AN RF LINEAR MODULATION CIRCUIT

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ABSTRACT

This paper describes a linear FM modulation circuit. The modulation circuit and oscillator, which are in microstrip, exhibit exceptional slope linearity and group delay with no external frequency compensation over a deviation bandwidth of 2% of the RF frequency. The baseband frequency response of the modulator/oscillator is greater than dc to 150 MHz. This modulation circuit has been used with microstrip oscillators at 1.8 and 5 GHz.

Introduction

Nearly all frequency modulated oscillators have the requirement that the carrier be set to a precise frequency and then deviated linearly over the peak deviation bandwidth. To perform this deviation with no external compensations or special varactor diodes is a difficult task with existing components and tank circuit designs. The described modulation circuit will set the center frequency of the oscillator precisely and then, when modulation voltage is applied, it will deviate the oscillator with excellent linearity. Parameters such as RF group delay distortion and slope linearity (the change in the modulation sensitivity slope over the deviation bandwidth) will be minimized as a result of the linear frequency versus voltage characteristics of the oscillator/modulator.

The oscillator and modulation circuit for the 1.8 GHz VCO are constructed using microstrip techniques. The oscillator is constructed on a 1 x 1 in. substrate using a common collector transistor. The modulation circuit is also constructed on a 1 x 1 in. alumina substrate, connected at the output of the oscillator, and uses readily available silicon tuning varactor diode chips. The construction of the VCO in microstrip eliminates many of the common mechanical and temperature problems present in cavity-type oscillators. Modulator deviation sensitivity is constant (within 1 dB) over temperature changes in the 0° to 120°F region, as shown in Figure 1, and the oscillator can be simply temperature compensated by means of varying the base bias of the transistor as a function of temperature.

Circuit Description

The oscillator design to be used with this modulation circuit must have as low a loaded Q as possible. The modulation circuit works by presenting a reactive change in the output load impedance of the oscillator, thereby pulling the frequency of oscillation. If an oscillator is designed with a high loaded Q it will be relatively insensitive to its load impedance and therefore will not be deviated significantly from center frequency. The oscillator for the FM modulator was constructed in the common collector configuration because of the ease with which the feedback necessary to produce a low Q negative resistance oscillator can be accomplished[1]. Figure 2 is a schematic of the 1.8 GHz oscillator used with the modulation circuit. The feedback capacitor is selected for the oscillator to provide negative resistance in as large a frequency bandwidth as possible, i.e., low Q. When this low Q negative resistance occurs then the frequency of oscillation is primarily dependent upon the output matching circuit and the load that the matching circuit is presented with. In the circuit described the output matching circuit was designed to place the oscillator at its center frequency. This was accomplished with a small reactance slope at the output of the oscillator so that the output matching circuit would not mask the reactive change in impedance by the modulation circuit, but would provide the necessary resistive level change to satisfy the criteria for oscillation.

The design goal set by the authors was a loaded Q of 2 for the oscillator. There is a tradeoff here between loaded Q and excess noise that perturbs the frequency of oscillation[5]. Overall system requirements must dictate how low a Q is possible for the communication oscillator[3]. Measured Q on the oscillators used was on the order of 6. This measurement was performed by placing a known mismatch at the output of the oscillator and then recording the frequency shift as a function of the mismatch location. With a Q of 6 the modulation sensitivity for 1.8 GHz oscillator was 16.5 MHz per volt, or a peak to peak deviation of 33 MHz for a modulation input of ±1 V. The 5 GHz oscillator had a deviation sensitivity of 50 MHz/V. These measurements are easily made with a dc modulation voltage, but are more difficult with higher modulation frequencies. Figure 3 is a plot of deviation

