A 39-46 GHz MMIC HBT Triple-Push VCO Using Cascode Configuration

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Abstract

This paper reports the development of a Q-band (33-50 GHz) triple-push VCO using GaAs heterojunction bipolar transistor (HBT) MMIC technology. The circuit adopts cascode configuration of HBTs in order to increase the negative resistance at high frequency and thus to obtain a higher oscillation frequency. Based on the measured results, MMIC VCO achieves a tuning frequency range of 39 to 46 GHz.

Ⅰ. Introduction

The availability of millimeter-wave frequency sources is crucial for advanced imaging, remote sensing applications, communication systems, and radar systems. MMIC can provide the advantage of size, weight and performance for those applications. However, the oscillation frequency of a fundamental frequency oscillator is limited to the maximum frequency of oscillation (f_{max}) of the transistors. To overcome this limitation, push-push oscillators consisting of two identical fundamental oscillators that can double the fundamental frequency of oscillation, have been proposed [1]-[5].

A novel triple-push oscillator concept to comprise three identical oscillators in order to increase the frequency limitation was proposed in [6]. In this approach, the fundamental and second harmonic frequency signals have 120 degree phase difference with one another and the third harmonic frequency signals of the three oscillators are in phase, thus the output frequency is tripled, as shown in Fig. 1. This approach has been verified by a 4.9-GHz hybrid oscillator and a 28.4-GHz MMIC oscillator [6]. In this work, due to the potential of higher negative resistance of a cascode transistor configuration [7], we used cascode HBTs in our VCO design to further increase the oscillation frequency, as well as the tuning range. The measurement results show that this MMIC triple-push VCO demonstrates a tuning frequency range of 39 to 46 GHz.

Ⅱ. Circuit Design

The triple-push cascode VCO circuit was fabricated using the GaAs HBT MMIC foundry on 4-mil GaAs substrate provided by WIN Semiconductors. The emitter size of HBT devices used in this oscillator was 2μm x 10μm. This HBT device has a unit current gain frequency (f_T) of 36 GHz and a maximum oscillation frequency (f_{max}) of 64 GHz. The maximum current density of the collector metal is 1.5mA/ μm. The thin film resistor of this process has a sheet resistance of 50Ω/ □ using sputtered TaN. The through via holes used for grounding are realized by inductively coupled plasma (ICP) etch.

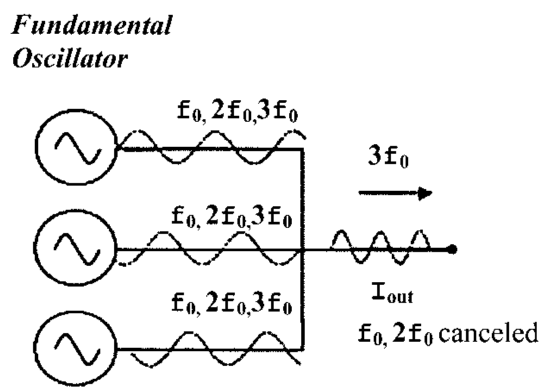

Fig. 1. The triple-push VCO architecture.

The triple-push VCO is composed of three fundamental oscillators designed around 15 GHz using microstrip lines. The circuit schematic diagram for one of the fundamental oscillator is illustrated in Figure 2. The resonator of the oscillator is formed with the capacitance C_{B1} and the inductor L_{B1} in series near the output end. For the convenience of the layout and the combination of the three oscillators, the inductor is replaced by 670 μm-long microstrip line. To ensure the instability, the first HBT connected in a common collector configuration and followed by a common emitter configuration with the second device in order to increase the power and the tuning range. The emitter capacitance (C_E) and the collector inductors (L_{C1}, L_{C2}) of the two HBTs are selected for an appropriate negative resistance looking into the devices. The resistors (R_{B1}, R_{B2}, R_{B3}) are used for self-biasing network. Furthermore, an emitter degeneration resistor (R_E) is employed to stabilize the dc biasing due to the temperature variation. The chip photograph is shown in Fig. 3 with a chip size of 1.5 mm x1.5 mm.

