

July 22, 1941.

J. F. MORRISON
FREQUENCY REGULATION

2,250,104

Filed March 30, 1940

2 Sheets-Sheet 1

FIG. 1

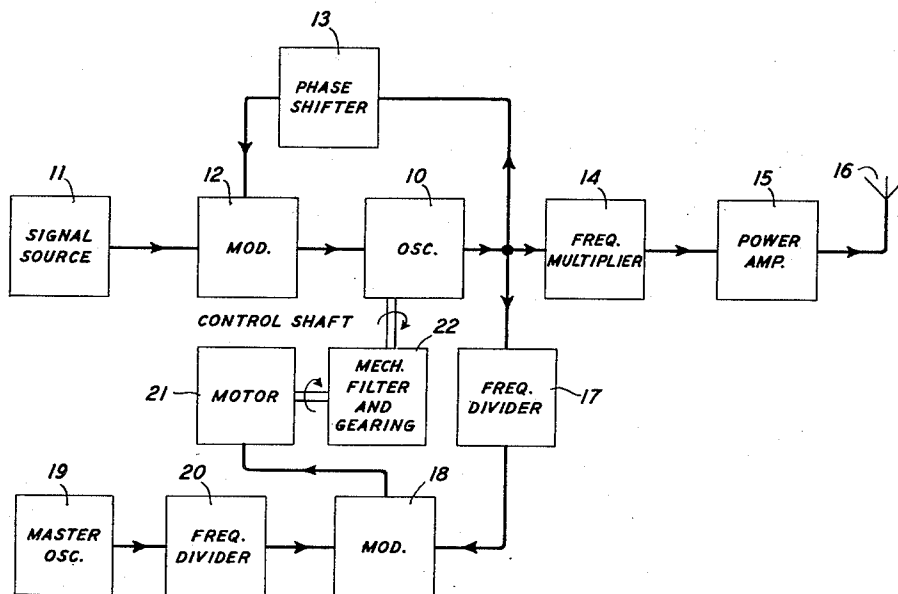
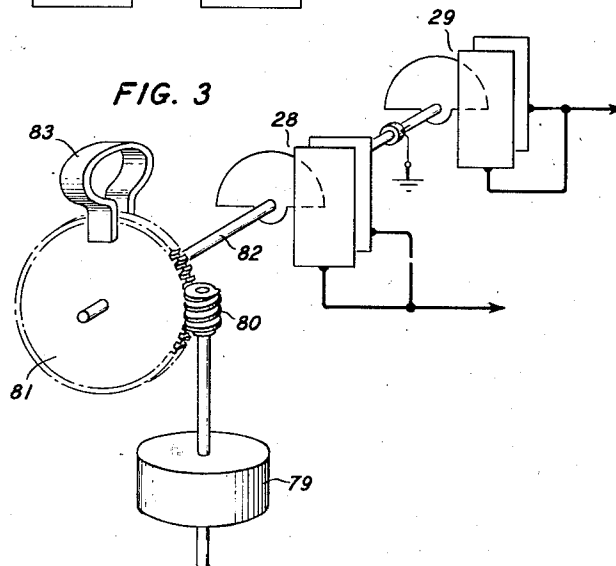


