Analog Electronic Circuits: Course Project Quadrature Oscillator

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***Abstract*—The project focuses on the implementation of a prototype quadrature down converter (QDC) for wireless receivers (RX) used in modern communication systems such as Bluetooth, Wi-Fi, and WLAN. The primary objective is to mitigate interference and enhance communication quality. The QDC plays a crucial role in improving wireless communication and offers potential benefits in various applications.**

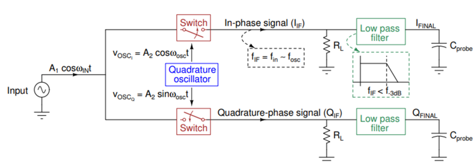
***Index Terms*—quadrature oscillator, mixer,opamps,IF (Intermediate Frequency),MOSFET,NMOS**

I. Introduction

In this project, we are making a Quadrature Down Converter (QDC) commonly used in modern-day wireless receivers.

The main purpose of the Quadrature down converter is to do frequency down-conversion of the signal (which is already up-converted and also has some noise with it).

In this prototype of QCD, we are implementing a switch (mixer) a quadrature oscillator and a simple RC low pass filter (LPF) which is shown below:



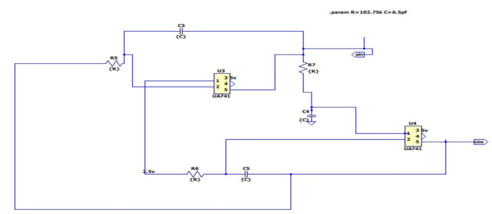
As shown in the figure, the input signal $V_{in} = A_1 \operatorname{Cos}(\omega_{\text{in}}\, t)$ is mixed with $V_{\text{osc }1} = A_2\,(\omega_{osc} t)$ and $v_{oscQ} = A_2 \operatorname{Sin}(\omega_{osc} t)$ to produce in-phase and quadrature-phase and the quadrature-phase signal have a phase difference of $90°$.

Mixing of two signals is equivalent to the product of those two signals, which gives a signal with two frequencies of $\omega_1 - \omega_2$, which is sufficiently low compared to $\omega_1 + \omega_2$ for high values of ω_1 and ω_2.

II. Quadrature Oscillator Design

A. Description of the model

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. Integrator: The integrator is responsible for integrating the incoming signal, typically a square wave, to produce a triangular wave. It acts as a low-pass filter, smoothing out the sharp edges of the square wave. The integrator consists of an op-amp and a capacitor. The input square wave is connected to the inverting input of the op-amp, and the output of the op-amp is connected to the junction of the capacitor and a resistor. When the input square wave transitions from low to high, the op-amp tries to maintain the inverting input at the same potential as the non-inverting input (usually grounded). The op-amp output rises, causing the capacitor to charge through the resistor



B. Topology and Calculations

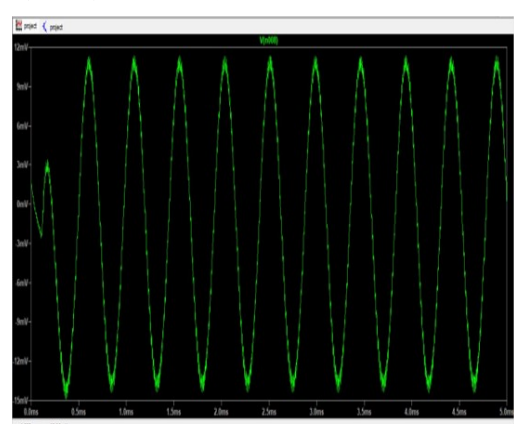
The resistor and capacitor values in the feedback path are calculated from the relation output frequency $f = \frac{1}{2\pi RC}$ where R, C are the values of the resistance and capacitance, whose values are the same across all feedback paths.

As the frequency required is 100KHz, we fix the Resistance to $102.75\ \text{K}\Omega$ and $C = \frac{1}{2\pi Rf}$, which is 6.5pF.

However, we observe less frequency than the desired output due to op-amp imperfection. To fix this issue, from calculated values of R and C, we decrease the resistance keeping capacitance constant till we observe the desired output frequency.

