# Quadrature Down Converter


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***Abstract*—The goal of this project is to design and build a Quadrature down converter. A quadrature down converter is a critical component in modern communication systems that is used for frequency down-conversion and quadrature signal demodulation. To validate the performance of the quadrature down converter, the project will include system-level analysis, circuit design, simulation, and practical implementation.**



***Index Terms*—Quadrature Oscillator, Mixer Circuit (Switch), Amplifier, Low Pass Filter**


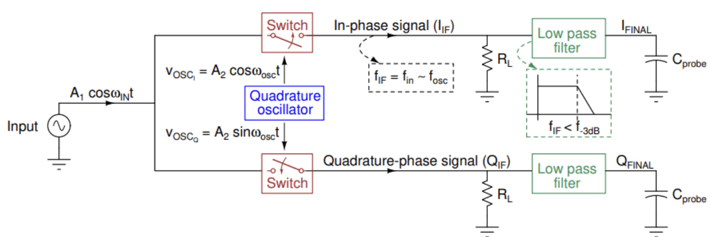


Fig. 1. Circuit Overview

## I. Introduction

The quadrature down converter is essential in modern communication systems because it allows high-frequency quadrature signals to be converted to baseband or intermediate frequency signals. It is a fundamental component in wireless communication since 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 utilisation.

The project's goal is to develop and build a quadrature down converter that fits the stringent criteria of current communication networks. This includes selecting appropriate components like as mixers, filters, and amplifiers. The project aims to achieve high linearity, low noise, broad bandwidth, and outstanding dynamic range by carefully developing and optimising the various stages of the down converter.

To guarantee that the intended performance standards are reached, the project will include extensive system-level analysis and simulation. The project will also include actual implementation and testing to validate the concept and evaluate its performance in real-world circumstances.

The successful creation of a high-performance quadrature down converter will help to progress communication systems by allowing for greater data transfer, higher signal quality, and more spectrum efficiency. It will find use in a variety of sectors, including wireless communication, radar systems, and software-defined radios.

It has three main components in it:

- Qudrature Oscillator: This oscillator circuit generates two high-frequency signals characterized by a phase disparity of 90°.
- 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.
- 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.

## II. CIRCUITS IN THE PROJECT

### A. *Quadrature Oscillator*

The Quadrature Oscillator takes in the noise from the environment and amplifies it to sine and cosine waves. Here Op Amps are used to give a negative feedback and add a phase of 180 °in each feedback.

If a phase difference of 90 °is given as feedback then, the amplitude would continuously rise. To avoid this, we need to make it 180 °.

### B. *Mixer Circuit (Switch)*

*1) **Charecterization of MOSFET**:* We Characterized the MOSFET such that it operates in Triode Region only,for which the proof is written below.

*2) **Working**:* This is used to produce a **sum of two Sinusoids**, one with high frequency and other with a low frequency.

The working of the circuit is as follows:

- voltage input from the oscilloscope $= V_{OSC} = A_1 sin(2\pi t \cdot 100k)$

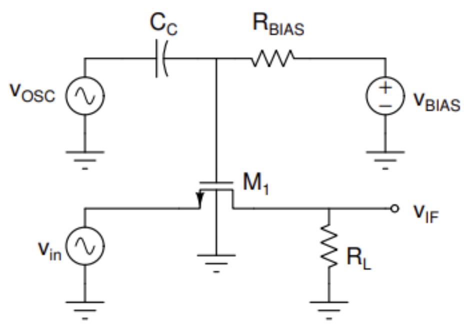


Fig. 2. Mixer Circuit

- voltage input from the external source $= V_{IN} = A_2 sin(2\pi t \cdot 99k)$
- Biasing Voltage $= V_{BIAS}$

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

Now,

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

Let, $V_{BIAS}$ be approximately equal to the Threshold Voltage of the MOSFET.

$$\therefore V_{GS} - V_{TH} = V_{OSC} - V_{IN}$$
$$\therefore \text{ if } V_{OSC} - V_{IN} < 0$$
$$\implies I_{DS} = 0$$
$$\implies \text{ the MOSFET is in Cut-off Region.}$$
$$\text{if } V_{OSC} - V_{IN} > 0$$
$$\implies \text{the MOSFET is in Triode region.}$$

