Quadrature Down Converter

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***Abstract*- In this project we design a quadrature down converter, a vital part of modern communication systems. The entire design process along with calculations, simulations, diagrams and experimental verification is included.**

***Index Terms*— Quadrature oscillator, Switch (Mixer), Low pass filter**

I. INTRODUCTION

The quadrature down converter converts high-frequency quadrature signals to baseband or intermediate frequency signals. It is very important in wireless communication as most devices cannot use high frequency signals directly. The down conversion process is required for demodulating and extracting information from received signals.

A quadrature down converter's principal function is to shift the frequency of the input signal while preserving the in-phase (I) and quadrature-phase (Q) components. This is commonly accomplished by combining mixing, filtering, and amplification stages.

The quadrature down converter has various advantages, including increased signal quality, noise performance, and effective spectrum utilization.

. We aim to achieve high linearity, low noise and broad bandwidth .

The converter consists of 3 main parts –

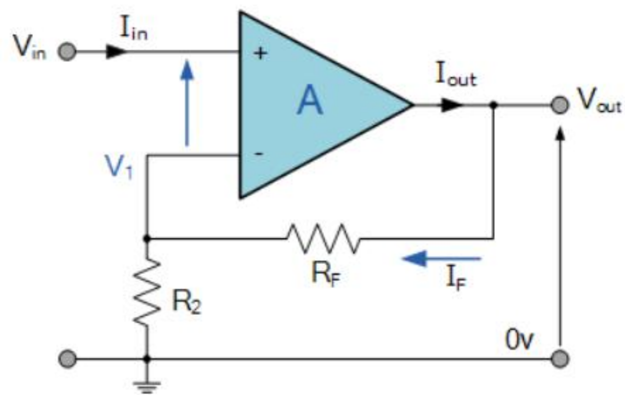
1) A quadrature oscillator
2) A Mixer
3) A Low Pass Filter

Concepts used-

Non-inverting amplifier-

In non-inverting operational amplifier configuration, the input voltage signal, (VIN) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes "Positive" in value in contrast to the "Inverting Amplifier" circuit we saw in the last tutorial whose output gain is negative in value. The result of this is that the output signal is "in-phase" with the input signal.

Feedback control of the non-inverting operational amplifier is achieved by applying a small part of the output voltage signal back to the inverting (–) input terminal via a R*f* – R2 voltage divider network, again producing negative feedback. This closed-loop configuration produces a non-inverting amplifier circuit with very good stability, a very high input impedance, Rin approaching infinity, as no current flows into the positive input terminal, (ideal conditions) and a low output impedance, Rout as shown below.



II. QUADRATURE OSCILLATOR

A. Working principle

We design a quadrature oscillator produces which produces two signals in quadrature with each other (phase difference of 90 degrees) at 100 kHz and with an oscillation amplitude of 1 V(p-p).

The Quadrature Oscillator takes in the thermal noise from the environment and gives out a sine wave and a cosine wave.

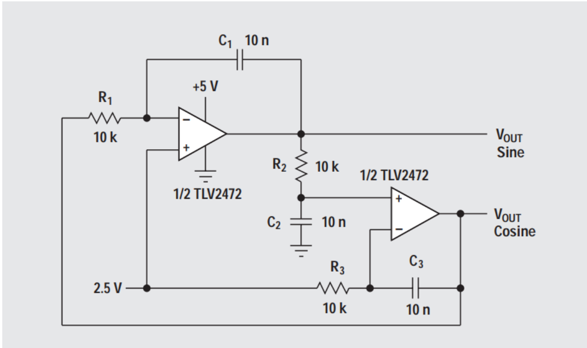
B. Components used-

- U714 opamps
- Capacitors
- Resistors
- Voltage sources
- Diodes
- DSO

C. Derivations and calculations-

According to Barkhausen criteria for stability,
|Gain| <=1 and phase shift should be 180 degrees
(to prevent indefinite rise or fall in amplitudes).

Op Amps are used in the negative feedback configuration and add a phase of 180 °in each feedback



The total gain is the product of three individual gains-

$$\frac{1}{SR_2C_2} \cdot \frac{(1 + SR_3C_3)}{SR_3C_3} \cdot \frac{1}{1 + SR_2C_2} = 1$$

Gain should be equal to 1 so that the amplitude is stable.

