New FM
FREQUENCY CONTROL CIRCUIT

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NEW FM FREQUENCY

Frequency modulated systems, particularly frequency modulated broadcast systems, present a number of problems. The system must be capable of modulation, but the center frequency must be accurately maintained. If the system is what is commonly called direct FM, the modulation is produced by varying the constants of the tank circuit of the primary oscillator at an audible rate. The extent of this frequency shift is approximately one tenth of one percent, at an audio frequency that may be as high as 15 kilocycles.

To build an oscillator that is capable of being modulated in this manner, it is necessary to keep the tank circuit capacity low and the inductance high. If a high C circuit is used, the oscillator will be so stable that it will be impossible to modulate it to the extent required, particularly at the higher audio frequencies.

On the other hand, the center frequency of the system must be maintained within approximately one five hundredth of one percent. Using the highest capacity and the lowest inductance practicable in the tank circuit, and using the best temperature compensation technique in building the oscillator, such stability is still not possible. The fact remains, also, that such an oscillator could not be frequency modulated even if it could be built.

Since the required stability can not be built into the oscillator, it becomes necessary to use some automatic frequency control system. There have been several such systems devised in the past, one of which utilized an LC discriminator to maintain the center frequency a fixed number of kilocycles away from a reference frequency which was crystal controlled. Naturally, any drift or mistuning of the discriminator resulted in a corresponding shift of the transmitter center frequency. Another disadvantage was that it was difficult to realize a high control ratio. Control ratios in the order of 15 to 20 were generally used.

An improved system consists of dividing a sample of the oscillator frequency enough times so that the phase shift resulting from the frequency modulation is approximately one radian or less. This frequency, along with two waves in quadrature from a crystal oscillator, are applied to the grids of a pair of mixer tubes. The output of these mixer tubes is the difference between the divided oscillator frequency and the crystal frequency. This output, being two phase, is used to run a synchronous motor which turns the oscillator tuning capacitor in the direction to correct the oscillator frequency. This system presents the usual problems associated with a multiplicity of tuned circuit and moving parts.

Another system, known as indirect FM, uses a crystal oscillator. The output of this oscillator is phase-modulated and subsequently multiplied enough times to obtain the required frequency excursion. In order to end with the correct carrier frequency, this phase modulation must take place at quite low frequencies, which requires carefully shaped band pass multipliers. Also, audio distortion inherent to this system requires that extra precautions be taken to limit it to low values.

All of the above systems have the property of basing the control on the average frequency. If a plot is made of frequency versus time, a line is drawn equal to the frequency without modulation, the areas enclosed by the curve on each side of the line will be equal.

Several systems of frequency control have been suggested which would correct to a different point. One of these would correct to where the total time that the frequency was above the assigned frequency would be equal to the total time that it was below, Fig. 1(A). If the modulation was a pure sine wave, such a system would correct to the assigned frequency. With unsymmetrical modulation, however, some of the sidebands, would often spill over into the adjacent channel. Another system proposed would adjust the frequency so that the maximum excursion above the assigned frequency was equal to the maximum excursion below the assigned frequency, Fig. 2(B). Such a system would keep the sidebands within the assigned frequency spectrum under steady state conditions, even though the wave form of the modulation was not symmetrical. Under transient conditions, such as are encountered with program material where a non-symmetrical waveform may be quickly followed by another non-symmetrical waveform of opposite polarity, there would be considerable spilling over into the adjacent channels if the correction were slow, or unwanted frequencies introduced if the correction were fast enough to minimize the adjacent channel interference.

Fig. 1(C) shows the correction based on the area enclosed on each side of the assigned frequency. If a crystal oscil-

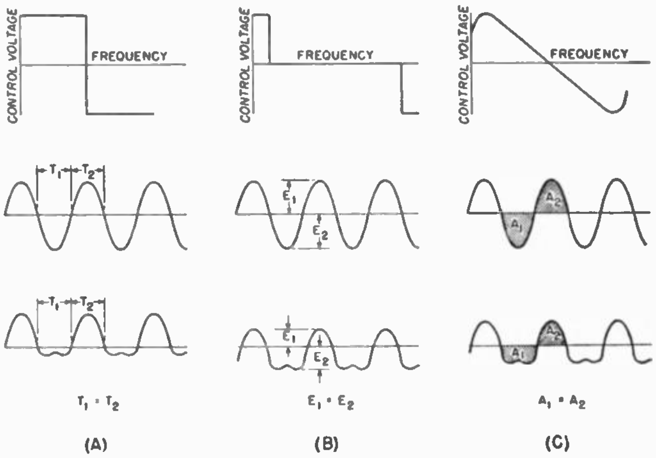

Figure 1. (Drawing 7422431)

