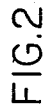


2,836,712

2 Sheets-Sheet 1



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May 27, 1958

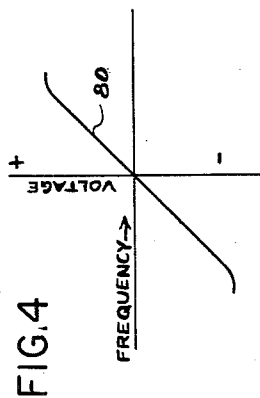
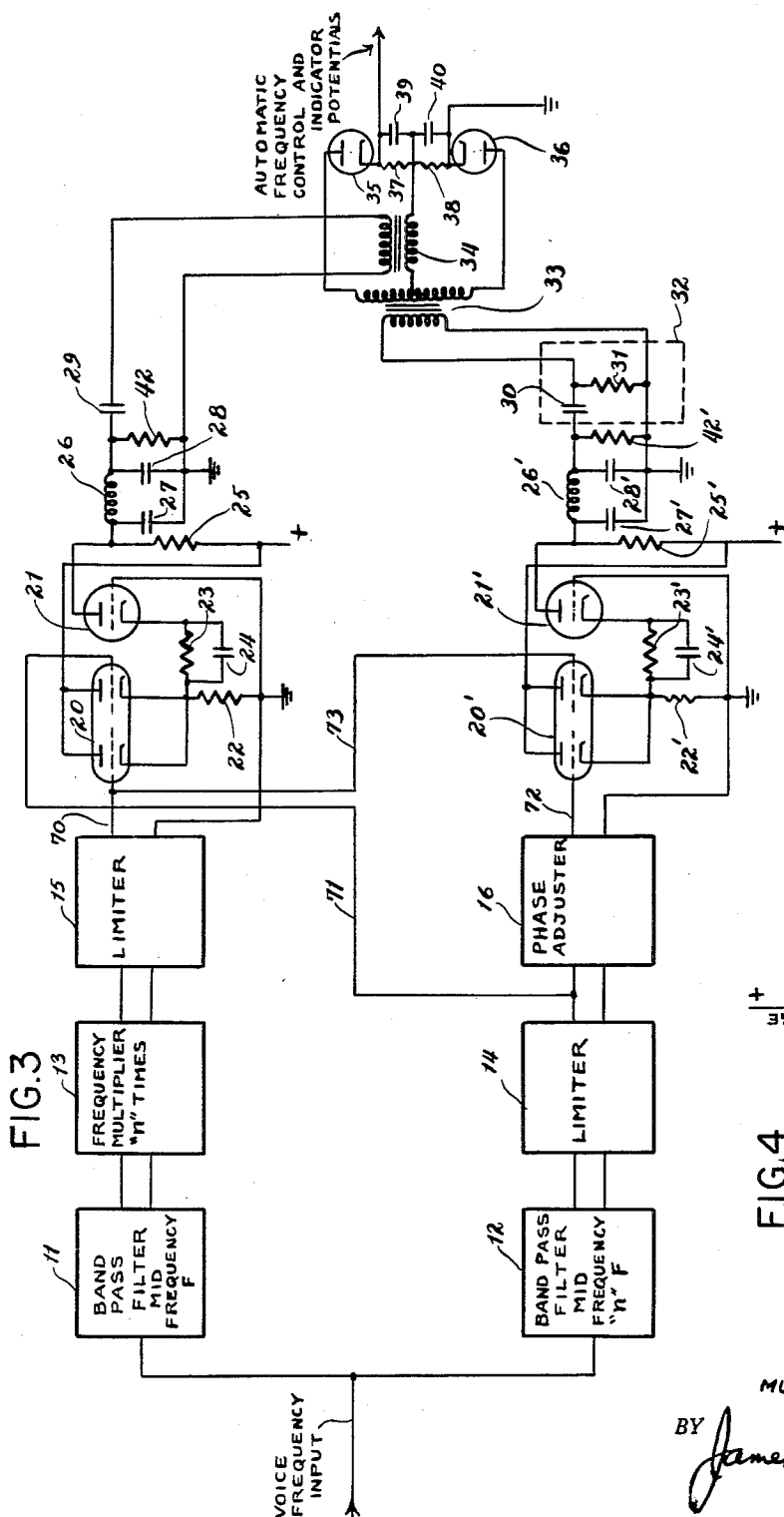
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AUTOMATIC FREQUENCY CONTROL AND TUNING INDICATOR

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2 Sheets-Sheet 2



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AUTOMATIC FREQUENCY CONTROL AND
TUNING INDICATOR

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Application June 29, 1956, Serial No. 594,984

15 Claims. (Cl. 250—20)

This invention relates to receivers, especially those receiving intelligence characterized by harmonically related frequencies.

