# Analog Electronic Circuits - Project Quadrature Down Converter (QDC)

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{2024102032, 2024112022, 2024112007}

***Abstract*—This project focuses on the design and implementation of a Quadrature Down Converter (QDC), a critical block in modern wireless communication systems such as Bluetooth, Wi-Fi, and FM receivers. In environments with multiple interferers such as overlapping police, WLAN, and public spectrum bands, signals often suffer corruption during downconversion, especially when a strong interferer falls near the desired signal frequency. To mitigate this, the QDC employs quadrature downconversion, producing two signals with a 90° phase difference using sinusoidal and cosine oscillations. This architecture enables effective separation of baseband signals based on phase and prevents self-interference in asymmetrically modulated signals. The complete system integrates three key modules: a Quadrature Oscillator, Mixer (Switch) Circuit, and RC Low Pass Filter. These blocks are designed, analyzed, and simulated individually, and then integrated into a functional prototype to demonstrate real-world applicability in interference-prone communication scenarios.**

## I. Need of Downconversion

During the transmission of signals, the message signal is modulated using a high frequency carrier signal, to get a high frequency passband signal. This is done because a high frequency is advantageous for transmission due to reduced Antenna length and high signal power that decreases SNR (Signal to Noise Ratio).

However, in the reciving part of the communication network, we need to demodulate the signal, ie, convert it back into a low frequency baseband signal with our original message. This process of removing the high frequency carrier signal, is Downconversion, since it reduces the frequency of the input signal.

The need for Downconversion lies in the fact that we need to successfully remove this carrier signal to get our original message signal back.

## II. Quadrature Oscillator

A quadrature oscillator is a type of electronic oscillator that generates two sinusoidal signals of the same frequency, but with a 90-degree phase difference between them. These signals are known as the in-phase (I) and quadrature-phase (Q) components.

### A. Circuit Diagram (Schematic)

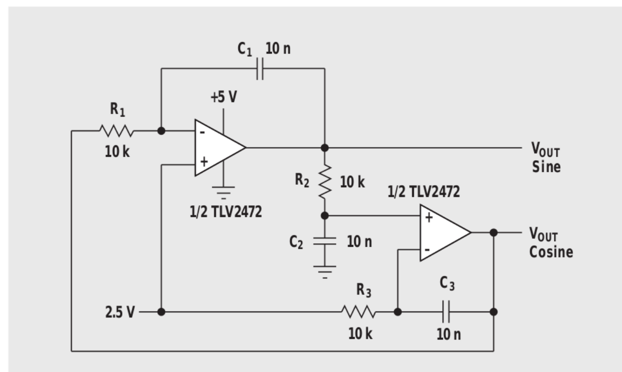


Fig. 1: Quadrature Oscillator Schematic

### B. Working of the Circuit

The working principle of a quadrature oscillator involves creating an unstable feedback loop using active components, such as operational amplifiers (op-amps), to sustain oscillations.

1) **Feedback Network:** The oscillator includes a feedback network made up of resistors, capacitors, and op-amps. This network provides the positive feedback needed to keep the oscillations going.
2) **Phase Shift:** To generate two signals 90 degrees apart, the circuit introduces a phase shift using reactive components such as capacitors or inductors in the feedback path.
3) **Feedback Connection:** The output of the second integrator is sent back to the input of the first integrator, but with the polarity inverted. This configuration helps establish the positive feedback loop that drives the oscillation.
4) **Barkhausen Criterion:** For the oscillator to work properly, the loop gain must be equal to one, and the total phase shift around the loop must be 360 degrees. This requirement, known as the Barkhausen criterion, ensures stable and sustained oscillations.
5) **Output Signals:** Once the circuit reaches a stable state, it produces two continuous sinusoidal signals that are exactly 90 degrees out of phase. These I and Q signals are widely used in communication systems, signal processing, and modulation schemes.

### C. Parameter Values

- Oscillator Resistance, $R_{\text{osc}} = 3.55\,\text{k}\Omega$
- Oscillator Capacitance, $C_{\text{osc}} = 160\,\text{pF}$
- Coupling Capacitors = $1\,\text{pF}$
- Load Resistor = $1\,\text{k}\Omega$

### D. Calculations

*1) Gain Derivations:* Deriving the gain when feedback is disconnected, we get:

$$V_{\text{osc}_\text{i}} = -\frac{1}{j\omega R_1 C_1} V_2, \tag{1}$$

$$A = -\frac{1}{j\omega R_1 C_1}. \tag{2}$$

The gain obtained in the feedback network is:

$$V_1 = V_{\text{osc}_\text{i}} \frac{X_{C_2}}{X_{C_2} + R_2} = V_{\text{osc}_\text{i}} \frac{1}{1 + j\omega R_2 C_2}, \tag{3}$$

$$V_2 = V_1 \Big(1 + \frac{X_{C_3}}{R_3}\Big) = V_1 \Big(1 + \frac{1}{j\omega R_3 C_3}\Big), \tag{4}$$

$$B = \frac{V_2}{V_{\text{osc}_\text{i}}} = \frac{1}{1 + j\omega R_2 C_2} \Big(1 + \frac{1}{j\omega R_3 C_3}\Big). \tag{5}$$

Assuming $R_1C_1 = R_2C_2 = R_3C_3 = RC$, the loop gain is:

$$AB = -\frac{1}{j\omega RC} \frac{1}{1 + j\omega RC} \Big(1 + \frac{1}{j\omega RC}\Big).$$

Applying the magnitude condition gives oscillation at:

$$|AB| = 1 \;\Rightarrow\; \omega = \frac{1}{RC}.$$

We need a frequency of 100KHz. Let us assume a Capacitance value of C = 160pF

$$\Rightarrow\; 2\pi(100kHz) = \frac{1}{R \cdot 160pF} \;\Rightarrow\; R = 9.94K\Omega$$

However we found that in practice 3.55K$\Omega$ was needed to realise this frequency due to opamp's upper cutoff frequency.

*2) Phase Derivation:*

$$\begin{aligned}
\angle AB &= \angle(-1) + \angle\frac{1}{j\omega RC} + \angle\frac{1}{1 + j\omega RC} + \angle\Big(1 + \frac{1}{j\omega RC}\Big) \\
&= \pi - \frac{\pi}{2} - \tan^{-1}(\omega RC) - \tan^{-1}\Big(\tfrac{1}{\omega RC}\Big) \\
&= \frac{\pi}{2} - \big[\tan^{-1}(\omega RC) + \tan^{-1}(\tfrac{1}{\omega RC})\big] \\
&= \frac{\pi}{2} - \frac{\pi}{2} = 0.
\end{aligned}$$

*3) Quadrature (90°) Phase Difference:* At the oscillation frequency $\omega = 1/RC$, split the feedback network into two parts:

$$H_{\text{LP}}(j\omega) = \frac{1}{1 + j\omega RC}, \quad H_{\text{HP}}(j\omega) = \frac{j\omega RC}{1 + j\omega RC}.$$

Their phases are:

$$\angle H_{\text{LP}} = -\tan^{-1}(\omega RC) = -\frac{\pi}{4},$$

$$\angle H_{\text{HP}} = \frac{\pi}{2} - \tan^{-1}(\omega RC) = +\frac{\pi}{4}.$$

Thus, the phase difference is:

$$\angle H_{\text{HP}} - \angle H_{\text{LP}} = \frac{\pi}{4} - \Big(-\frac{\pi}{4}\Big) = \frac{\pi}{2}$$

i.e., 90°.

