QUADRATURE DOWN CONVERTER

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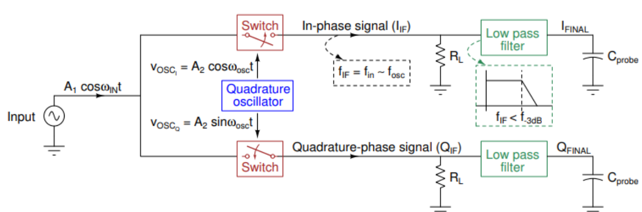
***Abstract*—The quadrature downconverter (QDC) is a critical component in modern wireless communication systems. This paper presents the design, simulation results, and working of a quadrature downconverter (QDC) for wireless receivers used in modern communication systems. It briefly explains the uses of down conversion and elaborates upon the working of the downconverter by dividing it into different parts and conducting analysis on each part, then integrating them into a single circuit. +This paper also includes a comparative analysis of the practical and theoretical simulation results.**

***IndexTerms*—quadrature downconverter,wireless communication, quadrature oscillator, mixer, low-pass filter.**

I. Introduction

The Quadrature Down Converter is used in modern systems such as Bluetooth, Wi-Fi, and WLAN. The height of the antenna that transmits signals is directly proportional to the wavelength decreases so the antenna size decreases, which decreases the cost of transmission. Down converters are used to down convert high frequency RF signals to a lower Intermediate frequency(IF). An I/Q down converter consists of two mixers: one for the I component and another for the Q component.The I mixer multiplies the RF signal by a local oscillator signal with a phase shift of 0 degrees.(In phase component). The Q mixer multiplies the RF signal by a local oscillator signal but with a phase shift of 90 degrees (quadrature component). By using quadrature down conversion, we create two versions of the down converted signal with a phase difference of 90 degrees which is used in doing the down conversion process.



II. Components of Oscillator

A. Quadrature Oscillator

An oscillator is a circuit that creates a continuous, alternating waveform from a DC source without any external input. A Quadrature Oscillator is used to produce two sinusoidal signals with a phase difference of 90 degrees. We have used two Op Amps to produce two sinusoidal waves with a phase difference of 90 degrees. It is used as a local oscillator in the down converter.

In the circuit, the noise gets integrated to a sine wave. the op-amps are in negative feedback. So, we get 180 degrees phase shift from both of the op-amps. As if there is a 90 degrees feedback then the signal is amplified and the output gets saturated at Vbias. We can divide the circuit into two parts. The op-amp on the top takes the cosine wave as input and integrates it into a sine wave and the output is fed into another integrator through a low pass filter which attenuates all the high frequencies present in the signal. The second op-amp on the right takes sine as input and integrates it into cosine waves. Both of the integrator circuits give 180 degrees phase shift to the signal and the low pass filter gives 90 degrees phase shift.

The output of the first integrator circuit is given as input to the second integrator circuit and the output of the second integrator circuit is given as input to the first integrator circuit.

The loop gain of the total circuit should be 1. If the gain is less than 1 then the signal keeps getting attenuated and dies off. If the gain is greater than 1 then the signal keeps getting amplified and gets saturated at bias voltages of the op-amp.

DERIVATION OF THE LOOP GAIN

- $V_{+2} = (1/C_3S) / (R_2 + 1/C_3S) V_{SIN} = 1/(1+R_3C_3S) V_{SIN}$
From the voltage divider circuit of R_3C_3

- $V_{COS} = ((1 + R_2C_2S)/ R_2C_2S) * V_{+2}$

From the gain equation of the non-inverting amplifier

- $V_{SIN} = (-1/R_1C_1S) * V_{COS}$

From the gain equation of the inverting amplifier.

To get the loop gain we multiply the gain at each stage of the circuit.

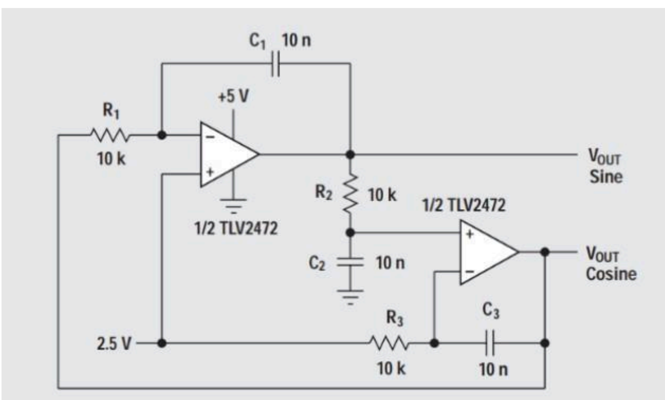
Loop gain = $1 = 1/(1+R_3C_3S)* ((1 + R_2C_2S)/ R_2C_2S)* (-1/R_1C_1S)$

R1C1 = R2C2 = R3C3 substituting this in the above loop gain equation we get

$(-1/RCS)(1/RCS) = 1 = (wRC) =(2*pi*fosc *RC)$

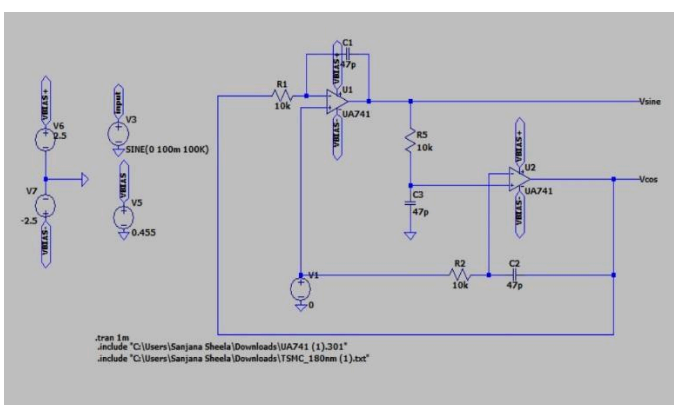
$Fosc= 1 /2*pi*RC$

This formula doesn't work in reality as there will be parasitic capacitances , capacitance of the probe and the resistance of the probe which play a role in the loop gain and also in the output of the circuit.

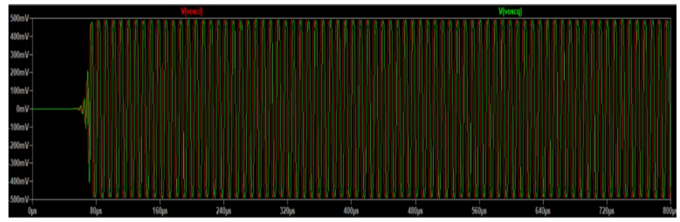


(Figure.1) Schematics of the Quadrature Oscillator III. LTSpice SIMULATIONS

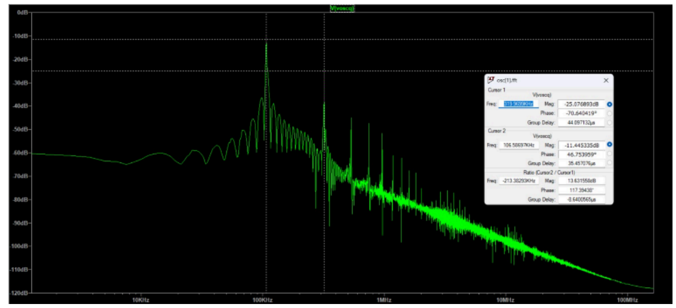
*LtSpice Simulations of **Quadrature Oscillator***



