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THE GRID-SUPPRESSOR CIRCUIT†

Discussion of Regenerative Amplifier from Viewpoint of Transmission and Oscillation Characteristics

By SYLVAN HARRIS*

On account of the complicated phenomena encountered in regenerative amplifiers such as the grid-suppressor type, any rigid theory of their operation must necessarily be quite involved, unless only a single stage of the amplifier were under consideration. The cascading of several stages, however, leads to complications due to the interaction of these stages, the causes of which are often quite obscure. A rational explanation of the mechanism of the amplifier may, however, be secured by considering the amplifier in the light of two characteristics, one of which *determines* the amplification, and other of which *limits* it. The former might be termed the *transmission characteristic* and the latter the *oscillation characteristic.*

The transmission characteristic is represented by the well-known formula

$$K = \omega L_2 \left[\frac{\left(\frac{\tilde{\omega} M}{r_p}\right)\mu}{r_2 + \frac{\omega^2 M^2}{r_p}} \right] \qquad (1)$$

in which the symbols have the customary meanings. The amplification of any amplifier stage may be calculated by means of this formula provided the resistance component of the tube is assumed to be removed from the tube and incorporated in R_2, and the reactance component of the tube impedance is considered as an additional element of the tuned circuit. When this is done the tube can be considered truly as a potentially operated device.

Referring to Fig. 1A, R is the grid-suppressor resistance; the input impedance of the tube can be represented[1] by a capacity c_g in series with a resistance r_g. The voltage impressed upon the input of the tube is the potential difference between G and F. The parallel circuit formed by R, r_g and c_g in parallel with C can be considered equivalent to a simple series circuit such as shown in Fig. 1B, between G and F. The voltage which is amplified by the tube is then the P. D. between G and F of Fig. 1B. The tube is now considered as taking no power from the tuned circuit.

The impedance GF (Fig. 1A) is given by

$$Z' = R' + j \frac{1}{\omega C'} \qquad (2)$$

$$R' = \frac{R + r_g}{(R + r_g)^2\, \omega^2\, C^2 + \left(1 + \frac{C}{c_g}\right)^2} \qquad (3)$$

$$C' = \frac{(c_g + C)^2 + (R + r_g)^2\, \omega^2\, c_g^2\, C^2}{(c_g + C) + (R + r_g)^2\, \omega^2\, c_g^2\, C} \qquad (4)$$

In equation (4) the terms involving the resistances are small compared with the others, so that C′ is approximately $C + c_g$. The resistance R′ is the resistance introduced into the tuned circuit by the input impedance of the tube and by the grid-suppressor. In the expression for R′ the first term of the denominator may be neglected, so that R′ is approximately

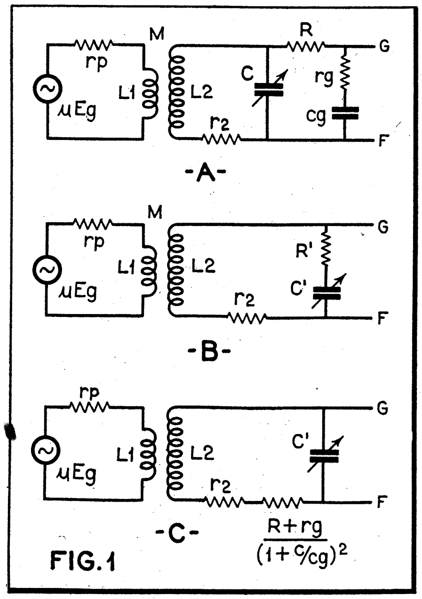

FIG. 1

$$R' = \frac{R + r_g}{\left(1 + \frac{C}{c_g}\right)^2} \qquad (5)$$

The value of r_g for an inductive load in the plate circuit is given by Miller as $-\, L_p\mu\ c_{gp}/r_p\ (c_{gp} + c_{gp})^2$ and $-L_p\mu c_{gp}/r_p\ (c_{gf} + c_{gp})^2$ and c_g is given by $c_{gf} + c_{gp}$ both of which are independent of frequency.

With this information we can now determine the amplification equation. The secondary current is given by

$$I_2 = \frac{\left(\frac{\omega M}{r_p}\right) \mu E_g}{r_2 + \frac{R + r_g}{\left(1 + \frac{C}{c_g}\right)^2} + \frac{\omega^2 M^2}{r_p}} \qquad (6)$$

neglecting the primary circuit reactance. The denominator of this fraction is the resistance of the coupled circuit referred to the secondary. It is seen that in addition to the resistance of the coil and the resistance reflected from the primary circuit, there is a term which depends upon the values of the grid-suppressor and the input consistants of the tube.

