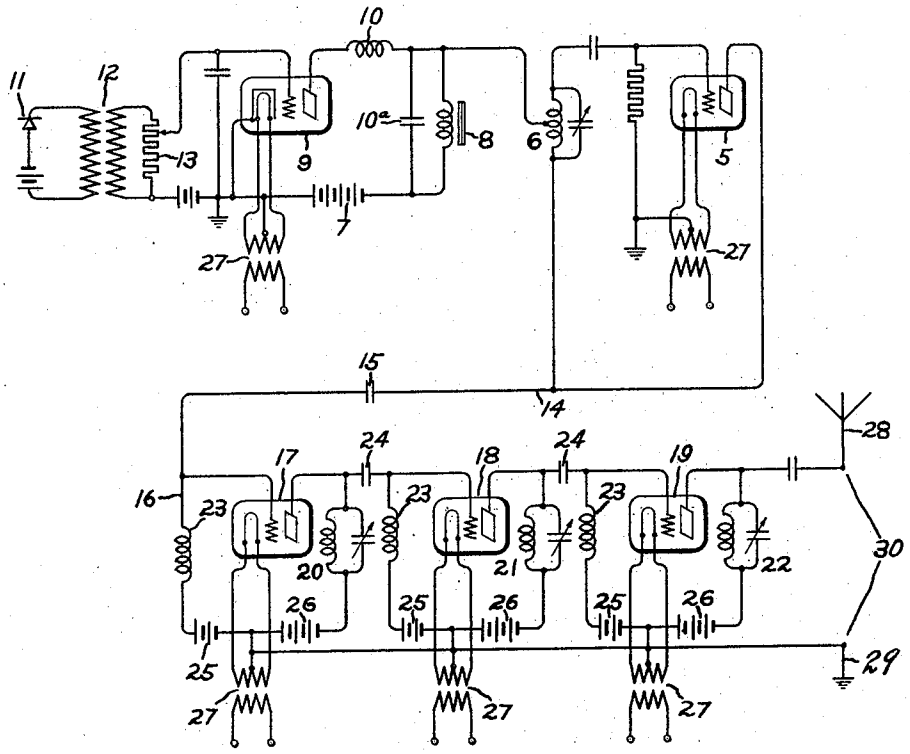
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FREQUENCY MODULATION

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FREQUENCY MODULATION

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My invention relates to the transmission of radio signals by frequency modulation of a carrier wave as distinguished from the amplitude modulation of a carrier wave which is generally used in present broadcasting systems. As is well understood, frequency modulation is a term applied to modulation which is effected by changing the carrier frequency of a radio transmitter at the rate of the modulation frequency and in a degree according to the amplitude of the modulation supplied.

In accomplishing frequency modulation, a modulated oscillator may be employed with practically any form of oscillator circuit but the difficulty lies in determining the method of modulating the oscillator and in preventing certain undesirable operating characteristics in the transmitting apparatus employed in conjunction with the oscillator.

For example, it has been found that with frequency modulation, amplitude modulation is present in the output of the oscillator and that the amplitude modulation superimposed upon the frequency modulation in a power amplifier following the oscillator, causes the amplifier tubes to overload and subjects the tuning system, particularly the tuning condensers associated with the amplifier tubes, to high stresses which often result in flashovers when the amplifier is over modulated. In frequency modulation systems heretofore, it has been customary to operate the amplifiers at lower power outputs so that peaks in the modulation would not cause the oscillator circuits to reach undesirable operating conditions such as those above mentioned.

It is obviously undesirable to operate a power amplifier in connection with a frequency modulation system at a lower power output, and it is also undesirable to transmit a frequency modulated signal in which amplitude modulation or other undesirable modulation effects are present as such effects have a tendency to reduce the quality of the received signals.

There are several methods for accomplishing frequency modulation, among which are mechanical methods involving vibrating electrostatic plates or variable inductors in connection with an oscillator circuit, the output from which circuit usually has a poor frequency characteristic because of mechanical resonance in the initial control means. Other methods involve various known electrical means for effecting frequency modulation but such systems have been found to involve oscillation voltages of extremely high value in the oscillator circuits and considerable amplitude modulation, thus affecting the frequency characteristic or quality as with the mechanical methods above mentioned.