The primary object of the invention is to generally improve such receivers. A more specific object is to provide a system for obtaining automatic frequency control or/and tuning indicator potentials for a receiver of voice transmission using carrier eliminated single-sideband modulation.

In the prior art of single-sideband reception, automatic frequency control or/and tuning indicator potentials were obtained from discriminator networks which were fed by the carrier, either the transmitted full carrier, or a transmitted pilot carrier. Such a system operates successfully for transmission in which either a full carrier or a reduced pilot carrier is radiated, but is not adaptable to that type of single-sideband transmission in which only the modulation sidebands are radiated, while the carrier is wholly suppressed. It is an object of this disclosure to provide an automatic frequency control or/and tuning indicator system which will operate on such transmission, that is, on carrier-eliminated single-sideband transmission.

Operation of my new system depends upon an inherent quality of the voice, which is that the complex wave which makes up the voice sound consists of a series of frequencies which are harmonically related. The basic structure of the speech wave is such that a fundamental wave is radiated, and the resonances of the mouth and larynx are shaped to select the proper harmonics of this fundamental wave in order to mold the speech sound. Data which describes this spectrum analysis of the voice wave is contained in a book entitled "Visible Speech" written by Potter and Green and published by S. Van Nostrand & Co. The many speech spectrum analyses given in that reference book clearly show this harmonic relation of the voice wave. It is thus known that the voice wave in its normal condition is comprised of fundamental and harmonics of a basic frequency.

The new system also may be used on any other complex wave similarly made up of frequencies which are harmonically related to a basic fundamental frequency. There are certain types of tone telegraph modulation which fall into this category. For instance, one standard tone system used in multiplex tone telegraphy uses 425 cycles, 595 cycles, 765 cycles, 835 cycles, etc. These are separated by a spacing of 170 cycles. The tones all may be derived from a generating system having a basic or fundamental frequency of either 42.5 or 85 cycles. The present invention is applicable to such a telegraph system, as well as to voice.

In accordance with a feature and object of the present invention, apparatus is provided which indicates, or which provides a potential in response to, a departure from harmonic relationship. For instance, let it be assumed that one of the voice frequencies is 300 cycles, and that a second harmonic component is present at 600 cycles. If this voice wave is being received on a single-sideband

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system, a detuning of 10 cycles will change the 300 cycle component to 310 cycles and the 600 cycle component to 610 cycles. The two frequencies then have lost their harmonic relationship, because the second harmonic of 310 cycles would be 620 cycles rather than 610 cycles. The present invention takes advantage of this difference.

To accomplish the foregoing general objects, and other more specific objects which will hereinafter appear, my invention resides in the receiver elements, and their relation one to another as are hereinafter more particularly described in the following specification. The specification is accompanied by drawings, in which:

Fig. 1 is a diagram partially in block form, showing one form of the invention;

Fig. 2 is a diagram in block form, showing a receiver system utilizing the invention;

Fig. 3 is a diagram partially in block form, showing a modified form of the invention; and

Fig. 4 is a graph explanatory of a detail of the invention.

Referring to the drawing, and more particularly to Fig. 2, the antenna 50 receives intelligence transmitted by sideband only, that is, without a carrier, and more specifically in the present case on a single sideband. Most of the diagram comprises means including one or more local oscillators, in this case the oscillators 53 and 57, for heterodyning the received energy to obtain low frequency energy. This is supplied to amplifier 82 and transducer 84, and in the present case also to another amplifier 86 and transducer 88, but a single amplifier and transducer may be used. Some of the low frequency energy is supplied to apparatus located in box 61, the output of which may have a potential indicative of departure from proper tuning.

This is supplied through conductor 90 to either a tuning indicator, the meter of which is shown at 65, or a means to alter the frequency of one of the local oscillators, in this case the oscillator 53, in that direction which corrects the tuning of the receiver. Two forms of the apparatus in box 61 are shown in Fig. 1 and Fig. 3, respectively.

