

Low Phase Noise X-band Dielectric Resonator Oscillator

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Abstract-- In this article, an X-band low phase noise dielectric resonator oscillator is investigated. For this purpose, a dielectric resonator as a frequency stabilization section at the almost center frequency of 12 GHz is designed. The active device is a packaged GaAs FET (an ATF-36077 pHEMT). Firstly, the ATF36077 microwave transistor has been biased. The substrate of this nonplanar oscillator is Rogers RT/Duroid 5880. Finally, the dielectric resonator oscillator has been introduced as a series feedback structure. This presented X-band dielectric resonator oscillator, operating at nearly 12 GHz, exhibits a phase noise of -71 dBc/Hz and -133 dBc/Hz at 1-kHz and 1-MHz frequency offset, respectively. Also, the output power level of nearly 7 dBm is achieved. The second and third harmonic power levels are more than 50 dB and 30 dB lower than the main harmonic power level.

Index Terms--X-band Oscillator, Dielectric Resonator, Microwave Transistor, Low Phase Noise.

I. INTRODUCTION

Oscillators are an important part of modern microwave communication and their phase noise (PN) is the most important parameter in performance [1]. The high Q-factor of resonators is the most effective parameter to reduce the PN of the microwave oscillators. The larger Q-factor, the better PN. Besides, insertion loss of feedback filter is another important parameter, which directly affects the PN performance of the oscillator [2, 3]. The low phase noise (LPN) oscillators with high Q-factor resonators such as the substrate integrated waveguide (SIW) resonators [4], resonators based on metamaterial [5], elliptic resonators [6], and dielectric resonators (DRs) [7] have been published.

The LPN microwave oscillators can be used in different frequency bands such as L-band [8, 9], S-band [10, 11], C-band [12, 13], X-band [14, 15], Ku-band [16, 17], K-band [18], and V-band [19, 20]. Also, the microwave resonators are employed in voltage-controlled oscillator (VCO) [21], antenna application [22], nanophotonic application [23], sensor application [24], plasmonic applications [25-29], and filter applications [30-32]. By employing the mutual coupling reduction methods [33-37], the compact microwave oscillators can be obtained,

The SIW resonators as parallel or series feedback structures

possess a high Q-factor which is used in the LPN applications. The SIW oscillators possess some advantages such as being appropriate in mass production, low fabrication cost, miniaturized, high Q-factor, suitable for the microwave monolithic integrated circuits (MMICs) and radio frequency integrated circuits (RFICs) [38, 39]. However, the LPN SIW oscillators have been rarely studied in low-frequency oscillators. Furthermore, the microstrip metamaterial structures possess simplicity, high Q-factor, low cost, and high flexibility in design. The metamaterial resonators are employed in microwave oscillators with LPN applications in the form of series and parallel feedback. There is a trade-off between a high Q-factor and a compact size for reducing the cost of the LPN MMIC metamaterial oscillators [40, 41]. Therefore, compact planar metamaterial resonators with a high Q-factor are required. Passive elliptic bandpass filters as a frequency stabilization part within the feedback loop of elliptic oscillators can allocate more Q-factors compared to single resonators [42,43]. Although, the unloaded Q-factors of printed planar resonators are limited owing to the radiation losses.

A practical method for designing LPN microwave oscillators is based on DRs. The DRs are employed as frequency stabilization elements in the form of series and parallel feedback structures. The DRs possess a very high Q-factor. As a result, low noise applications can be achieved [44-48]. Therefore, in the area of microwave and millimeter-wave systems, the LPN oscillators are widely used.

The dielectric resonator oscillators (DROs) are low-price microwave devices. The properties of these are temperature and frequency stability, low phase noise, high Q-factor, and miniature size which permit them to use in several applications such as LPN oscillators. The frequency in trends of electronics tends to climb. Therefore, the distributed elements are employed more than lumped elements. Also, the sharp development in semiconductor technology needs more stable LPN microwave oscillators [49].

In this article, firstly, the ATF36077 microwave transistor is biased. Then, the X-band LPN dielectric resonator oscillator is designed as series feedback. By using the DR, a high Q-factor is realized. After that, the matching network is proposed. Finally, the LPN microwave DRO is presented. The oscillator, operating at 11.995 GHz, exhibits a simulated phase noise of

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almost -70 dBc/Hz, -92 dBc/Hz, -112 dBc/Hz, and -132 dBc/Hz at 1-kHz, 10-kHz, 100-kHz, and 1-MHz frequency offset, respectively.

network, and microwave DR. Each of these items has been mentioned in detail. The substrate of this nonplanar oscillator is Rogers RT/Duroid 5880 with a dielectric constant of 2.2, a thickness of 20 mils, and a loss tangent of 0.0009. This low-loss tangent is suitable for low-noise applications, especially for microwave nonplanar oscillators. The input and output of the active device are matched to 50 Ω .

