MILLIMETER-WAVE MONOLITHIC GaAs IMPATT VCO

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ABSTRACT

A monolithic voltage controlled oscillator (VCO) has been constructed using a GaAs double-drift Read IMPATT as the active element and a similar diode biased below breakdown as the varactor. The chip produced 120 mW peak power over an electronically controlled tuning range between 47 to 48 GHz. A computer analysis based on characterized circuit parameters has been used to predict the performance of the chip.

INTRODUCTION

The similarity of doping profile for hyperabrupt varactors and GaAs Read IMPATT diodes suggests an approach to the development of a monolithic varactor tuned oscillator.[1,2,3]

Figure 1 shows the profile of the doping concentration and the electric field within a Read IMPATT. For the IMPATT diode, the spike determines the avalanche zone and improved the DC to rf conversion. When the diode is biased below breakdown voltage, it can also be used as a varactor.[4]

At zero bias voltage, the built-in potential is confined within the charge spikes. The depletion width is the spacing between charge spikes. As the reverse bias voltage increases, the depletion width widens toward the edge of the device. Normally, the depletion region will reach the device edge near the breakdown voltage as required by the IMPATT design. Therefore, the capacitance ratio of an IMPATT diode is roughly the ratio of the total device length over the avalanche zone length. This ratio is generally greater than three for a Q-band diode.

In the present work, a double-drift Read IMPATT doping profile was used to test the VCO design. Although double-drift IMPATTs have higher efficiency than single-drift diodes, the low mobility of holes results in a high parasitic series resistance and reduces the device Q when a double-drift IMPATT is used as a varactor. This effect will be seen in the test data which follows.

CIRCUIT DESIGN

The circuit design was based upon the monolithic IMPATT oscillator reported in reference 5. To incorporate the varactor into the oscillator, the following issues must be considered:

1. The varactor requires a separate dc bias voltage. Therefore, the IMPATT and the varactor must be DC isolated.

2. The varactor will be rf-coupled to the oscillator. Stronger coupling will give a greater frequency tuning range, but the parasitic series resistance in the varactor will load the oscillator, thereby reducing the output power.

A coupled line is used to establish the interaction between the IMPATT and varactor as shown in Fig. 2. The oscillator resonator is a section of 25 ohm microstrip line. The output coupling is made through a high impedance tap. A long taper is used to transform the impedance from 50 ohm to 90 ohm. The location of the 90 ohm tap determines the degree of load coupling. The varactor is connected in shunt to another 25 ohm microstrip line section, which is located alongside the resonator (forming a coupled line). The gap between the line elements is 10 µm. The remaining circuitry provides the varactor bias.

An analysis of coupled lines appropriate to the present case is given in reference 6. The highest sensitivity to varactor tuning occurs when the coupled line length is about a quarter wavelength. A detailed design was accomplished with the aid of a computer. Measured circuit parameters[4] were used in the analysis.

EXPERIMENTAL RESULTS

The monolithic VCO was fabricated on a double-drift Read profile GaAs IMPATT wafer. The fabrication procedure is described in reference 5. A picture of the completed chip is shown in Figure 3.

A transition between waveguide and microstrip line was built using anti-podal finline. A bias tee is also included in the transition for the IMPATT diode. The insertion loss of the transition is in the range 0.5 to 0.8 dB over the entire waveguide band.

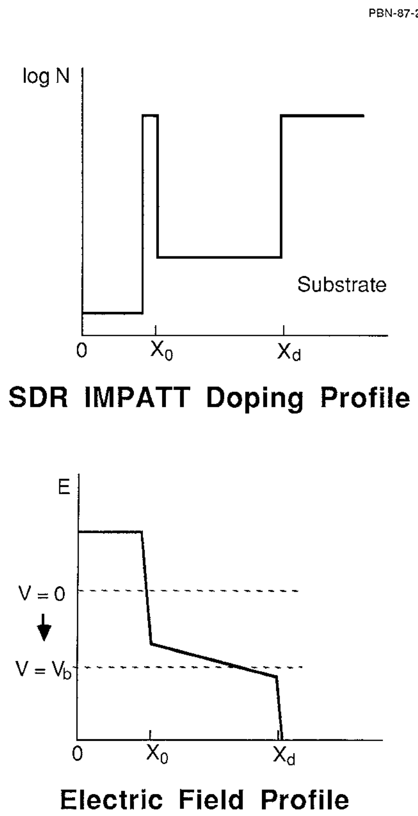

Fig. 1. Doping Profile and Electric Field within a Single-Drift IMPATT Diode.

