MONOLITHIC, W-BAND, VOLTAGE-CONTROLLED OSCILLATOR

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ABSTRACT

A 77 GHz monolithic voltage-controlled oscillator is described. The active element is a "low-noise" pseudomorphic HEMT. Tuning is achieved with a second HEMT in which the source and drain are connected and the gate-channel capacitance forms a varactor diode. The oscillator has a 3 dB tuning bandwidth of 230 MHz and an output power of 300 μW.

INTRODUCTION

As monolithic millimeter-wave components become less expensive and more reliable, the practicality of using radar in private automobiles grows. Millimeter-wave frequencies have become the carrier choice, due to the small size of the antennas required, spectrum availability, and the relatively short propagation distances. The Federal Communication Commission is proposing to designate four millimeter wave bands for use by vehicular radar systems [1]. These bands are 47.2–47.4 GHz, 76.0–77.0 GHz, 94.7–95.7 GHz, and 139.0–140.0 GHz.

Considerable activity has already focused on the 76.0–77.0 GHz band [2], with Europe having allocated 100 MHz bandwidth in this range for FM-CW anti-collision radar [3]. The rf power sources for these applications are required to produce 10–100 mW and tune over a few hundred MHz. Gunn and IMPATT diodes have been traditionally used for producing rf power at these frequencies; however, these device technologies can not be readily integrated with amplifiers, switches, and mixers required for a complete radar transceiver. For automotive radar, small area, MMIC chip sets must be developed to minimize production costs. This paper describes a first pass at designing a suitable monolithic 77 GHz voltage-controlled oscillator (VCO).

DESIGN

This 77 GHz VCO design is based on a successful 60 GHz oscillator [4] (see Fig. 1), designed at Cornell and fabricated by Martin-Marietta. The 60 GHz chip uses a 0.1 μm-gate-length device with a total gate periphery of 200 μm (8×25 μm). A small-signal equivalent circuit model for this device was modified to approximately simulate large-signal conditions [5], and the necessary loads at each terminal for oscillation were then computed using this model [6].

Each of the two source terminals is connected to a length of line feeding the resonant element, referred to as a "resonant-tee" [7]. Oscillation occurs when the input impedance of the tee approaches infinity, which is where the total length of the CPW line is a quarter-wavelength. The gate has a short length of

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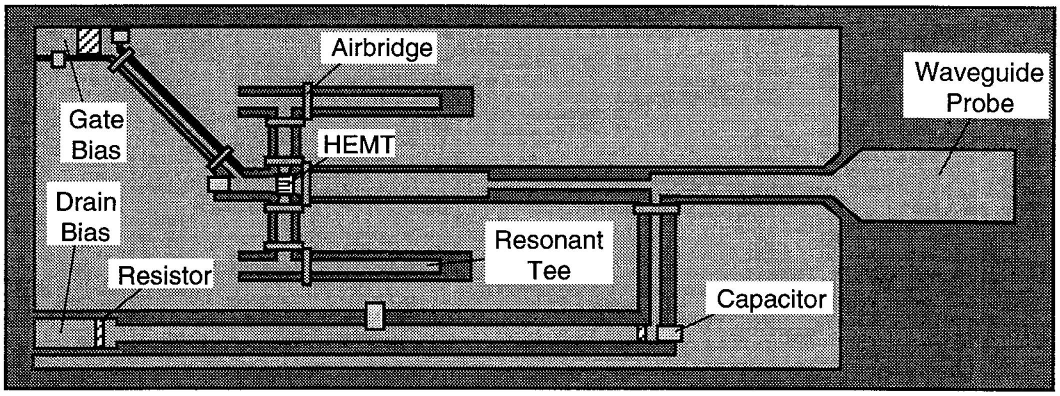

Figure 1: 60 GHz CPW oscillator design upon which the 77 GHz VCO circuit is based. Lighter shaded areas are metallized. Via holes connect front and backside ground planes for suppression of parallel plate modes. Chip size: 1.3 mm by 3.4 mm.

line connected to ground, through a dc blocking capacitor, and the drain circuit consists of a series of lines to match to the load impedance. The output power is launched into a V-band (WR-15) waveguide via the E-field, waveguide probe integrated on the chip.

Gate and drain bias is applied through the two bias circuits, which contain shunt capacitors and series resistors (to suppress low-frequency bias oscillations). With a drain bias of 5 V the oscillator produces over 25 mW of rf output power, and it has a maximum dc-rf efficiency of 11%.

To create the 77 GHz VCO shown in Fig. 2, the length of the resonant-tees were appropriately scaled, the transmission lines at the gate and drain were adjusted, and a varactor was added into the gate circuit, as diagrammed in Fig. 3. The varactor is another HEMT with a smaller gate periphery ($2\times25\,\mu$m). The drain and source terminals of this device are connected directly to the ground plane, and the gate-channel capacitance is used to tune the oscillator's frequency by varying the bias on the gate.

