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A Message From Our New President

IT would be superfluous for me to say that I appreciate the honor which has been bestowed upon me in selecting me as your President for the ensuing year. Every member of The Radio Club of America knows the magnitude and importance of this office and to be chosen to fulfill its duties is a distinction which imposes upon the man so elected the deepest sense of responsibility. It inspires him with a strong desire to emulate his distinguished predecessors and to carry on the work and activities of the organization in fully as wide a scope to meet the demands of its constant growth.

The present year, like others which preceded it, will mark an expansion both in membership and in the importance of The Radio Club of America. Whatever success marks my term in your most important office should not be credited to my efforts. Rather, it would be the natural result of a steady and healthy growth made possible by the efficient leadership of those who have gone before. It will be my duty merely to meet conditions as I find them and, if possible, to direct the activities of the Club in a more encompassing manner to care for new and different propositions which may present themselves. I realize the enormity of the task that confronts me and if I can achieve results comparable to those made possible by Past Presidents, I will be more than satisfied.

When I look back at the original group that met at the Hotel Ansonia, and later at Mr. King's residence in 1909-1910, and note that practically all of the same group are still active and have the interests of the Club at heart as much today as ever, I feel grateful that it has been my happy lot to spend those long years of pleasant association with them.

In the course of my retrospection, I find many things in the history of the Club of which its members can well be proud. We can point with pride to the fact that were it not for the active part played by the Club, we would not have had the early Radio Legislation which played such a tremendously important part in the later development of the industry.

It was a committee, delegated by The Radio Club of America, that visited the President of the United States and was responsible in no small measure for the law restraining ships from using wavelengths interfering with broadcast programs, when such ships were in or near port.

Louis Gerard Pacent

Some of the members will remember the suggestion at one of the Board meetings in which it was proposed to span the Atlantic by short waves—then, of course, meaning 200 meters and with not more than 1 kilowatt of power, as authorized by the Department of Commerce. Several engineers criticised the attempt, but a short time later it was done and became an accomplished fact. Radio Club of America members took part in the transmission and reception which constituted this pioneering effort.

Among our members are numbered men who were the first to realize the penetrating qualities of short waves; men, in our midst who are familiar with the behaviour of short waves to the extent that there are few, anywhere else in the world, who can match their knowledge of the subject.

We are proud of the part played by our Club during the World War. At that time The Radio Club of America, in its fostering of a keen interest in radio communication, contributed many of its members for technical service in the Army and Navy of the nation, several of whom enjoyed high honors bestowed by the United States and other Powers for their excellent work.

In the roster of our membership are listed the names of such men as E. H. Armstrong, who as an amateur, developed the super-regenerative circuit and superheterodyne circuit, papers on which were read and models demonstrated at our meetings.

L. A. Hazeltine first disclosed the neutrodyne circuit to our Club during the course of his membership. The late Dr. Hudson, inventor of the long-life coated filament tube which is used in Trans-Atlantic telephony, was very active in the Club, and was one of our early speakers, having delivered a paper before the Club in 1913.

We have in our membership several noted men in the Radio industry. Some of them are Honorary Members, though the majority are actively engaged in the organization. Time will not permit the mention of all of the outstanding names in the roll of our membership.

Our Past President, L. M. Clement, has completed a remarkably successful term and is to be congratulated upon the thoroughly efficient and business-like manner in which he handled the matters of great importance that came to his attention. The most complimentary thing that can be said of his record as leader of our organization is that it exemplified, in every detail, the success and esteem which is his in the outside world. I can only hope that the period of my office will be marked by an equally creditable discharge of my duties.

The public looks upon The Radio Club of America as a non-participant as far as commercialism is concerned. We are expected to look after their interests in the questions of legislation affecting transmission, reception and reproduction of radio programs. As non-partisans, we must assume responsibility for the freedom of the air to the independent experimenter and progressive amateur who has always been such an important factor in the development of the art. It is highly important that we take cognizance of the faith thus imposed in us—that we do not take the things expected of us too lightly.

Though we are concerned primarily with the development of radio, we do not and cannot afford to overlook the social aspect of our Club. We are more than a group of engineers and experimenters. Many of us have formed associations within the walls of this Club that are of many years duration, and it is the promotion of this feeling of friendship and good fellowship that will continue to make us in the future, as we were in the past—a Club that will foster the favorable opinion both of its members and of the public in general.

Louis Gerard Pacent.

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APPLICATION OF SCREEN-GRID TUBES TO AUDIO-FREQUENCY AMPLIFIERS†

Relative to the Construction of Proper Circuits Suitable to the Characteristics of the Typical Screen-Grid Tube

By *JOHN J. GLAUBER* *

THE advent of the photo-cell, condenser microphone, and other minute voltage generators has made it imperative to develop audio-frequency amplifiers possessing a high overall amplification, so that devices requiring considerable voltage or power may be operated by them. Such amplifiers employ many stages in cascade, and are therefore cumbersome and costly. It is the purpose of this paper to show how the screen-grid tube may be applied to such amplifiers.