Accordingly, it is the object of my invention to provide an improved method, and means for carrying out the method, whereby frequency modulated signals of high quality, without appreciable amplitude modulation or other undesirable characteristics may be produced, and whereby a radio transmitter may be operated at its normal or full power level with frequency modulation without endangering any of the apparatus in the transmitter and associated circuits.

In carrying out my invention several possible methods of changing the frequency of an oscillator may be employed but the method of varying the plate voltage has been found to be most satisfactory. The system of the present invention is, however, intended to be and is adapted for direct application to the control of any transmitter, whereby it may be adapted to operate with frequency modulation.

The invention will be better understood from the following description when considered in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing the figure is a schematic wiring diagram of a frequency modulation control apparatus embodying my invention.

Referring to the drawing, 5 is an oscillator tube or master oscillator which is tuned to produce a desired carrier frequency by a tuned or tank circuit 6 connected with its anode and grid in a well known manner, and which receives its anode current from a suitable source of supply 7 through a choke coil or impedance 8 in series with which impedance is connected also the anode circuit of a modulator 9. The anode circuit of the modulator tube is provided with a radio frequency choke coil 10, and with a suitable bypass capacitor 10*a* in shunt with impedance 8.

The modulator tube is controlled by any suitable input means, such as a microphone 11 connected with its grid circuit, through a suitable input transformer 12 which in turn is provided with a volume control resistor 13 interposed between the transformer second-

ary and the grid of the modulator tube. With this arrangement, when modulation signals are applied to the modulator tube through the medium of the microphone or input means, the plate voltage of the oscillator tube 5 is varied through the medium of the choke coil 8 which is in series with the anode circuit of the modulator tube as well as that of the oscillator. There are of course, several methods for changing the frequency of a master oscillator. For obvious reasons it is desirable to avoid mechanical methods as hereinbefore mentioned. This is especially true when certain electrical methods are found which are easily applied.

The method used in the present example is that of varying the plate voltage. This is a very simple and effective method since it involves merely plate modulating the oscillator with another tube in a conventional circuit which is substantially that shown in the drawing and above described. Results obtained from experiments indicate no limit to the frequency which can be used for modulation. For example, a frequency of 20,000 cycles may be used for modulation without difficulty.

The frequency of any vacuum tube oscillator is a function of the plate voltage and may be expressed as $f=\phi E$ where f represents the frequency of the oscillator, E represents the plate voltage and ϕ is a constant. If we vary the plate voltage from a particular value E_1 to a different value E_2 the frequency will, of course, be varied between the corresponding values f_1 and f_2, or over a range F where F is the difference between the two latter frequencies. Thus this range of variation may be expressed as follows:

$$F=\int_{\phi E_1}^{\phi E_2} d(\phi E)$$

If this change F takes place in time T, a frequency is produced which is the tone or character of the signal. Therefore it is merely necessary to vary the plate voltage of a vacuum tube oscillator, the amplitude or amount of the variation determining the tone amplitude and the rate of variation corresponding to the tone frequency. The first effects a variable frequency from the oscillator, while the second effects the necessary rate of variation in the carrier frequency. This can be accomplished as shown in the drawing and above described by the use of an impedance in series with the plate voltage to the oscillator. A variable voltage at the modulation frequency is set up across this impedance by the modulator tube and the fixed frequency of the oscillator 5 as determined by the tank circuit 6 is varied at the modulation frequency. Unfortunately, these variations in voltage produce a variation in the amplitude as well as the frequency of the oscillator output and it is the purpose of the following described means to smooth out this second class of variations.

It has been found that the reduction or removal of amplitude modulation and similar effects may be accomplished by employing a cascade arrangement of frequency multipliers. The amplitude modulation produces side bands $R-A$ and $R+A$ in which R is the signal frequency and A is the modulation frequency. Now if, for example, the 32nd harmonic is considered, then $R'-32A$, and $R'+32A$ are the extremes of the said band frequencies. This means a modulation frequency of 1000 cycles originally becomes 32,000 cycles, or beyond audibility and being above audibility tends to remove amplitude effects. The frequency modulation is unaffected however for instead of F we have 32F but this variation occurs in the same time as F occurred, so that the tone frequency is unchanged and no distortion is introduced. If the multipliers are then saturated in operation the amplitude variations are removed, or flattened, to a common level, but the frequency modulation is unaffected, since it is a function of time and frequency variation only.