In this article, the active device is a packaged GaAs FET (an ATF-36077 pHEMT transistor from Avago Technologies, which was selected to investigate the amplifier in the feedback network.) that is biased at a drain-source voltage of 1.5 V with a drain current of 10 mA. The model of this transistor is static and works at a frequency range of 2-18 GHz.

The E 4000 type of dielectric (from TEMEX company) is selected to design the resonator in 12 GHz frequency. This kind of dielectric possesses a dielectric constant of 29.5 and a Q-factor of 15000. Fig. 1 (a and b) shows the model and schematic of the DR, respectively. The length of the transmission line equals the wavelength of nearly 18 mm. The diameter and height of the designed DR are 4.4 mm and 3.6 mm, respectively.

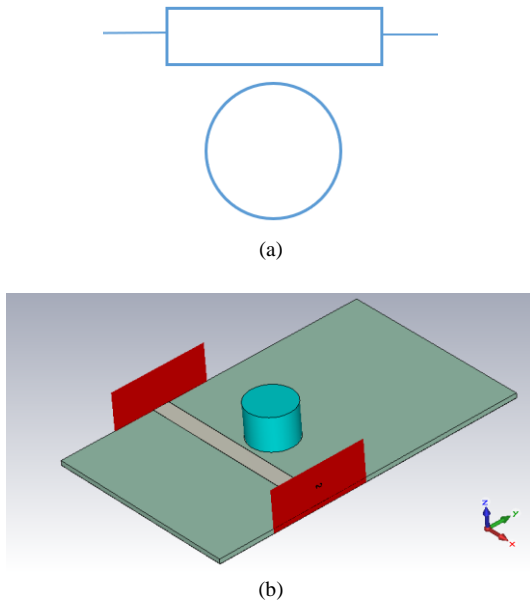


Fig. 1. The X-band dielectric resonator with transmission line coupling. (a) Model (b) Schematic

Fig. 2 (a and b) depicts the S11 and S21 parameters of the proposed DR, respectively. The return loss is improved by adjusting the distance between the DR and transmission line.

The transmission line which is coupled to the DR connects to the gate of the transistor. A transmission line is placed in the source of the transistor in order to destabilize the active device. The drain of the microwave transistor is connected to the load by a matched network. In an effort to achieve the desired frequency stability, the relation between the reflection coefficient which is seen in the drain and gate of the transistor,

II. DESIGN AND MODEL OF THE DRO

In the given prospect, the X-band DRO includes different sections such as microwave transistor, output-matched network, and the Γ_{out} , and the Γ_r , with the S-parameter of the active device is [50]:

$$\Gamma_{out} = S_{22} + \frac{S_{21}S_{12}\Gamma_r}{1 - S_{11}\Gamma_r} \quad (1)$$

$$\Gamma_r S_{11} = 1 \quad (2)$$

$$|\Gamma_r| = \frac{1}{|S_{11}|} \quad (3)$$

$$\angle \Gamma_r = -\angle S_{11} \quad (4)$$

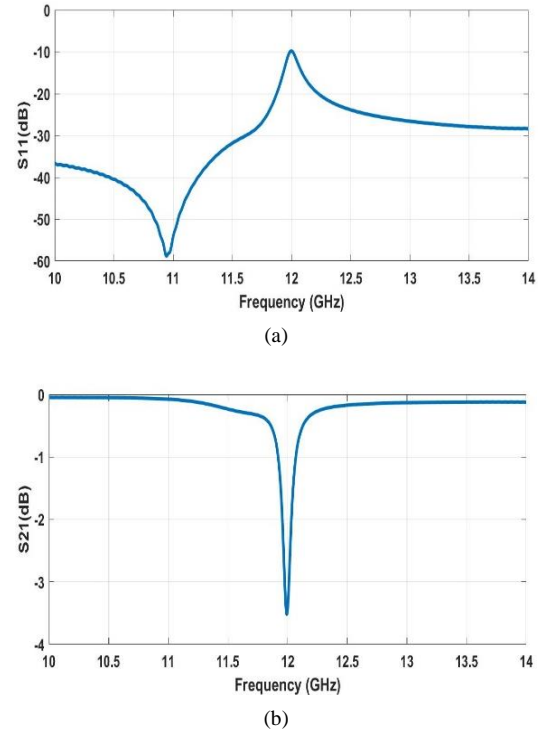


Fig. 2. The S-parameter of the proposed DR. (a) S11 (b) S21.

