A Novel K-band Push-Push Oscillator Using Gunn Diodes

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***Abstract* — In this paper, a novel Gunn diode push-push oscillator is proposed. Two Gunn Diodes and a coplanar waveguide resonator are used for the oscillator. The combination is considered to be an active resonator. The Gunn Diodes are arranged at both ends of the resonator. The magnetic filed at the both ends of resonator is coupled with the output circuit. The measured output power is +3.67 dBm at 19.8 GHz. The phase noise is -115.2 dBc/Hz at 1 MHz offset frequency. The oscillator is designed easily and achieves low phase noise performance with low cost by using the advantage of Gunn diode.**

***Index Terms* — Coplanar waveguides, double-sided circuit technology, gunn devices, k-band, push-push oscillator.**

I. INTRODUCTION

High frequency signals are essentially required for the transmission of large amount of information on the recent communication systems. However, the high frequency oscillators have a couple of practical problems, such as the phase noise, cost reduction, stability and output power. The push-push oscillator is effective for the solutions. The push-push oscillator enhances the even mode harmonics and suppresses the odd mode output. The circuit doubles the fundamental frequency so that higher oscillating frequencies can be obtained. The Q-factor is relatively higher than that of direct oscillators because the two sub-oscillators of push-push oscillators operate at the half desired output frequency. The upper frequency limit of a microwave oscillator is given mainly by the performance of the active devices used in it. Therefore, the push-push principle is very effective method to extend the oscillating frequency range. Moreover, the push-push oscillator achieves good phase noise performance because it is a type of mutually coupled oscillator.

In addition, comparing with frequency multipliers, the push-push oscillators have compact circuit structure without any additional buffer amplifiers and filters required in frequency multipliers. Therefore, the push-push oscillators are very promising method for generating microwave and millimeter-wave signals. Many papers on push-push principle have been published [1]-[8]. On the other hand, a microwave Gunn oscillator has been developed for the advantage that it is compact and simple in power supply [9]-[11]. Gunn diode oscillators have achieved high output power, low phase noise performance and low cost.

In this paper, a novel push-push oscillator using Gunn diodes and a coplanar waveguide resonator is proposed. A double-sided circuit technology is adopted for the circuit. The bias circuit of the oscillator is very simple and the area for that is very small. This oscillator is designed easily due to the very simple structure. The oscillator is designed and fabricated in K-band. As for the experimental results, the output power of +3.67 dBm at the second harmonic frequency of 19.8 GHz is obtained. The measured phase noise is -115.2 dBc/Hz at 1 MHz offset frequency.

II. CIRCUIT STRUCTURE AND BASIC DESIGN

A conventional push-push oscillator is composed of two identical sub-oscillators, a resonator and a power combining circuit. The sub-oscillators oscillate at a same frequency by using one common resonator. In the push-push oscillator, the sub-oscillators are operating at half the output frequency with a phase difference of 180°. By using a power combining circuit, the odd harmonic signals (f_0, $3f_0$, $5f_0$,,,) cancel themselves out and the even harmonic signals ($2f_0$, $4f_0$, $6f_0$,,,) are added constructively. The two signals of the sub-oscillators are represented by the following equations with the phase difference ($\omega_0\Delta t$) of π.

$$V_{osc1} = a_1 e^{j\omega_0 t} + a_2 e^{j2\omega_0 t} + a_3 e^{j3\omega_0 t} + a_4 e^{j4\omega_0 t} \cdots \tag{1}$$

$$\begin{aligned} V_{osc2} = a_1 e^{j\omega_0 (t-\Delta t)} &+ a_2 e^{j2\omega_0 (t-\Delta t)} \\ &+ a_3 e^{j3\omega_0 (t-\Delta t)} + a_4 e^{j4\omega_0 (t-\Delta t)} \cdots \end{aligned} \tag{2}$$

