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DIELECTRIC RESONATOR OSCILLATORS USING GaAs/(Ga,A1)As HETEROJUNCTION BIPOLAR TRANSISTORS

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ABSTRACT

This paper reports the first application of heterojunction bipolar transistors (HBTs) in microwave oscillators. A dielectric resonator (DR) is used to stabilize a 4-GHz shunt feedback oscillator. Using an npn grounded emitter GaAs HBT with 1.2- to 1.5-μm emitter width, microwave oscillator power in excess of 10 dBm with 30% efficiency was achieved. The oscillator frequency stability of 3 ppm/°C over −30° to +70°C, and FM noise of −73 dBc/Hz at 1-kHz off-carrier was measured. With further design optimization, improved performance is expected. The HBT phase-noise performance is comparable to silicon-bipolar and is superior to GaAs FET.

A mechanical tuning using metal screw gives a 9% tuning for 1-dB change in output power as compared to about 3% for dielectric tuning ($\epsilon_r = 38$). The dielectric tuning as implemented provides a controlled tuning slope but is found to be susceptible to mode jumping beyond 3% range.

INTRODUCTION

The progress recently accomplished in device fabrication has resulted in bipolar devices on semi-insulating GaAs substrate. The GaAs/(Ga,A1)As heterojunction bipolar transistors have been used previously for digital integrated circuits. Using similar advanced material growth techniques, such as MBE and MOCVD, the microwave HBTs have been fabricated. Microwave gain of 11 dB at 12 GHz for a small, 20-μm emitter periphery HBT and CW output power of 320 mW with 7-dB gain at 3 GHz for a large, 320-μm device have been reported[1,2]. Projections of gain, low phase-noise and high power performance exceeding that of GaAs FETs were made with further device structure optimizations.

Microwave HBTs, with maximum measured oscillation frequency, f_{max} above 25 GHz, enable realizations of oscillators and amplifiers to 20 GHz. The present work reports the first HBT oscillator studies carried out at 4 GHz. The performance of the HBT oscillator is compared, especially concerning spectral purity and phase noise, with those of more traditional oscillators using GaAs field effect and silicon-bipolar transistors.

A dielectric resonator ($\epsilon_r = 38$) is used to stabilize the frequency drift with temperature. Conventional mechanical tuning of the oscillator using a metal tuner allows an accurate frequency setting for many receiver/transmitter-type applications. Results of a dielectric tuner used to achieve a linear tuning with control on tuning rate are presented.

HBT DEVICE CHARACTERISTICS

Microwave HBTs used[1] are general-purpose npn grounded emitter devices, mounted in a 70-mil commercial stripline package. The device is fabricated using MBE on semi-insulating GaAs substrate. Ion implanted base and optical contact lithography was used to define emitter widths of about 1.2 μm. The dc breakdown voltage, V_{CE} is 4 to 5 volts, and the dc current gain, β, is of the order of 30. The microwave measurements, at a bias of 3 V/15 mA, resulted in the RF characteristics listed in table 1.

Table 1. RF Characteristics.

FREQUENCY GHz	S11		S21		S12		S22		MAX AVL GAIN (dB)	STAB FAC (K)
	MAG	ANG (DEG)	MAG	ANG (DEG)	MAG	ANG (DEG)	MAG	ANG (DEG)		
4 0	0 41	131 0	3 12	-117 0	0 06	-135 6	0 64	126 8	12 50	1 63
8 0	0 39	-89 8	1 87	0	0 08	9 0	0 63	-103 8	7 94	2 01
12 0	0 22	-5 0	1 46	92 0	0 07	126 0	0 55	-33 0	5 06	3 33

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The small-signal S-parameter showed insignificant bias dependence (V_{CE} of 2 to 3 volts and I_c of 10 to 20 mA). The microwave gain compression characteristics measured at 12 GHz, figure 1, showed a 6-dB gain, 35% power added efficiency and P_{sat} of 17 dBm (2.5 W/mm). Higher narrow-band gain of up to 11 dB at 12 GHz has been observed in amplifier mode for the HBT devices.

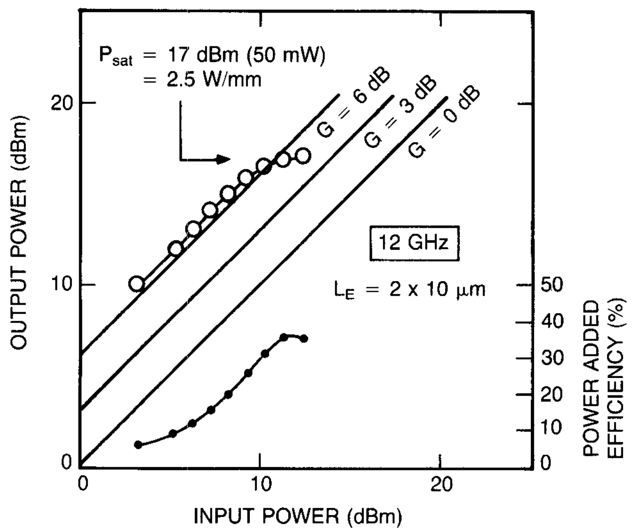

Figure 1. Saturation and Efficiency Characteristics of GaAs HBT.

