

PATENT SPECIFICATION

(11) 1 218 824

DRAWINGS ATTACHED



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- 1) Application No. 9618/68 (22) Filed 28 Feb. 1968
 (31) Convention Application Nos. 620 006 (32) Filed 2 March 1967
 648 667 26 June 1967 in
 (33) United States of America (US)
 (45) Complete Specification published 13 Jan. 1971
 (51) International Classification G 01 r 23/12
 (52) Index at acceptance
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(54) FREQUENCY DISCRIMINATOR APPARATUS

(71) We, RCA CORPORATION, formerly Radio Corporation of America, a corporation organised under the laws of the State of Delaware, United States of America, of 30 Rockefeller Plaza, City and State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to improved frequency discriminating apparatus. More particularly, it relates to such apparatus for deriving a frequency dependent error correction voltage which in a preferred embodiment controls the tuning of a local oscillator in a superheterodyne receiver, and which can be fabricated using integrated circuit techniques, if desired.

As used herein, the term "integrated circuit" refers to a unitary or monolithic semiconductor device or chip which is the equivalent of a network of interconnected active and passive circuit elements. At the present state of the art there exists no satisfactory way of providing an inductor, or a potentiometer, on an integrated circuit. In addition capacitors require a large area of the integrated circuit chip, even to provide a very small capacitance. Due to the limitations of present fabrication techniques, capacitors may represent a potential source of trouble due to the incidence of shorting of the capacitor plates.

It is an object of the present invention to provide improved frequency discriminating apparatus.

In accordance with the present invention there is provided frequency discriminating apparatus comprising a tuned discriminator transformer to which an input signal is applied and which yields at the ends of a centre-tapped secondary winding first and second combined signals each including a first and a second signal component, the phase relationship between said two components

varying oppositely in said first and second combined signals as the frequency of said input signal varies in one sense or the other from the resonant frequency of said transformer, together with first and second detector networks of similar construction, each said network including a pair of oppositely poled rectifiers each fed from a respective input terminal of the network, the outputs of said rectifiers being combined to form a respective combined output signal, the input terminals of said detector networks being oppositely connected to the ends of said secondary winding whereby the combined output signals of said detector networks are mutually in antiphase and the combined output signals of said detector networks being applied to respective input terminals of a differential amplifier.

As will become clear hereinafter, frequency discriminating apparatus embodying the invention and used in superheterodyne receivers includes a pair of oppositely poled detector networks. These networks may be of the type disclosed in Patent Specification No. 1,170,353.

In the accompanying drawings:

Figure 1 is a schematic circuit diagram of automatic frequency control circuitry embodying the present invention;

Figure 2 is a partial schematic circuit diagram of a modification of the circuitry of Figure 1;

Figure 3 is a schematic circuit diagram of a further modification of the automatic frequency control circuitry of Figure 1;

Figure 4 represents a pair of transistors which may additionally be included in the circuitry of Figure 3; and

Figures 5a and 5b represent partial block diagrams helpful in an understanding of the present invention.

While an illustrative embodiment of the invention will be described as an integrated circuit in the context of a television receiver, it will be understood that its fundamental concepts are more generally applic-

able, being useful in broadcast or communication receivers for example.

When a television viewer rotates the channel selector and adjusts the fine tuning control of his receiver, he is actually varying the frequency of a local oscillator in the television tuner. The signal output of this oscillator is heterodyned with the composite television signal received at the antenna and amplified in the radio frequency stage. This action creates both the sum and difference frequencies, as well as the original local oscillator and radio frequencies. All but the difference frequencies are filtered out. The remaining difference frequencies, or intermediate frequencies, are amplified and detected in the normal manner to recreate the desired audio and video information.

If the local oscillator is for any reason not set at the proper frequency, the intermediate frequencies will be incorrect, and may adversely affect the reproduced sound and picture. As is well known, this mistuning may be due to improper fine tuning by the television viewer, local oscillator drift, or inaccurate resetability of the mechanical detenting action of the tuner.

The schematic circuit diagrams of the drawing show examples of specific circuitry embodying the automatic frequency control apparatus of the invention. The apparatus operates as a frequency discriminator to develop a control voltage which is representative of the sense and degree that the resultant intermediate frequency signal departs from the desired intermediate frequency signal. The control voltage is applied to a voltage responsive reactance device in the local oscillator of the television receiver to correct the mistuning of the oscillator and optimize the sound and picture reproduction.

The dashed rectangle 10 in Figure 1 of the drawings schematically illustrates a monolithic semiconductor chip. The chip has a plurality of contact areas about its periphery, through which external connections to the circuits on the chip can be made. For example, the chip 10 has a pair of contact areas 11 and 12 which are coupled to a source of intermediate frequencies. The contact area 12 provides a common or ground potential contact area, which is connected to the various circuit-ground connections shown on the monolithic chip.