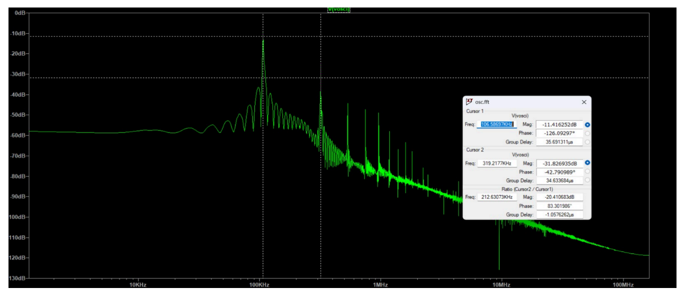
(Figure.2)Quadrature Oscillator in the LtSpice simulations



(Figure.2)Output of the Quadrature Oscillator in the LtSpice simulations
Green -> Voscq -> sine | Red -> Vosci -> cosine



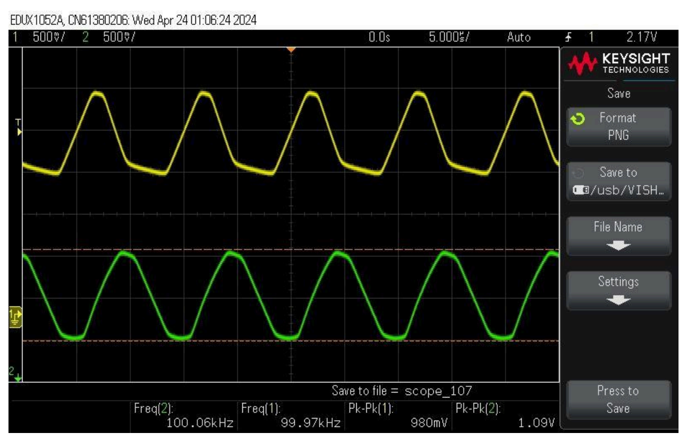
(Figure.2)Frequency Response of Cosine wave. We obtain a peak frequency at 106.56kHz



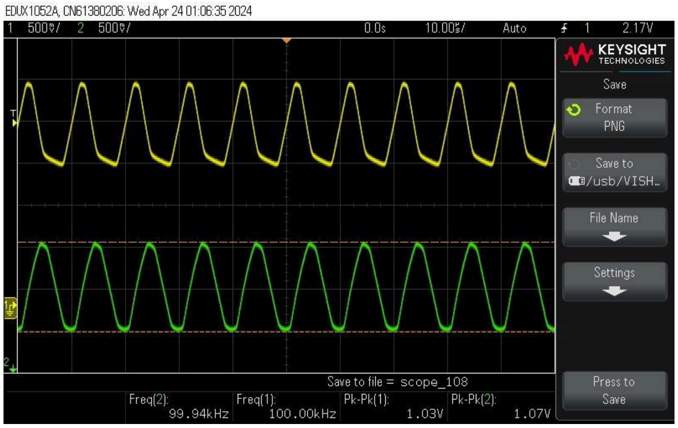
(Figure.3) Frequency Response of sine wave . We obtain a peak frequency at 106.5869kHz

Component	Simulation Value	Practical Value
R1 = R2 = R3	10k ohm	330 ohm
C1 = C2 = C3	47pF	5pF

*Hardware Outputs of **Quadrature Oscillator***



(Figure.4) Output of the Practical Quadrature Oscillator Circuit
Yellow -> Voscq -> sine | Green -> Vosci -> cosine



(Figure.5) Output of the Practical Quadrature Oscillator Circuit
Yellow -> Voscq -> sine | Green -> Vosci -> cosine

B. MIXER (switch)

Two mixers are used, one is fed with a sine wave and another with a cosine wave. Its function is to multiply two signals. In our circuit it is used to multiply the input signal which needs to be down converted with the two output sinusoidal waves from the quadrature oscillator. Multiplication of two signals is basically amplitude modulation of the input signal with the output of the quadrature oscillator. The output of the quadrature is used as the carrier wave.

The mosfet is biased in such a way that it is in linear mode. In linear mode mosfet acts as a switch. The gate voltage is biased to be at the threshold voltage of that mosfet. The output of the quadrature is given as the gate voltage(carrier signal). So when the carrier signal is positive then the mosfet switches on as it is in linear mode so the output of the switch will be proportional to the input of the mosfet as the current in the circuit is linear. When the carrier signal is negative the mosfet switches off as it goes into cut-off mode. In cut-off mode there is no current so the output of the mosfet will be at zero voltage. This switching action results in the multiplication of the two waves.

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

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

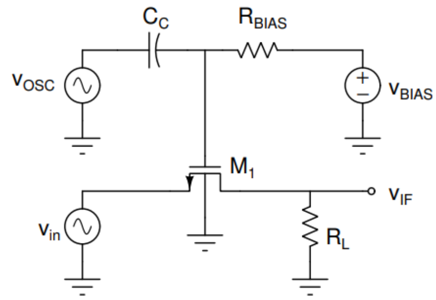
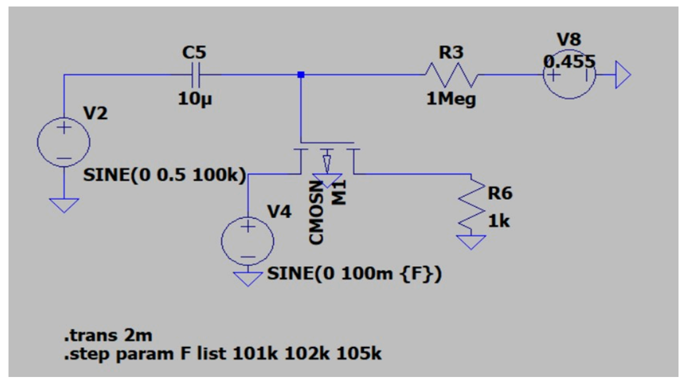
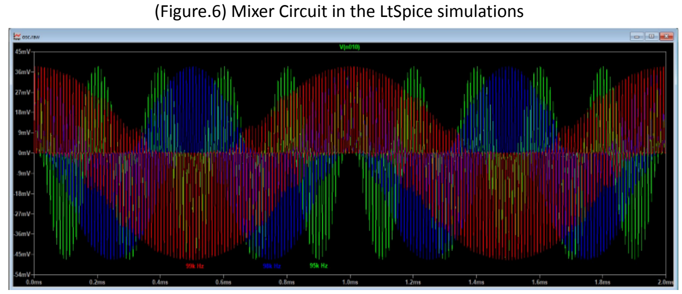


