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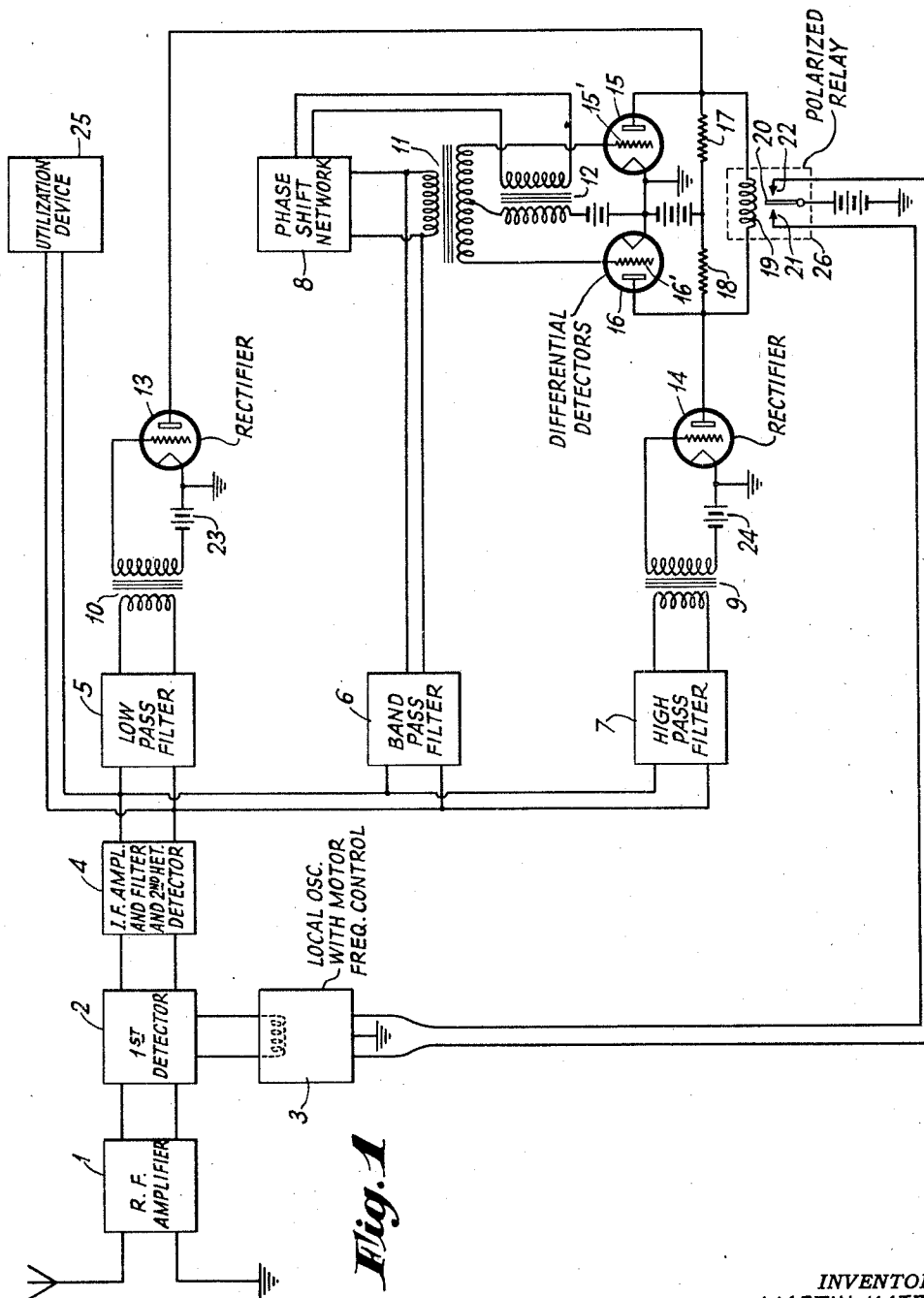
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2,232,390