Accordingly, the output from the oscillator tube is taken at 14 in the present example through a suitable coupling means such as a coupling condenser 15 and applied to the input circuit 16 of a cascade amplifier and multiplier embodying amplifier and multiplier tubes 17, 18 and 19 representing any suitable number of amplifier and multiplier tubes for carrying the amplification and multiplication to the desired degree. The amplifier is provided with a series of tuned circuits 20, 21 and 22 tuned to a harmonic of a preceding circuit which in the present example are the grid circuits, the anode circuits being the tuned circuits. Each grid circuit is provided with a choke coil 23 which is coupled with a tuned circuit by a coupling condenser 24. In the case of the input tube this choke is coupled with the oscillator through condenser 15.

The amplifier tubes are all biased to operate above the knee of the plate current-grid voltage characteristic curve, that is, to carry the anode or plate current beyond the knee of the plate-current grid-voltage characteristic curve by suitable bias means represented by batteries 25, and are provided with anode voltage from suitable means, represented by batteries 26. Alternating current filament supply means is indicated throughout the apparatus by filament transformers 27.

As above explained, by operating the amplifier tubes above the knee of the plate-current grid-voltage characteristic curve and by employing tuned circuits between the amplifier tubes, each circuit being tuned to a har-

monic frequency of a preceding circuit, the amplitude modulation produced in the oscillator 5 and delivered to the input circuit 16 of the amplifier is removed. In the present three stage amplifier the frequency output is eight times the frequency input. The frequency modulation effect however, is not changed since the amplitude of the frequency variations is the amplitude of the tone or signal and the rate at which the frequency is varied provides the tone or character of the signal.

The signal, with the amplitude modulation removed, has less tendency to overload the amplifier since the amplitude modulation and its corresponding effect upon the peak voltages in the amplifier circuits is removed. The resulting signal supplied by the amplifier may be transmitted without further amplification or may be applied to a transmitter for further amplification and transmission. In the present example, however, it is indicated as being transmitted directly through the medium of an antenna 28 and ground connection 29 applied to the output terminals 30 of the amplifier.

In the operation of a frequency modulation means substantially as shown in the drawing, the plate voltage has been varied over a wide range and the beat note of the received signal checked against an audio oscillator for change in frequency. The frequency of the beat note was found to be proportional to the plate voltage and to vary rectilinearly therewith.

From the foregoing description it will be seen that the method of the present invention consists essentially in changing the frequency of a master oscillator at a frequency f_0, and then by suitable harmonic frequency multipliers, raising the frequency to a value desired for radiation for communication requirements. The final frequency is, of course, nf_0, where n=the final harmonic of f_0.

Now if f_0 is changed by frequency modulation, to say (f_0+f_1), the nth harmonic will be, then, $n(f_0+f_1)$. Thus the effective change at the higher frequency will be $n(f_0+f_1)-nf_0=nf$.

A practical example of the above is here given:

Let master frequency, f_0	=50 kc.
Let harmonic frequency, nf_0	=5000 kc.
Where n	=100
Now let f_1 be as low as	=200 cycles
Then f_1+f_0	=50.2 kc.
And $n(f_1+f_0)$	=5020 kc.
When Δf_1 at 5000 kc.	=20,000 cycles

Thus it is shown how a very large change in frequency is made possible at some high frequency by shifting a lower sub-frequency only a few cycles. Another advantage of using the lower frequency as a master is that the final carrier has a very good tone when heterodyned with an oscillating receiver tube. The tone is found to be a close approach to that of crystal controlled transmitters.

To summarize the foregoing, a modulator tube is connected to control an oscillator tube the frequency of which is set at a constant value and controlled by a tank circuit in the grid and plate circuits. The oscillator is frequency modulated by means controlling its plate voltage, that is, it is plate modulated. Output energy frequency modulated by voice frequencies or by a suitable tone frequency through said means is applied to an amplifier and multiplier with means provided for operating above the knee of the plate current grid voltage characteristic curve and embodying tuned inter-stage circuits, each tuned to a higher harmonic frequency than the preceding circuit. By this arrangement the amplitude modulation is removed not only by the saturation characteristic of the amplifier but also because the side band frequencies are raised above audibility.