Now, the voltage drop between G and F of Fig. 1B is the product of the impedance of that leg of the network and the secondary current I_2.

Performing this operation and putting $\omega L_2 = 1/\omega\ (C + c_g)$ there is obtained

$$K = \frac{Z_{GF}\, I_2}{E_g} \qquad (7)$$

$$= \frac{\left(\frac{\omega M}{r_p}\right) \mu}{r_2 + \frac{\omega^2 M^2}{r_p} + \frac{R + r_g}{\left(1 + \frac{C}{c_g}\right)^2}} \times \omega L_2$$

$$\times \sqrt{\omega^2 \left[\frac{R + r_g}{\left(1 + \frac{C}{c_g}\right)^2}\right]^2 (C + c_g)^2 + 1}$$

The first term under the radical is small compared with unity, so that the voltage amplification per stage is given, very nearly, by

$$K = \frac{\left(\frac{\omega M}{r_p}\right) \mu \cdot \omega L_2}{r_2 + \frac{\omega^2 M^2}{r_2} + \frac{R + r_g}{\left(1 + \frac{C}{c_g}\right)^2}} \qquad (8)$$

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† *Delivered before the Club, May* 8, 1929.

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[1] *J. M. Miller, S.* 351, *Bureau of Standards.*

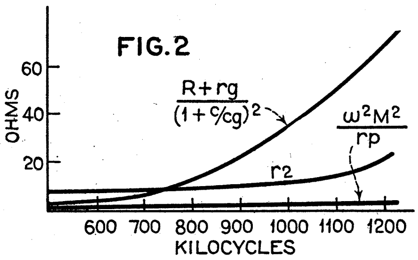


FIG. 2

This is the amplification equation of the circuit of Fig.1C, which may, therefore, be regarded as the approximately equivalent circuit of the amplifier. The manner in which the three components of the equivalent resistance vary with frequency is shown in Fig. 2, which has been calculated for a typical case. Likewise, in Fig. 3, there is shown a curve of voltage amplification, calculated by equation (8).

The effect of the grid-suppressor and the input impedance of the tube is therefore seen to be equivalent to introducing a rather large resistance into the tuned circuit, thus reducing the amplification considerably, even at low frequencies. The amplification increases with frequency up to a point beyond which the third resistance term in equation (8) increases so rapidly that the amplification begins to decrease. The frequency at which the amplification is maximum depends upon the values of the various circuit elements.

An inspection of Fig. 2 shows that, for values of grid-suppressor commonly used, the "true" resistance of the tuned circuit plays an important part only at the lower frequencies, and that at 1500 kc. the resistance due to the grid-suppressor and the tube impedance may be as much as four or five times the "true" tuned circuit resistance. The reflected resistance, likewise, is small, and at high frequencies it may even be omitted from consideration in most cases.

It is clear, from what has gone before, that unless something were done to neutralize the greater part of this resistance, indicated by the denominator of equation (8), very little amplification would be obtained, and the selectivity would certainly fall far short of commercial requirements. The resistance is partially neutralized by the feedback *within* each stage, (i.e., from plate to grid of the same stage), as indicated by the fact that r_g is intrinsically negative; but this is not sufficient since r_g is of the order of only several hundred ohms (negative), while R may be from four to ten times as great.

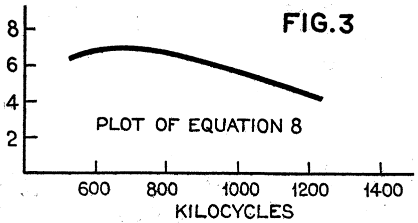


FIG. 3

When several stages are connected in cascade, a feedback current is established from *stage to stage*, which assists in neutralizing the circuit resistance. It is this stage to stage feedback which mainly determines the "oscillation characteristic" and limits the possible amplification. The plates and grids are coupled through a capacity c_{gp}, and were it not for the transformers, these capacities would all be in series. The coupling capacity between a given stage and those preceding it would then decrease arithmetically on passing from stage to stage, whereas the amplification from stage to stage increases geometrically. The power fed back would be attenuated more slowly than a signal applied to the input would be amplified. Consequently, on passing from stage to stage, a stage would eventually be reached in which the power fed back would be greater than the input circuit losses, and self-oscillation would result. From this it follows that the amplification of any stage cannot exceed the attenuation per stage of the feedback current.

