A Novel Low Phase Noise Positive Feedback Type Push-Push Oscillator

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Abstract

A novel method for phase noise reduction in a push-push oscillator is described. The push-push oscillator consists of two positive feedback type push-push oscillators and two RF multipliers used for the noise reduction. The phase noise of the oscillator can be improved because the multipliers fix the phase difference between the oscillation signals of the push-push oscillators. The second harmonic oscillator is designed and fabricated in K-Band. The output power is +5.83 dBm at 25.6 GHz with the phase noise of -115.5 dBc/Hz at 1MHz offset frequency.

1. Introduction

Microwave and millimeter wave oscillators are key components in all microwave and millimeter wave applications such as a wireless LAN, a radar system and a Dedicated Short Range Communication system (DSRC). The requirements for the microwave and millimeter wave oscillators are low noise, small size, low cost, high efficiency, high output power etc. in the high frequency bands. A push-push oscillator is very effective for the generation of high frequency signal with low cost. Many technical papers of Push-Push oscillators have been published so far [1-4]. The push-push oscillators can generate much higher frequency signal using comparatively inexpensive semiconductor devices for lower frequency applications. The push-push oscillators are very effective to extend the oscillating frequency range with low cost. However, the phase noise performance is not enough in positive feedback type push-push oscillators. Therefore, a method for the phase noise reduction has been required so far.

In this paper, a novel method for phase noise reduction in the push-push oscillator is proposed [5]. A RF multiplier is used for the phase noise reduction. Two positive feedback type push-push oscillators and two RF multipliers are formed in a same substrate by using a double-sided MIC technology [6]. The oscillators are connected via the RF multipliers. The second harmonic oscillator is designed and fabricated in K-band. As for the experimental results, the effect of the phase nose reduction is confirmed. The measured phase noise is excellent. The output power is +5.83 dBm at 25.6 GHz with the phase noise of -115.5 dBc/Hz at the offset frequency of 1MHz. The proposed structure of the oscillator using the RF multiplier is very promising method to reduce the phase noise.

2. Basic theory

Fig.1 show the basic structure of the proposed circuit. The push-push oscillators are connected each other via the RF multipliers. The RF multipliers fix the phase difference of the oscillating signals in the feedback loops of the oscillators. The phase noise reduction is achieved due to the synchronization of the phase of the oscillating signals.

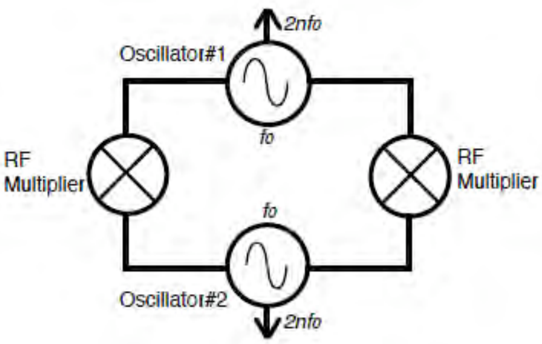

Fig.1 Basic structure of the proposed circuit.

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3. Positive feedback type push-push oscillator

Fig. 2 shows the basic schematic of the positive feedback type push-push oscillator [3] used in the proposed circuit. The microstrip lines are formed on a dielectric substrate, and a slot line on the reverse side. The oscillator has two feedback loops. The slot line is the common feedback loop. The oscillating frequency is determined by the electrical length of the feedback loop, which is designed to be 2π x n (n: integer) at the fundamental frequency (f_0). The fundamental signals in the two feedback loops are out of phase because the transmission mode of the slot line is balanced mode and the signal is divided out of phase in the slot-strip T-junction (part A in Fig. 2). The fundamental signals and the odd harmonics from the two RF amplifiers are out of phase to each other and the even harmonics are in-phase in principle due to the non-linearity of the RF amplifiers and the transmission mode of the slot line. The strip-slot T-junction (part B in Fig. 2) is in-phase power combining circuit for the even harmonic signals. Therefore, the in-phase even harmonic signals are obtained at the output port. On the other hand, the out of phase harmonic signals such as the fundamental signal and odd harmonics are transmitted to the part A in Fig. 2.

