A New Phase Noise Reduction Technique For MMIC Oscillators*

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ABSTRACT

A new technique for reducing oscillator phase noise has been demonstrated. The technique utilizes a pair of limiting diodes to keep the metal-semiconductor field-effect transistor operating in a linear region. An X-band monolithic microwave integrated circuit oscillator was designed, fabricated, and tested to demonstrate the concept. A reduction of 15 dB in phase noise at 5 kHz from the carrier was measured.

INTRODUCTION

Several techniques have been proposed to reduce phase noise in oscillators. Phase noise in oscillators is dominated by low-frequency 1/f noise up-conversion, which is caused by mixing effects between the carrier and the noise near DC which follows 1/f behavior, the common one being 1/f. Chen et al. [1] showed that eliminating even powers of the oscillator's nonlinearity (in the current-voltage relationship) will weaken the mixing effect and reduce near-carrier noise. The technique was implemented at microwave frequency [2]. A balanced oscillator using a source-coupled pair of transistors was built to reduce the resistive modulation, which contributes to 1/f type noise up-conversion. A reduction in phase noise was achieved using a balanced configuration. However, Hearn [3] pointed out some of the limitations of the technique used by Chen, and attributed the reduction in phase noise in Riddle's experiment [2] to changes in the capacitance-voltage relationship of the transistor, not as a consequence of Chen's technique. He further showed that, even in theory, such a technique cannot completely eliminate 1/f noise up-conversion, and that its success is limited to special circuit topologies. Prigent et al. [4] reduced 1/f noise up-conversion in a metal-semiconductor field-effect transistor (MESFET) oscillator by using appropriate low-frequency feedback between the drain and the gate. In addition to the work described above, numerous attempts were made to raise the quality factor of the oscillator's resonant circuit in order to reduce phase noise.

This paper presents a new phase-noise-reduction technique which can be used in combination with any of the above-named techniques to minimize 1/f noise up-conversion. This technique is very general and can be applied to most circuit topologies at frequencies ranging from RF to millimeter-wave (1 to 100 GHz). It is ideal for monolithic implementation and should also reduce phase noise in feedback-model oscillators, which have recently been reported to have respectable phase noise. The technique employs two limiting (clipping) diodes to symmetrically clip the amplitude of the oscillation voltage wave before the oscillation drives the transistor (MESFET or bipolar) into the nonlinear region, therefore maintaining the transistor in a linear region during operation. This, in turn, reduces the mixing effect responsible for 1/f noise up-conversion. This paper reports the first demonstration of applying such a technique to a MESFET monolithic microwave integrated circuit (MMIC) oscillator with a resulting improvement in phase noise.

MMIC DESIGN AND ANALYSIS

The current work was necessitated by a requirement for a very stable local oscillator source for satellite application using MMIC technology. To achieve this, a dielectric resonator oscillator (DRO) that can be phase locked was selected. The designed frequency of oscillation was 10.3 GHz. The negative resistance (or reflection amplifier) design approach was selected, and a buffer amplifier was also included at the output of the DRO. Both common-gate and common-source configurations are candidates for the oscillator topology. However, the common-gate configuration has the advantage of generating strong negative resistances in a narrow band by inductive feedback.

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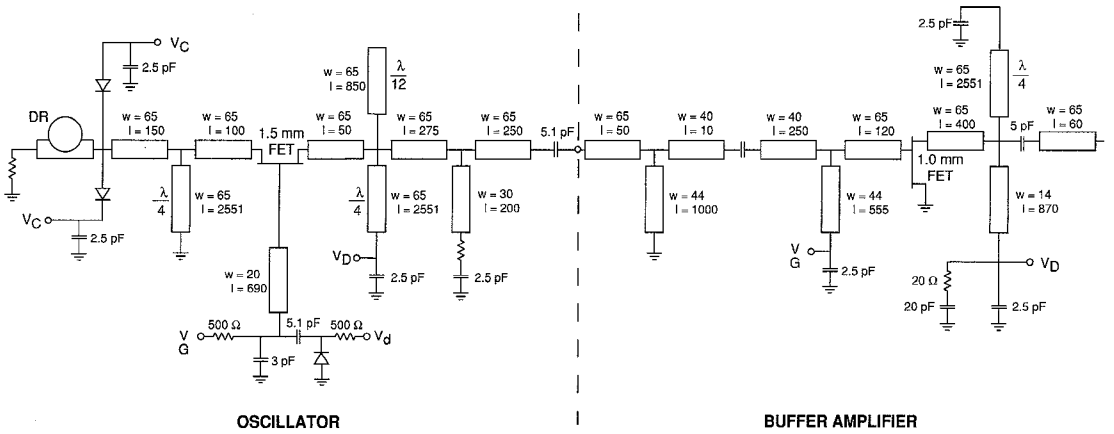

Figure 3. Circuit Schematic of Integrated Oscillator

was defined by the e-beam direct write process. The Si_3N_4 dielectric for the capacitors and circuit passivation was deposited using plasma-enhanced chemical vapor deposition (PECVD). Via-hole technology was used to achieve low-inductance grounding for the MESFETs and other elements. The fabricated MMICs and packaged oscillator are shown in Figure 4.