The transmission line's length at the transistor's source is selected at 6.8 mm. Therefore, the $|\Gamma_r|$ at 12 GHz frequency achieved is 0.32 and the magnitude of the S11 is obtained at 3.09.

The $\angle \Gamma_r$ is simulated -3.87 rad and the phase of the S11 of the DR, at 12 GHz frequency, is simulated -0.226 rad. Therefore, the length of the transmission line at the gate of the microwave active device is calculated at 5.25 mm.

$$\angle \Gamma_r = -0.226 - 2\beta l = -0.226 - \frac{4\pi}{\lambda_g} l = -3.87(\text{rad}) \quad (5)$$

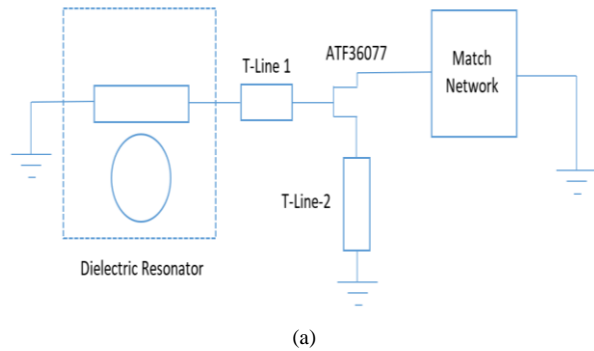
$$l = 0.29\lambda_g \approx 5.254\text{mm}$$

By considering the impedance which is seen at the drain of the transistor to the left side (Z_{out}), the output-matched network was designed. The real and imaginary notations of the Z_{out} , at

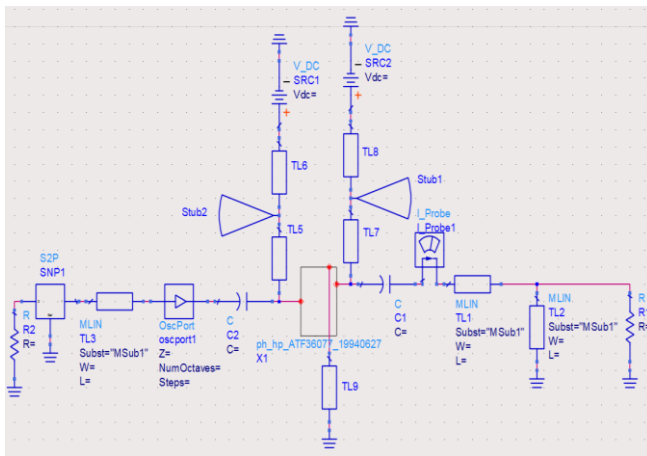
12 GHz frequency, are -49.8Ω and 0.10Ω , respectively given the oscillation is at [51]:

$$R_{out} + R_L < 0, \quad X_{out} = -X_L \quad (6)$$

The Z_L is the impedance that is seen at the drain of the transistor to the right side. The real and imaginary notations of the Z_L , at 12 GHz frequency, are 30Ω and -0.10Ω , respectively. Therefore, the matched network is designed at the side of the drain part of the active device. Fig. 3 (a and b) shows the model and schematic of the X-band DRO. The size of the introduced DRO is about $3 \times 5 \text{ cm}^2$.

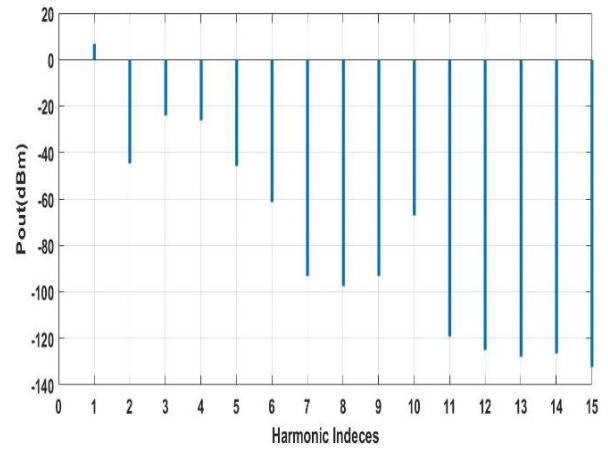


(a)

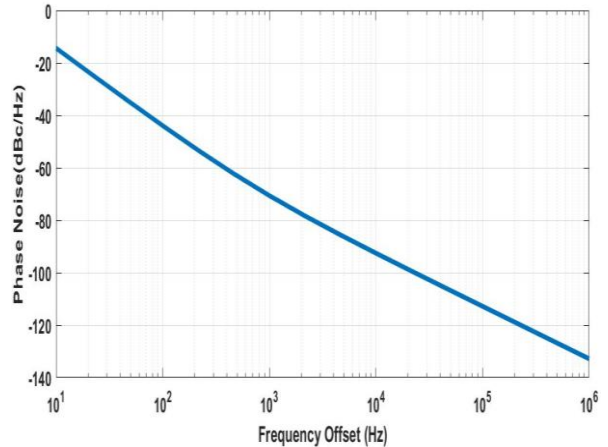


(b)

Fig. 3. The X-band ATF-36077 dielectric resonator oscillator. (a) model (b) schematic.



