Design of Low Phase-Noise Microstrip Resonator Oscillator

Dissertation submitted as a partial fulfillment for the Degree of Bachelor of Technology in Electronics and Communication Engineering

Submitted by
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West Bengal, INDIA

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CERTIFICATE

This is to certify that **Anish Pandey** bearing roll no. **13/EC/93**, has successfully completed his project on the thesis entitled, "**Design of Low Phase-Noise Microstrip Resonator Oscillator**" and submitted to National Institute of Technology Durgapur towards partial fulfillment for the award of the Degree of Bachelor of Technology in Electronics and Communication Engineering and this thesis is an authentic record of his own work carried out under my supervision.

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CERTIFICATE OF APPROVAL

The foregoing thesis entitled "**Design of Low Phase-Noise Microstrip Resonator Oscillator**" is hereby approved as a study of a technology subject carried out in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made, opinion expressed or conclusion drawn thesis only for the purpose for which it is submitted.

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External Examiner Internal Examiners

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Name of Candidate

Contents

Abstract

In this project, a method of designing a series feedback resonator oscillator with emphasize on phase noise study has been proposed. The split ring
Resonator, Hairpin shaped resonator (multi band), hairpin shaped resonator, quadral spiral resonator oscillator is consisted of an active device of ATF-36077, a GaAs PHEMT from Agilent, an array of resonators for frequency determining element and microstrip-based output matching network. Mainly, this work focused on modeling and designing an optimum performance of microstrip resonator oscillator in emphasizing the phase noise result. The simulation of oscillator has been modeled using Agilent Advanced Design System (ADS) and CST Microwave Studio
Software and Ansys HFSS . Six designs of resonator and three design of oscillator have been compared.
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Chapter 1 Introduction to Microstrip Design

1.1 Microstrip Design Development

In the first years of microwave development the Rectangular Waveguide become the dominant waveguide structure largely because high-quality components could be designed using it. One of the main issues was its narrow bandwidth due to the cut-off Frequency characteristic. Later, researchers try to find components that could provide greater bandwidth and possible miniaturization, and therefore they examined other waveguide types.

Ridge Waveguide offered a step in that direction, having one or more longitudinal internal ridges that serve primarily to increase transmission bandwidth by lowering the cut-off frequency.

Coaxial Line was very suitable, since it possessed a dominant mode with zero cut-off frequency, providing two important characteristics: very wide bandwidth, and the capability of miniaturization. The lack of a longitudinal component of field, made it more difficult to create components using it, although various novel suggestions were put forth. In addition, those components would be expensive to fabricate.

In an attempt to overcome these fabrication difficulties, the center conductor of the coaxial line was flattened into a strip and the outer conductor was changed into a rectangular box, and then fitted with connectors for use with regular coaxial line.
At about the same time, **Robert M. Barrett** when working for the **Air Force Cambridge Research Centre** in 1950s took a much bolder step. He removed the side walls altogether, and extended the top and bottom walls sideways. The result was called strip transmission line, or Stripline.

Like coaxial cable, Stripline it is non-dispersive, and has no cut-off frequency. Different methods were used to support the centre strip, but in all cases the region Between the two outer plates was filled with only one single medium, either dielectric material or air. A modification that emerged almost in the same time involved removing the top plate leaving only the strip and the bottom plate with a dielectric layer between them to support the strip. That structure was named **Microstrip**.
The first Microstrip developments were done shortly after the appearance of Barrett's Article, in 1952 by **D.D. Grieg** and **H.F. Engelmann** from the Federal Telecommunications Laboratories of ITT, presented as a competing printed circuit line. Because of the symmetry unbalance in Microstrip, all discontinuity elements possess some resistive content and therefore make the line to radiate to some extent.
At that time, regarding this radiation issue, additional remark was attempted to undermine the value of Microstrip line as the basis for microwave components.
So, the Microstrip line was compared to an antenna, and it was not until about 15 years
Later, when the Microstrip Patch Antenna was proposed, which was based on precisely the same concept.

1.2 Planar Transmission Lines

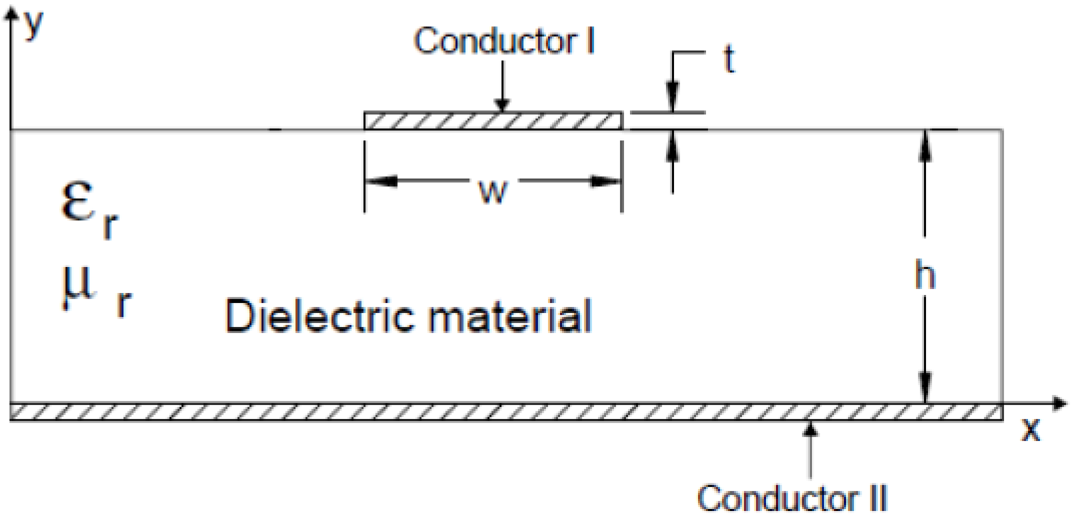
One of the most commonly used transmission lines are the planar types which can be constructed precisely using low-cost printed circuit board materials and processes. A number of these open, multi conductor transmission lines comprise a solid dielectric substrate having one or two layers of metallization, with the signal and ground currents flowing on separate conductors.

1.3 Skin Depth of Planar Conductors

At high frequencies, the current flowing in a conductor tends to get confined near the outer surface of the conductor. The higher the frequency, the greater the tendency for this effect to occur. The skin depth of a conductor is defined as the distance in the conductor (along the direction of the normal to the surface) in which the current density drops to 37% of its value at the surface .The skin depth of perfect inductor (with *Conductivity* $\sigma = \infty$) is zero. The conductivity of normal metals (which are used in conductors) is high, although finite, so the skin depth is therefore very small at microwave frequencies. The frequency where the skin effect just starts to limit the effective cross sectional area of the conductor (equal to half the thickness of the trace) is called the crossover frequency. Skin depth is inversely proportional to the square root of the frequency. Skin depth does not depend on the shape of the conductor. Skin depth is a distance measured in from the surface of the conductor toward the centre of the conductor. If skin depth is deeper than the centre of the conductor, the current is not limited by the skin effect and the current is flowing uniformly throughout the entire cross sectional area of the conductor. Therefore, a thicker conductor is limited by the skin effect at a lower frequency than is a thinner conductor. The skin effect, by changing the effective cross sectional area of a conductor, causes the effective resistance of the conductor to change with frequency. The skin effect is one of the two primary causes of losses in lossy planar transmission lines.

1.4 Microstrip Design

The Microstrip line it has become the best known and most widely used planar transmission line for RF and Microwave circuits. This popularity and widespread use are due to its planar nature, ease of fabrication using various processes, easy integration with solid-state devices, good heat sinking, and good mechanical support. In simple terms, Microstrip is the printed circuit version of a wire over a ground plane, and thus it tends to radiate as the spacing between the ground plane and the strip increases. A substrate thickness of a few percent of a wavelength (or less) minimizes radiation without forcing the strip width to be too narrow.



Figure(1):Microstrip structure

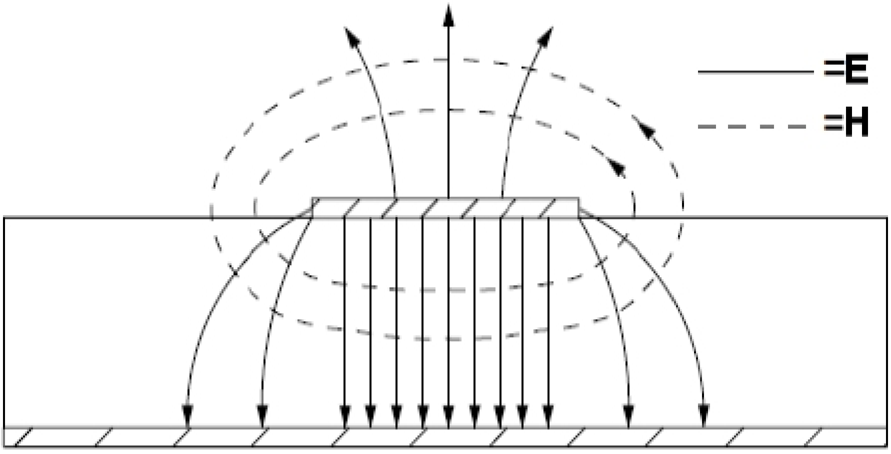
Microstrip causes its dominant mode to be hybrid (Quasi-TEM) not TEM, with the result that the phase velocity, characteristic impedance, and field variation in the guide cross section all become mildly frequency dependent. The Microstrip line is dispersive. With increasing frequency, the effective dielectric constant gradually climbs towards that of the substrate, so that the phase velocity gradually decreases. This is true even with a non-dispersive substrate material (the substrate dielectric constant will usually fall with increasing frequency).

