Aug. 11, 1936. H. A. WHEELER 2,050,679

RADIO RECEIVER

Filed Oct. 3, 1933 6 Sheets-Sheet 1

Fig. 1a,

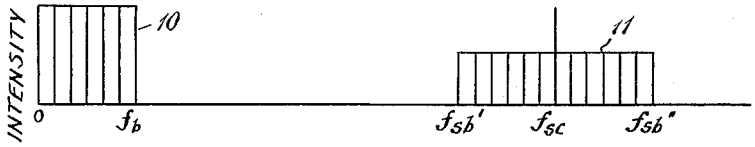


Fig. 1b,

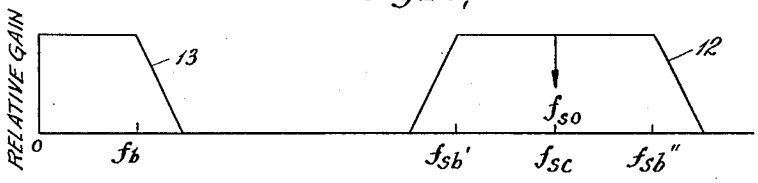


Fig. 1c,

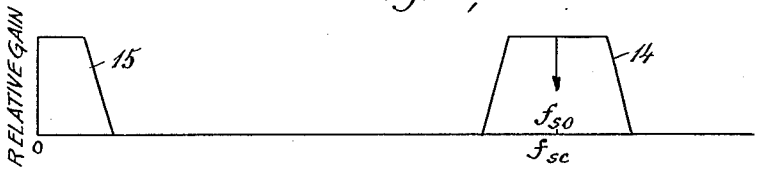


Fig. 1d,

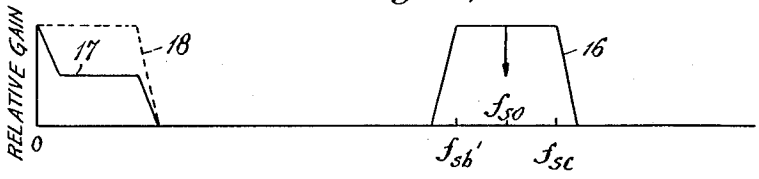


Fig. 1e,

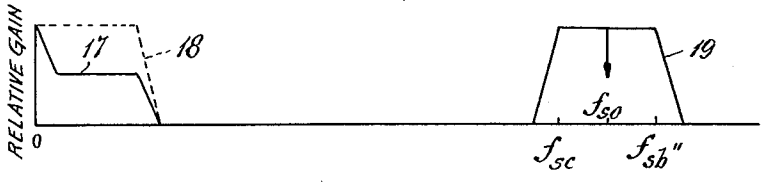
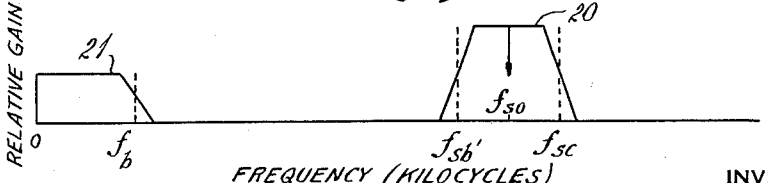


Fig. 1f,

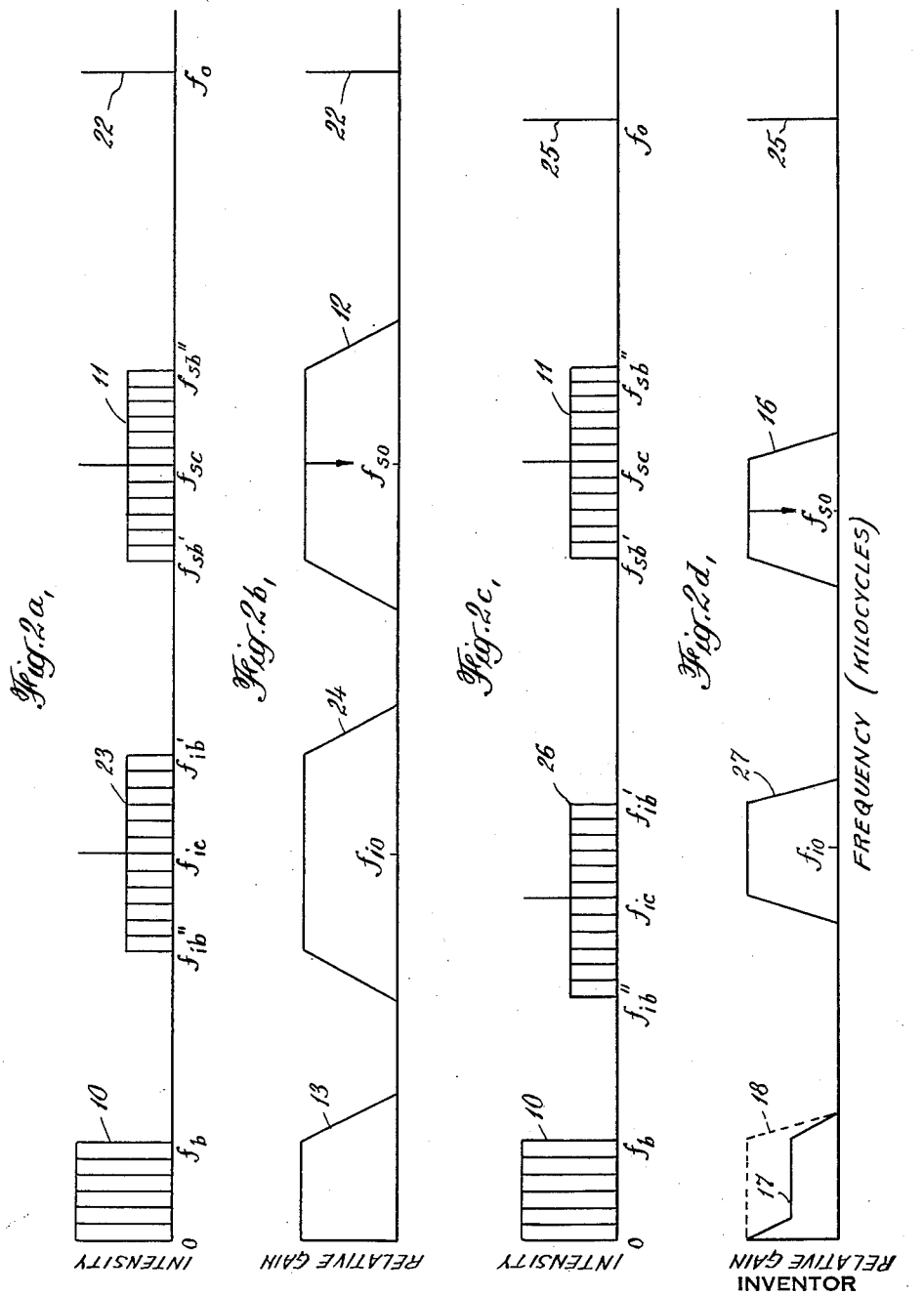


INVENTOR
Harold A. Wheeler
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

Aug. 11, 1936. H. A. WHEELER 2,050,679

RADIO RECEIVER

Filed Oct. 3, 1933 6 Sheets-Sheet 2



INVENTOR
Harold A. Wheeler
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

Aug. 11, 1936. H. A. WHEELER 2,050,679

RADIO RECEIVER

Filed Oct. 3, 1933 6 Sheets-Sheet 3

Fig. 3,

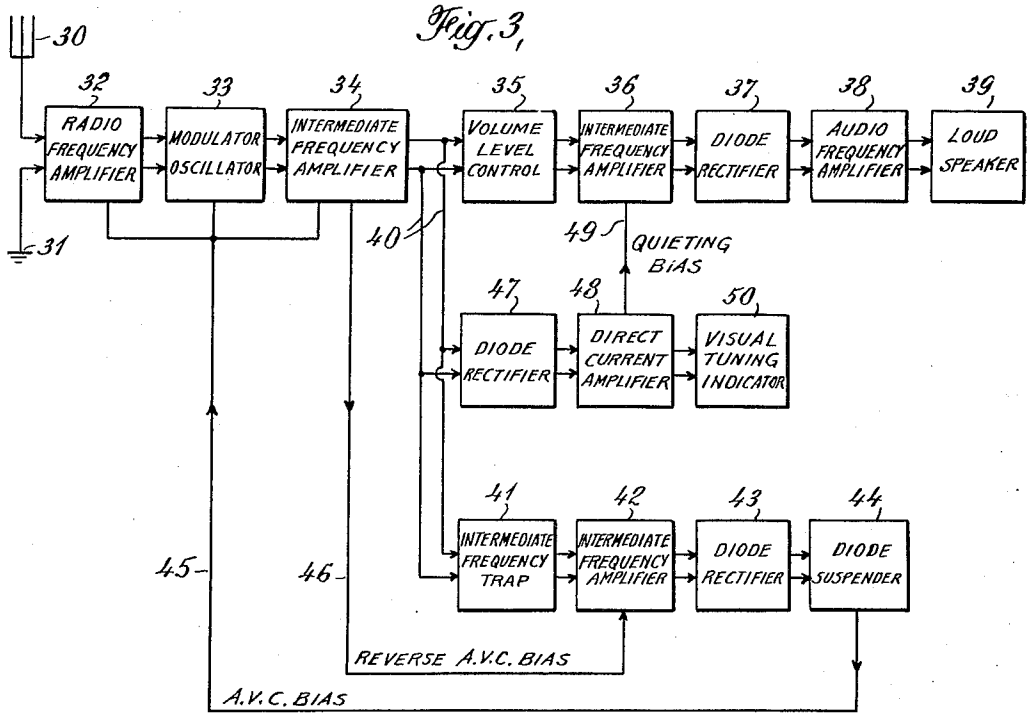


Fig. 4a

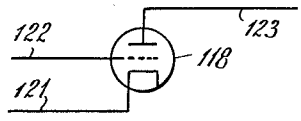


Fig. 4b,

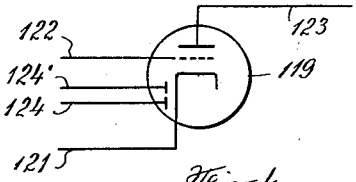


Fig. 4c,

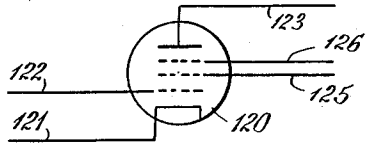


Fig. 4d,



Fig. 4e

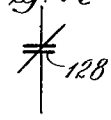
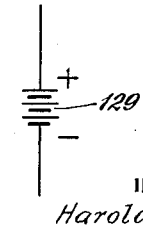


