A Low Phase Noise X-Band Microstrip VCO with Wideband Tuning Range

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***Abstract*—This report presents the design of an X-band Voltage Controlled Oscillator (VCO) with wideband tuning range. The oscillator was fabricated on a planar printed circuit board. The measured free running frequency of this VCO is 9.917 GHz, and a 2,004-MHz tuning range is obtained with an output power varying from 4.39 to 6.45 dBm. The measured phase noise is between -121.81 dBc/Hz and -110.16 dBc/Hz at 1-MHz offset over the whole tuning bandwidth. The average phase noise value at 1-MHz offset is -117.16 dBc/Hz.**

Keywords— voltage controlled oscillator, wideband tuning range.

I. Introduction

This report presents the design and implementation of an X-band Voltage Controlled Oscillator (VCO) with wideband tuning range. It took the first place award in the student design competition #4 titled as ‘Tunable X-Band Oscillator using Planar Resonator’ held at International Microwave Symposium in Phoenix, Arizona, in 2015. This work is also published as a journal article [1].

In microwave systems, an oscillator with low phase noise is vital to obtain good system performance. The increasing demand for X band microwave systems has leaded to a large amount of research in the domain of low cost and low phase noise Voltage Controlled Oscillators (VCOs). The Leeson’s phase noise model is often used in describing VCO phase noise and is based on a linear time-invariant analysis of the circuit [2]. Although oscillators are nonlinear time varying systems, the Leeson’s phase noise model can still be used to investigate the phase noise performance of an oscillator. From the modified Leeson equation given by (1), it is known that the phase noise of oscillators directly depends on the quality (Q) factor of the resonator [3].

$$\mathcal{L}(f_m) = 10log\left\{\left[1+\left(\frac{f_0}{(2f_mQ_L)(1-\frac{Q_L}{Q_0})}\right)^2\left(1\ \frac{f_c}{f_m}\right)\right]\frac{FkT}{2P_{s,av}} + \frac{2kTRK_0^2}{f_m^2}\right\} \quad (1)$$

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A resonator which has a high Q factor is generally designed using a dielectric resonator coupled to a microstrip line at X Band frequencies. Unfortunately, there is a trade-off between tuning range and quality factor of the resonator [4]. VCOs using dielectric resonators, for example, suffer from a narrowband tuning range. Although Yttrium Ion Garnet (YIG) tuned oscillators overcome this trade-off problem, they are not suitable for most microwave systems because they are bulky, expensive, and require complicated power supplies. In response to the above technology needs, the study described here presents the design of a low cost and compact size X Band microstrip Voltage Controlled Oscillator with wideband tuning range.

II. Design Steps

A. Frequency Determining Network

In varactor tuned voltage controlled oscillator designs, the tuning range is generally restricted by the tuning capability of the varactor diode. The broadband tuning range can be obtained by using varactor diodes with low minimum capacitance and a high capacitance ratio [5]. In this study, tuning is provided by a hyperabrupt GaAs varactor diode MACOM MA46H201 which satisfies both these capacitance metrics. In the design of the frequency determining network, the intent was to keep the real part of the input impedance as small as possible at the desired operating frequency range 10-12 GHz since the required negative impedance generated by the transistor is limited over the desired operating frequency range.

B. Oscillator Design

The determination of the transistor is a significant and critical step of the oscillator design. The most important specifications of the oscillator such as output power level and phase noise performance are directly related to the transistor’s performance. As seen from modified Leeson equation (1), the noise figure value of the transistor should be as small as possible to obtain good phase noise performance. Hybrid or hetero junction field effect transistors (HJ-FET) are preferred due to their improved noise figure performance. A super Low Noise GaAs HJ-FET NE3511S02 was selected for the design. This transistor’s minimum noise figure is 0.35 dB at 11 GHz (I_D=10 mA). For the design, the transistor was self-biased by 50 ohm source resistor (ID=12mA and VDD=2.5V). Rogers RO3003 (εr= 3.00 ± 0.04 and $tand$ = 0.0013) 0.76 mm substrate was used for the design. NI AWR Microwave Office was used in the design and prediction of the performance of the oscillator.

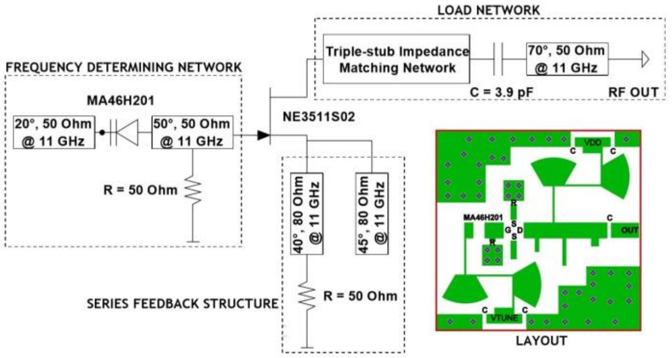

Fig. 1. RF schematic and layout of the designed Voltage-Controlled Oscillator

In this study, the oscillator design was based on the negative impedance approach. In contrast to single frequency oscillators, voltage controlled oscillators need to exhibit a wide turning range and so the significant challenge in this design was to obtain a negative resistance over the wideband tuning range. The common source series feedback topology shown in Figure 1 was used to obtain a negative impedance at the gate on the wideband and high output power at the drain.