The combined signal can be expressed by

$$\begin{aligned} V_{out} &= b(V_{osc1} + V_{osc2}) \\ &= b(a_1 e^{j\omega_0 t}(1 + e^{-j\pi}) + a_2 e^{j2\omega_0 t}(1 + e^{-j2\pi}) \\ &\quad + a_3 e^{j3\omega_0 t}(1 + e^{-j3\pi}) + a_4 e^{j4\omega_0 t}(1 + e^{-j4\pi}) \cdots) \\ &= 2ba_2 e^{j2\omega_0 t} + 2ba_4 e^{j4\omega_0 t} \cdots \end{aligned} \tag{3}$$

From the equation, it is confirmed that the odd harmonics cancel themselves out and the even harmonics are added.

Fig. 1 shows a basic concept of the proposed push-push oscillator. The proposed oscillator consists of two Gunn diodes which act as a negative resistance, a resonator and a output circuit. The combination of the Gunn diodes and the resonator is considered to be an active resonator [12] embedding Gunn diodes. The Gunn diodes are arranged at both ends of the coplanar waveguide resonator. The both ends of the resonator is coupled with the output circuit magnetically and the signals from the resonator are combined

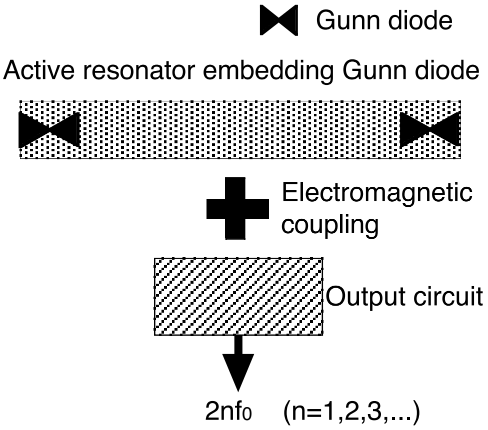


Fig. 1. Basic concept of proposed push-push oscillator

in the output port. The second harmonic signal is obtained as the desired output signal according to the push-push principle.

The push-push oscillator using Gunn diodes can be designed easily because it has very simple structure. Moreover, high frequency and high power signal can be obtained. The oscillator can generate efficiently the second harmonic and fourth harmonic signals of the Gunn diode oscillation. The features are very effective for achieving low cost millimeter-wave oscillators.

Fig. 2 shows current distributions on the half-wavelength coplanar waveguide resonator used in the proposed push-push oscillator. As the impedance of the Gunn diodes are very small, the current amplitude of the fundamental frequency signal and second harmonic signal are maximum at the both ends of the resonator where the Gunn diodes are arranged. However, the currents at the both ends are out of phase at the fundamental frequency, and the currents at the both ends are in phase at the second harmonic frequency.

Fig. 3 shows circuit configuration of the proposed push-push oscillator. The circuit is fabricated on a dielectric substrate, where f_0 represents the fundamental frequency and λ_g represents guided wavelength at f_0. On the obverse side, microstrip lines are formed. On the reverse side, a half-wavelength coplanar wave guide resonator is formed. The magnetic field at both ends of the coplanar waveguide resonator is coupled with the microstrip line on the obverse side. The microstrip lines whose lengths are represented by L_1, L_2 and L_3 are $\lambda_g/4$ open stubs. The stubs represented by L_1 and L_2 are used for the magnetic coupling. The stub represented by L_3 is used for suppression of the fundamental and odd harmonic signals. The length between the Gunn diode and the output port C (L_4) is $3\lambda_g/4$.