Fig. 4f,



INVENTOR
Harold A. Wheeler
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

Aug. 11, 1936. H. A. WHEELER 2,050,679

RADIO RECEIVER

Filed Oct. 3, 1933 6 Sheets-Sheet 4

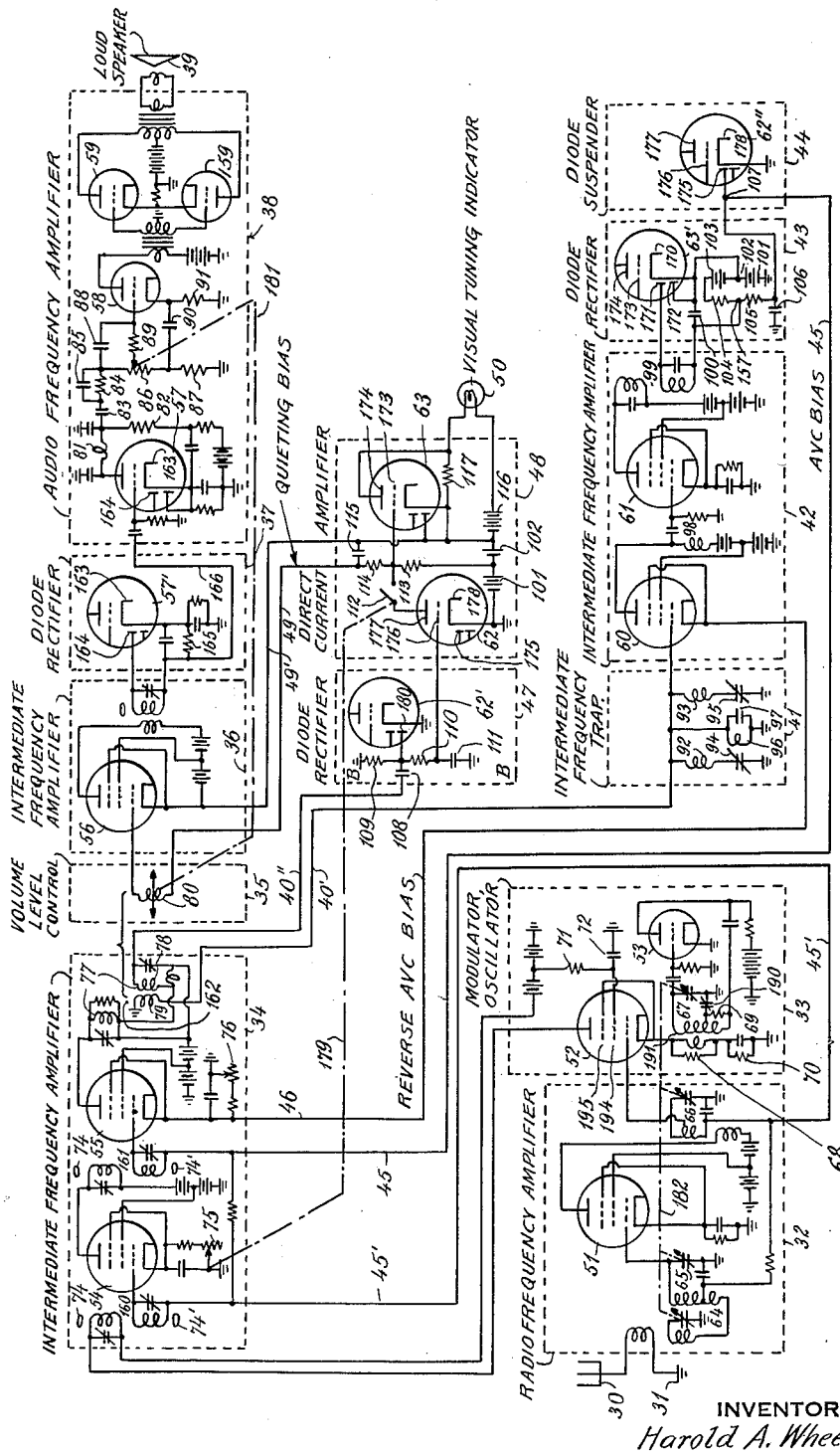


Fig. 4.

INVENTOR
Harold A. Wheeler
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

Aug. 11, 1936. H. A. WHEELER 2,050,679

RADIO RECEIVER

Filed Oct. 3, 1933 6 Sheets-Sheet 5

Fig. 5,

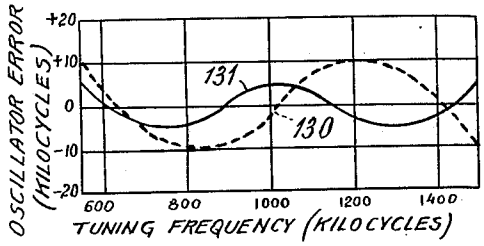


Fig. 6,

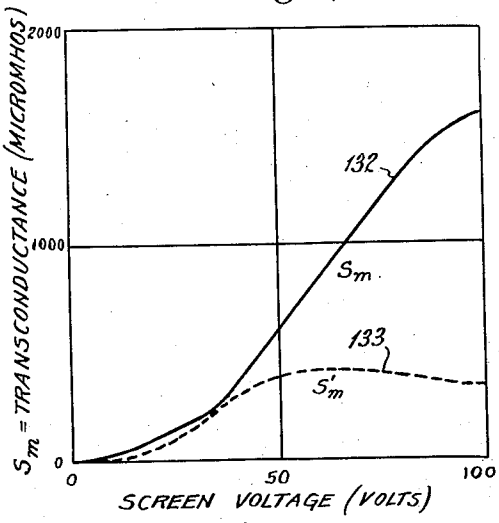
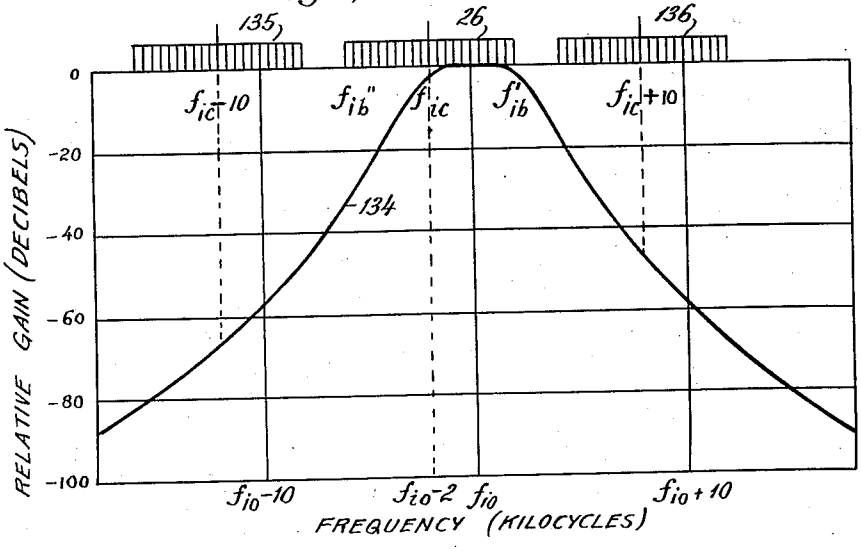


Fig. 7,



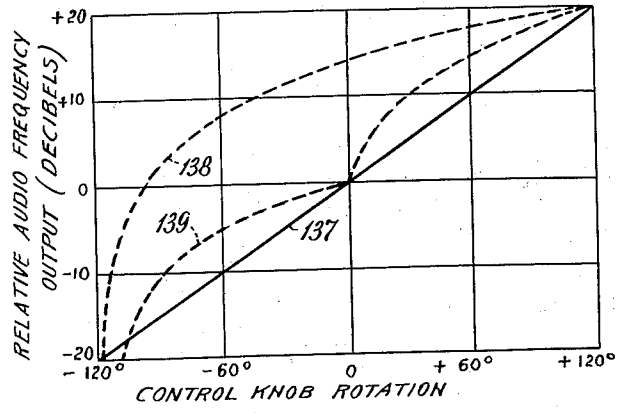


Fig. 8,

INVENTOR
Harold A. Wheeler
BY
Pennie, Davis, Marvin & Edmonds
ATTORNEYS

Aug. 11, 1936. H. A. WHEELER 2,050,679

RADIO RECEIVER

Filed Oct. 3, 1933 6 Sheets-Sheet 6

Fig. 9,

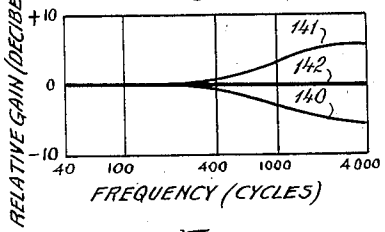


Fig. 10,

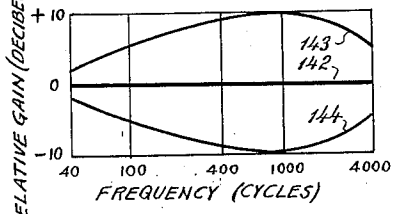


Fig. 11,

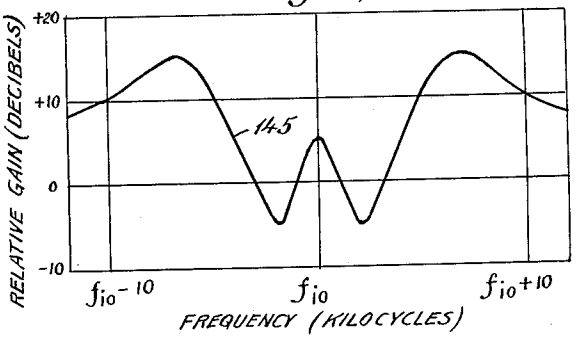


Fig. 14,

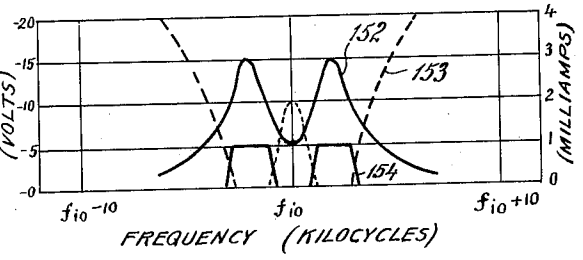


Fig. 12,

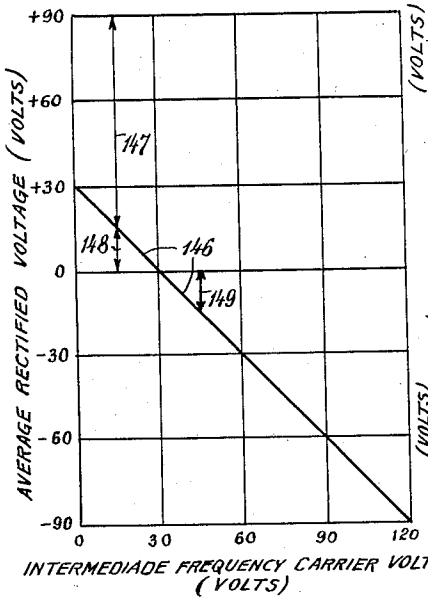
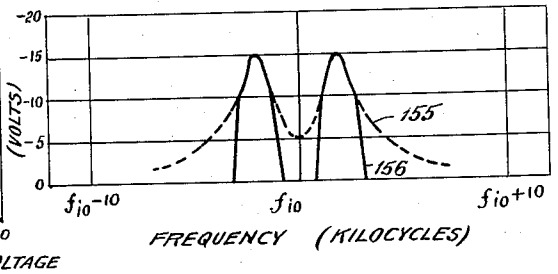


Fig. 15,



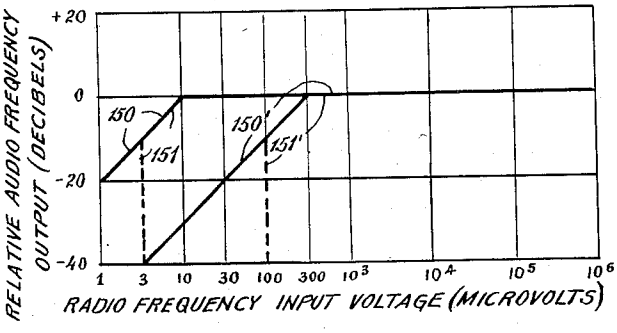


Fig. 13,

INVENTOR
Harold A. Wheeler
BY
Pennie, Davis, Marvin and Edmonds
ATTORNEYS

Patented Aug. 11, 1936 2,050,679

UNITED STATES PATENT OFFICE

2,050,679

RADIO RECEIVER

Harold A. Wheeler, Great Neck, N. Y., assignor to Hazeltine Corporation

Application October 3, 1933, Serial No. 691,927

44 Claims. (Cl. 250—20)

This invention relates to carrier wave signaling and more particularly to the distortionless and selective reception of radio signals free from interfering signals or disturbances.

