PHASE-LOCKING OF GRID OSCILLATORS

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ABSTRACT

In this paper, we report results of the first successful phase locking, to our knowledge, of a grid oscillator. A voltage controlled grid with a center frequency of 4.7GHz and with 300MHz electric tuning range was locked to a frequency synthesizer by way of a phase-locked loop (PLL). The loop was designed with 10kHz bandwidth and employs three operational amplifiers. Phase noise was improved to match the specification of the synthesizer locking source.

INTRODUCTION

Spatial power combining technique offers significant advantages for high power millimeter wave power combining sources by eliminating the losses associated with power combining circuitry [1]. The grid oscillator, a promising planar spatial power combining structure, has draw much attention in the past decade due to its capability of combining power from hundred of devices and the potential of integrating the circuits monolithically [2-4]. Voltage controlled grid oscillators have also been reported by different authors with three different configurations [5-8]. To date, the maximum frequency tuning range of 12% has been reported [7]. The phase noise and the frequency stabilization of the grid oscillators, however, have not been addressed directly, although it is generally acknowledged that external stabilization is essential to produced operational signal quality. York, *et. Al.*, have recently done a systematic study of injection locking and phase noise of coupled oscillators that is directly applicable to grid oscillators [9].

Phase locking is more desirable than injection locking because of lock is much less vulnerable to external upset. We have observed that any object present in front of the grid can easily affect the oscillating frequency of the grid oscillator due to a change in the direct coupling between the resonant circuit and free space. In some cases when the grid is illuminated by an interference sources with the frequency very close to the grid oscillator frequency, the grid will injection lock to the interference source.

In this paper we present our design and experiment results of loop phase locked 4×4 grid-oscillator array. The specially designed voltage controlled grid oscillator, which has two outputs, is phase locked to a frequency synthesizer, and hence, the frequency stability of the grid oscillator is the same as that of the synthesizer, and the phase noise is reduced to that of the synthesizer within the loop bandwidth.

VOLTAGE CONTROLLED GRID OSCILLATOR

Voltage controlled grid oscillators have been realized in three ways: namely, two-plane structure in which the transistors and varactors are on different substrates or on the opposite sides of one substrate, single

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plane gate feedback structure, and single-plane source-feedback structure. The comparison of these structures is discussed in [7]. In the work, we use the third structure due its potential wider tuning range or, equivalently, tuning-voltage sensitivity.

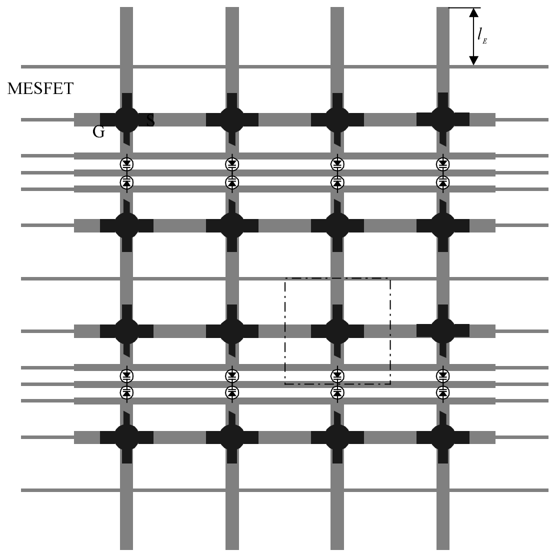


Figure 1. Circuit layout of voltage controlled grid oscillator.

Figure 1 shows the layout of a 16-element single-plane source-feedback voltage controlled grid oscillator array fabricated on a 0.01-inch thick RT/Duroid 5880 substrate. The transistors and varactor chips are attached to the metal grids with silver epoxy and wire bonding. The sizes of the unit cell are 8×8 mm. The transistors used here are Fujitsu GaAs MESFETs FHC30LG and the varactor diodes are Metelics MSV-34.

The analysis of the grid oscillator is based on the assumption that the grid structure is of infinite extent in both x- and y-direction. This assumption makes the theoretical predicted oscillation frequency deviates from the actual frequency. This is especially the case for small arrays. It is also found in our experiments that when the edge elements are not designed properly, the grid oscillates at multiple frequencies. To overcome this problem, adjustable length open stubs are added to the upper and lower edge elements as shown in Figure 1. The maximum effective isotropic radiated power from this oscillator was measured to be 29dBm.

