

March 28, 1939.

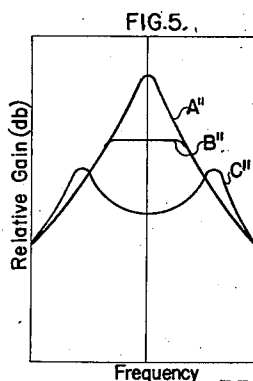
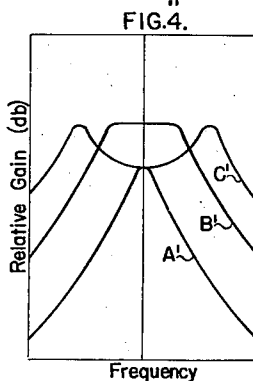
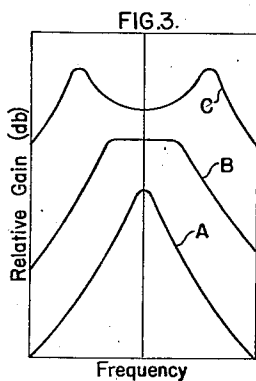
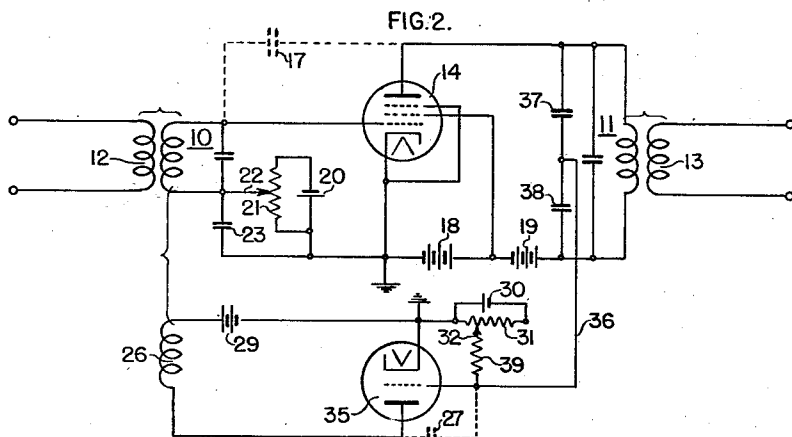
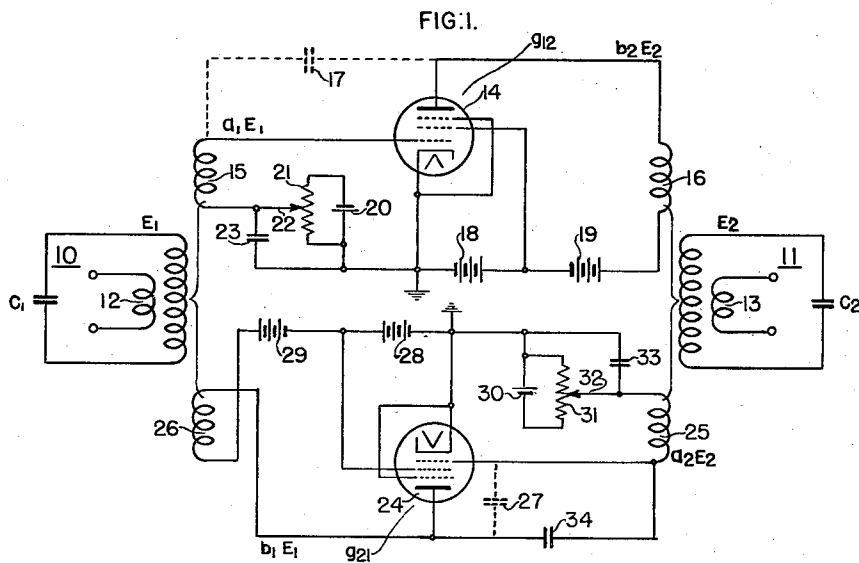
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2,152,618

AMPLIFIER SYSTEM

Filed July 21, 1936

3 Sheets-Sheet 1



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AMPLIFIER SYSTEM

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3 Sheets-Sheet 2

FIG. 6.

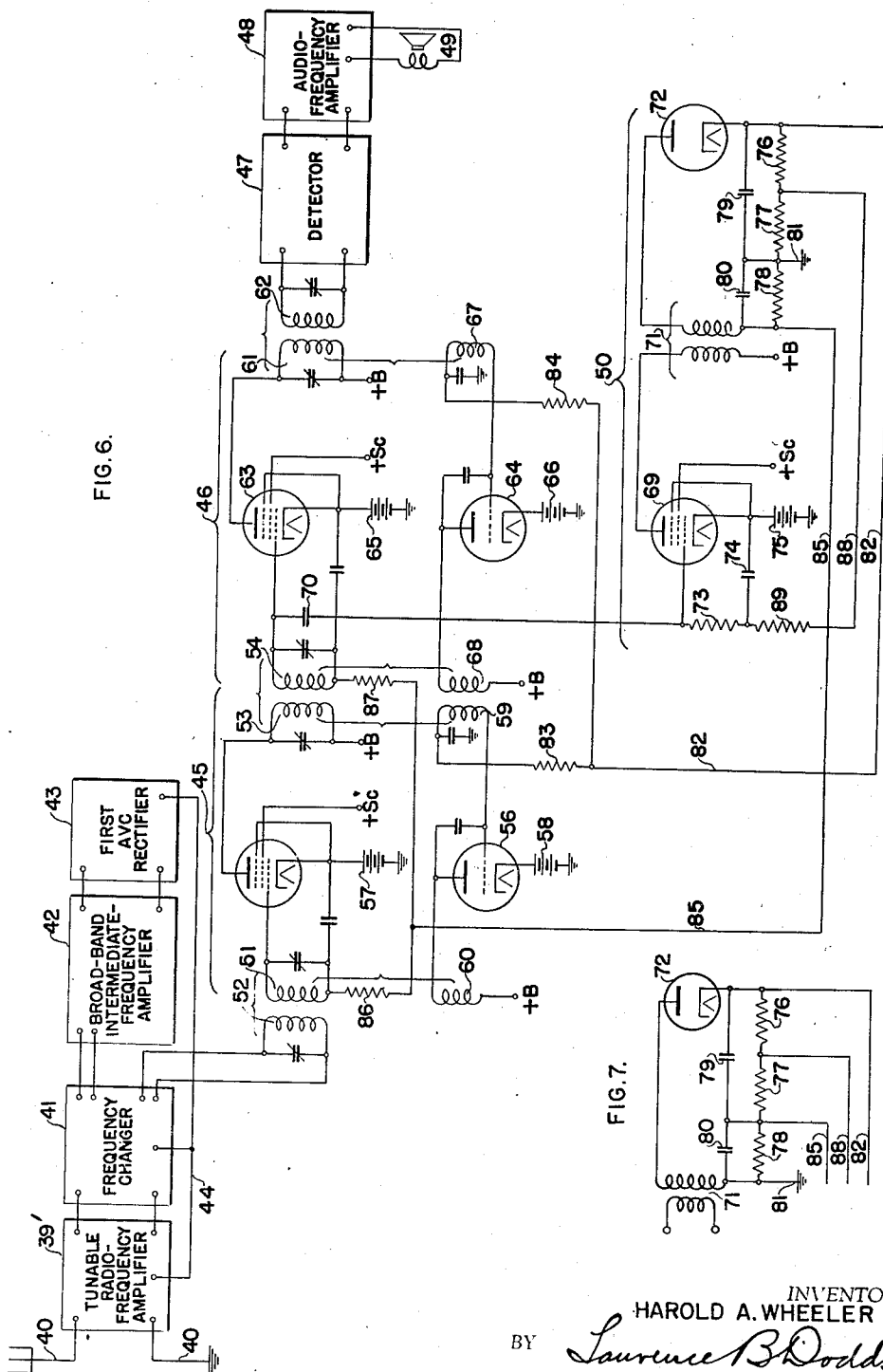
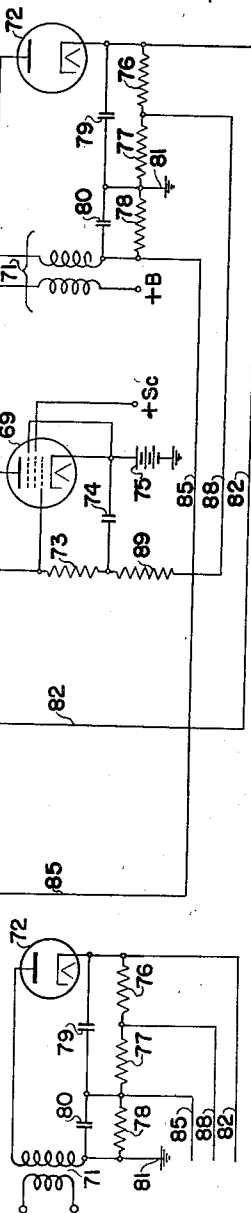


FIG. 7.



