EE211 Report (Group 4)

Hemraj Parmar
B18116

Shubrah Gupta
B18195

Nishant Vedwal
B18125

Pranjal Soni
B18186

***Abstract*—**

Design an LC oscillator with an oscillating frequency of 1 GHz with phase noise of -110 dBc/Hz and CL = 1 pF.
Perform DC, Transient and AC analysis to check the performance.

I. Theory

A. ***Oscillators***

Oscillators are defined as circuits having the ability to generate a continuous repeating waveform without any power supply. Alternating waveforms of desired frequency can be obtained by the oscillator from the DC supply.
Oscillators convert a DC input into associate degree AC output, which might have a large variations of various wave shapes and frequencies which will be either sophisticated in nature or straightforward sinusoidal function waves relying upon the appliance. The frequency of alternating waveforms can be adjusted by the circuit components.
The basic concept behind an oscillator can be observed by a LC oscillator circuit consisting of a precharged capacitor and an inductor.

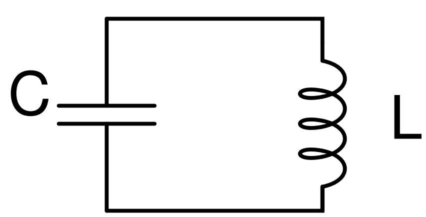

Fig. 1. LC Oscillator

Working of the Oscillators:-

As the charge of the capacitor starts to decrease, electromagnetic fields are produced from the electrical energy. The electromagnetic energy can be stored by the inductor. The current flow in the circuit will be 0 once the capacitor is fully discharged.
A back emf is generated by the stored electromagnetic field in the circuit. The direction of current will be the same as before. The current flow will be producing a back electromagnetic field from the electromagnetic energy. A cycle starts between the previous electromagnetic field and the back electromagnetic field. The charge of the capacitor will change according to the waveform obtained.
The amplitude of oscillations will start to decrease due to the energy loss due to the resistive load of the circuit. The damping nature can be seen as the amplitude will become zero after some time.

Characteristics of an Oscillator:-

- Amplification.
- Positive Feedback.
- Feedback network to determine frequency.
- The average loop gain is around unity.
- Oscillations get dampen in the span of time due to circuital losses.
- The output signal must be in the phase of input signal.

Types of Oscillators:-

The broad classification includes two types: Harmonic oscillators and Relaxation oscillators.
The direction of energy flow in case of harmonic oscillator is from active to passive component always. The feedback path is used for deciding frequency of oscillators.
In case of relaxation oscillations, the energy keeps on exchanging between the active and passive components. The charging discharging time constants determines oscillation frequency.
The output waveform from the harmonic oscillator is a low-distorted sine wave. While in the case of a relaxation oscillator the waveform generated is non-sinusoidal.
Considering the parameters such as output waveform shape and feedback mechanism, oscillators can be classified into different types.

- Positive, negative feedback oscillators based on feedback mechanisms.
- Square wave oscillators, sine wave oscillators, sweep oscillators based on the output waveforms.
- LC, RC oscillators, crystal oscillators based on types of frequency control used.
- Fixed , variable frequency oscillations based on nature of output waveforms.

Applications of oscillator:-

Due to the ease of generating specific frequency and cheapness, oscillators are used. Low frequency and high frequency can be generated by RC and LC oscillators respectively.
Some of the applications of oscillators are:

- Quartz watch (crystal oscillators).
- Audio and Video systems.
- Radio and TV.
- Communications device.
- Used in metal detectors and computers and for clock pulses for a microprocessor generator.
- Used as a VFO (variable-frequency oscillator).
- Superheterodyne receiver.
- Spectrum Analyser.

