Quadrature Down Converter

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***Abstract*—The objective of this project is to develop a Quadrature Down Converter (QDC), enabling frequency down-conversion. The project will involve a comprehensive analysis of system requirements, followed by the design, simulation, and practical realization of the QDC. Through systematic examination of operational needs, circuit design, virtual testing, and physical implementation.**

Keywords—Quadrature Oscillator, Mixer circuit, low pass filter

I. INTRODUCTION (*HEADING 1*)

The quadrature down converter converts the high-frequency quadrature signals into low-frequency signals. This conversion is essential for extraction of information from received signals. Internally, a quadrature down converter preserves the in-phase (I) and quadrature-phase (Q) components of the input signal while shifting its frequency. This is typically achieved through a combination of mixing, filtering, and amplification stages integrated into the converter's design.

In this project, we are developing a quadrature down converter by choosing and integrating essential components like mixers, filters, and oscillators. The primary goal is to create a high-performance system that can effectively convert high-frequency signals to low-frequency signals while preserving signal integrity. This involves optimizing each stage of the down converter to achieve efficient frequency conversion.

A QDC has three main components. They are:

1) *Qudrature Oscillator:*
This oscillator circuit generates two high-frequency signals characterized by a phase disparity of 90°.
2) *Mixer Circuit (or) Switch:*
This circuit (which includes MOSFET as an important component) performs signal mixing by combining two input signals, one sourced externally and the other derived from the oscillator, resulting in the generation of a mixed signal.
3) *Low Pass Filter:*
This filter selectively attenuates high-frequency signals while allowing low-frequency signals to pass through, based on its defined cut-off frequency.

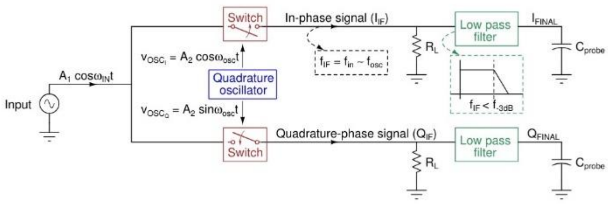


Fig.1: Quadrature Down Converter

II. CIRCUIT ANALYSIS

The Quadrature Oscillator is given an input of 0V, so the offset DC voltage is taken as input and the op-amp amplifies it to sine wave and cosine waves. Op Amps are used to give a negative feed-back and add a phase of 180 °in each feedback. If a phase difference of 90° is given as feed-back then, the amplitude would continuously rise. To avoid this, we need to make it 180°. In a Quadrature Down-Conversion (QDC) oscillator, the integrator and phase shifter are crucial components that work together to generate quadrature (90-degree phase-shifted) signals. These signals are essential in various applications, including frequency synthesis, modulation, and demodulation

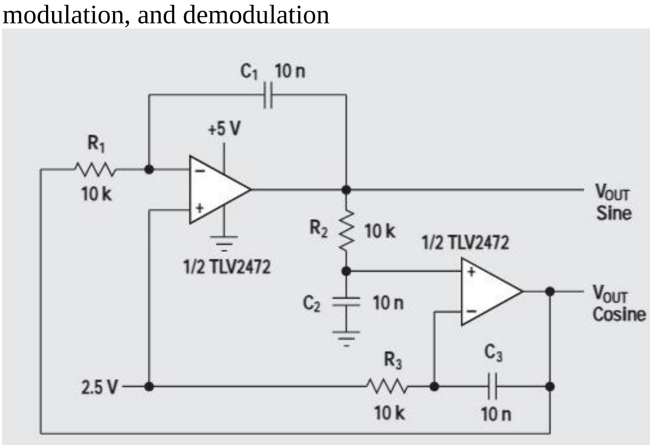


Fig.2: Quadrature Oscillator

The mixer circuit(switch) contains a MOSFET which operates in Triode region and the following is the working of it.
The working of the circuit is as follows:
• Voltage input from the oscilloscope =

$$V_{OSC} = A_1 \sin(2\pi t - 100k)$$

• Voltage input from the external source =

$$V_{IN} = A_2 \sin(2\pi t - 99k)$$

- Biasing Voltage = V_{BIAS}

$$V_g = V_{BIAS} + V_{OSC}$$
$$V_s = V_{IN}$$
$$V_b = 0$$

Now,

$$V_{GS} = V_{BIAS} + V_{OSC} + V_{IN}$$

V_{bias} is approximated to the value of Threshold voltage of MOSFET

$\therefore \quad V_{GS} - V_{TH} = V_{OSC} - V_{IN}$

$\therefore$ if $\quad V_{OSC} - V_{IN} < 0$

$\Longrightarrow I_{DS} = 0$

$\Longrightarrow$ the MOSFET is in Cut-off Region.

if

$$V_{OSC} - V_{IN} > 0$$

$\Longrightarrow$ the MOSFET is in Triode region

Note that the MOSFET never goes to saturation, because:

$V_{OUT} << V_{IN} << V_{OSC}$

$V_{DS} - V_{GS} = V_{OUT} - V_{IN} - V_{BIAS} - V_{OSC} + V_{IN}$

$V_{DS} - V_{GS} = V_{OUT} - V_{BIAS} - V_{OSC}$

$V_{DS} - V_{GS} < -V_{BIAS}$

for a triode to be in saturation,

$V_{DS} > V_{GS} - V_{TH}$

But, this condition is never satisfied. So, it can be said that MOSFET never enters saturation

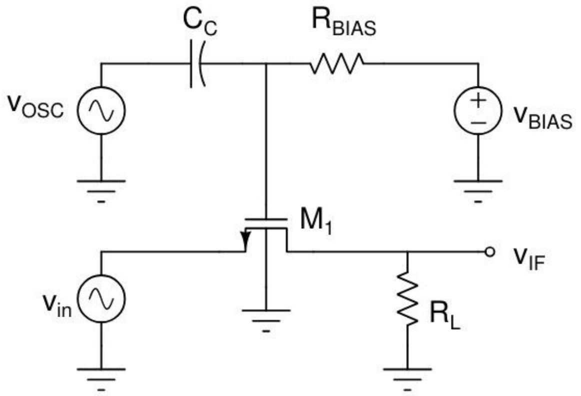


Fig.3: Mixer

A low-pass filter is designed to reduce or suppress high-frequency signals while allowing low-frequency signals to pass through with minimal alteration. The cutoff frequency marks the point where the filter begins attenuating higher frequencies. The roll-off characteristic indicates how rapidly the filter's attenuation increases beyond this cutoff frequency

