A 62-GHz Monolithic InP-based HBT VCO

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Abstract— **A monolithic V-band VCO using InP-based HBT technology has been designed, fabricated, and tested. This VCO delivers a peak output power of 4 dBm at a center frequency of 62.4 GHz with a tuning range of 300 MHz. The measured phase noise shows −78 dBc/Hz at 100 kHz offset and −104 dBc/Hz at 1 MHz offset. To our knowledge, this is the highest frequency fundamental-mode oscillator ever reported using bipolar transistors.**

I. Introduction

High-frequency and low-phase oscillators are required in millimeter-wave (MMW) systems. Although several monolithic VCO's operating at MMW frequencies have been reported using high electron mobility transistor (HEMT) technology [1]–[3], their phase noises have been limited by the high intrinsic $1/f$ noise present in HEMT's. The lower $1/f$ noise in heterojunction bipolar transistors (HBT's) makes them suitable for high-frequency oscillators with reduced phase noise; however, the reported maximum operating frequency of GaAs HBT-based oscillators has been limited to under 50 GHz [4]. On the other hand, InP-based HBT's have demonstrated impressive high-frequency performance for both discrete devices and circuits [5], [6]. Furthermore, they exhibit lower $1/f$ noise than GaAs HBT's because of the lower surface recombination velocity in InP-based materials and the absence of DX centers in the emitter [7], [8]. This property has also been investigated using both GaAs- and InP-based HBT's fabricated in TRW [13]. Moreover, a 19.5-GHz MMIC VCO using InP HBT demonstrated a 10-dB phase noise improvement at 1 MHz offset over the conventional $Al_{0.3}Ga_{0.7}As$/GaAs HBT counterpart due to the lower $1/f$ noise of the InP HBT [14].

This letter presents the recent development of a monolithic V-band VCO using InP-based HBT. The MMIC VCO has been designed, fabricated, and tested. This VCO exhibits the oscillation at 62.4 GHz with a tuning range of 300 MHz, and a peak output power of 4 dBm. The phase noise is −78 dBc/Hz at 100 kHz offset and −104 dBc/Hz at 1 MHz offset. To our knowledge, this is the highest frequency fundamental-mode oscillator ever reported using bipolar devices. The phase noise performance of this InP-based VCO is almost 20 dB better than reported 55-GHz HEMT free-running VCO and comparable with the 55-GHz HEMT DRO [3].

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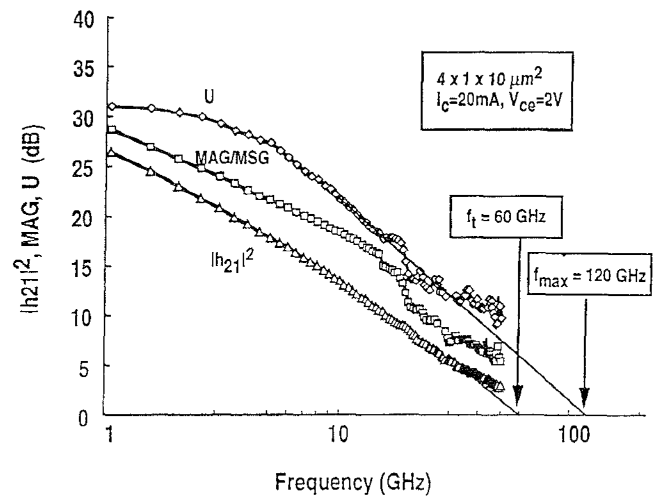

Fig 1 RF frequency characteristics of the InP-based HBT.

II. Device Characteristics and Circuit Design

The InP-based HBT MMIC is fabricated on a 2-in.-diameter InP substrate grown by MBE and utilizes a 1-μm fully self-aligned process using nonalloyed refractory ohmic contacts and conventional wet etching to define the device active areas. The InAlAs/InGaAs HBT epitaxial layer structure reported in [6] features InGaAs collector and base regions with a smoothly graded emitter-base junction. The $1 \times 10\ \mu m^2$ quad emitter HBT used in the VCO has a typical common emitter current gain β of 30 and a collector breakdown voltage BV_{ceo} of 11 V. At a current density of $5 \times 10^4\ A/cm^2$ and $V_{ce} = 2.0$ V, the device exhibits a unity current gain frequency (f_T) of 60 GHz and a maximum frequency of oscillation (f_{max}) of 120 GHz, as shown in Fig. 1.