### E. LT Spice Schematic

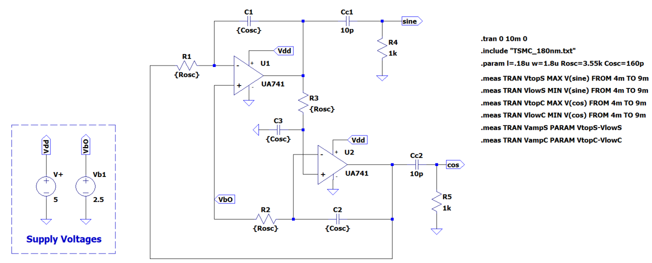


Fig. 2: LTSpice Schematic for Quadrature Oscillator

### F. Observations

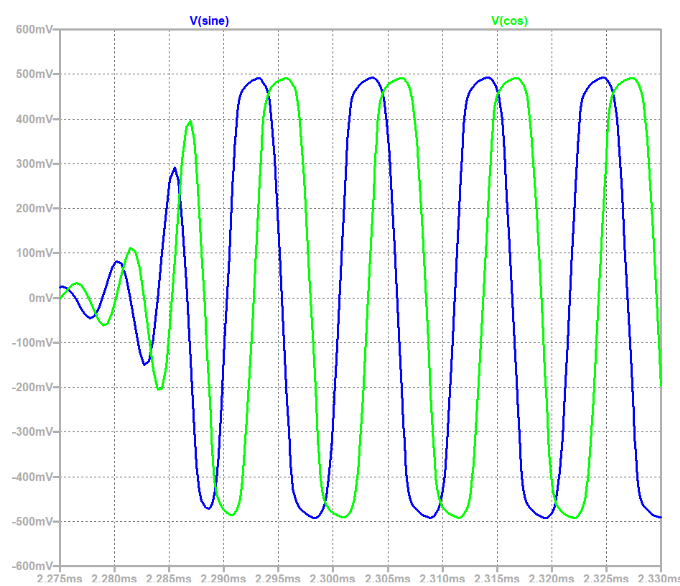


Fig. 3: V(sine) and V(cos)

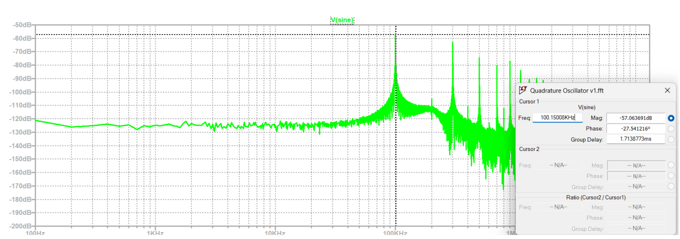

Fig. 4: V(sine) FFT with Phase $\approx$ $-27°$ and Frequency Measured as 100.15 kHz

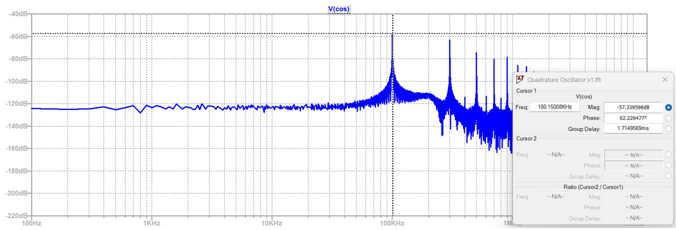

Fig. 5: V(cos) FFT with Phase ≈ 62° and Frequency Measured as 100.15 kHz

We get the Phase Difference between the 2 generated sinusoids as $\approx 62^\circ - (-27^\circ) = 90^\circ$

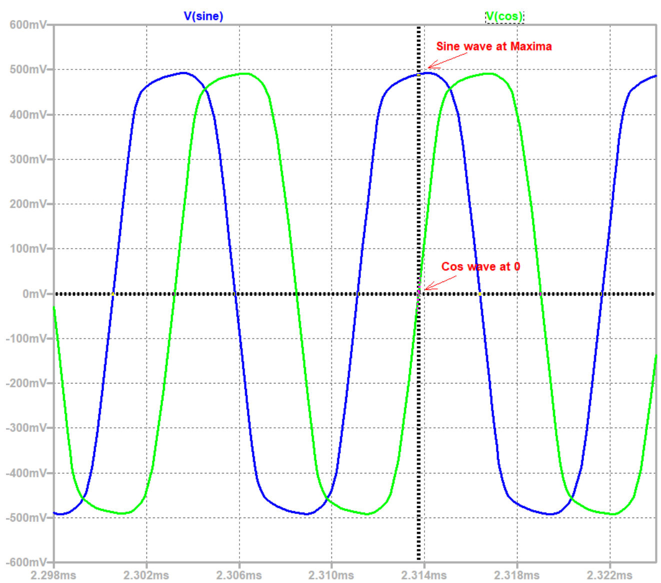


Fig. 6: Annotations Expressing the Phase Difference between V(cos) and V(sine)

```
vtopS: MAX(V(sine))=0.49267026782 FROM 0.004 TO 0.009
vlowS: MIN(V(sine))=-0.492460310459 FROM 0.004 TO 0.009
vtopC: MAX(V(cos))=0.491819649935 FROM 0.004 TO 0.009
vlowC: MIN(V(cos))=-0.492444634438 FROM 0.004 TO 0.009
vampS: vtopS-vlowS=0.985130578279
vampC: vtopC-vlowC=0.984264284372
```

Fig. 7: Amplitude Measurement of V(cos) and V(sine)

### G. Inference

We see that our Oscillator is able to produce 2 sinusoids with a phase difference approximately 90 degrees, with an amplitude of 1 volt peak to peak.

## III. Mixer (Switch) Circuit

A mixer circuit is used to shift the frequency of signals, typically by multiplying an input signal with a local oscillator signal. In a switch-type mixer, mosfet act as on/off switches controlled by the oscillating signal, enabling frequency translation without linear multiplication. The output contains both the sum and difference frequencies of the inputs. This principle is fundamental in radio receivers for downconversion to an intermediate frequency (IF).

### A. Circuit Diagram (Schematic)

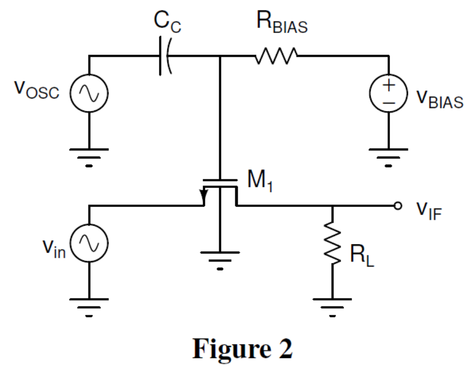


Fig. 8: Mixer Circuit Schematic

### B. Working of the Circuit

The mixer circuit utilizes a MOSFET operating as a switch, controlled by an oscillator signal $V_{osc}$ applied to the gate. The input signal $V_{in}$ is connected to the drain, while a bias resistor $R_{bias}$ is placed between the drain and supply to establish proper DC operation. The source is connected to a DC bias voltage $V_{bias}$, and the output is taken across the source as $V_{out}$.

When $V_{osc}$ is sufficiently high, the gate-source voltage $V_{GS} = V_{osc} - V_{bias}$ exceeds the threshold, turning the MOSFET ON and allowing $V_{in}$ to pass to the output. When $V_{osc}$ is low, $V_{GS}$ falls below threshold, turning the MOSFET OFF and blocking the signal path.

This periodic switching action effectively multiplies the input signal $V_{in}$ with the control signal $V_{osc}$, generating output frequency components at the sum and difference of the input and control signal frequencies,and also their harmonics. These components form the basis of frequency translation in mixer circuits.

