NOISE MEASUREMENTS OF W-BAND (75-110 GHz)
CW GaAs GUNN AND SILICON IMPATT OSCILLATORS

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ABSTRACT

This paper presents AM and FM noise data measured on commercially available CW Gunn and silicon IMPATT oscillators, and shows characteristic differences between these sources having similar external quality factors. Measured phase noise power spectral density of free running and injection locked IMPATT oscillators are shown to compare favorably with theoretical values predicted by a dynamic feedback servo model. The system used to measure external quality factor, Q_{ex}, and the noise measuring systems employed in these investigations are described briefly.

Introduction

Experimentally measured AM and FM noise spectra are presented in this paper for commercially available CW Gunn and silicon IMPATT diode oscillators operating at W-band (75-110 GHz) millimeter frequencies. Noise characteristics of free running and injection locked sources demonstrate the fundamental differences between these oscillators having similar external quality factor, Q_{ex}. The test set for accurately measuring Q_{ex} is discussed. This technique is related to the dynamic feedback servo model developed earlier[1] to explain phase noise suppression[2] of injection locked sources. Simple laboratory measurements of free running oscillator frequency, dynamic modulation transfer function, injection locked suppression of deliberate bias voltage modulation, and relative power levels provide all the information needed to apply this method. The dynamic feedback servo model permits calculations of injection locked characteristics which is in excellent agreement with measured injection locked data. Noise measuring systems used in these investigations and comparison of measured and calculated FM noise spectra are presented. AM noise is also compared.

Oscillator Quality Factor Measurement

The block diagram, cf. Fig. 1, illustrates the test procedure used to perform an accurate external quality factor, Q_{ex}, measurement and shows measured data and sample calculation. Oscillator output power P_o and injected power P_i are measured at the same reference point in the millimeter circuit, namely, at the output port of the locked oscillator. A typical measured power output versus dc bias voltage characteristic of a free running single drift region (SDR) IMPATT oscillator at 94 GHz is shown in Fig. 2. A deliberate sinusoidal bias voltage modulation ΔV_m is applied to the free running source under test which produces a free running frequency deviation $\Delta\omega_m$, at modulation rate ω_m, that is considerably greater than corresponding free running noise deviations $\Delta\omega_o$. The Crosby zero crossing method[3] is used to determine the exact deviation at some convenient video modulation rate ω_m. At the first carrier null

$$\Delta\omega_{m_{peak}} = 2.405\omega_m, \qquad (1)$$

and then by injection locking with a known gain a new deviation, $\Delta\omega_L$ is measured. Since the injection locked noise components $\Delta\omega_i << \Delta\omega_L$, both noise deviations $\Delta\omega_o$ and $\Delta\omega_i$ are insignificant. The resulting suppression factor[4,5]

$$S_{measured} = \left|\frac{\Delta\omega_L}{\Delta\omega_m}\right| \qquad (2)$$

is used to calculate the external quality factor[2]

$$Q_{ex} = \left[\frac{S}{1-S}\right]\left[\frac{\omega_o}{2\omega_m}\right]\sqrt{\frac{P_i}{P_o}}\ , \qquad (3)$$

where ω_o is the free running angular frequency, for the IMPATT oscillator. Since the suppression factor

$$S = \left|\frac{1}{1+G(s)}\right| \qquad (4)$$

is also related to the free running oscillator open loop gain[2]

$$G(s) = \left[\frac{\omega_o}{2Q_{ex}s}\right]\sqrt{\frac{P_i}{P_o}}\ , \qquad (5)$$

it is important that ω_m be much less than the angular cut-off frequency or closed loop bandwidth, ω_c, at which the open loop gain is unity, cf. Fig. 3, in order to insure $G(s)>>1$. The frequency domain transform notation

$$s = j\omega_m \qquad (6)$$

has been employed in correspondence with standard Bode plot terminology.

The same technique described above is used to determine Gunn oscillator suppression factors, S, and external quality factors, Q_{ex}.

