Dec. 28, 1948. W. L. CARLSON 2,457,207

ANGLE MODULATED CARRIER RECEIVER

Filed May 3, 1944 4 Sheets-Sheet 1

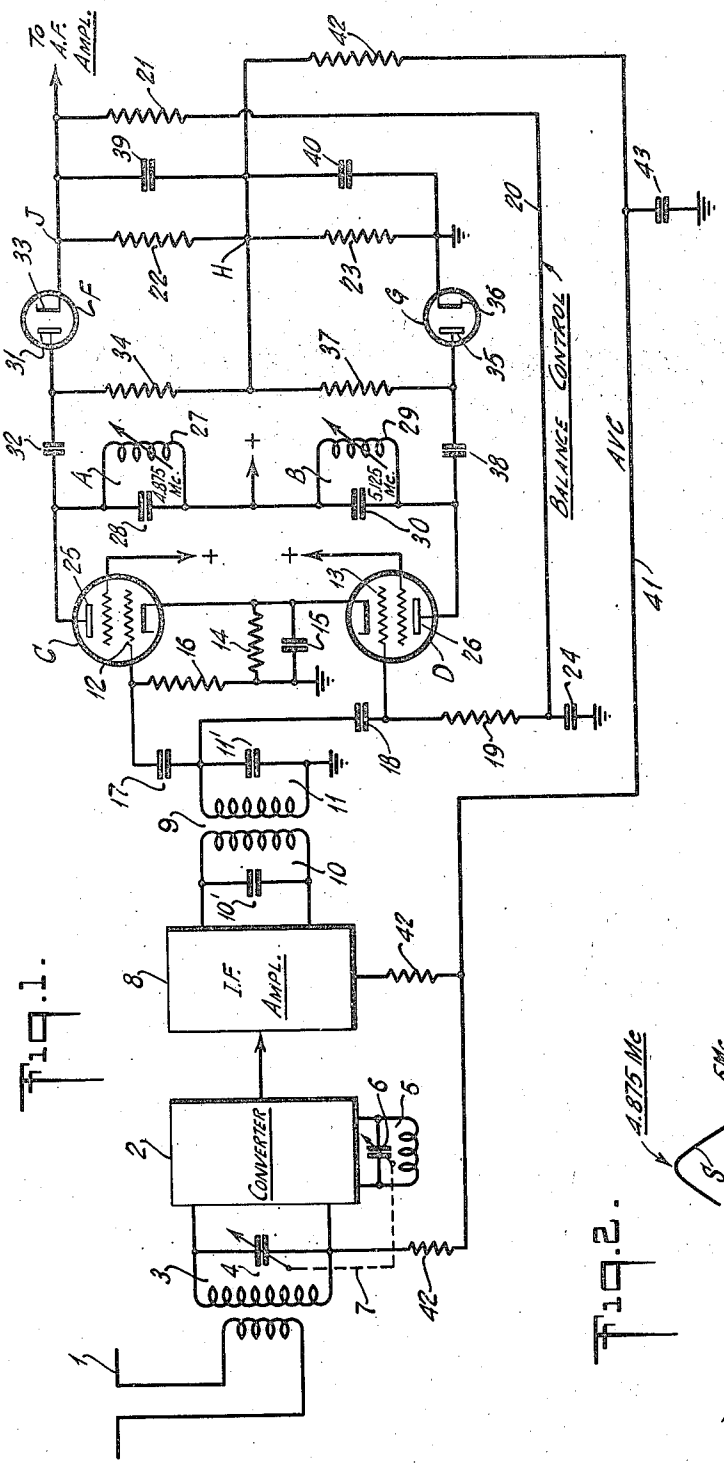


Fig. 1.

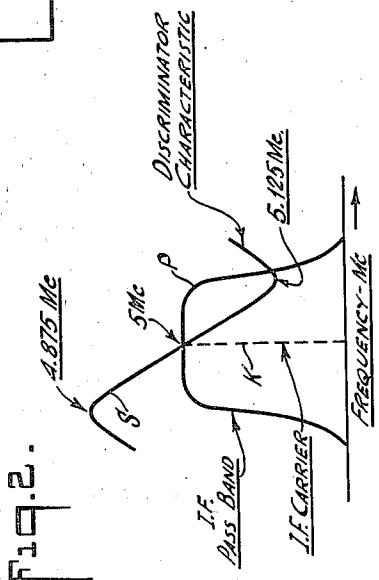


Fig. 2.

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Fig. 3.

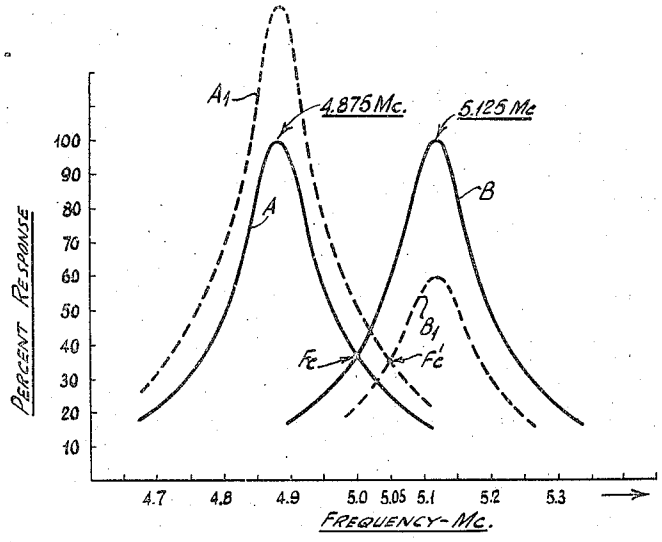
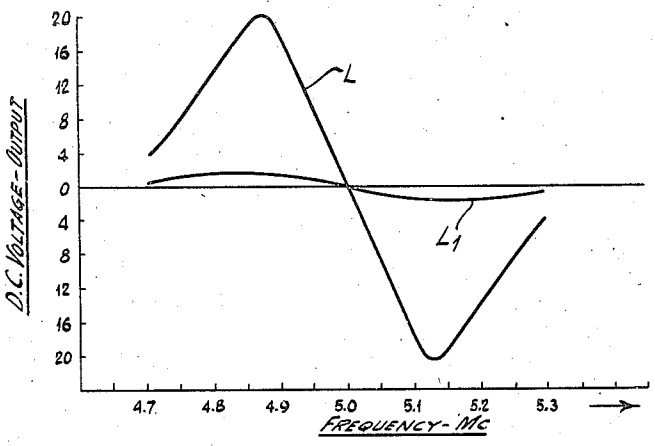


Fig. 4.



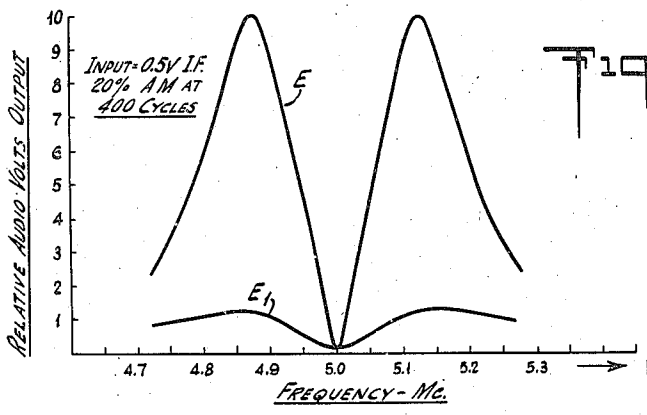


Fig. 5.