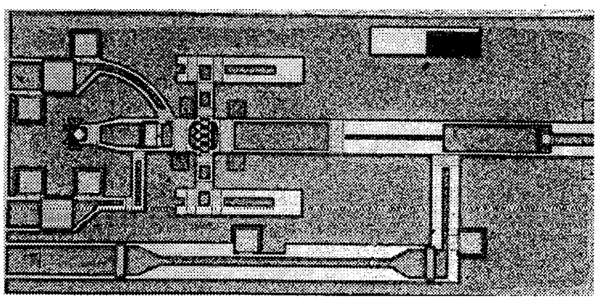

Figure 2: Photograph of the 77 GHz VCO chip The output CPW line on the right hand side feeds a W-band probe.

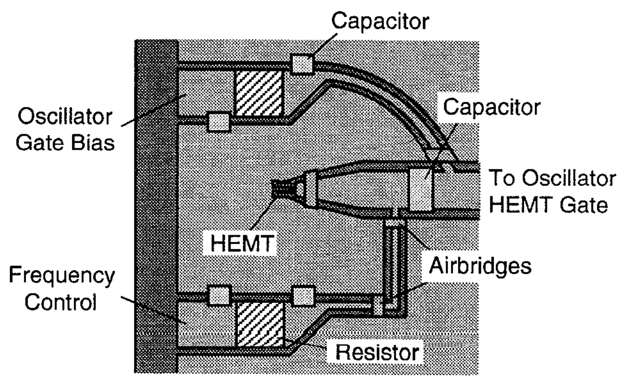

Figure 3: In the 77 GHz VCO a varactor is placed in the gate circuit. The varactor is a $2\times25\,\mu$m HEMT with the drain and source grounded.

MEASUREMENTS

The original designs were based on Martin Marietta's power pHEMT process; however, these circuits were fabricated on a low-noise wafer. Although the s-parameters differ significantly for the two processes, the final operating point was only shifted slightly below the design frequency. Best results were obtained for a circuit in which there was only one operating varactor gate finger. The resulting varactor capacitance is reduced roughly by half.

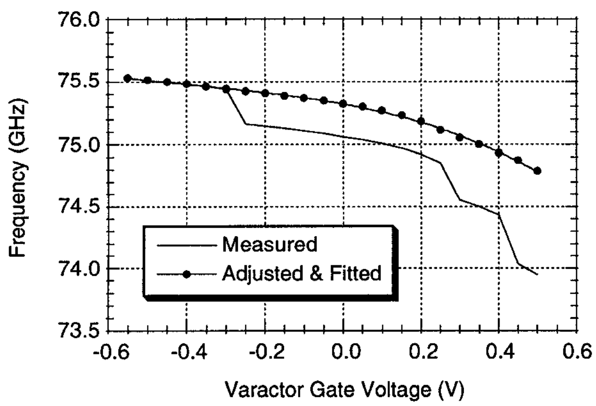

Figure 4: Measured frequency versus varactor-voltage curve indicates three mode changes. The points indicated by the dots show what the curve looks like without the frequency jumps—this is fitted well by a third-order polynomial.

The chip is epoxied onto a carrier and has the W-band probe extending into waveguide (WR-10), with a waveguide backshort located above it. Attached to the waveguide, through a transition, is an E-band, calibrated, harmonic mixer which is connected to a spectrum analyzer. This was used for measuring the oscillator's frequency (see Fig. 4) and approximate output power (Fig. 5) with a bias of $V_{ds} = 4.5\,\text{V}$ and $V_{gs} = 0.5\,\text{V}$

In the frequency curve there are three jumps of 200–300 MHz. These are places where the oscillator changes modes and the output power peaks. Were the

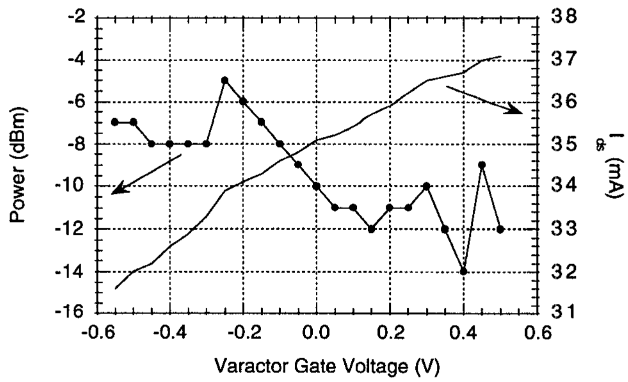

Figure 5: Measured power (to nearest dB, with no adjustment made for measurement losses) and oscillator HEMT drain current as a function of varactor bias.

oscillator to remain in the same mode throughout the tuning range, the curve would look like the "adjusted" one of Fig. 4. As shown in the figure, this smooth curve fits well to a third-order polynomial, and suggests that the varactor capacitance is a simple function of the bias.

The oscillator has a 3 dB, single-mode tuning range of 230 MHz and a maximum output power of approximately 300 μW. This first design operates from 74 to 75.5 GHz, or 2% below the proposed automotive radar band. In future iterations, with the multiple modes eliminated, the data here suggests that over 500 MHz of tuning is achievable, and since the frequency versus voltage curve is a cubic equation, it can be characterized with four polynomial coefficients. This would allow a microcomputer-based system to be factory-programmed easily for generation of the linear frequency sweep needed in FM-CW radar.

ACKNOWLEDGMENTS

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