B. LC Oscillators

LC oscillators also known as RF oscillators, are mainly used for generating high frequency waves as shown in fig.1
The capacitive and inductive reactance is inversely and directly proportional to frequency applied. So at lower frequencies, capacitive reactance is high and inductive reactance is very low and the elements act as open and short circuit respectively and vice-versa for high frequency.
The circuit will have a resonant frequency at a balanced reactance of capacitor and inductor. So the resistance will be present in the circuit to oppose the current and phase shift current will not be there. The current and voltage will have a phase difference of 0. The tank circuit as given above is used for sustaining the oscillations. The C and L components will be carrying some energy initially.

The frequency can be given as:

$$f = 1/2\pi\sqrt{LC}$$

(at resonance condition $X_L = X_C$)

C. Colpitts Configuration

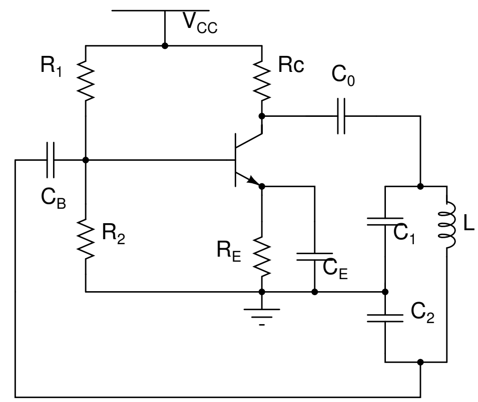

Fig. 2. Colpitts oscillator circuit

It's a linear type of oscillator whose origin and name owes to its creator Edwin Colpitts. Its oscillation frequency is a result of the derivative of positive feedback.
This configuration uses capacitors that are centre tapped in series with a parallel inductor to form its resonance circuit delivering oscillations that are sinusoidal in nature. The feature that distinguish Colpitts oscillators from others is taking in the active device feedback from a voltage divider that is made up from capacitors in series which is across its inductor.
It consists of a voltage divider network that is capacitive in nature. A single common inductor L is taken and the two capacitors C_1 and C_2 are placed across it. The conditions required for it are:

$$X_{C1} + X_{C2} = X_L$$

The benefit of using this configuration is that with reduced mutual and self-inductance within the tank circuit the frequency stability of the oscillator is increased also with added benefits of a simple design.
It can also be seen as a direct equivalent to a dual Hartley Oscillator which uses 2 inductors and a capacitor instead of 2 capacitors and an inductor as in the case of Colpitts configuration.
The output is connected to the input via a feedback loop achieved through a gain device. It includes bipolar junction transistors, vacuum tubes, operational amplifiers, field-effect transistors.

D. ***Barkhausen Criteria***

The Barkhaunsen criteria is a mathematical condition for oscillations applied to feedback looped-circuits. It is considered to be the initial requirement for designing an oscillator.
The transfer function,

$$A_f = A/(1 + AB)$$

where A = voltage gain without feedback and B = feedback factor and AB = open loop gain, states the closed loop gain for the oscillator circuit

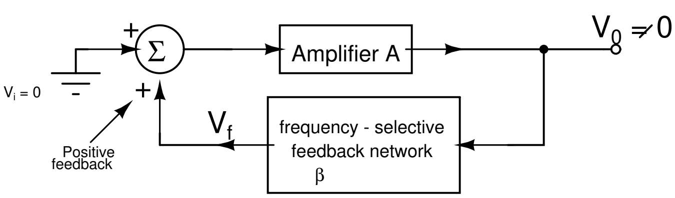

Fig. 3. circuit demonstrating Barkhausen criterion

The conditions for positive feedback oscillator to continue oscillating under this criteria are that for the oscillating frequency for the circuit,

- The magnitude of loop gain should be one i.e. $|AB|$ = 1.
- The phase shift for the entire should be either 0 or an integral multiple of 360°.

It is an important criteria to determine whether an oscillator is stable. The gain of the system at the frequency which satisfies this condition is very large.

E. ***Phase Noise***

Phase noise is the random fluctuation that is often observed in a signal. It indicates short-time stability in the domain of frequency, in which fluctuations are spontaneous. It is present in some amount in all of the signals.

