

May 6, 1947.

W. R. KOCH

2,420,248

AMPLITUDE LIMITER CIRCUIT

Filed July 19, 1944

4 Sheets-Sheet 1

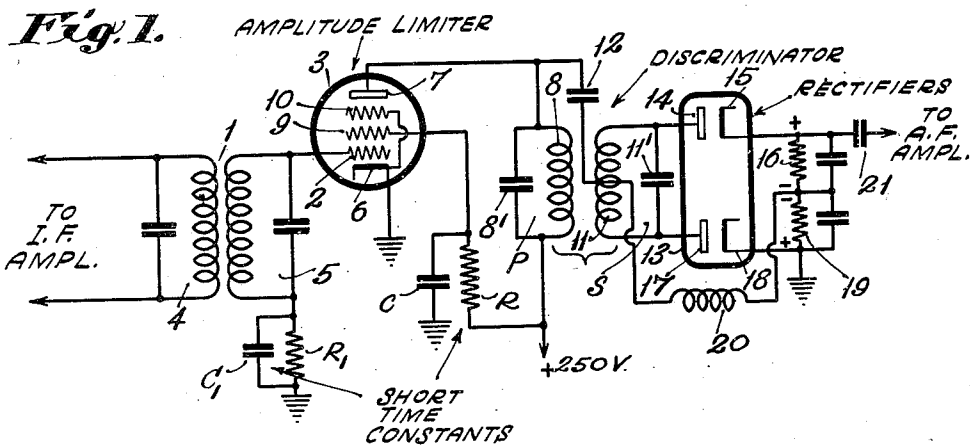


Fig. 2.

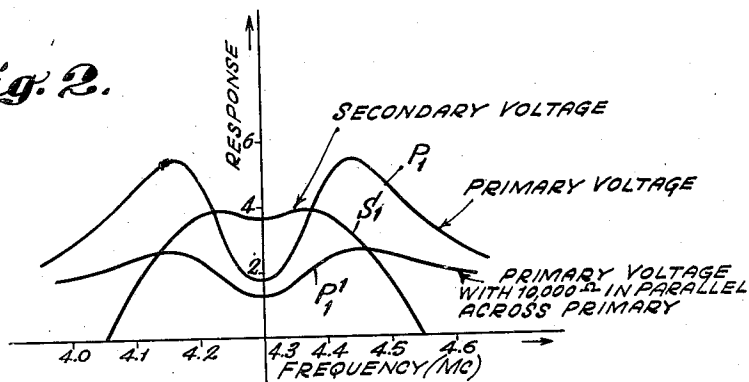
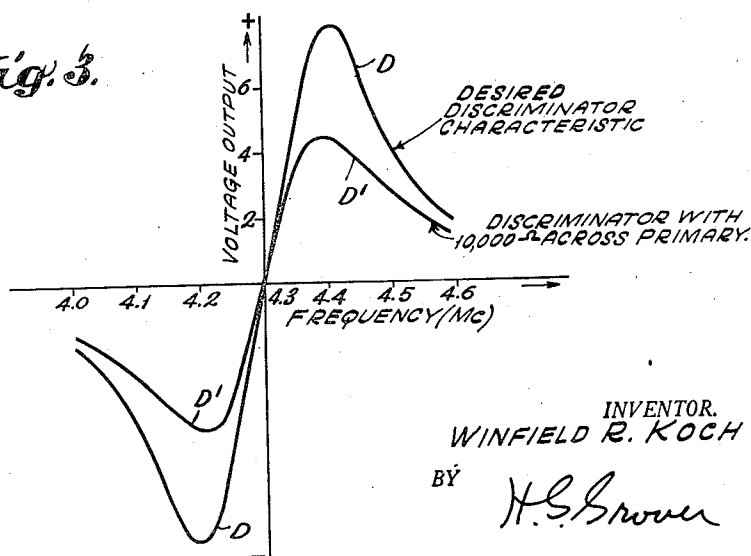


Fig. 3.



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Fig. 4.

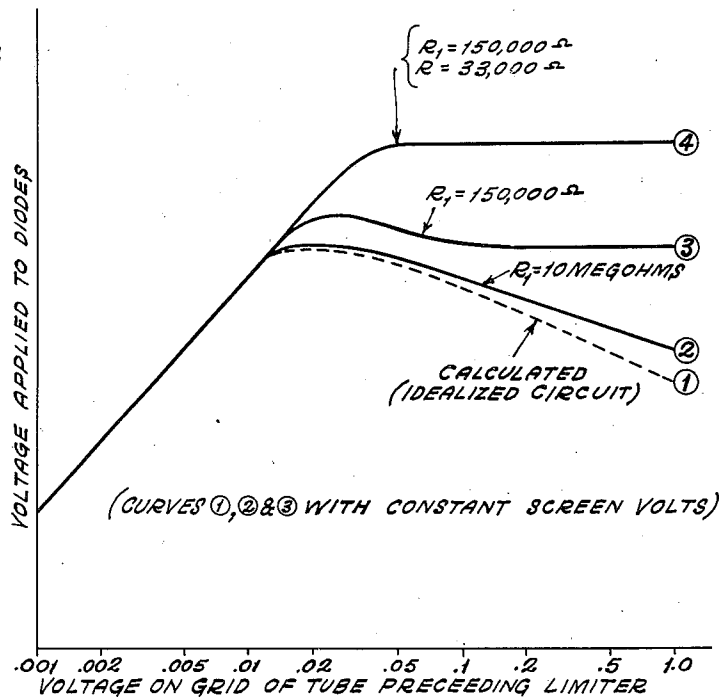
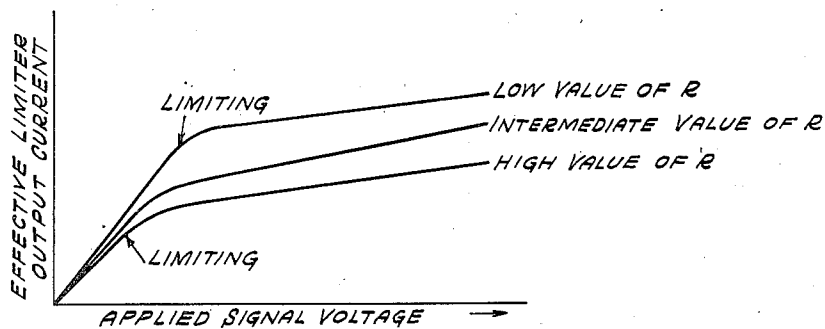