Figure 2

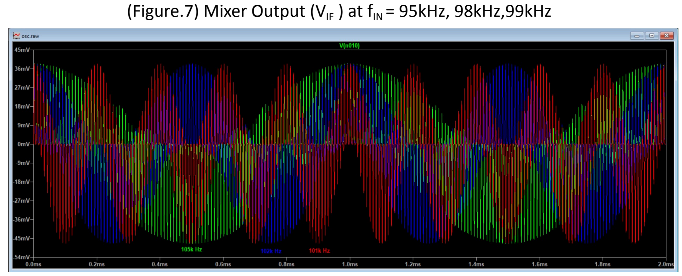
*LtSpice Simulations of **Mixer***



(Figure.6) Mixer Circuit in the LtSpice simulations



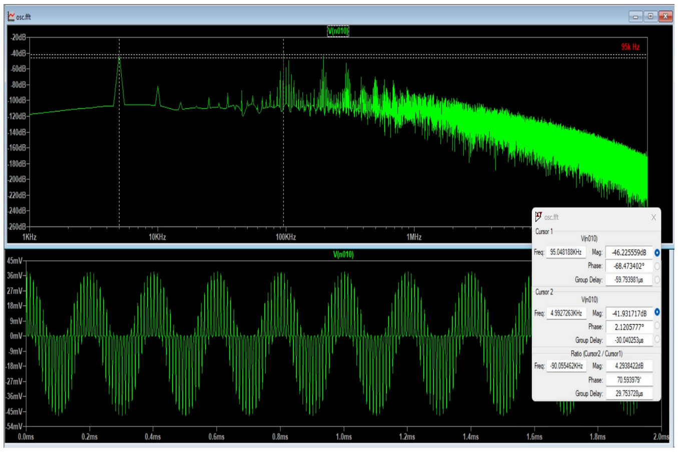
(Figure.7) Mixer Output (V_{IF}) at f_{IN} = 95kHz, 98kHz,99kHz



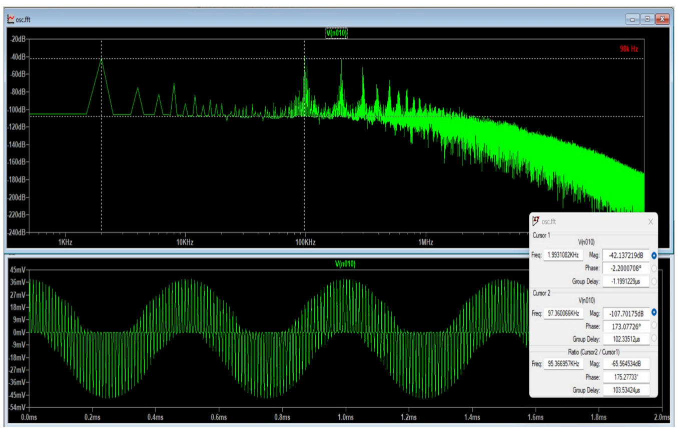
(Figure.8) Mixer Output (V_{IF})at f_{IN} = 101kHz, 102kHz, 105kHz

Components	Simulation Values	Practical Values
R bias	1M ohm	1M ohm
Cc	10uF	10uF
V bias	0.455V	1.8V

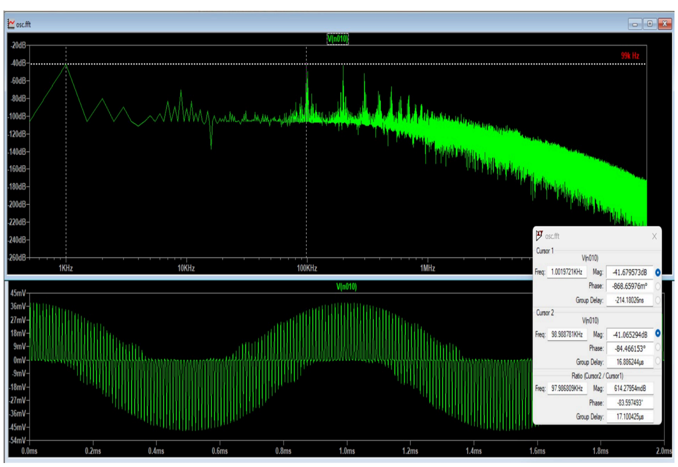
Mixer Outputs when Output of the Quadrature Oscillator is a sine wave



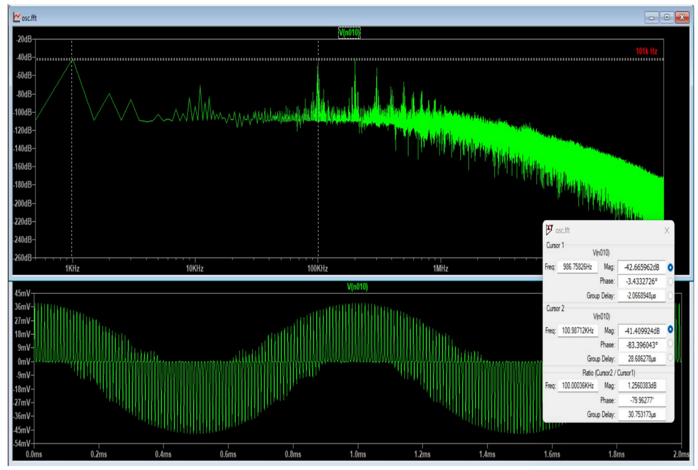
(Figure.9) FFT plot and output of V_{IF} at f_{IN} = 95kHz with peaks at approx 5kHz and 195kHz



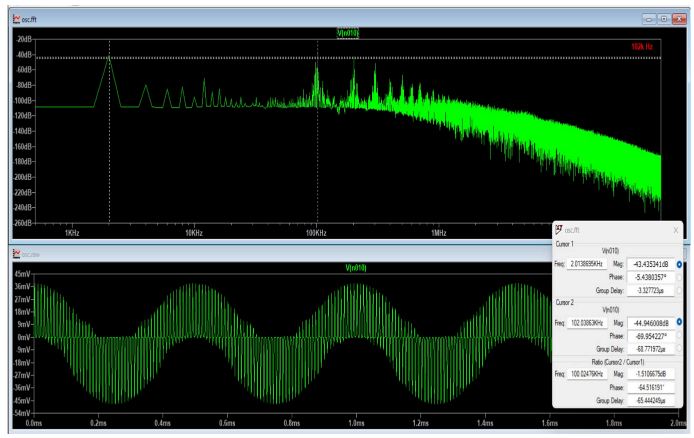
(Figure.10) FFT plot and output of V_{IF} at f_{IN} = 98kHz with peaks at approx 1.99kHz and 198.36kHz



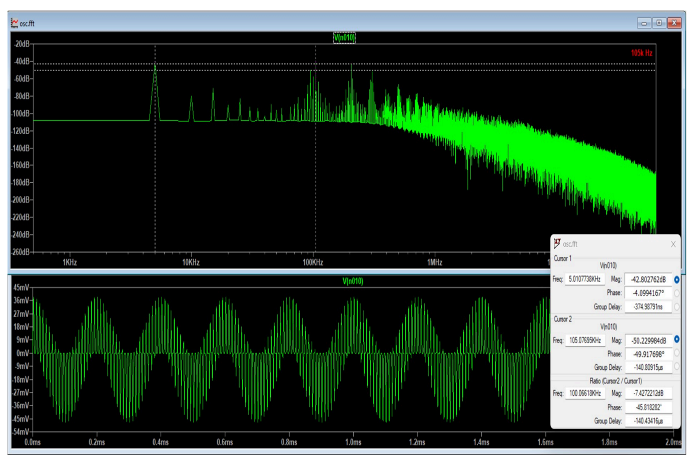
(Figure.11) FFT plot and output of V_{IF} at f_{IN} = 99kHz with peaks at approx 1.0019kHz and 198.98kHz



(Figure.12) FFT plot and output of V_{IF} at f_{IN} = 101kHz with peaks at approx 986.75Hz and 200.98kHz