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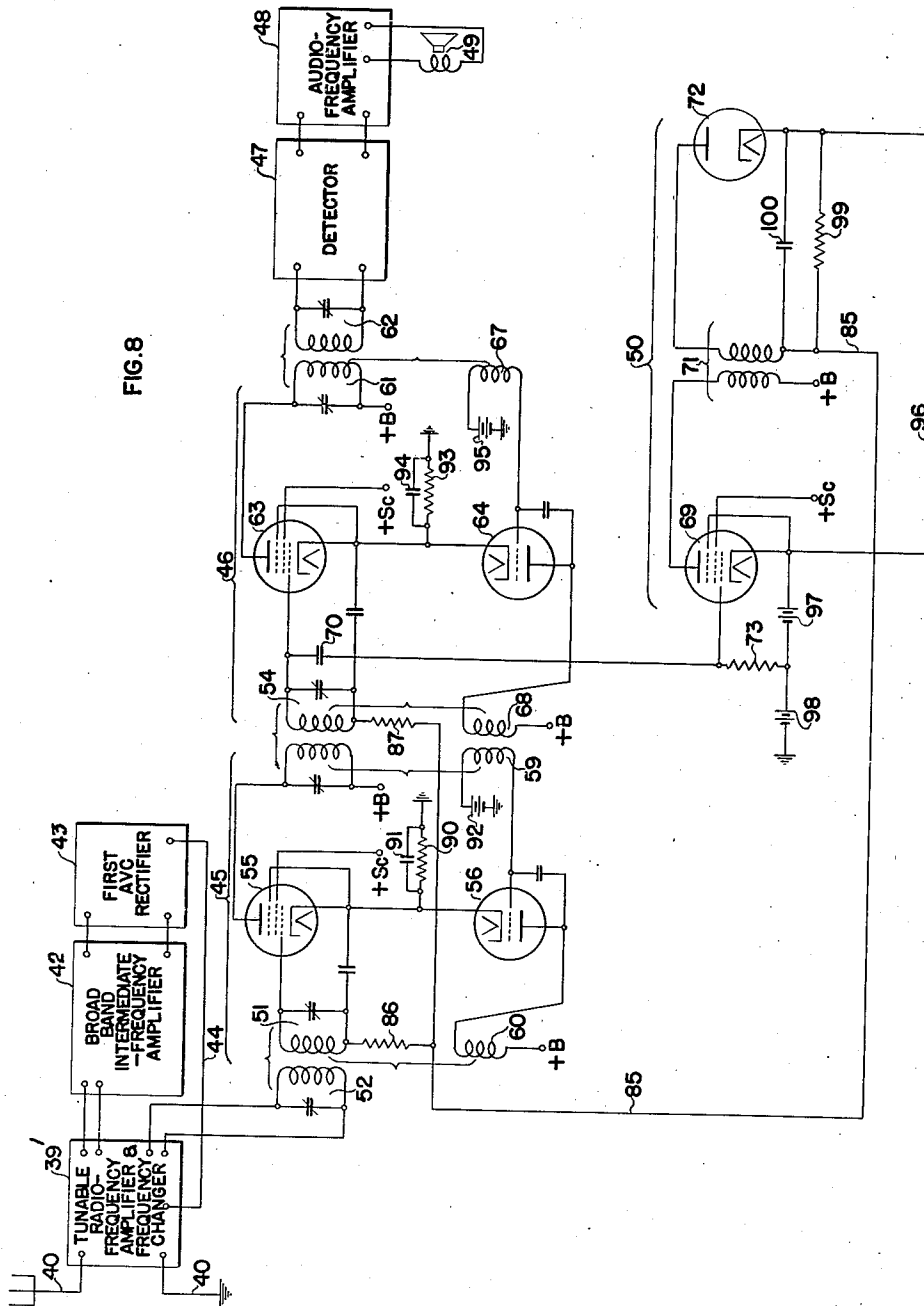
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AMPLIFIER SYSTEM

Filed July 21, 1936

3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,152,618

AMPLIFIER SYSTEM

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Application July 21, 1936, Serial No. 91,656

30 Claims. (Cl. 179—171)

This invention relates generally to vacuum tube amplifier systems, and more particularly to such systems which are adaptable for use in radio broadcast receivers for controlling the amplification and selectivity thereof.

There are a number of operating characteristics which it is desirable to impart to amplifier systems for use in the amplification of high-frequency signals and particularly in amplifiers to be used in radio broadcast receivers. In general, it is desirable that the gain and selectivity of such an amplifier system be easily adjustable over a wide range with a minimum amount of distortion of the amplified signals at any amplification level within the range. It is further desirable that the system be stable in operation over its operating frequency range, sensitive to small changes in the gain control bias, and highly efficient in its operation. In amplifiers subject to automatic or remote control for varying the gain and selectivity thereof, it is particularly desirable that the characteristics of simplicity of adjustment and sensitivity of control be provided. Amplifier systems at present known to the art are deficient in one or more of the above respects.

In the copending application Serial No. 70,172, filed March 21, 1936, by Harold M. Lewis, there is described and broadly claimed a system which, in general, meets the requirements for an amplifier and band-pass selector system as set forth above, the invention claimed therein forming no part of the present invention. Briefly described, the system comprises tuned input and output circuits coupled in both the forward and backward directions by directive coupling means which provide a coupling reaction between the circuits such that any desired amount of amplification is secured in the forward coupling means simultaneously with any desired width of the band-pass characteristic. The directive coupling means include, in the preferred arrangement, an amplifying vacuum tube coupling the circuits in the forward direction and another vacuum tube coupling the circuits in the backward direction. Changes in the band-pass characteristic and variations in the amplification are secured by proper adjustment of the directive transconductances of the vacuum tubes included in the two coupling means.

The proper control of an amplifier and band-pass selector system of the above character, when used in a radio receiver, is governed by the requirements of obtaining the desired amount of amplification together with faithful reproduc-

tion of a desired signal free from undesired signal interference and from static and other background noise, under all operating conditions. In general, the selectivity control should be effective to cause the system to pass a band of desired modulation frequencies sufficiently narrow greatly to reduce interference from undesired signals, as, for example, those on channels adjacent to the received carrier channel. Such narrowing of the selected band of frequencies, however, tends to impair the fidelity of reception of the desired signal, since the outer frequencies of the sidebands, which in radio broadcasting correspond to the higher audio frequencies of modulation, are suppressed. Accordingly, it is desirable that the width of the selected band of frequencies be contracted only when an undesired signal of sufficient amplitude to cause interference or noise is present, and that in its absence the selectivity control be effective to increase the width of the selected band sufficiently to admit and pass all of the sideband frequencies of the desired signal.

It is an object of the present invention to provide an improved amplifying system of the above general arrangement which is easily adjustable to secure variation of amplification over a wide range and which operates to amplify, without distortion, the signals passed through the system.

It is a further object of the invention to provide a system of the above character which is sensitive to small adjustments in the amplification control; is stable in operation at all frequencies within the operating range, and is highly efficient in its operation.

It is an additional object of the invention to provide a selectivity control arrangement for a modulated-carrier signal receiver in which the amplification and selectivity of the receiver are automatically and simultaneously controlled in a desired sense in accordance with the amplitude of a desired received signal carrier.

It is a still further object of the present invention to provide an improved, simple and economical non-mechanical arrangement which includes an amplifier and band-pass selector system having the above characteristics, for automatically controlling the selectivity of a modulated-carrier signal receiver to obtain maximum fidelity of reception consistent with any particular condition of reception.

More specifically, it is an object of this invention to provide an improved arrangement for automatically controlling the selectivity of a modulated-carrier signal receiver in which the selec-

tivity control remains inactive unless the amplitude of the desired received signal is greater than a predetermined magnitude.

Briefly stated, the above objects are attained in accordance with the present invention by providing, in combination with suitable control circuits, an amplifier and band-pass selector system of the general arrangement described in the above referred to application but with certain added improvements designed to procure the desirable characteristics described above. To this end, a vacuum tube of the sharp cutoff type is employed in the backward coupling path. It is known that this type of tube is inherently more efficient in operation than the type of tube known to the art as the gradual cutoff type. Also, it is more sensitive to changes in the control bias applied between the input electrodes thereof. However, when the bias is adjusted to approach the cutoff value, any signal voltage of considerable amplitude applied between the input electrodes is distorted in its reproduction in the output circuit, due to the extreme nonlinearity of the characteristic curve in the cut off region.

In accordance with this invention, the use of this type of tube in the backward coupling means is rendered feasible by suitably proportioning the couplings between the output circuit of the system and the respective forward and backward coupling means, so that the input voltage to this tube is very small as compared with the output of the system, whereby operation is limited to a relatively small increment of the tube characteristic, so that, over the sharply curved portion in the region of the cutoff, no appreciable distortion is caused. Stability of operation and symmetry of the resonance curves are insured by neutralizing the incidental capacitive couplings between the terminal circuits caused by the interelectrode capacitances of the tubes included in the forward and backward coupling paths.

