A Harmonic Synchronized Oscillator using Gunn Diodes Embedded on Slot Line Resonators

Kengo Kawasaki[1], Takayuki Tanaka, Masayoshi Aikawa

[1] Department of Electrical and Electronic Engineering, Saga University
1 Honjyo-machi, Saga-shi, Saga 840-8502, Japan
e-mail:Kawasaki@ceng.ec.saga-u.ac.jp

Abstract

This paper represents a novel second harmonic power combining oscillator using mutually synchronized Gunn diodes embedded on slot line resonators. A both-sided MIC technology is adopted in the oscillator. The oscillator consists of Gunn diodes, slot line resonators and microstrip lines. By embedding Gunn diodes on slot line resonators, desired harmonic RF signal can be generated very easily. The microstrip lines are used for the power combining output circuit. This oscillator has practical advantages such as easy circuit design, simple circuit configuration and miniaturization of the circuit size. The second harmonic oscillator is designed and fabricated in K-Band. The output power is +5.75dBm at the design frequency of 19.0 GHz with the phase noise of -111.7 dBc/Hz at the offset frequency of 1MHz. Excellent suppression of the undesired fundamental frequency signal of -39dBc is achieved.

1. Introduction

Microwave and millimeter wave oscillators[1] are essential components in all the microwave and millimeter wave transceivers for wireless LAN, radar systems and Dedicated Short Range Communication systems (DSRC), etc. Practical requirements for high quality microwave and millimeter wave oscillators are low noise, small size, low cost, high efficiency, high output power and high temperature stability. Many technical papers of Gunn diode oscillators have been published so far [2-7]. They can achieve high output power and low phase noise performance with comparatively low cost.

The main advantage of harmonic oscillators is a capability of generating much higher frequency signal using comparatively inexpensive semiconductor devices for lower frequency applications. Besides the Q-factor is relatively higher than that of direct oscillators because the active devices used in harmonic oscillators operate at a lower frequency of the desired output frequency. Therefore, the harmonic oscillator is very effective to extend the oscillating frequency range with low cost[5-7]. In addition, the harmonic oscillator has a compact structure without any additional buffer amplifiers which are required in frequency multiplier oscillator scheme.

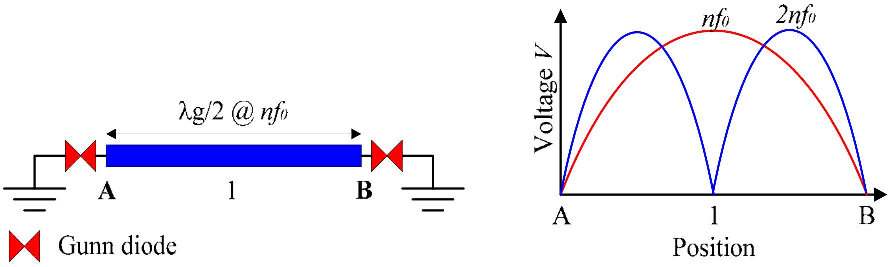
In this paper, an advanced design method for the harmonic oscillator is proposed, making use of the synchronous harmonic field on resonators and the feature of the Gunn diodes. They can provide an enhanced harmonic signal selectively due to the synchronous resonant fields, suppressing the undesired harmonics successfully. In the second harmonic oscillator, a ring-shaped slot line with a couple of Gunn diodes are used. A both-sided MIC technology[8] is effectively adopted for this circuit. A very simple circuit structure is realized by the technology. As the bias voltage is supplied to the Gunn diodes via the center conductor of the ring-shaped slot line, only one bias circuit is required. By mounting Gunn diodes on the ring-shaped structure, the DC bias is isolated from RF signals. Accordingly, the circuit structure is very simple and the area is very small.

The second harmonic oscillator is designed and fabricated in K-band. As for the experimental results, high output power at the desired second harmonic frequency is obtained. The measured phase noise and the suppression of undesired signals are also excellent. The concept of this Gunn harmonic oscillator using ring-shaped slot line is very promising method to realize more higher frequency oscillators.

