A Ka-Band Quadruple-Push Oscillator

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Abstract — **In this paper, a quadruple-push oscillator is proposed for the first time. The quadruple-push oscillator consists of four identical sub-circuits and a microstrip ring resonator. By using the ring resonator as common resonator, the four identical sub-circuits oscillate in the same fundamental frequency f_0, and the fundamental oscillating signal of each sub-circuit has a phase difference of 90°, 180° and 270° to that of the others. Therefore, the undesired fundamental signals (f_0), the second harmonic signals ($2f_0$), the third harmonic signals ($3f_0$) and so on can be suppressed in principle and the desired fourth harmonic signal ($4f_0$) is obtained when all the signals are combined. A Ka-band quadruple-push oscillator was designed and fabricated. The measured output power of the desired fourth harmonic signal ($4f_0$) was +1.67 dBm at the frequency of 35.8 GHz. The measured suppression of the undesired signals of the fundamental signal (f_0), the second harmonic signal ($2f_0$), the third harmonic signal ($3f_0$) and the fifth harmonic signal ($5f_0$) were -18.0 dBc, -17.9 dBc, -17.8 dBc and -35.5 dBc, respectively. The measured phase noise performance at 35.8 GHz was -104.0 dBc/Hz at an offset frequency of 1 MHz.**

I. INTRODUCTION

With the rapid growth of the wireless communication services, the frequency resources under the 10 GHz range would be crowded gradually. In order to meet the requirements of high speed, large capacity and high quality to the wireless communication systems, the operation frequency of these systems would be up to a millimeter wave frequency range.

The millimeter wave oscillators are the key components in these high frequency systems. There are three basic methods to generate millimeter wave signals, which are the direct oscillator method, the frequency multiplier method and the push-push oscillator method. Because the two sub-oscillators of push-push oscillators operate in the half desired output frequency, the Q-factor of the circuits is relatively higher than that of direct oscillators. Besides, push-push oscillator is a type of mutually coupled oscillator, so it can achieve better phase noise performance than direct oscillators. In addition, comparing with frequency multipliers, the push-push oscillators also have compact circuit structure without any additional buffer amplifiers and filters required in frequency multipliers. Therefore the push-push oscillator method is the very promising method for generating millimeter wave signals. Many papers on push-push oscillator have been published [1]-[6].

In this paper, a novel Ka-band quadruple-push oscillator is proposed. This quadruple-push oscillator consists of four identical sub-oscillator circuits and a microstrip ring resonator. By using the ring resonator as common resonator, the four identical sub-oscillator circuits oscillate in the same fundamental frequency f_0, and the fundamental oscillating signal of each sub-oscillator circuit has a phase difference of 90°, 180° and 270° to that of the others. Therefore, the undesired fundamental signals (f_0), the second harmonic signals ($2f_0$), the third harmonic signals ($3f_0$) and the fifth harmonic signals ($5f_0$), etc. can be suppressed in principle and the desired fourth harmonic signal ($4f_0$) is obtained when these signals are all combined in phase.

II. THE PRINCIPLE OF THE QUADRUPLE-PUSH OSCILLATORS

The basic circuit configuration of the quadruple-push oscillator is shown in Fig. 1. The quadruple-push oscillator consists of four identical active sub-circuits. By way of using a resonator in common, the four sub-circuits oscillate in a mutual injection mode. The oscillating signal from one sub-circuit is injected to the other ones, and then they can oscillate in the same fundamental frequency (f_0). In addition, the fundamental oscillating signal of each sub-

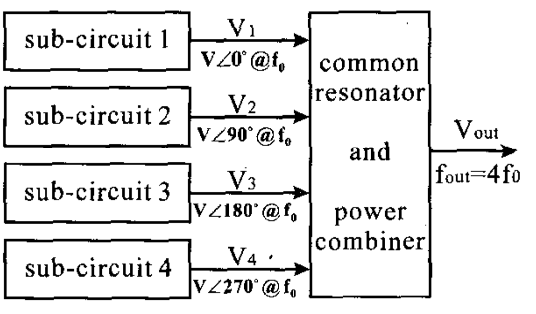

Fig. 1. The basic configuration of the quadruple-push oscillator.

circuit has a phase difference of 90°, 180° and 270° to that of the others. So the oscillating signals and their harmonic signals of each sub-circuit can be written in (1)-(4).

