DESIGN AND SIMULATION OF A 20 KHz TO 50 KHz VARIABLE FREQUENCY OSCILLATOR (VFO)

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ABSTRACT

A variable frequency oscillator have been design and simulated using electronic workbench software multisim 8.0. It is designed between 20 KHz to 50MHz using a colpitts oscillator configuration. The complete circuit is made up of a 2N3904 PNP transistor amplifier and two tank circuits which form the feedback network. The circuit was simulated and found to oscillate from 4.2MHz to 50MHz when inductor L2 from 1µH to 360µH and from 20 KHz to 4.8MHz when inductor L1 is varied from 1.0µH to 1mH. Result of distortion analysis for 20 KHz and 50 MHz show a low distortion of 0% and 6% respectfully while the grapher view of the spectrum analyzer and the oscilloscope shows good stability, low noise and constant amplitude of oscillation.

Keywords: *oscillator, transistor, capacitor and inductor*.

1. INTRODUCTION

An oscillator is the basic element of all ac signal sources and generates sinusoidal signals of known frequency and amplitude. It is one of the basic and useful instruments used in electrical and electronic measurement. Oscillators are used in many electronics circuits and systems providing the central clock signal that controls the sequential operation of the entire system [4]. Oscillators convert a DC input (the supply voltage) into AC output (the waveform), which can have a wide range of different wave shapes and frequencies that can be either complicated in nature or simple sine waves depending upon the applications. Oscillators are also used in many pieces of test equipment producing sinusoidal sine waves, square waves, saw tooth waves or triangular shaped waveforms or just a train of a variable or constant width. LC oscillators are commonly used in radio frequency circuits because of good phase noise characteristics and ease of implementation. An oscillator is basically an amplifier with positive feedback or regenerative feedback (in phase) and one of the many problem in electronic circuit design is stopping amplifier from oscillating while trying to get oscillator to oscillate [9]. Oscillator circuit is also employed in the "exciter" section of a transmitter to generate the RF carrier. Other applications include their use as "clocks" in digital systems such as microcomputers, in the sweep circuits found in TV sets and oscilloscopes [2],[5],[7]. Oscillators are also used in the teaching and research laboratories to produce signals and waveform for specific applications. It also finds wide applications in the industries for the manufacture of many electronics instruments.

1.1OPERATION OF OSCILLATOR

An oscillator has a small signal feedback amplifier with an open-loop gain equal to or slightly greater than one for oscillations to start but to continue oscillations the average loop gain must return to unity. In addition to these reactive components, an amplifying device such as an Operational Amplifier or Bipolar Transistor is required. Unlike an amplifier there is no external AC input required to cause the Oscillator to work as the DC supply energy is converted by the oscillator into AC energy at the required frequency [2].

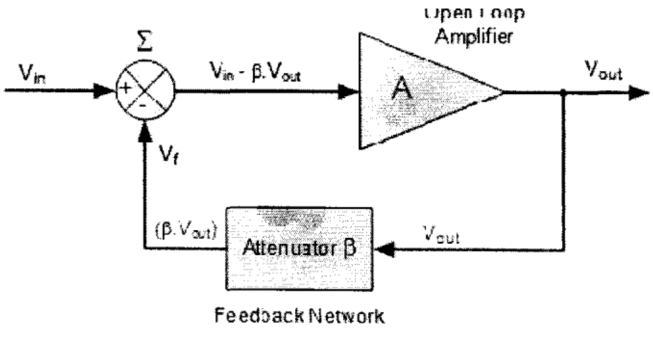


Fig 1.1 Basic Oscillator Feedback Circuit [1]

$A = \frac{V_{out}}{V_{in}}$

A= open loop voltage gain (i.e without feedback)

Now let a fraction β of the output voltage V_{out} be supplied back to the input.

$V_{in} = V_{in} + V_f = V_{in} + \beta V_{out}$ ………………………… 1.1

$V_{in} = V_{in} - V_f = V_{in} + \beta V_{out}$ …………………………..1.2

Equation 1.1 is for positive feedback while equation 1.2 is for negative feedback

Where V_S is the signal voltage and V_f is the feedback voltage.

That is:

$V_{in} = V_s \pm \beta V_{out}$

Considering negative feedback

$A(V_s - \beta V_{out}) = V_{out}$

$A.V_s = V_{out}(1 + A\beta)$

The term βA is called the feedback factor whereas β is known as the feedback ratio and 1+βA is known as loop gain.

$\frac{V_{out}}{V_s} = \frac{A}{1+A\beta} = A_f$ …………….1.3

A_f = the closed loop gain

This is normally refer to as the closed loop voltage gain for negative feedback and for positive feedback

$A_f = \frac{A}{1-A\beta}$ …………….1.4[1]

1.2LC OSCILLATOR

Oscillators are circuits that generate a continuous voltage output waveform at a required frequency with the values of the inductors, capacitors or resistors forming a frequency selective LC resonant tank circuit and feedback network. This feedback network is an attenuation network which has a gain of less than one (β <1) and starts oscillations when Aβ>1 which returns to unity (Aβ=1) once oscillations commence [5].

The LC oscillator's frequency is controlled using a tuned or resonant inductive/capacitive (L.C) circuit with the resulting output frequency being known as the Oscillation Frequency. By making the oscillators feedback a reactive network the phase angle of the feedback will vary as a function of frequency and this is called Phase-shift [2].

The frequency of the oscillatory voltage depends upon the value of the inductance and capacitance in the LC tank circuit. We now know that for resonance to occur in the tank circuit, there must be a frequency point were the value of X_C, the capacitive reactance is the same as the value of X_L, the inductive reactance (X_L X_C) and which will therefore cancel out each other out leaving Only the d.c resistance in the circuit to oppose the flow of current.

If we now place the curve for inductive reactance of the inductor on top of the curve for capacitive reactance of the capacitor so that both curves are on the same frequency axes, the point of intersection will give us the resonance frequency point, (f_r or ω_r) as shown below.

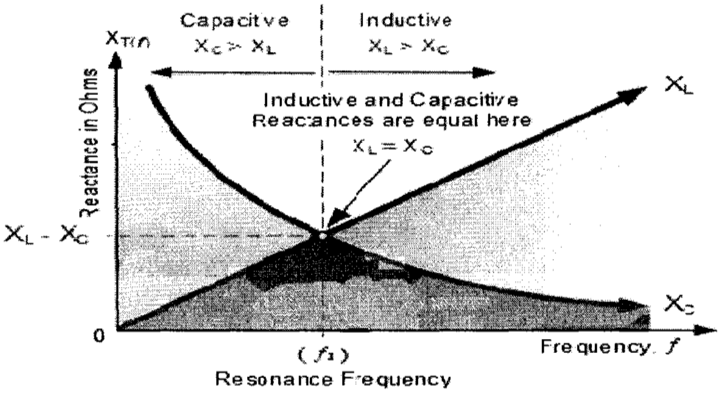


Fig 1.2 Resonance Frequency

Then the frequency at which this will happen is given as:

