As previously stated, if a crystal oscillator is used to provide the carrier signal, the frequency cannot be varied too much (this is a characteristic of crystal oscillators). Thus, crystal oscillators cannot be used in broadcast FM, but other oscillators can suffer from frequency drift. An automatic frequency control (AFC) circuit is used in conjunction with a non-crystal oscillator to ensure that the frequency drift is minimal.

Figure 4 shows a Crosby direct FM transmitter which contains an AFC loop. The frequency modulator shown can be a VCO since the oscillator frequency as much lower than the actual transmission frequency. In this example, the oscillator centre frequency is 5.1MHz which is multiplied by 18 before transmission to give ft = 91.8MHz.

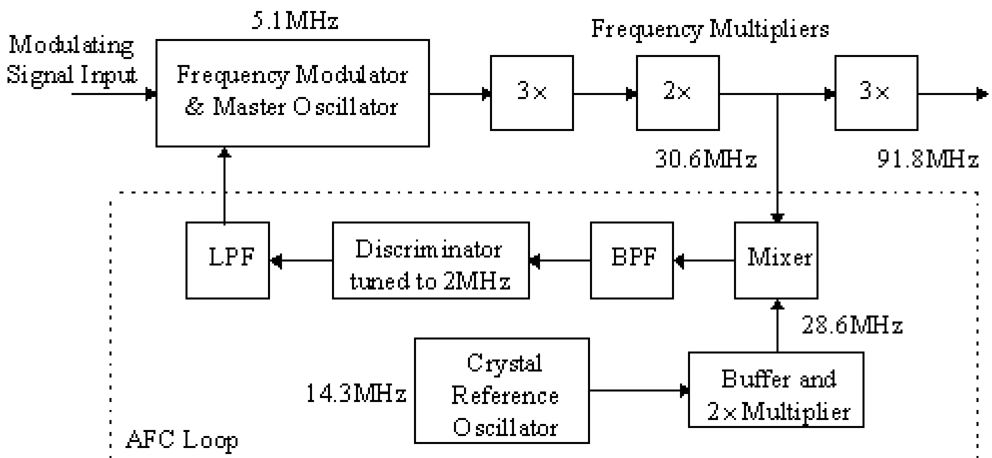


Figure 4 Crosby Direct FM transmitter

When the frequency is multiplied, so are the frequency and phase deviations. However, the modulating input frequency is obviously unchanged, so the modulation index is multiplied by 18. The maximum frequency deviation at the output is 75kHz, so the maximum allowed deviation at the modulator output is

$$\Delta f = \frac{75\text{kHz}}{18} = 4166.7\text{Hz}$$

Since the maximum input frequency is fm = 15kHz for broadcast FM, the modulation index must be

$$\beta = \frac{\Delta f}{f_m} = 0.2778$$

The modulation index at the antenna then is β= 0.2778 x 18 = 5.

The AFC loop aims to increase the stability of the output without using a crystal oscillator in the modulator.

The modulated carrier signal is mixed with a crystal reference signal in a non-linear device. The band-pass filter provides the difference in frequency between the master oscillator and the crystal oscillator and this signal is fed into the frequency discriminator. The frequency discriminator produces a voltage proportional to the difference between the input frequency and its resonant frequency. Its resonant frequency is 2MHz, which will allow it to detect low frequency variations in the carrier.

The output voltage of the frequency discriminator is added to the modulating input to correct for frequency deviations at the output. The low-pass filter ensures that the frequency discriminator does not correspond to the frequency deviation in the FM signal (thereby preventing the modulating input from being completely cancelled).

Indirect transmitters have no need for an AFC circuit because the frequency of the crystal is not directly varied. This means that indirect transmitters provide a very stable output, since the crystal frequency does not vary with operating conditions.

Figure 5 shows the block diagram for an Armstrong indirect FM transmitter. This works by using a suppressed carrier amplitude modulator and adding a phase shifted carrier to this signal. The effect of this is shown in figure 6, where the pink signal is the output and the blue signal the AM input. The output experiences both phase and amplitude modulation. The amplitude modulation can be reduced by using a carrier much larger than the peak signal amplitude, as shown in figure 7. However, this reduces the amount of phase variation.