The discussion will be limited to the type '24 a-c. screen-grid tube when used so that the grid nearer the cathode is the control electrode, the outer or screen grid having a fixed positive d-c. potential with respect to the cathode. The deleterious effects produced at the higher frequencies, due to the high amplification factor and the large interelectrode capacity existing between the plate and the adjacent control grid excludes its use as a space charge tube.

Fig. 1 shows the variation of amplification factor, plate resistance and mutual conductance with screen-grid voltage, (Egc=—1.5 volts, Ep=180 volts). By varying the screen-grid potential the tube characteristics may be changed materially. It is important to determine that particular value of screen potential necessary to give maximum amplification. Since a vacuum tube may be considered as an a-c. generator having a very high internal resistance, its voltage output will be a function of the impedance of the load. For maximum voltage output it is necessary to make the load impedance as high as possible. The circuit for such a device is shown in Fig. 2.

Where:

μ = amplification factor of tube

e_g = a-c. input voltage to tube

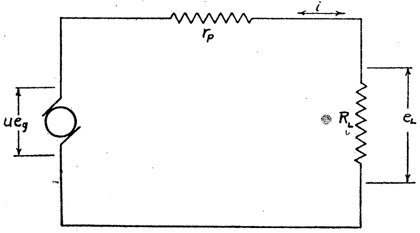

Figure 2

μe_g = voltage generated in plate circuit

γ_p = internal resistance

R_L = load impedance, taken as pure resistance for simplicity

e_L = output voltage

It may be shown that

$$\frac{e_L}{e_g} = \frac{\mu R_L}{\gamma_p + R_L} = A \qquad (1)$$

where A represents the stage voltage amplification. Since it is more difficult to measure the plate resistance of high-impedance tubes than the amplification factor and mutual conductance (G_m) it is desirable to eliminate γ_p from equation (1). It may be shown that the mutual conductance of a vacuum tube, i. e., the change in plate current produced by a change in grid voltage is

$$G_m = \frac{\mu}{\gamma_p} \qquad (2)$$

Substituting equation (2) in equation (1)

$$A = \frac{\mu G_m R_L}{\mu + G_m R_L} \qquad (3)$$

Equation (3) is accurate up to 10,000 cycles per second, above which a correction must be applied for the reactance in shunt with R_L due to the interelectrode capacity between plate and screen grid. The screen is at the potential of the cathode as far as a-c. is concerned, since a large by-pass condenser is always used between cathode and screen. The reactance in shunt with R_L will reduce the amplification per stage A.

By substituting various values in equation (3) for R_L and values of μ and G_m corresponding to various shield potentials from Fig. 1 a family of curves showing the relationship existing between the amplification per stage and shield potential was plotted and is shown in Fig. 3. The maximum amplification obtainable increases with an increase in load re-