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 trode to be in saturation,

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

which is not getting satisfied in the above circuit.
Continuing with the proof for the MOSFET being in Triode Region,

$$I_{DS} = \mu_n C_{OX} \frac{W}{L}((V_{GS} - V_{TH})V_{DS} - \frac{V_{DS}^2}{2})$$

let, $\mu_n C_{OX} \frac{W}{L}$ = k

$$V_{OUT} = I_{DS} R_L$$
$$V_{OUT} = R_L k((V_{OSC} - V_{IN})(V_{OUT} + V_{IN}) - \frac{(V_{OUT}+V_{IN})^2}{2})$$

after neglecting few terms, based on our above consederations,

$$V_{OUT} = R_L k V_{OSC} V_{IN}$$
$$V_{OUT} = R_L k A_1 sin(2\pi t \cdot f_1) A_2 sin(2\pi t \cdot f_2)$$

$$V_{OUT} = \frac{R_L k A_1 A_2}{2}(cos(2\pi t(f_1 - f_2)) - cos(2\pi t(f_1 + f_2)))$$
$$V_{OUT} = \frac{R_L k A_1 A_2}{2}(sin(2\pi t(f_1 + f_2)) + sin(2\pi t(f_1 - f_2)))$$

### C. Low pass filter

A low-pass filter is designed to attenuate or suppress high-frequency components while allowing low-frequency signals to pass through relatively unaltered. The cutoff frequency, denoted as $f_C$, determines the point at which the filter starts attenuating the higher frequencies. The roll-off characteristic defines the rate at which the attenuation increases beyond the cutoff frequency. The filter's transfer function can be described using various mathematical representations, including the Laplace transform or transfer function in the s-domain.

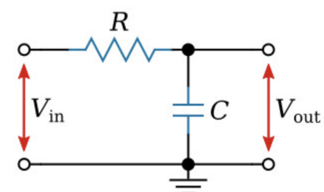


Fig. 3. Low Pass Filter

for a low pass filter with R and C as its restance and capacitance,

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

### D. Amplifier

An amplifier is generally used to Amplify the signal which doesn't have sufficient signal strength.Here, we have used an Non - Inverting Operational Amplifier to amplify the signal outcome from the Low pass filter of the Quadrature Down Converter.