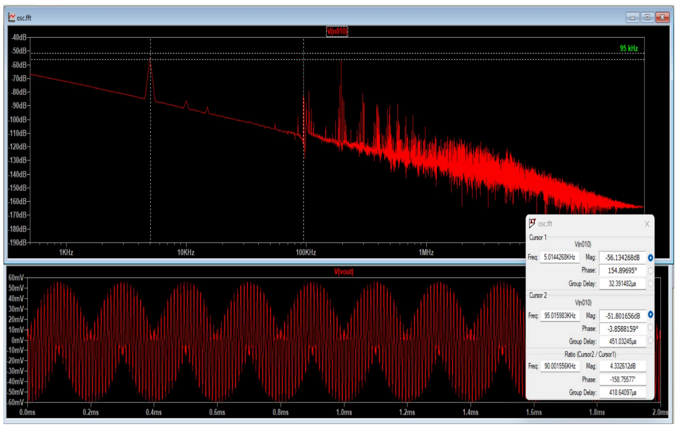


(Figure.13) FFT plot and output of V_{IF} at f_{IN} = 102kHz with peaks at approx 2.01kHz and 202.0386kHz

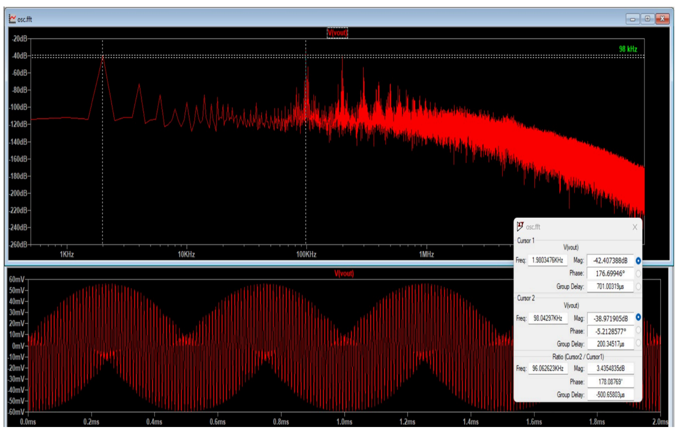


(Figure.14) FFT plot and output of V_{IF} at f_{IN} = 105kHz with peaks at approx 5.01kHz and 205.07kHz

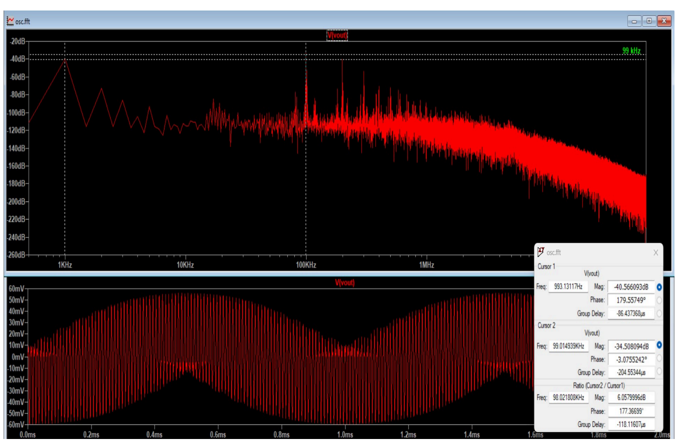
Mixer Outputs when Output of the Quadrature Oscillator is a cosine wave



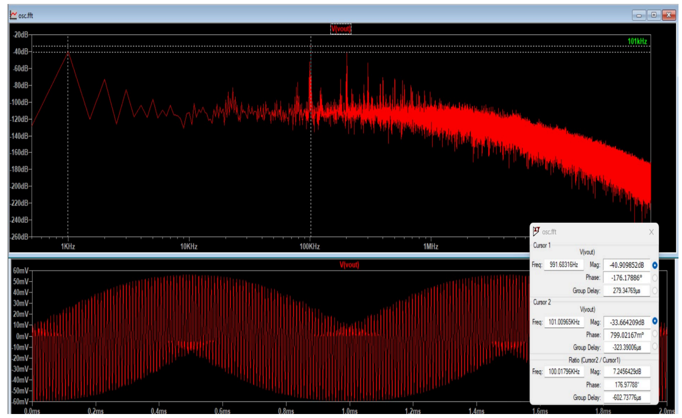
(Figure.15) FFT plot and output of V_{IF} at f_{IN} = 95kHz with peaks at approx 5.01kHz and 195.01kHz



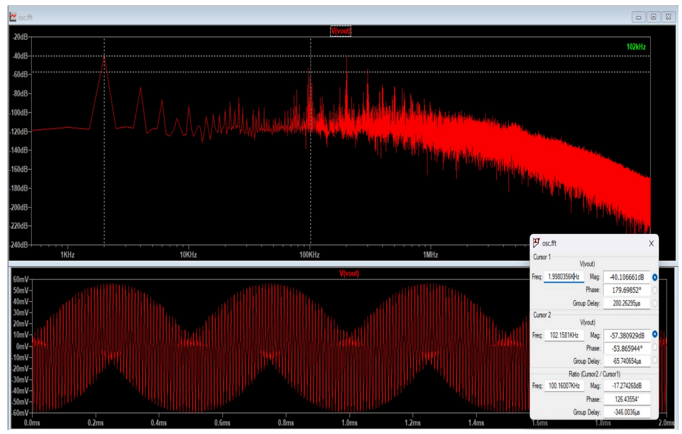
(Figure.16) FFT plot and output of V_{IF} at f_{IN} = 98kHz with peaks at approx 1.98kHz and 198.04kHz



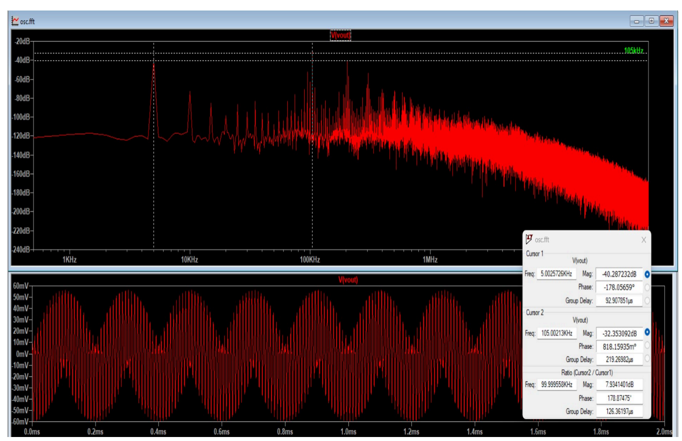
(Figure.17) FFT plot and output of V_{IF} at f_{IN} = 99kHz with peaks at approx 993.13Hz and 199.01kHz



(Figure.18) FFT plot and output of V_{IF} at f_{IN} = 101kHz with peaks at approx 991.68Hz and 201.00kHz



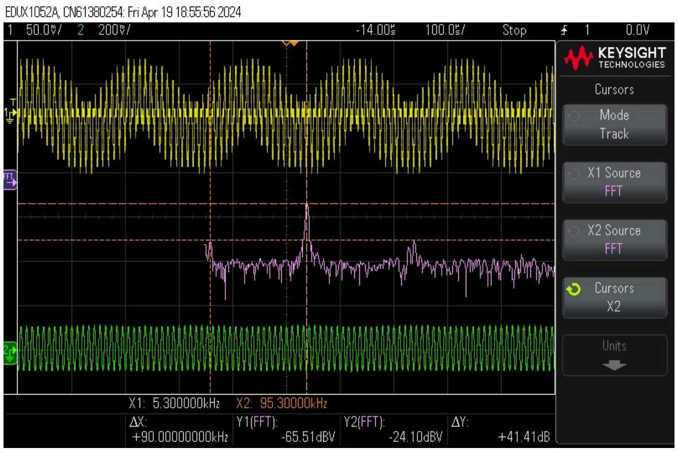
(Figure.19) FFT plot and output of V_{IF} at f_{IN} = 102kHz with peaks at approx 1.99kHz and 202.15kHz



