Monolithic Ka-Band VCOs

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ABSTRACT

Two distinct monolithic GaAs Voltage Controlled Oscillators have been developed: a Gunn diode based circuit and a FET based circuit. The Gunn VCO design incorporates 14 Gunn diodes, a varactor diode, power combiner, matching network and bias on a single integrated chip. The Gunn oscillator has delivered 125 mW at 32 GHz and 70 mW at 40 GHz. This is considerably above power levels reported for Ka-band Monolithic Oscillators to date. The FET circuit utilizes a 1/4 µm x 200 µm GaAs MESFET; it has produced up to 20 mW output power. This is the first publication of a millimeter wave, monolithic MESFET VCO to our knowledge.

INTRODUCTION

Monolithic microwave integrated circuits fabricated on GaAs substrates have shown several attractive advantages over hybrid technology in the area of cost (1), (2) and in some cases RF performance (3). For the most part at millimeter wave frequencies, amplifiers, mixers, switches, attenuators and a few other components have shown performance results that can rival their hybrid counterparts. In the area of MMW oscillators however, performance of the monolithic based units previously reported has been well below hybrid technology. The Gunn diode based monolithic oscillators of (4) and (5) have shown 4 mW CW at 41 GHz and 1.7 mW at 35 GHz, respectively. The Gunn diode based (with varactor tuning) monolithic VCO reported here has demonstrated up to 125 mW CW at several frequencies between 30 and 41 GHz with up to 500 MHz of electrical tuning bandwidth.

The FET based VCO reported here has produced up to 20 mW CW output power at 35 GHz and over 300 MHz of voltage tuning.

Monolithic oscillators with this type of performance offer a cost effective alternative to hybrid technology for high volume applications.

GUNN CIRCUIT DEVICES

The devices used in the monolithic Gunn VCO include a Schottky barrier varactor diode and 14 Gunn diodes. The varactor has a zero bias capacitance of approximately 0.7 pF and a 2:1 capacitance swing from 0-10 VDC. Typical series resistance on these diodes is three to five ohms. The Gunn diodes are circular with a diameter of approximately 28 µm and N_0L products in the 3.0 - 3.6 x 10^{12}/ cm^2 range. Figure 1 is a SEM photograph of a monolithic Gunn diode. The cathode connection to all diodes is accomplished using airbridge technology. These bridges are plated to approximately 6 µm thick to enhance thermal heat sinking.

GUNN CIRCUIT DESIGN

The circuit design began with thermal resistance calculations to determine the maximum allowable input wattage per device. The calculations were based on the thermal conductivity of the 150 µm thick GaAs substrate and knowledge of the maximum allowable temperature rise for the Gunn diode active area. The desired input wattage per device then defined the maximum allowable Gunn device area, and the number of devices required to achieve the desired ouput power assuming typical efficiency for Ka-band Gunn diodes.

The minimum distance separating each device was determined by the thermal consideration that approximately 90% of the heat dissipated by the diode is within a

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45° cone under the device. To provide thermal isolation, the devices must be separated by a distance at least twice the substrate thickness plus the device diameter.

With the device diameter and physical spacing determined as described above, a Wilkinson radial power combiner was chosen to power combine 14 Gunn devices each of which is 28 μm in diameter. The circuit layout is illustrated in Figure 2. Epitaxial resistors were located at a radius corresponding to a high impedance point on the radial lines to suppress out-of-phase oscillation between devices. Ground returns for the Gunn devices are provided by via holes contacting pads located beyond the radial combiner. Two Gunn devices contact each ground pad by airbridges. A resonant length of microstrip line is positioned between the center of the power combiner and the matching transformer which transforms the magnitude of the negative resistance and the reactance of the circuit to a 50 ohm real load. A parallel line coupler along the microstrip line couples the Schottky tuning varactor to the circuit. Varactor and Gunn bias voltages are applied through single section RF chokes also on the monolithic circuit.

