A K-Band Push-Push VCO MMIC using embedded frequency doubling mechanism

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***Abstract* — A K-Band Push-Push VCO MMIC which has small size, high output power and low phase noise is presented. This push-push VCO utilize the embedded frequency doubling mechanism of cross coupled topology. A commercial InGaP/GaAs HBT technology with the f_T of 60 GHz and the f_{MAX} of 110 GHz was used for the implementation. The oscillation frequency is from 21.02 GHz to 21.17 GHz. The peak output power of the VCO is 1.7dBm. The phase noise is -110dBc/Hz at 1MHz offset from 21.16 GHz. The chip size is 0.81 x 0.64 mm^2.**

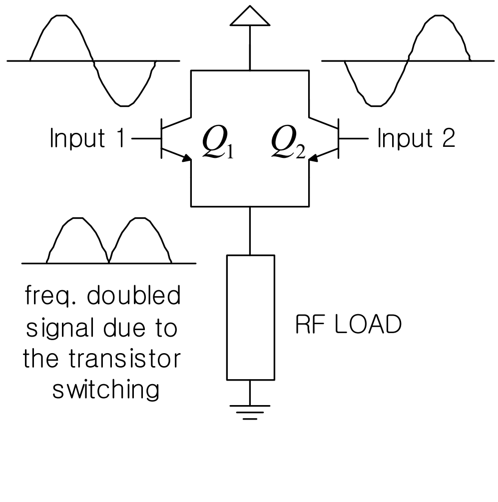
I. INTRODUCTION

Recently, the K-band is widely used in remote sensing systems and communication systems. The use of this band demand for a low phase noise, low cost, and high output power K-band VCO which is a key component of a frequency synthesizer. To achieve low phase noise and high output power characteristic, high Q resonator and low noise active devices are needed. Microstrip line inductor has been used instead of spiral inductor for the high Q and high self resonant frequency in K-band VCOs [1]. However, the use of microstrip line inductor increases the chip size. In a mm-wave VCO design, the push-push principle can extend the available frequency range of a given technology and, especially, of a spiral inductor. In this paper, push-push VCO which utilize the embedded frequency doubling mechanism of cross coupled topology is presented. This can reduce the chip size, yield high output power, and achieve low phase noise at the doubled frequency. For the implementation, InGaP/GaAs HBT technology was used because of its low 1/f noise, low manufacturing cost, and reliable fabrication process.

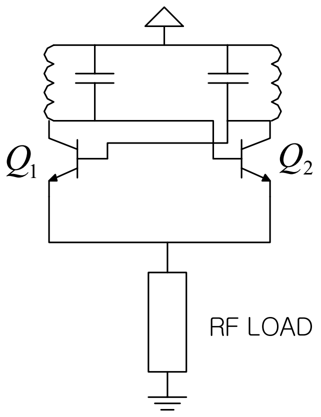
II. CIRCUIT CONFIGURATION

An embedded frequency doubler is used to double the signal frequency effectively. Fig.1.(a) shows balanced frequency doubler. If two anti-phase signals are inserted to the input 1 and input 2, a frequency doubled signal is loaded at the RF load because of the switching of the two transistors Q_1 and Q_2. The balanced frequency doubler in Fig.1.(a) has wide bandwidth and high conversion efficiency [2]. It can be changed to an oscillator easily by connecting additional LC resonator. Fig.1.(b) and Fig.1.(c) show the two types of oscillators evolved from the balanced frequency doubler. Fig.1. (b) is the same as the cross coupled oscillator, and Fig.1.(c) is the same as the balanced Colpitts oscillator where C_1 and C_2 are connected for the positive feedback. Because of the balanced topology, two anti phase signals are generated at the resonator. And, frequency doubled signal of the LC oscillator is loaded at the RF load because of the switching of the two transistors Q_1 and Q_2. The RF load can be any matching circuit or output 50 Ω load [3].

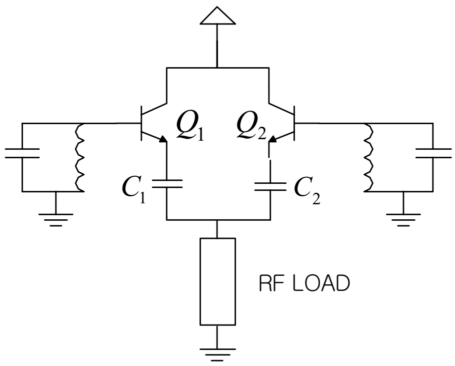
In mm-wave operation, Fig.1. (b) has more conversion gain than Fig.1.(c) because of the loading of the two feedback capacitors C_1 and C_2. In mm-wave, the capacitors C_1 and C_2 are comparable to the base to emitter capacitance C_π. That is, the feedback capacitors C_1 and C_2 can't have high value for the mm-wave operation because the feedback capacitors contribute to determine the oscillation frequency and have positive feedback. The feedback capacitors C_1 and C_2 reduce the base to emitter signal amplitude because of the voltage dividing between C_π and C_1, or C_π and C_2. This reduces the switching of the two transistors Q_1 and Q_2 in Fig.1.(c). Note that the conversion efficiency of the balanced frequency doubler is highly dependent on the switching of the two transistors. And, the signal at the RF load is reduced because of the C_1, C_2 loading. The type of Fig.1. (c) has previously reported in [3]. In this paper, cross coupled type push-push VCO using embedded frequency doubling mechanism is presented.