$X_L = 2\pi f L$ and $X_c = \frac{1}{2\pi f C}$

At resonance: $X_L = X_C$

$$\therefore 2\pi f L = \frac{1}{2\pi f C}$$

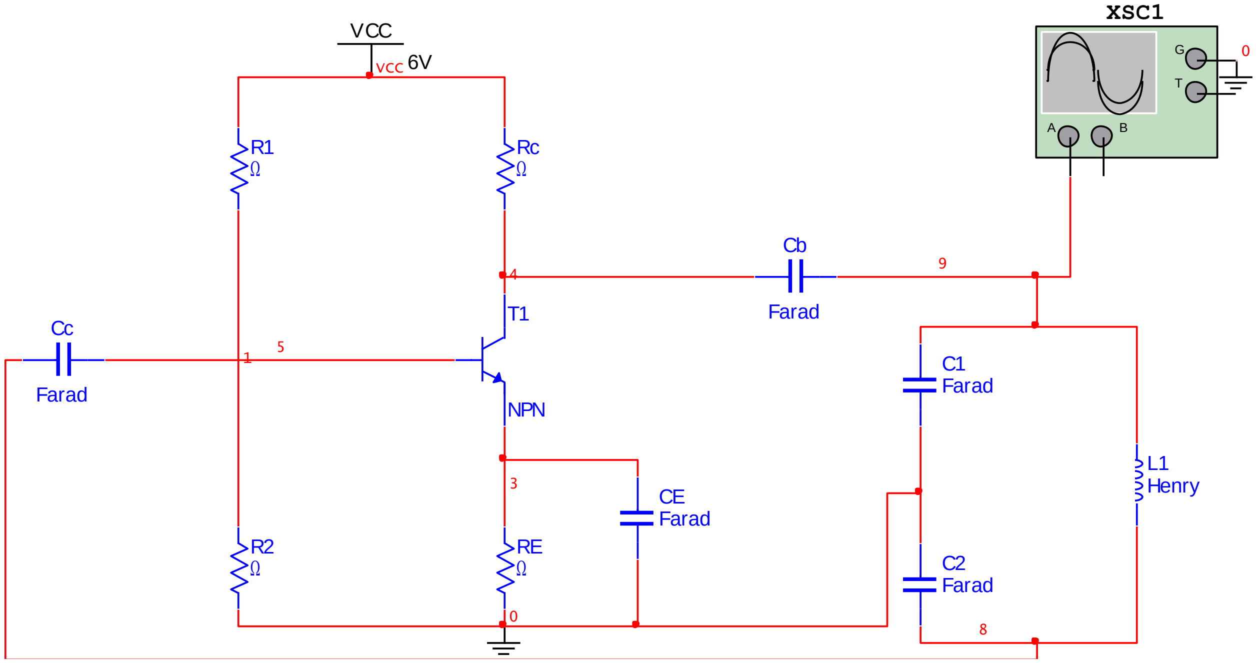
$$f^2 = \frac{1}{(4\pi^2 LC}$$

Therefore the resonance frequency of an LC oscillator is

$$\mathbf{f} = \frac{1}{2\pi\sqrt{LC}} \quad \text{……………………..}\mathbf{1.5}$$

Where:
L is the Inductance in Henries
C is the Capacitance in Farads
f_r is the Output Frequency in Hertz
This equation shows that if either L or C is decreased, the frequency increases. This output frequency is commonly given the abbreviation of (fr) to identify it as the “resonant frequency” [1].

2. CIRCUIT DESIGN

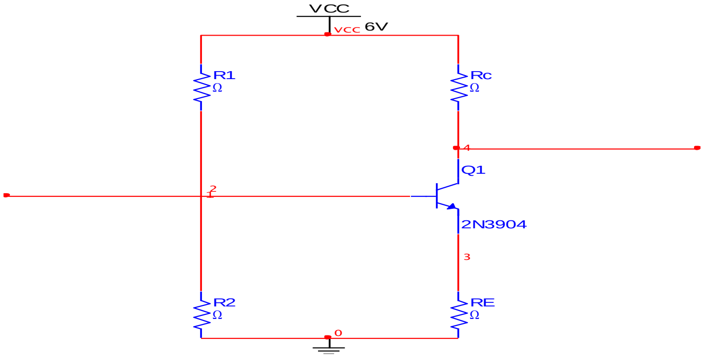


2.1 Complete schematic diagram of a colpitts oscillator

2.1 AMPLIFIER DESIGN:

A 2N3904 NPN transistor is chosen because of the high gain of 300, low noise with a collector current of about 200mA (max) and a transition frequency of up to 300MHz. it is a class A amplifier as the output current flow for full cycle of the input signal. It also allows the linear operation of the a.c signal and distortion reduced to minimum with correct biasing.

2.2 BIASING METHOD



Flg 2.2 voltage divider bias for transistor 2N3904

In most configurations the bias current Ic and voltage Vc are function of the current gain β of the transistor. However, because β is temperature sensitive, especially for silicon transistors, and the actual value of beta is usually not well defined, it would be desirable to develop a bias circuit that is less dependent on or in fact is independent of the transistor beta.

The voltage – divider bias is such a network, this is the most widely used biasing scheme in general electronics. For a single stage amplifier this circuit offers the best resilience against changes in temperature and device characteristics. If the circuit parameters are properly chosen, the resulting level of I_C and V_{CE} can be almost totally independent on beta. Since the Q – point is defined by a fixed level of I_C and V_{CE}, the level of I_b will change with the change in beta, but the operating point on the characteristics defined by I_C and V_{CE} can remain fixed if the proper circuit parameters are employed.

The approximate method is used; this approach permits a more direct analysis with a savings in time and energy[6].

2.3DESIGN METHODOLOGY

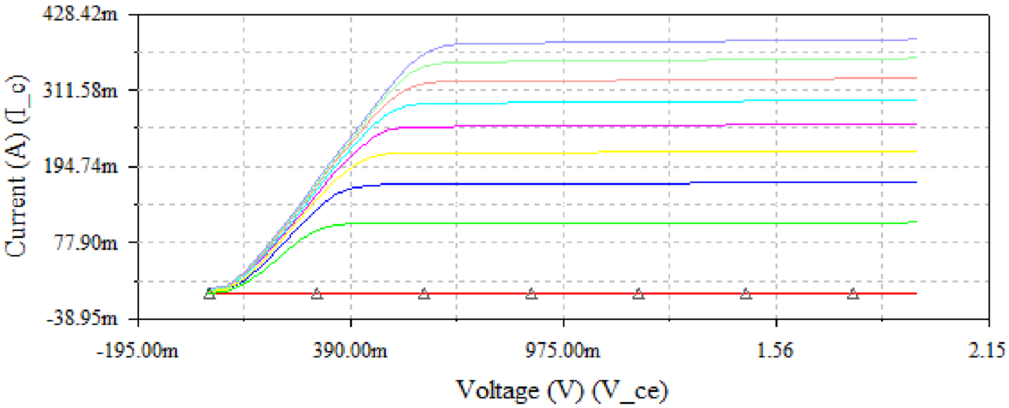


Fig 2.3 output characteristics using IV analyser

The design method applied to carry out this work was computer simulation using electronics work bench software – multisim 8.0

The IV analyzer in the software is used to measure the transistor characteristics. By taking I_b = 12μA, the Q – point was located at the intersection and the value of I_C at Q – point was obtained from the curve to be 1.2mA. From the values obtained for I_C, V_{CC}, V_{CE}, and I_B, the numerical values of the biasing resistors and capacitors were calculated from relevant design equation.

