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Research Paper

Implementation of a Low Cost 0 To 8GHz Oscillator Using Negetive Resistance Oscillation

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ABSTRACT
This research aims at design and implementation of 0.9 to 8 GHz Oscillator for 2G, 3G and 4G frequency bands. The work is targeted for use in carrying out practical work on telecommunication in higher institutions in line the need to equip students with experience useful for technological breakthrough in Nigeria. The oscillator was designed using ATF – 36077 BJT by Avago Technologies. The Simulated oscillator achieved an output power of 26.55 dBm and a comparatively low phase noise of -125 dBm/Hz. The stability circle of the amplifier was plotted, which showed that the amplifier is stable at 8 GHz. Also the design of microwave oscillator 2 at 7.5GHz was presented. It was fabricated on 0.8mm and 1.6mm Fr4 PCB substrates. Tests showed that the fabricated circuit oscillated at 5GHz instead of the designed 7.5 GHz due to mismatches in termination and over approximation of value of components used.

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I. INTRODUCTION

An oscillator can be said to be a DC to RF convertor consisting of an active device and a passive frequency determining resonant element. Oscillators form the backbone of most communications, surveillance, test or measurement systems as they provide the very important modulation clocking function for high speed digital systems (square waves, sine wave, saw tooth etc); enable frequency up and down conversion when used as local oscillators and also provide a reference for system synchronization (Paul, 2014). An oscillator is basically a circuit that produces an oscillating electrical current or voltage upon power up (Messer, 2009). Solid state oscillator uses non-linear devices e.g. diodes or transistors in conjunction with a passive circuit to convert DC to a steady state radio frequency. Magnetron and klystron are some of the most powerful oscillators/ amplifiers because they produce sufficient output power but these normally generate electron using principle of thermionic emission. Klystron and magnetron are relatively expensive because special structures needs to be designed with a vacuum chamber to ensure all necessary condition for thermionic emission is met, they are not affordable by our institutions because they are expensive ranging from 360-600 million naira.

Transistor oscillators are preferred in most cases over diode oscillators as they are readily compatible with monolithic integrated circuitry and consume less power. They are also more flexible since for a transistor, its operating characteristics can be adjusted to a greater degree by the bias point as well as the source or load impedances presented to the device. In order to generate a high frequency signal, the active device, most commonly a transistor needs to have sufficient gain so as to compensate for feedback losses (Messer, 2009). Since oscillation conditions have to be met for the circuit containing the passive and active components, oscillator topologies can be classified broadly into two with respect to how oscillation conditions are met. In the parallel feedback oscillator topology the frequency determining element is also the feedback element and is placed between the input and output in order to generate instability (Mwema et al, 2017). In the Negative Resistance Oscillator topology the reflection gain at a given terminal is used to satisfy the oscillation conditions when connected to the element that determines frequency with the proper phase conditions (Mwema et al, 2017).

In designing a microwave oscillator, an important factor to consider is the appropriate choice of transistor for low phase noise and frequency stability.

At microwave frequencies, Scattering or S - parameter method is the most preferred choice for oscillator design because it is very difficult to measure voltage or current directly at these frequencies.

S - parameters are useful design aids that most manufacturers supply for their high frequency transistors. These are widely used because of their ease to measure and work with than Y- parameters, while S-parameters used normalized incident and reflected travelling waves at each network port. However, with S - parameter, there is no need to present a short circuit to the two-port device. Instead, the network is always terminated in the characteristic impedance of the measuring system.

DESIGN OF OSCILLATOR 1

Figure 1 presents an oscillator circuit designed to oscillate at 8 GHz using ATF-36077 Bipolar Junction Transistor (BJT) with common emitter configuration. The bias points of the transistor were set at [1-2] , I_C = 5 mA, $V_{CE} = 2V$, $h_{fe} = 180$, $V_{BE} = 0.7\ V$, and $V_{CC} = 5\ V$ in order to achieve the condition of stable oscillation i. e. (K <1, $\Gamma_{in}\Gamma_g = 1$, $\Gamma_{out}\Gamma_L = 1$) as obtained by equations (1) – (4).