Fig. 6.



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4 Sheets-Sheet 3

Fig. 5a.

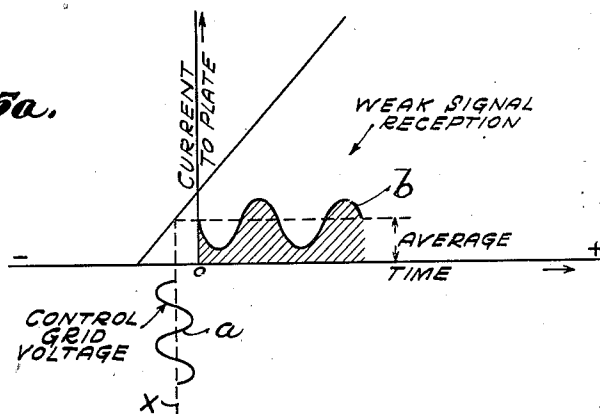


Fig. 5b.

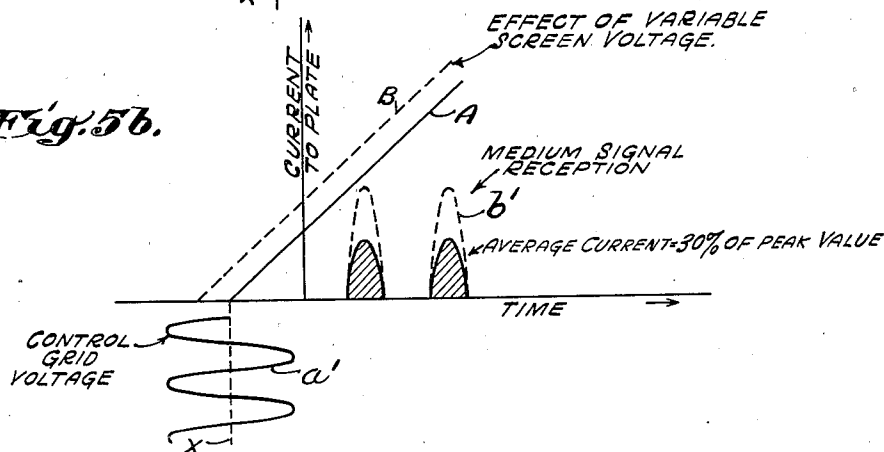
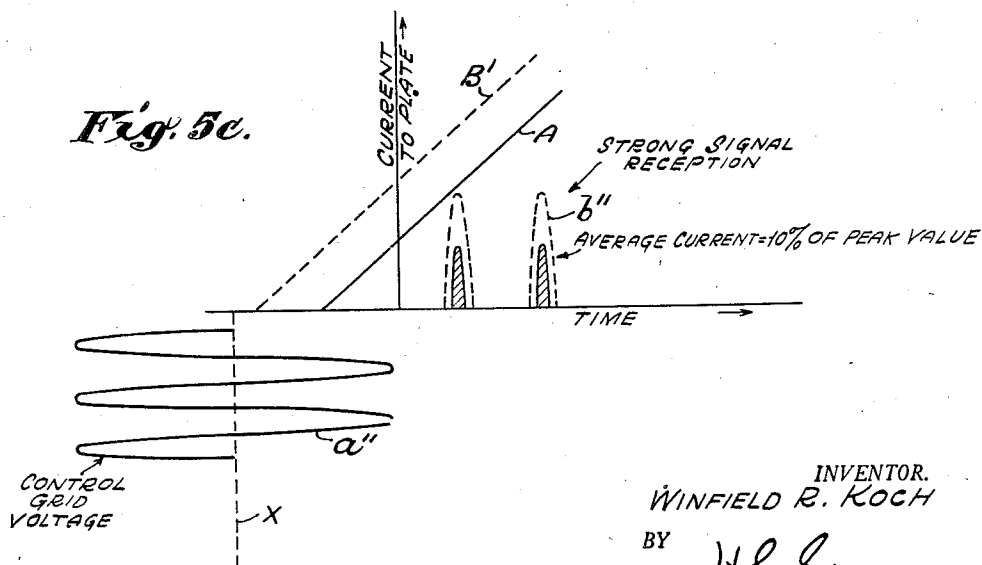


Fig. 5c.