Ideally any signal produced by an oscillator should represent a single frequency in Fourier's domain, but due to different noise components as well as the temperature induced noise causes the spread of unwanted frequencies. According to IEEE, phase noise is the instability in the one-sided spectrum of signal denoted as a sideband.
It is capable of corrupting the signal paths, both the up and down-converted paths. Some electronic components face problems due to the phase noise,

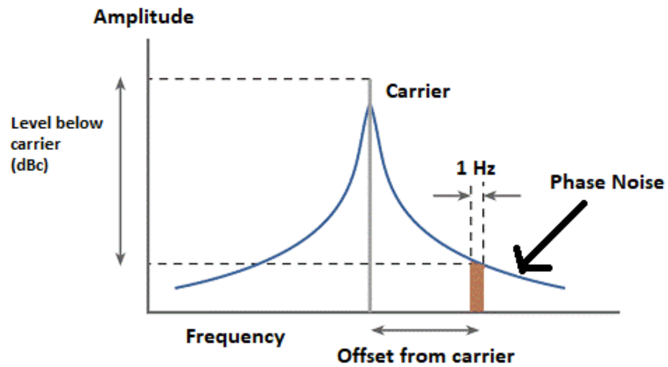

Fig. 4. noise spectrum

and the attempts are made to minimise them while in Radio communication, it is considered as an important parameter in functioning. This is because it is critical for the operation of some device components.
It is measured in spectrum analyser and has unit dBc/Hz.

II. CALCULATIONS

For oscillator:

$$Loop\ Gain(AB) = -1$$

$$Phase\ Condition = 360°$$

We know that:

$$Closed\ loop\ gain = AF = \frac{1}{1 + BA}$$

$$\implies if AB = -1, AF \to \infty$$

Output exists even in the absence of input.
Phase shift should be equal to 0° or 360° for the entire circuit. Forward amplifier (A) and the feedback (B) must either produce phase shift of 180° each or 0° each.

BJT Amplifier Biasing:-
In order for BJT to work as amplifier, we need to ensure that its region of operation should be in active region. BJT biasing leads to Q-point oe operating for functioning of BJT amplifier.

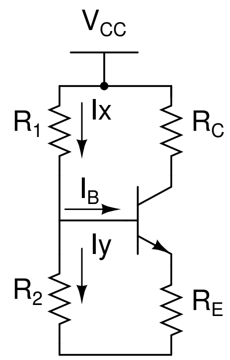

Fig. 5. DC equivalent of Colpitts oscillator circuit

We choose BJT to be of the model npn type BC 548A.
From the BC 548A dataset:-

$$
\begin{aligned}
&V_{BE} = 0.65V\\
&V_{CE} = 0.5V\\
&V_{CE}(Saturation) = 0.6V\\
&\beta_{min} = 110, \beta_{max} = 220
\end{aligned}
$$

Some approximations for calculations:

$$R_2 <= \beta R_E/10 \tag{1}$$

$$I_X > 10 I_B \tag{2}$$

For finding limit in equation 1,

$$
\begin{aligned}
&R_2 = \beta R_E/10\\
&Let\ R_E = 1K\Omega\\
&\beta_{av} = \sqrt{\beta_{min}\beta_{max}}\\
&\quad = \sqrt{110 \times 220}\\
&\quad = 156\\
\implies &R_2 = (1561K)/10\\
&\quad = 15.6K\Omega\\
\implies &R_2\ has\ to\ be\ less\ than\ 15.6K\Omega
\end{aligned}
$$

$$R_2 <= 15.6K\Omega \tag{3}$$

By Kirchoff's law:

$$I_B = I_X - I_Y \tag{4}$$

Considering upper loop in fig 3:
Applying KVL:

$$
\begin{aligned}
-I_y \times R_2 + (I_C + I_B)R_E + V_{BE} = 0\\
\implies I_y R_2 = V_{BE} + I_B \times R_E(\beta + 1)\\
as(I_C = \beta I_B)
\end{aligned}
$$

