# RF and Microwave Oscillator Design using p-HEMT Transistor

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***Abstract-*** This paper presents a systematic approach to designing negative-resistance and Colpitts oscillators using p-HEMT transistor. Various models such as, common source and common gate configuration in negative-resistance oscillators, common source series feedback in Colpitts oscillator is selected to analyze the output power and stability presented by the p-HEMT transistor. These oscillators are designed at 2.45 GHz frequency for which we find application in Bluetooth and Wi-Fi. In this paper, these designs are studied and tested, with their results analyzed below. Further, study proved that the Colpitts oscillator designed gave more output power and stability than the negative-resistance oscillators.

***Index Terms-*** Negative resistance, stability, output power.

## I. INTRODUCTION

RF and microwave oscillator is the significant component in modern wireless communication and radar systems. It serves as the signal source in a simple transmitter. In more complicated transmitters like super heterodyne, the local oscillators are used to generate carrier signal. In this case, the oscillator signal is modulated by the low-frequency information signal to be transmitted [1]. In super regenerative receivers, super regenerative oscillators are used to improve the operating range and receiver sensitivity [2]. Oscillators are not only used in communication systems, but are also employed in radars, sensors, navigation, surveillance, RF identification and medical. Hence, it is crucial to have oscillators with good output power, high dc-to-RF efficiency, low noise, good stability, and good frequency tunability etc, because of their ever increasing demand [1].

Negative-resistance oscillators are generally preferred at microwave frequencies since various functions other than that of fixed frequency oscillations can be performed [3]. At lower microwave frequencies (MHz), lumped-element oscillator configurations like Colpitts, Hartley, and Clapp oscillators are commonly used. At higher frequencies (GHz), negative-resistance design procedure is used as, some or all the feedback for oscillation is provided by parasitic capacitances of the packaged transistors and also all the design information is provided by the S-parameter of the active device [4].

## II. CONCEPT OF NEGATIVE-RESISTANCE OSCILLATOR

To design oscillator using negative-resistance concept, first oscillator topology is selected that provides the required output power. Second, transistor in this configuration and at desired oscillation frequency must be unstable. Third, terminating and load network must be designed to provide the proper resonance condition [5].

Figure 1 shows the concept of two-port negative resistance oscillator design. The transistor is characterized by S-parameters; load impedance is denoted by $Z_L$, terminating impedance by $Z_T$, and transistor's output impedance by $Z_{out}$. In this design, output port is selected as terminating port, which makes $|\Gamma_{in}| > 1$, this is the required condition to start the oscillation. Input port is used to terminate the load network, which determines the oscillation frequency. The S-parameters of a transistor is given by [5]

$$[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \qquad (1)$$

and the stability factor (K) of the transistor is defined as

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |S_{11}S_{22} - S_{12}S_{21}|^2}{(2)(|S_{21}S_{12}|)} \qquad (2)$$

Following conditions has to be satisfied, for oscillations to occur at a frequency $f_0$:

$$|R_{in}(V, f_0)| > R_L \qquad (3)$$

$$X_{in}(V, f_0) + X_L\ (f_0) = 0 \qquad (4)$$

When the power supply voltages ($V_{ds}$, $V_{gs}$) of the pHEMT is switched on, the oscillations starts to assemble from the noise level. Depending on the voltage, current, and power; the output amplitude continues to grow until it is limited by saturation level of the transistor. As a result, the circuit can be examined using small-signal techniques. As said earlier negative resistance $R_{in}$ is a function of voltage and it decreases as the oscillation power is increased. Oscillation will die when this resistance becomes lower than load resistance. Thus, while designing, the magnitude of the negative resistance must be made large than the load at voltage V=0 [1].

The conditions for oscillation can also be expressed as [1]

$$K < 1,$$
$$\Gamma_{in}\Gamma_T > 1,$$
$$\Gamma_{out}\Gamma_L > 1. \qquad (5)$$

The advantage of this design procedure is that it develops the oscillations at both the ports.

