

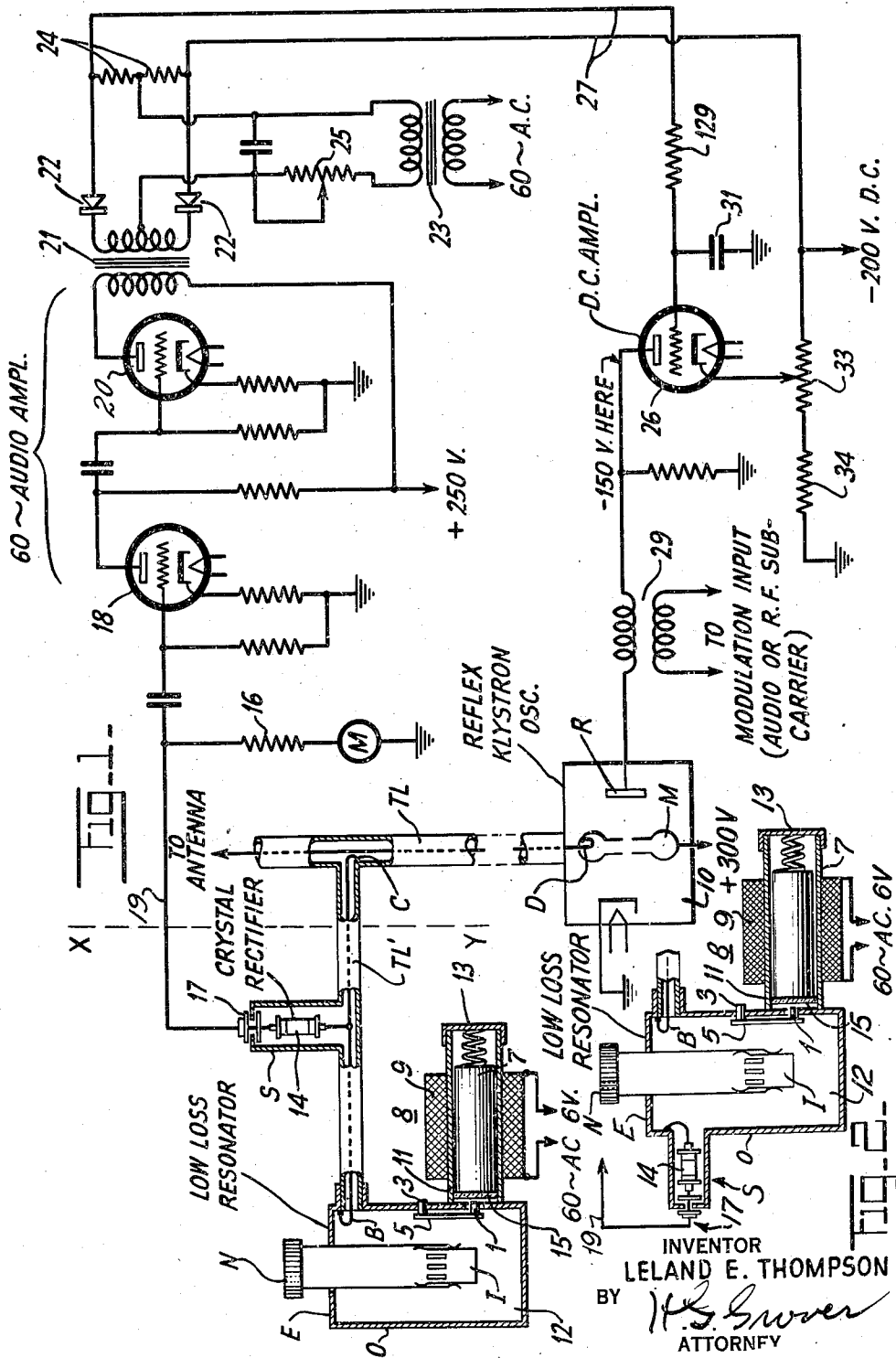
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AUTOMATIC FREQUENCY CONTROL

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AUTOMATIC FREQUENCY CONTROL

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9 Claims. (Cl. 250—36)

1

This invention relates to a method of and apparatus for automatically controlling the frequency of oscillators generating very high frequency oscillations, of the order of 500 megacycles and higher.

