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A SINGLE-RESONATOR GaAs FET OSCILLATOR WITH NOISE DEGENERATION*

M. J. Bianchini, J. B. Cole, R. DiBiase, Z. Galani, R. W. Laton, R. C. Waterman, Jr.

Raytheon Company, Missile Systems Division
Bedford, Massachusetts 01730

ABSTRACT

A low noise GaAs FET oscillator circuit is presented. It uses a single dielectric resonator both in the oscillator feedback circuit and as the dispersive element of a discriminator in a frequency-locked loop used for noise degeneration. An FM noise level of -120 dBc/Hz at 10 kHz offset was measured at X-band.

INTRODUCTION

The high frequency performance of GaAs FET oscillators has made them attractive candidates for applications at X-band and above, but their marginal FM noise performance has precluded their use in many low noise applications.

Dielectric resonators may be incorporated into GaAs FET oscillators to substantially improve their FM noise performance compared to more conventional microstrip GaAs FET oscillators. This improvement can be approximated by the ratio of the Q_L (loaded Q) of the dielectric resonator to the Q_L of the microstrip tuned circuit. At X-band the improvement can be as high as 30 dB, limited by the attainable Q_L of the dielectric resonator in the oscillator circuit.

The FM noise of an X-band microstrip GaAs FET oscillator is typically -65 dBc/Hz at 10 kHz offset from the carrier[1,2]. Use of a dielectric resonator could reduce this noise to -95 dBc/Hz at the same offset frequency. That noise can be degnerated to a lower level by means of a frequency-locked loop, and a novel realization of such is circuit is presented in the following section.

THEORY OF OPERATION

A block diagram of the GaAs FET oscillator with noise degeneration is shown in Figure 1. The uniqueness of this circuit lies in its utilization of one dielectric resonator in both the basic oscillator and the discriminator within the frequency-locked loop. The use of a common resonator in the two circuits also eliminates potential frequency acquisition problems that are characteristic of conventional frequency-locked loops.

The basic oscillator consists of a single-stage GaAs FET amplifier with a parallel feedback circuit

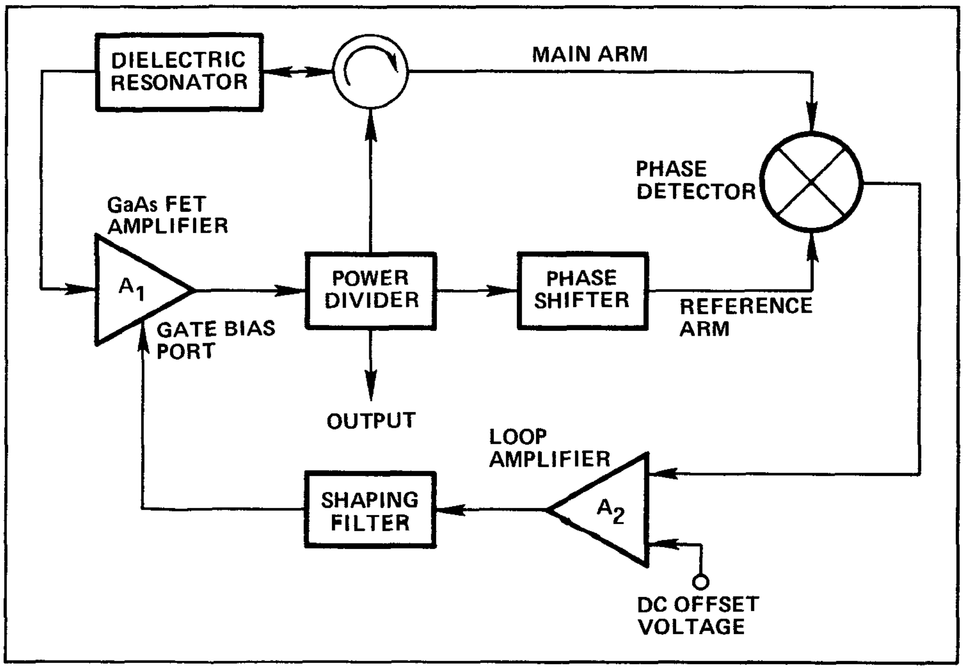

Figure 1. Block Diagram of the GaAs FET Oscillator with Noise Degeneration

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composed of the transmission mode dielectric resonator (resonant at frequency f_o), circulator, and power divider. The conditions for oscillation at f_o are satisfied if, at that frequency, the gain of the amplifier exceeds the total loss of the feedback path and the loop phase shift is an integral multiple of 2π.