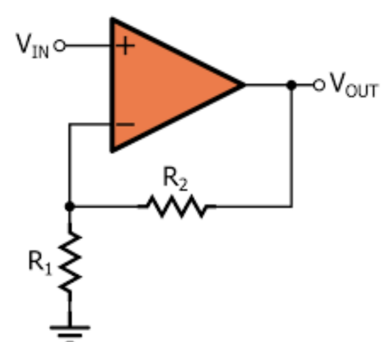


Fig. 4. Non Inverting op Amp Amplifier

## III. SPICE SIMULATIONS

### A. Quadrature Oscillator

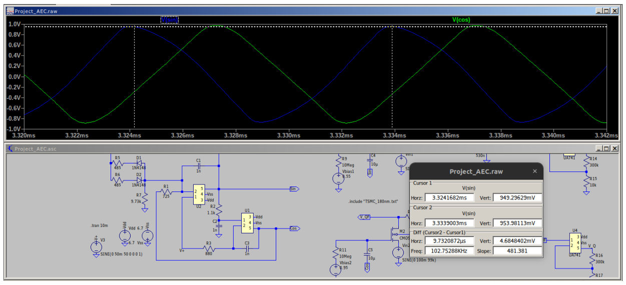

Fig. 5. Output From the Quadrature Oscillator

### B. Mixer Circuit (Switch)

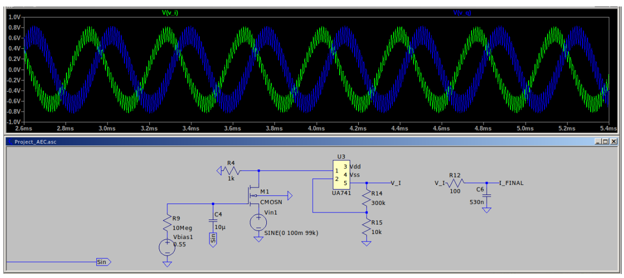

Fig. 6. In phase and Quadrature phase Outputs from Mixer Circuit

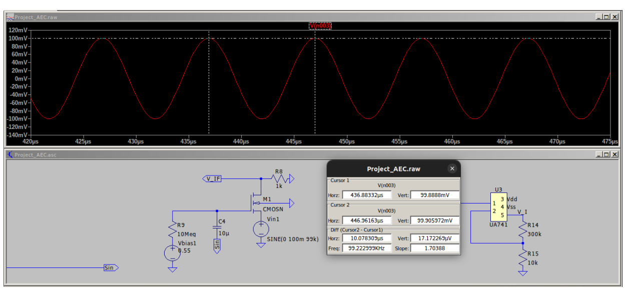

Fig. 7. Input Voltage to Mixer circuit

### C. Low pass filter

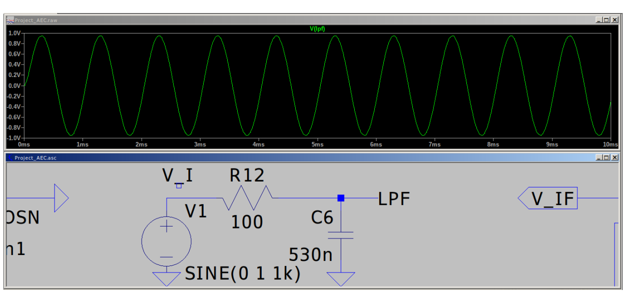


Fig. 8. LPF output for 1 Kilo hertz input

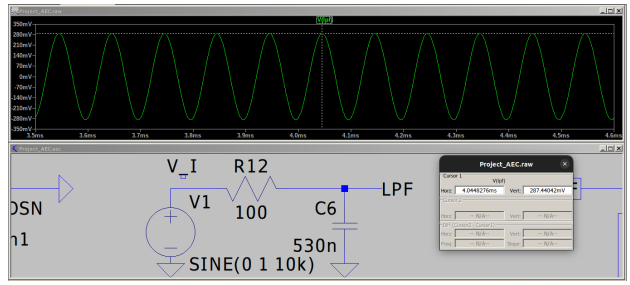


Fig. 9. LPF output for 10 Kilo hertz input

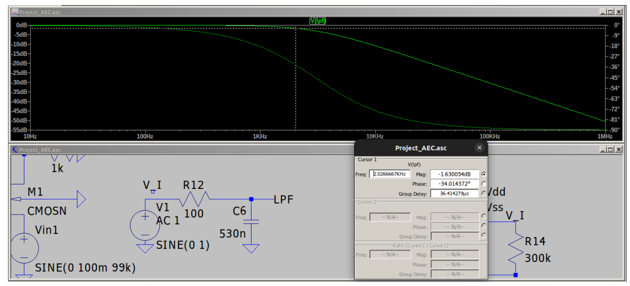


Fig. 10. AC analysis of The Low Pass Filter

From the above simulation, we can see that, the graph stats falling rapidly from 3 Kilo Hertz. The cutoff frequency of our circuit is 3.003 kilo hertz.

