Ka-Band Monolithic InGaAs/InP HBT VCO's in CPW Structure

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***Abstract*—Two Ka-Band monolithic voltage controlled oscillators (VCO's) designed in coplanar waveguide (CPW) structure are described in this letter. Each VCO utilizes a InGaAs/InP heterojunction bipolar transistor (HBT) as the active device and a HBT base-collector junction as the tuning varactor. These two VCO's are biased at a very low voltage of V_{CE} = 1.5 V and the emitter current is less than 10 mA. Under this low dc power dissipation, the VCO's with center frequencies of 26.5 and 33.5 GHz show high dc-to-rf conversion efficiencies over 10% and 5% within the frequency tuning ranges of 1.6 and 1.2 GHz, respectively. The measured phase noise at 1 MHz offset frequency is −110 dBc/Hz.**

I. Introduction

As the wireless communications of voice, video, and data grows, the increasing demand of channels and bandwidths is driving the transceiver systems toward millimeter-wave frequencies. Currently, there are several applications in Ka-band and 60 GHz [1]. Low phase-noise oscillator with high efficiency is a key component in the transceiver front end. III–V HBT's with low $1/f$ noise and high efficiency are suitable active devices for building oscillators at microwave and millimeter-wave frequencies [2], [3].

Recently, Ka-band MMIC VCO's using GaAs- or InP-based HBT technology were demonstrated [4]–[6]. A GaInP/GaAs HBT VCO at 28 GHz with phase noise of −65 dBc/Hz at 100 kHz off carrier and tuning bandwidth of 5.5 GHz was reported [4]. Using the same material structure, a 35 GHz VCO with phase noise of −80 dBc/Hz at 100 kHz off carrier and tuning bandwidth of 1 GHz was fabricated [5]. In addition to the GaAs-based HBT VCO, an InP-based (InAlAs/InGaAs) HBT VCO at 31 GHz was reported without phase noise characteristics [6].

In this letter, we report on InGaAs/InP HBT VCO's at 26.5 and 33.5 GHz. Phase noise levels at 100 kHz and 1 MHz offset frequencies are −80 dBc/Hz and −110 dBc/Hz, respectively. With a low dc bias voltage of 1.5 V and low current of less than 10 mA, the dc-to-rf conversion efficiencies for the VCO's at 26.5 and 33.5 GHz is higher than 10% and 5%, respectively. The coplanar waveguide (CPW) structure, which eliminates the processing of via holes, is first introduced into the Ka-band MMIC VCO design.

II. Design

The oscillators were designed in a CPW structure using common base configuration. Two separate VCO's designated

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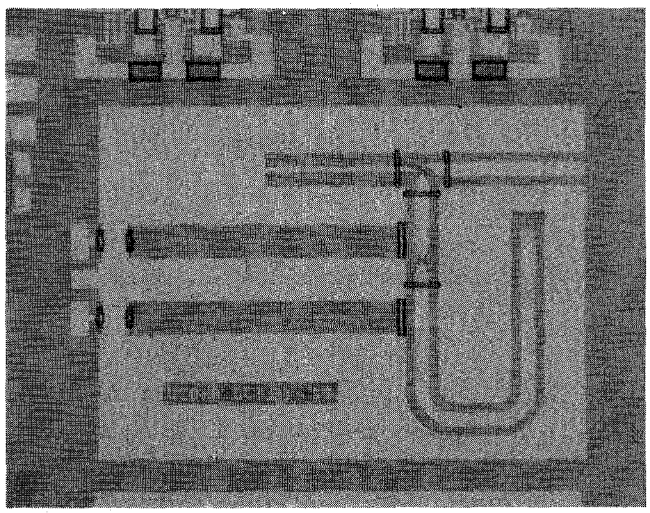

Fig. 1. Photograph of VCO-A (26.5 GHz).

