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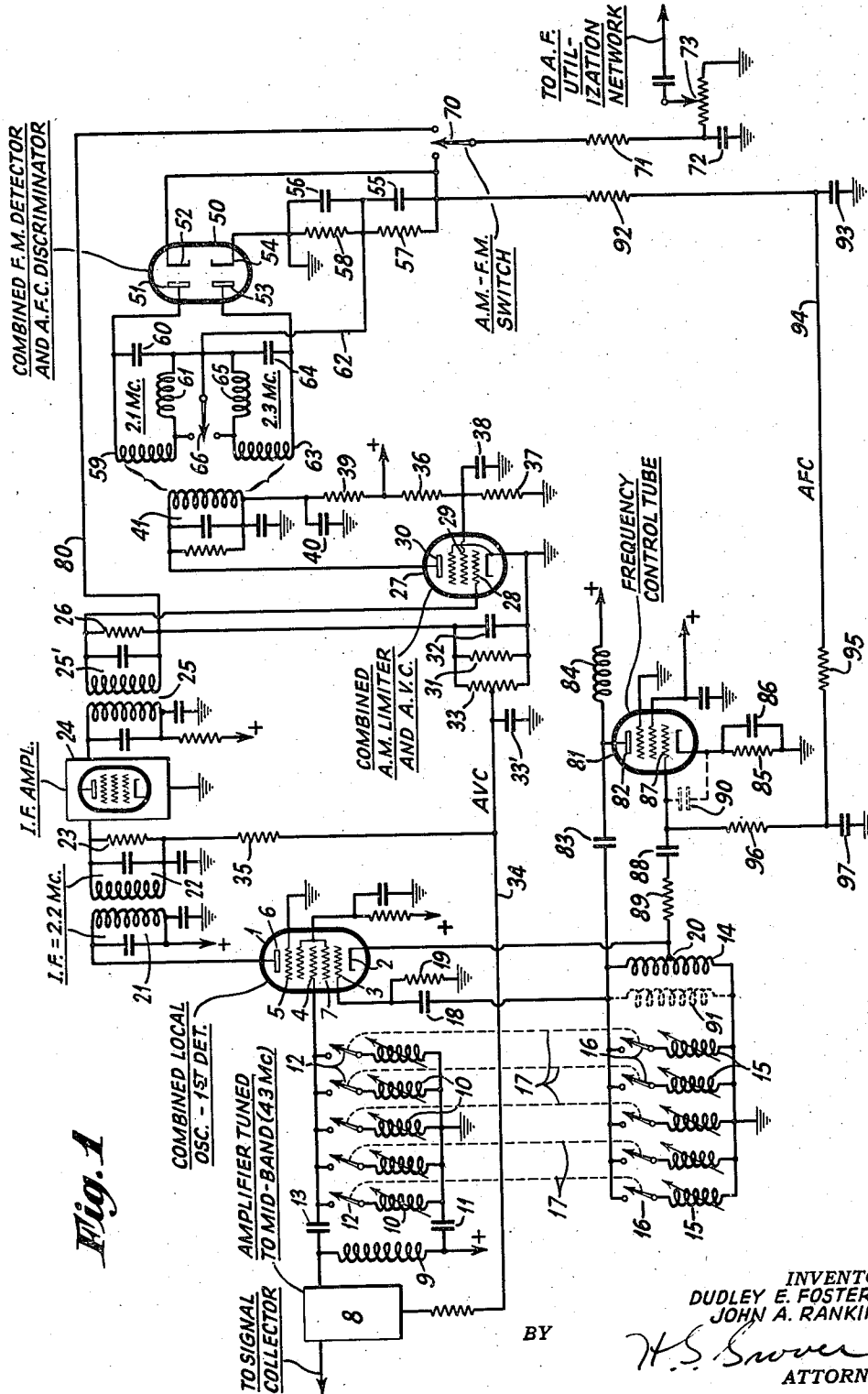
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2,273,097