AUTOMATIC FREQUENCY CONTROL

Filed April 27, 1938

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

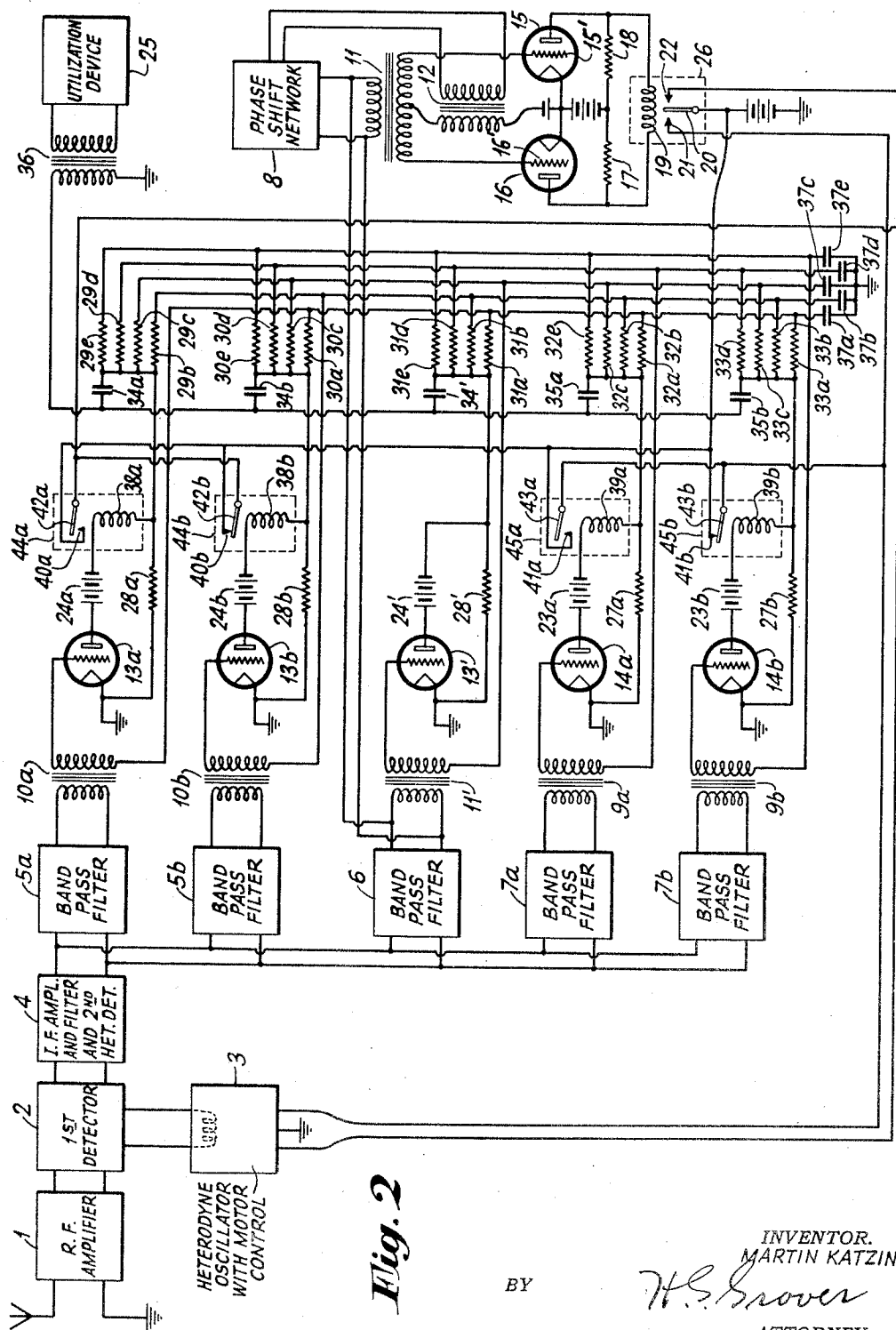


Fig. 2

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AUTOMATIC FREQUENCY CONTROL

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4 Claims. (Cl. 250—20)

This invention concerns a method of and means for improving the operation of an automatic tuning control wherein it is made possible to control and utilize much weaker signals than heretofore and also to control signals which are unstable in the respect that they may suffer sudden jumps of frequency to outside the normal control range.