A detailed description of the invention follows in conjunction with a drawing wherein Fig. 1 illustrates one embodiment of the automatic frequency control system of the invention, and Fig. 2 illustrates a modification of a portion of Fig. 1 which can be substituted for that portion to the left of vertical dash line X—Y.

Referring to the drawing there is shown a reflex "Klystron" oscillator 10 whose frequency is to be stabilized, a reference tuned circuit 12 of high Q (low loss) whose frequency is to be compared with the frequency of the oscillations produced by the oscillator 10, and a frequency correcting circuit comprising a crystal rectifier 14, a resistor 16 across which the voltages rectified by the crystal 14 appear, an audio amplifier 18, 20, a balanced phase detector system including a pair of rectifiers 22 and a pair of equal resistors 24, and a direct current amplifier 26.

The reflex "Klystron" oscillator 10 whose frequency is to be controlled is illustrative of any suitable oscillator generating very high frequency oscillations. By way of example, this oscillator may generate oscillations of the order of 4000 megacycles, although this frequency is given merely by way of illustration. Oscillator 10 is shown as comprising an evacuated envelope having therein a cathode K for producing a beam of electrons, a toroidal cavity resonator M of suitable dimensions and having apertures in both sides to permit the beam of electrons from the cathode K to pass therethrough, and a reflector or repeller electrode R. The voltage on the repeller electrode is of negative polarity relative to the cathode and repels the electrons passing through the toroidal resonator M. The electrons in this "Klystron" oscillator move to and fro through the cavity resonator M until they are finally collected. The dimensions of the cavity resonator M and the voltage on the reflector electrode R determine to a large extent the frequency of the oscillations generated by the reflex "Klystron" 10. Such an oscillator is well known in the art and no claim is made to it per se.

Output from the Klystron oscillator 10 is taken from a loop D located in the interior of the cavity resonator M. This loop is coupled to a coaxial transmission line TL which extends to an antenna (not shown). The system as illustrated

2

may be employed either in a transmitter or a receiver.

The reference tuned circuit 12 may be any suitable cavity resonator but is here shown as a concentric line tuned circuit having an outer conductor O and an adjustable inner conductor I. The inner and outer conductors are connected together by a metallic end plate E. The length of the inner conductor controls the frequency of the tuned circuit 12 and is adjustable by means of a tuning knob N. It is preferred that the conductors of this tuned circuit be made of Invar, which is a low temperature coefficient material, and coated with highly conducting electrical material such as silver, gold or copper. This tuned circuit is preferably sealed against humidity so that its resonant frequency is very constant and its stability comparable to that of a quartz crystal. The Q of the tuned circuit 12 is made to be very high, on the order of 2000 to 4000, by way of example.

A crystal rectifier 14 is coupled very loosely to the reference resonator 12 by means of concentric line TL' and loop B. Loop B enters the interior of the resonator 12 and is coupled to the electromagnetic field within this concentric line tuned circuit.

The frequency of the low loss resonator 12 is modulated or changed up and down at an audio frequency rate by means of a polarized vibrating plunger or vibrator circuit 8. This vibrator comprises a permanent magnet 7 located within a coil 9 which is coupled to a source of 60 cycle alternating current. This 60 cycle alternating current may, by way of illustration, have a voltage of 6 volts. A suitable vibrator spring 5 located in the interior of the concentric line resonator 12 is fixed at one end to a spacer 3 and has its other end secured to an iron button 1. This iron button vibrates with the spring 5 and moves in and out of an aperture in the outer conductor O. Between the solenoid 9 and the permanent magnet 7 there is provided a brass tube 11 one end of which is sealed off by a suitable cap 13 and the other end of which is sealed off by a suitable non-magnetic material 15 such as polystyrene, in order to prevent moisture or air from entering the interior of the outer conductor O through the aperture. It is preferred that the coaxial resonator 12, together with the oscillator 10 and the circuit in which the crystal rectifier 14 is located, be located in a temperature control box, not shown.