$$V_1 = Ve^{j\omega_0 t} + a_1 e^{j2\omega_0 t} + a_2 e^{j3\omega_0 t} + a_3 e^{j4\omega_0 t} + \cdots \quad (1)$$

$$V_2 = Ve^{j(\omega_0 t - \frac{\pi}{2})} + a_1 e^{j2(\omega_0 t - \frac{\pi}{2})} + a_2 e^{j3(\omega_0 t - \frac{\pi}{2})} + a_3 e^{j4(\omega_0 t - \frac{\pi}{2})} + \cdots \quad (2)$$

$$V_3 = Ve^{j(\omega_0 t - \pi)} + a_1 e^{j2(\omega_0 t - \pi)} + a_2 e^{j3(\omega_0 t - \pi)} + a_3 e^{j4(\omega_0 t - \pi)} + \cdots \quad (3)$$

$$V_4 = Ve^{j(\omega_0 t - \frac{3\pi}{2})} + a_1 e^{j2(\omega_0 t - \frac{3\pi}{2})} + a_2 e^{j3(\omega_0 t - \frac{3\pi}{2})} + a_3 e^{j4(\omega_0 t - \frac{3\pi}{2})} + \cdots \quad (4)$$

All the signals are combined, then the output signal V_{out} is written in (5),

$$V_{out} = \alpha e^{j4\omega_0 t} + \beta e^{j8\omega_0 t} + \cdots \quad (5)$$

The undesired fundamental signals (f_0), the second harmonic signals ($2f_0$), the third harmonic signals ($3f_0$) and the fifth harmonic signals ($5f_0$) are suppressed due to the phase relations described above, while the desired fourth harmonic signals ($4f_0$) are combined because of their in phase relations.

According to this principle, the power combing of four identical fundamental frequency sub-oscillators in the phase relations described above results in the complete suppression of the undesired harmonic signals such as f_0, $2f_0$, $3f_0$, $5f_0$ and so on, while the desired fourth harmonic signal ($4f_0$) can be obtained.

III. The Circuit Structure of The Quadruple-Push Oscillator

By using the approach of the push-push oscillator with the simplified circuit structure [2], [3], the Ka-band quadruple-push oscillator is formed. In this approach, the additional power combiner circuit such as the Wilkinson combiner required in the usual push-push oscillators [1], [4]-[6] are unnecessary, so the circuit structure is very simple. It is also very suited for forming quadruple-push oscillators easily.

The crucial point of the quadruple-push oscillator is how to realize the phase difference of the fundamental oscillating signals of 90°, 180° and 270° between one sub-circuit and the other three ones. In order to achieve these phase relations, a ring resonator [7]-[9] is used in our design to realized the accurate phase difference between one sub-circuit and the other three ones.

Ring resonators have unique resonance characteristics such as orthogonal resonance modes due to the symmetrical configuration, so that it can be used to form quadruple-push oscillator. The model of a one-wavelength ring resonator with four ports is shown in Fig. 2.

The four ports are arranged on the vertical and horizontal symmetrical planes of the one-wavelength ring resonator evenly (Fig. 2). Therefore, for the fundamental frequency f_0, there is an electrical distance of $\lambda_g/4$ between the two contiguous ports, such as the port 1 and 2, the port 2 and 3, the port 3 and 4 as well as the port 4 and 1 in Fig. 2. When an exciting signal at frequency of f_0 is added at port 1 (Fig. 2), the resonance voltages of the fundamental exciting signal (f_0) and its harmonic signals are shown in Fig. 3. It shows that only the resonance voltages of the fourth harmonic signals ($4f_0$) at each port on the ring resonator are in phase. And the resonance voltages of the exciting signal and the other harmonic signals at port 2, 3 and 4 have a phase difference to those at port 1. For example, for the fundamental exciting signal (f_0) at port 1, the resulting resonance voltage on the ring resonator at port 2, 3, 4 have the phase difference of 90°, 180° and 270° to that at port 1, respectively. Besides, because there

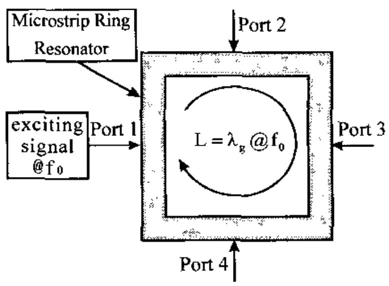

Fig. 2. The model of a one-wavelength ring resonator with four ports.