FREQUENCY MODULATED WAVE RECEIVER

Filed Feb. 20, 1940

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

Fig. 2

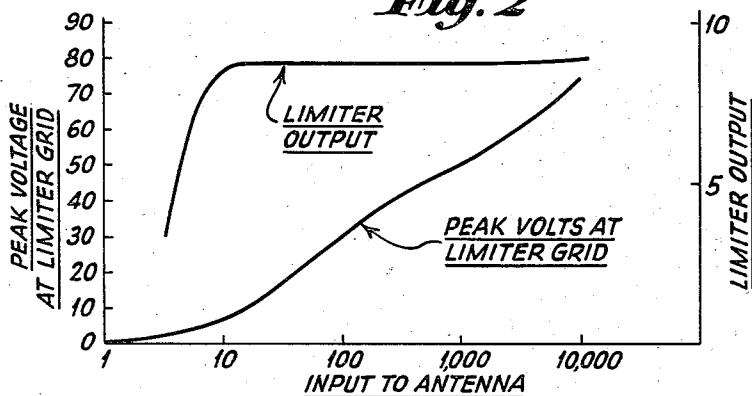


Fig. 3

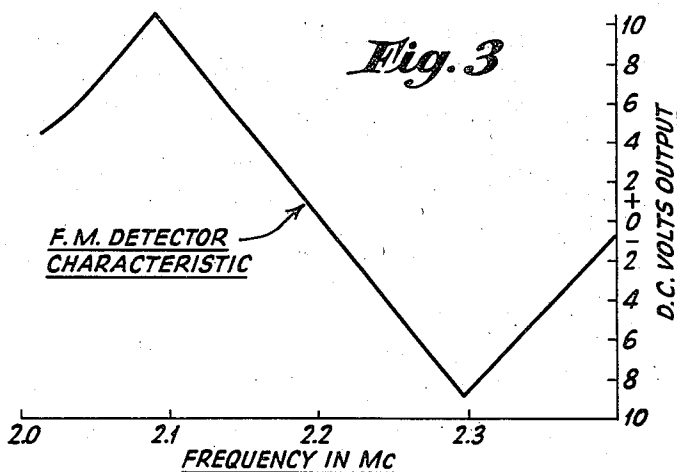
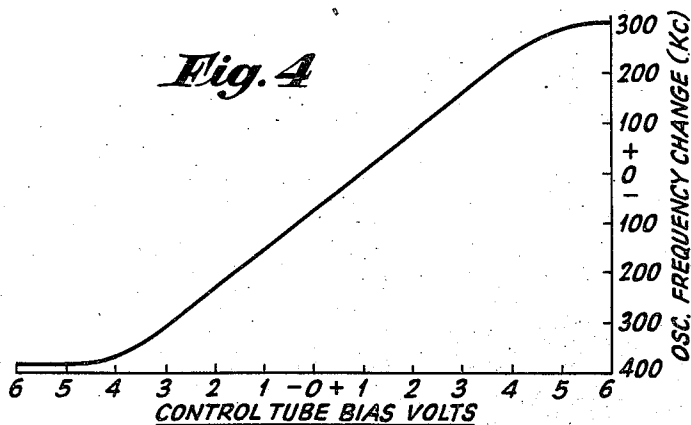


Fig. 4



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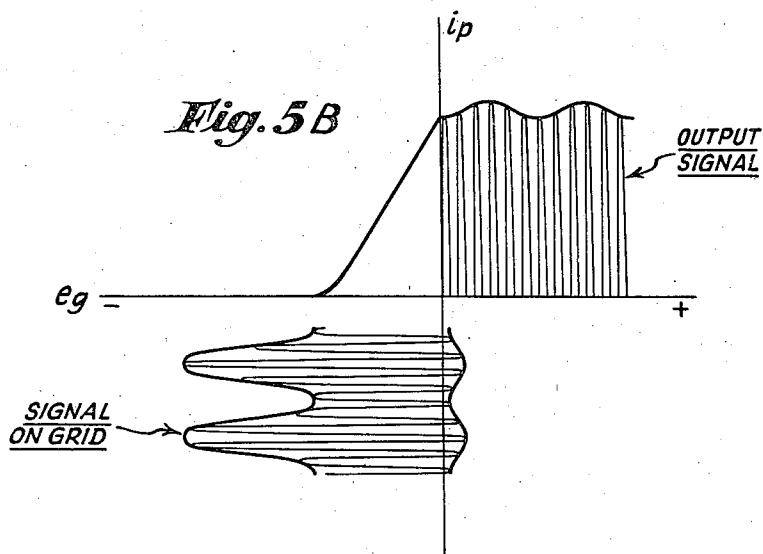
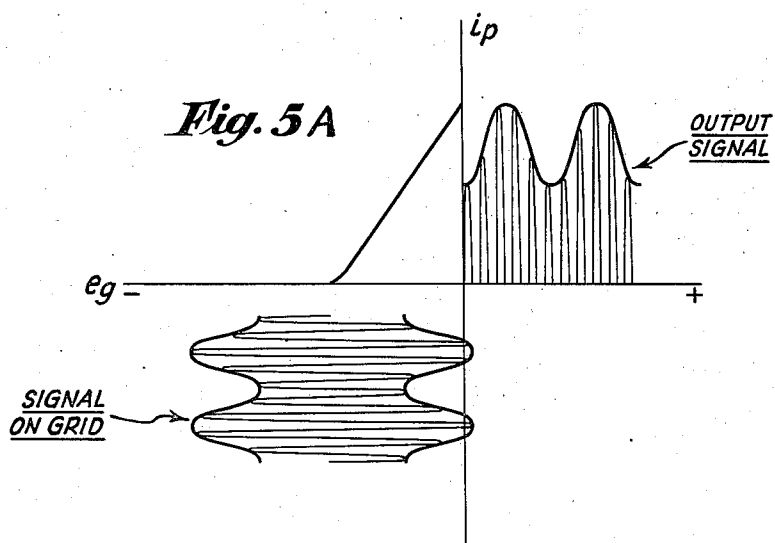
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FREQUENCY MODULATED WAVE RECEIVER

Filed Feb. 20, 1940

3 Sheets-Sheet 3



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2,273,097

FREQUENCY MODULATED WAVE RECEIVER

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Application February 20, 1940, Serial No. 319,830

11 Claims. (Cl. 250—20)

Our present invention relates to radio receivers of the ultra-high frequency type, and more particularly to a system adapted to receive frequency modulated waves.

In co-pending application Serial No. 320,103, filed February 21, 1940, by D. E. Foster there is disclosed a frequency modulated wave (hereinafter referred to briefly as FM) receiver adapted to receive signal waves located in the ultra-high frequency band of 42.6 to 43.4 megacycles (mc.). The receiver is of the superheterodyne type, and utilizes push-button tuning for a plurality of channels within the aforesaid operating band, or range. Automatic frequency control (AFC) is there employed to minimize the effect of frequency drift.

An important object of our present invention is to improve the limiter network operation of an FM receiver; the grid circuit of the limiter tube providing grid-current developed bias across a time constant network whose discharge time constant is not too large to follow amplitude fluctuations of the highest frequency it is desired to limit.

Another important object of this invention is to provide in an FM receiver an improved detector of the back-to-back type consisting of two tuned circuits and associated rectifiers connected in phase opposition, and wherein the tuned circuits may be off resonance with respect to a predetermined operating intermediate frequency (I. F.) and yet be readily and simply aligned.

Still another object of our invention is to provide, in an ultra-high frequency receiver, an AFC circuit utilizing an improved frequency control tube circuit which is adapted to provide a simulated inductive effect across a local oscillator tank circuit without damping effect on the latter.