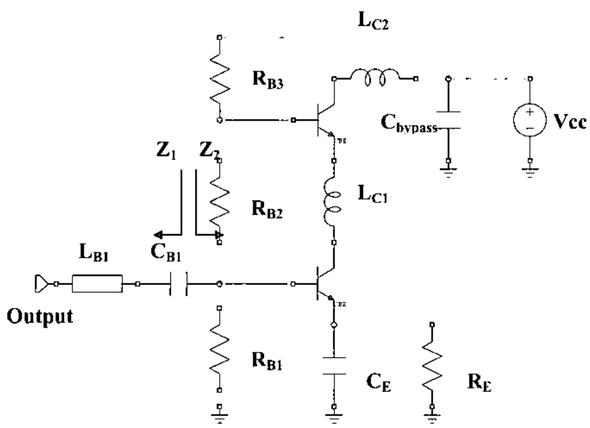

Fig. 2. Schematic diagram for one fundamental frequency oscillator using cascode HBTs of the triple-push VCO.

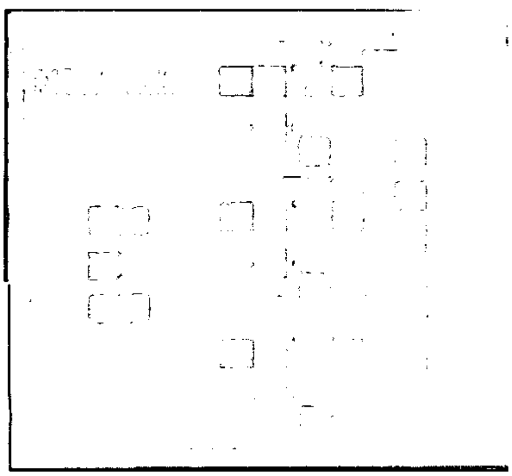

Fig. 3. Chip photograph of the Q-band HBT triple-push cascode VCO with a chip size of 1.5 mm x1.5mm.

There exist both even mode and odd mode currents in a triple-push oscillator. In the circuit design, the even mode currents have to be quenched since all the harmonic signals are in phase. On the other hand, the odd mode currents are excited to generate 15-GHz signal, as suggested in [6]. For the even mode, the oscillation condition should be prevented with the load resistance to be 150Ω, that is,

$$\mathrm{Im}(Z_1+Z_2)\neq 0 \qquad (1)$$

or

$$\mathrm{Re}(Z_1+Z_2)>0\,, \qquad (2)$$

as shown in Fig. 4(a), where Z_1 and Z_2 are the input impedances looking into the resonator and the devices respectively, which are illustrated in Fig. 2. On the other hand, the oscillation condition should be satisfied for the odd mode, that is,

$$\mathrm{Im}(Z_1+Z_2)=0 \qquad (3)$$

and

$$\mathrm{Re}(Z_1+Z_2)<0\,, \qquad (4)$$

at the desired frequency when the load is a virtual ground [6], as s shown in Fig. 4(b). The time domain analysis was performed with the HBT Gammel-Poon model. The simulated output current waveforms for the three fundamental oscillators are shown in Fig. 5(a). The three odd mode currents are 120 degree out of phase before combining together, with the same frequency of 15 GHz, which is the fundamental oscillation frequency of the oscillator. The amplitude of the simulated odd currents is 20 mA. At the output port, the fundamental and second harmonic currents were cancelled out and the third harmonic currents were combined in phase, as shown in Fig. 5(b). The simulated combined third harmonic current has an output signal of 45-GHz frequency as predicted to be three times of the fundamental frequency. The current waveform has also been transformed to the spectrum domain, which is shown in Fig. 5(c). The simulation results show that the power of 45-GHz signal is –10dBm, with the 15-GHz signal power to be –42dBm and the power of –27dBm for the 30-GHz signal .