$$\implies I_y = \frac{V_{BE} + I_B R_E(\beta + 1)}{R_2} \tag{5}$$

$$
\begin{aligned}
Assuming\ R_2 = 4K\Omega \quad [Satisfieseq.(3)]\\
I_y = (0.65 + (157) I_B 1000)/4000
\end{aligned}
$$

$$I_y = 0.163m + 39 I_B \tag{6}$$

According to eq (2):

$$I_X > 10 I_B$$

$$Let\ I_X = 48 I_B \tag{7}$$

From eq.(4),(6),(7):

$$
\begin{aligned}
I_B &= 48 I_B – (0.163m + 39 I_B)\\
I_B &= 0.0204mA\\
I_B &= 20.4 \mu A\\
I_x &= 48 I_B = 979.2 \mu A\\
&= 0.979mA\\
I_C &= \beta I_B = 3182.4 \mu A\\
&= 3.184mA
\end{aligned}
$$

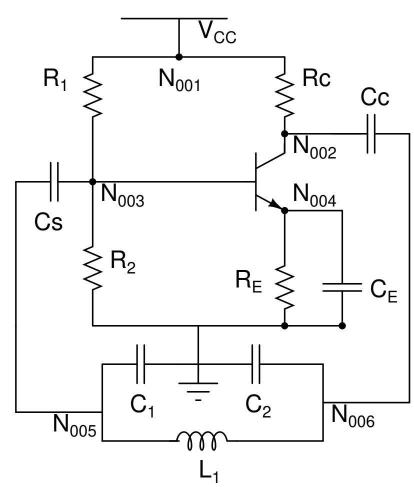

Fig. 6. Colpitts-configured oscillator circuits

Applying KVL on fig 6 circuit:-

$$R_1 = \frac{V_{CC} - V_{BE} - I_B(\beta+1)R_E}{I_X}$$
$$\implies R_1 = 8.15/0.979\Omega$$
$$\implies R_1 = 8.323K\Omega = 8.4K\Omega$$

Also, $\mathrm{V}_{CE} = V_{CC} – I_C(R_C + R_E)$
$\implies V_{CE} = 3.5V$
$\implies (\beta)I_B(R_C + R_E) = 12–3.5$
$\implies R_C = 1.6709K\Omega$

DC ANALYSIS :

For the circuit given in fig 4, we performed the operation of obtaining DC operating point in LT spice and the resultant data is shown below.

```
       --- Operating Point ---

V(n001):          12               voltage
V(n002):          6.94121          voltage
V(n003):          3.84169          voltage
V(n004):          3.17255          voltage
V(n005):          1.05386e-009     voltage
V(n006):          1.05386e-009     voltage
Ic(Q1):           0.00316174       device_current
Ib(Q1):           1.08052e-005     device_current
Ie(Q1):           -0.00317255      device_current
I(Cs):            3.84169e-022     device_current
I(Cc):            6.94121e-022     device_current
I(C2):            7.37281e-034     device_current
I(C1):            -1.2288e-033     device_current
I(Ce):            3.17255e-018     device_current
I(L1):            -4.1359e-022     device_current
I(Re):            0.00317255       device_current
I(R2):            0.000960422      device_current
I(R1):            0.000971227      device_current
I(Rc):            0.00316174       device_current
I(Vcc):           -0.00413297      device_current
```

Fig. 7. DC operating point

AC ANALYSIS :