As to physical dimensions, the chip 10 may be of the order of 50 mils $\times$ 50 mils, or smaller. The manner of making the various transistor, diode and resistor functional portions described below in a monolithic chip is known in the art, one such method, for example, being illustrated by United States Patent No. 3,271,685.

For ease of understanding, the automatic frequency control apparatus on the

integrated chip 10 may be considered to be comprised of five stages: a voltage supply 20, a buffer amplifier 30, a pair of oppositely poled detectors 40 and 50, and a differential amplifier output stage 60.

Intermediate frequency signals are supplied to the chip 10 by means of the contact areas 11 and 12 while direct current control signals indicative of their deviations from a reference frequency are derived at the differential amplifier contact areas 13 and 14.

The voltage supply 20 includes diodes 21, 22 and 23, transistor 24, and resistors 25, 26 and 27. Diodes 21—23 are serially connected between resistors 25 and 26, and poled so as to conduct current from resistor 25 to resistor 26. The end of resistor 25 remote from diode 21 is connected via a contact area 15 to a source of potential (not shown), and the end of resistor 26 remote from diode 23 is connected to ground. The junction between resistor 25 and diode 21 is connected to the base electrode of transistor 24, the collector and emitter electrodes of which are respectively connected directly to the contact area 15 and via resistor 27 to ground.

It will be noted that diodes 21—23 are shown as being fabricated from a transistor structure rather than from a rectifier structure. This technique, wherein the collector and base regions are interconnected to form the anode of the diode while the emitter region forms the cathode of the diode, is employed to minimize any parasitic transistor action in the rectifier structure.

The voltage developed across resistor 27 in the supply 20 is used to bias the buffer amplifier 30 and the differential amplifier 60. With a plus 10 volt potential source and with the component values set forth in the drawing, this voltage is approximately plus 2.2 volts. (In this respect it should be pointed out that the voltage drop across each of the diodes 21—23 and the voltage drop across the base-to-emitter junction of transistor 24 is about 0.7 volts.) As will subsequently become clear, the bias voltage is applied to the differential amplifier 60 in such a manner that its current is independent of temperature variations.

The buffer amplifier 30 comprises an emitter coupled amplifier-limiter stage including a pair of transistors 31 and 32 and a resistor 33. The collector electrode of transistor 31 is connected to the potential source contact area 15 while the base electrode of transistor 32 is connected to the emitter electrode of transistor 24 in the voltage supply unit 20. The emitter electrodes of transistors 31 and 32 are connected together. This junction is connected to the grounded contact area 12 through resistor 33. The base electrode of transistor 31 is connected by way of the contact area 11 to

one end of a parallel resonant circuit 100, the other end of which is connected through a coupling capacitor 101 to an input signal terminal 102.

5 Terminal 102 may represent the output circuit of the video intermediate frequency amplifier of a television receiver, in which case the resonant circuit 100 is tuned to 47.25 MHz. Such tuning is effective to pass 10 the 45.75 MHz intermediate frequency video carrier and to trap or reject the adjacent channel sound carrier in the intermediate frequency band.

15 The base electrode of transistor 31 is also connected via the contact area 11, a signal decoupling choke 103 and a contact area 16 to the emitter electrode of transistor 24 in the voltage supply 20. This connection completes the bias circuit arrangement for the buffer stage 30. A signal bypass capacitor 104 is connected between the contact 20 area 16 and ground.

The collector electrode of transistor 32 is connected through a contact area 17 to the 25 primary winding 105 of a phase shift discriminator transformer 106. Transformer 106 is tuned to the 45.75 MHz video carrier frequency. The secondary winding 107 of the transformer 106 is connected between a 30 pair of contact areas 18 and 19, and is also tuned to 45.75 MHz. A tertiary winding 108 is connected between a center tap on the secondary winding 107 and the contact area 16.

35 The detector network 40 includes a pair of oppositely poled diodes 41 and 42. It also includes a pair of load resistors 43, 44 connected in series between the cathode electrode of the diode 41 and the anode electrode of the diode 42. The anode electrode of diode 41 and the cathode electrode of diode 42 are respectively connected to the contact areas 18 and 19 to form a series 40 circuit including the tuned secondary winding 107. The detector 40 further includes a third resistor 45 connected between the junction of resistors 43 and 44 and the emitter electrode of the voltage supply transistor 24.

50 The detector network 50 similarly includes a pair of oppositely poled diodes 51 and 52 and a pair of load resistors 53 and 54 serially connected with the secondary 55 winding 107. More particularly, the cathode electrode of the diode 51 is connected to the contact area 18, the anode electrode of the diode 52 is connected to the contact area 19, the anode electrode of the diode 51 is connected to one end of the resistor 53, and 60 the cathode electrode of the diode 52 is connected to one end of the resistor 54. The detector 50 likewise includes a third resistor 55 connecting the other ends of the resistors 53 and 54 to the emitter electrode of transistor 24.

