Design of Quadrature Down Converter

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***Abstract*— A Quadrature down converter is used in wireless communication systems for the process of frequency down conversion. In this document, we build and analyze the working of the quadrature down converter. The design includes three main components, namely, a quadrature oscillator, a signal mixer and a low-pass filter. The Quadrature Oscillator generates the required sine and cosine waves, while the Mixer multiplies the input/received signal with the generated waves. The Low Pass Filter isolates the desired low-frequency component, enabling the extraction of the in-phase and quadrature phase signals. We start off with the basic equations that govern the working of the device followed by the translation of the equations into electronic circuits using basic electronic components like operational amplifiers and MOSFETs and justify the design using LTSpice simulations and hardware implementation results.**

Keywords*— *Quadratic Down Converter, wireless communication, Quadrature oscillator, Mixer, Low Pass Filter

I. Introduction

The Quadrature Down Converter is a crucial component in wireless communication systems, responsible for extracting the in-phase and quadrature phase components of a received message signal. This enables us to transmit the signal as an electromagnetic wave using an antenna. These are then converted into baseband signals, multiplied with orthogonal sinusoids and added (frequency up conversion). The final passband signal is then transmitted. To recover the message signal, a series of actions are performed which includes frequency down conversion, sampling, converting baseband signals into bitstreams and decoding. This paper presents a design for a Quadrature Down Converter and discusses its key components and functionality.

II. Quadrature Down Converter Components

Quadrature oscillator

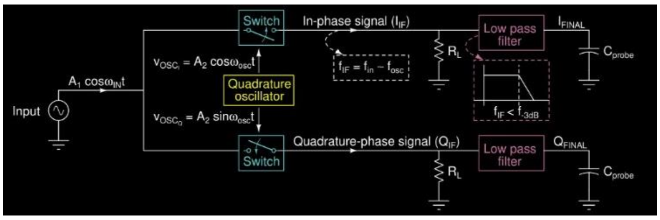
The Quadrature Oscillator generates the required sine and cosine waves of a decided frequency. It ensures accurate phase and frequency synchronization for the Quadrature Down Converter operation.

MIXER

The Mixer is used to multiply the input signal with the generated sine and cosine waves separately. By this process, the Mixer enables the extraction of the in-phase and quadrature phase signals.

LOW PASS FILTER

The Low Pass Filter selectively allows the desired low-frequency component from the mixed signal obtained from the Mixer. It removes high-frequency noise. The filtered outputs represent the in-phase and quadrature phase signals.



III. Circuit Design

To design a complete working model of the Quadrature Down Converter, each component (Quadrature Oscillator, Mixer, and Low Pass Filter) needs to be individually designed, tested, and optimized. Once the individual components have been successfully developed, they are combined and connected to form the complete Quadrature Down Converter system.

IV. Conclusion

In conclusion, the design of a Quadrature Down Converter is essential for extracting the in-phase and quadrature phase components of a received message signal in wireless communication systems. The Quadrature Oscillator, Mixer, and Low Pass Filter are key components that work together to achieve this functionality. By designing and integrating these components effectively, a reliable and efficient Quadrature Down Converter can be realized.

V. Quadrature Oscillator

The Quadrature Oscillator is a type of Phase Shift Oscillator that generates two sine waves with a 90° phase shift. In our design, we require a 90° phase shift between the two generated sine waves, each having an amplitude of 1 Vpp. To achieve this, we made sure that the loop gain of the circuit is greater than or equal to 1.

$$\left(\frac{1}{R1C1s}\right) * \frac{R3C3s+1}{R3C3s(R2C2s+1)} >= 1$$

We used the relations:

R1C1 = R2C2 = R3C3 = RC

where R = 390Ω and C = 1nF.

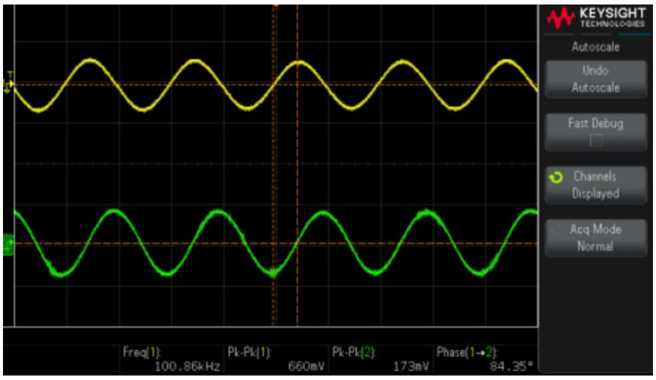
The values of R and C have been decided by us such that they follow the constraint for loop gain and give the desired output characteristics. We arrived at the conclusion that the frequency of oscillation can be calculated using the formula:

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

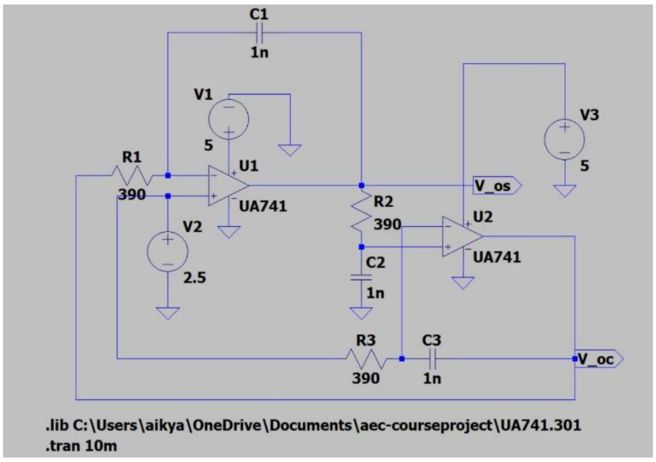
After realizing the same in the lab, we carefully adjusted the value of resistance and capacitances as a trade-off to amplitude to obtain the desired frequency on hardware.

DSO OUTPUT:

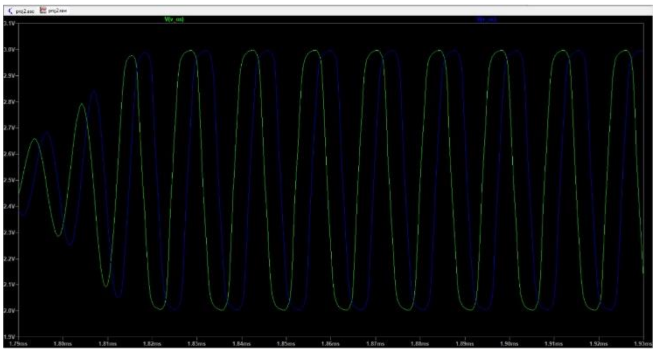
XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE



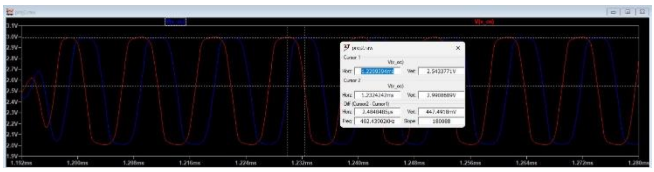
LT SPICE CIRCUIT:



SIMULATION RESULTS:



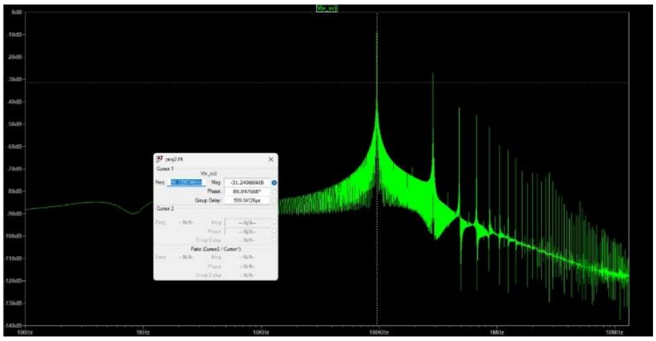
Calculating phase difference:



$$Phase\ difference = \frac{(1.2299-1.2324)*10^{-3}}{10} * \frac{1}{10^{-6}}*360$$

=90

FFT of one of the waves (as they have similar frequency spectrum) :

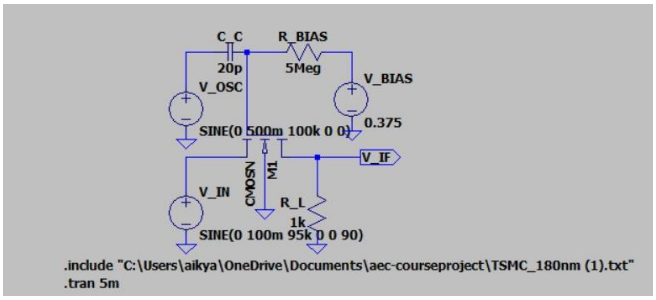


The first peak is observed at around 96kHz which is close to the decided value of 100kHz. The subsequent peaks denote higher harmonics which arise due to clipping of the wave, making the wave close to a square wave in those regions for which we use a low pass filter with a suitable cutoff frequency.