2.4 DESIGN EQUATIONS

$$V_E = 10\% \text{ of } V_{CC} \qquad .2.1$$

The biasing voltage is given as

$$V_B = V_E + V_{BE} \qquad 2.2$$

Using Ohm’s law, the emitter resistor

$$R_E = \frac{V_E}{I_E} \qquad 2.3$$

The Collector emitter amplification factor

$$\beta = \frac{I_C}{I_B} \qquad 2.4$$

$$R_2 = \frac{V_b}{10 \times I_B} \qquad 2.5$$

$$R_1 = \frac{V_{CC} - V_b}{10 \times I_B} \qquad 2.6$$

$$R_C = \frac{V_{CC}}{I_C} \qquad 2.7$$

For Silicon $V_{BE} = 0.6V$

$$10R_2 \leq \beta R_E \qquad 2.8$$

From potential divider of fig 2.1

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} \qquad 2.9$$

The coupling capacitor C_C and the bypass capacitor C_E were obtained from Reactance of capacitor C_b

$$X_{C_b} = \frac{R_{in}}{10} \qquad 2.10$$

$$\Rightarrow \frac{10}{2\pi f C_b} \ll R_{In}$$

$$C_b \gg \frac{10}{2\pi f R_{in}} \qquad 2.11$$

$$R_{in} = \frac{R_1 R_2}{R_1 + R_2} \qquad 2.12$$

Reactance capacitor C_C

$$X_{C_C} = \frac{R_{in}}{10} \qquad 2.13$$

$$C_C = \frac{10}{2\pi f_{max} R_C} \qquad 2.14$$

$$C_E = \frac{10}{2\pi f_{min} R_E} \qquad 2.15$$

[6], [7], [2], and [3]

2.5 DESIGN CALCULATIONS

From equation 2.3

$$V_E = 10\% \; of \; V_{CC} = 10\% \; of \; 6V$$

$$V_E = 0.6V$$

Since V_{BE} for silicon transistor is approximately 0.6V

$$V_B = V_E + V_{BE} = 0.6V + 0.6V = 1.2V$$

Also $I_E = I_B + I_C$

since $I_C \gg I_B$

$$I_E \cong I_C = 1.2mA$$

$$\beta = \frac{I_C}{I_B} = \frac{1.2mA}{12\text{▯}A} = 100$$

$$R_E = \frac{V_E}{I_E} = \frac{0.6V}{1.2mA} = 500\Omega$$

We will use 1.0kΩ for this design for better stability

From equation 2.7

$$R_C = \frac{6{,}0V}{1.2mA}$$

$$R_C = 5K\Omega$$

Verifying with the following equations we have

From equation 2.6

$$R_1 = \frac{6.0V - 1.2V}{10 \times 1.2\mu A}$$

$$R_1 = 40K\Omega$$

From equation 2.7

$$R_2 = \frac{1.2V}{10 \times 1.2\mu A}$$

$$R_2 = 10K\Omega$$

$$R_2 \leq \frac{1}{10}\ \beta R_E$$

$$R_2 \leq \frac{1}{10}\ X\ 100\ X\ 1000$$

$$10K\Omega \uparrow \leq = 10K\Omega$$

From equation 2.9

with $V_{CC} = 6V$

$$V_B = \frac{R_2}{R_1 + R_2}\ V_{CC}$$

$$V_B = \frac{40K\Omega}{10K\Omega + 10K\Omega}\ X\ 6V$$

$$V_B = 1.2V$$

COUPLING CAPACITORS C_b and C_C

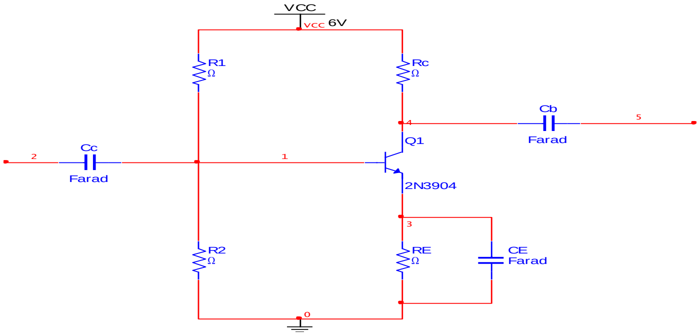


Fig 2.4 circuit diagram to determine the coupling and bypass capacitors

From equation 2.11

$$X_{C_b} = \frac{R_{in}}{10}$$

Where

$$R_{in} = \frac{R_1 R_2}{R_1 + R_2} = \frac{10K\Omega \times 40K\Omega}{10K\Omega + 40K\Omega} = 8K\Omega$$

Using *the minimum frequency of* $10kH_z$

$$C_b = \frac{10}{2\pi f_{min}\ R_{in}} = \frac{10}{2\pi x\ 10kH_z X8K\Omega}$$

$$C_b = 0.02\mu f$$

Although from simulation one can use $10\mu f$, which is found to accommodate higher frequencies with the feedback circuit.

Also, from equation 2.13

$$X_{C_c} = \frac{R_c}{10}$$

$$C_C = \frac{10}{2\pi f_{max}\ R_C} = 3.2nf$$

EMITTER BYPASS CAPACITOR C_E

An amplifier usually handles more than one frequency. Therefore, the value of C_E is so selected that it provides adequate bypass for the lowest of all the frequencies. Then it will also be a good bypass (X_L α 1/f) for all the higher frequencies. The C_E is considered a good bypass if at f_{min}

$$X_{C_E} = \frac{R_E}{10}$$

For this design the lowest frequency f_{min} =10KHz and R_E =1kΩ

$$C_E = \frac{10}{2\pi f_{min}\ R_E} \cong 1.6\mu f$$

An approximate value of 2µf was used for this design in other to accommodate higher frequencies.

2.6DETERMINATION OF OSCILLATING FREQUENCY

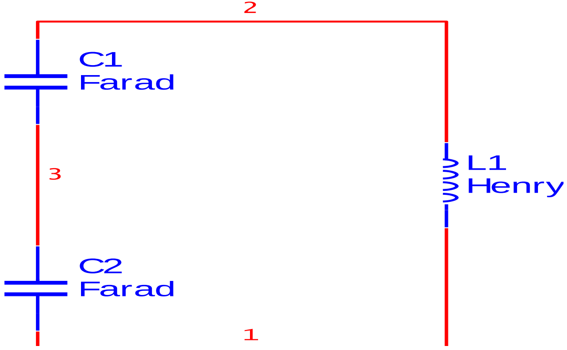


Fig 2.5 tank circuit for colpitts oscillator

The frequency is determined by the tank circuit and is varied by varying the values of the variable inductor L and keeping the values of capacitor C_1 and C_2 constant. This can also be achieved by gang-tuning the two capacitors C_1 and C_2 as obtained in Hartley oscillator. As the inductor L is been tuned, the ratio of the two capacitances remain the same.

From equation 2.15

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

where

$$C=\frac{C_1C_2}{C_1+C_2}$$

Calculating the value of the tuning range of the variable inductor L for the lowest frequency of 20 KHz using capacitance values of C_1 = 1nf and C_2 = 100nf respectively gives:

$$C=\frac{1nf\ \times 100nf}{1nf\ +100nf}=0.99nf\cong 1nf$$

Therefore C =1nf.

$$L=\frac{1}{(2\pi f)^2\times C}$$

$$L=\frac{1}{(2\pi\times 20KHz)^2\times 1nf}$$

$$L = 63.3mH$$

Using the same equation for the highest frequency of 50MHz with the values of C_1 = 1pf and C_2 = 100pf:

$$C=\frac{1pf\ \times 100pf}{1pf\ +100pf}=0.99pf\cong 1pf$$

$$L=\frac{1}{(2\pi\times 50MHz)^2\times 1pf}$$

$$L = 10.1\mu H$$

From the calculated values for the lowest frequency of 20KHz and maximum required frequency of 50KHz.. The tank circuit will require the variable inductor to be varied from 63mH to 10µH.