Other objects of our invention are to improve generally the simplicity and efficiency of ultra-high frequency signal receivers, and more particularly to provide an FM receiver capable of being economically manufactured and easily assembled.

The novel features which we believe to be characteristic of our invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawings in which we have indicated diagrammatically a circuit organization whereby our invention may be carried into effect.

In the drawings:

Fig. 1 shows a circuit diagram of an FM receiver embodying our invention,

Fig. 2 graphically shows the limiter characteristics,

Fig. 3 illustrates the FM detector characteristic,

Fig. 4 graphically shows the frequency control characteristic of the AFC tube.

Fig. 5A illustrates the effect on the limiter action of a discharge time constant which is too long,

Fig. 5B shows the improvement secured in the limiter action when employing our invention.

Referring now to the accompanying drawings, and specifically to Fig. 1, the networks of the FM receiver up to the limiter tube may be similar to those described and claimed in the aforesaid Foster application. Hence, such networks will be only generally described in this application. The tube 1, of the 6SA7 type, is a pentagrid converter tube provided with a cathode 2, oscillator grid electrode 3, signal input electrode 4, a grounded suppressor grid 5, an output electrode 6 and positive screen grids 7 surrounding the signal grid 4.

The collected signal energy is impressed upon a radio frequency amplifier which is tuned to the mid-band frequency. Since the complete frequency band is 42.6 to 43.4 mc., then the mid-band frequency of amplifier 8 is 43 mc. The signal collector can be a dipole, and at the output terminals of amplifier 8 there will be present in amplified form the various modulated carrier waves in the desired frequency band. By having the input circuit of the amplifier 8 of the bandpass type and covering the entire spectrum of frequencies desired, there will be developed across the signal input circuit coil 9 voltages of the various frequencies in the desired signal frequency band. Channel selection is accomplished by providing in shunt with coil 9 five independent channel selection coils. Each of the coils 10 is shown with an arrow passing therethrough, and it is to be understood that the arrow denotes the fact that the inductance value of each of the coils is adjusted by the utilization of an adjustable brass cylinder, as disclosed in the aforesaid Foster application.

The grounded terminals of each of coils 10 is connected to the low potential end of coil 9 through a direct current blocking condenser 11, while the opposite ends of each of coils 10 are connected to the adjustable contact arms of each of a plurality of push-button switches 12. The

contact points of each of switches 12 are connected to the signal grid lead, and the direct current blocking condenser 13 is inserted between the high potential terminal of coil 9 and the contact points of switches 12. It will be understood that the value of each of coils 10 is adjusted so that upon closing of a particular one of push-buttons 12 there will be selected from the band of impressed signal energy solely signal voltage of the channel frequency representative of the particular push-button depressed.

The tunable oscillator tank circuit is constructed in a manner similar to the signal input circuit just described. That is to say, the tank circuit coil 14 has connected in shunt therewith a plurality of independent channel selection coils 15, and the latter coils are constructed in the same manner as explained in connection with coils 10. The push-button switches 16 are connected so that closing of a particular push-button connects the corresponding coil 15 in shunt with the tank coil 14. The oscillator tank circuit frequency range is higher than the signal input frequency range, and is constantly different therefrom by the value of the operating I. F., which is chosen to be 2.2 mc. The dotted line 17 is to be understood as symbolically representing the mechanical couplings between each corresponding pair of switches 12 and 16. That is to say, each of switches 12 has a corresponding tank circuit switch 16, and they are closed in pairs to effect channel selection. The channels themselves are arranged at intervals of 0.2 mc.

The oscillator grid 3 is connected to the high potential end of coil 14 through a condenser 18, while the resistor 19 connects the grid end of condenser 18 to ground. The low potential end of coil 14 is established at ground potential, and the cathode 2 of tube 1 is connected to an intermediate tap 20 on the oscillator tank coil 14. There is developed across the I. F.-tuned output circuit 21 the FM wave energy which has been selected at the input circuit, but the mid-channel frequency has the I. F. value of 2.2 mc. It is not believed necessary to describe the manner in which I. F. voltages are developed by the converter tube, since those skilled in the art are fully aware of the manner of functioning of an electron-coupled converter of the type shown herein. The tube 1 and its associated circuits provide the well known form of electron-coupled combined local oscillator and first detector network.

The I. F. signal energy is transmitted through the bandpass network which comprises circuits 21 and 22 each fixedly tuned to the I. F. of 2.2 mc., it being pointed out that a resistor 23 is shunted across secondary circuit 22 in order to provide a wide band transmission network which is readily able to handle a wide band of I. F. energy. While the I. F. value may be generally chosen in the range of 2 to 4 mc., it is preferred to select an I. F. value of 2.2 mc., the band width being of the order of 200 kilocycles (kc.). In general, the coupling between each of the I. F. transformer circuits is so adjusted that the desired band width is attained with the secondary damping resistor 23. The numeral 24 denotes an I. F. amplifier stage, and the tube employed may be of the same type as employed in stage 8, and an additional I. F. amplifier stage may follow tube 24 if desired. Each of these amplifier tubes may be, for example, of the 6AC7 type.

The amplified I. F. energy is then transmitted through the I. F. transformer 25 which feeds the input electrodes of the limiter tube. The transformer 25 has its primary and secondary circuits each fixedly resonated to the operating I. F. value, and the secondary damping resistor 26 performs a function similar to that described in connection with resistor 23. The numeral 27 denotes the 6AC7 type limiter tube. By virtue of its associated circuits this tube functions as a combined amplitude modulation (AM) limiter and automatic volume control (AVC) stage. The function of the limiter tube is essentially substantially to eliminate any amplitude modulation effect in the output thereof. That is to say, since the energy applied to the following FM detector should be a pure FM wave, it is necessary to subject the output of the I. F. amplifier to a limiting device in order to suppress any amplitude modulation which may have appeared on the envelope of the FM carrier wave. In brief, then a limiter stage is a device whose output is constant for wide variations in the amplitude of the applied signal. However, this is necessary only because of the inherent limitations of the detector, and thus the limiter might properly be considered as an integral part of the detection circuit.