(a)



(b)

Fig. 4. The X-band ATF-36077 dielectric resonator oscillator. (a) harmonics power level (b) phase noise curve.

III. RESULTS AND DISCUSSION

Fig. 4 (a) depicts the harmonic spectrum of the X-band DRO. It also shows the PN curve of the designed DRO. The proposed oscillator, operating at 11.995 GHz, exhibits a simulated PN of -70.5 dBc/Hz , -92.5 dBc/Hz , -112.8 dBc/Hz , and -132.8 dBc/Hz at 1-kHz, 10-kHz, 100-kHz, and 1-MHz frequency offset, respectively.

The oscillator output power is 6.93 dBm. The second and third harmonic power levels are more than 50 dB and 0 dB lower than the main harmonic power level, respectively.

The performance of the proposed GaAs FET dielectric resonator oscillator with the recently reported microwave DROs is compared and is shown in Table I.

The SiGe HBT ceramic-based dielectric resonator oscillator shows a PN of -135 dBc/Hz at 10-kHz frequency offset which is the best PN so far. GaAs FET dielectric resonator [17] depicts the best amount of the output power level (18.3 dBm) in this category.

algorithm for driving an LPN DRO is shown in Fig. 5.

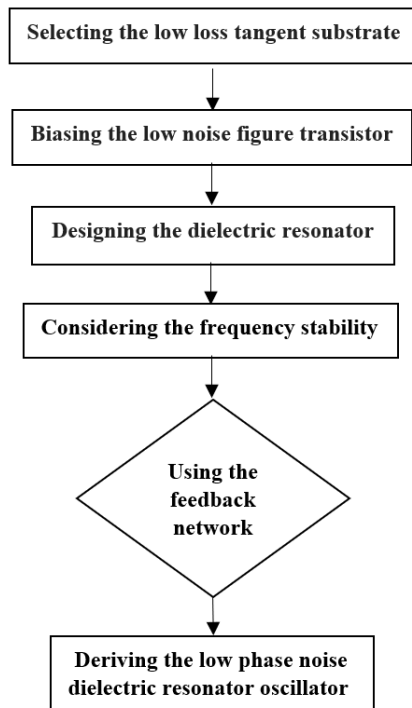


Fig. 5. The design algorithm of the LPN DROs.

IV. CONCLUSION

In this paper, a low phase noise X-band dielectric resonator oscillator is implemented on a Rogers RT/Duroid 5880 with a dielectric constant of 2.2 and a thickness of 20 mils, and a loss tangent of 0.0009. The active device is ATF-36077 and the microwave dielectric resonator is designed at a 12 GHz frequency. The oscillator, operating at 11.995 GHz, exhibits a simulated phase noise of almost -70 dBc/Hz, -92 dBc/Hz, -112 dBc/Hz, and -132 dBc/Hz at 1-kHz, 10-kHz, 100-kHz, and 1-MHz frequency offset, respectively.

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TABLE I

Comparison of the Proposed GaAs FET DRO with Other Reported Microwave Dielectric Resonator Oscillators.

Device	Resonator	f_0 (GHz)	P_0 (dBm)	PN (dBc/Hz) @ 10-kHz
GaAs FET [7]	Ceramic-based Dielectric Resonator	13.3	8	-122
GaAs FET [14]	Dielectric Resonator	11.8	-1.8	-81**
SiGe HBT [15]	Ceramic-based Dielectric Resonator	10	12	-135
GaAs FET [17]	Dielectric Resonator	12.6	18.3	-83
HEMT [18]	Nonradiative Dielectric Multiple Ring Resonator	23.3	7	-96*
SiGe HBT [20]	Dielectric Resonator	58	-8	-105*
SiGe HBT [44]	Ceramic Resonator	13	-	-95
GaAs FET [45]	LTCC Dielectric Resonator	16	0.5	-100**
GaAs FET [46]	Dielectric Resonator	9.8	6	-118**
GaAs FET [47]	Dielectric Resonator	9.8	8.5	-117**
Si BJT [48]	Active Dielectric Resonator	8	7.8	-145.1**
GaAs FET [Proposed]	Dielectric Resonator	12	6.9	-93***

* 1-MHz

** 100-kHz

*** Simulated Result

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