From here,

$$w = \frac{1}{2\pi RC}$$

The required frequency is 100kHz.

Taking,

$$R_1C_1 = R_2C_2 = R_3C_3 = RC = 1000 \cdot 10^{-9}$$

We also get,

$$V_{os} = \frac{1}{R_1C_1S} V_{oc}$$

We want both their amplitudes to be equal to 1 so RCS=1

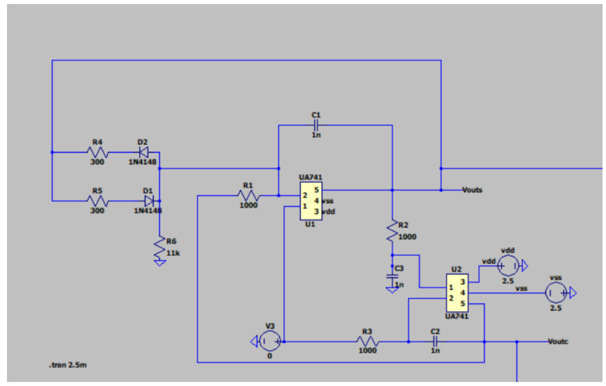
Op amp-1 (Negative feedback, Inverting configuration) This op amp converts noise to a sine wave.

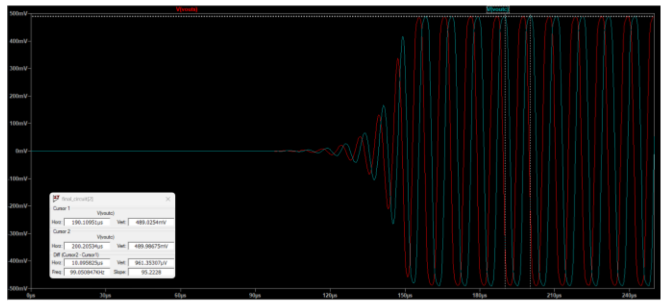
Op amp-2 (Negative feedback, Non-Inverting configuration) This op amp is part of a integrator circuit where the sine wave gets converted to a cos wave.

We also use a diode limiter circuit as a stabilizing mechanism. When the amplitude increases beyond a certain point, the diodes become forward-biased and start conducting, effectively cutting off the excess signal and thus preventing the amplitude from rising further.
They also introduce non-linearity into the feedback path. It is vital in shaping the waveform of the oscillation, ensuring it remains sinusoidal even as the amplitude changes .
The shape of the wave may be triangular without the diode circuit.

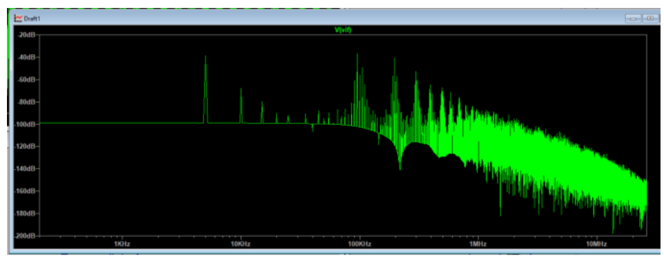
There is no input wave given to this circuit.
The output is a pair of waves 90 ° to each other.