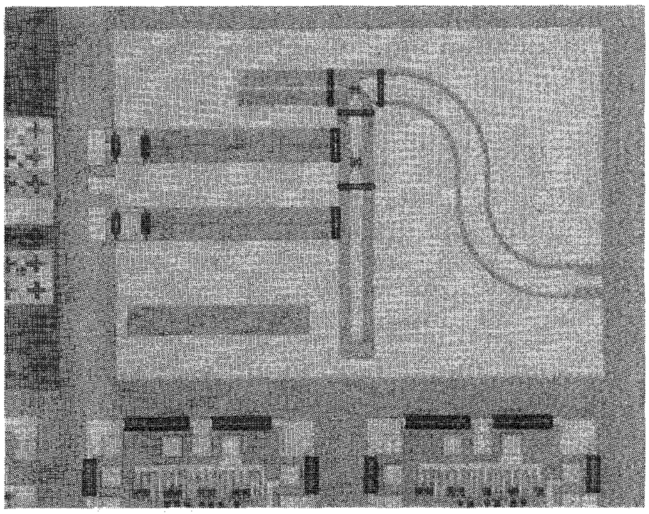

Fig. 2. Photograph of VCO-B (33.5 GHz).

A and B were designed for 26.5 GHz (Fig. 1) and 33.5 GHz (Fig. 2). The base is connected to the ground through a CPW short-circuited stub. A varactor utilizing the base-collector junction of a transistor is inserted in the resonant tank connected to the emitter of the HBT. The collector is connected to the VCO output port via a section of CPW line for impedance matching. Cross-over bridges are placed near junctions of transmission lines to avoid the excitation of even mode (coupled slot mode). High impedance CPW lines and Metal-Insulator-Metal (MIM) capacitors were used as dc bias

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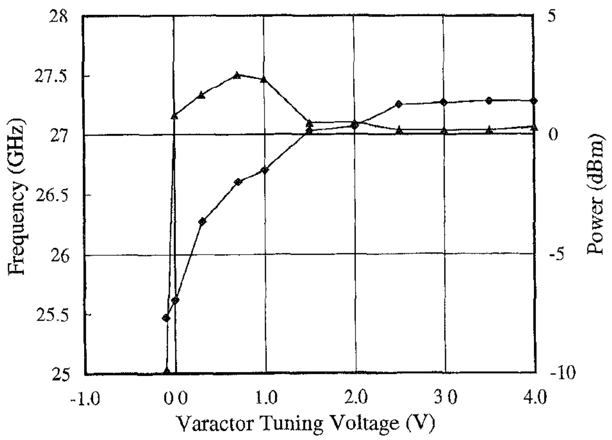

Fig 3. Frequency tuning and output power of VCO-A. —◆—: Frequency; —▲—: Power.

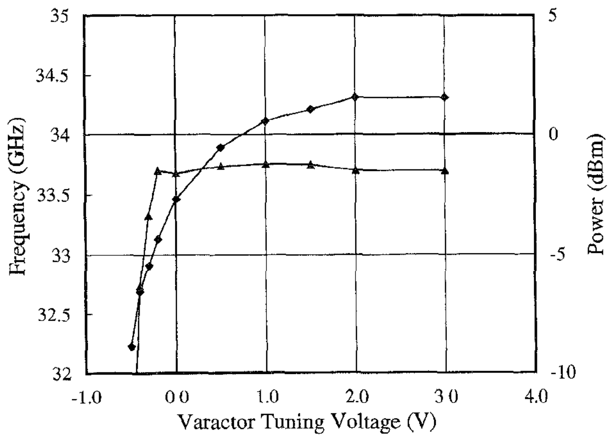

Fig. 4. Frequency tuning and output power of VCO-B. —◆—. Frequency, —▲—· Power.

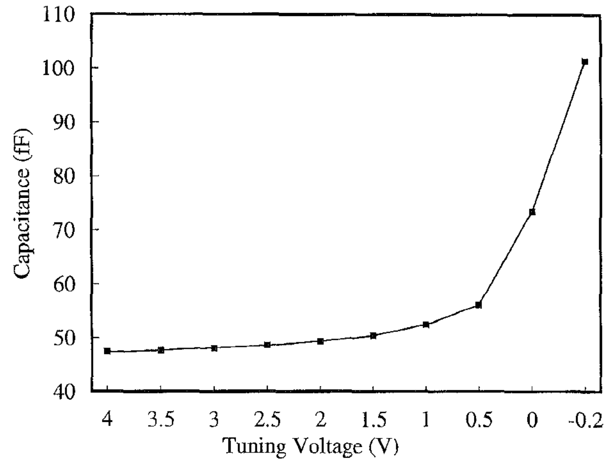

Fig. 5 Capacitance tuning performance of varactor diode.