### C. Parameter Values

- $R_{bias} = 10$ MΩ
- $V_{bias} = 0.52$ V
- $C_c = 10$ $\mu$F
- $V_{osc} = 1$ $V_{P\text{-}P}$ sine wave, $f = 100$ kHz, with 90° phase shift
- $V_{in} = 100$ mV sine wave of frequency $f_{in}$
- $R_L = 1$ kΩ
- MOSFET Parameters: $L = 0.18$ $\mu$m, $W = 1.8$ $\mu$m, $V_{th} \approx 0.4$ V

### D. Calculations

In a switching mixer, the MOSFET alternates between cutoff and linear region (negligible time is spent in saturation), as per the frequency of the Local Oscillator Signal $v_{LO}(t)$. From the Schematic, we observe that,

$$V_{out} - I_d R_L = 0 \tag{6}$$
$$\implies I_d = \frac{V_{out}}{R_L} \tag{7}$$
$$V_{GS} = V_{osc} + V_{bias} - V_{out} \tag{8}$$
$$\approx V_{osc} + V_{bias} \tag{9}$$
$$V_{DS} = V_{in} - V_{out} \approx V_{in} \tag{10}$$

We know that for a MOSFET in linear region,

$$I_d = \frac{1}{2} K_n (2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2) \tag{11}$$
$$\implies V_{out} = \frac{R_L}{2} K_n (2(V_{osc} + V_{bias} - V_{TH})V_{in} - V_{in}^2 \tag{12}$$
$$\tag{13}$$

If we take $V_{bias} \approx V_{TH}$, and assume that $V_{in}$ is small,

$$V_{out} = \frac{R_L K_n}{2}(2 V_{osc} V_{in}) \tag{14}$$
$$V_{out} = R_L K_n V_{osc} V_{in} \tag{15}$$

At cutoff, we know that $V_{out} = 0$. Taking in this result as well, we get out final output signal as,

$$V_{out} = \begin{cases} R_L K_n V_{osc} V_{in} & V_{osc} > 0 \\ 0 & V_{osc} \leq 0 \end{cases} \tag{16}$$
$$\implies V_{out}(t) = R_L K_n V_{osc}(t) V_{in}(t) s(t) \tag{17}$$

Where $s(t)$ is a square wave, alternating between 1 and 0 with the same frequency as $V_{osc}$. Since in this expression $V_{osc}t$ only matters if it is positive, we can approximate it to $s(t)$. (Square Wave Approximation).

$$V_{out}(t) = R_L K_n V_{in}(t)(s(t))^2 = R_L K_n V_{in}(t) s(t) \tag{18}$$

We know that the Fourier Series Representation of a square wave is $s(t) = \sum_k \frac{1}{k} \sin(2\pi k f_{osc} t)$, where k ranges over all the odd Natural numbers. Therefore, our output signal, if we take $V_{in} = A_{in} \cos(2\pi f_{in} t)$,

$$V_{out}(t) = R_L K_n A_{in} \sum_k \frac{1}{k} \sin(2\pi k f_{osc} t) \cos(2\pi f_{in} t) \tag{19}$$
$$\implies V_{out}(t) = \frac{R_L K_N A_{in}}{2} \sum_k [\sin(2\pi(k f_{osc} - f_{in})t) \tag{20}$$
$$+ sin(2\pi(k f_{osc} + f_{in})t)] \tag{21}$$

Since we need only the $f_{osc} - f_{in}$ component (Goal Of the Downconversion Process), we can pass the output signal through a low pass filter, which results in our output signal as,

$$V_{out}(t) = \frac{R_L K_N A_{in}}{2} \sin(2\pi(f_{osc} - f_{in})t) \tag{22}$$

### E. LT Spice Schematic

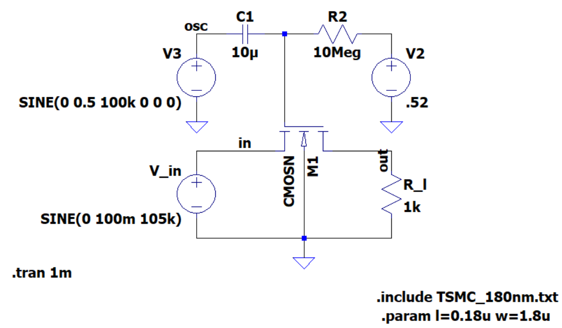


Fig. 9: LTSpice Simulation of Mixer Circuit

### F. Observations

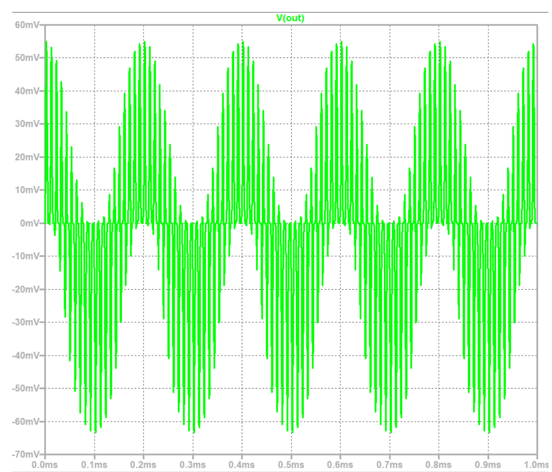


Fig. 10: Output of Mixer at 95khz Input

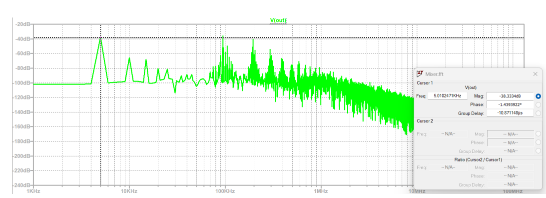

Fig. 11: FFT of Output of Mixer at 95khz, showing a peak at approx 5kHz

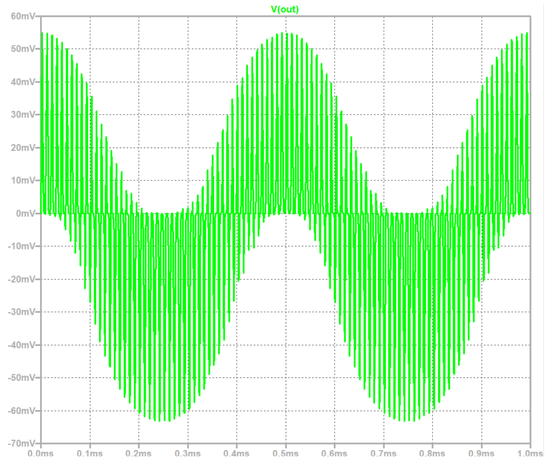

Fig. 12: Output of Mixer at 98khz Input

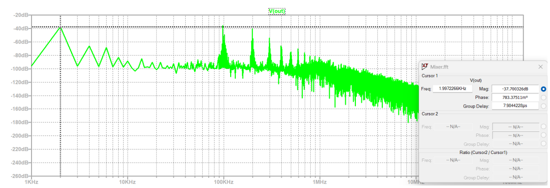
Fig. 13: FFT of Output of Mixer at 98khz, showing a peak at approx 2kHz

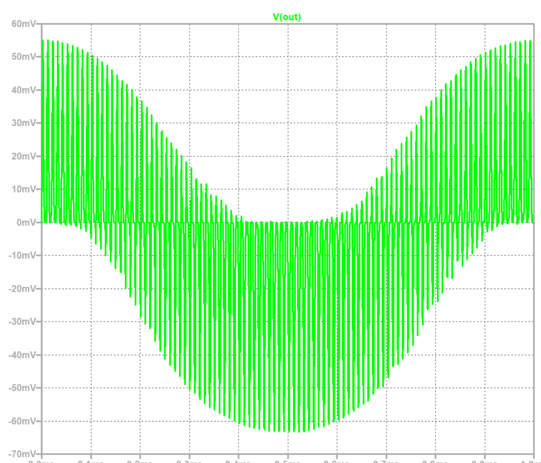

Fig. 14: Output of Mixer at 99khz Input

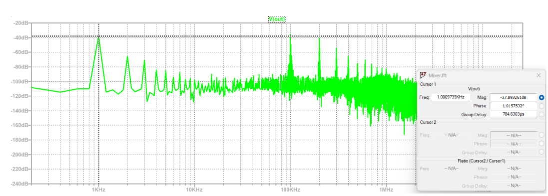
Fig. 15: FFT of Output of Mixer at 99khz, showing a peak at approx 1kHz