Fig. 2 shows the circuit schematic diagram and photograph of the V-band monolithic VCO. The chip size is $2.0 \times 1.5\,mm^2$. A $1 \times 10\,\mu m^2$ quad HBT device is employed in this VCO circuit. The VCO is a common emitter design and the oscillation frequency is adjusted by the base current. The output power is coupled out of the collector via microstrip edge coupled lines. Radial stubs provide RF bypass for the bias lines and thin-film resistors and metal-insulator-metal (MIM) capacitors are used for the bias networks. The substrate is thinned and polished to a thickness of 100 μm and via holes are wet-etched to provide low-inductance ground connections.

The design procedure follows the example illustrated in [9]. A short stub RF ground by the quarter wavelength radial stub from the base of the HBT is used as a series feedback element to bring the device to an unstable region. A linear device

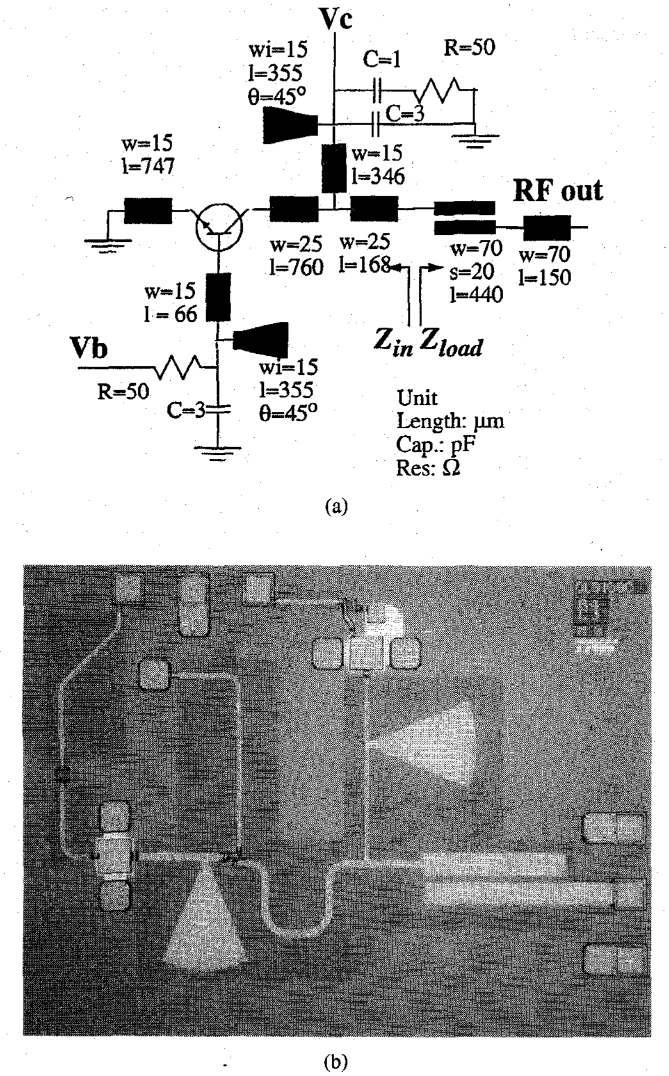

Fig. 2. The (a) circuit schematic diagram and (b) chip photograph of the monolithic V-band VCO.

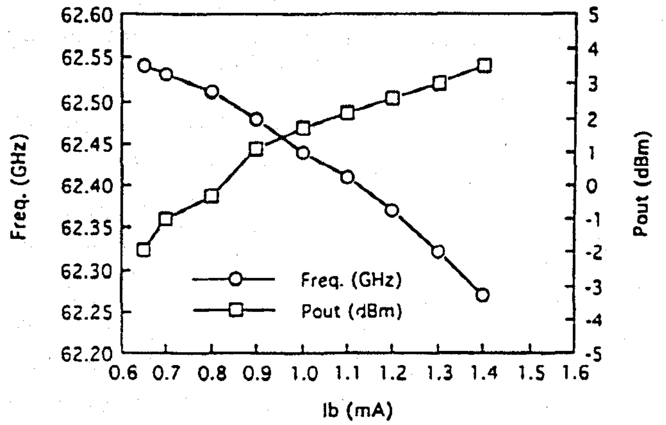

Fig. 3. The oscillation frequency and output power as functions of base current for the monolithic V-band VCO.