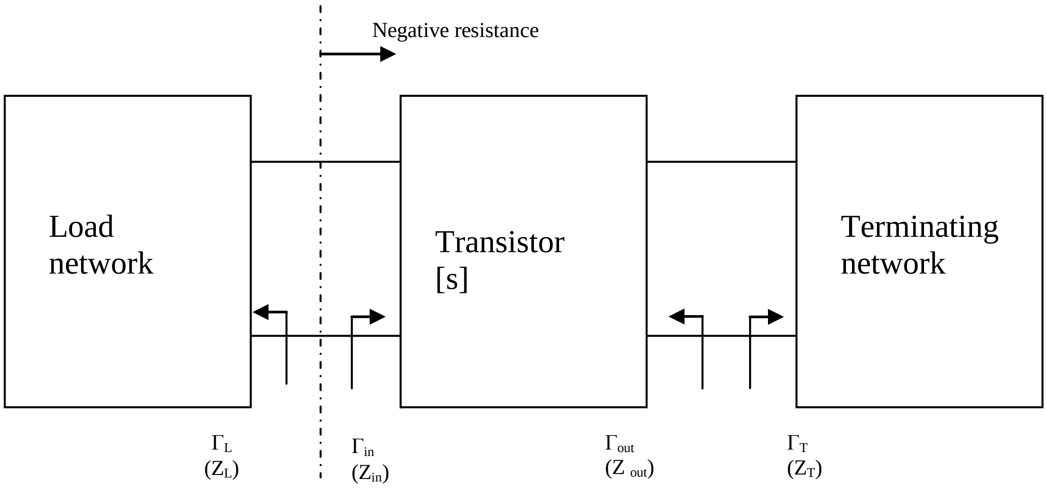


**Figure 1: Two-port negative resistance oscillator design [6]**

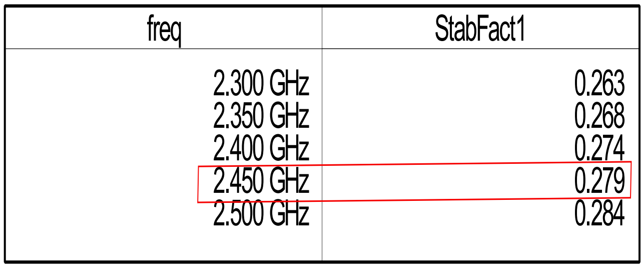
For designing oscillators, high degree of instability is required in the circuit. Further to improve the instability of the transistor, capacitor or inductor is added in the feedback network [5]. Design procedure below shows the steps to design both common source and common gate configurations at frequency of 2.45 GHz in ADS.

## III. DESIGN STEPS FOR NEGATIVE RESISTANCE OSCILLATOR

FPD200P70, high frequency packaged pHEMT from RFMD has been selected to propose an oscillator. Oscillators are designed using ADS software.

### *2.45 GHz common source oscillator*

Step1: Transistor is to be potentially unstable at the frequency of oscillation. This is shown in figure 2. At 2.45GHz, the stability factor is 0.279 (k<1), which makes the transistor unstable.



| freq | StabFact1 |
|---|---|
| 2.300 GHz | 0.263 |
| 2.350 GHz | 0.268 |
| 2.400 GHz | 0.274 |
| 2.450 GHz | 0.279 |
| 2.500 GHz | 0.284 |

**Figure 2: Data plot of "stabfact1" palette**

Step 2: Terminating network is designed by choosing $Z_T$ in the unstable region of the source stability circle. Figure 3 shows the plot of source stability circle in ADS. 50 ohm load impedance is terminated at $Z_T = Z_0*(0.2+j1.4)$, using an open circuit stub and is connected to the output port of the transistor, to make $|\Gamma_{in}|$ >1. This condition starts the oscillations in the circuit.

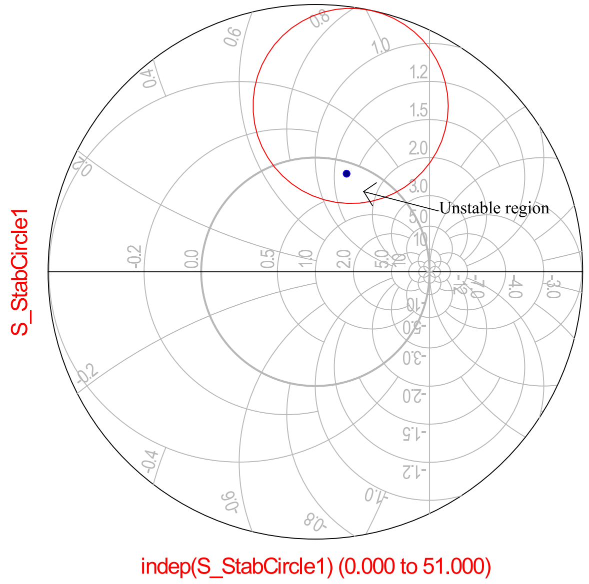


**Figure 3: Plot of source stability circle**

Step 3: Load network is chosen according to the oscillation conditions as below:

$$X_L = -X_{in}(f_0) \quad (6)$$

$$R_L(f_0) = \frac{1}{3}|R_{in}(0,f_0)| \quad (7)$$

This is matched to the 50 ohm load using an open circuit stub and is connected to the input port of the transistor. The oscillations occur simultaneously at both ports and figure 4 shows the circuit design for 2.45GHz common source oscillator configuration.