D. LT SPICE simulations-

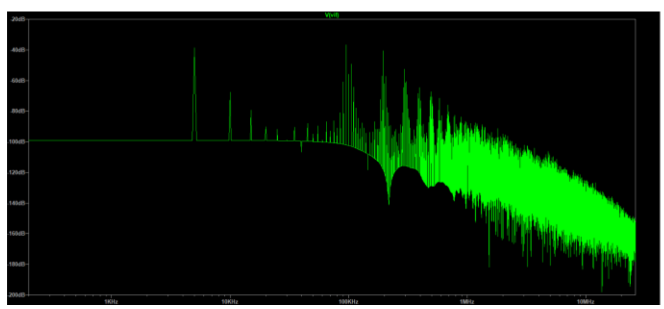




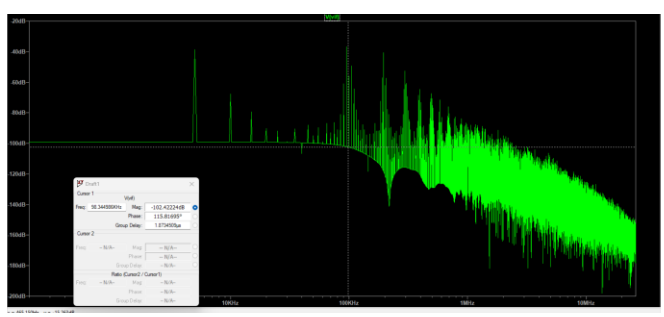
95k



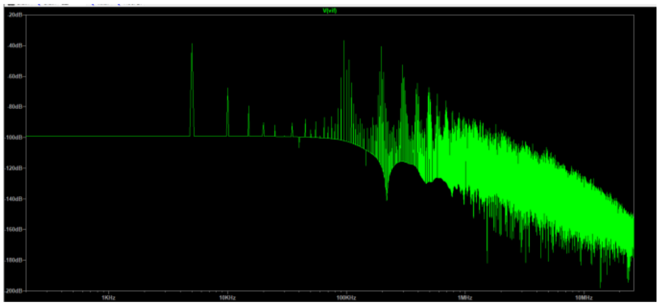
98k



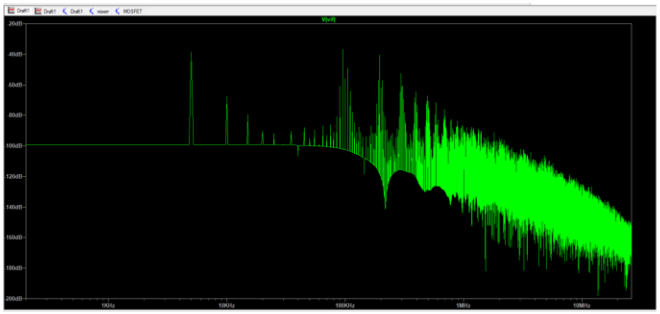
99k



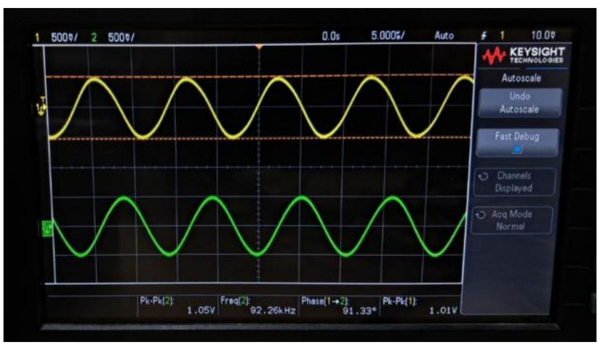
101k



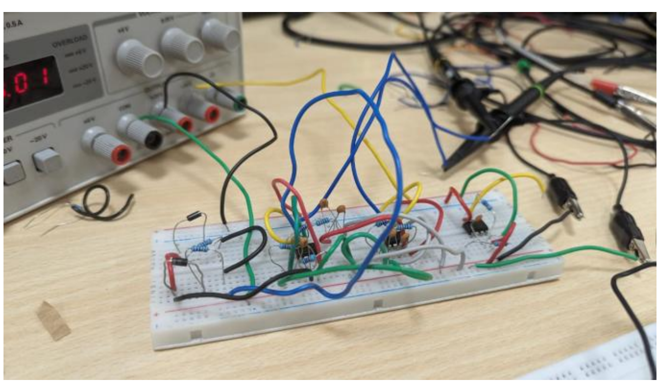
105k



E. DSO output-



F. Circuit diagram



III. SWITCH (MIXER)

A. Working principle

A MOSFET is used as a switch, where the oscillator signal is applied to the gate of the device, input is applied at the source and the frequency output is taken at the drain end. The principle is that the MOSFET turns off and on many times in a second performing a sampling action of the signal.

