A FAMILY OF FOUR MONOLITHIC VCO MIC's COVERING 2-18 GHz

Bentley N. Scott, Marianne Wurtele, Barton B. Cregger

Texas Instruments Incorporated
Central Research Laboratories
Dallas, Texas 75265

Abstract - Four GaAs monolithic voltage controlled oscillator chips were designed and fabricated which cover the 2-4 GHz, 4-7 GHz, 7-12 GHz, and 12-18 GHz bands. Minimum output power of the four bands was +12 dBm in the 12-18 GHz band with a maximum output power of +20 dBm in the 7-12 GHz band. Typical power flatness was ± 5 dBm in any band. The monolithic chips include a FET, two varactors, gate and source inductors, bypass capacitors, and bias resistors. The paper will discuss design considerations and performance.

INTRODUCTION

While GaAs market projections show rapid increases in the number of vendors and in analog circuit devices, MMIC voltage controlled oscillator (VCO) GaAs technology has primarily been at X-band and above.[1,2,3] This paper will discuss a family of four GaAs VCO chips which cover 2-4, 4-7, 7-12, and 12-18 GHz. These chips all include a field effect transistor (FET), two varactors, inductors, bypass capacitors, and bias resistors. The output matching network, consisting of a series inductor and shunt capacitor, was not included on chip due to the additional area required and the rf insensitivity to these inexpensive external components.

The broadband VCO outlined in this paper is an appropriate application of monolithic technology over hybrid circuit techniques. The varactor diode used in these monolithic circuits is a single implanted structure into semi-insulating material and is formed with the same active region used for the FET. The frequency and bandwidth setting inductors are included on the monolithic chip to assure repeatable performance.

The microwave broadband VCO design engineer has been restricted to the use of hybrid varactor diodes with the major design parameters changing on each lot received. Consistent resistance, starting capacitance and capacitance ratio are necessary to maintain repeatable oscillator performance. Epitaxial techniques used to grow the multiple active layers required for high ratio hyperabrupt varactor diodes are at best non-uniform across the same slice. Upright varactors for use at 7 GHz and above with starting capacitances under 2 pF typically have 50 μm or less contact diameters. The small area becomes a problem in wirebond attachment and mechanical pull strength. The gate inductors for the hybrid 7-12 GHz and 12-18 GHz VCO's are gold bondwires .6 mm to 1 mm in length and it is this length that sets the starting frequency. In the case where the bondwire is made too short during assembly, the varactor must be replaced since the pull strength of the varactor bondpad is too low for the first wire to be removed and a second wire to be attached. These critical components are all defined by photolithography for the monolithic VCO to be described.

ANALYSIS

The common gate configuration of a FET using a gate inductor for the regenerative feedback element exhibits tunable negative impedances that are available at the source terminal when the drain is terminated into a load of approximately 15 ohms. A capacitance placed in the source terminal will cancel the phase of the available negative impedance allowing the circuit to oscillate. If a varactor is used in place of the fixed source capacitor, the frequency of oscillation can be tuned across the available negative impedances. The addition of a varactor in series with the gate inductor will allow the frequencies at which the negative impedances appear to be moved up-band as the gate varactor capacitance decreases. This circuit allows power to be taken out of the drain and is tolerant of drain impedance changes that cause start-up or bandwidth problems in other configurations.

Previously described design techniques are used for selection of the FET size, inductor and varactor values[4]. The values are selected to allow for minimum feasible inductor length while maintaining a reasonable FET gate width. Since the basic starting frequency of oscillation is approximately determined by the gate inductor resonating with the gate-source FET capacitance[5], this trade-off which impacts the chip size can be readily made.

A 300 μm FET was selected for the 12-18 GHz design instead of a 600 μm device because an extremely small gate inductor was required for the larger FET. The circuit would then require a smaller zero bias varactor capacitance and the associated varactor Q would decrease due to the smaller diode area. This reduction in starting capacitance would make the circuit more sensitive to process changes while the reduction in Q coupled with the larger power swing of the 600 μm FET would degrade frequency stability.

Similar trade-offs were made in the other designs with the lowest band chip requiring additional considerations. In the 2-4 GHz design the power loss due to the long lengths of gate inductor was a major concern in selection of a 2400 μm device instead of the 1200 μm FET used in the 4-7 GHz design.

A schematic of the basic circuit is shown in Figure 1 with the element values for the four band designs given in Table 1. The area outlined on the schematic within the dashed lines shows the elements included on the monolithic chip. Figure 2 includes photographs of the actual monolithic chips showing their physical size relative to each other.