In the practice of automatic frequency control it has been usual to combine signal voltages obtained from two different paths in a set of differential detectors, one signal voltage being applied anti-phasiially to the detector grids and the other signal voltage passed through a phase shifting network and then applied cophasially to the detector grids. The phase shifting network may be in the path of the anti-phasiially applied voltage if desired. The phase shifting network has the characteristic of providing a phase shift dependent upon the signal frequency, and the automatic control functions to hold the signal at a frequency for which the phase shift through the phase shift network is 90° or some odd multiple of 90° .

In order to hold the signal within close limits of frequency it is necessary to have a network which has a steep phase shift vs. frequency characteristic. This may be accomplished by using filter sections, it being characteristic of a number of types of filters that there is a 180° change of phase shift through the network between the low frequency and high frequency cut-offs of a section. However, in order to produce a steep phase shift-frequency characteristic it is necessary either to use a number of sections of filter or to choose a filter with a very narrow pass band. The first alternative suffers the disadvantage that there are a number of points at which the phase shift is an odd multiple of 90° —in fact as many such points as there are sections in the filter—and as a consequence there will be that many points at which the control can hold the signal frequency. The second method, i. e., using a very narrow pass band, suffers the drawback that, should the signal fade to below the noise level and then reappear but with its frequency having moved to a point outside the narrow pass band of the phase shift network, the control function is lost. The same would be true should the signal frequency suddenly jump to a point outside the network band. Furthermore, in order to utilize very weak signals for communication it is necessary to employ very narrow receiving bands in order to reduce the noise level, and it therefore becomes impor-

tant, yet difficult, to apply automatic frequency control in such cases where the signal frequency is subject to the type of frequency changes described above.

It is the object of the present invention to provide a system in which a steep phase shift vs. frequency characteristic can be obtained in a phase shift network yet at the same time permitting the control to function in restoring the signal to the desired frequency, should the types of frequency change described above occur. It is another object of this invention to provide a means for controlling weak signals which suffer the same types of fluctuations.

In describing my invention reference will be made to the attached drawings wherein

Figure 1 is a circuit illustrating a frequency control system arranged in accordance with my invention as outlined above, and

Figure 2 is a modification of the arrangement of Figure 1.

Figure 1 shows one specific embodiment of this invention. Referring to this figure, the signal is amplified by radio frequency amplifier 1 then heterodyned in first detector 2 against local oscillations generated in 3, the frequency of these oscillations being controlled by a reversible motor unit, or equivalent means, as described later. From first detector unit 2 the heterodyned signal is passed through intermediate frequency amplifier and filter unit 4 and therein heterodyned to a low intermediate frequency by a fixed frequency oscillator contained in unit 4. The frequency to which the signal is reduced here may be in the audio frequency band and will be referred to as an audio frequency although it may be higher than audio. From unit 4 the audio frequency carrier may choose any of three paths through low pass filter 5, band pass filter 6, or high pass filter 7, and is also led to utilization device 25. The frequency bands of the filters are arranged adjacent to each other, i. e., the cut-off frequency of the low pass filter is placed at the lower cut-off frequency of the band pass filter and the cut-off frequency of the high pass filter at the upper cut-off frequency of the band pass filter, preferably with a slight overlap. The output of band pass filter 6 is connected to both phase shift network 8 and transformer 11. Transformer 11 feeds the grids of differential detector tubes 15 and 16 anti-phasiially, while the output of phase shift network 8 feeds these grids cophasially through transformer 12. The operation of these differential detectors in conjunction with phase shift network 8 has been

described in detail in M. G. Crosby's United States Patent #2,065,565 dated December 29, 1936, and briefly hereinafter. Resistors 17 and 18 in the plate circuits of tubes 15 and 16, respectively, provide means for securing differential voltage to feed current through coil 19 of polarized relay 26. This relay controls the direction of rotation of the motor depends on the relative positions of tongue 20 and contacts 21 and 22.