B. Components used-

- MOSFETS – CD4007
- Capacitors
- Resistors
- Voltage sources
- DSO

C. Derivations-

1) MOSFET characterization: The MOSFET has been biased to operate in triode region where $V_{DS} << V_{GS}$- V_T

2) Working: This circuit essentially multiplies the two waves which produces two waves, one with a frequency equal to the sum of the frequencies and one with the difference of the two frequencies.

$$v_{IF_I} = v_{in} \times v_{OSC_I} = \frac{A_1 A_2}{2}\left(cos(\omega_{in}t - \omega_{OSC}t) + cos(\omega_{in}t + \omega_{OSC}t)\right)$$

$$v_{IF_Q} = v_{in} \times v_{OSC_Q} = \frac{A_1 A_2}{2}\left(sin(\omega_{in}t + \omega_{OSC}t) - sin(\omega_{in}t - \omega_{OSC}t)\right)$$

In the triode region,

$$I_D = \mu C_{ox}\frac{W}{L}(V_{GS} - V_T)V_{DS}$$

V_{GS} =Output from the oscillator (either sine or cos)
$V_{DS} = V_{IN}$ (Since V_{OUT} is very less compared to V_{IN})

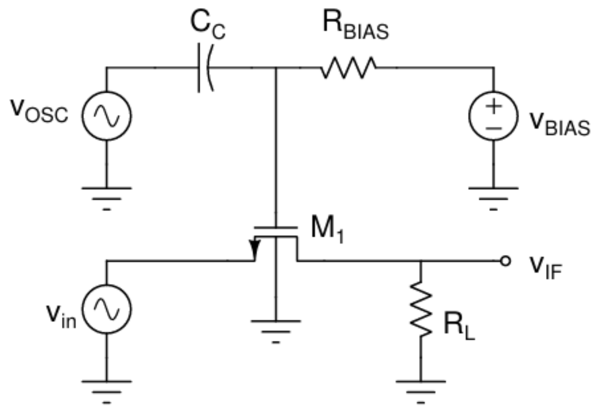
$V_{BIAS} = V_T$ = 0.5V. We are shifting the operation point so that if V_{OSC} is lesser than V_T the MOSFET switches off else it switches on.

I_D is directly proportional to (Vgs)(Vds). Current will be proportional to Vin* Vosc. And $I_D$is directly proportional to V_{IF}

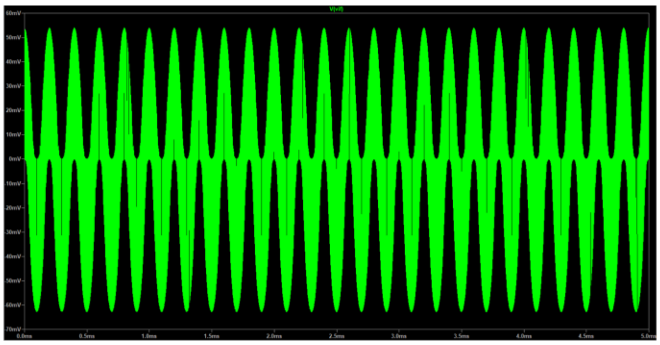
R_{BIAS} should be high so that there is no loss in Vosc. There is also a high pass action so R_{BIAS} and C values must be chosen such that the frequency of V_{OSC} passes through it.
Because Vosc turns off and on rapidly small impulses are generated which make up the output signal. It contains the summation of low and high frequency waves.

R_{BIAS}= 1 MegaOhm
C=10 microFarad

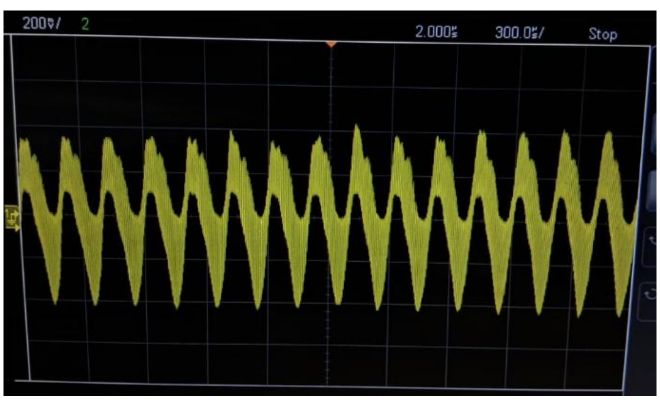
Since the output of the mixer is very small,we can use an op amp to amplify the Vout.