The invention is particularly applicable to the reception of modulated carrier signals, as commonly employed in radio broadcasting, wherein the radio-frequency carrier wave is modulated by a modulation, or audio, frequency so that the transmitted signals comprise the radio-frequency carrier together with two associated sidebands of modulation.

According to this invention, the desired distortionless and selective reception is provided by the use of apparatus which selects and translates in its entirety only one sideband of the modulated carrier signal. Since only one sideband, instead of the usual two, is entirely utilized, the signal selecting circuits of the receiver may be designed to pass only about one half the band of frequencies which would be required in the case of the usual double sideband reception. A smaller selected band width thus serves to eliminate undesired signals and minimize interference.

Although the single sideband type of reception may be utilized with other types of receivers, it is particularly applicable to receivers of the superheterodyne type; and most of the detailed description and drawings relate specifically to a superheterodyne single sideband receiver.

A further advantage of the single sideband type of reception is that either one or the other of the two sidebands normally transmitted by a transmitting station, may be selected at will. Hence, in the event interfering signals happen to be encroaching upon the frequencies of one of the sidebands, a slight adjustment of the tuning dial will select the other sideband, which in all probability will be free from interference. It is very unusual for both sidebands of a transmitting station to be subject to interference from other stations.

A feature of the present invention is that the signal selecting circuits are preferably adjusted so that the radio signal carrier frequency is located at either one edge or the other of the narrow modulation band which is permitted to be passed. This means that the selecting circuits, instead of being tuned symmetrically to the carrier frequency, as is usually the case, are tuned to the mid-frequency of the sideband being utilized.

A particular feature is a system of "selective admission" which increases the audible response of the receiver sharply to a maximum when the receiver is unsymmetrically tuned in the proper condition to uniformly receive only the carrier and one sideband. This is preferably accomplished by cooperation between a selective trap network and the automatic volume control.

Another feature resides in the form of automatic volume control system associated with the receiver. The automatic volume control is of a "suspended" type, whereby the control operates only after a predetermined signal strength is reached, and its operation is independent of modulation.

The output of the receiver is maintained unusually uniform by virtue of a "reversed automatic volume control", associated with the automatic volume control system, which provides the required ultimate variation of bias voltage for gain control.

A further feature is the use of a "quieting" system by reason of which the receiver is maintained unresponsive unless the received signal strength exceeds a predetermined value, and unless the receiver is correctly tuned.

Both the automatic volume control and quieting systems referred to above are provided with a "time lag" which is comparable with the period of the lowest audio or modulation frequency. The time lag of the quieting system is made as great, or greater than, the time lag of the automatic volume control.

The above and other features of the invention will become apparent from the following detailed description in conjunction with the accompanying drawings.

Of the accompanying drawings, Figs. 1*a*–1*f* illustrate graphically the selectivity characteristics of double and single sideband radio receivers;

Figs. 2*a*–2*d* similarly illustrate the selectivity characteristics of double and single sideband superheterodyne receivers;

Fig. 3 is a diagram showing in generalized form a single sideband receiving system of the superheterodyne type, in accordance with this invention;

Fig. 4 is a schematic circuit diagram of a receiver constructed in accordance with the diagram of Fig. 3;

Figs. 4*a*–4*f* illustrate symbols and conventions used in the schematic diagram of Fig. 4;

Fig. 5 shows graphically the alignment errors of the local oscillator in the system of Fig. 4, relative to the radio-frequency amplifier;

Fig. 6 shows graphically how the transconductance and the modulation of the modulator vary with change of control grid bias in the superheterodyne receiver of Fig. 4;

Fig. 7 shows graphically the selectivity of the intermediate-frequency amplifier of Fig. 4;

Fig. 8 shows graphically the variation of the receiver output with angular rotation of the manual volume control;

Fig. 9 shows graphically the fidelity of the audio amplifier of Fig. 4 and illustrates the compensation in the audio amplifier for the loss of part of a sideband in the receiver;

Fig. 10 shows the change of audio-frequency fidelity upon change of volume level;

Fig. 11 illustrates the relative gain or responsiveness of the intermediate-frequency trap of Fig. 4, which creates the "selective admission" feature;

Fig. 12 shows the change of automatic volume control bias voltage with change of intermediate-frequency carrier voltage, in the receiver of Fig. 4;

Fig. 13 illustrates the automatic volume control and quieting of the audio-frequency output of the receiver of Fig. 4; and

Figs. 14 and 15 show the "selective admission" and related quieting of the receiver of Fig. 4.

A transmitted radio telephone signal comprises a carrier frequency which is modulated at audio frequencies. This modulation does not alter the carrier frequency component of the signal wave, but merely superimposes thereon two symmetrical bands of frequencies which are known as sidebands. The lower of these sidebands contains, for each audio frequency of modulation, a component whose frequency is equal to the difference of the carrier and audio frequencies, and the upper sideband contains, for each audio frequency of modulation, a component whose frequency is equal to the sum of the carrier and audio frequencies. Ordinarily, no single frequency component of a sideband can exceed half the intensity of the carrier frequency; that is to say, the sum of two symmetrical sideband components cannot ordinarily exceed the carrier frequency intensity, otherwise the modulation would exceed 100%. Each sideband individually represents half the total modulation of the signal, and therefore contains a complete picture of all the modulations, even though at a reduced intensity as compared with the total modulation represented by both sidebands.

Since in ordinary broadcast reception, the carrier frequency and both sidebands are utilized, there is required for such reception a receiver which selects and passes a frequency band whose width is double the highest audio frequency utilized in the reception. This considerable band width places a limitation upon the selectivity of the receiver against interference from undesired signals, even in instances where one of the sidebands is entirely free from interference.

Single sideband reception is a method of reception which utilizes completely only one of the two sidebands, although the carrier frequency and the inner edge (representing the lower audio frequencies) of the other sideband may also be utilized to advantage. For any given signal, this type of reception requires a receiver which selects and passes a frequency band of width only equal to the highest audio frequency utilized in the reception. As a result, a single sideband receiver can be greatly improved in selectivity as compared with a double sideband receiver, and this improvement is not accompanied by the loss of any of the desired audio frequencies of modulation.

To furnish a better understanding of the invention, the operation of simple double sideband and singe sideband receivers will be briefly described before introducing the single sideband receiver of this invention. The general operation and relationships of such receivers are described with reference to Figs. 1 and 2, the following symbolic notations being employed:

f_a=an audio frequency of modulation.

f_b=the highest required audio frequency of modulation=the width of one sideband.

f_c=a carrier frequency in general.

f_s=a radio signal frequency in general.

f_{so}=the nominal tuning frequency indicated on the dial of the receiver=the center frequency of the signal frequency band determined by all selectors in the receiver.

f_{sc}=the signal carrier frequency.

$f_{sa'}=f_{sc}-f_a$=a lower side frequency, a component of the lower sideband.

$f_{sa''}=f_{sc}+f_a$=an upper side frequency, a component of the upper sideband.

$f_{sb'}=f_{sc}-f_b$=the lower boundary of the lower sideband.

$f_{sb''}=f_{sc}+f_b$=the upper boundary of the upper sideband.

Fig. 1 shows a number of graphs, each plotted with frequency indicated along the horizontal axis, the ordinates in the case of Fig. 1*a* representing relative component frequency intensities, and in the case of Figs. 1*b* to 1*f*, inclusive, representing relative gain or responsiveness. In Fig. 1*a*, graph **10** represents the frequency spectrum of audio-frequency telephone currents, and graph **11** represents the carrier and sideband spectrum of a radio-frequency signal wave modulated by these audio-frequency currents.

Fig. 1*b* shows the selection characteristics of an ordinary double sideband receiver. Graph **12** shows the responsiveness of all the selector circuits combined, the responsiveness being uniform over both sidebands and falling off abruptly beyond the extreme frequencies of each sideband. Graph **13** shows the responsiveness of the receiver to audio modulation, this being determined by the two symmetrical portions of graph **12** at either side of the signal carrier frequency f_{sc}, as effecting the respective sidebands. From these graphs, it is observed that a double sideband receiver having these selection characteristics is uniformly responsive to audio modulation within the required range of audio frequencies.

In Fig. 1*c*, graphs **14** and **15** show the selection characteristics for signal and audio frequencies, respectively, of a double sideband receiver which is made too selective. Graph **14** is only half as wide, in the frequency scale, as graph **12**, which causes the outer half of each sideband to be cut off. Graph **15** shows the audio-frequency effect that the receiver is unresponsive to modulation at the higher audio frequencies.

Fig. 1*d* shows the selection characteristics of a single sideband receiver operating according to this invention. Graph **16** is the same as graph **14** but is displaced in the lower frequency direction by an amount approximately equal to half the width of a sideband. This is effected by adjusting the signal selective circuits off center (with respect to the signal-carrier frequency f_{sc}), so as to include all of the lower sideband and exclude most of the upper sideband. Graph **17** shows the resulting effect upon the audio frequency, namely, that the receiver is more or less responsive to modulation at all required audio frequencies. The low audio-frequency modulation is carried by side frequencies very near the car-

rier frequency where the receiver is responsive on both sides of the carrier, whereas the high audio-frequency modulation is carried by the outer side frequencies where the receiver is responsive on only one side of the carrier. The responsiveness to high audio frequencies is, therefore, reduced to half of what it would be in the case of double sideband reception. This deficiency of the higher audio frequencies may be readily corrected, however, by doubling the gain of the audio amplifier at the higher audio frequencies, the resulting uniform response being illustrated by graph **18**.

Fig. 1*e* is similar to Fig. 1*d* except that graph **19** shows tuning off center (with respect to the signal carrier frequency) in the opposite direction from that shown in Fig. 1*d*, so that the upper, instead of the lower, sideband is passed. The resulting audio-frequency response, shown by graphs **17** and **18**, is the same as in the case represented by Fig. 1*d*.

Fig. 1*f* shows a method for obtaining uniform responsiveness in a single sideband receiver, without compensating correction in the audio amplifier. Comparing with Fig. 1*d*, graph **20** is not as wide as graph **16**, although the detuning from the carrier frequency f_{sc} is just as great; hence, the receiver is only half as responsive at the carrier and the immediately adjacent side frequencies as in the case of Fig. 1*d*. For any given audio frequency of modulation, the total responsiveness at all side frequencies is the same, as shown by graph **21**.

The operation of double sideband and single sideband reception as applied to superheterodyne receivers will be described with reference to Fig. 2. For the purpose of such description, the following additional notation is employed, which assumes that the superheterodyne oscillator frequency is greater than the received carrier signal frequency, but less than double the signal frequency.

f_i=an intermediate frequency in general.

f_{io}=the nominal intermediate frequency=the center frequency of the intermediate-frequency band determined by the intermediate-frequency selectors.

$f_o=f_{so}+f_{io}$=the oscillator frequency

$f_{ic}=f_o-f_{sc}$=the intermediate carrier frequency.

$f_{ia}'=f_o-f_{sa}'=f_{ic}+f_a$.

$f_{ia}''=f_o-f_{sa}''=f_{ic}-f_a$.

$f_{ib}'=f_o-f_{sb}'=f_{ic}+f_b$.

$f_{ib}''=f_o-f_{sb}''=f_{ic}-f_b$.