III. Fabrication and Measurement

The circuit was fabricated using a laser PCB prototyping technique using an LPKF Protolaser and soldering was done by hand. The implemented circuit was placed in a metal box and is shown in Figure 2.

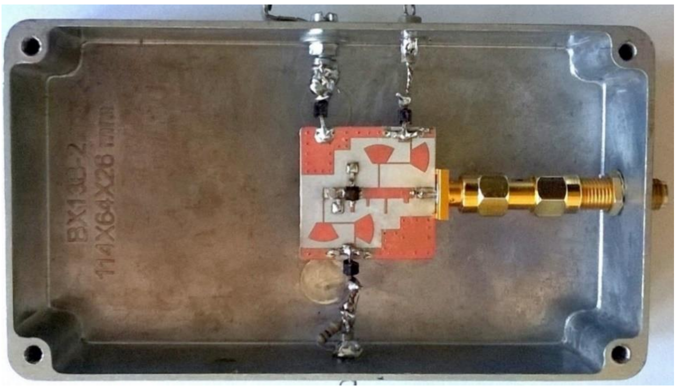

Fig. 2. The implemented circuit in metal box

Oscillation frequency range, output power and phase noise measurements were measured using an Agilent E5052B Signal Source Analyzer (10 MHz – 7 GHz) operating with E5053A Microwave Down-converter (3 – 26.5 GHz) at room temperature (25 ℃). The measurement result of oscillation frequency is presented in Figure 3. The oscillator frequency can be tuned from 9.917 to 11.921 GHz (20.2% tuning range) with a maximum output power variation of 2.06 dB (4.39-6.45 dBm) for a tuning voltage ranging from 0 to 20 V. The oscillator consumes about 30 mW power (2.5 V, 12 mA) with an average output power of 5.43 dBm with 11.6% DC-RF efficiency. The measured phase noise of the designed VCO was between -121.8 dBc/Hz and -110.2 dBc/Hz at 1 MHz offset over the whole tuning bandwidth, as seen from Figure 4.

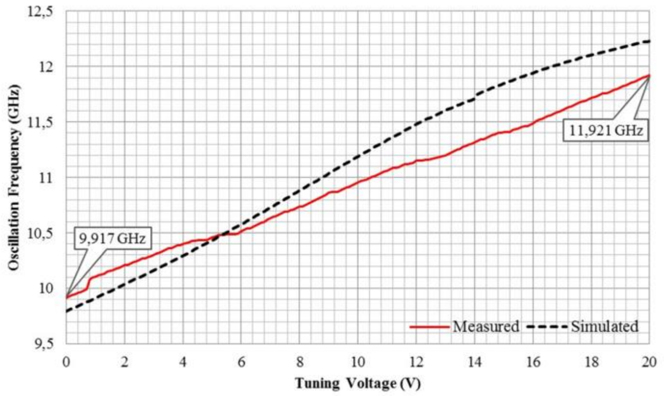

Fig. 3. Measured and simulated oscillation frequency of VCO versus tuning voltage

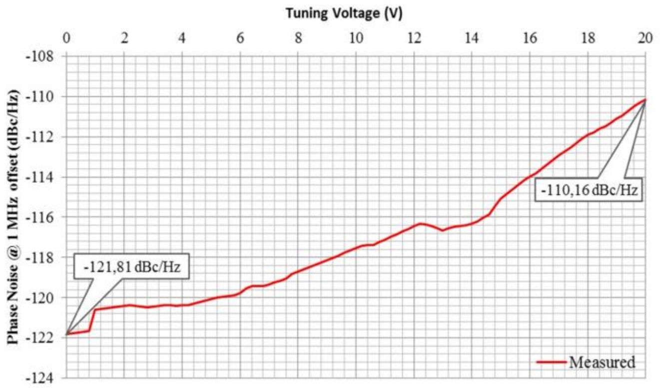

Fig. 4. Measured phase noise @ 1 MHz offset of VCO versus tuning voltage

IV. Motivation and Career Plans

The IEEE MTT-S Undergraduate/Pregraduate Scholarship motivated me to further pursue research in the RF/Microwaves area. This project and my trip to IMS 2015 in Phoenix, Arizona (funded by this scholarship) was important in showing me the influence of this research area in many applications, as well as the wide range of opportunities present in this field. I graduated from the Istanbul Technical University, Turkey with a Bachelor's degree in 2015. I'm currently PhD student at Sabanci University, Turkey. I would like to continue working in the field of Microwave/Millimeter-wave integrated circuit design.

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