AN HBT MMIC WIDEBAND VCO

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ABSTRACT

A wideband MMIC Voltage Controlled Oscillator (VCO) has been developed using AlGaAs/GaAs Heterojunction Bipolar Transistors (HBTs). Test results indicate a very wide tuning range of 7 to 15GHz, with a minimum output power of 9 dBm. This MMIC also exhibits low power dissipation (5 V and 25 mA) and excellent phase noise (75 dBc/Hz @ 100 KHz) for a broadband VCO. In addition to the basic oscillator this MMIC also includes a buffer amplifier to provide better load isolation and power output stability. All the required biasing and matching circuitry except for the resonator is contained within the chip that measures 30 X 40 mils (0.8 mm X 1 mm).

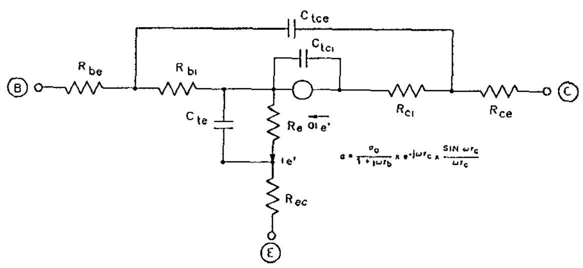
INTRODUCTION

Modern microwave systems require stable, wideband, low-phase-noise tunable oscillators with sufficient output power and low power dissipation. Previous work on monolithic VCO's has demonstrated their great potential [Ref 1, 2].

Wideband oscillators are one of the key application areas for HBTs because HBTs are capable of generating a wideband negative resistance (due to their high transconductance) [Ref. 3, 4, 5]. In addition, the vertical structure of the HBT eliminates the surface-state problem associated with Gallium Arsenide FETs, thus resulting in superior phase noise characteristics. The HBT oscillator reported in this paper has been designed as a negative resistance generator cascaded with a buffer amplifier on one monolithic IC. This circuit topology offers several advantages. A negative resistance generator can be used in several different kinds of oscillators, including dielectric resonator oscillators (DROs), YIG oscillators and VCOs. The only part required external to the MMIC to form an oscillator is the resonator. The incorporation of the buffer amplifier isolates the resonator from the load and minimizes the effects of frequency pulling. The buffer amplifier stage also operates in saturation, which provides repeatable output power and minimizes output power variation with temperature.

CIRCUIT DESIGN

Small signal characteristics of a 40 um^2 HBT cell were measured at various bias levels to provide the basic device model for the circuit design. Figure 1 shows the small-signal model derived from these measurements along with the parameter values [Ref. 6]. In addition, a large-signal model was also extracted for use in Spice simulation.



R_{be} = 1 75	R_{ce} = 16 0	C_{te} = 0 4pF
R_{bi} = 1 05	R_{ci} = 6 8	τ_b = 0 6pS
R_e = 2 9	C_{tce} = 0 0074pF	τ_c = 0 7pS
R_{ec} = 2 2	Ctci = 0 0184pF	α_0 = 0 93

Figure 1 HBT Device Model and Parameter Values

The VCO circuit consists of a common base oscillator with a capacitively loaded emitter to generate the wide-band negative resistance. This is followed by a common emitter buffer amplifier to isolate the oscillator from the load and to provide constant power output. Figure 2 shows a functional schematic of the VCO. Both the oscillator and the buffer amplifier use HBTs of 40 um^2 area. The two devices are biased in a series totem-pole configuration to reduce the current consumption. Tantalum nitride biasing resistors as well as MIM

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bypass capacitors have been integrated on the chip that measures 40 mils X 30 mils (0.8mm X 1mm) in size. The circuit requires only two external varactors to form a complete wideband VCO.