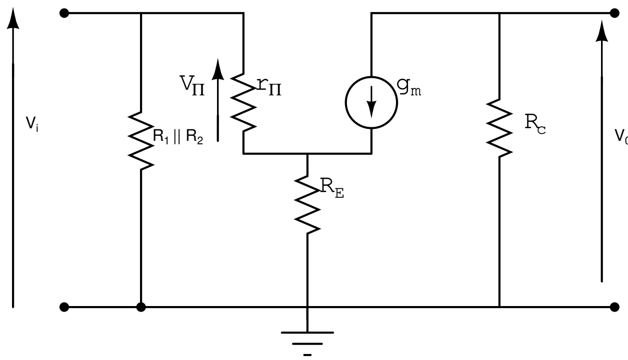

Fig. 8. Small signal model

$$A_V = -\frac{V_{out}}{V_{in}}$$
$$R_{in} = R_1||R_2||r_\pi$$
$$R_{out} = R_c$$
$$r'e = Equivalent\ AC\ resistance$$
$$= 26mV/I_E = 8.125\Omega$$
$$r_\pi = \beta \times r'e = 1.268K\Omega$$
$$g_m = I_C/V_T = 3.1824mA/26mV$$

$Now,$

$$A_V = -V_{out}/V_{in}$$
$$= \frac{-g_m V_\pi R_C}{(V_\pi + V_\pi(R_e)(g_m – 1/r_\pi))}$$
$$\implies A_V = -1.667$$
$$|AB| = |Av| = 1.667$$

For the feedback, we would use the sub-circuit:-

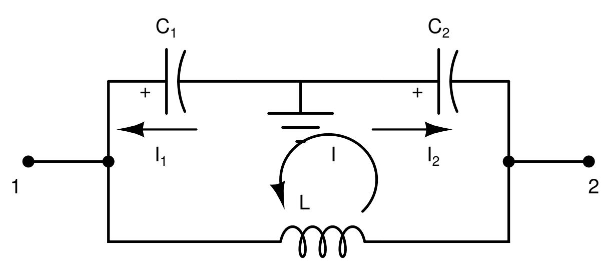

Fig. 9.

Since, oscillating frequency = 1 GHz and

C_T = 1 pF

$$f_{oscillating} = \frac{1}{2\pi \times \sqrt{((L_1 \times C_T))}}$$
$$L_1 = \frac{1}{(4 \times \pi^2)}\mu H = 25nH$$
$$B = Feedback\ factor = \frac{V_{feedback}}{V_{output}}$$
$$\implies B = \frac{I \times X_{C1}}{I \times X_{C2}}$$
$$\implies B = -C_2/C_1$$

$|B|$ = C$_2/C_1$
$|A| = C_1/C_2$

Since, the capacitors are connected in centre-tap, phase-shift caused by them is 180°(as apparent by negative sign in the value of B) Phase shift caused by BJT- CE configuration = 180°.
$|AB|$ = 1

$$\implies |B| = \frac{1}{1.667} = 0.6 = \frac{C_2}{C_1}$$
$$We\ know\ that,\ C_T = 1pF$$
$$C_1 = 1.166pF$$
$$C_2 = 0.6996pF$$

NOISE ANALYSIS

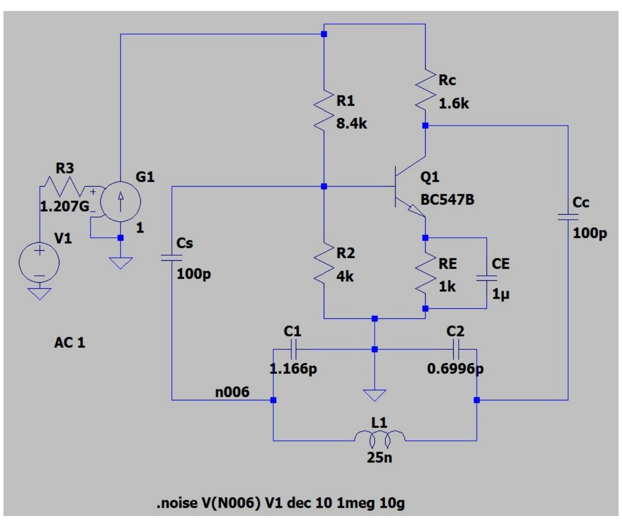

Fig. 10. circuit with noise-equivalent components

The phase noise in the circuit is denoted by the voltage noise of resistors.