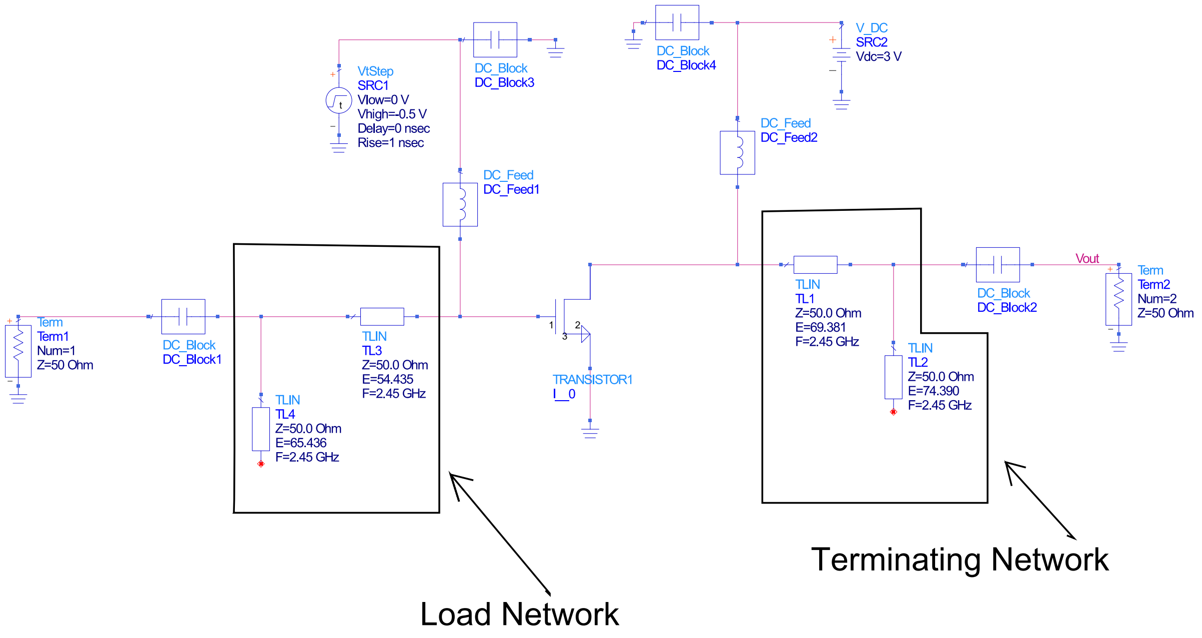


**Figure 4: Circuit design for 2.45GHz common source oscillator**

## IV. SIMULATION RESULTS

To see whether the device is oscillating or not, transient analysis is performed on the circuit. Figure 5 shows the transient response of common source oscillator. To examine the output power of the device, FFT of the complete wave is to be calulated. This is done using the equation dbm(fs(Vout)). Figure 6 shows the plot of this equation.