In order to take sample signal from the voltage controlled grid oscillator for phase detection, a small loop antenna was mounted on the mirror surface used to back the oscillator. This loop is made sufficiently small that its presence poses a negligible effect on the oscillator's performance. The power collected by this loop antenna was measured to be around 0.07mW, which is used for phase comparison in the phase detector.

PHASE LOCKED LOOP DESIGN AND PHASE NOISE MEASUREMENT

The purpose of phase locking is to improve the phase noise and frequency stability of the oscillator. The voltage controlled grid oscillator was phase locked to a microwave frequency synthesizer with a basic phase locked loop [10] as shown in Figure 2. The phase detector used is a double balanced loop mixer. The output voltage of the phase detector is a sinusoidal function of the phase difference between the two signals. The high gain loop filter is utilized in the loop, with a loop bandwidth designed at 10 kHz.

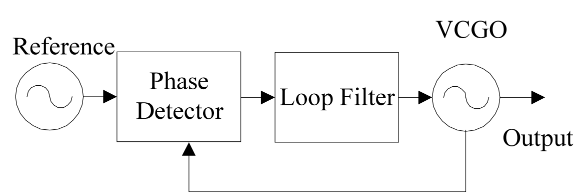
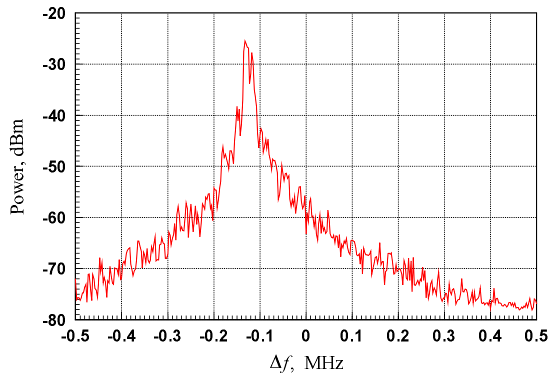
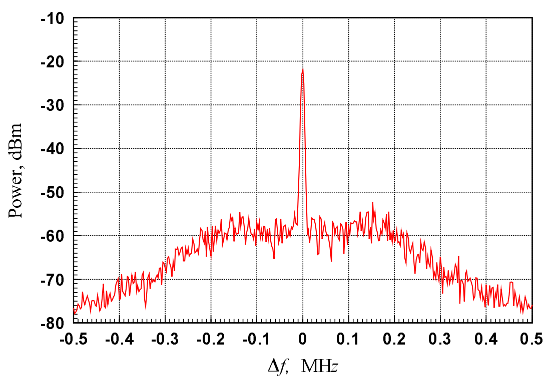


Figure 2. Diagram of the phase-locked loop.

The spectra of the free running oscillator and the phase-locked oscillator are given in Figure 3. From the figure one can see that the phase noise improvement is significant. A rough measurement of the phase noise has been done with a spectrum analyzer [11]. The results, listed in Table 1, are almost the same as the reference frequency synthesizer within the loop bandwidth.



(a). Free running grid oscillator



(b). Loop phase locked grid oscillator

Figure 3. The spectra of free running and loop phase locked grid oscillator; center frequency 4.643GHz, filter bandwidth 3kHz.

Table 1. Measured phase noise of the locked grid and the reference source.

f_{offset}	Locked Grid	Reference
100Hz	73dBc	70dBc
1kHz	78dBc	78dBc
10kHz	84dBc	86dBc
100kHz	88dBc	106dBc
1MHz	107dBc	N/A

The current configuration is intended to accommodate phase modulation of the array *external to the loop*. The narrow loop bandwidth is used to buffer the oscillator against short duration phase reversals. Work is currently underway to perfect this modulation scheme.

CONCLUSIONS

Voltage controlled grid oscillator is successfully phase locked to a microwave frequency synthesizer by loop phase locking technique with significant phase noise improvement. This demonstrated that the phase locking of a quasi-optical oscillator does not necessarily require that the sampling signal must be taken quasi-optically. Using a simple device like loop antenna mounted on the mirror and traditional phase locked loop, one can obtain really good oscillator performance.

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