REDUCED PHASE NOISE IN MICROWAVE OSCILLATORS DUE TO OPTICAL SIGNAL INJECTION

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ABSTRACT

Optical injection of MESFET oscillators shifts the circuit's operating frequency locks the microwave frequency to the optical carrier, and reduces the frequency noise of the oscillator. The main result is the phase noise is decreased -110 dBc/Hz when locked to the modulated lasers. Phase noise is measured with no optical injection, with a single modulated laser injected and with a heterodyned injection locked laser signal.

INTRODUCTION

Optical injection of MESFETs directly affects the operating characteristics of the devices. The MESFET properties, induced by optical injection, can shift and stabilize oscillator operating frequency. These properties can be used to develop feasible integrated microwave-optical devices. Systems applications include phased array radar and computer clock control. The goal is to lock the oscillator frequency without effecting the system cost, limiting the size, and without signal interference.

In phased array radar and computer clock control applications, low noise optical signals are distributed via single mode fiber. Local oscillators are located at the array elements or on the computer board. The optical signal is injected into the MESFET active region to shift the frequency and/or to lock the oscillator to the optical signal. The MESFET oscillators are inexpensive and noisey, but optical injection locking reduces the single sideband phase noise of the oscillator to -110 dBc/Hz[1].

The contribution of this paper is the phase noise in a microwave oscillator is reduced via optical injection. The oscillator phase noise decreases with increasing optical mode stability. Although there has been much research in the area of optical injection of MESFETs, the phase noise measurement via direct optical injection of oscillators is rare in the literature. Furthermore, this research rigorously measured the oscillator noise about the center which graphically illustrates the influence of injection locking on different frequency noise sources. The power spectral density of the frequency deviation and the single side band phose noise to carrier are computed.

The experimental setup is discussed fully in [1]. The phase noise experiments and results are presented here. Conclusions are drawn in the final section.

OSCILLATOR PHASE NOISE BEHAVIOR

The origins of oscillator phase noise are random processes which modulate the free running frequency of the circuit. Stochastic processes produce frequency and amplitude modulation (AM) of the free running oscillator frequency. In general, AM is invariably accompanied by phase noise and some amount of incidental frequency modulation (FM). The free running circuit frequency and the frequency noise components lock to the optical signal. Hence, the phase noise of the circuit is extinguished through this locking process.

The device line and impedance locus diagrams of Kurakowa[2] are the starting point for quantitative understanding of the oscillator noise origins. Kurakowa's work has been coupled with a quantum mechanical reservoir theory to describe an injection locked microwave oscillator and an injection locked laser system with a change of constants[1].

The short term stability of the device is a characteristic of the FM or phase noise. The noise is considered in terms of modulating the existing frequencies of the oscillator. The effective modulation spectrum contains many frequency components. All of the energy surrounding the free frequency can be interpreted in terms of frequency modulation by a random signal of limited spectrum (i.e., noise). The experimental results show the greatest noise reduction in the realm of white FM noise and flicker phase modulation.

PHASE NOISE MEASUREMENTS

Two types of noise were measured: the frequency deviation $\Delta\nu$ and the single sideband phase noise $\mathcal{L}(f_m)$. The power spectral density (PSD) of the frequency deviation is denoted by $S_{\Delta\nu}(f_m)$. The single sideband phase noise $\mathcal{L}(f_m)$ is defined as the power ration of the noise level to the carrier.

To accurately compare the measured noise characteristics, it is necessary to normalize the measurements. The standard method is using an equivalent per Hertz representation of the power level. Noting that the square of the RMS voltage is power, the equivalent per Hertz representation of the measured signal is calculated. In this manner, the bandwidth of the measurement BW1 can be converted to an equivalent per Hertz bandwidth BW2.