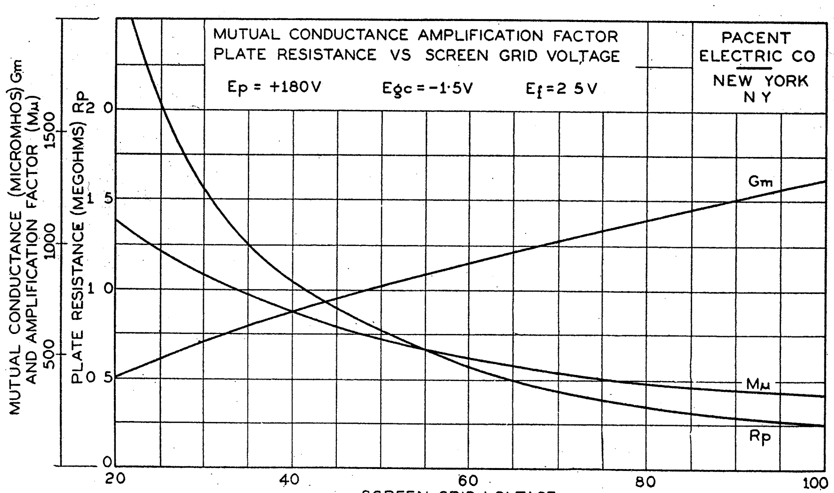

Figure 1

†*Delivered before the Club, December 11, 1929.*

* *Engineering Dept., Pacent Electric Company.*

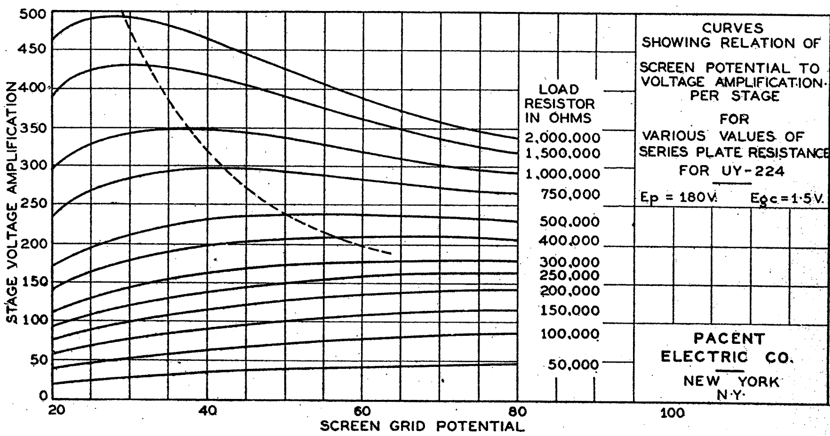

Figure 3

sistance and, for each value of load resistor there is a definite shield potential for maximum amplification.

To determine the d-c. operating point a family of curves showing the relationship between plate potential in volts (E_p) and plate current in milliamperes (I_p) for shield potentials (E_{gs}) of 20, 30 and 40 volts, for a constant control-grid bias of negative 1.5 volts, is shown in Fig. 4. With 500 volts assumed as the available potential at the source, load lines of 0.5, 0.75, 1.0, 1.5 and 2.0 megohms were drawn. The slope is the reciprocal of the resistance expressed in ohms. If projected to the right all load lines would intersect the X-axis at $E_b = 500$ volts. The 1.5 and 2.0 megohm lines intersect the E_p-I_p curves shown where the plate voltage is equal to or less than or but slightly greater than the screen potential. In this region the relation between E_p and I_p is non-linear and varies considerably for different tubes of the same type. If curves were plotted for control-grid biases less than and greater than negative 1.5 volts, for each value of shield potential shown, curves parallel to those shown would have been obtained. That is, there would be a family of three parallel curves for each value of shield potential. For distortionless amplification it is essential that the load line intersect the particular family at which it is desired to operate, at points having the same slope. This obtains at the higher plate potentials where the E_p-I_p curves are substantially linear. For the UY-224 the plate potential should not be less than 135 volts. The point of intersection of the load line with the E_p-I_p curve may be shifted by decreasing the screen potential, by increasing the control-grid bias or by increasing the plate supply voltage. To obtain maximum amplification from the 2-megohm resistor requires $E_{gs}=30$, $E_p=180$ and $I_p=0.81$. The plate supply voltage required would be $E_b=1800$ volts. The 1.5 megohm load would require $E_b=1395$ volts. The 1 megohm load requires $E_{gs}=37.5$ volts for maximum amplification (see Fig. 3). It would also intersect the E_p-I_p curve in the unstable region (see Fig. 4). Examination discloses that it intersects the E_p-I_p curve for $E_{gs}=20$ at $E_p=180$ volts. This is a desirable operating point and the decrease in amplification from the maximum obtainable is not sufficient to warrant increasing the plate supply voltage to 1385 volts.

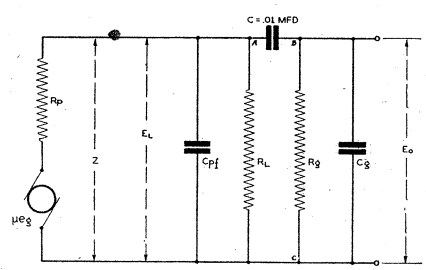

Figure 5

Thus far only a pure resistance to determine the operating point has been considered. To be of any use the output must be coupled to a succeed- tube or device. Since the impedance in the plate circuit determines the a-c. amplification, it is important to know the impedance of the coupling system over the useful frequency range. The output of the tube may be coupled without further voltage amplification to a power tube, or if greater amplification is required, to one or more stages in cascade and then into a power tube. It will be assumed that the output of the screen-grid tube is to be coupled to the input of a type '27 tube.

The high plate impedance of the screen-grid tube excludes transformer or impedance coupling. Only resistance and direct coupling remain. Since direct coupling is merely a simplification of resistance coupling, and as it usually gives a much poorer frequency response over the audio range, (due to the high input capacity of the following tube) when high values of load resistance are used, the analysis of the coupling system will be limited to the conventional method of resistance coupling. The equivalent of such a circuit is shown in Fig. 5.

Where:

ue_g, γ_p, E_L and R_L are as for Fig. 2

C_{pf} = output capacity of tube (approx. 12 mmf.)

C = coupling condenser (.01 mf.)