C. LT Spice Simulations

The following plots are time domain plots and FFTs of output signals generated by the Quadrature oscillator:



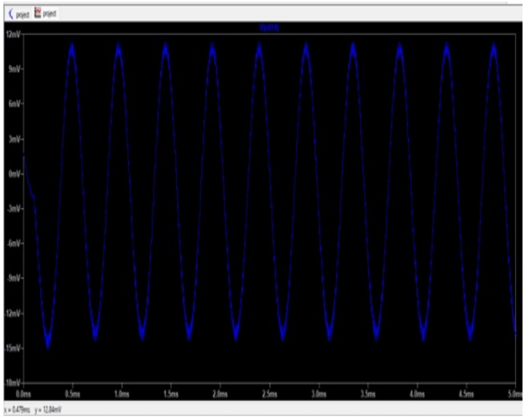


Fig. 3. Output of quadrature Oscillator showing in-phase and quadrature component

In both FFTs, we observe the first peak (fundamental frequency) at the frequency of the output signal. To check the difference between two signals, We can check the difference

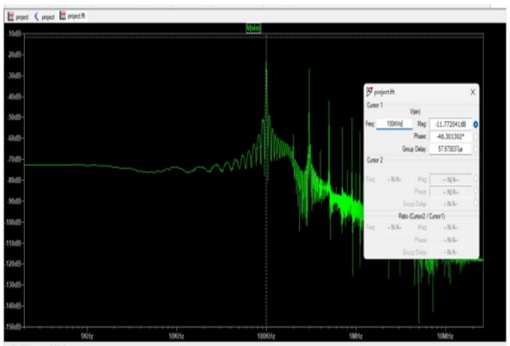


Fig. 4. FFT of in-phase Component (Sine)

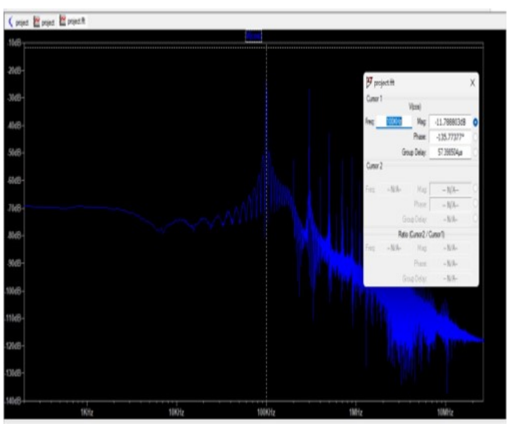


Fig. 5. FFT of quadrature component (Cos)

between phases at any point of two different signals which gives the phase difference. For the circuit that we made, we observed the magnitude of phase difference to be almost 90°.

III. Switch (Mixer) Design

A. Description of the model

A mixer (switch) is a multiplier which multiplies two signals. A simple mixer consists of a MOSFET, a coupling capacitor, a bias and a load resistor, and a DC supply which is called bias voltage.

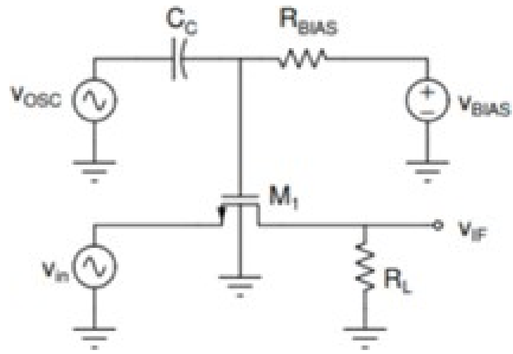


Fig. 6. Characteristics of NMOS

We are using a quadrature oscillator and a mixer in our circuit. To cascade the output of the oscillator with the mixer, we have included a coupling capacitance. This capacitor acts as a buffer and prevents any signal disturbance while cascading from one device to another.

To control the MOSFET's on/off state, we are providing VBIAS (bias voltage). We have given a high bias resistance to direct the oscillator's signal towards the MOSFET's gate instead of the bias resistor. We are using a bias resistor of RBIAS=1M and a coupling capacitance of 10F in our design.

We have set the bias voltage around the MOSFET's threshold voltage (just greater than it) to ensure proper switching on and off of the MOSFET. In our design, we have used an NMOS, and its characteristics are specified in the following section for a better understanding.