FIG. 3



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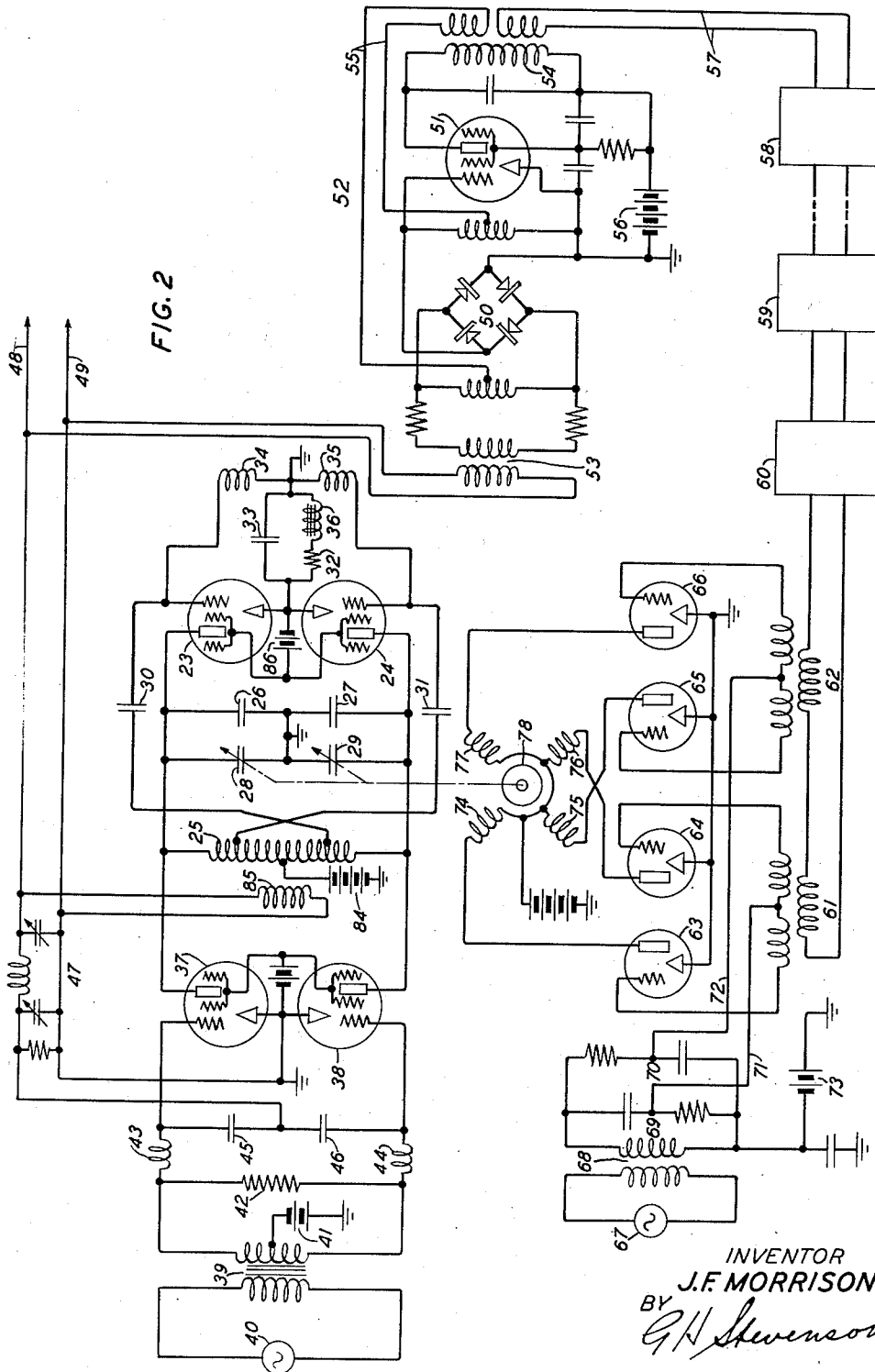
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2 Sheets-Sheet 2



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FREQUENCY REGULATION

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8 Claims. (Cl. 179—171.5)

This invention relates to frequency modulation systems and more particularly to arrangements for controlling the frequency of carrier wave generators in frequency modulation transmitters.

Objects of the invention are to prevent drifting of the mean frequency of a frequency modulated carrier wave; to maintain the mean frequency of a frequency modulated carrier wave at an assigned value within close limits; to control the mean frequency of a carrier wave oscillator, the frequency of which is varied through a wide range by a modulating signal; and to effect the mean frequency control continuously during the occurrence of frequency modulation.

One method of accomplishing frequency modulation of a carrier wave which has been found to be practicable and efficient consists in applying the signal currents to vary the tuning of the frequency determining circuit in a vacuum tube oscillator. This method permits frequency variations of large amplitudes linearly related to the signal voltages to be obtained without difficulty, but it is subject to the disadvantage that oscillators of the types that can be modulated by the signal currents to produce wide frequency swings are likely to be sensitive to other influences also. Drifting of the mean frequency of the oscillation is therefore likely to occur and some auxiliary control arrangement becomes necessary to hold the carrier wave within its assigned frequency limits.