R_g = grid resistor

C_g = input capacity of succeeding tube (approx. 39 mmf. for UY-227)

E_o = voltage applied to succeeding tube

Z = impedance in output circuit of generator

For such a network the impedance

$$Z = \frac{R_L [1 + j \omega R_g (C_g + C)]}{1 - \omega^2 R_L R_g (C_g C_{pf} + C_{pf} C + C_g C) + j \omega (R_g C_g + R_g C + R_L C_{pf} + R_L C)}.$$

Rationalizing and collecting terms

$$Z = \frac{R_L [1 + \omega^2 R_g \{ R_g (C_g + C)^2 + R_L C^2 \} - j \{ \omega R_L (C_{pf} + C) + \omega^3 R_L R_g^2 (C_g^2 C_{pf} + 2 C_g C_{pf} C + C_g^2 C + C_{pf} C^2 + C_g C^2) \}]}{1 + \omega^4 R_L^2 R_g^2 (C_g C_{pf} + C_{pf} C + C_g C)^2 + \omega^2 [R_g^2 (C_g + C)^2 + R_L^2 (C_{pf} + C)^2 + 2 R_g R_L C^2]}$$

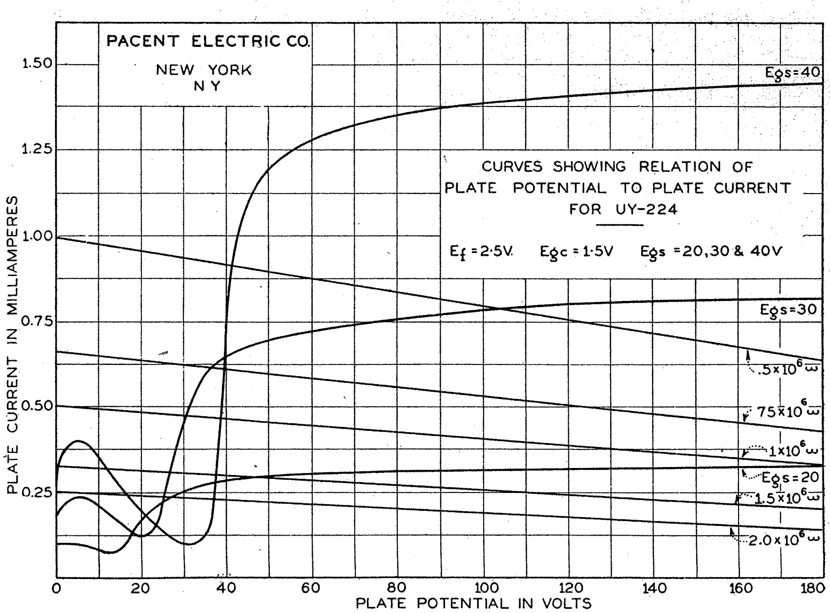

Figure 4

C_g and C_{pf} are usually negligble compared to C, the resistive and reactive components of Z become:

$$R_z = \frac{R_L\,[1 + \omega^2 R_g C^2 (R_g + R_L)]}{1 + \omega^4 R_L^2 R_g^2 C^2 (C_{pf} + C_g)^2 + \omega^2 C^2 (R_g + R_L)^2} \qquad (4)$$

$$-jX_z = \frac{-j R_L\,[\omega R_L C + \omega^3 R_L R_g^2 C^2 (C_{pf} + C_g)]}{1 + \omega^4 R_L^2 R_g^2 C^2 (C_{pf} + C_g)^2 + \omega^2 C^2 (R_g + R_L)^2} \qquad (5)$$

$$Z = R_z - jX_z$$

Both components vary with frequency. For given values of R_L and R_g the capacities C_{pf} and C_g are important factors in determining the value of Z at the higher frequencies, while C is important in determining the value of Z at the lower frequencies. If $C_g = 0 = C_{pf}$, equations (4) and (5) become

$$R_z = \frac{R_L R_g}{R_g + R_L} \qquad (6)$$

$$-jX_z = \frac{-j R_L^2}{\omega C (R_g + R_L)^2} \qquad (7)$$

when C is large.

In Fig. 6 are plotted curves, computed from Eqs. (4) and (5), of the impedance Z of Fig. 5 for a few combinations of R_L, R_g and C_g; the constants being given in the figure. The