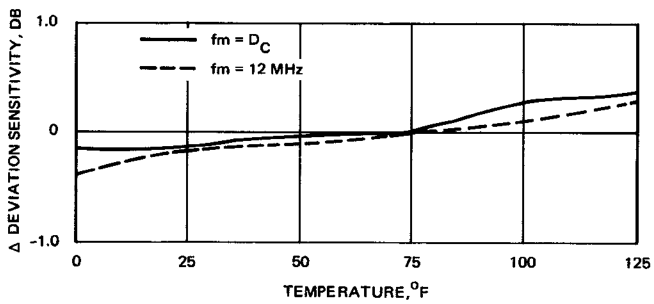

FIGURE 1. DEVIATION SENSITIVITY VERSUS TEMPERATURE

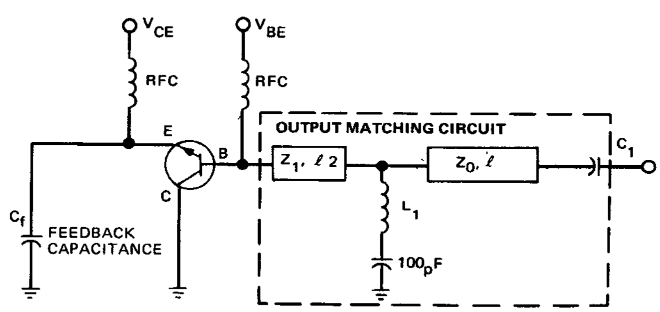

FIGURE 2. 1.8 GHz OSCILLATOR

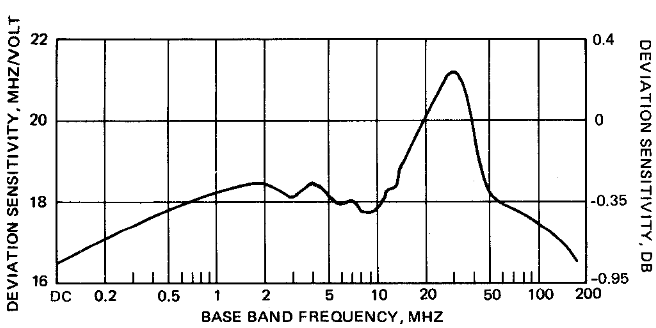

FIGURE 3. DEVIATION SENSITIVITY VERSUS MODULATION FREQUENCY

sensitivity as a function of the frequency of modulation voltage for the 1.8 GHz oscillator. This measurement was performed by keeping the modulation index, β, constant and then recording the magnitude of the modulation voltage required to keep a constant β for the various baseband frequencies. The value of β must be kept low for an accurate measurement. A first sideband-to-carrier ratio of -40 dB corresponding to a β of 0.02 was used in this measurement. There is some error involved in the setting of the -40 dB carrier to sideband ratio, but the measurement is useful in showing overall performance of the modulator. The unit was designed to perform with a baseband frequency response of dc to 8.5 MHz for the 1.8 GHz oscillator/modulator.

The modulation circuit is composed of two varactor diodes (tuning or abrupt junction) in series or in parallel (depending on type of negative resistance, i.e., "Z" or "N" type) with the RF oscillator output port. The varactors are separated by a quarter wavelength of line. To present the correct impedance for the oscillator, each of the varactors are series or parallel resonated with an inductive length of line. The value of varactors must be selected in such a manner that when the modulation voltage is applied they will present a reactive change large enough to pull the oscillator's frequency. This is directly related to the Q of the oscillator. Therefore, the C_{J-4} value of the varactors is determined by the Q of the oscillator. For the modulation circuit used with the 1.8 GHz oscillator, a 0.6 pF value of C_{J-4} was selected. These varactors were used in series with the RF power (a schematic is shown in Figure 4). The other factor in the selection of the varactors is the breakdown voltage. The breakdown voltage must be large enough to provide for proper back biasing with respect to the modulation voltage, but also the generated RF voltage across the diode must be taken into consideration when selecting the breakdown voltage. Too small a capacitance for the timing varactor will cause the RF voltage to become large and the tuning varactor will appear nonlinear to the applied RF signal.

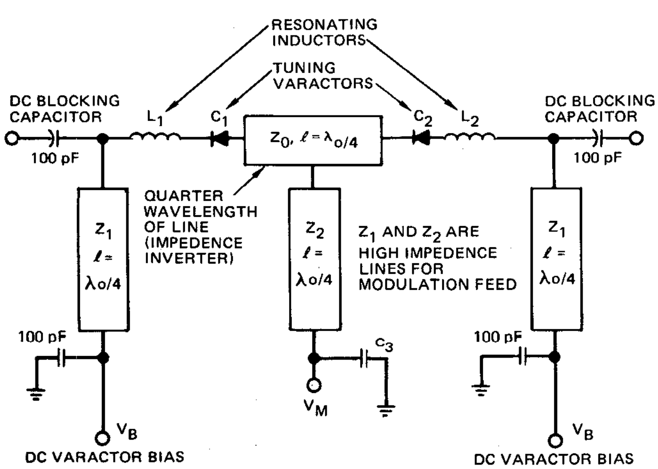

FIGURE 4. LINEAR MODULATION CIRCUIT

Theoretical Calculations

If the schematic of Figure 4 is taken, and the series inductance, bias lines, and dc blocking capacitors are removed for simplicity, we have the circuit shown in Figure 5. This circuit is resonant at some unknown frequency where the $I_m\left[Z_{1N}\right] = 0$. Therefore, to show this, the input impedance must be solved for. The input impedance is then given by