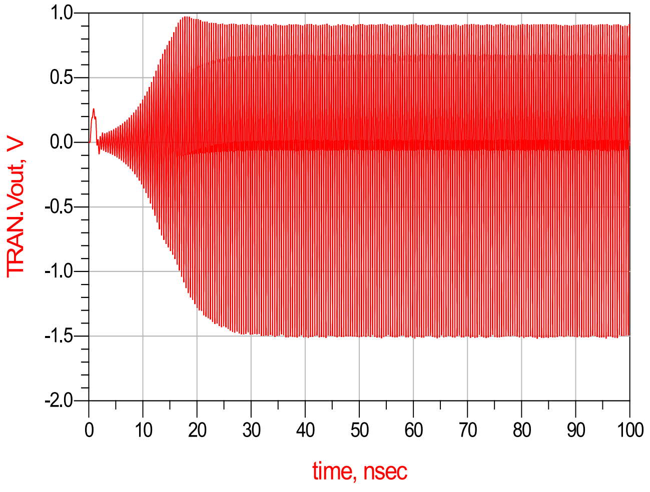


**Figure 5: Transient response of 2.45 GHz common source oscillator**

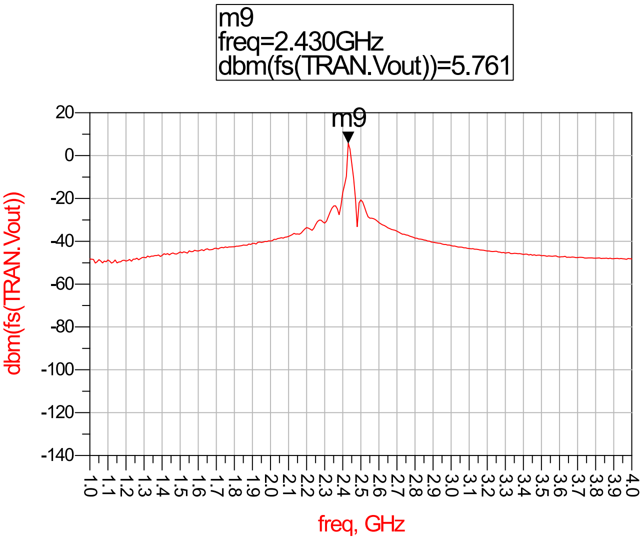


**Figure 6: Output power of 2.45 GHz common source oscillator**

### *A. 2.45 GHz common gate oscillator*

In common gate configuration, input is given to the source and output is taken from the drain, and gate is common (grounded) to both the terminals. In this design inductor is added at the gate side. This provides positive feedback which in turn enhances the instability of the transistor. Same design procedure is followed as common-source oscillator configuration. First, the terminating network is chosen to make $|\Gamma_{in}|$>1. Second, load network is designed based on the equations 6 and 7. Figure 7 shows the complete circuit design of 2.45 GHz common gate oscillator configuration.

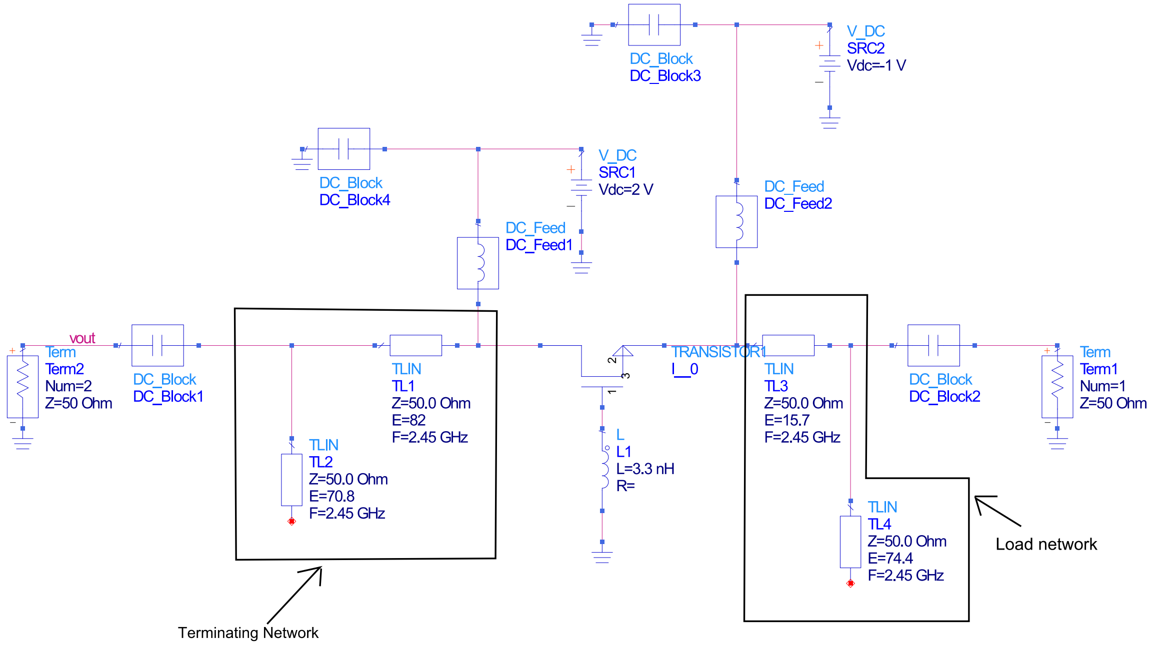


**Figure 7: Circuit design for 2.45GHz common gate oscillator**

**Simulation result:**

Figure 8 and 9 shows the transient response and output power of the common gate oscillator.