The system of the present invention, as described generally above, is particularly adaptable for use in the intermediate-frequency channel of a superheterodyne radio receiver to control the gain and selectivity thereof. In this application a number of individual systems are coupled in cascade, and suitable control means are provided for automatically adjusting the coupling reaction between the resonant input and output circuits of the individual selector systems to control in a desired manner the amplification obtained in the forward coupling between the terminal circuits of the intermediate-frequency channel and the shape and width of the band-pass characteristic curve. Desired control of the two factors noted is procured by varying the transconductances of the forward and backward coupling tubes as a particular function of the amplitude of the desired signal carrier. Preferably the backward coupling means is maintained substantially ineffective until the signal amplitude exceeds a predetermined value. For excess of signal intensity above this value, the control means becomes effective to decrease the forward coupling at a relatively low rate and to increase the backward coupling at a considerably greater rate, and vice versa. In this manner the gain control and the selectivity control functions are combined and the desired relative properties of both are secured.

In one embodiment of the invention, there is provided means for adjusting one of the directive coupling means directly in response to the

intensity of a received carrier to vary the amplification of the system and additional means responsive to a variable effect of adjustments of the above-mentioned coupling means to vary the width of the frequency band passed by the system.

The novel features which are believed to be characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which Figs. 1 and 2 illustrate band-pass selectors constituting different embodiments of the invention; Figs. 3, 4 and 5 are curves illustrating certain operating characteristics of the systems shown in Figs. 1 and 2; Fig. 6 illustrates the embodiment of a band-pass selector in accordance with the present invention in a complete superheterodyne receiver; and Figs. 7 and 8 illustrate modifications of the control circuit of Fig. 6.

Referring more particularly to Fig. 1 of the drawings, there is illustrated an amplifier system constructed and arranged generally in accordance with the invention described in the above-identified copending application and including certain of the improvements of the present invention. The system comprises a resonant input or terminal circuit 10 and a resonant output or terminal circuit 11, which are coupled to a source of high-frequency current to be amplified, and to a utilizing circuit through inductors 12 and 13, respectively. Adjustable directive coupling means are included between the two circuits 10 and 11 for coupling these circuits in both the forward and backward direction. Preferably, for most purposes, a very loose inductive coupling is provided between the input circuit 10 and the circuit including the inductor 12, and between the output circuit 11 and the circuit including the inductor 13. The purpose of loosely coupling the indicated circuits is to minimize the effect on the circuits 10 and 11 of the circuits coupled respectively therewith.

In order to couple the input and output circuits 10 and 11 in the forward direction, there is provided a vacuum tube amplifier 14 having its input electrodes coupled by means of an inductor 15 to the input circuit 10, and its output electrodes coupled by means of an inductor 16 to the output circuit 11. The tube 14 is preferably of the well-known gradual cutoff type having only a small residual plate-to-grid capacitive coupling minimized by the presence of a screen grid therebetween, and having adjustable directive transconductance. The residual capacitive coupling between the input and output electrodes is indicated by the condenser 17 shown in dotted lines. Screen-grid and plate voltages are supplied from the direct current sources indicated at 18 and 19, respectively.

For the purpose of varying the forward coupling between the circuits 10 and 11, there is provided means for varying the value of transconductance of the tube 14. This means comprises a control circuit including a voltage source 20 shunted by a voltage divider 21 having an adjustable arm 22 connected to the control grid of the tube 14 in the manner indicated. The active portion of the voltage divider is by-passed to ground for high-frequency currents by a condenser 23.

In order to couple the input circuit 10 and the

output circuit 11 in the backward direction, there is provided feed-back means which includes a vacuum-tube repeater 24 having its input electrodes inductively coupled to the output circuit 11 by means of an inductor 25, and its output electrodes coupled to the input circuit 10 by means of an inductor 26. The vacuum-tube repeater 24 is preferably of the well-known pentode type having small plate-to-grid capacitive coupling, adjustable directive transconductance, and a sharp cutoff. The input-output electrode capacitive coupling in this tube is indicated by the dotted line condenser 27. Suitable screen-grid and plate voltage sources are indicated by the batteries 28 and 29.

In order to adjust the bias on the control electrode of the tube 24 to vary the transconductance of the tube and thereby to change the value of the backward coupling between the circuits 11 and 10, there is provided a source of biasing potential 30 shunted by a voltage divider 31 having an adjustable contact arm 32 connected to the grid of the tube 24 in the manner illustrated. The active portion of the voltage divider 31 is by-passed to ground for high-frequency currents by a condenser 33.

Both the forward and backward coupling means, described above, are designed to be substantially nonselective with respect to frequency; the circuit constants of the two coupling means being so proportioned as to render these means much less frequency-selective than the resonant input and output circuits 10 and 11. The purpose of making these coupling means substantially less frequency-selective than the two terminal circuits is to prevent the amplifier system from oscillating at off-resonant frequencies and to insure stability of operation at all frequencies within the operating frequency range.

The operation of the system in Fig. 1 will now be described generally without particular reference to the improvements constituting the present invention. It will be seen that, by utilizing the tube 14 in the forward coupling means and assuming no phase reversals in the inductive coupling with the terminal circuits, the alternating voltages appearing in the output circuit 11 are substantially reversed in phase with respect to the voltages across the input circuit 10 at frequencies in the vicinity of the resonant frequencies of the circuits 10 and 11, at which frequencies these circuits are of high impedance and are substantially resistive. A second phase reversal is secured in the feed-back path through the coupling between the output circuit 11 and the inductance 25. By including the single tube 24 in the backward coupling path, to cause a third reversal, the voltages impressed on the input circuit 10 through this path are substantially reversed in phase, at the frequencies indicated, with respect to the input voltages directly impressed upon this circuit. If the circuits 10 and 11 have the same resonant frequency, which is the preferred arrangement, the input and feed-back voltages are in phase opposition at this frequency. At the resonant frequency the circuits 10 and 11 also have their maximum impedance, so that the signal transfer of the tubes 14 and 24 is maximum and the voltages developed across the circuit 10 and the feed-back voltages are both maxima. Therefore, the system is degenerative to the maximum degree at this frequency.

At frequencies substantially above the resonant frequencies of the two circuits 10 and 11, these

circuits are capacitively reactive so that the voltages across the circuit 11 lag the input voltages by an additional phase angle approaching 90 degrees, while the feed-back voltages impressed on the circuit 10 are similarly retarded by an additional relative amount also approaching 90 degrees, so that feed-back voltages are nearly in phase with the input voltages. However, at these frequencies the impedances of the circuits 10 and 11 are much less than at resonance, reducing the signal transfer of the stages including the tubes 14 and 24 and thus reducing the amplitudes of the feed-back voltages. Therefore, the system is regenerative but not excessively so. At frequencies intermediate the limiting frequencies, just discussed, the feed-back voltages have intermediate amplitudes and phase angles with respect to the input voltages, and the feed-back characteristic of the system has a gradual transition from degeneration to regeneration. Obviously, at frequencies below the resonant frequencies of circuits 10 and 11, the same relationships between the magnitude and phase of the feed-back and directly impressed voltages exist except that at these frequencies the feed-back voltages are subject to leading instead of lagging phase shifts.

The resonance curves obtainable with the circuit of Fig. 1 are similar in shape to those obtained with the same tuned circuits having inductive coupling therebetween instead of the forward and backward coupling tubes. Therefore, the vacuum-tube coupling may be compared with inductive coupling on this basis. The apparent coefficient of coupling by the tubes may be stated as being equal to the value k of inductive coupling which would be required to obtain the same shape of resonance curve, and may be expressed in terms of the circuit values, as follows:

$$k = \sqrt{\frac{-a_1 a_2 b_1 b_2 g_{12} g_{21}}{\omega_1 \omega_2 C_1 C_2}} \quad (1)$$

where:

ω_1 and ω_2 = the respective natural frequencies of the circuits 10 and 11.

a_1, a_2, b_1 and b_2 = voltage transformation ratios between the windings as indicated in Fig. 1.

g_{12} = transconductance of the forward tube 14.

g_{21} = transconductance of the backward tube 24.

C_1 = capacitance of tuning condenser in circuit 10.

C_2 = capacitance of tuning condenser in circuit 11.

If the tuned input and output circuits 10 and 11 have the same power factor and are tuned to the same resonant frequency, the condition for "optimum" coupling and a relatively flat-top resonance curve is:

$$-a_1 a_2 b_1 b_2 g_{12} g_{21} = G_1 G_2 \quad (2)$$

where:

G_1 = apparent shunt conductance of circuit 10 including all resistance and dissipation therein.

G_2 = apparent shunt conductance of circuit 11 including all resistance and dissipation therein.

If the effective forward transconductance $a_1 g_{12} b_2$ and the effective backward transconductance $a_2 g_{21} b_1$ are equal, the signal transfer from either circuit to the other has the same magnitude as for a pair of coupled circuits with equal coefficient of coupling. If $a_1 g_{12} b_2$ is greater or

less than $a_2 g_{21} b_1$, the signal transfer in the forward direction is greater or less in the ratio

$$\sqrt{\frac{a_1 g_{12} b_2}{a_2 g_{21} b_1}} \quad (3)$$

From Equation 2 it will be noted that the shape of the resonance curve depends upon the product of the forward and backward transconductances g_{12} and g_{21} , while Equation 3 shows that the forward transfer depends on the ratio of the two transconductances. By properly proportioning the values of transconductance, any desired shape of resonance curve may be obtained simultaneously with any desired amount of amplification. Amplification occurs in the system when the effective forward transconductance is much greater than the effective backward transconductance.