$$Z_{1N} = \frac{-j}{\omega C_2} + \frac{\left[\left(R_L - \frac{j}{\omega C_1}\right)\cot\beta\ell + jZ_o\right]\left[\left(\cot\beta\ell + \frac{1}{\omega C_1 Z_o}\right) - j\frac{R_b}{Z_o}\right]}{\cot\beta\ell + \left(\frac{1}{\omega_1 C_1 Z_o}\right)^2 + \left(\frac{R_b}{Z_o}\right)^2}$$

solving for $I_m\left[Z_{1N}\right]$

$$I_m\left[Z_{1N}\right] = \frac{-1}{\omega C_2} + \frac{\left(Z_o - \frac{1}{\omega C_1}\cot\beta\ell\right)\left(\cot\beta\ell + \frac{1}{\omega C_1 Z_o}\right) - \frac{R_b{}^2}{Z_o{}^2}\cot\beta\ell}{\left(\cot\beta\ell + \frac{1}{\omega C_1 Z_o}\right)^2 + \left(\frac{R_L}{Z_o}\right)^2}$$

making the approximation that at frequencies slightly off resonance

$$\cot\beta\ell \approx \frac{\pi}{4}\,\frac{\Delta\omega}{\omega_o}$$

then

$$I_m\left[Z_{1N}\right] = \frac{-1}{(\omega_o - \Delta\omega)C_1} + \frac{1}{(\omega_o - \Delta\omega)C_2} + \frac{\pi}{4}\,\frac{1}{Z_o}\left(\frac{1}{\omega_o C_1}\right)^2 \frac{\Delta\omega}{\omega_o} = 0$$

substituting for C_1 and C_2 and letting

$$\frac{V_1 - V_m}{\phi} = 1 + V_m$$

we have

$$I_m\left[Z_{1N}\right] = \frac{-(1 + (1 + V_{m1}))^{1/3}}{(\omega_o - \Delta\omega)C_{o1}} + \frac{(1 + (1 + V_{m2}))^{1/3}}{(\omega_o - \Delta\omega)C_{o2}} + \frac{\pi}{4Z_o}\left[\frac{(1 + (1 + V_{m1}))^{1/3}}{\omega_o C_{o1}}\right]^2 \frac{\Delta\omega}{\omega}$$

if we let

$$C_{o1} = C_{o2}$$

$$V_{m1} = -V_{m2}$$

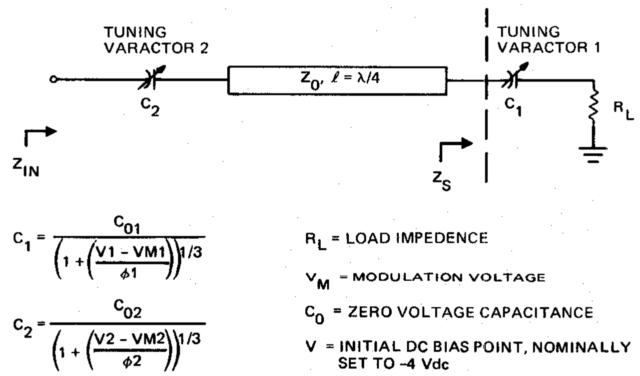

FIGURE 5. LINEAR MODULATION CIRCUIT WITH DC BLOCKING CAPACITORS REMOVED

and solve for $\Delta\omega$ as a function of Vm we obtain Figure 6, a plot of resonant frequency versus modulation voltage for the 1.8 GHz oscillator. It is this change in resonance that is used to modulate the oscillator.