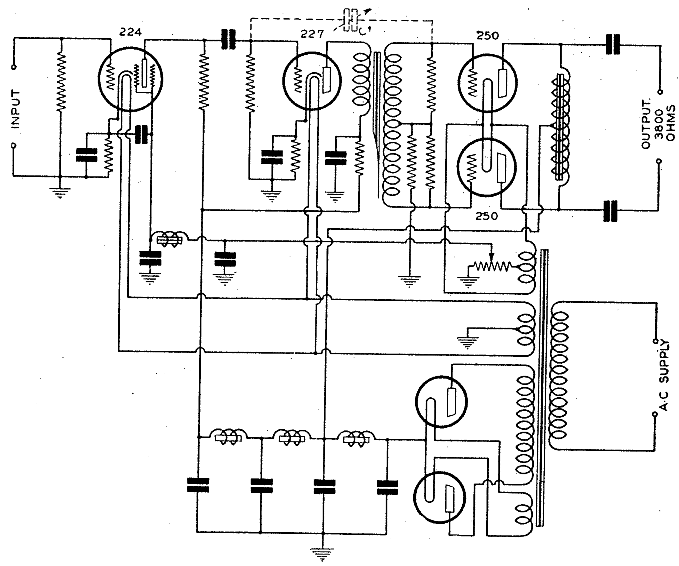

Fig. 8. Complete circuit digram of an amplifier.. incorporating a screen - grid tube resistance coupled to a -27 tube.

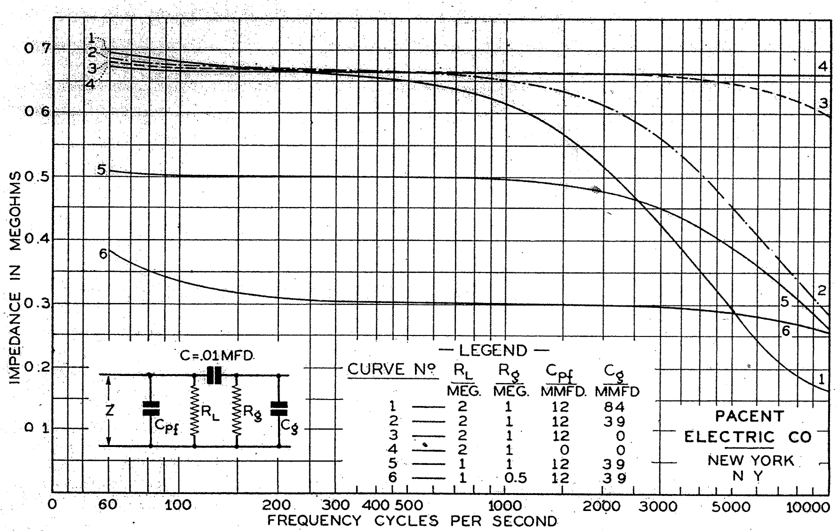

Figure 6

ideal frequency-impedance characteristic is a straight line of zero slope. The higher the impedance the greater will be the amplification obtainable. It is important to note how the impedance varies from the ideal with high values of R_L and R_g when C_{pf} and C_g are present. The ideal characteristic is shown by curve 4 and was computed for $C_{pf} = 0 = C_g$. Curve 3 was computed for $C_g = 0$ and $C_{pf} = 12$ mmf. Comparing curves 1, 2, and 3, which differ only in the value of C_g the reduction in impedance at the higher frequencies due to the input capacity C_g of the 27-type tube is shown. For a three-element tube,

$$C_g = C_{gf} + C_{gp}\left(\frac{\mu R_L}{R_L + \gamma_p} + 1\right)$$

where:

C_{gf} = direct grid to cathode capacity

C_{pg} = direct grid to plate capacity

RL is assumed to be large compared to r_p.

For a '27 tube C_g is approximately 39 mmf. However, due to the socket and wiring capacities this may, if care is not exercised, be increased to 100 mmf. To approach the ideal frequency-impedance characteristic the values of R_L and R_g should be so chosen that each is less than the capacitative reactance in shunt with it at the highest frequency to be reproduced. In Fig. 7 is shown the computed amplification, obtained by substituting Z for R_L in equation (3), for the UY-224 if the optimum value of screen potential for $R_L = 1$ megohm were used ($E_{gs} = 37.5$) and for the actual potential used ($E_{gs} = 20$) for values of $R_g = 0.5$ and 1 megohm. The dash-line curves shown at the low-frequency end of each solid line curve is the amplification available at E_o Fig. 5. This is the amplification available across the input circuit of the following stage. This was obtained by multiplying EL by the ratio of the impedances BC to AC. Above 500 cycles the coupling condenser reactance is negligible compared to R_g and from there on the dash and solid line curves coincide. The dot-dash curve is the actual amplification obtained from test for RL=1 and $R_g = 0.5$ megohm. A variable frequency input was fed to the control grid of the UY-224, the output voltage E_o being measured by a high input impedance vacuum-tube voltmeter. The prox-

