Low Phase Noise Oscillator with Flicker (1/f) Noise Suppression Circuit*

Leonard D. Cohen

AIL Systems Inc.
Commack Road
Deer Park, NY 11729

ABSTRACT

Oscillator pushing (frequency change with bias voltage) is a controlling factor in 1/f noise generation in a Gunn diode. Suppression of 1/f noise in the output spectrum of a Gunn oscillator has been demonstrated at 10 GHz with a unique oscillator circuit that provides for zero oscillator pushing. Application areas include communication systems and Doppler radar.

INTRODUCTION

Phase noise close to the carrier on signal sources used as transmitters and receiver local oscillators (LO's) can cause a degradation in radar and digital communication system performance. In a digital communication system, near-carrier phase noise can affect system bit-error rate. In a CW and pulsed Doppler radar application, near-carrier phase noise of the transmitter and LO sources can set a detection limit on Doppler shifted target returns.

An oscillator must generally use a noise reduction technique (e.g., phase locking) to meet system performance requirements on close-in phase noise. This paper will describe a new and simple oscillator circuit enhancement, demonstrated with a 10-GHz Gunn oscillator, that suppresses the generation of flicker (1/f) noise which is the major contributor to phase noise close to the carrier. The suppression of 1/f noise is accomplished by circuit means, integral to the Gunn oscillator, that reduces the oscillator pushing (frequency change with bias voltage) to zero. The technique is capable of 1/f noise suppression from the 1/f noise corner (approximately 25 kHz for a Gunn diode) to carrier frequency.

TECHNICAL DISCUSSION

The character of the phase and FM noise of a Gunn oscillator has been analyzed and reported in the literature [1, 2]. As described in these references, Gunn oscillator phase or FM noise can be characterized as a low frequency flicker (1/f) noise that is predominant at frequencies close to the carrier, and a white noise at frequencies far from the carrier. In the intermediate frequency region, both types of noise are present. Low frequency 1/f noise is upconverted to output frequency in a Gunn diode by its dynamic capacitance and negative differential resistivity.

Theory and experiment [1] have shown that the pushing ($\Delta f/\Delta V_G$) of a Gunn oscillator is a controlling factor in 1/f noise generation. An expression for the FM noise of a Gunn oscillator is given by [1],

$$\Delta f_{rms} = \sqrt{\frac{f_0^2 K T_N B}{Q_L^2 P_C} + \frac{\left(\frac{\delta f}{\delta V_0}\right)^2 N}{f_m^{\alpha}}} \qquad (1)$$

where $\frac{\delta f}{\delta V_0}$ is the pushing factor.

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The first term in this expression is white FM noise. The second term is the flicker (1/f) noise contribution and shows that oscillator frequency pushing is a controlling parameter.

Expressed in terms of the spectral density of phase fluctuations $S_\phi(f_m)$,

$$S_\phi(f_m) = \frac{f_0^2 K T_N B}{Q_L^2 P_C f_m^2} + \frac{\left(\frac{\delta f}{\delta V_0}\right)^2 N}{f_m^3} \qquad (2)$$

where the exponent $\alpha = 1$.

Phase noise from Eq. 2 is plotted in Figure 1 as a function of f_m, the offset frequency from the carrier, for a 10-GHz lumped-element, Gunn oscillator. The calculation is based on an oscillator with an output power of 10 mW, external Q of 50, Gunn diode noise measure of 25 dB, and a pushing factor of 100 MHz/V. The noise measure was obtained from a measurement of the noise of the oscillator. Flicker (1/f) is seen to contribute an additional 10 dB/decade of noise above white noise to the oscillator output.

The 1/f noise suppression circuit that was added to the oscillator circuit was designed to make the frequency/voltage pushing of the Gunn oscillator have zero value. Theory (Eq. 1 or 2) shows that with zero pushing, 1/f noise will be eliminated from the output spectrum of the oscillator. The dotted portion of the noise spectrum shown in Figure 1 is the calculated oscillator phase noise with use of the 1/f noise suppression circuit. In the absence of 1/f noise, the phase noise in this region is an extension of the white noise of the oscillator. Hence, the oscillator will exhibit low phase noise since the elimination of 1/f noise diminishes oscillator noise by 10 dB/decade from the 1/f noise corner (20 kHz) to the carrier.