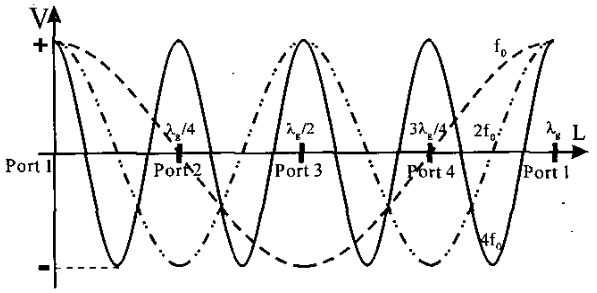

Fig. 3. The resonance voltages of the fundamental exciting signal (f_0) and its harmonic signals added on the ring resonator.

are the phase differences of 180° for the second harmonic signal ($2f_0$) between any two contiguous ports shown in Fig. 3, this indicates that there is the phase difference of 90° between any two contiguous ports for the fundamental frequency (f_0).

Therefore, four fundamental frequency (f_0) sub-oscillator circuits are arranged at each port, and the ring resonator is used as a common resonator by the four sub-circuits, then they can oscillate in the same fundamental frequency (f_0). The circuit structure of the quadruple-push oscillator is shown in Fig. 4. Each sub-circuit resonates with the other ones through the common ring resonator. Every two contiguous sub-circuits can oscillate in a mutual interaction with a phase difference of 90°, and every two opposite sub-circuits are mutually interacted out of phase [2]. The fundamental oscillating signals (f_0) from the four sub-circuits at every port are shown in Fig. 5, and the resonance voltages of the second harmonic signals ($2f_0$) as well as the third harmonic signals ($3f_0$) on the ring resonator are similar to that of the fundamental oscillating signals (f_0). It shows that the oscillating behavior on this quadruple-push oscillator agrees with the basic principle ((1)-(4)) described in Section II. Therefore, the undesired fundamental oscillating signals (f_0) and the undesired harmonic signals can be completely suppressed in principle, and the desired fourth harmonic signal is obtained effectively at the output port.

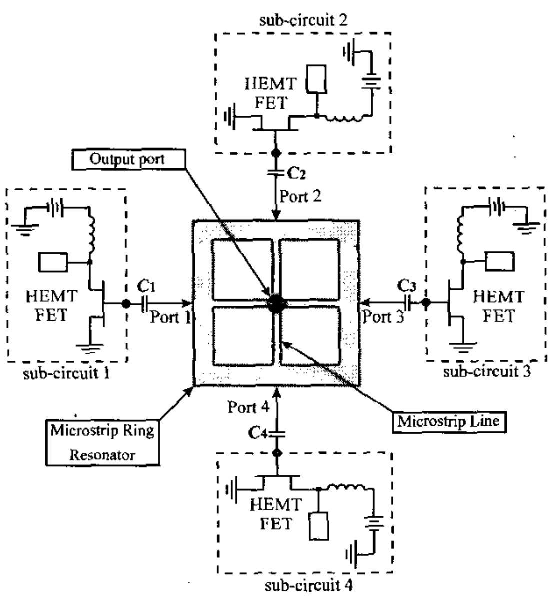

Fig. 4. The circuit structure of the quadruple-push oscillator using ring resonator.

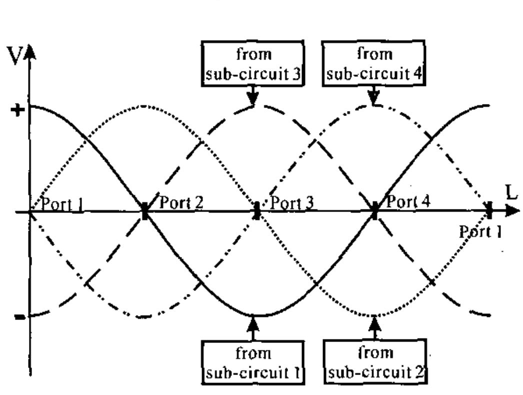

Fig. 5. The fundamental oscillating signals (f_0) from the four sub-circuits added on the ring resonator.

IV. Circuit Design and The Experiment of The Quadruple-Push Oscillator

The circuit structure of the quadruple-push oscillator proposed in this paper is shown in Fig. 4. The fundamental resonance frequency of the ring resonator was designed to be 9 GHz, and the calculated unloaded quality factor of the ring resonator was about 46. The active sub-circuit was also designed as a one-port circuit to generate negative resistance at 9 GHz. The active devices used here were HEMT FETs (Fujitsu's FHX35LG).