The output of low pass filter 5 is fed through transformer 10 to the grid of rectifier 13; similarly the output of high pass filter 7 feeds through transformer 9 to the grid of rectifier 14. The plate of rectifier 13 is connected to the plate of differential detector tube 15 and the plate of rectifier 14 is connected to the plate of differential detector tube 16. Batteries 23 and 24 provide suitable bias for rectifiers 13 and 14.

The operation of the specific embodiment shown in Figure 1 may now be explained as follows:

The received signal is amplified in radio frequency amplifier 1, heterodyned to intermediate frequency in first detector 2 against oscillations generated in 3, further amplified at intermediate frequency and then heterodyned to low intermediate or audio frequency in unit 4. Suppose that the local oscillator 3 has been set to such a frequency that the resultant audio frequency emanating from 4 lies within the pass band of band pass filter 6. This filter will then pass the energy along with substantially no attenuation while filters 5 and 7 will offer a very high attenuation to the signal so that practically no energy passes through them to rectifiers 13 and 14. From filter 6 one path taken by the signal is through transformer 11 to grids 15' and 16', these being thus fed antiphasially. Another path is through phase shift network 8 which applies a phase shift whose magnitude depends on the frequency of the audio signal, and then through transformer 12 to feed detectors 15 and 16 cophasially. If the phase shift applied by network 8 is 90° each detector grid receives audio frequency potentials in phase quadrature, and as long as they are in phase quadrature each detector produces output energy characteristic of the resultant of the phase quadrature excitation voltages. The outputs oppose and cancel in resistances 17 and 18. If the phase shift applied by network 8 differs from 90° there will be resultant differential voltage across the detectors. That is, if the frequency of the low intermediate frequency or audio carrier impressed on 6 and 8 shifts in frequency for any cause, the network 8 no longer produces a 90° shift in the audio carrier and the phase quadrature relation described above no longer exists and each detector grid gets a new resultant excitation voltage, one of which is higher than the other. That will result in unequal voltage drops across resistors 17 and 18 in the plate circuits of 15 and 16, which, in turn, results in a flow of current through polarized relay coil 19, causing tongue 20 to move into connection with either contact 22 or 21, depending upon whether the audio carrier frequency is below or above the frequency for which network 8 applies substantially a 90° phase shift. The operation of the relay causes a motor not shown, driving a vernier condenser, not shown, in the oscillatory circuit of unit 3 to rotate in the proper direction to change the resultant audio carrier frequency toward the frequency at which network 8 applies a phase shift of 90°, which is ap-

proximately the mid-band frequency of filter 6. At this frequency there ceases to be any differential voltage across the detectors 15 and 16, so that, in turn, no difference in voltage drop appears across resistances 17 and 18 and no current flows through relay coil 19. Therefore, the relay tongue 20 rests in the mid or neutral position and the motor in unit 3 is stopped. Thus, whenever the incoming signal frequency varies, provided this variation is not too rapid for the motor driven condenser to follow, the audio signal frequency will always be restored to the same value.

Controlled motor tuning means of this nature are known in the art, see for example, Usselman United States Patent #2,044,749 dated June 16, 1936, and the above description thereof is deemed sufficient.

However, should the incoming signal vary more rapidly than the motor can follow, or should it suffer a sudden jump, or, should it fade out and, during the fade, change frequency so that upon regaining strength the audio carrier frequency no longer lies within the pass band of filter 6 and network 8, the differential control would be unable to restore the frequency to the correct value. In such a case the audio signal-frequency would fall within the pass band of either low-pass filter 5 or high-pass filter 7. Let us suppose that it lies in the pass band of the low-pass filter 5. The signal energy will then pass through 5 and then through transformer 13 to the grid of rectifier 13, giving rise to an increase in plate current which, flowing through resistor 17, renders unequal the voltage drops across resistances 17 and 18, resulting in current through relay coil 19, thus applying the proper direction of frequency correction to move the audio signal frequency back into the pass band of filter 6 and network 8, whereupon this channel once more takes up control and centers the frequency at the right point.