The following values were obtained from the calculations and are used to design the colpitts Oscillator.

That is: I_B = 12 µA, I_C=I_E=1.2mA, V_{CC}=6V, V_{BE} =06V, R_1= 40Ω, R_2= 10KΩ

R_E = 1KΩ, C_b = C_c = 10µF ,C_E= 2.0µf, C_1= 1pf, C_2 = 100pf for variable inductor of 1µH to 360mH and C_1 =1nf, C_2 =100nf for variable inductor of 1µH to 82mH, V_E=0.6V, β=100, V_B=1.2V.

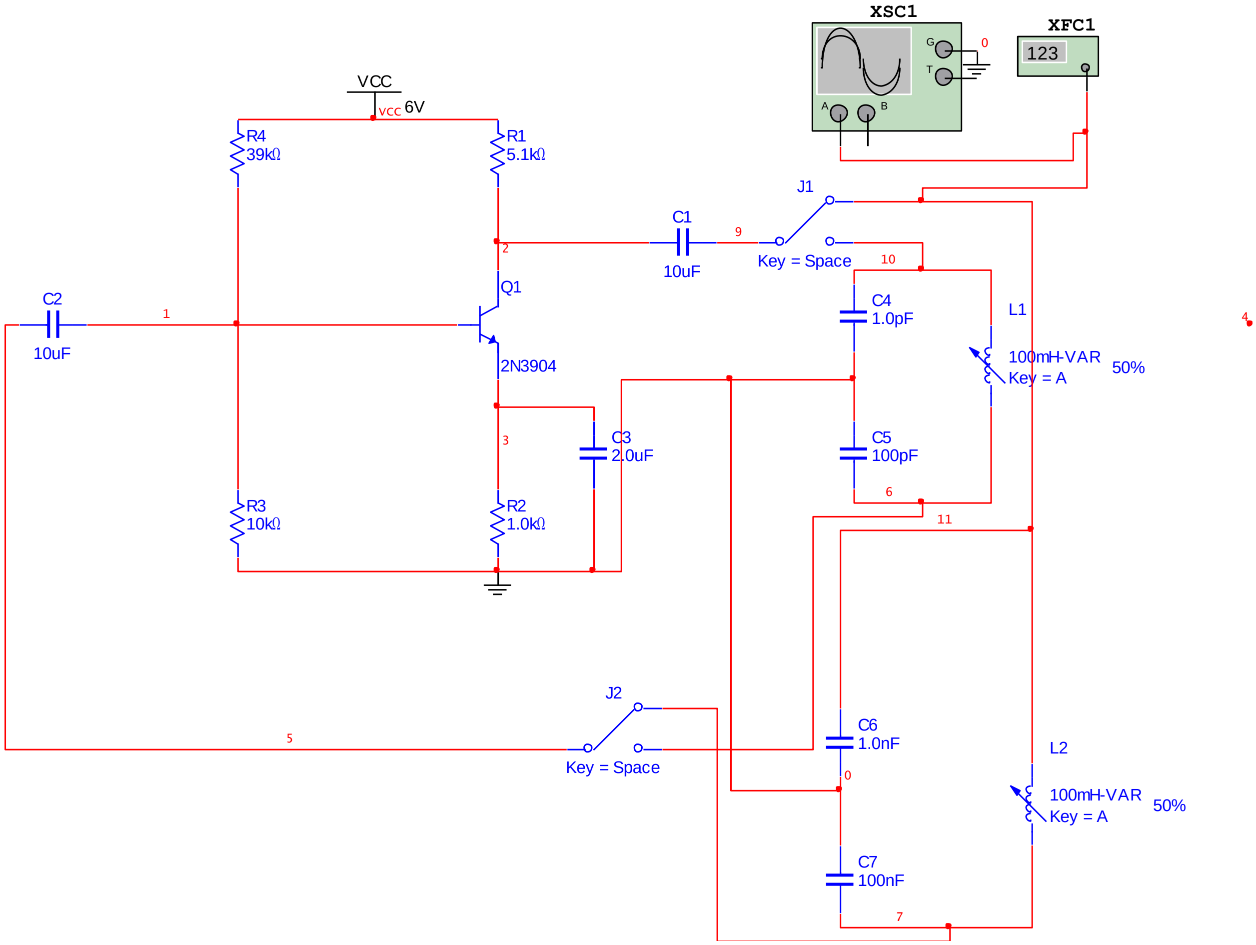


Fig 2.6 complete circuit diagram of a variable frequency colpitts oscillator

3. SIMULATION AND RESULT

Before the implementation of the circuit on a permanent board preferably printed circuit board (pcb) the circuit was simulated using computer software electronic work bench multisim 8.0

The complete circuit diagram was placed on the work bench space and connected to a frequency counter and an oscilloscope. The following results were obtained for C_1= 1pf and C_2 = 100pf while the value of L was varied from 1μH to 360μH and for C_1 =1nf and C_2 =100nf the value of L was varied from 1μH to 62mH.

Table 3.1 simulation result for selected frequency for variable inductor from 1μH to 360μH

C_1	C_2	L	Frequency
1pf	100pf	2.4μH	50MHz
1pf	100pf	3μH	45MHz
1pf	100pf	5μH	34MHz
1pf	100pf	10μH	24MHz
1pf	100pf	20μH	17MHz
1pf	100pf	30μH	14MHz
1pf	100pf	43μH	12MHz
1pf	100pf	68μH	10MHz
1pf	100pf	100μH	8MHz
1pf	100pf	150μH	6MHz
1pf	100pf	330μH	4.3MHz
1pf	100pf	360μH	4.2MHz

Table 3.2 simulation result for selected frequency for variable inductor from 1µH to 62mH

1nf	100nf	1µH	4.8MHz
1nf	100nf	2µH	3.4MHz
1nf	100nf	3µH	2.7MHz
1nf	100nf	5.1µH	2.1MHz
1nf	100nf	10µH	1.5MHz
1nf	100nf	20µH	1.1MHz
1nf	100nf	30µH	870KHz
1nf	100nf	51µH	665KHz
1nf	100nf	100µH	478KHz
1nf	100nf	150µH	388KHz
1nf	100nf	220µH	321KHz
1nf	100nf	300µH	274KHz
1nf	100nf	390µH	241KHz
1nf	100nf	430µH	229KHz
1nf	100nf	470µH	219KHz
1nf	100nf	510µH	210KHz
1nf	100nf	560µH	202KHz
1nf	100nf	620µH	191KHz
1nf	100nf	680µH	183KHz
1nf	100nf	750µH	174KHz
1nf	100nf	820µH	166KHz
1nf	100nf	910µH	158KHz
1nf	100nf	1mH	150KHz
1nf	100nf	2mH	107KHz
1nf	100nf	4.3mH	74KHz
1nf	100nf	9.1mH	52KHz
1nf	100nf	10mH	49KHz
1nf	100nf	16mH	40KHz
1nf	100nf	20mH	36KHz
1nf	100nf	24mH	33KHz
1nf	100nf	30mH	30KHz
1nf	100nf	39mH	26KHz
1nf	100nf	36mH	27KHz
1nf	100nf	51mH	23KHz
1nf	100nf	62mH	2OKHz