The frequency-locked loop is composed of the oscillator, frequency discriminator, loop amplifier, and shaping filter. The discriminator is an interferometer [3,4] with the circulator and resonator in the main arm, and a phase shifter in the reference arm. The resonator, operating in the reflection mode, is connected to the main arm via the circulator. The power divider couples a signal level of approximately 0 dBm to the reference port of the phase detector, and most of the remaining oscillator output power is applied to the resonator to reduce the losses in the feedback circuit. The outputs of the two discriminator arms are adjusted for phase quadrature at f_o. The baseband output of the discriminator is amplified by the loop amplifier, filtered by the shaping filter, and fed back into the gate of the FET through the gate bias port. A DC offset is summed into the loop amplifier to satisfy the gate biasing requirements. The frequency-locked loop is designed to degenerate the FM noise of the oscillator to the level of its noise floor, typically related to the noise of the phase detector diodes.

CIRCUIT DESIGN CONSIDERATIONS

The primary oscillator design goal was to achieve the lowest possible FM noise at X-band using a fundamental circuit.

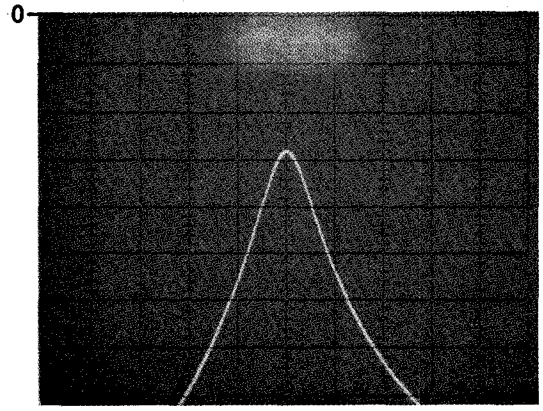
The inverse dependence of oscillator FM noise on the Q_L of its resonator motivated the realization of a circuit with the highest possible Q_L. It was found, however, that the quadratic dependence of the resonator transmission loss upon its Q_L limited the useful value of Q_L to approximately 65% of Q_U (the unloaded Q). As previously stated, the FM noise of a narrowband microstrip GaAs FET oscillator (Q_L = 50) is typically -65 dBc/Hz at 10 kHz offset frequency [1,2]. Since the Q_U of an X-band dielectric resonator coupled to microstrip medium was measured to be 4200, its optimum value of Q_L would be 2800, and would yield an FM noise of -100 dBc/Hz at the same offset frequency. However, use of this resonator in the oscillator feedback circuit (in the transmission mode) and in the discriminator (in the reflection mode) would require a reduction of its Q_L to an estimated value of 1500. With this value the FM noise of the basic oscillator would be -94.5 dBc/Hz at 10 kHz offset frequency.

The minimum RMS frequency deviation detectable by the discriminator, estimated for a Q_L of 1500, corresponds to an FM noise level of -117 dBc/Hz and -137 dBc/Hz at 10 kHz and 100 kHz offset frequencies, respectively. Hence, a properly designed frequency-locked loop would degenerate the noise of the oscillator to these limits. Without noise degeneration, a comparable FM noise performance would require a resonator with a $Q_L > 20{,}000$.

The amount of noise degeneration provided by a frequency-locked loop equals its open loop gain, given by the product of the oscillator pushing figure, discriminator sensitivity, and the transfer functions of the loop amplifier and shaping filter. In this application, the open loop gain of the frequency-locked loop should be at least 23 dB at 10 kHz and is realizable using conventional design techniques.

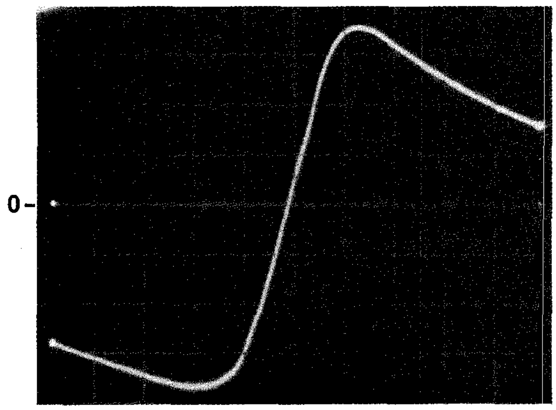
EXPERIMENTAL RESULTS

The circuit described in the block diagram of Figure 1 was assembled and tested to verify its predicted FM noise performance. The single-stage RF amplifier used a Raytheon GaAs FET with 500 μm gate periphery and exhibited a small signal gain of 10 dB at 10 GHz. The resonant frequency of the dielectric resonator was mechanically tuned to 10 GHz and its Q_L was computed to be 1465 from the measured transmission characteristic of Figure 2. The resultant discriminator "S" curve is shown in Figure 3, and it has a slope of 180 mV/MHz.