In exactly the same way high pass filter 7 with its associated transformer 9 and rectifier 14 acts also to move the audio signal frequency back into the pass band of filter 6, should the incoming signal frequency give an audio signal frequency lying above the pass band of filter 6, and therefore within the pass band of filter 7.

By utilizing lower control frequencies in the phase shifting network a more accurate and rapid phase shift in the audio carrier applied to the differential detectors from the 90° relation can be obtained when the frequency of the received wave or oscillations at 3 changes. Moreover, this improvement in phase change can be obtained with simplified phase shifting networks at the lower frequencies used here.

The filter design and structure is also simplified since it is easier to produce filters with the desired high, low and band pass characteristics when operating at lower intermediate frequency or audio frequencies than when operating at higher frequencies.

A second form of this invention which is desired to permit the reception of weak signals and the application to them of automatic frequency control is shown in Figure 2. Here the signal passes through radio frequency amplifier 1, is heterodyned to intermediate frequency in first detector 2 against oscillations derived from 3, and is amplified at intermediate frequency and then heterodyned to audio frequency in unit 4. The output of unit 4 feeds a group of band pass filters 5a, 5b, 6, 7a, 7b, whose pass bands

overlap to form a substantially continuous spectrum, the frequencies of filters 5a, 5b lying below that of filter 6, and the frequencies of filters 7a, 7b lying above that of filter 6. These filters feed through transformers 10a, 10b, 11', 9a, 9b, respectively, to detector tubes 13a, 13b, 13', 14a, 14b. Across resistors 28a, 28b, 28', 27a, 27b, in the plate circuits of these tubes, respectively, appear the direct current and signal frequency voltages. The signal frequency voltages appearing across said resistances are passed through condensers 34a, 34b, 34', 35a, 35b, respectively, and through transformer 36 to utilization device 25. The direct current voltages charge condensers 37a, 37b, 37c, 37d, 37e through time-constant resistors 29b, 29c, 29d, 29e, 30a, 30c, 30d, 30e, 31a, 31b, 31d, 31e, 32a, 32b, 32c, 32e, 33a, 33b, 33c, 33d. Condensers 31a, 37b, 37c, 37d, 37e in turn supply bias voltages to detector tubes 13a, 13b, 13', 14a, 14b. The plate voltages for these detector tubes are supplied by batteries 24a, 24b, 24', 23a, 23b, respectively, and the plate currents of tubes 13a, 13b, 14a, 14b flow through relay coils 38a, 38b, 39a, 39b, respectively. The output of filter 6 is also connected to transformer 11, whose secondary feeds the grids 15' and 16' of differential detector tubes 15 and 16 antiphasially, and to phase shift network 8 which connects to transformer 12 and supplies energy cophasially to the grids 15' and 16' of 15 and 16. Resistors 17 and 18 in the plate circuits of 15 and 16, respectively, provide means for securing differential voltage to feed current through coil 19 of polarized relay 26. This relay controls the direction of rotation of a motor in oscillator unit 3 through tongue 20 and contacts 21 and 22. This motor rotates a vernier condenser in the oscillatory circuit to adjust the heterodyning oscillator frequency. Across contact 22 are connected contacts 40a, 40b of relays 44a, 44b, and across contact 21 are connected contacts 41a, 41b, of relays 45a, 45b.

The device shown in Figure 2 operates as follows:

The received signal is amplified in radio frequency amplifier 1, heterodyned to intermediate frequency in first detector 2 against oscillations generated in 3, further amplified at intermediate frequency and then heterodyned to low intermediate or audio frequency in unit 4. Suppose the resultant audio carrier frequency lies within the pass band of band pass filter 6. Energy will then pass freely through filter 6 and through transformer 11' to the grid of tube 13', while the other filters 5a, 5b, 7a, 7b will pass substantially no carrier energy. As a result of the carrier voltage on the grid of tube 13', direct current and signal frequency voltages appear across resistor 28'. The signal frequency voltage passes through condenser 34' and transformer 36 to utilization device 25. The direct current voltage charges condensers 37a, 37b, 37d, 37e through resistors 31a, 31b, 31d, 31e, respectively, thus supplying cut-off bias to tubes 13a, 13b, 14a, 14b, and therefore preventing the noise which penetrates filters 5a, 5b, 7a, 7b from reaching utilization device 25. The output of filter 6 also passes to transformer 11 and phase shift network 8, and the process of frequency control is thus identical with that described before in explaining Figure 1, so need not be repeated here.