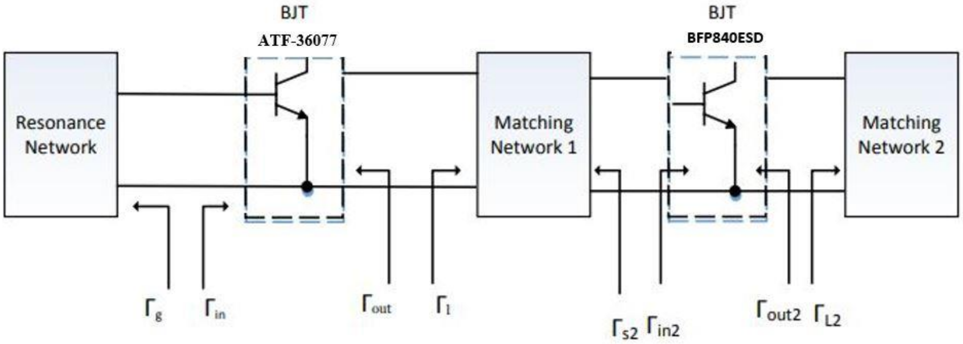

Figure 1: Oscillator with One stage Amplification

$$K = \frac{1+|\Delta|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{12}S_{21}|} \quad \text{……………………..… (1)}$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad \text{…………………………… (2)}$$

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \quad \text{………………………….. (3)}$$

$$\Gamma_{out} = S_{22} + \frac{S_{11}S_{21}\Gamma_S}{1-S_{11}\Gamma_S} \quad \text{………………………….. (4)}$$

The S-parameters of Avago Technologies's ATF-36077 transistor at 8 GHz with Z_o of 50Ω [1].
is presented as:
$S_{11} = 0.759\angle -120^0$, $S_{12} = 0.078\angle 8^0$
$S_{21} = 3.820\angle 62^0$, $S_{22} = 0.46\angle -99^0$

From (1) and (2) $K = 0.943$. Since the stability factor K <1, it implies that stable oscillation can be obtained. Also, simulation results show $\Gamma_S = 1\angle -98.45^0$ and $\Gamma_L = 0.245\angle -13.216^o$.

Amplifier Design

Microwave amplifiers formed one of the major electronics components that combined active elements with passive transmission line circuits to provide functions critical to microwave systems and instruments.

Amplification is one of the most basic and predominant microwave circuit functions in the modern RF and microwave systems.

Microwave transistor amplifiers are low cost, rugged, and reliable and can easily be integrated in hybrid and monolithic integrated circuitry.

The design specifications consist of 8.0 GHz operating frequency, micro-strip line with substrate Ɛr = 4.5, thickness of 1.6mm and tan of 0.019. The primary design goal of microwave amplifier is to obtain maximum value of gain.

An important and significant factor in amplifier design is careful and proper selection of transistor. Usually, the biasing point is chosen in such a way that it will keep the transistor in active mode for different forms of circuit technique.

The amplifier was designed using BFP840ESD BJT set at the following bias points:

I_C = 5 mA, $V_{CE} = 2V$, $h_{fe} = 200$, $V_{BE} = 0.7\ V$, and $V_{CC} = 5\ V$.
Its S - parameters were as follows:
$S_{11} = 0.544\angle - 104.263^0$, $S_{12} = 0.051\angle\ 8.229^0$
$S_{21} = 3.326\angle - 11.717^0$, $S_{22} = 0.480\ \angle 138.430^0$

The first step in the design of an amplifier circuit is determining the stability of the active device i.e conditionally stable or unconditionally stable.

Oscillations are possible in a two-port network when a negative resistance is presented by either the input or the output port. This occurs when $|\Gamma_{IN}|> 1$ or $|\Gamma_{OUT}|> 1$, which for a unilateral device ($S_{12} \cong 0$) is when $|S_{11}|> 1$ or $|S_{22}| > 1$. But in practical cases S_{12} is not equal to 0 and thus the unilateral assumption cannot be made.