Fig. 7. fig: Characteristics of NMOS

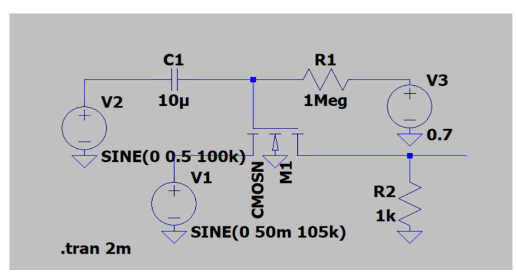


Fig. 8. Design of Mixer on LTSpice

B. Working of Mixer and Plots

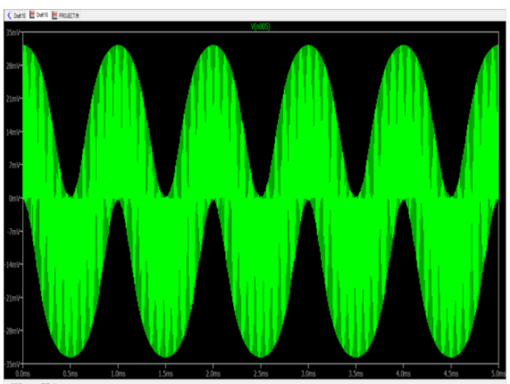
Let's analyse how the mixer works:

- From the circuit, we observe the voltage at the gate terminal to be: $V_{GS} = V_{OSC} + V_{BIAS} = V_{OSC} + V_T$

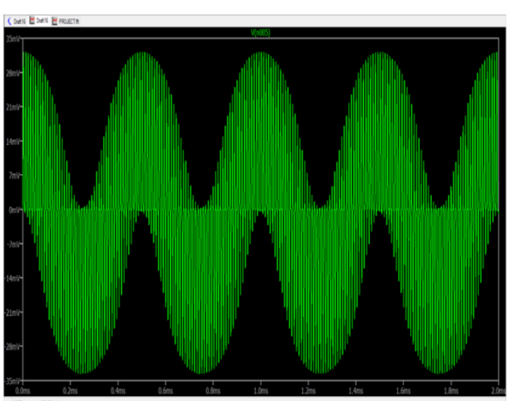
- We know that for an NMOS to be on $V_{GS} \geq V_T$
- At the positive half cycle of the oscillator signal, $V_{OSC} + V_T \geq V_T$

which means, the MOSFET is on and allows the source signal to pass into the drain terminal which is the output of the mixer.

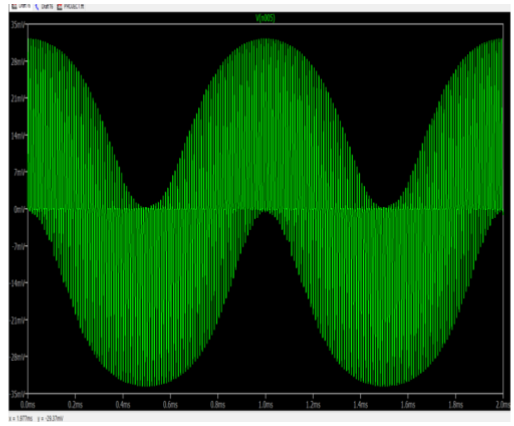
- At the negative half cycle of the oscillator signal, $V_{OSC} + V_T \leq V_T$ which means, the MOSFET is off and blocks the source signal from passing into the drain terminal of the MOSFET.
- As the frequency of the oscillator signal is large enough, it will be oscillating from +ve to -ve half very quickly, thus the MOSFET will be on and off very quickly and we observe the input signal to be mixed with a square pulse (generated due to on/off of MOSFET) at the output of the mixer which is given below for different input frequencies:



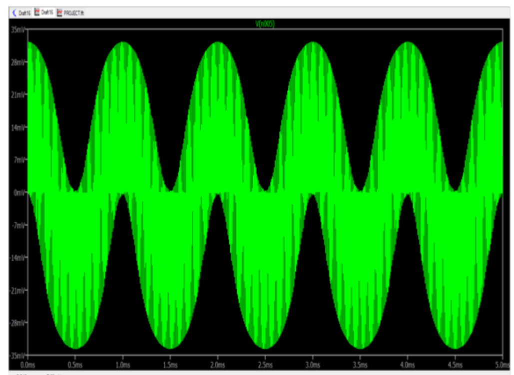
Output for f = 95kHz



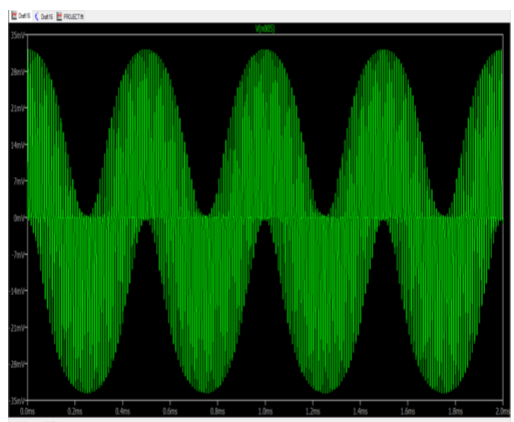
Output for f = 98kHz



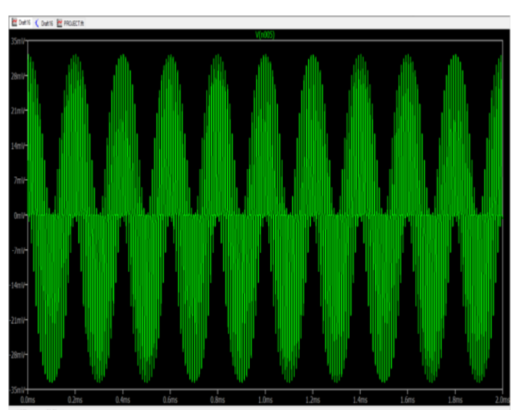
Output for f = 99kHz



Output for f = 101kHz

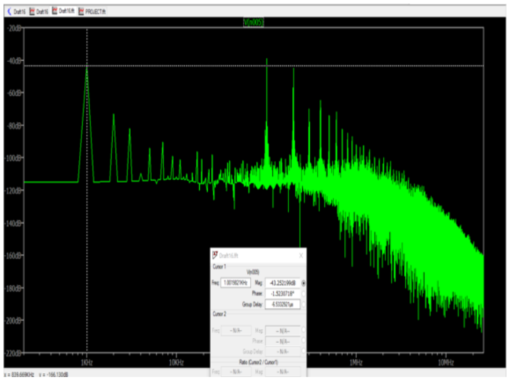


Output for f = 102kHz



Output for f = 102kHz

If VBIAS exceeds VT, the MOSFET will remain ON, preventing mixing.



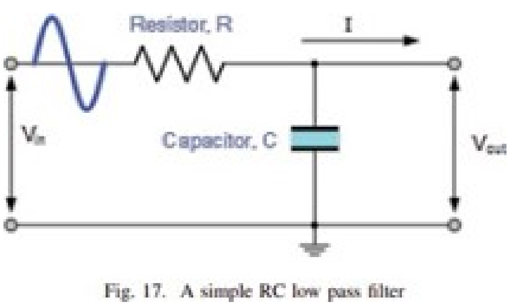
FFT of Output

From the above FFT, we observe three major peaks at frequencies $\omega_{in} - \omega_{OSC}, \omega_{in} \& \omega_{in} + \omega_{OSC}$ respectively because the output signal consists of these three major frequency components. We observe similar plots for both in-phase and quadrature-phase components.

IV. Low Pass Filter

A. Description of the model

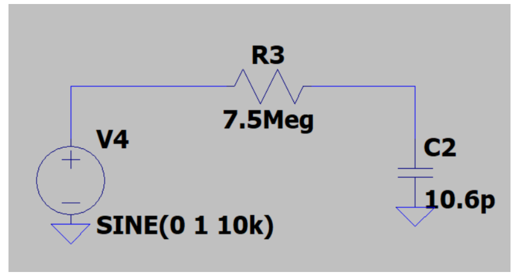
A simple RC low pass filter consists of a resistor and a capacitor with a -3 dB frequency (cut-off frequency) of $\frac{1}{2\pi RC}$. A simple RC LPF circuit is given below:

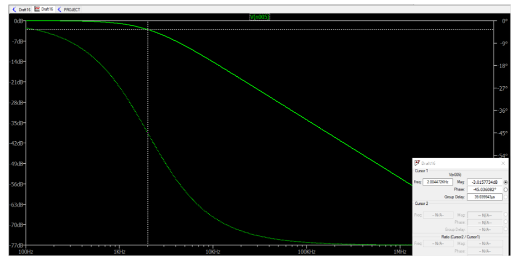


A simple RC low-pass filter

B. Working of LPF

When a signal is passed into an RC filter it attenuates (decreases the amplitude of the signal) the input signal to a higher extent if the input frequency is greater than the cutoff frequency of the RC filter. The cut-off frequency of the RC filter is determined by the value of $\frac{1}{2\pi RC}$ where R, C are the values of resistance and capacitance. If the input signal's frequency is less than the cutoff frequency, the input signal is less attenuated and the output looks almost the same. For designing a low pass filter with -3 dB frequency of 2KHz, we choose R, C values such that product RC is constant i.e., $\frac{2\pi}{f_{-3dB}}$. On choosing R as $7.5\text{M}\Omega$ we get $\text{C} = 10.6\text{nF}$ approximately.