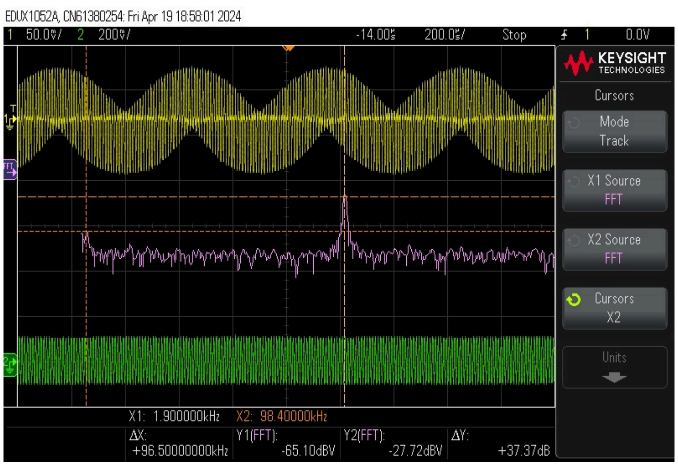
(Figure.20) FFT plot and output of V_{IF} at f_{IN} = 105kHz with peaks at approx 5.00kHz and 205.00kHz

Hardware Outputs of ***Mixer***

***Practical Outputs** of the Mixer when Output of the Quadrature Oscillator is a sine wave*

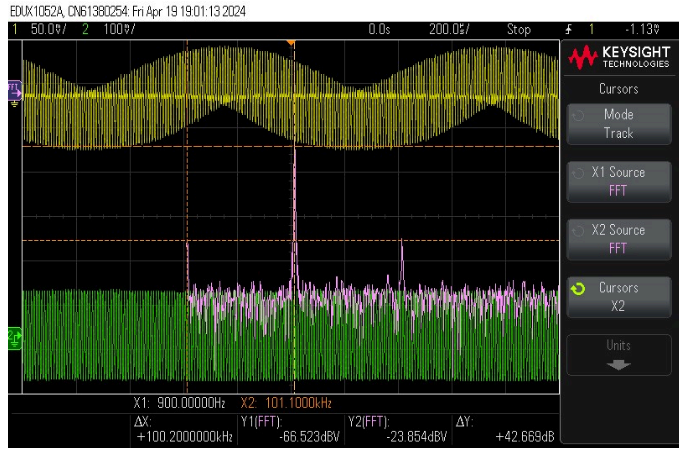


(Figure.21) FFT plot and output of V_{IF} at f_{IN} = 95kHz in the DSO with peaks as shown.

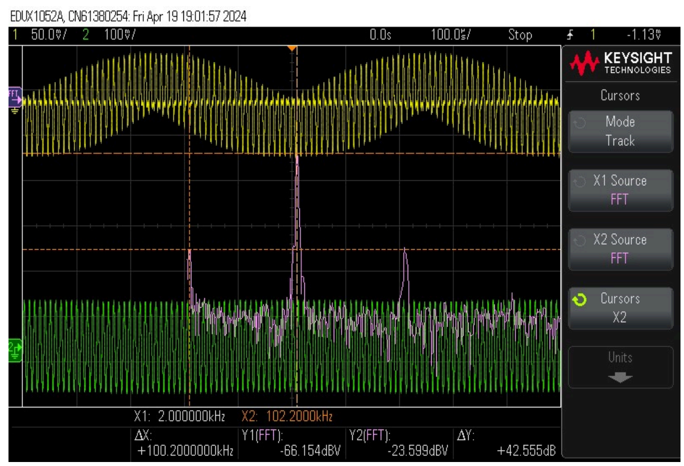


(Figure.22) FFT plot and output of V_{IF} at f_{IN} = 98kHz in the DSO with peaks as shown.

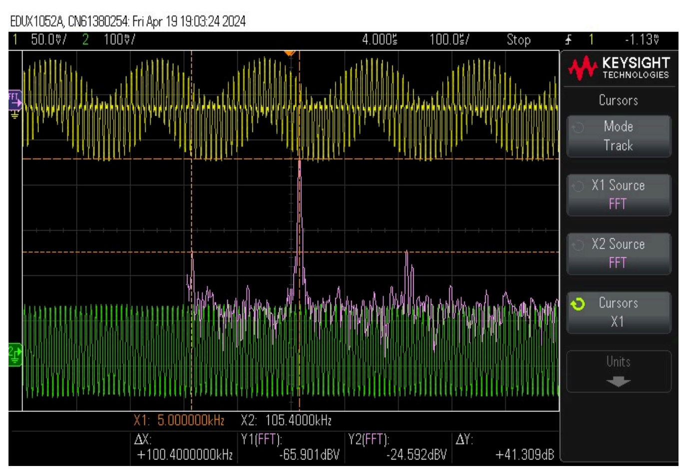
(Figure.23) FFT plot and output of V_{IF} at f_{IN} = 99kHz in the DSO with peaks as shown.



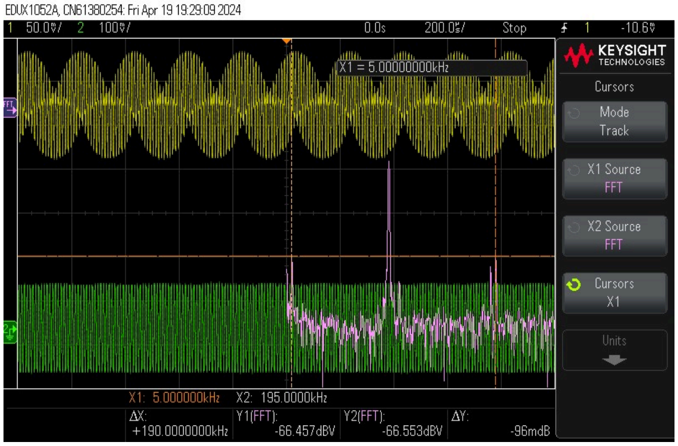
(Figure.24) FFT plot and output of V_{IF} at f_{IN} = 101kHz in the DSO with peaks as shown.



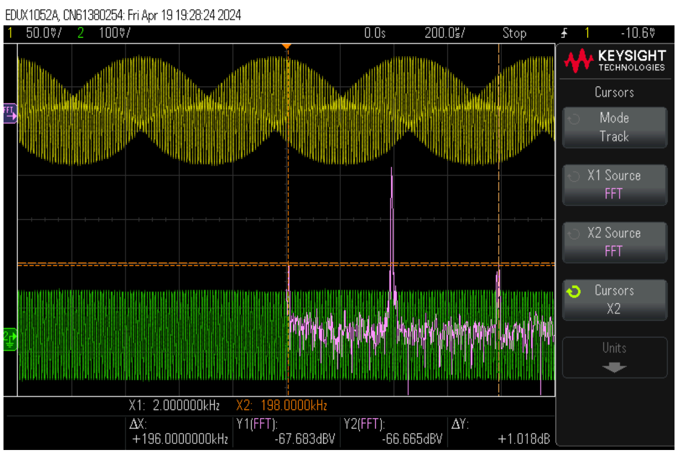
(Figure.25) FFT plot and output of V_{IF} at f_{IN} = 102kHz in the DSO with peaks as shown.