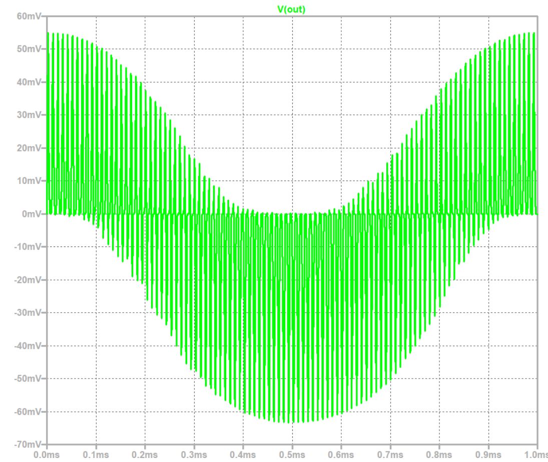

Fig. 16: Output of Mixer at 99khz Input

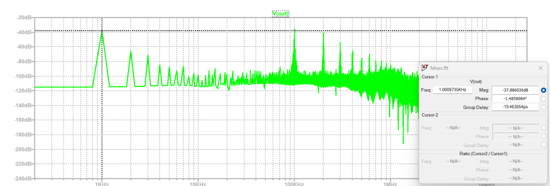
Fig. 17: FFT of Output of Mixer at 101khz, showing a peak at approx 1kHz

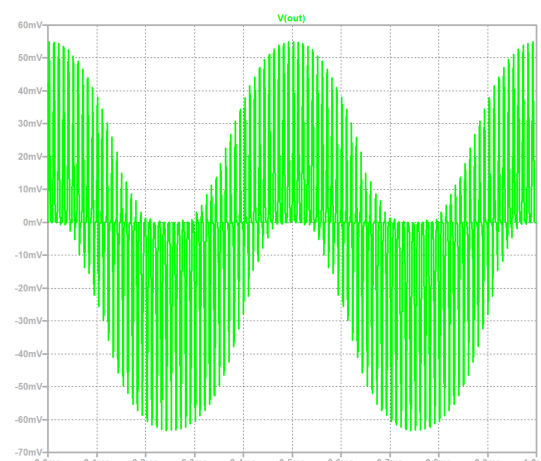

Fig. 18: Output of Mixer at 102khz Input

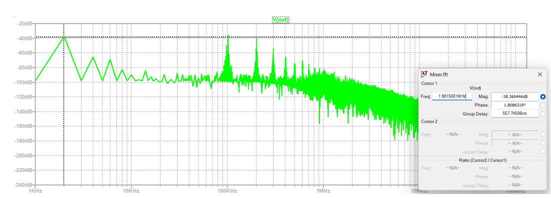
Fig. 19: FFT of Output of Mixer at 102khz, showing a peak at approx 2kHz

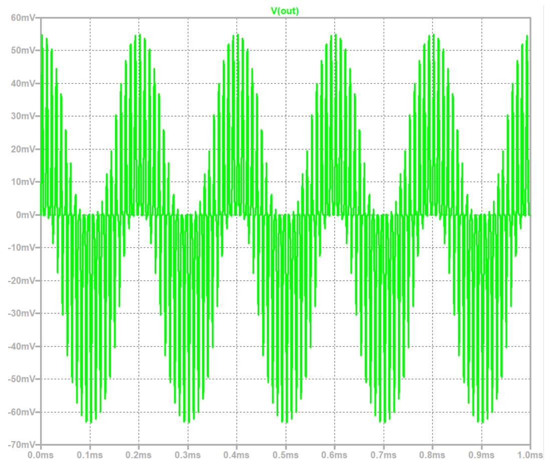


Fig. 20: Output of Mixer at 105khz Input

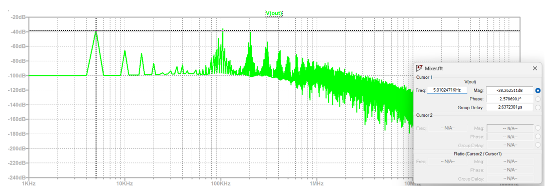

Fig. 21: FFT of Output of Mixer at 105khz, showing a peak at approx 5kHz

### G. Inference

We see that we get our first prominent peak, in the FFTs of the output, at approximately $|f_{osc} - f_{in}|$, which matches with our expected values.

## IV. RC Low Pass Filter

An RC low pass filter allows signals with frequencies lower than a certain cutoff to pass through while attenuating higher frequencies. It consists of a resistor (R) and capacitor (C) connected in series, with the output taken across the capacitor. This filter smoothens high-frequency noise and is commonly used after mixing to extract the baseband signal. Its cutoff frequency is determined by the values of R and C.

### A. Circuit Diagram (Schematic)

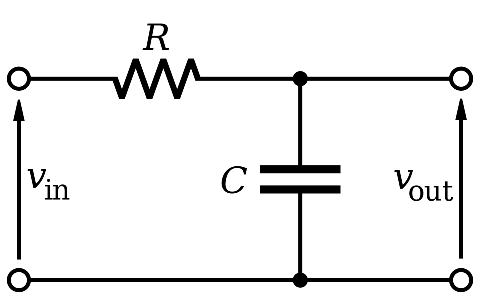


Fig. 22: RC Low Pass Filter Schematic

### B. Working of the Circuit

This filtering behavior arises due to the frequency-dependent reactance of the capacitor, given by $X_C = \frac{1}{2\pi f C}$. At low frequencies, $X_C$ is high, so the capacitor blocks current flow and the signal appears across the output. At high frequencies, $X_C$ is low, allowing the capacitor to short the signal to ground. As a result, high-frequency components are attenuated, and low-frequency signals pass through, making it a low-pass filter.

### C. Parameter Values

- R = 10 kΩ
- C = 2.65 pF

### D. Calculations

When the frequency of the input waveform increases the capacitive reactance given by $Z_C = \frac{1}{\omega C} = \frac{1}{2\cdot\pi\cdot f_{\text{in}}\cdot C}$ decreases. $V_{\text{OUT}}$ is given by the expression

$$V_{\text{OUT}} = \frac{\frac{1}{j\omega C}\cdot V_{\text{in}}}{\frac{1}{j\omega C} + R}$$

Which simplifies to

$$V_{\text{OUT}} = \frac{V_{\text{in}}}{1 + j\omega RC}$$

Taking Magnitude we get,

$$|V_{\text{OUT}}| = \frac{V_{\text{in}}}{\sqrt{1 + (\omega RC)^2}}$$

The cutoff frequency for the above circuit is defined as the frequency at which the output amplitude becomes $\frac{1}{\sqrt{2}}$ the input amplitude AC signal.

Thus, We find the cutoff frequency of the above circuit to be $f_c = \frac{1}{2\pi RC}$. For a 3dB frequency of 6kHz and choosing a reasonable value of $R$ say 10kΩ, we find $C$ to be

