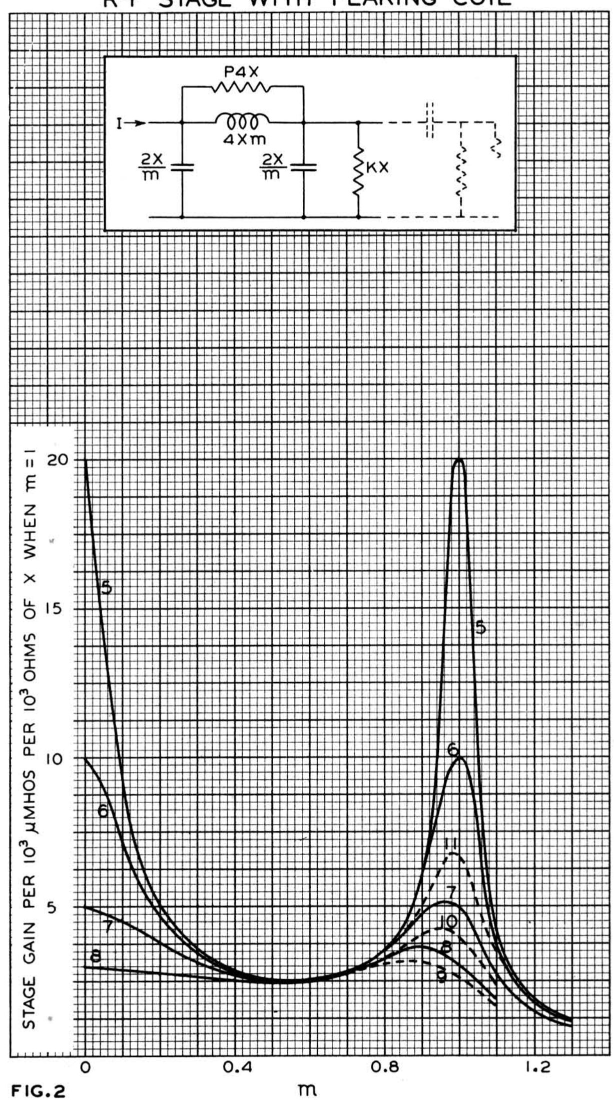

FIG.2

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THEORETICAL STAGE-GAIN CURVES
FOR CIRCUIT OF FIG. 2 WHEN USING THE 6SG7

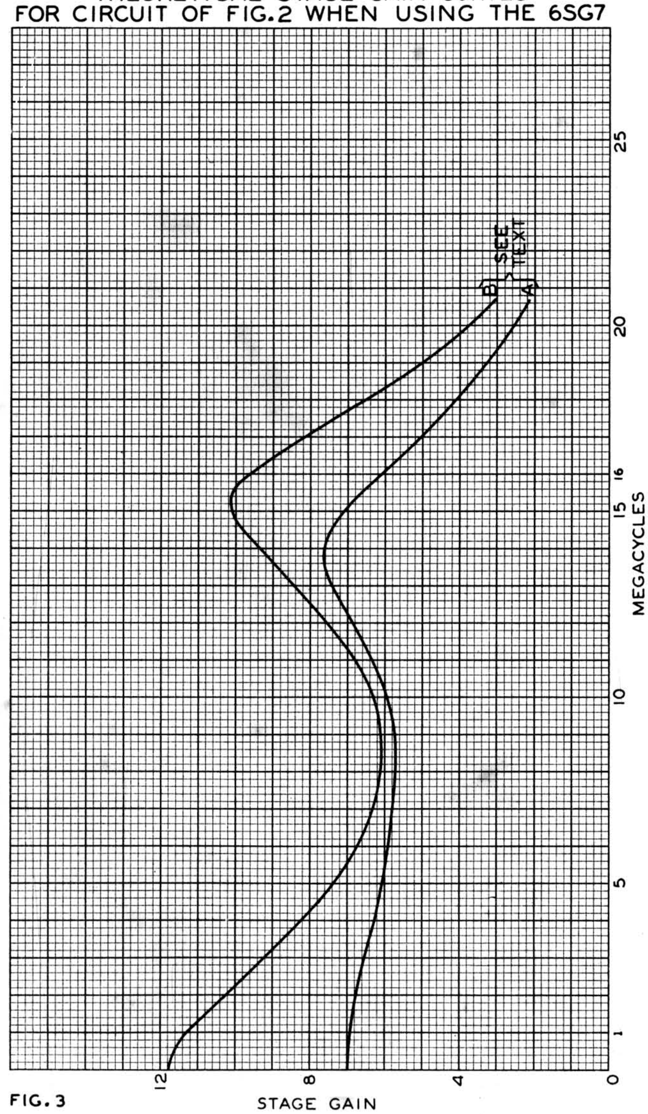

FIG. 3

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