This manner of viewing the problem has been applied by A. W. Hull to the determination of the maximum amplification obtainable in a tuned impedance coupled amplifier employing screen-grid tubes. However, the situation is considerably more complicated in circuits employing tubes which have appreciable internal capacities, since any or all of the stages may be sources of feedback currents; and furthermore, the phases of the currents will vary not only with frequency, but also from point to point in the circuits. However, it is known that the limiting amplification decreases with frequency in a manner somewhat as indicated by the "O" curves of Fig. 5.

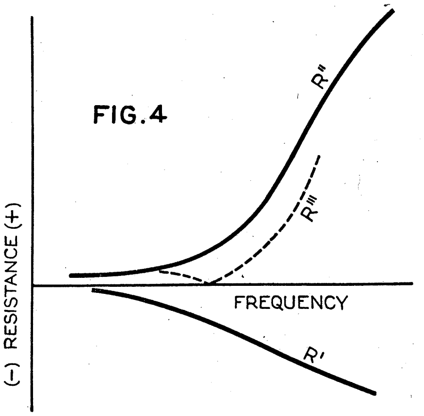


FIG. 4

The overall feedback increases steadily with frequency, having the effect of introducing into the tuned circuits a negative resistance, as indicated by the curve R' of Fig. 4. In that illustration, R'' represents the total circuit resistance before cascading (i.e., the denominator of equation (8), or the sum of the curves of Fig. 2), and R''' is the resulting resistance after cascading.

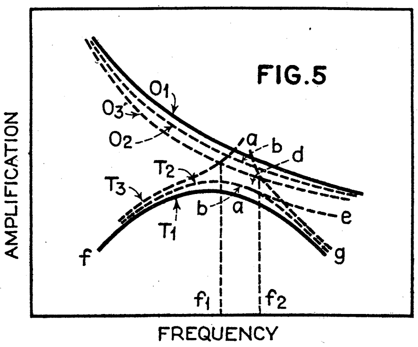


FIG. 5

In Fig. 5, the "T" curve is the "transmission characteristic;" this must not intersect the "O" curve if self-oscillation is to be avoided. The separation between the curves is the *margin of stability*. a-a represents the margin of stability of an amplifier having the characteristics O_1 and T_1. If the grid-suppressor is reduced permitting an increase of feedback, O_1 is lowered to O_2. The regenerative effect is now greater and, due to the apparent reduction of circuit resistance, T_1 becomes T_2. The margin of stability is now b-b. Upon further reducing the grid-suppressor the new amplification curve T_3 intersects the new oscillation characteristic O_3. The margin of stability is now zero over a portion of the tuning range, and oscillations occur between the frequencies f_1 and f_2. At f and g, Fig. 5, the regenerative effect is small, therefore, changes made in the attenuation of the feedback, such as reducing the grid-suppressor, mainly effect the portion of the curve near the peak. This is illustrated in Fig. 6, which shows amplification curves taken on an amplifier for various values of grid-suppressor. The circuit constants were adjusted to make the peak occur near the middle of the tuning range.

The peak of the curve may be made to occur anywhere within the tuning range or may even be made to occur outside of the range. As Fig. 6 indicates, reducing the grid-suppressor moves the peak slightly toward the higher frequencies. This effect is small and is of little value in design. The initial effect of cascading, however, shifts the peak considerably to a higher frequency, as can be seen by comparing Figs. 3 and 6. Increasing the mutual inductance of the transformers moves the peak toward the lower frequencies and, as can be seen by equation (8) increases the amplification as well. This may, however, require an increase of grid-suppressor in order to maintain stability, depending upon the initial margin of stability. It is possible to keep the net circuit resistance low (i.e., the R''' curve of Fig. 4), by employing loose coupling and at the same time keeping the grid-suppressor small, but the amplification will also be small. By the time the coupling has been loosened sufficiently to afford the required low resistance (or the required selectivity) the amplification will have either fallen below the commercial requirement, or the amplifier will have been made unstable in order to maintain this amplification. On the other hand, it is possible to employ a substantial coupling and obtain considerable amplification, and, at the same time, obtain the required selectivity by properly adjusting the regenerative effect throughout the tuning range.