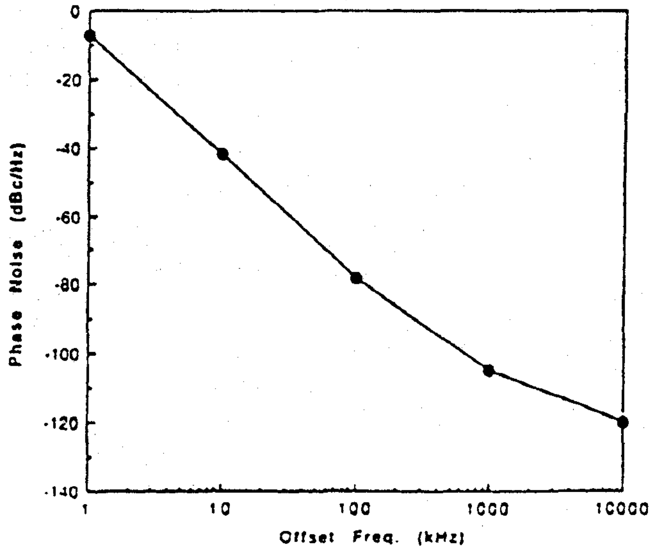

Fig. 4. Phase noise performance of the monolithic V-band VCO for offset frequencies ranging from 1 kHz to 10 MHz.

model was used to ensure the correct start-up condition at the oscillation frequency of 60 GHz, which are

$$\mathrm{Re}\,[Z_{in} + Z_{load}] < 0 \tag{1}$$

and

$$\mathrm{Im}\,[Z_{in} + Z_{load}] = 0 \tag{2}$$

where Z_{in} is the impedance looking into the device collector and Z_{load} is the impedance looking into the coupled line and output port, as shown in Fig. 2(a). To achieve a good output power of the VCO, the negative resistance looking into the collector is designed to be near three times the resistance looking into the output load, i.e.

$$-\mathrm{Re}\,[Z_{in}] \approx 3\mathrm{Re}\,[Z_{load}]. \tag{3}$$

Models for passive elements were obtained from full-wave EM analyses to overcome the inaccuracies of quasistatic models at millimeter-wave frequencies [10].

III. Measurement Results

A diced MMIC VCO chip was mounted on a fixture for testing. Anti-podal finline transitions on a fused silica substrate were used to couple the output signal from the microstrip line to the waveguide. The insertion loss of back-to-back transitions was 1.2 dB; therefore, the output power of the VCO was corrected assuming half the loss (0.6 dB) for a single transition.

The effects of the bias tuning on the oscillation frequency and output power are shown in Fig. 3 for the V-band VCO. A tuning range of 300 MHz centered around 62.4 GHz was observed. Compared with the simulated 60-GHz oscillation frequency, there is a 2.4-GHz frequency shift. This could be due to the HBT device modeling accuracy limitation at this frequency. The maximum output power of 4 dBm was obtained at 62.2 GHz for $V_{ce} = 2.5$ V. The VCO phase noise was evaluated via a single-oscillator phase-noise measurement technique using a delay line as an FM discriminator [11], [12]. The phase noise as a function of the offset frequency away from center frequency is plotted in Fig. 4. It shows -78 dBc/Hz at 100 kHz offset and -104 dBc/Hz at 1 MHz offset.

The phase noise performance of this InP-based VCO is 18 dB better than reported 55-GHz HEMT free-running VCO [3] and comparable with the 55-GHz HEMT DRO [3].

IV. SUMMARY

The 62.4-GHz oscillator reported in this letter represents the highest frequency fundamental-mode oscillator implemented using HBT devices. The monolithic VCO demonstrates a tuning range of 300 MHz with a peak output power of 4 dBm. The excellent phase noise performance of −78 dBc/Hz at 100 kHz offset and −104 dBc/Hz at 1 MHz offset illustrates the suitability of InP HBT technology for high performance V-band radar and communication system applications.

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