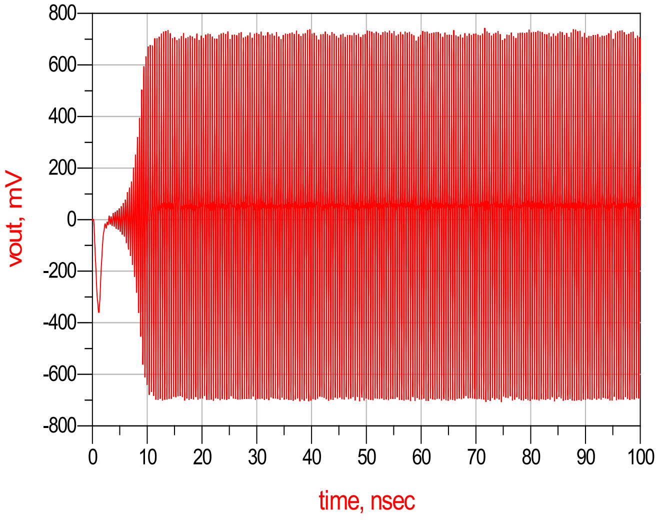


**Figure 8: Transient response of 2.45 GHz common source oscillator**

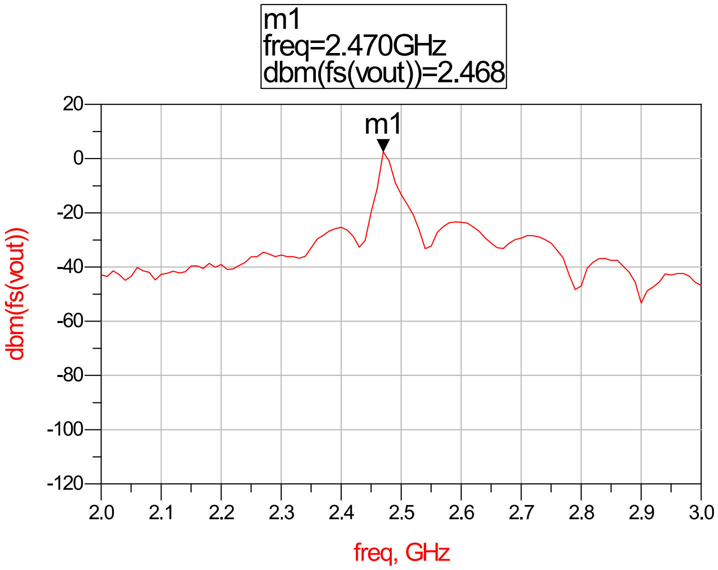


**Figure 9: Output power of 2.45 GHz common source oscillator**

## V. CONCEPT OF COLPITTS OSCILLATOR

Colpitts oscillator consists of two parts: active circuit and the resonator. For this paper, common source series feedback Colpitts oscillator is designed. This design is chosen for studying because it offers trade-off between high gain and low phase noise than compared to the parallel feedback configuration. In this design, active circuit is designed as the reflection amplifier and the resonator using LC circuit. In the circuit, capacitors $C_1$ and $C_2$ form the potential divider for providing the feedback voltage. The voltage built across the capacitor $C_2$ acts as a regenerative feedback which is required for sustained oscillations [6] and the resonator inductor decides the frequency at which the circuit oscillates. Transistor gives a feedback of $180^0$ and tank circuit gives another $180^0$ phase shift, which is an essential condition for developing oscillations.

## VI. DESIGN STEPS FOR COLPITTS OSCILLATOR

First the reflection amplifier of the Colpitts oscillator is designed using the capacitive feedback network as shown in the figure 10 [7]. The amount of feedback is determined by the ratio of capacitors $C_1$ and $C_2$. In the design shown in the figure 10, the p-HEMT device must exhibit an absolute value of open circuit voltage gain greater than or equal to the ratio $C_2/C_1$ in order to obtain the sustained un-damped oscillation. This condition makes sure that the attenuation created by the feedback network is compensated by the gain of the reflection transistor [8]. Here the value of capacitor chosen is 1pF each. The frequency of oscillation is given by the resonant frequency of the LC tank circuit:

$$f = \frac{1}{2 * \pi * \sqrt{L * C_{eq}}} \qquad (8)$$

where,

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2} \qquad (9)$$

By modifying this equation the value of inductor for tank circuit is calculated. The modified equation is