Unconditional stability of a two-port network at a given frequency is said to occur if the real parts of Z_{IN} and Z_{OUT} are greater than zero for all passive load and source impedances. For bilateral cases (S_{12} not equal to 0) the condition K > 1 is only a necessary condition for unconditional stability where K is the Rollet's factor or stability factor.

Using (1) – (4), $K = 1.786$ at 8 GHz. Since $K > 1$, it means the amplifier is stable at the designed frequency. Also, $\Gamma_{S2} = 0.547\angle\text{-}\ 115.177^0$ and $\Gamma_{L2} = 0.478\ \angle\text{-}154.09^0$.

Testing for stability in amplifier design is a necessary step because different conditions require appropriate design methods. Before an amplifier is built, it is possible to calculate its potential instabilities in transistors. This calculation serves as a useful approach in finding a suitable transistor for a particular application. Achieving unconditional stability of the circuit is among the goals of the designer. Unconditional stability means that any load present at the output of the device will not oscillate.

Advanced Design System (ADS) by Agilent, Matlab and Proteus software were used to design and simulate the complete oscillator circuit shown in Figure 2.

It can be seen that impedance matching networks were incorporated in Figure 2 in order to compensate for the impedance mismatch in the circuit because Maximum power is delivered when the load is matched to the line and power loss in the feed line is minimized. Impedance matching of sensitive receiver components (such as antenna, low noise amplifier, etc.) improves the signal-to-noise power ratio of the system.

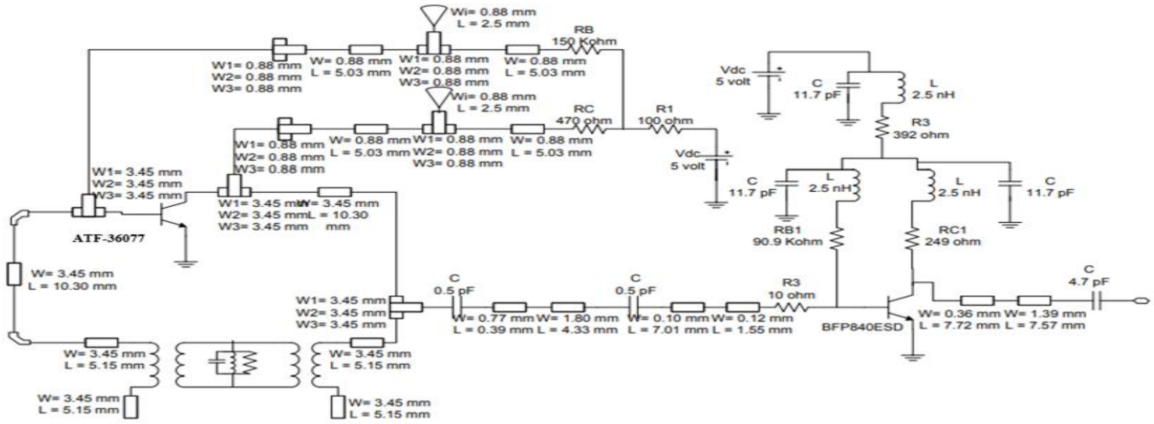

Figure 2: Circuit Diagram of the oscillator 1 in ADS platform

OSCILLATOR 1- SIMULATION RESULTS AND DISCUSSION

The two important parameters that determined the performance of an oscillator are: Output power and phase noise.

Figure 3 show the simulation result of the output power of the oscillator designed at 8 GHz.

