Low phase noise microwave oscillator using meander spurline resonator for X-band application

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We present a simple compact meander spurline resonator and its application to low phase noise oscillator. The resonator which has a bandstop characteristic is used in the series feedback of oscillator. This miniaturized resonator consists of a defected meander spurline with inductive characteristics and capacitive characteristics. The microwave oscillator using the meander spurline resonator shows excellent phase noise performances of -103.23 dBc/Hz at a 100 kHz offset from the carrier frequency of 9.0 GHz with an output power of 15.23 dBm due to the high $Q$ value of the defected meander spurline resonator. The structure of resonators reduces the size and the cost.

Keywords: Microwave oscillator, Spurline resonator, Microstrip resonator, Hybrid oscillator

Microwave oscillator is a key circuit for generating carrier sinusoidal signals for radio frequency (RF) communication systems. Low phase noise microwave oscillator is a key circuit for the system. In order to get a low phase noise, the resonator-$Q$ factor or a loaded $Q$ should be a high since the resonator is the main part of the oscillator. There are various types of resonators used in oscillators such as hairpin resonators, dielectric resonators (DR), LC resonators, so on. These all resonators are not compact in size and the important parameter, the $Q$ factor, is not so high. The LC resonator cannot be used for high frequency application due to its parasitic capacitance and lead length inductance issues. Similarly, the DR has high $Q$ and can be used in high frequency but it has problem of size and cost. A hairpin resonator has its inherent low $Q$ factor and bigger size. However, in the defected meander spurline resonator, $Q$-value can be increased by increasing the coupling potential between the meander spurline structures. Therefore, we can get higher coupling between spurlines. The trend of using low cost materials and making miniaturized microwave devices is increasing day-by-day. To overcome such problems, in this work, hybrid oscillators utilizing a miniaturized a meander spurline resonator are designed, fabricated and characterized. A spurline is a simple embedded internal defected line structure; it can be fabricated by a simple etching process and the defected meander spurline also exhibits inductive characteristics. These microstrip resonators are also easy to integrate into circuits due to their inherent compact size. The applications of such resonators are popular in building resonators and filters due to their bandstop characteristics, inherently compact size, and band-gap characteristics. Haiwan, Reinhard et al. used spurline and meander spurline resonators to build band stop filters and circuit modeling due to their good results. But the good performances of these resonators as a frequency determining network, have not implemented yet to oscillators. Therefore, we developed the meander spurline resonator utilizing its characteristics and implemented them for oscillators in order to have low phase noise characteristics. The application of these resonators overcomes the integration problem found in hybrid microwave integrated circuit (HMIC) techniques and such resonators incorporated with a microwave oscillator can also be feasible in microwave monolithic integrated circuit (MMIC) as in reference.

Design and Simulations

We designed and simulated a resonator with high $Q$ value and integrated with a microwave oscillator. The meander spurline microstrip resonator was simulated using the SONNET Lite 3D planar analysis EM simulator and the whole circuit was simulated using ADS 2008.

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Spurline resonators

The meander spurline resonator was designed, fabricated and characterized and then implemented into microwave X-band oscillator. The resonator was fabricated using a Teflon substrate with the thickness 0.54 mm and the dielectric constant of 2.54. The schematic and the equivalent circuit of the meander spurline resonator are depicted are Figs 1 and 2, respectively. The structure of the meander spurline has a slot width \( w \) of 0.15 mm, a slot length \( l \) of 3.2 mm and a slot height \( h \) of 1.35 mm. The slot gap provides a capacitive effect while the narrow line exhibits an inductive effect. Thus, the effective permittivity of the dielectric substrate increases as the effective inductance and capacitance of the microstrip line which is improved by spurlines. The meander spurline enhances the \( Q \) value of the resonator; therefore, it has potential to achieve low phase noise when implemented in a microwave oscillator.

As mentioned above, the \( Q \) factor is a determinant factor to achieve a low phase noise of an oscillator. The loaded \( Q \) can be found using the following equation:

\[
Q_L = \frac{\omega_0}{\Delta \omega}
\]

where \( \Delta \omega \) is the difference in 3 dB bandwidth of insertion loss. The spurline resonator provides a higher insertion loss and a narrow bandwidth.

