Design of Low Phase Noise 7.7 GHz Dielectric Resonator Oscillator

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Abstract

In this work, a dielectric resonator stabilized oscillator with output frequency at 7.7 GHz is designed, simulated and measured. The oscillator topology is based on the series feedback dielectric resonator oscillator (DRO) structure. The precise design procedure of the series feedback dielectric resonator oscillator is presented. A λ/4 open stub microstrip line is arranged at the output port in order to improve the suppressions of harmonic frequencies. The simulation results show that, the phase noise exhibits about -100 dBc/Hz@10KHz while the output power at 7.7 GHz is 10 dBm and the suppression of harmonic frequencies are better than -50dBc. In the practical measurements, the phase noise exhibits -95dBc/Hz@10KHz while the output power is 9.4 dbm and the suppression of harmonic frequencies are better than -40 dBc.

1. Introduction

In the whole microwave systems oscillators represent the basic microwave energy source. The oscillators with a single output frequency are widely used in many fields such as radar, communication and electromagnetic countermeasure [1]. Resonators are the main component of oscillator structures. It was first presented by R. D. Richtymer [2] that cylindrical dielectric structure would act like a resonator. Many years after that discovery very different type of dielectric resonator oscillators were realized. The dielectric resonator oscillators (DRO) are known as one of the most suitable devices for generating low-cost and highly stable microwave signals. Its properties of having low phase noise, small size, high quality factor, temperature and frequency stability permit these devices having progressively extending area of usage in many applications [3] such as measuring the material properties [4], oscillators [5], antennas [6], filters [7] that require low noise profile. Since the sizes of dielectric resonators are small they are mostly preferred in high frequency applications.

In this paper, a 7.7 GHz series feedback dielectric resonator oscillator is designed and realized. The output power at 7.7 GHz reaches 10 dBm in simulation and the suppression at second harmonic frequency is better than -50dBc by employing quarter wavelength open stub. Also, a good correlation between simulation and measurement results are achieved.

2. Design Procedure of DRO with Series feedback

The design method of dielectric resonator oscillator with series feedback is based on the theory of negative resistance oscillator [8]. The schematic diagram is shown in Fig. 1. The condition of stable oscillation is

$$\Gamma_{in}\Gamma_L = 1 \tag{1}$$

According to the theory of microwave network, Γ_{out} can be expressed as following

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{11}\Gamma_L} \tag{2}$$

where S_{11}, S_{12}, S_{21}, S_{22} are the scattering parameter of transistor. Obviously, when (1) is satisfied, then

$$\Gamma_{out}\Gamma_L = 1 \tag{3}$$

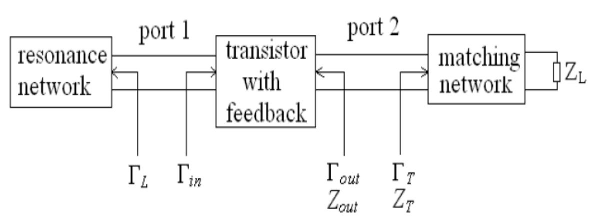

Fig. 1. Schematic diagram of negative resistance oscillator

The oscillator circuit using FHX13LG GaAs HEMT from Eudyna is shown in Fig. 2. GaAs HEMT has different configurations such as common gate, common drain and common source [9]. In this work, common source configuration is employed. The source was connected to a short microstrip line to add positive feedback in order to increase instability of the transistor. In Table 1. Stability factor (K) of the transistor is given over 1 GHz – 20 GHz band. After adding a short microstrip line to the source of the transistor, new stability factor values were calculated. These results are also given in Table 1. At 8 GHz, stability factor of transistor and unstabilized transistor with short line is 1.02 and 0.35, respectively.

Table 1. Simulation results for negative resistance condition

Frequency (GHz)	Stability factor of FHX13LG	Stability factor of FHX13LG with short line
1	0.11927	1.6634
2	0.22234	-0.1801
3	0.35139	-0.69
4	0.44168	-0.6443
5	0.57136	0.6645
6	0.70012	0.7401
7	0.82045	0.71
8	1.0269	0.35
9	1.073	0.40054
10	1.1286	0.7355
11	1.2418	0.43467
12	1.3093	0.23532
13	1.3053	0.20502
14	1.2694	0.83906
15	1.1965	0.80555
16	1.1377	-0.3012
17	1.0427	0.1644
18	0.95852	0.9970
19	0.93622	1.6338
20	1.0396	3.2406

Reflection coefficient Γin can achieve suitable magnitude by adjusting length and width of the line. Dielectric resonator is coupled with the microstrip line connected to the gate. Phase condition of stable oscillation can be achieved by adjusting electrical length of this line. This microstrip line is terminated with a 50Ω resistor to avoid parasitic reflection. Open-stub microstrip line is used in the matching network at output port.