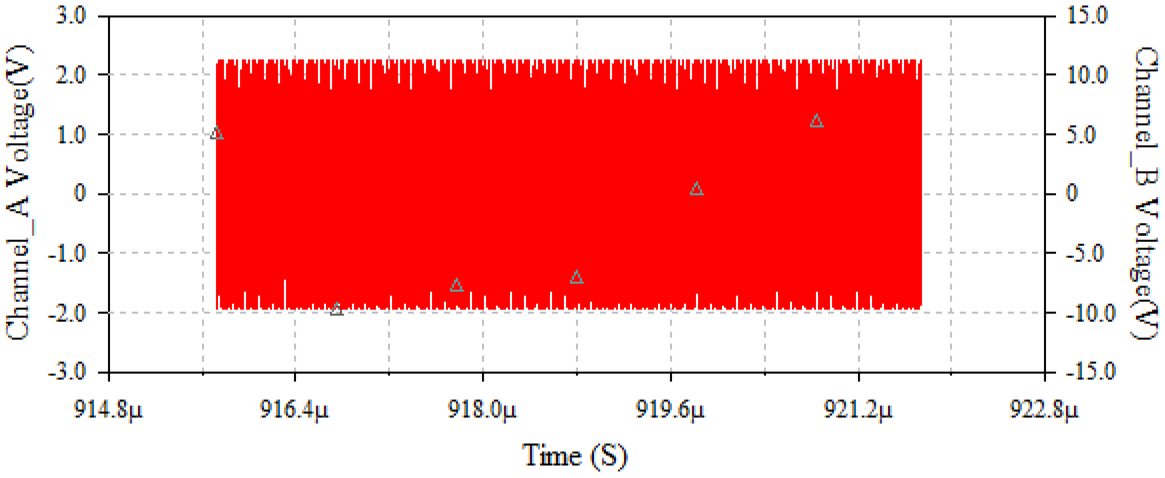


Fig 3.1 output waveform for 50MHz

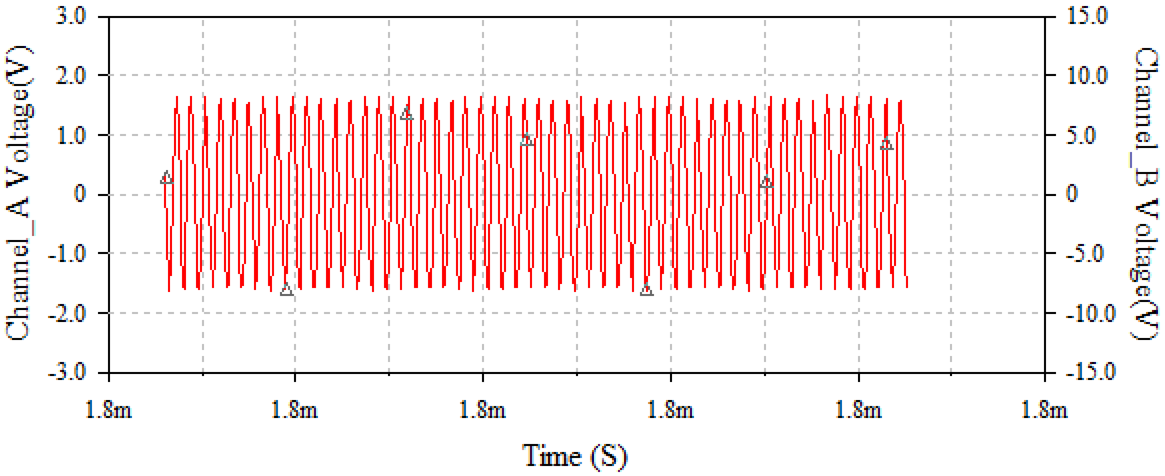


Fig 3.2 output waveform for8MHz

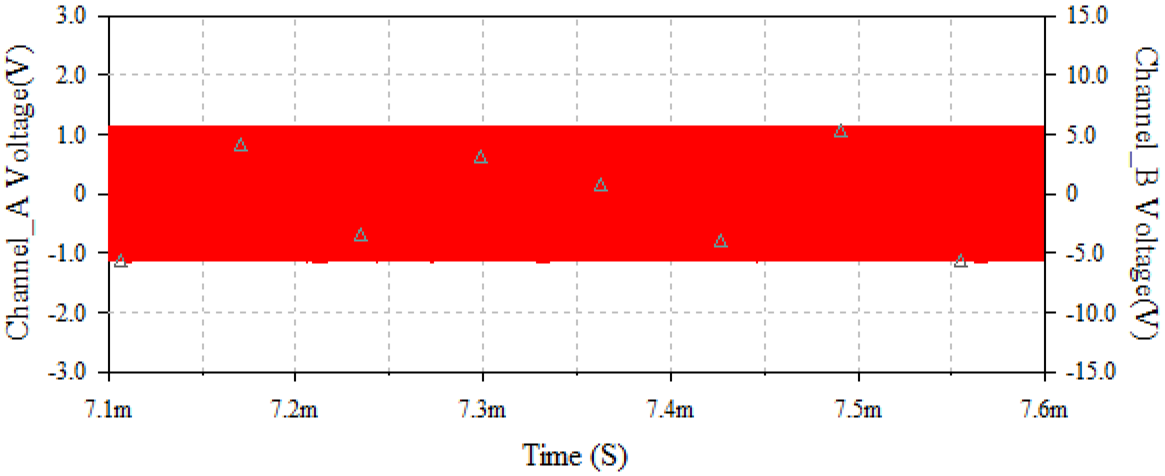


Fig 3.3 output waveform for 6MHz

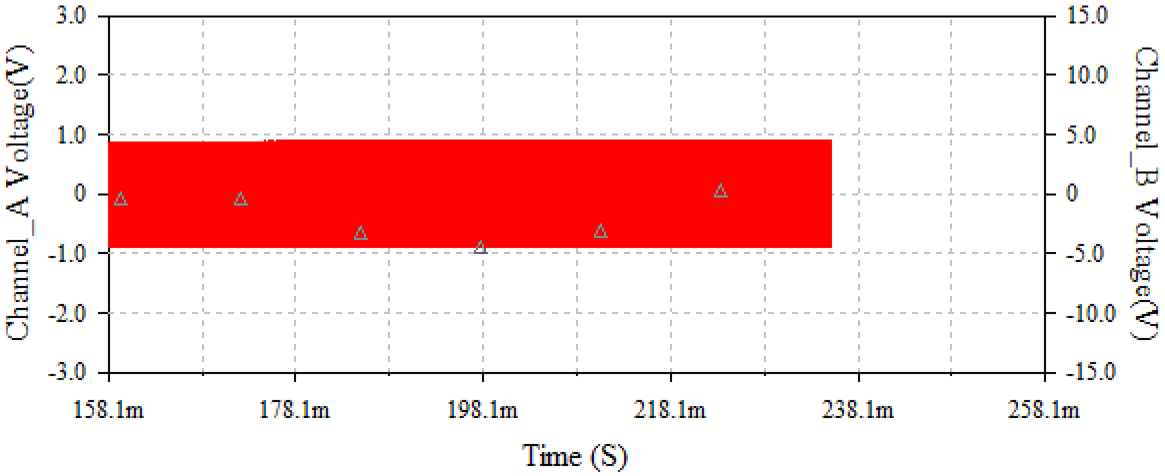


fig 3.4 output waveform for 202KHz

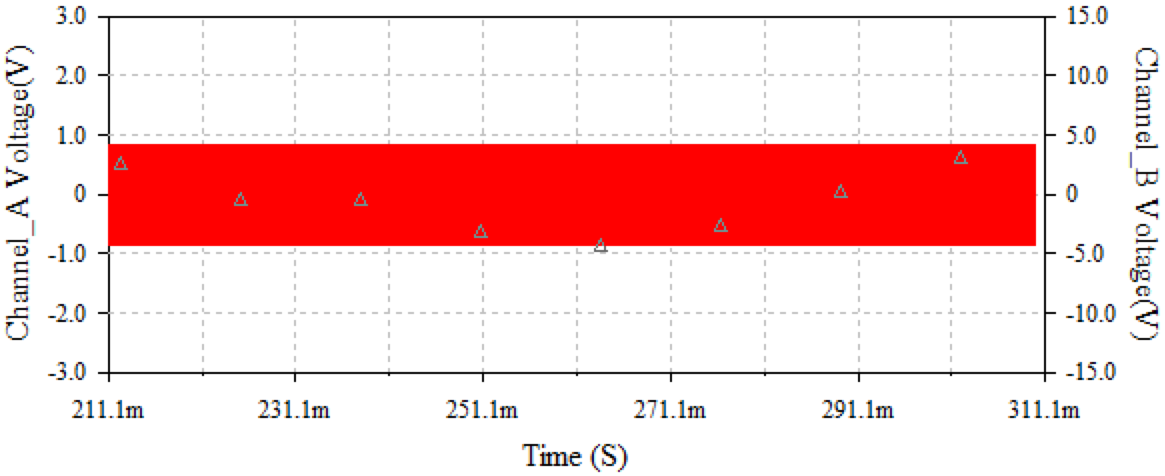


Fig 3.5 output waveform for 150KHz

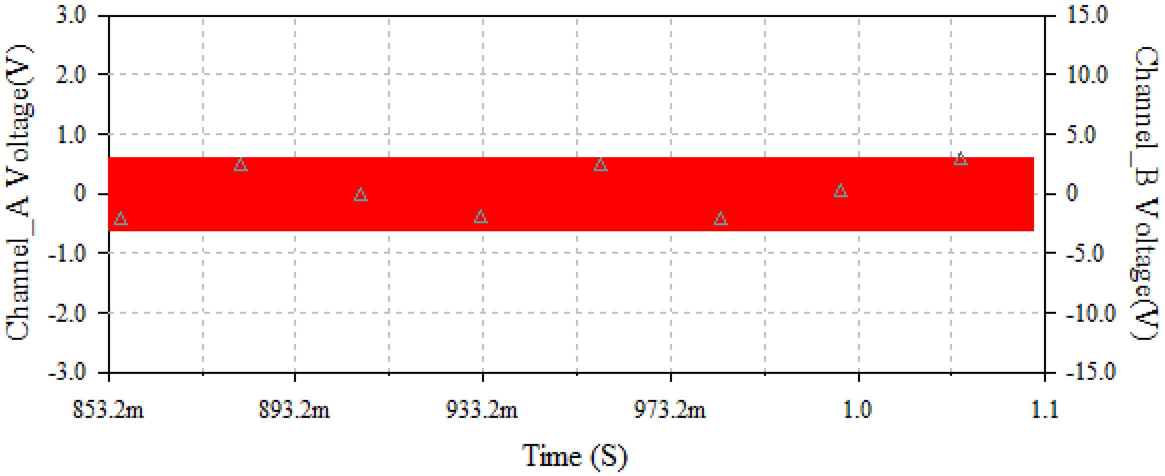


Fig 3.6 output waveform for 20KHz

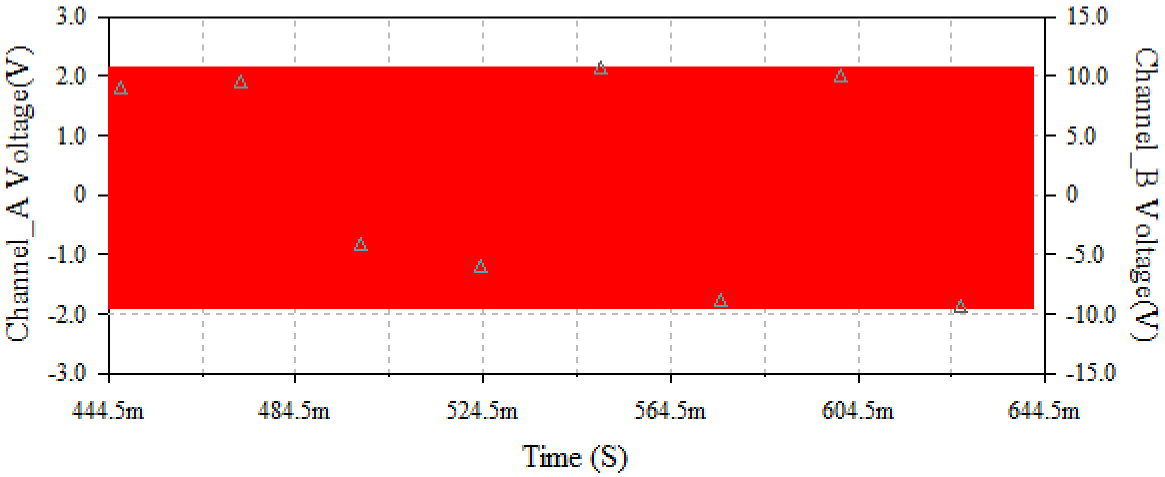


Fig 3.7 output waveform for 40KHz

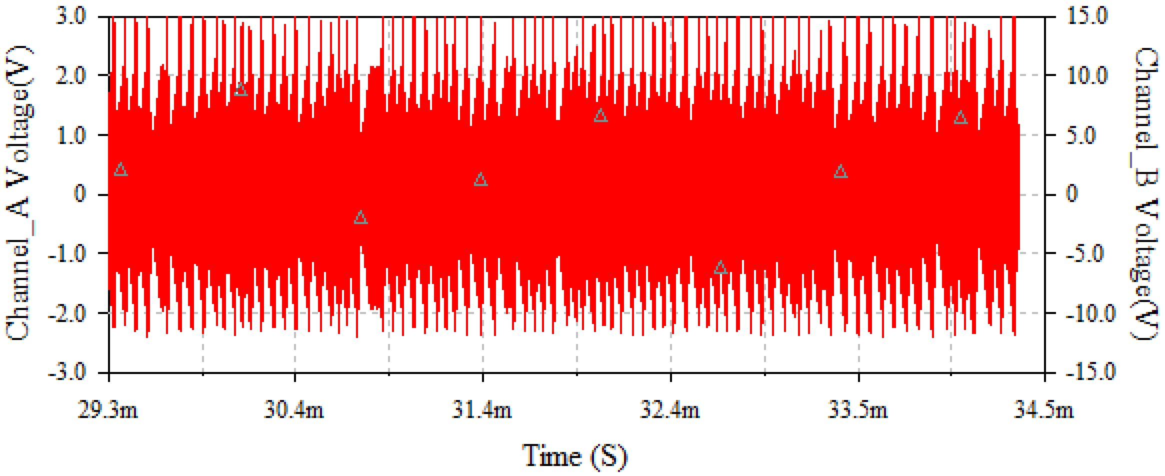


Fig 3.8 output waveform for 2.1MHz

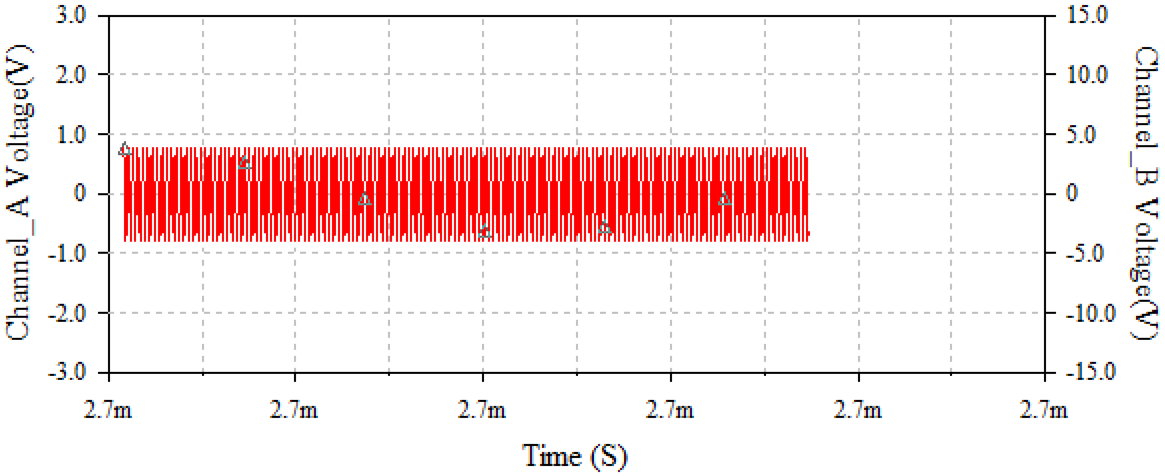


Fig 3.9 output waveform for5MHz

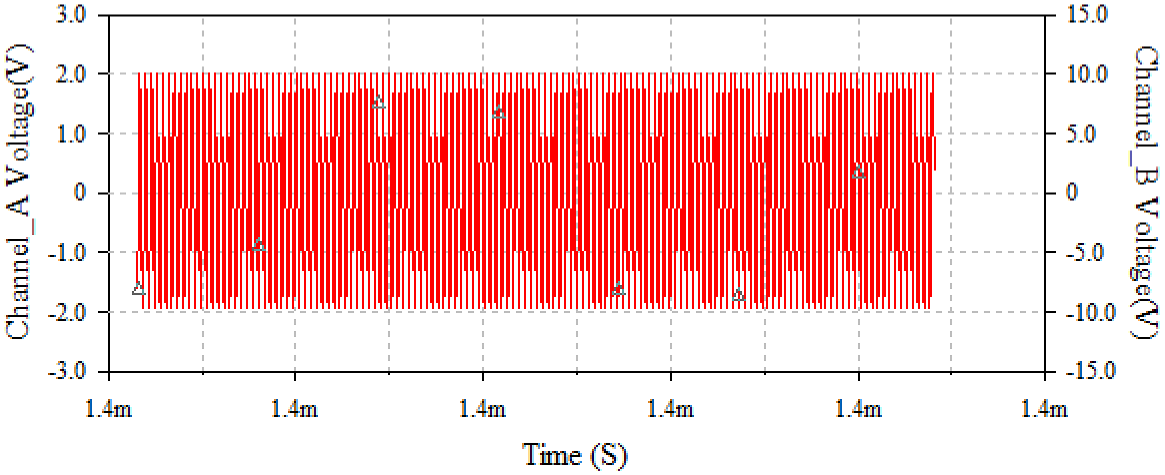


Fig 3.10 output waveform for 10MHz

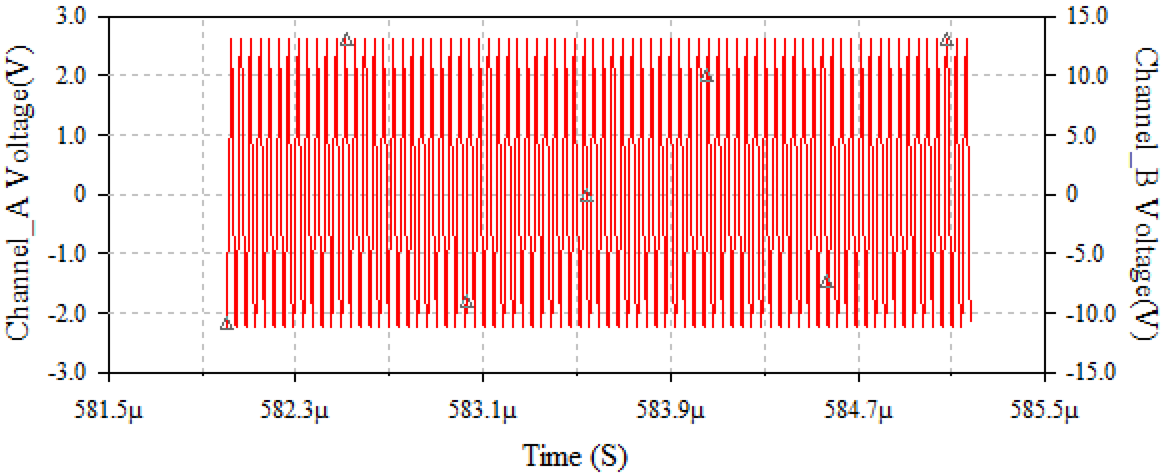


Fig 3.11 output waveform for 24MHz

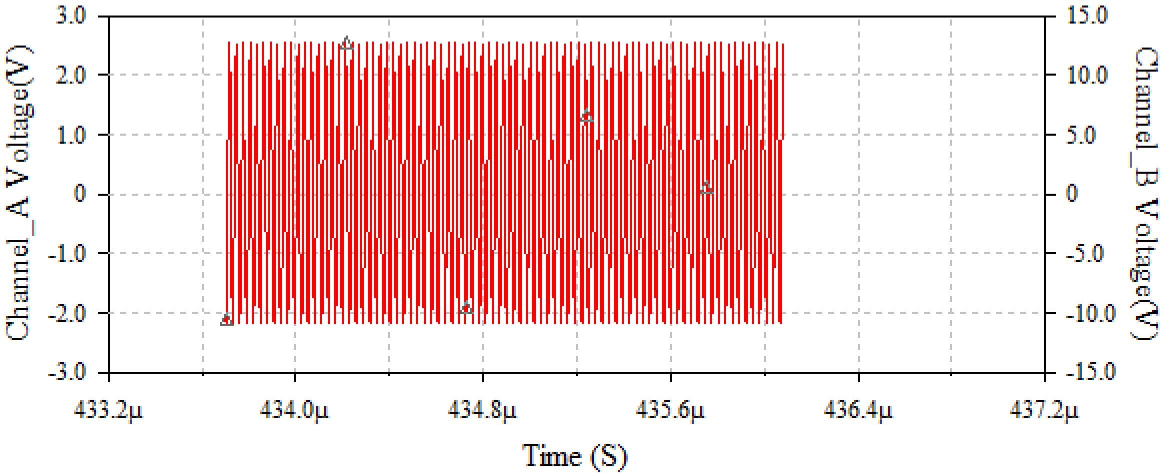


Fig3.12output waveform for 34MHz

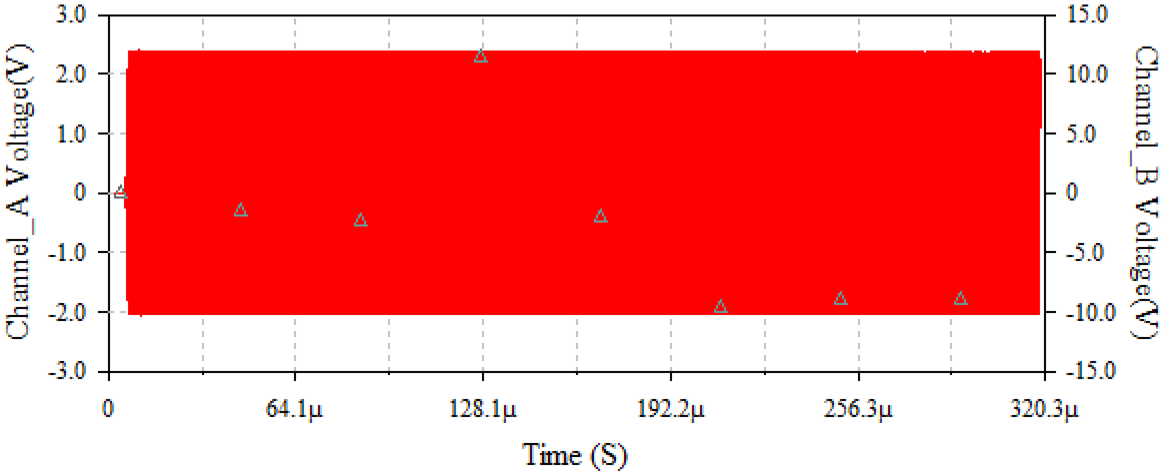


