MONOLITHIC Ka BAND VCO USING QUARTER MICRON GaAs MESFETs AND INTEGRATED HIGH-Q VARACTORS

M.G. McDermott, C. Sweeney, M. Benedek and G. Dawe

GAMMA Monolithics
(A partnership between Martin Marietta Corporation and
Alpha Industries Inc.)
20, Sylvan Road, Woburn, MA 01801, U.S.A.

Abstract.

High Q GaAs abrupt varactor diodes and 0.25μm GaAs MESFETs have been combined on a semi-insulating GaAs substrate for millimeter wave MMIC applications. Based on the measured series resistance and capacitance, the diodes have a calculated Q at -4V, 50MHz of approximately 19,000. The MESFETs have a measured gain of >6dB at 35GHz with extrapolated values for f_t and f_{max} of 32GHz and 78GHz respectively. A monolithic Ka band VCO using these devices has been built and tested. Output powers of 60mW with 70MHz of tuning bandwidth and 40mW with 120MHz of tuning bandwidth have been measured at 32GHz.

Introduction.

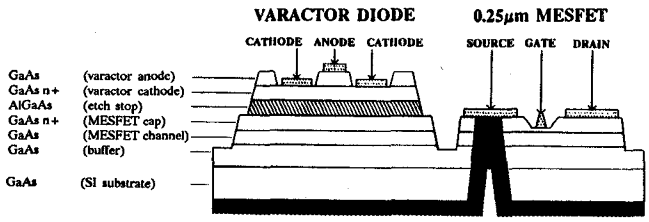
Previous efforts to produce monolithic GaAs VCOs using MESFETs as the tuning elements have usually yielded limited performance in terms of available tuning range and Q. This is due to the fact that the series resistance of the MESFET rapidly increases as the gate bias is increased towards pinch-off.

The aim of this work was to design a process and build a GaAs monolithic Ka band VCO using the best performing active devices available for both the tuning element and oscillator itself. For this frequency the optimum performance would be achieved by using 0.25μm GaAs MESFETs and high Q varactors having the vertical geometric design of a typical discrete diode. If successful, the process could be extended to monolithically integrate 0.25μm GaAs MESFETs or HEMT devices and other types of diodes whose performance typically benefits with a vertical structure.

Material Design.

The material structure used is shown in figure 1. As can be seen, the bottom three layers form the buffer, channel, and cap layers respectively for the MESFET. The fourth layer is a thin (~200A) AlGaAs layer which is to ultimately act as an etch stop during the fabrication process.

The fifth and sixth layers are regions which will be contacted to form the cathode and anode of the varactor respectively. This structure has been successfully synthesized with MBE and multi-wafer MOCVD systems.



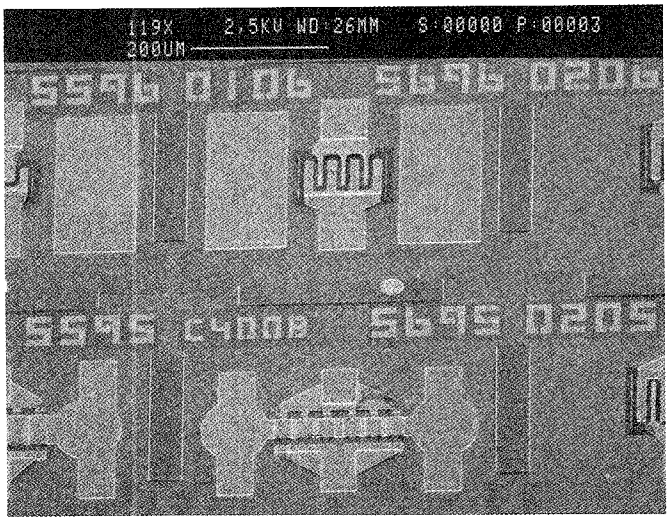
Schematic Cross Section Through the Varactor Diode and 0.25μm GaAs MESFET

Figure 1.

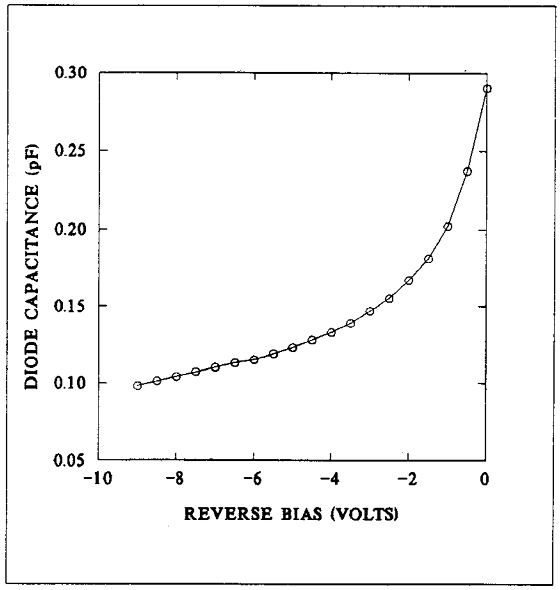
Fabrication.

