Dielectric Resonator Oscillator Design and Realization at 4.25 GHz

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Abstract

In this paper design and realization of dielectric resonator oscillator operating 4.25 GHz is explained. The oscillator is designed as a negative resistance oscillator where chip-amplifier is used as the negative resistance by adding feedback. The dielectric resonator is simulated using High Frequency Structure Simulator. The simulation and realization results are discussed.

1. Introduction

It was first presented by R.D. Richtymer [1] that cylindrical dielectric structure would act like a resonator. Many years after that discovery, such circuits containing dielectric resonators are realized.

The dielectric resonator oscillators (DRO) are known as one of the most suitable devices for generating low-cost microwave signals. Its properties of having low phase noise, small size, high quality factor, temperature and frequency stability, which allow it to have progressively extending area of usage in many applications [2] such as measuring the material properties [3], oscillators [4], antennas [5], filters [6] that require low noise profile. Since the sizes of dielectric resonators are small they are mostly preferred in high frequency applications.

Due to the frequency in applications of electronics tends to increase, microwave oscillators have gained importance. Higher frequency causes lumped elements to gain different characteristics, thus usage of lumped elements are not preferable in microwave frequencies. Distributed elements are used instead of lumped elements. Furthermore, the rapid development in semiconductor technology led the design of more stable and low-noise microwave oscillators.

The important characteristics of the microwave resonators are the resonant frequency f_0, the quality factor Q, which defines the bandwidth of the resonance and the input impedance of the resonator. [7]

2. DRO Design

Dielectric resonators can be used in both negative resistance (reflection) and feedback type oscillators [8]. The property of being easily coupled to a microstrip line is another reason to use dielectric resonators on integrated circuits [9].

Many types of active devices can be applied to the DRO design. GaAs technology is considered as one of the most suitable transistor for microwave applications because of its temperature frequency stability and low noise characteristic [10]. On the other hand, GaAs MESFET is able to offer better performance than GaAs FET [11,12].

Considering the advantages of GaAs MESFET, an amplifier chip of GaAs MESFET, MGA72-543 is used as the active device in our circuit. The negative resistance oscillator model is chosen for the design. In the following sections, the design procedure of the DRO will be considered.

2.1 DRO Simulation

The placement of the resonator is an important parameter. The width and the length of the microstrip line, as well as the distance of the resonator to the microstrip line must be thoroughly analyzed. The resonator is modeled as parallel RLC resonant circuit and RLC parameters as well as quality factors are calculated from the simulated S-parameter values.

For the microstrip substrate, Taconic TLY 3 CH is used. The substrate has a relative dielectric constant of the 2.33 ±.02 and substrate height of 0.76 mm. As the dielectric resonator, Trans-Tech 8300 series dielectric resonator is used. The dielectric constant of the resonator is 35.5. The unloaded quality factor of this resonator can be up to 15000.

It is calculated that for our substrate, at 4.25 GHz, the λ/2 microstrip line must have a width of 2.23 mm and length of 25.10 mm. S-parameters are obtained by high frequency electromagnetic simulation program HFSS v.11. The S-parameters of the simulated dielectric resonator configuration can be seen in Fig.1 and the phases of S_{11} and S_{21} can be seen in Fig. 2.