The whole design procedures can be described as follows: First, simulate the coupling between DR and microstrip in field simulation software, adjust the distance between them to obtain proper reflection coefficient Γ_L and quality factor Q. This coupling model can be considered as a component with determined scattering parameter. Secondly common-source configuration must be adopted. A short-end microstrip line is connected to the source to increase the instability. Thus, negative resistance is presented at the input port. This model should be optimized to satisfy that

$$|S_{11}| \approx |\Gamma_L| \tag{4}$$

As third criterion, a microstrip line is inserted between the coupling model in step 1 and the gate of FET to satisfy that

$$\angle S_{11} = \angle \Gamma_L^* \tag{5}$$

When (4) and (5) are satisfied, it's obviously that the magnitude of Γout will be large, since the denominator of (2) approaches zero. Thus, a large negative resistance will be presented at port 2. At lastly design the matching network according to the condition of stable oscillation. We can easily get following impedance condition from (3):

$$Z_{out} + Z_T = 0 \tag{6}$$

To ensure that oscillation will be motivated, the following criterion is required:

$$\begin{aligned} R_T &= -R_{out}/3 \\ X_T &= -X_{out} \end{aligned} \tag{7}$$

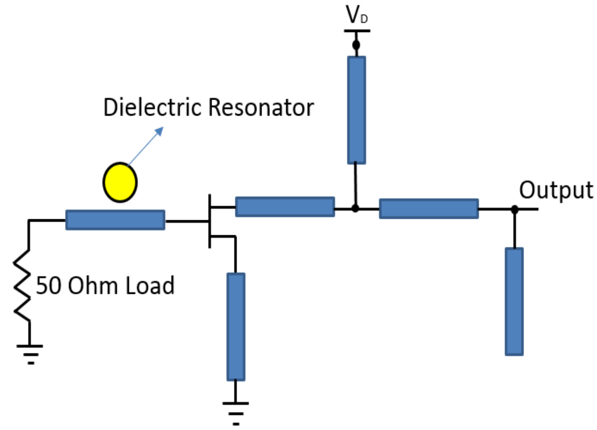

Fig. 2. General schematic of the series feedback dielectric resonator oscillator

3. Simulations and Measurement Results

Simulations are made with the aid of AWR Microwave Office. All microstrip line lengths and widths were optimized to get the best result. Realizations are made on the low loss dielectric substrate with dielectric constant of 3.38 and thickness of 20 mil. The unloaded quality factor of the resonator is 15000. The dielectric constant of the resonator is 30 from Murata Resomics series. The DRO simulation schematic is shown in Fig 3. Dielectric resonator is modeled as parallel RLC circuit. DC supply voltage for transistor is 3V.

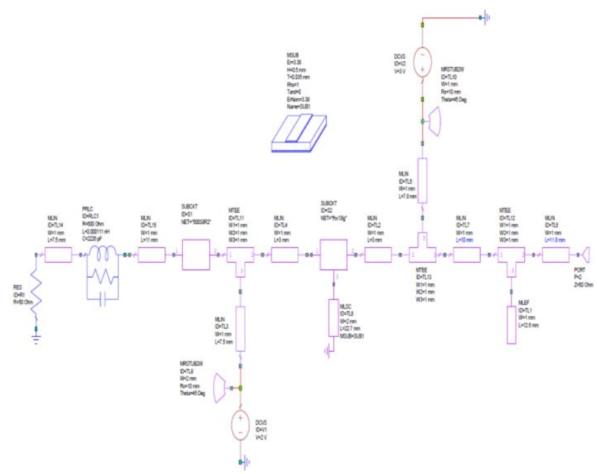

Fig. 3. AWR schematic of designed series feedback dielectric resonator oscillator circuit

After having several simulations and optimizations procedures, negative resistance oscillator conditions are satisfied. As shown in Table 2., the conditions (1), (2) and (3) are fully satisfied at 7.7 GHz frequency.

Table 2. Simulation results for negative resistance condition

Frequency (GHz)	Γr	Γin	Rout	Xout	Rhemt	Xhemt
7.400	0.0084707	3.4102	23.451	50.093	-44.448	-12.783
7.500	0.0031597	2.5224	30.056	56.774	-50.622	-22.119
7.600	0.0043978	1.8036	39.799	60.391	-53.157	-36.366
7.700	0.84428	1.4167	48.412	55.499	-47.794	-53.808
7.800	0.012203	1.1986	41.631	46.946	-31.078	-68.564
7.900	0.018022	1.0668	23.677	56.11	-6.9853	-71.902
8.000	0.023494	0.98621	11.861	82.401	14.452	-62.752
8.100	0.028743	0.93971	7.066	121.28	27.949	-47.606

The phase noise and the output power measurements are performed consecutively. The prototype which is realized in practice is shown in Fig. 4. The measurements of the prototype board are made with Rohde&Schwarz FSP spectrum analyzer and a DC power supply of Agilent E3630A.