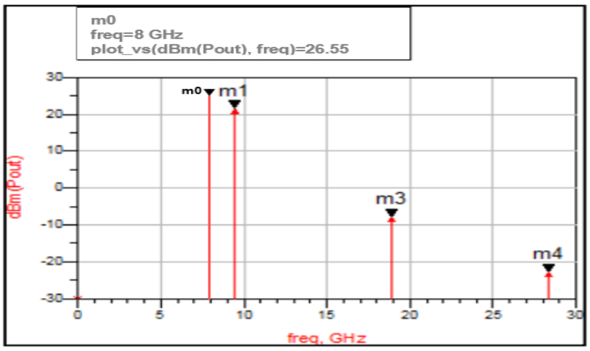

Figure 3: Output Power of the Oscillator

It can be seen that at the designed frequency, the oscillator has achieved an output power of 26.55 dBm. Figure 4 shows the simulation result of the phase noise of the oscillator. It can be seen that at 100 kHz offset, the simulated phase noise was obtained to be -125 dBm/Hz. This indicates a low phase noise performance because most of the reported oscillators have phase noise between -100 dBc/Hz and -120 dBm/Hz at 100 kHz frequency offset.

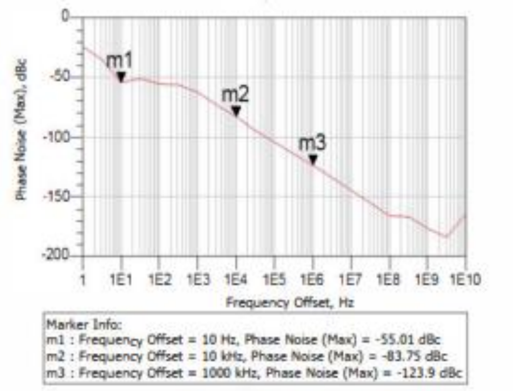

Figure 4: Phase Noise of the Oscillator

Figure 5 is the stability circle of the amplifier at the designed frequency. From the regions on the plot in Figure 5, it showed that the amplifier can operate at 8 GHz without oscillating.

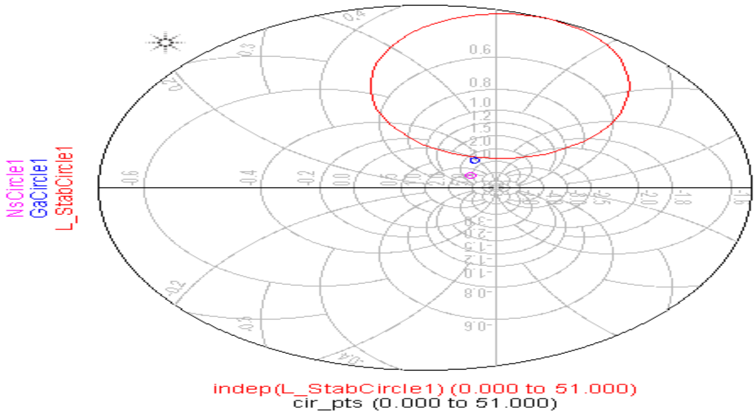

Figure 5: Amplifier Stability Circle

VALIDATION WITH PREVIOUS WORKS

Table 1 gives the comparison between this work and some previously reported literatures.

Author(s)/Freq	[3]/9.75 GHz	[4]	[5]	This work/8 GHz
Output Power (dBm)	9.7	Not mentioned	10	26.55
Phase noise @ 100kHz (dBm/Hz)	-115	-125	-98.7	-125

Based on the comparison in Table 1, the designed oscillator has achieved a high output power and low phase noise.

DESIGN OF OSCILLATOR 2

Skimmed parts of design from [6] given below gives a simpler layout that is cheaper to fabricate using the Fr 4 substrate materials for distributed parameters. There are three-transistor configurations that can be utilized to design 2-port oscillators:

1. Common source
2. Common drain
3. Common gate

The common source configuration is selected.