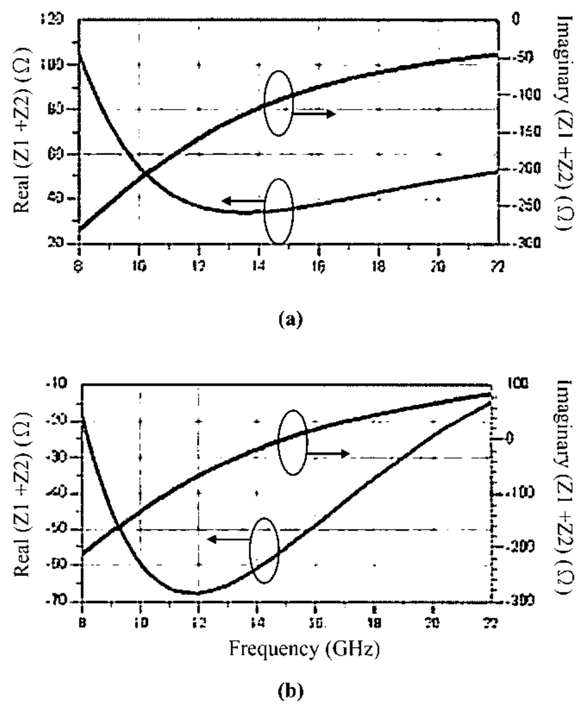

Fig. 4. Simulated (a) even mode, (b) odd mode, input impedance for the summation of real and imaginary part of the single oscillator designed around 15 GHz.

Ⅲ. Measurement Results

The chip is measured via on wafer probing. The fundamental oscillator was measured first with the other two oscillators turned off. The self-bias voltage is fixed at 7 V with collector current of 4 mA. An output power of –10dBm at 14.5 GHz was obtained. The powers of the second and third harmonic frequency signals are –32dBm and –37dBm, respectively. The output power is relatively low since a small device was selected in the design.

The complete triple-push VCO was measured next at the bias voltage at 6 V. Figure 6(a) presents that the circuit oscillates at the center frequency of 45 GHz and the output power is –15dBm. The fundamental and second harmonic signals are –24.5dBm and –24.6dBm, respectively. The fundamental and second harmonic signals were not cancelled out completely. This may be due to the asymmetricity in the circuit layout and the variations of the devices.

In order to optimize the performance, the bias voltage of each oscillator was adjusted to further suppress the fundamental and the second harmonic frequency. A better performance was achieved when the output signal is 39 GHz with output power of –13.5dBm. The fundamental frequency power is –49.8dBm and the power of the second harmonic signal is –47dBm as shown in the spectrum plot in Fig. 6(b). Table I summarizes the measurement performance at the two different frequencies. The frequency tuning range of this VCO was also investigated and this VCO demonstrated a tuning range from 39 to 46 GHz, which is 16.5%. Over the 7-GHz tuning range, the fundamental and second harmonic frequency rejections are all better than 8 dB. Figure 7 shows the plot of tuning frequency versus output power. The power deviation in the tuning range is less than 7 dB.

IV. Summary

A Q-band triple-push HBT MMIC VCO using a cascode configuration is developed. The measured results demonstrate a tuning of 7 GHz from 39 to 46 GHz. This is the first demonstration of a triple-push VCO in millimeter-wave frequency range.

Acknowledgements

This work is supported in part by National Science Council (NSC 89-2213-E-002-178, NSC 89-2219-E-002-042), and Research Excellence Program funded by Department of Education (ME 89-E-FA06-2-4) of Republic of China. The authors would like to thank WIN Semiconductors to provide the GaAs HBT MMIC foundry service. Thanks also go to Chun-Shien Lien and Kun-You Lin for their suggestions in the chip design and Hong-Yeh Chang for his help on chip testing.