Vertical: 2.5 dB/DIV
Horizontal: 5 MHz/DIV

Figure 2. Dielectric Resonator Transmission Characteristics. Center Frequency: 10 GHz



Vertical: 50 mV/DIV
Horizontal: 1 MHz/DIV

Figure 3. Discriminator RF Frequency Response. Center Frequency: 10 GHz

The FM noise of the oscillator without noise degeneration was measured to be -100 dBc/Hz at 10 kHz offset and -128 dBc/Hz at 100 kHz offset, as shown in Figure 4. To degenerate this noise to the previously estimated frequency-locked loop noise floor, the circuit was designed with excess open loop gain, and had gains of 14 dB at 100 kHz and 34 dB at 10 kHz as shown in Figure 5. The frequency response of the oscillator/discriminator circuit was measured (see Figure 6) and was used, in conjunction with Figure 5, to determine the response of the loop amplifier and shaping filter.

The degenerated FM noise was measured (see Figure 4) to be -120 dBc/Hz at 10 kHz and -142 dBc/Hz at 100 kHz offset frequencies. These noise levels were reasonably close to the estimated noise floor of the discriminator but it is conceivable that higher loop gain at 100 kHz could result in additional noise degeneration.

The measured AM noise is shown in Figure 7 and has a level of -139 dBc/Hz at 10 kHz and -153 dBc/Hz at 100 kHz offset frequencies.

CONCLUSIONS

The oscillator described in this paper has exhibited extremely low FM noise levels using relatively simple, small size, and lightweight circuitry. Its design is applicable to electronically tunable oscillators by replacing the dielectric resonator with a tunable resonator such as a varactor-tuned cavity or a YIG filter.

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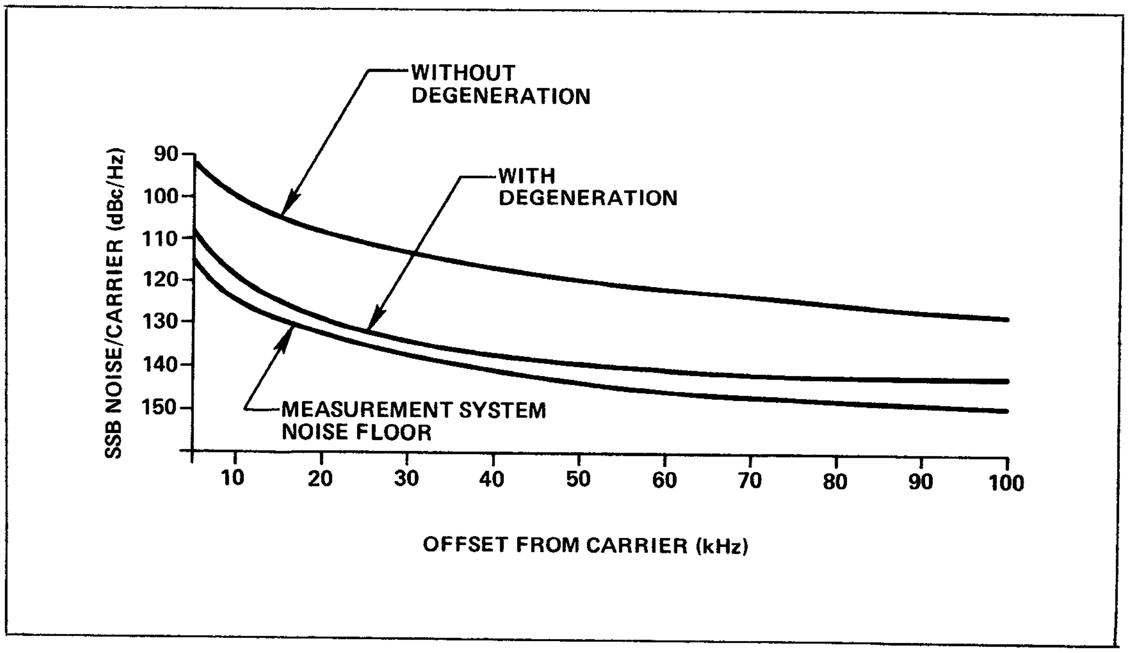