Should the audio carrier frequency at the output of 4 jump to a point within the pass band of filter 5a or 5b, say 5a, then the grid of tube

13' will no longer receive carrier energy, thus removing direct current and signal voltage from resistor 28'. As a consequence, condensers 37a, 37a, 37d, and 37e discharge, removing the cut-off bias from tubes 13a, 13b, 14a, 14b. The audio carrier frequency which now passes freely through filter 5a and transformer 10a excites the grid of tube 13a, giving rise to plate current which builds up direct current and signal frequency voltages across resistor 28a as well as energizing the coil 38a of relay 44a. The signal frequency voltages pass through condenser 34a and transformer 36 to utilization device 25. The direct current voltage across 28a charges condensers 37b, 37c, 37d, 37e through resistors 29b, 29c, 29d, 29e, thus applying cut-off bias to tubes 13b, 13', 14a, 14b, and therefore preventing the noise which penetrates filters 5b, 6, 7a, 7b from reaching utilization device 25. The plate current of tube 13a which passes through coil 38a of relay 44a causes tongue 42a to move into connection with contact 40a, which causes motor driven condenser in oscillator unit 3 to rotate the same as if polarized relay 26 had operated to close tongue 20 to contact 22. Thus, the frequency of the audio signal is raised until it passes out of the band of filter 5a and into the band of filter 5b. The whole process of discharge of the charged condensers now repeats itself, thus allowing tube 13b to assume control and cutoff the remaining filter channels, and continue to apply frequency correction, now through relay 44b. Then the frequency of the audio carrier is moved into the band of filter 6 and the procedure first described in detail takes place, finally holding the audio frequency approximately in the center of the band of filter 6.

In exactly the same manner it will be seen that filters 7a and 7b with their associated equipment act to lower the audio signal frequency into the band of filter 6, should the incoming signal frequency change to a value such that the resultant audio signal frequency lies in the pass band of filter 7a or 7b. But during all these changes and adjustments the signal energy penetrates through to utilization device 25 so that communication is uninterrupted, yet at the same time the received noise level is greatly reduced because the effective band width corresponds to that of only one of the narrow band filters.

Suitable modifications may be applied to the embodiments described above. For example, a cut-off tube may be inserted to disconnect the frequency control when the received signal becomes too weak, as described in M. G. Crosby's United States application Serial #16,591 filed April 16, 1935, now Patent #2,123,716 issued July 12, 1938.

In Figure 1, band pass filter 6 is not essential, since phase shift network 8 has a similar acceptance band width.

Figure 2 has been shown with two filters each below and above the frequency band of filter 6. It is obvious that any number of such filters and associated apparatus can be included to span any desired portion of the frequency spectrum, as well as the use of a number of band pass filters together with a low pass and a high pass filter. The mechanism of applying cut-off bias to the tubes not exercising control as in Figure 2 may of course be extended to Figure 1.

In Figure 2, the relays 44a, 44b, 45a, 45b may be replaced by suitably biased rectifier tubes whose plates are connected to the plates of tubes 15 75

and 16, respectively, as with tubes 13 and 14 of Figure 1.

Also, Figure 2 may be used as a means of receiving weak signals without the use of automatic frequency control, it merely being necessary to provide enough filters to cover the normal frequency variations expected of the signal. In this case relays 44a, 44b, 45a, 45b, phase shift network 8, and the differential frequency control detectors with their associated equipment would not be needed.