In accordance with the invention control of a frequency modulated carrier wave is accomplished by synchronizing the mean or central frequency of a subharmonic oscillation with a low frequency master oscillation, the frequency of which is held accurately constant. The subharmonic oscillation, which may be obtained from the modulated carrier by frequency division or other equivalent process, is beat with the fixed reference oscillation and the resulting beat current of the difference frequency is applied to control the carrier oscillation frequency in such sense as to reduce the beat frequency towards zero. Since the subharmonic oscillation and, therefore, the beat current will be modulated in frequency in the same manner as the carrier wave, the frequency variations of the beat current corresponding to the signal would tend to influence the control of the carrier oscillation and thus to vitiate the regulation of the mean frequency. This difficulty is overcome by the invention by reducing the modulations of the beat current to a point at which any effect they could have upon the control would be unimportant. In addition to this, the

effects of the beat current frequency modulations upon the control are suppressed by the use of suitable filtering means.

The frequency modulation of the subharmonic oscillation takes place at the same rate as the modulation of the carrier wave from which it is derived, but the extent of the frequency deviation is diminished in proportion to the reduction of the frequency. In accordance with the invention the frequency reduction is carried sufficiently far so that the amplitude of the modulation is reduced to a value less than the lowest important frequency of the modulating signal. Under this condition the modulation of the subharmonic oscillation, and also of the beat current, appears principally as a small phase libration, the amplitude of which is substantially less than one radian and is generally of the order of a few degrees. On the other hand the phase shift of the beat current due to a gradual shift of the carrier from its assigned frequency is cumulative and reaches a substantial value in a short interval of time. By making the adjustment of the carrier responsive to this cumulative phase shift the possible effect of the rapid superimposed fluctuations becomes relatively unimportant. A substantial suppression of the action of the superimposed fluctuations in the control of the carrier wave is effected by the use of a filter included in the control means so proportioned as to discriminate against rapid variations and to permit only those variations to actuate the control which occur at rates substantially lower than the lowest signal frequency.

In the preferred form of the invention the master oscillation and the subharmonic of the carrier are beat together in such manner as to produce two-phase beat currents. These are applied to drive a synchronous alternating current motor which in turn effects a mechanical adjustment of a frequency controlling element in the carrier wave generator. So long as the two waves remain in synchronism the armature of the motor will not rotate although it may tend to oscillate to a slight extent about its steady position in response to the rapid phase fluctuations of the beat current. If the mean value of the carrier frequency should drift away from synchronism, the motor armature will rotate in a direction depending on the sense of the drift and by an amount proportional to the cumulative phase shift produced by the drift. The rotation of the motor adjusts the carrier generator control element in such direction as to compensate the drift and to bring about a correction of the mean

frequency. Suppression of the effects of the rapid fluctuations of the phase is provided by mechanically filtering the rotational motion of the motor so that only the slow variations representative of changes in the mean carrier frequency are transmitted to the frequency controlling element. For most purposes sufficient filtering is provided by the inertia and friction of the mechanical moving parts but additional filtering means of known types may be used if necessary.

These and other features of the invention are described more fully in the detailed specification which follows and are illustrated by the accompanying drawings, of which:

Fig. 1 is a block schematic of the system of the invention;

Fig. 2 shows the principal features of the circuit arrangement in one embodiment of the invention; and

Fig. 3 is a schematic showing in perspective one form of the mechanical control device used in the invention.

Referring to Fig. 1, 10 is a carrier wave generator which preferably consists of a vacuum tube oscillator, the frequency of which is determined by a tuned circuit. A signal source 11 furnishes telephone signal currents to a modulator 12 by means of which the oscillation frequency of the generator 10 is varied in accordance with the signal. The complete modulation system comprises the oscillator 10, modulator 12, and a phase shifting means 13 which delivers to the modulator a voltage in quadrature to the voltage across the tuned circuit of the oscillator. The modulation method used is preferably that disclosed in U. S. Patent 2,076,264, April 6, 1937, to Chireix et al. or some modification thereof such as is shown in French Patent 840,443, published April 26, 1939. From the output of the oscillator the modulated currents are applied to a frequency multiplier 14 and from thence to a power amplifier 15 and an antenna 16.