The half-wavelength coplanar waveguide resonator is used for stabilization of the oscillating frequency. The oscillating frequency is determined by the resonant frequency of the resonator. Moreover, the signals at the both ends (A and B) of the coplanar waveguide resonator are out of phase at the

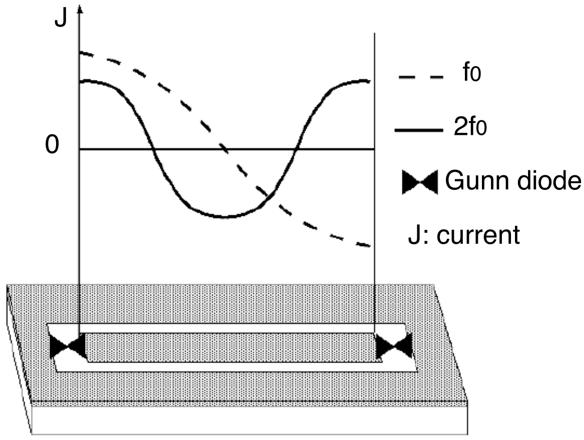


Fig. 2. Current distribution on half-wavelength (at f_0) coplanar waveguide.

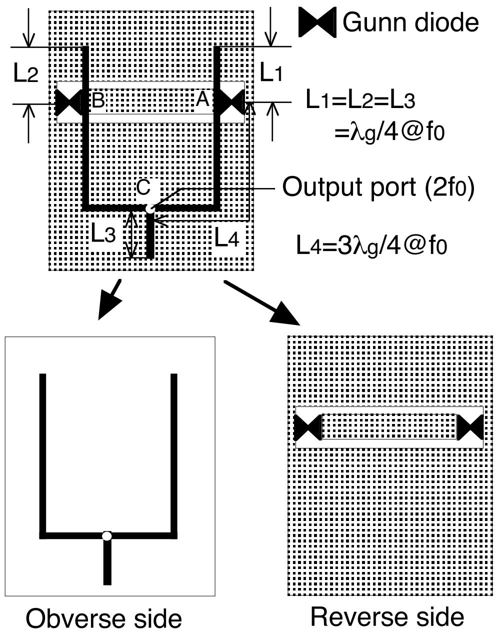
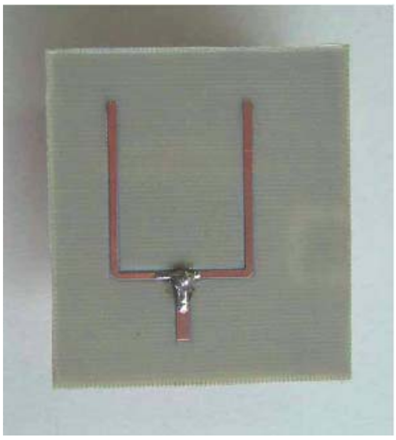


Fig. 3. Circuit configuration of push-push oscillator using Gunn diodes.

fundamental frequency f_0 and in phase at the second harmonic frequency $2f_0$. At the output point C, the signals from point A and point B are combined in phase. The fundamental frequency signals are out of phase. The second harmonic signals are combined in phase. In addition, the point C is a null point for the fundamental frequency signal due to the open stub (L_3). The fundamental frequency signals are not transferred to the output port C because the impedances looking into the output port from the port A and B are very high at the fundamental frequency due to the line length of L_4. As a result, the desired second harmonic signal is successfully obtained as the output signal at the output port C, suppressing the undesired signals such as the fundamental signal.

III. Fabricated Circuit and Measurement

The proposed oscillator is fabricated and the oscillating signal is measured. In this circuit, the Gunn diodes used for the negative resistance are MG49618-11 (Microwave Device Technology). Fig. 4 is photograph of the fabricated oscillator. The design frequency ($2f_0$) is 20 GHz. The length of the coplanar waveguide on the reverse side of the substrate is a half wavelength at 10 GHz. The characteristic impedance of the coplanar waveguide is 100 Ω. The characteristic impedance of the microstrip line on the obverse side is also 100 Ω. A coaxial connector is mounted to the output port through a via hole from the reverse surface of the substrate. The bias voltage is supplied to the Gunn diodes via the center conductor of coplanar waveguide. Table I shows parameters of the dielectric substrate used here. Table II shows the specifications of Gunn diode.



(a) obverse side

(b) reverse side

Fig. 4. Fabricated push-push oscillator.