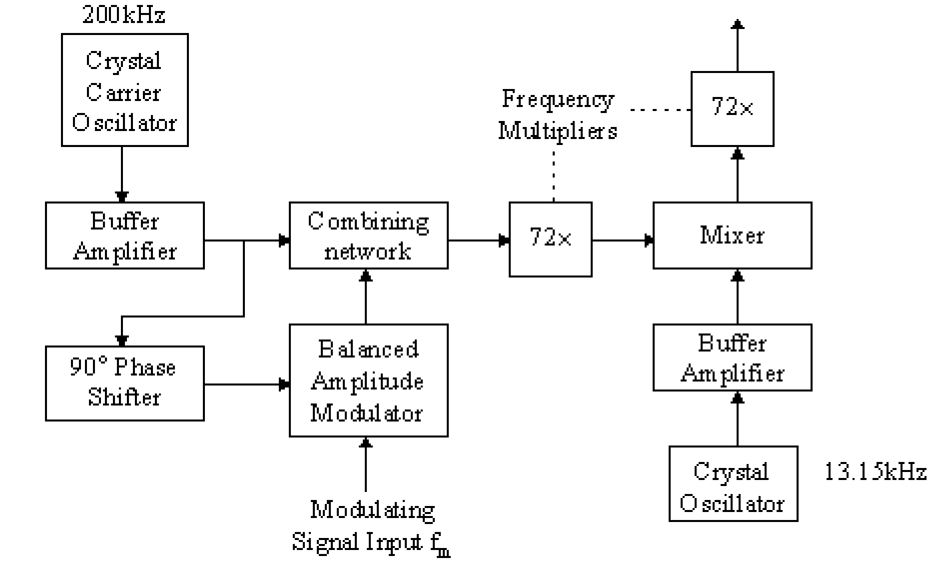


Figure 5 Armstrong Indirect FM transmitter

Figure 6 Phase modulation using amplitude

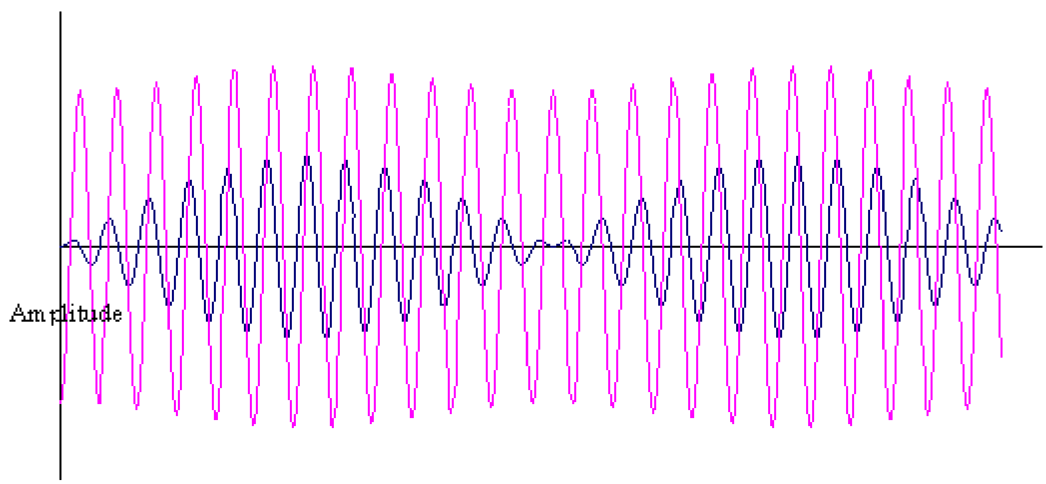
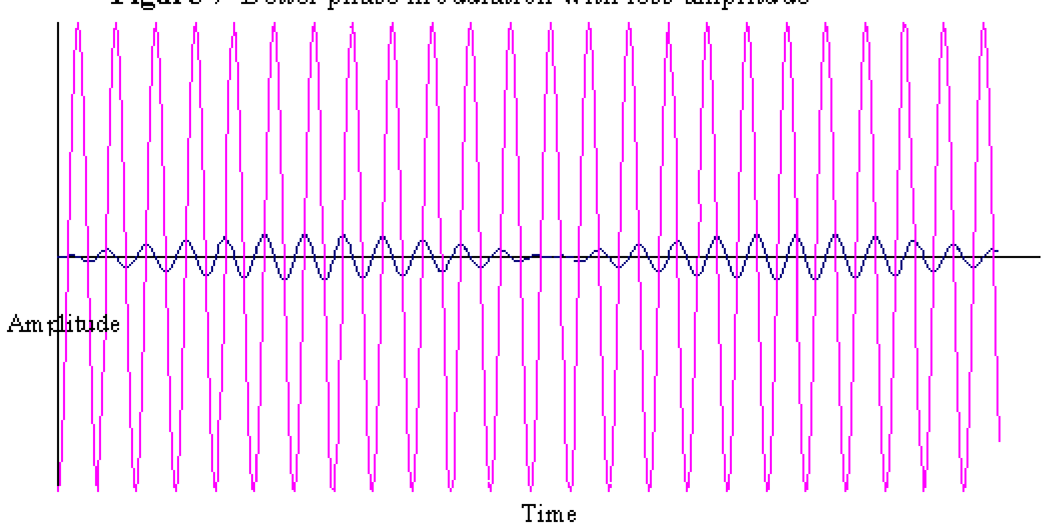


Figure 7 Better phase modulation with less amplitude



The disadvantage of this method is the limited phase shift it can provide. The rest of figure 5 shows the frequency shifting to the FM broadcast band by means of frequency multiplication (by a factor of 72), frequency shifting and frequency multiplication again. This also multiplies the amount of phase shift at the antenna, allowing the required phase shift to be produced by a small phase variation at the modulator output.

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