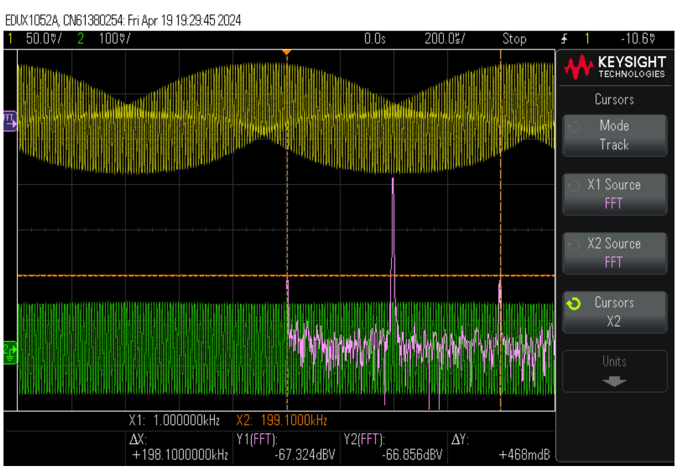
(Figure.26) FFT plot and output of V_{IF} at f_{IN} = 105kHz in the DSO with peaks as shown.



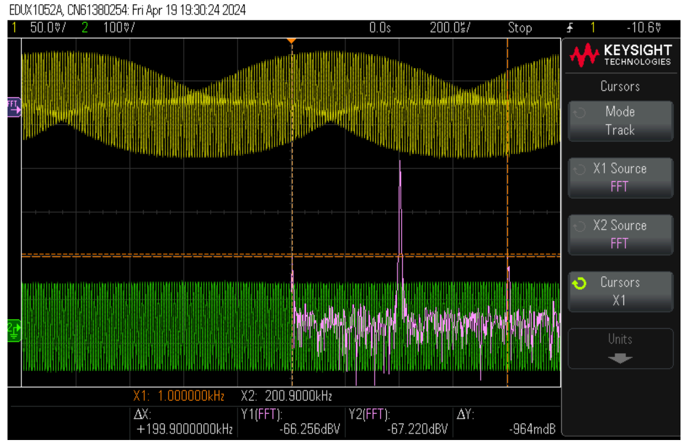
(Figure.27) FFT plot and output of V_{IF} at f_{IN} = 95kHz in the DSO with peaks as shown.



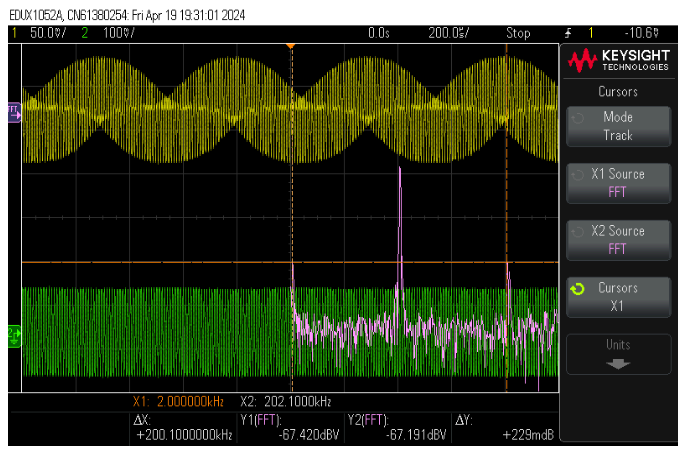
(Figure.28) FFT plot and output of V_{IF} at f_{IN} = 98kHz in the DSO with peaks as shown.



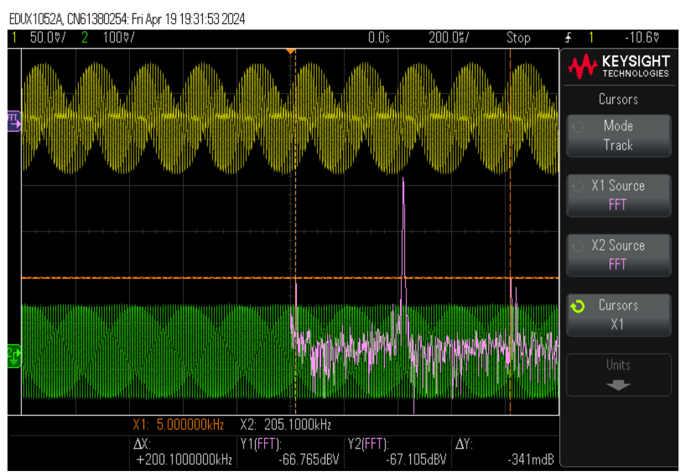
(Figure.29) FFT plot and output of V_{IF} at f_{IN} = 99kHz in the DSO with peaks as shown.



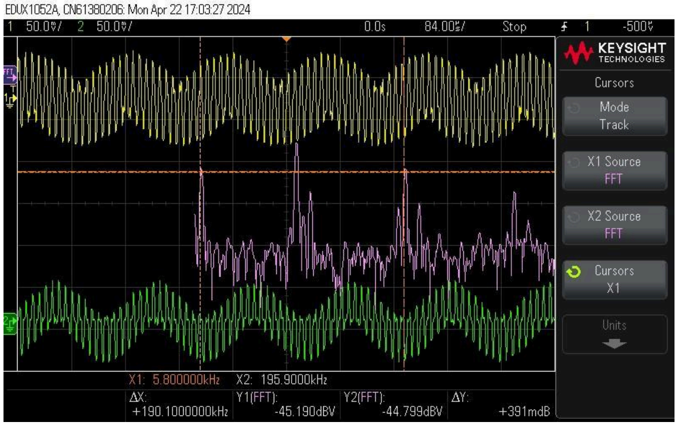
(Figure.30) FFT plot and output of V_{IF} at f_{IN} = 101kHz in the DSO with peaks as shown.



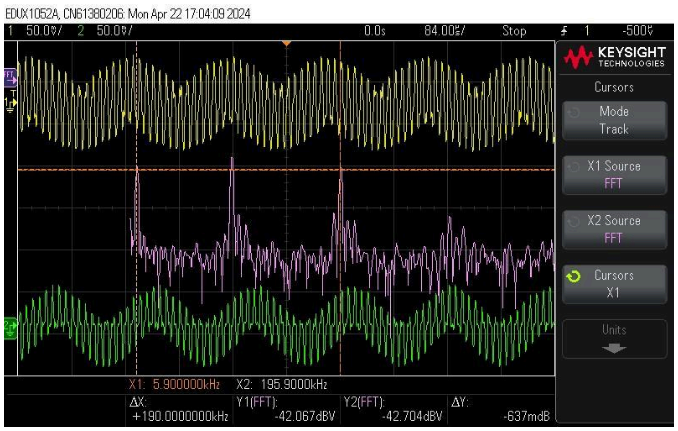
(Figure.31) FFT plot and output of V_{IF} at f_{IN} = 102kHz in the DSO with peaks as shown.



(Figure.32) FFT plot and output of V_{IF} at f_{IN} = 105kHz in the DSO with peaks as shown.