Fig 3.13 output waveform for 45MHz

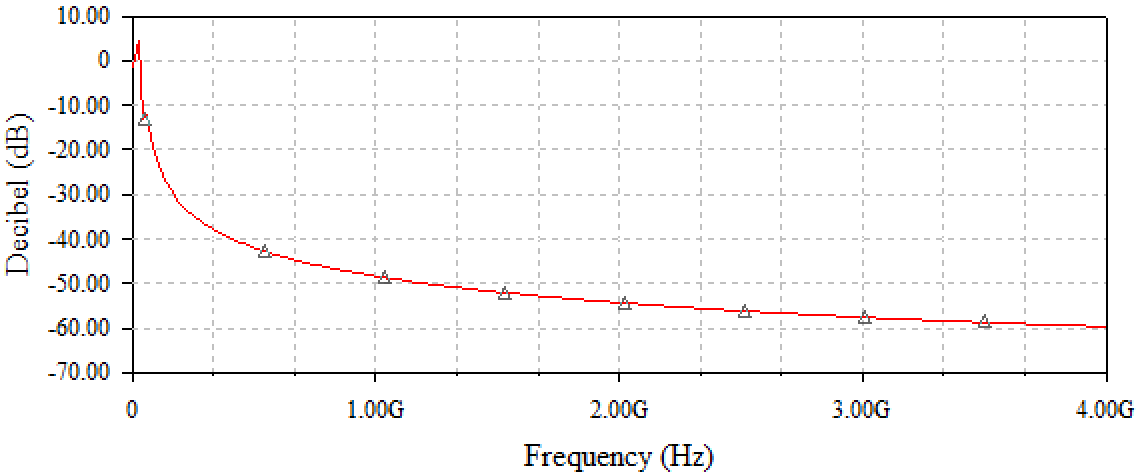


Fig 3.14 graph of amplitude against frequency for 50MHz

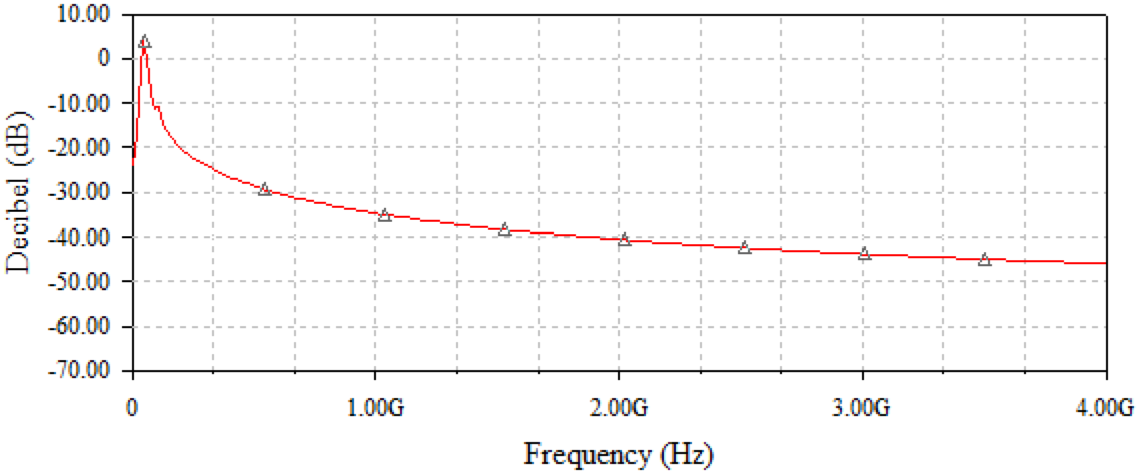


Fig 3.15 graph of amplitude against frequency at 50MHz

DISCUSSION

Table 3.1 and 3.2 shows the frequency of oscillation for constant capacitance value C_4, C_5, C_6 and C_7 when the inductor was varied from 1µH to 1mH and from 1µH to 360µH respectively. Figures 3.1 to 3.13 show the grapher view of the output waveform as displayed on the oscilloscope for some selected frequencies. The graphs show no signs of noise or distortions. Each of the graphs shows a steady output voltage with time of oscillation. The values of the distortion were measured to be 6% and 0% respectively for 50MHz and 20 KHz oscillating frequency. The grapher view of the spectrum analyzer is shown in figures 3.14 and 3.15. It shows the amplitude of oscillation with frequency.

CONCLUSION

