

## **PUSH-PUSH DIELECTRIC RESONATOR OSCILLATOR USING SUBSTRATE INTEGRATED WAVEGUIDE POWER COMBINER**

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**Abstract**—A novel Ku-band push-push dielectric resonator oscillator (DRO) using substrate integrated waveguide (SIW) power combiner is presented. Compared with the traditional push-push oscillator, the proposed push-push DRO can realize high fundamental harmonic suppression, due to the use of a SIW power combiner, whose cut-off frequency is designed within the range of the fundamental and second harmonic frequency. Moreover, the isolation of two fundamental frequency oscillators can be enhanced, while the power combiner operates at the second harmonic frequency to maximize the output power. As shown in the experimental results, the centre frequency of push-push DRO is 14 GHz, with a frequency tuning range of 30 MHz. The suppression of the fundamental frequency is 28.59 dBc while the third harmonic suppression is 22.54 dBc. Furthermore, the phase noise can achieve  $-98.01$  dBc/Hz at 100 kHz offset from the centre frequency.

### **1. INTRODUCTION**

The push-push oscillators have been the focus of much attention owing to their advantage of breaking through the limited available frequency of active devices [1–3]. The basic theory of push-push oscillator is to cancel out the odd harmonic frequencies and enhance the even harmonic frequencies. It means that the push-push oscillator can realize the function of oscillator and frequency doubler. However, during the fabrication of push-push oscillator, it is difficult to realize the symmetry and balance between two fundamental frequency oscillators, due to the differences of transistors and processing errors

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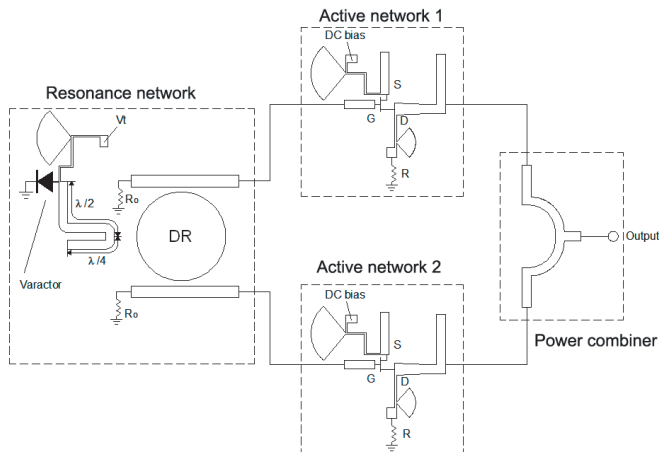
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of circuits. Moreover, the power combiners used in traditional push-push oscillators are often designed at the second harmonic frequency to maximize the output power. Therefore, in most cases, the odd harmonic frequency suppression of push-push oscillator cannot satisfy the need of actual use especially the suppression of fundamental frequency. Furthermore, the isolation of two identical fundamental frequency oscillators is poor, thus, the frequency pulling of one oscillator due to the interference of the other oscillator is serious.

Substrate integrated waveguide (SIW) is a novel transmission structure proposed in recent years [4–6]. Based on the cut-off frequency characteristics of SIW, the corresponding SIW power combiner can achieve the suppression of fundamental harmonic component of the oscillation signal additionally, and further, the second harmonic component of the oscillation signal can also be maximized. Moreover, the isolation between two fundamental frequency oscillators can be improved. Among those push-push oscillators, the push-push dielectric resonator oscillators (DRO) are the most popular, because of their low phase noise. Therefore, a novel Ku-band push-push DRO using SIW power combiner is investigated theoretically and experimentally in this paper.