Referring now to Fig. 1, there is a filter 11 which selects one frequency component or band, another filter 12 arranged in parallel, to simultaneously select another frequency component or band which is "n" times the first, and a frequency multiplier 13 which multiplies the output of filter 11 "n" times. The apparatus shown at the right end of Fig. 1 is a means for comparing the resulting frequencies to see if they are alike, as they should be, and in the event of discrepancy, to deliver a potential which may be used to indicate or/and correct any such departure.

Continuing with Fig. 1, the input may be assumed to be a voice frequency input, obtained from a single-sideband receiver. The filter 11 is a mid-frequency filter which may be tuned at, say, 350 cycles, with a band width of from, say, 300 to 400 cycles. The filter 12 has a frequency multiplied by an integer "n" which, in the present case, may be assumed to be two, in which case it has a mid-frequency of 700 cycles, and a band width of from 600 to 800 cycles.

Frequency multiplier 13 multiplies the output of bandpass filter 11 by "n" times, in order to raise its frequency to exactly the same range of frequencies as that of the bandpass filter 12. Accordingly, in the present case frequency multiplier 13 will multiply by two, and will have a bandpass filter in its circuits which select the same range as filter 12, which is assumed to be 600 to 800 cycles.

After the selection and multiplication of filter 11 and multiplier 13, and the selection of bandpass filter 12, there are two selections of the voice wave which should

be at the same frequency and the same bandpass. These two outputs may be fed to limiters 14 and 15 to provide more constant energy for feeding to the detector, and can be adjusted to the proper phase by a phase adjuster 16. One of the outputs is fed to the transformer 17, and the other to the transformer 18, of a phase detector system which uses diodes 19 and 20, together with diode resistors 21, 22, and bypass capacitors 23, 24. Thus one output is fed in push-pull, while the other is fed in parallel.

The phase detector system provides potentials at terminal 25 which are positive if the detuning departs in one direction, and negative if the detuning departs in the other direction. Phase adjuster 16 is so adjusted as to bring the voltages at transformers 17 and 18, 90 degrees apart in phase, for the condition of zero departure (i. e. proper tuning). Any departure then from proper tuning will cause the two selected channels to depart in their frequency synchronism, and the phase detector will provide an indication of the departure.

Fig. 2 shows how the system of Fig. 1 may be connected to a single-sideband receiving system. This system comprises an antenna 50 feeding a superheterodyne receiver 51, which feeds an intermediate frequency output to a converter 52. This intermediate frequency output may be at the conventional frequency of approximately 455 kilocycles. Converter 52, together with oscillator 53, heterodyne the 455 kc. intermediate frequency output down to a lower frequency, with upper and lower sidebands. The intermediate frequency is sufficiently low for satisfactory filtering by an upper sideband filter 56, and a lower sideband filter 55. Examples of typical suitable frequencies for filters 55 and 56 are 25 kc. or 100 kc. or 250 kc., or others in the same range.

A carrier is then supplied by another oscillator 57. Detectors 58 and 59, in conjunction with carrier oscillator 57, detect the output of the single sideband filters 55 and 56, in order to provide an audio output. Only one output or the other is used. These detectors may be product detectors, preferably of the triple-triode type described in detail in my article in the May 1956 issue of QST.

The detected audio output of one or other of the sideband filters is selected by a switch 60, and thence is fed to an automatic frequency control system 61, which may comprise the circuits shown and described in Fig. 1. Either the upper or lower sideband output may be chosen by means of the switch 60. The direction of the automatic frequency control potentials or/and indicator potentials obtained therefrom reverses as the switch is thrown from one sideband to the other. Hence a polarizing switch may be used at the output of the automatic frequency control, and such a switch is shown at 68 in Fig. 2.

The automatic frequency control or/and indicator potentials from unit 61 are fed to a time constant network 62, 63, and thence to a reactance tube 54. This reactance tube controls the frequency of oscillator 53. Thus if the frequencies start to depart from proper tuning, a potential will appear at the grid of the reactance tube to control oscillator 53 in the proper direction to correct the tuning, in the normal manner of known automatic frequency control systems.

Twin triode 64, together with resistors 66 and 67, and meter 65, comprise an indicating system which will show the direction of frequency departure on the meter 65, thereby providing a tuning indicator meter. Thus there is both indication and control, but either could be used alone.

In Fig. 2 I show two amplifiers 82, 86, and two transducers 84, 88. This is customary in receivers such as that shown, but is not essential. One amplifier and transducer could be connected to the poles of switch 60, and so would be connected to the selected channel along with the circuits of box 61.