Considering, first, the electrical connections to the electrodes of the limiter tube, the cathode is established at ground potential, while the low potential end of the input circuit 25' is connected to the grounded cathode through a resistor 31 shunted by condenser 32. The signal input electrode 28 of the limiter tube is connected to the high potential end of the input circuit. Across resistor 31 is developed a direct current voltage which is derived from the grid current flow of the limiter tube. The direct current voltage is utilized as a bias for grid 28, and for a function to be later described. The voltage is, furthermore, employed for securing AVC action, and for this purpose there is shunted across resistor 31 a second resistor 33, an intermediate point thereof being connected to the lead 34 designated as "AVC."

Those skilled in the art are fully aware of the manner of utilizing an AVC circuit, and it is only necessary to point out that lead 34 applies the AVC bias to the signal grids of each of amplifiers 8 and 24 through filter resistors 35. The applied AVC bias acts to increase the effective signal grid bias of each of the controlled amplifiers so as to reduce the gain of each of the controlled amplifiers. In this way it is possible to maintain the selected mid-channel frequency amplitude at the input circuit 25' at a desired amplitude. As mentioned in the aforesaid Foster application each of the controlled amplifiers preferably includes a degenerating resistor in its cathode circuit in order to prevent detuning effects on the controlled amplifier input circuits due to the variable signal grid biasing action of the AVC circuit.

The screen grid 29 of tube 27 is connected to the source of positive voltage which also supplies the plate 30 through a resistor 36, the screen grid, furthermore, being connected to ground through a second resistor 37, the screen grid end of the resistor 37 being by-passed by a condenser 38. The plate 30 is connected to the positive potential source through a resistor 39 whose plate end is, also, by-passed to ground through a condenser 40. Across the I. F.-tuned

output circuit 41 there is developed I. F. energy practically free of amplitude modulation on its modulation envelope. A damping resistor may be shunted across the circuit 41 in order to impart the desired wide band characteristic thereto. The AM limiter operates with grid current-developed bias and with reduced screen potential to secure limiting action on both the positive and negative halves of the wave envelope. The limiting on the positive half of the wave envelope is due to the developed grid bias fluctuations, and on the negative half of the wave the limiting action is secured by virtue of plate current cut-off. The action of the limiter and the reasons for the choice of circuit constants can better be understood by reference to Figs. 5A and 5B.

Resistor 31 and condenser 32 determine the time constant on discharge. Resistor 26 is the secondary circuit damping resistor. Resistors 37 and 36 comprise the bleeder for fixing the screen potential, and hence the plate current characteristic. The time constant for charging condenser 32 is determined by the value of the condenser and the value of the charging resistance. The equivalent resistance on the charge portion of the cycle is due to resistor 26, the I. F. transformer impedance, and the limiter tube.

If the discharge time constant of 31-32 is too long, amplitude variations in the positive direction will not be limited, as is graphically shown in Fig. 5A. This figure represents a condition when the discharge time constant is appreciably longer than the charge time constant, and is long in comparison with the time of amplitude variation cycle. The signal on the limiter input grid is seen to consist of a carrier with amplitude modulation imposed thereon. Under these conditions the bias developed across the resistor 31 will be proportional to the peak signal, and only the tips of the applied wave draw grid current. The negative half of the envelope is seen to swing beyond plate current cut-off so that amplitude variations in that direction do not appear in the output. However, amplitude variations in the positive direction do appear in the output signal.

The condition when charge and discharge time constants are made sufficiently short to follow variations in amplitude at modulation rate, but are still long compared to the time of a carrier frequency cycle, are illustrated in Fig. 5B. Under such conditions the bias, developed by the grid current, changes during the amplitude variation cycle. The grid of the limiter tube acts like a diode, and if it were an efficient diode only enough grid current would be drawn from the charging source to supply the necessary bias, and the positive peaks of the wave would be "lined up" along the zero grid potential axis. Due to the fact that no diode is perfect, and the fact that the charge source has some resistance, some variation in positive direction still exists, but much reduced over the condition shown in Fig. 5A.

Under the conditions of Fig. 5B, when the signal is sufficiently large to swing in a negative direction beyond plate current cut-off, the limiting is obtained on both halves of the wave envelope. The charge time constant is usually sufficiently small, but attention must be paid to the value of the discharge resistance 31 and the capacitor 32 so that their product is not too large to follow amplitude fluctuations of the highest frequency it is desired to limit. For example, if it is desired to limit amplitude modulation fluctuations up to 10,000 cycles per second,

then network 31-32 should be of the order of the time of $\frac{1}{4}$ cycle of that wave, or 25 micro-seconds. This value is still large compared with the time of the 2 mc. intermediate frequency cycle, in other words, 0.5 micro-seconds, so it will not vary at the carrier rate. It is for this reason that there should be employed limiter discharge time constants of the order of the 1 to 25 micro-seconds.

If applied I. F. signal voltage is very large compared to the bias for plate current cut-off, current will be drawn only on the tips of the carrier wave. The tube is then operating as a class C amplifier, and in addition to the energy at the I. F., harmonics thereof will be generated. The I. F. transformer in the output circuit of the limiter tube can pass only the fundamental component so that the signal energy delivered to the detector will then decrease. This effect is evidenced by a limiter characteristic which reaches a maximum output as the signal input is increased from zero, and then the output decreases with further increase in signal. One way of preventing this decrease in limiter output with large signals is to apply AVC to some of the tubes preceding the limiter tube. The use of AVC will prevent a falling limiter characteristic, and, in addition, if applied to the radio frequency amplifier 8 will prevent generation of ultra-high frequency harmonics through over-shooting of the signal grid bias of the converter tube. The 43 mc. band is sufficiently narrow so that the harmonics of the oscillator and signal just fail to fall within the I. F. value, but it is conceivable that some of the stations adjacent to that band may cause difficulty in the absence of AVC. By tapping off for AVC action a substantially less amount of the direct current voltage developed across resistor 31, it is possible to secure maximum benefit from the AVC action. If all the AVC bias were used the point at which limiting starts would occur at a higher input level.