In Figure 1, the PSD of the frequency deviations $S_{\Delta\nu}(f_m)$ and in Figure 2 the single sideband phase noise $\mathcal{L}(f_m)$ are plotted for three cases: no injection, modulated master injected and locked to the microwave oscillator, and the heterodyned beat produced from the locked lasers. For each case, five measurements were at spans of 10, 50 and 100 KHz, 1 and 100 MHz in order to obtain fine enough resolution to plot the noise near the carrier. In all cases, the oscillator bias was set at Vgs=-0.55v and Vds=1.348v. The laser modulation frequency was 2.9805 GHz. The detected spectra were digitized and used to compute $\mathcal{L}(f_m)$ and $S_{\Delta\nu}(f_m)$ on an equivalent per Hertz basis via the set of equations in [1]. Corrections for the analyzer's log amplifier (1.45 dB) and the IF the detector (1.05 dB) were added to the calculations. Also, the bandwidth shape factor was used to adjust for the finite extent of the gaussian shaped resolution bandwidth filter of the analyzer (1.2*Resolution Bandwidth of the measurement). In both $S_{\Delta\nu}(f_m)$ and $\mathcal{L}(f_m)$, the most striking decrease in noise occurs for the single modulated laser injection rather than for the heterodyned beat injection. This is directly attributed to the magnitude of power injected. The single laser power is 44μW and the heterodyned beat power is 8μW. The magnitude of the injection plays a significant role in stopping the frequency movement about the injected frequency. The difference in phase noise magnitude between the single laser and heterodyned beat at 1000Hz from the carrier is 20%. Also, the ratio of the two injected power levels is 20%.

Furthermore, the phase noise of the optically injected oscillator reported here are better than those previously reported[3,4,5]. This research rigorously measures the phase noise of direct injection oscillators and not indirect. Indirect optical injection locking is detecting an optical signal by a high speed photodiode and then using the amplified electrical output to lock an oscillator[6].

CONCLUSION

The oscillator spectrum has been studied under optical injection. The MESFET's current, impedance, and ultimately, frequency are influenced by an optical signal. The output spectrum characteristics of the oscillator were experimentally shown to improve when locked to a modulated laser. The model was used to describe locking and phase noise produced by random frequency fluctuations. The best reduction of phase noise reported to date was realized. The main result is the oscillator phase noise at 1 KHz from the carrier is the decreased to -110 dBc/Hz when locked to the modulated lasers. The heterodyned beat note was anticipated to reduce the oscillator phase noise beyond the single modulated laser injection case because of the 10 times narrower optical linewidth[1]. This was not the case in the experiment because the optical power level of the beat note. The oscillator was modeled shown to exhibit the same locking characteristics as the experimental device[1].

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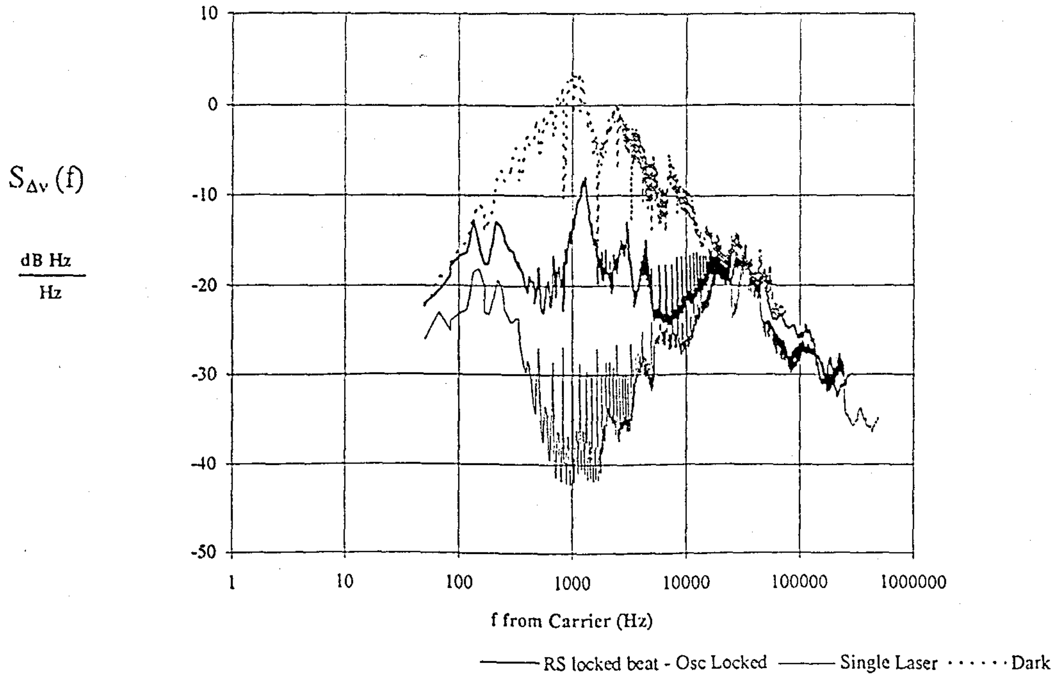