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AMPLITUDE LIMITER CIRCUIT

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6 Claims. (Cl. 250—20)

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My present invention generally relates to amplitude limiting systems, and more particularly to amplitude limiter circuits adapted for use in receivers of angle modulated carrier waves.

In the reception of angle modulated carrier waves it is necessary that the demodulator of the receiver be presented with modulated carrier wave energy whose amplitude variations are an accurate representation of the angle modulations of the received waves. This is insured by employing an amplitude limiting device prior to the discriminator section of the demodulator to prevent undesired amplitude variations in the received angle modulated waves from causing a response in the output of the demodulator. The generic term "angle modulated" is to be understood as including frequency modulation (FM), or phase modulation (PM), or hybrid modulations having characteristics of both FM and PM. By way of specific illustration the present description will be explained in connection with a system for receiving FM carrier waves, although my invention is not restricted to such reception.

One of the most widely known and used forms of discriminator-rectifier circuits is that disclosed and claimed by S. W. Seeley in his U. S. Patent No. 2,121,103, granted June 21, 1938. As commonly used in accordance with the Seeley patent, the discriminator section comprises a pair of coupled resonant circuits each tuned to a predetermined operating frequency (usually the intermediate frequency of a receiver of the widely-used superheterodyne type). The amplitude limiter tube usually includes in the plate circuit thereof the primary of the two coupled circuits, while a pair of opposed rectifier devices are connected to opposed ends of the secondary circuit coil which is center-tapped. The rectified voltages of the rectifier devices are combined in polarity opposition, and the resultant voltage is accurately representative of the frequency variations of the received FM waves.

The well known frequency deviation vs. voltage output characteristic of the Seeley demodulator system is generally an inclined, approximately linear characteristic whose upper and lower ends are bent in opposite directions. The linearity of the characteristic depends upon the degree of coupling between the primary and secondary circuits of the discriminator section, and the effective selectivity of these circuits. Usually the coupling is approximately critical coupling, under which condition the primary circuit voltage response has a pronounced double hump. Unlike the normal I. F. transformers preceding the limiter tube, the response curve of the primary of the discriminator transformer is of large importance. The pronounced, double-hump response of the primary provides a "correction" for inherent central curvature in the normal fre-

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quency deviation vs. voltage output characteristic of the demodulator.

The amplitude limiters employed in the past with the Seeley discriminator, or more generally any discriminator wherein the primary one of coupled tuned circuits possesses a double-humped response curve, have generally been so constructed as inherently to alter under varying conditions of operation the optimum response curve of the discriminator primary circuit. For example, in one form of prior amplitude limiter circuit the object has been to maintain a constant signal voltage at the plate of the limiter tube. The effect of such a constant voltage source across the discriminator primary circuit is effectively to shunt the latter by a substantially zero impedance. As a consequence the response curve of the primary circuit is flattened out under conditions of operation which will herein-after be further described, and the voltage response characteristic of the secondary may approach that of a single tuned circuit. Because of this the linearity and length of the discriminator characteristic are reduced. Hence, the advantages of a pair of coupled tuned circuits are largely lost. The frequency deviation vs. voltage output characteristic will depend on the strength of the received FM waves, and for strong signal reception the characteristic will have a shorter length, and be of increased slope, than for weak signals.

It may, therefore, be stated that it is an important object of my present invention to provide an improved amplitude limiter, and, more particularly, an amplitude limiter which affords an output of uniform amplitude and which does not deleteriously affect the operation of the succeeding discriminator. More specifically, one of my objectives is to preserve under varying conditions of operation the desirable double-humped response curve of the primary circuit of the discriminator transformer by feeding FM waves thereto through an amplitude limiter tube circuit which possesses a substantially constant plate current characteristic in contradistinction to a constant plate voltage characteristic.

Another important object of my invention is to provide an amplitude limiter tube of the screen grid type, wherein the control grid and screen grid voltages are varied at a relatively fast rate in response to applied signals so as to maintain the plate current flow substantially constant over a range of signal voltage amplitudes above a predetermined value.

Another object of my invention is to provide an amplitude limiter whose tube has the plate thereof operated at a positive direct current voltage of relatively high value, while the tube is provided with a screen grid whose positive direct current voltage is lower than the plate voltage

and is varied at a relatively fast rate in response to relatively excessive increases in amplitude of applied high frequency currents thereby to maintain the signal frequency component of the plate current substantially constant.

Another object of my invention is to improve the efficiency and construction of FM receivers by improving the amplitude limiter operation and preventing the limiter from adversely affecting the desired response characteristic of the discriminator.

A more specific object of my invention is to provide an amplitude limiter tube whose signal input grid circuit and screen grid circuit each include resistor-condenser networks of relatively short time constants, and whose plate circuit contains only very small direct current impedance.

A further object of my invention is to provide an amplitude limiter tube of the type including a screen grid having means in circuit therewith to permit it to vary over a wide range of positive voltages thereby to co-operate in maintaining a substantially constant plate current, and other means being operative to prevent the screen voltage from becoming too low and causing the gain of the tube to fall for weak signals.