## 2. THEORY OF PUSH-PUSH DIELECTRIC RESONATOR OSCILLATOR

Figure 1 shows the traditional configuration of push-push DRO. It is composed of two identical fundamental frequency oscillators using

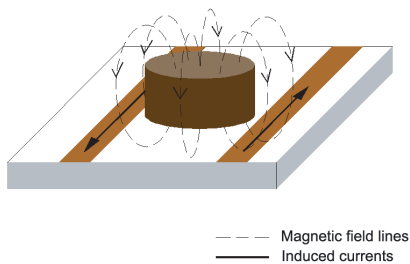


**Figure 1.** The configuration of push-push DRO.

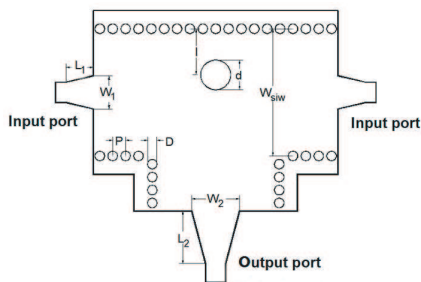
common dielectric resonator (DR) resonance network and a microstrip power combiner. In the following sections, the theories and design methods of push-push DRO are studied in detail.

The design of single oscillator, consisting of a DR resonance network and a negative resistance active network, is based on the theory of series feedback oscillator [7]. According to the theory of series feedback oscillator, the fundamental frequency DR resonance network operates as a frequency selection and stabilization element. As an essential part of the push-push structure, the magnetically coupling structure of the DR and two microstrip lines is shown in Figure 2. The DR operates at the dominant mode  $TE_{01\delta}$  [7], and the fundamental frequency of DR used in the proposed push-push DRO is 7 GHz. As shown in Figure 2, the induced currents in two microstrip lines are out of phase at the fundamental frequency. Further, the two microstrip lines are terminated with stabilization resistors  $R_0$  having characteristic impedance to avoid the terminal power reflection. In order to realize the electrically tunable of DRO additionally, the resonance network includes a coupling structure of the DR and varactor. The varactor is coupled by a  $3\lambda/4$  microstrip open-circuited stub, as shown in Figure 1. The  $\lambda$  is the fundamental wavelength. Based on the repeatability characteristics of  $\lambda/2$  microstrip line and the transformation characteristics of  $\lambda/4$  microstrip line, this structure can realize a strong coupling between DR and varactor.

After the design of the DR resonance network, the negative resistance active network should be designed to satisfy the oscillation condition. Firstly, the self-bias circuit is used to set the quiescent point of FET, as shown in Figure 1. Then, based on the DC bias, a microstrip open-circuited stub is added to the source of the FET. Afterwards, the length of stub is tuned until the reflection coefficient



**Figure 2.** The coupling structure of DR and two microstrip lines.



**Figure 3.** The configuration of SIW  $T$  junction power combiner.

$\Gamma_{in} > 1$  at the fundamental frequency, seen from the gate of the FET. It means that the negative resistance characteristics of active network are realized. Moreover, through the design of the output matching network at the drain of the FET, the output power can be maximized. Finally, as shown in Figure 1, by connecting the negative resistance networks with the common DR resonance network and power combiner, the two identical fundamental frequency oscillators can generate two oscillation signals, whose odd harmonic components are out of phase.

### 3. DESIGN AND APPLICATION OF SIW POWER COMBINER

The SIW power combiner used in the proposed push-push oscillator is a 3 dB  $T$  junction power combiner [8], as shown in Figure 3 and consists of two perpendicular SIW structures, three SIW-microstrip transitions and an inductive post formed by metallic via hole. According to the theory of metallic waveguide  $T$  junction power combiner, the three ports of 3 dB SIW power combiner cannot be matched simultaneously. When the output port is matched, the return loss of input port is 6 dB. Thus an inductive post positioned at the centre of power combiner is processed to match the output port [9]. It operates by changing the diameter and position to adjust the reflection and scattering of the input signals. The theoretical value of distance between the centre of post and SIW margin is  $\lambda_g/4$ , and  $\lambda_g$  is the cut-off wavelength of SIW structure. The cut-off frequency of the SIW power combiner is designed at 12.5 GHz, within the range of fundamental frequency (7 GHz) and the second harmonic frequency (14 GHz). The initial dimensions of SIW power combiner can be calculated by formula (1) [7] and empirical formula (2) [10]:

$$f_{cTE10} = \frac{1}{2W\sqrt{\epsilon_r}} \quad (1)$$

$$W = W_{siw} - 1.08\frac{D^2}{P} + 0.1\frac{D^2}{W_{siw}} \quad (2)$$

where  $f_{cTE10}$  is the cutoff frequency of metallic rectangular waveguide,  $\epsilon_r$  the permittivity of the substrate,  $W$  the width of the corresponding metallic rectangular waveguide,  $W_{siw}$  the width of SIW waveguide,  $D$  the diameter of metallic via holes, and  $P$  the distance between two vias.