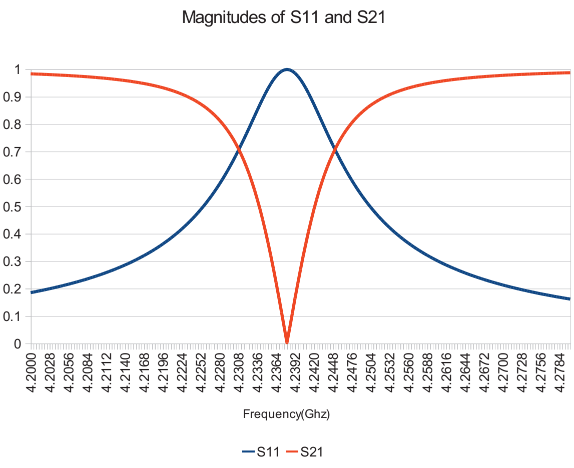

Fig. 1. Magnitudes of S_{11} an S_{21}

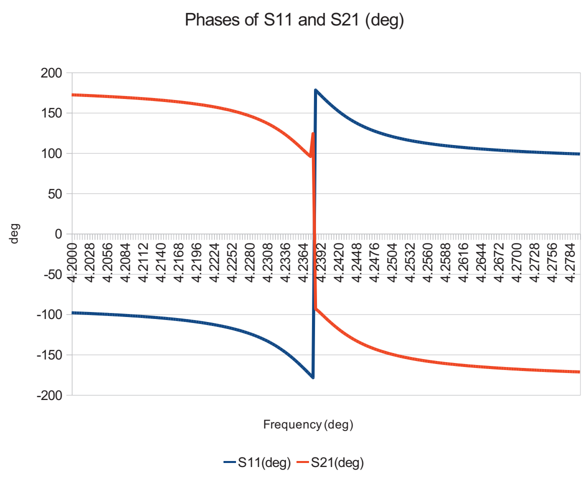

Fig. 2. Angles of S_{11} an S_{21}

The distance between the dielectric resonator and the microstrip line is chosen as 1.5 mm. The resonant frequency is observed as 4.2384 GHz. It is clear that near resonant frequency, S_{11} has its maximum value around 0 dB, indicating a full reflection. This means that the oscillator acts like an open circuit near resonance.

2.2 Negative Resistance

In order to achieve negative resistance, S_{11} and S_{22} parameters of the active device must be greater than unity. The S_{11} and S_{22} parameters are even desired to be at least 1.2 for start-up oscillation [13]. In order to achieve these conditions positive feedback must be added.

The MGA 72543 is a single stage MESFET amplifier. At this point, negative resistance by adding a positive feedback element is obtained by the active device property of the MESFET. The feedback element can be added to the source of the FET (Fig. 3). Obtained S parameters and stability factor is seen in Fig. 4.

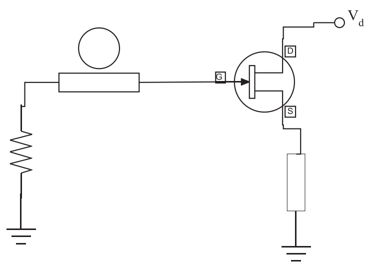

Fig. 3. Source feedback FET configuration

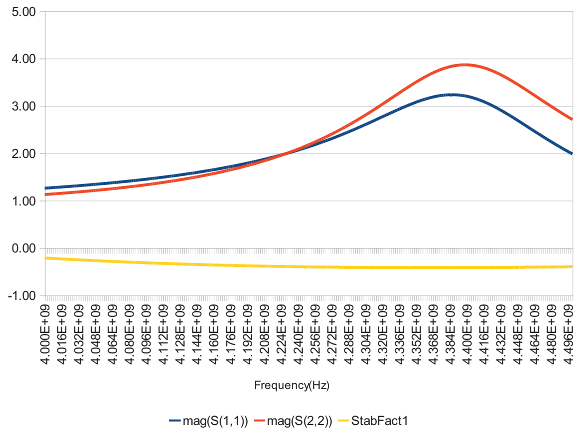

Fig. 4. Magnitudes of S_{11}, S_{22} and stability factor.

2.3 Harmonic Balance Analysis

The harmonic balance simulation is a technique for analyzing frequency domain behaviors of non-linear systems. An oscillator can be considered as a nonlinear system which may be represented by a canonical set of differential equations. The harmonic balance method tries to find the solution to a steady-state non-linear design by iteratively solving for a set of variables, named as state variables [14]. The convergence of the iteration depends on choosing the initial values of state variables and oscillation frequency [15].

For validating our design, Advanced Design System Harmonic Balance Simulation is used. The initial value of the oscillation frequency is given as 4 GHz. The simulation is done on a fast speed computer (Intel Core i7 2.93 GHz, 3 GB RAM, 1 TB HDD). The order of harmonics is chosen as 9 and the simulation takes 3.49 seconds. The simulation also calculates the phase noise of the oscillator system. The simulation results are shown in Fig. 5.