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ANGLE MODULATED CARRIER RECEIVER

Filed May 3, 1944 4 Sheets-Sheet 3

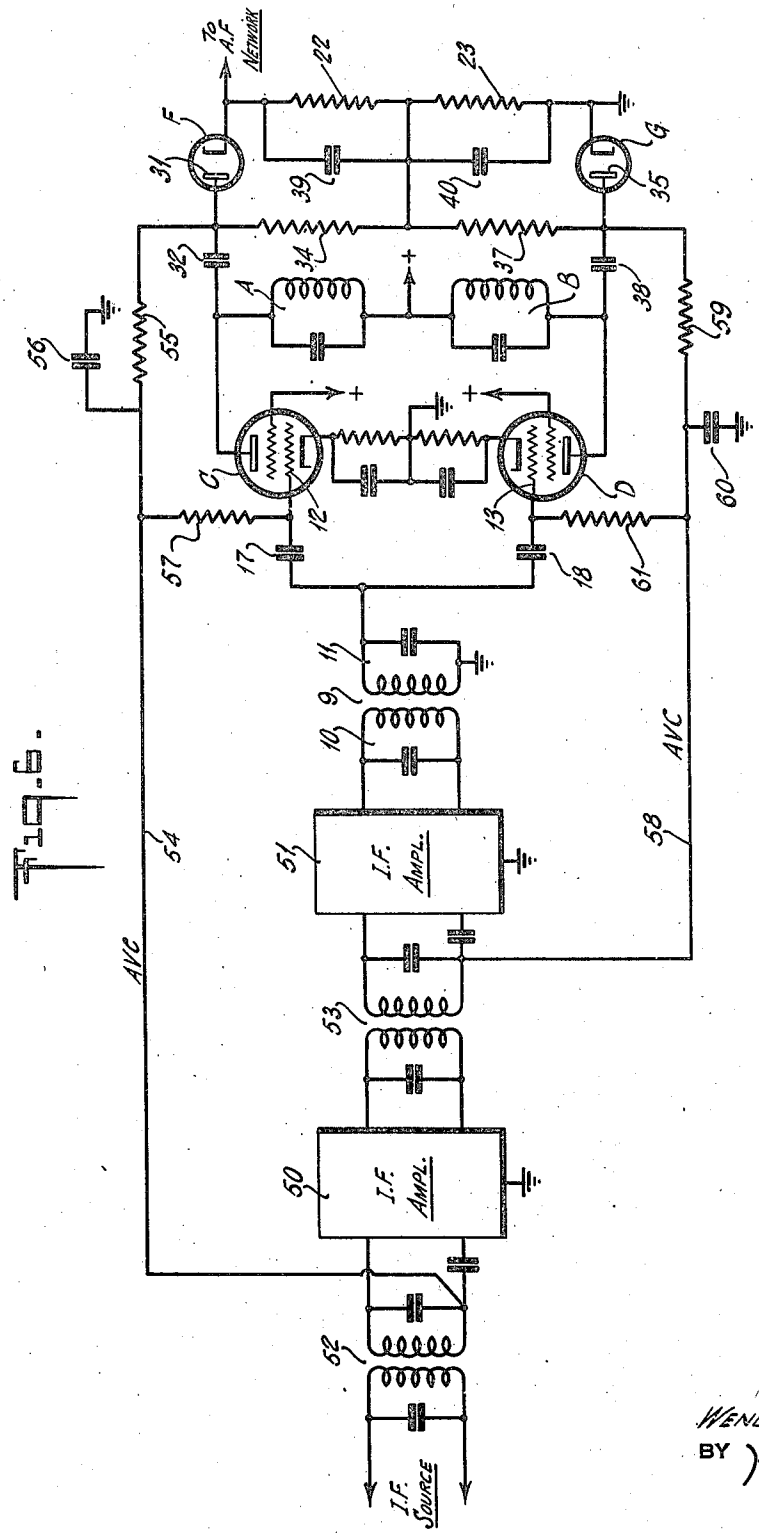


Fig. 6.

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ANGLE MODULATED CARRIER RECEIVER

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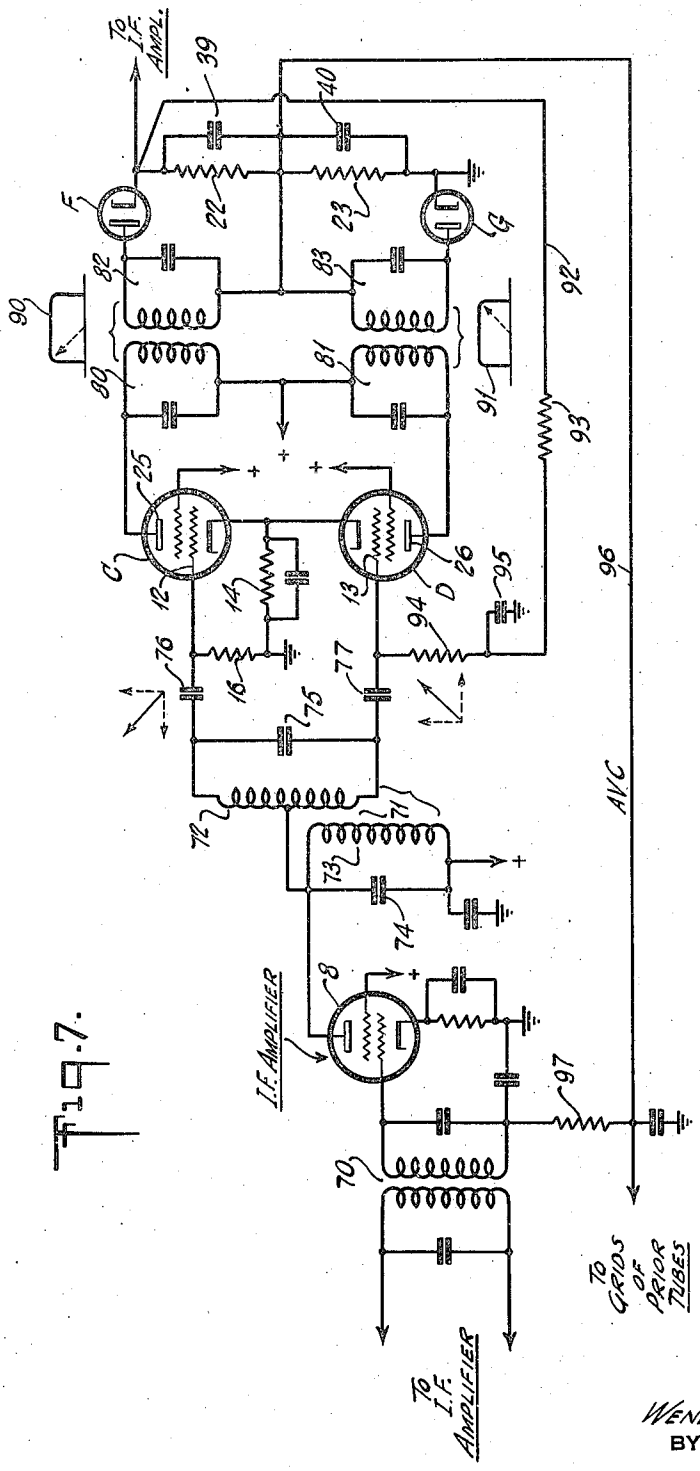


Fig. 7.

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Patented Dec. 28, 1948

2,457,207

UNITED STATES PATENT OFFICE

2,457,207

ANGLE MODULATED CARRIER RECEIVER

Wendell L. Carlson, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application May 3, 1944, Serial No. 533,917

28 Claims. (Cl. 250—27)

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My present invention relates generally to improved receivers of angle modulated carrier waves, and more particularly to balanced frequency modulation (FM) receivers which are substantially non-responsive to amplitude modulation (AM) effects over a wide range of tuning.

The prior conventional FM receiver requires accurate tuning to a desired FM carrier frequency to balance out amplitude variations on the carrier. Under this "balance" condition the opposed demodulator rectifiers, usually diodes, carry equal average signal current amplitudes. As the receiver is detuned from resonance with the carrier or mean frequency of the desired FM wave, the signal currents applied to the respective demodulator-rectifiers may be made unequal by the varying response of the tuned circuits of the receiver. Hence, AM effects originally present on the FM carrier wave or resulting from detuning of the receiver may pass on to the audio frequency amplifier circuits. One of the reasons for employing an amplitude limiter prior to the discriminator section (or FM translating network) of the demodulator, is to reduce undesired AM effects on the carrier wave and thereby avoid the necessity for critical tuning to the exact center or carrier frequency of a desired FM wave.