In Fig. 2 there is shown graphically the characteristics of the limiter stage. The upper curve shows the relation between the output of the limiter as a function of the input voltage on the signal collector of the receiving system, as measured in the detector stage with a signal tuned approximately 80 kc. off the center frequency. This curve indicates that the full output of the limiter is developed with about 7 micro-volts input. The lower curve shows the peak voltage developed across the limiter grid bias resistor 31 as a function of input voltage at the signal collector. By virtue of the tapped resistor 33 in shunt with resistor 31, about 23 percent of the voltage is used as the AVC bias. The bias is proportional to the signal. At no-signal state no bias (other than the small amount due to contact potential and initial electron velocity) is developed. As the signal is increased the bias increases, and the limiter output likewise increases until the signal becomes greater than the value required for plate current cut-off of the tube. Further increase in signal increases bias still further, but that portion of signal swing beyond cut-off is not reproduced in the output, thereby giving limiting action for negative grid swing direction. The value of cut-off bias is dependent on screen voltage; the lower the screen voltage the lower the bias which will produce plate current cut-off. However, the screen voltage cannot be made too low or the initial electron velocity comes into play. The practical lower limit is some 20 or 30 volts. The value of screen potential sets the output of the

limiter, and hence of the detector for a given frequency deviation. As the screen voltage is raised more signal on the grid is required, and hence more output results before limiting action takes place.

Resistors 36—37 draw current which is high compared to the current drawn by the screen so that as the grid bias is changed by the applied signal the screen potential does not change. The screen potential exercises the predominant effect in determining the bias at which plate current cut-off occurs. The plate potential is determined by the connection of resistor 39 to the B plus voltage terminal and by the voltage drop due to plate current flow through resistor 39. With no signal input the plate potential is of the same order as the screen potential. It is desirable to use an unvariable screen potential so that the plate current cut-off characteristic of the tube does not change with magnitude of applied signal.

The AVC action tends to hold the signal voltage applied to the limiter constant as the signal varies, but cannot completely accomplish this purpose because the decreased gain of the amplifier tubes to which AVC is applied results from increased bias, and some increase in signal is necessary to provide this increased bias. The output of the limiter is prevented from rising despite the increased signal on the negative excursions of grid potential by plate current cut-off, but may rise in the positive direction because of the finite grid impedance of the tube. That is, the positive excursions of the signal extend into the positive grid region. If the plate potential is maintained at a high fixed potential the limiter output rises with increasing signal input, because, as has been pointed out, AVC action cannot be perfect. If the plate potential be maintained at a low fixed value, on the other hand, the limiter output will decrease with increasing signal above the value of input which causes plate voltage overload. If, now, the plate is fed through a dropping resistor, as shown, the potential of the plate rises with signal increase since the higher developed grid bias reduces the alternating plate current, and, hence, the voltage drop through resistor 39. By proper choice of the value of resistor 39 the plate potential may be made to increase in proper proportion to increased signal so that the output from the limiter is constant for any value of signal above that necessary to initiate plate current cut-off. The combination of partial AVC; fixed screen potential and plate potential variable with signal is thus seen to provide a more constant limiter output than can be obtained without this combination of effects.

The purely FM signal energy at circuit 41 is applied to the input circuits of the double diode tube 50, which may be of the 6H6 type. The tube has two pair of independent diode electrodes therein. Anode 51 and cathode 52 comprise one diode, while anode 53 and cathode 54 provide the second diode. The cathodes 52 and 54 are connected by a pair of resistors 57 and 58. The junction of the resistor 58 and cathode 54 is at ground potential, and independent I. F. carrier bypass condensers 55 and 56 shunt each of the resistors. The diode 51—52 has an input circuit comprising coil 59 and shunt condenser 60, and the input circuit is fixedly tuned to a frequency of the order of 2.1 mc. The auxiliary coil 61 is arranged in series with the coil 59 and condenser 60, and coil 59 is magnetically cou-

pled to circuit 41. The lead 62 connects the resistor section in series with the space current path of diode 51—52.

The input circuit of diode 53—54 comprises coil 63, auxiliary coil 65 and condenser 64. Lead 62 connects the junction of resistors 57 and 58 to the junction of condensers 60 and 62. The input coil 63 is magnetically coupled to circuit 41. Each of circuits 59—60 and 63—64 are tuned by equal frequency amounts to opposite sides of the I. F. value. For example, the circuit 59—60 may be fixedly resonated to 2.1 mc., while the other input circuit is tuned to 2.3 mc. Hence, there will be developed across each of resistors 57 and 58 rectified signal voltage. The rectifiers being in opposed relation, there will be tapped off at the cathode end of resistor 57 the difference of the voltages across the two load resistors.

Switch 70, when closed on the lower contact provides a path for tapping off the audio voltage developed across the resistive load of the rectifiers. The resistor-condenser path 71—72, shunted across the detector output, provides a de-emphasizing network for the high frequency components of the modulation voltage output. Since FM transmitters usually employ some high audio frequency component emphasis, the path 71—72 will provide a compensation therefor; this action arises by virtue of the attenuation of the high audio components. The audio voltage across condenser 72 is then utilized by any desired form of audio utilization network, and the usual tone-compensated audio volume control device 73 may be connected across condenser 72.