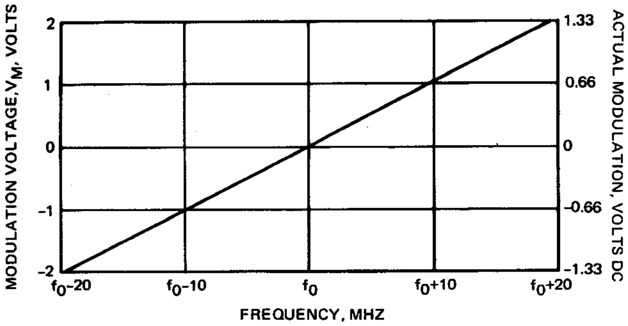

FIGURE 6. FREQUENCY VERSUS MODULATION VOLTAGE

Experimental Results

Figure 6 also shows the measured static frequency versus dc modulation voltage characteristic of the 1.8 GHz oscillator when used with the previously described modulation circuit. Figure 7 is a photograph of this oscillator and modulator combination. This circuit required a peak to peak deviation of 34 MHz, or approximately 2% of the RF frequency. As seen from the graph, the oscillator/modulator is linear over the required deviation bandwidth, and the frequency versus modulation voltage does not start to become nonlinear until the deviation is in excess of 40 MHz. Figure 8 is the slope linearity and group delay of this oscillator for a deviation of ±20 MHz (marked in picture). The scale for the slope linearity is 1%/cm and for the group delay it is 1 ns/cm. This measurement, as well as the group delay, is made by sweeping the oscillator with a 60 Hz sine wave of peak to peak amplitude to provide full deviation, while at the same time modulating the carrier with a low level 500 kHz signal. To perform these tests the modulating source is a Hewlett Packard 3701A transmission generator. The output of the VCO is then mixed down to 70 MHz and demodulated with an HP 3702A demodulator display unit. The group delay measurement is made with

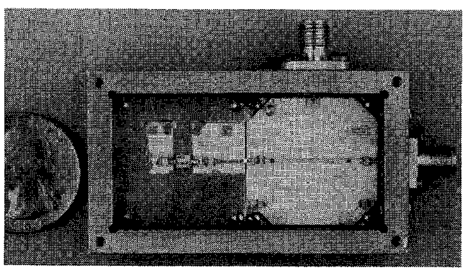

FIGURE 7. 1.8 GHz OSCILLATOR AND MODULATOR

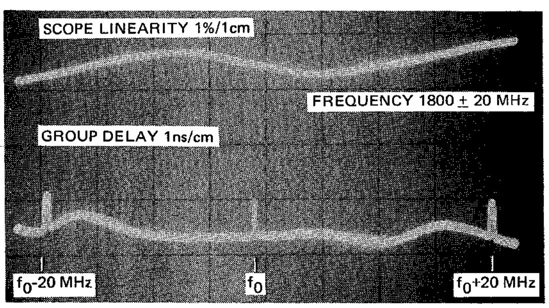

FIGURE 8. SLOPE LINEARITY AND GROUP DELAY OF 1.8 GHz VCO

an HP 3703A group delay detector — a plug-in unit for the demodulator.

The modulation circuit described has also been used with a 5 GHz FET oscillator designed for a peak to peak deviation of 100 MHz. The oscillator and modulator are shown in Figure 9. The oscillator is a common-gate FET[2,4]. The inductance in the gate provides the necessary current phase shift to produce a negative resistance over a wideband, i.e., low Q. The common gate was chosen over the common source oscillator due to the ease with which the low Q was obtained, also, there is very little matching that must be done at the drain port of the FET, thereby allowing the oscillator to see the full impact of the reactive change of the modulation circuit. The varactors were selected to be in parallel with the RF line for this oscillator. The measured static frequency versus dc modulation voltage characteristic of this type VCO (5 GHz FET oscillator) is shown in Figure 10.

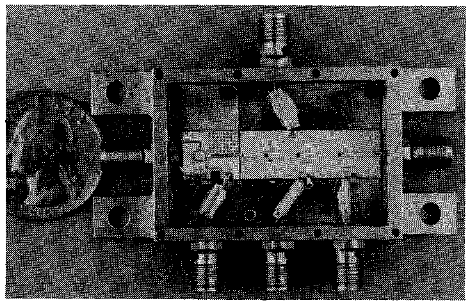

FIGURE 9. 5 GHz FET OSCILLATOR AND MODULATOR

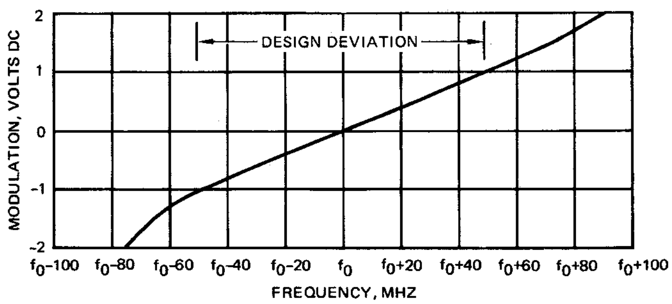

FIGURE 10. FREQUENCY VERSUS VOLTAGE CHARACTERISTIC

Acknowledgements

The authors wish to gratefully acknowledge Dr. R. A. Gaspari for his help in producing a computer model of the modulation circuit and D. K. Kumamoto for his help in applying the circuit to practice.

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