For the purpose of frequency control, part of the output current from the oscillator 10 is delivered to a frequency divider 17 from the output of which a low frequency subharmonic is impressed upon modulator 18. Currents of fixed frequency from a master oscillator 19 are supplied through a second frequency divider 20 to the modulator 18 from the output of which the difference frequency beat current is applied to a synchronous alternating current motor 21. The armature of motor 21 is mechanically coupled to a frequency controlling element in oscillator 10 through a mechanical filter and gearing 22.

The modulator 18 is preferably of a type adapted to produce two-phase beat currents and may, for example, be arranged as shown in U. S. Patent 1,762,725, June 10, 1930, to W. A. Marri-
son. The frequency divider 17 should be capable of producing a submultiple frequency of a very low order and may comprise a series of dividers of the type shown in U. S. Patent 2,159,595, May 23, 1939, to R. L. Miller. The fixed reference frequency which is applied to the modulator 18 is shown in Fig. 1 as being derived by frequency division from a higher frequency master oscillation, but this step of frequency division may be omitted where a stable oscillation of the desired low frequency is available.

The operation of the system will be described with reference to a particular example illustrative of the application of the invention in a frequency modulated transmitter designed for op-

eration at a frequency of about 40 megacycles. Oscillator 10 generates a carrier wave at a relatively high frequency such that only a small amount of multiplication is needed to raise the frequency to the desired radiation level. It will be assumed that the oscillator frequency has a normal value of 5,120 kilocycles per second which is multiplied eight times to provide a radiation frequency of 40,960 kilocycles per second. Generation at this relatively high level simplifies the selection of the desired harmonics in the subsequent steps of frequency multiplication and avoids any difficulties from the transmission of undesired harmonics through the system. The maximum frequency swing of the radiated wave due to the signal modulation will be taken as 100 kilocycles per second above and below the normal carrier frequency. This corresponds to a deviation of 12.5 kilocycles in the oscillator frequency, which can be obtained readily by the modulation method.

The modulation of the subharmonic obtained from the output of frequency divider 17 should have an amplitude less than the lowest significant frequency of the speech signals, which may be taken at about 60 cycles per second. To insure this low degree of modulation the divider 17 is arranged to develop a subharmonic which is the 1024th part of the carrier frequency or 5,000 cycles per second. This may be accomplished by the use of ten dividers in tandem, each of which reduces the frequency by one-half. For the maximum initial modulation of 12,500 cycles per second the diminished modulation of the subharmonic frequency will be only about 12.5 cycles per second. Assuming that all of this modulation can be produced by the lowest speech frequency of 60 cycles per second, the phase change which accompanies the frequency modulation will amount at most to only 12 degrees. The master oscillator 19 and frequency divider 20 are arranged to deliver a fixed frequency of 5,000 cycles per second. For this purpose the oscillator may comprise a crystal controlled vacuum tube oscillator operating at 80 kilocycles and the frequency divider may be arranged to derive the 16th subharmonic of the master oscillation.

If the subharmonic of the modulated carrier wave remains in synchronism with the 5,000 cycle master oscillation with respect to its mean frequency, the beat current impressed on motor 21 will have zero frequency but will be subject to an alternating phase shift of about 12 degrees or less occurring at a voice frequency rate. No continuous rotation of the motor will result but some slight rapid oscillation may take place because of the phase librations. These, however, are suppressed by the inertia and friction of the motor and the connected mechanical parts. In the event of the carrier oscillator drifting slightly in frequency from its assigned value the motor 21 will rotate at a rate determined by the finite value of the beat frequency and in a direction depending on the sense of the carrier wave deviation. This rotation will be transmitted to the control element of the oscillator which may consist of a small variable condenser included in the tuned circuit and will bring about an adjustment of the oscillator frequency in such a direction as to correct the deviation.

The effectiveness of the frequency division of the carrier wave in reducing the action of the signal modulations on the control system may be

illustrated also by a comparison of the spectra of the frequency modulated carrier wave and the subharmonic oscillation. The modulation of the carrier wave is produced by signal currents of all frequencies in the range of the telephonic signal, but in the case of speech or musical signals, the components of greatest amplitudes and, therefore, those that produce the greatest modulation swings are generally the lower frequency components in the range around 300 cycles per second. The extent of the modulation may therefore be as great as forty times the frequency of the signal producing it and in general will be very large compared with the signal frequency.