From Equation 1 it is evident that a real value of the coefficient of coupling is secured only when an odd number of the factors in the numerator are made negative. In the system described above, a_2 is made negative by properly poling the inductance 25 relative to the inductance in the tuned circuit 11 in order to obtain the desired real coefficient of coupling. As was noted above, this condition of polarities causes degenerative feedback at frequencies in the vicinity of the resonant frequencies of the circuits 10 and 11, and regenerative feedback at lower and higher frequencies, but never can cause oscillation. The system is, therefore, stable, as distinguished from ordinary regenerative feed-back circuits.

The effects which may be procured by varying the transconductance of either or both of the tubes 14 and 24, to vary either or both of the forward and backward couplings, are illustrated graphically by the curves of Figs. 3, 4 and 5. In each of these figures the curves A, B and C represent, respectively, successively greater values of the coefficient of coupling (k) between the circuits 10 and 11, which coefficient, as was noted above, depends on the product of the individual forward and backward transconductance values g_{12} and g_{21} .

In Fig. 3 the effect of varying only the forward transconductance g_{12} in tube 14 is shown. Curve A corresponds to a nominal value of backward coupling and a relatively small forward coupling. Curve B is obtained by adjusting the arm 22 of the voltage divider 21 to increase only the forward transconductance of the tube 14 by decreasing the negative bias applied to its control electrode. As shown by this curve, with such an adjustment of the transconductance, the gain or responsiveness of the system is increased and the degenerative action becomes appreciable at frequencies near the mean resonant frequency of the system, while the phase and magnitude of the feed-back voltage components of frequencies above and below the mean resonant frequencies are such that the regenerative action is of no appreciable effect. A further increase in the transconductance of the tube 14 further increases the responsiveness of the system, and also the amplitude of the feed-back components. As a result, the feedback becomes considerably degenerative at the mean resonant frequency and regenerative at frequencies substantially displaced from the means resonant frequency, as shown by curve C, wherein the double peak on both sides of the mean resonant frequency is accentuated.

The family of curves A', B' and C' of Fig. 4

is obtained by proportionate and simultaneous increases in both the forward and the backward couplings, whereby the product of the two couplings is increased while the ratio of the two is maintained constant. This family of curves has the same relative disposition as in the well-known simple case of two coupled circuits, the only difference from the case noted being that, by employing the arrangement described above, a considerable amount of amplification is secured from one circuit to the other.

The family of curves A'', B'' and C'' of Fig. 5 is obtained by maintaining the forward coupling constant and increasing the transconductance of the tube 24 to increase the backward coupling only.

A comparison of the three families of resonance curves yields valuable information as to the utility of this form of coupling when subjected to suitable control. It may be deduced from these curves that the transconductance in the forward path has the main effect on the responsiveness of the system at frequencies substantially removed from the mean resonant frequency of the system. Variation of the forward transconductance varies the gain and the width of the frequency band in the same sense, while variation of the backward transconductance varies the gain and the band width in opposite senses. The results obtained by varying only the backward transconductance are equivalent to those caused by symmetrically detuning a pair of coupled resonant circuits, in the manner described in an article by the applicant Wheeler and J. K. Johnson, entitled "High fidelity receivers with expanding selectors", published in the Proceedings of The Institute of Radio Engineers, June 1935, pages 594-609. This type of control causes a resulting change in the resonance curve of the system which is well adapted to some forms of automatic selectivity control circuits, in which are desired simultaneously increasing band width and decreasing responsiveness of the system.

Referring now more particularly to certain features of the above-described circuit included in the scope of the present invention, the coupling relations between the circuits 10 and 11 and the forward and backward coupling means, including the tubes 14 and 24, respectively, will be considered. The advantages of employing a tube of the sharp cutoff type in the backward coupling path have already been mentioned. The use of this type of tube is rendered feasible by proportioning the couplings between the output circuit 11 and the two coupling means in such a manner that distortion in the system is reduced to a negligible value, even when the bias applied to the control electrode of the tube 24 is adjusted to values near the cutoff value and the system is operating at maximum normal power output. This desired proportioning of the two couplings may be obtained by following a few simple rules. The first step is to adjust the forward transconductance of the tube 14 to its maximum value and to make the product of the ratio a_1 , between the input circuit 10 and the inductance 15, and the ratio b_2 , between the inductance 16 and the output circuit 11, sufficiently large to secure the desired amount of amplification in the forward coupling means. This product will be unity if the input and output electrodes of the tube 14 are connected, respectively, directly across the input and output circuits 10 and 11. Following this adjustment, the

value of the backward transconductance of the tube 24 is made moderately large, and the product of the couplings between the circuit 11 and the inductance 25, and between the inductance 26 and the circuit 10, is adjusted to secure the desired coefficient of coupling and width of resonance curve. Preferably the coupling between the input electrodes of the tube 24 and the output circuit 11 is made very small and much less than the coupling between the output circuit and the output electrodes of the tube 14. Also, the coupling between the input electrodes of the tube 24 and the output circuit 11 is preferably made much less than the coupling between the output electrodes of the tube 24 and the input circuit 10. In this manner the voltage applied between the input electrodes of the tube 24 is maintained at a very small value even when the system is operating at maximum normal power output. Also, by making the coupling between the output electrodes of the tube 24 and the input circuit 10 relatively large as compared to that between the output circuit 11 and the input electrodes of this tube, the factor $a_2 g_{21} b_1$ is not unduly lowered with the result that the product $a_1 a_2 b_1 b_2 g_{12} g_{21}$, appearing in the numerator of Equation 1, is not unduly decreased. Hence, the coefficient of coupling k is not appreciably decreased by the small coupling between the output circuit 11 and the input electrodes of the tube 24.

By making the input voltage to the tube 24 small in the manner noted, operation of this tube is limited to a small increment of its grid voltage-anode current characteristic, irrespective of the bias applied to the control grid of this tube. Thus, when the bias is adjusted to a value near the cutoff value, that is, the region of greatest nonlinearity of the characteristic, no substantial distortion is produced in the anode current of the tube and, consequently, the feed-back voltages impressed between the input electrodes of the tube 14 are free of distortion.

Operating stability of the system at all frequencies within the operating frequency range and symmetry of the frequency response characteristic are insured by the cancelling effect of the input-output electrode capacitances of tubes 14 and 24 on each other. Since each of these tubes is shielded, these capacitances, indicated by the dotted line condensers 17 and 27, respectively, represent the residual capacitances, denoted by C_3 and C_4 , respectively, between the input and output electrodes of the respective tubes, and cause only small incidental capacitive coupling between the input and output circuits 10 and 11 in the forward and backward directions, respectively. Also, with the circuit arrangement shown, and with the polarities of coupling such that a real coefficient of coupling is obtained, these small capacitive couplings are substantially in opposed phase relation and tend to neutralize each other, thereby to minimize the over-all incidental capacitive coupling between the two terminal circuits. The condition for complete neutralization of capacitive coupling in the system is given by the equation:

$$a_1 b_2 C_3 + a_2 b_1 C_4 = 0 \quad (4)$$

Due to the relatively small coupling between the output circuit 11 and the input circuit to the tube 24, the coupling caused by the capacitance 27 between the two circuits 10 and 11 is effectively much less for the same inter-electrode capacitance than that caused by the capacitance

17 of the tube 14, and the condition stated above may not be satisfied. Accordingly, if complete neutralization is desired, it may be necessary to augment the capacitance 27 by additional means comprising a condenser 34, connected between the anode and the control grid of the tube 24. This additional condenser may be of such size as to reduce to zero the over-all capacitive coupling between the two terminal circuits 10 and 11.

Referring now more particularly to Fig. 2 of the drawings, there is shown a modification embodying certain features of the invention, in which the input electrodes of the forward coupling tube 14 are directly connected across the terminals of the resonant input circuit 10 and the output electrodes are directly connected across the terminals of the output circuit 11. The backward coupling means includes a vacuum tube 35, of the well-known unshielded three-electrode type having a sharp cutoff characteristic and a substantial capacitance between the input and output electrodes thereof. This coupling means is coupled to the output circuit 11 by the lead 36 connected to an intermediate point of a capacitive voltage divider comprising two condensers 37 and 38, connected in series across the output circuit 11. The input circuit to the tube 35 includes the backward coupling control means comprising the source of biasing potential 30 shunted by the voltage divider 31 having a resistance 39 in the adjustable arm thereof. The desired phase relation between the voltage directly impressed on the input circuit 10 and the feed-back voltage impressed thereon is obtained by properly polling the coupling between the inductive branch of the input circuit 10 and the inductance 26 connected across the output electrodes of the tube 35.

The operation of the system of Fig. 2 is, in general, the same as that described above in connection with the system of Fig. 1, and a further amplification of this description is deemed to be unnecessary to a ready understanding thereof. The use in the backward coupling means of the unshielded tube 35 having interelectrode capacitance considerably greater than that of the shielded tube 14 may render an additional neutralizing condenser unnecessary. It is pointed out that it is most desirable to minimize capacitive coupling between the input and output circuits 10 and 11 in the forward tube 14, since it is this tube in which amplification of the signal occurs.