One of the main objects of my present invention is to reduce the need for critical tuning of an FM receiver, or more generically an angle modulated carrier wave receiver.

Another important object of my invention is to provide an automatic control circuit in an FM receiver, which automatically "locks" the center balance (i. e. cross-over), frequency of the discriminator network substantially in step with the mean frequency of applied FM wave energy.

Another important object of my invention is to provide various arrangements for automatically adjusting, in response to an undesired mean frequency shift of an FM wave relative to a predetermined reference frequency, the frequency responses of a pair of independent signal transmission channels feeding a pair of opposed rectifiers, and the adjustment being made in a sense to accommodate the center balance frequency of the channels to the mean frequency of the FM wave.

Still other features 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.

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In the drawing:

Fig. 1 shows a preferred form of the invention embodied in an FM receiver,

Fig. 2 illustrates ideal relations which are desirable between typical characteristics of the discriminator and preceding circuits,

Figs. 3, 4 and 5 show respectively different operational characteristics of the system,

Fig. 6 illustrates a modification of the invention,

Fig. 7 shows another modification of the invention.

Referring now to the accompanying drawings, wherein like reference characters in the different figures denote similar circuit elements, there is shown in Fig. 1 an FM receiver of the superheterodyne type. While my invention is readily incorporated in any form of receiver of FM waves, I prefer to explain the preferred form of the invention in connection with a superheterodyne receiver system. It is to be understood that the present invention is not restricted to reception of FM waves, since phase modulated (PM) carrier waves could be received as well. In general, I employ the generic term "angle modulated wave" in this specification to include an FM wave or a PM wave. An FM wave is produced at the transmitter by deviating the carrier wave relative to its mean frequency to an extent proportional to the amplitude of the modulations and independent of the modulating frequency. A PM wave differs in having a frequency deviation which increases with modulating frequency. The above generic expression is, also, intended to include a modulated wave of preferably constant amplitude wherein the modulation is neither pure FM nor pure PM, but contains components resembling one or both of them and is, therefore, a hybrid modulation.

In the present application it is assumed, by way of specific example, that the receiver is designed to operate in the FM broadcast band of 42–50 megacycles (Mc.), and that each transmitter radiates an FM wave having a maximum frequency range up to 75 kilocycles (Kc.) with respect to the normal transmitter frequency. These are the assigned frequency values of the present-day FM broadcast band. The receiver may include any desired form of signal collector, as for example a dipole 1. The collected FM signal waves are applied to the converter 2 for reduction of the mean frequency value without change of the deviation. The converter may be of any desired construction, and is preferably

preceded by one or more stages of selective high frequency amplification. The numeral 3 designates the usual tunable selector circuit preceding the converter. The circuit 3 is to be understood as being symbolic of one or more similar selector circuits whose selecting device 4, usually a variable condenser or adjustable inductor, is adjusted to receive a desired FM station. The device would, of course, preferably be adjusted accurately to resonate the selector circuit to the center or mean frequency of the desired FM station.

The numeral 5 generally designates the tunable local oscillator tank circuit. The reactance device 6, usually a variable condenser or adjustable inductor, is customarily adjusted concurrently with the device 4 so that circuit 5 will be tuned to a local oscillation frequency differing from the desired carrier frequency by the operating intermediate frequency (I. F.). The selective circuits of and preceding converter 2 may, of course, be of the fixedly tuned type, if desirable. The intermediate frequency is usually chosen from a range of 2 to 15 Mc., say, merely by way of example, 5 Mc. The dotted line 7 denotes any suitable actuating mechanism for operating the selecting devices 4 and 6. The converter may use the well-known pentagrid tube, or it may use separate oscillator and mixer tubes. These various circuits and circuit components are very well-known to those skilled in the art of radio communication, and need only be briefly referred to.

The I. F. amplifier 8 may embody one or more amplifiers selectively tuned to the operating I. F. value of 5 mc. Of course, all signal transmission circuits between the collector 1 and the demodulator will be so constructed as to pass efficiently a band at least 150 kc. wide. It is also usual to design the signal transmission circuits to have a pass band of approximately 200 kc. in width to provide for reasonable tolerances.

The output transformer 9 of the final I. F. amplifier tube has its primary and secondary circuits 10 and 11 each tuned to the I. F. value. The pass band will preferably, as stated above, be chosen to be of the order of 200 kc. wide, while the mean or center frequency of the band is 5 mc. In Fig. 2 the curve P is an ideal representation of the I. F. pass band curve of transformer 9, it being understood, of course, that the prior I. F. selector circuits will have similar pass band characteristics.

In accordance with my invention, the high alternating potential side of circuit 11 is connected in parallel to the respective control grids 12 and 13 of a pair of amplifier tubes C and D. These tubes, by way of specific illustration, may be screen grid tubes of the 1852 type; my invention is to be understood, however, as being completely independent of any particular tube types. The cathodes of tubes C and D are connected in common to the ungrounded end of biasing resistor 14, the latter being bypassed for I. F. currents by condenser 15. Grid 12 of tube C is connected to the grounded end of bias resistor 14 through a resistor 16.

The separate condensers 17 and 18 couple the respective parallel control grids 12 and 13 to the high potential side of input circuit 11, while the low potential side of the latter is grounded. The grid 13 of tube D returns for direct current potential to the grounded end of bias resistor 14 through a series path comprising resistor 19, lead 20, resistor 21, resistor 22 and resistor 23 to ground. The lower end of resistor 19 is bypassed to ground for all alternating currents by condenser 24.

The plates 25 and 26 of tubes C and D are connected to respective tuned circuits A and B. The common junction of tuned circuits A and B is connected to a point of desired positive voltage of a direct current energizing source (not shown). The screen grids of tubes C and D may, also, be connected to suitable positive potential points of said current source. Plate 25 is connected, as shown, to the upper end of circuit A, the latter comprising parallel-connected coil 27 and condenser 28. The parallel resonant circuit A is preferably adjusted, as by varying the effective inductive magnitude of coil 27, to tune the circuit to 4.875 mc.

Circuit B consists of parallel-connected coil 29 and condenser 30, and, as shown, the lower end of the circuit is connected to plate 26. The inductance of coil 29 may be adjusted so as to resonate circuit B to a frequency of 5.125 mc. It it, therefore, seen that circuits A and B are normally resonated to frequencies located on opposite sides of the center frequency of 5 mc. of band pass circuits 10—11. Further, the predetermined normal frequencies of circuits A and B differ by equal amounts from the center frequency. The frequency difference between the spaced frequencies is 250 kc., which is well in excess of the maximum frequency swing that will normally be encountered in the received FM signals. Circuits A and B function as the discriminator section of the demodulator or detector network. The discriminator section functions to develop amplitude modulated (AM) wave energy from the FM wave energy delivered to the parallel amplifiers C and D.

The AM wave energy derived from the FM waves is rectified by a pair of opposed diodes F and G. The diode electrodes may be in separate tube envelopes, or they may be house in a common envelope as in the case of the well-known 6H6 tube. Diode F has its anode 31 coupled to plate 25 by direct current blocking condenser 32, while its cathode 33 is connected to the upper end J of load resistor 22. The direct current return resistor 34 connects anode 31 to the lower end H of resistor 22. Diode G has its anode 35 coupled to plate 26 by direct current blocking condenser 36. Cathode 36 of the diode is connected to the grounded end of load resistor 23, while direct current return resistor 37 is connected between the ungrounded end of resistor 23 and anode 35. The junction of resistors 34 and 37 is directly connected to the junction H of load resistors 22 and 23. Each of load resistors 22 and 23 is shunted by a respective one of condensers 39 and 40 to bypass all I. F. currents.

