A MICROSTRIP LOW-NOISE X-BAND VOLTAGE-CONTROLLED OSCILLATOR

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ABSTRACT

Design and performance of an X-band microstrip bipolar varactor-tuned oscillator integrated with an FET amplifier is presented. Wide temperature operation (−55° to 71°C), constant high power (0.5 W), low post-tuning drift (0.75 MHz) for 8 percent tuning range, and exceptionally low FM noise (−132 dB/Hz at 1 MHz) is reported.

Introduction

An X-band voltage-controlled oscillator (VCO) has been developed that exhibits the desired characteristics of low FM noise, which will provide low system noise levels, low post-tuning drift to permit rapid and accurate frequency changing, and high output power that is constant over frequency and temperature. A fine-frequency-tuning varactor port is incorporated with constant modulation sensitivity over the coarse tuning voltage excursion in order to provide a constant transfer function for phase-locking applications. Optimal integration of a low power bipolar transistor oscillator (10 mW) with an FET amplifier has resulted in the achievement of the key requirements. In addition, the unit is constructed entirely of soft substrate microstrip (duroid* and epsilam 10† clad to aluminum ground plate), using devices in hermetic packages as opposed to costly coaxial cavities, making the unit relatively low in cost and easily manufactured and tuned, with superior spectral noise under vibration. This unit has FM noise typically 10 dB lower than commercially available cavity-stabilized Gunn diode varactor-tuned oscillator types, which require heater circuitry.

Oscillator Circuit

The phase noise of bipolar and FET devices as large-signal amplifiers was investigated to determine a suitable candidate for the oscillator transistor. Figure 1 illustrates the amplifier phase noise spectrum for a 1-micron FET and bipolar transistor with 8.5-GHz common-emitter cutoff frequency. Under large-signal conditions, the phase noise of the bipolar transistor was approximately 10 dB lower than that of the FET. To achieve the −130 dB/Hz FM noise sidebands at a modulation frequency (f_m) of 1 MHz, a resonator Q of 60 would be required for this bipolar transistor, assuming the phase noise power spectrum of the amplifier is multiplied by $(F_o/Q2f_m)^2$ when f_m is within the half bandwidth of the resonator, F_o being the carrier frequency.

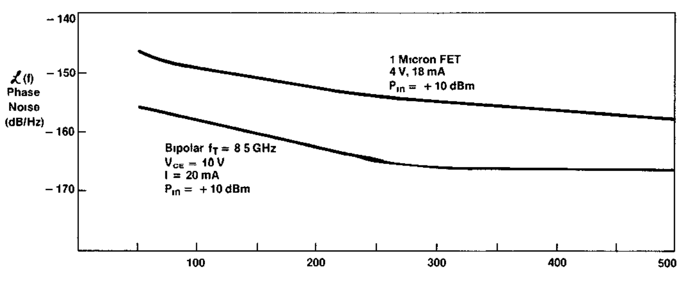

Figure 1. Phase Noise vs Frequency from Carrier for X-Band FET and Bipolar Amplifiers

Numerous authors[1,2] have reported bipolar oscillators at X-band with unpackaged transistors using inductance in the base lead of the common-base transistor configuration. This oscillator used a common-collector packaged transistor with a common-emitter cutoff frequency of 8.5 GHz. An emitter inductance to ground with no feedback from emitter to base was determined to be optimal through the use of S parameter data, resulting in an 8-dB return gain at the base terminal. Figure 2 illustrates the measured base impedance for inductive feedback

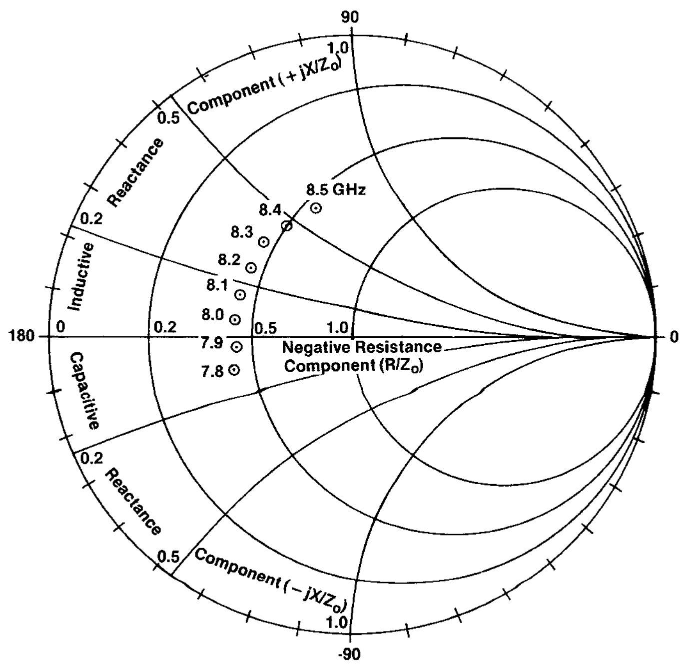

Figure 2. Measured Base Impedance of Bipolar Transistor

* Rogers Company
† 3M Company

consisting of a short length of 80-ohm line terminated by a chip capacitor. Maximum power of 60 mW was measured for a load reflection coefficient of 0.78. Oscillation was initiated for a load reflection coefficient of 0.4. The transistor was biased at − 10 V emitter voltage and 40 mA collector current, representing a 15 percent efficiency.