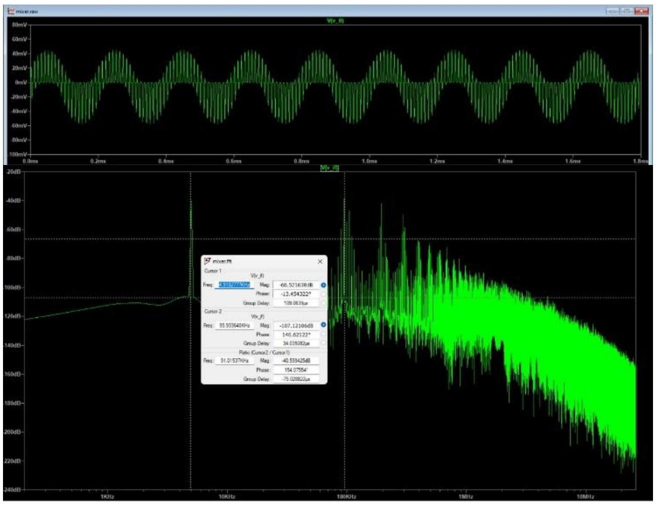
VI. MIXER(SWICTH)

The objective of the Mixer is to multiply the received signal with the generated sine and cosine waves. For this purpose, we can use an NMOS switch biased to remain in the saturation region, with the received signal connected to the source and the oscillator input connected to the gate. The desired output of the mixer can be obtained by extracting the mixed frequency signal from the drain. Since threshold voltage of MOSFET is 0.38, we choose V_BIAS as 0.375, R=5M Ω, C=20pF.

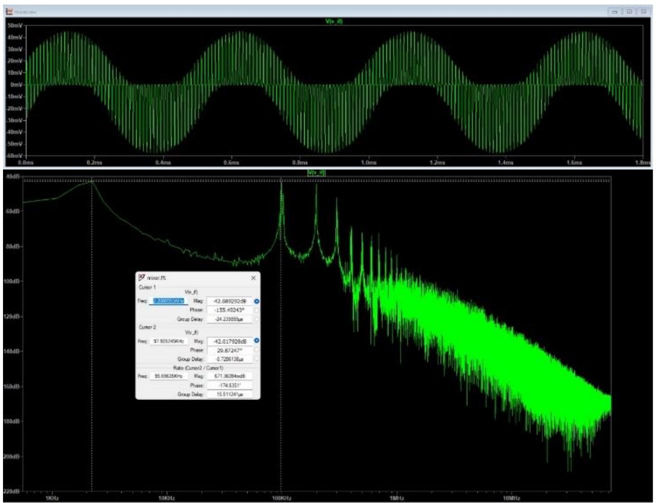
LT SPICE CIRCUIT:

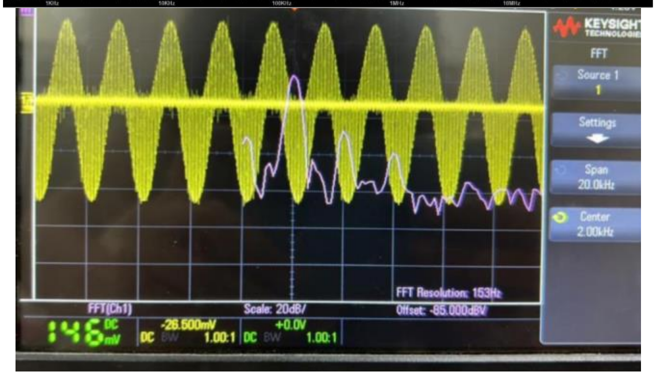


RESULTS FOR VARIOUS VALUES OF FIN:
F=95kHz

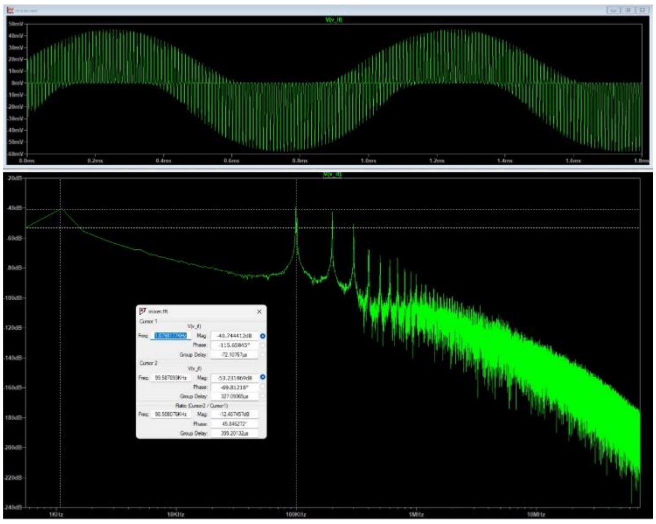


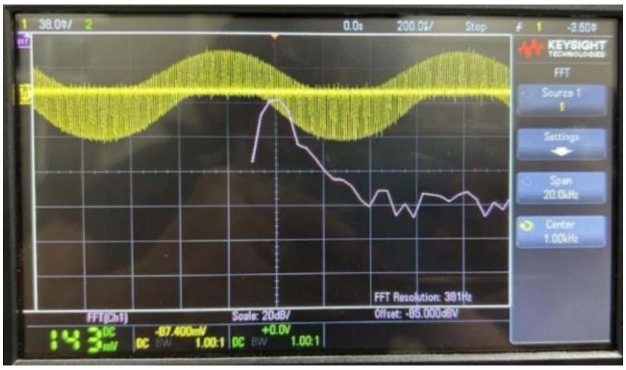
F=98kHz



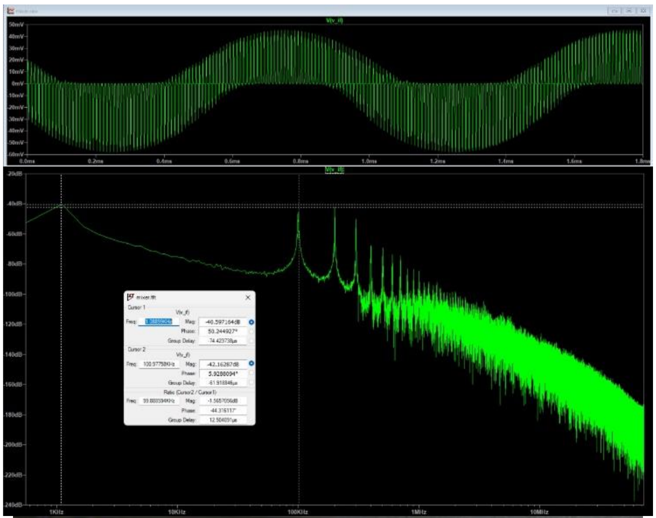


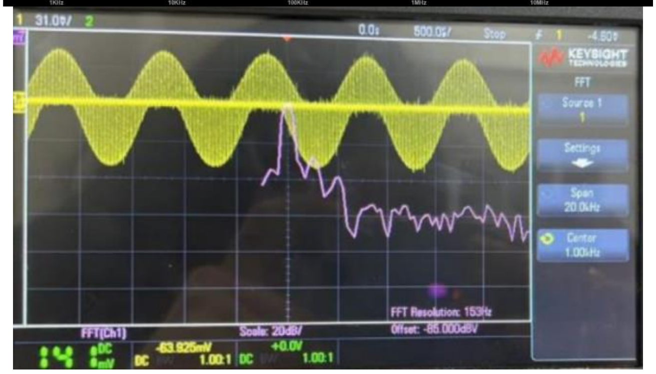
F=99kHz



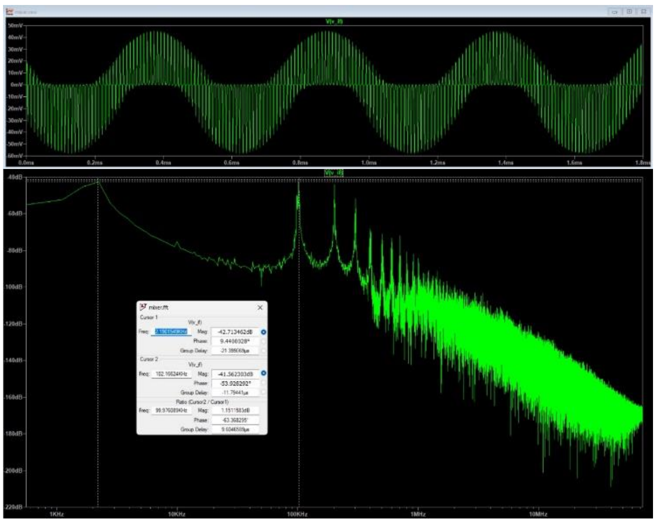


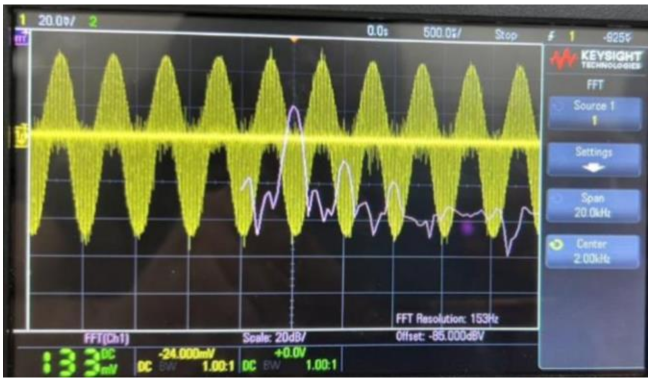
F=101kHz



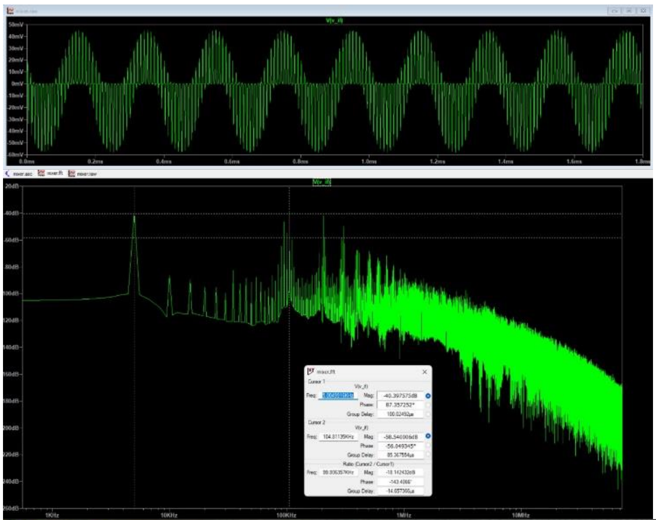


F=102kHz





F=105kHz



As we can observe, first peak occurs at |fosc − fin|. 2nd peak occurs fin. 3rd peak always occurs at fosc + fin. Frequency of the required component (in phase or quadrature phase) = |fosc − fin|.

VII. LOW PASS FILTER

• A low pass filter is a filter that passes signals with frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than cutoff frequency.

• In general, since we receive a signal which has both low frequencies and high frequencies, we use a low pass filter to attain the required signal