Still other objects of my invention are to improve amplitude limiter circuits for FM reception, and more particularly to provide a limiter-discriminator network of desirable characteristics.

Still other features of my invention will best be understood by reference to the following description, taken in connection with the drawing, in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows one embodiment of the invention;

Fig. 2 shows idealized response curves of the discriminator transformer;

Fig. 3 illustrates typical discriminator characteristics, both with and without the invention;

Fig. 4 shows limiter characteristics both calculated and experimental;

Figs. 5a, 5b, 5c show graphically the operation of the limiter tube for weak, medium and strong signals respectively;

Fig. 6 illustrates graphically the effect of varying the value of R in the screen grid circuit of the limiter tube;

Fig. 7 shows a modification of the system of Fig. 1, and

Fig. 8 illustrates a further modification of Fig. 1.

Referring now to the various figures of the accompanying drawings, wherein like reference letters and numerals in the different figures designate similar elements, there is shown in Fig. 1 so much of an FM receiver as is essential to a proper understanding of my invention. It is assumed that the limiter and demodulator of Fig. 1 are embodied in a superheterodyne receiver, since that form of receiver is most widely employed at present. The customary selective radio frequency amplifier, converter and I. F. amplifier precede the input transformer 1 which feeds the I. F. signals to the signal grid 2 of limiter tube 3. Those skilled in the art of radio communication, and more specifically FM communication, are fully aware of the details of circuit design prior to limiter tube 3. The received FM waves may have a carrier or center frequency in any of the known frequency bands allocated to FM or PM reception. The present FM broadcast range extends from 42 to 50 megacycles (mc.).

Assuming operation in the 42-50 mc. range, the

selector circuits of the receiver between the antenna and discriminator network will each be designed satisfactorily to pass a band of frequencies of the order of 200 kilocycles (kc.). This relatively wide band pass selector characteristic is required, because in compliance with present standards of FM broadcasting the maximum frequency deviation at each FM transmitter is up to 75 kc. on either side of the normal carrier frequency. As pass band width of 200 kc. insures the acceptance of the overall 150 kc. frequency swing of a selected modulated carrier. The frequency variations of the signal energy are, of course, representative of the modulation applied to the carrier wave at the transmitter, the extent of the frequency variation or deviation being proportional to the amplitude of the modulating signals while the rate of deviation is dependent on the modulation frequencies per se. Since a PM wave essentially differs from an FM wave in that the extent of frequency deviation is proportionately higher for the higher modulating frequencies, it will be clear that the FM receiver may be employed for detection of PM waves with de-emphasis correction subsequent to the demodulator.

Assuming, now, that there has been applied to the primary circuit 4 of I. F. transformer 1 the FM energy whose center or carrier frequency has been reduced to the I. F. value of 4.3 mc., each of circuits 4 and 5 is tuned to the I. F. value. The circuits 4 and 5 are coupled to provide a substantially band pass response characteristic about 200 kc. wide. As previously stated, this is also true of the selector circuits prior to transformer 1. Limiting is accomplished by means of tube 3, shown as a pentode tube by way of specific illustration. The cathode 6, either indirectly or directly heated, is preferably connected directly to ground, while the low potential side of input circuit 5 is connected to ground by a resistor R₁ shunted by condenser C₁. The magnitudes of these components R₁ and C₁ are so chosen as to provide a relatively short time constant. For example, and in no way restrictive, R₁ may be 150,000 ohms while C₁ may be 22 micro-microfarads. The control grid 2 is connected to the high alternating potential side of circuit 5.

The plate or anode 7 of limiter tube 3 is connected to operate at a relatively fixed direct current potential. Thus, the plate 7 is connected through the inductance 8 of the primary circuit P of the discriminator network to a point on a direct current source (not shown) having a potential of, for example, +250 volts. It will be observed that between the +250 volts point and the plate 7 there is no material direct current resistance, the direct current resistance of coil 8 being very small. This is the reverse of the construction of limiters well known in the prior art, wherein substantial resistance is deliberately introduced into the plate circuit to reduce the normal plate voltage to such a low positive value that the tube will readily saturate.

The screen grid 9 of tube 3 is connected to the +250 volts point through a resistor R whose upper end is connected to ground by condenser C. The values of R and C are so chosen that network R, C has a relatively short time constant. By way of specific example, and in no way restrictive, R may have a value chosen from a range of 33,000 ohms to 120,000 ohms. The condenser C may have a value of the order of 68 micro-microfarads. The normal no-signal voltage of the screen grid 9 will be relatively small

compared to the plate voltage. For example, the no-signal screen voltage may be as low as +70 volts. However, during signal reception the voltage of the screen will vary at a relatively rapid rate by virtue of the short time constant of network R, C. Here, again, the present limiter construction is the reverse of that employed in the prior art, since in the past it has usually been proposed to maintain the screen voltage invariable throughout signal reception while permitting the plate voltage to vary. The suppressor grid 10 is connected to the cathode 6 within the tube envelope, and performs its usual function of suppressing secondary electron emission from plate 7.