$$F_c = 1/2\pi RC$$

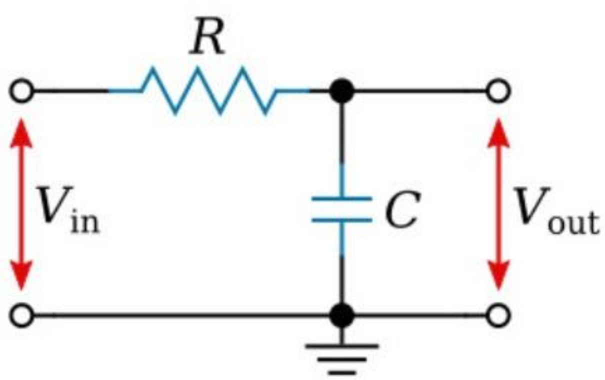


Fig.4: Low pass filter

III. Quadrature Oscillator Design

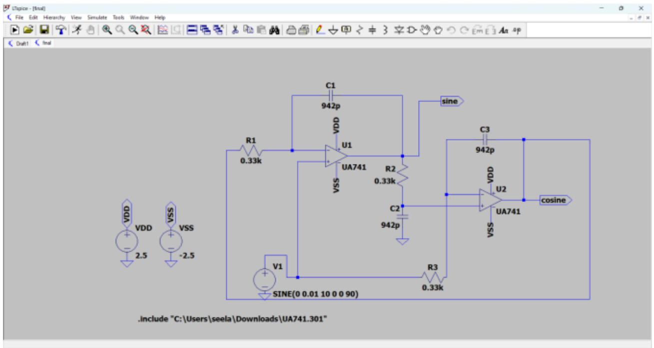


Fig.5: LTSPICE of Quadrature Oscillator

2. Given freq of V_{osc1} & V_{osc2} = 100kHz

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

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

$$RC = \frac{1}{200k\pi}$$

$$\boxed{RC = 1.59\times10^{-6}}$$

Ideally we have to take

$$RC = 1.59\times10^{-6}$$

But for the equipment needs, we have took

$$R = 0.3k$$

$$C = 942p$$

Fig.6: Calculations of R and C

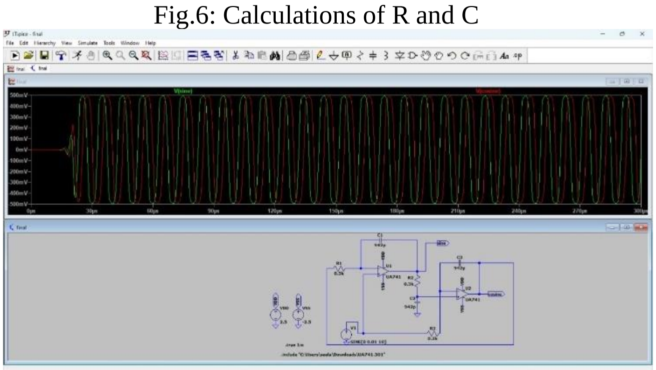


Fig.7: V_{OSCI} and V_{OSCQ} Transient Plots

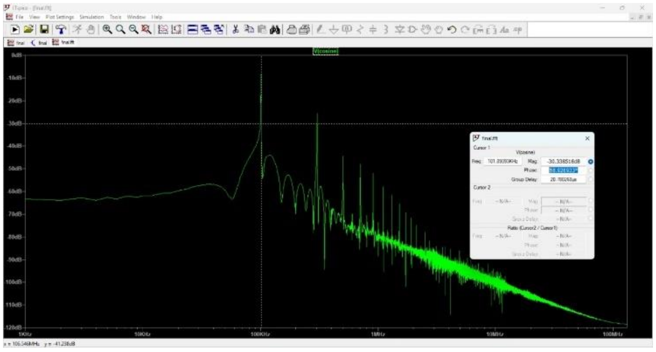


Fig.8: FFT of cosine

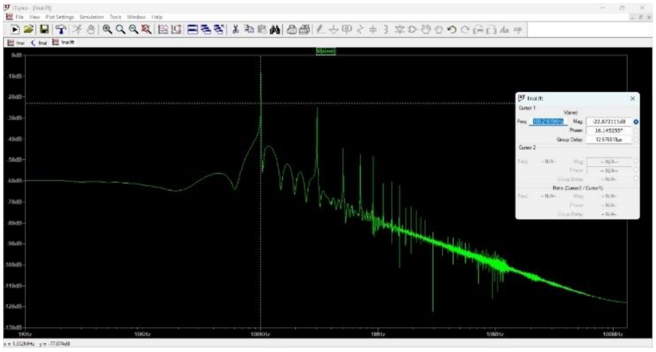


Fig.9: FFT of sine

To calculate phase diff

$$\phi_1 - \phi_2 = 2\pi f \left(t_{peak_{sine}} - t_{peak_{cosine}}\right)$$

$$= 360 \times 100k \times (2.498 \mu s)$$

$\left(t_{peak_{sine}} - t_{peak_{cosine}}\right)$ is obtained from transient simulations in Ltspice.

$$= 36 \times 2.498$$

$$= 89.928^\circ$$

$$\approx 90^\circ$$

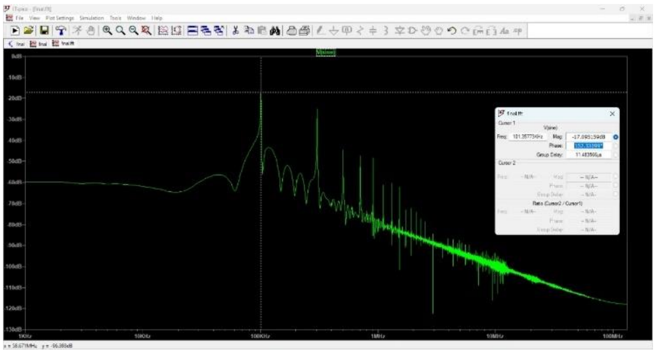


Fig.10: Phase of sine

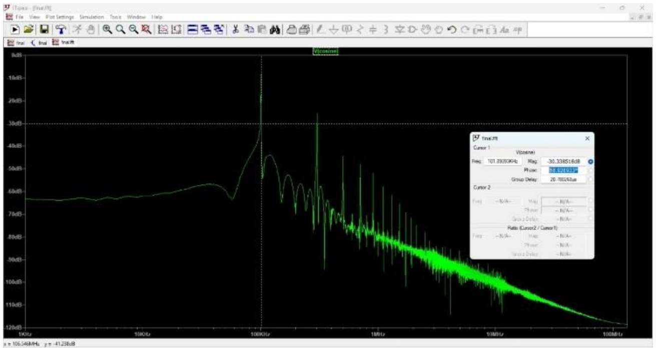


Fig.11: Phase of cosine

Fig.12: Transient waveforms

Fig.13: FFT of sine

Fig.14: FFT of cosine

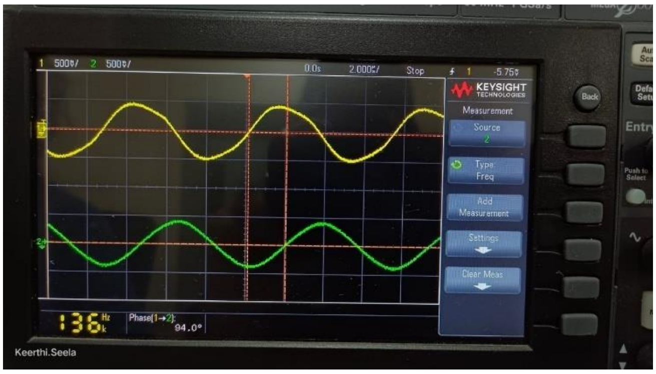


Fig.15: Phase difference

IV. SWITCH(MIXER) DESIGN

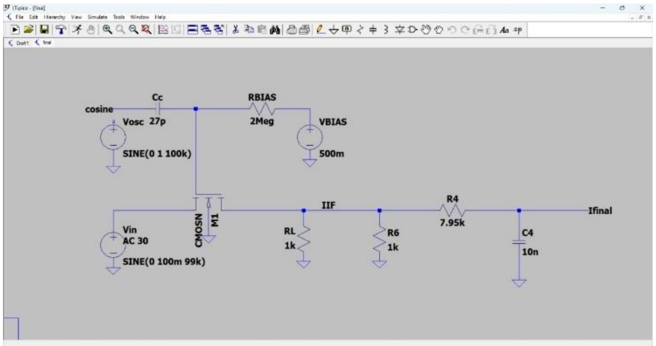


Fig.16: LTSPICE of Mixer

$V_{IF_1} = V_{in} \times V_{osc_1} = \frac{A_1 A_2}{2}\left[\ 1\ \ \ \right]$

$\cos(\omega t - \ldots)$

In the given circuit

$V_{in} = 100\,mV$ $V_{osc} = 1V$

$\frac{A_1 A_2}{2} = \frac{1 \times 100\,mV}{2} = 50\,mV$

V_{IF_1}'s Amplitude calculated through LT spice

$= 48.32\,mV \approx 50\,mV$

∴ So, when the V_{osc}'s sine wave is in Positive values the circuit operates in on condition, if it is in negative values, circuit operates in off condition.