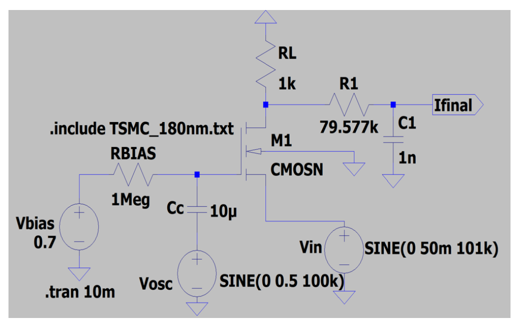
Bode plot of passive LPF with cut-off frequency 2kH

C. Working of LPF along with Mixer

As we know, after mixing the oscillator and the input signal, we send that signal into a low pass filter which removes all unnecessary frequency components and gives out respective in-phase and quadrature-phase components with frequency down-conversion.

As the mixer output consists of two frequencies $\omega_{in} - \omega_{OSC} \& \omega_{in} + \omega_{OSC}$, the low pass filter removes the frequency component $\omega_{in} + \omega_{OSC}$ and gives signal only with frequency component of $\omega_{in} - \omega_{OSC}$ at the output

with a certain extent of attenuation which depends on the cutoff frequency of the filter.



Design of Mixer on LTSpice

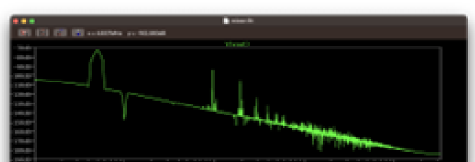
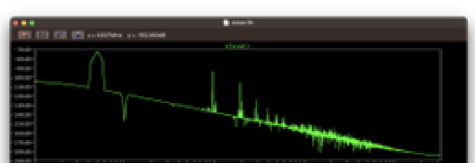


Fig. 10. Fig: FFT of the input signal of LPF

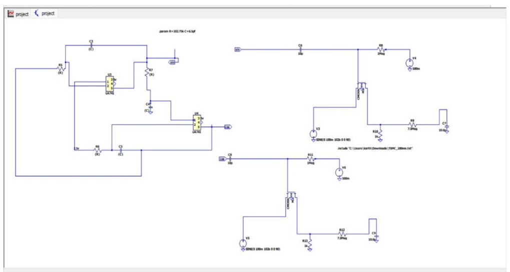


FFT of the input signal of LPF

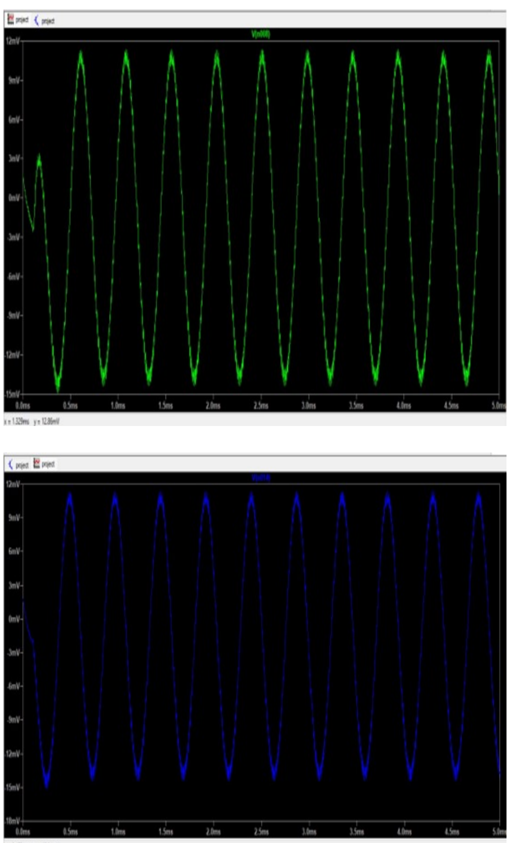
From the above two FFT plots we observe that all the unwanted harmonics are removed by the filter as they have frequencies greater than the cut-off and we observe only the significant harmonics with the frequencies of $\omega_{in} - \omega_{OSC}, \omega_{in} \& \omega_{in} + \omega_{OSC}$ respectively. We observe similar things for both in-phase and quadrature-phase components.