The cathode end J of resistor 22 connects to any succeeding audio frequency amplifier followed by a suitable reproducer. The point J is also connected by lead 20, which includes the series resistors 21 and 19, to the grid control 13 of tube D. The connection 20 is designated as the "Balance Control"; the reasons for this designation will be more fully explained at a later point. The resistors 21 and 19 and condenser 24 function to provide a filter for all alternating current components so that solely a variable direct current voltage will be applied to grid 13. The voltage applied over line 20 varies in polarity as well as magnitude, and is derived similarly to the automatic frequency control (AFC) voltage which has been employed in previously known superheterodyne receivers to correct the tuning of the local oscillator. However, my invention embodies im-

portant and valuable distinctions, as will hereinafter appear.

Automatic volume control (AVC) bias for the various tubes preceding transformer 9 may be provided by the AVC connection 41 from the junction point H of load resistors 22 and 23. Filter resistors 42 and condenser 43 are provided in the AVC connection in the well-known manner. The potential of point H is derived by rectification of the signal impressed on diode G, and varies in response to variations in amplitude of the applied carrier wave energy. The function of AVC line 41 is to vary the gain of each controlled tube in a sense such as to maintain the carrier amplitude at transformer 9 substantially uniform despite substantial signal amplitude variations at collector 1. The filter network 42—43 has its time constant so chosen as to permit the AVC to respond to slow variations in carrier amplitude.

Those skilled in the art of FM communication are fully aware of the functioning of a discriminator-rectifier of the general type disclosed in Fig. 1. A pair of opposed rectifiers provided with separate resonant input circuits, individually detuned in opposite senses by equal frequency amounts relative to a predetermined center frequency, comprise a system for demodulating FM waves shown by F. Conrad in U. S. Patent 2,057,640, granted October 13, 1936. In accordance with my invention the general Conrad type of FM demodulator is highly improved, and is provided with means for automatically adjusting the center balance frequency of the discriminator under the control of the signal being received.

Before describing the functions performed by my invention, the ideal relations depicted in Fig. 2 will first be explained. Curve P shows a typical I. F. band pass curve of network 10—11 feeding the parallel amplifiers C and D. The curve S is a typical discriminator characteristic having spaced peaks located at the resonant frequencies of 4.875 mc. and 5.125 mc. of tuned circuits A and B respectively. The ideally linear section between the peaks has its center frequency of 5 Mc. located at the center frequency of band pass curve P. When the resonance curve P of circuit 10—11 (as well as prior selector circuits) is related to discriminator characteristic S of the discriminator circuit A—B as shown, the two circuits are said to be in perfect alignment. While such alignment is highly advantageous, it is equally advantageous to have the mean frequency of the I. F. energy applied to transformer 9 fall at the center frequency of 5 Mc. The dotted vertical line K represents the I. F. carrier or mean frequency. When the condition shown in Fig. 2 exists, there will be no need for an amplitude limiter between I. F. amplifier 8 and the discriminator circuits. So long as noise potentials in the receiving system do not exceed the signals reception of FM signals will be satisfactory, and it will be relatively free of noise without an amplitude limiter being employed.

Should now the line K, representing the carrier frequency, be shifted from the center frequency position, while remaining within the band P, there may occur considerable noise production or signal distortion, because of amplitude variations resulting from working down on one of the slopes or legs of the band pass response curve. In the past an amplitude limiter was employed to reduce such effects, since it was known that the ideal relations of Fig. 2 were difficult to secure. It may, also, be pointed out that even if the I. F. carrier K is located at the center of curve P, but the curve S is shifted to one side within curve P. i. e. the tuning of the discriminator circuits is not accurately aligned with the I. F. selector circuits, unsatisfactory and noisy reception may result, including beat note interference from an adjacent channel station. Here, again, an amplitude limiter has been previously considered to be at least a partial solution of the problem of reducing the noise. I secure the operating advantages of the perfect alignment depicted in Fig. 2 by providing means for automatically locking the center balance (i. e. cross-over) frequency of the discriminator (center of curve S) substantially in step with the applied I. F. carrier or means frequency (line K). This insures that the discriminator balance frequency (assumed to be 5 mc.) can be effectively aligned with the center frequency of the I. F. amplifier (also preferably 5 mc.), assuming that the signal is tuned in at the center frequency of the I. F. amplifier, even when the discriminator and I. F. amplifier circuits are mistuned due to production tolerances or changes in circuit constants during operation and life of the receiver.

The present automatic balance control circuit also reduces thermal and other low amplitude interference for the case when the receiver is carelessly tuned. It must be understood that curves S and P can be determined in the construction of each individual receiver, but that the location of K, the I. F. mean frequency, is a variable depending solely on how the operator tunes his receiver.

Considering, now, the manner of operation of the automatic balance control system, it should first be noted that the two resonant circuits A and B are fed from two separate amplifiers C and D, rather than from one amplifier as is usual in a Conrad type of discriminator. Furthermore, there is preferably no appreciable inductive coupling between resonant circuits A and B. Hence, these two circuits tune independently of each other. The amplifiers C and D have different biasing means, although they have biasing resistor 14 in common. The voltage across resistor 14 provides the sole bias for control grid 12. The grid 13 of tube D, however, receives its bias in part from the voltage developed across resistor 14, and in part from the direct current voltage developed across load resistors 22 and 23 and taken off at point J. The voltage at point J is, of course, the differential voltage of the opposed rectified voltages developed across the two load resistors 22 and 23. Hence, it is a variable quantity, and causes the gain of tube D to vary in a sense, and to an extent, dependent respectively upon the polarity and magnitude of the potential of point J. The AVC voltage at point H, as stated above, is employed to control the gain of preceding tubes, if they are not to act as limiters when receiving strong signals.

Considering now the resonance curves, or response characteristics, of circuits A and B, the solid line curves A and B of Fig. 3 represent the respective response characteristics of the discriminator tuned circuits. The cross-over or balance frequency of the curves is designated by F_c. This point falls at 5 Mc., and the discriminator is, therefore, aligned with the band pass network 10—11. Furthermore, let it be assumed that the I. F. energy applied to circuit 10 has a mean or center frequency of 5 Mc. In other words the ideal situation depicted in Fig. 2 exists. In this case rapid deviations in frequency of signal energy are translated into variable amplitude currents at

each of circuits A and B. These variable amplitude currents are rectified by rectifiers F and G. The rectified currents flowing through respective load resistors 22 and 23 provide rectified voltages of opposed polarity. Point J will have a potential which is the differential of the rectified voltages. Hence, point J will supply modulation voltage, since the polarity and magnitude of that point depend on the sense and extent of frequency deviation of the signal energy at the output of amplifier 8.

The mean frequency of the I. F. energy, however, remains at 5 Mc. by assumption, and, hence, the steady or direct current voltage of point J will remain substantially constant. The filter 21—24—19 prevents any pulsating or modulation components at J from being applied over line 20. As long as the mean frequency of the I. F. energy is 5 Mc., and except for modulation frequency potentials which are removed by filter 21—24—19, there will be developed rectified voltages of the same magnitude across resistors 22 and 23. Therefore, the effective differential resultant voltage impressed on grid 13 is zero relative to ground. The grids 12 and 13 of amplifiers C and D will, then, have the same negative bias (i. e., the bias developed across bias resistor 14). This means that tubes C and D are operating at the same gain thereby passing equal magnitudes of I. F. signal energy from circuit 11 to circuits A and B.

Assume, now, that for some reason the mean or carrier frequency of the I. F. energy shifts to 5.05 Mc. This could happen because of poor adjustment of tuning mechanism 7, or because the discriminator and I. F. tuning circuits are misaligned and 5.05 Mc. is at the center of the I. F. band pass response curve. The effect of the mean frequency shift is to cause the direct current voltage of point J to become negative relative to ground. This happens because rectifier G has applied to it a greater amount of the signal at the mean frequency of 5.05 Mc., since that value is closer to the frequency of circuit B than to circuit A. The direct current voltage across resistor 23 exceeding that across resistor 22, point J will be effectively negative.