as $V_{osc} > V_T$ of MOSFET → on condition

Fig.17: Working of mixer

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

$V_{Bias} = V_{Th}$ of MOSFET

to allow 100kHz in to the circuit

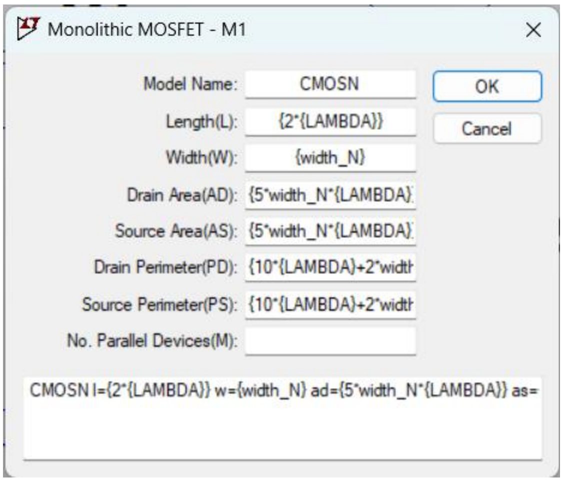
$100\,kHz > \frac{1}{2\pi RC}$

$RC > \frac{1}{2\pi \times 10^5}$

$RC > \frac{10^{-5}}{2\pi}$

we choose R_{bias} as $2M\Omega$
C_c as $27\,pF$

Because C_c should be small enough to allow V_{osc}, whereas R_{bias} should be high enough, so that V_{osc} Completely enters into MOSFET


Monolithic MOSFET - M1

Model Name:	CMOSN
Length(L):	{2*{LAMBDA}}
Width(W):	{width_N}
Drain Area(AD):	{5*width_N*{LAMBDA}
Source Area(AS):	{5*width_N*{LAMBDA}
Drain Perimeter(PD):	{10*{LAMBDA}+2*widtl
Source Perimeter(PS):	{10*{LAMBDA}+2*widtl
No. Parallel Devices(M):	

OK
Cancel

CMOSN l={2*{LAMBDA}} w={width_N} ad={5*width_N*{LAMBDA}} as=

MOSFET parameters

2. $\frac{W}{L} = \frac{1.8\mu}{0.18\mu}$

$V_{DS} = 50mV$

$V_{BS} = 0V$

a) From LTSpice simulations, we got maximum slope $m = 161.08558\mu\,\Omega^{-1}$