A lumped-element circuit [3] was the preferred circuit configuration for the Gunn oscillator. The layout of the 10-GHz lumped-element oscillator with the 1/f suppression circuit is shown in Figure 2. The oscillator circuit was assembled in the housing shown in Figure 3. The components associated with the 1/f noise suppression portion are the varactor, its bias circuit, and fixed capacitor C_S. A key feature is the common bias connection between the Gunn and varactor diodes which makes their biasing interdependent.

At a fixed applied varactor bias, a change in Gunn voltage will produce an equal change in varactor bias due to their common bias connection. A decrease in Gunn bias voltage (Gunn domain capacitance decrease) will produce an in-situ decrease in varactor reverse bias (varactor capacitance increase). This frequency compensating effect is the basis for establishing a zero frequency/voltage pushing condition, and hence, 1/f noise suppression. Capacitor C_S was used to trim the slope of the tuning characteristic such that zero pushing occurred at the desired frequency.

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MEASURED PERFORMANCE

A 10-GHz lumped-element Gunn oscillator with a 1/f noise suppression circuit, as shown in Figure 2, was fabricated and tested. This oscillator used a silicon abrupt junction varactor in series with a silicon fixed capacitor to establish the condition of zero pushing. The oscillator was varactor tunable from 9.82 to 10.80 GHz with a corresponding tuning voltage range of 0 to –30 V. Maximum output power was +9.8 dBm and a minimum output was +8.8 dBm.

The measured pushing characteristic of the oscillator, as a function of tuning (varactor) voltage, is shown in Figure 4 and exhibits the desired condition of zero pushing. Zero pushing was obtained at two values of tuning voltage, in the low and high voltage portions of the pushing characteristic. The pushing characteristic exhibits a positive slope in the low voltage portion of the tuning voltage range which indicates the predominance of the positive slope of the varactor tuned characteristic over the negative slope of the intrinsic pushing characteristic due to the Gunn diode. At the high end of the tuning voltage range, the converse effect occurs and the pushing characteristic has a negative slope.

The measured pushing characteristic of the oscillator (Figure 4) is shown for both a 0 2 and a 0.5 V change in Gunn bias voltage. The change in zero crossing with incremental Gunn bias voltage in the low voltage portion of the characteristic is seen to be significantly less than that for the zero crossing in the high voltage portion. The zero pushing point in the low portion of the tuning voltage range was the preferred operating condition since it best provides 1/f noise suppression. Oscillator phase noise measurements were subsequently made with varactor voltage fixed at –3.5 V, the value for zero oscillator pushing.

Phase noise measurements were made in both the white noise and 1/f noise regions of the output spectrum of the oscillator. The measured phase noise of the oscillator is shown in Figure 5 and compared to the calculated phase noise with and without the 1/f noise suppression circuit. Measurements in the white noise region were made to an offset frequency of 1 MHz and measurements in the 1/f region were made to 1 kHz. The measured data below the 20 kHz 1/f noise corner follows the slope of the white noise (20 dB/decade) rather than a slope (30 dB/decade) that would be characteristic of the presence of 1/f noise in the output spectrum. This measured data shows that the 1/f noise normally experienced with Gunn oscillator has been suppressed by the zero pushing condition, at least to the lowest measured offset frequency of 1 kHz.

SUMMARY

A simple and unique means has been demonstrated that provides suppression of the flicker (1/f) noise that is normally exhibited by a Gunn oscillator in its output spectrum close to the carrier. Suppression of 1/f noise was accomplished by making the pushing of the oscillator have zero value. The suppression technique was demonstrated with a 10-GHz Gunn oscillator but can be readily implemented with millimeter-wave Gunn oscillators. The suppression technique has general applicability and can be applied to oscillators using other active devices in which frequency pushing is a significant contributor to 1/f output noise.