The point J becoming negative with respect to ground, grid 13 will be caused to become more negative in potential. The grid 12 will be unaffected in potential so far as the change in potential of point J is concerned. Therefore, the gain of tube D will be decreased with respect to its gain when the mean frequency of the I. F. energy is at 5 Mc. Since the space current of tube D flows through the bias resistor 14, a reduction in space current of tube D will cause the voltage across resistor 14 to decrease. This causes the effective voltage of grid 12 to become less negative, and the gain of tube C will, therefore, increase.

Hence, it will be further seen that tube C will provide a greater amplification of I. F. signal energy than amplifier D. In Fig. 3 the dotted curves A_1 and B_1 show illustratively the effect of the aforesaid control on the response curves of circuits A and B. It is assumed in Fig. 3 that the gain of tube D has been reduced 40%, and that the gain of tube C has been increased 40%. The result of such changes in the relative gains of tubes D and C is to cause the response characteristics to assume the approximate relations represented by the dotted curves A_1 and B_1.

The result of this action is to move the discriminator balance to a higher frequency, approaching the carrier frequency at 5.05 Mc. In

Fig. 3 the new point of balance or frequency of equal response has been shifted from F_c to F'_c. In other words, there has occurred an automatic adjustment of the center balance frequency of the discriminator circuit substantially to the I. F. carrier frequency. Such automatic adjustment effectively reduces audio distortion and interference, as well as noise production, which would have otherwise occurred had the automatic balance control circuit not been used.

Should the I. F. carrier frequency shift to a frequency less than 5 Mc., for example 4.95 Mc., then the reverse of the action described above will take place. In this case point J will assume a positive direct current potential relative to ground, due to circuit A receiving a greater amount of signal energy than circuit B. Rectifier F will, therefore, provide a greater rectified voltage across resistor 22 thereby causing point J to be positive relative to ground. In that case the control grid 13 of tube D will be biased less negative thereby increasing its gain. This will cause the bias across resistor 14 to increase, and the gain of tube C will decrease. Hence, the balance frequency will change in the reverse of the relation shown for A_1 and B_1, and the new balance point will be at 4.95 Mc.

It will be observed that only the gain to circuits A and B is changed. The voltages of the carrier delivered to the two diodes are to be equalized. The resonance curves A_1 and B_1 in Fig. 3 are the same as curves A and B. Only the amplification of the tubes feeding these circuits A and B has been changed. Curves A and A_1 represent circuit A and amplifier tube C at two different bias values.

The curves in Fig. 3 may be taken as representing maximum degree (50 Kc.) of shift of the cross-over point of the discriminator characteristics which should be provided for, assuming that the difference between the peak frequencies of the discriminator circuits is 250 Kc. This is because with the cross-over point at 5.05 Mc. the slope of curve B_1 is just long enough to allow for a signal deviation of 75 Kc. on the high frequency side of the carrier. The invention has been practised successfully with frequency differences between discriminator circuit peaks up to or in excess of 400 Kc., in which case the circuits may be designed for increased shifts of the cross-over point from the desired mean frequency. In other words, the greater the frequency difference between the discriminator peak frequencies, the greater may be the automatically-effected shift of the cross-over frequency.

From another viewpoint it can be said that my invention contemplates an FM receiver wherein there is provided a direct current voltage at the output of a discriminator-rectifier, and the voltage is fed back to the input of the discriminator in a manner to cause the discriminator center balance to follow the carrier frequency as the carrier is shifted over the I. F. acceptance band during the tuning of the receiver system. The curves of Fig. 4 show the direct current voltage output from the demodulator for unmodulated carrier inputs to tubes C and D of 0.5 volt, and at frequencies between 4.7 and 5.3 Mc. Curve L shows the variation in direct current voltage when the balance control of this invention is not used, while curve L_1 indicates the effect of using the present invention. The control circuit tends to "flatten out" the typical characteristic L showing that substantial accommodation of the discriminator balance frequency to the I. F. carrier value is constantly provided. If the automatic

compensation were perfect, i. e., if the balance followed the carrier exactly, then curve L_1 would be a straight horizontal line.

In Fig. 5 there is shown the noise-reducing effect of the automatic balance circuit. There is depicted the automatic reduction of AM (which may be noise) when tuning the receiver through the pass band. The audio voltage output of the demodulator is plotted against carrier frequency, and the carrier is assumed to be about 20% amplitude modulated with 400 cycles, the input being about 0.5 volt I. F. Curve E shows the expected high increase in audio output as the I. F. carrier departs from the 5 Mc. balance value, the present invention not being employed. Curve E_1 shows the marked action of the control circuit in reducing the audio voltage output to somewhat above 1 volt (as against a peak of 10 volts) when the I. F. carrier has shifted from the center frequency. The AM effects are substantially balanced out by a shiftable balance point. The ideal relations of Fig. 2 are approximated to the extent that the discriminator balance frequency is caused to "lock in" with, or track, the I. F. carrier within the flat top portion of curve P of Fig. 2.

The following list of circuit constants have been used in one embodiment of my invention as shown in Fig. 1. It should be clearly understood that the following magnitudes are purely illustrative, and that they are in no way restrictive:

$C_{10'}$=56 micromicrofarads (mmf.)
$C_{11'}$=100 mmf.
$C_{18'}$, C_{17}=80 mmf.
$C_{43'}$ C_{24}=0.05 microfarad (mf.)
C_{15}=5600 mmf.
C_{28}, C_{30}=100 mmf.
C_{39}, C_{40}, C_{32}, C_{38}=33 mmf.
R_{14}=2.7 megohms
R_{34}, R_{37}=34,000 ohms
R_{22}, R_{23}=120,000 ohms
R_{21}, R_{42}=1 megohm

In the receiver shown in Fig. 1 the gain of I. F. amplifier **8** may be varied either by AVC bias, a limiter or manually. Actual listening tests with a system of the type shown in Fig. 1 revealed that thermal fluctuations and other interferences, not exceeding the carrier amplitude in intensity, were substantially reduced during the operation of tuning the receiver when employing the present balance control circuit. The noise null point was broadened in a manner similar to the action in a conventional FM receiver employing a limiter. This action, it will be noted, is predictable from the curves of Fig. 5. The same improvement was observed when the discriminator circuits A and B were deliberately mistuned, or when the amplifier tubes C and D were picked at random. Tuning is less critical for tolerable audio frequency distortion when the automatic balance control circuit is utilized.

When one or both of the discriminator circuits A and B were deliberately mistuned by adding capacity to the resonant circuits, the automatic balance control circuit restored the discriminator center balance frequency to the middle frequency of the I. F. amplifier as the carrier was tuned to that frequency. A combination of thermal fluctuations, ignition impulses and beat note interference is most effectively reduced in its interference effect on the desired signal, when the relation shown in Fig. 2 exists. That is, the effective reduction takes place when the center frequency of the I. F. amplifier and the balance frequency of the discriminator are both in tune with the I. F. carrier frequency. This is also the condition for minimum audio amplitude distortion.

In Fig. 6 I have shown a modification of the invention; separate AVC connections are employed in place of the automatic balance control circuit of Fig. 1. Furthermore, each of amplifiers C and D are concurrently controlled with a respective one of a purality of cascaded I. F. amplifiers feeding the parallel tubes C and D. Referring to Fig. 6, the I. F. amplifiers are designated as **50** and **51** respectively. These amplifiers may be of any well-known form. It will be understood that the input transformer **52** of amplifier **50** will have a band pass characteristic similar to that represented by curve P in Fig. 2. Similarly each of I. F. transformers **53** and **9** will have a band pass characteristic as represented by curve P in Fig. 2. Amplifiers C and D have their signal control grids **12** and **13** connected in parallel through the respective direct current blocking condensers **17** and **18** to the high potential side of the resonant secondary circuit **11** of transformer **9**.

It will be recognized that the opposed rectifiers F and G are included in rectifier circuits connected to the respective discriminator circuits A and B in the same manner as was described in connection with Fig. 1. The essential difference in the system shown in Fig. 6 from that shown in Fig. 1 is that separate AVC connection lines are taken from the respective anodes **31** and **35** of the two diodes. The action of this system is substantially the same as that of Fig. 1, and the curves of Fig. 3 apply equally well to Fig. 6.