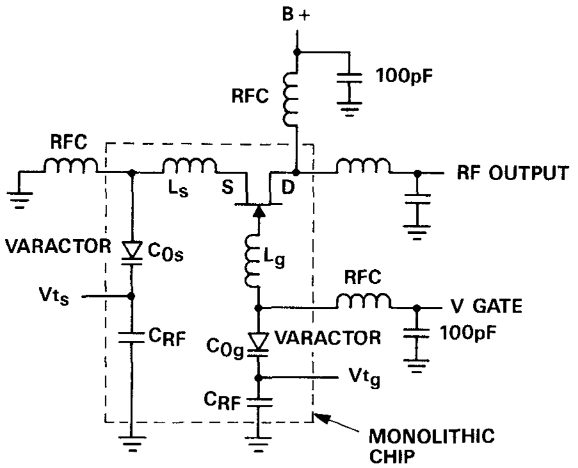

Figure 1. Monolithic VCO schematic.

FABRICATION

The designs were implemented on 2 inch liquid encapsulated Czochralski (LEC) grown Cr doped material with an active region ion implanted to 2 x 10^{17} cm^{-3} with silicon. Epitaxial material was initially used on the 12-18 GHz design but ion implanted material gave excellent uniformity, equal performance in power and bandwidth, and a larger number of possible circuits per slice due to the increased wafer area.

The lateral varactor diodes described previously in the literature were used in these circuits.[6] The varactors for the higher three bands were designed using 75 μm x 2 μm anode fingers. The lowest band used 100 μm x 2 μm fingers.

The varactor anode fingers and FET gates were written with E-beam lithography. These gates and anodes were titanium-platinum-gold metallization. The ion implanted material was either mesa isolated or isolated by a boron implant with no mesa. Gold-germanium nickel ohmic contacts were formed by conventional evaporation and lift-off techniques. Plasma deposited Si_3N_4 was used for the capacitor dielectric and to passivate the devices. Plated gold air bridges were used to interconnect the FET sources and to connect the capacitor top plates to the varactor cathodes.

TABLE 1 BASIC CIRCUIT ELEMENT VALUES

BAND	2-4 GHz	4-7 GHz	7-12 GHz	12-18 GHz
C_{os}	2 9 pF	2 3 pF	1 5 pF	1 1 pF
C_{og}	5 1 pF	3 6 pF	2 2 pF	1 4 pF
L_s	1 3 nH	1 4 nH	17 nH	06 nH
L_g	13 5 nH	5 9 nH	2 1 nH	6 nH
C_{RF}	45 pF	45 pF	40 pF	21 pF
FET Gatewidth	2400 μ	1200 μ	600 μ	300 μ

EXPERIMENTAL PERFORMANCE

Frequency and power for the four chip designs are given in Figure 3 through Figure 6. A summary of this performance is given in Table 2. Varactor capacitance ratios were typically 8:1 or greater.

A 7-12 GHz VCO and a 12-18 GHz VCO chip have been cascaded with a monolithic two stage amplifier to achieve an output power across each of the two bands of +18 to +20 dBm. Figures 7 and 8 show the resulting performance. The amplifier input match was selected to present the correct impedance for the oscillator chip.

The two varactors were driven with an inverting operational amplifier which supplied the voltage offset between the source and gate varactors required to obtain the maximum bandwidth. An additional voltage breakpoint was included to minimize tuning sensitivity. Actual tuning voltage swing across the varactors was typically seven to ten volts.

Performance to date on a number of slices has proven the feasibility of building monolithic VCO's. Unlike the hybrid counterpart these monolithic VCO's do not require intensive assembly and technician labor. Uniformity within a single slice is sufficient to maintain the starting frequency to within $\pm$500 MHz and the bandwidth essentially constant. Output power variations are typically $\pm$5 dBm across a slice. Slice to slice starting frequency variation is approximately 10%. With actual production slices these variations will be further decreased.

CONCLUSION

Four monolithic VCO chips have been described that cover the 2-18 GHz frequency band. All of the rf sensitive components have been integrated on the monolithic chip.

Hybrid VCO's are expensive and difficult to reproduce due to the intense labor involved and the reproducibility requirements on circuit element values. This new family of GaAs MMIC VCO's has achieved performance and yields that are significantly better than wideband hybrid circuit VCO's.