Since the detector stage comprises a pair of oppositely mistuned, relative to I. F. value, rectifiers having output load resistors connected in phase opposition, or back-to-back, the detector characteristic will be a slope between the off-resonance frequencies of the rectifiers. The output of the detector will depend on frequency variation, and not on amplitude variation. In an FM wave the instantaneous frequency is varied at an audio rate, so that if such a wave is applied to the detector shown the output will vary at the audio rate, and, hence, reconstitute the original modulation imposed on the transmitter. The magnitude of the audio frequency output is proportional to the slope of the detector characteristic and to the amount of frequency deviation. The slope of the characteristic is dependent on circuit constants. Hence, in a given detector, the output is proportional to frequency deviation; that is, to the amplitude of the audio frequency wave modulating the transmitter.

Despite the fact that off-resonance circuits are used, alignment of the two detector input circuits may be performed at the center I. F. value. The auxiliary coils 61 and 65 function as the aligning coils. During alignment connection is made to the upper contact by switch arm 66; that is, coil 61 is short circuited. In this position of switch 66 the circuits 41, 59—60, 63—64 are each tuned to the I. F. value of 2.2 mc. The switch arm 66 is then shifted to the lower contact to short circuit coil 65. This results in a decrease of the resonant frequency of circuit 59—60, and a concurrent increase of the resonant frequency of circuit 63—64 by a like frequency amount. The coils 59 and 63 may have the same magnitudes, but coils 61 and 65 are of different values.

In Fig. 3 there is shown the FM detector characteristic. The separation between the peaks of

the curve depends upon the ratio of the inductance of coils 61 and 65 to that of coils 59 and 63. Inductances 61 and 65 may conveniently be outside the I. F. shield can so that its value may be readily varied to obtain the desired separation of the resonance peaks during the aligning process. While a single coil could be used in place of the two auxiliary coils 61—65 by connecting the single coil in series between the coils 59 and 63, yet with two coils the desirable symmetrical characteristic of Fig. 3 is obtained. This curve shows clearly how the frequency shifting carrier is converted into amplitude modulation, and rectified. If an FM wave is one with unvarying amplitude whose frequency is cyclically altered above and below its mean unmodulated value (I. F.), then Fig. 3 shows how each rectifier supplies the variable unidirectional voltage from its load resistor. The algebraic sum of the two voltages, varying at an audio rate, is supplied to the audio circuit when switch 70 is closed on the lower contact. If, however, switch 70 is closed on the upper contact, the grid circuit of the limiter tube functions as a diode rectifier, and provides audio voltage over lead 80 to the audio circuit. The latter is the A. M. reception position of switch 70. The detector now acts solely as an AFC discriminator in the usual manner.

As explained in the aforesaid Foster application, it is highly necessary to apply AFC to the local oscillator because of the use of push-button tuning, and the fact that at the ultra-high frequencies employed slight departures from correct oscillator frequencies will result in considerable mistuning and consequent severe distortion. The tolerance in frequency drift is materially less in these high frequencies. Further, since it is essential to have the applied I. F. energy have a mid-channel frequency located at the center between the two peaks of the characteristic of Fig. 3, AFC becomes practically essential for ease of tuning operation.

The FM detector obviously is inherently an AFC discriminator; Fig. 3 illustrates this fact. Those skilled in the art are fully aware of the manner of employing AFC in a superheterodyne receiver. Reference is made to application Serial No. 130,630 filed March 13, 1937, of D. E. Foster to show such an AFC system. In the present application, a highly desirable and improved form of frequency control tube circuit is utilized across the oscillator tank coil 14. The control tube 81 is a high transconductance tube of the 6AC7 type, and its plate 82 is connected to the high potential side of coil 14 by the direct current blocking condenser 83. The plate is connected to a source of positive potential through a choke coil 84. The cathode of tube 81 is connected to ground through self-bias resistor 85 shunted by bypass condenser 86. There is applied to grid 87 an alternating voltage which is in quadrature with the plate alternating potential. The grid 87 is connected to point 20 on coil 14 for this purpose through a path including direct current blocking condenser 88 and resistor 89.

The oscillator tank circuit current flowing through the path including resistor 89, condenser 88 and the grid to cathode capacity 90 (shown dotted) develops across capacity 90 the quadrature voltage. As is known, and as explained in the aforesaid Foster AFC application, between the plate 82 and ground is simulated an inductive effect which appears in shunt to coil 14. The dotted coil 91 is the simulated inductive effect

due to tube 81. The magnitude of the inductance 91 depends on the gain of tube 81. Hence, the signal grid 87 is connected to ground through a source of frequency-dependent direct current voltage. The latter source is the direct current voltage developed across resistive load 57—58. The audio pulsations of the voltage across the latter are filtered out by filter resistor 92 and condenser 93. The lead 94, designated as the "AFC" lead, connects resistor 92 to grid 87 through filter resistors 95 and 96, the junction of the latter being bypassed to ground by condenser 97.

The characteristic of the frequency control tube circuit is shown in Fig. 4. There are plotted "Control tube bias volts" against "Oscillator frequency change (kc.)." It will be noted that a satisfactorily wide range of correction can be secured with the circuit. This characteristic together with that of the detector (Fig. 3) determine the mistuning correction of the AFC circuit for signals above the limiter stage threshold. This control action is seen to be approximately 10 to 1 so that mistuning of the oscillator tank circuit of 100 kc. would cause a mistuning from the I. F. value of only 10 kc. It will be clear to those skilled in the art that if the I. F. energy has a center frequency which departs from the assigned 2.2 mc. value, that rectifier whose input circuit is closer to the shifted value will dominate in direct current voltage production. The resulting bias applied over AFC lead 94 will vary the gain of tube 81 in that sense, and to an extent, such that the effect 91 will vary to cause the oscillation frequency to be shifted so as to compensate for the I. F. center frequency shift. It is pointed out that the inductance 91 increases in value as the gain of the control tube is decreased by AFC bias, and that an increase in shunt inductance results in a decreased tank frequency.