Figure 4. Oscillator FM Noise Performance

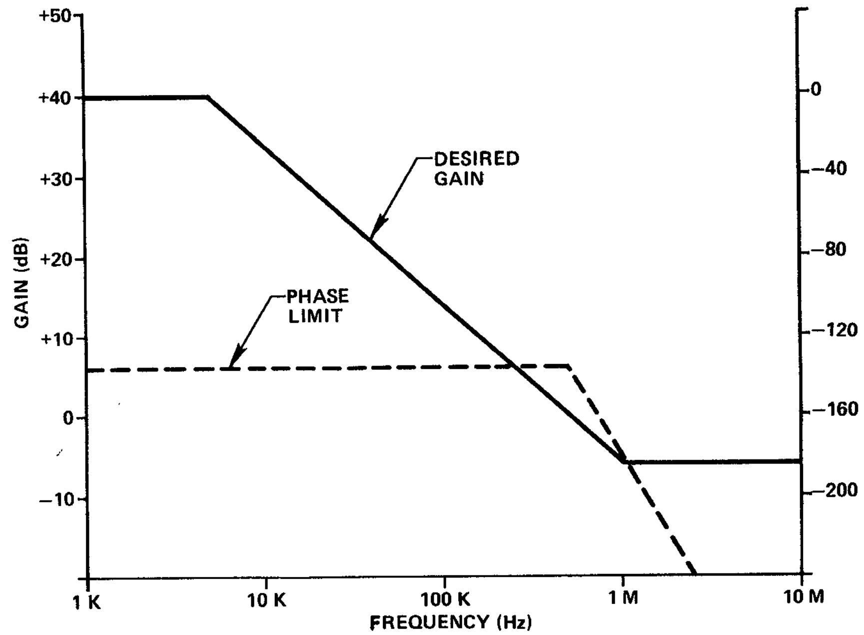

Figure 5. Desired Loop Frequency Response

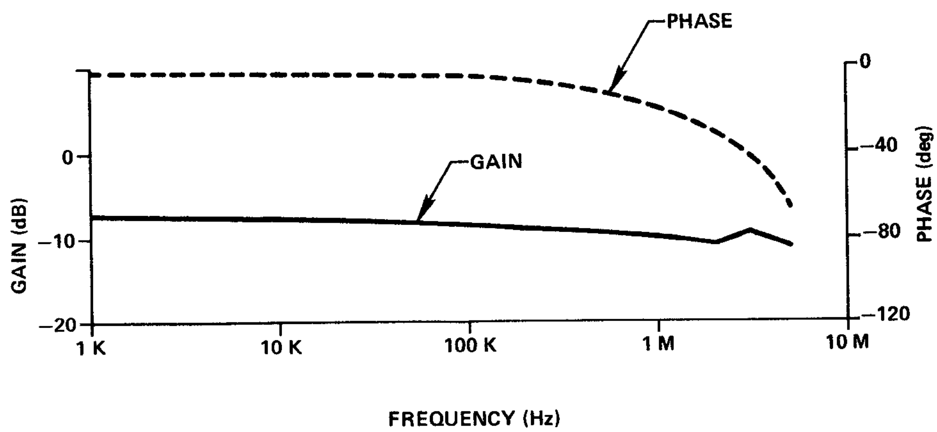

Figure 6. Oscillator/Discriminator Frequency Response

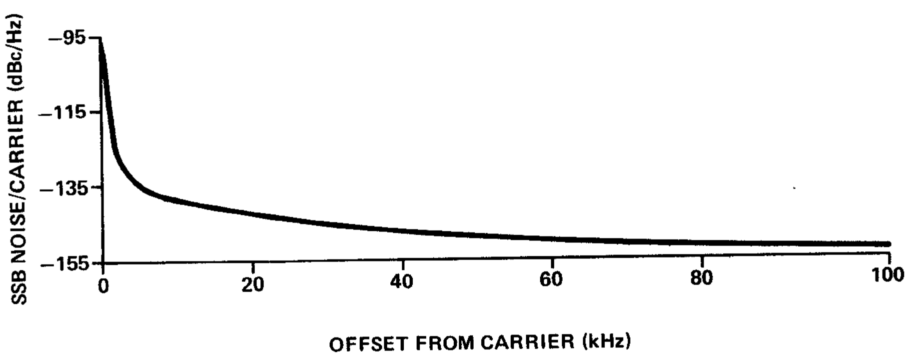

Figure 7. Oscillator AM Noise Performance