### D. Complete Circuit

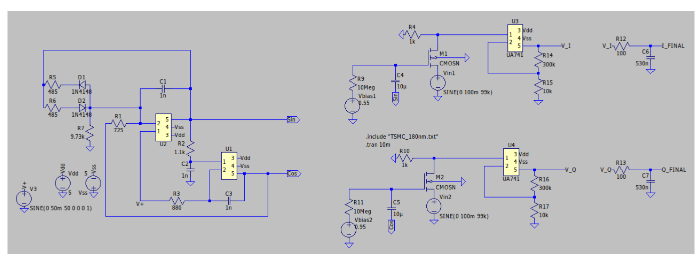

Fig. 11. Circuit Overview

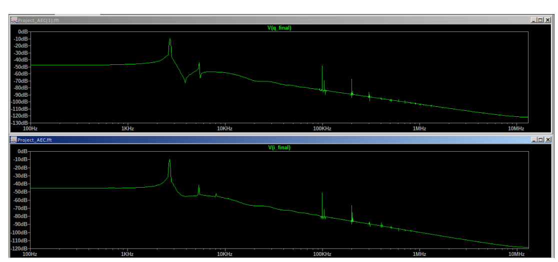

Fig. 13. FFT of final output received

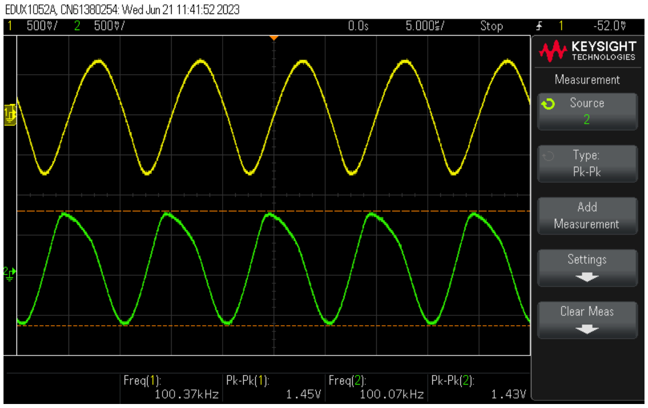


Fig. 14. Output from the Quadrature Oscillator

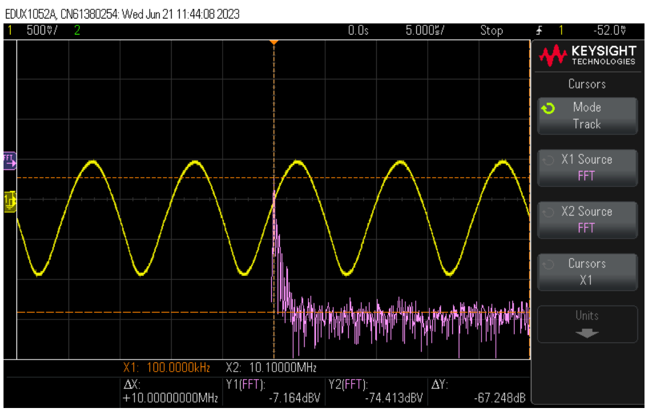


Fig. 15. FFT of Sine wave received from Quadrature Oscillator

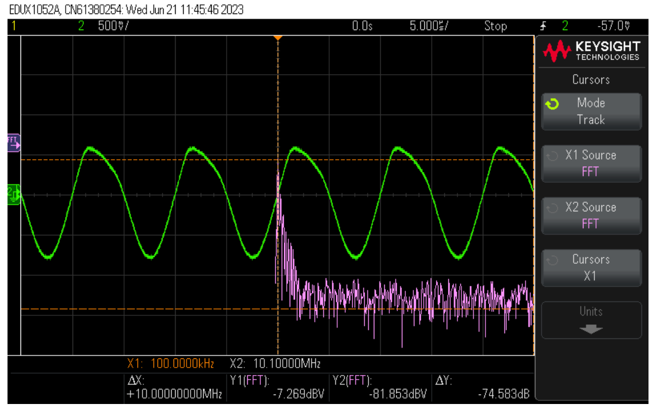


Fig. 16. FFT of cpine wave received from Quadrature Oscillator

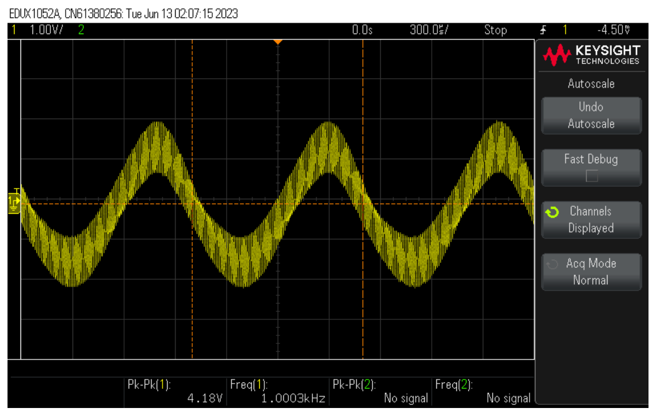


Fig. 17. Output from Mixer circuit

## IV. Hardware Demonstration

### *A. Quadrature Oscillator*

### *B. Mixer Circuit (Switch)*

### *C. Amplifier*

### *D. Low pass filter (Fed with an external Output)*

We can see that the signal passses through the filter without getting attenuated.

we can clearly see from the FFT plots that The 10 kHz frequency is getting attenuated as the cutoff frequency is 3.3 kHz which is less than 10 kHz.

### *E. Low pass filter (Fed with an Amplified Mixer Output)*

### *F. Complete Circuit*

this is a Video Link to the observations of the circuit

## V. Spice Versus Hardware

The Values will differ much from the LTSpice simulations and the realization. The differcenes can be seen in the table. These differences are due to

## VI. Contributions

**Busam Karthikeya**

- Simulations in LTSpice
- Oscillator
- LPF

**Koluguri Sri Rama Rathan Reddy**

- Mixer Circuit
- Amplifier
- Repport and PPT

TABLE I
PERFORMANCE SUMMARY AND COMPARISON

| Paramertes | Measured | Simulated |
|---|---|---|
| Oscilator frequency (I-phase) | 100.37 KHz | 101.81 kHz |
| Oscilator frequency (Q-phase) | 100.07 KHz | 102.05 kHz |
| Oscillator Amplitude (I-phase) | 1.45 V | 1.82 V |
| Oscillator Amplitude (Q-phase) | 1.43 V | 1.86 V |
| Input frequency | 99 kHz | 99 kHz |
| Supply - $V_{DD}$ | 5.49 V | 5 V |
| Supply - $V_{SS}$ | 5.49 V | 5 V |
| $V_{BIAS}$ | 2.5 V | 0.95 V |
| $C_C$ | 10 µF | 10 µF |
| R - LPF | 100 Ω | 100 Ω |
| C - LPF | 500 nF | 530 nF |