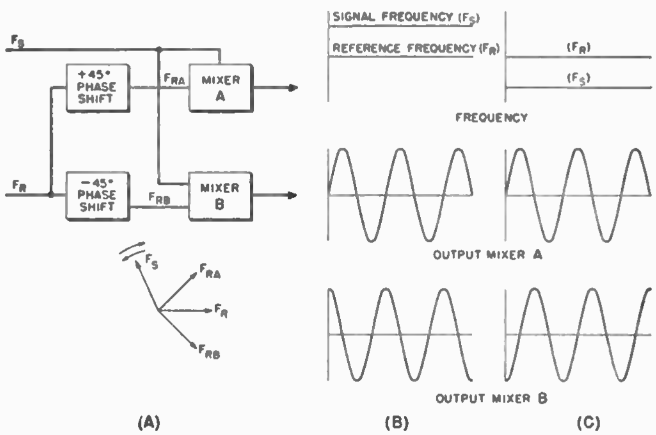

Figure 2. (Drawing 7422432)

CONTROL CIRCUIT

lator is built to operate on the assigned center frequency and mixed with the output of the modulated oscillator into a non-linear impedance, a beat note will be produced which has an instantaneous frequency equal to the instantaneous excursion of the modulated oscillator. The total number of cycles of beat note produced while the oscillator is on one side of the assigned frequency will be exactly proportional to the area enclosed by that part of the curve. It follows, therefore, that if the total number of cycles produced while the oscillator is on the high side of the assigned frequency is equal to the total number of cycles produced while the oscillator is low in frequency, then the transmitter is operating at the correct point.

A new system of frequency control has been developed which takes advantage of this latter fact. Each cycle of beat frequency between the signal frequency and the reference frequency is used to generate a pulse. The pulses are separated into two circuits, one circuit receiving the pulses when the signal frequency is higher than the reference frequency and the other receiving the pulse when the reference frequency is the higher. A pulse counting circuit is so arranged that when a pulse appears on one of these circuits, a definite charge is transferred from a point of fixed potential to a storage capacitor. When a pulse appears on the other circuit, a charge of the same number of coulombs is transferred from the storage capacitor to a point of fixed potential. Since there is no bleeder resistor across the storage capacitor, the charge on the storage capacitor tends to remain constant during any period when there are no pulses. The voltage appearing across the capacitor, which is proportional to the charge stored in it, is used as a control on a reactance tube which controls the frequency of the master oscillator.

Referring to Fig. 2(A), the signal from the modulated oscillator is designated by F_s, and the reference frequency from the crystal oscillator is F_r. This crystal frequency is fed through two 45 degree phase shift networks, each consisting of one resistor and one capacitor of approximately the same number of ohms. One of these networks shifts the phase forward by 45 degrees and the other retards the phase by the same amount. Mixer A and mixer B are used to mix these quadrature voltages with the signal frequency.

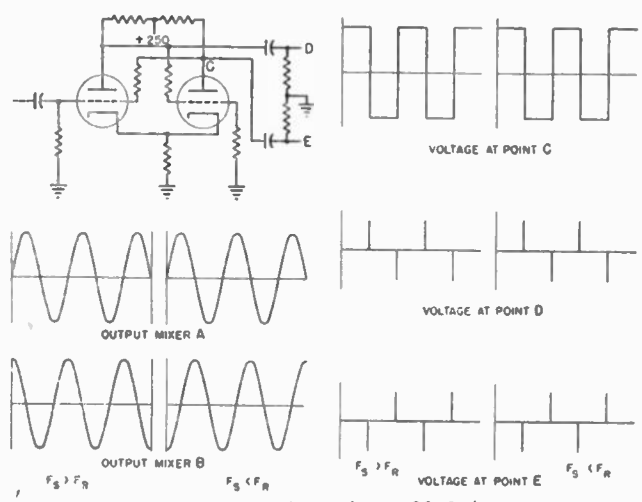

Figure 3. (Drawing 7422433)

Fig. 2(B) shows the relative output of the two mixers when the frequency of the modulated oscillator is higher than that of the crystal. It will be noticed that the output of mixer B leads the output of mixer A by 90 degrees. In Fig. 2(C), the signal frequency is lower than the reference frequency and consequently the output of mixer B lags the output of mixer A.