REFERENCES

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3. Cohen, L. D., and Sard, E., "Recent Advances in the Modeling and Performance of Millimeter-Wave InP and GaAs VCO's and Oscillators," 1989 I.E.E.E.-MTT-S International Microwave Symposium Digest, pp. 1927 – 30.

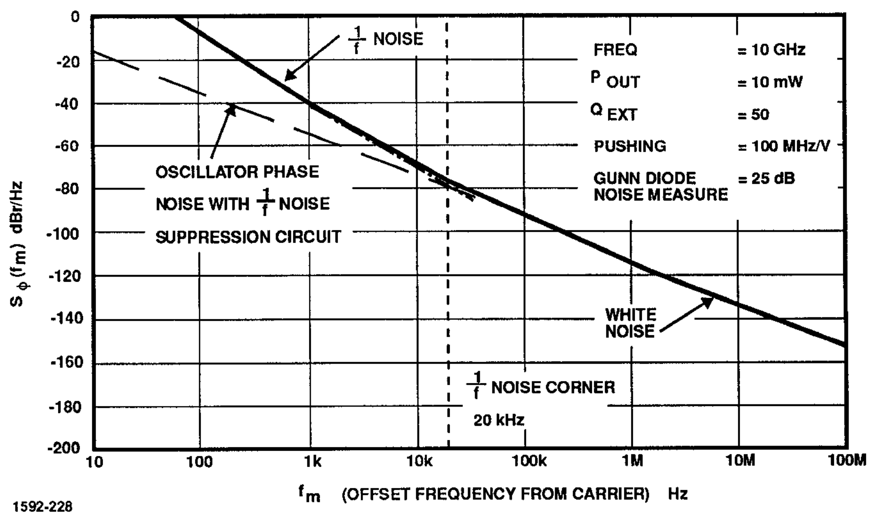

Figure 1. Calculated Phase Noise S_ϕ (f_m) of a Gunn Oscillator with and without a 1/f Noise Suppression Circuit

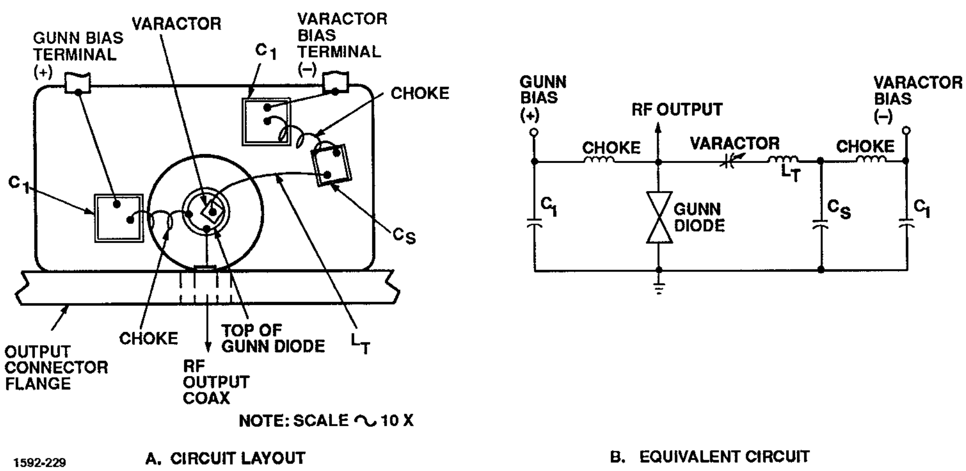

Figure 2. 10-GHz Lumped-Element Gunn Oscillator with a 1/f Noise Suppression Circuit