The crystal rectifier 14 is located in a suitable metallic stub S and is preferably tuned. One

terminal of the crystal rectifier is connected to the inner conductor of line TL'. The line TL' is coupled at one end by way of loop B to the resonator 12 and at the other end coupled by way of loop C to the line TL extending to the antenna. The other terminal of the crystal rectifier 14 is connected to the by-pass condenser 17 at the closed end of the stub. This by-pass condenser comprises a pair of metallic plates on opposite sides of and suitably spaced from the end of stub S. This last terminal of the crystal rectifier is connected via lead 19 to one end of a resistor 16 whose other end is connected to ground through a meter M. Lead 19 is also connected to a 60 cycle or 120 cycle audio amplifier comprising a pair of vacuum tube triode stages, 18 and 20 arranged in cascade.

The output of the 60 cycle audio amplifier 18, 20 is coupled to a balanced phase detector circuit comprising a pair of rectifiers 22 connected to opposite ends of the secondary winding of an audio transformer 21. It should be understood, however, that the rectifiers 22 may be replaced by diodes, if it is so desired. A pair of equal value resistors 24 are connected in series across the output of the balanced phase detector. Alternating current in the form of 60 cycle energy is supplied to the balanced phase detector through an audio transformer 23 and a variable phase adjuster 25. Output from the balanced phase detector is taken by way of leads 27 and fed to a direct current amplifier 26. This direct current amplifier furnishes negative voltage to the reflector electrode R of the "Klystron" oscillator 10 of a magnitude and sense necessary to correct the frequency of the "Klystron" oscillator in order to cause this frequency to conform with the frequency of the reference tuned circuit 12.

If the system is used as a transmitter, modulation potentials may be supplied to the oscillator 10 by way of a transformer 29. This modulation may be in the form of an audio or a radio frequency sub-carrier. If audio modulation is employed, the transformer 29 should be an iron core transformer whereas if a radio frequency sub-carrier frequency is employed the transformer 29 should be an air core transformer. The radio frequency sub-carrier modulation may be amplitude or frequency modulation. Whichever type of modulation is employed, whether audio or radio frequency sub-carrier, the result will be a frequency modulation of the oscillations produced by the reflex "Klystron" 10.

In the operation of the system, the permanent magnet 7 of the vibrator 8 normally exerts force to pull the lower end of the vibrator spring 5 toward it. The application of the 60 cycle alternating current to the coil 9 causes the flux produced in the vibrator during one-half cycle to oppose the pulling force of the permanent magnet and hence permit the spring 5 to move back toward the inner conductor I of the resonator 12. During the other half cycle, the flux produced by the coil 9 aids that produced by the magnet and pulls the vibrator spring towards the permanent magnet. The movement of the spring toward and away from the inner conductor changes the capacity of the resonator 12 and hence changes the resonant frequency of this resonator. This occurs at a rate of 60 cycles per second.

The alternating current output from the crystal rectifier 14 is either near zero or has a frequency of 120 cycles when the oscillator 10 is in tune with the coaxial line resonator 12, and this output increases or the 60 cycle component

increases when the resonator 12 becomes detuned by the vibrator. This alternating current output from the crystal rectifier is amplified by the 60 cycle audio amplifier 16, 18 and operates the frequency correcting circuit. This frequency correcting circuit functions in such manner as to hold the frequency of the oscillations produced by the oscillator 10 to the frequency of the reference resonator 12. Very loose coupling is employed between the reference resonator 12 and the oscillator 10, and also between the reference resonator 12 and the crystal rectifier 14.

When the oscillator 10 is exactly in tune with the reference resonator 12, a direct current voltage will appear across the crystal rectifier load resistor 16. In this condition, there will be either no alternating voltage across resistor 16 or there will exist across this resistor the second harmonic of the 60 cycle modulating supply. The vibrator causes the resonant frequency of the resonator 12 to change from one side to the other side of the resonant frequency of the resonator 12 at a period of 60 cycles per second, and this produces an alternating current variation of the crystal current at a period of 120 cycles per second. This 120 cycle current is amplified by the audio amplifier 18, 20 and applied to the balanced phase detector but this 120 cycle current does not produce any direct current output potential from the balanced phase detector. If the frequency of the oscillator 10 drifts in a direction so as to be higher than the desired frequency of the oscillator 10, then a 60 cycle voltage component will appear across resistor 16. This 60 cycle voltage or component is developed in the crystal rectifier 14 and is amplified by a two-stage audio amplifier 18, 20 and fed to the balanced detectors 22. The potential produced by the balanced phase detector in this case will be a direct current output which may be in a negative direction. It should be noted that the detectors or copper oxide rectifiers 22 are excited in parallel by the same 60 cycle alternating current source which modulates the reference resonator 12. Normally, the rectifier currents in the resistors 24 are equal and opposite in direction, so that the sum is zero. However, when 60 cycle alternating current is supplied to the detectors 22 from the audio amplifier, the currents through the resistors 24 become unbalanced so that the sum voltage is not zero but is either positive or negative.