The output of mixer A is used to trigger a direct coupled multivibrator. This multi serves as an electronic switch to make square waves from the sine wave input. Since the input to the multi is much greater than the amount required to trigger it, the time at which the multi turns over will be approximately the time at which the voltage of the output of a mixer A passes through zero. At this time the output of mixer B is at either a positive or negative peak, Fig. 3.

The voltage on each of the two multi plates is differentiated by a series capacitor and shunt resistor. The resultant two voltages appear as a series of pulses of opposite polarity. Figs. 4A and 4B show the result when these pulses are superimposed on the output of mixer B. It will be noticed

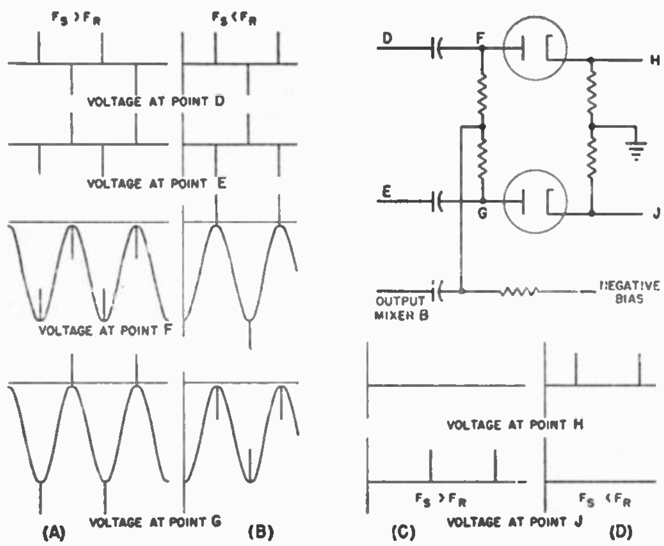

Figure 4. (Drawing 7422434)

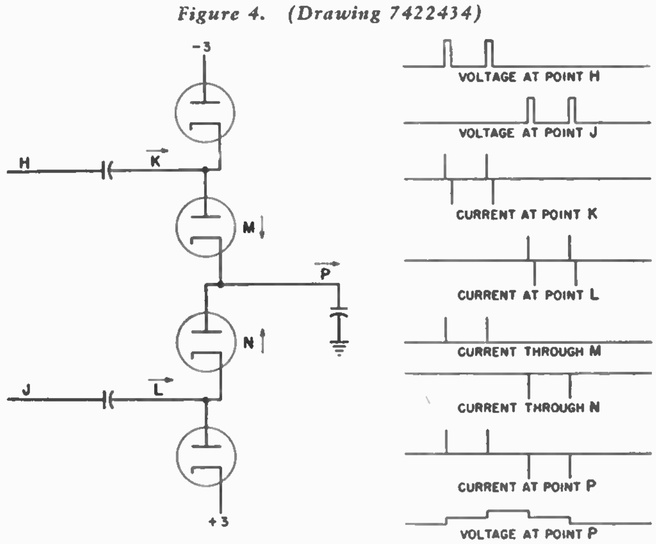

Figure 5. (Drawing 7422435)

