PROCEEDINGS
of the
RADIO CLUB *of* AMERICA

Vol. I No. 3 May, 1920

R.C.A. SPECIAL NOTICES

To the Membership:

It is with extreme regret that we announce the resignation of our Corresponding Secretary, Mr. Thomas J. Styles, due to his departure for sunny France. Mr. Styles, better known and revered by his friends as "Tom," sails on April 26th with his family to organize and take charge of the Paris Branch of the Bankers Trust Company. As Corresponding Secretary of the Club for the past three years, Tom has labored faithfully for the best interests of the Radio Club of America with a devotion and zeal seldom met with in the ordinary walks of life and no small measure of our growth is due to his conscientious efforts.

Therefore, Tom, we pause to wish you Bon Voyage—and you bear with you the best wishes of the entire club for the increasing success which we know will be yours.

An important meeting of the Board of Directors is scheduled for April 22nd at which time important subjects influencing the welfare and growth of the Club will be discussed. The Board of Directors will appreciate ideas of the members at any time. Suggestions from the membership on questions of increasing the value of the Club to the individual and the art are always most welcome.

We have no record of the correct mailing address of the following members. If they chance to see these Proceedings will they communicate with the Editor in order that they may promptly receive their copy:—

Atwater	Elkins	Schedler
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The Vacuum Tube as a Detector and Amplifier

By L. M. Clement

Part II of a paper presented before The Radio Club of America at Columbia University, January 16, 1920

Amplifiers

For the amplification of speech currents, the current in the output of the amplifier must be an accurate copy of the input signal. By the proper choice of tube and circuit constants for a given set of conditions this can be easily accomplished. If an amplifier is operated under improper conditions, so much distortion may result as to render the speech signal entirely unintelligible; but if the amplifier is to be designed for telegraph signals only, the question of distortion is not so important as it will not affect the readability of the signals.

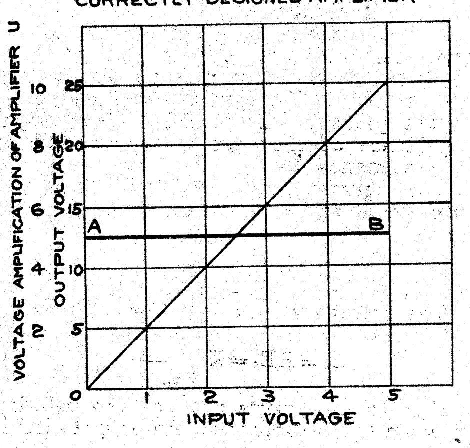
Since the speech wave is composed of a number of different frequencies of different amplitudes, it is obvious that for a distortionless amplifier the output voltage must vary directly with the input voltage and the amplification must be independent of frequency over the voice frequency range.

Fig. 13 is a curve showing the relation between the input and output of an amplifier. The line AB shows the ratio between output and input voltage and is constant over the range of input.

Amplifiers can be divided into two general classes; namely, Voltage Amplifiers and Power Amplifiers. The voltage amplifier is used to amplify extremely small voltages of low energy content to such a point that when applied to the grid circuit of a power tube the desired current or power output is obtained.

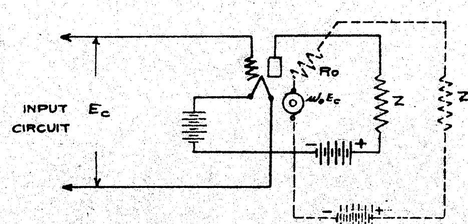
-FIG. 13-

CURVE SHOWING THE RELATION BETWEEN THE INPUT AND OUTPUT VOLTAGE OF A CORRECTLY DESIGNED AMPLIFIER



- FIG. 14 -

OUTPUT EQUIVALENT CIRCUIT



In the case of the voltage amplifier, great care is taken so that no power is wasted in the grid-filament circuit of the tubes, and the circuit is arranged to give maximum voltage amplification. In the power amplifier, the circuit is arranged to deliver maximum power to the load.