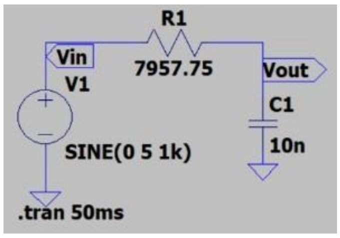
• We design a simple RC low pass filter such that the cutoff frequency is greater than the required frequency and less than the higher frequency.

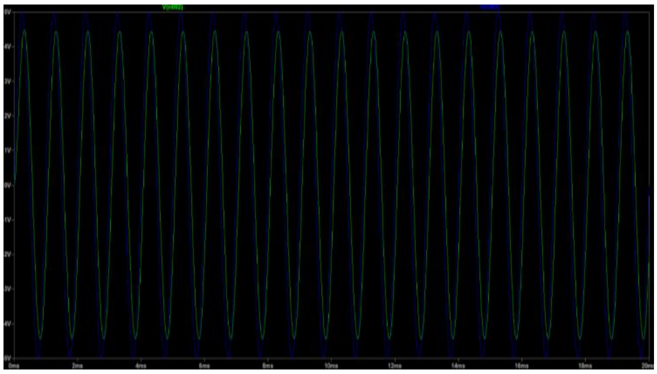
• Cutoff frequency lies between first peak and second peak of the output of the mixer circuit

• Since cutoff frequency of a simple RC filter $f = 1/2\pi RC$,

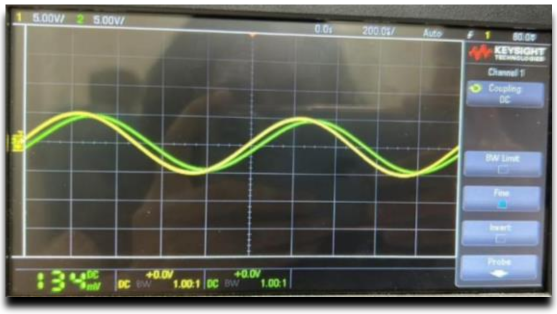
• We have selected -3dB frequency to be 2 kHz, we take R and C values as R = 7957.75 Ohm and C = 10nF.

TRANSIENT ANALYISIS FOR FREQUENCY 1K:



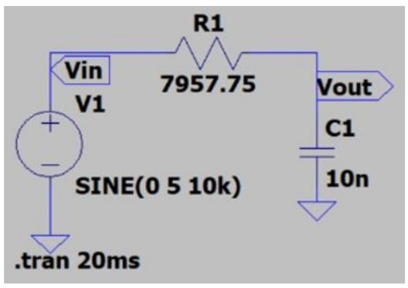


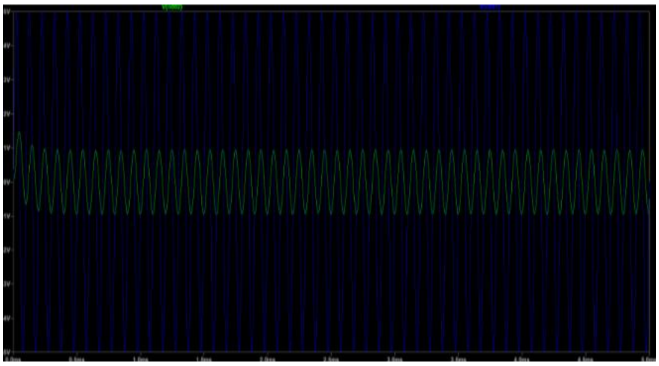
DSO output:



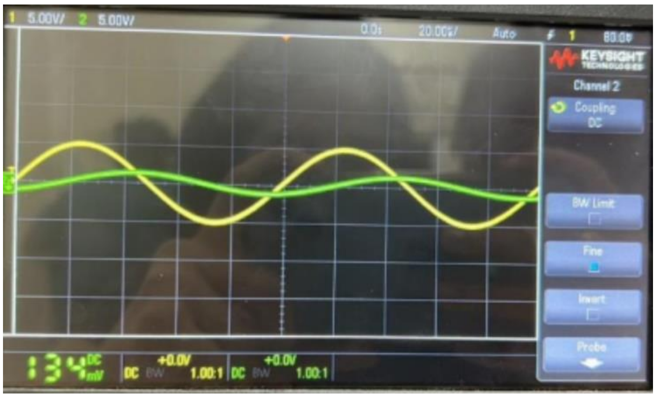
We see that when the input signal frequency is 1kHz the output is almost the trace of the input signal.