The first step in device fabrication is to define regions for the varactor ohmic contacts. The GaAs is then etched back to expose the n+ layer before depositing AuGe/Ni/Au contacts. Mesas for the varactor are then defined and etched down to the 200A AlGaAs using an etchant which preferentially etches GaAs over AlGaAs with a selectivity of >20:1 [1]. On removing the AlGaAs, mesas for MESFET and varactor isolation are etched.

To cope with the highly non-planar topology of the wafer at this and subsequent stages, a highly tolerant photolithographic process has been developed which is based on the image reversal properties of AZ5218E photoresist. Using this process, ohmics for the MESFETs were defined and then alloyed simultaneously with the varactor diode cathode contacts. From this stage on, the process is identical to that of our standard 0.25μm GaAs MESFET MMIC process [2] which uses electron beam direct write for definition of the gates. Figure 2 shows a scanning electron micrograph of a multi-finger varactor diode (top) and a 0.25μm x 400μm GaAs MESFET.



Scanning Electron Micrograph of Varactor Diode (top) and 0.25μm x 400μm GaAs MESFET.
Figure 2.

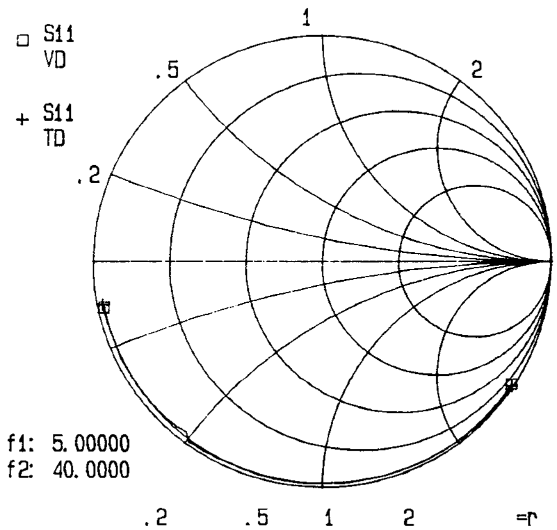


Capacitance - Voltage Characteristic of a Reverse - Biased Varactor Diode.
Figure 3.

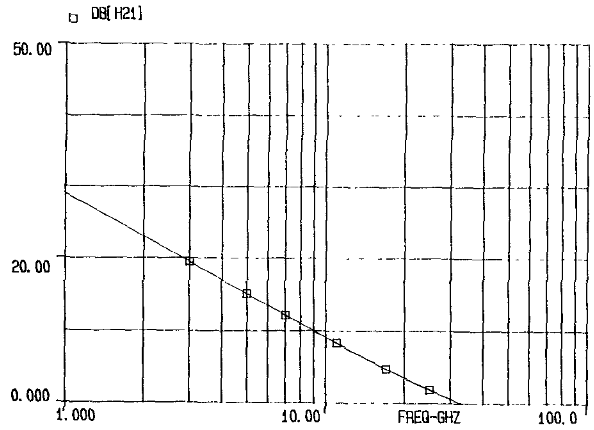
Device Characterization and Performance.

Figure 3 is a capacitance-voltage plot of a typical varactor diode as measured from 0-10V at 1MHz showing a near-theoretical capacitance swing of approximately 2.1:1 over the required bias range of 0V to -4V. The forward bias DC characteristic yields an ideality of 1.05, a series resistance (measured using a 4 point probe technique) of 1.1Ω and a reverse breakdown voltage in excess of 12V. The scattering parameters of the varactors were measured on-wafer from 5.0-40.0GHz using a Cascade wafer prober and a Wiltron 360 automatic network analyzer and then modelled using Touchstone. Figure 4 shows the typical measured scattering parameters of the varactor diode at -4V bias in a shunt configuration.

The MESFETs were also measured on-wafer from 1.5-40.0GHz in the same manner used for the varactor diodes. Figures 5 and 6 show plots of H21 and MAG based on measurements to 40.0GHz and extrapolated to give an f_t of 32GHz and f_{max} of 78GHz respectively. Figure 7 shows a typical model derived from these measurements at 50% Idss and a drain voltage of 5V.