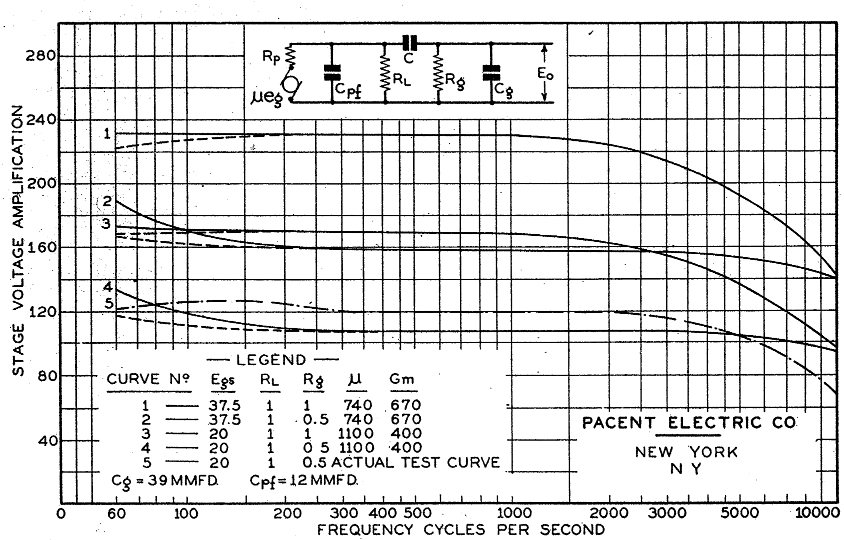

Figure 7

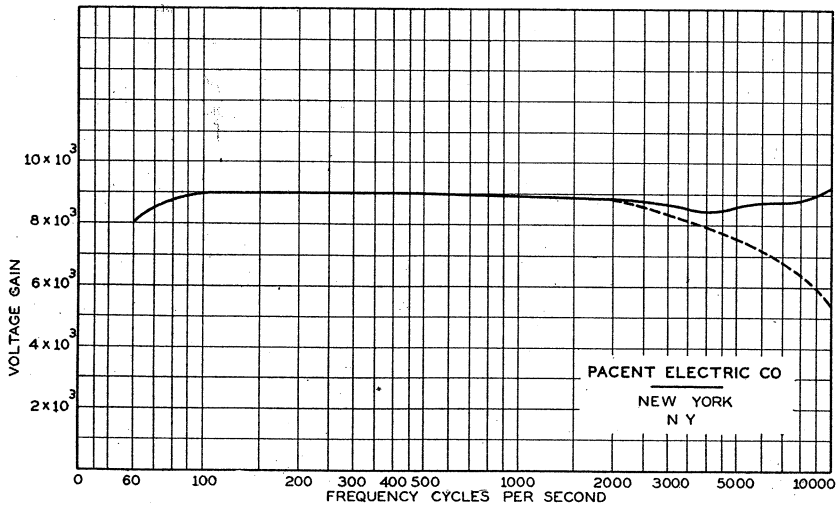

Figure 9

imity of the test curve to the computed curve for identical values of R_L and R_g shows the accuracy with which the gain of a tube and its coupling system may be computed. The more rapid falling off at the higher frequencies is due to stray capacities unaccounted for in the computed results.

Fig. 8 is the complete circuit diagram of an amplifier incorporating a screen-grid tube resistance coupled to a UY-'27, the output of which is transformer coupled to a pair of UX-250's in push-pull. An over-all voltage gain of 9000 was obtained. The simplicity of the circuit is of interest. It was found that the gain of this amplifier varied considerably for different screen-grid tubes of the same type. This was due to the wide variation in the screen currents of these tubes which materially affects their operating characteristics. To obtain a uniform gain it was found necessary to adjust the screen-grid potential slightly for different tubes. The screen potential is obtained from the 84-volt bias of the output tubes and the screen voltage is adjustable. A filter in the screen-grid circuit eliminates any a-c. which may be due to the filament center-tap being eccentric.

The dash-line curve of Fig. 9, which, below 2000 cycles coincides with the full-line curve, shows the frequency characteristic of such an amplifier. The deficiency at the high end is not bad and it may be remedied, as shown by the full-line curve, by the introduction of a small condenser C^1 shown in dotted lines in Fig. 8. This provides regeneration at the higher frequencies. Too great a value of C^1 will produce sustained oscillations at an audible frequency. This is extremely undesirable and care must be taken to make C^1 as small as possible. It is important in using such a device to connect it to the grid of the push-pull tube in phase with the grid to which the energy is to be fed back to. This may be determined by trial. If the improper grid is connected a greater suppression of the higher frequencies will be had than if no condenser were used. The above means of increasing the gain at the higher frequencies is of laboratory interest only as the adjustment of C^1 is too critical to be incorporated in commercial amplifiers. It is possible to neutralize the input capacity of the UY-'27 but this entails additional expense. The input capacities of the push-pull tubes are readily neutralized by inter-connecting through small variable capacities the grid of each tube to the plate circuit of the other tube.

The resistors between grid and ground of each push-pull tube, although not essential, are used to make the input circuit practically a pure resistance.