There are several means of increasing the amplification at the higher frequencies, other than moving the peak of the curve to that region. One means is to shunt the grid-suppressor by a small fixed condenser, reducing the attenuation of the feedback as the frequency increases. The effect of such an arrangement is shown in Fig. 7. In amplifiers which are unshielded the effect may be created by the capacity between the stators of the transformers, or between the stators of the tuning condensers, or by a small amount of inductive coupling between the stages.

It is a simple matter to compute the amplification of a single stage without considering the regenerative effects produced by cascading, but this by itself would be of no value. It was necessary therefore, in order to test the theory, to devise a method of measuring the regenerative effect. An agreement between the amplification curve obtained experimentally and the computed curve would then afford simultaneous proof of the validity of both the theory of operation of the amplifier and of the method of measurement.

The method used for measuring the voltage amplification was the usual one of impressing at the input of the amplifier a known r-f. voltage (obtained as a voltage drop in a small resistor) and measuring the output voltage with a calibrated vacuum tube voltmeter. The detector tube of the radio receiver was used as the V. T. V. M. The ratio of the two voltages then gave the voltage amplification.

In any given stage of the amplifier the voltage amplification is proportional to the voltage drop in C, Fig. 1c, and hence to the current flowing through it. This current is given by

$$I'_2 = \frac{\left(\frac{\omega M}{r_p}\right) \mu E_g}{R_2} \qquad (9)$$

where R_2 is the apparent value of the total circuit resistance, including the effects of cascading. Now, if without making any other changes, a small resistance be added to the circuit, the secondary current becomes

$$I''_2 = \frac{\left(\frac{\omega M}{r_p}\right) \mu E_g}{R_2 + r} \qquad (10)$$

The ratio of these two equations furnishes

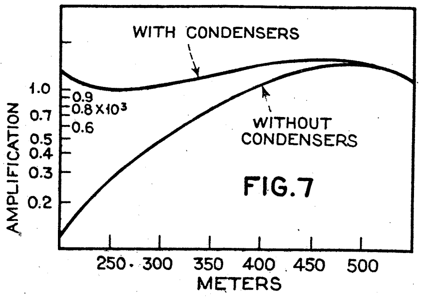


FIG.7

$$R_2 = \frac{r}{\left(\frac{I'_2}{I''_2}\right) - 1} = \frac{r}{\left(\frac{K'}{K''}\right) - 1} \qquad (11)$$

in which K′ and K″ are the voltage amplifications, as measured, before and after inserting the resistance r. The resistance R_2 is the sum of four components, viz.,

$$R_2 = r_2 + \frac{R + r_g}{\left(1 + \frac{C}{c_g}\right)^2} + R_3 + \frac{\omega^2 M^2}{r_p} \qquad (12)$$

in which R_3 is the negative resistance added to the circuit due to the feedback resulting from cascading the stages. This resistance may now be substituted for the denominator of equation (8) and the amplification of the stage computed.

A set of curves showing the variation of R_2 with wavelength is shown in Fig. 8, for various values of grid-suppressor resistance. It is to be noted that the wavelength at which zero resistance occurs is in agreement with the wavelength at which oscillations occur, as indicated in Fig. 6. Fig. 8, however, applies only to a single stage of the amplifier.

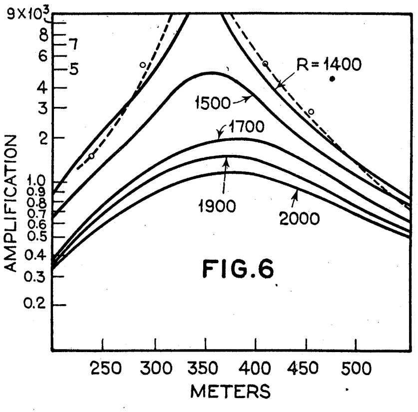


FIG.6

Due to the fact that the feedback originating in the fourth stage can feed back through three stages, and that originating in the third stage can feed back through two stages, and so on, it is clear that the regeneration conditions cannot be the same in all stages.

This is in addition to the fact that the feedback currents vary in their phase relations both with frequency and from point to point in the amplifier. From all this it follows that R_2 will differ from stage to stage despite the fact that the circuit elements in all the stages may be identical. Fig. 9 shows this variation from stage to stage of an experimental amplifier. In computing the amplification, therefore, it is necessary to separately measure R_2 for each stage, and then to separately calculate the amplification for each stage. The overall amplification can then be obtained by multiplying the stages together.