The output from the balanced phase detector appears in leads 27 and is fed to the direct current amplifier 26. The resistor 129 and the capacitor 31 filter out the 60 cycle component and apply the resultant direct current voltage to the direct current amplifier 26. A change in anode voltage then occurs in the direct current amplifier 26 and this change is applied to the repeller electrode R of the oscillator 10 in order to correct the frequency of the oscillations produced by the reflex "Klystron" oscillator.

It should be understood that if the frequency of oscillations from the oscillator 10 drifts down in frequency, then the phase of the 60 cycle voltage appearing across resistor 16 is opposite or reversed 180° from the phase of the 60 cycle voltage appearing across this same resistor when the oscillator frequency drifts upward. The polarity of the direct current voltage in the output of the balanced phase detector is reversed or opposite in the case of the oscillator frequency 10 drifting down than in the case when the oscillator frequency drifts upward. It is this reversal of phase of the 60 cycle voltage appearing across resistor

16 (as the frequency of the oscillator 10 changes from one side of the resonant frequency of the resonator 12 to the other side) that causes the frequency correction circuit to function.

In the system of the invention, it should be observed that the coupling loop C picks up or collects only a small percentage (perhaps 1%) of the power fed to the antenna, and this small percentage of radio frequency energy is fed to the crystal rectifier 14. The resonator 12 variably absorbs energy from the loop B, depending upon the resonant frequency of the concentric line resonator. When the frequency of the concentric line resonator 12 is the same as the transmitter frequency, then the resonator 12 absorbs a maximum and the radio frequency current rectified by the crystal 14 is a minimum. When the resonator 12 absorbs energy, it does this at the expense of the energy being rectified by the crystal rectifier 14. When the resonant frequency of the resonator 12 changes to either side of the frequency of oscillations produced by the transmitter or oscillator 10, then less energy is absorbed by the resonator 12 and hence more current is rectified by the crystal rectifier 14.

An important feature of the invention is the location of the crystal rectifier which is between the reference resonator 12 and the high frequency oscillator 10. An advantage of this location lies in the fact that the portion of the line TL' between the crystal rectifier 14 and the loop C can be made to be any length, for example five feet, more or less. This is because the distance between the upper terminal of the crystal rectifier 14 and the closed end of the stub S is made to be a fixed dimension, in order to provide an impedance match to the line TL' over a wide frequency range. By way of illustration, in one embodiment of the invention actually tried out in practice, there was employed a frequency range of 3900 megacycles to 4400 megacycles produced by the oscillator 10, and the foregoing impedance match was a good one over this entire range of frequencies.

Another important feature of the invention lies in the use of the variable phase adjustment 25 for adjusting the phase of the 60 cycle alternating current voltage fed to the balanced detector. This adjustment, which is in the form of a tap on a resistance, permits adjustment of the phase of the 60 cycle alternating current voltage with respect to the alternating current voltage output from the crystal rectifier. This assures maximum control of the transmitter and prevents undesired frequency changes of the transmitter oscillator 10 which might otherwise occur in the event the phase of the two alternating current voltages to be compared are different from the necessary value.

It should be noted that the cathode of the direct current amplifier 26 is connected to a potentiometer 33. This potentiometer 33 is connected in series to a fixed high resistance 34. The value of resistance 34 is chosen so that the "bleeder" current through 33 and 34 is several times the anode current of 26, so that objectionable degeneration does not occur in the direct current amplifier 26.

The potentiometer control 33 is used to initially adjust the "Klystron" repeller voltage to the correct value, preferably before the vibrator in resonator 12 is started.