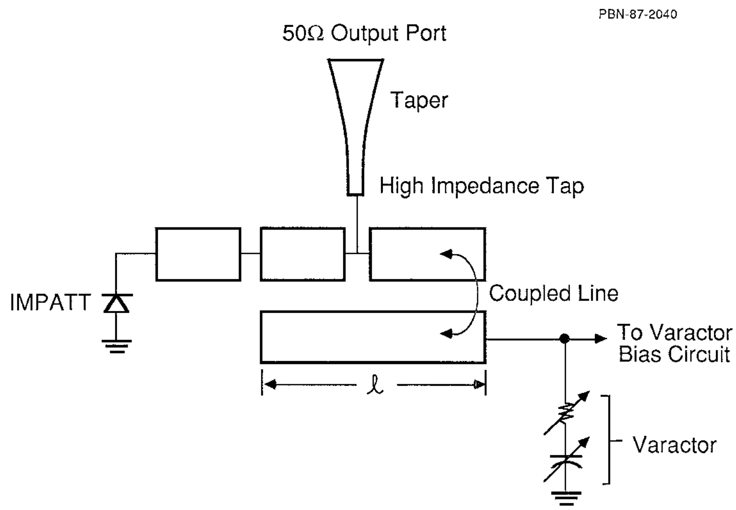

Fig. 2. Schematic Drawing of the VCO Circuit.

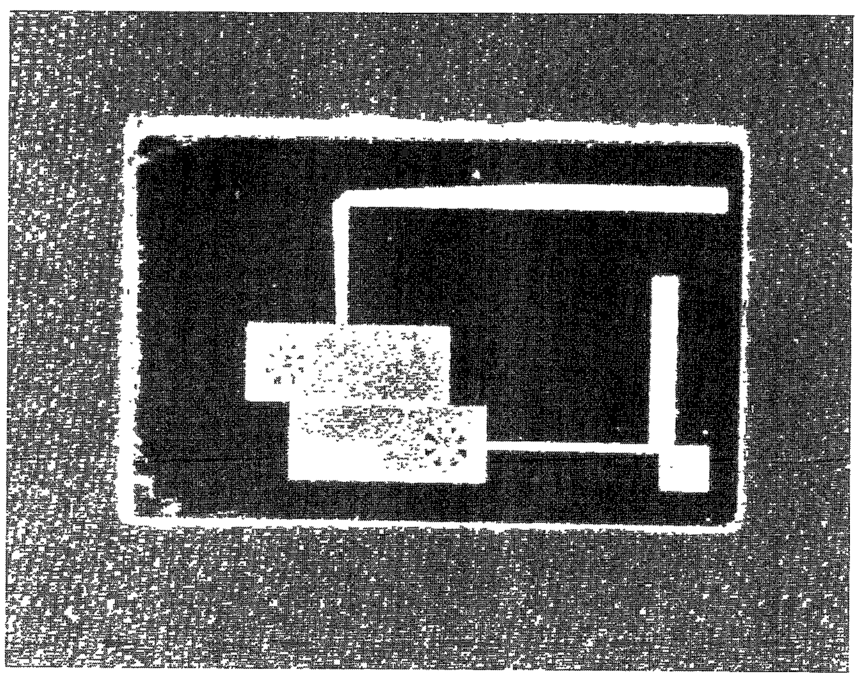

Fig. 3. Photograph of the VCO Chip.