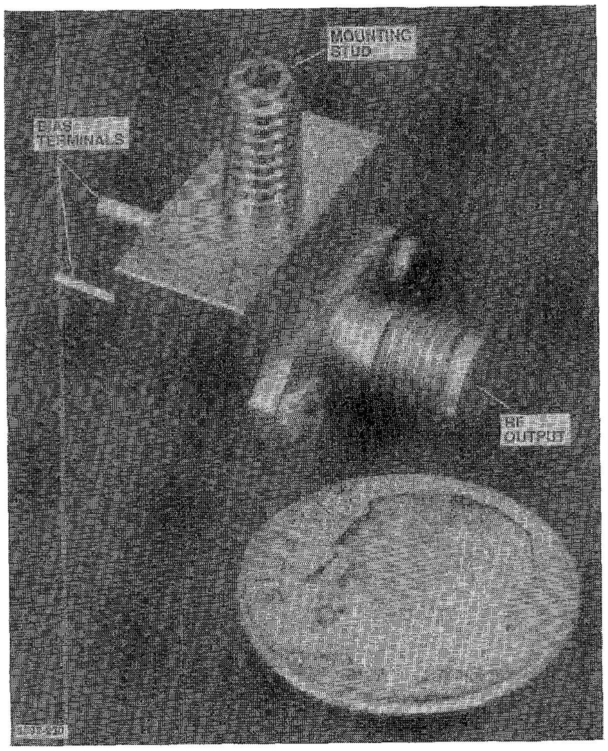

Figure 3. 10-GHz Lumped-Element Gunn Oscillator with a 1/f Noise Suppression Circuit in Housing with Coaxial Output

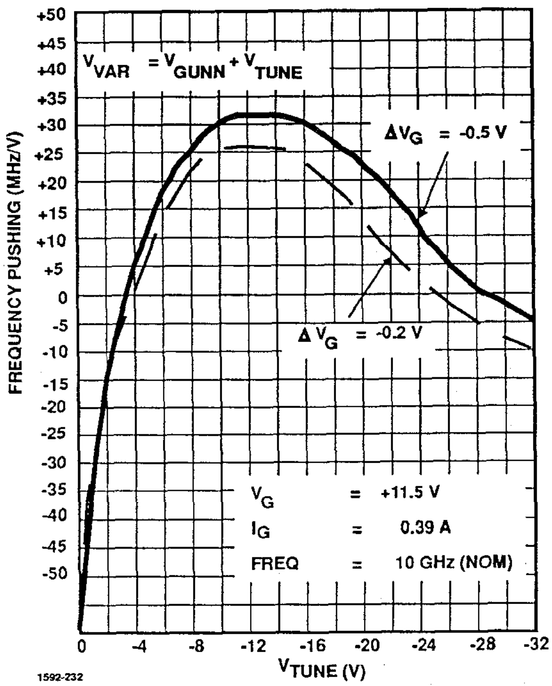

Figure 4. Measured Pushing Characteristic of Gunn Oscillator with a 1/f Noise Suppression Circuit

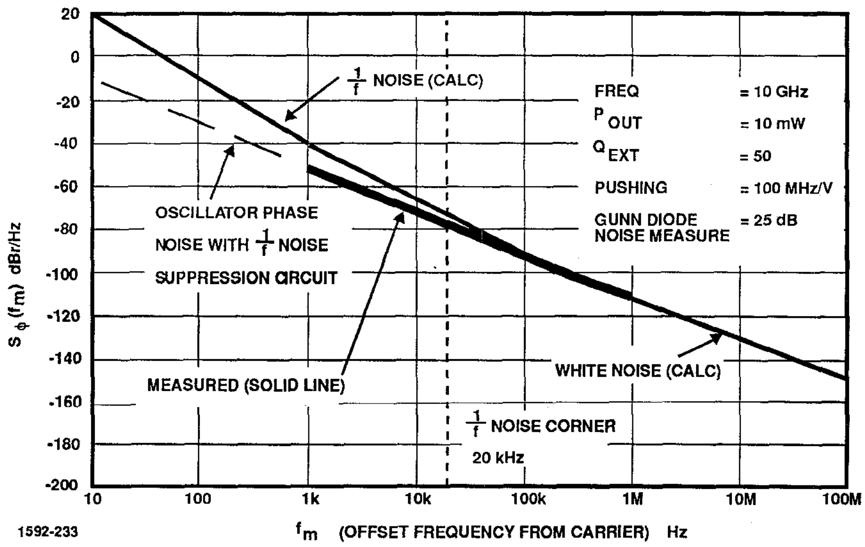

Figure 5. Measured and Calculated Phase Noise $S_\phi(f_m)$ of a Lumped-Element Gunn Oscillator with a 1/f Noise Suppression Circuit