(a) Balanced frequency doubler



(b) Cross coupled oscillator



(c) Balanced Colpitts Oscillator

Fig.1. Evolution from balanced frequency doubler to oscillator (bias not shown)

III. CIRCUIT DESIGN AND IMPLEMENTATION

Fig.2. shows the K-band push-push VCO schematic. To decouple the DC bias between collector and base, decoupling capacitor C_B was inserted to the cross feedback loop. And, the base is biased through the resistor. This DC decoupling technique increases the oscillation amplitude at the LC resonator. This is because of the fact that the collector and the base should be reverse biased to operate the transistor in active region. For the DC biasing and output matching, L_1 and C_D was connected at the common emitter node. The inductance of L_1 and the capacitance of C_D was selected to deliver maximum power to the 50 Ω load. Spiral inductors and MIM capacitors were used for the LC resonator and output matching. The use of spiral type inductor is helpful to reduce the chip size. 50 Ω output load was connected in series to the capacitor C_D. The circuit design was simulated and optimized using Agilent ADS. The base-collector junction varactor was used for the frequency tuning. The VCO was fabricated using Knowledge* on InGaP/GaAs HBT HS foundry. 1 finger 2 x 10 um^2 emitter size HBTs were used for the VCO core and the varactor. This HBT has the cut off frequency f_T of 60GHz and maximum oscillation frequency f_{MAX} of 110GHz. Turn on voltage of the HBT is about 1.21 V. Fig.3.shows the photograph of the fabricated VCO. The chip size is 0.81 x 0.64 mm^2.

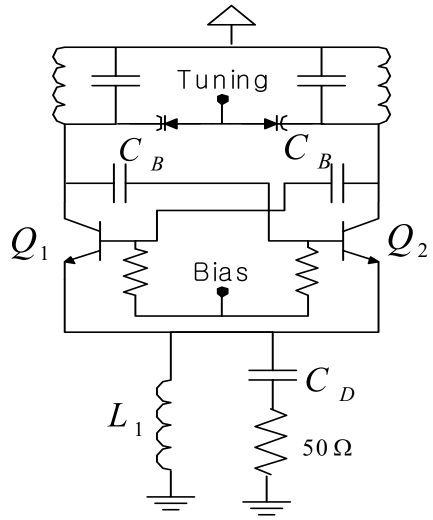


Fig.2. K-band push-push VCO schematic

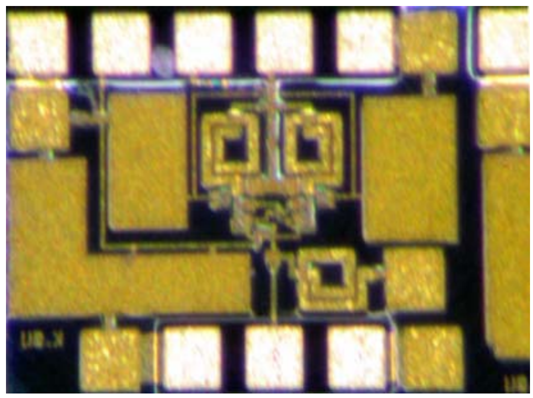


Fig.3. The photograph of the fabricated VCO (chip size: 0.81 x 0.64 mm^2)

IV. MEASUREMENT RESULTS

The output frequency, the output power, and the phase noise were measured on wafer using a GSG probe. Agilent 8564E spectrum analyzer was used to measure the performance. Fig.4. shows the output spectrum of the fabricated VCO. The losses throughout the cable, microprobe and connectors are about 4.7dB. Fig.5. shows the output spectrum from fundamental to 3^{rd} harmonic. The fundamental output power is suppressed about -13dB lower than that of the push-push output. Fig.6. shows the measured phase noise from 21.16GHz signal. The data Fig.4. and Fig.6. was measured at the optimum varactor control bias. Fig.7. shows the oscillation frequency, output power and phase noise as varying the varactor control bias. The total DC power consumption is 120mW. The oscillation frequency varies from 21.02GHz to 21.17GHz as varying the varactor control voltage. 150MHz tuning range was achieved. The peak output power was 1.7dBm. The minimum output power in the tuning range was -5dBm. The minimum phase noise was -110dBc/Hz at 1MHz offset from 21.16GHz signal. The phase noise in the tuning range varies from -110dBc/Hz to -105.33dBc/Hz. Table.1. shows comparison with previously reported K-band VCOs. The fabricated VCO in this paper has high output power, low phase noise, and small size compare to the previously reported VCOs.