$$C = \frac{1}{2\pi R f_{\text{cutoff}}}$$

Substituting the values we have

$$C = \frac{1}{2\pi \cdot 10k\Omega \cdot 6kHz} \approx 2.65nF$$

### E. LT Spice Schematic

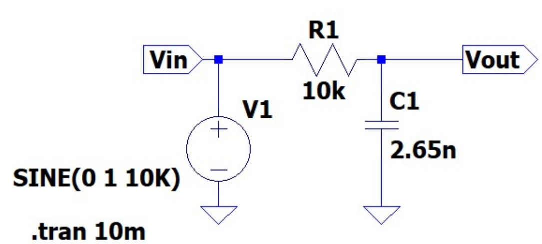


Fig. 23: LTSpice Simulation of Low Pass Filter

## F. Observations

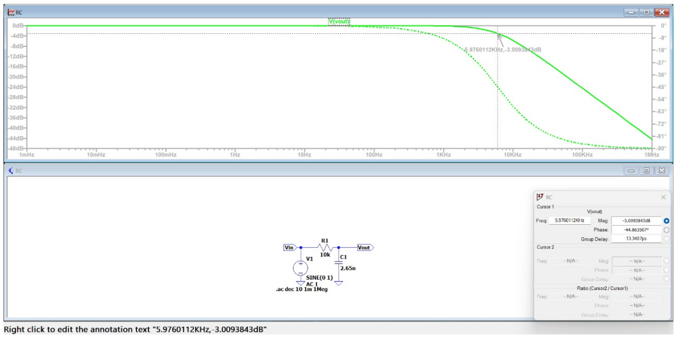


Fig. 24: Frequency Response

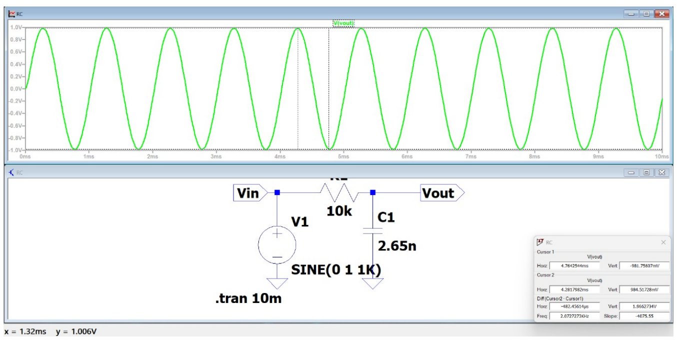


Fig. 25: Transient Response for f=1kHz

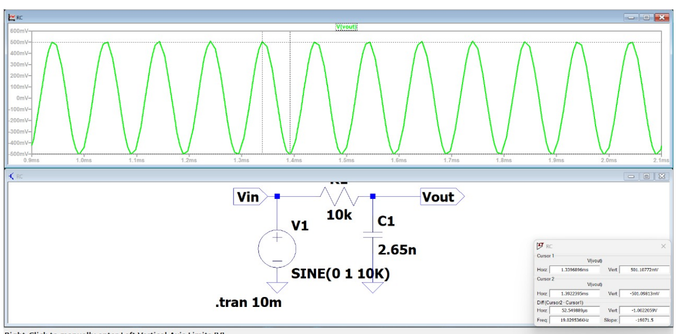


Fig. 26: Transient Response for f=10kHz

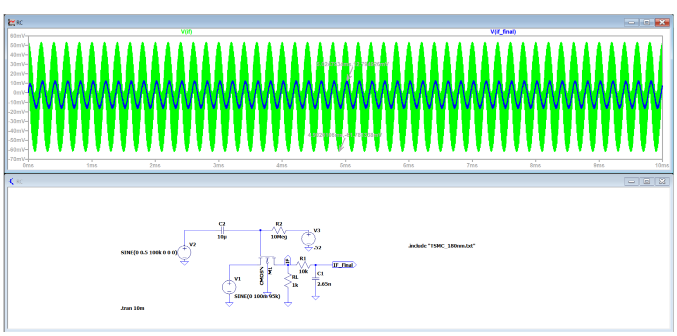

Fig. 27: Mixer with LowPass Transient Response at 95KHz

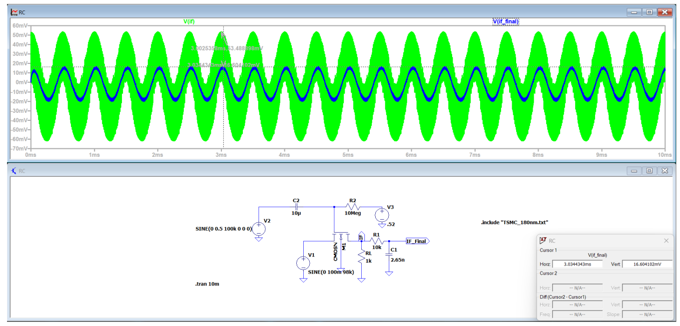

Fig. 28: Mixer with LowPass Transient Response at 98KHz

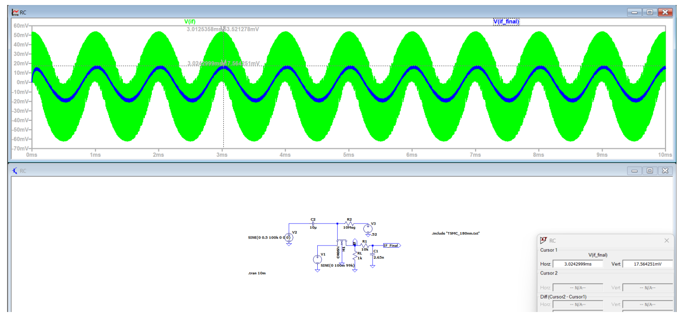

Fig. 29: Mixer with LowPass Transient Response at $f_{in}$ =99KHz

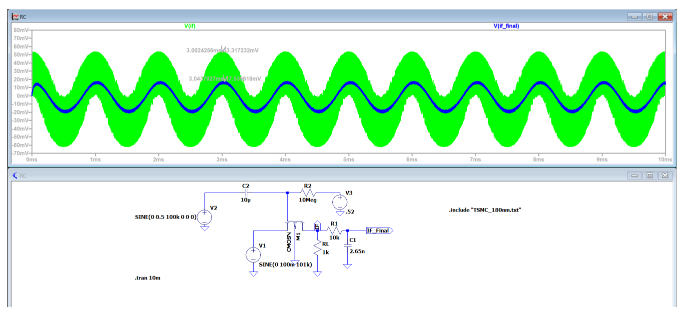

Fig. 30: Mixer with LowPass Transient Response at $f_{in}$ = 101KHz

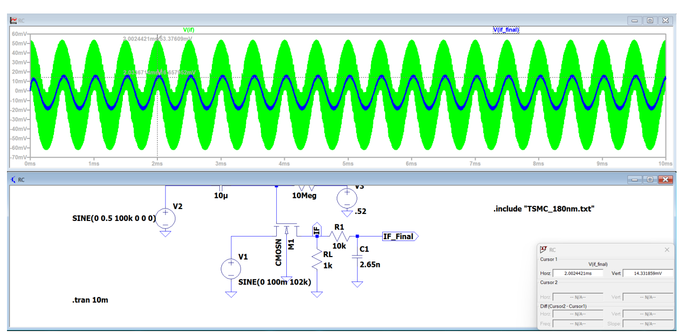


Fig. 31: Mixer with LowPass Transient Response at $f_{in}$ = 102KHz

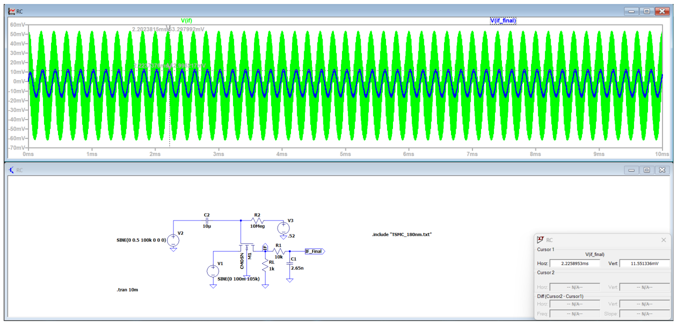

Fig. 32: Mixer with LowPass Transient Response at $f_{in}$ =105KHz

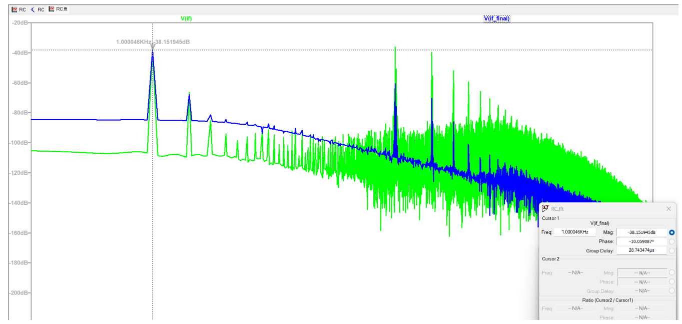

Fig. 35: Mixer with LowPass FFT at $f_{in}$ =99KHz, getting First Harmonic Peak at $\approx 1kHz$, and Final Output(blue)'s Higher Harmonics begin attenuated