at $(x, y) = (716.57183mV, 26.465053\mu A)$

$y - 26.465053\mu A = (161.08558\mu\,\Omega^{-1})(x - 716.57183mV)$

$(y=0)$ For x-intercept,

$$\frac{-26.465053\mu A}{161.08558\mu\,\Omega^{-1}} + 716.57183\,mV = x$$

$$\boxed{V_T = x = 0.55228017\,V}$$

Calculation of $V_T = V_{BIAS}$

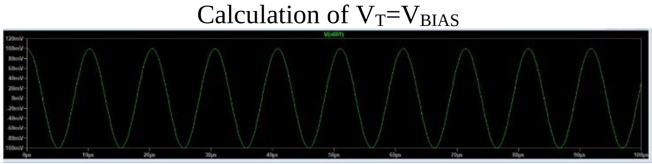


Fig.18: Transient plot of V_{in}

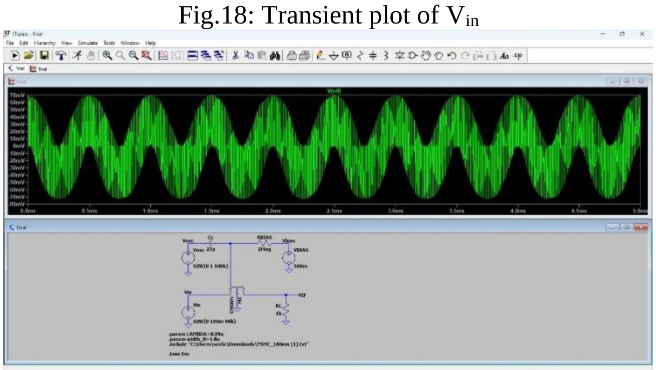


Fig.19: Transient plot of V_{IF} for f=98kHz

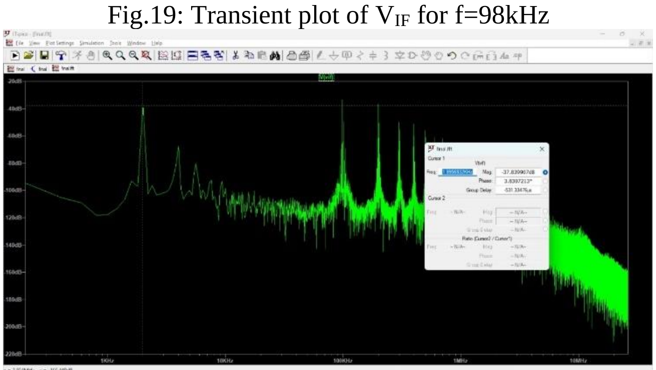


Fig.20: FFT of V_{IF} for f=98kHz

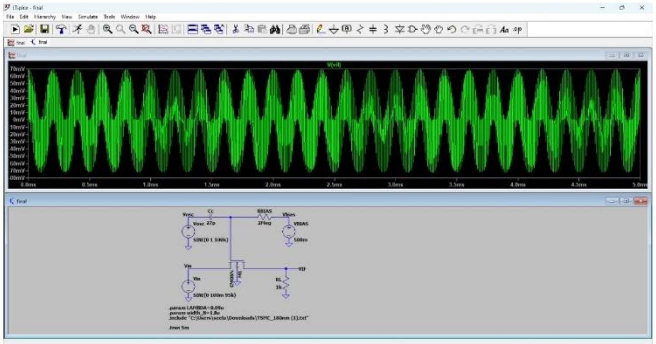


Fig.21: Transient plot of V_{IF} for f=95kHz

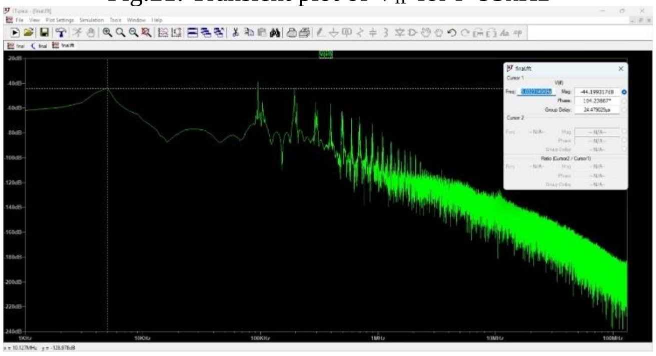


Fig.22: FFT of V_{IF} for f=95kHz

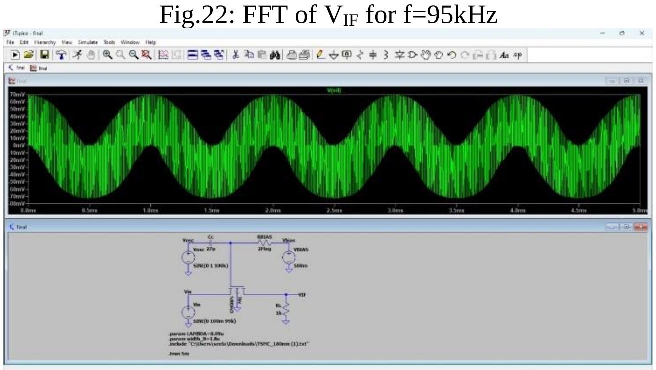


Fig.23: Transient plot of V_{IF} for f=99kHz

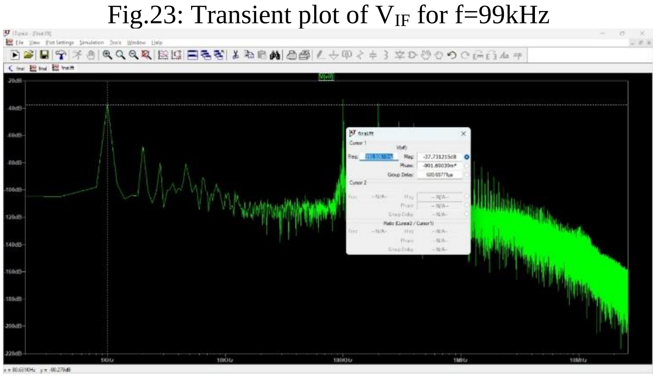


Fig.24: FFT of V_{IF} for f=99kHz

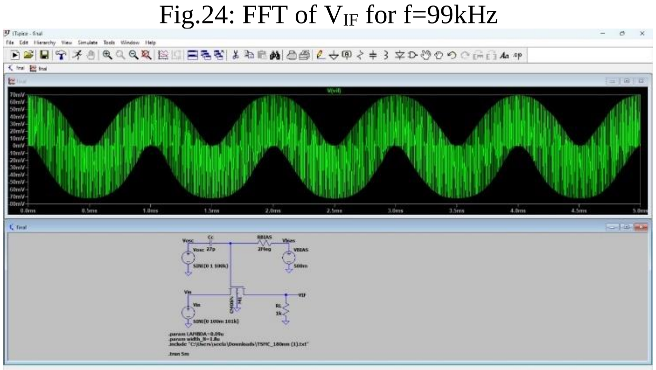


Fig.25: Transient plot of V_{IF} for f=101kHz

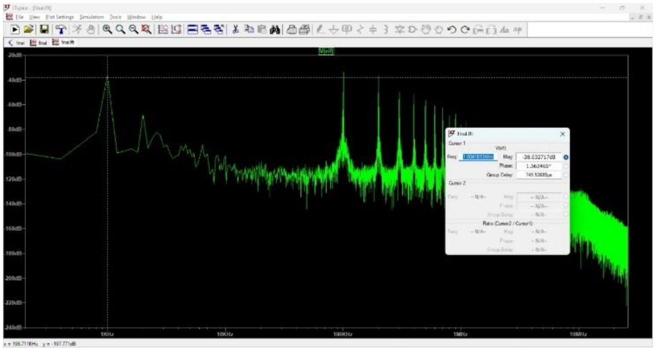


Fig.26: FFT of V_{IF} for f=101kHz

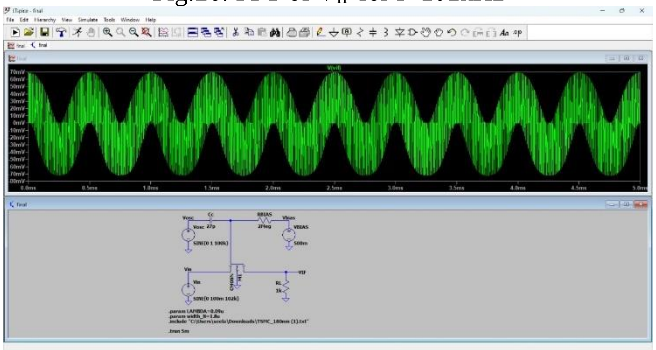


Fig.27: Transient plot of V_{IF} for f=102kHz