The coils 8 and 11 are of the respective primary and secondary windings of the discriminator transformer. Coil 8 and condenser 9' provide the resonant primary circuit P, while the secondary coil 11 and condenser 11' in parallel with it provide the resonant secondary circuit S. Each of circuits P and S is tuned to the operating I. F. value of 4.3 mc. These circuits are preferably coupled so as to provide a substantially double-humped response curve for the primary circuit P, while providing a band pass curve for the secondary circuit. The high alternating potential side of primary circuit P is connected to the mid-point of coil 11 through a direct current blocking condenser 12 which functions as a direct connection so far as the I. F. currents are concerned. In other words condenser 12 imparts no phase shift to the I. F. currents applied to the mid-point of coil 11.

The circuits P and S constitute a discriminator network of the type described in the aforesaid Seeley patent, and referred to herein as a "Seeley discriminator." It is relatively widely used in FM receivers, and its functions are well-known to those skilled in the art of radio communication. It is sufficient for the purposes of the present application to explain that at the instant when the applied I. F. energy has a frequency equal to the resonant frequencies of circuits P and S, then the signal voltage across circuit S will be 90° out of phase with the voltage across primary circuit P. This is due to the magnetic coupling between resonant circuits P and S. However, the connection including condenser 12 will also inject into the circuit S primary signal voltage which has not been subjected to any phase shift.

Due to the fact that the primary voltage is applied to the mid-point of coil 11, it will be seen that from each end of coil 11 to ground there will exist primary signal voltage in phase quadrature with the induced phase-shifted signal voltage, the induced voltages in each half of the secondary coil 11 being of opposite polarity. Hence, there will exist between each end of coil 11 and ground a resultant voltage which is the vector sum of the phase quadrature-related voltages across each half of secondary winding 11 and the primary voltage. These resultant voltages will be of equal magnitude at the instant when the I. F. energy applied to circuit P is equal to the resonant frequencies of the discriminator circuits. However, should the instantaneous signal frequency deviate or shift with respect to the predetermined reference frequencies of circuits P and S, then the resultant voltages at the opposite ends of coil 11 will become unequal because of phase changes away from the quadrature phase relation. The inequality will be dependent upon the magnitude

of frequency deviation from the reference frequency, while the direction of the inequality will depend upon the direction of frequency deviation. In this way the frequency-variable waves are translated or transformed into a pair of voltages which are equal in magnitude at the instant when the signal frequency is equal to the discriminator reference frequency, but which vary with respect to each other for frequency deviations from the center frequency. The function of the tube 13 is to provide a pair of rectifier devices for rectifying the aforesaid pair of variable voltages.

Tube 13, while shown by way of example as a 6H6 type tube embodying a pair of separate diodes, may be replaced by a pair of independent diode tubes or other suitable rectifiers. The anode 14 and cathode 15 of the upper diode device are connected between the upper side of circuit S and the upper end of load resistor 16. The lower diode device 17, 18 is connected between the grounded end of load resistor 19 and the lower side of circuit S. The midpoint of secondary coil 11 is connected by I. F. choke coil 20 to the junction of load resistors 16 and 19. Hence, the resultant I. F. voltage applied to anode 14 will be rectified, and the rectified voltage will appear across resistor 16. In the same way the resultant I. F. voltage applied to diode anode 17 will be rectified, and the rectified voltage will appear across resistor 19. Since the rectified voltages across resistors 16 and 19 are combined in polarity opposition relative to ground, the resultant potential at the end of resistor 16 connected to cathode 15 will be zero at the instant when the frequency of the applied FM waves is equal to the reference frequency of the discriminator circuits P and S, and will vary in magnitude and polarity depending upon the extent and direction of frequency deviation. The resistors 16 and 19 are each bypassed by suitable I. F. bypass condensers, and the modulation frequency component of the resultant rectified voltage is applied through coupling condenser 21 to any suitable audio frequency modulation amplifier network.

In Fig. 2 there are shown the primary and secondary response curves P_1 and S_1 of circuits P and S respectively. These curves are secured by plotting "frequency" as abscissa against "response" as ordinate. As explained previously, it is highly desirable to have the response curve P_1 markedly double-humped. The secondary response curve S_1 is relatively flat-topped with somewhat of a depression at its center. In practice the transformer windings 8 and 11 are coupled approximately to the critical coupling value, which provides the curve P_1 . It should be noted that the primary is coupled to the diodes 14, 15 and 17, 18 both through the transformer windings and through condenser 12. Because of the connection including condenser 12, the response curve of the primary circuit P (as well as the secondary circuit S) is important to the operation of the discriminator. The best overall discriminator characteristic, both as to linearity and length, is obtained when the response of primary P is substantially in accordance with the double-humped curve P_1 in Fig. 2.

In Fig. 3 the curve D relates "frequency" as abscissa against "voltage output" as ordinate. The portion of curve D between the peaks thereof is substantially linear by virtue of the correction introduced by the double-humped primary response curve P_1 . If, now, there occurs any flattening of the primary response curve, say to P_1'

(Fig. 2) the effect will be to change the overall discriminator characteristic from D toward or beyond the curve D' (Fig. 3). Such a change would be highly undesirable, since it shortens and otherwise deleteriously affects the linear portion of the discriminator characteristic.