$$L = \frac{1}{(2 * \pi * f)^2 * C_{eq}} \qquad (10)$$

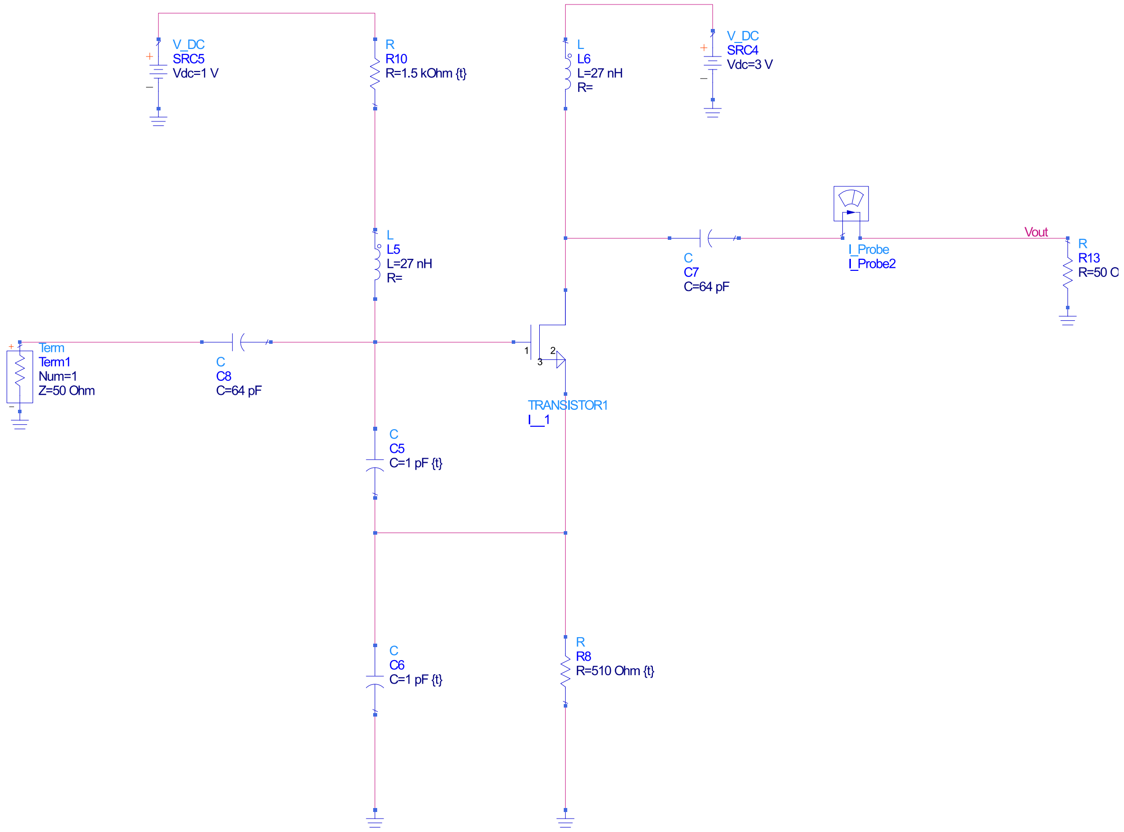


**Figure 10: Circuit showing reflection amplifier as part of the Colpitts oscillator**

Simulation result:

Harmonic analysis has been carried out rather than transient analysis to see the oscillation frequency and output power as transient analysis cannot accurately solve the high-frequency circuits. Figure 11 shows the harmonic analysis of Colpitts oscillator and plot of output power is shown in figure 12.