The graphs of Fig. 2 are plotted similarly to those of Fig. 1, frequency being indicated along the horizontal axis, the ordinates of Figs. 2*a* and 2*c* representing relative component frequency intensities, and the ordinates of Figs. 2*b* and 2*d* indicating relative gain or responsiveness. The graphs which are like those of Fig. 1 are similarly numbered.

Figs. 2*a* and 2*b* correspond to Figs. 1*a* and 1*b*, respectively, and show the general operation and characteristics of the ordinary superheterodyne double sideband receiver. The oscillator frequency f_o is tuned above the signal carrier frequency f_{sc} by the amount of the nominal intermediate frequency f_{io}. The oscillator frequency is represented by the line **22**, which corresponds to a dial indication f_{so}, at the receiver, equal to the signal carrier frequency f_{sc}. The signal and oscillator frequencies are combined in the superheterodyne modulator to produce the difference frequency components represented by graph **23**, the converted carrier wave having its frequency f_{ic} equal to the nominal intermediate frequency f_{io}. It is noted that the lower and upper sidebands are interchanged in the process of converting from signal to intermediate frequency. This is because the signal upper sideband is nearer the oscillator frequency, and therefore produces lower difference frequencies.

The graph **24** in Fig. 2*b*, centered at the nominal intermediate frequency f_{ic}, shows that the intermediate-frequency selectors respond uniformly over a frequency band which includes both of the intermediate-frequency sidebands. Graph **12** of Fig. 2*b* shows the responsiveness of the modulator and intermediate-frequency selectors in terms of signal frequency, and takes into consideration the fact that the latter frequency is to be converted to the intermediate frequency in the modulator. The resulting audio-frequency responsiveness, shown by graph **13**, is the same as in the case of Fig. 1*b*.

Figs. 2*c* and 2*d* show the operation and characteristics of a superheterodyne single sideband receiver, Fig. 2*d* corresponding to Fig. 1*d*. The oscillator frequency is tuned lower than in the case of the double sideband reception of Figs. 2*a* and 2*b*, by an amount equal to one half of the highest audio frequency required. The oscillator frequency in this case is represented by the line **25** and corresponds to a dial indication f_{so} which is likewise lower than the signal carrier frequency f_{sc}. The signal and oscillator frequencies are combined to produce the difference frequency components represented by graph **26**. The converted carrier frequency f_{ic} is lower than in the case of Figs. 2*a* and 2*b* by one half of the frequency f_b, and likewise lower than the frequency f_{io}.

The graph **27** in Fig. 2*d* shows that the intermediate-frequency selectors respond uniformly over a frequency band which includes only one of the sidebands, graph **27** being half as wide, in frequency, as graph **24**. The graph **27** is centered at the same frequency f_{io} as in the case of double sideband reception illustrated in Fig. 2*b*, but includes all of only one sideband, as a result of detuning the receiver. In Fig. 2*d*, graph **16** shows the responsiveness of the modulator and intermediate-frequency selectors in terms of the signal frequency. The resulting audio-frequency responsiveness, shown by graph **17** (and **18** when audio-frequency compensation is employed), is the same as in the case of Fig. 1*d*.

Fig. 2 shows exactly how a superheterodyne receiver would be operated to secure the double sideband and single sideband characteristics of Figs. 1*b* or 1*d*, respectively. From that description, it is apparent how to design and operate a superheterodyne receiver with the characteristics of Figs. 1*d*, 1*e*, or 1*f*.

With respect to superheterodyne receivers, the following considerations should be appreciated:

(1) The signal carrier frequency f_{sc} is fixed at the transmitter and cannot be varied by adjusting the receiver.

(2) The nominal intermediate frequency f_{io} is predetermined by the design of the intermediate-frequency selectors and cannot be varied by adjusting the tuning dial of the receiver. The band width of the intermediate-frequency selectors, shown by graph **24** or **27**, is likewise predetermined.

(3) The nominal tuning frequency f_{so}, indicated on the tuning dial, may be varied at will. The main function of the tuning dial is to vary the oscillator frequency f_o, which is normally equal to f_{so} plus f_{io}. The direct effect of varying the oscil-

lator is to vary the intermediate carrier frequency f_{ic}, relative to the nominal intermediate frequency f_{io}. The indirect effect of varying the oscillator is to vary the position of graph **12** or **16** in Figs. 2*b* or 2*d*, which is determined by the oscillator and the intermediate-frequency selectors, and which is centered at f_{so}, assuming the oscillator frequency f_o is always equal to f_{so} plus f_{io}.

(4) The superheterodyne receiver can be regarded as a simple receiver, for most purposes, provided the oscillator frequency f_o is always equal to f_{so} plus f_{io}.

Circuit arrangement and general operation

Fig. 3 is a generalized circuit diagram illustrating the arrangement of a superheterodyne type of single sideband receiver in accordance with this invention. The path traversed by signals between the antenna and the loudspeaker is largely conventional. There is provided an antenna **30** and ground **31** for intercepting the signals, which are then supplied in order to a radio-frequency amplifier **32**; a local oscillator and modulator **33**; intermediate-frequency amplifiers **34** and **36** having interposed therebetween a volume level control **35**; a diode rectifier **37**; an audio-frequency amplifier **38**; and the loudspeaker **39**.

With reference to this main signal path, the radio-frequency signal is received in the usual manner by the antenna **30** and selected and amplified at the signal frequency in the radio-frequency amplifier **32**, which for broadcast reception is capable of tuning over the frequency range of about 550–1500 kilocycles. The oscillator and modulator system **33** converts the signal carrier frequency to an intermediate carrier frequency in the manner well understood in the art. The intermediate carrier frequency will be one of two frequencies depending upon which of the two sidebands is being selected. These two alternative intermediate carrier frequencies will therefore differ by the width of a sideband which is about 4 kilocycles. These frequencies may conveniently be 110 or 114 kilocycles, depending upon which sideband is to be utilized. The signal is further amplified in the intermediate-frequency amplifier wherein the carrier and one sideband are selected, the band width passed by this amplifier being, for the particular intermediate carrier frequencies mentioned above, 110–114 kilocycles. The volume level is controlled by the level control **35** interposed between the two intermediate-frequency amplifiers **34** and **36**.

The diode rectifier **37** produces from the carrier and the single intermediate-frequency sideband the audio frequencies of modulation, which are then amplified in the usual manner by the audio amplifier **38**, from whence they are supplied to the loudspeaker **39**. For the purpose of maintaining the volume output of the receiver substantially constant in spite of wide variations of received signal intensity, there is provided an automatic volume control system comprising connections **40** from the output terminals of intermediate-frequency amplifier **34** to the following elements connected in succession: an intermediate-frequency trap **41**, an intermediate-frequency amplifier **42**, a diode rectifier **43**, and a diode "suspender" **44**. The functions of the intermediate-frequency trap **41** and of the diode suspender **44** are described below. In accordance with the operation of the automatic volume control system, there is created at the diode suspender **44** a uni-directional voltage which varies with the received signal intensity; and this unidirectional voltage is applied through the automatic volume control bias connection **45** to the control elements of amplifiers **32** and **34** and modulator **33**. For the purpose of insuring the proper variation of control bias voltage over a wide range of received signal intensities, there is provided a connection **46** from the intermediate-frequency amplifier **34** of the main signal path to a control element of the intermediate-frequency amplifier **42** in the automatic volume control system. The function and operation of this "reverse control bias" is more fully described below.

There is also provided a quieting system also operated from connections **40**, this quieting system comprising in succession a diode rectifier **47** and a direct-current amplifier **48** wherein there is created a direct-current bias which is applied to a control element of intermediate-frequency amplifier **36** for maintaining this latter amplifier inoperative until the signal intensity at connections **40** rises above a predetermined value. This inoperativeness of amplifier **36** under the condition of relatively weak signals can be brought about by the use of a high negative bias on its control element. When the signal strength becomes stronger, this quieting bias on the control element is reduced, permitting normal operation. There is also associated with the quieting system a visual tuning indicator **50** connected to the output of amplifier **48**, the purpose of the tuning indicator being to enable an operator to readily determine the correct position of the tuning dial.

In accordance with a feature of the invention, there is created what is here termed "selective admission", this being effected by the action of the intermediate-frequency trap **41** of the automatic volume control system, and perfected by the cooperation of the quieting system. The trap **41** contains a number of selective circuits proportioned to cause the automatic volume control bias of conductor **45** to become partially relaxed when the receiver is so tuned that the intermediate carrier frequency is located exactly at one edge or the other of the frequency band transmitted by the intermediate frequency amplifier; in this case, 110 or 114 kilocycles. At these tuning points, which represent the proper adjustment of the receiver, the intermediate-frequency carrier voltage present at connections **40** is maintained at a substantially higher level than in the case of any other tuning points. This means that when the receiver is tuned to one or the other of the correct tuning points, the output of amplifier **34** rises abruptly and therefore causes the signal at connections **40** to exceed the critical value above which the quieting action is released. At these correct tuning points, the visual indicator abruptly gives maximum indication to show correct tuning.

Fig. 4 is a detailed circuit diagram illustrating a single sideband receiver designed according to the general arrangement of Fig. 3. The rectangular boxes of Fig. 3 are indicated in Fig. 4 in dotted lines and are similarly numbered.

Before proceeding with a description of Fig. 4, there will be explained some of the conventional notations and symbols used therein. The more important of these symbols are defined with reference to Figs. 4*a*–4*f*. The tube **118** illustrates a triode having a cathode **121**, a control grid **122** usually negative relative to the

cathode, and a plate or anode **123**, usually positive relative to the cathode. Tube **119** is the symbol used for a "double-diode triode" type of tube, in which the triode elements are cathode **121**, control grid **122**, and plate **123**, while the plates **124** and **124'** are diode plates or anodes. Tube **120** illustrates the symbol used for a pentode tube having a cathode **121**, a control grid **122**, a screen **125** usually having a positive voltage relative to the cathode, a suppressor grid **126**, usually tied to the cathode, and a plate **123**. The symbol for a variable tuning condenser which is varied while tuning the receiver is shown at **127**, while condenser **128** is the symbol for an adjustable (but usually preadjusted) condenser. The battery **129** represents a source of direct voltage, the positive side of which is conventionally indicated by a long line.

Although batteries such as **129** are shown in many places in Fig. 4, it is understood that these represent any source of direct voltage, and the same source may be used simultaneously in several or many places where the symbol **129** is shown. It is also observed that the double-diode triode tube **119** is a multi-purpose tube, that is, the triode elements may be used in one portion of the system and each of the diode elements in different portions. Hence, where such a tube as **119** is used, it is separately shown at each position in Fig. 4 where any of its elements are used.

In Fig. 4, the radio-frequency amplifier **32** comprises a pentode tube **51** suitably coupled to the antenna **30**, and has associated therewith three simultaneously tunable selecting circuits, two of which, designated **64** and **65**, are located ahead of the amplifier and the other of which, **66**, is coupled between the amplifier and the modulator **52**.

The oscillator and modulator arrangement **33** comprises the local oscillator tube **53** and the modulator tube **52**. The general arrangement of this part of the system is understood in the art and requires no detailed description here. Particular features are described below.

The output of the modulator is the input of the intermediate-frequency amplifier **34** which comprises two amplifying tubes **54** and **55** and the three intermediate-frequency coupling systems **160**, **161**, and **162** located before, between and after the amplifying tubes.

The volume level control **35** comprises a movable coil **80** in the input circuit of the following intermediate-frequency amplifier stage **36**. The coil **80** is coupled with coil **78** of coupling system **162** and is preferably coaxial therewith. Therefore the signal intensity applied to tube **56** of stage **36** can be varied at will by axial motion of coil **80**.