Returning now to the limiter tube, the known arrangements of the prior art wherein a constant signal voltage is maintained at the limiter plate 7 may cause upon reception of signal energy of varying intensities approximately the change in primary response curve from P_1 to P_1' . This may be explained as follows. If the screen grid voltage is maintained invariable, and the direct current plate voltage is permitted to vary in order to provide a constant signal voltage output from the primary circuit, there is provided the equivalent of a zero impedance across the primary winding 8. That is, no matter what impedance is put in the plate circuit of tube 3 the voltage across it will be the same. Since this means in effect that the primary 8 is being shunted by a very low resistance, the effect is greatly to dampen the primary response curve. Hence, the desirable double-humped curve P_1 may in the reception of strong signals be changed to the relatively flattened response curve P_1' . At the same time the selectivity due to circuit P will largely be cancelled, and the tendency will be for the secondary circuit S alone to supply selectivity whereby the discriminator transformer will act like a single tuned circuit with a rounded top, instead of the relatively flat top S_1 of Fig. 2. If the voltage across the primary of the discriminator transformer were held constant, the overall discriminator characteristic would depend on the strength of the received signal, would be narrow for signals strong enough to cause limiting, and might actually change from curve D to one even worse than D'. If, on the other hand, as in the use of my invention, the limiter plate voltage is kept high so that it never swings over the knee of the plate-current vs. plate-voltage characteristic, the discriminator characteristic will remain like D.

What is desired, however, is a constant signal frequency current in the plate circuit of the limiter tube. This corresponds to a very high plate resistance of the limiter tube. If this is many times as high as the impedance of the primary circuit P, as is usually the case, then the overall discriminator characteristic D will be the same for weak signals as for strong signals. Further, the linearity of the characteristic will be preserved, since the desirable double-humped response curve P_1 will be maintained and will not be degenerated to response curve P_1' .

I secure the desired limiter action by the relatively simple arrangement shown in Fig. 1. The resistor R in the screen voltage lead and associated condenser C cause the screen voltage to vary at a fast rate so that carrier amplitude variations due to amplitude modulation will vary the electron flow to the plate 7 in a manner to maintain a substantially constant signal frequency plate current. In Fig. 4 I have shown four curves secured by plotting "voltage on grid of tube preceding limiter" as abscissa against "voltage applied to diodes" as ordinate. Curve 1 is a calculated curve using an idealized tube characteristic with an invariable screen voltage, but with $R_1=10$ megohms. In other words, R is not in circuit with the screen grid 9, and the condenser C is removed. Also no plate limiting impedances are employed. The "calculated" curve shows that the output of the limiter tube drops appreciably

as the signal voltage rises above the threshold value of 0.02 volt on the preceding grid. Curve 2 shows the actual characteristic secured with $R_1=10$ megohms.

Upon decreasing the value of R_1 to 150,000 ohms and C_1 being chosen as 22 micro-microfarads (and elements R and C still being omitted), the improved limiter characteristic depicted by curve 3 is obtained. Reducing the grid resistor value caused the excessive droop of curve 2 to be reduced. However, there is still a substantial droop in the horizontal part of the characteristic. The effect of introducing suitable resistance, shunted by suitable capacity, into the screen grid circuit is shown by curve 4. Here the resistor R is given a value of 33,000 ohms, and C is chosen of the order of 68 micro-microfarads; R_1 is 150,000 ohms and C_1 is 22 micro-microfarads. The limiter characteristic is now flat above the signal input voltage of 0.04 volt on the grid at the preceding tube. My present view is that what has been done is that the screen grid has been given a rapid time constant so that it functions in the manner of a fast-acting automatic gain control element and provides self-regulation of the limiter tube, augmenting the fast-acting gain control action of the grid 2 caused by network R_1 and C_1 in the grid circuit. A point involved in my invention is that grid circuit limiting alone does not give a uniform output from the limiter-discriminator circuits for different intensities of applied signal voltages. Plate circuit limiting when used with grid circuit limiting changes the discriminator characteristic. By including a fast time constant resistor-condenser combination in the screen grid circuit, the limiter can be made to give a uniform output, and the discriminator characteristic can be maintained without change at varying signal intensities.

The magnitude of screen resistor R determines the threshold or limiting point of the limiter tube. In order to provide limiting action at as low an input voltage as possible, a low normal screen voltage is desired. This necessitates a relatively high value of R. Hence, in Fig. 6 I have shown a family of "applied signal voltage" vs. "effective limiter output current" curves to show the effect on the limiting point of the magnitude of R. At lower initial or normal operating voltages of the screen grid, say +70 volts for example, the limiting will commence at lower signal input voltages. It is desirable, therefore, to use higher values (say of the order of 120,000 ohms) for R when receiving weak signals than when receiving strong signals. There could be provided an adjustment for the value of R so as to permit the set operator to adjust the limiting point depending upon the reception area he finds himself in. It will be noted from Fig. 6 that the value of R may be chosen in order to provide the flattest limiting characteristic, or a second value may be chosen which will start limiting sooner for weaker signals, but which will not be quite so flat.