The transistor FPD200P70 (pHEMT) is a depletion mode AlGaAs High Electron Mobility Transistor. It utilizes a (0.25 x 200)µm Schottky barrier gate field effect transistor. The negative impedance circuit in common source configuration utilizing the FDP200P7 transistor is given in figure 6

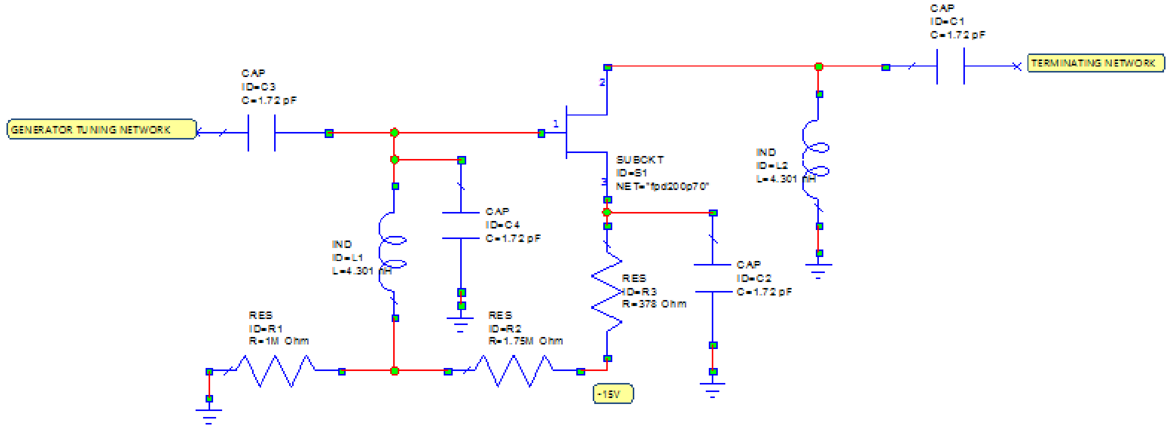

Figure 6: Common Source DC Biasing of FET [6]

Common Source FET DC Biasing:

VDS = 5V
IDS = 30mA
VGG = -15V
IDSS = 60mA
Vt = -0.85V
IDS = 30 mA
VD = 0V
VS = -5V

The design method requires that the transmission lines and the matching terminations be calculated for the frequency of operation.

VGS = -0.45V
VG = VDS + VGS = -5+ (-0.45) = -5.45
(-5.45) x [R2/ (R1+R2)] = (-15)
R2 = 1MΩ, R1 = 2R2 =1.75 MΩ
Rs = V/I = 10.75/30mA = 378Ω
V= VDS - VG = -5-(-15.75) = 11.35V

Terminating Matching Network

ℓOA = (0.47λ – 0.25λ) = 0.22λ (open shunt stub)

ℓAB = (0.50λ – 0.47λ + 0.411λ) = 0.441λ (transmission line). Figure 7 shows circuit for matching network and Figure 8 shows the transmission line circuit linking generator and termination network..