Although the features of the circuit of Figs. 1 and 2 have been described with particular reference to their application to amplifier systems employing tuned input and output circuits, it will be understood that in their broadest aspects of amplification control they are also applicable to amplifier systems in which the input and output circuits are aperiodic or have negligible frequency selectivity.

Referring now more particularly to Fig. 6 of the drawings, there is illustrated a superheterodyne radio broadcast receiver including, in the intermediate-frequency channel thereof, two cascaded band-pass selector and amplifier systems, each constructed and arranged in accordance with the above description, and control circuits arranged in accordance with another feature of the present invention for automatically controlling the selector and amplifier systems. Briefly described, the receiver comprises a tunable radio-frequency amplifier 39' having its input circuit coupled to an antenna-ground circuit 40 and its output circuit coupled to a frequency changer 41, 75

A broadly tuned auxiliary intermediate-frequency amplifier 42, provided for a purpose to be described hereinafter, is coupled to the output circuit of the frequency changer 41 and has its output circuit, in turn, coupled to a first AVC rectifier 43. The rectified AVC output from the rectifier 43 is impressed on the input circuits of one or more of the amplifier tubes included in the radio-frequency amplifier 39' and the frequency changer 41 through the lead 44.

The main signal channel following the frequency changer 41 includes, in cascade, two intermediate-frequency amplifier and band-pass selector systems indicated generally at 45 and 46, each embodying the above-described features of the invention, a detector 47, an audio-frequency amplifier 48, and a sound reproducing device 49. The responsiveness and selectivity of the systems 45 and 46 are automatically controlled in accordance with the intensity of carrier voltages appearing across the input of the system 46 by control means, indicated generally at 50.

Neglecting for the present the novel characteristics of the selector systems 45 and 46 and the associated control apparatus, the system described above comprises a conventional superheterodyne receiver, the operation of which is well understood in the art. In brief, signals intercepted by the antenna are selected and amplified in the radio-frequency amplifier 39', converted to intermediate-frequency signals in the frequency changer 41, further selected and amplified in the selector and amplifier systems 45 and 46, and supplied to the detector 47 wherein the audio-frequency components are derived. The audio-frequency output from the detector 47 is amplified in the amplifier 48 and supplied to the device 49 for reproduction.

Referring now more particularly to the amplifier and selector systems 45 and 46, each of the systems is arranged generally in the same manner as the system of Fig. 1. Thus, the system 45 comprises an input circuit 51 loosely coupled to the output circuit 52 of the frequency changer 41 and an output circuit 53 loosely coupled to the input circuit 54 of the system 46. The input and output circuits 51 and 53 are coupled in the forward and backward directions, respectively, by means of vacuum tubes 55 and 56. Suitable voltage sources 57 and 58 are provided for biasing the respective control electrodes of the tubes 55 and 56 to the proper potentials. The output circuit 53 is coupled to the input electrodes of the tube 56 through the mutual inductance between the inductor of this circuit and an inductor 59 properly poled with respect thereto and connected between the input electrodes of the tube 56. The output electrodes of this tube are coupled back to the input circuit 51 through the mutual inductance between the inductor of the circuit 51 and an inductor 60. Preferably, the tube 55 is of the shielded, gradual cutoff type and the tube 56 is of the unshielded, sharp cutoff type. The couplings between the input and output electrodes of the two tubes and the input and output circuits 51 and 53 are proportioned in the manner set forth above to secure the desired operating characteristics.

The system 46 is identical in all respects with that of 45 and includes, in addition to the input circuit 54, an output circuit 61 coupled to the input circuit 62 of the detector 47 and directive coupling means comprising vacuum tubes 63 and 64 coupling the circuits 54 and 61 in the forward and backward directions, respectively. Voltage

sources 65 and 66 are provided for biasing the respective control electrodes of the tubes 63 and 64 to the proper potentials. The coupling between the output circuit 61 and the input electrodes of the tube 64 comprises the mutual inductance between the inductor of the circuit 61 and an inductor 67, and the coupling between the output electrodes of the tube 64 and the input circuit 54 comprises the mutual inductance between the inductor of the circuit 54 and an inductor 68, as in the system 45. Each of the circuits 51-54, inclusive, 61 and 62 is tuned to the intermediate frequency of the receiver. Suitable screen grid and anode voltages are supplied to the indicated electrodes of the several tubes through the terminals indicated by +Sc and +B.

The general arrangement and performance of the tuned circuits of the cascade-connected systems 45 and 46, described above, is similar to that outlined in the above referred to article appearing in the I. R. E. Proceedings. This arrangement utilizes six permanently tuned intermediate-frequency circuits shown, of which four are sharply tuned and the other two are relatively broadly tuned to the intermediate frequency. The ideal relation is that the four sharply tuned circuits each have a very small power factor, which may be denoted p , and the other two each have double this power factor, which may be denoted $2p$. Particularly advantageous results are secured by coupling the sharply tuned circuits in pairs and utilizing the broad circuits to flatten out the double peaks of the coupled sharply tuned circuits. The present arrangement differs from that described in the above referred to publication in the order of arrangement of the six permanently tuned circuits relative to the amplifier tubes 55 and 63 in that loose coupling is employed in each of the three intermediate-frequency transformers comprising the inductors of the six tuned circuits and the terminal circuits of the intermediate-frequency channel, namely, the circuits 52 and 62 are the broadly tuned circuits.

The control means 50, which operates automatically to control the amplification and the shape of the band-pass characteristics of the systems 45 and 46, comprises an amplifier tube 69 having its input electrodes coupled to the circuit 54 through a condenser 70, and its output electrodes coupled through a broad band transformer 71 to a diode rectifier 72. A grid leak resistor 73 is provided which is connected in series with a filter condenser 74 between the cathode and control grid of the tube 69. The control electrode of this tube is biased to the proper potential by the voltage source 75. Control bias voltages for the forward and backward coupling tubes are derived from a voltage divider comprising series-connected resistors 76, 77 and 78 by-passed for high-frequency currents by condensers 79 and 80 and constituting the load circuit of rectifier 72, the junctions between the series-connected resistors 77 and 78 and between the condensers 79 and 80 being grounded at 81. A potential which varies in accordance with the intensity of the carrier voltage across the circuit 54 is developed across resistors 76 and 77, and is positively applied to the control electrodes of the backward coupling tubes 56 and 64, through a connection 82 and intermediate-frequency and audio-frequency blocking resistors 83 and 84, respectively, for varying the backward coupling between the respective output and input circuits. Similarly, a potential variable in accordance with the in-

tensity of the carrier voltage is derived from the resistor 78 of the voltage divider and applied negatively to the control electrodes of the forward coupling tubes 55 and 63 through a connection 85 and intermediate-frequency and audio-frequency blocking resistors 86 and 87 to vary the forward coupling between the input and output circuits.

In order to stabilize the effects of the forward and backward control means and to insure a carrier input of constant amplitude to the detector 47, there is provided a third control means comprising a connection 88 including a filter resistor 89 from the junction between the resistors 76 and 77 to the control grid of the amplifier tube 69.

In considering the operation of the amplifier and band-pass selector systems in conjunction with the associated control means, it will be assumed that, in the absence of a received carrier, the bias potentials impressed on the control electrodes of the backward coupling tubes 56 and 64, by the voltage sources 58 and 66, respectively, are of sufficient magnitude to bias these tubes considerably beyond cutoff, and that the bias voltages 57, 65 and 75 are of a magnitude to avoid overloading in the associated tubes. With the backward coupling tubes biased in this manner and with a weak received signal carrier, the bias derived from the voltage divider and applied negatively to the control grids of the forward coupling tubes 55 and 63 through the lead 85 is small and, consequently, the gain of these tubes is large, while the bias applied positively to the backward coupling tubes 56 and 64 through the lead 82 is insufficient to overcome the negative bias on these tubes from the bias voltage sources 58 and 66 and, consequently, no backward coupling or feedback is present between the terminal circuits of the two systems 45 and 46. Changes in the amplitude of the received carrier result in like changes in the negative bias applied to the control grids of the forward coupling tubes, which tend to maintain constant the amplitude of modulated intermediate-frequency carriers supplied to the input of the detector 47 in a well-known manner. When the received signal exceeds a predetermined value, the positive bias applied to the control grids of the backward coupling tubes 56 and 64 is sufficient to overcome their normal negative bias and to effect a backward coupling between the terminal circuits of the two systems 45 and 46 to expand the width of the frequency band transmitted through these systems and simultaneously to decrease the amplification therein.

When the carrier amplitude increases beyond this predetermined value, the control means 50 is effective simultaneously to decrease the amplification and increase the band width by increasing the backward coupling, and further to decrease the amplification by decreasing the forward coupling between the terminal circuits of the two systems. Obviously, with decreasing carrier amplitude the converse action occurs.

Preferably, the connections 85 and 88 to the voltage divider of the rectifier 72 are such that the forward tube transconductances are varied slightly with variations of signal intensity when the signal intensity is above the predetermined value at which the backward coupling means becomes effective. The transconductance product and the resulting coefficient of coupling, therefore, increase and cause expansion of the band width with increasing signal intensity. In this manner the automatic volume control and

selectivity control may be combined, and the desired related characteristics of both obtained by properly proportioning the relative bias voltages applied to the forward and backward coupling tubes.