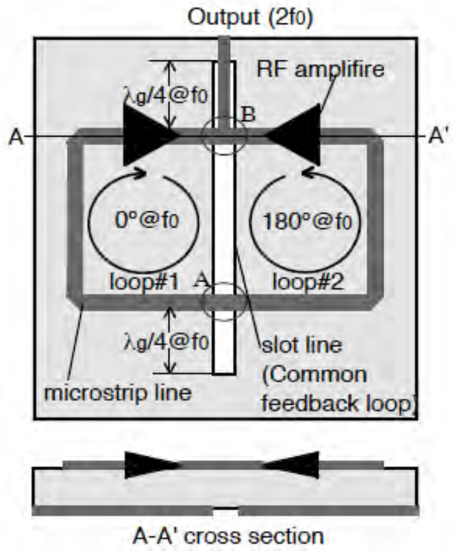


Fig.2 Push-Push oscillator.

4. RF multiplier

Fig.3 (a) shows the RF multiplier used for the phase noise reduction. A rat-race circuit is modified for the circuit. The multiplier consists of microstrip lines, a slot ring and two schottky barrier diodes. The diodes are mounted on the slot line. The microstrip lines are coupled with the slot line. The distances between the coupling point (port1) and the diodes are a quarter wavelength. The distance between the coupling point (port2) and the diode #2 is a quarter wavelength as well. The distance between the coupling point (port2) and the diode #1 is three quarter wavelength. Therefore, an input signal from the port1 is supplied to the diodes in-phase. On the other hand, an input signal from the port2 is supplied to the diodes out of phase. A RF multiplier has three ports. In the multiplier used here, the ports are the port1, the port2 and the inner conductor of the slot ring (port3).

Fig.3 (b) shows an equivalent circuit of the RF multiplier. Equation (1), (2) represent the RF voltage of the diodes.

$$v_{D1} = V_1 \sin(\omega t + \theta_1) \tag{1}$$

$$v_{D2} = V_2 \sin(\omega t + \theta_2) \tag{2}$$

i_Q is represented by the next equation due to the non-linearity of the diode characteristics, where the K is a constant.

$$i_Q = -\left(i_1 + i_2\right) = \mathrm{K}\left(v_{D2} + v_{D1}\right)^2 - \mathrm{K}\left(v_{D2} - v_{D1}\right)^2 = 4\mathrm{K} v_{D1} v_{D2} \tag{3}$$

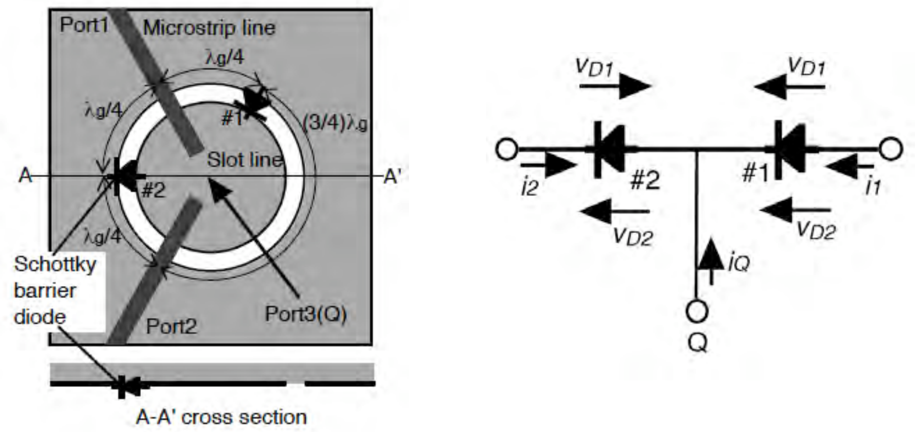
From the equations (1), (2), (3), the next equation is derived.

$$v_{D1} v_{D2} \propto \cos\left(\theta_1 - \theta_2\right) \tag{4}$$

The phase difference of the RF signals at the port1 and port2 is fixed if the bias voltage of the diodes is fixed. By adjusting the bias voltage, the phase difference between the signals at the input ports can be controlled. When the bias port3(Q) is grounded, the next equation is derived,

$$\cos\left(\theta_1 - \theta_2\right) = 0 \tag{5}$$

The equation means that the phase difference is 90 degrees. As a result, the oscillating signals in the push-push oscillators are synchronized and the phase noise performance is improved by the effect of the RF multiplier.



(a) Circuit pattern. (b) Equivalent circuit.

Fig.3 RF multiplier.

