An Injection Locked Push–Pull Oscillator at Ku-Band

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Abstract— **A new MESFET push–pull oscillator at Ku-band has been designed and tested. This configuration demonstrated 1) a larger subharmonic injection locking range and 2) lower FM noise without using a frequency stabilized dielectric resonator. This new oscillator demonstrated significant potential for use in subharmonic optically synchronized local oscillators in phased array.**

I. Introduction

IN OPTICALLY CONTROLLED phased array antennas for satellite communication at millimeter wave frequencies, fiberoptic links provide frequency reference signals to synchronize distributed local oscillators and data signals to or from T/R modules [1]. High-efficiency, large subharmonic injection locking range, and low FM noise are the major concerns when we select a circuit topology and the device characteristics for the local oscillator design. This letter presents a novel MMIC compatible injection locked push–pull oscillator. Except for some preliminary reports [2], [3], to the best of our knowledge very little information on the concept of free-running push–pull oscillator has been reported. Furthermore, no information is available about the selection of the operating point of transistors for achieving optimum locking range. The goal of this letter is to discuss the operation of a push–pull oscillator and then report on the selection of optimum operating point for maximizing the subharmonic injection locking with a low FM noise characteristics.

The block diagram of the proposed circuit is depicted in Fig. 1. A matching pair of NEC MESFET transistors is separated by a 180° phase shift at the oscillator frequency of f_o so that the FETs operates as a push–pull amplifier, providing the required gain for the push–pull oscillator. The oscillation condition is assured at f_o by providing a parallel positive feedback at f_o from the drain(s) to the gate(s) of the two transistors so that the FET's operates as a push–pull pair. The synchronizing signal is subharmonically injected to the push–pull oscillator through a bandpass network at subharmonic frequency of f_{inj} to stabilize the free running oscillator frequency. The input at the gate of T_2 is not used in the present set of experiments; however, it can be employed as the RF port for a self-oscillating mixer [4]. Instead of using 180° hybrid to combine the output of the oscillator, we split them for the frequency and phase locking experiments [5].

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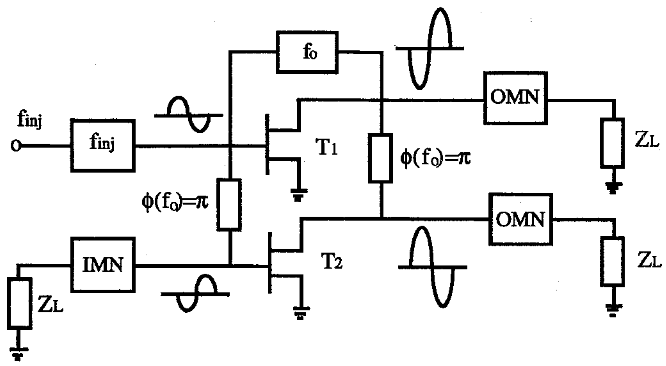

Fig. 1. The schematic diagram of the push–pull injection locked oscillator. The IMN and OMN blocks are the matching circuits for the input and output ports, respectively. The f_{inj} block is the matching circuit for the injection locking signal. The two phase shifter ($\beta 1 = \pi$) at the oscillating frequency provide the phase requirement for the FET pair operating in the push–pull condition. The voltage wave forms indicate the operation situation at different nodes of the transistors T_1 and T_2. The f_o block is the circuit that provides the positive feedback for the oscillator.

II. Experimental Results

To demonstrate the superior performance of this oscillator topology, a circuit was designed and fabricated according to the concept shown in Fig. 1. The nonlinear model of the NEC FET, derived from fitting it to the measured S-parameters at different bias points, was employed in design and simulation of the oscillator via a nonlinear CAD simulator.