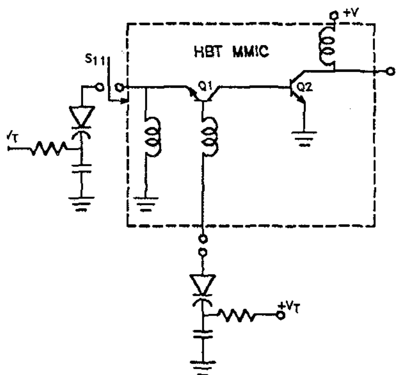

Figure 2 Functional Schematic of HBT MMIC VCO

The inductance on the base provides positive feedback through the internal base-emitter capacitance to generate the required negative resistance at the emitter over the broad frequency range of greater than an octave. The initial design of the oscillator was done using small-signal models and was aimed towards achieving a positive reflection coefficient at the input of the device over as wide a frequency band as possible. Figure 3 shows the simulated small signal input return loss S11 for two values of the emitter varactor. It shows that this chip has a minimum of +4 dB of input reflection gain over the 6 to 16 GHz frequency band.

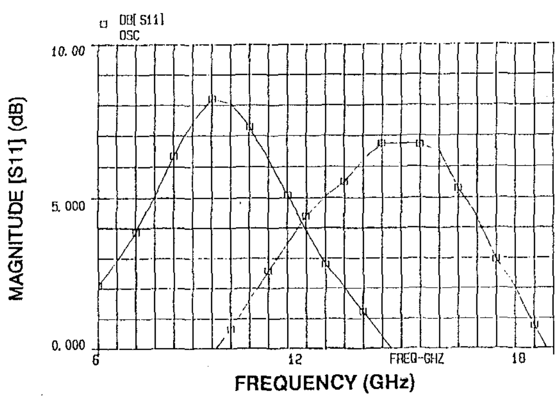

Figure 3 Simulated S11 of HBT MMIC VCO for Two Values of Emitter Varactors

After the small-signal design was completed a large-signal Spice simulation of the circuit was performed with a resonator connected to the input. A current pulse was used to initiate the oscillation. Figure 4 is the steady state voltage waveform at the output obtained from Spice. It shows a peak amplitude of approximately 1 Volt at a frequency of 15 GHz. By varying the capacitance at the emitter and the base the oscillation frequency can be varied from 7 to 15 GHz. Figure 5 shows a layout of the MMIC.

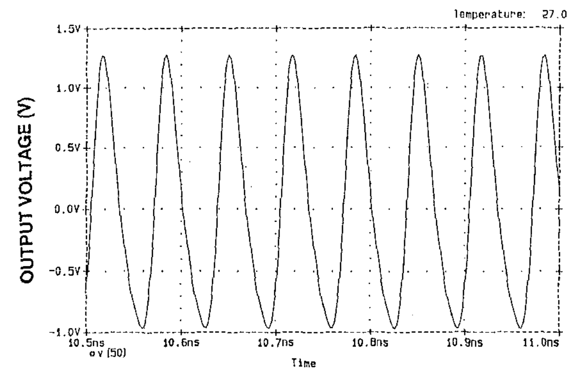

Figure 4 Simulated Output Waveform of HBT MMIC VCO

LAYOUT OF HBT MMIC VCO

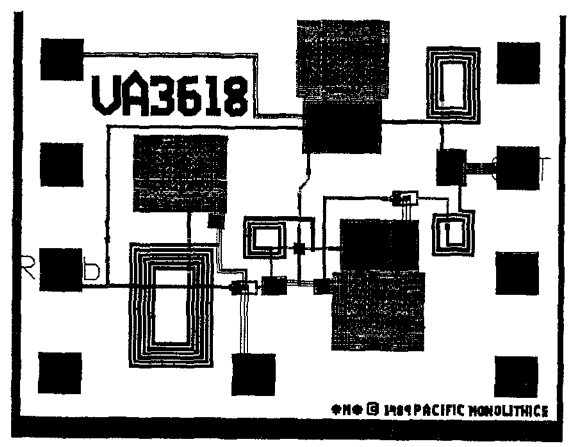

Figure 5 Layout of HBT MMIC VCO (Chip Size 30 X 40 mils)

MMIC FABRICATION

The AlGaAs/GaAs HBT used in this MMIC were produced from MBE grown wafers with a base doping from 1 X $10^{19}/cm^3$ to $5X10^{19}/cm^3$. A dual-liftoff self-aligned process was employed for device fabrication in order to minimize base resistance and collector-base capacitance. The emitter finger width used was 2 um, resulting in an f_t of 40 GHz and an f_{max} of 80 GHz [7]. A complete MMIC process with two layers of metal interconnects, nitride resistors, and MIM capacitors was then integrated with the device processing to enable the HBT monolithic circuit implementation. Optical projection lithography was used for MMIC fabrication resulting in a high-yield process without the need for fine-line E-beam lithography.