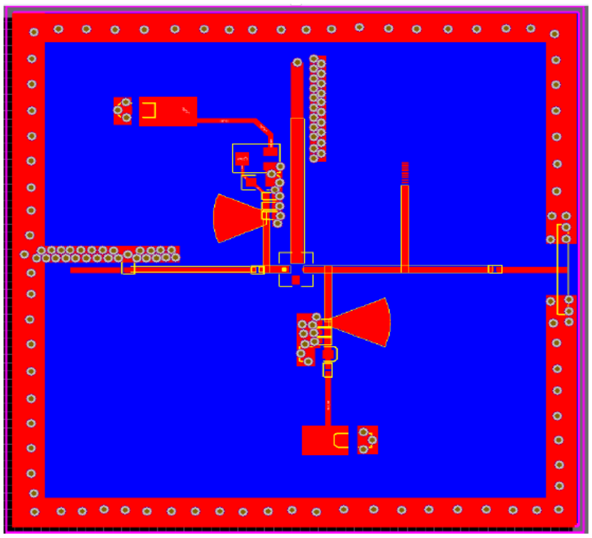

Fig. 4. The layout design of 7.7 GHz dielectric resonator oscillator

In Fig. 4, the layout of DRO is given. The microstrip line parameters in the layout are designed by using AWR Microwave Office. The realized Prototype board of the series feedback DRO is shown in Fig. 5. The dimension of whole circuit is 50 mm x 50 mm. Fig. 6 shows the output power simulation and measurement results of the prototype board. Phase noise measurement result of DRO is given in Fig. 7.

4. Conclusions

The design and realization of a 7.7 GHz series feedback dielectric resonator oscillator is presented in this paper. The fundamental frequency output power is about +10 dBm. The phase noise is -100dBc/Hz@10KHz while the suppression of second and third harmonic frequencies are about -50dBc and -40 dBc, respectively.

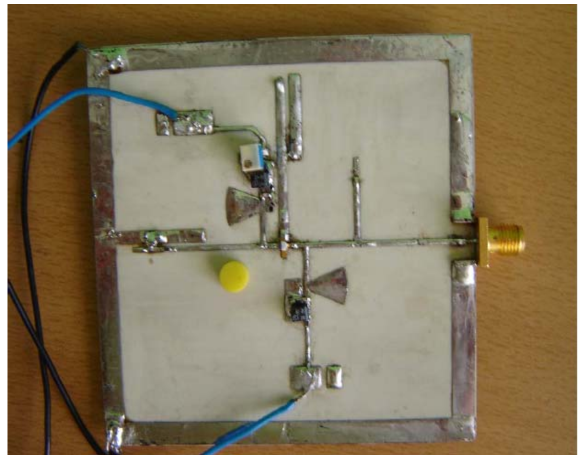

Fig. 5. Prototype board of the dielectric resonator oscillator

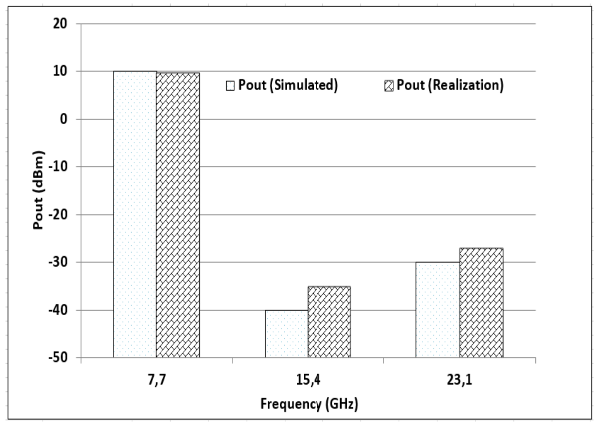

Fig. 6. Output power of DRO

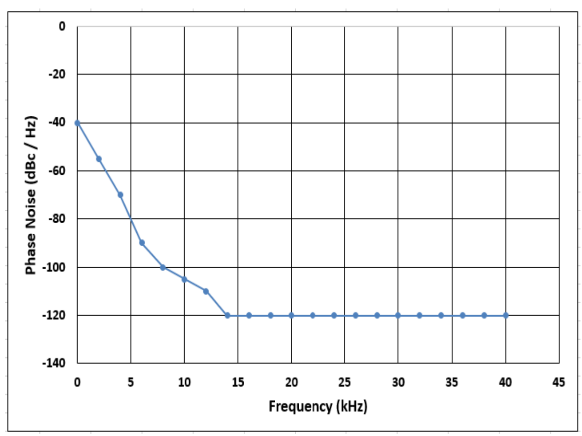

Fig. 7. Measured phase noise of DRO

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