One of the AVC connections comprises a lead **54** which is connected to anode **31** of diode F, and includes the filter network consisting of series resistor **55** and shunt condenser **56**. The filter network **55—56** suppresses any pulsating voltage components in the voltage applied over line **54** to the grid circuit of I. F. amplifier **50**. It will be undertood that the AVC connection to the signal grid circuit of amplifier **50** is made in the well-known and usual manner to the low potential side of the tuned secondary circuit of transformer **52**. The AVC line **54** is also connected to the control grid **12** through the resistor **57**.

The second AVC connection comprises the line **58** which includes the series filter resistor **59** and shunt condenser **60**. The function of filter network **59—60** is, also, to suppress any pulsating voltage component in the voltage transmitted over line **58** to the grid circuit of amplifier **51**. Here the AVC connection is made to the low potential side of the resonant secondary circuit of I. F. transformer **53**. The resistor **61** connects the AVC line **58** to the control grid **13** of amplifier tube D. It will, therefore, be seen that AVC connection **54** applies AVC bias to the signal control grids of I. F. amplifier **50** and amplifier C, whereas the AVC connection **58** controls the signal grid biases of I. F. amplifier **51** and amplifier D. The AVC connections are the sole sources of variable bias in this modification.

In actual operation the AVC voltage which is applied over connection **54** to amplifiers **50** and C, is obtained from the rectified voltage developed across series-arranged resistors **34** and **23**. On the other hand the AVC voltage for amplifiers **51** and D is obtained from the rectified voltage developed across series-arranged resistors **37** and **23**. The resistors **22** and **23** may preferably be smaller than resistors **34** and **37** so as to minimize the

control of direct current voltage across resistor 23 which affects both channels. In general, the separate AVC connections 54 and 58 function to control the transmission of signal energy to the discriminator circuits A and B in much the same fashion as was explained in connection with Figs. 1 to 5 inclusive. As the carrier frequency shifts over the frequency band, the gain of tubes C and D respectively rises and falls, or vice versa, so as automatically to hold the voltage to the diodes nearly constant.

The discriminator section of the demodulator need not be of the Conrad type shown in Fig. 1. It may be of the type disclosed and claimed by S. W. Seeley in U. S. Patent No. 2,121,103, granted June 21, 1938. In that case, and as shown in present Fig. 7, the pair of resultant vector voltages formed in the Seeley type of discriminator are separately amplified prior to rectification, and the relative amplification may be controlled in the manner generally described in connection with Fig. 1. In the system of Fig. 7 the receiver is similar to a conventional FM receiver up to tubes C and D.

The I. F. amplifier 8 in the modification of Fig. 7 is shown in more detail than in Fig. 1. However, it will be recognized that amplifier 8 is conventional in construction and connections. Its input transformer 70 has a band pass characteristic of the type illustrated by curve P in Fig. 2. The output transformer 71 has the midpoint of its secondary winding 72 connected directly to the plate end of primary winding 73. Shunt condenser 74 tunes winding 73 to the operating I. F. value (5 Mc. in the illustrative case of Fig. 1). The shunt condenser 75 tunes winding 72 to the same I. F. value. The resonance curve of magnetically coupled circuits 74—73 and 72—75 is similar to that of curve P of Fig. 2. Due to the connections between the primary and secondary circuits of transformer 71 there is provided the frequency discriminatory action disclosed in the aforesaid Seeley patent.

The opposite sides of secondary circuit 72—75 are connected to the respective signal control grids 12 and 13 of amplifier tubes C and D by respective direct current blocking condensers 76 and 77. The plates 25 and 26 of amplifiers C and D are connected to opposed sides of the resonant output circuits 80 and 81. The B+ terminal of the direct current source is connected in common to the junction of the circuits 80 and 81. Resistor 14, bypassed for I. F. currents, provides a common negative bias for both grids 12 and 13; this is similar to the function of the cathode bias resistor in Fig. 1. The circuits 80 and 81 are each tuned to the operating I. F. value.

The opposed diodes F and G have respective resonant input circuits 82 and 83. The junction of series load resistors 22 and 23, each of the latter being bypassed by respective condensers 39 and 40 for I. F. currents, is connected directly to the junction of resonant input circuits 82 and 83. The latter input circuits are, also, each tuned to the operating I. F. value. Resonant circuits 80 and 82 are magnetically coupled to provide a band pass network whose response characteristic is a typical band pass curve depicted by curve 90 above the coupled circuits 80—82. In the same way the curve 91 indicates a band pass curve typical of the magnetically coupled resonant circuits 81 and 83. Each of 80—82 and 81—83 provides a band pass network whose center frequency is the operating I. F. value. Hence, each band pass network 80—82 and 81—83 will pass variable amplitude signal energy to respective rectifiers F and G. The magnitude of signal energy transmitted through these band pass networks is automatically controlled in response to any shift in the center or mean frequency of the I. F. signal energy from the predetermined reference frequency of the discriminator circuits.

The automatic balance control circuit is provided by connecting the cathode end of resistor 22 to the control grid 13 by means of a lead 92. The lead 92 includes the series filter resistors 93 and 94, the junction of these resistors being bypassed to ground for alternating currents by condenser 95. It will, therefore, be seen that the control grid 13, as in the case of Fig. 1, is returned to the grounded end of bias resistor 14 through the series-connected load resistors 22 and 23. This means that variations in potential at the cathode end of resistor 22 will cause a variation in bias of grid 13 with a concurrent change in gain of amplifier D. The usual AVC circuit 96 is connected from the junction of resistors 22 and 23 to the signal grids of those tubes which are to be controlled in gain to reduce slow variations in carrier amplitude. The AVC circuit is shown connected through filter resistor 97 to the low potential side of the tuned input circuit of I. F. amplifier 8.

The operation of the system of Fig. 7 is, in general, similar to that described in connection with the system of Fig. 1. The frequency discriminator which provides the respective resultant vector voltages for grids 12 and 13 of amplifier tubes C and D functions in the well-known manner described in the Seeley patent. There is induced in the tuned secondary circuit of transformer 71 a pair of signal voltages. One of these voltages is directly applied to the secondary circuit from the primary circuit at the midpoint of the coil 72. Since grids 12 and 13 are connected to the midpoint of coil 72 in parallel relation, the I. F. voltage will be applied in parallel to control grids 12 and 13. On the other hand, the magnetic coupling between the coil 73 and 72 will cause a substantially 90° phase shift in the I. F. voltage induced in the secondary circuit.

This phase-shifted I. F. voltage will be applied in push-pull relation to grids 12 and 13 relative to the midpoint of coil 72. Hence, each grid 12 and 13 has applied to it a parallel I. F. voltage component and a phase-shifted voltage component, but the latter components being of opposite polarity. Therefore, there will be effectively applied to each control grid a resultant vector voltage. These resultant vector voltages are of equal magnitude if, the mean frequency of the I. F. signal energy is equal to the predetermined resonant frequency of transformer 71. Should the mean frequency depart from, or shift with respect to, the predetermined resonant frequency, then the resultant vector voltages at respective grids 12 and 13 will vary in relative magnitudes depending upon the direction and extent of the aforesaid frequency shift.

In Fig. 7 I have, for the purposes of specific illustration only, depicted the vectors representing the parallel voltages and the phase-shifted voltages, as well as the resultant vector voltages. These vectors are shown at the input connections to tubes C and D. The resultant voltages are shown in solid lines, while the quadrature-related voltages are shown in dotted lines. The vector relations shown in Fig. 7 are for the case when the mean frequency of the I. F. energy is equal

to the predetermined I. F. value of the transformer 71. It is these resultant vector voltages which are transmitted in amplified form to the output circuits 80 and 81. I have, therefore, shown within each of the band pass curves 90 and 91 the resultant vector voltages in dotted lines. This will indicate that the effective magnitude of the resultant voltages transmitted through the parallel amplifier channels C and D are of equal magnitude at the balance frequency of the discriminator network, and that the variations of each resultant vector voltage occur within the response curves 90 and 91.