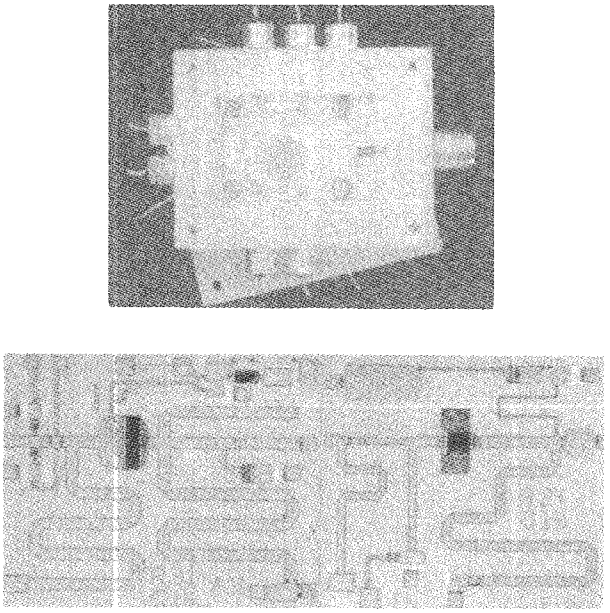

Figure 4. X-Band MMIC Oscillator (a: MMIC, b: Packaged Oscillator)

MEASURED RESULTS

Phase noise was measured using the HP phase noise measurement system and the corresponding software package at X-band The best oscillator that was measured provided a phase noise of -115 dBc/Hz at 100 kHz from the carrier (Figure 5).

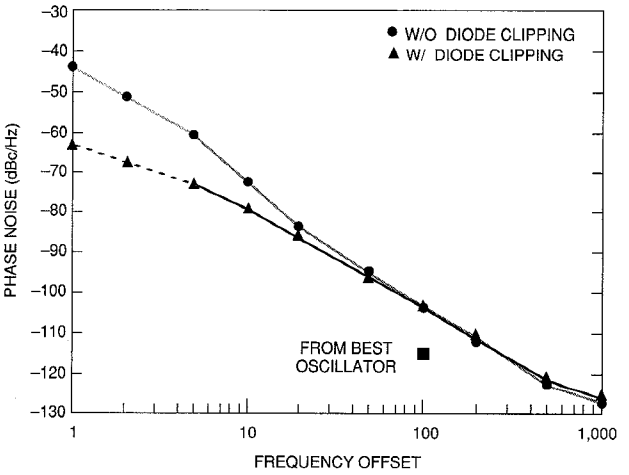

Figure 5. Effect of Clipping Diodes on Phase Noise

To determine the effect of the clipping diodes on noise performance, six measurements of phase noise were taken from another oscillator, with the lower clipping diode biased at Vc = -1 and the upper clipping diode at V_c = +1 V. A similar set of measurements was taken with V_c disconnected. In this case, both diodes were reverse bias and presented an open circuit to the oscillation waveform. The average of each set of data (with/without clipping) was computed and plotted, as shown in Figure 5. This figure shows that phase noise was reduced by about

The basic circuit topology of the DRO is shown in Figure 1. To implement the new phase-noise-reduction technique, a pair of diodes was included in the oscillator circuit between the source of the MESFET and the DRO (V_1 in Figure 1). Although adding a pair of diodes (along with their 1/f noise sources) introduces new nonlinearities in the circuit, overall 1/f noise will be reduced since the MESFET is operated in a linear region. In other words, the nonlinearities and 1/f noise sources introduced by adding the pair of diodes are small compared with those of the MESFETs.

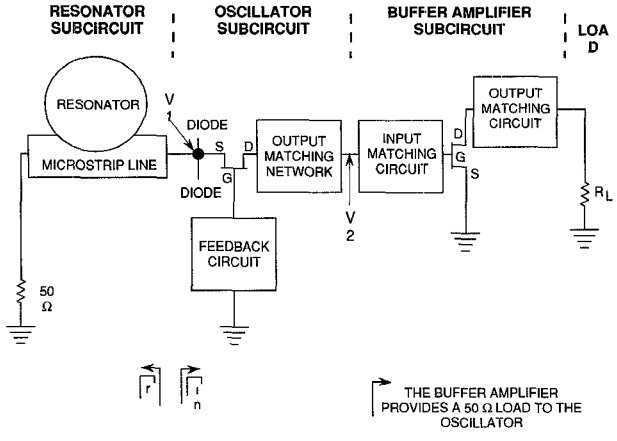

Figure 1. Basic Circuit Topology of Integrated Oscillator

The function of the two diodes is to limit (clip) the oscillation wave symmetrically. The bias voltage of the diodes, V_c, controls the amount of clipping, with $V_c = 0$ corresponding to maximum clipping. If V_c is not connected, the capacitor at the end of each diode clamps the diode to a voltage equal to V_{max} of the oscillation wave. Therefore, in the absence of V_c, the capacitors charge until they reverse bias the diodes, making them invisible to the circuit.