The circuit design was accomplished with the use of the Super Compact CAD program. The approach taken was to define the 14 diode combiner structure and its seven ground pads and via holes as one circuit that was used as terminating impedance for the oscillator circuit. The Gunn device impedance was determined from (6). In the computer model, the real part of the Gunn diode impedance was defined as a positive resistance equal in magnitude to the negative resistance of the device. A good match with zero phase then simulates oscillation conditions. This approach lends itself to a realizable scale model in which resistors and lumped reactances simulate Gunn diodes.

In the computer model, the optimization routine was used to iterate the resonator, varactor coupler and matching transformer to provide a good conjugate match at the desired frequency. The performance predicted by the computer model is illustrated in Figure 3 in the form of matching to the power combiner (S11). Varactor capacitance was chosen for maximum tuning bandwidth as predicted by the computer model. The model predicted 300 MHz of tuning.

The circuit design was verified with a scale model utilizing copper tape on stycast substrate at approximately 1 GHz.

GUNN VCO MEASURED PERFORMANCE

Output powers in excess of 125 mW CW have been obtained. Figure 4 illustrates the output power and frequency tuning of a unit providing 125 mW and 60 MHz of tuning at a center frequency of 32 GHz. Several versions of the circuit have been made, including variations in the degree of varactor coupling and a number of center frequencies ranging from 30 GHz to 41 GHz.

A tradeoff between output power and tuning bandwidth has been observed, Table I illustrates typical output power and tuning bandwidths for the coupler iterations in the 32 GHz circuit. Likewise, the maximum output power obtained decreases as the center frequency increases, Table II indicates output power obtained for various circuit iterations.

Table I

Output Power vs. Varactor Tuning
Monolithic Gunn VCO at 32 GHz

Power	125 mW	70 mW	10 mW
Tuning BW	60 MHz	180 MHz	500 MHz

Table II

Output Power vs. Center Frequency
with approximately 60 MHz tuning BW

Frequency	32 GHz	36 GHz	40 GHz
Power	125 mW	100 mW	70 mW

FET DEVICE

The 0.25 μm gate length MESFET device was fabricated on high quality MBE materials. The material structure consists of 5000Å N+ cap layer doped to 3×10^{18} cm^{-3}, 1000Å of channel layer doped to 6×10^{17} cm^{-3} and one micron undoped GaAs buffer layer grown on LEC semi-insulating GaAs substrate.

The device geometry consists of six unit gate widths of 33.3 microns with three gate feeds connected by airbridges to the central gate pad.

FET CIRCUIT DESIGN

The FET VCO circuit design began with the formation of equivalent circuit models for the 1/4 μm FET to be used, at 15% Idss, 50% Idss and 100% Idss. The FET model is based on dc characterization and S-parameter measurements from 1.5 GHz to 26.5 GHz. The FET model used was the standard 13 element FET model in the Touchstone CAD program. Element values were iterated to fit the measured data.

The FET model was then embedded in a Touchstone circuit file depicting a Colpitts oscillator in which the reactive elements are realized with open circuit microstrip stubs. The topology of the circuit is illustrated in Figure 5. The output matching element was chosen to be a parallel line coupler to provide a dc block as well as output matching. Dimensions for the parallel line coupler were iterated to provide a transformed load impedance equal to one half of the magnitude of the small signal negative resistance plus the small signal conjugate reactance. This condition should deliver optimum power transfer assuming cubic non linearity of the FET in saturation.

Open circuit stubs on the source and gate were iterated to provide narrow band instability at the desired oscillating frequency. The VCO mode was designed by optimizing the circuit with three FET models corresponding to 100%, 50% and 15% Idss.

Using this technique, a tuning bandwidth of 500 MHz was simulated on the computer.

MEASURED PERFORMANCE

As much as 20 mW output power was obtained from the microstrip monolithic MESFET oscillator operating at 7 VDS and 60% Idss (about 35 mA). This circuit demonstrates over 300 MHz of tuning bandwidth with good linearity as illustrated in Figure 6. Thermal stabilities for this circuit are -5 MHz/^{o}C and -.05 dB/^{o}C. Phase noise is -85 dB_C/Hz 1 MHz off carrier when operating at 15% Idss.