FM Noise Suppression

FM noise spectra of free running oscillators and injection locked source have been measured, with known locking Gain. Theoretical noise suppression factor

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$$S_{calculated} = \frac{\Delta\phi_i}{\Delta\phi_o} = \frac{1}{1 + \frac{\omega_c}{\omega_m}} \quad (7)$$

where again ω_c is the angular cut-off frequency or closed loop bandwidth at which the open loop gain is unity, cf. Fig. 3, was calculated[1] and is plotted in Fig. 4. Suppression curves with the injection source and free running oscillator at the same millimeter frequency have been constructed. Excellent agreement was obtained between measured suppression (2) at known injection gain by modulating the bias voltage, and the calculated noise suppression (7). Typical phase noise data of an IMPATT oscillator with various injection locked gains are shown in Fig. 5. When the level portions of the injection locked noise data are projected they intersect the free running noise characteristic at the theoretical dynamic bandwidth, ω_c.

Noise Measuring System

The noise measuring set, employing a high Q-millimeter reaction cavity[6] carrier suppression filter, in the phase bridge described in detail elsewhere[7], was used to measure oscillator noise close to the carrier. A TE 013 mode copper cavity developed and optimized for 90 GHz operation, then modified for 94 GHz, has its active surface diamond tooled. Theoretical loaded quality factor Q_L(theoretical) = 7,450 compares favorably with measured Q_L(measured) = 6,510.

Noise components far off the carrier were obtained using a low noise broad band balanced mixer[8] followed by a series of low noise 0-2 GHz amplifiers having overall mixer to IF conversion gain of 60 dB. This system was also used to study low order bias circuit oscillations inherently present in Gunn oscillators[9]. AM noise measurements can be similarly obtained using these systems, cf. Fig. 6. For close to carrier measurements the carrier suppression path of the phase bridge is deactivated.

Conclusions

Injection phase locked noise characteristics of millimeter IMPATT and Gunn oscillators can be quantitatively predicted using a Type 1 feedback servo model. Simple laboratory measurements permit easy determination of the model parameters without knowledge of device impedance parameters. This model serves as the basis for accurately measuring external oscillator quality factors. The model can also be used to predict injection lock time, injection lock bandwidth, Rieke diagrams, and more.

Noise measurement systems developed earlier for use at microwave frequencies have been effectively employed at millimeter frequencies using a high quality passive cavity resonator in conjunction with extremely low noise mixers.

Acknowledgements

The high quality 94 GHz resonant cavity which constitutes the carrier suppression filter required for phase noise measurements was designed and constructed by H. Barth of AEG Telefunken[6] while the low noise broadband mixers were designed and constructed by A. G. Cardiasmenos[8] of TRG/Division of Alpha Industries, Inc.

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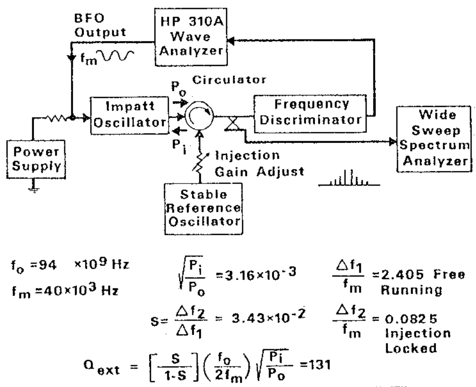