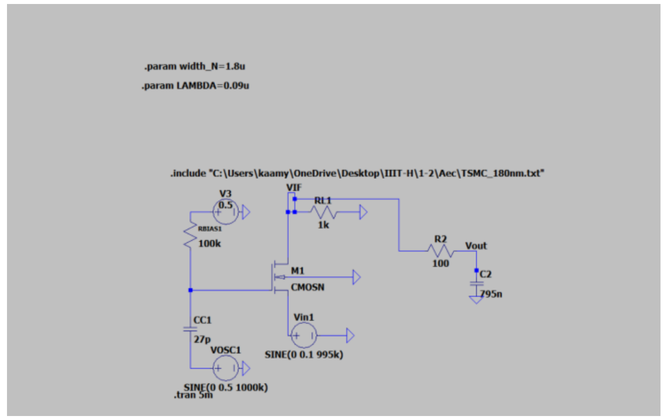
D. LT SPICE simulations-



E. DSO output-



F. Circuit diagram-



IV. Low Pass Filter

A. Working principle

A low-pass filter (LPF) is a circuit that only passes signals below its cutoff frequency while attenuating all signals above it.

B. Components used-

- Capacitors
- Resistors
- Voltage sources

C. Derivations-

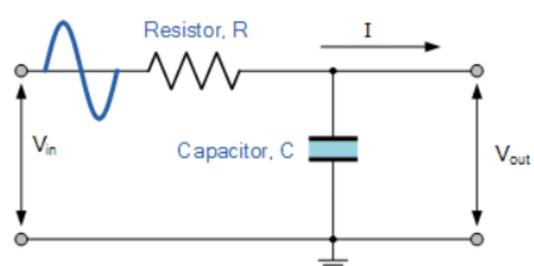
Vout = 1/SRC

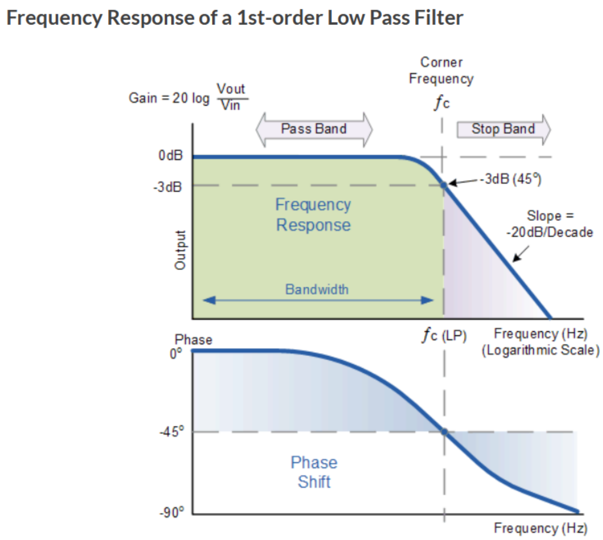
This circuit must let the wave with lower frequency pass but must not let the wave with the higher frequency pass.

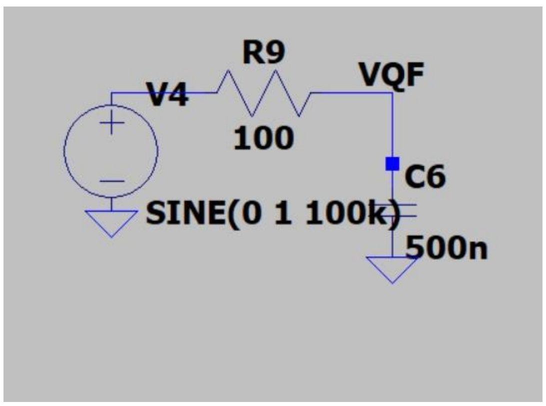
So f= 1/RC

Our output frequency is of the 100kHz range so
1/RC << 100k.