Three circuit parameters were used to synthesize and calculate circuit values to achieve high circuit Q, constant output power vs frequency, and flat fine-tuning frequency-voltage modulation sensitivity. These key terms are transistor negative quality factor Q_T, varactor and circuit tuning Q_C, and varactor and circuit $Q(f_n)$.

$$Q_T = \frac{f_o}{2R} \; \frac{X_T(f_2) - X_T(f_1)}{f_2 - f_1}$$

$$Q_C = -\frac{f_o}{2R_C} \; \frac{X_C(V_2, f_2) - X_C(V_1, f_1)}{f_2 - f_1}$$

$$Q(f_n) = \frac{f_n}{2R_C} \; \frac{d X_C(f_n)}{df}$$

where:

f_o = center frequency of oscillator
$X_T(f_n)$ = transistor reactance at frequency f_n
f_1 = lower oscillator frequency
f_2 = upper oscillator frequency
R_C = resistance of varactor and load circuit
$X_C(V_n, f_n)$ = reactance of varactor and load circuit at varactor voltage V_n and frequency f_n
V_n = varactor voltage corresponding to frequency f_n
R = transistor negative resistance

For oscillation to occur between the specified voltage limits (4 to 20 V) and frequencies (7.85 to 8.5 GHz) at optimal power, three conditions are required:

- The varactor and load resistance must be transformed to the optimal large-signal resistance of the transistor
- At the center frequency, the sum of the transistor, varactor, and load reactance must be equal to zero
- The magnitude of the transistor negative Q must be equal to the transformed value of the varactor and circuit tuning Q, the latter having a positive value.

A symmetrical circuit using quarter-wavelength transforming sections (figure 3) achieves all key requirements. Since the impedance of the transistor is inductive, a length of 50-ohm line Z02 is used to parallel-resonate the transistor. At this position, the fine-tuning diode circuit, transformed varactor, and output circuit are connected. A silicon varactor packaged diode was chosen over a GaAs diode because of better post-tuning drift characteristics. The Q of the diode at X-band is 31. A small tuning inductance L1 was added to series-resonate the diode at the center operating frequency. The calculated value of the varactor tuning Q was 135 while the value of the large signal transistor Q was − 43, indicating excess tuning capability existed. The coupling of the output load and circuit losses and transformations will reduce the varactor tuning Q. Moderate transformations are required to transform the varactor and load resistance to the transistor negative resistance value, which was incorporated utilizing quarter-wavelength sections. The transformers were selected so that 20 percent of the transistor-generated power was delivered to the load to obtain both high circuit Q and external Q. The final circuit $Q(f_n)$ under these conditions is calculated to be 55 to 70 over the operating band. Fine tuning was incorporated by adding a small capacitance in series with the fine-tuning varactor.

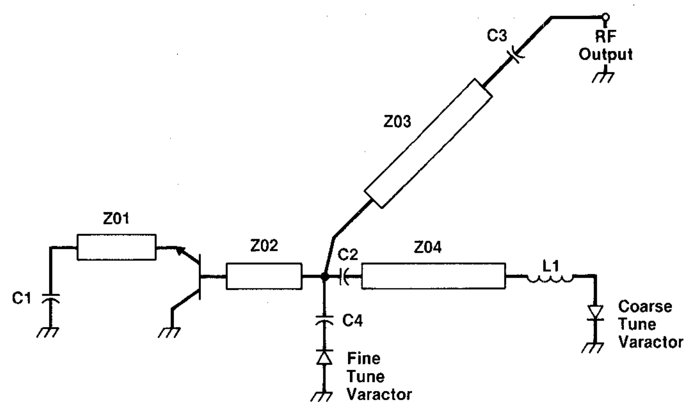

Figure 3. Oscillator Schematic

Figure 4 depicts the VCO assembly. The oscillator is fabricated on a 1.3- x 1-inch substrate of duroid laminated to an aluminum plate. The oscillator exhibited 10 mW of power flat over the frequency band within ± 0.15 dB. The power remained essentially constant from − 55 to 21 °C and decreased 2 dB at 71 °C with flat characteristics vs frequency.