For stable operation careful shielding is advisable. In shielding, care must be exercised to keep the grid-to-plate, grid-to-ground and plate-to-ground capacities at an absolute minimum.

Screen-grid tubes may be operated in push-pull. It is advisable in such cases to provide an adjustment for varying the screen potential as described above, for each screen-grid tube, so as to equalize their characteristics.

In conclusion, the writer wishes to express his appreciation of the assistance rendered by the *Engineering Department* of the *Pacent Electric Company.*

DISCUSSION ON GLAUBER PAPER

THERE is a well-defined tendency toward the use of a single stage in the audio-frequency amplifier of present-day receivers. That this is good engineering is evidenced by the quality curves of several well-designed receivers using only one audio stage, their freedom from acoustical regeneration and the decreased detector distortion due to the unavoidable use of a power detector. When a screen-grid tube is used as a detector, the engineer is face to face with the problems of voltage amplification by means of a high impedance tube. Many receiver designers have accepted the screen-grid detector tube as an audio-frequency amplifier for phonograph combinations. Mr. Glauber's practical work has a particular significance to these engineers and it is in this connection that probably the greatest use of this kind of an amplifier will be found.

When the screen-grid tube is coupled by the conventional resistor-condenser combination to the power stage, it may not be amiss to caution the designer about the stability of the bias on the power stage. Because of the high internal impedance of the screen-grid tube, high impedance coupling units must be used to obtain sufficient voltage amplification. If a high resistance grid coupling member is used to put bias on the grid of the power stage, there is a danger from that kind of grid current which flows from the grid and effectively opposes the applied bias. This reduces the effective bias, thereby increasing the plate current. With certain tubes, the action gets worse and eventually ruins the power tube.

There is another problem mentioned in this paper which needs some amplification in view of some misconceptions which appear to exist. The conclusions reached by some who are enthusiastic for such a system, indicate that it has been assumed that coupling means referred to as "direct coupling" (as opposed to the resistor-condenser

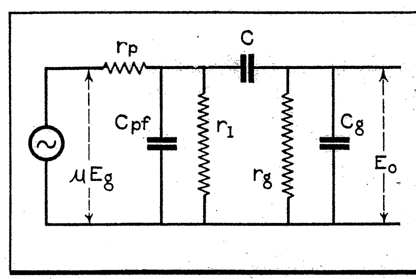

Figure 10

coupling means), acts as a pure resistance. This is not true at high frequencies. Even if the capacities across the various parts of the voltage dividing resistance which supplies the several stages of this type of amplifier were negligible, there remains the input capacity of the various tubes. If this could be avoided elsewhere, it can hardly be avoided in coupling the last screen-grid tube to the power stage, particularly if this stage is made up of three-element tubes.

The possibility of employing regeneration to obtain improved high-frequency response has been pointed out. While this may be done, it should be remembered that its use may be a source of trouble in a radio receiver which has to endure the vagaries of manufacture. Variations between units and tolerances in the construction of the set, decrease the amount of permissible regeneration from that allowable in a laboratory set-up.

For many years, I have been using a simple trick in calculating the amplification of resistance- and impedance-coupled amplifiers. Because of the simplification involved, the method and results will be briefly illustrated using the author's nomenclature as far as possible. The equivalent circuit used by the author is as shown in Fig. 10.

This circuit may be redrawn by considering the effective impedance of (C_{pf}) and (r_l), and (C_g) and (r_g) respectively as parallel network. The other circuit elements are generalized as shown in Fig. 11.

Now, the effective amplification of the stage is:

$$\mu_o = \left[\left(\frac{E_o}{E_l}\right)\left(\frac{E_l}{E_g}\right)\right]$$

$$= \left[\mu\left(\frac{Z_l Z_g}{Z_l Z_l + Z_l Z_2 + |Z_l Z_2|}\right)\right]$$

Where:

$$Z_2 = (Z_g + Z_c) \text{ and } Z_c = (-j\,|X_c|)$$

A simplication results in calculating the reciprocal of the percentage amplification $\left(\frac{\mu_o}{\mu}\right)$. This step eliminates all rationalization and results in

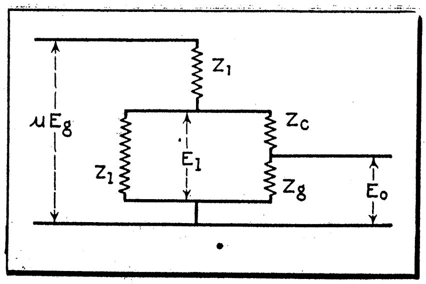

Figure 11

a relatively simple vector expression whose magnitude may then be evalued. The reciprocal of its magnitude is the desired result. Thus from the above expression:

$$\frac{\mu}{\mu_o} = \left(\frac{Z_l}{Z_g} + \frac{Z_2}{Z_g} + \frac{Z_l Z_2}{Z_l Z_g}\right)$$