Table III below constrasts the performance of the monolithic Gunn and FET VCOs.

Table III

	CW Output Power	Efficiency	Tuning Bandwidth	Freq. Stabil.	Power Stabil.
Gunn VCO	125 mW	2%	60 MHz	-5.5 MHz /^{o}C	-.05dB /^{o}C
FET VCO	20 mW	8%	300 MHz	-5.0 MHz /^{o}C	-.05dB /^{o}C

CONCLUSION

Gunn and FET based, Ka-band monolithic VCOs have been successfully developed. These circuits rival the performance of hybrid Ka-band VCOs

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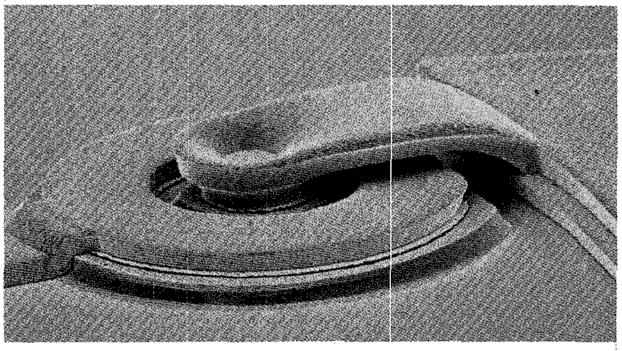


Figure 1 Monolithic Gunn Diode

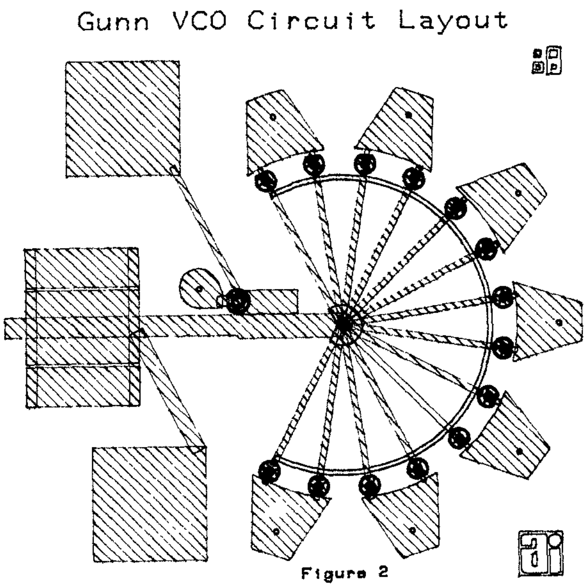


Figure 2

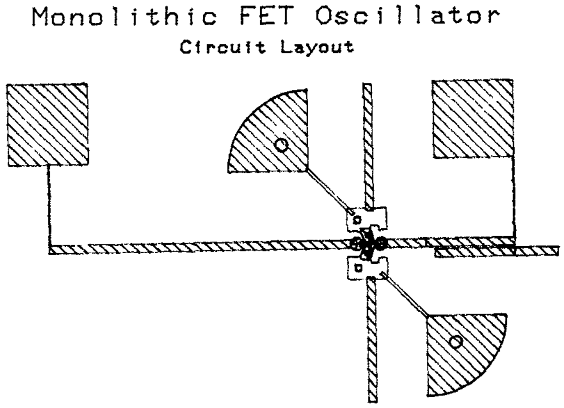
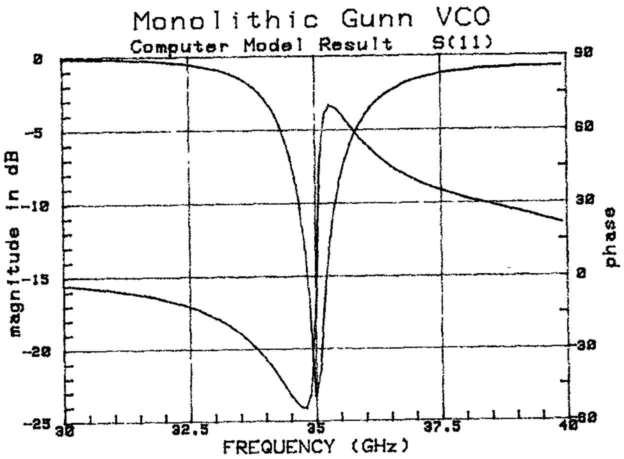