FIG.1 BLOCK DIAGRAM OF EXTERNAL QUALITY FACTOR MEASURING SYSTEM

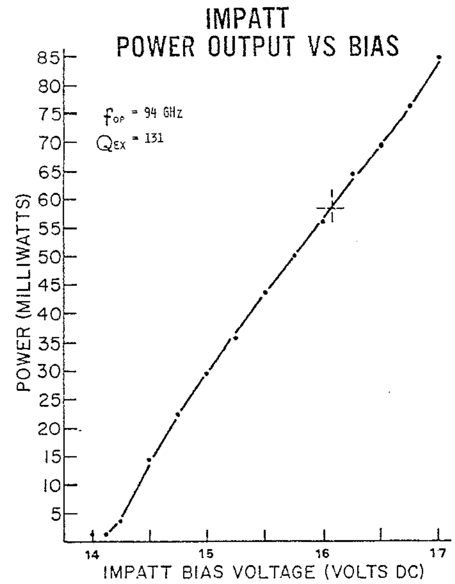

FIG. 2 TYPICAL POWER OUTPUT VERSUS BIAS VOLTAGE OF A FREE RUNNING IMPATT OSCILLATOR

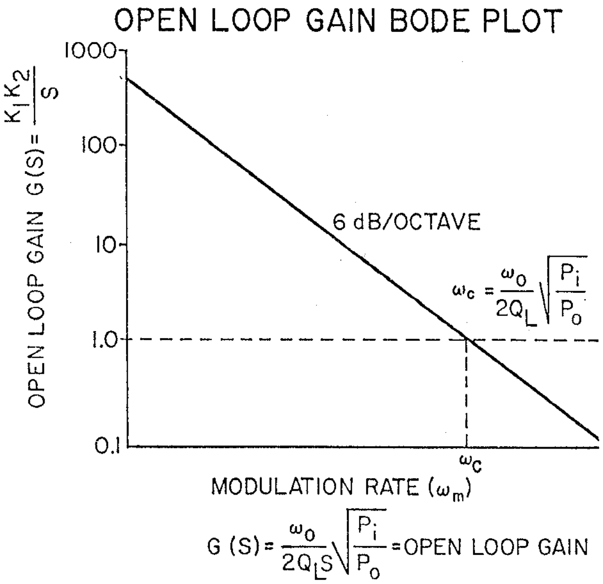

FIG. 3 OPEN LOOP GAIN BODE PLOT FOR TYPE 1 FEEDBACK SYSTEM

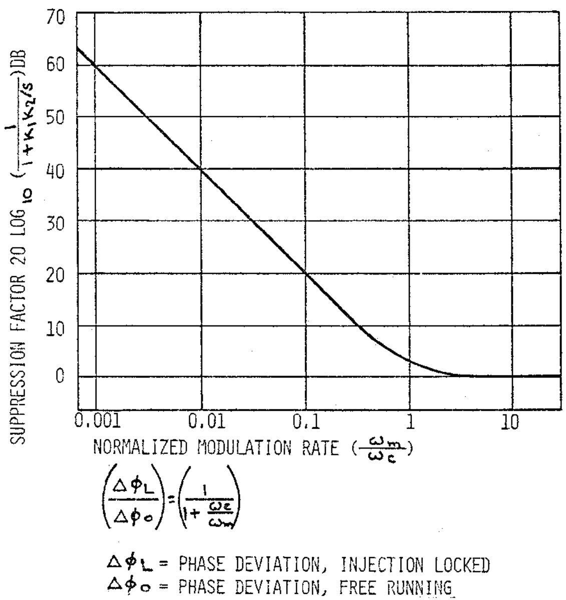

FIGURE 4. NORMALIZED NOISE SUPPRESSION FACTOR

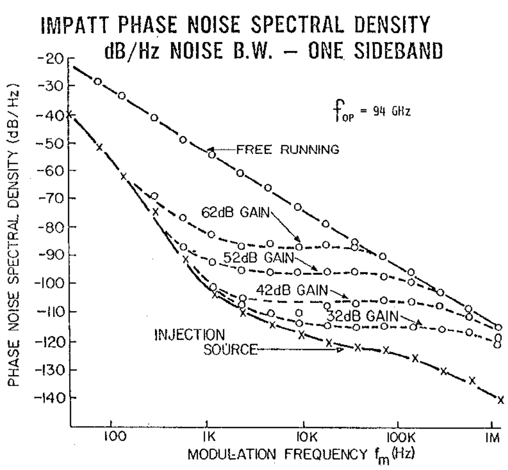

FIG. 5 TYPICAL FM NOISE SPECTRA OF IMPATT OSCILLATORS

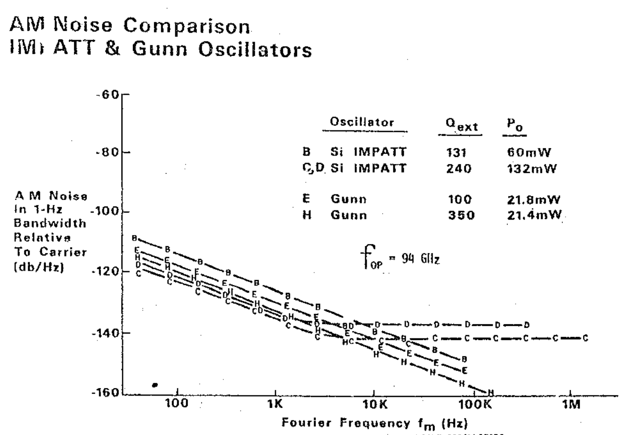

FIG. 6 TYPICAL AM NOISE SPECTRA OF SILICON IMPATT AND GUNN DIODE OSCILLATORS.