An analytical study was first performed in which the diode effect was analyzed using the large signal CAD LIBRA program at different V_c's. As can be seen in Figures 2(a) and 2(b), the voltage waveform at the diodes (V_1 in the figures) is clipped to a value equal to (V_c + 0.7) V (0.7 V is the p-n junction forward threshold voltage). The simulated output signal,V_2, can also be seen in Figures 2(a) and 2(b).

Spectral analysis of the output signal (large signal analysis) predicted less harmonic content when the signal was clipped than when it was not clipped, indicating that the circuit's nonlinearity was reduced. Figure 3 is a circuit schematic block diagram of the designed oscillator.

A tuning varactor diode has been included in the feedback circuit of the oscillator. Changing the diode's capacitance through bias voltage modifies the inductance

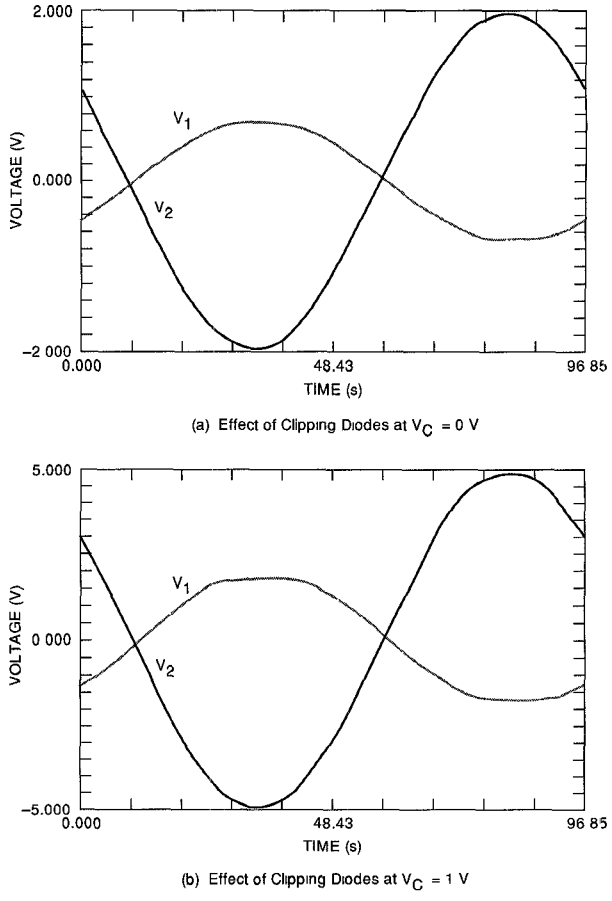

Figure 2. Simulated Oscillation Waveforms at FET and Oscillator Output

of the feedback circuit, resulting in a shift in oscillation frequency. Therefore, the oscillator is a voltage-controlled oscillator (VCO), which can be used in a phase-locked loop to achieve less phase noise and higher stability.

A buffer amplifier was cascaded with the oscillator subcircuit to accomplish two objectives: to provide a 50-Ω load to the oscillator subcircuit independent of the actual load resistance at the output of the amplifier, thus preventing frequency pulling; and to amplify to the oscillator's signal, which was reduced by clipping to a level appropriate for systems integration.

In order to reduce the harmonics generated by nonlinearities, second and third harmonic traps were included in the oscillator and the buffer amplifier designs to filter these harmonics from the output signal.

MMIC FABRICATION

The oscillator circuit and buffer amplifier were fabricated using inhouse standard MESFET MMIC processing. The active layers were grown on gallium arsenide (GaAs) substrate using molecular beam epitaxy. The 0.5-mm-gate

7 dB 10 kHz and 15 dB at 5 kHz from the carrier. Below 5 kHz, the phase noise measurments became less accurate. However, as can be seen from the plots, improvement of phase noise through the reduction of 1/f noise upconversion in oscillator operation can be obtained.

CONCLUSIONS

Reducing an oscillator's nonlinearity by operating its MESFET in a linear region has been shown to reduce the mixing effect responsible for low frequency l/f noise upconversion. A general phase-noise-reduction technique was presented and experimentally verified. Reduction in phase noise was accomplished at 20 kHz and below from the carrier in an X-band MMIC, GaAs MESFET-based oscillator.

The new technique is ideal for GaAs monolithic implementation, and can also be applied to silicon bipolar-based oscillators for phase-noise reduction. Another advantage of the new technique is that it can be implemented with any other phase-noise-reduction technique to achieve further improvement in oscillator performance.

ACKNOWLEDGMENTS

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