1.5 Effective Dielectric Constant

In Microstrip development a new concept of **Effective Dielectric Constant εeff** was introduced, which takes into account that most of the electric fields are constrained within the substrate, but a fraction of the total energy exists within the air above the board. The Effective Dielectric Constant **εeff** varies with the free-space wavelength λ0.The dispersion becomes more pronounced with the decreasing ratio of strip width to substrate thickness, *W*/*h*. Dispersion is less pronounced as the strip width becomes relatively wider, and the Microstrip line physically starts to approach an ideal parallel-plate capacitor. In this case we get: **εr ~ εeff**. The Effective Dielectric Constant **εeff** is expected to be greater than the dielectric constant of air (*ε* = 1) and less than that of the dielectric substrate.

$$\varepsilon_{eff} = \frac{\varepsilon + 1}{2} + \frac{\varepsilon - 1}{2}\frac{1}{\sqrt{1 + 12h/W}}$$

In this expression shielding is assumed to be far enough from the Microstrip line. *Electric E* and *Magnetic H* field lines for fundamental Quasi-TEM in Microstrip Effective Dielectric **εeff** can be obtained by static capacitance measurements. If the static capacitance per unit length is *C* with partial dielectric filing, and *Co* with dielectric removed, we get εeff = C/Co.



Figure(2): **Electric E** and **Magnetic H** field lines for fundamental Quasi-TEM in Microstrip

Guided Wavelength in Microstrips is given by **λ0 / √ εeff** where λ0 is the wavelength in free space. Microstrip hot conductor is equipotential (every point in it is at the same potential).

1.6 Characteristic Impedance

A simple but accurate equation for Microstrip **characteristic Impedance** is:

$$Z_0 = \frac{60}{\sqrt{\varepsilon}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right) (\Omega) \qquad \text{for } \frac{W}{h} \leq 1$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon}\left[\frac{W}{h} + 1.393 + 0.667 \ln\left(\frac{W}{h} + 1.444\right)\right]} (\Omega) \qquad \text{for } \frac{W}{h} \geq 1$$

The characteristic impedance of the Microstrip line changes slightly with frequency (even with a non-dispersive substrate material).The characteristic impedance of non-TEM modes is not uniquely defined, and depending on the precise definition used, the impedance of Microstrip either rises, falls, or falls then rises with increasing frequency. Microstrip frequency limitation is given mainly by the lowest order transverse Resonance, which occurs when width of the line (plus fringing field component) approaches a half-wavelength in the dielectric. Have to avoid using wide lines. For very wide lines, the fields are almost all in the substrate, while narrower lines will have proportionally more field energy in air.

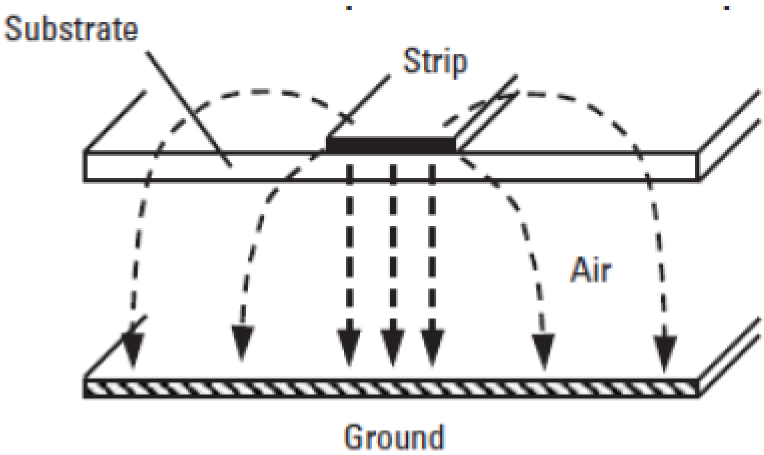
1.7 Attenuation and Radiation losses

Any practical Microstrip line has following **Sources of Attenuation**, due to:

- Finite conductibility of the line conductors.
- Finite resistivity of the substrate and its dumping phenomena.
- Radiation effects.
- Magnetic loss plays a role only for magnetic substrates, such as ferrites.

In Microstrip case (since the Microstrip is an open transmission line) radiation effects are present at any discontinuity section. For Microstrip using high dielectric materials ***εr*** and accurate conductor shape and matching, conductor and dielectric losses are predominant in relation to the radiation losses.

Radiation Losses depend on the dielectric constant, substrate thickness, and the circuit geometry. The lower the dielectric constant, the less the concentration of energy in the substrate region, and, hence, the greater the radiation losses. The real benefit in having a higher dielectric constant is not only reducing radiation losses but also that the package size decreases by approximately the square root of the dielectric constant.



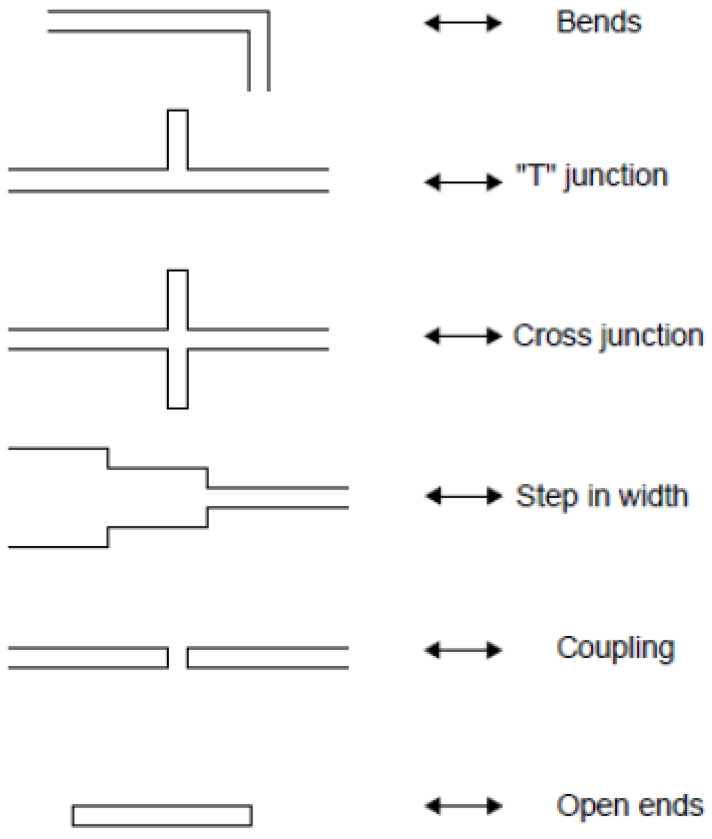
Figure(3): separation of ground plane with substrate to minimise loss

One way to lower the loss of Microstrip line is to suspend the substrate over the air: The air between the bottom of the substrate and the ground plane contains the bulk of the electromagnetic field. The insertion loss of the Microstrip is reduced because, air essentially has no dielectric loss compared to standard circuit board substrates, and in addition, the width of the Microstrip line increases because of the lower effective dielectric constant. Wider lines have lower current density, and thus, lower ohmic loss. Suspending Microstrip means that the separation between the signal and ground paths increases, and so does the Microstrip's tendency to radiate, particularly at discontinuities such as corners. From this reason, suspended Microstrip mostly is used only up to a few GHz.

In a Microstrip line, conductor losses increase with increasing characteristic impedance due to the greater resistance of narrow strips. Conductor losses follow a trend that is opposite to radiation loss with respect to *W*/*h*. Important to remember, a smaller strip width leads to higher losses.

1.8 Microstrip Discontinuities

Surface waves are electromagnetic waves that propagate on the dielectric interface layer of the Microstrip. The propagation modes of surface waves are practically TE and TM. Due to the practical homogeneity of the Stripline dielectric, this phenomenon can be neglected in Stripline devices and so, this section is pertinent to Microstrip lines only. Surface waves are generated at any discontinuity of the Microstrip. Once generated, they travel and radiate, coupling with other Microstrip of the circuit, decreasing isolation between different networks and signal attenuation. Surface waves are a cause of crosstalk, coupling, and attenuation in a multi microstrip circuit. For these reasons the surface waves are always an undesired phenomenon.



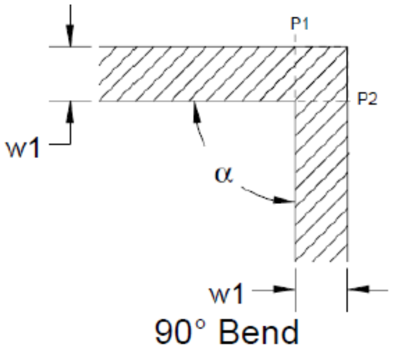
Figure(4):Typical Microstrip Discontinuties

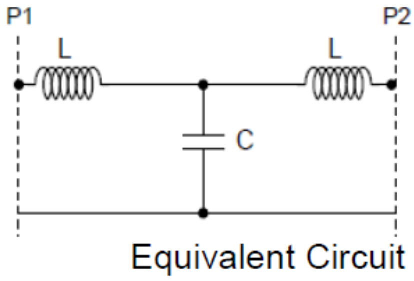
A discontinuity in a Microstrip is caused by an abrupt change in geometry of the strip conductor, and electric and magnetic field distributions are modified near the discontinuity. The altered electric field distribution gives rise to a change in capacitance, and the changed magnetic field distribution to a change in inductance.

Discontinuities commonly encountered in the layout of practical Microstrip circuits are Steps, Open-Ends, Bends, Gaps, and Junctions.
It is possible to reduce the parasitic effects associated with Open-Ends, Steps, Bends, and Junctions by using constant impedance tapers.