Figure 5



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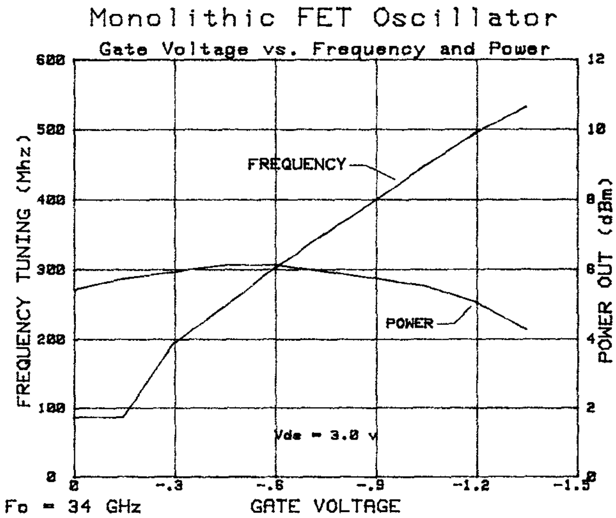

Figure 6a

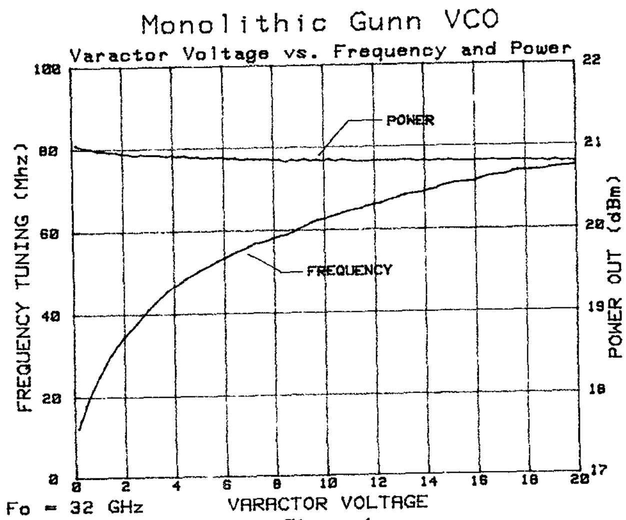

Figure 4

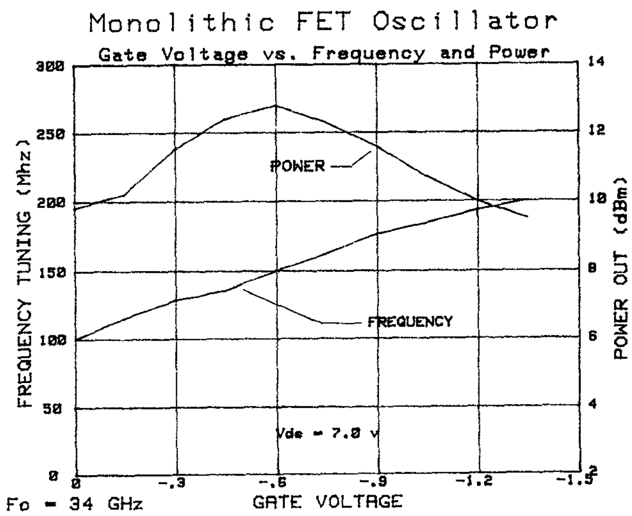

Figure 6b