The detector networks 40 and 50 are of the kind disclosed in Patent Specification No. 1,170,353. As is therein described, the 70 illustrated construction does away with the need for the large capacitors normally used in prior art detectors and eliminates the known problems large capacitors present to integrated circuit design. At the same time, such construction permits the use of a relatively small amount of capacitance to filter 75 the applied signals. That capacitance, for example, may be provided in Figure 1 by the distributed capacitance of the load resistors 43 and 44 for the detector 40, and 53 and 54 for the detector 50. 80

The differential amplifier 60 includes two transistors 61 and 62 and three resistors 63, 64 and 65. The emitter electrodes of the transistors 61 and 62 are connected together and to ground by way of resistor 63. The 85 collector electrodes of these transistors are each coupled to the contact area 15. The collector electrode of the transistor 61 is coupled to contact area 15 through the resistor 64 and the collector electrode of the transistor 62 via the resistor 65. These electrodes are also respectively connected to 90 output terminals 110 and 111 by means of the contact areas 13 and 14.

95 Emitter follower circuits 70 and 80 respectively couple the base electrodes of the transistors 61 and 62 to the detector circuits 40 and 50. The circuit 70 includes a transistor 71 having an emitter electrode connected to ground through a resistor 72. The 100 base electrode is connected to the junction of resistors 43 and 44 in the detector 40. The collector electrode is connected to the potential source contact area 15. The circuit 80 similarly includes a transistor 81 105 having an emitter electrode referenced to ground by way of resistor 82. The base electrode is connected to the junction of resistors 53 and 54 in the detector 50. The collector electrode is connected to the contact area 15. The emitter electrode of transistor 71 is also connected to the base electrode of transistor 6. The corresponding emitter electrode of transistor 81 is additionally connected to the base electrode of transistor 62. 115

Patent Specification No. 1,170,353 also describes the use of reverse biased diodes as small capacitors to augment the signal filtering provided by the detector network. 120 One such diode 46 is included in the detector network 40. Its cathode electrode is connected to the junction of resistors 43 and 44 and its anode electrode is grounded. Another such diode 56 performs the additional 125 filtering in the detector network 50. The diode 56 has its cathode electrode connected to the junction of resistors 53 and 54 and its anode electrode connected to ground.

The diodes 46 and 56 are reverse biased 130

in the following manner. By returning the tertiary winding 108 to a positive voltage, 2.2 volts with respect to ground as shown in the drawing, the input electrodes of the diodes 41, 42, 51 and 52 are also raised to this voltage. The load impedance at the junction of the load resistors 43 and 44 is large relative to either of these two resistors. Therefore, the same plus 2.2 volts appears at the center signal frequency and is strong enough to drive the diodes 41 and 42 into conduction. The diode 46 is thus reverse biased by the plus 2.2 volt potential. Since the detector circuits 40 and 50 are each symmetrical, the same set of conditions exist at center signal frequency for the resistors 53 and 54. The diode 56 is therefore reverse biased by the 2.2 volt potential established at the junction of resistors 53 and 54.

Each of the detector circuits 40 and 50, furthermore, include a second reverse biased diode; 47 in the case of the circuit 40 and 57 in the case of the circuit 50. These diodes provide symmetrical loading to the opposite ends of the secondary winding 107 of the discriminator transformer 106.

More particularly, the diode 47, with its anode electrode connected to ground and its cathode electrode connected to the cathode electrode of the diode 41, adds a capacity to that exhibited by the anode region of the diode 41 so as to balance the higher capacity presented by the cathode region of the diode 51 to the secondary winding 107 at contact 18.

Similarly, the anode and cathode electrodes of the diode 57 are respectively connected to ground and to the cathode electrode of the diode 52, to add a capacity to that exhibited by the anode region of the diode 52 so as to balance the higher capacity presented by the cathode region of the diode 42 to the winding 107 at contact 19. In this respect, it will be understood that the anode and cathode regions of these diodes are constructed from P and N type semiconductor material respectively.

An average direct current potential of about 1 volt is developed across each of the resistors 43 and 44 in the detector 40, and across each of the resistors 53 and 54 in the detector 50 due to rectification of the applied carrier signal. This potential is added to the existing potential of plus 2.2 volts, so that each of the diodes 47 and 57 are reverse biased by about 3.2 volts.

The operation of the automatic frequency control apparatus of Figure 1 is as follows: Intermediate frequency signals of a nominal 45.75 MHz frequency are applied to the terminal 102. These signals are coupled through the capacitor 101, the 47.25 MHz resonant trap 100, and the contact area 11 to the buffer or emitter coupled amplifier 30.

The buffer stage 30 amplitude limits the input signals so that the output current in the collector circuit of the transistor 32 is essentially a square wave. This wave is applied through the tuned primary and secondary windings of the phase-shift transformer 106 to the detector networks 40 and 50. As was previously mentioned, these networks provide an average type detection with a substantially resistive load.