OSCILLATOR DESIGN

A parallel feedback-type oscillator circuit configuration is selected and the HBT is operated in common emitter mode. The circuit is constructed on 0.025-inch-thick duroid substrate with $\epsilon_r = 10.2$. Oscillator design was carried out using S-parameter method[3]. The S-parameters of a dielectric resonator, coupled to a pair of 50-ohm lines, were used to characterize coupling coefficients. Figure 2 shows the circuit and layout of the shunt feedback DRO. Similar technique was used to design FET and silicon-bipolar dielectric stabilized oscillators for comparative studies. A 50-ohm resistor on the base or gate is used for suppressing undesired mode and for achieving good out-of-band stability.

The location of the resonator was selected to give a light coupling, thereby minimizing phase noise and reducing harmonics (resulting from the overdriven gate or base of the device). Additionally, the dielectric resonator is placed on a carefully selected thin quartz spacer above the duroid substrate.

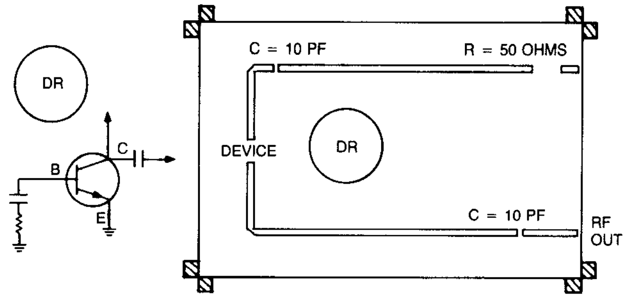

Figure 2. Layout of Shunt Feedback DRO.

PHASE NOISE AND OTHER PERFORMANCE CHARACTERISTICS

Figure 3 shows the frequency response of the HBT-DRO. An output power of 10.2 dBm and second harmonic power of −15 dBc or less were measured.

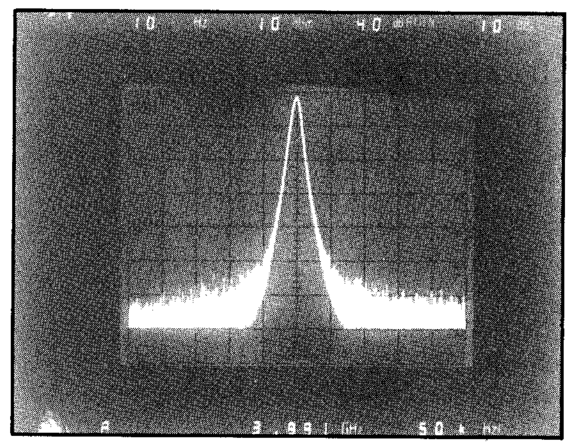

Figure 3. Frequency Response of 4 GHz HBT-DRO, Biased at 2.5 V/15 mA.

Efficiency of 30% was achieved and frequency stability of 3 ppm/°C was measured for operation over −30° to 70°C (figure 4). The tuning range of 100 MHz was achieved with output power variations of 1 dB or lower.

Close-in phase-noise performance for HBT-DRO at microwave frequencies of −73 dBc/Hz at 1 kHz away from the carrier was measured (figure 5). This is about 12 dB better than FET but almost the same as bipolar. The phase noise of HBT degrades to FET or worse at 10 kHz and beyond. This crossover behavior is currently under investigation.

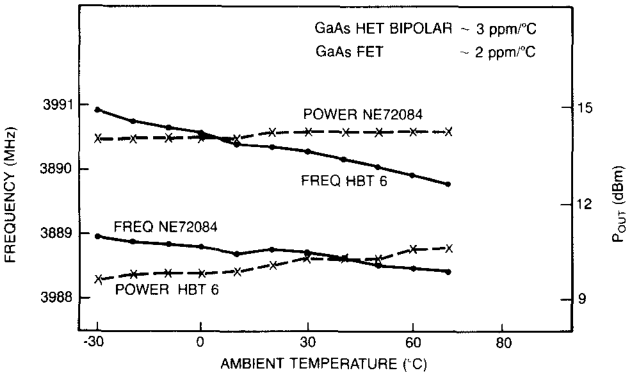

Figure 4. Frequency Stability and Power Variation With Temperature, for GaAs Oscillators.

Table 2. DRO Microwave Characteristics.