V. Complete Circuit Prototype Design

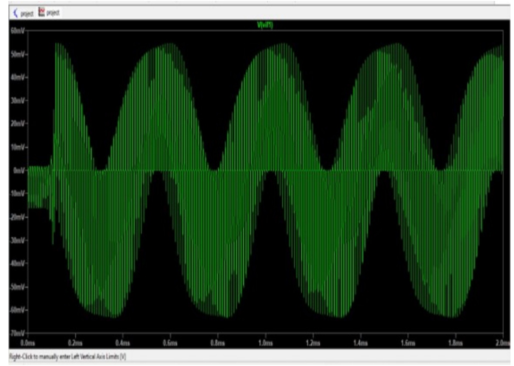
A. Transient Simulations in LTSpice



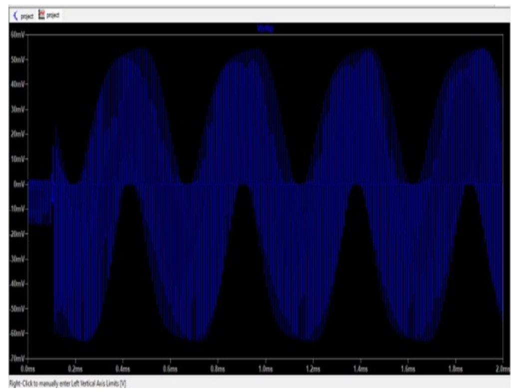
Complete Circuit Diagram



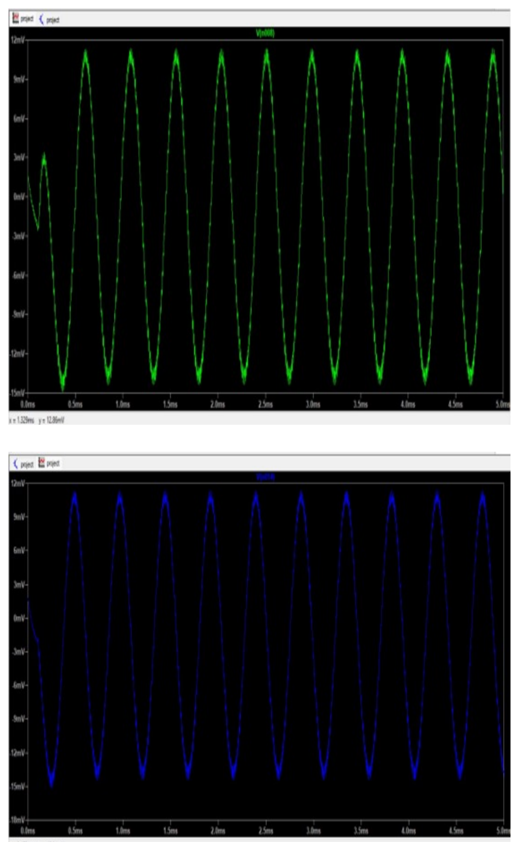
Oscillator Output for Final Circuit



WIFI



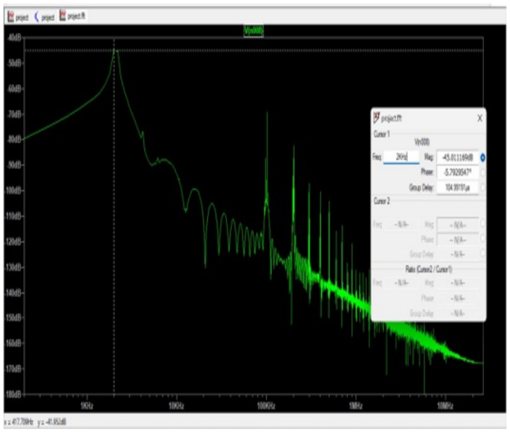
VIFQ



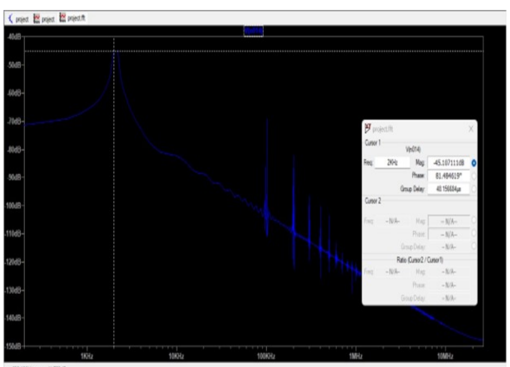
IF Final Output

B. FFTs of final output

We can determine the phase difference between two signals, one in-phase and the other quadrature, with the same amplitude and frequency, by analyzing their Fast Fourier Transforms (FFTs). The phase difference can be calculated by measuring the peak phase difference between the two FFTs.