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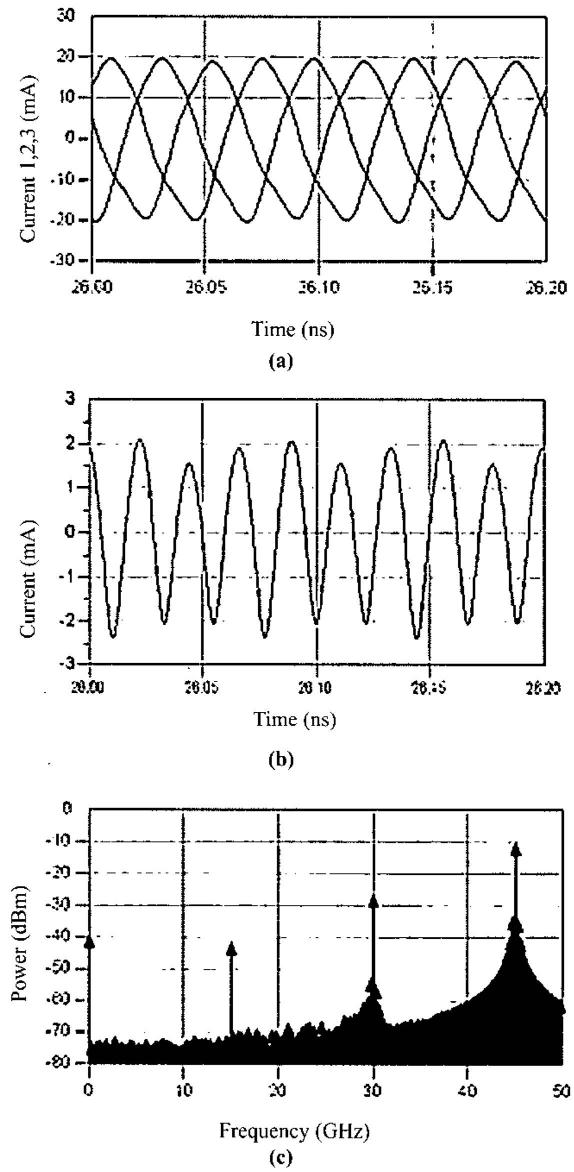
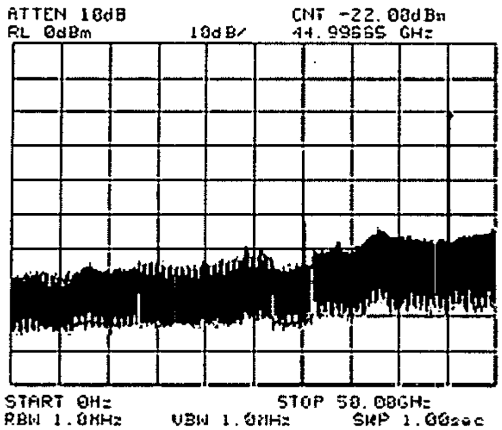
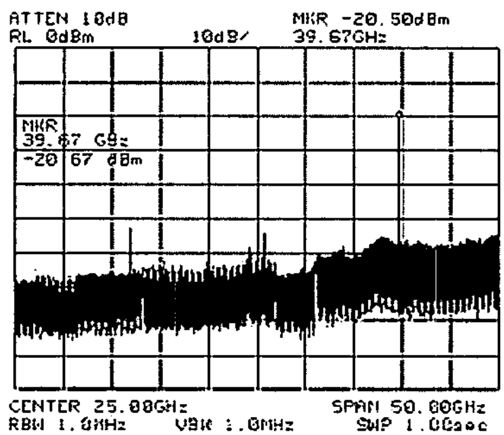


Fig. 5. (a) Simulated fundamental frequency currents of the three identical oscillators designed around 15 GHz. (b) Simulated current at the output port after combining the three identical oscillators, which presents 45 GHz signal. (c) Simulated signal at the output end after the combination of three identical oscillators in spectrum domain.



(a)



(b)

Fig. 6. For (a) 45 GHz, (b) 39 GHz, output signal. It is observed that the fundamental and second harmonic suppression is very good at 39-GHz output frequency.

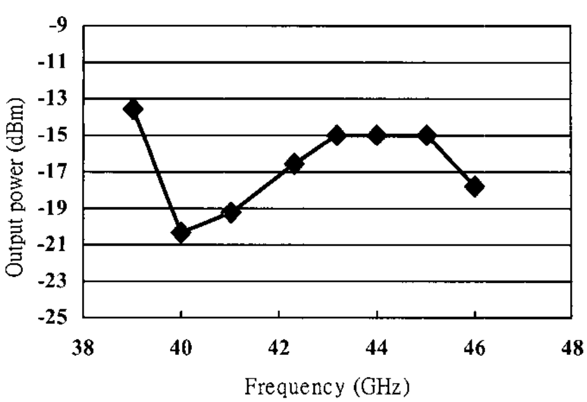


Fig. 7. Measured output power as function of the tuning frequency. The tuning range is 16.5%

Table. I. Measured power at the output port for 39 GHz and 45 GHz.

Output frequency	Fundamental frequency	Second harmonic	Third harmonic (Desired signal)
45 GHz	-24.5dBm	-24.6dBm	-15dBm
39 GHz	-49.8dBm	-47dBm	-13.5dBm