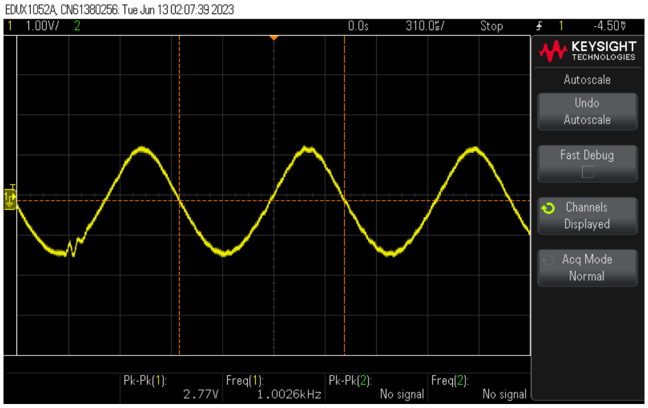


Fig. 18. Output from Low pass filter which is fed with Mixer Output

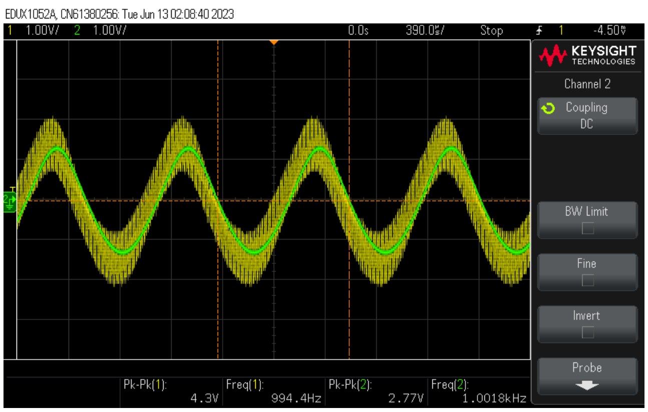


Fig. 19. Both Mixer and LPF Output together

### 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 Instrument, 2000.

[5] Ralph Holzel, "A Simple Wide-Band Sine Wave Quadrature Oscillator", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 42, NO. 3, JUNE 1993.)