In addition, the dimension parameters of the SIW-microstrip transitions and inductive post are also shown in Figure 3, where  $W_1$  and  $W_2$  are the widths of transitions, and  $L_1$  and  $L_2$  the lengths of

**Table 1.** Parameters of SIW power combiner.

Parameters	Value [mm]
$W_{\text{siw}}$	6.90
$W_1$	1.80
$L_1$	1.50
$W_2$	2.60
$L_2$	2.85
$D$	0.50
$P$	0.70
$d$	1.60
$l$	2.50

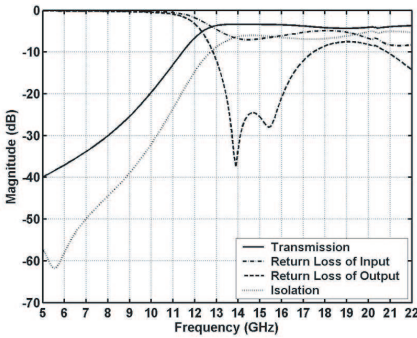
transitions,  $d$  the diameter of inductive post, and  $l$  the distance between the centre of the post and SIW margin.

The optimization of the SIW power combiner is carried out with the electromagnetic (EM) simulator HFSS. Formula (1) indicates that the cut-off frequency is decided almost monotonously by the width of SIW structure. Therefore, after the modeling of SIW structures, only the dimensions of SIW-microstrip transition and inductive post need to be optimized to realize the output port matching. The optimization results of all parameters are shown in Table 1.

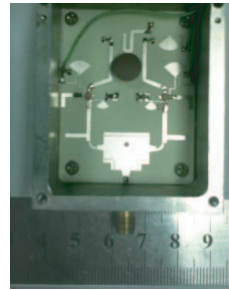
Figure 4 shows the simulation results of SIW  $T$  junction power combiner. The isolation and suppression at the fundamental frequency (7 GHz) between two input ports are 49.86 dB and 33.84 dB, respectively, and the insertion loss between the input and output ports at the second harmonic frequency (14 GHz) is 3.35 dB. The simulation results indicate that the SIW  $T$  junction power combiner can be used to enhance the suppression of fundamental harmonic frequency. Furthermore, it can enhance the isolation between two fundamental frequency oscillators and maximize the output power of the second harmonic frequency. As indicated by the theory and simulation results of SIW  $T$  junction power combiner, the reflection of the oscillation signal due to the mismatch of input port may disturb the operation of oscillator. Therefore, during the simulation of the whole proposed pushpush DRO, the output matching network is designed to decrease the influence on the quiescent point of FET, in addition to enhance the output power of the second harmonic frequency.

### 4. EXPERIMENTAL RESULTS

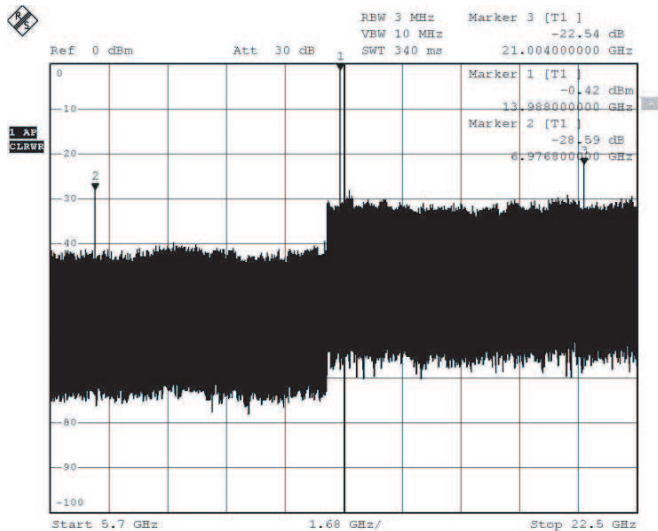
Figure 5 shows the photograph of the proposed push-push DRO where Rogers 4350 ( $\epsilon_r = 3.66$ ,  $\tan \delta = 0.004$  and thickness of 20 mil) was used. The SMV1233 varactor (Alpha) and MGF1801 GaAs FET (Mitsubishi), whose maximum available frequency is 12 GHz, were used in the proposed oscillator. In addition, the operating source-to-drain voltage and current of each FET were 5 V and 35 mA, respectively.