1.8.1 Bends

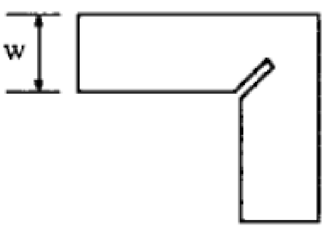
Bends are the most frequently encountered discontinuities.
The simplest bend is the 90° bend. This bend does not work well above few GHz, due to a high VSWR. The same holds true for bends with angles α greater than 90°.
90° Bend Equivalent Circuit. A T-network is the equivalent circuit for a short line length. However, because of the excess capacitance at a square corner the characteristic impedance value will be lower than that of the uniform connecting lines.



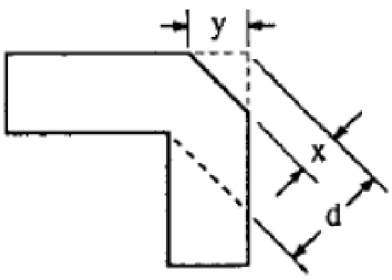


Figure(5):Bend figure(6): equivalent circuit

The **Bend Discontinuity Effect** it will increase with frequency, with the number of bends used in cascade, and with the line width. Compensation for Microstrip corner bend can use either, increased inductance or decrease capacitance techniques. For both, the curved and mitered bends, the electrical length is somewhat shorter than the physical path-length of the Microstrip line.



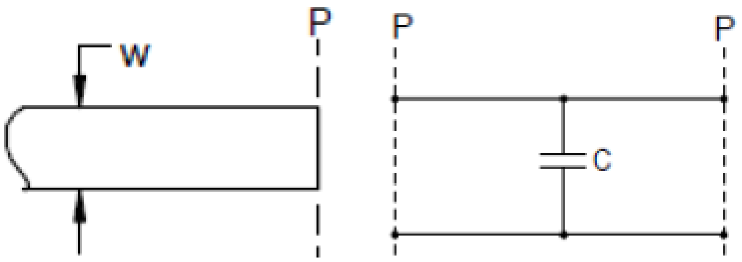
Figure(7):increasing inductance in bends



Figure(8):decreasing capacitance in bends

1.8.2 Open-Ends

Open-Ends are encountered any time a Microstrip is open terminated. Typical devices where open ends are encountered are **Microstrip Filters** and **Matching Stubs**. At the **Open-End** of a Microstrip line with a width of *w*, the fields do not stop abruptly, but extend slightly further because of the effect of fringing field. This effect can be modelled either with an equivalent shunt capacitance *C*, or with an equivalent length of transmission line Δl.

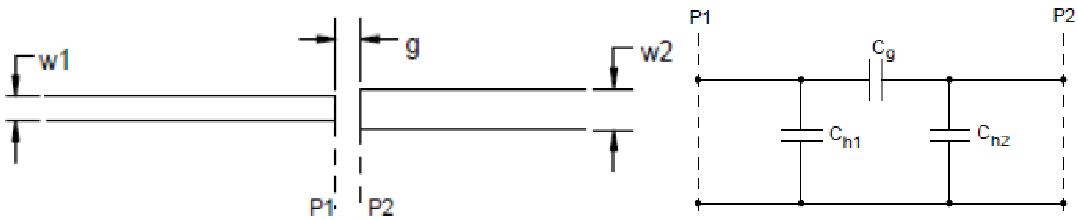


Figure(9):Open end microstrip and its equivalent circuit

The simplest way to compensate for the increase in line length is to reduce the length of the designed line by the correct amount. A distance of at least the equivalent line length should be allowed between the end of an open-ended stub and the substrate edge. For thicker substrates and for wider Microstrip lines, radiation from an **Open-End** discontinuity becomes significant.

1.8.3 Gap Coupling

Gap Coupling is a type of discontinuity is can be found in **Microstrip Filters** and in **DC blocks**. A *Gap* in a Microstrip line can be equivalently represented as a π capacitor circuit. This circuit between the two reference planes P1 and P2 at each end of the gap consists of a series coupling capacitance Cg, and two parallel fringing capacitances Ch1 and Ch2 between the conductor open ends and the ground. For narrow gaps, Ch1 and Ch2 approaches zero and Cg increases.



Figure(10):Gap in microstrip line and its equivalent circuit

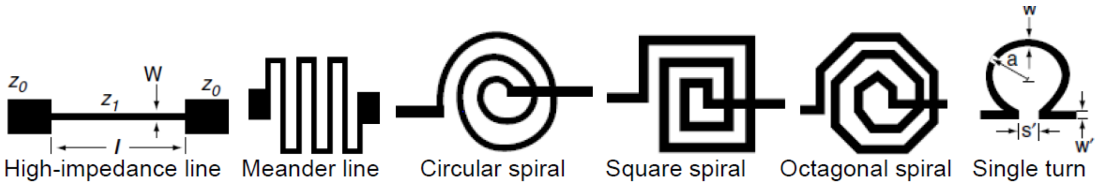
Practical series capacitance values are approximately 0.01pF to 0.5pF.For a very large gap, the capacitance values Cg approach zero and this discontinuity becomes equivalent to an open-end circuit.

1.9 Lumped Microstrip Components

Lumped components have the advantage of small size, low cost, and wide-band characteristics, but have lower *Q* factor. To function well as a lumped element at microwave frequencies, the length of the equivalent inductor and capacitor elements should not be longer than 12% (30°) of a wavelength λ, or they will begin to lose their lumped equivalency effect. Lumped inductors and capacitors circuits will only function for that particular dielectric constant, board thickness, and frequency used in the original equivalency calculations. Due to Microstrip's electromagnetic field leakage, when shielding Microstrip lumped equivalent capacitors and inductors (as well any Microstrip's transmission lines), the RF shield should be kept at least five substrate thicknesses above the copper, or a disruption within the field, with resulting impedance variations, can occur.

1.9.1 Microstrip Inductors

The inductance value of a Microstrip inductor is determined from the total length, the number of turns, spacing, and line width. Narrow tracks are more inductive but carry less current, so there is a trade-off between them. Spiral track inductors have more inductance because the magnetic fields from each turn of the spiral add up, creating a larger field through the middle of the spiral and mutual inductance between all the turns.



Figure(11):Types of Microstrip Inductor

1.9.2 Microstrip Capacitors

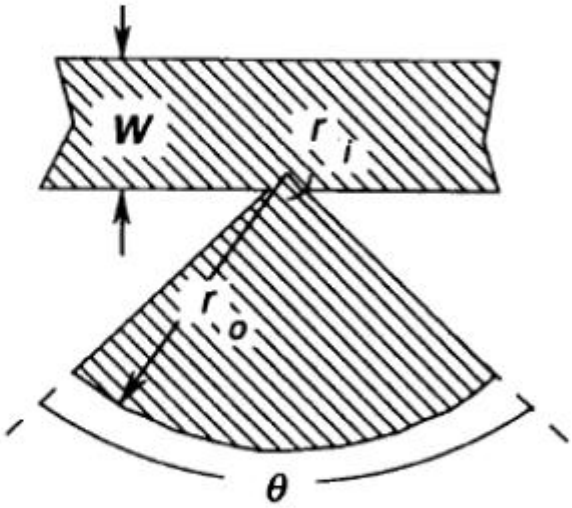
Capacitors are lumped circuit elements that store energy by virtue of electric fields. The ***Gap Capacitor*** can be described as two coupled open-ended Microstrip lines. The capacitance *C* refers to the open-end capacitance and the series gap capacitance *Cg* describes the electrical coupling. Up to approximately 20 GHz, the frequency dependence of the equivalent capacitances is negligible.
The series gap interrupts the conductive strip of the Microstrip line, and the DC power cannot be transmitted. RF power transfer is accomplished by electrical field coupling. A Gap Capacitor can provide a series capacitance of 0.05pF to 0.5pF.

1.9.3 Quasi-Lumped Microstrip Elements

Microstrip line short sections and stubs, whose physical lengths are smaller than $\lambda g/4$ (quarter of guided wavelength) at which they operate, are the most common components for approximate microwave realization of lumped elements .
They may also be regarded as lumped elements if their dimensions are even Smaller , say smaller than $\lambda g/8$. A stub is a length of a straight transmission line that is short or open-circuited at one end and connected to the circuit at the opposite end.

1.10 Radial Stubs

Radial stub is an open-circuit stub realized in radial transmission line instead of straight transmission line. Radial stub it is a useful element, primarily for providing a clean (no spurious resonances) broadband short circuit, much broader than a simple open-circuit stub. It is special useful on bias lines at high-frequencies. Radial stubs are shorter than uniform stubs, they cannot be folded or bent; therefore they take up a lot of substrate area. There is no simple equation to describe the radial stub adequately, and practical experiments work better than any formula.



Figure(12):Radial Stub element

Chapter 2 Microstrip Resonators and Oscillator

2.1 Microstrip Resonators

A **Microstrip Resonator** is any structure that is able to contain at least one oscillating electromagnetic field. Microstrip Resonators may be classified as lumped-element or quasi-lumped-element resonators, and distributed-line resonators or patch resonators.

Lumped-Element Resonators formed by the lumped or quasi-lumped inductors and capacitors will resonate at $\omega 0 = 1/\sqrt{LC}$. They may resonate at some higher frequencies, at which their sizes are no longer much smaller than a wavelength, and by definition, are no longer lumped or quasi lumped elements.