In this work a variable frequency oscillator (VFO) from 20 KHz to 50MHz have been design, simulated and analyzed using electronics workbench multisim 8.0. We were able to study the variation in frequency at constant capacitance value when the inductance of the inductor was varied from 1µH to 1mH for both tank circuits. The results obtained will make it easy to construct any oscillator that finds application within the design frequencies without necessary passing through any design stress.

5. REFERENCES

[1]. Lulian,R.,(2013) High frequency VCO design and schematics.http//www.qsl.net/va3iul/ (retrieved 15/01/13).

[2]. Gupta, J.B. (2011): An Integrated Course in Electronic Engineering. Published by S.K Kataria & Sons Ansari Road Daryayni Road New Delhi 2nd edition Pp578-599.

[3]. Jasper Bank.(2006) A harmonic – oscillator Design Methodology based on Describing Functions Thesis for PHD. Department of signal and systems circuit design group. Chalmers University of tech. Goteborg Sweden ISBN 91-72 to 748-2.Http//www.oscillator design.com (retrieved 20/8/2012).

[4]. Makram, M. M and Mohammed M .M., (2008): On the design of low Phase –Noise CMOS LC-Tank Oscillators 2008 International Conference on Micro-electronics. Http//www.colpittoscillator.com (retrieved 12/7/2012)

[5]. Metha, V.K and Metha R., (2008): Principle of Electronic S.Chand & company Ltd Ram Nagar, New Delhi 11th Edition Pp 141-191.

[6]. Robert, L. Boylestard and Louis Nashelsky (2009): Electronic Device and Circuit Theory Published by Pearson education Inc., Prentice Hall 10th Edition Pp763-767.

[7]. Sedha, R.S (2006): Applied Electronics. S. Chand & company Ltd Ram Nagar, New Delhi 13th Edition Pp780-781.

[8]. Theraja, B.L and Theraja, A.K (2006): Electrical Technology S.Chand & company Ltd Ram Nagar, New Delhi 24th Edition Pp2416-2421.

[9]. Wayne, S., (2013), Tuned LC oscillator tutorial and oscillator basis. Http//www.variable LC oscillator.com (retrieved 15/01/13).