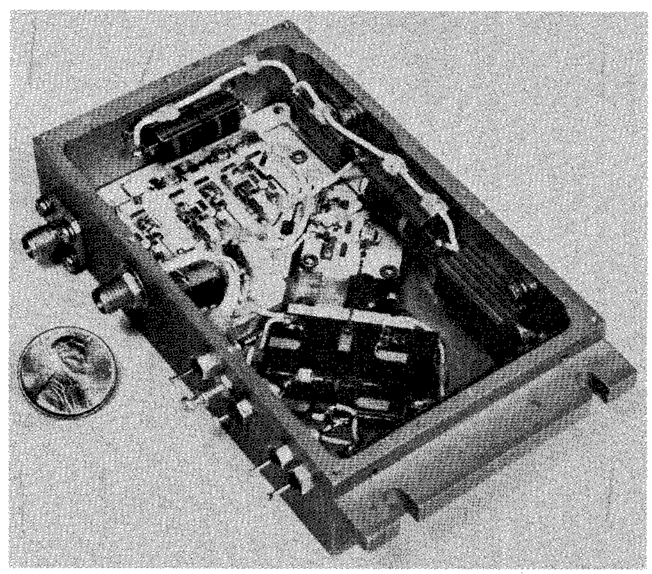

Figure 4. VCO Assembly

Amplifier Circuit

A four-stage partially saturated FET amplifier integrated with the oscillator was used to achieve the required output power of 0.5 watt with less than ± 1.5 dB output power variation over temperature (− 55 to 71 °C) and frequency. The small signal gain was 23 dB, while the operational gain was 18 dB.

The total current required was 600 mA. An active bias circuit (figure 5) was used on all transistors to maintain constant drain current over temperature. This circuit operates by sensing the drain current through R1 and equalizing the current by adjusting the gate voltage via the divider R2 and R3.

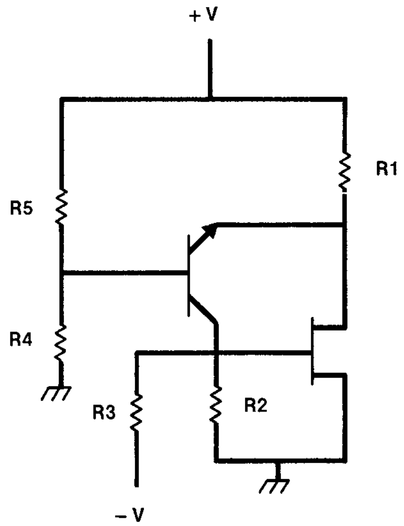

Figure 5. FET Active Bias Circuit

The amplifier was fabricated on epsilam 10 dielectric laminated to an aluminum plate. The FET transistors are in hermetic packages which are soldered to the gold-plated aluminum ground plane. A ferrite microstrip isolator was used between the oscillator and the amplifier.

Experimental Performance

Table 1 lists the measured performance of the oscillator.

TABLE 1
OSCILLATOR MEASURED PERFORMANCE

Parameter	Frequency (GHz)		
	7.85	8.17	8.5
Output Power (dBm) − 55°C	28.0	27.5	26.0
+ 20°C	27.9	27.9	27.0
+ 71°C	25.5	28.7	26.7
Coarse Tuning Voltage (V) − 55°C	− 3.80	− 9.68	− 17.98
+ 20°C	− 3.99	− 9.26	− 16.06
+ 71°C	− 3.60	− 9.28	− 17.10
Coarse Tuning Slope (MHz/V) 20°C	100	55	25
Fine Tuning Sensitivity (MHz/V) 20°C	1.90	2.0	2.0
FM Noise (− dB/Hz) 20°C			
100 kHz	103		112
1 MHz	131		134

The post-tuning drift for a positive 650-MHz frequency step was 0.25 MHz while, for the negative frequency step, the drift was 0.75 MHz. This drift was measured in the 2 to 500 μsec time period referenced after the voltage step.

Figure 6 illustrates the FM noise versus frequency from the carrier at the center frequency for the oscillator.

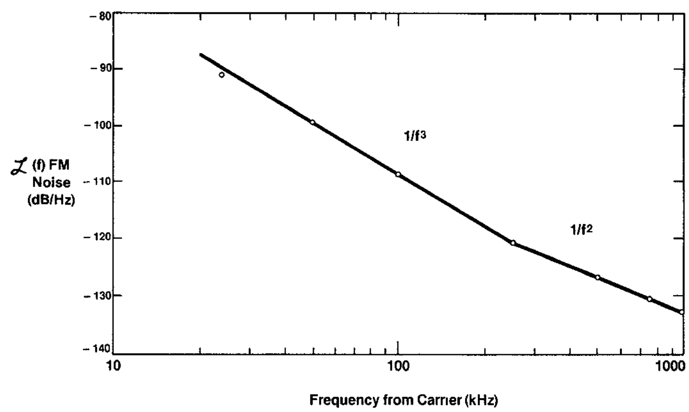

Figure 6. VCO FM Noise

Conclusions

A new low-noise varactor-tuned microwave oscillator has been developed using devices, materials technology, and design procedures that have led to significant improvements in performance, reproducibility, and cost over previously reported X-band microwave VCO's.

Acknowledgement

The authors appreciate the guidance and helpful suggestions of D.C. Buck in the application of microstrip circuits to this oscillator.

References

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