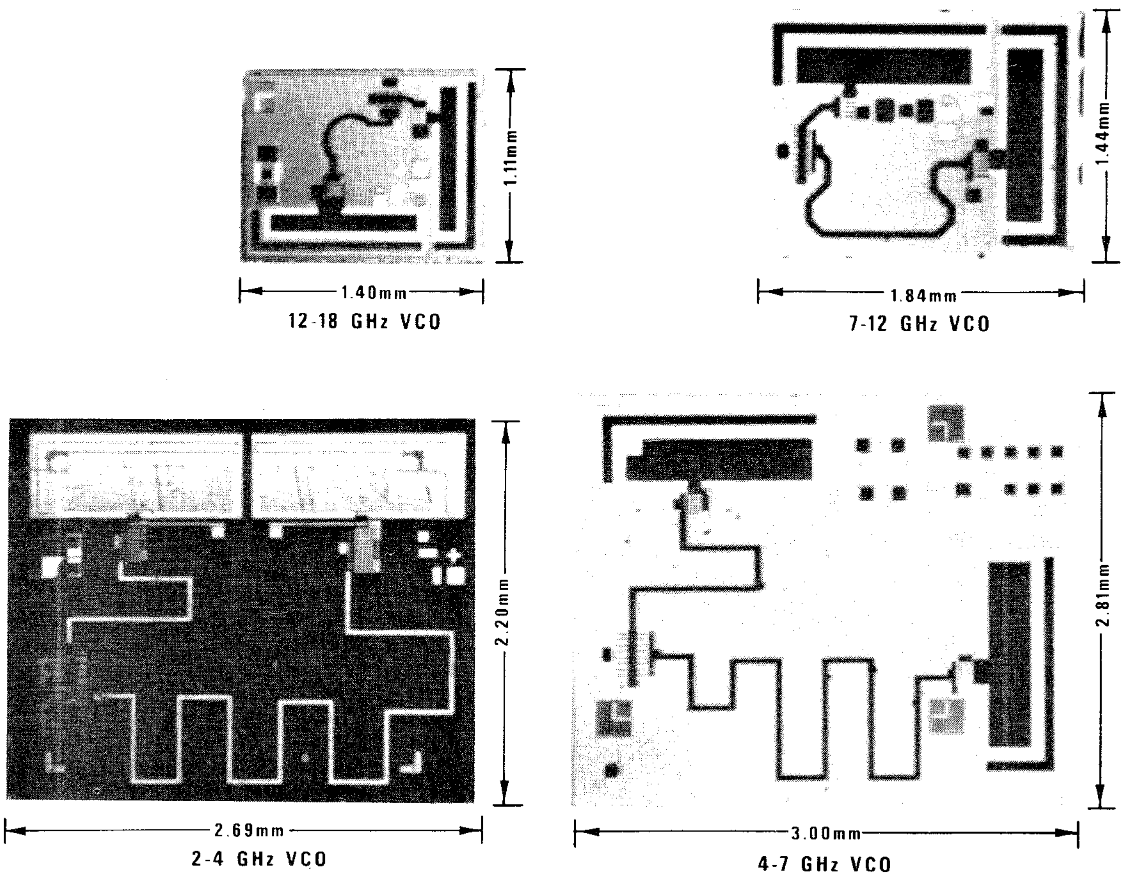

Figure 2. Monolithic VCO chip dimensions.

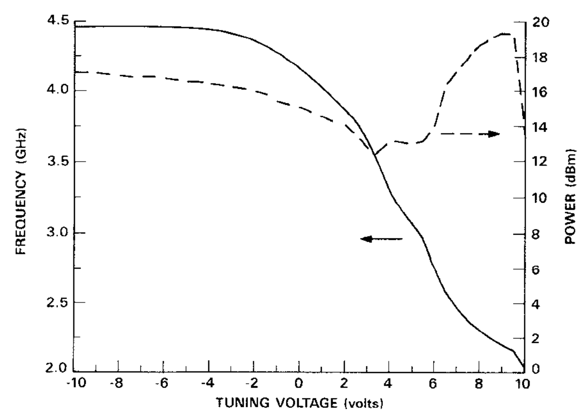

Figure 3. Tuning curves for 2-4 GHz monolithic VCO.

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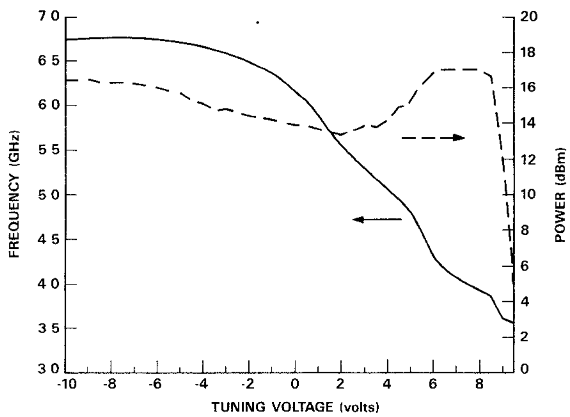

Figure 4. Tuning curves for 4-7 GHz monolithic VCO.