R_{noise} is given by :–
R_{noise} = $2 \times (10)^{L_{dBc/Hz}/10}$/(16.568 $\times 10^{-21}$) [for T = 300 K]

$$L_{dBc/Hz} = -110dBc/Hz$$
$$R_{noise} = 1.207G\Omega$$

We use a voltage controlled current source G1 for this purpose. Its mutual conductance is set to G = 1. The voltage source V1 is kept to facilitate the analysis of the noise.
We connect G1 and R3 = Rnoise with the source voltage V1 and simulate the circuit.

III. SIMULATION RESULTS:

Transient Analysis:

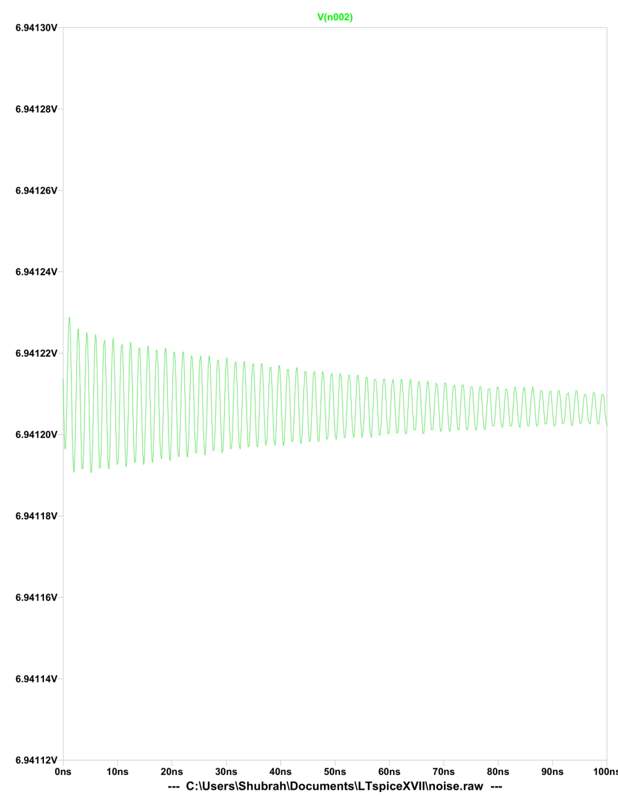

Fig. 11. transient analysis 01

We performed Transient analysis on our oscillator till the stop time 100 ns and found out that the voltage at node 002 had higher value initially, which keeps decreasing in amplitude as the time progresses.

The amplitude lies between 6.94119 V and 6.94123 V.