The entire system, then, may be said to have three components. The first is the means for varying the frequency, the second is the master oscillator whose frequency undergoes variation, and the third is the frequency multiplier chain which reduces amplitude modulation effects to a minimum.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a frequency modulation system, the combination of a master oscillator, means for adjusting the output frequency of said oscillator to a predetermined value, means for applying a signal to the oscillator to vary the output frequency thereof in accordance with the amplitude of the signal and produce a frequency modulated output which is modulated at a rate which is dependent upon the frequency of the applied signal, and a frequency multiplying means connected with the oscillator for receiving the output therefrom, said means including a series of cascade connected electric discharge devices and a tuned circuit associated with each of said devices, each of said circuits being tuned to a higher harmonic of the frequency to which a preceding circuit is tuned, and one or more of the electric discharge devices being excited with oscillations from the previous discharge device of such value that it operates in a region above the knee of the anode current grid voltage curve whereby any amplitude modulation produced during frequency modulation of said oscillator is suppressed and the tuned circuit associated with the last of said discharged devices being tuned to a harmonic frequency so high that side band frequencies produced by amplitude modulation are displaced from the carrier frequency in the frequency spectrum by an amount greater than the audio range.

2. In combination, a source of constant frequency oscillations including an electric discharge device having an anode circuit, means for providing a variable signal frequency, means for modulating said constant frequency by said variable signal frequency including an electric discharge device having a grid circuit connected with said first named means, an anode circuit for said second named device and an impedance in a portion of said anode circuit which is common with the first named anode circuit, an amplifier connected with said constant frequency producing means for receiving the modulated output therefrom, said amplifier including a series of cascade connected electric discharge amplifier devices arranged to have an operating range wherein amplitude modulation is suppressed, and including a series of tuned circuits interposed between said devices, said circuits being each responsive to one of a series of harmonic frequencies of the output frequency from said source, whereby side-band frequencies due to amplitude modulation are displaced in the frequency spectrum from the carrier frequency by amounts greater than the audio range.

3. In combination, an oscillator including an electric discharge device having grid and anode circuits and a tank circuit connected in said grid and anode circuits for controlling the frequency of the oscillator, a modulator for said oscillator including an electric discharge device having an anode circuit impedance in common with the anode circuit of the oscillator whereby the frequency of the oscillator is controlled by said modulator, and means for amplifying and multiplying the modulated output of the oscillator, said means including a series of electric discharge devices and a series of tuned circuits arranged to provide a cascade connected amplifier, each successive stage of said amplifier being tuned to a higher harmonic frequency than the preceding stage, whereby the output frequency of said amplifier is increased, said amplifier being provided with such a number of said stages that the side band frequencies produced by amplitude modulation of the output are displaced from the output carrier frequency in the frequency spectrum by amounts greater than the audio range.

4. The method of producing frequency modulated signals which comprises generating oscillations at a normally constant lower frequency, varying the frequency of said oscillations from normal in accordance with the amplitude of a signal to be amplified and at a rate which is dependent upon the frequency of the signal, multiplying said modulated lower frequency to a higher frequency of such value that the side band frequencies thereof produced due to variation in amplitude of said oscillations are displaced from the carrier in the frequency spectrum by an amount greater than the audio range and at the same time suppressing the amplitude modulation component of such multiplied lower frequency, and transmitting the resultant signal at the higher frequency.

5. The method of producing frequency modulated signals which comprises generating oscillations at a certain lower frequency, varying the frequency of said oscillations in accordance with the amplitude of a signal and at a rate corresponding to the frequency of said signal, and subsequently suppressing the amplitude modulation component of such modulated signal and raising the frequency of such signal to a higher value at which the side band frequencies produced by amplitude modulation are displaced in the frequency spectrum from the carrier frequency by an amount greater than the audio range.

6. The combination in a frequency modulation system of an oscillation generator including an electron discharge device having an anode circuit, a second electron discharge device having an anode circuit and a grid, an inductance common to both of said anode circuits, means to supply signal electromotive force to said grid of said second discharge device thereby to vary the potential on said inductance whereby the oscillations produced by said oscillation generator are modulated both with respect to amplitude and frequency, and means to multiply the frequency of oscillations produced to such an extent that the side band frequencies produced due to said modulation with respect to amplitude are displaced from the multiplied carrier frequency in the frequency spectrum by an amount greater than the audio range, said means comprising an electron discharge device having an anode, a cathode and a grid, and means to supply to said grid oscillations from said generator, said electron discharge device being arranged to operate above the knee of its anode current grid voltage characteristic thereby to produce oscillations of constant amplitude on said anode notwithstanding variations in amplitude of oscillations supplied to said grid.

In witness whereof, I have hereunto set my hand this 18th day of July, 1929.

ROBERT B. DOME.