TABLE 2. PERFORMANCE SUMMARY OF MONOLITHIC VCO CHIPS

BAND	FREQUENCY COVERAGE (GHz)	POWER IN BAND (dBm)	% BW
2 - 4 GHz	2 04 - 4 46	12 6 - 19 4	74%
4 - 7 GHz	3 56 - 6 74	13 3 - 17 1	62%
7 -12 GHz	6 97 - 12 2	15 2 - 20 1	55%
12 - 18 GHz	11 6 - 20 0	5 5 - 15 8	53%

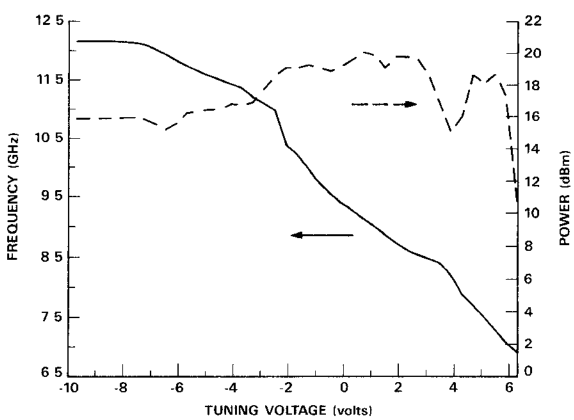

Figure 5. Tuning curves for 7-12 GHz monolithic VCO.

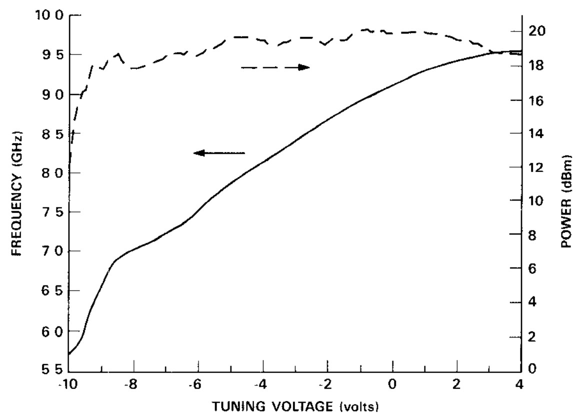

Figure 7. 7-12 GHz VCO performance cascaded with two-stage amplifier.

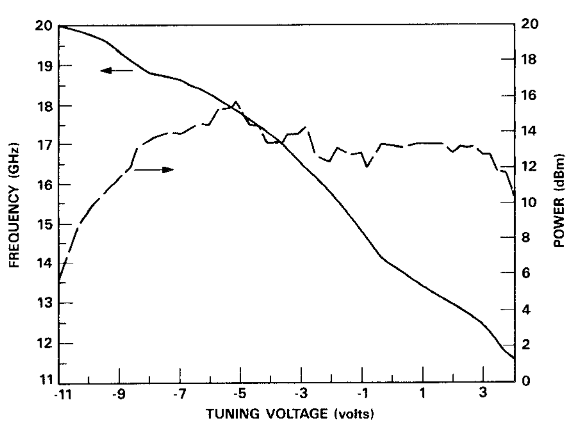

Figure 6. Tuning curves for 12-18 GHz monolithic VCO.

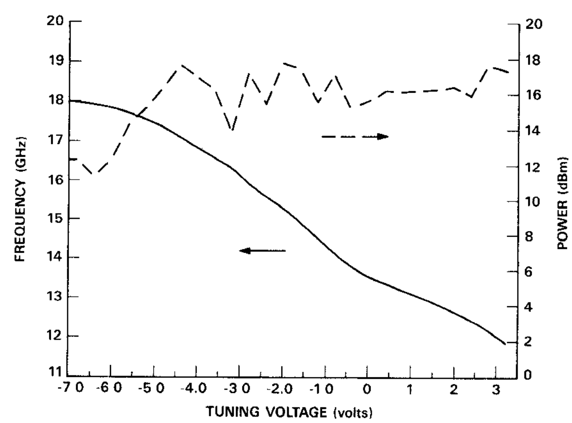

Figure 8. 12-18 GHz VCO performance cascaded with two-stage amplifier.