[6] Lecture notes, tutorials and labs conducted in this course


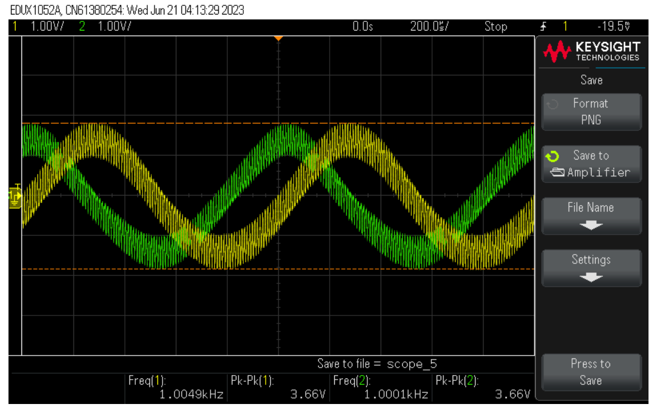


Fig. 20. In phase and Quadrature phase output from the ampilifer

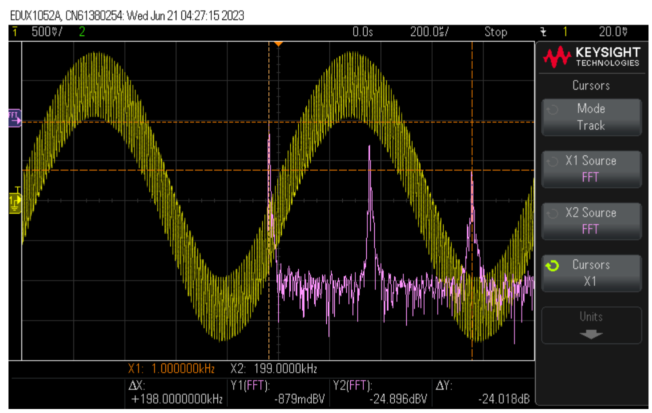


Fig. 21. FFT for the wave received

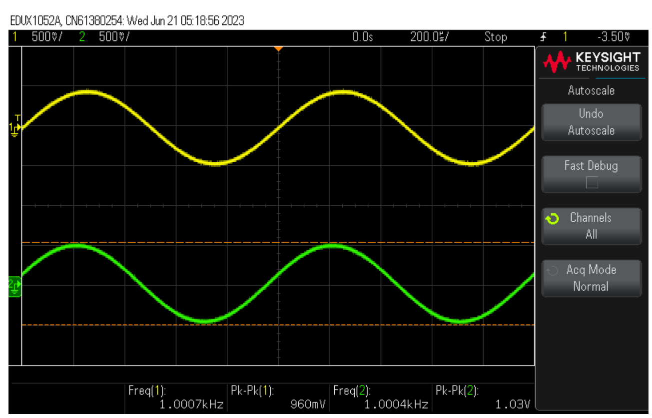


Fig. 22. For 1 kHz, Yellow $\Longrightarrow$ Input to LPF, Green $\Longrightarrow$ Output from LPF

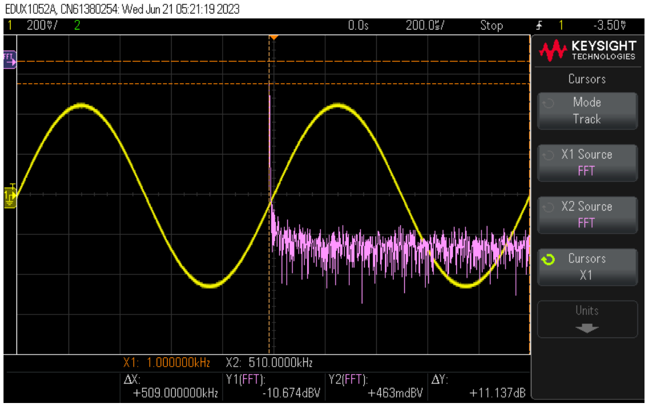


Fig. 23. FFT for the wave

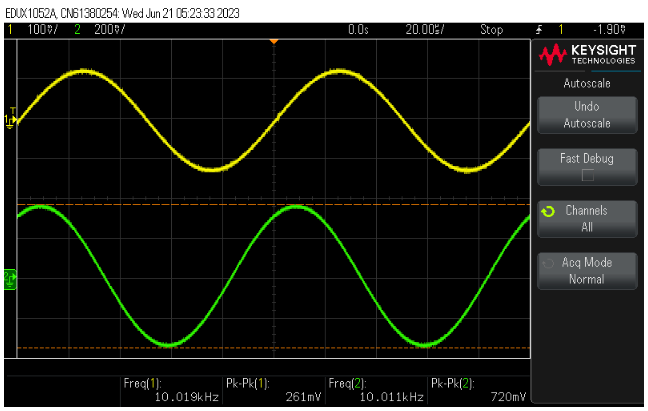


Fig. 24. For 10 kHz, Yellow $\implies$ Input to LPF, Green $\implies$ Output from LPF