TABLE I
SUBSTRATE PARAMETERS

Substrate thickness (h)	0.8 mm
Metal thickness (t)	0.018 mm
Relative dielectric constant (ε_r)	2.15
Loss tangent (tan δ)	0.001

TABLE II
SPECIFICATIONS OF GUNN DIODE

Oscillating frequency (center)	10.525 GHz
Operating bias voltage (nominal)	8.0 V
Operating bias current (max.)	80 mA
Output power	5 mW

Fig. 5 shows the measured output power spectrum in full range of 50 GHz. Fig. 6 shows the measured output power spectrum for estimating the phase noise. The results are measured using a spectrum analyzer (Agilent 8565EC).

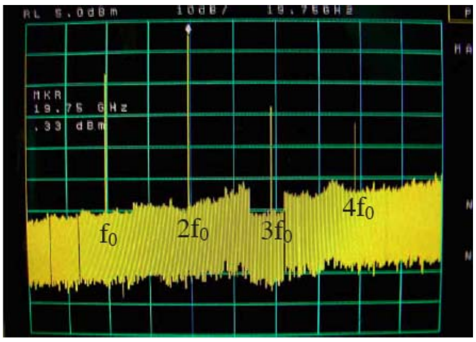


Fig. 5. Output spectrum in full range of 50 GHz.

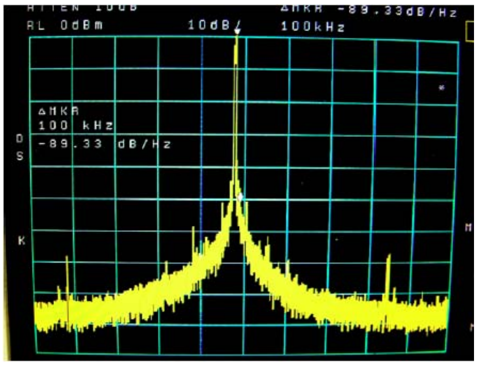


Fig. 6. Output spectrum for estimating phase noise (10 MHz span).

TABLE III
MEASURED OUTPUT PERFORMANCE AT 2f0

2f0	Output power	Phase noise at 1 MHz offset	Phase noise at 100 kHz offset
19.8 GHz	+3.67 dBm	-115.2 dBc/Hz	-89.3 dBc/Hz

TABLE IV
SUPPRESSION OF UNDESIRED SIGNALS

Frequency	9.9 GHz (f0)	29.6 GHz (3f0)	39.5 GHz (4f0)
Suppression	-16.0 dBc	-25.8 dBc	-28.3 dBc

Table III shows the measured output performance at 2f0. Table IV shows the suppression of the undesired signals. The output power at the second harmonic frequency (2f0) is measured by using a power meter (Agilent 53152A). In the measurement, the bias voltage and the bias current of the Gunn diodes are 10 V and 130 mA, respectively. A maximum output power of +3.67 dBm at the desired frequency (2f0) is measured. The phase noise performances are -115.2 dBc/Hz at 1 MHz offset frequency and -89.3 dBc/Hz at 100 kHz offset frequency. The suppression of undesired signals are -16.0 dBc at the fundamental frequency and -25.8 dBc at the 3rd harmonic frequency and -28.3 dBc at the 4th harmonic frequency. The oscillator achieves comparatively low phase noise performance.

IV. CONCLUSION

A novel K-band Push-Push Oscillator using two Gunn diodes which act as negative resistance circuit and one coplanar waveguide resonator is presented. In the proposed oscillator, the combination of the Gunn diodes and the resonator is considered to be an active resonator embedding Gunn diodes. The circuit area is very small due to the advantage of the Gunn oscillator that it is compact and simple in power supply. The output power of +3.67 dBm at the desired second harmonic frequency of 19.8 GHz is obtained. The measured phase noise is -115.2 dBc/Hz at 1 MHz offset frequency and -89.3 dBc/Hz at 100 kHz offset frequency. The oscillator achieves comparatively low phase noise performance and is effective for millimeter wave oscillation.

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