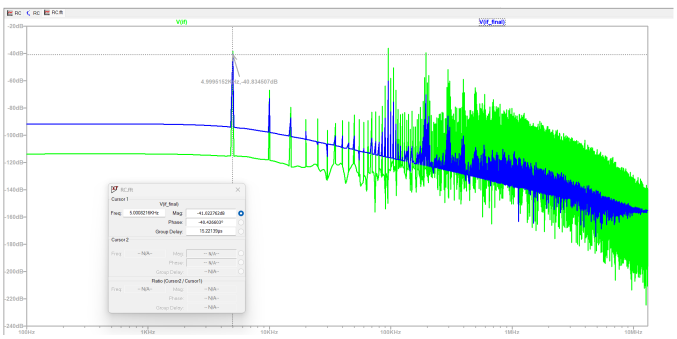

Fig. 33: Mixer with LowPass FFT at $f_{in}$ =95KHz, getting First Harmonic Peak at $\approx 5kHz$, and Final Output(blue)'s Higher Harmonics begin attenuated

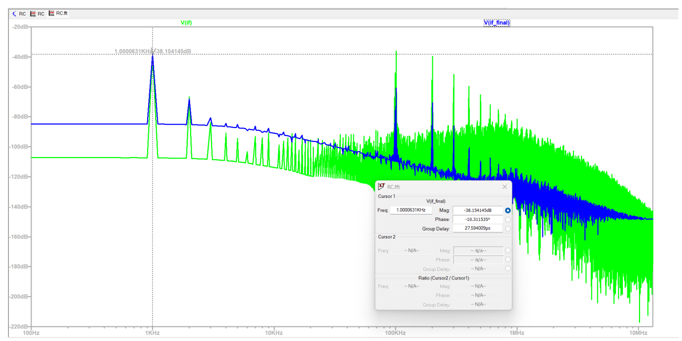

Fig. 36: Mixer with LowPass FFT at $f_{in}$ =101KHz, getting First Harmonic Peak at $\approx 1kHz$, and Final Output(blue)'s Higher Harmonics begin attenuated

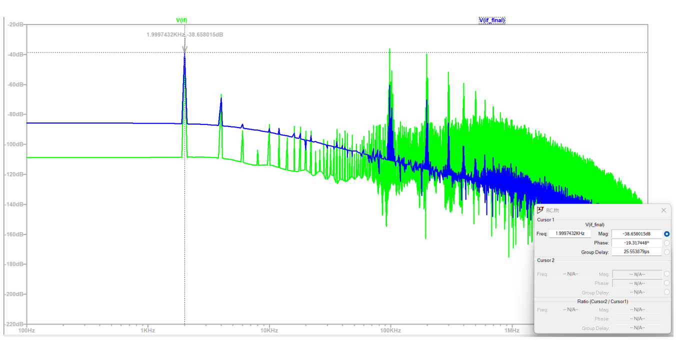

Fig. 34: Mixer with LowPass FFT at $f_{in}$ =98KHz, getting First Harmonic Peak at $\approx 2kHz$, and Final Output(blue)'s Higher Harmonics begin attenuated

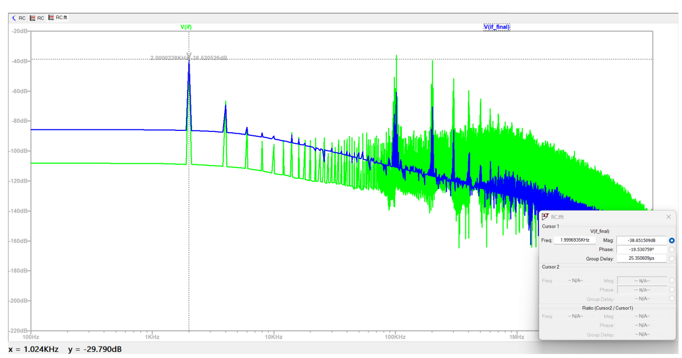

Fig. 37: Mixer with LowPass FFT at $f_{in}$ =102KHz, getting First Harmonic Peak at $\approx 2kHz$, and Final Output(blue)'s Higher Harmonics begin attenuated

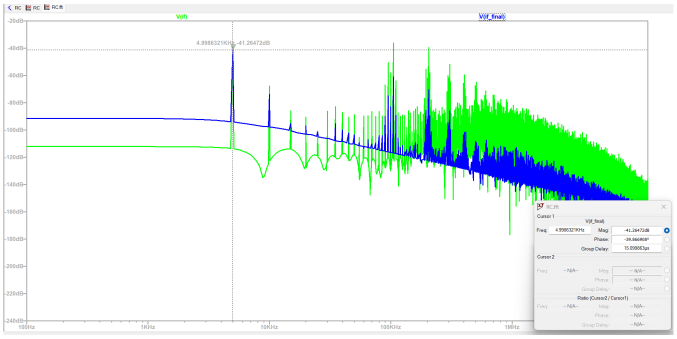

Fig. 38: Mixer with LowPass FFT at $f_{in}$ =105KHz,, getting First Harmonic Peak at $\approx 5kHz$, and Final Output(blue)'s Higher Harmonics begin attenuated

### G. Inference

We observe negligible attenuation for the 1kHz signal (since it is below the cutoff frequency) and significant attenuation for the 10kHz signal, (since it is lying above the cutoff frequency of the filter, 6kHz), matching with our expected output.

In the Mixer + Low Pass Circuits, all the higher harmonics are attenuated and the $|f_{osc} - f_{in}|$ passes through with minimal attenuation. The attenuation is a bit higher for $f_{in} = 95kHz$ and $f_{in} = 105kHz$, since they are closer to the cutoff frequency of the Low Pass Filter (6kHz).

## V. Final Circuit

By connecting all the building blocks — the oscillator, mixer, and filter — the complete circuit is formed. This final setup generates two output signals: IF Final (in-phase) and QF Final (quadrature), which represent the in-phase and quadrature components of the input signal. These two signals are sinusoidal and maintain a 90 degree phase difference between them.

### A. Block Diagram

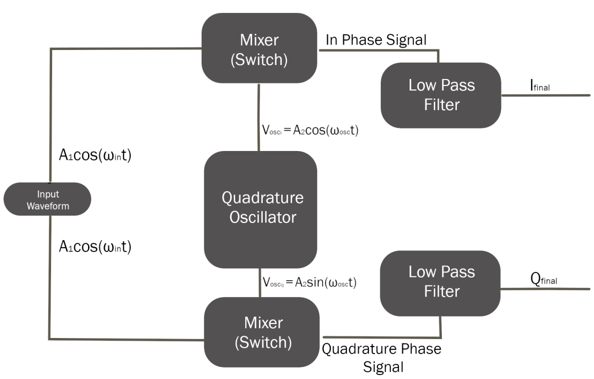


Fig. 39: Block Diagram

### B. Working of the Circuit

The final circuit comprises three main components: a quadrature oscillator, mixers, and low-pass filters. Each plays a crucial role in generating the in-phase (IF Final) and quadrature-phase (QF Final) components of the intermediate frequency (IF and QF) signal. The working is as follows:

1) **Quadrature Oscillator:** The circuit begins with a quadrature oscillator that generates two sinusoidal signals of the same frequency but with a 90° phase difference. These signals are referred to as the local oscillator (LO) signals: $LO_I$ (in-phase) and $LO_Q$ (quadrature-phase).
2) **Mixing Stage:** The incoming radio frequency (RF) signal is fed into two mixers. Each mixer multiplies the RF signal with one of the LO signals:
   - Mixer 1 multiplies RF with $LO_I$, producing a signal containing sum and difference frequency components. (IF)
   - Mixer 2 multiplies RF with $LO_Q$, also producing sum and difference frequency components. (QF)
3) **Low-Pass Filtering:** The outputs of the two mixers are then passed through low-pass filters. These filters remove the high-frequency components (sum frequencies and their harmonics), leaving behind only the difference frequencies — the desired intermediate frequency (IF Final and QF Final) components.
   - The output of Mixer 1, after filtering, becomes **IF Final** — the in-phase component of the IF signal.
   - The output of Mixer 2, after filtering, becomes **QF Final** — the quadrature-phase component.
4) **Final Output:** The final output consists of the IF Final and QF Final signals. These are two sinusoidal waveforms of the same frequency, $|f_{osc} - f_{in}|$ with a constant phase difference of 90°, making this circuit ideal for ,in this case, demodulation