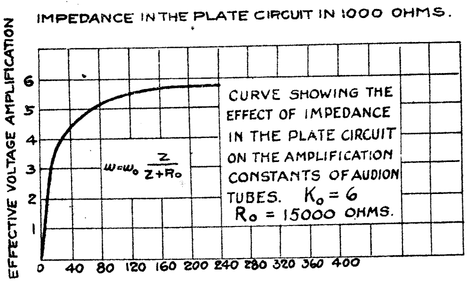
Distortion

In speech amplifiers distortion to any great extent should not occur because of its obvious effect on the signal. The general causes of distortion may be classified as follows:

1. The alteration of the wave form of the signal by the variable absorption of power in the grid circuit. This is due to the change in the grid-to-filament resistance when the grid is allowed to assume positive values. This is shown on Fig. 17.
2. The alteration of the output current wave form by the application of the input signal to the non-linear position of the grid-voltage-plate-current characteristic of the audion. See Figures 18-19.
3. The distortion of the signal by the attached apparatus such as transformers, etc.

The resistance of the grid-filament circuit of an audion is almost infinite where the grid is charged negatively with respect to the filament. However, when it becomes positive due to the electrons which are attracted to it, the resistance falls to a finite value and decreases with increase of grid potential. This circuit therefore acts as a variable resistance shunt on the input circuit and tends to reduce the maximum value of the positive half of each cycle of the incoming signal. This is shown clearly in Fig. 17. The curve ABCDE at the

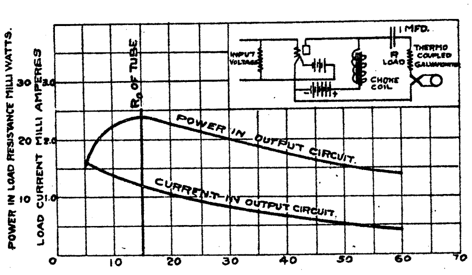
-FIG. 15-



lower part of the figure shows the original form of the input voltage wave. Due to the absorption of power by the grid circuit the maximum positive value of the input voltage is reduced and looks like $ABCD_1E$. This distorted wave impressed on the grid circuit of the tube produces the similar distorted plate current $abcd_1e$. In order to prevent this type of distortion a negative voltage must be applied to the grid which will be greater than the input voltage. This is to insure the grid from being driven positive with respect to the filament at any time. Distortion of this sort is only serious when the energy in the signal is very small.

When the negative potential on the grid is increased the current in the plate circuit decreases until a point is reached when it is zero. This value of E_c is said to be the cut-off voltage. Obviously, then, if a potential such as ABC is applied to a tube such that BM plus MN (Figure 18) is greater than this cut-off value, the resultant current in the plate circuit will look like abcde, which shows very bad distortion. The same effect takes place, although to a much less degree, if the voltage is allowed

-FIG.16-



to act on the curved portion of the E_cI_b curve; Fig. 19. If the E_cI_b curve were a straight line and the grid of the tube were not allowed to assume a positive value, distortionless amplification would result. While it is not possible to build audions which will give the sort of characteristic illustrated in Fig. 20, it is possible to approximate the results obtained.

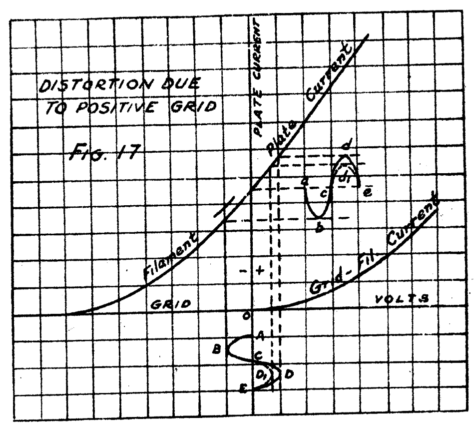
It has been found that the characteristic curve is straightened by the addition of resistance and experience has shown that when the resistance is of the order of the output impedance of the tube, distortion due to the curved portion of the curve is of little importance provided the input voltage is kept within proper limits.