(Figure.33) Yellow - Mixer output when V_{IN} is a sine wave at f_{IN}= 95kHz
Green - Mixer output when V_{IN} is a cosine wave at f_{IN}= 95kHz
Violet - FFT plot of sine wave described above



(Figure.34) Yellow - Mixer output when V_{IN} is a sine wave at f_{IN}= 95kHz
Green - Mixer output when V_{IN} is a cosine wave at f_{IN}= 95kHz
Violet - FFT plot of cosine wave described above

C. LOW PASS FILTER

A low pass filter is designed to allow the low frequency signals to pass through it and attenuate all the high frequency components.

$$H_a(s) = \frac{1}{R_1 C_1 s + 1}$$

The output of the mixer circuit has two frequencies $\omega_{in}t - \omega_{out}t$ and $\omega_{in}t + \omega_{out}t$. First frequency is a low frequency so it is allowed to pass through the low pass filter and the second one is attenuated. Thus we have successfully converted a high frequency signal to a low frequency signal.

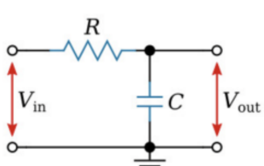
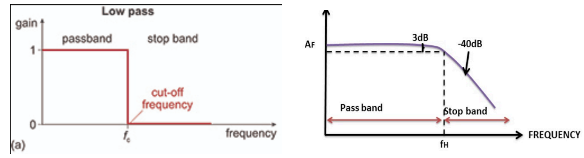


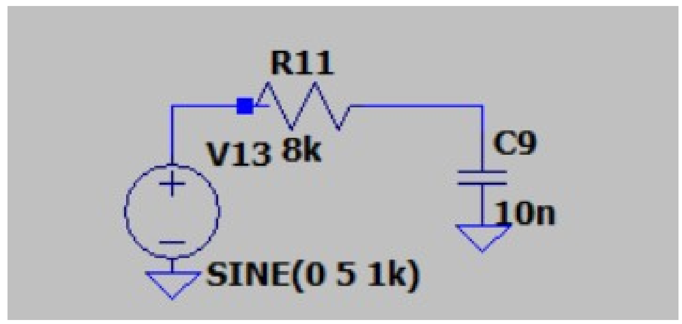
Fig. 3. Low Pass Filter



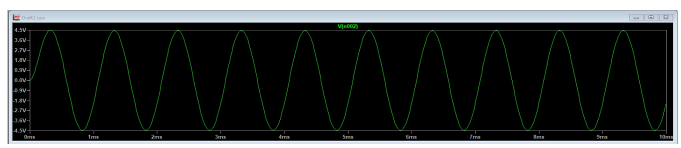
The low pass attenuates some of the frequencies just above the cut-off frequency partially. So, there will be other frequency components which are above the cut-off frequency and got partially attenuated. To attenuate these frequencies more we can cascade low pass. By the transfer characteristics we can observe that the high frequencies in the output of the cascade of the low pass filter is attenuated more.

To get a better output we cascade two low pass filters.

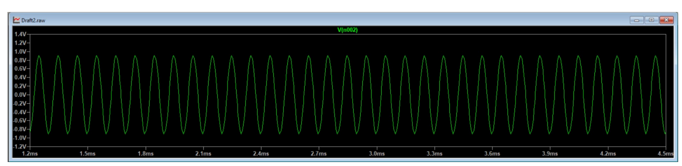
LtSpice Simulations of ***Low Pass Filter***



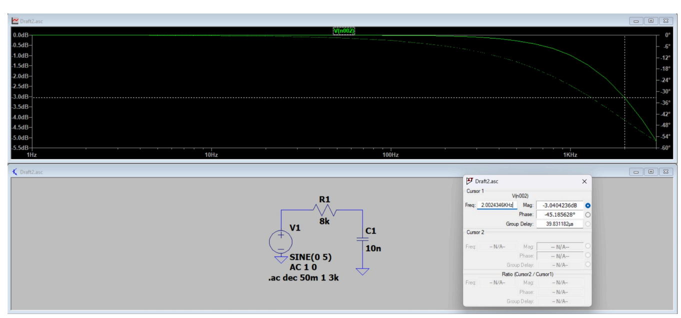
(Figure.35) Low Pass Circuit for the LtSpice simulations



(Figure.36) Transient Response for 1kHz input signal



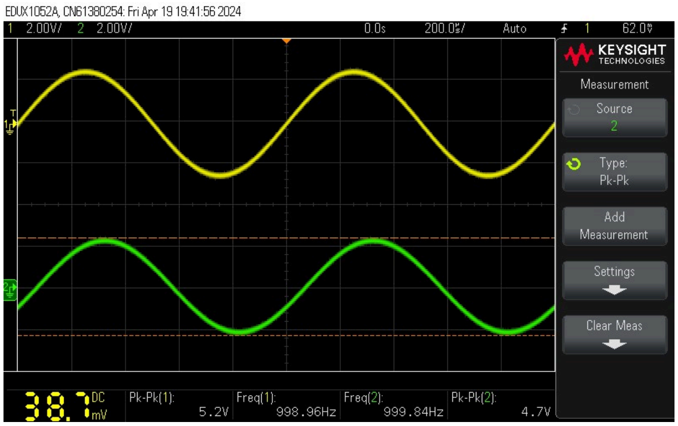
(Figure.37) Transient Response for 10kHz input signal



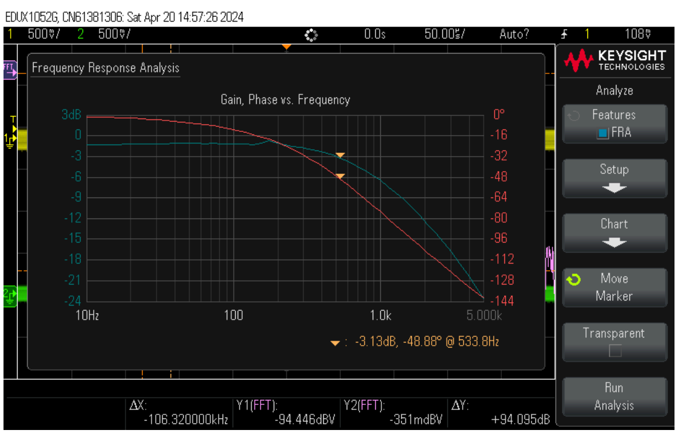
(Figure.38) Frequency Response from AC analysis in LTSpice simulations.

Components	*Simulation Value*	*Practical Values*
R	*8.2k ohm*	*8.2k ohm*
C	*10nF*	*10nF*

*Hardware Outputs of **Low Pass Filter***



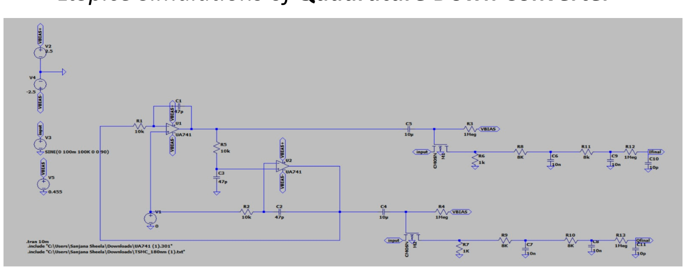
(Figure.39) Practical Hardware output of the Low Pass Filter at 1kHz



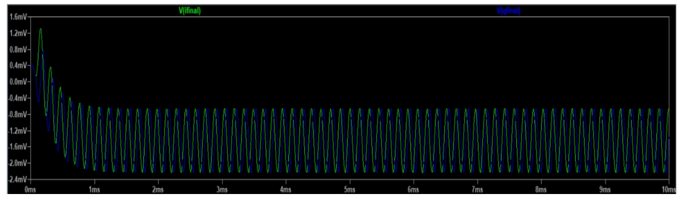
(Figure.40) Frequency Response of the Low Pass Filter
-3 dB frequency is obtained at approximately 533.8 kHz