The detector network 40 develops an output voltage which is proportional to the sine of the phase angle shift imparted by the discriminator transformer 106 to the signal wave developed across its secondary winding 107. The phase angle shift is developed with respect to the wave applied to primary winding 105. This is described in Patent Specification No. 1,124,276, of which Patent Specification No. 1,170,353 represents an improvement. As is pointed out in Specification No. 1,124,276, the imparted phase angle shift is proportional to the frequency difference between the applied signal and the frequency to which the discriminator transformer is tuned (i.e., the center frequency). Where the applied signal is of a higher frequency than this center frequency, the phase shift and the output voltage are of positive value. Where the applied signal is of a lower frequency, the phase shift and output voltage are negative.

The detector network 50 develops an output voltage which also is proportional to the sine of the imparted phase shift. This voltage, however, is of a polarity opposite to the voltage developed by the network 40. This is because the two networks are oppositely poled. The direction of current flow in the detector 40 is from the high to the low side of the secondary winding 107. The current flow is just the opposite in the detector 50. Any frequency deviation of the applied signal from the center or reference frequency thus produces a change in the output voltage at the junction of resistors 43 and 44 in the network 40. This change is equal in magnitude but in the opposite polarity direction to that produced at the junction of the resistors 53 and 54 in the network 50.

The resistors 45 and 55 are respectively connected between the two above-mentioned junctions and the plus 2.2 volt supply 20. These resistors ensure balanced discriminator action over a wide range of applied signal levels. The function of this resistor is described in Patent Specification No. 1,170,353 above referred to, where it is noted that without such resistor connections, the discriminator characteristic would undergo a direct current voltage shift for low level signals. Such a voltage shift in this environment would impair the pull-in characteristics of the AFC apparatus.

The output voltages developed by the detector networks 40 and 50 are respectively coupled in push-pull relation through the emitter follower stages 70 and 80 to opposite sides of the differential amplifier 60. At the center frequency, equal voltages are applied to the opposite sides and the amplifier 60 exhibits a common mode gain equal to the ratio between the parallel equivalent of the load resistors 64 and 65 and the emitter coupling resistor 63. With the component values shown in Figure 1, this common mode gain is approximately six times. The particular values were selected so that the differential amplifier 60 would develop approximately 5.0 volts at both terminals 110 and 111 at center frequency.

For applied signal frequencies different from the center frequency, the differential amplifier 60 exhibits a differential mode gain of about 100 times. (In this respect it will be understood that a common mode condition is characterized by signals of substantially equal amplitude and of the same polarity being applied to the opposite sides of the amplifier 60; a differential mode condition then exists when the applied signals are of substantially equal amplitude but of opposite polarity.)

As was previously mentioned, the detector output voltages applied to the sides of the differential amplifier 60 are equal in magnitude but opposite in polarity. Frequency deviations in one direction (e.g., increase) from the 45.75 MHz center frequency cause positive voltages to be applied to the base electrode of the differential amplifier transistor 61 and negative voltages to be applied to the base electrode of the transistor 62. Conversely, frequency deviations in the other direction (e.g., decrease) from the 45.75 MHz frequency cause negative and positive discriminator voltages to be respectively applied to the transistors 61 and 62.

The output voltage developed by the differential amplifier 60 as a function of signal frequency is shown in Figure 1 at the terminals 110 and 111. The voltage characteristics A and B are of the form of the well known discriminator characteristic or "S curve", with the output voltage being about 5 volts at the 45.75 MHz center frequency f_c . Their 10 and zero volts maximum and minimum values were reached at approximately 50 KHz deviation from that center frequency. The voltage characteristics C and D, of which curves A and B show the respective central portions on an expanded frequency axis illustrate approximately a ± 1 MH pull-in range for the apparatus. This range is established by the Q and the coupling of the discriminator transformer 106.

The voltages developed at the output

terminals 110 and 111 of the differential amplifier 60 are used to control variable reactance circuitry in the local oscillator of the television tuner to control its frequency. In the case of a UHF tuner, the voltage developed at either one of these output terminals may be coupled in a known manner to change the capacitance exhibited by a varactor diode included in the frequency determining network of the oscillator. In the case of a VHF tuner, the voltages developed at these terminals may be coupled to the base and collector electrodes of a transistor included in the frequency determining network.

Such an arrangement, is disclosed in Patent Specification No. 1,169,521, wherein it is described how, with the emitter electrode open circuited, the transistor exhibits the characteristics of a voltage variable capacitor. In either case, the voltage responsive capacity device is selected to adjust the oscillator frequency so as to set the intermediate frequency signal at 45.75 MHz when the voltage developed at terminals 110 and 111 is plus 5 volts. Figures 5a and 5b may respectively represent these two alternative arrangements.

As was previously mentioned, one feature of the AFC configuration of the drawing is that the current flowing in the differential amplifier 60 is independent of temperature variations. Were this not so, the amplifier 60, having a differential gain of 100 or more, would produce an erroneous frequency control voltage of substantial proportion as the operating temperature changed. A similar situation would exist under conditions of varying supply voltage. The apparatus of Figure 1, however, is insensitive to such temperature and/or voltage supply variations.