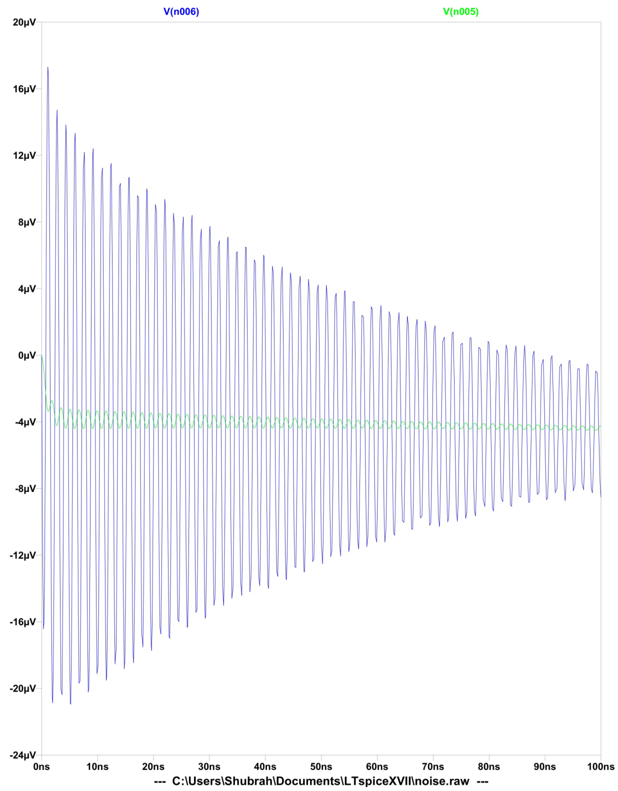

Fig. 12. transient analysis 02

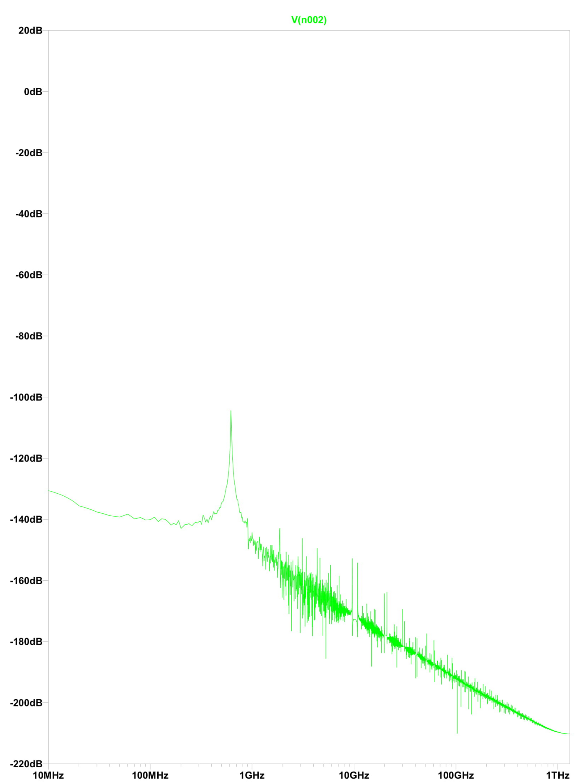

Fig. 13. Fourier Transform

When we measure voltage on node 005 and 006, we got wave forms showing similar trends as shown in figure above only to be scaled down due to presence of capacitor C_C.

We performed Fourier transform on the above waveform to check the frequency of the simulation circuit and we got peak at frequency nearly equal to 1 GHz which is the oscillating frequency for the circuit as below, thus complying with the calculations.

<u>AC Analysis :</u>

We grounded the DC source in the circuit and connected an AC source to the input. We obtained the waveforms of magnitude vs frequency for node 005 and 006 as shown below-