5. Circuit configuration and experiment

Next, the performance of the low phase noise positive feedback type push-push oscillator using the RF multiplier is presented. Fig. 4 shows the circuit configuration of the proposed oscillator. Microstrip lines are arranged on a dielectric substrate surface, and a slot ring is arranged on the reverse side. The RF amplifiers are mounted on the microstrip line surface. Schottky barrier diodes are mounted on the slot ring surface. This circuit incorporates the RF multiplier between the positive feedback loops. Fig. 5 shows the fabricated circuit. The design frequency of the oscillator is 25.0 GHz. The RF multiplier is designed at 12.5 GHz because the multipliers operate at the fundamental frequency of the push-push oscillator. The dielectric substrate used for the circuit is Teflon grass fiber with the relative dielectric constant ε_r of 2.15. The substrate thickness is 0.8 mm. Table 1 shows parameter of the dielectric substrate used here. As for the active devices, HEMTs (Fujitsu FHX35LG) are used. The drain bias voltage is 3.8 V and the gate bias voltage is 0.0 V.

The output power and the phase noise of the oscillator are measured using a spectrum analyzer (Agilent 8565EC). Table 2 shows the output performance of the oscillator. Fig.6 shows the output power spectrum for estimating phase noise performance. Table 3 shows the phase noise performance. The oscillation frequencies at the output ports are synchronized. The desired second harmonic signal of output #1 is +5.83 dBm at 25.6 GHz. The phase noise is -115.5 dBc/Hz at 1 MHz offset frequency and -93.0 dBc/Hz at 100 kHz offset frequency. The authors have reported a positive feedback type push-push oscillator [3] which is the prototype oscillator of this study. The phase noise of the proposed circuit at 1 MHz offset frequency is 16 dB better than that of the prototype oscillator. Although the suppression of the undesired fundamental signal is not enough, good phase noise performance is successfully achieved with high output power.

Table 1 Parameter of substrate.

Substrate thickness [mm]	0.8
Metal thickness [mm]	0.018
Relative dielectric constant (ε_r)	2.15
Loss tangent (tan δ)	0.0004

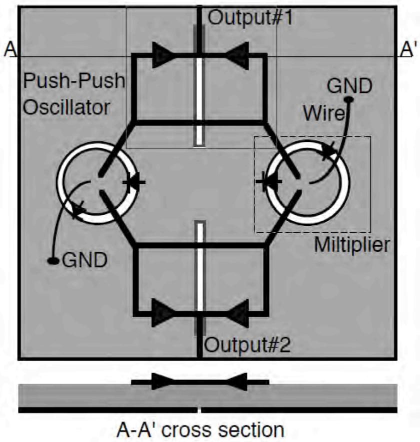


Fig. 4 Circuit configuration.

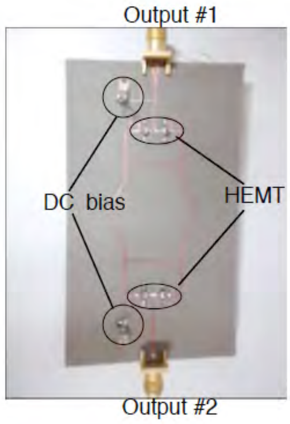


Fig. 5 Fabricated circuit.

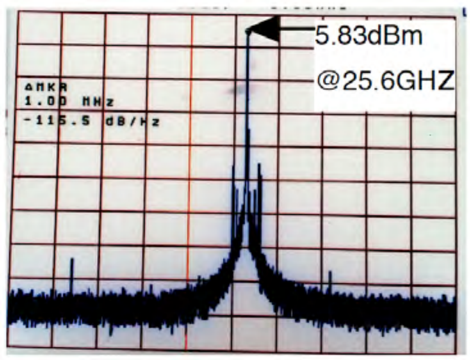


Fig. 6 Power spectrum (phase noise).

Table 2 Output performance of the proposed oscillator.

Output #1	Frequency [GHz]	Output [dBm]	Harmonic suppression [dBc]	Output #2	Frequency [GHz]	Output [dBm]	Harmonic suppression [dBc]
f0	12.8	1.50	-4.33	*f0*	12.8	-0.17	-4.50
2f0	25.6	5.83	--------	*2f0*	25.6	4.33	--------
3f0	38.3	-39.17	-45.00	*3f0*	38.3	-28.33	-32.66

Table 3 Phase noise performance.

@1MHz offset frequency	@100 kHz offset frequency
-115.5 dBc/Hz	-93.0 dBc/Hz

6. Conclusion

In this paper, a low phase noise positive feedback type push-push oscillator is presented. By using the RF multiplier, the oscillator achieves the phase noise of -115.5 dBc/Hz at 1 MHz offset frequency. The phase noise is improved 16 dB in comparison with that of the prototype oscillator. The effect on the phase noise reduction is confirmed experimentally and a novel approach for the phase noise reduction is successfully demonstrated.

7. References

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