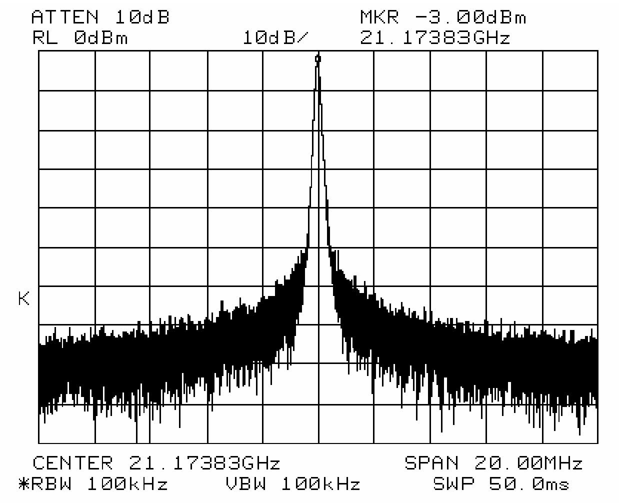


Fig.4. Output spectrum of the fabricated VCO

V. CONCLUSION

K-band push-push VCO using embedded frequency doubling mechanism of the cross coupled topology was presented. This VCO shows high output power, low phase noise, and small size. Because of the frequency doubling mechanism, high output power of 1.7dBm was achieved. To reduce the chip size, spiral inductors were used for the LC resonator and output matching. The fabricated VCO has small size of 0.81×0.64 mm^2. Varying the control voltage, the oscillation frequency was varied from 21.02GHz to 21.17GHz. The phase noise was varied from -110dBc/Hz to -105.33dBc/Hz.

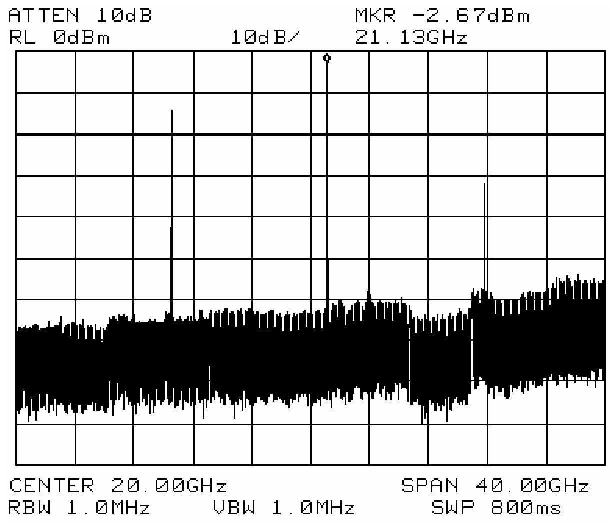


Fig.5. Output spectrum (from 1st to 3rd)

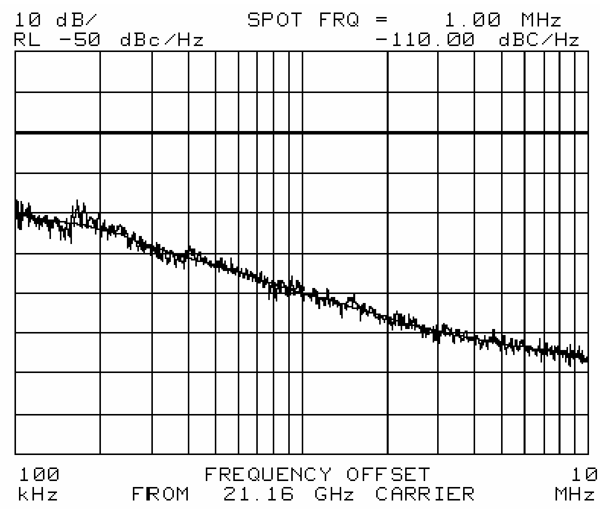


Fig.6. Measured phase noise of the VCO

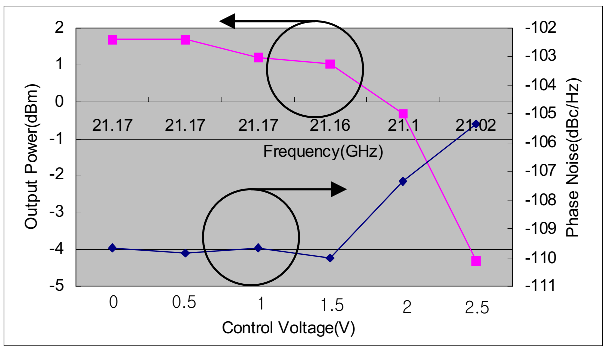


Fig.7. The oscillation frequency, output power and phase noise at 1MHz offset as varying the varactor control voltage

Technology	Frequency (GHz)	Output Power (dBm)	F.O.M (dBc/Hz)	Tuning Range (%)	Size (mm^2)	
SiGe HBT	23.5	-10	-165	1.78	0.60×0.30	[4]
InGap/GaAs HBT	22.1	-0.3	-173	1.9	0.84×1.00	[1]
InP HBT	17.6	-2.8	-154	45	1.20×0.60	[5]
InGap/GaAs HBT	21	1.7	-176	0.7	0.81×0.64	This Work

TABLE 1

COMPARISON WITH PREVIOUSLY REPORTED K-BAND VCOS

ACKNOWLEDGEMENT

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