With respect to the simulated inductive effect 91, it can be shown that its value is:

$$L = \frac{RC}{KG_m}$$

In the aforesaid formula, C is the capacity 90; R is the series resistor; G_m is the mutual conductance of the control tube; and K is the portion of the tank voltage appearing between tap 20 and ground. Since K is less than unity this would appear to give a higher L; therefore, less shift than if across the entire coil. However, one may reduce R in proportion to K and obtain the same voltage across C as if the entire coil voltage were used. Suppose K were 0.3 then if R is reduced by some factor from the value that would be used across the entire coil, the same radio frequency voltage is applied to the control tube grid. But if $K=0.3$ the inductance across which it is tapped becomes 0.09 of total inductance (inductance being approximately proportional to the square of the number of turns) so that the shunting effect of R and of input resistance of tube is decreased by a factor of 0.3 thereby giving more nearly pure quadrature voltage, and better control action.

The grid 87 of tube 81 is tapped down to 20 for the following reason. All amplifier tubes that might be used as tube 81 have high input conductance (low resistance) at the ultra-high frequencies, hence they seriously load any tuned circuit if connected across the entire tuned circuit. By tapping the grid down this loading effect is

reduced. The grid circuit of grid 87 is tapped down to the oscillator cathode tap. However, this is not necessarily the only place that it could be tapped. It could be tapped either above or below the cathode tap, and, further, the oscillator circuit might not use a "hot" cathode but might obtain feedback coupling by mutual inductance coupling. In the case of an oscillator using mutual inductance coupling the advantage of tapping the grid circuit of grid 87 across part of the coil would still prevail at ultra-high frequencies.

The advantages of the present frequency control tube circuit will be seen to involve the following. Firstly, the inherent capacity 90 can be employed as a quadrature condenser. Second, the grid tap 20 on coil 14 prevents the low input resistance of tube 81 from damping the tank circuit. Thirdly, the high transconductance tube 81 gives sufficient control with the small inductances 15 required for the ultra-high frequency range.

The receiver shown herein will readily receive FM transmissions using deviations of about 75 kc. and transmitting modulation frequencies up to 15,000 cycles. If the deviation is less a proportionate reduction in I. F. band width should be made, and if less than 15,000 cycle modulation is employed then the audio pass band should be likewise reduced to maintain noise reducing capabilities. The receiver will deliver 0.5 watt output with 12 kc. deviation for any input over 3 microvolts, and it will be sensitive. The noise threshold for fluctuation noise is at about 3 microvolts so that noise reduction is obtained above that input. Since the limiter operates fully at 6 microvolts above the latter input the receiver will be completely quiet as far as fluctuation noise is concerned.

It is pointed out that the present system is adapted for receiving phase modulated carrier waves. Since the electrical relations between phase and frequency modulation are similar, it is obvious that a common receiving system can be used for receiving both types of waves. The term "timing modulation" is used herein to describe a common characteristic of phase and frequency modulated waves, since in both cases the modulation varies the timing of the carrier wave frequency with respect to a hypothetical point. The expression "timing modulated carrier waves" used in the claims, accordingly, is to be understood as a generic expression covering either phase or frequency modulated carrier waves.

Since in phase modulation the frequency deviation is proportional to the modulating frequency, uniform output for all audio frequencies when the receiver herein described is supplied with phase modulated waves may be secured by appropriate values of resistor 71 and capacitor 72. For example, if resistor 71 be made high in comparison with the reactance of 72 for even low audio frequencies (say down to 30 cycles) the voltage across 72 will be inversely proportional to audio frequency, and uniform frequency response will be secured from phase-modulated waves.

The following circuit constants are given, it being clearly understood however that they are in no way restrictive, but are merely illustrative:

R₃₉=2000 ohms
R₄₆=50,000 ohms
R₄₅=50,000 ohms
R₄₅=500 ohms
R₇₁=20,000 ohms
R₄₂=1 megohm
R₄₇=250,000 ohms

R₄₈=250,000 ohms
R₃₉=100,000 ohms
R₃₆=10,000 ohms
R₃₇=9,000 ohms
R₃₃=1 megohm+300,000 ohms
R₃₁=50,000 ohms
R₂₈=25,000 ohms
L₄₄=40 microhenries
L₄₁=56 microhenries
L₅₉=56 microhenries
L₄₃=56 microhenries
L₆₁=5.6 microhenries
L₆₅=5.0 microhenries
C₃₂=50 micromicrofarads (mmf.)
C₃₃=0.1 microfarad (mf.)
C₄₀=5000 mmf.
C₅₅=50 mmf.
C₅₆=50 mmf.
C₇₂=1000 mmf.
C₆₃=0.1 mf.

While we have indicated and described a system for carrying our invention into effect, it will be apparent to one skilled in the art that our invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of our invention, as set forth in the appended claims.

What we claim is:

1. In a frequency modulation receiver, a tube having input and output electrodes, a frequency modulated wave input circuit, an impedance network connected between said frequency modulated wave input circuit and said tube input electrodes, an output circuit connected to the output electrodes, said impedance network deriving a direct current voltage from the frequency modulated wave applied thereto, the direct current voltage so derived serving to bias the input electrode, and the time constant of said impedance network being of the order of 1 to 25 microseconds.

2. In a frequency modulation receiver, a tube having input and output electrodes, a frequency modulated wave input circuit, an impedance network connected between said frequency modulated wave input circuit and said tube input electrodes, an output circuit connected to the output electrodes, said impedance network deriving a direct current voltage from the frequency modulated wave applied thereto, the direct current voltage so derived serving to bias the input electrode, the time constant of said impedance network being of the order of 1 to 25 microseconds, said tube including a positive screen grid, and resistive means in circuit with the screen grid to maintain it at an invariable direct current potential.