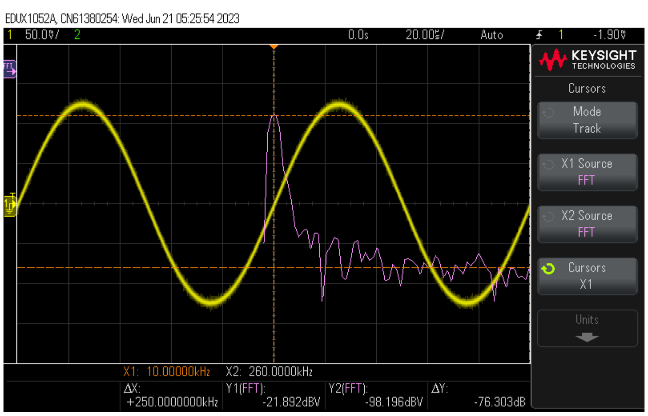


Fig. 25. FFT for Input Wave

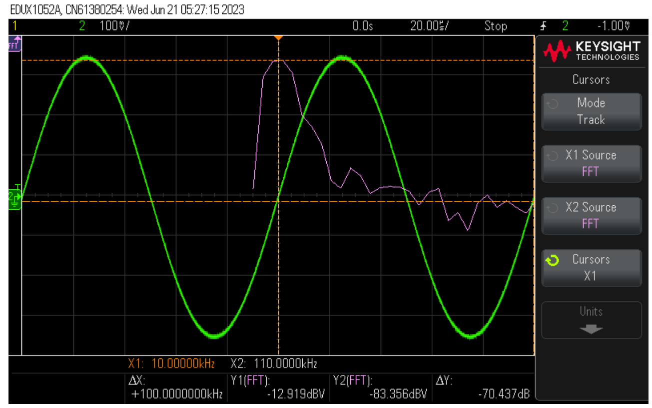


Fig. 26. FFT for Output Wave

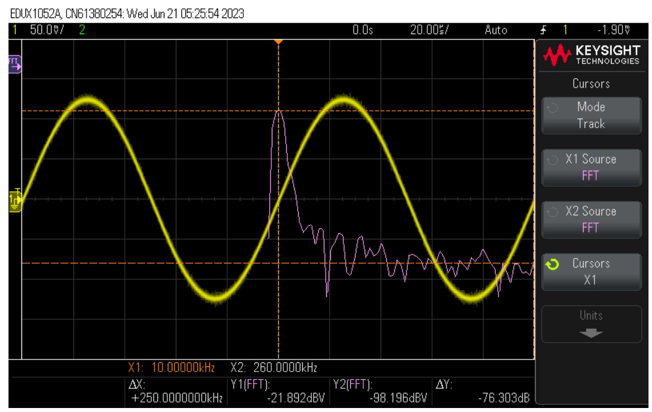


Fig. 27. Green $\implies$ Input to LPF, Yellow $\implies$ output from LPF

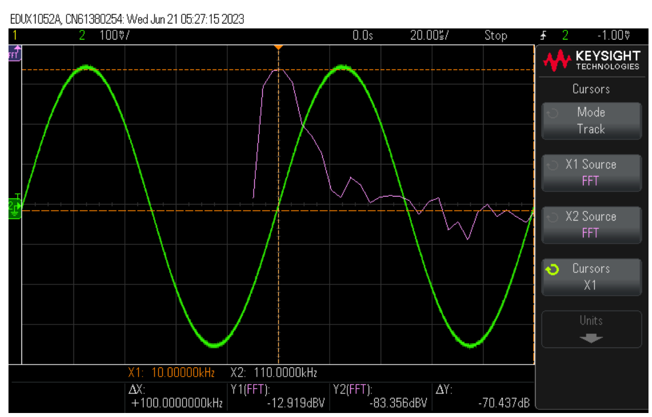


Fig. 28. FFT for Output Wave received from LPF

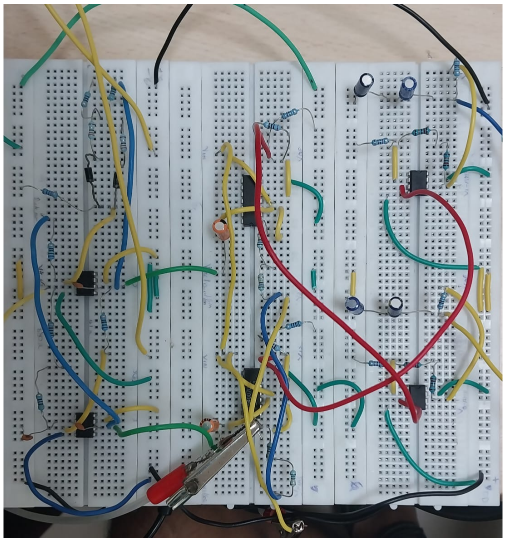

Fig. 29. Circuit Overview

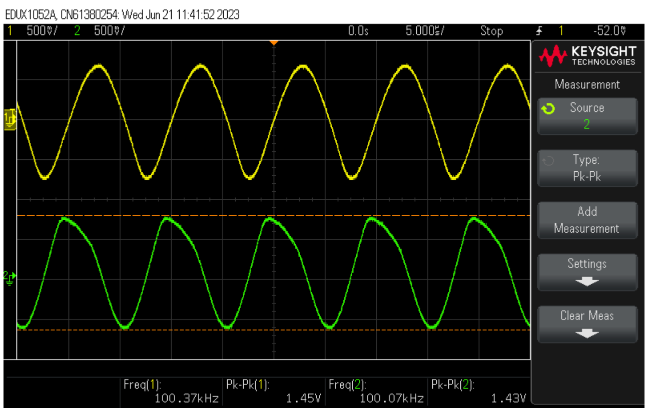