Consider, first, a change in the environmental temperature. This change causes a voltage drop across the base-to-emitter junction of all the transistors in the circuit. This voltage drop is designated ΔV_{be} . Thus, the voltage drop across each of the diodes 21-23 in the voltage supply 20 changes by an amount ΔV_{be} . Because the automatic frequency control apparatus is incorporated on a single monolithic chip 10, the voltage drop across the emitter-to-base junctions of the transistors 24, 61, 62, 71 and 81 also changes by ΔV_{be} . This change is in the same direction as the change across the diodes 21-23. It will be apparent that the substantially $3\Delta V_{be}$ change at the base electrode of the transistor 24 due to this temperature variation is effectively offset by the individual ΔV_{be} changes in the transistor chains 24, 81 and 62, and 24, 71, 61. The bias at the differential amplifier 60 thus remains substantially constant so that temperature

variations exert no effect upon the output voltages it develops.

Consider, next, a change in the source potential applied to the contact area 15. This causes the 2.2 volts developed at the emitter electrode of the voltage supply transistor 24 to change by an amount ΔV . Because symmetrical drive is used for the differential amplifier transistors 61 and 62, however, any resulting disturbance produced at the base electrode of one is offset by an equal disturbance at the base electrode of the other. Balanced operation once again results, and the differential amplifier output voltages remained unchanged.

As was previously mentioned, a 47.25 MHz absorption trap 100 is coupled in the input circuit of the buffer amplifier stage 30. This trap is included to prevent a strong adjacent channel sound signal from capturing the limiter amplifier 30 in the presence of a weaker, mistuned 45.75 MHz intermediate frequency signal. Although a strong adjacent sound signal would produce substantially no error voltage if the resonant trap were omitted, it being outside the 1 MHz pull-in range of the apparatus, by so capturing the amplifier 30, it would suppress any weaker, mistuned 45.75 MHz signal of interest and any error voltage tending to be produced thereby.

The automatic frequency control action may be summarized as follows. If any difference exists between the sampled video carrier intermediate frequency and the 45.75 MHz reference frequency of the transformer 106, opposite polarity signal phase shifts are developed at the inputs to the detector networks 40 and 50. These phase shifts produce equal and opposite voltage changes at the output terminals of the differential amplifier 60. The extent and direction of these voltage changes from an initial plus 5 volt at center frequency is determined by the character of the respective phase shift.

The output voltage(s) from the amplifier 60 is (are) coupled to a voltage responsive capacitance coupled to the local oscillator of the television tuner. The voltage adjusts the capacity and thereby alters the local oscillator frequency so as to vary the intermediate frequency signal in a direction opposite to the original frequency error that existed from mistuning.

The AFC apparatus and the variable capacitance network thus combine to maintain the generation of a 45.75 MHz video carrier and 41.25 MHz sound carrier to ensure accurate reproduction of the picture and sound information in the received television signal.

In cases of signal interference or reception of an extremely weak station, it may be desirable to fine tune the local oscillator manually. Such control is generally required

also in setting up a detented or pre-programmed channel selector in the television receiver. For VHF operations, the automatic frequency control action provided by the apparatus of Figure 1 may be defeated by short circuiting the terminals 110 and 111.

For UHF operations, the automatic control may be defeated by short circuiting to a plus 5 volt reference supply, the terminal 110 or 111 supplying the error voltage to the variable reactance circuitry in the local oscillator. The fine tuning can then be accomplished in either mode of operation by manually varying a local oscillator reactance in a known manner. The automatic fine tuning control is reinstated upon removal of the respective short circuits.

A 5 volt supply as referred to above may also be constructed on the monolithic chip 10. It is shown in Figure 1 by the notation 90, and includes transistors 91 and 92 and resistors 93, 94 and 95. The collector electrode of transistor 91 is connected to the potential source contact 15 through the resistor 93. The collector electrode of transistor 92 is directly connected to that contact area. The emitter electrodes of these transistors are each referenced to ground, the emitter electrode of transistor 91 by means of the resistor 94 and the emitter electrode of transistor 92 via the resistor 95.

The base electrode of transistor 91 is connected to the emitter electrode of transistor 92. The base electrode of transistor 92 is connected to the collector electrode of transistor 91. The emitter electrode of transistor 92 is also coupled via a contact area 9 to the supply output terminal 113.

The supply 90 develops a 5.0 volt output at the emitter electrode of transistor 92. In general, however, the voltage developed will be equal to one-half the value of the potential applied to the contact area 15. The voltage developed, furthermore, will continue at this one-half value, independent of temperature variations. A voltage supply of this type is more fully described in United States Patent Specification No. 3,383,612.