Since the apparent resistance of the circuits, R_2, is a direct measure of the margin of stability, a set of curves such as shown in Fig. 9 or in Fig. 8 is of great value in determining manufacturing tolerances for the supression elements. In addition, Fig. 9 indicates that it may sometimes be desirable to design the various stages of the amplifier differently. For example, Fig. 9 indicates that the third stage has the smallest margin of stability. Slight changes in this stage may lead to self-oscillation; a more desirable condition would be obtained by slightly increasing the grid-suppressor of this stage and reducing that in the first or the fourth stage. In this particular amplifier the primary winding of the fourth transformer was "reversed" in order to point out the effect on the regeneration conditions of a phase reversal, giving to the fourth stage the largest margin of stability, whereas it would otherwise have the least.

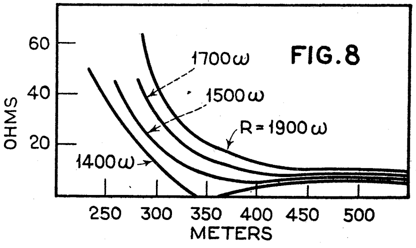


FIG.8

The final amplification per stage, after cascading, is given by

$$K_f = \frac{\left(\frac{\omega M}{r_p}\right) \mu \omega L_2}{R_2} \qquad (13)$$

Dividing this by equation (8) there is obtained

$$K_r = \frac{r_2 + \frac{\omega^2 M^2}{r_p} + \frac{R + r_g}{(1 + C/c_g)^2}}{R_2} \qquad (14)$$

which gives the regenerative amplification obtained by cascading the stages.

By making measurements of R_2 in each stage, computing K for each stage by equation (13), and then multiplying the stages together, fair agreement with the experimental curve for R = 1400 ohms in Fig. 6 was obtained. This is indicated by the broken curve of Fig. 6.

References

C. W. Pierce—Electric Oscillations and Electric Waves p. 162 (New York 19 0).

H. T. Friis and A. G. Jensen—High Frequency Amplifiers, Bell System Technical Journal, April 1924.

F. H. Drake and G. H. Browning—An Efficient Tuned Radio Frequency Transformer, Proc. I. R. E., Dec. 1925.

R. S. Glasgow—Tuned Radio-Frequency Amplifiers, Jour. A. I. E. E., May, 1928.

H. Diamond and E. Z. Stowell—Note on Radio Frequency Transformer Theory, Proc. I. R. E. Sept. 1928.

A. W. Hull—Measurements of High Frequency Amplification with Shielded Grid Pliotrons, Phys. Rev. 27, No. 4, p. 447.

J. M. Miller—Dependence of the Input Impedance of a Three Electrode Vacuum Tube upon the Load in the Plate Circuit, Bureau of Standards, S. 351, 1919.

H. W. Nichols, Phys. Rev. 13, p. 405, 1919.

Stuart Bellantine, Phys. Rev. May, 1920.

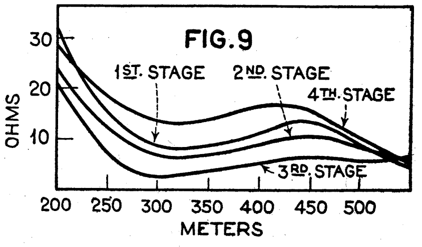
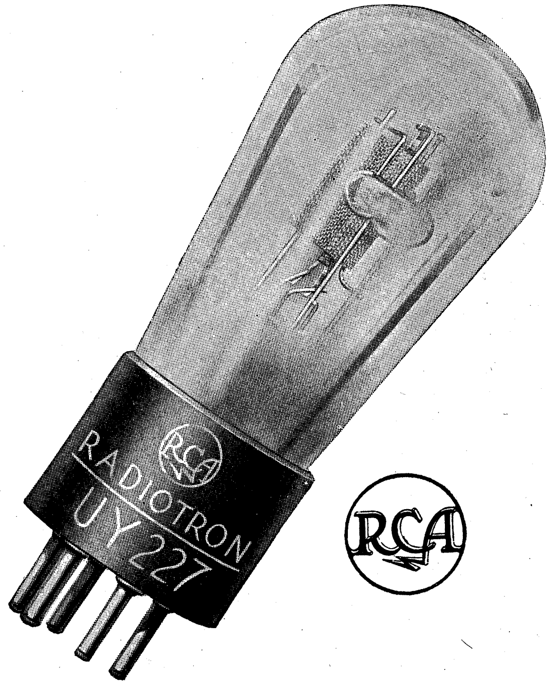


FIG.9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