2. The *n*-th Harmonic Synchronized Oscillator using $\lambda g/2$ Active Resonator

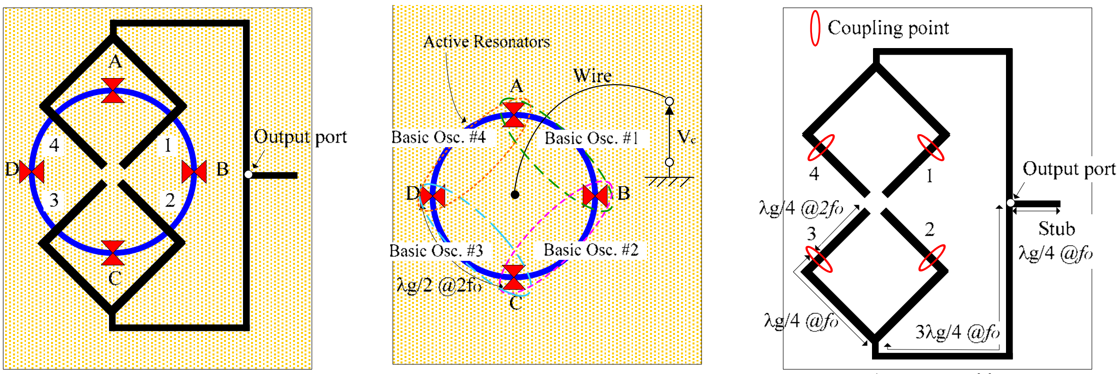
Harmonic oscillators have very attractive advantages such as much higher frequency generation, especially in millimeter wave and sub-millimeter wave bands, because the output signal is the harmonic, where comparatively low frequency semiconductor devises and resonators can be used. Consequently, inexpensive millimeter wave oscillators can be realized easily. Authors have proposed a concept of the harmonic oscillator using active resonators[9]. Negative resistances (N.R.) are reasonably embedded on the active resonators. The N.R.s enhance the desired harmonic resonant field, suppressing undesired signals. For example, undesired odd harmonic signals can be selectively suppressed by the N.R.s. Forming the output circuit at the opportune points, the desired harmonic signal can be available selectively. This concept is enable to generate higher harmonics such as the 4th harmonic. Some technical papers based on this concept have been published by authors [6-7].

Figure 1(a) shows the proposed basic oscillator using Gunn diodes and a half wave length ($\lambda g/2$) line resonator at $nf0$ based on the above mentioned concept harmonic oscillator, where $f0$ is the fundamental frequency of the Gunn diodes, and n is an integer. The oscillator uses Gunn diodes as N.R. and is considered to be an active resonator embedding Gunn diodes at the both ends of the $\lambda g/2$ line resonator. The both ends of the resonator have a short-circuited boundary condition due to the low RF impedance characteristic of Gunn diodes. The two Gunn diodes are mutually synchronized at $nf0$. Figure 1(b) shows the absolute resonant voltage distribution on the $\lambda g/2$ line resonator. The active resonator is $\lambda g/2$ resonator for the n-th harmonic signal ($nf0$) and a λg resonator for the 2n-th harmonic signal (2$nf0$). Only integer multiple harmonic signals of the n-th harmonic ($nf0$) can be resonating on the resonator, suppressing the undesired fundamental signal ($f0$) and all the odd harmonics due to the above mentioned boundary condition of the active resonator. As the output circuit is formed at the center point “1” shown in Figure 1, only the $nf0$ harmonic signal can be effectively available from this point of the active resonator. The 2n-th harmonic signal (2$nf0$) is not available because the point 1 is null for the harmonic.