The auxiliary broadly tuned intermediate-frequency amplifier 42 and first AVC rectifier 43, operating to control the gain in the initial stages of the receiver, function to render the width of the frequency band transmitted through the intermediate-frequency channel dependent upon the presence of a strong undesired signal, as, for example, one located on a channel adjacent that of the desired received carrier. The construction and operation of this portion of the receiver is identical with that disclosed in the application Serial No. 46,081, filed October 22, 1935 by the present applicant, Harold A. Wheeler. In brief, the auxiliary amplifier 42 is designed to be equally or more responsive to undesired signal carriers adjacent the desired signal carrier than to the desired signal. As thus arranged, the negative bias voltage derived from the rectifier 43 and applied to the initial stages of the receiver is considerably increased when a strong undesired signal is present. The result is a decrease in gain through the amplifier 39' and a corresponding decrease in the amplitude of the intermediate-frequency carrier input to the selector system 45. Hence, the presence of such a strong undesired signal results in a narrowing of the band-pass characteristic of the amplifier and selector systems 45 and 46 in exactly the same manner as an actual decrease in the intensity of the desired signal.

A substantially constant carrier amplitude in the detector 47 is secured by the action of the "reverse automatic amplification control" or "reverse AVC" comprising the connection 83 between the voltage divider and the control grid of the amplifier tube 69. This type of control is described in detail in a copending application, Serial No. 691,927, filed October 3, 1933 by Harold A. Wheeler, now Patent No. 2,050,679, and its effect is to adjust the amplification of the amplifier tube 69 simultaneously with and in opposite sense to the amplification of the forward coupling tubes 55 and 63. In brief, a tendency for the amplitude of the carrier input to the tube 69 to increase causes an increase in the voltage across the resistor 77 which changes the bias on the control grid of the tube 69 in a direction to increase the amplification in this tube. This results in an amplified increase in the negative bias applied to the control grids of the forward coupling tubes and the positive bias supplied to the control grids of the backward coupling tubes, which tends further to decrease the amplification in the systems 45 and 46 and to compensate for the increased signal input thereto and maintain the signal input to the detector nearly constant. Obviously, the reverse tendency, namely, a tendency for the carrier input to the tube 69 to decrease, produces the converse result.

The form of "reverse AVC" described above produces amplified variations in the gain through the systems 45 and 46 and is desirable where the variations of the control bias potentials in response to variations in carrier amplitude are alone not totally effective to provide uniform carrier amplitude input to the detector 47. In the event that variations in these potentials are alone so great as to change the gain by too large an amount, so that the slope of the AVC curve is reversed, this condition may be corrected by

applying a control bias negatively to the tube 69 through the connection 88. The three control actions described above are automatic and their effects may be proportioned so that the desired selectivity control is obtained while maintaining substantially constant the amplitude of the intermediate-frequency carrier input to the detector 47.

In the receiver of Fig. 6, the control means 50 provides a form of control in which the total change in amplification caused by a given change in signal intensity is greater than the change of amplification caused by the degenerative feedback action for signal intensities above the predetermined value necessary to render the backward coupling tubes effective. This by virtue of the fact that the bias voltages applied to the forward and backward coupling tubes are both of such polarity as to decrease the amplification with increasing signal strength, and vice versa.

In Fig. 7 there is shown a modification of the control means 50, whereby the relation between the band width and the signal strength is rendered more critical so that there is secured a change in band width for a given change in signal intensity which is greater than that secured in Fig. 6. In Fig. 7 the voltage divider is grounded at its negative terminal, so that the potential impressed on the control grids of the forward coupling tubes through the connection 85 varies positively with increasing signal amplitude. The effect of this positive change of potential is to decrease the negative bias and thereby to increase the amplification in the forward coupling tubes with increasing signal strength. However, when the signal strength exceeds the predetermined value noted, the backward coupling tubes become effective to decrease the amplification in the system in the manner previously described. The bias potentials applied to the forward and backward coupling tubes are so proportioned that a change of much greater ratio is produced in the backward coupling transconductance than in the forward coupling transconductance for a given change in signal intensity. The final result is that the two transconductance adjustments tend to counteract each other so far as amplification is concerned and, since the adjustment of the backward coupling tube transconductance is the greater, the effect of the backward coupling tube predominates in determining the over-all amplification. Since, with this arrangement, the change in the value of the backward coupling transconductance caused by a predetermined change in signal intensity is preferably considerably greater than that produced by the same carrier amplitude change in the arrangement of Fig. 6, the sensitivity of the selectivity control to signal intensity changes is greatly augmented. Obviously, any desired selectivity control sensitivity may be secured by making the connection 85 to the proper point of the voltage divider shown.

Referring now more particularly to Fig. 8 of the drawings, there is illustrated a modified arrangement wherein a single control bias connection is employed between the control means 50 and the control electrodes of the tubes included in the amplifier and selector systems 45 and 46. The general arrangement is the same as that shown in Fig. 6, and the same reference characters have been used to identify corresponding elements. In this arrangement the cathodes of the tubes 55 and 56 are connected together and have included in their common circuit a biasing

resistor 90 shunted by an intermediate-frequency by-pass condenser 91. The control grid of the backward coupling tube 56 is biased positively with respect to ground by means of the voltage source 92. Similarly, the cathodes of the forward and backward coupling tubes 63 and 64 of the system 46 are connected together and include in their common circuit a biasing resistor 93 shunted by an intermediate-frequency by-pass condenser 94. A voltage source 95 is provided for biasing the control grid of the tube 64 positively with respect to ground.

The control means 50 included in the receiver of this figure differs from that of Fig. 6 in that the cathodes of the tubes 69 and 72 are connected together through a connection 96, are biased positively with respect to the control grid of tube 69 by means of a voltage source 97, and are biased more positively with respect to ground by means of the source 97 and a second voltage source 98. The bias connection 85 for the forward coupling tubes 55 and 63 is connected to the negative terminal of a resistor 99 included in the rectifier circuit and shunted by an intermediate-frequency by-pass condenser 100.

The operation of the circuit of Fig. 8 is most easily described by considering the biasing potentials applied to the input electrodes of the tubes. Due to the presence of the voltage sources 97 and 98, the cathodes of the tubes 69 and 72 are substantially positive with respect to ground. Therefore, in the absence of a received carrier, the control grids of the forward coupling tubes 55 and 63 are held substantially positive with respect to ground, but not relative to their cathodes. This positive potential is made sufficiently great so that the space currents in the tubes 55 and 63 cause voltages across the resistors 90 and 93, respectively, which bias the backward coupling tubes 56 and 64 considerably beyond cutoff. Resistors 90 and 93 have such resistance values that the voltage thereacross in conjunction with the bias supplied from the connection 85 maintains the amplification of the forward coupling tubes at maximum without overloading.

With increasing intensity of received signal, the connection 85 becomes increasingly negative relative to the cathode connection 96, which is held at a relatively unvarying positive potential by the voltage sources 97 and 98. This increasingly negative potential, which is applied to the forward coupling tubes 55 and 63 through the connection 85, reduces the bias and thereby decreases the space current in these tubes and consequently lowers the positive bias applied to the cathodes of the tubes 56 and 64 across the biasing resistors 90 and 93, respectively. When the positive bias applied to these cathodes is lowered to a sufficiently low value corresponding to a given value of signal intensity, the backward coupling tubes become operative by virtue of decreasing effective negative bias thereon. For signal intensities above this value, the varying bias caused by changing signal intensity, which is applied to the control electrodes of the backward coupling tubes 56 and 64, serves to determine the amount of the backward coupling and, to a lesser extent, the amount of the forward coupling, thereby to determine the amplification and the band-pass characteristics of the systems 45 and 46. The circuit constants and cutoff characteristics of the tubes may be chosen so that a relatively small change of the space current and amplification in the forward coupling tubes as accompanied by a relatively large change of 75

space current and amplification in the backward coupling tubes. By properly proportioning the fixed bias voltages and variations in effective bias voltages with changing signal strength, a single connection from the control means is enabled to cause the desired variation of both the forward and backward transconductances. The control bias applied over the connection 85 is thus effective to vary directly the effect of the forward coupling tubes 55 and 63 in response to the intensity of a received signal so that their transconductance is decreased with increased signal strength. The common cathode resistors 90 and 93 for tube sets 55, 56 and 63, 64, respectively, therefore, provide an additional means for providing an indirect control of the backward coupling responsive to the adjustments of the forward coupling in each case. The relative variations and the results obtained are similar to those described above in connection with the circuit of Fig. 6.