Voltage Amplification

In order properly to proportion the circuit of the amplifier the values of maximum amplification constant K and internal output impedance R_o must be known.

The ratio of the output voltage divided by the input voltage of a one tube amplifier is the effective amplification K of the device, and this is obviously less than the maximum constant of the tube K_o.

The following is an approximate method of determining the effective amplification



factor K of an amplifier with resistance in its output circuit.

Fig. 14 shows a circuit which is the equivalent of the output circuit of an audion. If the input voltage on the grid of the tube is E_c, then the voltage acting in the plate circuit is KE_c. The output impedance of the tube is represented by the resistance R_o.

The current through Z will also flow through R_o and is equal to

$$I_b = \frac{K_oE_c}{R_o + Z}$$

The voltage across Z is then I_bZ, or

$$E_s = KE_c = K_o\frac{E_cZ}{Z + R_o}$$

Fig. 15 is a curve showing the relation between the resistance in the output circuit and the effective voltage amplification K in a particular case in which $K_o = 6$ and $R_o = 15000$ ohms.

In the design of voltage amplifiers, if we are not limited in the type of tube to be used or the voltage supply, it is best to choose a tube **with a high amplification factor (K_o)** in order to obtain as great an amplification as is practical in a single stage. The impedance of a tube in general goes up with its amplification constant so that it will be necessary to use choke coils whose impedance is large with respect to R_o in order to obtain the high effective amplification.

By the use of tubes of low K_o and R_o and coupling transformers, approximately the same result can be obtained. The total amplification of such an amplifier is as follows:

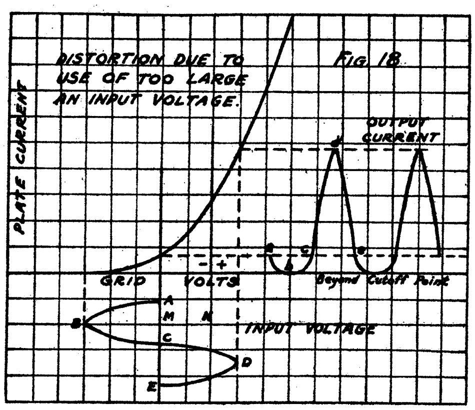
Suppose the transformer T of Figure 14 has a ratio of secondary to primary turns of e and an impedance as measured from the primary side of Z. Considering the transformer as an impedance Z, the ratio of the voltage across it to the input voltage can be calculated and is

$$K = K_o \frac{Z}{Z + R_o}$$

The voltage step-up of the transformer is practically equal to turns-ratio e so that the total voltage amplification is

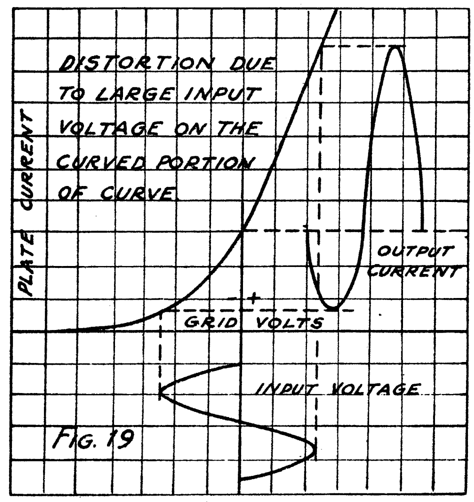
$$K = K_o e \frac{Z}{Z + R_o}$$

For amplification of speech signals, the transformers should be carefully designed



to transform a band of frequencies (400—2000 cycles per sec. approx.) more or less equally so that the speech signal will not be distorted to any great extent.