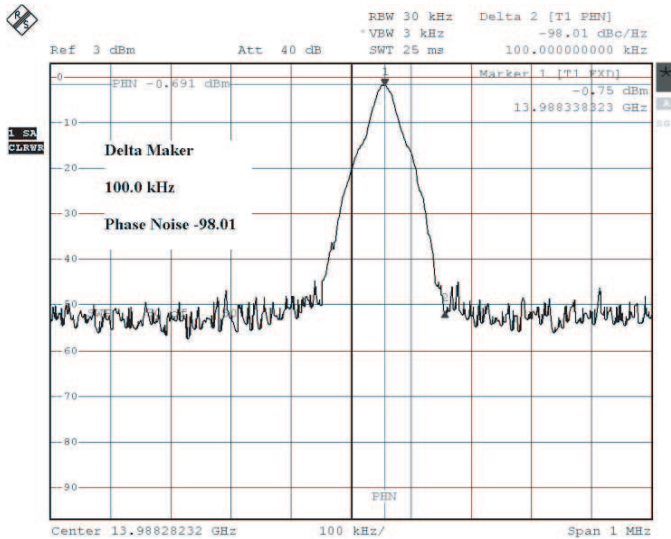
**Figure 4.** The simulation results of SIW  $T$  junction power combiner.



**Figure 5.** The photograph of proposed push-push DRO.



**Figure 6.** The measured frequency spectrum.



**Figure 7.** The measured phase noise spectrum.

The oscillator is measured by the spectrum analyzer Rohde & Schwarz FSP40, with function of measure phase noise. The measured frequency spectrum is shown in Figure 6. The output frequency is 13.988 GHz with an output power of  $-0.4$  dBm, when the tuning voltage of varactor  $V_t = 0$  V. Furthermore, the fundamental frequency and third harmonic frequency suppression are 28.59 dBc and 2254 dBc, respectively. Also, the push-push DRO has a frequency tuning range of 30 MHz, enough for the application of phase-locked loop (PLL) single point frequency source. Figure 7 shows the measured phase noise of proposed oscillator. The phase noise can achieve  $-98.01$  dBc/Hz at 100 kHz offset from the centre frequency.

Table 2 shows the performance comparison with the other previous studies. Although the operating frequency of other works is higher than this proposed one, the fundamental harmonic suppression of push-push oscillator mainly depends on the symmetry and the design method of two oscillators. So, it is unnecessary to take into account the operating frequencies of referenced oscillators. As shown in Table 2, the fundamental frequency suppression of the proposed oscillator is obviously better than that of the other works. Furthermore, the phase noise and output power are also good, compared with the other works. According to Table 2, the proposed push-push DRO shows comparable performance, especially the suppression of fundamental frequency.

**Table 2.** Comparison performance.

	Device	Frequency [GHz]	Power [dBm]	Fundamental harmonic suppression [dBc]	Phase noise [dBc@100 kHz]
Ref. [1]	HBT	58	-14	17	-100
Ref. [2]	FET	17.4	-14	15	-95
Ref. [3]	FET	34	3	15	-99
This work	FET	14	-0.4	28.59	-98

## 5. CONCLUSIONS

A novel Ku-band push-push DRO using SIW power combiner is designed and fabricated. The SIW power combiner can maximize the isolation between two identical fundamental frequency oscillators, thus, they can operate independently. Moreover, as shown by the measured results, the fundamental frequency suppression of proposed push-push DRO is better than other referenced oscillators, which justifies the advantage of the proposed structure.

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