(a)Basic oscillator using Gunn diodes and $\lambda g/2$ resonator (b)Resonant voltage on a $\lambda g/2$ resonator at nf_0

Figure 1 Basic n-th harmonic oscillator



(a) Circuit configuration (b)Obverse side (c) Reverse side

Figure 2 Circuit configuration of the 2nd harmonic synchronized oscillator using Gunn diodes

3. The 2nd harmonic synchronized oscillator using Gunn diodes

3.1 Practical Circuit Configuration

The circuit configuration of the proposed second harmonic synchronized Gunn diode oscillator is shown in Figure 2. In the design process, four basic 2nd harmonic oscillators are combined as shown in this figure. A both-sided circuit technology is adopted in the oscillator. On the obverse side, ring-shaped four $\lambda g/2$ (at 2$f0$) slot line resonators with Gunn diodes are formed. A bias circuit for the Gunn diodes is also formed on the obverse side as shown in Figure 2(b). An output circuit using microstrip lines is formed on the reverse side as shown in Figure 2(c) The DC bias is supplied to the Gunn diodes through a single conductor wire. This is a practical advantage of the circuit. The circuit area can be reduced because only one simple bias circuit is required. The bias point for the DC power is the center conductor of the oscillator. As the RF signal in the slot line is distributed along the slot line resonators, no RF signal exists at the bias point. Each slot line is coupled with the microstrip lines of the output circuit electromagnetically at point 1-4 as shown in Figure 2(a). At these coupling points, the voltage of the second harmonic signals is maximum. The fundamental and odd harmonic signals can be suppressed at these coupling points due to the boundary conditions on the active resonator. The four coupling points are null for the fourth harmonic signal (4$f0$). At the output port, the desired signals (2*f*0) from the coupling point are effectively combined, because they are all in phase. Consequently, the desired second harmonic signal (2*f*0) can be selectively obtained at the output port.

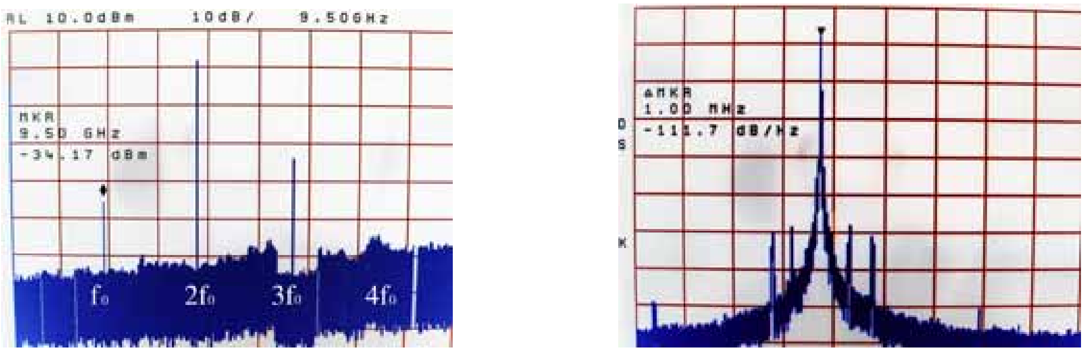
3.2 Fabricated Circuit and Experimental Results in K-Band

The second harmonic synchronized oscillator is designed in K-band and the oscillating signal is measured. The Gunn diodes, MG49618-11 (Microwave Device Technology) are used in the experimental oscillator. Table 1 shows the specifications of the Gunn diode. Table 2 shows parameters of a dielectric substrate used in the fabricated oscillator. Figure 3 is the fabricated oscillator in K-Band. The desired 2nd harmonic frequency (2*f*0) is 19 GHz. The length of each slot line resonator is $\lambda g/2$ at 19 GHz. The characteristic impedance of the slot line is 92 Ω. The characteristic impedance of the microstrip line on the reverse side is 100 Ω. A coaxial connector is mounted on the obverse surface of substrate. Figure 4(a) shows the output power spectrum in full range of 50 GHz. Figure 4(b) shows the output power spectrum to estimate the phase noise. They are measured using a spectrum analyzer (Agilent 8565EC). In the measurement, the bias voltage and the bias current for the four Gunn diodes are 9.0 V and 250 mA, respectively.

Table 3 shows the measured output performance at the second harmonic frequency (2*f*0). The high output power of +5.75 dBm at the desired frequency of 19 GHz is measured. Table 4 shows the suppression of the undesired signals. The suppressions of the fundamental signal (*f*0) and the third harmonic signal (3*f*0) are -39.92 dBc and -34.08 dBc, respectively. Moreover, the fourth harmonic signal (4*f*0) can not be measured because the power level is too low. The high output power of the desired second harmonic signal (2*f*0) means good efficiency of the in-phase power combining. The suppressions of the undesired fundamental signal (*f*0) and the third harmonic signal (3*f*0) are very excellent. The phase noise is -111.7 dBc/Hz at 1MHz offset frequency and -82.5 dBc/Hz at 100 kHz offset frequency. The phase noise performance is relatively good.