Increasing the ratio of an intertube transformer beyond a certain point does not increase the amplification. This is due to the fact that the input circuit of the tube has a definite impedance due to the capacity reactance of the grid-filament

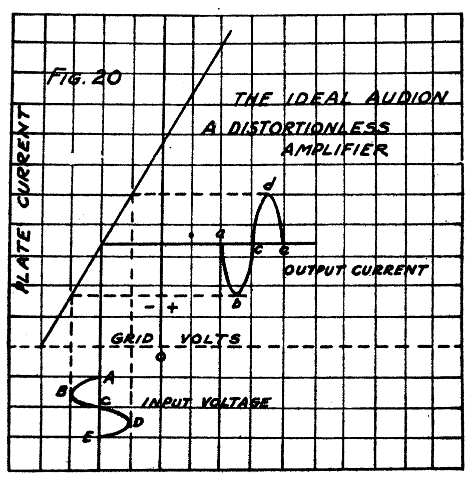


circuit of the tube which acts as a short circuit on the high side of the transformers. The capacity is not the value measured when the tube is not in operation but its effective capacity in the circuit used. This may be many times the value of the cold grid-to-filament capacity.

In practice, it is found that there is little gain in using transformers whose secondary impedance is above 750,000 ohms.

Feed Back Amplification

It is possible to obtain considerable amplification from a single tube by impressing a part of the amplified signal



voltage from the plate circuit on the grid of the tube in such a way as to tend to sustain oscillations. See Figure 21. The arrangement of L_o and L_1 must be used which will amplify rather than decrease the signal strength. Really what happens in the case of this hook-up is as follows: The radio frequency signal is impressed upon the input circuit of the detector and the audio frequency detected current flows in the output coil L_o. The audio frequency current in L_o induces a voltage in L_1 which is again amplified by the audion. In an amplifier of this sort the adjustment is apt to be rather critical and in general it is not very widely used.

Radio Frequency Amplification

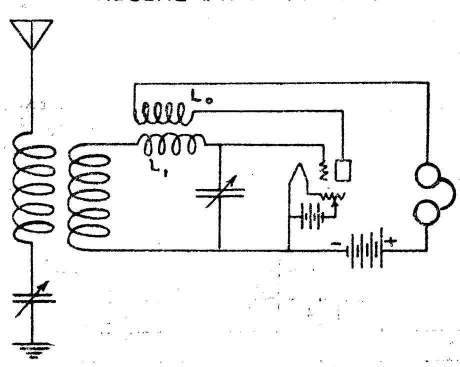
The use of loop and ground antennas with their low receiving efficiencies has necessitated the use of many stages of amplification. This has been attended with many difficulties due to amplification of extraneous noises to the same extent as that of the signals. The noises are probably due to any or all of the following causes.

1. Mechanical vibration of tubes
2. Noisy batteries or connections
3. Induction from various sources

By the use of radio frequency amplifiers which are designed so as to discriminate against the audio frequency noises, this difficulty can be partly overcome.

-FIG. 21 —

REGENERATION AMPLIFICATION.

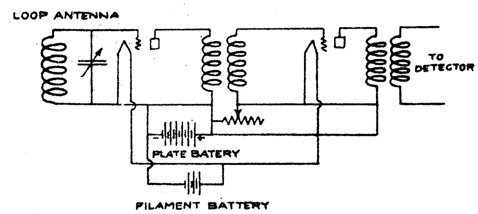


A resistance coupled radio frequency amplifier is shown diagramatically in Fig. 23. The condenser C between the succeeding stages offers but a low reactance to the radio frequency currents to be amplified and a high reactance to low frequency disturbances. An amplifier so constructed will amplify the radio frequency signals and discriminate against the audio frequency noises. In actual amplifiers of this type about 90% of the radio frequency voltage is passed and only about 9% of the noise frequency gets through.

The same results can be accomplished by the radio frequency transformer coupled amplifier illustrated in Fig. 22. Because of the low inductance of the transformers they are exceedingly inefficient in the transformation of audio frequencies and

-FIG 22-

RADIO FREQUENCY TRANSFORMER AMPLIFIER



therefore do not amplify these disturbances to any great extent.

The potentiometer shown in the diagram is to present the proper positive grid potential to be applied to the amplifier so that it will not oscillate. Amplifiers of this type are designed to operate over a band of frequencies at satisfactory efficiency.