The character of the spectrum of a frequency modulated wave is described by Van der Pol in an article entitled Frequency Modulation published in the Proceedings of the Institute of Radio Engineers, July 1930. There it is shown that when the modulation swing is large compared with the rate of modulation, the spectrum of the wave consists of a multiplicity of side-bands, or side frequencies in the case of modulation by a simple tone, extending symmetrically to each side of the normal carrier frequency and accompanied by only a vestigial component of the normal carrier frequency. Selection of the mean frequency component becomes manifestly impracticable under such conditions. However, when the modulation swing is reduced, as the result of frequency division, to an amplitude less than the lowest signal frequency, the character of the spectrum is greatly altered. It then consists of a strong mean frequency component accompanied by only two side-band components, upper and lower, the amplitudes of which are relatively very small. The enhancement of the mean frequency component renders it readily available for synchronizing purposes and the reduction of the side frequency components makes their effect on the control small and easily suppressed.

Referring to Fig. 2, which shows the circuit arrangements in detail, the carrier oscillator comprises two vacuum tubes 23 and 24 and a frequency determining circuit made up of inductance 25, a pair of principal tuning condensers 26 and 27 of equal capacity and a pair of variable condensers 28 and 29 also of equal capacity. The center points of the tuning condenser are connected together and grounded. Vacuum tubes 23 and 24 are preferably of the screen-grid pentode type, the screens being polarized by the source of potential 86 and the plates by the source of potential 84 connected to the mid-point of inductance 25. The oscillator is of the push-pull type, the feedback from the plates to the grids being provided by condensers 30 and 31 which are connected to symmetrical points in inductance 25. The grids of the vacuum tubes are self biased by resistance 32 connected in the cathode lead and shunted by radio frequency by-pass condenser 33. Radio frequency choke coils 34 and 35 provide circuits for impressing the bias potential developed in resistance 32 on the vacuum tube grids. Choke coil 36 included in series with the resistance 32 develops across its terminals a voltage proportional to any fluctuations which may take place at the signal frequency rates in the plate currents of the vacuum tubes. These voltage fluctuations are impressed upon the grids in like phase and in such sense as to produce a negative feedback and so diminish the fluctuations. By this means amplitude modulation of the oscillations is substantially eliminated.

Modulation of the oscillation frequency is ef-

fectured by means of control tubes 37 and 38, the plates of which are connected in push-pull across the terminals of the tuning inductance 25 and the grids of which are connected likewise in push-pull through transformer 39 to a signal source 40. A negative bias voltage for the grids is provided by a source of potential 41 which is connected to the mid-point of the secondary winding of transformer 39. The input circuit includes also a resistor 42 connected across the transformer secondary, radio frequency choke coils 43 and 44 and radio frequency by-pass condensers 45 and 46. A coupling between the oscillator tuned circuit and the grids of the control tubes is provided by means of a coil 85 coupled loosely by mutual inductance to the tuning coil of the oscillator and connected through a phase shifting network 47 to the cathodes of the control tubes and the mid-point connection of condensers 45 and 46. The network 47 comprises a series inductance and a pair of variable shunt capacities which are adjusted to produce at the input terminals of the control tubes a radio frequency voltage exactly in quadrature with the voltage across the oscillator tuning coil.

Coupling coil 85 furnishes current also to output leads 48 and 49 which are connected to the frequency multiplier 14 and the power multiplier 15 of Fig. 1. A branch connection from these leads diverts part of the current to the frequency divider system, one unit of which is shown in detail at 52. This unit is of the type disclosed in Patent 2,159,595 of May 23, 1939 to R. L. Miller and comprises a vacuum tube 51, a bridge network 50 of copper-oxide rectifiers, an input transformer 53, a tuned output circuit 54 and a feedback circuit 55 coupled to the inductance of the tuned circuit 54 and to the terminals of the copper-oxide bridge through a pair of bridging inductances. Plate current to the vacuum tube is furnished by a potential source 56. For a detailed description of the operation of this device reference is made to the above-mentioned Miller patent. In the present system the divider is arranged to reduce the output frequency to one-half the input frequency, the tuned circuit 54 being tuned to the reduced frequency. From the output of the first stage of the divider a circuit 57 leads to nine additional stages connected in tandem, three of which are indicated at 58, 59 and 60. The final oscillation from the output of the last stage of the frequency divider is impressed upon the input circuits of two balanced modulators through transformers 61 and 62. The balanced modulators, which correspond to the device 18 in Fig. 1, comprise four vacuum tubes 63, 64, 65 and 66 connected together in pairs with their cathodes grounded. The secondary winding of transformer 61 is connected to the grids of tubes 63 and 64 in push-pull relation and the secondary winding of transformer 62 is similarly connected to the grids of tubes 65 and 66. A master frequency oscillation source 67 also furnishes potentials to the modulator grids. The connection comprises a transformer 68 to the secondary winding of which are connected two phase-splitting networks 69 and 70 each comprising a resistance and a capacity in series. The potential across the resistance of network 69 is transmitted to the grids of tubes 63 and 64 in like phase through conductor 71 which is connected to the mid-point of the secondary winding of transformer 61. Similarly, the quadrature potential across the capacity of network 70 is impressed on the grids of tubes 65 and 66 in like