The designed circuit was fabricated on RT/Duroid®; the circuit was biased at $V_{ds} = 4V$ throughout all measurements. The spectral power density of the oscillator at bias level of $v_{gs} = -0.61$ V, shown in Fig. 2, indicates a relatively clean oscillation at a frequency of 11.735415 GHz with an output power of ≈8 dBm. A much smaller close-in to carrier phase noise than that of the conventional FET oscillators was measured for this oscillator. The reasons for this low FM noise level can be traced to the differential characteristics of a push–pull oscillator and use of batteries for dc biasing.

The injection locking characteristics of the oscillator was then investigated using an HP 8340B synthesizer as the reference signal. Both the fundamental and second subharmonic injection locking figures of merit was measured. The spectra of oscillator locked to the frequency reference of $f_{\text{inj}} = 11.735415$ GHz and its second subharmonic at $f_{\text{inj}} = 5.8677075$ GHz at the injection power level of -15 dBm are also shown in Fig. 2, depicting a dramatic FM noise reduction for the fundamental injection locked oscillator. The FM noise reduction for the second subharmonic is not as dramatic

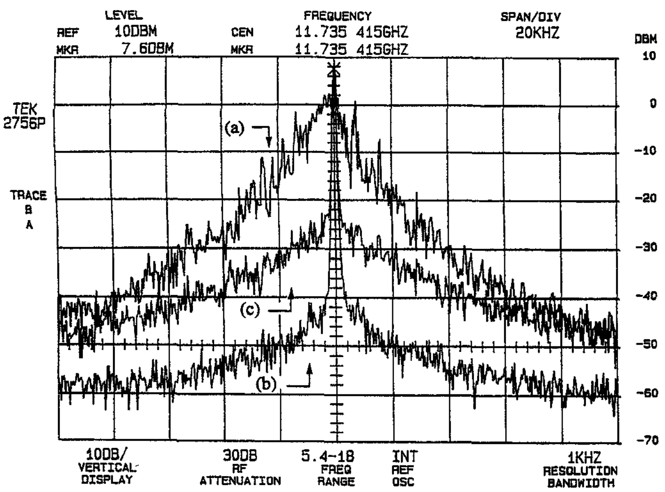

Fig. 2. Measured spectra of the oscillator; (a) free running; (b) fundamentally injection locked; (c) second subharmonic injection locking. (Center frequency of 11.735415 GHz, vertical scale of 10 dB/div, horizontal scale of 20 kHz/div, and resolution of bandwidth 1 kHz.) Injected power level of −15 dBm.

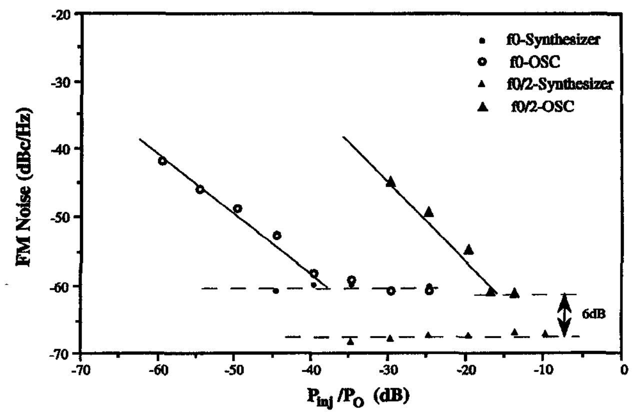

Fig. 3. Measured close-in to carrier FM noise of the injection locked oscillator at 100 Hz offset carrier under fundamental and the second subharmonic injection locking. The *cross over points* between the oscillator intrinsic FM noise and the injected reference signal are identifiably.