It will now be seen that when the mean frequency of the I. F. energy output of amplifier 8 shifts relative to the predetermined balance or center frequency of the discriminator network, then one of the resultant vector voltages will exceed the other in magnitude. This will result in the development of a voltage at the cathode end of resistor 22 whose polarity and magnitude will depend upon the direction and extent of the last mentioned frequency shift. This voltage will vary the bias of grid 13 thereby to change the gain of tube D. The latter change causes the gain of tube C to vary in an opposite sense and, to a degree such as to equalize the effective magnitudes of the resultant vector voltages transmitted to rectifiers F and G.

It will be seen that in the form of the invention shown in Fig. 7, there are located parallel amplifier channels between a Seeley type of discriminator and the opposed rectifiers. The gain of each amplifier channel is controlled as in Fig. 1, but unlike the latter the frequency discrimination is provided prior to the amplifier tubes C and D. However, the curves of Figs. 3, 4 and 5 apply equally well to the system of Fig. 7. In common with the systems of Figs. 1 and 6, there is provided in the system of Fig. 7 means for automatically controlling the gain of the parallel channels so as to feed substantially equal carrier voltages to the rectifiers.

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. A frequency discriminator-rectifier circuit comprising a signal transmission channel including a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, resonant circuit means coupled to said rectifiers to provide different respective amplitude-frequency response characteristics with different peak frequencies, said resonant circuit means having frequency response curves which cross each other substantially at said input circuit frequency, means for applying frequency modulated wave energy to said resonant circuit means, and amplifier means provided in said signal transmission channel for automatically locking the cross-over point of the frequency response curves of the discriminator network substantially in step with the mean frequency of the applied frequency modulated wave energy.

2. A frequency discriminator-rectifier circuit comprising a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of frequency modulated carrier energy, resonant circuit means coupled to the inputs to said rectifiers to provide different respective amplitude-frequency response characteristics with different peak frequencies, said resonant circuit means having frequency response curves which cross each other substantially at said input circuit frequency, and means including an amplifier and coupled to said discriminator-rectifier circuit for automatically changing said cross-over point of the frequency response curves, as viewed from said source of frequency modulated carrier energy, upon change in the carrier frequency of the received signal energy.

3. A frequency discriminator-rectifier circuit comprising a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a selective circuit substantially symmetrically responsive to frequencies adjacent to a center frequency corresponding to a preferred carrier frequency, resonant circuit means coupled to said rectifiers to provide different respective amplitude frequency response characteristics with different peak frequencies, said resonant circuit means having frequency response curves which cross each other substantially at said input circuit frequency, and amplifier means coupled to said rectifiers for automatically changing said cross-over point of the frequency response curves, as viewed from said selective circuit, upon change in the carrier frequency of the received signal energy and in the same frequency direction as the change in the received carrier frequency.

4. In combination, a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of frequency modulated carrier energy, circuit means for feeding energy from said source to said rectifiers including a different channel for each rectifier, and an amplifier in each of said channels responsive to the rectifier output potential for reducing the efficiency of transfer of energy to one of said rectifiers through its respective channel upon change of the carrier frequency in one direction.

5. In combination, a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of frequency modulated carrier energy, circuit means for feeding energy from said source to said rectifiers including an individual channel for each of said rectifiers, and amplifier means in said channels responsive to the rectifier output potential for decreasing the efficiency of transfer of energy to one of said rectifiers through its associated channel and simultaneously increasing the efficiency of transfer of energy to said other rectifier through the other of said channels, or vice versa, depending upon change of the carrier frequency in one direction to the other respectively.

6. A frequency discriminator-detector circuit comprising a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference

between the potentials created across their respective load impedances, a source of frequency modulated carrier energy, a circuit for feeding energy from said source to said rectifiers through a different channel for each of said rectifiers, and vacuum tube amplifier circuits in said channels coupled to said output load impedances and responsive to the rectifier output potential for decreasing the efficiency of transfer of energy to one of said rectifiers through its associated channel and simultaneously increasing the efficiency of transfer of energy to said other rectifier through the other of said channels.

7. In combination, a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of angle modulated carrier energy, means for feeding energy from said source to said rectifiers through different channels respectively, and means in said channels responsive to direct current potentials across said impedances for decreasing the efficiency of transfer of energy to one of said rectifiers through its respective channel relatively to the efficiency of transfer of energy to said other rectifier through the other of said channels, or vice versa, depending upon change of the carrier frequency in one direction or the other respectively.

8. A discriminator circuit comprising a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of angle modulated carrier energy, means for feeding energy from said source to said rectifiers through different channels respectively, and vacuum tube amplifier circuits in said channels responsive to direct current potentials across said impedances for decreasing the efficiency of transfer of energy to one of said rectifiers through its respective channel relatively to the efficiency of transfer of energy to said other rectifier through the other of said channels, or vice versa, depending upon change of the carrier frequency in one direction or the other respectively.

9. In a system of the type described, a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of angle modulated carrier energy, means for feeding energy from said source to said rectifiers through different channels respectively, at least one vacuum tube in each of said channels for passing on the alternating current energy impressed upon the inputs of said tubes, and means for controlling the transfer of signal energy in a tube in one of said channels in accordance with direct current potentials derived from the outputs of said rectifiers to decrease the efficiency of transfer of energy to one of said rectifiers through its respective channel relatively to the efficiency of transfer of energy to said other rectifier through the other of said channels.

10. A frequency modulation detector circuit comprising a pair of opposed rectifiers each having an output load impedance, said rectifiers providing an output potential which is the difference between the potentials created across their respective load impedances, a source of frequency modulated carrier energy, means for feeding energy from said source to said rectifiers through different channels respectively, resonant circuit means in said channels for increasing signal energy transfer to one of said rectifiers relatively to the other upon change of signal frequency in one direction or the other respectively, and thermionic vacuum tube means responsive to direct current potentials across said impedances for decreasing the efficiency of transfer of energy to either of said rectifiers when the carrier frequency of the received signal moves in a direction, such as otherwise to cause increase of energy transfer to said rectifier.

11. In combination with a pair of resonant circuits having respective amplitude-frequency response characteristics with different peak frequencies, a separate pair of output terminals for each resonant circuit, a resonant signal input circuit tuned to a frequency located equidistantly from said peak frequencies, a pair of parallel signal transmission channels having a common input connection to said input circuit, each channel being connected to a respective one of the pair of resonant circuits, and means for regulating the relative signal transmission efficiencies of said parallel channels.

12. In combination with a pair of resonant circuits having respective amplitude-frequency response characteristics with different peak frequencies, a pair of output terminals for each resonant circuit, a signal input circuit tuned to a frequency located between said peak frequencies, said resonant circuits having frequency response curves which cross each other substantially at said input circuit frequency, a pair of parallel signal transmission channels having a common input connection to said input circuit, each channel being connected to a respective one of the pair of resonant circuits, and means for automatically regulating the relative signal transmission efficiencies of said parallel channels to provide substantially equal signal voltages across said resonant circuits.

13. In combination with a pair of resonant circuits tuned to different resonant frequencies, a pair of output terminals for each resonant circuit, a signal input circuit tuned to a frequency located equidistantly from said resonant frequencies, a pair of parallel signal transmission channels having a common input connection to said input circuit, each channel being connected to a respective one of the pair of resonant circuits, and means, responsive to a difference between the mean frequency of applied frequency-variable signals and said input circuit frequency, for regulating the relative signal transmission efficiencies of said parallel channels.

14. In a system for receiving frequency modulated carrier waves, a frequency discriminator net work for deriving from received waves a pair of modulated wave voltages in phase quadrature relation in response to the mean frequency of said received waves being equal to a predetermined center balance frequency, a pair of separate transmission channels for the respective voltages, separate rectifiers respectively connected to said channels, means combining the rectified voltage outputs of said rectifiers in polarity opposition, and means, responsive to a departure of said mean frequency from said center balance frequency, for regulating the relative wave transmission efficiencies of said channels in a sense to compensate for said departure.