The **Distributed-Line Resonators** may be termed as the quarter-wavelength Resonators, since they are $\lambda g0 / 4$ long, where $\lambda g0$ is the guided wavelength at the fundamental resonant frequency $f0$. A $\lambda g0/4$ short-circuited stub operates as a parallel LC, and the open-circuit stub as a series LC resonator. The main difficulty with the use of Distributed-Line resonator is caused by the end effects.

The **Ring Resonator** is another type of Distributed-Line resonator, where r is the median radius of the ring. The ring will resonate at its fundamental frequency $f0$ when its median circumference is: $\mathbf{2\pi r \approx \lambda g0}$. The higher resonant modes occur at:
$\mathbf{f \approx nf0}$ **for** $\mathbf{n = 2, 3, \ldots}$

The coupling gap is an important part of the ring resonator. It is the separation of the feed lines from the ring that allows the structure to only support selective frequencies.

2.2 Oscillators

The circuits that are used to produce a periodic signal are called oscillator circuits. This circuit category has been on an exponentially increasing trend for circuit applications, especially in the microwave and digital world.

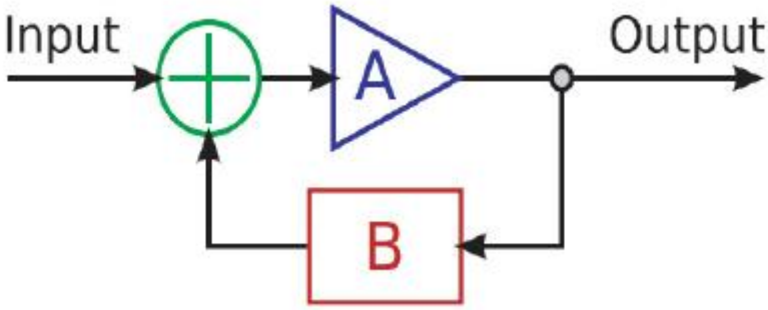


Figure (13): Closed Loop Gain Feedback Model

The basic function of the oscillator circuit is to convert a fragment of DC power into an output which is periodic in nature. Diodes and Transistors in combination can be used for Solid State oscillators. This can be combined with a passive circuit combination to produce steady sinusoidal state signals. Hence it can be concluded that it does not necessarily need a periodic signal as input. An efficiently designed oscillator can sustain the oscillations for a longer period of time.

2.2.1 Introduction to Oscillator

For an efficient oscillator design, it is required to have a nonlinear active device. Furthermore, it also needs to have a negative resistance so that it can produce RF power. Various types of diode such as Tunnel, IMPATT and GUNN are the best examples of two terminal negative resistance devices. Transistors such as BJT and FET are the best examples of three terminal negative resistance devices.

When the voltage and current are out of phase by 180 degrees, it leads to negative resistance and is related to power generation. Negative resistance is a very important concept for an oscillator. It is an indication that when there is an increase of voltage across a particular resistance, it will lead to a decrease in current. And this is true the other way around.

The oscillator relies heavily on the concept of power generation. Three terminal devices are used to design a two port oscillator. Two port devices are operated in an unstable region in contrast to an amplifier circuit. Amplifiers require microwave signal as an input, whereas an oscillator does not require such signal to operate.

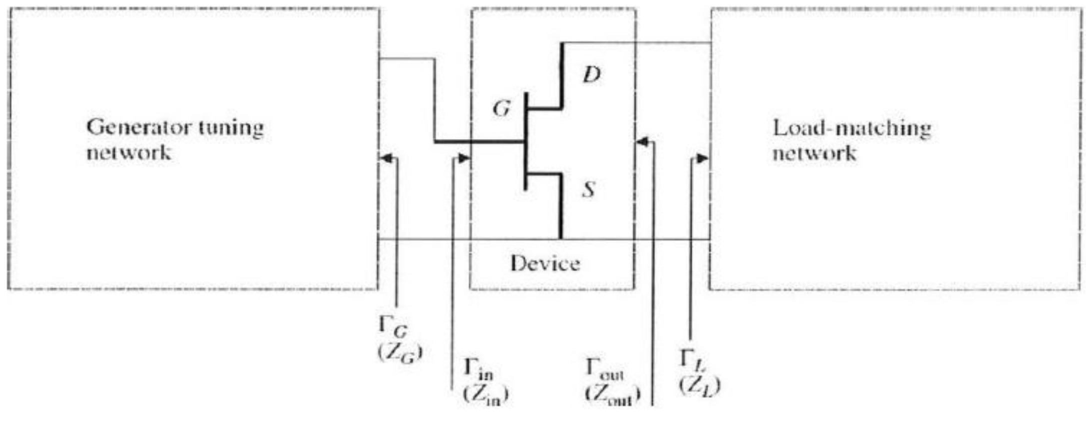


Figure (14): Basic Oscillator block diagram

The block diagram of an oscillator based on the RF circuit is as shown in Figure 1.2. In this diagram, we have a common source based FET and this orientation can be shown in any other possible way. The S-parameter will be in correspondence with that orientation. To obtain oscillations, the working of the circuit needs to fulfil these conditions:
Condition # 1 $\Gamma_{IN}.\ \Gamma_G = 1$
Condition # 2 $\Gamma_{OUT}.\ \Gamma_L = 1$
At the oscillating frequency, these above-mentioned conditions imply that the passive terminations for Z_G and Z_L need to be considered in addition. This will help to obtain the resonance of the active devices at input and output ports.

2.2.2 Two Port Negative Resistance Oscillator

Most modern oscillator topologies utilize a two port active device (typically some form of transistor) as the gain producing element. This is primarily because transistors tend to be more cost effective, reliable, low noise and lead to more miniaturized oscillators. Gunn and Impatt diodes were used as one port active devices in the 1960's and only required the application of a DC bias to produce a negative resistance. However, using these devices limited the design of the oscillator to only the design of the output matching circuit. In addition, oscillators utilizing these diodes may have problems in locking to spurious frequencies and require adequate heat sinking.
To design a proper two port oscillator, conditions need to be satisfied which allow both ports of the device to be unstable after oscillation has stabilized.

2.3 Fundamental Parameters for a Microwave Design

2.3.1 Scattering Parameters

Scattering parameters or S-parameters can be defined to be a set of complex numbers. This clarifies the understanding of how the electrical waves travel with radio frequency in the background. S-parameter shows the characteristics of an RF system .

It is important to describe the working of a two-port network. It is a basic concept in the analysis and simulation of RF circuits. It enables the illustration of networks with the help of a single device. The circuit analysis of the physical structure of any circuit is significantly broken down for simplification since the properties of the individual components are taken out of the equation effectively .
The set of S-parameters can be used to show the characteristics of the two port. This can be shown by :
S11 which corresponds to Input Reflection Coefficient
S12 which corresponds to Reverse Gain Coefficient
S21 which corresponds to Forward Gain Coefficient

S22 which corresponds to Output Reflection Coefficient

Alternatively, there is also descriptive parameters for two port networks. For example, chain, impedance, hybrid and admittance parameters. All of the above parameters can be calculated at higher frequencies by either short or open circuit which is not that simple to carry out precisely. On the other hand, the S-parameters are measured under the conditions of matching and mismatching. This is the reason why S-parameters are used widely in the applications of the microwave .

2.4 Active (Non-linear) Device Determination

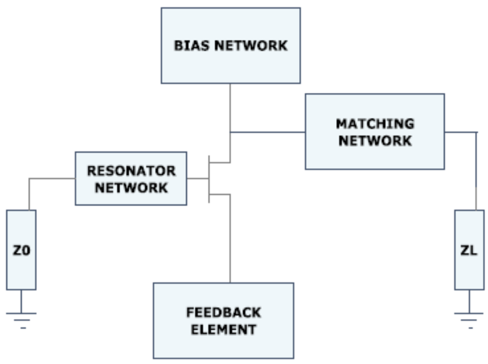
The determination of the active device is an extremely critical aspect of the oscillator design. In most oscillator topologies, the amount of the power, noise, efficiency, and stabilization is dictated by the active transistor device.

In the past, bipolar junction transistors (BJT) were the ideal type of active device to be used in oscillator designs because of the very low noise figure typically associated with them. However, limitations in higher operating frequencies led to the use of field effect transistors. The disadvantage with FET type oscillators was the need for negative voltage DC biasing and increased associated noise figure. Hybrid or hetero-junction type FET's have become more popular in recent years due to the improvement of this noise figure and ability to work at a very wide range of frequencies. A lower noise figure leads to a lower oscillator phase noise.

When trying to determine how much power a given oscillator is capable of producing, certain characteristics of the transistor (with or without feedback) needs to be known.

2.5 Oscillator Design

Microstrip resonator oscillator consists of active device, a resonator at operating frequency, RF choke network, DC bias circuit and output matching network. The microstrip resonator oscillator is designed to make the resistance generated by the feedback element negative enough to compensate the loss generated by the resonator. By rule of thumb, in a series circuit at least 1.2 times of the load resistance is required by the negative resistance to satisfy the start-up condition for the oscillator.At the speed of light and operating frequency of 10 GHz with the dielectric constant of substrate is 3.38, the calculated wavelength is 16.32 mm which will give the quarter wavelength value of 4.08 mm.



Figure(15):Basic oscillator model

2.5.1 DC Bias Circuit

The oscillator design as stated in Fig.31 indicates that the oscillator is biased by power supply to the active device in order to operate. However, this design only requires one power supply, *VDD*. We are providing VDD is 3V, *ID* is 10 mA, *VDS* is 1.5 V. Since oscillation of GaAs FET (HEMT) can be operated when we have negative ***Vgs*** voltage .hence we have applied -0.4 V at *Vgs.* To avoid DC supply from providing admittance to the radio frequency, a DC blocking network is placed in series before output terminal.