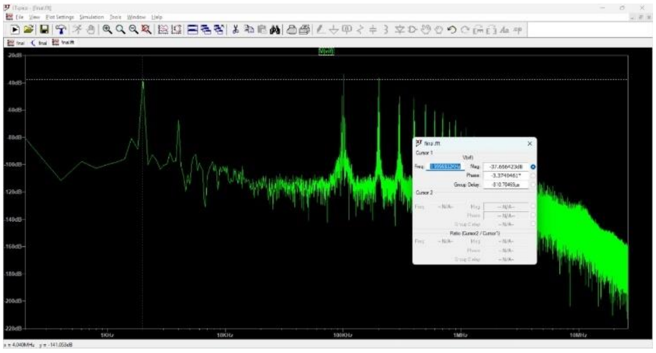


Fig.28: FFT of V_{IF} for f=102kHz

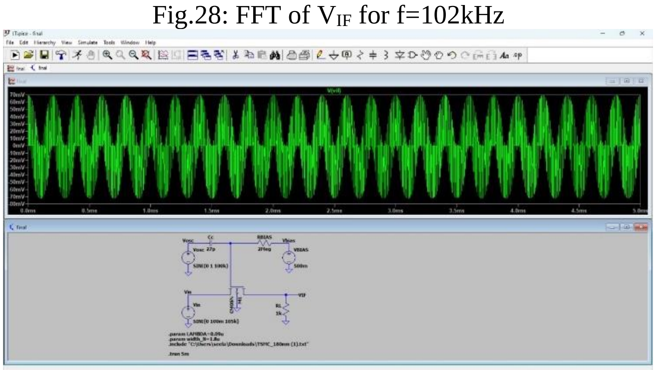


Fig.29: Transient plot of V_{IF} for f=105kHz

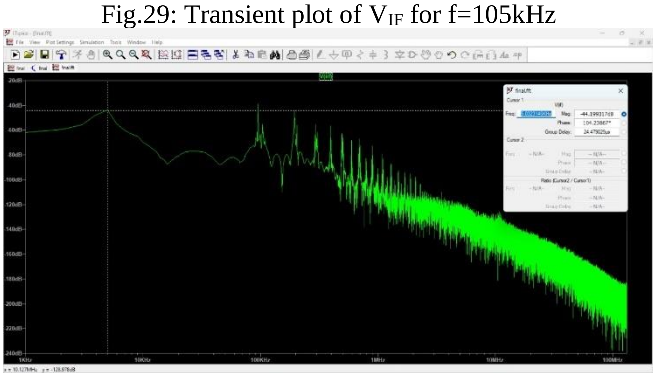


Fig.30: FFT of V_{IF} for f=105kHz

HARDWARE OF MIXER CIRCUIT

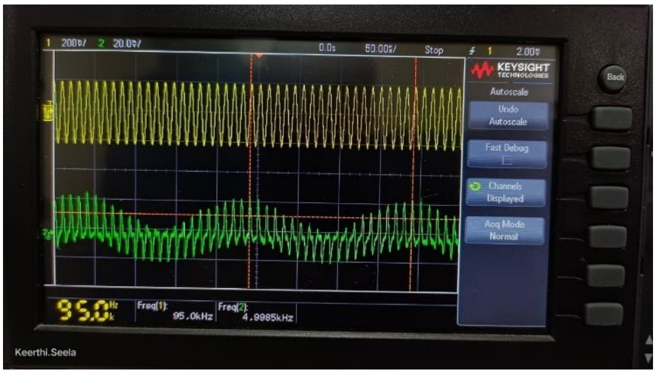


Fig.31: Transient plot of V_{IF} for f=95kHz

Fig.32: FFT of V_{IF} for f=95kHz

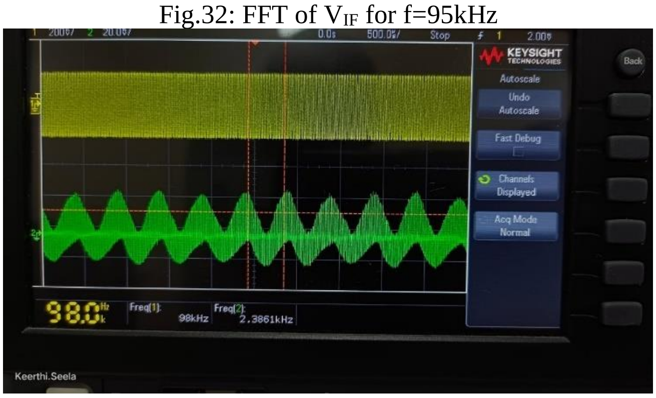


Fig.33: Transient plot of V_{IF} for f=98kHz

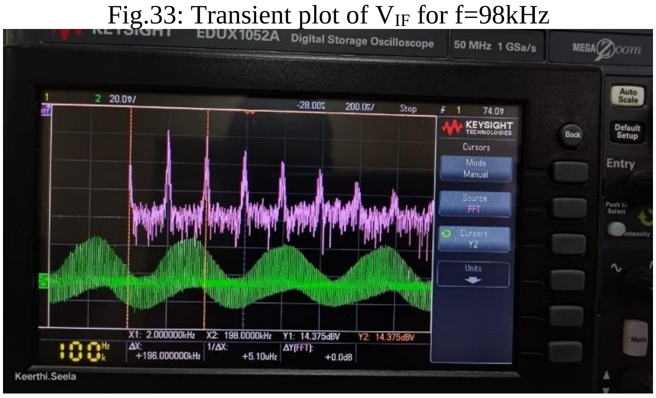


Fig.34: FFT of V_{IF} for f=98kHz

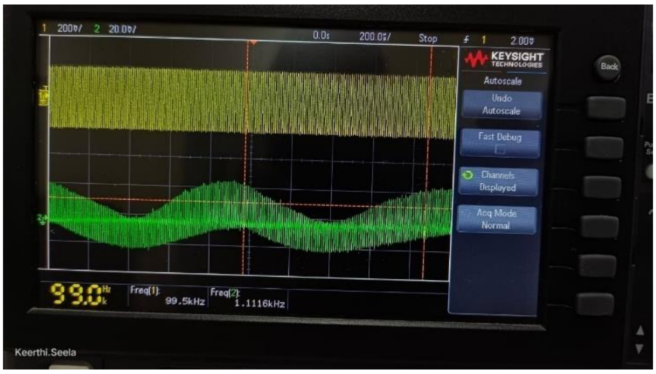


Fig.35: Transient plot of V_{IF} for f=99kHz

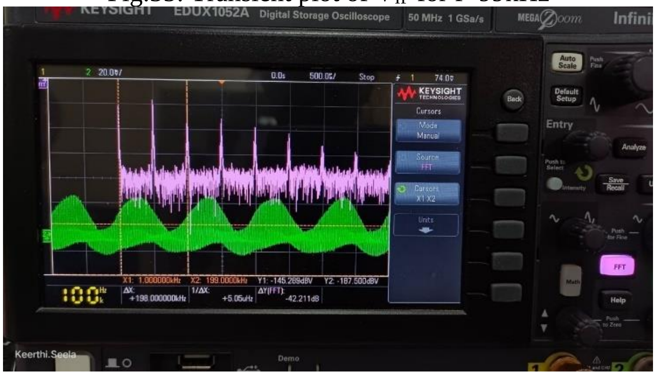


Fig.36: FFT of V_{IF} for f=99kHz

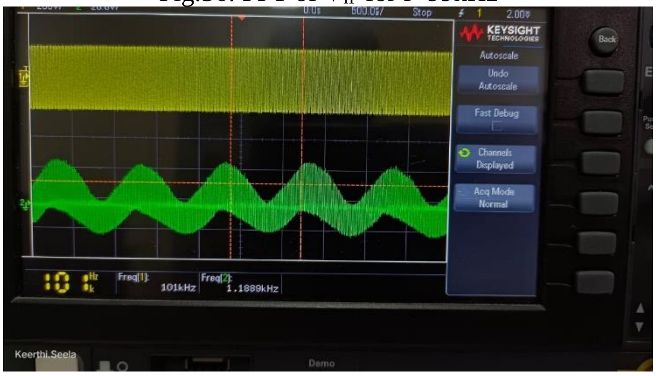


Fig.37: Transient plot of V_{IF} for f=101kHz

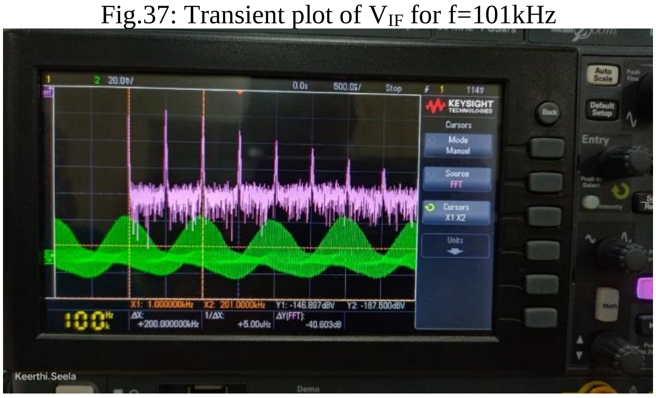


Fig.38: FFT of V_{IF} for f=101kHz

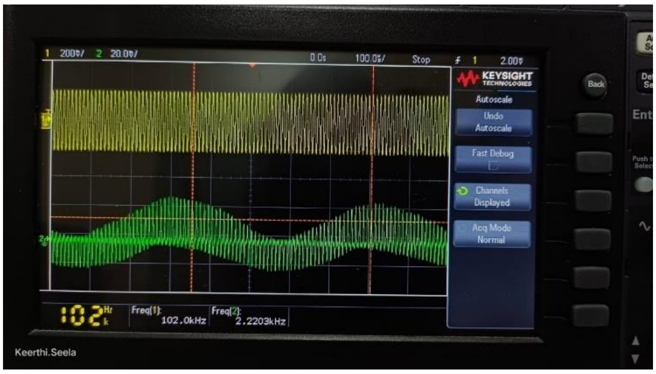


Fig.39: Transient plot of V_{IF} for f=102kHz

Fig.40: FFT of V_{IF} for f=102kHz

Fig.41: Transient plot of V_{IF} for f=105kHz