R= 100 ohm C = 500nF

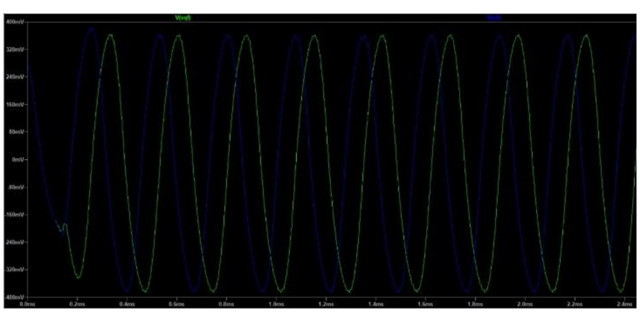


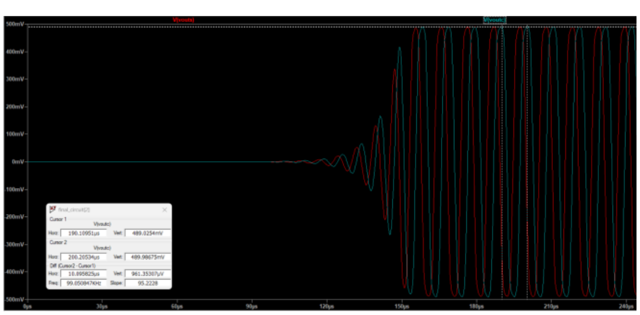


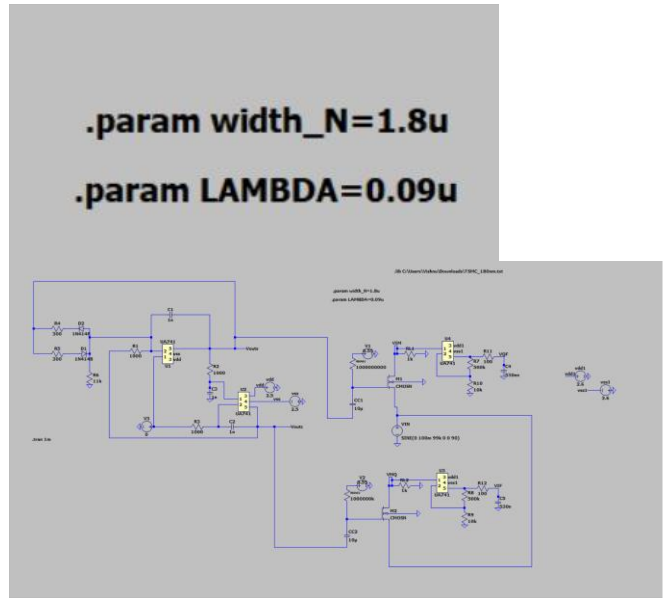


V. Complete Circuit Prototype

A. LT SPICE-

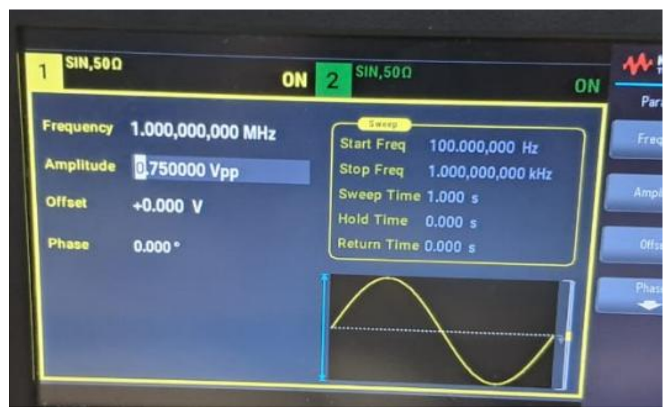




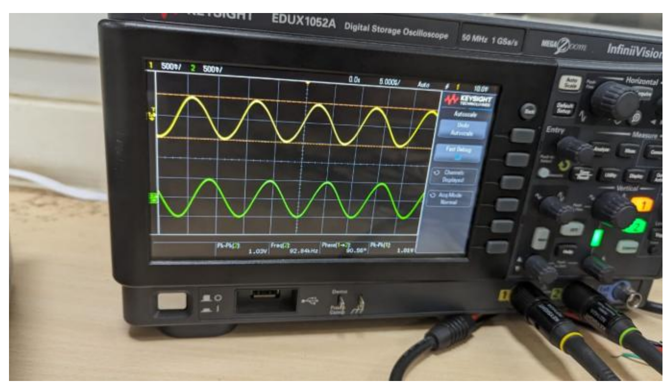


B. DSO-

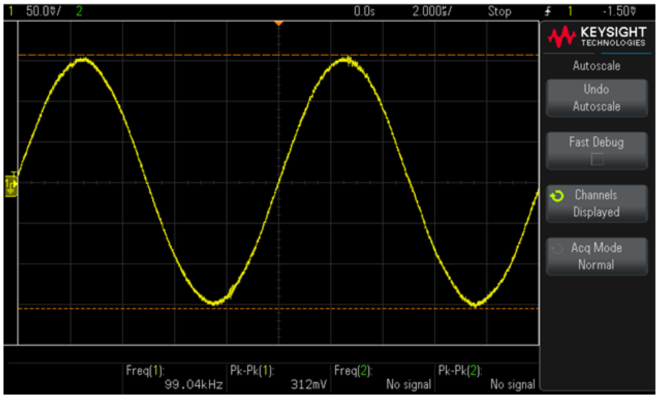
Input Voltage-



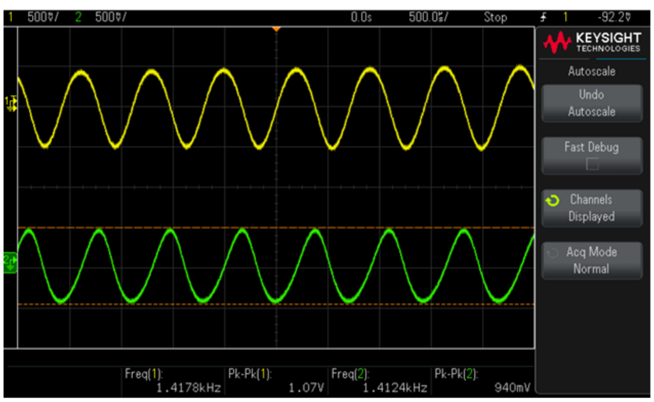
Output of the quadrature-

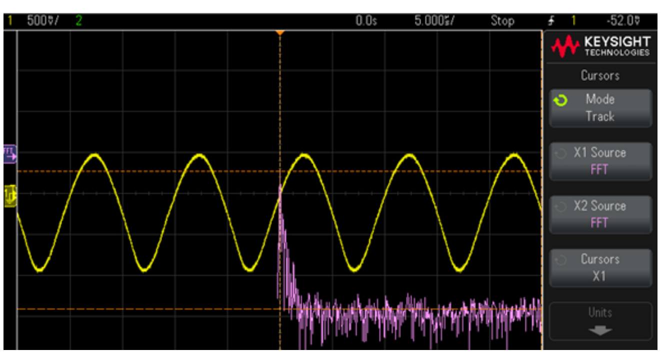


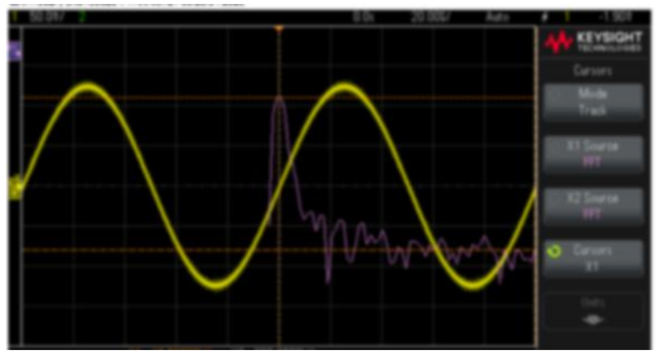
Input to the mixer circuit-



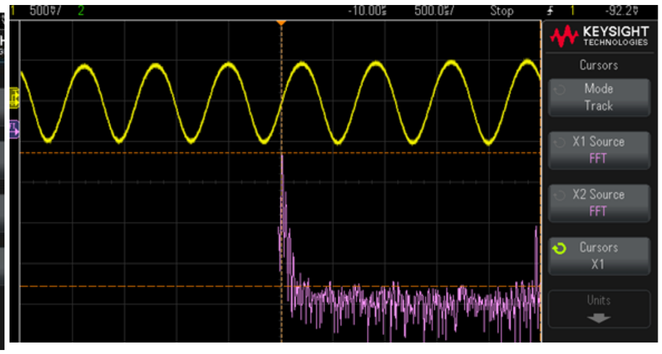
Output of lpf-



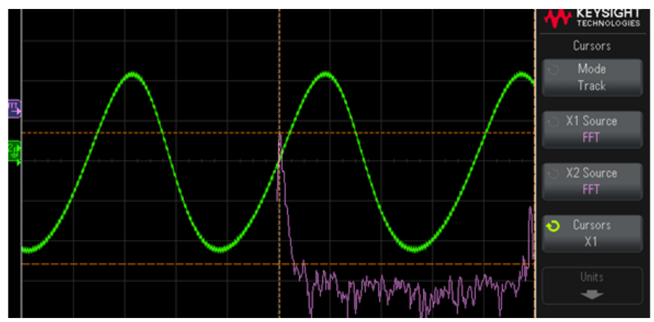




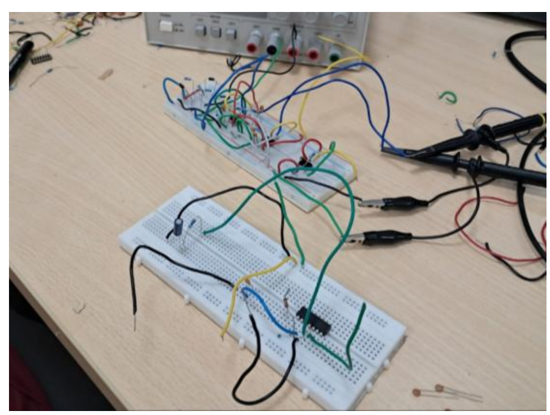
Fft of sine wave-

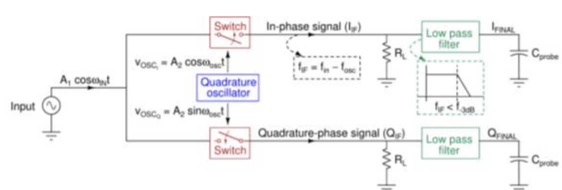


Fft of cos wave-



C. *Circuit diagram-*