### C. LT Spice Schematic

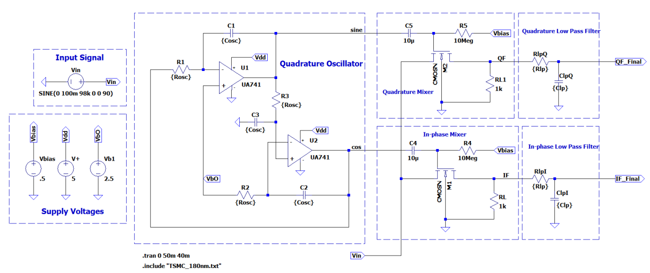

Fig. 40: LT Spice Simulation of Final Circuit

### D. Parameters

- Oscillator Frequency:
  - Theoretical: 280.202 kHz
  - Observed: 100.20792 kHz
- Oscillator Amplitude:
  - Quadrature Component: 0.9857 V
  - In-phase Component: 0.9845 V
- Input Signal:
  - Frequency: 98 Hz

- Amplitude: 200 mV (peak-to-peak)
- Supply Voltages:
  - Positive Supply for Op-Amps ($V_{DD}$): 5 V
  - Oscillator Bias: 2.5 V
  - Mixer Bias: 0.5 V
- Coupling Capacitances: 10 $\mu$F
- Low-Pass Filter Cutoff Frequency: 6 kHz