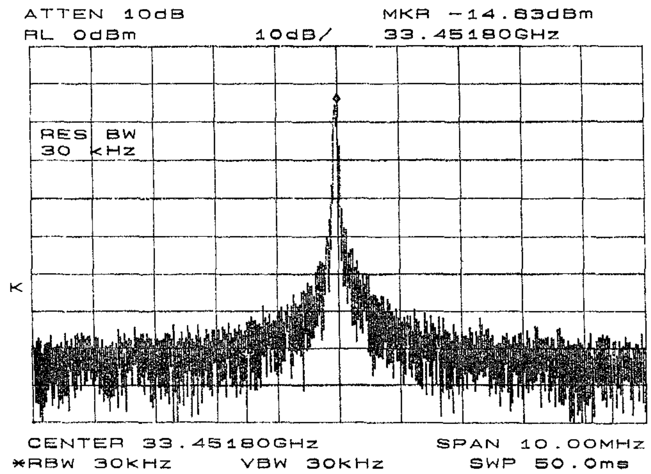

Fig. 6. Output spectrum of VCO-B at 33.45 GHz.

lines. The chip size is 1.75 mm × 1.2 mm for both VCO-A and VCO-B.

III. Fabrication

The InGaAs/InP HBT wafers were grown in the Metal-Organic Molecular Beam Epitaxy (MOMBE) system. The HBT device used in the VCO has an emitter size of 3 μm × 10 μm. The collector doping and thickness are 1×10^{16} cm^{-3} and 500 nm, respectively. The short-circuited current gain cutoff frequency f_T is 100 GHz and the maximum oscillation frequency $f_{\max}$ is greater than 60 GHz. The maximum available gain at 30 GHz is 7 dB with a collector current of 15 mA. SiO_2 is used for passivation as well as the dielectric layer of MIM capacitor. To reduce the parasitic capacitance and support the cross-over bridges, polyimide with thickness of 1 μm is used. Since the ground plane is on the same side of the circuitry, no via hole processing is needed.

IV. Result

Frequency tuning and output power were measured at the bias condition of $V_{\rm CE} = 1.5$ V ($V_{\rm BE} = 1.0$ V and $V_{\rm CB} = 0.5$ V). The emitter current I_E was 6.8 mA for VCO-A and 9.5 mA for VCO-B. The result is shown in Figs. 3 and 4. The capacitance tuning performance of varactor is shown in Fig. 5. The tuning capacitance ratio is 1.5:1 from 0 to 4 V for VCO-A and 2.1:1 from −0.2 to 3 V for VCO-B. The frequency tuning range of VCO-A is 1.6 GHz and the output power varies from 0.2 to 2.5 dBm. For VCO-B, the frequency tuning range is 1.2 GHz and the output power is within -1.43 ± 0.2 dBm. The overall dc-to-rf conversion efficiency within the tuning range is 10% for VCO-A and 5% for VCO-B. At tuning voltage of 0.7 V, the conversion efficiency of VCO reaches 17% at 26.6 GHz. An output spectrum of VCO-B is shown in Fig. 6. The measured phase noise levels at 100 kHz and 1 MHz offset frequencies are −81 and −112 dBc/Hz for VCO-A and −79 and −107 dBc/Hz for VCO-B.

The output power of the circuit increases as $V_{\rm CE}$ and I_C increase. With the constrained bias voltage of $V_{\rm CE} = 1.5$ V, however, the HBT VCO's designed here are not optimized for output power but for a combination of dc-to-rf conversion efficiency, phase noise, and frequency tuning range.

V. Conclusion

Monolithic Ka-band VCO's were developed using InGaAs/InP HBT and CPW circuit design. Frequency tuning ranges of VCO's with center frequencies at 26.5 and 33.5

GHz are 1.6 and 1.2 GHz, respectively. DC-to-rf conversion efficiencies of 10% and 5% were achieved with a low dc bias voltage $V_{CE} = 1.5$ V and emitter current less than 10 mA. The features of low dc power dissipation, high efficiency, and low phase noise enable this HBT VCO technology to be applied in low-power wireless communications.

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