Fig. 3 shows an alternative method of providing the automatic-frequency-control or/and indicator potentials. This alternative method provides a potential which is more

responsive to frequency than to phase. The same filters 11 and 12, frequency multiplier 13, limiters 14 and 15, and phase adjuster 16 are used, as were used in Fig. 1. The two synchronized and selected outputs are fed to two product detectors, preferably of the triple-triode type 20, 21 and 20', 21'. Thus conductor 70 goes from limiter 15 to one grid of tube 20, while conductor 71 goes from limiter 14, ahead of the phase adjuster 16, to the other grid. Conductor 72 goes from phase adjuster 16 to one grid of tube 20', while conductor 73 goes from limiter 15 to the other grid of tube 20'. The object is to detect the beat note difference frequency between the two selected channels.

Thus if the frequency of one channel is 610 cycles, and the frequency of the other 620 cycles, which represents a departure in tuning of 10 cycles, a beat note will appear at the output of the product detectors of 10 cycles. Each product detector is fed at one of its grids by one of the channels, and at the other of its grids by the other channel. Cathode resistors 22, 23 and bypass condenser 24, as well as 22', 23' and 24', provide the usual couplings and bias of the triple-triode detectors. Plate resistors 25 and 25' feed low-pass filters 26, 27, 28 and 26', 27' and 28'. Resistors 42 and 42' damp the low-pass filters. Condenser 29 is a blocking condenser to prevent direct current from passing through transformer 34. The cutoff frequency of the low-pass filters might be approximately 200 cycles. The two product detectors then would provide a beat note of up to 200 cycles for tuning departures of up to 200 cycles.

Phase adjuster 16, which is in the circuit of the lower product detector only, produces a shift of 90°. A shift of one of two beating frequencies shifts the beat 90°. Thus adjuster 16 is adjusted so that phase relations are proper to shift the beat note from one of the product detectors to be 90° out of phase with that from the other. A further shift of 90° is produced by means of an audio phase shifter 32, comprising a resistor 31 and a condenser 30. This makes the two beat notes add in phase on one side of zero beat, and subtract out of phase on the other side of zero beat.

Thus when these two frequencies are fed to a balanced modulator detector system 33, 34, 35 and 36, a positive potential is obtained at terminal 41 for a departure of frequency in one direction, and a negative potential for a departure of frequency in the opposite direction. Diode resistors 37, 38 together with bypass condensers 39, 40, add the two detector outputs of the in-phase and out-of-phase combination provided by transformers 33 and 34.

The simple type of phase shifter shown in box 32 has an important advantage. It has a response characteristic which is proportional to frequency, so that the output of the channel feeding transformer 33 falls off as the frequency goes towards zero. This provides a linear output potential from the detector system, as the frequency departs from the "in tune" condition. This is shown by Fig. 4, in which response curve 80 is linear for an adequate portion of its length.

The phenomenon of the phase reversal of the two beat note outputs of the product detectors in Fig. 3 may not be apparent. Hence the following example is given to show how it takes place. Let it be assumed that the frequency departure is the amount "f" cycles in the negative direction.

A frequency component passing the upper path 11-13-15 will be given by the following:

$$e_1 = E_1 \sin 2\pi n(F-f)t \quad (1)$$

The frequency component passing the lower channel 12-14-16 will be given by:

$$e_2 = E_2 \sin 2\pi(nF-f)t + \theta \quad (2)$$

It will be noted that the wave in the upper channel differs from that in the lower channel by the manner in which the multiplier "n" operates. In the upper channel, the multiplication "n" times effected by multiplier

13 operates to multiply the error "f" by "n". In the lower channel, multiplication is not involved so that the error remains at the value "f."

When the two waves of Equations 1 and 2 are fed to the product detector a difference frequency phase angle is obtained given by:

$$\omega_0 t = 2\pi(nF - f)t + \theta - 2\pi(nF - nf)t \quad (3)$$

which reduces to:

$$\omega_0 t = 2\pi(-f + hf)t + \theta \quad (4)$$

In Equation 4; "n"=2; and $\theta=90^\circ$. Hence:

$$\omega_0 t = 2\pi ft + 90^\circ \quad (5)$$

The beat note is therefore given by:

$$f_0 = f + 90^\circ \quad (6)$$

When the error is in the opposite direction, Equations 1 and 2 become:

$$e_1 = E_1 \sin 2\pi n(F + f)t \quad (1a)$$

$$e_2 = E_2 \sin 2\pi(nF + f)t + \theta \quad (2a)$$

which, when solved for the difference frequency results in

$$f_0 = f - 90^\circ \quad (7)$$

The 90° phase difference present on the two inputs of the product detector is thus converted to a plus 90° error on one side of zero beat, and a -90° error on the other side of zero beat. The additional 90° provided by audio phase shifter 32 converts the $+90^\circ$ and -90° to $+180^\circ$ and 0° , which is the desired phase difference to provide cancellation or addition of the two detected notes as the tuning goes through zero beat.