D. FINAL OUTPUTS

*LtSpice Simulations of **Quadrature Down Converter***

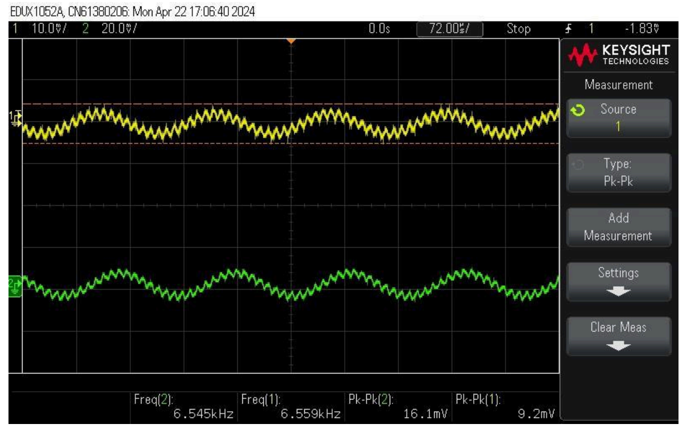


(Figure.41) Final Circuit of the Quadrature Down Converter

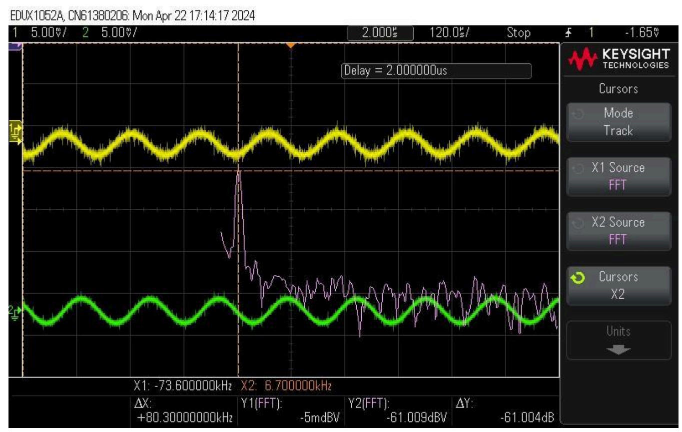


(Figure.42) Final output of the Quadrature Down Converter

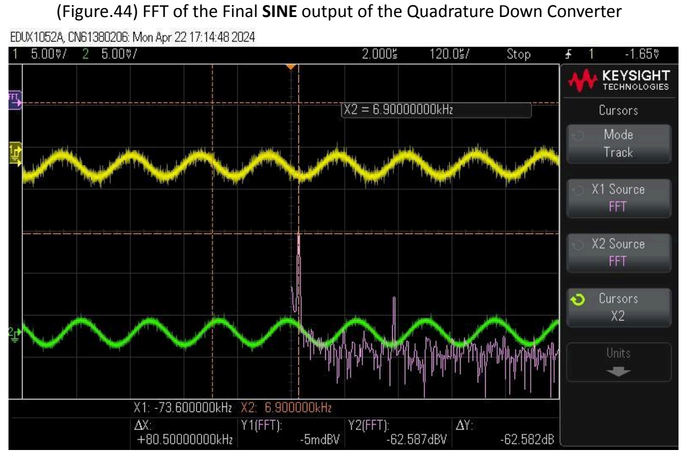
Hardware Outputs of **Quadrature Down Converter**



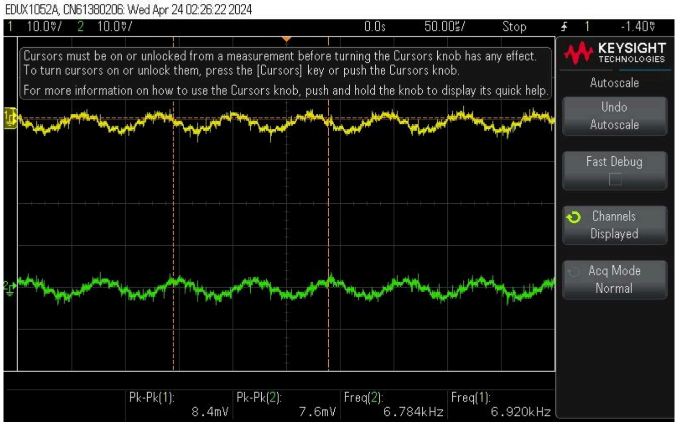
(Figure.43) Output of the combined final circuit after passing through 1st Low Pass Filter



(Figure.44) FFT of the Final **SINE** output of the Quadrature Down Converter



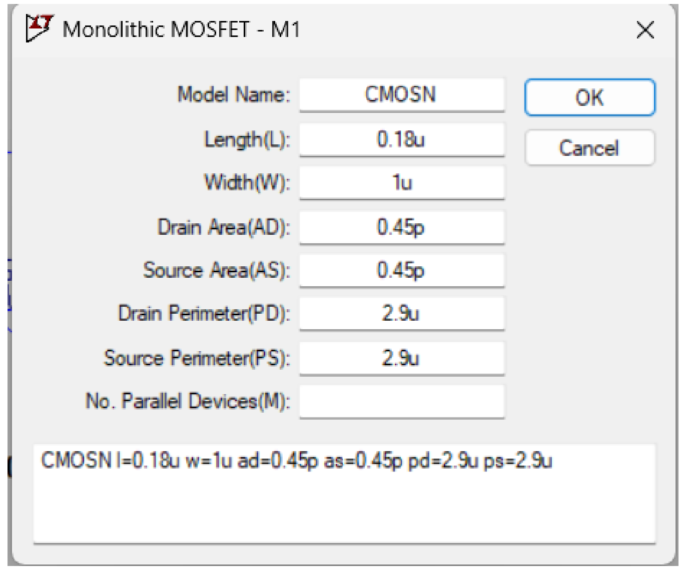
(Figure.45) FFT of the Final **COSINE** output of the Quadrature Down Converter



(Figure.46)

V. COMPARISON BETWEEN THE HARDWARE AND SOFTWARE

Component	Simulation Values	Practical Values
Oscillator Frequency	106.58 kHZ	100.006 kHz
Oscillator Amplitude (I-phase)	0.996V	1.03V
Oscillator Amplitude (Q-phase)	0.99V	1.07V
Input Frequency	95kHz	95kHz to 105kHz
Vdd Supply	2.5V	5V
Vss Supply	-2.5V	0V
V bias	0.455V	1.8V
Cc	10uF	10uF
R bias	1M ohm	1M ohm
R (oscillator)	10k ohm	330 ohm
C(oscillator)	47pF	5pF
R - LPF	8k ohm	8k ohm
C - LPF	10nF	10nF



(Figure.47)Parameters of the MOSFET in LtSpice

E. CONTRIBUTIONS

Sanjana Sheela

- Simulations of LtSpice
- Oscillator
- Low Pass Filter
- Hardware

Khyathi Sri Basireddy

- Project Report
- Mixer
- PPT presentation
- Hardware

F. REFERENCES

[1]A_simple_wide-band_sine_wave_quadrature_oscillator.pdf

[2] TI_opamp_osc.pdf

[3] “Microelectronic Circuits” by Sedra and Smith