It will be appreciated that the automatic frequency control provided by the apparatus of Figure 1 may further be defeated by biasing off either or both of the transistors 31 and 32 in the amplifier 30. Because of the circuit symmetry employed, no differential voltages will be applied to the base electrodes of the transistors 61 and 62. The collector electrodes of these transistors will thus each be at the 5 volt initial reference. This method applies both VHF and UHF control in which regard it will be noted that the latter no longer requires the 5 volt supply 90.

The automatic frequency control apparatus embodying the principles of the inven-

tion has also been constructed using a modified voltage supply unit and modified coupling from the detector networks to the differential amplifier. Such an arrangement is shown in Figure 2 of the drawings wherein similar notations are used to identify corresponding components of the apparatus of Figure 1.

It will be noted that a voltage supply diode 23 and the emitter follower coupling networks 70 and 80 have been omitted. With the arrangement of Figure 2, approximately plus 1.5 volts is developed at the emitter electrode of the voltage supply transistor 24. Temperature compensation is again afforded by the base-emitter junctions of transistors 24, 61 and 62. These base-emitter voltage drops vary with temperature in a manner to offset similarly produced changes in the voltages developed across the diodes 21 and 22. The control action provided by the apparatus of Figure 2 is substantially similar to that provided by the apparatus.

The automatic frequency control apparatus of Figure 3 also employs a modified voltage supply unit and a modified coupling from the detector networks to the differential amplifier. More particularly, the unit 20 is replaced by an internally regulated supply 150 and the emitter follower coupling circuits 70 and 80 have been omitted.

The supply 150 includes a pair of 5 volt zener diodes 151 and 152 serially coupled with a junction diode 153 between the contact area 15 and ground. A resistive voltage divider 154 is coupled across the zener 151 to provide substantially the same 2.2 volts previously used in the arrangement of Figure 1 to bias the buffer amplifier 30 and the differential amplifier 60.

The inclusion of the diode 153 extends the range of control voltages developed at the output terminals 110 and 111. It does so by adding an additional 0.7 volts drop to that provided by the zener diodes 151 and 152, and thereby increasing the possible voltage swing at the contact areas 13 and 14. The diode 153 thus extends the pull-in range of the apparatus as determined by the voltage responsive capacity device.

The configuration of Figure 3 further employs a constant current transistor 155 in place of the common emitter resistor 63 of the differential amplifier 60. A diode 157 couples the base electrode of the transistor 155 to ground to provide temperature stabilization in a known manner. A resistor 158 additionally couples that base electrode to the contact area 15. Such an arrangement is desirable because it makes possible the obtaining of a stable, temperature independent reference voltage for disabling the automatic fine tuning control. Such an arrangement is also desirable in that it simplifies

the temperature compensation previously provided by the transistor chains 24, 81, 62 and 24, 71, 61 in Figure 1, in combination with the diodes 21, 22 and 23.

As was previously mentioned with respect to the apparatus of Figure 1, the automatic fine tuning control can be defeated on VHF operation by short circuiting the error voltage output terminals 110 and 111. Such an approach still applies in the arrangement of Figure 3. Defeat of the automatic control on UHF operation, however, can also be accomplished in this manner. It will be understood that this approach is to be taken in the Figure 3 arrangement. The reference voltage supply 90 used in disabling the automatic fine tuning on UHF in Figure 1 can thus be omitted from the circuit of Figure 3 since a corresponding 5 volt potential will nominally be developed at terminals 110 and 111 when short circuited.

Besides the advantages of simplified temperature compensation and automatic fine tuning disable, the apparatus of Figure 3 offers other desirable features. One such feature is an improved pull-in characteristic on UHF while another is an increased smoothness in manual tuning.

Consider, first, the improved pull-in feature. It will be appreciated that production variations in the circuit of Figure 1 may well cause the X axis of the frequency discriminator characteristic measured at the terminals 110 and 111 to be at a voltage different from that of the reference supply 90. Since that reference voltage is used in manually setting up the local oscillator of the receiver on UHF, any difference in voltage at the terminal used to supply the single ended control voltage after the automatic control disable is removed would be interpreted as an error voltage indicating some degree of mistuning.

The apparatus of Figure 1 would operate to adjust the local oscillator frequency in response, but would do so at the expense of the possible pull-in range. A one volt difference, for example, might be compensated in a manner to cause the effective pull-in range to decrease from 1 MHz to 500 kHz. However, with the UHF reference voltage formed by short circuiting terminals 110 and 111 as in the arrangement of Figure 3, the pull-in range tends not to be so restricted because both the error and reference voltages tend to depart from the nominal 5 volt value by the same amount.

It will be noted, in addition, that the reference voltage obtained by short circuiting terminals 110 and 111 is stabilized in the presence of temperature variations by the temperature compensated constant current transistor 155. This, together with the fact that the constant current transistor 155 makes the biasing of the differential ampli-

fier transistors 61 and 62 less critical, also results in an improvement in the pull-in characteristic of the control apparatus.