Figure 2 shows the equivalent circuit of the spur meander line. It consists of an RLC network. In this model, the LC circuit was used in order get the resonant characteristics and the \( R \) is considered for the evaluation of the radiation effect and loss. The value of RLC can be determined using the following equations based on transmission theory:

\[
R = 2Z_0 \left( \frac{1}{|S_{21}|} - 1 \right) f = f_0
\]

\[
C = \frac{\sqrt{0.5(R + 2Z_0)^2 - 4Z_0^2}}{2.83\pi Z_0 R \Delta f}
\]

\[
L = \frac{1}{(4\pi f_0)^2 C}
\]

where \( S_{21} \) is the insertion loss, and \( \Delta f \) is the -3 dB bandwidth of \( S_{21} \), \( f_0 \) is the resonant frequency, and \( Z_0 \) is the 50 \( \Omega \) characteristic impedance of the transmission line. The extracted parameters of the spurline resonator simulated by the advance design system (ADS2008) are \( L=1.49 \text{ nH} \), \( C=0.2 \text{ pF} \) and \( R=3.97 \text{ k\Omega} \). The measured and simulated results of the resonators are plotted on the graph shown in Fig. 3 showed excellent agreement between the EM simulations and measurement results. The resonator resonated at very close to the simulated results. The \( Q \) factor of the meander spurline is high and it assists to
lower the phase noise when implemented in microwave oscillator.

**Microwave oscillators**

The meander spurline resonator was implemented to the oscillator to achieve low phase noise characteristics. During the simulation of the microwave oscillator performed by ADS2008, the Barkhasen criterion was satisfied. The transistor was made unstable by using positive feedback at the source. Generally, a microwave oscillator consists of an active device, a frequency determining network, and a resonator. In this work, a GaAs based FET (ATF13786) transistor and a spurline resonator with a high \( Q \) value are used as the active device and the resonator, respectively, as shown in Fig. 4. The resonator is placed in a series connection with the gate of the transistor. Bypass capacitors are used for RF grounding, and the radial open stubs are used as an RF choke in both the drain and the source. The oscillator is biased using a self biasing network built by using \( \lambda/4 \) microstrip lines. A microstrip DC block is used on the output of the oscillator.

**Results and Discussion**

The schematic of microwave oscillator is shown in Fig. 4. The pattern of the mask was transferred to the Teflon substrate with a thickness of 0.54 mm, which was done by an etching process. The designed spurline resonator and the incorporated oscillator were done using separate etching processes with a clear pattern on the substrate. The fabricated microwave oscillator is shown in Fig. 5. The meander spurline resonator was measured using an Agilent (HP) 8510C vector network analyzer (VNA). The simulated return loss and insertion loss results were compared with measured results. The graph showed a good agreement between the simulated and the measured data of resonator. The measured result of the meander spurline resonator resonated at 9.09 GHz which was close to the simulated results. The measured results of resonator showed the insertion loss below -25 dB as shown in Fig. 3.

The microwave oscillator is characterized using Agilent’s E4440A PSA spectrum analyzer. The oscillator using the meander spurline resonator showed an output spectrum with harmonics, shown in Fig. 6, which exhibited a second harmonic.
suppression of -30.41 dBc. The phase noise of the oscillator incorporated with the meander spurline resonator exhibited a -103.08 dBc at 100 kHz offsets from the carrier frequency of 9.09 GHz (Fig. 7) with an output power of 15.23 dBm when supplying a 3 V bias voltage along with a drain current consumption of 40 mA. The output power and phase noise at the 100 kHz offsets of this work showed the best results and are given in Table 1. The low phase noise characteristic of the microwave oscillator was achieved due to a high Q factor of the meander spurline resonator. That means it exhibited high capacitive and inductive reactance at 9.09 GHz with less series resistance.

Conclusions

The microwave oscillator incorporated with the meander spurline resonator was designed, fabricated and characterized for X-band application. The oscillator using the microstrip meander spurline resonator achieved low phase noise characteristics of -103.08 dBc at 100 kHz offsets with the high output power of 15.23 dBm. Due to the defected nature of the resonator, it has further potential for integration. The phase noise characteristics and the output power are quite comparable to the results reported in the literature. The designed oscillator is possible to fabricate commercially at a low cost and this research has practical significance in the microwave field.

Acknowledgment

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References


Table 1—The comparison of the present results with reported results

<table>
<thead>
<tr>
<th>References</th>
<th>Oscillation frequency, GHz</th>
<th>Output power, dBm</th>
<th>Phase noise@100 kHz, dBc/Hz</th>
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<td>10.16</td>
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<td>101.4</td>
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Figure 7—The phase noise characteristic.