(a) Obverse side (b)Reverse side

Figure 3 The fabricated 2nd harmonic synchronized oscillator in K-Band



(a)The output power spectrum of the output signal (b)Phase noise power spectrum of the output signal

Figure 4 Experiment results of the 2nd harmonic oscillator

Table 1 Specifications of Gunn diode

Operating frequency	10.5GHz
Operating bias voltage	8.0V
Operating bias current	80mA
Output power	5mW

Table 2 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 3 Measured Output Performances at $2f_0$

$2f_0$	Output Power	Phase noise (1MHz offset)	Phase noise (100kHz offset)
19.0 GHz	+5.75 dBm	-111.7 dBc/Hz	-82.5 dBc/Hz

Table 4 Suppression of Undesired Signals

Frequency	Output power	Suppression
9.50 GHz(f_0)	-34.17 dBm	-39.92 dBc
28.50 GHz($3f_0$)	-28.33 dBm	-34.08 dBc
38.00 GHz($4f_0$)	negligible	negligible

4. Conclusion

In this paper, a novel *n*-th harmonic synchronized oscillator using Gunn diodes is proposed. Using the active harmonic resonant field and the synchronized oscillators, high output power of desired harmonic signal can be obtained. Moreover, undesired fundamental signal, including both the higher even and odd harmonics can be suppressed very well. Undesired signals of the fundamental frequency signal (f_0) and odd harmonic signals are successfully suppressed. The higher power can be expected to combine more of the basic oscillators. Therefore, this type of the harmonic oscillator using Gunn diodes is very suited for generating high frequency signal up to sub-millimeter wave bands.

5. References

1. U. L. Rhode, A. K. Poddar, and G. Bock, "The Design of Modern Microwave Oscillators for Wireless Applications,"Johon Wiley & Sons, 2005.

2. T. Makino, and A.Hashima, "A Highly Stabilized MIC Gunn Oscillator Using Dielectric Resonator, "IEEE Trans Microw. Theory Tech., vol. MTT-27, no. 7, pp. 633-638, 1979.

3. H. Eisele and G. I. Haddad, "Efficient Power Combining with D-Band(110-170GHz) InP Gunn Devices in Fundamental Mode Operation, "IEEE Microw. and Guided Wave Letters ., vol. 8, no. 1, pp. 24-26, 1998.

4. L.E.Norton, R.E.Enstron, and I.J.Hegyi, "High-Power 1- GHz Coplaner Gunn-Effect Oscillators, "IEEE Trans. Microw. Theory Tech., vol. 16, no. 7, pp. 480-481, 1968.

5. A. Mortazawi, H.D.Foltz, and T.Itoh, "A Periodic Second Harmonic Spatial Power Combining Oscillator "IEEE Trans. Microw. Theory Tech., vol. 40, no. 5, pp.851-856, 1992.

6. T. Tanaka, and M. Aikawa, "A Novel K-Band Push-Push Oscillator Using Gunn Diodes, "Proc. of the 36th European Microwave Conference 2006 (EuMC 2006), pp. 83-86, 2006.

7. K. Kawasaki, T. Tanaka, and M. Aikawa, "A Novel K-Band Push-Push Oscillator Using Slot Ring Resonator Embedding Gunn diodes, "Proc. of the 37th European Microwave Conference 2007 (EuMC 2007), pp. 755-758 , 2007.

8. M. Aikawa, and H. Ogawa, "Double-sided MIC and their applications, "IEEE Trans. Microwave Theory Tech., vol. 37, no.2, pp. 406-413, 1989.

9. M. Aikawa, E. Nishiyama, T. Tanaka, "Advanced Utilization of Microwave Resonant Field and Its Applications to Push-Push Oscillators and Reconfigurable Antennas, "IEICE Trans. Electron., vol. E89-C, no.12, pp. 1798-1805, 2006.