DEVICE	HBT ROCKWELL	FET NE72084	BIPOLAR NE68135
OSCILLATION FREQUENCY (MHz)	3990 4	4006 8	3968 0
OUTPUT POWER (dBm)	10 2	16 0	14 9
POWER OF SECOND HARMONIC FREQUENCY (dBm)	-6 0	-1 0	-8 0
EFFICIENCY (%)	29 4	44 2	12 9
FREQUENCY STABILITY (ppm/°C) -30 TO 70°C	2 802	1 361	15.29
TUNING RANGE FOR 1 dBm POWER VAR (MECH) (%)	2 8	2 1	3.0
FM NOISE (dBc/Hz) AT 1 kHz OFF-CARRIER FREQUENCY	-73 0	-61 0	-78 0
AT 10 kHz OFF-CARRIER FREQUENCY	-95 0	-95 0	-108 0

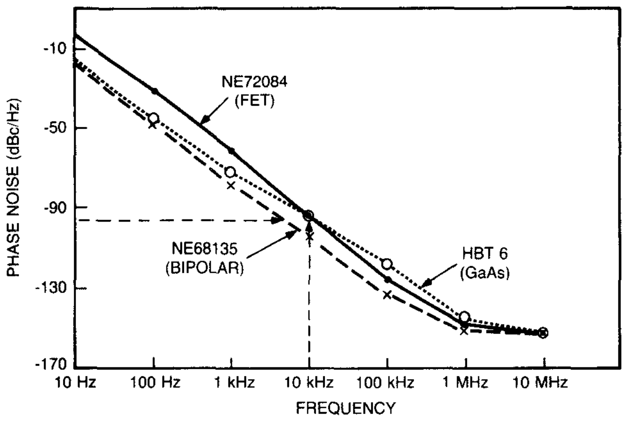

Figure 5. FM Noise Behavior of GaAs HBT/FET and Silicon Bipolar.

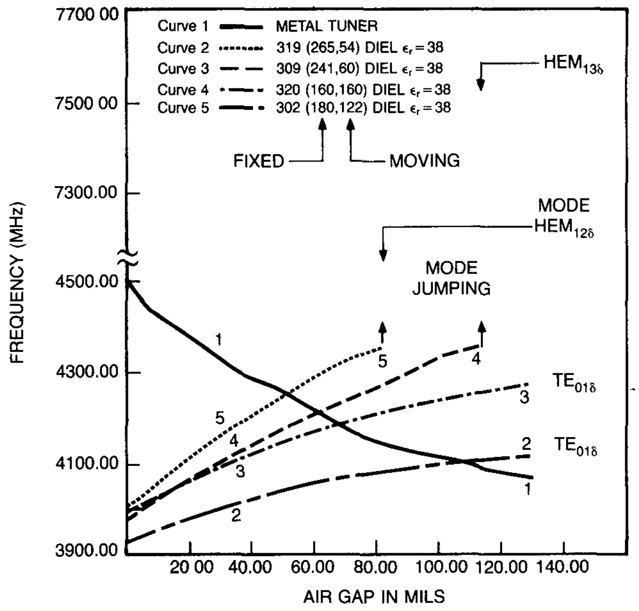

Figure 6. Measured Tuning Characteristics of DROs (1 Metal Tuner, 2-5 Dielectric Tuners).

All these results have been summarized in table 2. The silicon-bipolar stability as measured on the unit was rather poor, and later confirmed as an oscillator assembly problem. Typical stability results of 5 ppm/°C have been achieved on silicon-bipolar DROs for operation over −30° to +70°C.

FREQUENCY TUNING OF DROs

Mechanical tuning with metal and high-dielectric tuners was measured (figure 6). Since the RF output power, P_{OUT} of the oscillators changes with tuning, a criteria of 1 dB or less change in P_{OUT} was selected to compare tuning capability. The metal tuner has about 9% tuning capability (curve 1). For dielectric tuning, ($\epsilon_r = 38$) material was used for the tuner. The thickness of resonator was divided in various ratios resulting in variable tuning slope (MHz/turn or degree). A maximum of 3% to 4% tuning was achieved with good stability. For higher slopes and wider tuning (up to 8%), one has to be careful due to the tendency of the oscillator to jump to higher order mode. This problem would be minimized by leaving the main resonator to nearly its correct size and tuning with an external dielectric tuner. This idea is being pursued.

CONCLUSION

It has been demonstrated that microwave oscillators with good output power, efficiency, phase-noise, and temperature stability can be realized using GaAs heterojunction bipolar transistors. Phase noise comparable to silicon bipolar is possible using GaAs HBTs and with advances in HBT device design, improved performance with heterojunction bipolar on Gallium Arsenide at frequencies to 20 GHz or more is predicted.

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