3. In a frequency modulation receiver, a tube having input and output electrodes, a frequency modulated wave input circuit, an impedance network connected between said frequency modulated wave input circuit and said tube input electrodes, an output circuit connected to the output electrodes, said impedance network deriving a direct current voltage from the frequency modulated wave applied thereto, the direct current voltage so derived serving to bias the input electrode, and the time constant of said impedance network being of the order of 1 to 25 microseconds, said tube including a positive anode electrode with resistance included in the anode circuit to permit the anode direct current potential to rise as the frequency modulated

wave is applied in increasing amplitude to the input electrode.

4. In a frequency modulation receiver, a tube having input and output electrodes, a frequency modulated wave input circuit, an impedance network connected between said frequency modulated wave input circuit and said tube input electrodes, an output circuit connected to the output electrodes, said impedance network deriving a direct current voltage from the frequency modulated wave applied thereto, the direct current voltage so derived serving to bias the input electrode, and the time constant of said impedance network being of the order of 1 to 25 microseconds, and means connected to said impedance network for applying at least a portion of said voltage to a point of said receiver preceding said input circuit thereby to control the amplitude of the modulated waves at said input circuit.

5. In combination, in an amplitude limiter network for timing modulated carrier waves, a tube provided with at least a cathode, wave input electrode and an output electrode, a wave input circuit upon which said waves are impressed coupled to the cathode and input electrode, a resistor element in circuit with said input electrode and cathode for developing thereacross a unidirectional voltage from current flowing between the cathode and input electrode, said tube including a screen grid electrode at a positive direct current potential, resistive means in circuit with the screen grid to maintain its said potential invariable, and a reactive element operatively associated with the resistor element, said reactive element and resistor element having charge and discharge time constants which are sufficiently short to follow variations in amplitude at modulation rate, but which are still long compared to the time of a carrier frequency cycle.

6. In combination, in an amplitude limiter network, for timing modulated carrier waves, a tube provided with at least a cathode, wave input electrode and an output electrode, a wave input circuit upon which said waves are impressed coupled to the cathode and input electrode, a resistor element in circuit with said input electrode and cathode for developing thereacross a unidirectional voltage from current flowing between the cathode and input electrode, and a reactive element operatively associated with the resistor element, said reactive element and resistor element having a time constant of the order of 1 to 25 micro-seconds, and resistive means in circuit with the output electrode for permitting the direct current potential thereof to vary in response to variations in the input electrode direct current potential.

7. In a system for transmitting timing modulated carrier waves, a network for limiting amplitude modulation effects in said waves, said network comprising a tube provided with at least an electron emission element, an input electrode and an output electrode, a modulated carrier wave input circuit connected between said input electrode and emission element, an impedance network connected between said emission element and input electrode for developing a unidirectional voltage from current flowing between said element and input electrode, said voltage being applied to said input electrode as a bias therefor, and resistive means in circuit with said output electrode for permitting the direct current potential thereof to rise as said modulated waves are applied to said input circuit in increasing amplitude.

8. In a system for transmitting timing modulated carrier waves, a network for limiting amplitude modulation effects in said waves, said network comprising a tube provided with at least an electron emission element, an input electrode, a positive screen grid, and an output electrode, a modulated carrier wave input circuit connected between said input electrode and emission element, an impedance network connected between said emission element and input electrode for developing a unidirectional voltage from current flowing between said element and input electrode, said voltage being applied to said input electrode as a bias therefor, resistive means in circuit with said output electrode for permitting the direct current potential thereof to rise as said modulated waves are applied to said input circuit in increasing amplitude, and resistive means in circuit with said screen grid to maintain it at an invariable direct current potential.

9. In a system for transmitting timing modulated carrier waves, a network for limiting amplitude modulation effects in said waves, said network comprising a tube provided with at least an electron emission element, an input electrode, a positive screen grid, and an output electrode, a modulated carrier wave input circuit connected between said input electrode and emission element, an impedance network connected between said emission element and input electrode for developing a unidirectional voltage from current flowing between said element and input electrode, said voltage being applied to said input electrode as a bias therefor, resistive means in circuit with said output electrode for permitting the direct current potential thereof to rise as said modulated waves are applied to said input circuit in increasing amplitude, resistive means in circuit with said screen grid to maintain it at an invariable direct current potential, and means for applying a predetermined fraction of said voltage to a point in said system prior to said input circuit thereby to improve said limiter action.

10. In combination with the intermediate frequency transmission network and detection network of a superheterodyne receiver of timing modulated carrier waves, a limiter network for minimizing amplitude modulation effects in said waves, said limiter network comprising a tube having at least a cathode, control grid and output electrode, a wave input circuit coupled to said transmission network and connected to said grid and cathode, means coupling said output electrode to said detection network, a resistor in circuit with the grid and cathode to develop direct current voltage from grid current flow whereby said voltage serves as a bias for the grid, a condenser in shunt with the resistor, said resistor and condenser having a time constant which is sufficiently short substantially to reduce amplitude variations in the limiter output electrode circuit, and means in circuit with said output electrode to permit variation of the output electrode direct current potential with modulated carrier wave amplitude variation.

11. In combination with the intermediate frequency transmission network and detection network of a superheterodyne receiver of timing modulated carrier waves, a limiter network for minimizing amplitude modulation effects in said waves, said limiter network comprising a tube having at least a cathode, control grid and output electrode, a wave input circuit coupled to said transmission network and connected to said grid and cathode, means coupling said output

electrode to said detection network, a resistor in circuit with the grid and cathode to develop direct current voltage from grid current flow whereby said voltage serves as a bias for the grid, a condenser in shunt with the resistor, said resistor and condenser having a time constant which is sufficiently short substantially to reduce amplitude variations in the limiter output electrode circuit, means in circuit with said output electrode to permit variation of the output elec- 10

trode direct current potential with modulated carrier wave amplitude variation, and means for applying at least a portion of said developed voltage to said intermediate frequency transmission network thereby to control the transmission efficiency thereof in a sense to improve the action of said limiter.

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