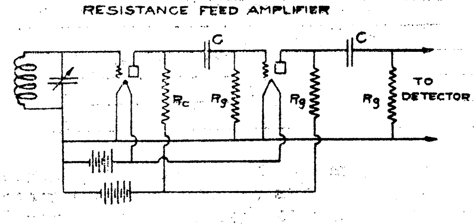
Detection

The audion, as we have seen, can be made to function as a more or less distortionless amplifier by arranging the circuit so that the input voltage is applied to the straight position of the E_cI_b curve. By arranging the circuit so that distortion results, apparent rectification takes place and the tube can be used as a detector. This is accomplished by making use of the curved portion of the E_cI_b curve to produce this distortion and is exactly the effect to be avoided in the design of an amplifier.

Sufficient negative grid voltage should be applied to the detector so that it will never assume positive values with respect to the filament. Operating the detector in this manner absorbs practically no power from the grid circuit and therefore does not increase the damping of the attached tuned circuit. The action of the audion can probably be best explained by considering the following example:

-FIG. 23-

RESISTANCE FEED AMPLIFIER



The characteristic curve shown in Figure 24 was taken and a constant value of E_c was applied to the grid which reduced the steady plate current to the value X'. The signal MN is now applied to the grid and is of such a value that the grid is never driven positive.

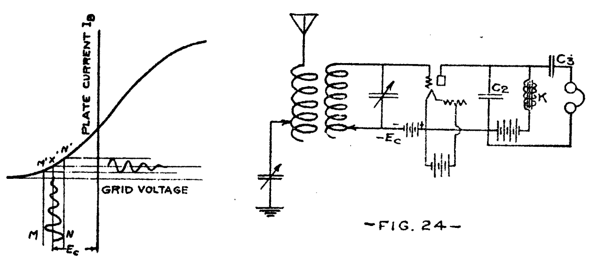
From the figure it is clearly seen that for equal positive and negative voltages on the grid the plate current is increased a greater amount than it is decreased, due to the bend in the E_cI_b curve. This means that the average space current is increased by the application of the signal, and a response is obtained in the telephone.

Van der Bijl has found that maximum detection takes place when the drop across the filament of a tube is equal to the sum of the plate voltage divided by the amplification constant plus the value of grid voltage plus a small constant, epsilon (e).

This is expressed by the following equation.

$$\frac{E_b}{K_o} + E_c + e = E_a$$

For the J or VT-1 type of tube best detection occurs when the effective plate



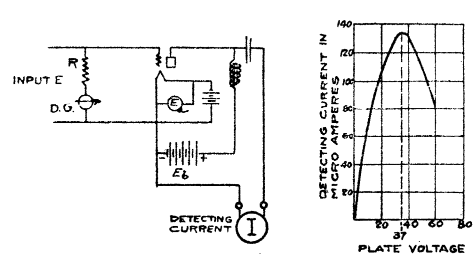
-FIG. 24-

voltage is 17. The effective plate voltage is equal to E_c plus E_b.

The curve in Fig. 25 is an experimental curve which verified the above equations and shows the best plate voltage to be used for detection. The input voltage was measured by observing the current through a resistance R by a Duddell Oscillation Galvanometer

The E_cI_b characteristic curve bends at its upper as well as its lower end and obviously detection can also take place around this latter point. This upper detection point is never used, however; first, because of the high plate current, which

-FIG. 25-



exhausts the plate batteries more rapidly than is necessary; and, second, because the grid is maintained at such a positive potential that a considerable energy loss takes place in the grid circuit. Hence most detectors confine their operations to the lower bend in the characteristic only.

A great deal has been written during the past few years upon the operation of the audion as a detector and therefore this portion of the paper has been limited to a few general considerations in which detection is distinguished from amplification. Also each type of amplifier described herein has been treated at great length from time to time; but it is hoped that the fundamentals explained in this paper which apply to amplification in general will assist the radio experimenter to obtain a clearer view of the reasons for use of any particular amplifier in various circuits.