2.5.2 RF Frequency Choke Network

An oscillator consists of Radio Frequency choke or RF choke, which can be defined as a low pass filter since it is able to block a high frequency. The RF choke blocks AC signals specifically within a certain frequency band from propagating on DC signal paths. In other word, the DC voltage is supplied to the active device, at the same time it blocks the RF signal generated by an active device from going to the power supply circuit. If the RF leaks to the power supply circuit, it will reduce the gain and produce instability of the output frequency.

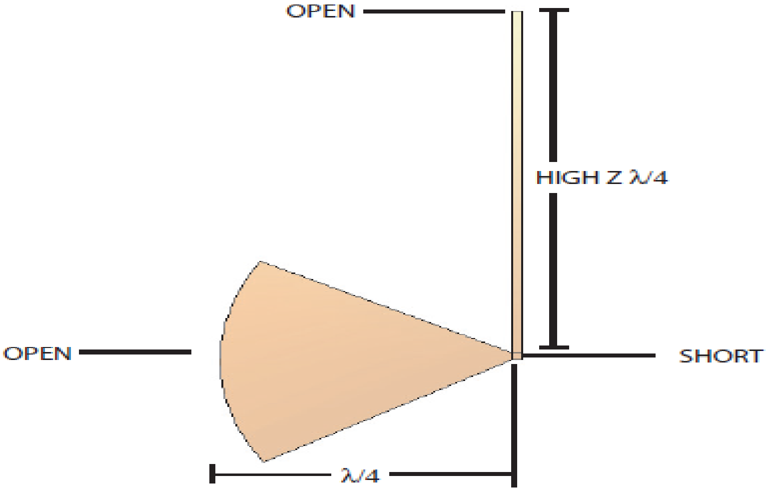


Figure (16):RF choke coil model

2.5.3 Output Matching Network

Output matching for this work is included to stabilize the circuit and provide an additional gain. The matching networks are tuned or optimized until the desired result is achieved. Such step will ensure maximum reflection at the load looking into the oscillator output circuit. It is crucial to ensure that 50 Ω lies in the unstable region by looking at the instability circle of the oscillator. As a result, a small negative resistance at the oscillator port will occur.

Chapter 3 Device Simulation, Measurement & Result

3.1 Basic introduction to designing process and software

The implementation of resonator using the microstrip line has attracted a lot of attention due to its simplicity. One of the applications is incorporating this resonator into an oscillator design. As it is well known, Q factor of the resonator determine the phase noise dominantly. Thus microstrip based resonators are incorporated with the microwave FET to generate oscillation. Designing a low phase noise oscillator is important because noise produced by an oscillator or other signal source may severely degrade the performance of the system. Therefore, a huge amount of effort has been invested to reduce the phase noise.

Microstrip-based resonator has been known for its limitation for reducing the phase noise because of the low Q-factor. However, resonators designed have the ability to provide higher Q-factor . In addition, micro strip resonators also provide easy fabrication, low radiation loss, high frequency stability and sharp selectivity in desired resonant frequency . microstrip resonators are a cost effective solution for achieving a highly stable and low phase noise in the RF oscillator. Therefore, in this paper a 10 GHz resonator oscillator incorporating different designs will be designed, compared and analyzed using three simulation tools, i.e. CST Microwave Studio , Anys Electronics Desktop HFSS and Agilent ADS.

3.2 Resonator Modelling:

The inductance is represented by the area of resonator patch while capacitance is represented by coupling gap . In addition, the gaps with the total length of SRR also control the resonance frequency. The figure given below shows the schematic diagram of a single split-ring resonator ,hairpin resonator, hairpin shape resonator,single spiral resonator,double spiral resonator,qudral spiral resonator with its parameters.

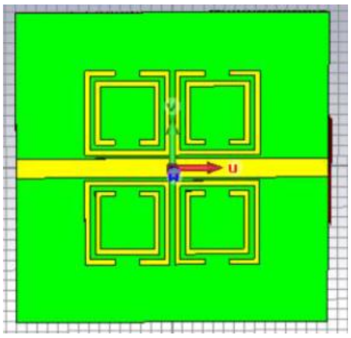


Figure (17): Split ring resonator

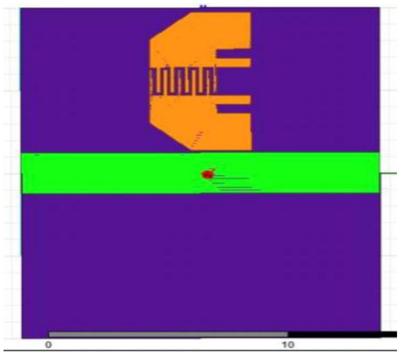


Figure (18): Hairpin shape resonator

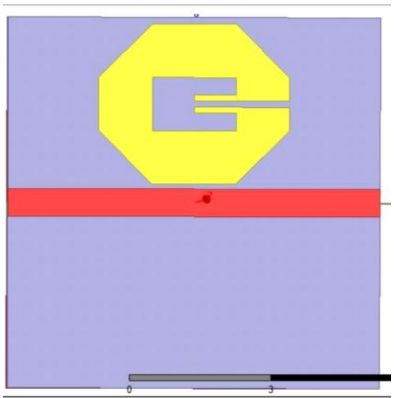


Figure (19): Hairpin shape Resonator

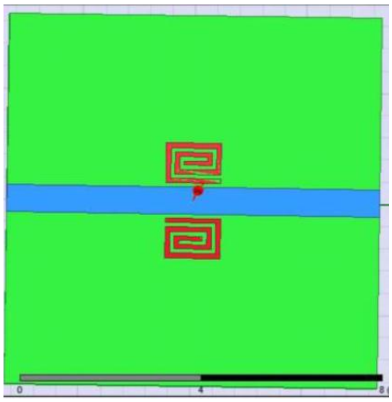


Figure (20): Double Spiral Resonator

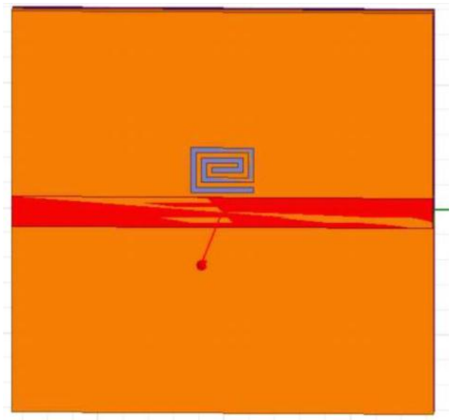


Figure (21): Double Spiral Resonator

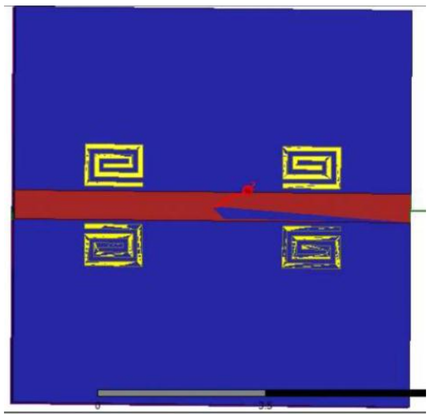


Figure (22): Double Spiral Resonator

For this work, the SRR design is implemented in 3D software called CST Microwave Studio (MWS) and Ansys electronics Desktop HFSS in which the coupling gap between the microstrip line and the resonators is analysed and optimized to meet the resonator requirement.
Since only passive device can be implemented in CST MWS,HFSS another tool called ADS from Agilent is used for oscillator design.

The resonators array is modelled together with the RO4003C substrate and a 50 Ω microstrip line. The substrate has a thickness of 0.813 mm and a dielectric constant of 3.38. The dimension of a 50Ω transmission line with a width of 1.8653 mm and length of 30 mm. The model design structures split ring resonators with one microstrip line with width and length calculated using LineCalc of ADS. For substrate in this design, it has been laminated with copper layer at both sides. The copper layer has an electrical conductivity of 5.9E+007 S/M and a height of 0.035 mm. The coupling gap between the microstrip and resonator is 0.1mm. There are six designs of resonator that produce the best results. Their response and parameters are slightly different from each they are measured in mm. It can be seen from the results in that the resonant frequency for the resonator model occurs at approximately 10 GHz except double spiral resonator and quadrat spiral resonators. The coupling between the microstrip transmission line and the resonator structure is generated by orienting the magnetic momentum of the resonator. From the S-parameter results in Fig. 4, the resonant frequency is acquired by looking at the frequency point where the port 2 insertion loss, S (2, 1) dips down the most. It is adequate to just consider S (2, 1) the insertion loss at port 2 for the model because it is reciprocal to S (1, 2) the insertion loss of port 1.

Hence from the S11 and S21 parameter graphs of all six resonators shown below and the resonator frequency of all the six resonators are given in Table I.