The system of Fig. 3 is connected to a single-sideband receiving system in the manner shown in Fig. 2, that is, the system of Fig. 3 is located in the box 61 shown in Fig. 2.

It is believed that the construction, operation and underlying theory of my improved automatic frequency control or/and tuning indicator, as well as the advantages thereof, will be apparent from the foregoing detailed description. It will also be apparent that while I have shown and described my invention in several preferred forms, changes may be made in the circuits shown, without departing from the scope of the invention, as sought to be defined in the following claims.

I claim:

1. Apparatus for automatic frequency control for a receiver for intelligence made up of harmonically related audio frequencies, said apparatus comprising a receiver for reproducing the audio frequency intelligence, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, means for comparing the resulting frequencies to see if they are alike as they should be, and means responsive to any departure in one direction or the other to alter the tuning of the receiver in that direction which reduces the departure.

2. Apparatus for automatic frequency control for a receiver for intelligence transmitted by sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, means for comparing the resulting frequencies to see if they are alike as they should be, and means responsive to any departure in one direction or the other to alter the frequency of one of the aforesaid local oscillators in that direction which reduces the departure.

3. Apparatus for automatic frequency control for a receiver for voice intelligence transmitted by single sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, means for comparing the resulting frequencies and balancing the same if they are alike as they should be, and means responsive to any unbalance or departure in one direction or the other to alter the frequency of one of the aforesaid local oscillators in that direction which reduces the departure.

4. Apparatus for automatic frequency control for a receiver for intelligence transmitted by sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the resulting outputs, means to shift the phase of one of the outputs by 90 degrees, and a detector system including means to supply one of the outputs to a pair of tubes in parallel and another of the outputs to said pair of tubes in series, whereby the outputs are balanced when alike and are unbalanced when there is a departure from proper tuning, and circuitry from said phase detector system to utilize any unbalance in one direction or the other to alter the frequency of one of the aforesaid local oscillators in that direction which reduces the unbalance.

5. Apparatus for automatic frequency control for a receiver for voice intelligence transmitted by single sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the resulting outputs, means to shift the phase of one of the outputs by 90 degrees, and a phase detector system including means to supply one of the outputs to a pair of tubes in parallel and another of the outputs to said pair of tubes in series, whereby the outputs are balanced when alike and are unbalanced when there is a departure from proper tuning, and circuitry from said phase detector system to utilize any unbalance in one direction or the other to alter the frequency of one of the aforesaid local oscillators in that direction which reduces the unbalance.

6. Apparatus for automatic frequency control for a receiver for intelligence transmitted by sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the outputs, means to shift the phase of one of the limited outputs by 90 degrees, a pair of product detectors, means feeding both of the outputs ahead of the phase shifter to one of the product detectors in such fashion as to beat the same to obtain a very low frequency beat, means to feed both outputs to the other product detector to obtain a very

low frequency beat, one of the outputs in the latter case following the phase shifter, whereby the low frequency beat produced by the second product detector is also shifted 90 degrees, means to shift the latter an additional 90 degrees, the last means comprising a capacitance and a resistor, whereby its output varies with frequency, a detector system including means for feeding one of the low frequency outputs to a pair of tubes in parallel and the other of the low frequency outputs to said pair of tubes in series, and circuitry for utilizing the output of said detector system to alter the frequency of one of the aforesaid local oscillators in that direction which reduces the departure.

7. Apparatus for automatic frequency control for a receiver for voice intelligence transmitted by single sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the receiver energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the outputs, means to shift the phase of one of the limited outputs by 90 degrees, a pair of triple triode product detectors, means feeding both of the outputs ahead of the phase shifter to one of the product detectors in such fashion as to beat the same to obtain a very low frequency beat, means to feed both outputs to the other product detector to obtain a very low frequency beat, one of the outputs in the latter case following the phase shifter, whereby the low frequency beat produced by the second product detector is also shifted 90 degrees, means to shift the latter an additional 90 degrees, the last means comprising a capacitance and a resistor, whereby its output varies with frequency, a phase detector system including means for feeding one of the low frequency outputs to a pair of tubes in parallel and the other of the low frequency outputs to said pair of tubes in series, and circuitry for utilizing the output of said phase detector system to alter the frequency of one of the aforesaid local oscillators in that direction which reduces the departure.