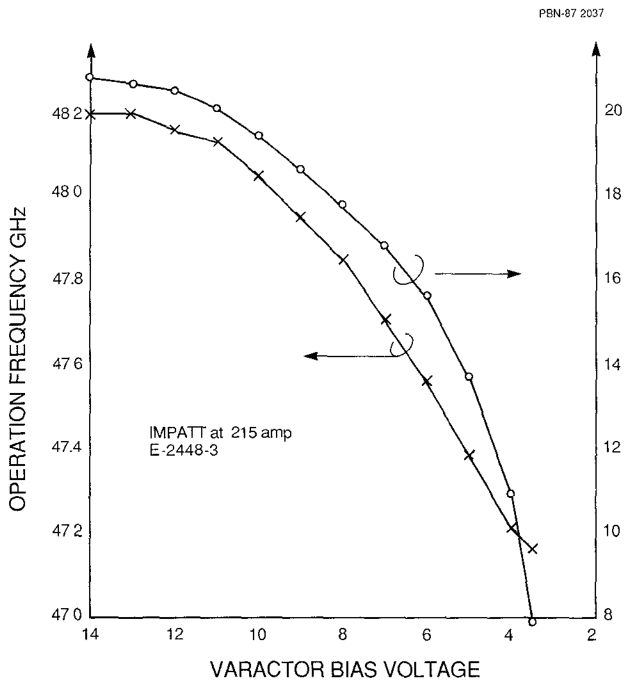

Fig. 4. Operation Frequency and Output Power Versus the Varactor Bias Voltage.

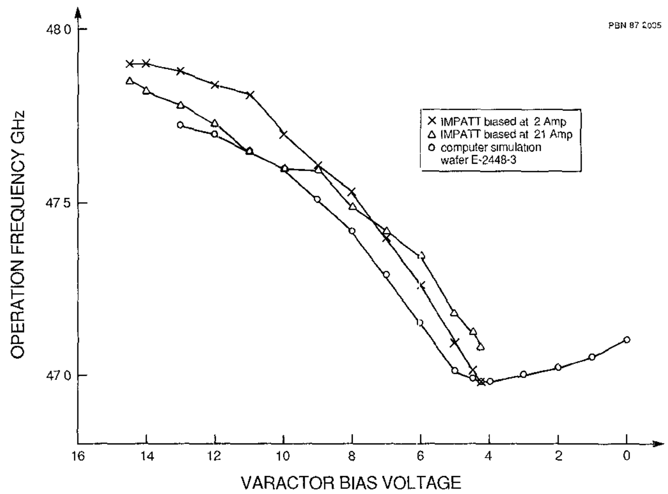

Fig. 5. Operation Frequency of a VCO at Two Bias Current Levels, Together with the Result of a Computer Simulation.

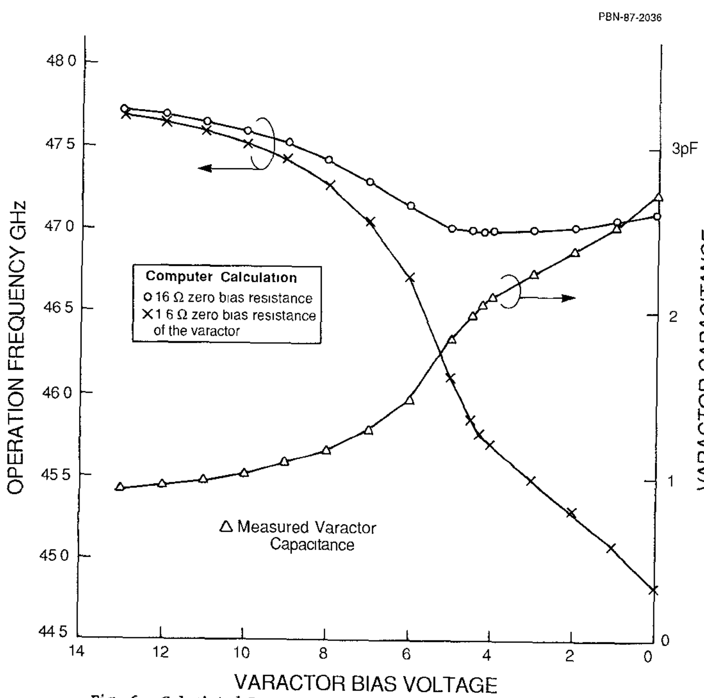

Fig. 6. Calculated Resonance Frequency with Different Series Resistance Values and the Measured Varactor Capacitance as a Function of Bias Voltage.