Fig. 30. Output from the Quadrature Oscillator

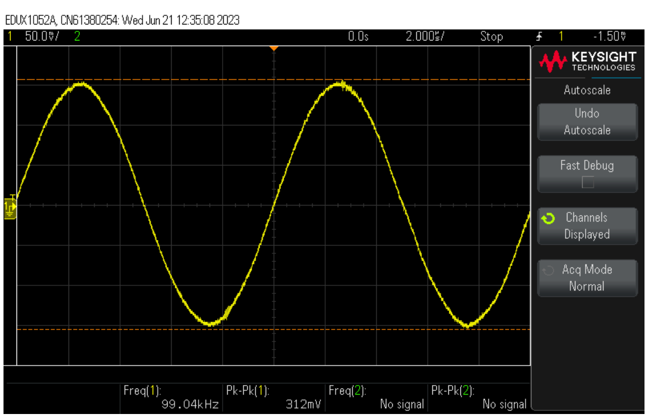


Fig. 31. Input Signal to the Mixer circuit

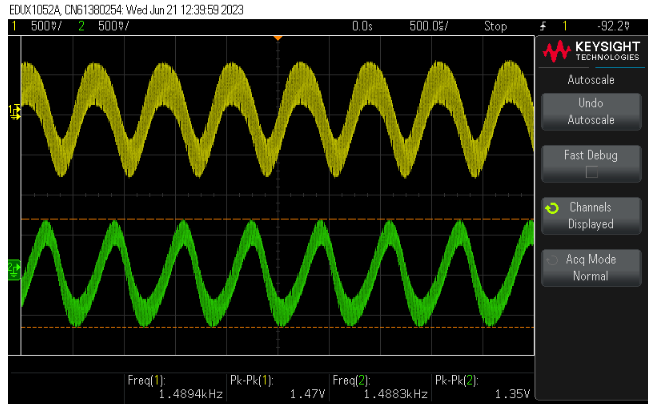


Fig. 32. Amplified Output from Mixer Circuit

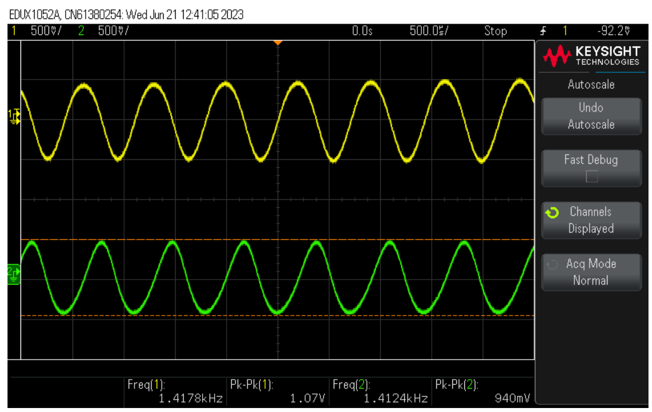


Fig. 33. Output from LPF

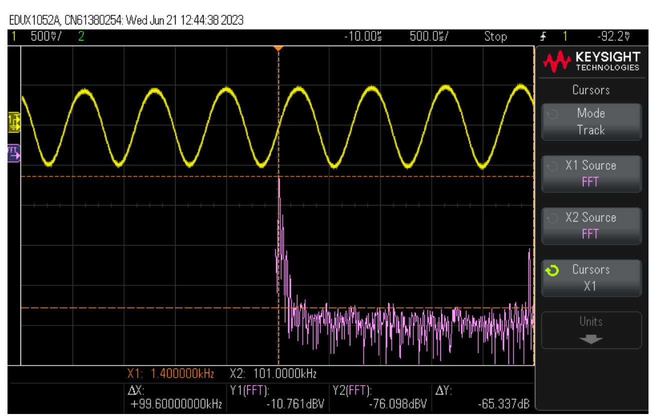


Fig. 34. FFT for the sine wave

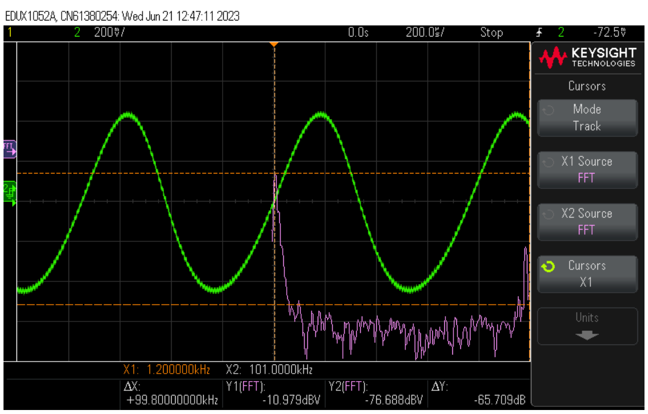


Fig. 35. FFT for the cosine wave