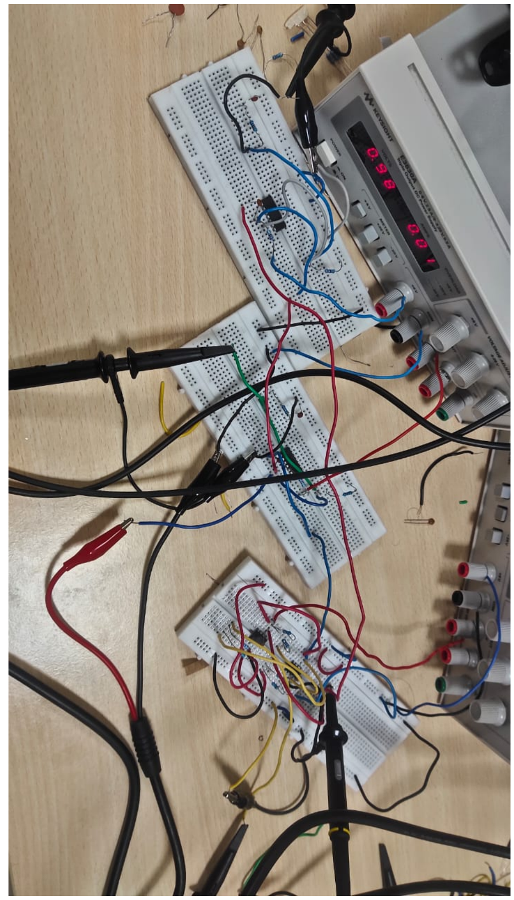
FFT of Vif(I)



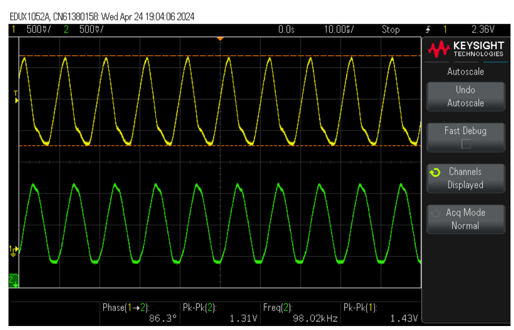
FFT of Vif(Q)

VI. Hardware Part Output and Analysis

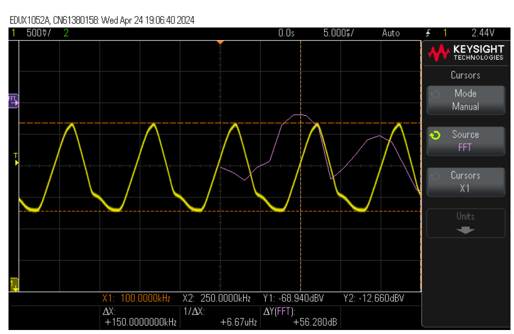
A. Quadrature Down Converter

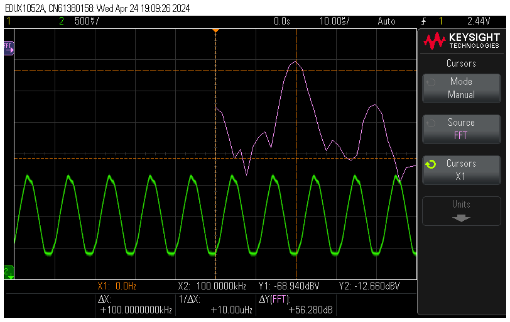


Complete Circuit diagram



Oscillator Output for Final Circuit

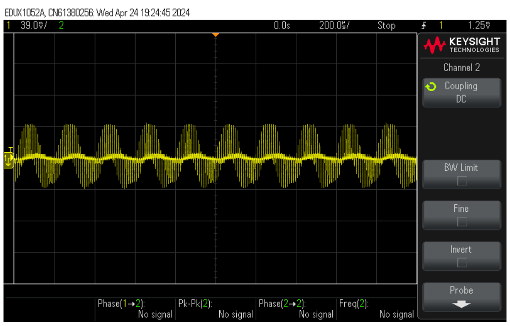




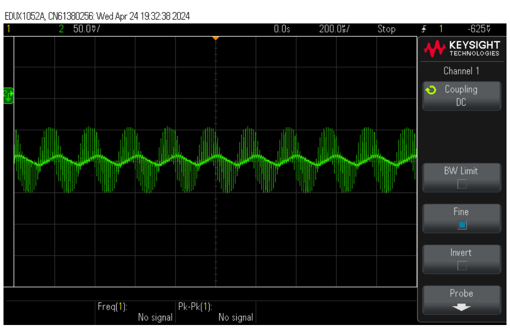
FFt of output plots

B. Switch (Mixer) Design

All the hardware simulations for 101kHz input and 100kHz oscillator signal where the three major frequency components are 1kHz, 100kHz and 101kHz :