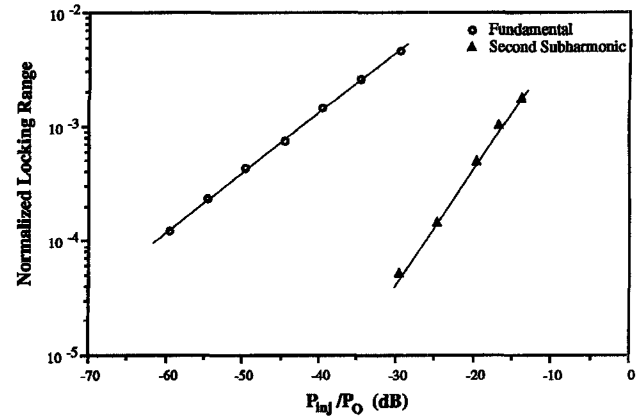

Fig.4. Measured normalized injection locking range at fundamental and second subharmonic injection versus injection power ratio.

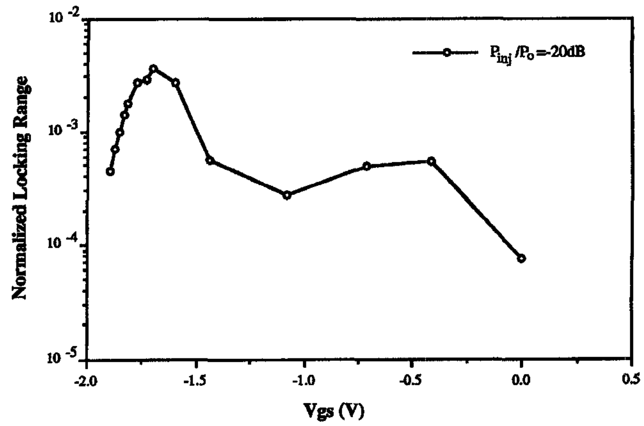

Fig. 5. Measured second subharmonic injection locking range as a function of the transistors' operating point at the injection power ratio as −20 dB.

as the fundamental for the injection level of −15 dBm. A close in FM noise level measurement of the injection locked oscillator as a function of the injection locking power ratio (i.e., P_{inj}/P_o) is shown in Fig. 3. The FM noise measurements were conducted at 100 Hz offset carrier for fundamental and subharmonic injection locking cases. The *cross over point* for the fundamental injection locking is at −38 dB, where as for the second subharmonic is above −17 dB; hence, the close-in FM noise level of the second subharmonic, shown in Fig. 2, was not as low as the fundamental injection locking [6]. At injected power levels above the *cross over points*, the intuitively expected phase noise difference of 6 dB was measured. A plot of the normalized locking range for fundamental and second subharmonic injection locking as a function of the injection locking power ratio (i.e., P_{inj}/P_o) appears in Fig. 4, which shows a low-locking range for the subharmonic frequency.

Improving the subharmonic locking range is possible by changing the nonlinear behavior of the FET transistors. In particular, as the even coefficients of the nonlinear I–V relationship of the transistors are enhanced, the second subharmonic injection locking range is increased [4]. Our goal is to demonstrate the increase in the subharmmonic locking range by the proper selection of the operating point of the transistors. The operating point of the transistors was adjusted from class A to class B by changing the gate to source voltage, V_{gs} from zero to pinch-off voltage. Since the output power of the oscillator depends on the operating point of the transistors, the injected power was adjusted while a fixed injection locking power ratio was maintained, to accurately demonstrate the locking range dependence on the operating point of the transistors. The measured second subharmonic injection locking range as a function of the of v_{gs} for the fixed value of injection locking power ratio of −20 dB, shown in Fig. 5, indicates at least a ten fold improvement at the operating points close to the pinch-off. The peak value in the subharmonic locking range occurs at $v_{gs} \approx -1.7$ V. Therefore, at this operating point, a much lower value of the injection locking power ratio for the cross over points can be obtained.

III. Conclusion

A novel injection locked push–pull oscillator was designed and tested at Ku-band. The second subharmonic injection locking experimental results indicate that a large locking range and low FM noise are easily attainable. To the best of our knowledge, this study is the only reported work demonstrating an optimum operating point for the subharmonic injection locked push–pull oscillator. The compatibility of this design with the MMIC's makes this design topology attractive in the antenna remoting and phased array antenna applications.

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