The signals are rectified in the diode portion of a double-diode triode tube **57'** in stage **37**. Only one of the diodes is employed for signal detection, this particular diode comprising the cathode **163** and one of the diode anodes **164**. The triode elements of this tube are used as the first portion of audio-frequency amplifier **38**. For the purpose of illustration, therefore, tube **57'** is shown again in the audio amplifier **38** where it is designated as tube **57**. This second illustration of the same physical elements is proper and convenient because in so far as circuit operation is concerned, it acts as two separate and distinct tubes.

The rectified current flows through a resistor **165**, from whence rectified voltage is impressed upon the control grid of audio amplifier **57** through conductor **166**. The anode of amplifier **57** is coupled to the second audio-frequency amplifier **58** through a system of resistances and reactances which include resistance **84** and condenser **85**, the function of the latter two elements being to provide proper audio-frequency compensation as will be more fully described hereinafter. The audio signals are further amplified in the push-pull amplifier including tubes **59** and **159**, from whence they are conducted to the loudspeaker **39**.

Single sideband relations

Since it is of primary importance that the receiver select a band of frequencies having a width about equal to the highest required audio frequency of modulation, this selection is provided by the permanently tuned intermediate-frequency coupling systems of intermediate-frequency amplifier **34**. The coupling systems **160**, **161**, and **162** each include a double-tuned transformer having syntonous primary and secondary circuits individually tuned to the intermediate frequency, and the coupling is preferably designed to have about the "optimum" value to provide a uniform transmission characteristic over a band of frequencies corresponding in width to one sideband. In the particular receiver being described, the band seelcted by the intermediate-frequency selecting system is 110–114 kilocycles. The resulting selectivity is illustrated by the curve **134** of Fig. 7 which is shown to be flat within two decibles over a band 4 kilocycles wide and centered at the frequency f_{io} equal to 112 kilocycles. The signal-selecting circuits of radio-frequency amplifier **32** cannot be as accurately tuned as the intermediate-frequency coupling systems, and are, therefore, more broadly tuned; hence, the selection is accomplished mainly in the intermediate-frequency amplifier according to the curve of Fig. 7. The responsiveness of the radio-frequency amplifier may and should be kept uniform within about one decibel over the corresponding radio-frequency sideband, and is therefore designed to pass a band about twice as wide.

At the top of Fig. 7, there is shown the frequency spectrum **26** of a desired signal, carrier and both sidebands being shown as indicated by the designations f_{ic}, f_{ib}', and f_{ib}''. There are also illustrated the positions of the carrier and both sidebands, **135** and **136**, of each of two other signals in adjacent broadcast channels. The curve **134** shows that the receiver is tuned so that the intermediate-frequency amplifier transmits the upper intermediate-frequency sideband (the lower radio-frequency sideband). For the purpose of this example, it is assumed that signal **135** is stronger than signal **136**; hence, the receiver is shown to be properly tuned to the sideband which is furthest away from the strongest signal. The intermediate carrier frequency of signal **135** is subject to 20 decibels more attenuation than that of signal **136**, and the nearest sideband frequency of signal **135** is subject to 30 decibels more attenuation than is the nearest sideband frequency of signal **136**. Both of the adjacent channel signals are attenuated much more than they would be if the curve **134** were doubled in width, as required for double sideband reception, and it is shown how the receiver may be tuned to discriminate most against the stronger of the signals in the two adjacent channels.

Each of the intermediate-frequency trans-

formers 160, 161 and 162, is provided with two co-axial closed turns of wire 74 and 74' on the side of each transformer coil which is remote from the other transformer coil. These two closed coils are moderately coupled with the corresponding transformer coil, preferably in a coaxial cylindrical shield and serve the purpose of increasing the width of curve 134 to the required value. The desired effect may be obtained by varying the position of the closed turn or by changing the wire size; and for any given kind of wire a size is found which has the greatest effect.

Two of the most important problems encountered in the use of this receiver are: (1) to cause the operator to properly tune the receiver so that the intermediate carrier frequency is located at one edge of the selected frequency band, as shown in Fig. 7; and (2) to compensate for the loss of nearly all of the rejected sideband.

The first of these problems is solved by a system of "selective admission", which greatly lessens or entirely quiets the response of the receiver when not properly tuned. This system, which has been mentioned above and is described below in more detail, is made necessary or at least desirable because the sound at the loudspeaker is harsh and unpleasant when the carrier frequency is tuned too far off of the edge of the transmitted sideband.

The second of these problems is solved by the use of resistor 84 and condenser 85 in the audio-frequency amplifier 38. In Fig. 9, which is plotted as relative gain or responsiveness against audio frequency, curve 140 indicates the equivalent audio-frequency loss resulting from the cutting out of most of one sideband. This loss is shown to be about 3 decibels at one kilocycle and 6 decibels at 4 kilocycles in the case of the particular receiver under discussion. Accordingly, the elements 84 and 85 are proportioned to produce a relative audio-frequency gain which varies substantially as represented by curve 141. This latter variation being complementary to that of curve 140, uniform overall audio-frequency response is produced as represented by curve 142.

Automatic volume control

The proper operation of the quieting system requires that the output of the intermediate-frequency amplifier 34 be maintained at a constant predetermined value, substantially independent of both the received signal intensity and the percentage of modulation. In so far as is known, none of the usual systems of automatic volume control meet both of these requirements. The novel type of automatic volume control system used with the present receiver does meet these requirements, and the arrangement and operation of the system is described with reference to Figs. 3, 4, 12, and 13. For the purpose of maintaining the output of amplifier 34 constant across coil 78 in Fig. 4, coil 79 is coupled to coil 78 and connected by connection 40' to the intermediate-frequency trap 41 from where it is amplified in intermediate-frequency amplifier tubes 60 and 61 and then rectified in the rectifier tube 63'. The coupling systems 98 and 99, which couple these latter three tubes in succession, are each tuned to a broad band centered at the mid-frequency of the intermediate-frequency band, 112 kilocycles in this case.

Rectifier 63' is shown as being part of a double-diode triode tube, but for rectification only that diode portion comprising cathode 170 and anode 171 is utilized. The remaining diode anode 172 is tied to the cathode so that it is inert, and the grid 173 and plate 174 are utilized as the elements of the triode amplifier 63 associated with the visual tuning indicator in the quieting system, described below.

There is associated with the diode rectifier 63', a bridge circuit formed by resistors 104 and 105 connected in series across direct voltage sources 101, 102, and 103, the point 157 between these resistances being connected to the lower side of the secondary coil of coupling system 99, and the lower end of resistance 105 being connected to the diode anode 175 of another diode 62'', called the "suspender diode". The point between voltage sources 102 and 103 is connected to the cathode 170.

The suspender diode 62'' is physically like tube 63', that is, it comprises also a triode having a control grid 176 and a plate 177, these triode elements being utilized in the triode amplifier designated 62 of the quieting system, described below. Although voltage sources 101 and 102 are shown in the diode rectifier section 43 as directly connected in series without any other element connected between them, there is actually a connection from between these two sources to the anode 177 of triode 62.

Each of the diodes 63' and 62'' is a uni-directional conductor having, relative to resistors 104 and 105, much less resistance to current in the more conductive direction and much more resistance to current in the opposite direction. Therefore, each of these diodes has an internal resistance, when its anode is positive relative to its cathode, which is much lower than the value of either of the resistances 104 or 105. Therefore, the diode anode 175, which is point 107, is in effect grounded to cathode 178 so long as the junction 157 has a positive voltage relative to ground. In the absence of a signal, point 157 is maintained at a positive voltage by voltage sources 101, 102, and 103, the resulting current flowing through resistors 104 and 105 and diode 62''. These resistors and voltage sources are so proportioned that the open circuit voltage at the junction 157 is substantially the same as that at the junction of sources 102 and 103. Consequently, the connection of the cathode 170 and anode 171 of diode 63' between these two junctions of the bridge produces little or no effect in the absence of a signal, because then there is little or no flow of current through this diode.

When an intermediate-frequency voltage is impressed on diode 63' from coupling system 99, there is produced a rectified current which flows through the bridge and divides between resistors 104 and 105, increasing the current in the former resistor and decreasing the current in the latter resistor and diode 62''. Therefore there is superimposed upon the initial voltage of the junction point 157 a rectified voltage having an average value approximately equal to the root-mean-square value of the intermediate-frequency voltage impressed upon this diode. This constitutes a form of linear detection, and the rectified voltage is an undistorted replica of the intermediate-frequency envelope. To produce this result, condenser 100, connected between cathode 170 and junction point 157, is so small that its charging current is negligible at audio frequencies; while condenser 106 connected between point 107 and ground is so large that its audio-frequency impedance is considerably less than that of resistor 105, and therefore the audio-fre-

quency voltage at point 107 is negligible at all times regardless of the impedance of diode 62''.

Fig. 12 is a chart in which average rectified voltage is plotted against intermediate-frequency carrier voltage, and which shows the approximate relations in the rectifier and suspender circuit as a function of the intermediate-frequency carrier voltage applied to diode 63'. The straight line 146 shows the average voltage of the junction point 157 relative to ground, which voltage changes in the negative direction in proportion to the impressed carrier voltage. It is observed that the total voltage of sources 101, 102 and 103 is 90 volts, sources 101 and 102 together accounting for 30 volts and source 103 for 60 volts. In the absence of an intermediate-frequency signal, the voltage of point 157 relative to ground is +30 volts, as indicated by the upper end of the graph 146. When an intermediate-frequency voltage of any intensity is applied to the rectifier, the dimension 147 indicates the voltage across resistor 104, and the dimension 148 indicates the voltage across resistor 105. When the signal intensity increases to the point where the voltage of junction point 157 becomes negative, the current in diode 62'' is reduced to zero, and the average voltage of point 107 then becomes equal to the average voltage of point 157. The voltage of point 107 relative to ground is indicated by dimension 149, and is shown for this example to increase from zero in a negative direction when the intermediate-frequency carrier voltage exceeds 30 volts. The voltage of point 107 is applied through the conductor 45 to the control grids of intermediate-frequency amplifier tubes 54 and 55, and through connection 45' to the control grid of modulator 52 and of radio-frequency amplifier 51. The action of such automatic volume control biasing connections for controlling the gain of amplifiers and modulators is well understood in the art and requires no detailed discussion here. It is sufficient to state that the connection 45 causes the control grids of the controlled tubes to become more negative when the signal strength increases above a predetermined value, thereby maintaining the output level fairly uniform.

Changes in the degree of modulation of the received signal are prevented from affecting the automatic volume control bias in the following manner. The rectified voltage at point 157 is an undistorted replica of the intermediate-frequency modulation envelope, and therefore the average rectified voltage is equal to the rectified intermediate-frequency carrier voltage, for any degree of modulation up to 100%. Since the audio modulation frequency components of rectification are filtered out by condenser 106, the automatic volume control bias and the effect of diode 62'' depends only upon the intermediate-frequency carrier voltage. This type of "suspended" automatic volume control utilizing a suspender diode 62'', which fails to exert any volume controlling influence until the carrier voltage exceeds a predetermined value, is a preferred method of performing this result. This advantage plus freedom from modulation effects is not obtained in other systems now in common use.

In the particular receiver under discussion, it is desired that the amplification be capable of 100 decibels variation by the automatic volume control action, in order that received signals varying in intensity from 10 micro-volts to 1 volt may produce a uniform output. This requires that the bias represented by the dimension 149 in Fig. 12, applied to the control grids of tubes 51, 52, 54, and 55, shall vary from zero to about 30 volts negative relative to ground, corresponding to the above minimum and maximum received signal voltages. The production of this wide variation of control bias requires that the intermediate carrier frequency voltage applied to diode 63' shall vary from about 30 to 60 volts over the same range of received signal intensity, smaller intensities producing no volume control bias. These relationships are shown in Fig. 12.