Where:

$$Z_l = \left(\frac{r_l}{1 + j\frac{r_l}{|X_{cp}|}}\right)$$

$$\frac{Z_2}{Z_g} = \left(1 + \frac{Z_c}{Z_g}\right) = \left[1 - j\left(\frac{|X_c|}{r_g}\right)\left(1 + j\frac{r_g}{|X_{cg}|}\right)\right]$$

Hence:

$$\frac{\mu}{\mu_o} = \left[\left\{1 + \frac{r_p}{r_g} + \frac{r_p}{r_l} + \left|\frac{X_c}{X_{cg}}\right| + \frac{r_p}{r_l}\left|\frac{X_c}{X_{cg}}\right|\right\} + j\left\{\frac{r_p}{|X_{cg}|} + \frac{r_p}{|X_{cp}|} + \frac{r_p}{X_{cp}}\left|\frac{X_c}{X_{cg}}\right| - \frac{|X_c|}{r_g} + \frac{r_p}{r_g}\left|\frac{X_c}{X_{cp}}\right| - \frac{r_p}{r_l}\frac{|X_c|}{r_g}\right\}\right]$$

In employing this equation, consider that portion to the left in direct line with the section above.

It will be observed that the real part of this expression is independent of frequency while three terms of the imaginary part vary directly with frequency and the remaining two vary inversely with frequency. Calculation from this equation is a comparatively simple matter. It is to be remembered that the symbols (X) are real numbers without sign.

The absolute magnitude may now be found and by dividing the amplification factor of the tube under those conditions by this number, the effective voltage amplification of that stage is known. The simplicity of this method of calculation is evident and because of this, its inclusion in this discussion is felt to be well warranted.

DR. ELLSWORTH D. COOK,
United Research Corp.

The Radio Club of America, Inc.

55 West 42nd Street :: New York City

TELEPHONE — LONGACRE 6622

SUGGESTIONS TO CONTRIBUTORS

CONTRIBUTORS to the Proceedings, by bearing in mind the points below, will avoid delay and needless expense to the Club.

1. Manuscripts should be submitted typewritten, double-spaced, to the Chairman of the Papers Committee.* In case of acceptance, the final draft of the article should be in the hands of the Chairman on or before the date of delivery of the paper before the Club.

2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are inacceptable.

3. Corrected galley proofs should be returned within 12 hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The Club reserves the right of decision on the publication of any paper which may be read before the Club.

* For 1930 the Chairman of the Papers Committee is Mr. L. G. Pacent, 91 Seventh Avenue, New York City.

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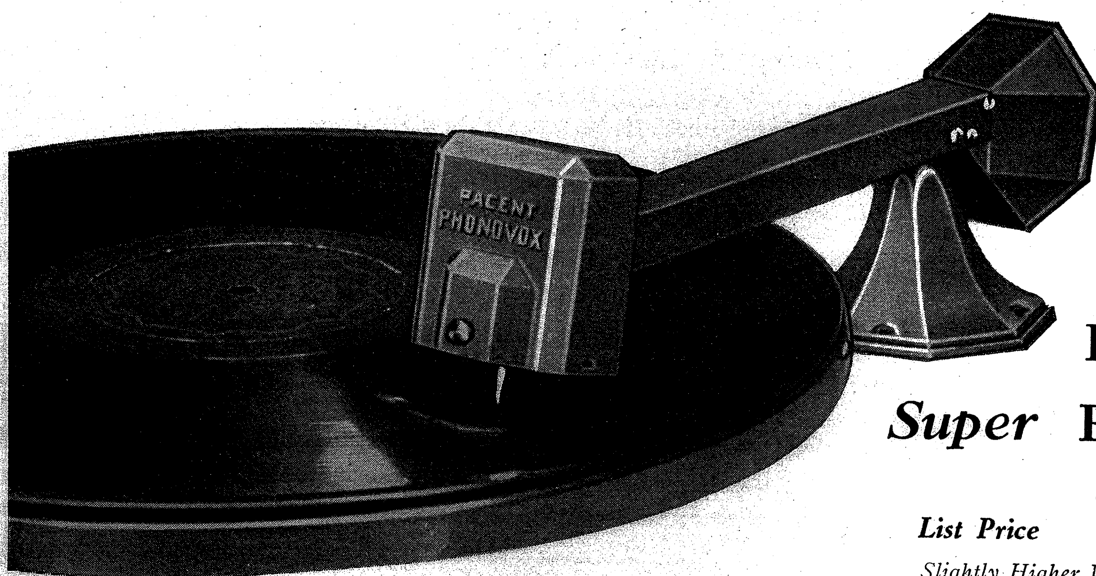
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