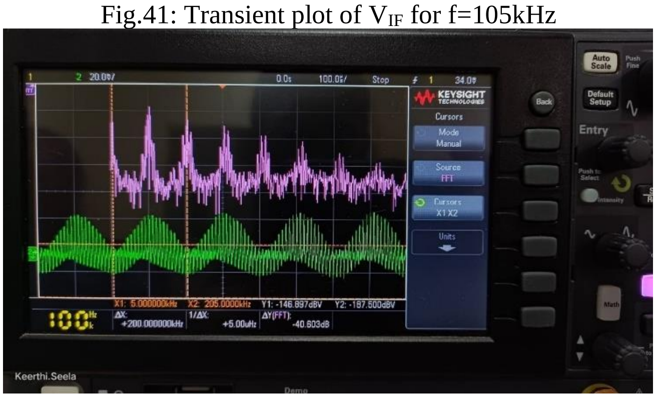


Fig.42: FFT of V_{IF} for f=105kHz

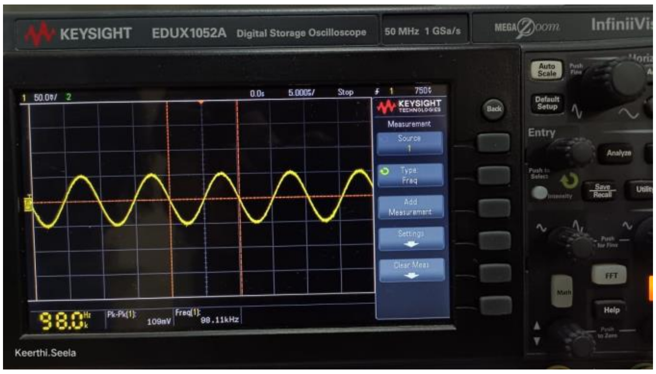


Fig.43: Transient plot of V_{IN}

V. LOW PASS FILTER DESIGN

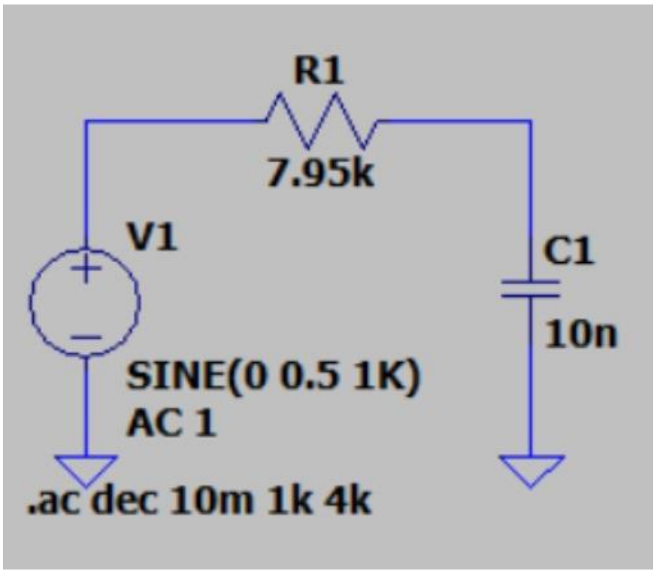


Fig.44: Design of LPF

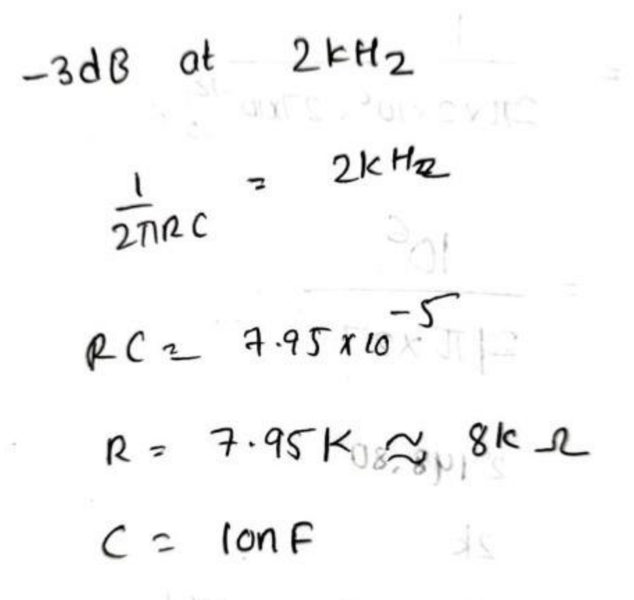


Fig.45: Calculations of R and C

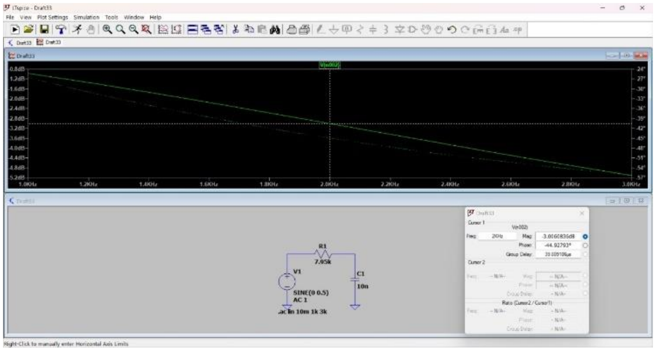


Fig.46: Frequency response

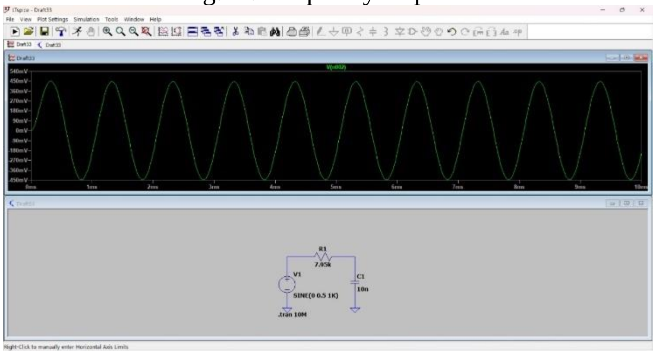


Fig.47: Transient response for 1kHz

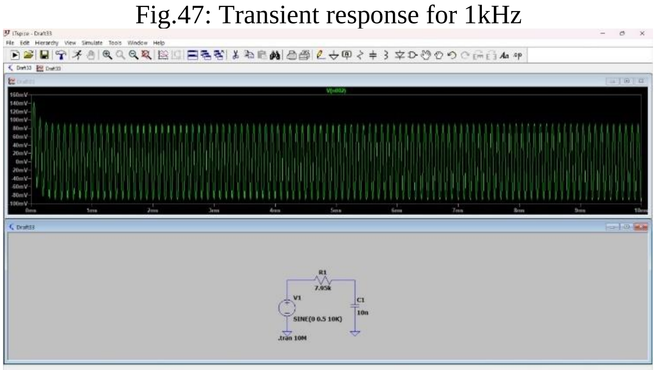


Fig.48: Transient response for 10kHz

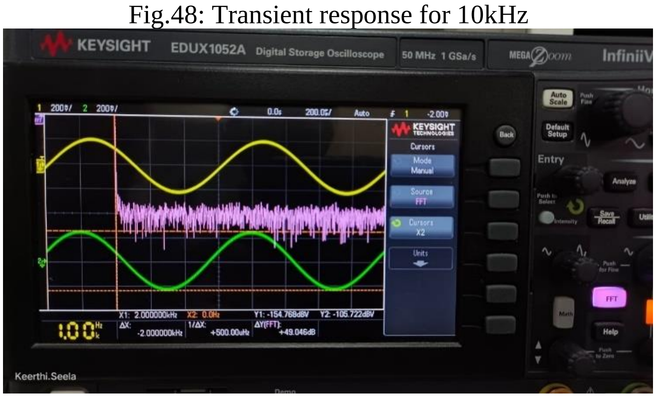


Fig.49: LPF FFT

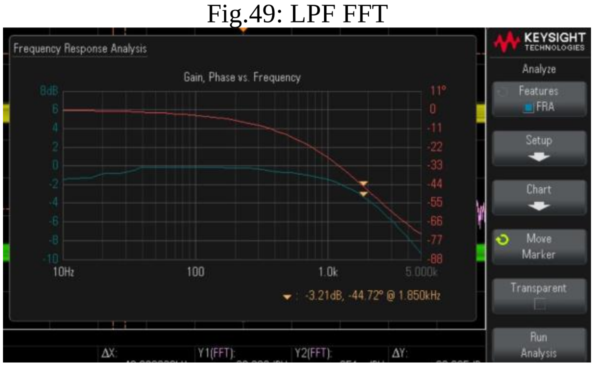


Fig.50: Frequency response in Hardware

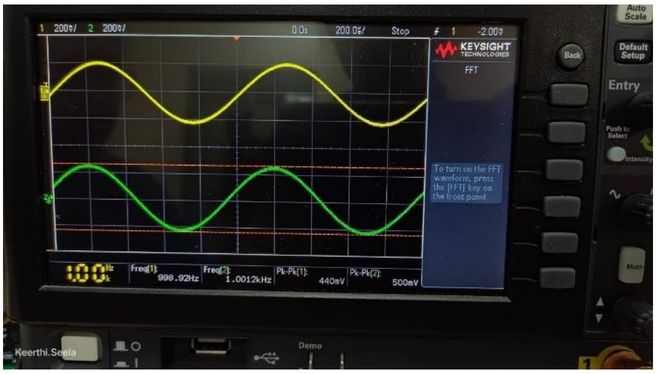


Fig.51: Transient response for 1kHz

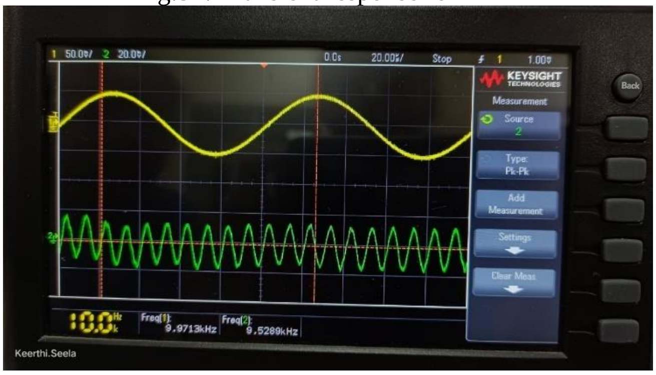


Fig.51: Transient response for 10kHz

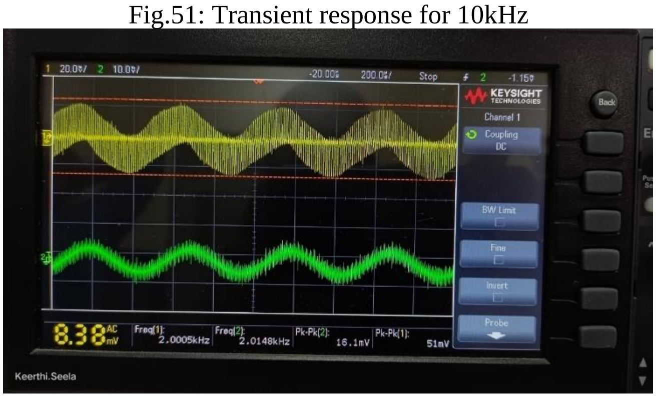


Fig.52: Outputs of Mixer and LPF when connected

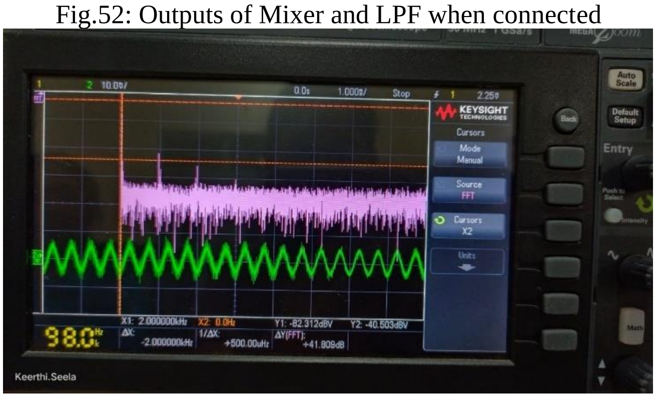


Fig.53: FFT of LPF output
When Mixer and LPF are connected

VI. Complete Circuit Prototype Design

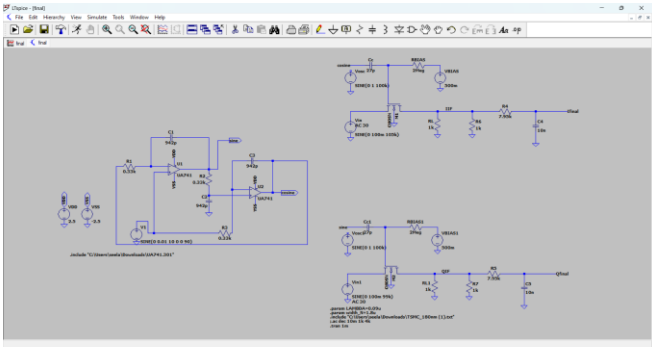