TRANSIENT ANALYISIS FOR FREQUENCY 10K:

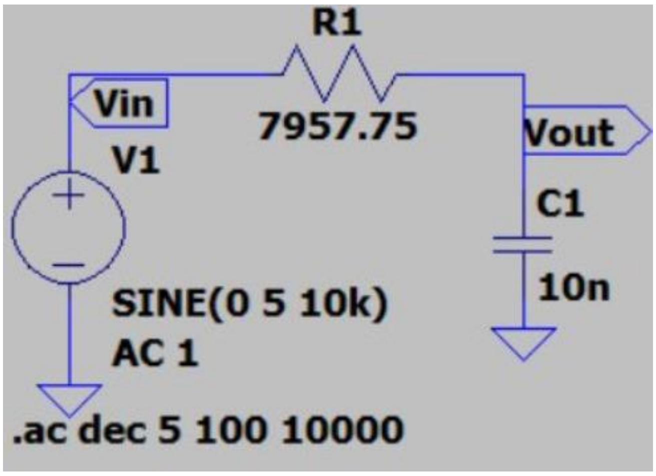


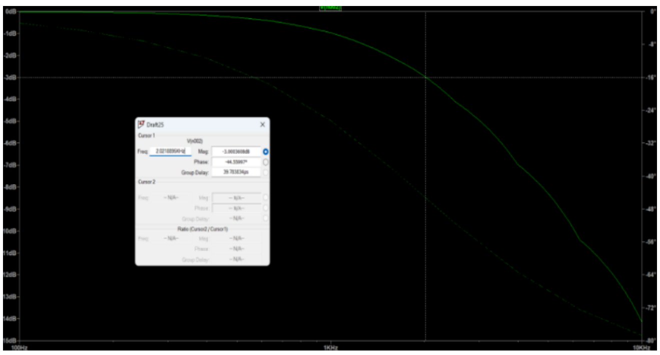


DSO output:



AC Analysis



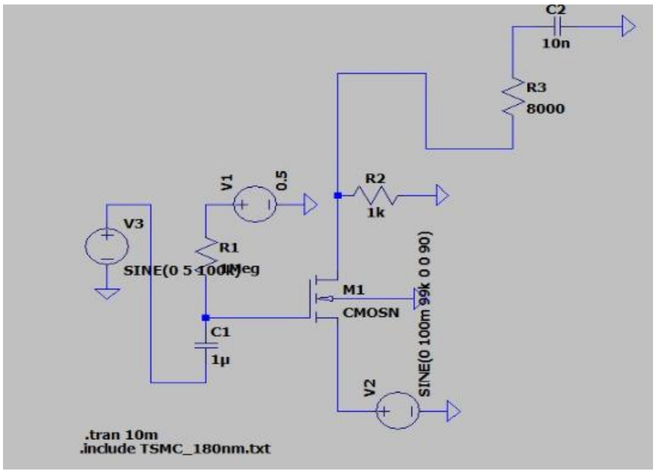


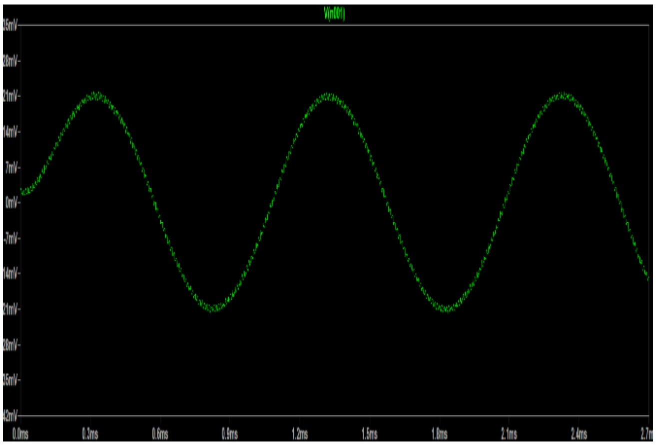
Frequency response on DSO

• The frequency response at -3dB refers to the point at which the output signal of a filter is attenuated by 3 decibels (dB) relative to its maximum amplitude. In the context of a low pass filter, the -3dB frequency represents the cutoff frequency, which separates the range of frequencies that are allowed to pass through from those that are attenuated.