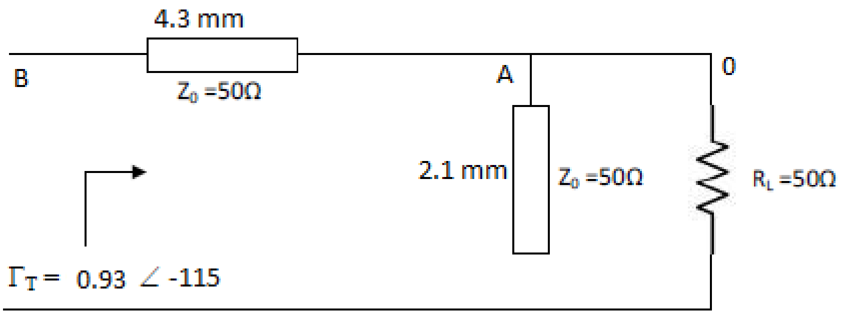

Figure 7: Circuit for terminating network

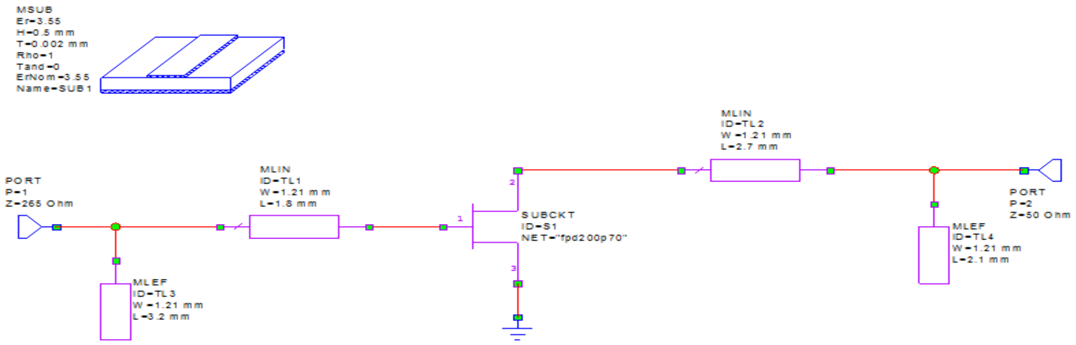

Figure 8: Transmission line circuit for Generator tuning and Terminating Network

Micro-strip calculation for transmission line

The transmission line consists of a strip of the conductor with width (w) and thickness (t), which is placed above the dielectric substrate (εr) as shown below in figure 9. In this design, a dielectric constant (εr = 3.55) and a dielectric thickness (h = 0.5 mm) is selected based on the Rogers data sheet

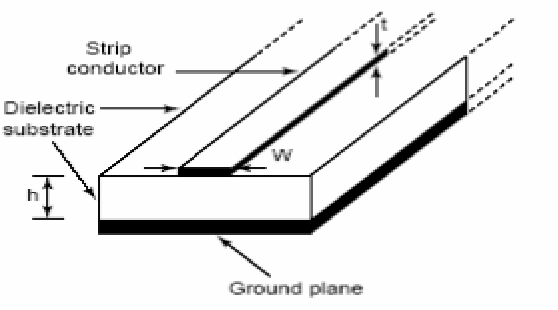

Figure 9: Basic Diagram for Transmission Line

Transmission line of 50Ω is designed based on 18.5 GHz frequency by selecting the εr and h from the datasheet available from the Rogers datasheet. By these two specification the remaining width, wavelength, and εeff are calculated.

f = 18.5 GHz, Z_0 = 50Ω, C = 3 x 10^8 m/s, λo = c/f = 16.2 mm 26

W = 2.27 x 0.5 = 1.13 mm

Length of the terminating network

Open shunt stub:

ℓ = 2.13 mm

Transmission line:

ℓ = 4.27 mm

Length of the generator-tuning network

Open shunt stub:

ℓ = 1.76 mm

Transmission line:

ℓ = 3.17 mm

Micro-strip calculation for Characteristic impedance:

W = 1.13 mm

ℓ = 0.38 mm

Quarter wave transformer:

$\lambda g = 10.28$ mm

ℓ = 2.57 mm

To find width consider $Z0 = 120\Omega$

W = 0.40 x 0.5 = 0.2 mm

Cut-off frequency: (f_0)

f_0 (GHz) = $0.3\sqrt{(50 / 0.05\sqrt{(3.55-1)})} = 7.5$ GHz

FABRICATION OF PROTOTYPE

This last part of the work has to do with fabricating the prototype of the 8GHz oscillator. From design calculations a cutoff frequency of 7.5GHz is expected. Being a high frequency system, fabrication must be done very carefully in an automated or semi-automated environment, to drastically minimize presence of parasitic components that may negatively affect the performance. Such parasitic components come from unwanted inductance and capacitance and create mismatches in the circuit. The design circuit of oscillator 1 was not fabricated due to costs.

The components of the oscillator 2 circuit in figure 10 are adjusted to values closest to design values which are obtainable in the market.