Since it is highly desirable to provide the networks R, C and R_1 , C_1 with as short time constants as possible, it may be found under some conditions that condensers C and C_1 do not have sufficiently low impedances for optimum operation. In Fig. 7 I have shown means enabling use of a time constant of each of R, C and R_1 , C_1 while using condensers C and C_1 which might otherwise present more than the desired impedance. Each of condensers C and C_1 is shunted by a series-resonant circuit consisting of a coil

30 and 30' and condenser 31 and 31' respectively, each tuned to the operating I. F. value. These respective series-tuned circuits 30, 31 and 30', 31' provide a very low impedance for the I. F. current. The condensers C and C₁ are necessary to bypass harmonics, but can be of smaller capacity and consequently higher impedance than where the series-tuned circuits 30, 31 are not used. The time constants used should be short enough to insure that limiting will be the same for all rates of amplitude variation from very slow up to the upper limit of audibility. It may be possible, if desired, to dispense with each of C and C₁ when using the respective series-tuned circuits 30, 31 and 30', 31'.

It may be desirable to prevent the screen voltage from becoming too low and thereby dropping the gain for weak, or low amplitude, input signals. By employing diode 40, shown in Fig. 8, in association with screen grid 9 it is possible to use a higher value for screen resistor R than would normally be the case without the diode. The higher the value of R the lower the value of signal input voltage for which limiting begins. Diode 40 has its cathode connected to the screen grid end of R while its anode is connected to a suitable point 42 on potentiometer resistor 41 connected between the +B voltage terminal and ground. Hence, point 42 is normally less positive than the +B end of resistor 41. A condenser 43 bypasses point 42 and the diode anode to ground for I. F. currents. The signal grid network R₁, C₁ is shown in an electrically equivalent arrangement relative to that shown in Fig. 1. The diode 40 is normally conductive for weak signal input to circuit 5. Hence, the voltage of screen 9 will be at the potential of point 42 during weak signal inputs. However, when the input voltage at signal grid 2 becomes stronger the screen current through R becomes less, with the result that the cathode of diode 40 may for rapidly recurring potentials become more positive than its anode, inasmuch as the latter is grounded for I. F. currents, thereby disconnecting the screen grid 9 from point 42. The full voltage across the series resistor R is, therefore, applied to the screen grid, and the limiter tube from this point on acts as it does in the circuit of either Fig. 1 or Fig. 7. Diode 40, therefore, provides a controlled minimum screen voltage for the limiter tube, but without affecting the plate voltage.

Regardless of whether or not the modifications of Figs. 7 and 8 are used, the limiter circuit of my present invention functions to provide a substantially uniform and constant signal frequency current in the plate circuit of the limiter tube. This corresponds to a very high plate resistance of the limiter tube. It is preferred that the plate resistance of the limiter be many times as high as the impedance of primary circuit P. In this way the desirable response curve P₁ shown in Fig. 2 will be maintained.

In Figs. 5a, 5b and 5c I have graphically and ideally shown the manner in which the limiter tube acts to maintain the desirable constancy of signal frequency current in its plate circuit. Each of these figures shows "control grid voltage," i. e., signal voltage on grid 2, plotted against "current to plate" and also plate current as against "time." For weak signal reception the curve *a* in Fig. 5a depicts signal wave voltage applied to the signal grid 2 of limiter tube 3. The signal grid is normally at ground potential. Upon the signal energy charging the grid 2 positive during the first few positive cycles thereof, grid current flows and

produces a voltage across R₁ thereby charging condenser C₁ negative. This negative bias, indicated by broken line X, of grid 2 determines the operating point of the tube. As the signal passes through its alternate negative and positive cycles, the screen and plate currents each will follow the curve *b* as to contour, the plate current in the tubes which I have used being, however, of the order of four times the screen grid current.

Upon the signal intensity increasing to *a'*, for example as shown in Fig. 5b, the negative bias for grid 2 increases to the point where the tube characteristic looks like a class B amplifier characteristic. The positive half of each signal wave produces a rectified plate current pulse *b'*. Since the time constant of R₁, C₁ is fast, the bias on grid 2 will quickly follow the signal amplitude variations, i. e., will become more negative as indicated in Fig. 5b by the line X being moved further to the left. The fast-acting control network R, C will function to provide a gain control voltage due to screen current flow decrease which tends to reduce the drop in resistor R, causing higher screen voltage which in turn tends to prevent a reduction in instantaneous plate current flow. This effect is also shown in Fig. 5b which indicates that such increase in the positive screen voltage raises the plate current curve from the full line A to the broken line B. This allows the plate current upon a positive half-cycle of signal voltage to be in accordance with the broken line *b'* in Fig. 5b instead of the shaded area which shows what the operation would be if the resistor R were not present in the screen grid circuit. This further means that the signal frequency current in the plate circuit is increased from that corresponding to curve 3 of Fig. 4 to that corresponding to curve 4 of that figure. In other words, each fast change in screen voltage causes the tube to operate along a new characteristic of the family of possible plate current-control grid (grid 2) characteristics. The gain control by the screen grid is in a sense to oppose the signal carrier variations due to amplitude modulation which would otherwise occur following curve 3 in Fig. 4. Although the peak value of plate current has been increased in Fig. 5b over Fig. 5a, the average plate current tends to remain uniform because the average plate current, under the conditions of Fig. 5b, will be only of the order of 30% of peak value, as compared with a much larger percentage in Fig. 5a. This is largely due to the breaks in the plate current as the negative grid potential reaches or exceeds cut-off value.