phase through conductor 72 and the secondary winding of the transformer 62. The bias voltage for the grids of the modulator tubes is furnished through conductors 71 and 72 from source 73. The plates of the four modulator tubes are connected respectively to windings 74, 75, 76 and 77 of an alternating current motor 78, the armature of which is mechanically linked as indicated by the dotted lines to the variable condensers 28 and 29 in the oscillator tuned circuit. The motor 78 may be of the type shown in Patent 1,959,449, May 22, 1934 to H. M. Stoller.

The general principles of the modulator circuit are described in the above-mentioned Patent 2,076,264 to Chireix et al. Briefly, the action of the control tubes and the feedback connection established through phase shifting network 47 is to vary the effective inductance of the coil 25 by a small amount proportional to the amplitude of the signal currents and at the rate of the signal frequency. In this way the tuning of the oscillator circuit is varied, thereby producing modulations of the oscillator frequency in accordance with the signals. The use of two control tubes connected in push-pull which is described in the above-noted French Patent 840,443, has the advantage of giving an improved degree of linearity to the modulation of the high frequency currents. The arrangement has the further advantage that variations of the grid bias voltage have little effect on the frequency of the oscillator, since the principal effect is obtained when the two grid voltages are varied in opposite senses.

It will be noted that the control of the oscillator frequency by motor 78 is accomplished by the adjustment of condensers 28 and 29 whereas the signal modulation is accomplished by an effective variation of inductance 25. The two controls are independent of each other, which arrangement has the advantage that the drift control does not disturb the condition of the circuit with respect to modulation by the signal currents.

The connection between the motor and the adjustable condensers 28 and 29 is illustrated in Fig. 3. The motor armature 79 is connected through a worm 80 and gear 81 to a shaft 82 on which are mounted the variable elements of condensers 28 and 29. The armature 79 has a considerable amount of inertia and this is augmented by the inertia of the gear 81 and the plates of condensers 28 and 29, the effect of which is amplified by the gear reduction ratio. This inertia together with the friction of the gear and the bearings is generally adequate to provide substantial suppression of any rapid oscillations transmitted to the motor armature. Additional suppression may be had if necessary by increasing the damping of the system which may be accomplished by the use of an eddy-current damper comprising a permanent magnet 83 surrounding the gear wheel 81. In addition to this the motor shaft may be made sufficiently flexible torsionally to provide a spring coupling between the motor and the drive or if need be the shaft may be divided and a spring coupling inserted between the two parts.

What is claimed is:

1. The method of regulating the average frequency of a frequency modulated carrier wave oscillator which comprises producing from the modulated carrier wave by frequency division a subharmonic oscillation having diminished frequency modulation and a mean frequency such that the side-bands of higher order than the first representing the diminished modulation are sub-

stantially suppressed, beating the subharmonic oscillation with oscillations of fixed frequency to produce a beat current of the difference frequency, and controlling the frequency of the carrier wave in accordance with the mean frequency of the beat oscillation in such sense as to diminish the beat oscillation frequency.

2. The method of regulating the mean frequency of a frequency modulated carrier wave which consists in deriving from the carrier wave a subharmonic oscillation of such low frequency that the diminished frequency modulation has an amplitude less than the lowest frequency of the signal producing the modulation, and regulating the frequency of the carrier wave in accordance with slow variations of the mean frequency of the subharmonic oscillation from an assigned value.