In either of the arrangements illustrated in Figs. 6 and 8, the selectivity of the terminal coupling transformer comprising the coupled inductors of the tuned circuits 61 and 62 is beyond the influence of all automatic control and, therefore, furnishes apparent selectivity which is an aid in tuning the receiver. The reason for this independence is that the expansion in the system 46 is obtained by impedance reaction on the tuned grid circuit 54, which reaction does not affect the amplification from the grid of the tube 63 to the detector 47. Another advantage over conventional systems of similar nature common to the two arrangements described resides in the use of the relatively broadly tuned "2p" circuits 52 and 62 as terminal circuits of the intermediate-frequency channel. This avoids the requirement of a critical value of coupling between the frequency changer and the intermediate-frequency amplifier system 45, or between the system 46 and the detector 47. Also, the input terminals of the auxiliary broad band amplifier 42 may be connected directly across the first circuit 52, which connection would be impractical if this circuit were too sharply tuned. In addition, the detector 47, which is ordinarily a diode rectifier having a substantial damping effect on any circuit connected thereto, may be coupled to the broadly tuned circuit 62 without substantially affecting the response characteristic of the selector systems.

The importance of using tubes of the sharp cut-off type as the backward coupling tubes is apparent from the above description wherein it is pointed out that there are desired large changes in the transconductance of these tubes relative to the accompanying changes in the forward amplifying tubes transconductance. Also, the fact that these backward coupling tubes are operated in the cutoff region emphasizes the desirability of proportioning the couplings included in the systems 45 and 46, in the manner described above, to reduce to a negligible value distortion in the feed-back transconductance.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An amplifier system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance variable with bias coupling said circuit in the backward direction, and means for applying an adjustable bias to said second device to vary said admittance, said second device having a sharp cut-off relation between its bias and admittance, said coupling means together providing a coupling reaction between said circuits which is variable with said admittance to vary the amplification in said system, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when said bias is adjusted to values approaching the cut-off value.

2. An amplifier system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying vacuum tube coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second vacuum tube having transconductance variable with bias voltage coupling said circuits in the backward direction, and means for applying an adjustable bias voltage to said second vacuum tube to vary said transconductance, said second vacuum tube having a sharp cut-off relation between its bias voltage and transconductance, said coupling means together providing a coupling reaction between said circuits which is variable with said transconductance to vary the amplification in said system, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when said bias voltage is adjusted to values approaching the cut-off value.

3. An amplifier system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including a vacuum tube amplifier coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said backward coupling means including a vacuum tube having input electrodes coupled to said output circuit and output electrodes coupled to said input circuit, and means for applying an adjustable bias between said input electrodes to vary the transconductance of said vacuum tube, said vacuum tube having a sharp cut-off relation between its bias voltage and transconductance, said coupling means together providing a coupling reaction between said circuits which is variable with said transconductance to vary the amplification of said system, and the couplings between said input electrodes and said output circuit and between said forward coupling means and said output circuit being proportioned to minimize distortion in said system when said bias is adjusted to values near the cut-off value.

4. An amplifier system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance adjustable with bias coupling said circuits in the backward direction, and means for applying an

adjustable bias to said second device to vary said admittance, said second device having a sharp cut-off relation between its bias and admittance, said coupling means together providing a coupling reaction between said circuits which is variable with said admittance to vary the amplification in said system, and the coupling between said second device and said output circuit being substantially less than the coupling between said amplifying device and said output circuit and being proportioned relative thereto to reduce to a negligible value the distortion in said system when said bias is adjusted to values approaching the cut-off value and said system is operating at maximum normal output.

5. An amplifier system comprising tuned input and output circuits, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance adjustable with bias coupling said circuits in the backward direction, and means for applying an adjustable bias to said second device to vary said admittance, said second device having a sharp cut-off relation between bias and admittance, said coupling means being substantially less frequency-selective than said tuned circuits and providing a coupling reaction between said circuits which is variable with said admittance to vary the amplification in said system, and the couplings between said output circuit and said forward and backward coupling means being proportioned to minimize distortion in said system when said bias is adjusted to values near the cut-off value.

6. An amplifier system comprising tuned input and output circuits, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, coupling means coupled to each of said circuits and including a second device having admittance adjustable with bias coupling said circuits in the backward direction, means for applying an adjustable bias to said second device to vary said admittance, said second device having a sharp cut-off relation between its bias and admittance, said coupling means being substantially less frequency-selective than said circuits and together providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of the resonant frequencies of said tuned circuits and regenerative at lower and higher frequencies and which is variable with said admittance to vary the responsiveness and selectivity of said system, and the couplings between said output circuit and said forward and backward coupling means being proportioned to minimize distortion in said system when said bias is adjusted to values near the cut-off value.

7. An amplifier system comprising tuned input and output circuits, coupling means coupled to each of said tubes and including an amplifying vacuum tube coupling said circuits in the forward direction, separate coupling means including a second vacuum tube coupled with each of said circuits and having transconductance adjustable with bias voltage coupling said circuits in the backward direction, means for applying an adjustable bias voltage to said second vacuum tube to vary said transconductance, said second vacuum tube having a sharp cut-off relation between its bias voltage and transconductance, said coupling means both being substantially less fre-

quency-selective than said circuits and together providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of the resonant frequencies of said circuits and regenerative at higher and lower frequencies and which is variable with said transconductance to vary the amplification and selectivity in said system, and the coupling between said second vacuum tube and said output circuit being substantially less than the coupling between said amplifying vacuum tube and said output circuit and being proportioned relative thereto to reduce to a negligible value the distortion in said system when said bias voltage is adjusted to values approaching the cut-off value and said system is operating at maximum normal output.

8. An amplifier system comprising input and output circuits of high impedance, untuned directive coupling means including a vacuum tube amplifier coupled to each of said circuits and coupling said circuits in the forward direction, said coupling being primarily transconductive and incidentally capacitive, separate untuned coupling means coupled to each of said circuits and coupling said circuits in the backward direction with a polarity opposite to that of said first-mentioned directive coupling means, said backward coupling being primarily conductive and incidentally capacitive, the couplings between one of said means and said input and output circuits being substantially less than the couplings between the other of said means and said circuits, and the incidental capacitive coupling included in said one of said coupling means being substantially larger than that included in the other of said coupling means and being effective at least partially to neutralize the coupling effect of the incidental capacitive coupling in said other coupling means.

9. An amplifier system comprising input and output circuits of high impedance, directive coupling means including a vacuum-tube amplifier coupling said circuits in the forward direction, said forward coupling being primarily transconductive and incidentally capacitive, separate coupling means coupling said circuits in the backward direction, said backward coupling being primarily conductive and incidentally capacitive, one of said incidental capacitive couplings being greater than the other, and means in said coupling means having the lesser incidental capacitive coupling, comprising the incidental capacitive coupling thereof and additional means, for neutralizing the coupling effect of the incidental capacitive coupling of the other coupling means.

10. An amplifying system comprising input and output circuits of high impedance, directive coupling means coupled to each of said circuits and including an amplifying vacuum tube coupling said circuits in the forward direction, said forward coupling being primarily transconductive and incidentally capacitive, separate coupling means coupled to each of said circuits and coupling said circuits in the backward direction, said backward coupling being primarily conductive and incidentally capacitive, the couplings between said backward coupling means and said input and output circuits being substantially less than the couplings between said forward coupling means and said circuits, and said incidental capacitive coupling included in said backward coupling means being substantially greater than that included in said forward coupling and being effective at least partially to neutralize the capacitive coupling between said circuits.

11. An amplifier system comprising input and output circuits of high impedance, directive coupling means including a vacuum-tube amplifier coupling said circuits in the forward direction, said forward coupling being primarily transconductive and incidentally capacitive, separate coupling means coupling said circuits in the backward direction and including a vacuum tube having input electrodes coupled to said output circuit and output electrodes coupled to said input circuit, the capacitive coupling between said input and output electrodes being effective at least partially to neutralize the incidental capacitive coupling included in said forward coupling means, and additional capacitive means coupled between said input and output electrodes for neutralizing any remaining incidental capacitive coupling between said circuits.

12. An amplifier system comprising input and output circuits of high impedance, and two separate coupling means each including a vacuum tube having transconductance and incidental capacitance individually coupling said circuits in the forward and backward directions, said incidental capacitance in said backward coupling tube being substantially larger than that in said forward coupling tube, and said coupling means providing a coupling reaction between said circuits which is primarily degenerative, whereby said incidental capacitive couplings are of opposite polarity and the incidental capacitive coupling of the backward coupling tube tends to neutralize that of the forward tube.

13. An amplifier system comprising input and output circuits of high impedance, directive coupling means including a first vacuum tube with interelectrode shielding having input electrodes coupled to said input circuit and output electrodes coupled to said output circuit, said forward coupling being primarily transconductive and including the residual capacitive coupling between said input and output electrodes, separate coupling means coupled to each of said circuits and coupling said circuits in the backward direction, said backward coupling means including a second vacuum tube without interelectrode shielding having input electrodes coupled to said output circuit and output electrodes coupled to said input circuit, said backward coupling being primarily transconductive and including the capacitive coupling between the input and output electrodes of said second tube, the couplings between said backward coupling means and said input and output circuits being substantially less than the couplings between said forward coupling means and said circuits, and means including the capacitive coupling between the input and output electrodes of said second tube for neutralizing said residual capacitive coupling of said first tube.