15. In a system for receiving frequency modulated carrier waves, a frequency discriminator network for deriving from received waves a pair

of modulated wave voltages in substantially phase quadrature relation in response to the mean frequency of said received waves being equal to a predetermined center balance frequency, a pair of separate amplifier channels for the respective voltages, said channels being each tuned to said center balance frequency, separate rectifiers respectively connected to said channels, means combining the rectified voltage outputs of said rectifiers in polarity opposition, and means connected to said combining means, responsive to a departure of said mean frequency from said center balance frequency, for regulating the relative gains of said amplifier channels in a sense to apply the wave voltages substantially equally to said rectifiers.

16. In a frequency detector of the type comprising a pair of decoupled resonant circuits each feeding into a respective rectifier and said resonant circuits having amplitude-frequency characteristics which overlap at a predetermined center balance frequency between the peak frequencies of the characteristics; the improvement which comprises at least two parallel amplifiers having a common input connection adapted to be connected to a source of frequency modulated signal energy, separate connections from each amplifier to a respective one of the resonant circuits, means responsive to the differential output voltage of the rectifiers for varying the gain of one of said two amplifiers in one sense, and means responsive to a change in the gain of said one amplifier for varying the gain of the second amplifier in the opposite sense.

17. In combination, a pair of decoupled resonant circuits having respective amplitude-frequency response characteristics with different peak frequencies, a pair of output terminals for each resonant circuit, a resonant signal input circuit tuned to a frequency located equidistantly from said peak frequencies; and the improvement comprising a pair of parallel signal transmission channels having a common input connection to said input circuit, each channel being connected to a respective one of the pair of resonant circuits, and means for regulating the relative signal transmission efficiencies of said parallel channels in opposite senses.

18. In a system of type comprising a pair of resonant circuits having respective amplitude-frequency response characteristics with different peak frequencies, a pair of output terminals for each resonant circuit, a resonant signal input circuit tuned to a frequency located equidistantly from said peak frequencies, said characteristics being overlapped and having a cross-over frequency substantially equal to said equdistant frequency; the improvement comprising a pair of parallel signal transmission channels having a common input connection to said input circuit, each channel being connected to a respective one of the pair of resonant circuits, and means for regulating the relative signal transmission efficiencies of said parallel channels in opposite senses and to an extent such as to maintain signal voltages at said pair of resonant circuits substantially equal.

19. In a system of the type comprising a pair of resonant circuits having respective amplitude-frequency response characteristics with different peak frequencies, a separate rectifier for each resonant circuit, a signal input circuit tuned to a frequency located equidistantly from said peak frequencies; the improvement comprising a pair of parallel signal amplifiers having a common input connection to said input circuit, each amplifier being connected to a respective one of the pair of resonant circuits, and means, responsive to a differential voltage output of the rectifiers caused by a difference between the mean frequency of applied frequency-variable signals and said input circuit frequency, for regulating the relative gains of said parallel amplifiers.

20. In a system for receiving angle modulated carrier waves, means for deriving from received waves a pair of modulated wave voltages in phase quadrature relation in response to the mean frequency of said received waves being equal to a predetermined center balance frequency, a pair of separate amplifiers for the respective voltages, separate rectifiers respectively connected to said amplifiers, means combining the rectified voltage outputs of said rectifiers in polarity opposition, and means, responsive to a departure of said mean frequency from said balance frequency, for regulating the gains of said amplifiers in opposite senses to compensate for said departure.

21. In a system for receiving frequency modulated carrier waves, a frequency discriminator network for deriving from received waves a pair of modulated wave voltages in phase quadrature relation in response to the mean frequency of said received waves being equal to a predetermined center balance frequency, a pair of parallel amplifiers for the respective voltages, separate rectifiers respectively connected to said amplifiers, means combining the rectified voltage outputs of said rectifiers in polarity opposition, and means connected to said combining means, responsive to a departure of said mean frequency from said balance frequency, for regulating the gains of said amplifiers in opposite senses to compensate for said departure.

22. In a frequency detector of the type comprising a pair of resonant circuits each feeding into a respective diode rectifier, said resonant circuits having amplitude-frequency characteristics which overlap at a predetermined center balance frequency between the peak frequencies of the characteristics; the improvement which comprises a source of frequency modulated signal energy, at least two parallel amplifiers having a common input connection to said source, a separate output connection from each amplifier to a respective one of the resonant circuits, means varying the gain of one of said two amplifiers in one sense in response to said one amplifier feeding a predominant signal voltage to its respective resonant circuit, and means responsive to a change in the gain of said one amplifier for varying the second amplifier in the opposite sense thereby to substantially equalize the application of signal voltages to said rectifiers.

23. In combination with a frequency discriminator comprising a pair of resonant circuits having respective amplitude-frequency response characteristics of different peak frequencies, a separate detector for each resonant circuit, a resonant signal input circuit tuned to a frequency located between said peak frequencies, a pair of parallel signal amplifiers having a common input connection to said input circuit, each amplifier being connected to a respective one of the pair of resonant circuits, and bias control means responsive to the output signal of said detectors for automatically controlling the gain of said parallel amplifiers so as to feed substantially equal signal voltages to the detectors.

24. In combination with a frequency discriminator comprising a pair of resonant circuits having respective amplitude-frequency response

characteristics of different peak frequencies, a separate detector for each resonant circuit, a resonant signal input circuit tuned to a frequency located between said peak frequencies, a pair of parallel signal amplifiers having a common input connection to said input circuit, each amplifier being connected to a respective one of the pair of resonant circuits, and a bias control connection for each of said amplifiers responsive to a differential output voltage from said detectors controlling the relative gain of said amplifiers.

25. In combination with a pair of opposed detectors of angle modulated carrier waves, said detectors having respective frequency response curves which cross each other at a predetermined cross-over frequency, parallel amplifier channels feeding modulated carrier wave voltages to said detectors, and a bias control connection for said amplifier channels responsive to the detector output voltage controlling the relative gain of said channels thereby to adjust said response curves sufficiently to change said cross-over frequency.

26. In combination, a pair of resonant circuits having respective amplitude-frequency response curves with different peak frequencies, said response curves crossing each other at a desired frequency, a pair of output terminals for each resonant circuit, the improvement comprising a pair of parallel signal transmission channels having a common signal input connection, each channel being connected to a respective one of the pair of resonant circuits, and bias control means responsive to the voltage developed across said pair of resonant circuits regulating the relative response curves of said parallel channels to adjust said cross-over frequency.

27. In a system for receiving frequency modulated carrier waves, a frequency discriminator network for deriving from received waves a pair of modulated wave voltages of equal value in response to the mean frequency of said received waves being equal to a predetermined center balance frequency, a pair of parallel amplifiers for

the respective voltages, separate rectifiers individually connected to said amplifiers, means combining the rectified voltage outputs of said rectifiers in polarity opposition, and a bias control connection for each of said amplifiers responsive to a differential output voltage from said detectors regulating the relative gains of said amplifiers in opposite senses to compensate for a departure of said mean frequency from said balance frequency.

28. In detector of the type comprising a pair of resonant circuits each feeding into a respective rectifier, said resonant circuits having amplitude-frequency characteristics which overlap at a predetermined center balance frequency between the peak frequencies of the characteristics; the improvement which comprises a source of frequency modulated signal energy, at least two parallel amplifiers having a common input connection to said source, a separate output connection from each amplifier to a respective one of the resonant circuits, means responsive to the differential output of the rectifiers for varying the gain of one of said two amplifiers in one sense in response to said one amplifier feeding a predominant signal voltage to its respective resonant circuit, and means in the space current path of said one amplifier responsive to a change in the gain of said one amplifier for varying the second amplifier in the opposite sense thereby to substantially equalize the application of signal voltages to said rectifiers.

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