The desired highly uniform output of intermediate-frequency amplifier 34 is accomplished by means of a "reverse automatic volume control" bias voltage provided by a connection 46 extending from the cathode of amplifier tube 55 to the cathode of amplifier tube 60 of the automatic volume control system. This common cathode connection 46 is connected to ground through a resistance including rheostat 76 which carries the space current of both tubes; hence, the space current of tube 55 partially controls the grid-cathode bias of tube 60, and therefore the gain of this tube. This bias on tube 60, however, varies oppositely from that on the controlled amplifier and modulator tubes of the main signal path. When the grid-cathode bias of amplifier 55 becomes greater by automatic volume control action, its amplification and space current decrease, and consequently the grid-cathode bias on tube 60 decreases, causing the gain of the latter tube to increase somewhat. Therefore, the increased intermediate-frequency voltage, which is required by diode 63' to decrease the amplification of amplifier 34, is supplied by the increased gain of tube 60 and without any increase of the input to the latter tube, or of the output of amplifier 34. This action is called reverse automatic volume control because the gain of tube 60 is automatically varied oppositely to that of tubes 51, 52, 54, and 55. Quantitatively, the gain of tube 60 can be just about doubled by this reverse automatic volume control connection, this being sufficient to vary the intermediate-frequency voltage on diode 63' over the above-mentioned range of 30 to 60 volts without any appreciable variation of the intermediate-frequency input to tube 60.

The foregoing discussion describes the operation of the "reverse" and the "suspended" automatic volume control actions. These cooperate to maintain the output of intermediate-frequency amplifier 34 very nearly uniform, within plus or minus 1 decibel, during received signal intensity variations up to 100 decibels, this representing approximately a 99% approach to perfect automatic volume control. For the particular quantitative example described, the resulting automatic volume control action is illustrated by curve 150 of Fig. 13 which shows the relative audio-frequency output in decibels plotted against the received radio-frequency input voltage in microvolts.

An adjustment of the output level of amplifier 34 is furnished by the rheostat 76, whose function is to control the gain of tube 60 and thereby to determine the output level of amplifier 34 which is required to operate the automatic volume control system. The adjusting rheostat 76 is preferably preadjusted to the proper value and not changed during operation of the receiver. Its proper setting is mainly determined by the action of the quieting circuit described below in detail.

The sensitivity control of the receiver is provided by a rheostat 75 connected between the cathode (and outer screen) and ground of am-

plifier tube **54**, this constituting a manual variation of the grid bias of the tube which, therefore, controls its gain, and is able to make it less sensitive to noise and to weak signals too noisy to be useful. When the rheostat **75** is adjusted for minimum sensitivity of the amplifier, the automatic volume control characteristic of the receiver is modified somewhat as shown at curve **150'** in Fig. 13, which shows the change of audio-frequency output with radio-frequency input. Incidentally, it is desired that the sensitivity control **75** be mechanically connected, as indicated by broken line **179**, with a switch **112** associated with amplifier **62** of the quieting system so that the latter switch is automatically opened when the control **75** is adjusted to or beyond maximum sensitivity, thereby rendering the quieting circuit inoperative and placing the receiver in condition to respond to all signals and noises however weak.

Selective admission

The "selective admission", mentioned above, is provided for causing the operator to correctly tune the receiver for single sideband reception. This includes means for causing the audio-frequency output to sharply reach a maximum value when the intermediate carrier frequency is tuned on either edge of the band selected in the intermediate-frequency amplifier **34**. This action is an effect of the frequency-discriminating circuits of trap **41** in cooperation with the other sections **42**, **43**, and **44** of the automatic volume control channel, and is perfected by the cooperation of the quieting circuit.

Curve **145** of Fig. 11 shows the relative gain or responsiveness of the intermediate-frequency trap or discriminating network **41**, the ordinates representing relative gain in decibels and the abscissas representing the frequencies in and near the selected intermediate-frequency band. Curve **145** then represents the relative gain from the output coil **78** of amplifier tube **55** to the grid of tube **60**, the amplifier output being applied to the trap through the connection **40'** from coil **79** which is coupled to coil **78**. In the trap network, coil **92** and condenser **94** are sharply tuned to the upper edge of the selected sideband ($f_{io}+f_b/2=112+2=114$ kilocycles, in this case) and produce the right minimum of the trap curve **145**. Coil **93** and condenser **95** are equally sharply tuned to the lower edge of the sideband ($f_{io}-f_b/2=112-2=110$ kilocycles, in this case) and produce the left minimum of the trap curve. The four elements **92**, **93**, **94**, and **95**, taken together, form a parallel circuit resonant at the mid-frequency f_{io} of the band (112 kilocycles in this case) and serve to produce the center maximum at frequency f_{io}. Coils **79** and **96** and condenser **97**, in parallel, are likewise resonant at the frequency f_{io} and cooperate with the other four elements of the trap to produce the higher maxima on either side of the band.

In this arrangement, coil **79** is only moderately coupled to coil **78** so as not to materially affect the characteristics of the latter in the tuned intermediate-frequency circuit. The loss of voltage in the trap circuits is more than made up by the gain in amplifier **42**. The trap circuits are preferably enclosed in a shield, and the junctions of elements **92** and **94** and of elements **93** and **95** enclosed therewithin, thus preventing accidental coupling to these elements. These elements should also be shielded from each other. A particular advantage of this arrangement is that the grid-cathode capacity of tube **60**, or any other outside circuit properties, do not in any way affect the frequencies of minimum gain of the trap.

The effect of the selective admission feature upon the output of intermediate-frequency amplifier **34** is illustrated by curve **152** of Fig. 14 and curve **155** of Fig. 15, these latter two figures having negative rectified intermediate-frequency voltage plotted as ordinates and frequency as the abscissas. Curves **152** and **155** are inversely proportional to curve **145** in Fig. 11. They represent the effect of the trap in making the automatic volume control action dependent on the intermediate carrier frequency and therefore on the tuning of the receiver. Curve **152** of Fig. 14 represents the rectified voltage from diode **62'** of the quieting channel, due to the connection **40''** from amplifier **34** to the quieting channel. For a given setting of the volume level control **80**, curve **155** of Fig. 15 shows the variation of the rectified voltage at diode rectifier **57'**, due to the intermediate-frequency voltage impressed thereon from amplifier **56**. In Fig. 15, the ordinates are proportional to the audio-frequency sound from the receiver.

Automatic quieting

The automatic quieting system proper comprises connection **40''**, tubes **62'** and **62**, and the quieting connections **49** and **49'**. It is the means for quieting the receiver at all times except when the receiver is properly tuned to receive a signal above the noise level. This system quiets undesired noises and distorted signals, which would otherwise be produced when the receiver is not properly tuned to a useful signal. As used in this receiver, the quieting system cooperates with the trap **41** and the automatic volume control system to perfect the "selective admission".

The quieting action is performed by automatically varying the bias between control grid and cathode of intermediate-frequency amplifier tube **56**, this bias being maintained so highly negative under the condition of no signals or too weak signals that this tube is substantially inoperative. When the signal strength rises above a predetermined threshold value, the connection **49** restores the bias to its normal operating value and tube **56** is made operative. This bias is determined by the voltage of source **102**, and by the additional voltage which supplies the normal bias voltage, produced across resistor **113** by the plate current of triode **62**, assuming switch **112** is closed. When this plate current is considerable, the grid bias of tube **56** is sufficient to reduce its gain to zero.

In operation, the intermediate-frequency voltage at connection **40''** is rectified by diode **62'**, which is of the linear type producing an undistorted replica of the modulation envelope. The audio-frequency modulation components of this rectification are filtered out by a resistor **110** and condenser **111** connected in the order recited between the anode **180** and ground, and the uni-directional rectified component, proportional to carrier but independent of modulation, is applied to the grid **176** of triode **62** from the junction of resistor **110** and condenser **111**.

As shown above, the plate current of triode **62** serves, in the absence of a signal, to apply an excessive bias on tube **56**, thereby quieting the receiver. But when the amplified intermediate carrier frequency voltage on connection **40''** increases, the rectified current of rectifier **62'** in-

creases, the grid 176 is made more negative, and the plate current of tube 62 flowing through resistor 113 is reduced. When the amplified carrier voltage exceeds a predetermined value, the plate current of tube 62 is reduced substantially to zero and the bias of amplifier 56 is thereby reduced substantially to its normal value for operation as an amplifier.

The quieting of noise and weak signals is illustrated in Fig. 13 by curves 151 and 151', which are respectively like curves 150 and 150' except for the dotted portions. Curves 151 and 151' show that when the signal input falls below a given threshold value, the receiver is quieted by reducing the audio-frequency output to zero. The threshold value of the signal input voltage is determined by the setting of rheostat 75, as previously mentioned. When the quieting system is disabled by setting rheostat 75 for minimum resistance and thereby opening switch 112, the operation of the receiver is characterized by curve 150. Curve 150' can be obtained by operating switch 112 independently when rheostat 75 is set for high resistance.

The quieting system cooperates with the trap 41 to perfect the selective admission, during the reception of any signal strong enough to operate the automatic volume control system, in the manner shown graphically in Figs. 14 and 15. In Fig. 14, curve 152 shows the variation of the rectified intermediate-frequency voltage in diode 62', as a function of the intermediate carrier frequency. Curve 153 shows the corresponding variation of the negative grid-bias voltage applied to the grid of tube 56 through connection 49, this curve being similar in shape to the upper part of curve 145 in Fig. 11. Curve 154 illustrates the corresponding variation of the plate current of tube 56, showing that space current flows only when the negative grid bias impressed by connection 49 drops to a low value. This illustrates the quieting action due to this tube. The selective admission without quieting produces at the diode 57' a variation of rectified intermediate carrier frequency voltage shown by curve 155 of Fig. 15. When the quieting action is cooperating, the rectified voltage at diode 57' varies as shown in curve 156.

When the operator tunes the receiver, he varies the intermediate carrier and sideband frequencies. Figs. 11, 14, and 15 therefore show the operation of the quieting and selective admission while tuning the receiver. Curve 156, in particular, shows that the signal is heard only when the receiver is tuned very close to one of the two points where the intermediate carrier frequency is on one edge of the band selected according to curve 134 of Fig. 7.

When a weak distant station is being tuned in at the same time that a strong local station is transmitting on an adjacent channel, the latter operates to quiet the receiver when the receiver is tuned to the sideband of the distant signal which is nearer the local signal channel. This action is desirable, because under such circumstances the distant signal can be heard free from interference only when tuned to the sideband further from the local signal channel.

Visual tuning indicator

There is connected to the plate of tube 62 the grid 173 of triode tube 63 in the direct current amplifier 48. In the space current path of tube 63 is a visual tuning indicator in the form of a low current incandescent lamp 50. There is applied through the lamp an initial current through resistor 117 from direct voltage source 116, sufficient to heat the lamp filament to the point of incipient incandescence when no space current is flowing in tube 63. The grid bias of triode 63 varies in the same manner as that of tube 56, so that no space current flows in tube 63 until the signal strength reaches a predetermined value. The space current of tube 63 fluctuates simultaneously with that of tube 56 (since both are connected to the plate of tube 62) and therefore the relative lamp brilliancy is indicated by curve 154 of Fig. 14. The condition of greatest brilliance indicates the correct tuning position. The switch 112 must be closed to render the tuning indicator operative.