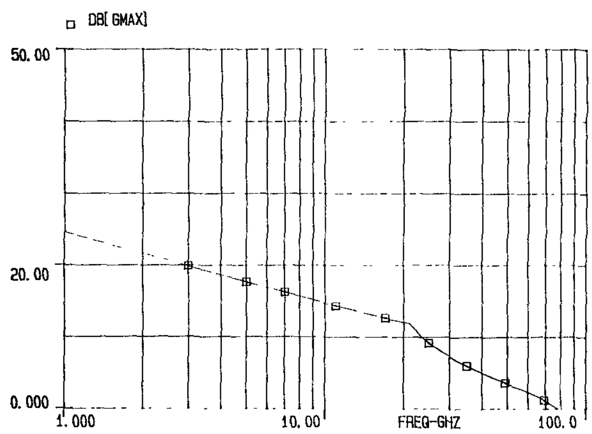


Measured S11 Characteristic of a Shunt - Mounted Varactor Diode (5.0GHz - 40.0GHz)
Figure 4.



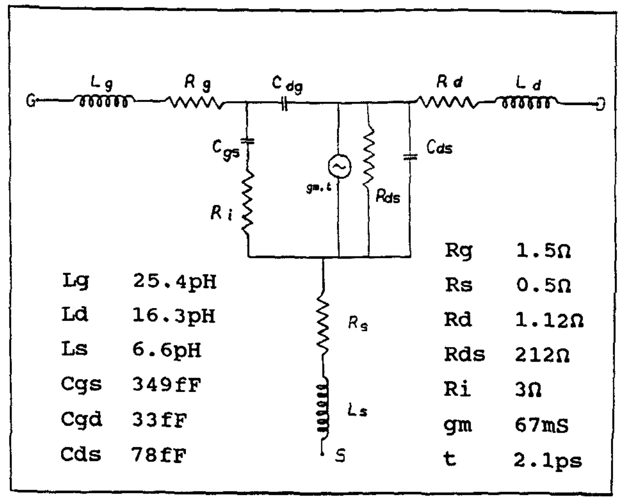
H21 Measured from 1.5GHz-40.0GHz and Extrapolated to H21=0 for 0.25μm x 400μm GaAs MESFET.

Figure 5.



MAG Measured from 1.5GHz-40.0GHz and Extrapolated to MAG=0 for 0.25μm x 400μm GaAs MESFET.

Figure 6.



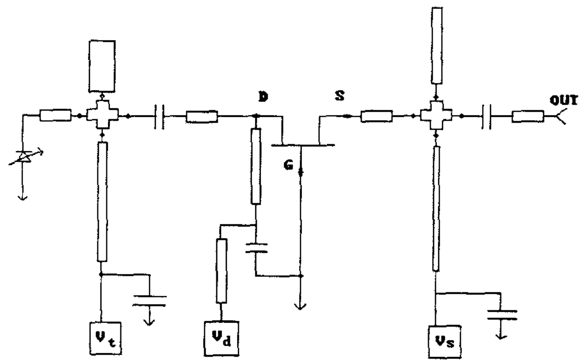
Equivalent Circuit Model for 0.25μm x 400μm GaAs MESFET at Vds = 5.0V, Ids = 50% Idss.

Figure 7.

<u>VCO Circuit Design.</u>

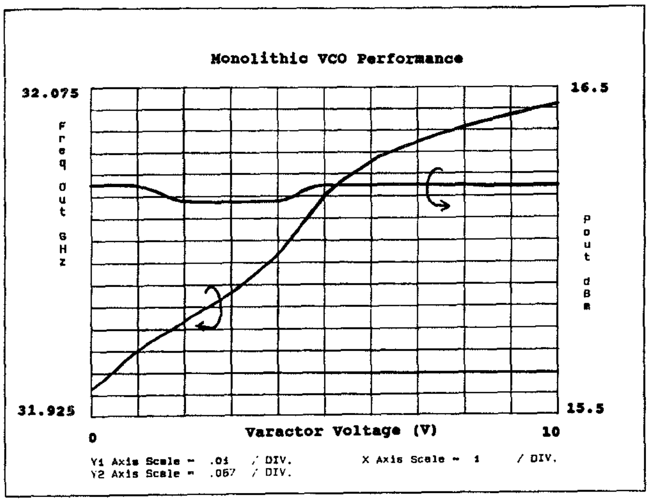
The monolithic VCO with integrated varactor and 0.25μm GaAs MESFET is shown schematically in figure 8 and in a scanning electron micrograph in figure 9. The circuit uses a single 400μm power MESFET in common gate configuration with a gate that is grounded (both DC and RF) through a via hole. The output power is coupled out of the source terminal. The drain circuit contains the tank resonator. This resonator is made up of an open stub and the integrated varactor diode. A shorted stub on the drain increases the magnitude of negative resistance available by matching the drain impedance to the resonator. MIM capacitors are used to both de-couple the output and bias voltages as well as filter the DC supplies. Three bias voltages Vd, Vs and Vt are brought into the circuit through on chip bias networks.