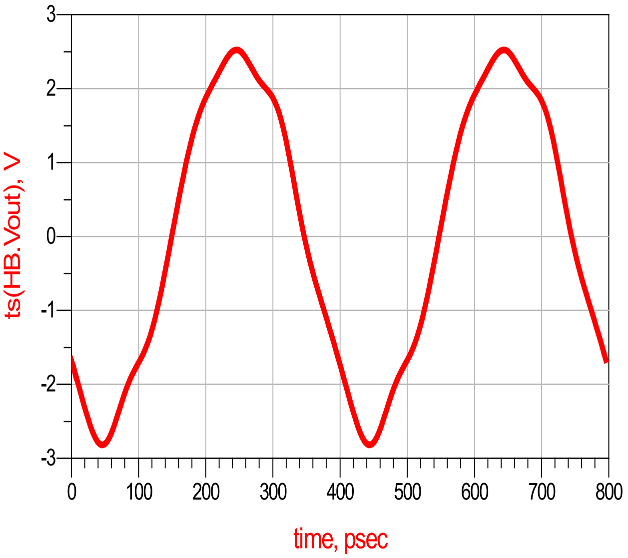


**Figure 11: Steady-state response of 2.45 GHz colpitts oscillator**

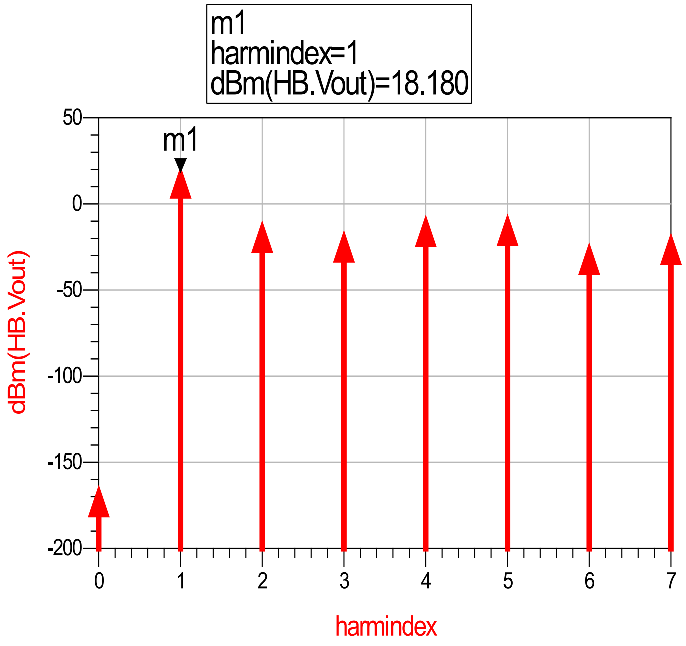


**Figure 12: Plot of output power**

## VII. MEASURED RESULTS AND CONCLUSION

Figure 13 shows the set-up to measure the oscillator circuit. The measurement set-up includes power supply, spectrum analyzer, and 50 ohm broadband load.

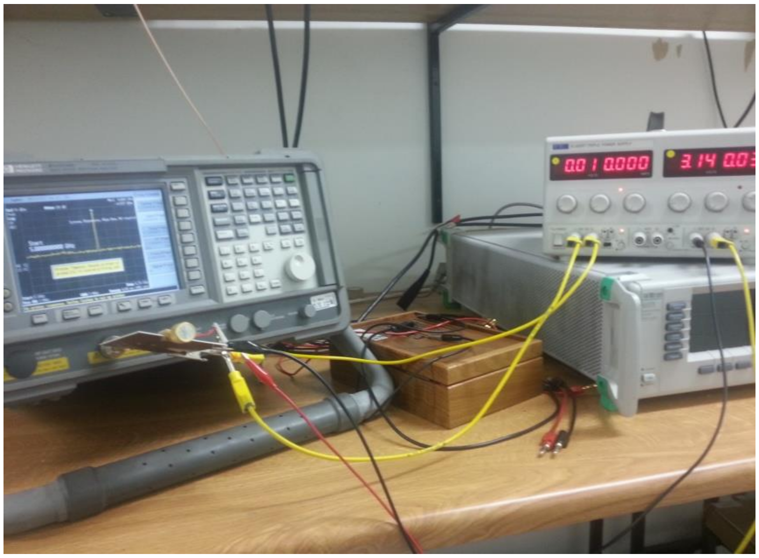


**Figure 13: Measurement set-up to measure oscillators**

Figure 14 and 15 show the measured result of the common source and common gate oscillator respectively. While measuring the common source oscillator, the oscillations was not stable; it was wobbling around. It happened because there was no feedback element present in the circuit to fix the oscillation at certain frequency. In common gate circuit, oscillations was fixed at one frequency as there was a feedback inductor present at the gate. In both circuit measurements it was noted that there was a huge shift in the frequency of operation; 2.35 GHz shift in case of common source and 4.012 GHz shift in case of common gate. It occurred due to the bypass capacitors present in the biasing network. As capacitors used are not ideal, they didn't present short circuit to the microwave signals. Thus, capacitor value had to be increased to present zero impedance to the RF signal.