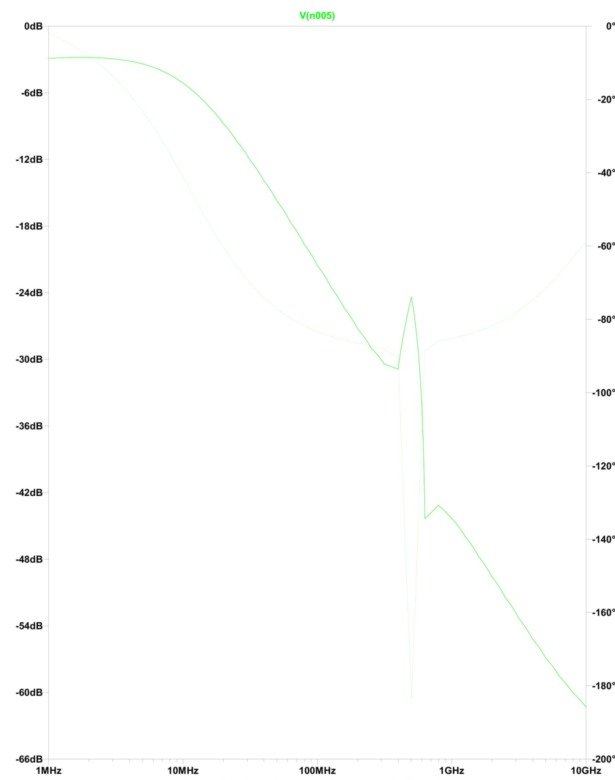

Fig. 14. Ac analysis

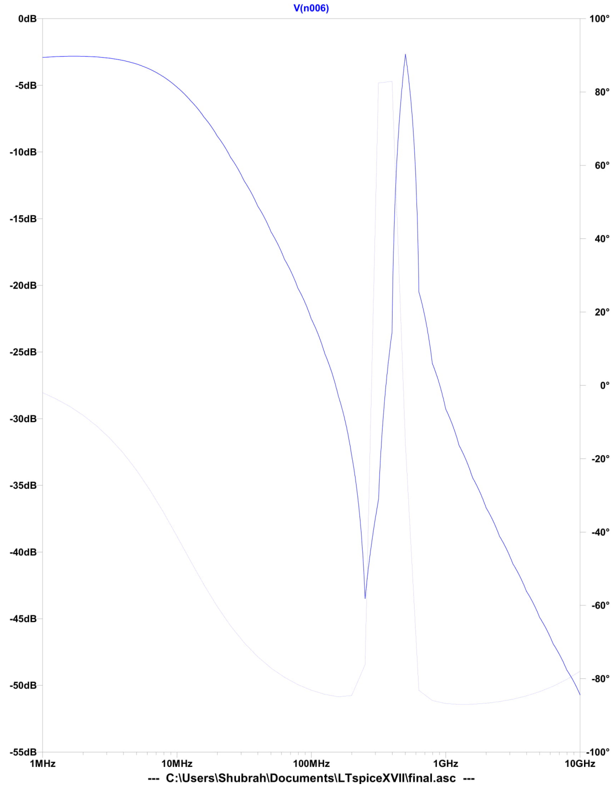

Fig. 15. Ac analysis 2

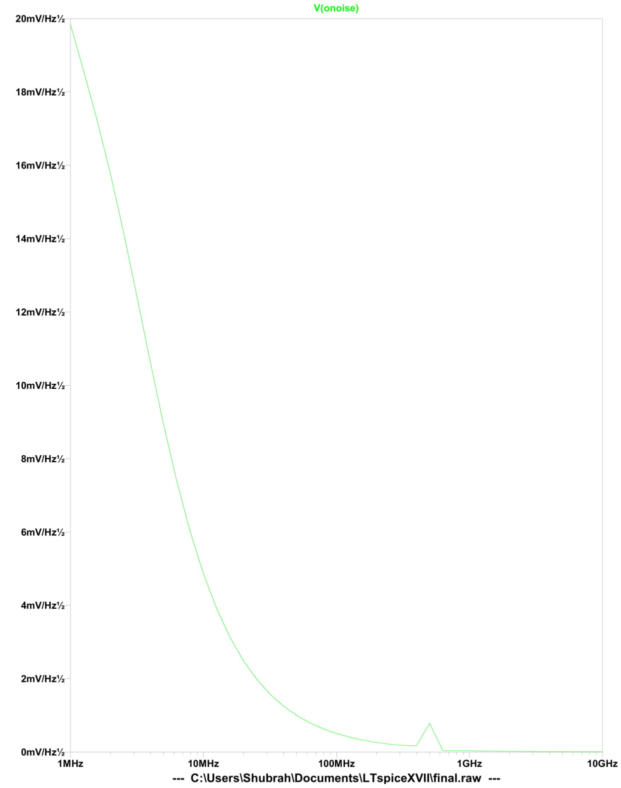

Fig. 16. Noise Analysis :

Noise Analysis :

After performing the noise analysis, we obtain the waveform shown above which has a hump near 1 GHz. This is a direct result of using the Voltage-controlled current source G1 which generates phase noise of –110 dBc/Hz.

References

[1] Cadence. Colpitts Oscillator Circuits and Other Linear/Nonlinear Oscillator Functions.

[2] Pieter Willem Van der Walt. A Guide to Phase Noise Analysis of Single and Multi-PLL Frequency Synthesizers with LTSpice.

[3] Electrical4U. Oscillator What Are They? (Definition, Types, and Applications).

[4] electronicnotes. What is Phase Noise: phase jitter.

[5] Electronics Hub. LC Oscillator Basics.