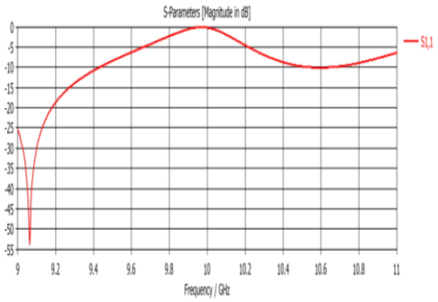


Figure (23): S11 parameter of Split ring resonator

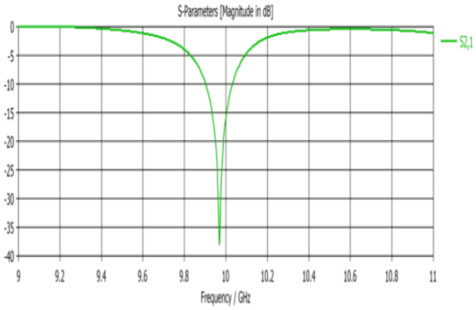


Figure (24): S21 parameter of Split ring resonator

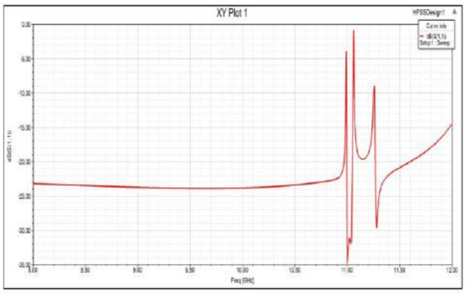


Figure (25): S11 parameter of Hairpin Shaped resonator

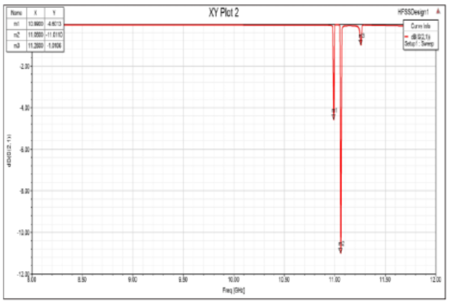


Figure (26): S21 parameter of Hairpin Shaped resonator

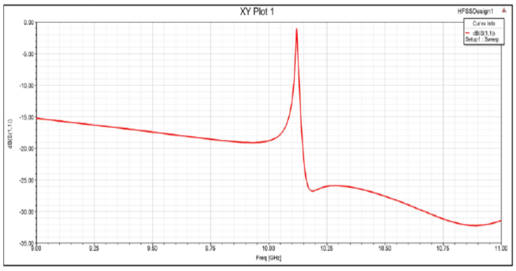


Figure (27): S11 parameter of Hairpin Shaped Resonator

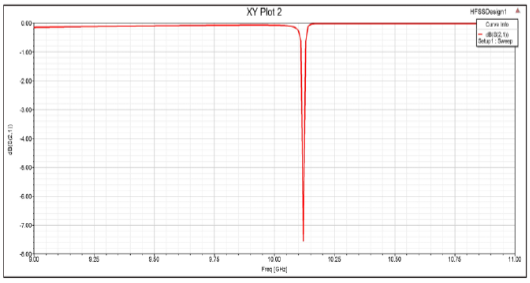


Figure (28): S21 parameter of Hairpin Shaped Resonator

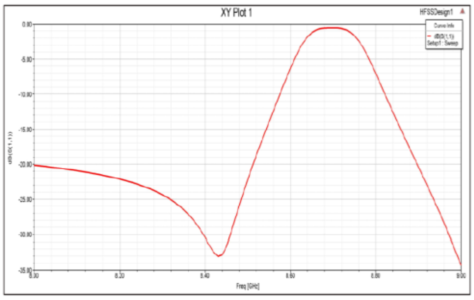


Figure (29): S11 parameter of Double Spiral Resonator

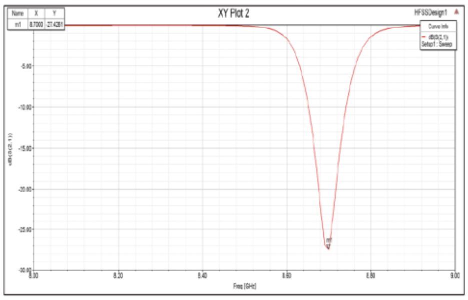


Figure (30): S21 parameter of Double Spiral Resonator

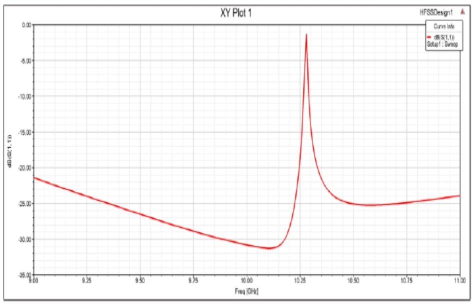


Figure (31): S11 parameter of Single Spiral Resonator

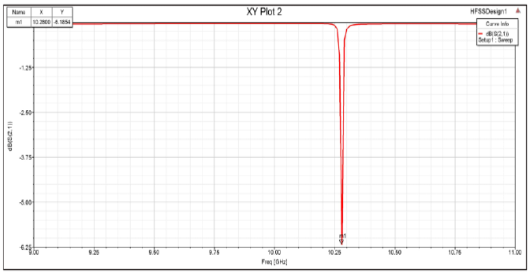


Figure (32): S21 parameter of Single Spiral Resonator

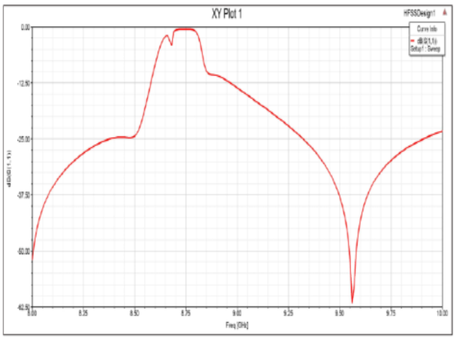


Figure (33): S11 parameter of Quadra Spiral Resonator

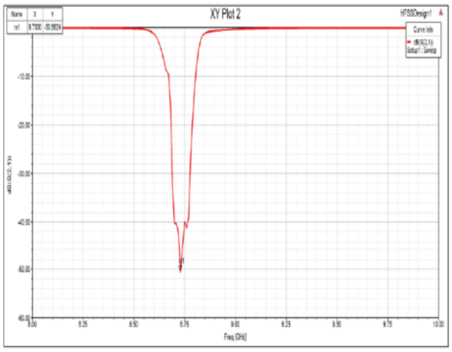


Figure (34): S21 parameter of Quadra Spiral Resonator

Table -1

S.No.	Name of the resonator	Resonant frequency
1	Split ring resonator	9.9677 GHz
2	Hairpin shaped resonator	10.99GHz,11.06GHz,11.26GHz
3	Hairpin shaped resonator1	10.12 GHz
4	single spiral resonator	10.28 GHz
5	double spiral resonator	8.7 Ghz
6	Quadral spiral resonator	8.75 GHz

From the above data and parameter, we can suggest that Hairpin Shaped Resonator (1) , single spiral Resonator and Split ring Resonator are best for resonating with 10 Ghz frequency and also have very high Quality factor .Hairpin Shaped Resonator has multiple resonating frequency and shows multiband property.

3.3 Oscillator Architecture

Initial designs of the three 10 GHz oscillator were attempted. The purpose of this design was to attain the maximum output power from the oscillator at 10GHz without considering the phase noise response.

A low noise FET transistor (biased at 3 V, 10 mA) was used as the active device. The load network was initially designed for maximum output power using, but then optimized using the large signal harmonic balance analysis tool in ADS to maximize the output power. The use of ADS microstrip models were employed by entering material parameters in the ADS MSTUB tool and using a variety of ADS microstrip types (opens, radial stubs, tapered lines, etc.) to design the circuit . No full wave simulation was conducted on this circuit.

The three oscillator design and the resulting simulated output power and the noise at offset frequency is show in the plot below:

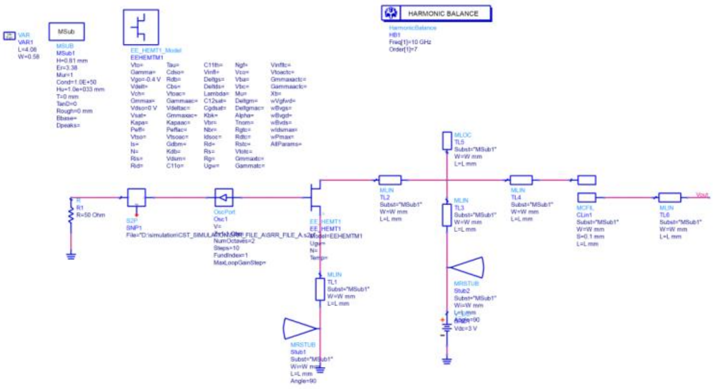
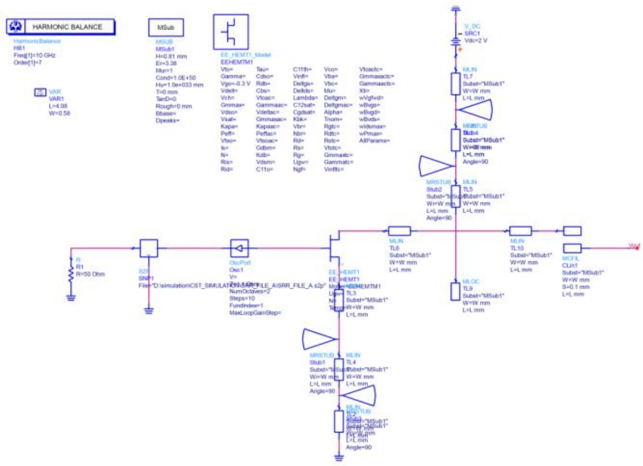