3. The method of controlling the mean frequency of a carrier wave the frequency of which is modulated in accordance with a telephonic signal, comprising the steps of deriving by frequency division of the modulated carrier wave an oscillation of an integral submultiple frequency of such low value that the phase librations corresponding to the diminished frequency modulation of the submultiple oscillation are substantially less than one radian, modulating the submultiple oscillation with oscillations of a fixed frequency equal to the desired mean frequency of the submultiple oscillations to produce a beat oscillation of the difference frequency, controlling the frequency of the carrier wave in accordance with the mean frequency of the beat oscillation, and suppressing the effect upon the control operation of variations of the beat oscillation frequency occurring at the signal rate.

4. The method of controlling the mean frequency of a carrier wave the frequency of which is modulated in accordance with a telephonic signal, comprising the steps of deriving by frequency division of the modulated carrier wave an oscillation of an integral submultiple frequency, the phase librations of which, corresponding to the diminished frequency modulation are substantially less than one radian, beating the submultiple oscillation with oscillations of a fixed frequency equal to the desired mean frequency of the said submultiple oscillations to produce a beat oscillation of the difference frequency, and controlling the frequency of the carrier wave in accordance with the mean frequency of the beat oscillation.

5. The method of controlling the mean frequency of a carrier wave the frequency of which is modulated in accordance with a telephonic signal, comprising the steps of producing under the control of the carrier wave an oscillation having a frequency which is a fixed fraction of the carrier wave frequency small enough so that the phase librations corresponding to the diminished frequency modulation of the fractional oscillation are substantially less than one radian, modulating the reduced frequency oscillation with oscillations of a fixed frequency equal to the desired mean frequency of the said reduced frequency oscillation to produce a beat current of the difference frequency, and controlling the carrier wave frequency in accordance with the mean frequency of said beat current in such sense as to diminish the frequency of the beat current.

6. The method of controlling the mean frequency of a carrier wave oscillator the frequency of which is modulated in accordance with a tele-

phone signal, comprising the steps of deriving by frequency division of the modulated wave an oscillation having an integral submultiple frequency of such low value that the phase librations corresponding to the diminished frequency modulation of the multiple oscillation are substantially less than one radian, modulating the submultiple oscillation with oscillations of a fixed frequency to produce a plurality of beat currents of the difference frequency displaced in phase with respect to each other, producing a rotating magnetic field by said beat currents, controlling the frequency of the carrier oscillator in accordance with the rotation of the magnetic field and in such sense as to diminish the frequency of the said beat currents, and suppressing the effect upon the control operation of velocity variations of the rotating field occurring at the signal rate.

7. In a frequency modulation transmitter comprising a carrier oscillation generator, a source of telephone signals, and means for modulating the frequency of the carrier oscillations in accordance with signals from said source, means for controlling the average frequency of the carrier oscillations comprising frequency dividing means for deriving from the modulated carrier wave a subharmonic oscillation of frequency low enough relative to the carrier frequency so that its diminished frequency modulations have amplitudes less than the lowest frequency of the signal, a source of fixed frequency oscillations of frequency equal to the desired mean frequency of the subharmonic oscillations, means for combining the oscillations

of said fixed frequency and the said subharmonic oscillations to produce beat oscillations of the difference frequency, means actuated by said beat oscillations to vary the frequency of the carrier oscillator generator in such sense as to reduce the beat oscillation frequency, and means for suppressing the effect upon said frequency varying means of frequency modulations of the beat current occurring at the signal rate.

8. In a frequency modulation transmitter comprising a carrier oscillation generator, a source of telephone signals, and means for modulating the frequency of the carrier oscillations in accordance with the signals from said source, means for regulating the average frequency of the carrier oscillations comprising means for producing under the control of the modulated carrier wave an oscillation having a frequency which is a fixed fraction of the carrier wave frequency small enough so that the phase librations corresponding to the diminished frequency modulation of the reduced frequency wave are substantially less than one radian, a source of fixed frequency oscillations, a modulating device, circuits for impressing said reduced frequency oscillations and said fixed frequency oscillations on said device to produce beat oscillations of the difference frequency, and means responsive to the average frequency of said beat oscillations for varying the frequency of said carrier generator in such sense as to diminish the beat oscillation frequency.

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