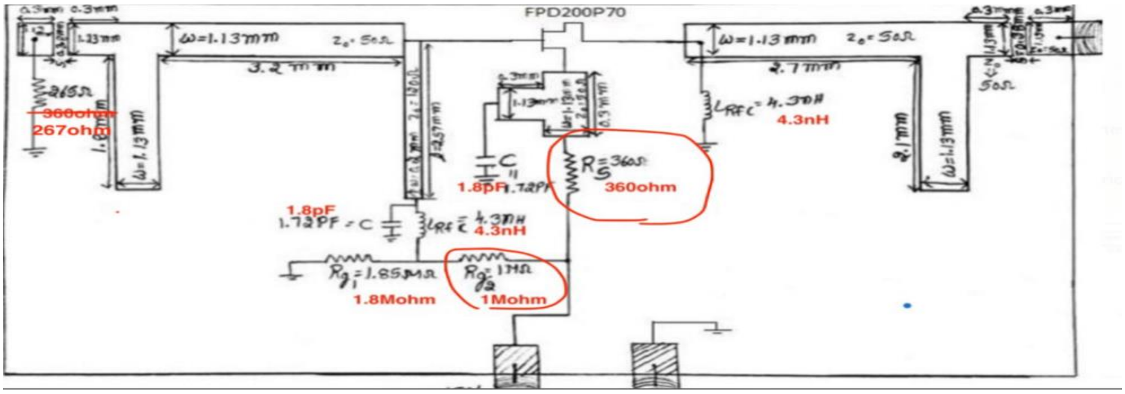

Figure 10: Adjusted component values of the designed circuit.

The fabrication requires etching all transmission lines to the designed dimensions and the layout is first designed in Proteus to cut out solid copper lines from the Fr4 copper clad board. All places where components are to be soldered are opened with the equivalent dimensions that will support easy placement and avoid parasitic inducements. Figure 11 shows the circuit layout for etching and Figure 12 and 13 shows the adjusted Proteus bit map profile without and with the components placed in surface mount positions in the required spaces. The 3D view of the spaces for component placement are shown in Fig 14. The profile in Figure 12 and the associated Gerber files will be used to set the machines for auto etching, placement and soldering of the circuit to precision dimensions calculated in the design.