If desired, the crystal 14 may be coupled directly to the cavity resonator circuit 12, rather than be positioned in the location shown in the

drawing, in which case it is not necessary to tune the crystal circuit and the transmission line between the cavity resonator and the oscillation generator tube can be very short. Such an arrangement is shown in Fig. 2 which is a fragmentary view showing only those parts of the system necessary for an understanding of the modification and which can be substituted for that portion of Fig. 1 to the left of vertical dash line X—Y. The same elements in both Figs. 1 and 2 are identified by the same reference characters, and the connections 19 and TL of Fig. 2 extend to the same circuits as the same numbered leads in Fig. 1. The means for utilizing the variable voltage produced by the balanced detecting system for controlling the frequency of operation of the high frequency oscillator is not shown in Fig. 2 in the interest of simplifying the drawing but is identical with that shown in Fig. 1.

What is claimed is:

1. In combination, a generator of high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, a source of low audio frequency current coupled to said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a rectifier within a metallic shell coupled to said last coupling circuit and located between said resonator circuit and said generator, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

2. In combination, a generator of very high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, a source of low audio frequency current coupled to said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a rectifier coupled to said last coupling circuit and located between said resonator circuit and said generator, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, a variable phase adjusting circuit located between said phase detecting system and said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

3. In combination, a generator of very high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, said vibrator circuit including a permanent magnet, a coil surround-

7

ing said magnet, and a vibrator spring at one end of said magnet and located within said resonator, a source of low audio frequency current coupled to the coil of said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a rectifier within a metallic shell coupled to said last coupling circuit and located between said resonator circuit and said generator, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

4. In combination, a generator of very high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, a source of low audio frequency current coupled to said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a rectifier within a metallic shell coupled to said last coupling circuit and located between said resonator circuit and said generator, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, said balanced phase detecting system including a pair of copper oxide rectifiers, a variable phase adjuster located between said rectifiers and said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

5. In combination, a generator of oscillations, a stable circuit tuned to a desired frequency of oscillations generated by said generator, said stable circuit being coupled to said generator so as to be excited by oscillations generated by said generator, a source of relatively low audio frequency waves, means responsive to waves from said low audio frequency source for cyclically varying the tuning of said stable circuit about a desired frequency of operation, a rectifier connected to a point intermediate the ends of an energy transfer circuit extending between said stable circuit and said generator for rectifying waves derived from said generator, said rectifier being positioned within a metallic stub and capacitively coupled at one end to the upper end of said stub, the distance between said one end of said rectifier and the opposite end of said stub being fixed, to thereby provide an impedance match over a wide band of frequencies to that portion of said energy transfer circuit which is located between said rectifier and said generator, a balanced detecting system responsive to and comparing waves derived from said rectifier and from said relatively lower frequency source so as to produce a voltage which varies in polarity depending upon departures in frequency of said oscillation generator away from a desired fre-

8

quency of operation, and instrumentalities responsive to the voltage produced by said balanced detecting system to reduce the departure in frequency of operation of said generator away from the desired frequency of operation.

6. In combination, a generator of very high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, a source of low audio frequency current coupled to said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a rectifier coupled to said resonator circuit, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, a variable phase adjusting circuit located between said phase detecting system and said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

7. In combination, a generator of very high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, said vibrator circuit including a permanent magnet, a coil surrounding said magnet, and a vibrator spring at one end of said magnet and located within said resonator, a source of low audio frequency current coupled to the coil of said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a rectifier coupled to said resonator circuit, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

8. In combination, a generator of high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, a source of low audio frequency current coupled to said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a crystal rectifier within a metallic shell directly coupled to said resonator circuit, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, said balanced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the

variable voltage so produced for controlling the frequency of operation of said generator.

9. In combination, a generator of very high frequency waves, a stable low loss tuned resonator circuit tuned to a desired frequency of operation, a vibrator circuit coupled to said resonator circuit for changing the frequency of operation of said resonator circuit, a source of low audio frequency current coupled to said vibrator circuit and energizing the same to operate at the frequency of said source, a circuit coupling said generator to said resonator circuit for exciting said resonator circuit with waves derived from said generator, a crystal rectifier directly coupled to said resonator circuit, a balanced phase detecting system coupled to said rectifier and to said source of low audio frequency current, said balanced phase detecting system including a pair of copper oxide rectifiers, a variable phase adjuster located between said rectifiers and said source of low audio frequency current, said bal-

anced detecting system producing a variable voltage as the frequency of said generator varies with respect to the mean frequency of operation of said variably tuned resonator circuit, and means utilizing the variable voltage so produced for controlling the frequency of operation of said generator.

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