Figure (35):Oscillator design 1



Figure(34):Oscillator design 2

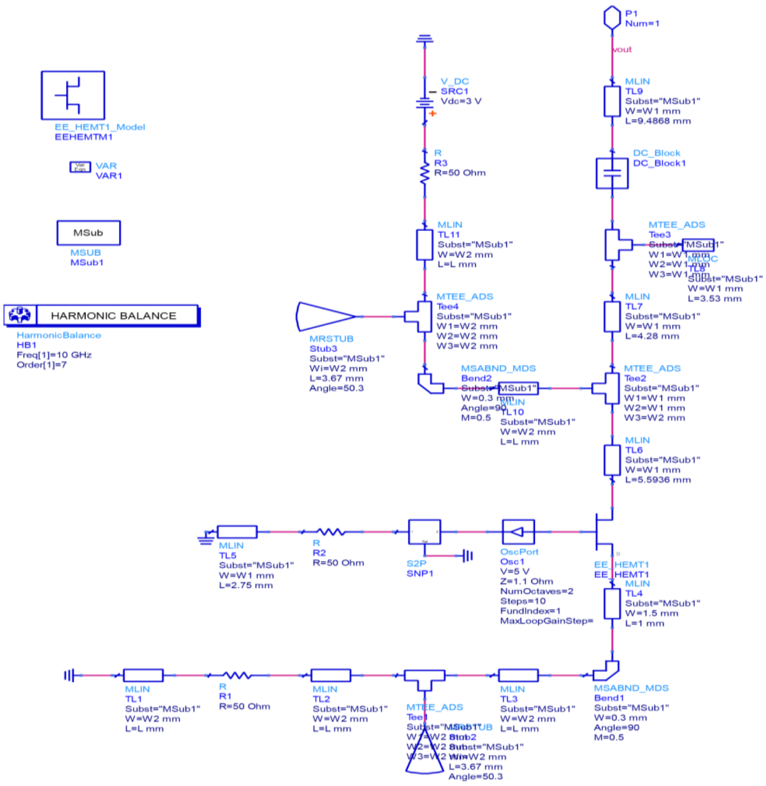
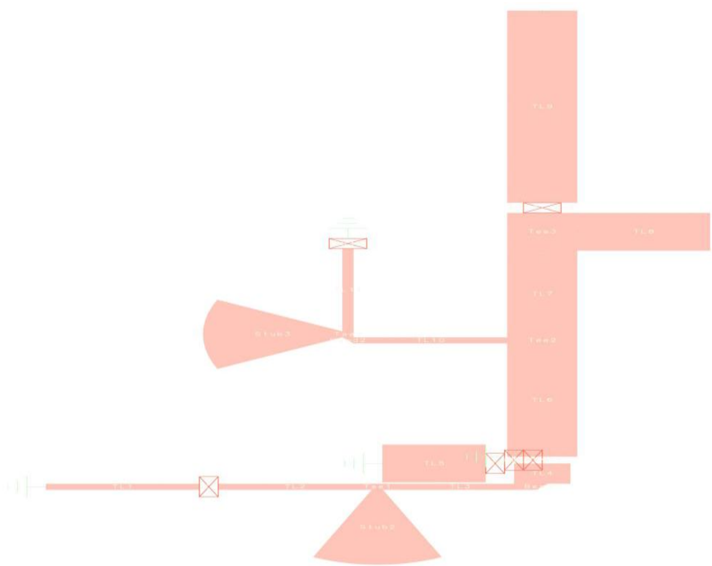


Figure (35): Oscillator design 3

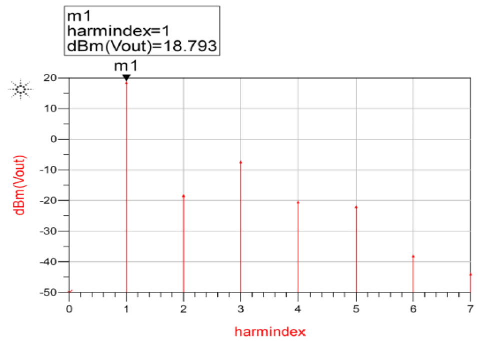


Figure(36):Layout of oscillator design 3

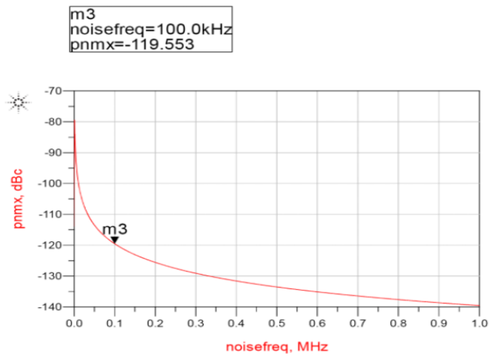
To feed the resonating frequency of the resonator to the oscillator. S parameter is the important factor and we know that active component like transistor cannot be implemented in the software like CST microwave Studio and Anys HFSS. All the above oscillator is designed in Keysight Advanced Design System.To operate these above design, we have to calculate the S parameter from these two software and export the sNp file (touchstone file) from these software. These file are browsed into the S2P tool present in the Advanced Designed System design. Hence Harmonic balance simulation is done with the design to get the output power and a noise.

3.4 Output voltage and phase noise measurement:

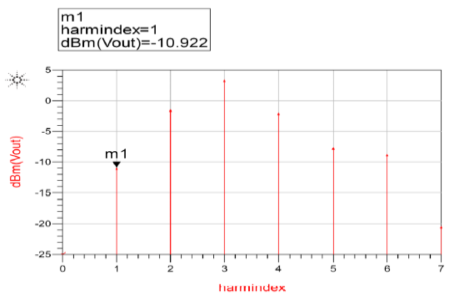
3.4.1 Plot of split ring resonator with different oscillator:



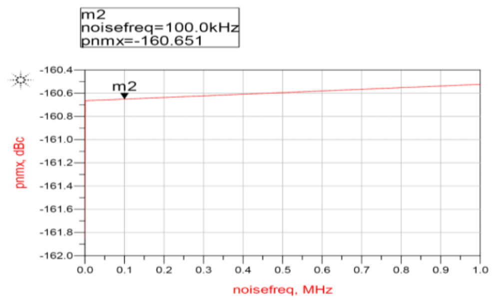
Figure(37): Vout (dBm) versus Harmonic Index Plot in Oscillator 1



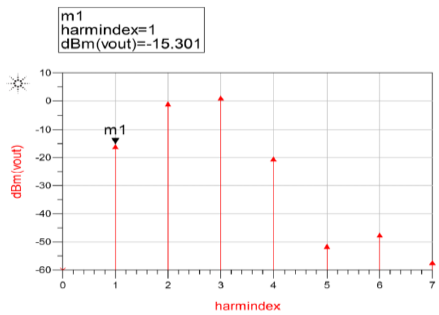
Figure(38): Phase noise at 100 KHz offset frequency in Osc. 1



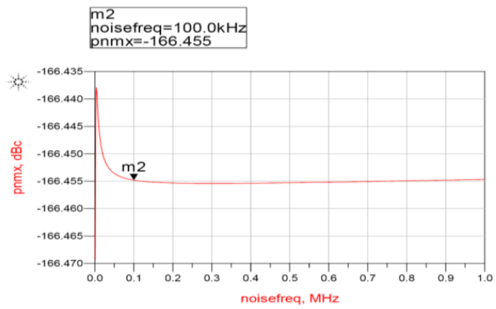
Figure(39): Vout (dBm) versus Harmonic Index Plot in Oscillator 2



Figure(40): Phase noise at 100 KHz offset frequency in Osc. 2



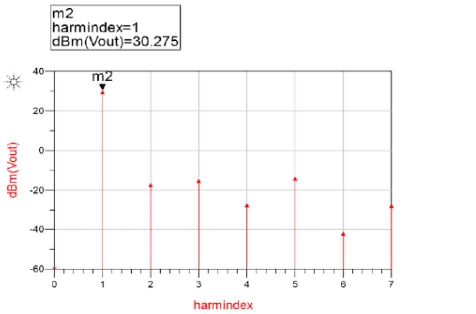
Figure(41): Vout (dBm) versus Harmonic Index Plot in Oscillator 3



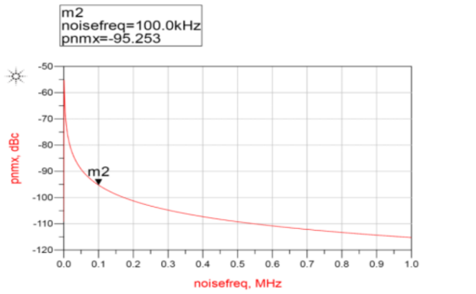
Figure(42): Phase noise at 100 KHz offset frequency in Osc. 3

3.4.2 Plot of Hairpin Shaped resonator with different oscillator:

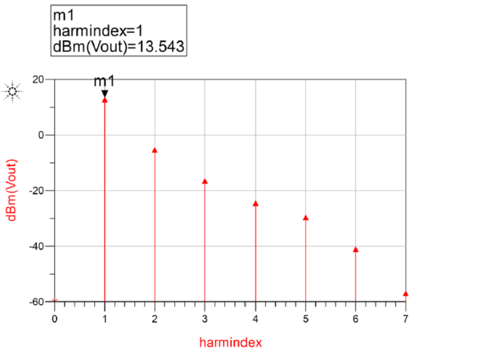
(Mono-band)



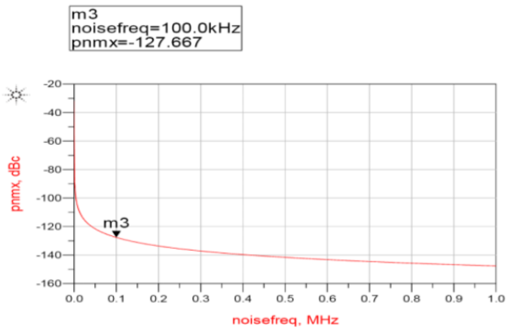
Figure(43): Vout (dBm) versus Harmonic Index Plot in Oscillator 1