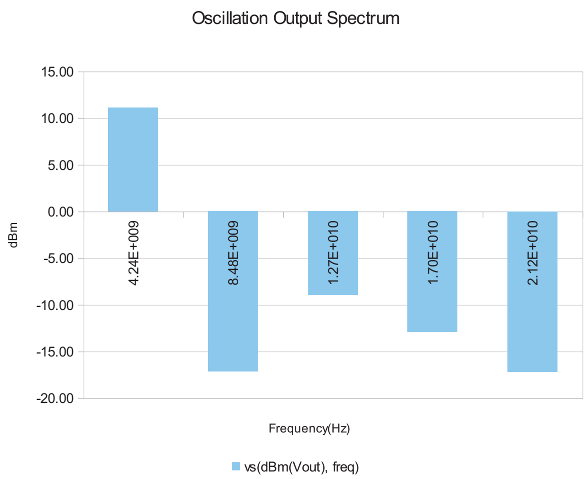

Fig. 5. Harmonic balance simulation results - spectrum components

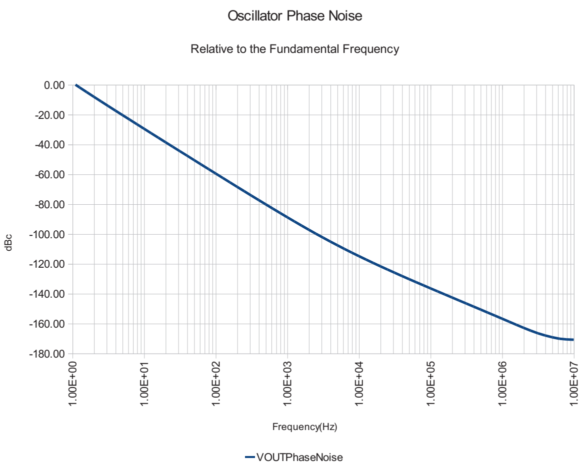

Fig. 6. Harmonic balance simulation results - phase noise relative to the fundamental frequency

The harmonic balance simulation shows (Fig.5. and Fig.6.) the oscillation frequency as 4.24 GHz and the first harmonic's power as 11.13 dBm. The phase noise relative to the fundamental frequency is about -29.283 dBc.

3. Realization of DRO

The layout of the circuit is drawn with Eagle free edition. The circuit is printed by LPKF ProtoMat S62 which is available in the Printed Circuit Board Laboratory. The capacitors and the inductors are the size of 0805 package. MGA 72543 is in SOT-73 package. In Fig. 7. the final board layout is displayed.

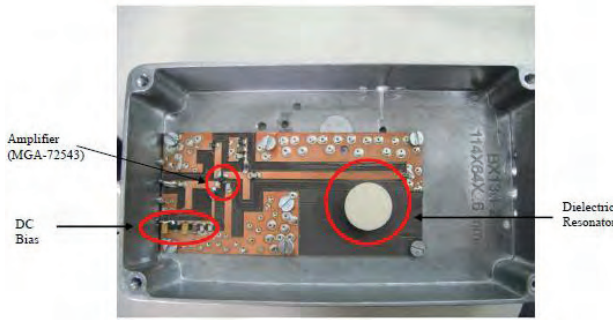

Fig. 7. Picture of the printed circuit board

4. Results

The measurements of the final design are done with Hewlett Packard 8592B spectrum analyzer. DC source is connected to the DC bias block of the dielectric resonator oscillator.

A serial multimeter is connected in order to measure the current ID which is the device current. In order to prevent the pulling effect of the spectrum analyzer, the output is connected to the isolator.

Fig. 8 shows the observed output spectrum of the dielectric resonator. The oscillation frequency is measured as 4.30 GHz. The maximum measured output power is 6.5 dBm which corresponds to 4.47 mW. The second harmonic which is 8.60 GHz and the third harmonic at 12.90 GHz has a power of -45.92 dBm and -13.06 dBm which correspond to 0.26 µW and 49 µW, respectively (Fig. 8, Fig. 9, Fig. 10).

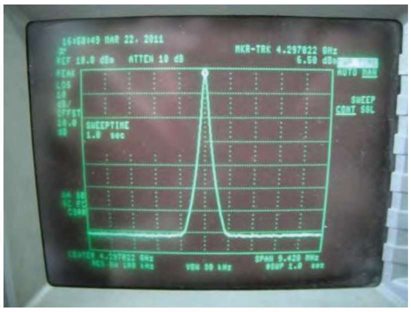

Fig. 8. Output spectrum of the dielectric resonator oscillator

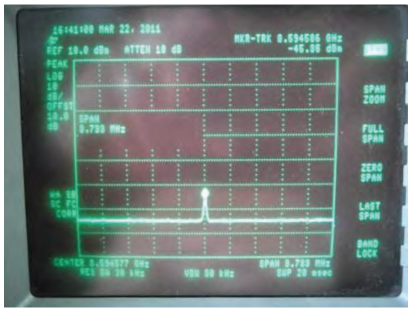

Fig. 9. Power spectrum of the second harmonic of the oscillation frequency.