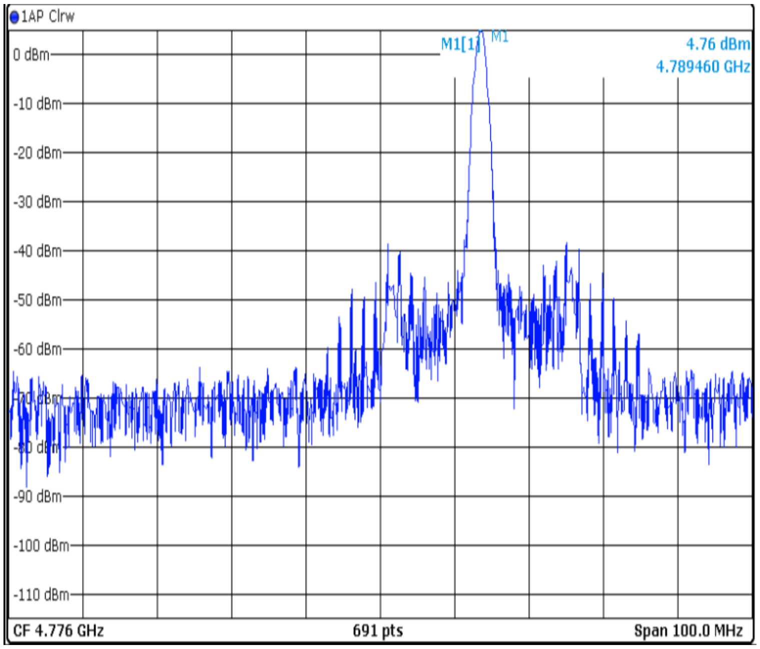


**Figure 14: Measured result of 2.45 GHZ CS oscillator**

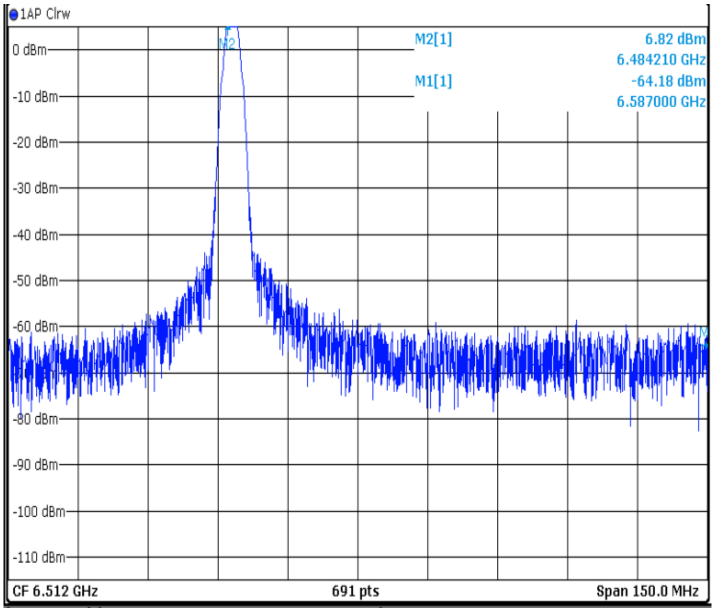


**Figure 15: Measured result of 2.45 GHZ CG oscillator**

Measured result in figure 16 shows the final oscillation frequency at 1.91 GHz with 19.24 dbm output power. A shift of 500 MHz is observed because the footprint of the components was different from the actual component size and due to the addition of parasitic capacitance by soldering. The output power obtained in this circuit design is high than in negative resistance oscillator. This is because; the p-HEMT transistor is used as a reflection amplifier where the entire gain of the transistor is used to compensate the loss of the resonant circuit. Since the frequency is dictated by the resonant component of the circuit, fixed frequency oscillation is obtained.

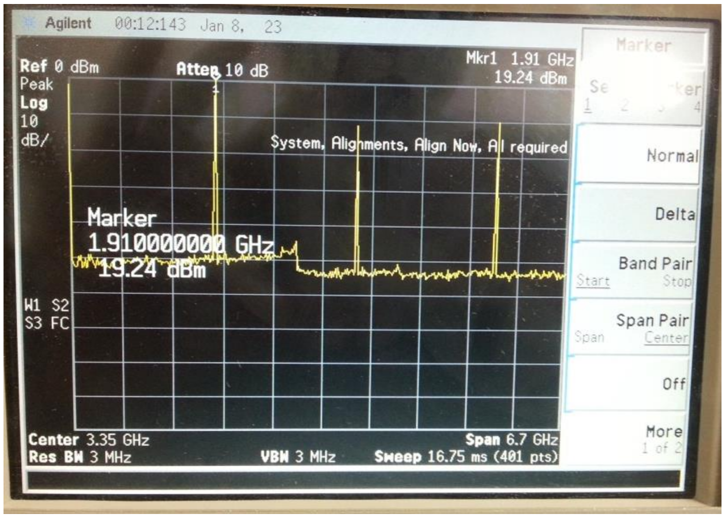


***Figure 16: Measurement result of 2.45 GHz Colpitts oscillator***

## ACKNOWLEDGEMENT

I would like to extend my thanks to the technicians of the laboratory of the electronics and electrical department of Glasgow University for their help in offering me the resource in running the program.

Finally, I wish to thank my parents for their support and encouragement throughout my study.

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