In Fig. 5c there are shown the curves *a''* and *b''* for strong signal reception. The tube now acts in the manner of a class C amplifier, and the average plate current may be only 10% of peak value or less. The effect of the fast-acting gain control by the variable screen voltage is again shown. It will be noted that the plate current-control grid characteristic has been raised further to the position B', and the bias line X has been moved still further negative. The rise in the plate current peaks is compensated by increased time spacing between the plate current pulses. The shaded area again illustrates the decreased plate current which would result if resistor R were omitted from the screen grid circuit.

Summing up the action of the limiter tube Figs. 5a, 5b and 5c show that as the applied signal amplitude increases, the average screen current decreases by reason of the increased negative bias on grid 2. The voltage drop across the screen resistor R is dependent on the average screen cur-

rent flowing through the resistor. Consequently when the average screen current decreases, the effective screen voltage increases by virtue of a decrease in voltage drop across the screen resistor. This tends to increase the average screen current. The higher screen voltage, also tends to bring up the average plate current. The overall action is such as to tend to maintain a constant average plate current. This, in turn, will tend to produce a signal frequency component of the plate current that is uniform for all input amplitudes above the threshold value. So far as the relations between the R, C networks in the control grid circuit and screen grid circuit are concerned, it may generally be stated that the time constant in the screen grid circuit is relatively faster than that in the control grid circuit. Generally speaking both time constant networks may be chosen from a range of the order of 1 to 10 microseconds.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention.

What I claim is:

1. In combination between a source of frequency modulated wave energy and a frequency discriminator circuit having a predetermined response characteristic, an amplitude limiter tube including a cathode, signal grid, plate and auxiliary cold electrode adjacent the plate, means for applying a positive potential to each of the auxiliary cold electrode and the plate, means in circuit with each of said signal grid and auxiliary cold electrode for providing a fast-acting gain control over the limiter tube for carrier amplitude variations in excess of a predetermined value, and means in circuit with the auxiliary electrode for providing a controlled minimum voltage therefor.

2. In combination between a source of frequency modulated wave energy and a frequency discriminator circuit having a predetermined response characteristic, an amplitude limiter tube including a cathode, signal grid, plate and auxiliary cold electrode adjacent the plate, means for applying a positive potential to each of the auxiliary cold electrode and the plate, means in circuit with each of said signal grid and auxiliary cold electrode for providing a fast-acting gain control over the limiter tube for carrier amplitude variations in excess of a predetermined value, said last means consisting of a resistor and a condenser cooperating to provide a relatively short time constant, and a series resonant circuit, tuned to the center frequency of said wave energy, electrically connected to each resistor and associate condenser for rendering more rapid each time constant.

3. In a system for receiving frequency modulated carrier wave energy, an amplitude limiter tube provided with a cathode, a signal grid, a plate and a screen grid interposed between the signal grid and plate, a signal input circuit connected between said signal grid and cathode, a frequency discriminator comprising a primary circuit and a secondary circuit tuned to a common frequency, said primary and secondary circuits being coupled to impart a substantially double-humped response curve to the primary

circuit, means for establishing said plate at a substantially constant positive potential of relatively high magnitude, a first resistor and condenser network in circuit with said signal grid and cathode providing a relatively short time constant, a second resistor and condenser network in circuit with said screen grid for providing a relatively shorter time constant than the first time constant and auxiliary means in circuit with said screen grid providing a controlled minimum voltage therefor.

4. In combination between a source of frequency modulated wave energy and a frequency discriminator circuit having a predetermined response characteristic, an amplitude limiter tube including a cathode, signal grid, plate and auxiliary cold electrode adjacent the plate, means for applying a positive potential to each of the auxiliary cold electrode and the plate, means in circuit with each of said signal grid and auxiliary cold electrode for providing a fast-acting gain control over the limiter tube for carrier amplitude variations in excess of a predetermined value, and diode means in circuit with said auxiliary cold electrode for providing a controlled minimum voltage therefor.

5. In combination between a source of frequency modulated wave energy and a frequency discriminator circuit having a predetermined response characteristic, an amplitude limiter tube including a cathode, signal grid, plate and auxiliary cold electrode adjacent the plate, means coupling said grid to said source, means for applying a positive potential to each of the auxiliary cold electrode and the plate, means in circuit with each of said signal grid and auxiliary cold electrode for providing a fast-acting gain control over the limiter tube plate current, for carrier amplitude variations in excess of a predetermined value, said last means consisting of a resistor and a condenser co-operating to provide a relatively short time constant, and means connected to each resistor to render more rapid each time constant.

6. In combination between a source of frequency modulated wave energy and a frequency discriminator circuit having a predetermined response characteristic, an amplitude limiter tube including a cathode, signal grid, plate and auxiliary cold electrode adjacent the plate, means for applying a positive potential to each of the auxiliary cold electrode and the plate, means in circuit with each of said signal grid and auxiliary cold electrode for providing a fast-acting gain control over the tube space current for carrier amplitude variations in excess of a predetermined value, said frequency discriminator consisting of a primary circuit and a secondary circuit coupled to impart a double-humped characteristic to the primary circuit, and means operatively associated with the means in circuit with the auxiliary cold electrode to provide a controlled minimum auxiliary cold electrode voltage.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
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