The incandescent filament lamp is satisfactory, since the variation of its current during the tuning operation may be several milliamperes. A neon or other type of lamp can be used satisfactorily for the same purpose with good results.

Time lag relations

Good operation of the receiver requires that the automatic volume control should operate in a time comparable with the period of the lowest audio-frequency modulation to be reproduced. This time lag of automatic volume control operation is determined mainly by resistor 105 and condenser 106, the time constant of which may well be 1/40th second.

The time lag of operation of the quieting system should be at least as great, and preferably greater, than that of the automatic volume control, so that while a signal is being tuned in, the receiver will remain quiet until the automatic volume control has had time to operate. The time lag of the quieting system is determined mainly by resistance 114 and condenser 115, and secondarily by resistance 110 and condenser 111. The time constant of the former two elements may well be the same as that of the automatic volume control, 1/40th second, and the time constant of the latter two elements may well be 1/100th second. The total time constant of the quieting system, as thus proportioned, will therefore be .035 second which is 40% greater than that of the automatic volume control.

The lamp 50 has sufficient time lag due to thermal inertia, so that the electrical time lag is undesired. The electrical time lag is reduced by connecting the grid of triode 62 ahead of elements 114 and 115, so that the total electrical time constant for the lamp is that due to elements 110 and 111, or 1/100th second.

Volume level control

Referring now to the volume level control, coils 78, 79, and 80 are preferably located coaxially within a non-magnetic metallic cylindrical shield. Angular rotation of the control knob imparts axial displacement to coil 80, and therefore it is found that the mutual inductance between coils 78 and 80 varies exponentially with the displacement. Plotted in terms of decibels variation of output against angular displacement, this relation is represented by the straight line 137 of Fig. 8, this being the ideal relation between displacement and audio-frequency output. Curve 138 shows the corresponding curve of variation for a linear (instead of exponential) potentiometer, and curve 139 shows the corresponding characteristic of a linear potentiometer having a high resistance half and a low resistance half. The

smoother and superior operation of the exponential type of variation is apparent.

The potentiometer 86 is controlled simultaneously by the same knob, as indicated by broken line 181, which controls the volume level control 35. This potentiometer serves to modify the audio-frequency fidelity simultaneously with volume level. Experience teaches that the normal ear desires less change of intensity at the higher and lower audio frequencies than at the medium audio frequencies. The fidelity control is designed to satisfy this desire of the ear. At the greatest volume level, the contact of potentiometer 86 is situated at the upper end thereof. In this position, the elements are proportioned so that the fidelity is according to curve 143 of Fig. 10, which is plotted in terms of relative gain against audio frequencies. At the lowest volume level, the contact is at the lower end, and in this position, condenser 90 causes the fidelity curve to slope upward at the lower frequencies as shown by curve 144. The condenser 8 and resistor 89 at the same time cause the curve to slope upward at the higher frequencies, as shown. At mean volume level, the fidelity is according to curve 142, which is substantially level.

Oscillator and modulator

The tuning condenser of the tuned circuit 67 of oscillator tube 53 is like those of the radio-frequency selector circuits 64, 65, and 66, all being on the same shaft as indicated by broken lines 182, and all having the same variation of capacitance. The oscillator frequency is required to be always greater than that of the radio-frequency selective circuits by a constant amount, which is 112 kilocycles in this case. This is ordinarily accomplished by adjusting three properties of the oscillator tuned circuit to be different from the selective tuned circuits as follows:

(*a*) A relatively large adjustable condenser 190 is added in series with the oscillator tuned circuit;

(*b*) The oscillator tuned inductance 191 is made somewhat smaller than those of the signal selective circuits;

(*c*) The minimum value of the oscillator tuning condenser is adjusted to be slightly larger than that of the other tuning condensers.

The above three degrees of freedom permit adjustment of the oscillator alignment to be exactly correct at three points throughout the tuning range, but the errors at other frequencies in the range may be substantial. This is shown by curve 130 of Fig. 5, in which oscillator error is plotted against tuning frequency. The points where the curve crosses the horizontal zero axis are the three points made correct by the three adjustments.

The alignment error can be further reduced by adding a fourth degree of freedom, which is:

(*d*) One or more resistors 68 and 69 may be connected across coils fairly closely coupled to the oscillator tuned circuit.

The resulting errors of alignment when the fourth degree of freedom is employed are as indicated by curve 131 of Fig. 5, which crosses the zero axis at four points and shows much less error. The above degrees of freedom have been named in the order of decreasing effect at lower frequencies and increasing effect at higher frequencies. The last is most effective at the high end of the tuning range.

The cathode conductance of the modulator 52 is substantially equal to its transconductance s_m, and is located across resistor 68. Since the transconductance varies with the automatic volume control bias on the control grid of the modulator, the volume control system has some undesired effect upon the oscillator frequency. It is desired to minimize this undesired effect without impairing the modulator performance.

Curve 132 of Fig. 6 shows the transconductance s_m of modulator 52 as a function of the voltage on its screen 195, in the case of a small initial negative bias on control grid 194. While the transconductance determines the straight amplification of the tube, its modulation is determined by

$$s_m' = \frac{ds_m}{de_g}$$

where e_g represents the grid-cathode bias. The variation of the quantity s_m' with screen voltage is shown by curve 133.

In the case under consideration, it is observed that reducing the screen voltage from 100 to 40 volts does not appreciably affect the value of s_m' but does reduce the transconductance s_m in the ratio of 5:1. This fact is of great advantage in minimizing changes of oscillator frequency. It also has the advantage of reducing the straight intermediate-frequency gain of the tube, such gain not being desired in a modulator, as it serves to increase noise and interference.

The use of a fixed low screen voltage is not desirable, because the grid-bias control would become less gradual and thereby increase distortion in the modulator. The best result is obtained by the use of resistor 71 and by-pass capacity 72 associated with the screen 194. The resistor reduces the screen voltage at low values of grid bias but causes the screen voltage to resume the normal rated value when the screen current is decreased by the presence of greater automatic volume control bias. As a result of this arrangement, there are obtained all the benefits of lower screen voltage when the grid bias is at its minimum value, and also the benefit of higher screen voltage when the grid bias is greatly negative.

I claim:

1. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, indicating means responsive to the carrier, and a selective network coupled to the output of said selector and associated with said indicating means for causing the latter to give a critical predetermined indication only when said frequency difference is half the width of said band.

2. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, visual indicating means responsive to the carrier, and a selective network coupled to the output of said selector and associated with said indicating means for causing the latter to give a critical predetermined visual indication only when said difference is half the width of said band.

3. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means responsive to the carrier for

automatically determining the signal output of the receiver, and a selective network coupled to the output of said selector and associated with said auxiliary means for causing the latter to produce maximum signal output when said frequency difference is half the width of said band.

4. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means responsive to the carrier and unresponsive to modulation for automatically determining the signal output of the receiver, and a selective network coupled to the output of said selector and associated with said auxiliary means for causing the latter to produce maximum signal output when frequency difference is half the width of said band.

5. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means responsive to the carrier for automatically determining the carrier output of the receiver, and a selective network coupled to the output of said selector and associated with said auxiliary means for causing the latter to produce maximum carrier output when said difference is half the width of said band.

6. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a frequency band sufficiently wide to include the carrier and one sideband but too narrow to include both sidebands, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means responsive to the carrier for automatically determining the signal output of the receiver, and a selective network coupled to the output of said selector and associated with said auxiliary means for causing the latter to produce maximum signal output when said frequency difference is half the width of said band.

7. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for adjusting the carrier frequency, auxiliary means responsive to the carrier for automatically determining the signal output of the receiver, and a selective network coupled to the output of said selector and associated with said auxiliary means for causing the latter to produce maximum signal output when the carrier frequency is adjusted to one edge of said band.

8. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for adjusting the carrier frequency, and auxiliary means responsive to the carrier for producing maximum signal output only when the carrier frequency is adjusted to either edge of said band.

9. In a modulated carrier frequency signal receiver including a tunable selector uniformly responsive only within a narrow frequency band, auxiliary means responsive to the carrier for automatically determining the signal output of the receiver, and a selective network coupled to the output of said selector and associated with said auxiliary means for causing the latter to produce maximum signal output only when one edge of said band is tuned to the carrier.

10. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, means for adjusting the carrier frequency, and auxiliary means responsive to the carrier for producing maximum signal output only when the carrier is tuned to either edge of said band.

11. In a modulated carrier frequency signal receiver, signal selecting means for uniformly selecting the carrier together with all of one sideband and only the inner edge of the other sideband, means for rectifying the selected signal to produce the modulation frequencies, means for amplifying the lower modulation frequencies for which both sidebands are selected, and means for doubly amplifying the higher modulation frequencies for which only one sideband is selected, both said means for amplifying being embodied in a common amplifier including in one stage in series a coupling impedance having resistance and capacitance in parallel for doubling the amplification of the higher modulation frequencies.

12. In a modulated carrier frequency signal receiver including a frequency band selector and an amplifier, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means for automatically reducing the amplifier gain in proportion to increasing carrier intensity and a selective network for coupling the output of the amplifier to the auxiliary means, said network being proportioned to minimize the action of the gain reducing means when said frequency difference has a predetermined substantial value not exceeding half the width of said band.

13. In a modulated carrier frequency signal receiver including a frequency band selector and an amplifier, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means for automatically reducing the amplifier gain in proportion to increasing carrier intensity, and a selective network for coupling the output of the amplifier to the auxiliary means, said network being proportioned to magnify the action of the gain reducing means when said frequency difference has a value substantially exceeding half the width of said band.

14. In a modulated carrier frequency signal receiver including a frequency band selector and an amplifier, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means for automatically reducing the amplifier gain in proportion to increasing carrier intensity, and a trap circuit sharply tuned to a frequency in said band but substantially displaced from the mid-frequency thereof for coupling the output of the amplifier to the auxiliary means, whereby the action of the gain reducing means is minimized when the carrier frequency is equal to the trap frequency.

15. In a modulated carrier frequency signal receiver including a frequency band selector and an amplifier, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means for automatically reducing the amplifier gain in proportion to increasing carrier intensity, and a trap circuit sharply tuned to one edge of said band for coupling the output of the amplifier to the auxiliary means, whereby the action of the gain reducing means is minimized when said frequency difference has a value equal to half the width of said band.

16. In a modulated carrier frequency signal

receiver including a frequency band selector and an amplifier, tuning means for varying the frequency difference between the carrier and the middle of said band, auxiliary means for automatically reducing the amplifier gain in proportion to increasing carrier intensity, and a double trap circuit sharply tuned to both edges of said band for coupling the output of the amplifier to the auxiliary means, whereby the action of the gain reducing means is minimized when said frequency difference has a value equal to half the width of said band.

17. In a modulated carrier frequency signal receiver, an amplifier, a selective system for selecting a band of frequencies which includes a carrier frequency and an associated modulation sideband to be translated, an automatic volume control system responsive to the output of said amplifier for maintaining said amplifier output relatively constant in spite of wide changes in the intensity of the signal input to said amplifier, and a discriminating network interposed between the amplifier output terminals and said automatic volume control system which is least responsive at an edge of said band of frequencies, whereby the signal output of said amplifier is caused to be greatest when said carrier frequency is located at said edge of said band.

18. In a modulated carrier frequency signal receiver, an amplifier, a selecting system for selecting a band of frequencies which includes a carrier frequency and an associated modulation sideband to be translated, an automatic volume control system responsive to the output of said amplifier for maintaining said amplifier output relatively constant in spite of wide changes in the intensity of the signal input to said amplifier, and a discriminating network interposed between the amplifier output terminals and said automatic volume control system which is least responsive at each edge of said band of frequencies, whereby the signal output of said amplifier is caused to be greatest when said carrier frequency is located at either edge of said band.