Furthermore, any of the various means of applying frequency correction to the heterodyning oscillator may be applied; see Crosby Patent #2,065,565 dated December 29, 1936. The multi-grid detector described in Crosby Patent #2,063,588 dated December 8, 1936, may be used in place of the two differential detector tubes 15 and 16.

The two embodiments described utilized audio frequency filters following the intermediate frequency amplifier and filter. It is obvious of course, that the same idea could be carried out at intermediate frequency, using, for example, crystal filters.

While my invention has been described in connection with a receiving system it will be understood that it is equally applicable to wave transmission systems of any type.

I claim:

1. In a frequency control circuit a source of wave energy and tunable means for controlling the frequency of said source of wave energy at a selected frequency, a band pass filter having an input connected with said source of wave energy, a low pass filter having an input connected with said source of wave energy, a high pass filter having an input connected with said source of wave energy, differential rectifying means having an input coupled in phase opposition to the output of said band pass filter and coupled in phase to the output of said band pass filter, phase shifting means in one of said connections, means connecting the output of said rectifying means in a circuit including differential impedances, a rectifier for said low pass filter a rectifier for said high pass filter, each of said rectifiers having a control electrode and an output electrode, a load circuit coupled to all of said rectifiers, means coupling the output electrode of each of said rectifiers to said differential impedances, gain control circuits interconnecting the rectifier coupled to the low pass filter to the rectifier coupled with the high pass filter whereby when one is energized the other is biased to cut off and vice versa so that noise developed in the filter not excited by said wave energy is prevented from reaching said load circuit, and means coupling said differential impedances to said tunable means to control the tune thereof.

2. In a signalling system, a utilization circuit, a source of wave energy, the frequency of which may vary and which is adjustable, a plurality of band pass filters, having overlapping band pass characteristics so that they cover a relatively wide frequency spectrum, coupled with said source, rectifying means coupling each of said

band pass filters to said utilization circuit, and means connected with each of said rectifying means for biasing the remaining ones of said rectifying means to cut off when the energy from said source falls within the band pass of the filter connected with the rectifier so biasing said other rectifiers whereby signals reach said utilization device irrespective of deviations in frequency of said wave energy and energy produced in the band pass filters not passing wave energy is prevented from reaching said utilization circuit.

3. A signal receiving means comprising in combination, signal wave amplifying means including tuning means, a utilization circuit, a plurality of paths each having an input coupled to said amplifying means, separate rectifying means coupling the output of each of said paths to said utilization circuit, a frequency discriminating means having an input coupled to the output of that path which passes wave energy including wave energy of the mean frequency of the wave energy normally supplied by said amplifying means to said paths, rectifying means having an input coupled to said frequency discriminating means and an output coupled with said tuning means, additional means coupled with each of said remaining paths for retuning said amplifying means when the wave energy passed thereby falls within the band passed by one of the said paths of the remaining paths and biasing circuits interconnecting a plurality of the rectifiers connected with said utilization circuit to render rectifiers inoperative which are connected to paths which pass energy outside of the frequency band being supplied by said amplifying means to the inputs of said paths to thereby prevent noise developed in those paths not supplying energy to the utilization circuit from reaching said utilization circuit.

4. In a signalling system, a utilization circuit, a source of wave energy, the mean frequency of which may vary and which is adjustable, a plurality of band pass filters having overlapping band pass characteristics covering a continuous frequency spectrum coupled with said source, rectifying means coupling each of said band pass filters to said utilization device, means connected with each of said rectifying means for biasing the remaining rectifying means to cut-off when the frequency of the energy from said source falls within the band pass of the filter connected with one rectifier, means connected with one of said rectifiers and responsive to deviations of the mean frequency of said wave energy within small limits from a frequency lying substantially in the center of the frequency spectrum passed by the filter connected to said last named rectifier, for adjusting the frequency of said source within small limits, and means connected with other rectifiers coupling the other of said band pass filters to said utilization circuit responsive to substantial deviations of said wave energy from the mean frequency of the spectrum passed by all of said band pass filters for changing the frequency of said source by a substantial amount.

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