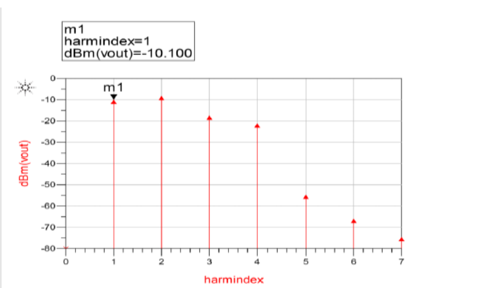
Figure(44): Phase noise at 100 KHz offset frequency in Osc. 1



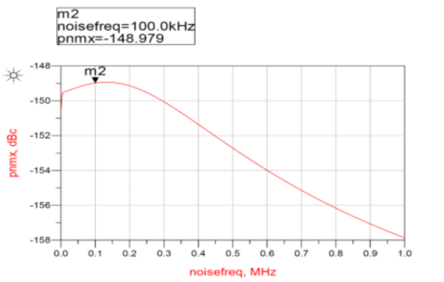
Figure(45): Vout (dBm) versus Harmonic Index Plot in Oscillator 2



Figure(46): Phase noise at 100 KHz offset frequency in Osc. 2



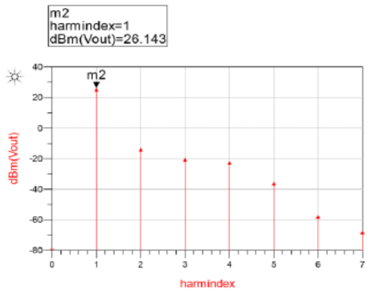
Figure(47): Vout (dBm) versus Harmonic Index Plot in Oscillator 3



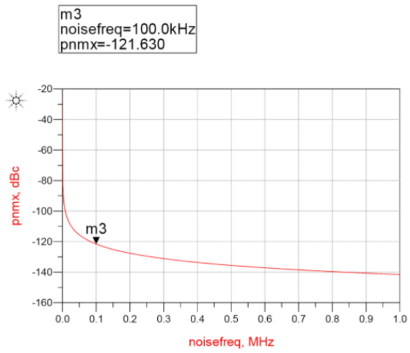
Figure(48): Phase noise at 100 KHz offset frequency in Osc. 3

3.4.3 Plot of Hairpin Shaped resonator with different oscillator:

(Multi-band)

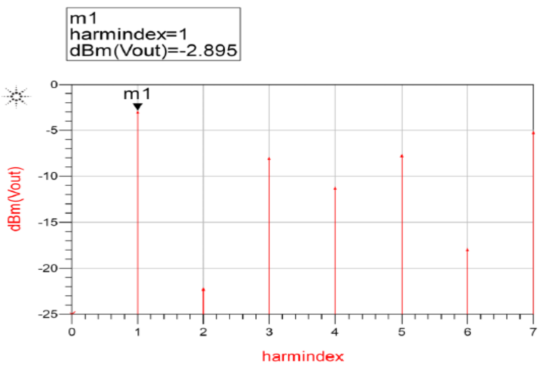


Figure(49): Vout (dBm) versus Harmonic Index Plot in Oscillator 3

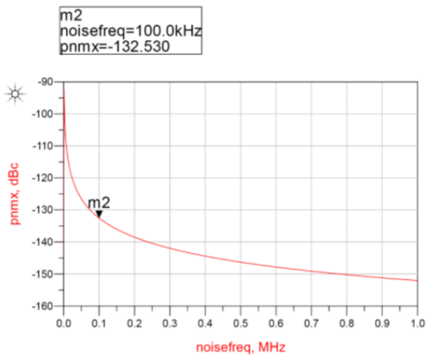


Figure(50): Phase noise at 100 KHz offset frequency in Osc. 3

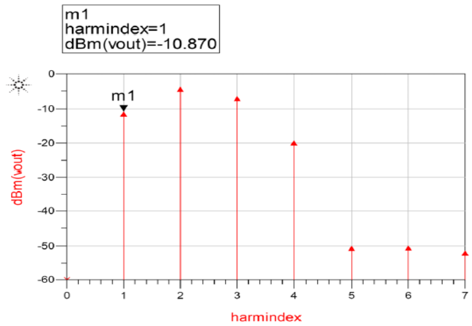
3.4.4 Plot of Double Spiral Resonator with different oscillator:



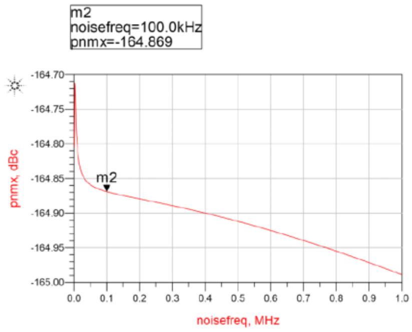
Figure(49): Vout (dBm) versus Harmonic Index Plot in Oscillator 2



Figure(50): Phase noise at 100 KHz offset frequency in Osc. 2

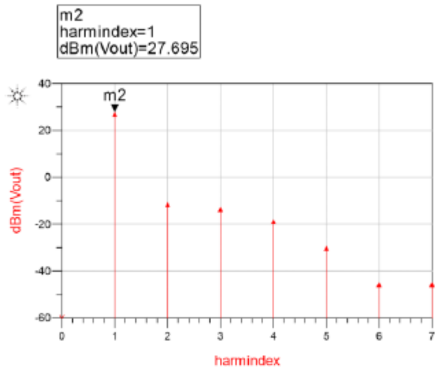


Figure(49): Vout (dBm) versus Harmonic Index Plot in Oscillator 3

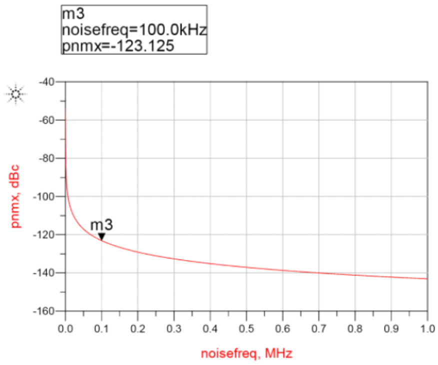


Figure(50): Phase noise at 100 KHz offset frequency in Osc. 3

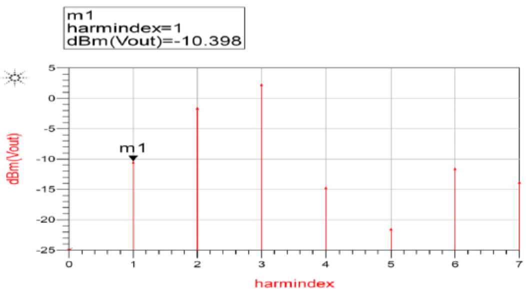
3.4.5 Plot of Single Spiral Resonator with different oscillator:



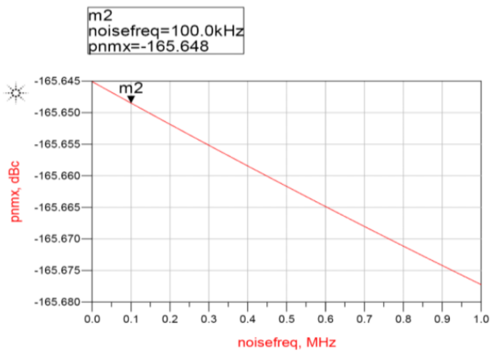
Figure(49): Vout (dBm) versus Harmonic Index Plot in Oscillator 1



Figure(50): Phase noise at 100 KHz offset frequency in Osc. 1



Figure(51): Vout (dBm) versus Harmonic Index Plot in Oscillator 2



Figure(52): Phase noise at 100 KHz offset frequency in Osc. 2

Conclusions:

Table-II

S.No	Name of the resonator	Resonating frequency	Vout(dBm)in Osc. 1	pnmx(dBc)inOsc.	Vout(dBm)in Osc. 2	pnmx(dBc)in osc	Vout(dBm)in Osc. 3	pnmx(dBc)in osc.
1	Split ring resonator	9.9677 GHz	18.793	-119.553	-10.922	-160.651	-15.301	-166.455
2	Hairpin shaped resonator	10.99GHz,11.06GHz,11.26GHz	N.A	N.A	N.A	N.A	26.143	-121.63
3	Hairpin shaped resonator1	10.12 GHz	30.275	-95.253	13.543	-127.667	-10.1	-148.979
4	single spiral resonator	10.28 GHz	27.695	-123.125	-10.398	-165.648	N.A	N.A.
5	double spiral resonator	8.7 Ghz	N.A	N.A	-2.895	-132.53	-10.87	-164.869
6	Quadral spiral resonator	8.75 GHz	N.A	N.A	N.A	N.A	N.A	N.A.

From the above comparison, oscillator designed 3 is most accurately designed oscillator which gives minimum phase noise at 100 kHz offset frequency whereas, oscillator 1 comes worst in terms of better result as phase noise is very high and the output voltage is high indicating the power loss.

Among resonator Split ring resonator is the most accurate resonator resonating very close to 10 GHz along with hairpin shaped resonator 1 and single spiral resonator. There is one resonator (Hairpin Resonator) which is giving multi band resonating properties but, the phase noise is quite high and there output power is non-negative, hence there is a major chances of decaying a signal or mass radiation loss will be there .

Reference:

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[4] C. Jaewon and S. Chulhun, "Microstrip Square Open-Loop Multiple Split-Ring Resonator for Low-Phase-Noise VCO
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