8. A detecting system, responsive to a heterodyne action between a first energy from a local generator and a second energy comprised of harmonically related components, including means whereby one or more detected lower frequency components of said heterodyne action are multiplied and compared with corresponding unmultiplied higher frequency components of said heterodyne action, and means to produce an indication or control potential in proportion to the departure of said detected components from harmonic relation.

9. Apparatus for automatic frequency indication for a receiver for intelligence made up of harmonically related audio frequencies, said apparatus comprising a receiver for reproducing the audio frequency intelligence, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, means for comparing the resulting frequencies to see if they are alike as they should be, and means responsive to any departure in one direction or the other to indicate the departure.

10. Apparatus for automatic frequency indication for a receiver for intelligence transmitted by sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the

first, a frequency multiplier for multiplying the output of the first filter by "n" times, means for comparing the resulting frequencies to see if they are alike as they should be, and means responsive to any departure in one direction or the other, to indicate the departure.

11. Apparatus for automatic frequency indication for a receiver for voice intelligence transmitted by single sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, means for comparing the resulting frequencies and balancing the same if they are alike as they should be, and means responsive to any unbalance or departure in one direction or the other to indicate the departure.

12. Apparatus for automatic frequency indication for a receiver for intelligence transmitted by sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the resulting outputs, means to shift the phase of one of the outputs by 90 degrees, and a detector system including means to supply one of the outputs to a pair of tubes in parallel and another of the outputs to said pair of tubes in series, whereby the outputs are balanced when alike and are unbalanced when there is a departure from proper tuning, and circuitry from said phase detector system to utilize any unbalance in one direction or the other to indicate the same.

13. Apparatus for automatic frequency indication for a receiver for voice intelligence transmitted by single sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the resulting outputs, means to shift the phase of one of the outputs by 90 degrees, and a phase detector system including means to supply one of the outputs to a pair of tubes in parallel and another of the outputs to said pair of tubes in series, whereby the outputs are balanced when alike and are unbalanced when there is a departure from proper tuning, and circuitry from said phase detector system to utilize any unbalance in one direction or the other to indicate the same.

14. Apparatus for automatic frequency indication for a receiver for intelligence transmitted by sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the outputs, means to shift the phase of one of the limited outputs by 90 degrees, a pair of product detectors, means feeding both of the outputs ahead of the phase shifter to one of the product detectors in such fashion as to beat the same to

obtain a very low frequency beat, means to feed both outputs to the other product detector to obtain a very low frequency beat, one of the outputs in the latter case following the phase shifter, whereby the low frequency beat produced by the second product detector is also shifted 90 degrees, means to shift the latter an additional 90 degrees, the last means comprising a capacitance and a resistor, whereby its output varies with frequency, a detector system including means for feeding one of the low frequency outputs to a pair of tubes in parallel and the other of the low frequency outputs to said pair of tubes in series, and circuitry for utilizing the output of said detector system to indicate a departure from tuning.

15. Apparatus for automatic frequency indication for a receiver for voice intelligence transmitted by single sideband without a carrier, said intelligence being made up of harmonically related frequencies, said apparatus comprising means including one or more local oscillators to heterodyne the received energy to obtain low frequency energy, a filter to select one frequency component or band, another filter arranged in parallel to simultaneously select another frequency component or band "n" times the first, a frequency multiplier for multiplying the output of the first filter by "n" times, limiters for the outputs, means to shift the phase of one of the limited

outputs by 90 degrees, a pair of triple triode product detectors, means feeding both of the outputs ahead of the phase shifter to one of the product detectors in such fashion as to beat the same to obtain a very low frequency beat, means to feed both outputs to the other product detector to obtain a very low frequency beat, one of the outputs in the latter case following the phase shifter, whereby the low frequency beat produced by the second product detector is also shifted 90 degrees, means to shift the latter an additional 90 degrees, the last means comprising a capacitance and a resistor, whereby its output varies with frequency, a phase detector system including means for feeding one of the low frequency outputs to a pair of tubes in parallel and the other of the low frequency outputs to said pair of tubes in series, and circuitry for utilizing the output of said phase detector system to indicate a departure from tuning.

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