Figure 1 Power Spectral Density of Frequency Fluctuations

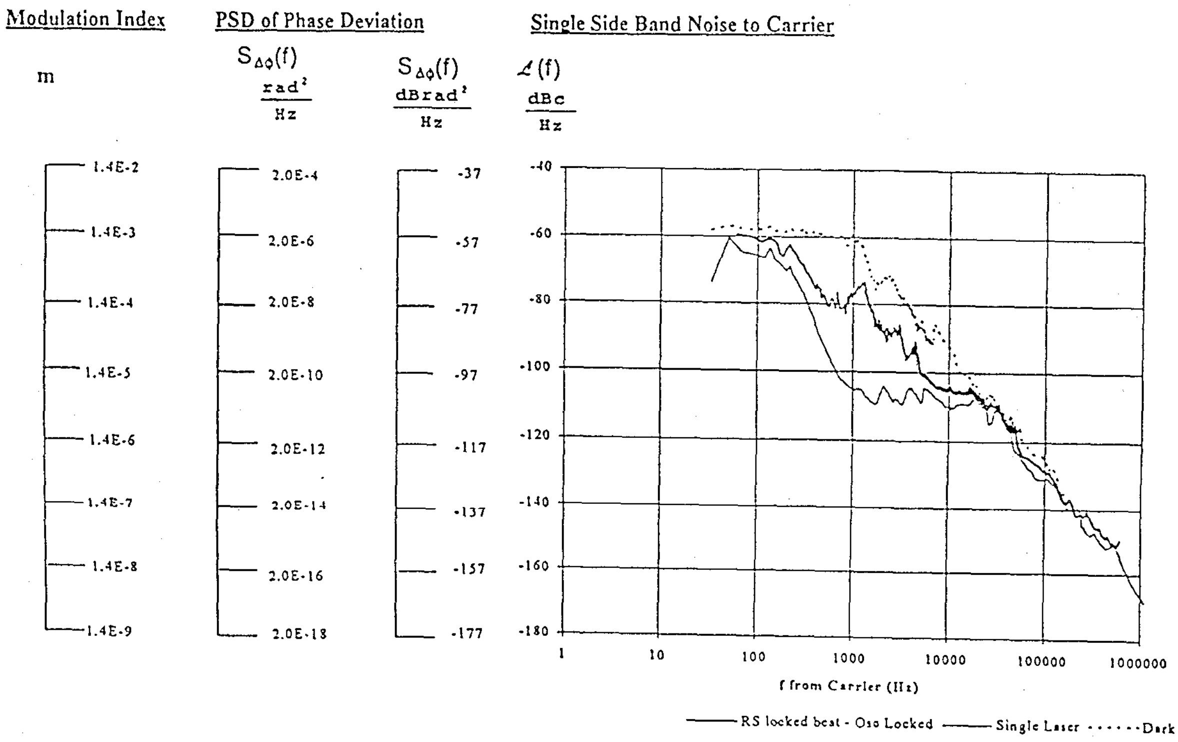

Figure 2 Phase Noise