### E. Observations

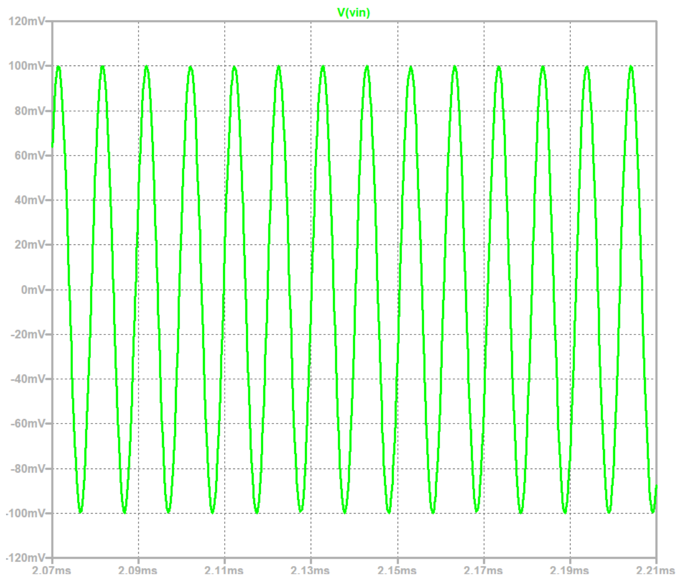


Fig. 41: Input Signal

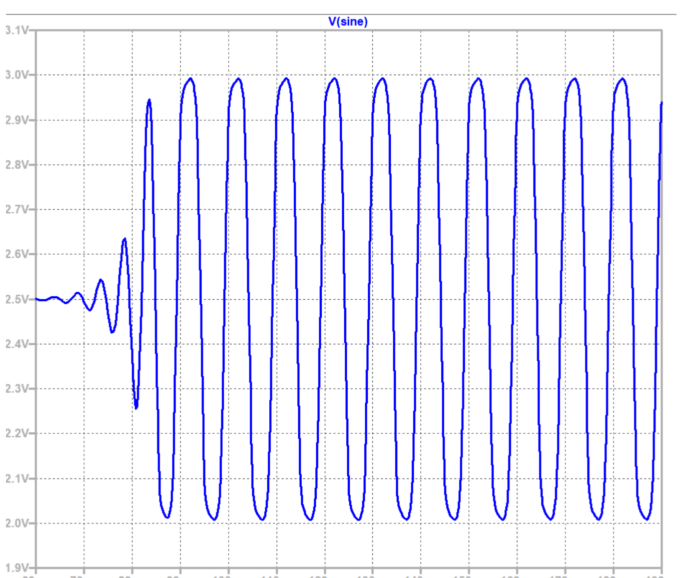


Fig. 42: $V_{osc_Q}$ Sine Wave

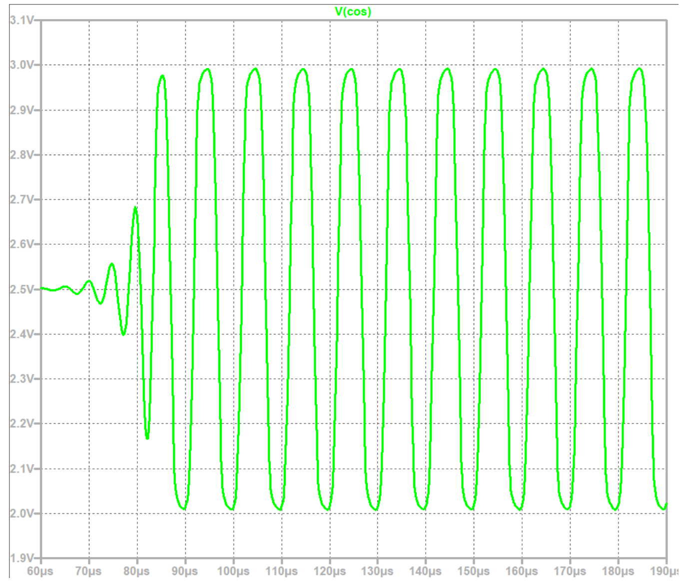


Fig. 43: $V_{osc_I}$ Cos Wave

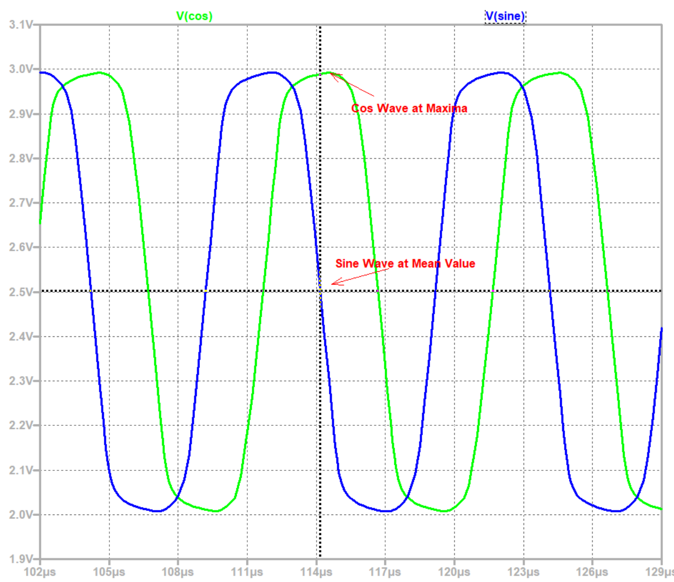


Fig. 44: Phase Comparison for $V_{osc_Q}$ and $V_{osc_I}$

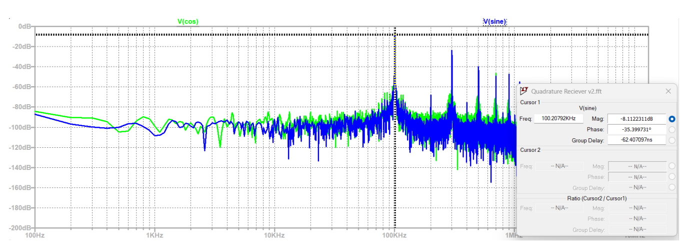


Fig. 45: FFT for Frequency Measurement of $V_{osc_Q}$ and $V_{osc_I}$

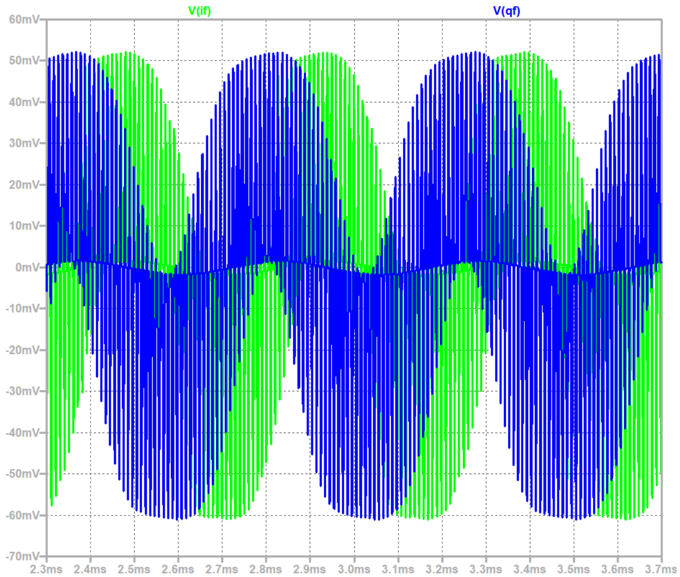


Fig. 46: IF vs QF

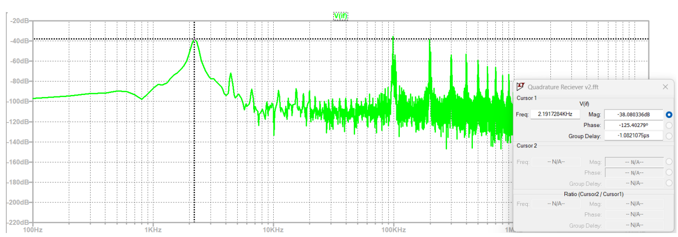


Fig. 47: IF FFT with Phase $\approx -125.402°$ and First Harmonic Peak at 2.191kHz

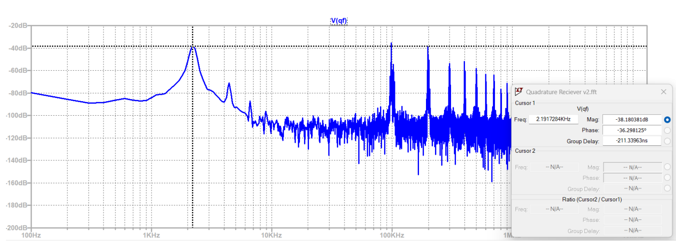


Fig. 48: QF FFT with Phase $\approx -36.298°$ and First Harmonic Peak at 2.191kHz

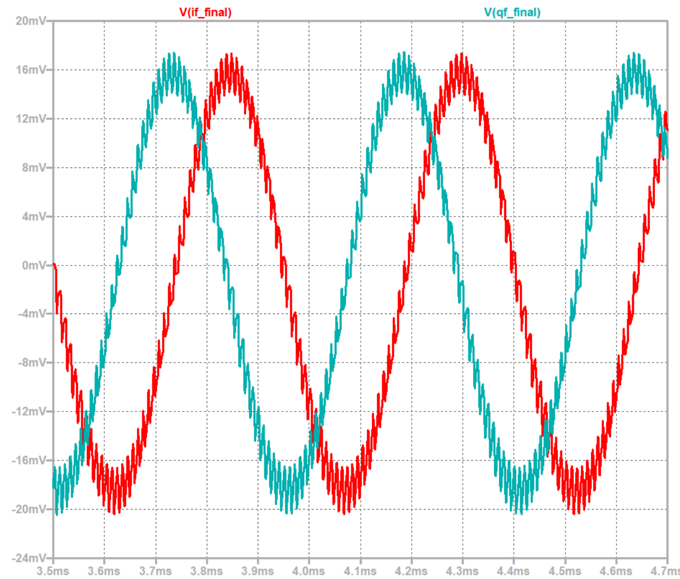


Fig. 49: IF Final vs QF Final

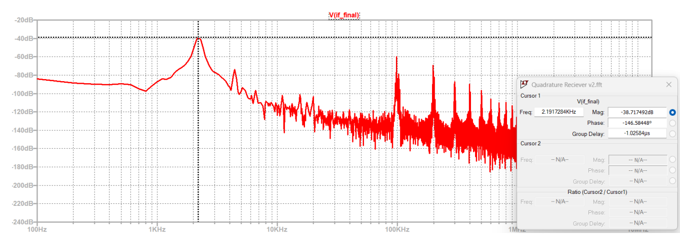


Fig. 50: IF Final FFT with Phase $\approx -146°$ and First Harmonic Peak at 2.191kHz

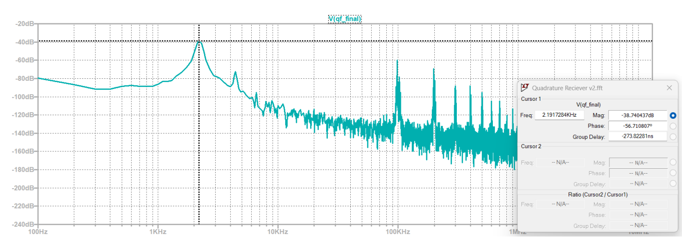


Fig. 51: QF Final with Phase $\approx -56°$ and First Harmonic Peak at 2.191kHz

$$\text{Phase Difference} \approx -146° - (-56°) = -90°$$

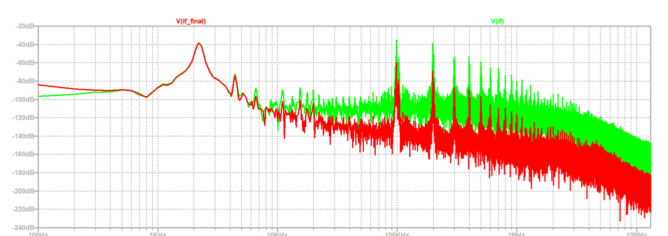


Fig. 52: IF vs IF Final

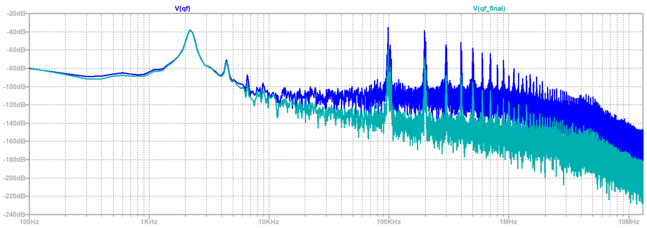

Fig. 53: QF vs QF Final

```
VtopS: MAX(V(sine))=2.99278068542 FROM 0.004 TO 0.009
VlowS: MIN(V(sine))=2.00710940361 FROM 0.004 TO 0.009
VtopC: MAX(V(cos))=2.99228453636 FROM 0.004 TO 0.009
VlowC: MIN(V(cos))=2.00780248642 FROM 0.004 TO 0.009
VampS: VtopS-VlowS=0.985671281815
VampC: VtopC-VlowC=0.984482049942
```

Fig. 54: Measured Amplitudes

### F. *Inference*

We see that our IF Final and QF Final, have a phase difference of about 90°and a fundamental frequency equal to $|f_{osc} - f_{in}|$. Therefore, we are able to successfully downconvert our input signal into a lower frequency signal, satisfying our objective.


## ACKNOWLEDGMENT

The Authors of this paper would like to thank International Institute of Information Technology, Hyderabad for the sponsored access to several scientific websites like IEEE. Thanks are given to Prof. Zia Abbas for providing support and this platform to study and present ideas on this topic. The authors also give thanks to the teaching assistants of the Analog Electronic Circuits course of the Institute for their help and useful comments on the paper.


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