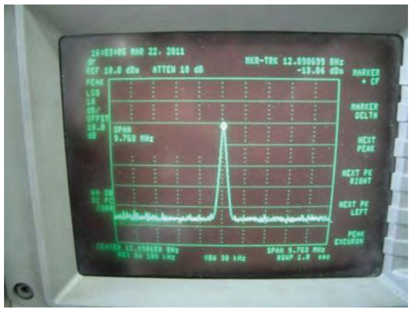

Fig. 10. Power spectrum of the third harmonic of the oscillation frequency.

The spectrum analyzer can be used in noise measurements in a simple way. If linear approach is used, the single-sideband noise (in dBc/Hz) can be defined as:

$$\mathfrak{L}(f_m) = \frac{N(1Hz\ BW)}{C} \qquad (1)$$

In equation (1), N is the power of noise in 1Hz bandwidth at f_m away from the carrier and C is the power of the carrier. Using a spectrum analyzer, one can calculate by reading the carrier power which is the power of oscillation frequency, reading the power at f_m away from the oscillation frequency and calculating the ratio of those two. However, this technique has some drawbacks because of the working principle of the spectrum analyzer [10]. The filters and amplifiers at the input of the spectrum analyzer must be taken into account as well as the non-existence of 1 Hz bandwidth band pass filters. According to equation (1), the noise power must be measured through bandpass filter with a bandwidth of 1 Hz. So the measurements must be corrected by reducing the noise power by 10 dB per decade if the internal filter of the spectrum analyzer has a bandwidth larger than 1 Hz.

Using these relations the phase noise of the realized DRO is found as in Fig.11.

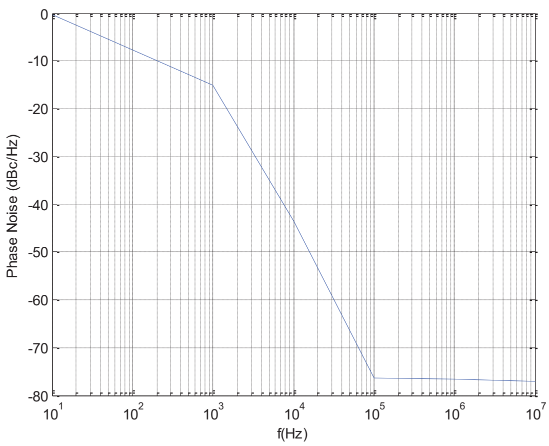

Fig. 11. Measured phase noise of the realized DRO

6. Conclusions

In this paper, design and realization of a dielectric resonator oscillator operating at 4.25 GHz is presented. The oscillator operates at 4.30 GHz. The fundamental harmonic of the oscillator is 6.5 dBm. Total harmonic distortion is approximately -20 dBm.

Stabilizing the bias conditions of the active device in resonator circuits is an important issue. By using a single chip amplifier, this difficulty is overcome. Also, by using high frequency structure simulator through the design process, deriving s-parameters of the dielectric resonator becomes more accurate

The phase noise measurement gives an overview of the noise performance of the realized DRO despite the drawbacks of the measurement method. -43.55 dBc/Hz at10 kHz from the carrier was observed. However, very low noise DRO designs are available in the literature [12].

As a result, the designed oscillator works with an error of 1.46 percent in terms of oscillation frequency compared to the simulation results. The main reason for this is that the bias conditions were obtained with an error of 1.36 percent in terms of the device current. The difference of harmonic powers between the simulation of the oscillator and the practical one is mainly due to the mismatch at the output which occurs as a result of improper soldering of the SMA connector. Beside, the chassis should be at the same size of the printed circuit board in order to concentrate the electromagnetic energy inside the chassis. These improvements can be applied in order to obtain more accurate results.

7. References

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