14. An amplifier system comprising tuned input and output circuits, coupling means including a first vacuum tube with interelectrode shielding having transconductance and residual input-output electrode capacitance coupling said circuits in the forward direction, separate coupling means including a second vacuum tube without interelectrode shielding having transconductance and incidental input-output electrode capacitance coupling said circuits in the backward direction, the couplings between said circuits and said first tube being substantially greater than the couplings between said circuits and said second tube whereby substantial amplification is secured in said system, said coupling means providing a cou-

pling reaction between said circuits which is primarily degenerative whereby said incidental and residual capacitive couplings are of opposite polarity, and capacitance between the input-output electrodes of said second tube and including the incidental capacitance thereof for substantially neutralizing the residual capacitance of said first tube.

15. In a modulated-carrier signal receiver, an amplifier system for amplifying a band of frequencies comprising a signal-modulated carrier, said system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance variable with bias coupling said circuits in the backward direction, said second device having a sharp cut-off relation between its bias and admittance, said coupling means together providing a coupling reaction between said circuits which is variable with said admittance to vary the amplification in said system, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when said bias is adjusted to values approaching the cut-off value, and means for applying to said second device a bias variable with the amplitude of a received carrier to vary the amplification in said system inversely in accordance with the amplitude of said carrier.

16. In a modulated-carrier signal receiver, an amplifier system for amplifying a band of frequencies comprising a signal-modulated carrier, said system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance variable with bias coupling said circuits in the backward direction, said second device having a sharp cut-off relation between its bias and admittance, said coupling means together providing a coupling reaction between said circuits which is variable with said admittance to vary the amplification in said system, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when said bias is adjusted to values approaching the cut-off value, and means for applying to said second device a bias variable with the amplitude of a received carrier to vary the amplification in said system inversely in accordance with the amplitude of said carrier, said last-named means being effective to vary the amplification only when the amplitude of said carrier is above a predetermined value.

17. In a modulated-carrier signal receiver, an amplifier system for amplifying a band of frequencies comprising a signal-modulated carrier, said system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance variable with bias coupling said circuits in the backward direction, said second device having a sharp cut-off relation between its bias and admittance, said coupling means together providing a coupling reaction

between said circuits which is variable with said admittance to vary the amplification in said system, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when said bias is adjusted to values approaching the cut-off value, and means including means responsive to the amplitude of a received carrier for applying a bias to said second device variable with the amplitude of said carrier over a range including said cut-off value to vary the amplification in said system.

18. In a modulated-carrier signal receiver, an amplifier system for amplifying a band of frequencies comprising a signal-modulated carrier, said system comprising input and output circuits of high impedance, coupling means coupled to each of said circuits and including an amplifying device coupling said circuits in the forward direction, separate coupling means coupled to each of said circuits and including a second device having admittance variable with bias coupling said circuits in the backward direction, said second device having a sharp cut-off relation between its bias and admittance, said coupling means together providing a coupling reaction between said circuits which is variable with said admittance to vary the amplification in said system, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when said bias is adjusted to values approaching the cut-off value, means for biasing said second device beyond the cut-off value in the absence of a received carrier, and means responsive to the amplitude of a received carrier for applying to said second device a bias opposing the bias of said first-named biasing means and variable with the amplitude of said carrier to vary the resultant bias applied to said second device through the cut-off value thereby to vary the amplification in said system.

19. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube amplifier coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of said resonant frequencies and regenerative at higher and lower frequencies, and means for adjusting both of said coupling means in accordance with the intensity of a received carrier simultaneously to vary the amplification in said system and the width of the frequency band passed by said system in opposite senses, said last-named means being effective to cause, for a predetermined change in said carrier intensity, a change in the adjustment of said backward coupling means much greater than the attendant change in the adjustment of said forward coupling means.

20. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising input and output circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube amplifier coupling said circuits in the forward direction, separate coupling means including a vac-

uum tube having transconductance variable with bias voltage coupling said circuits in the backward direction, said last-named vacuum tube having a sharp cutoff relation between its bias voltage and transconductance, said coupling means together providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of said resonant frequencies and regenerative at lower and higher frequencies and which is variable with said bias voltage to vary the selectivity and responsiveness of said receiver, and the couplings between each of said coupling means and said output circuit being proportioned to minimize distortion in said system when the value of said bias voltage is near the cutoff value, means for biasing said vacuum tube beyond the cutoff value in the absence of a received carrier, and means responsive to the amplitude of a received carrier for applying to said tube a bias opposing the bias of said first-named biasing means and variable with the amplitude of said carrier to vary through the cutoff value the resultant bias applied to said tube and thereby to vary the amplification in said system.

21. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube amplifier coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of said resonant frequencies and regenerative at lower and higher frequencies, means for adjusting said backward coupling means directly with the intensity of a received carrier to vary the amplification in said system and the width of the frequency band passed by said system, and means for adjusting said forward coupling means inversely with the intensity of said carrier further to vary the amplification in said system and the width of the frequency band passed by said system, said two last-named means being so proportioned that the change in the adjustment of said forward coupling means caused by a predetermined change in carrier intensity is much less than that of said backward coupling means.

22. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube repeater coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of said resonant frequencies and regenerative at lower and higher frequencies, means for varying the backward coupling between said circuits in accordance with the intensity of a received carrier directly to vary the width of the frequency band transmitted through said system and inversely to vary the responsiveness of said system, means for varying the forward coupling inversely in accordance with the intensity of said carrier further to vary

said responsiveness in the same sense, and means affecting said two last-named means directly to vary the ratio of said backward coupling and inversely to vary the ratio of said forward coupling to the amplified carrier output from said system in accordance with variations of the carrier input to said system, whereby a substantially constant carrier intensity output is secured from said system irrespective of the intensity of said received carrier.

23. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube repeater coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of said resonant frequencies and regenerative at lower and higher frequencies, and means for adjusting both of said coupling means in accordance with the intensity of a received carrier, one of said coupling means being adjusted inversely to the other, simultaneously to vary the amplification in said system and the width of the frequency band passed by said system, said last-named means being effective to adjust said backward coupling means only when the intensity of the received carrier exceeds a predetermined value.

24. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube repeater coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is degenerative at frequencies in the vicinity of said resonant frequencies and regenerative at lower and higher frequencies, means for adjusting both of said coupling means with the intensity of a received carrier, one of said coupling means being adjusted inversely to the other, simultaneously to vary the amplification in said system and the width of the frequency band passed by said system, and means for preventing said last-named means from adjusting said backward coupling means until the intensity of the received carrier exceeds a predetermined value.

25. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube repeater coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is adjustable to vary the responsiveness and selectivity of said system, means for adjusting said forward coupling means inversely in accordance with the intensity of a received carrier to vary the amplification in said system, and additional means responsive to ad-

justment of said forward coupling means for adjusting in a greater ratio said backward coupling means directly in accordance with the intensity of said received carrier to vary the width of the frequency band passed by said system.

26. In a modulated-carrier signal receiver, a variable band-pass selector system for controlling the selectivity and responsiveness of the receiver comprising a pair of circuits resonant at frequencies within said band, directive coupling means including a vacuum tube coupling said circuits in the forward direction, separate coupling means including a second vacuum tube coupling said circuits in the backward direction, said coupling means being substantially less frequency-selective than said circuits and providing a coupling reaction between said circuits which is adjustable to vary the responsiveness and selectivity of said system, means for adjusting said forward coupling means inversely in accordance with the intensity of a received carrier to vary the amplification in said system, and additional means comprising a biasing resistance element for said backward coupling tube connected in the space-current paths of both of said tubes for adjusting in a greater ratio said backward coupling means to vary the width of the frequency band passed by said system directly in accordance with the intensity of said carrier.

27. In a modulated-carrier signal receiver, a variable band-pass selector system comprising terminal circuits resonant at frequencies within said band, directive coupling means coupling said circuits in one direction, separate coupling means coupling said circuits in the other direction, means for adjusting one of said coupling means directly in response to the intensity of a received carrier to vary the amplification in said system, and additional means responsive to a variable effect of adjustments of said one of said coupling means for adjusting the other of said coupling means indirectly in response to the intensity of said received carrier to vary the width of the frequency band passed by said system.

28. In a modulated-carrier signal receiver, a variable band-pass selector system comprising terminal circuits resonant at frequencies within said band, directive coupling means coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, means responsive to the intensity of a received carrier for adjusting said forward coupling means to vary the response of said system inversely in accordance with said received carrier intensity, and additional means responsive to the adjustment of said forward coupling means for adjusting said backward coupling means directly in accordance with said received carrier intensity to vary the width of the frequency band passed by said system.

29. In a modulated-carrier signal receiver, a variable band-pass selector comprising terminal circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube repeater coupling said circuits in the forward direction, separate coupling means coupling said circuits in the backward direction, means responsive to the intensity of a received carrier for adjusting the transconductance of said vacuum tube, and means controlled by the space current of said vacuum tube for varying the effect of said backward coupling means.

30. In a modulated-carrier signal receiver, a variable band-pass selector system comprising

terminal circuits resonant at frequencies within said band, directive coupling means including a vacuum-tube repeater coupling said circuits in a forward direction, separate coupling means including a vacuum-tube repeater coupling said circuits in a backward direction, means responsive to the intensity of a received carrier for adjusting

the transconductance of said forward tube, and a common cathode-biasing resistor for said tubes whereby variations in the space current of said forward tube cause inverse variations in the transconductance of said backward tube.

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