This circuit was examined using the linear simulation program Touchstone. The scattering parameters of the 400μm FET were embedded in the circuit topology and lengths and widths were optimized to achieve maximum negative resistance at the frequency of interest. Varactor frequency tuning was simulated by changing the C_j of the varactor model and observing the change in predicted oscillation frequency. Although all discontinuities were accounted for using the standard models, the frequency of the actual circuit was somewhat lower than predicted by approximately 1.5 GHz. Overall, however, good agreement between predicted and measured results was obtained. Tuning bandwidth and output power prediction when biased for tuning bandwidth were typically within ten percent of the predicted values (bandwidth predicted = 110 MHz, Pout predicted 40mW).



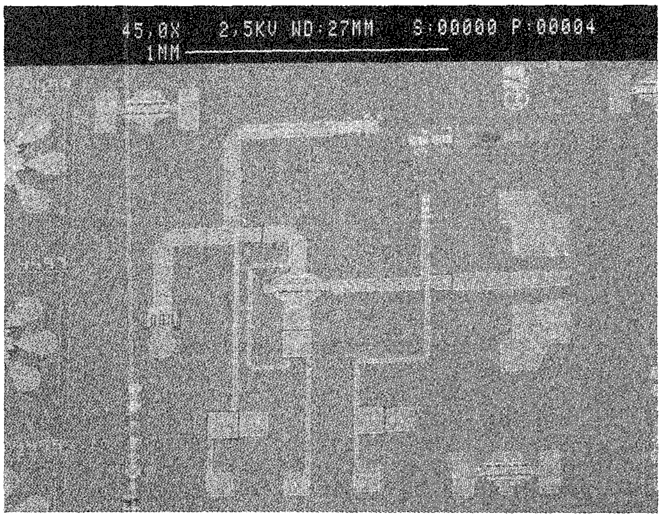
Schematic of Monolithic VCO

Figure 8.



VCO Output Power Versus Frequency as a Function of Varactor Bias Voltage.

Figure 10.



Scanning Electron Micrograph of Monolithic VCO

Figure 9.

Measured VCO Test Data.

The monolithic VCO was measured for output power and frequency tuning. Depending on the C_j and the FET bias used, different frequencies and power levels may be obtained.

When biased for output power, the monolithic VCO typically delivers 60mW with 70MHz of tuning bandwidth centered at 32GHz. The lower power bias typically produced 40mW with 120MHz of tuning bandwidth (0V to -10V on the varactor). This performance is shown in figure 10. By removing air bridges on the drain and source open circuit stubs, the center frequency could be coarsely altered. However, if too many are removed, oscillation is lost. Typically, the center frequency can be increased from 32GHz to 33.5GHz in this manner though the output power is reduced to 16mW.

Conclusions.

The monolithic integration of high Q GaAs varactor diodes with 0.25µm gate length GaAs MESFETs has been achieved. Using this technology, a Ka band VCO with 60mW of output power with 70MHz of tuning bandwidth and 40mW of output power with 120MHz of tuning bandwidth has been demonstrated at 32GHz. This technology can be readily extended to integrate 0.25µm MESFETs or HEMTs with other diode devices that inherently benefit from a truly vertical structure.

Acknowledgements.

The authors gratefully acknowledge the encouragement and support extended by Terry Duffield of Martin Marietta Corporation and Craig Fingerman and Lamberto Raffaelli of Alpha Industries Inc., throughout this work and wish to thank Cam Nguyen, formerly of Martin Marietta Corporation, for his contribution during the initial design stage. We also acknowledge the help of Dan Donoghue and Bob Goldwasser in the design and simulation of the varactor diodes and are also grateful to John Kane for his processing expertise and John Borelli and Joe DeAngelis for the vector RF measurements.

References.

[1] "Selective Etching Characteristics of Peroxide/Ammonium-Hydroxide Solutions for GaAs/$Al_{0.16}Ga_{0.84}As$", K. Kenefick, J. Electrochem. Soc.: Solid-State Science and Technology, Oct. 1982.

[2] "A 35GHz Monolithic MESFET LNA", S. Bandla, G. Dawe, C. Beddard, R. Tayrani, D. Shaw, L. Raffaelli and R. E. Goldwasser, IEEE 1988 Microwave and Millimeter-Wave Monolithic Circuits Symposium.