Correspondence

Injection Locked Phase Modulator*

This communication describes a novel type of phase modulator based on the injection locking principle.[1] The particular device described utilizes a klystron but the technique is not restricted to the microwave region of the frequency spectrum. The technique may be applied to any oscillator that has a voltage tuning characteristic. The frequency of most oscillators is somewhat dependent on the voltages applied to various parts of the oscillator circuit and heretofore many techniques have been devised to overcome this effect. The injection locked phase modulator makes use of the voltage tuning effect which may be inherent or induced by inclusion of a voltage variable capacitor, or other device.

Fig. 1 shows a one-port microwave oscillator (typically a reflex klystron) connected to a circulator and synchronized to the input signal by the injection locking technique. Repeller modulation ordinarily results in a free-running frequency deviation (FM), but with the oscillator locked to the injected signal the result is a change of phase of the oscillator output. The phase modulation is, of course, limited to less than $\pm 90°$ or synchronization will be lost; $\pm 30°$ is readily obtainable. The phase deviation is related to the system parameters by

$$\theta = \sin^{-1}\left[2Q\frac{\Delta f_0}{f_0}\left(\frac{P}{P_1}\right)^{1/2}\right] \qquad (1)$$

where

P = oscillator power
P_1 = injected power
$\Delta f_0 = f_0 - f_1$
f_0 = free-running frequency
f_1 = injected frequency
Q = figure of merit of oscillator circuit.

For fixed operating conditions.

$$\theta = \sin^{-1} K\Delta f_0, \quad \text{where } K = \frac{2Q}{f_0}\left(\frac{P}{P_1}\right)^{1/2}.$$

For a reflex klystron the free-running frequency deviation and repeller modulation are essentially linearly related for small deviations (<0.3 per cent of oscillator frequency); *i.e.*,

$$\Delta f_0 = ae_m$$

a = oscillator voltage tuning coefficient in cps/v.
e_m = modulation voltage amplitude.

Substitution gives $\theta = \sin^{-1}(Kae_m)$. Examination of the sine function shows that good linearity is obtained for $\theta < \pm 30°$. Thus, for phase deviations less than 30° there is an approximately linear relationship between phase shift and modulation voltage amplitude. For greater deviations equalization could be made in either receiver or transmitter.

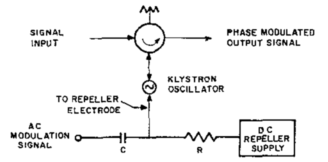

Fig. 1—Injection locked phase modulator.

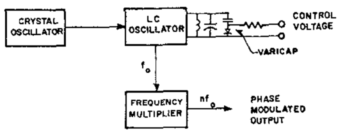

Fig. 2—Lower frequency configuration.

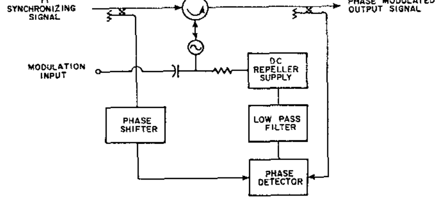

Fig. 3—Feedback to compensate for voltage and thermal drifts.

Again subject to a deviation of $\theta < \pm 30°$, the upper useful modulation frequency (corresponding to half-power frequency concept) is given approximately by

$$f_{m_{\max}} = \frac{f_0}{2Q}\left(\frac{P_1}{P}\right)^{1/2} \text{ cps.}$$

For example, an X-band klystron with typical values of $f_0 = 10^{10}$, $Q = 100$, $P_1/P = 0.001$ (30-db injection ratio) would have an upper useful modulation frequency of

$$f_m = \frac{10^{10}}{2(100)(31.6)} = 1.5 \text{ Mc.}$$

Fig. 2 shows how the principle may be used at lower frequencies. A crystal controlled oscillator is used to synchronize an LC oscillator incorporating a voltage variable capacitor to enhance the voltage tuning effect. If larger phase deviations are required than are conveniently obtainable from the synchronized oscillator the frequency is multiplied by the usual techniques; the phase deviation is increased by the multiplication ratio.

Drifts in the klystron voltages, or thermal drifts may cause the modulator to drift out of synchronization. The stability of the system can be improved by placing feedback around the modulated oscillator as shown in Fig. 3. A portion of the synchronizing input signal and the modulated output signal are compared in a phase detector. The phase detector output is set to zero by the phase shifter with the modulation input disabled. With the modulation signal applied, the phase detector output will contain components from the phase modulation and from the slower voltage or thermal drifts. The low-pass filter rejects the modulation components and the drift output is fed back to the repeller power supply in the phase required to result in a correction of the drift.

Frequency Modulation

Subject to the limitation that $\theta \leq 30°$, then

$$\theta = Kae_m.$$

The instantaneous output voltage may be written

$$e_i(t) = \cos(w_c t + \theta) = \cos\phi$$

where w_c is the carrier frequency and ϕ is the instantaneous phase. The instantaneous frequency is given by

$$w_i = \frac{d\phi}{dt} = w_c + \frac{d\theta}{dt} = w_c + ka\frac{de_m}{dt}.$$

Thus if the modulation voltage is integrated before application to the locked oscillator the instantaneous frequency varies directly with e_m and frequency modulation is achieved.

$$w_i = w_c + ka\frac{d}{dt}\int e_m dt.$$

Limitation

To insure that $\theta \leq 30°$ the amplitude of the modulation voltage must not exceed some maximum value. For a sinusoidal modulation voltage, *i e.*,

$$e_m = A\cos w_m t$$

then

$$A \leq \frac{\pi/6}{Ka}.$$

Richard C. Mackey
Engineering Dept.
University of California
Los Angeles, Calif.

* Received October 24, 1962.

[1] R. C. Mackey, "Injection locking of klystron oscillators," IRE Trans. on Microwave Theory and Techniques, vol. MTT-10, pp. 228–235; July, 1962.

A Reflex Klystron Amplifier for Microwave Spectroscopy*

There are situations in microwave resonance studies when the microwave power level must be kept very low in order not to

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