19. In a modulated carrier frequency signal receiver, an amplifier, a selecting system for selecting a band of frequencies which includes a carrier frequency and an associated modulation sideband to be translated, an automatic volume control system responsive to the output of said amplifier for maintaining said amplifier output relatively constant in spite of wide changes in the intensity of the signal input to said amplifier, and a discriminating network interposed between the amplifier output terminals and said automatic volume control system which is least responsive at both edges of said band of frequencies and is most responsive at frequencies between and beyond said edges, whereby the signal output of said amplifier is caused to be greatest when said carrier frequency is located at either edge of said band.

20. In a modulated carrier frequency signal receiver, an amplifier, a selecting system for selecting a band of frequencies which includes a carrier frequency and an associated modulation sideband to be translated, an automatic volume control system responsive to the output of said amplifier for maintaining said amplifier output relatively constant in spite of wide changes in the intensity of the signal input to said amplifier, and a discriminating network interposed between the amplifier output terminals and said automatic volume control system, said network having two resonant trap circuits, one of which is resonant at one edge of said band and the other of which is resonant at the other edge of said band, whereby the signal output of said amplifier is caused to be greatest when said carrier frequency is located at either edge of said band.

21. In a modulated carrier frequency signal receiver, an amplifier, a selecting system for selecting a band of frequencies which includes a carrier frequency and an associated modulation sideband to be translated, an automatic volume control system responsive to the output of said amplifier for maintaining said amplifier output relatively constant in spite of wide changes in the intensity of the signal input to said amplifier, a quieting system for rendering a portion of said translating system inoperative when the amplifier output is below a predetermined level, and a discriminating trap associated with said automatic volume control system which is least responsive at the frequency of an edge of said frequency band, whereby the signal output of said amplifier is caused to be greatest when said carrier frequency is located at an edge of said band, and is caused to decrease sufficiently to actuate the quieting system when said carrier frequency is not so located.

22. In a modulated carrier frequency signal receiver including a carrier amplifier, auxiliary means excited by the carrier output of said amplifier for producing a unidirectional voltage tending to vary directly with the carrier output amplitude, means for utilizing said voltage to vary inversely with carrier input amplitude the gain of said amplifier, and means for simultaneously varying directly with the carrier input amplitude the unidirectional voltage produced in said auxiliary means by an unvarying value of said carrier output applied thereto, all of said means being relatively proportioned automatically to maintain the carrier output of said amplifier substantially constant.

23. In a modulated carrier frequency signal receiver including a carrier amplifier, auxiliary means for further amplifying and then rectifying the carrier output of said amplifier, and means for utilizing the rectified carrier to reduce the gain of said amplifier and simultaneously to increase said amplification in said auxiliary means, both said means being relatively proportioned to automatically maintain the carrier output of said amplifier substantially constant.

24. In a modulated carrier frequency signal receiver including a carrier amplifier having a vacuum tube, auxiliary means including a carrier rectifier and also a vacuum tube for coupling the carrier output of said amplifier to said rectifier, means for utilizing the rectified carrier voltage from said rectifier negatively to bias said vacuum tube and thereby to reduce the gain in said amplifier with increasing carrier amplitude, and means including a connection between the cathodes of both said vacuum tubes and a resistor common to the circuits of said cathodes, said latter means and said resistor being relatively proportioned automatically to maintain the carrier output of said amplifier substantially constant.

25. In a modulated carrier frequency signal receiver, a first carrier amplifier for repeating signals to detecting apparatus, means for automatically controlling the carrier amplification in said amplifier, comprising a second carrier amplifier, a rectifier responsive to the carrier output of said second amplifier whereby said rectifier develops

a unidirectional voltage increasing with carrier amplitude, a connection from an output electrode of said rectifier to a control electrode of the first amplifier for biasing said control element negatively with said unidirectional voltage, whereby the amplification in said first amplifier is decreased with increasing carrier amplitude, and a connection from a point of said first amplifier to a point of said second amplifier for causing the effective bias voltage on a control electrode of said second amplifier to decrease with increasing bias on said control element of said first amplifier, said bias voltages being proportioned to maintain the carrier output of said first amplifier substantially constant.

26. In a modulated carrier frequency signal receiver including means for quieting the receiver when the carrier amplitude is less than a threshold value, the arrangement for adjusting the quieting effect which comprises adjustable means for controlling the threshold value by adjusting the gain of the receiver, and a switch linked to said adjustable means for cutting out the quieting action only when the gain of the receiver is adjusted to maximum.

27. In a modulated carrier frequency signal receiver, a carrier frequency adjustable volume control circuit, a rectifier, a vacuum tube for coupling the volume control circuit output to said rectifier, and means for automatically reducing the translation ratio of said tube when the input to said volume control circuit is less than a predetermined threshold value, whereby disturbances below said threshold value are subject to reduction prior to rectification in said rectifier.

28. In a modulated carrier frequency signal receiver, means for tuning said receiver to a desired carrier frequency, means for quieting said receiver when the desired carrier amplitude is less than a predetermined threshold value, and selective means most responsive to interfering signals on slightly different frequencies, for operating the quieting means when the ratio of interfering signal to desired carrier amplitude exceeds a predetermined value.

29. In a modulated carrier frequency signal receiver including a carrier amplifier, means for tuning said receiver to a desired carrier frequency, selective means for automatically reducing the amplifier gain with increasing sum of the amplified desired carrier amplitude plus a multiple of the amplitude of any amplified interfering signals on slightly different frequencies, and means for automatically quieting said receiver when the sum of the amplitudes of all amplified signals is less than a predetermined threshold value, whereby the system is quieted when the amplitude ratio of interfering signal to desired carrier exceeds a predetermined value.

30. In a modulated carrier frequency signal receiver, means for automatically quieting the system when the carrier amplitude is less than a predetermined threshold value, means for delaying the quieting action to avoid its responding to impulses of short duration, and means for visually indicating with less delay the condition of the quieting means at all times.

31. In a modulated carrier frequency signal receiver including a carrier amplifier, means for automatically reducing the amplifier gain with increasing carrier amplitude, means for quieting the receiver when the carrier amplitude is less than a predetermined threshold value, means for delaying the gain reducing action to avoid its responding to low frequency modulation, means for delaying to a greater degree the quieting action, and means for visually indicating without substantial delay the condition of the quieting means at all times.

32. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, indicating means responsive to the carrier, and a selective network less responsive at the edge frequencies of said band than at the intermediate frequencies of said band and all frequencies without said band, said network being coupled to the cutput of said selector and being associated with said indicating means for causing the latter to give a clear indication when said frequency difference is half the width of said band.

33. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, indicating means responsive to the carrier, and a selective network less responsive at an edge frequency of said band than at the intermediate frequencies of said band and of frequencies without said band, said network being coupled to the output of said modulator and being associated with said indicating means for causing the latter to give a clear indication when said frequency difference is half the width of said band.

34. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, visual indicating means responsive to the carrier, and a selective network less responsive at the edge frequencies of said band than at the intermediate frequencies of said band and all frequencies without said band, said network being coupled to the output of said selector and being associated with said indicating means for causing the latter to give a clear indication when said frequency difference is half the width of said band.

35. In a modulated carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier and the middle of said band, visual indicating means responsive to the carrier, and a selective network less responsive at an edge frequency of said band than at the intermediate frequencies of said band and all frequencies without said band, said network being coupled to the output of said selector and being associated with said indicating means for causing the latter to give a visual indication when said frequency difference is half the width of said band.

36. In a modulated carrier frequency signal receiver, signal selecting means for uniformly selecting the carrier together with all of one sideband and only the inner edge of the other sideband, a diode rectifier circuit for producing linear rectification of a strongly modulated selected signal to produce the modulation frequencies, said rectifier having the property of distortionless rectification of carrier and sidebands when both sidebands are present and their sum is less than the carrier, and also when only one sideband is present and does not greatly exceed half the carrier.

37. In a modulated carrier signal receiver in-

cluding a carrier amplifier, auxiliary means responsive to the carrier output of said amplifier for producing a unidirectional voltage increasing with said carrier output, means utilizing said voltage for reducing the gain of said amplifier with increasing carrier output thereof, and means responsive to the carrier input to said amplifier for simultaneously increasing with increase in said carrier input the uni-directional voltage produced in said auxiliary means in response to a given value of said carrier output, all of said means being relatively proportioned to vary automatically the gain of said amplifier in the inverse ratio of said carrier input without appreciable variation of said carrier output for a wide variation of said carrier input.

38. In a modulated carrier frequency signal receiver including a carrier amplifier, means for tuning said receiver to a desired carrier frequency, means for automatically controlling the amplifier gain, selective means coupling the output of said amplifier to said gain control means and including a trap circuit proportioned to cause said gain control means to reduce said amplifier gain with increasing sum of the amplified desired carrier amplitude plus a multiple of the amplitude of any amplified interfering signals on slightly different frequencies, and means for automatically quieting said receiver when the sum of the amplitude of all amplified signals is less than a predetermined threshold value, whereby the system is quieted when the amplitude ratio of the interfering signal to the desired carrier exceeds a predetermined value.

39. In a modulated carrier frequency signal receiver, a band selector for selecting a band of frequencies including a desired signal, an amplifier, auxiliary means for automatically reducing the amplifier gain in response to the signal output thereof, and selective means substantially more responsive at frequencies outside said band than at the desired signal frequency, said selective means coupling the output of said amplifier to said auxiliary means and magnifying the action of the gain reducing means toward any interfering signal on said frequencies outside said band relative to the action thereof toward said desired signal, whereby the amplifier gain is reduced in response to such interfering signals to a greater extent than in response to desired signals of the same order of intensity.

40. In a modulated-carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between the carrier of a desired signal and the middle of said band, indicating means, and a selective network more sharply tuned than said selector and controlling said indicating means as a function of said frequency difference for causing the latter to give a critical predetermined indication only when said frequency difference is half the width of said band.

41. In a modulated-carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for varying the frequency difference between a desired signal carrier and the middle of said band, auxiliary means for determining the signal output of the receiver, and means including a selective network more sharply tuned than said selector and controlling said auxiliary means as a function of said frequency difference for causing the latter to produce maximum signal output when said frequency difference is half the width of said band.

42. In a modulated-carrier frequency signal receiver including a selector uniformly responsive only within a narrow frequency band, tuning means for adjusting the carrier frequency, and auxiliary means for controlling the output of the receiver as a function of the frequency difference between a desired signal carrier and an edge of said band for producing maximum signal output only when said frequency difference is zero.

43. In a signaling system, an amplifier producing an amplified signal output, auxiliary means responsive to said amplified signal output for producing a unidirectional voltage, means for varying the amplification in said amplifier inversely in accordance with said unidirectional voltage and means for simultaneously varying the responsiveness of said auxiliary means directly in accordance with said unidirectional voltage whereby the ratio of said unidirectional voltage to said amplified signal output is increased when the signal input to said amplifier increases.

44. In a modulated-carrier-frequency signaling system, a carrier-frequency amplifier producing an amplified carrier output, means responsive to said amplified carrier output for producing a unidirectional voltage, said means including an auxiliary amplifier and a rectifier, means for varying the amplification in said carrier amplifier inversely in accordance with said unidirectional voltage, and means for simultaneously varying the amplification in said auxiliary amplifier directly in accordance with said unidirectional voltage, whereby a change in the intensity of the input voltage to said carrier amplifier is caused to produce a greater rate of change in the unidirectional voltage than in said carrier output.

HAROLD A. WHEELER.