Consider, next, the increased smoothness in manual tuning. With the resistor 63 included in the common emitter circuits of the differential amplifier transistors 61 and 62 in Figure 1, it has been observed that the reference voltage obtained at the terminals 110 and 111 when short circuited tended to decrease the degree of mistuning. At 1 MHz off center frequency, for example, the reference voltage might be down from nominal 5 volt level at approximately 4 volts. Simultaneous with the tuning of the local oscillator towards the center frequency, then, is the development of a reference voltage of increasing value. This increase gives an uneven feel to the vernier fine tuning control as it is being adjusted.

With the constant current transistor 155 substituted for the common emitter resistor 63, however, as in the apparatus of Figure 3, a smoother and more even feel to the tuning results because the reference voltage obtained by short circuiting the terminals 110 and 111 is unaffected by variations in the drive of the discriminator transformer 106.

A pair of Darlington connected transistors may also be included in the automatic control apparatus of Figure 3 to improve its sensitivity. These transistors, together with the manner of their connections to the circuit of Figure 3, are shown in Figure 4.

As shown, the transistors couple the detector circuits 40 and 50 to their respective differential amplifier input electrodes in much the same manner as do the emitter follower coupling circuits 70 and 80 of Figure 1. The balanced circuit arrangement continues to provide its own stable reference voltage, as in Figure 3, when terminals 110 and 111 are short circuited. This applies whether the reference voltage so developed at those terminals is to be applied in push-pull fashion to defeat the automatic fine tuning control (VHF) or is to be applied as a single ended disabling voltage (UHF).

Two important factors should be noted with respect to the automatic frequency control apparatus of Figures 1 through 4. First, circuit symmetry is employed in each to balance the critical elements of the apparatus. For example: a) symmetrical, oppositely poled detector networks are used to provide the push-pull signals to the balanced differential amplifier; b) the detector networks are driven from a common phase shift circuit and are equally loaded thereby; c) the detector networks and the differential amplifier share a common bias supply; and d) the output potentials of both halves of

the differential amplifier are temperature compensated.

Second, the ratios of the resistors are more important to the maintenance of stability than their absolute values. This is of special significance in integrated circuit fabrication since the resistors can all be formed at the same time and their ratios readily maintained, whereas the absolute resistance values are a function of the variables in the fabrication processes. Accordingly, with a given process procedure and with the high dependence placed on circuit symmetry and maintenance of resistor ratios, yields of useable circuits upwards of 98% have been obtained.

While the AFC apparatus of the drawings have been described as employing a common frequency discriminator transformer, it will be apparent that other phase shift devices could be used as well. Quartz crystal filters and solid state piezoelectric devices, for example, are also capable of converting frequency variations into changes in amplitude, and may be used. Arrangements which do not use a phase shift device to drive the detector networks 40 and 50 in common, but use instead a pair of such devices, are less desirable in that they may cause asymmetrical loading of the detector networks 40 and 50, and a resulting imbalance in the operation of the differential amplifier 60.

It will also be apparent that the type of voltage responsive, variable capacity device used in the VHF and UHF oscillators will determine whether push-pull or single ended voltages are needed to effect the frequency control function provided by the apparatus of Figures 1-4. Where both devices are varactor diodes, for example, only single ended control voltages need be supplied.

WHAT WE CLAIM IS:—

1. Frequency discriminating apparatus comprising a tuned discriminator transformer to which an input signal is applied and which yields at the ends of a centre-tapped secondary winding first and second combined signals each including a first and a second signal component, the phase relationship between said two components varying oppositely in said first and second combined signals as the frequency of said input signal varies in one sense or the other from the resonant frequency of said transformer, together with first and second detector networks of similar construction, each said network including a pair of oppositely poled rectifiers each fed from a respective input terminal of the network, the outputs of said rectifiers being combined to form a respective combined output signal, the input terminals of said detector networks being

fier transistors 61 and 62 less critical, also results in an improvement in the pull-in characteristic of the control apparatus.

Consider, next, the increased smoothness in manual tuning. With the resistor 63 included in the common emitter circuits of the differential amplifier transistors 61 and 62 in Figure 1, it has been observed that the reference voltage obtained at the terminals 110 and 111 when short circuited tended to decrease the degree of mistuning. At 1 MHz off center frequency, for example, the reference voltage might be down from nominal 5 volt level at approximately 4 volts. Simultaneous with the tuning of the local oscillator towards the center frequency, then, is the development of a reference voltage of increasing value. This increase gives an uneven feel to the vernier fine tuning control as it is being adjusted.

With the constant current transistor 155 substituted for the common emitter resistor 63, however, as in the apparatus of Figure 3, a smoother and more even feel to the tuning results because the reference voltage obtained by short circuiting the terminals 110 and 111 is unaffected by variations in the drive of the discriminator transformer 106.