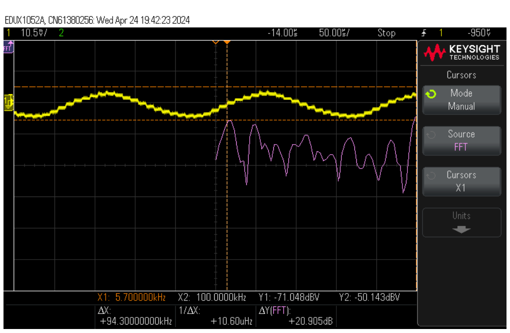


Output of Mixer which is a phase component

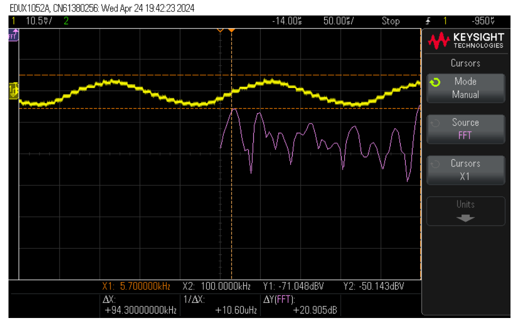


Output of Mixer which in quadrature phase component

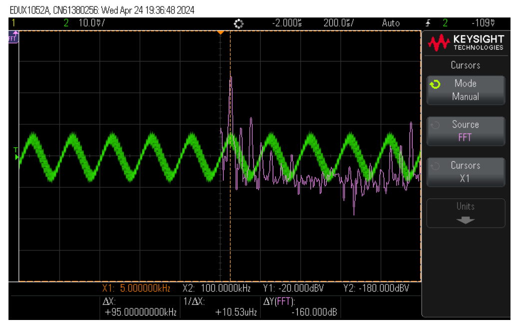
C. Low Pass Filter



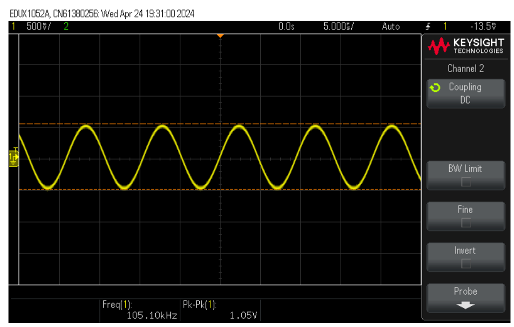
Output of Oscillator + Mixer + LPF



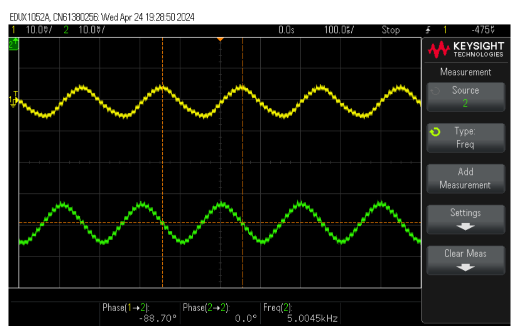
FFT of (VIF)FinalI



FFT of (VIF)FinalQ



Input Signal



D. Performance Analysis

Parameter	Measured
Oscillator Frequency	100KHz
Oscillator Amplitude(I-phase)	1Vpp
Oscillator Amplitude(Q-phase)	1Vpp
Input Frequency	105KHz
IF	5Khz
SUPPLY	5 V
BIAS	0.7 V
C_C	1nF

Table Experimental Values

Parameter	Simulated
Oscillator Frequency	99KHz
Oscillator Amplitude(I-phase)	1.31Vpp
Oscillator Amplitude(Q-phase)	1.2mVpp
Input Frequency	105KHz
IF	5Khz
SUPPLY	7.5 V
BIAS	0.67 V
C_C	1nF

Table Measured Values

REFERENCES

[1] Chp 14: RC op-amp oscillators, Microelectronics Circuits by Adel S. Sedra Kenneth C. Smith.

[2] Ron Mancini," Design of op-amp sine wave oscillators", Texas Instrument, 2000,

[3] ElectronicsTutorials for RC low pass filter.

[4] PDF for the whole description of the project.

[5] Class Notes.