Fig.54: Complete Circuit LTSPICE

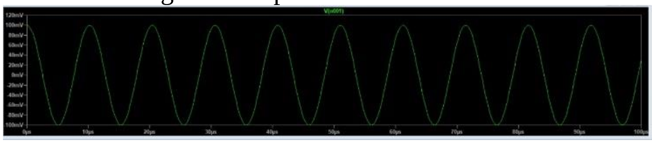


Fig.55: Transient simulation of input

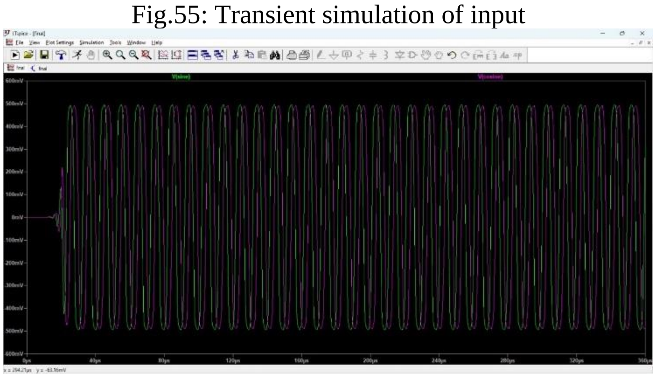


Fig.56: Transient simulation of oscillator output

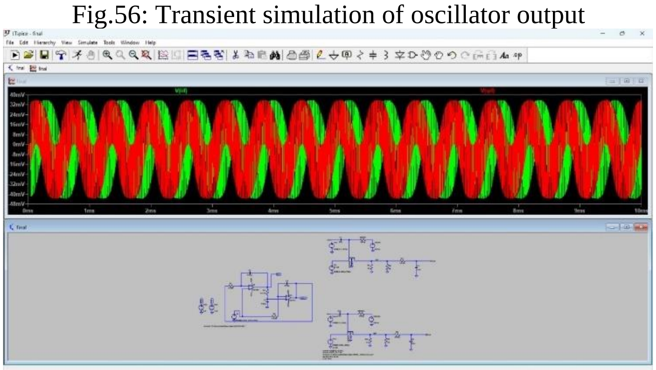


Fig.57: Transient simulation of IF and QF

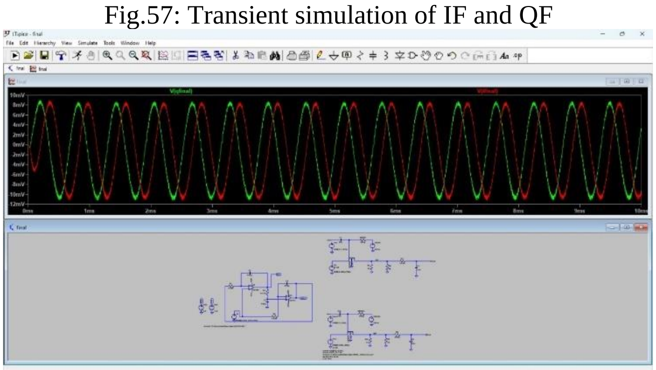
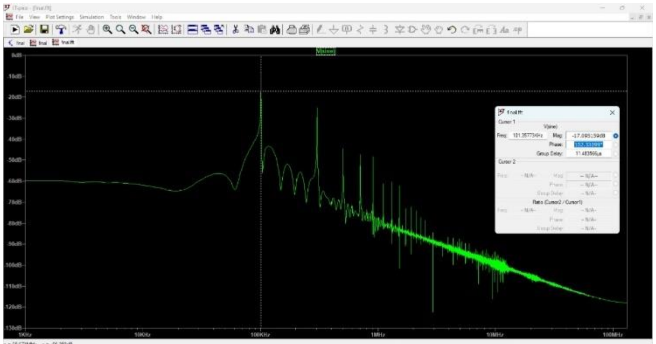
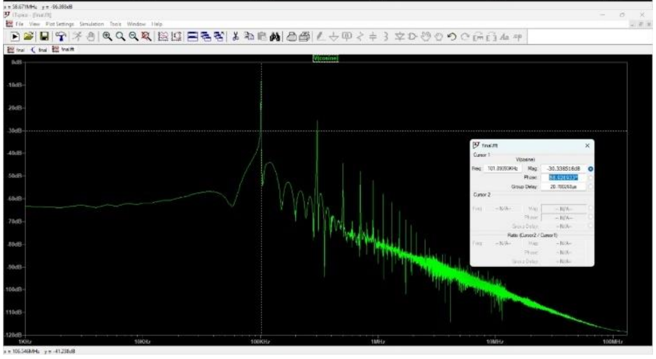


Fig.58: Transient simulation of IF(final) and QF(final)





To calculate phase diff

$$\phi_1 - \phi_2 = 2\pi f \left(t_{peak_{sine}} - t_{peak_{cosine}}\right)$$

$$= 360 \times 100k \times (2.498\,\mu s)$$

$\left(t_{peak_{sine}} - t_{peak_{cosine}}\right)$ is obtained

from transient simulations in Ltspice.

$$= 36 \times 2.498$$

$$= 89.928^{\circ}$$

$$\approx 90^{\circ}$$

The above three figures are reported to annotate the phase difference I-Q components

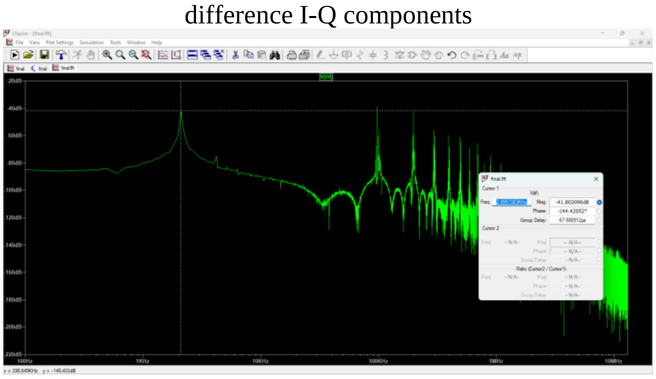


Fig.59: FFT plots of IF

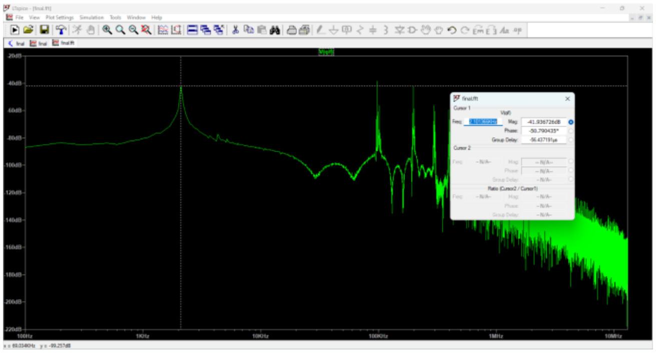


Fig.60: FFT plots of QF

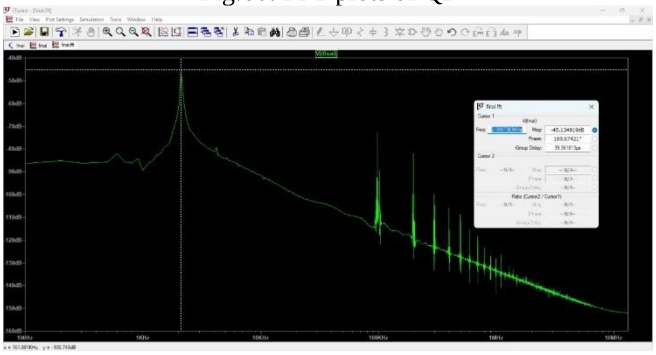


Fig.61: FFT plots of IF(final)