• We can conclude that -3 dB is obtained at nearly 2 KHz from the DSO LTspice Simulations

MIXER AND LOW-PASS FILTER

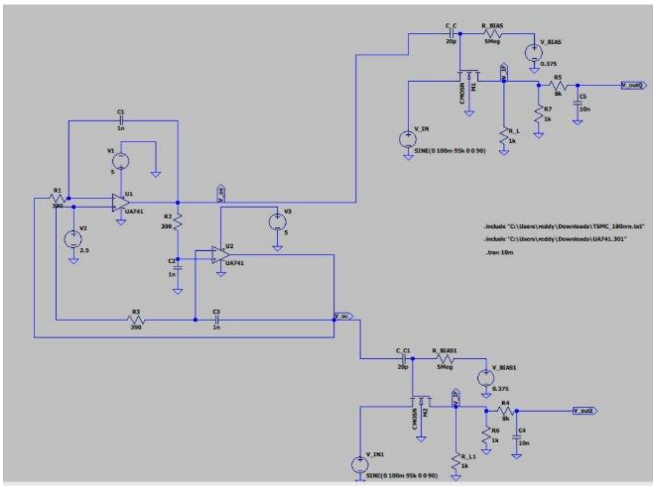


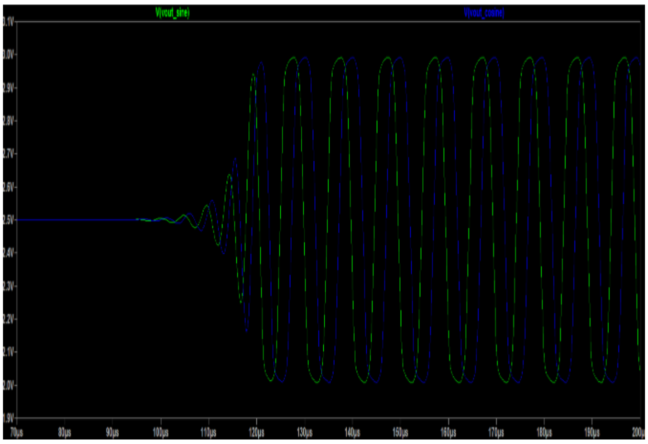


VIII. COMPLETE CIRCUIT INTEGRATION

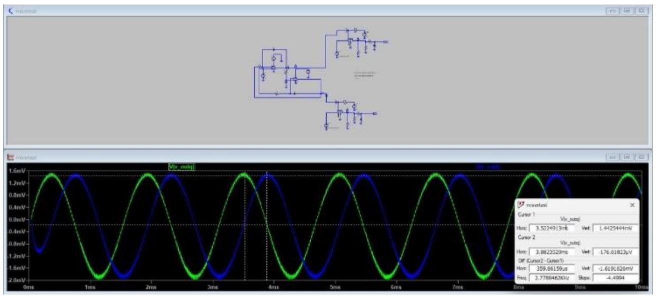
Now that we are ready with the three parts of our circuit, the next step is integration of all three parts to make the complete circuit of quadrature down converter.

LT Spice simulations:

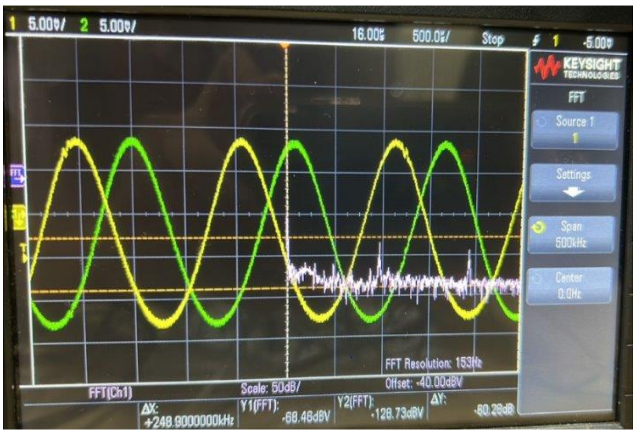


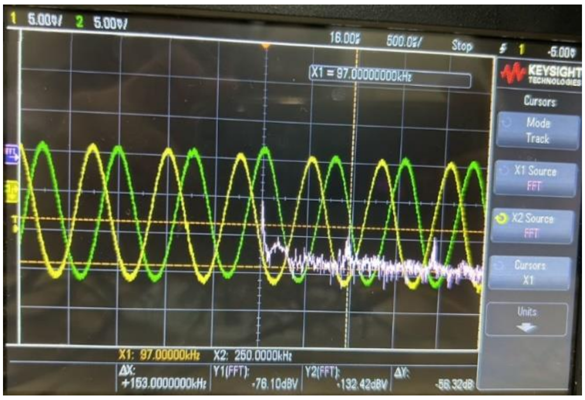


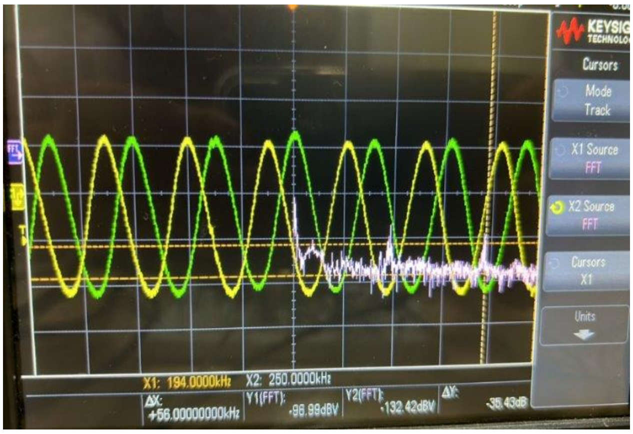
Phase difference calculation:



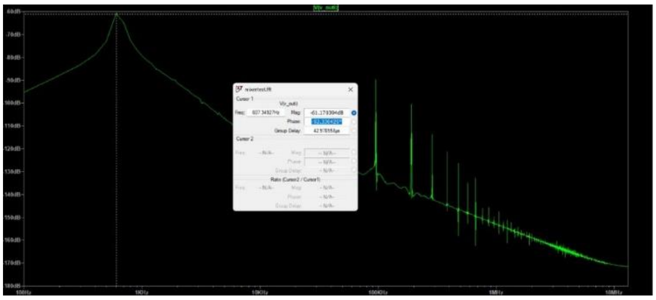
DSO OUTPUTS: With FFT and pointing to the peeks



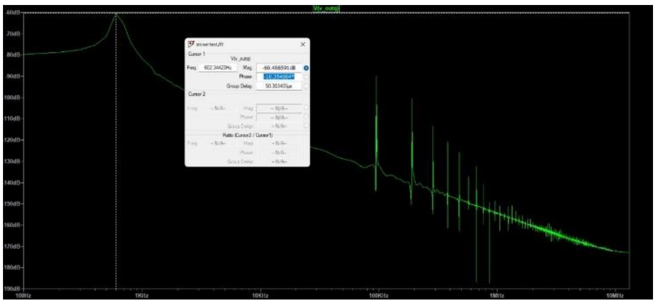




We now perform frequency analysis on the final output waves by plotting the FFTs of both the components. First, on plotting the FFT of the in-phase component.



We get an almost identical plot for the FFT of the quadrature phase component.



RF Input: The high-frequency RF signal that needs to be down-converted.

Local Oscillator (LO): Two LO signals that are 90 degrees out of phase with each other.

Mixers: Two mixers are required, one for each LO signal, to perform the mixing process.

Low Pass Filters: Each mixed signal needs to be filtered using a low pass filter.

Adder/Complex Mixer: A circuit is needed to combine the filtered I and Q signals.

Further Processing: Depending on your application, you may require additional components like filters, amplifiers, and analog-to-digital converters for further signal processing.

We can conclude that we got the desired output meeting the above requirements.

IX. BONUS

In modern wireless communication systems, the utilization of quadrature (I-Q) operation in down-conversion/mixing is pivotal for efficient signal processing and demodulation. This technique enables the separation of the incoming signal into its in-phase (I) and quadrature (Q) components, facilitating the processing of complex modulation schemes such as Quadrature Amplitude Modulation (QAM) or Phase Shift Keying (PSK).

Mathematically, the down-conversion process involves multiplying the incoming signal by two orthogonal sinusoids, typically represented as *cos* $(2\pi fc\ t)$ and *sin* $(2\pi fc\ t)$, where fc *is* the carrier frequency. This multiplication generates the in-phase ($x\_I(t)$) and quadrature ($x\_Q(t)$) components of the signal:

$$x\_I(t)=x(t)\cdot\cos(2\pi fct)$$

$$x\_Q(t)=x(t)\cdot\sin(2\pi fct)$$

This separation enables coherent demodulation techniques, maintaining phase synchronization between the transmitter and receiver, crucial for accurate communication even in the presence of phase variations due to channel impairments.

Moreover, quadrature operation allows for the representation of the signal in a complex baseband form, $x(t)=xI(t)+jxQ(t)$, simplifying signal processing algorithms and enhancing the receiver's ability to discriminate between different modulation symbols.

Spectrally, quadrature operation enhances efficiency by enabling the transmission of higher data rates within limited bandwidth allocations, crucial for modern wireless communication standards such as LTE, Wi-Fi, and 5G.

In summary, quadrature (I-Q) operation plays a vital role in modern wireless receivers by facilitating efficient demodulation of complex modulation schemes, maintaining phase coherence, enhancing spectral efficiency, and simplifying signal processing algorithms. Its utility is evident across various wireless communication standards, enabling high-speed data transmission and reliable connectivity.