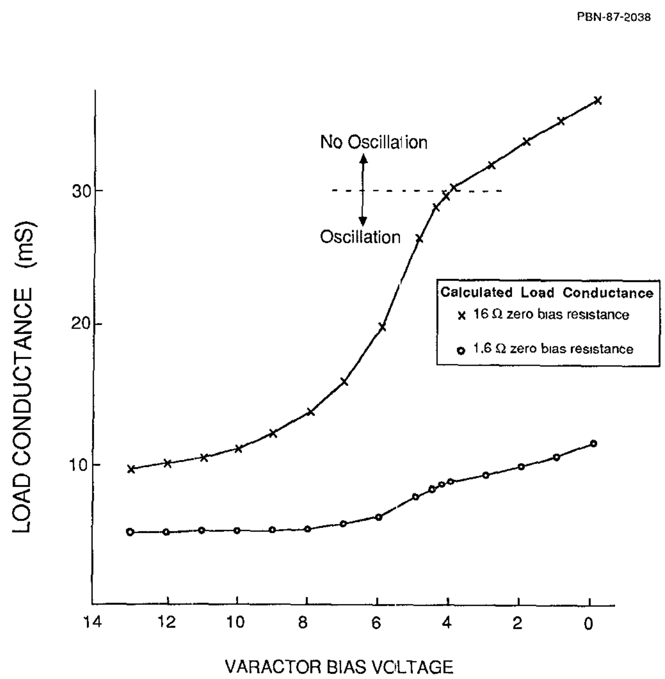

Fig. 7. Calculated Load Conductance at Two Different Series Resistance Values.

The VCO was tested in pulse operation using a pulse width of 300 ns and a duty cycle of 6%. Figure 4 shows the operation frequency and the output power as a function of the varactor bias voltage. A 1 GHz tuning range is achieved. The power drops monotonically as the varactor bias voltage is lowered. Below 3.5 V, oscillation is no longer obtained. This phenomenon strongly suggests that the series resistance of the varactor diode provides excessive loading to the IMPATT diode.

Figure 5 shows the frequency tuning of another oscillator at two different bias current levels. The capacitance of the varactor diode was measured as a function of voltage and the zero bias series resistance of the varactor was calculated. The measured capacitance value and a voltage-dependent series resistance were used as input for computer analysis. The relationship between the R_s and the voltage is assumed to be

$$R_s(V) = R_{so} \times \left(5 - \frac{C_0}{C(V)}\right)/4.$$

where R_{so} is the zero bias series resistance. C_0 is the zero bias capacitance. The factor of 5 is the ratio of total device length over the avalanche zone length. This equation assumes that the depletion region extends equally into p- and n-drift regions at all the bias voltage. Since C(V) is measured, $R_s(V)$ can be calculated accordingly.

The prediction is shown as the third curve of Fig. 5. The agreement between the analysis and experiment is excellent. Below 4 V bias on the varactor, no oscillation can be observed from the VCO. However, the resonance frequency can still be predicted by the computer. The load conductance predicted by the computer program increases monotonically as the varactor bias voltage decreases.

The high series resistance of the varactor limits the performance in two ways:

1. It reduces the resonance frequency tuning range.

2. It loads the oscillator so heavily that no oscillation can take place.

Figure 6 illustrates the effect of series resistance in the model calculation. One curve is the simulation of the experiment as shown in Fig. 5. The other is the prediction of the model under the assumption of one-tenth the series resistance. This value of series resistance would be typical of a single-drift device where only n-type GaAs is used. Also shown for reference is the measured varactor capacitance versus voltage. The tuning range for the small resistance case is 2.87 GHz.

Plotted in Fig. 7 is the load conductance for the two values of series resistance. The low varactor resistance case shows a much lower conductance, which would result in oscillator output throughout the entire varactor bias range.

CONCLUSION

A monolithic Q-band GaAs IMPATT diode voltage-controlled oscillator has been built and tested. A frequency tuning range from 47 to 48 GHz was achieved with 120 mW peak power. Computer predictions based on measured circuit parameters accurately predict the operation frequency. The key limiting factor in the power and tuning is the presence of large parasitic series resistance in the varactor. By utilizing a single-drift doping profile, improved performance can be expected.

ACKNOWLEDGEMENT

The authors appreciate the support of Mr. D. Masse and Dr. M. G. Adlerstein.

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