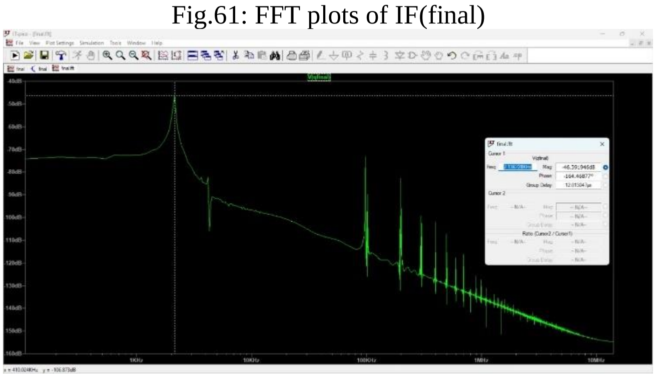


Fig.62: FFT plots of QF(final)

Yes. We can process the FFT plots to find the phase of final I and Q components.

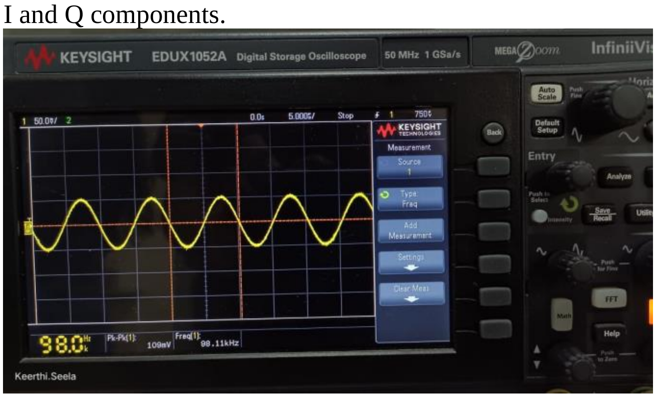


Fig.63: Transient plots of V_{IN}

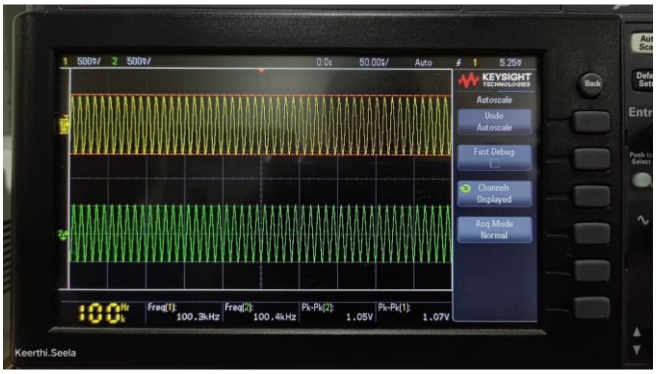


Fig.64: Transient plots of V_{OSCI} and V_{OSCQ}

Fig.65: Transient plots of V_{IFI} and V_{IFQ}

Fig.66: Transient plots of $V_{IF(FINAL)I}$ and $V_{IF(FINAL)Q}$

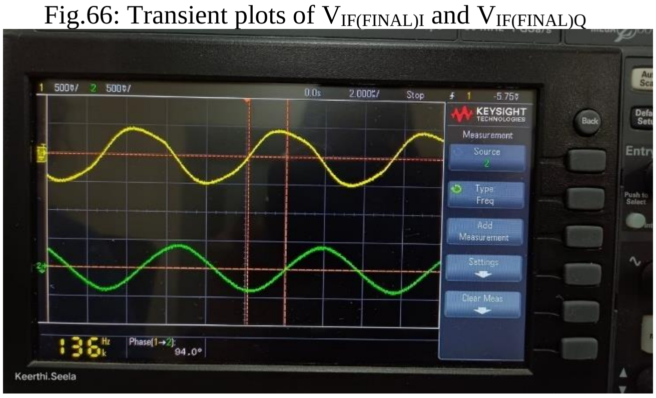


Fig.67: Phase difference of V_{OSCI} and V_{OSCQ}

Fig.68: Phase difference of V_{IFI} and V_{IFQ}

Fig.69: Phase difference of $V_{IF(FINAL)I}$ and $V_{IF(FINAL)Q}$

Fig.70: FFT plots of $V_{IF(FINAL)I}$

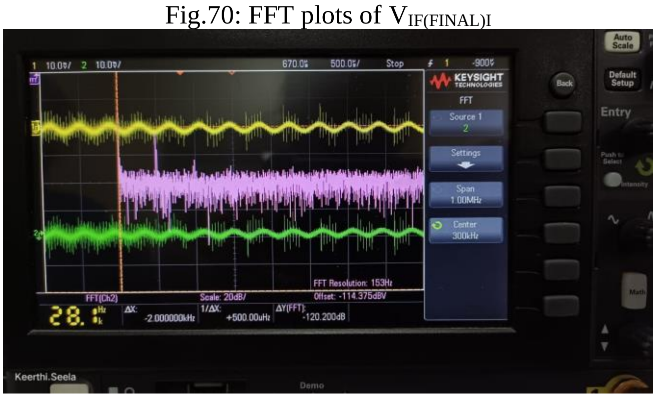


Fig.71: FFT plots of $V_{IF(FINAL)Q}$

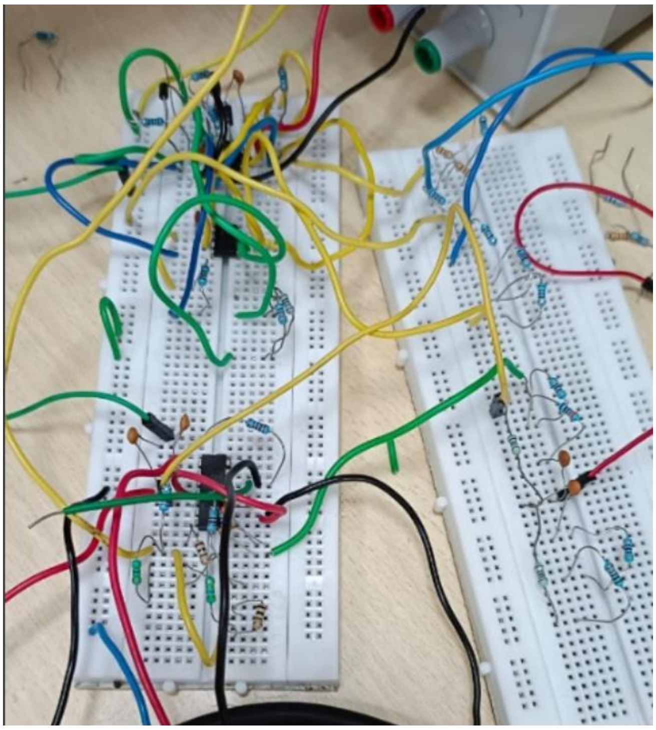


Fig.72: Circuit Overview

Parameters	Simulated	Measured
Oscillator Frequency (I-phase)	100kHz	100.3kHz
Oscillator Frequency (Q-phase)	100.18kHz	100.4kHz
Oscillator Amplitude (I-phase)	1V	1.05V
Oscillator Amplitude (Q-phase)	1V	1.07V
Input frequency	98kHz	98kHz
Supply – V_{DD}	2.5V	6.72V
Supply - V_{SS}	-2.5V	-6.72V
V_{BIAS}	0.5V	1.76V
C_C	27pF	5pF
R – LPF	7.9kΩ	8kΩ
C – LPF	10nF	10nF

VII. Contributions

Keerthi Seela

- Simulations in LTSPICE
- Oscillator
- Report

Anumula Venkata Sai Sree Sahithi

- Mixer Circuit
- LPF
- Report and PPT