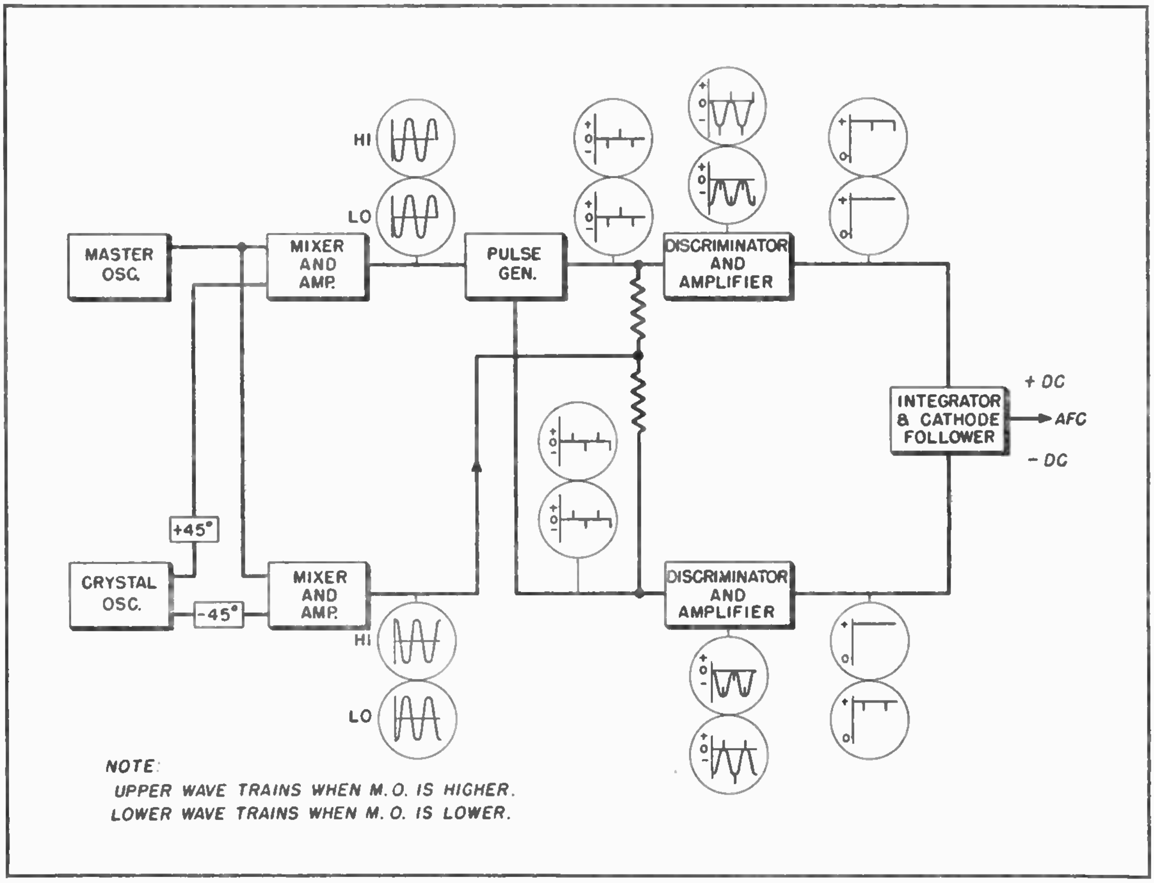

Figure 6. (Drawing 7422436)

that when the pulses appearing at point D are superimposed on the output of mixer B, the pulses subtract from the sine wave if the signal frequency is higher than the reference frequency, and add to the sine wave if the signal frequency is lower than the reference frequency. In the case of the pulses appearing at point E, the pulses add to the sine wave if the signal frequency is higher and subtract if it is lower. These two signals, appearing at F and G of Fig. 4 are passed through biased diodes which are used as pulse discriminators. The bias on these diodes is set just above the peak value of the output of mixer B. The result is that when the pulses add to the sine wave, the bias is overcome and the pulse is passed through the diode. When the pulse subtracts from the sine wave, the bias prevents the diodes from conducting and the pulse is not passed. This arrangement serves to separate the pulses onto two circuits. One circuit is energized by one pulse for each cycle of beat when the signal frequency is high, and the other circuit is energized by one pulse for each cycle of beat when the signal frequency is low.

Figure 5 shows two pulse counters arranged in a balanced circuit to control the charge in the storage capacitor C_s. The voltage across the storage capacitor is used to actuate a cathode follower which in turn controls the bias on the modulator tube. Since the modulator tube controls the frequency of the modulated oscillator, the frequency is a direct function of the charge on the storage capacitor C_s. It will be noticed that there is no bleeder resistor across this storage capacitor, hence the system has no natural frequency which the frequency control must overcome. If the average frequency of the modulated oscillator is different from the reference frequency, the charge on the storage capacitor is continually changed in the direction to overcome the difference. When the difference has been overcome, the system becomes balanced, and the only tendency to pull off is due to stray leakages which cause negligible frequency drift.

The modulated oscillator is operated on one ninth of the assigned frequency of the transmitter. It has been found that simple tuned circuits in the multiplier stages provide adequate selectivity without cutting the side bands when the modulation is applied in this region. When frequencies very much lower are used, special band pass filters must be employed to provide the band width and selectivity at the same time.

There are a number of advantages offered by this circuit. Perhaps the most important of which is the lack of tuned circuits and critical components. The Frequency Control Unit proper contains no tuned circuits, dividers, or locked oscillators. No test instruments are needed to place this equipment in operation. Another important advantage is that tube characteristics are not important. Since each tube in the circuit is driven from grid current to cut-off, merely acting as electronic switches, the actual condition of the tubes becomes relatively unimportant. Long before any tube would become inoperative in the circuit, it would be discarded because of routine tube checks.