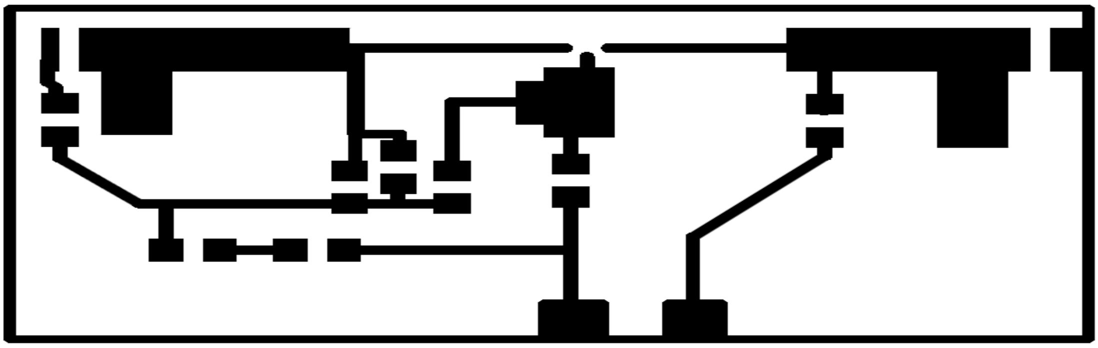

Figure 11: Circuit layout for Etching PDF

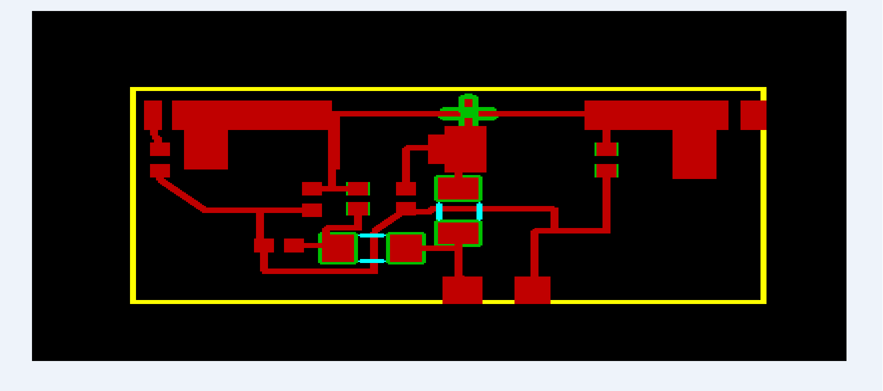

Figure 12: Adjusted Bit Map Layout for Etching

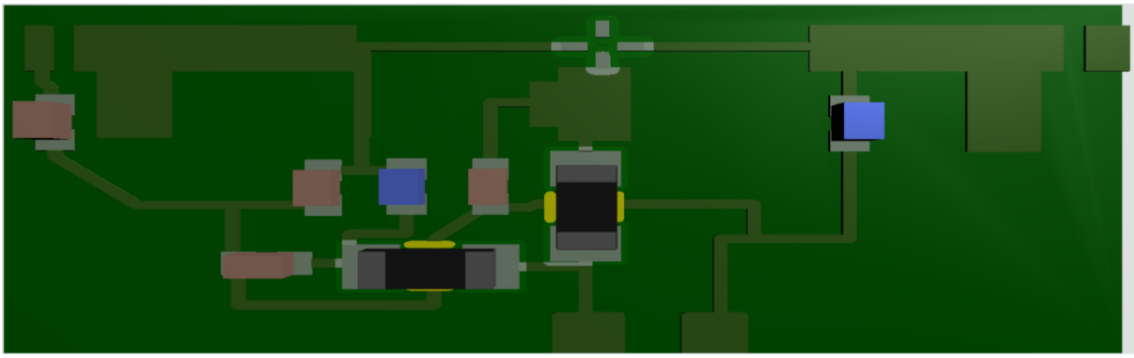

Figure 13: Proteus Bit Map Layout for Etching

Figure 14 also shows the Proteus 3D layout in inverted format to show how it will appear in real life.

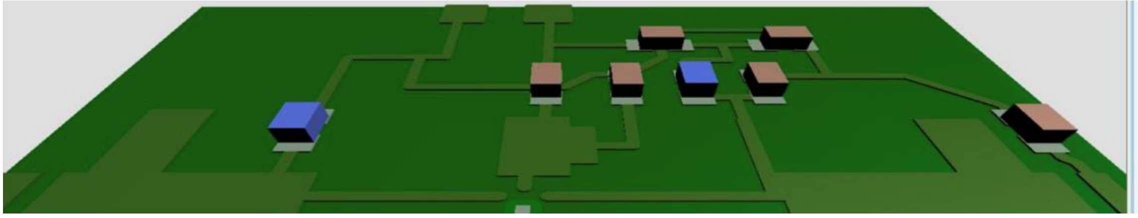

Figure 14: Inverted Proteus 3D layout of Oscillator Circuit

Plate 1 shows test rig for the fabricated prototype giving a measured frequency of 5GHz. The circuits were fabricated at an approximate unit cost of N40,000 each. This cost will be better if the fabrication machines are sourced from within..

Plate 1: Frequency showing Frequency generated by the Oscillator

II. DISCUSSION

The cut off frequency from the s-parameter design was at 7.5GHz. The frequency obtained during testing was 5GHz. The shortfall was as a result of limitations of precision in fabrication, use of approximated components and lack of use of proper matched terminations. Some of these limitations can be overcome by precision handling and mismatch corrections.

III. CONCLUSION

In this article, the design and simulation of microwave oscillator 1 at 8 GHz was presented. The oscillator was designed using ATF – 36077 BJT by Avago Technologies. The Simulated oscillator achieved an output power of 26.55 dBm and a comparatively low phase noise of -125 dBm/Hz. The stability circle of the amplifier was plotted, which showed that the amplifier is stable at 8 GHz.

Also the design of microwave oscillator 2 at 7.5GHz was presented. Manual fabrication was done but achieved no results. The design was auto fabricated on 1.6mm Fr4 PCB substrates. Tests showed that the fabricated circuit oscillated at 5GHz instead of the designed 7.5 GHz due to mismatches in termination and over approximation of value of components used.

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