D. *Overall working*

*T*he final output must be a signal which has all the characteristics of the Input signal but of low frequency which devices can easily work with.

VI. CONTRIBUTIONS-

Pragnya-

- PPT, report
- Mixer circuit
- LPF
- LTSPICE simulations for quadrature oscillator, lpf, combined
- Report

Kaamya-

- PPT, report
- Quadrature oscillator circuit
- Amplifier
- LTSPICE simulations for mixer, down converter combined
- Report

VII. SPICE VERSUS HARDWARE

There is a slight difference between the simulated and experimental results.This is due to external factors such as noise and imperfections in MOSFETs and op amps.

Paramertes	**Measured**	**Simulated**
Oscillator frequency (I-phase)	92.33 KHz	99.05 kHz
Oscillator frequency (Q-phase)	94.33 KHz	98.89 kHz
Oscillator Amplitude (I-phase)	1.01 V	1.00 V
Oscillator Amplitude (Q-phase)	1.05 V	1.00 V
Phase	91,2	90
Input frequency	99 kHz	99 kHz
Supply - V_{DD}	7.14 V	5 V
Supply - V_{SS}	-7.14 V	-5 V
V_{BIAS}	2.5 V	0.5 V
C_C	10 µF	10 µF
R – LPF	100 Ω	100 Ω
C – LPF	500 nF	500 nF

VIII. REFERENCES

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[2] Chapter 3 and 4 from 'RF Microelectronics' (2nd edition) by Behzad Razavi.)
[3] Chapter 2 and 14 from 'Microelectronic Circuits' (7th edition) by Sedra and Smith.
[4] Ron Mancini, "Design of op amp sine wave oscillators", Texas Instruments, 2000.
[5] Ralph Holzel, "A Simple Wide-Band Sine Wave Quadrature Oscillator", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASURE MENT, VOL. 42, NO. 3, JUNE 1993.)
[6] Lecture notes, tutorials and labs conducted in this course.