The circuit was fabricated on a Teflon glass fiber substrate with the relative dielectric constant of 2.15. The thickness of the structure is 0.8 mm. The photo of this fabricated circuit is shown in Fig. 6. A coaxial connector was mounted to the output port (shown in Fig.4) through a via hole on the back surface of the substrate. The circuit size was 70 mm x 70 mm.

The output signal was measured with a spectrum analyzer (Agilent HP8565EC) and a frequency counter (Agilent 5312A 46GHz counter). The measured results and the power spectrum of the output signal are shown in Table I and Fig. 7, respectively. The output power of +1.67 dBm at the frequency of 35.8 GHz ($4f_0$) was measured when the drain bias voltage was 3.8 V and the total drain current was 160 mA. Considering the RF characteristic of the HEMT FET, the output power performance of the desired fourth harmonic signals ($4f_0$) shows that power-combining efficiency of the desired fourth harmonic signals ($4f_0$) was successfully higher. The DC-RF efficiency was about 0.24%.

The suppression performances of the undesired signals are shown in Table II. The suppression performances of the undesired fundamental oscillating signal (f_0), the second harmonic signal ($2f_0$), the third harmonic signal ($3f_0$) and the fifth harmonic signal ($5f_0$) were -18.0 dBc, -17.9 dBc, -17.8dBc and –35.5 dBc, respectively. These good suppression performances of the undesired signals show that the accurate phase difference of 90° for the every two contiguous sub-circuits and the accurate phase difference of 180° for the every two opposite sub-circuits were achieved in the quadruple-push oscillator.

The phase noise performance of -104.0 dBc/Hz and -82.3 dBc/Hz at an offset frequency of 1 MHz and 100 KHz were obtained, respectively. The low phase noise performance was realized due to the mutual injection oscillation behavior in this quadruple-push oscillator.

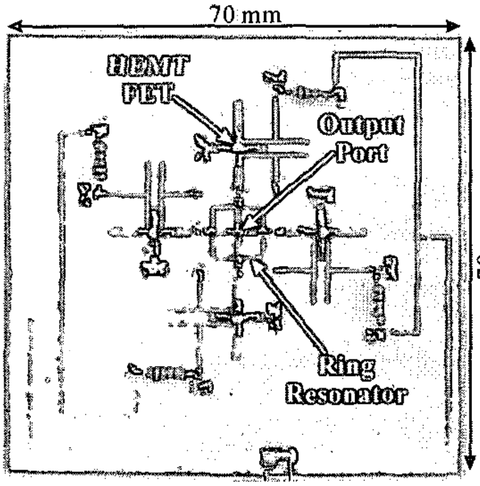

Fig. 6. The fabricated circuit of the quadruple-push oscillator.

TABLE I

THE MEASURED OUTPUT PERFORMANCES

The desired frequency	The output power	P/N @ 1 MHz Offset
35.8 GHz	+1.67 dBm	-104.0 dBc/Hz

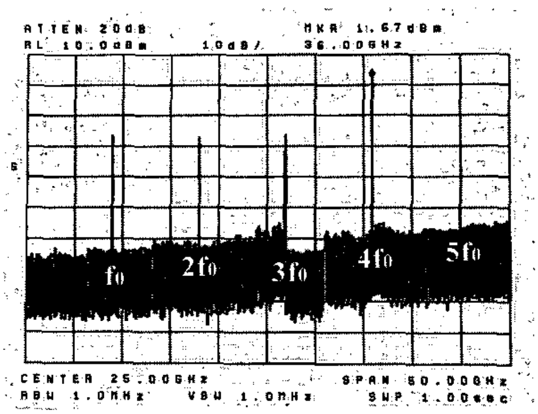

Fig. 7. The output spectrum of the quadruple-push oscillator.

TABLE II

THE SUPPRESSION OF THE UNDESIRED SIGNALS

The undesired signals	f_0	$2f_0$	$3f_0$	$5f_0$
Suppression (dBc)	-18.0	-17.9	-17.8	-35.5

V. CONCLUSION

A novel quadruple-push oscillator approach for generating the desired fourth harmonic signal ($4f_0$) is presented in this paper. According to this novel approach, a Ka-band quadruple-push oscillator has been realized for the first time. In this circuit, the undesired fundamental oscillating signals (f_0) and the other undesired harmonics signals are suppressed excellently without any additional filters, and the desired fourth harmonic signal ($4f_0$) is efficiently obtained. This approach shows a remarkable ease of the generation of millimeter-wave signals. Moreover, it is very suited for MMIC applications, especially 3D-MMICs.

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