A pair of Darlington connected transistors may also be included in the automatic control apparatus of Figure 3 to improve its sensitivity. These transistors, together with the manner of their connections to the circuit of Figure 3, are shown in Figure 4.

As shown, the transistors couple the detector circuits 40 and 50 to their respective differential amplifier input electrodes in much the same manner as do the emitter follower coupling circuits 70 and 80 of Figure 1. The balanced circuit arrangement continues to provide its own stable reference voltage, as in Figure 3, when terminals 110 and 111 are short circuited. This applies whether the reference voltage so developed at those terminals is to be applied in push-pull fashion to defeat the automatic fine tuning control (VHF) or is to be applied as a single ended disabling voltage (UHF).

Two important factors should be noted with respect to the automatic frequency control apparatus of Figures 1 through 4. First, circuit symmetry is employed in each to balance the critical elements of the apparatus. For example: a) symmetrical, oppositely poled detector networks are used to provide the push-pull signals to the balanced differential amplifier; b) the detector networks are driven from a common phase shift circuit and are equally loaded thereby; c) the detector networks and the differential amplifier share a common bias supply; and d) the output potentials of both halves of

the differential amplifier are temperature compensated.

Second, the ratios of the resistors are more important to the maintenance of stability than their absolute values. This is of special significance in integrated circuit fabrication since the resistors can all be formed at the same time and their ratios readily maintained, whereas the absolute resistance values are a function of the variables in the fabrication processes. Accordingly, with a given process procedure and with the high dependence placed on circuit symmetry and maintenance of resistor ratios, yields of useable circuits upwards of 98% have been obtained.

While the AFC apparatus of the drawings have been described as employing a common frequency discriminator transformer, it will be apparent that other phase shift devices could be used as well. Quartz crystal filters and solid state piezoelectric devices, for example, are also capable of converting frequency variations into changes in amplitude, and may be used. Arrangements which do not use a phase shift device to drive the detector networks 40 and 50 in common, but use instead a pair of such devices, are less desirable in that they may cause asymmetrical loading of the detector networks 40 and 50, and a resulting imbalance in the operation of the differential amplifier 60.

It will also be apparent that the type of voltage responsive, variable capacity device used in the VHF and UHF oscillators will determine whether push-pull or single ended voltages are needed to effect the frequency control function provided by the apparatus of Figures 1-4. Where both devices are varactor diodes, for example, only single ended control voltages need be supplied.

WHAT WE CLAIM IS:—

1. Frequency discriminating apparatus comprising a tuned discriminator transformer to which an input signal is applied and which yields at the ends of a centre-tapped secondary winding first and second combined signals each including a first and a second signal component, the phase relationship between said two components varying oppositely in said first and second combined signals as the frequency of said input signal varies in one sense or the other from the resonant frequency of said transformer, together with first and second detector networks of similar construction, each said network including a pair of oppositely poled rectifiers each fed from a respective input terminal of the network, the outputs of said rectifiers being combined to form a respective combined output signal, the input terminals of said detector networks being



- oppositely connected to the ends of said secondary winding whereby the combined output signals of said detector networks are mutually in anti-phase and the combined output signals of said detector networks being applied to respective input terminals of a differential amplifier.
2. Frequency discriminating apparatus in accordance with claim 1, wherein each of said detector networks in combination with said discriminator transformer forms a ratio detector.
3. Frequency discriminating apparatus in accordance with claim 1, wherein each of said detector networks comprises first and second diode rectifiers, first and second resistances connected together at a junction and connected in series between the cathode of said first diode and the anode of said second diode and a third resistance connected for direct current between said junction and a first source of direct potential, the current paths through said first and second resistances being capacitatively coupled to a-c signal ground point to filter said respective combined output signal appearing at said junction in response to said first and second combined signals, one input to said detector being applied to the anode of said first diode, the other input to said detector being applied to the cathode of said second diode.
4. Frequency discriminating apparatus in accordance with claim 3, wherein said discriminator transformer has the said secondary winding centre-tap connected by another of its windings to said first source of direct potential.
5. Frequency discriminating apparatus as claimed in claim 4, wherein said another of the discriminator transformer windings is a tertiary winding.
6. Frequency discriminating apparatus in accordance with claim 4 or 5, wherein said differential amplifier comprises first and second transistors, first and second resistors, and a second direct potential source with first and second terminals at direct potentials respectively lower than and higher than that provided at said first direct potential source; the emitters of said first and second transistors being coupled to said first terminal of said second direct potential source by said first resistor, the base electrodes of said first and second transistors each being direct current coupled to separate ones of said junctions of said first and second detector networks, the collector electrode of said first transistor being direct current coupled to said second terminal of said second direct potential source, and said second resistor coupling said collector electrode of said second transistor to said second direct potential source, the potential variations at the collector electrode of said second transistor constituting said output signal.
7. Frequency discriminating apparatus substantially as described with reference to Figure 1, 2, 3 or 4 of the accompanying drawings.
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Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1971.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY,
from which copies may be obtained.



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