HBT MMIC PERFORMANCE

The MMIC VCO was assembled on a kovar carrier with external silicon varactors. Figure 6 shows the assembled MMIC. Measurements were made with a supply voltage of 5 volts and a supply current of 25mA. Figure 7 is a plot of the frequency and the power output as a function of the tuning voltage. It can be seen that when the tuning voltage is varied from 0.4 to 25 volts the output frequency varies from 6.9 to 15 GHz. Such a wide tuning range was achieved because of the high gain of the HBT devices. The power output varies from 9 to 12 dBm. Figure 8 shows the output spectrum of the HBT MMIC VCO. The phase noise at 100 KHz offset is -75 dBc/Hz.

ASSEMBLED HBT MMIC VCO

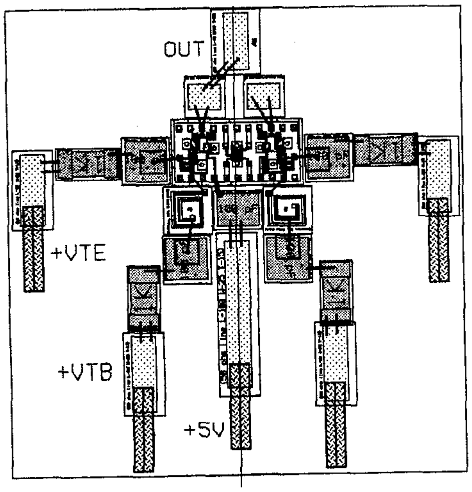

Figure 6 Assembled HBT MMIC VCO

HBT MMIC VCO

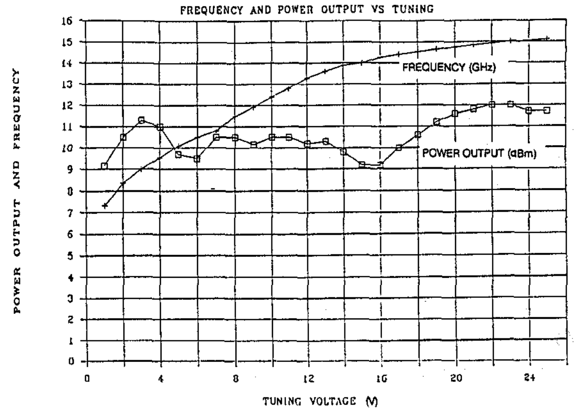

Figure 7 Tuning and Power Output of HBT MMIC VCO

OUTPUT SPECTRUM OF HBT MMIC VCO

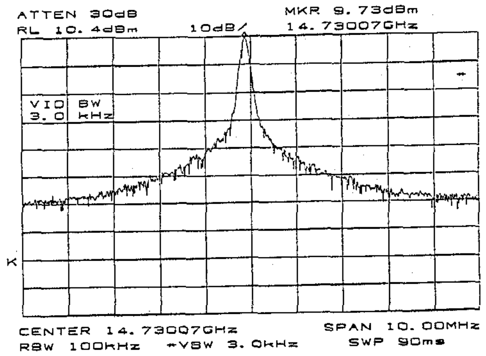

Figure 8 Output Spectrum of HBT MMIC VCO

CONCLUSIONS

From the results presented in this paper it can be concluded that HBT devices can generate wideband negative resistances and are therefore well suited for wideband VCOs. Furthermore it is shown that a buffer amplifier can be integrated along with the basic oscillator in a small-sized HBT MMIC, thus enhancing the overall performance of the oscillator. When used in oscillator subsystems such monolithic circuits can provide several advantages over discrete components, including reduced cost, shortened assembly time, and improved reliability. The excellent performance obtained demonstrates the great potential of HBT's for low cost, wideband MMIC VCO's.

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