Design of Quadrature Down Converter for Wireless Communication Systems

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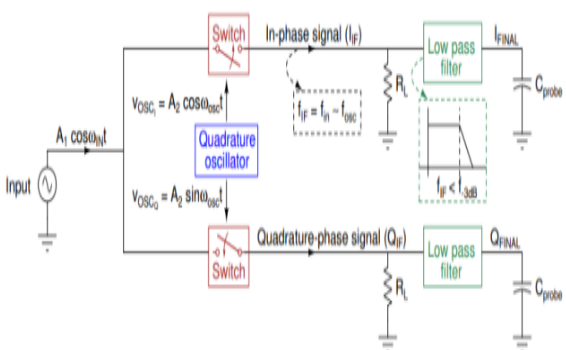
***Abstract*—This document presents a design for Quadrature Down Converter, which plays a critical role in wireless communication systems. The converter extracts the in-phase and quadrature phase components of a received message signal. The design includes three main components: a Quadrature Oscillator, a 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. The individual components are designed, tested, and optimized before integration into a complete working prototype.**

***Index Terms*—Quadrature 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 paper presents a design for a Quadrature Down Converter and discusses its key components and functionality.



II. Quadrature Down Converter Components

The Quadrature Down Converter can be divided into three main components:

A. Quadrature Oscillator

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

B. Mixer

The Mixer multiplies the input or received signal with the generated sine and cosine waves. By combining the input signal with the quadrature components, the Mixer enables the extraction of the in-phase and quadrature phase signals.

C. Low Pass Filter

The Low Pass Filter isolates the desired low-frequency component from the mixed signal obtained from the Mixer. It removes high-frequency noise, allowing only the essential low-frequency components to pass through. The filtered output represents the in-phase and quadrature phase signals.

III. Circuit Design and Integration

To design a complete working prototype 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 integrated 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.

A. 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 have implemented the following quadrature oscillator circuit:

$$R1C1 = R2C2 = R3C3 = RC$$

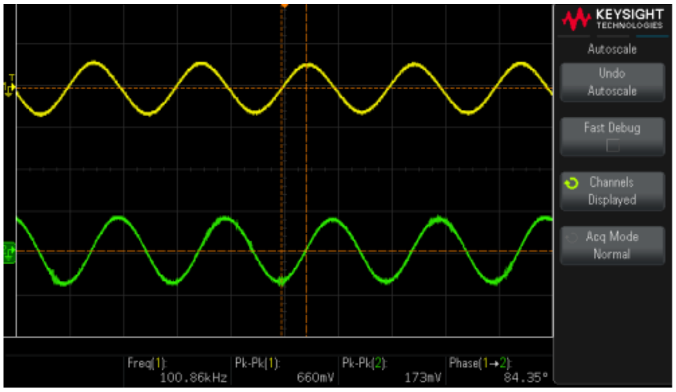
where $R = 5.6\,k\Omega$ and $C = 100\,pF$.

The frequency of oscillation can be calculated using the formula:

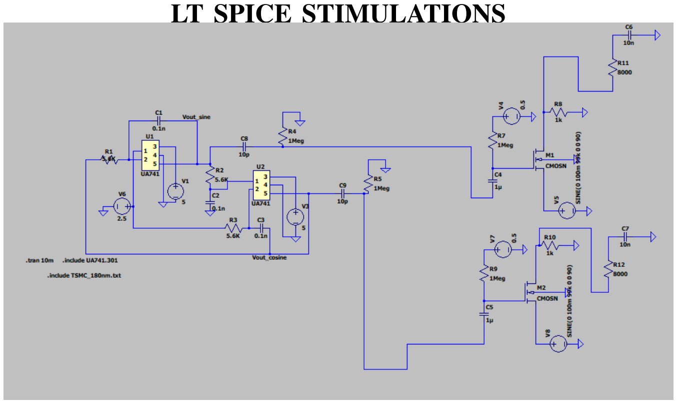
$$f = \frac{1}{2\pi RC}$$

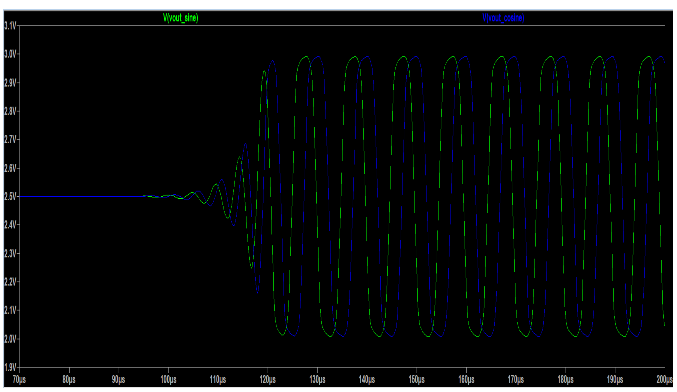
Circuit realization in lab After realizing the same circuit in lab we observed two signals we have observed a phase difference of 90° We carefully adjusted the value of resistance and capacitances as a trade-off to amplitude in order to obtain the needed frequency on hardware.

DSO OUTPUT

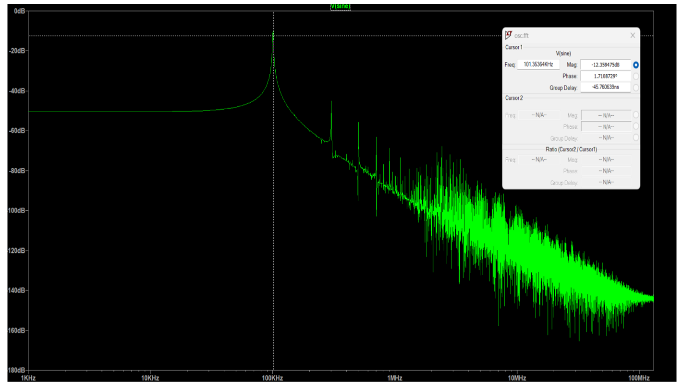


LT SPICE STIMULATIONS

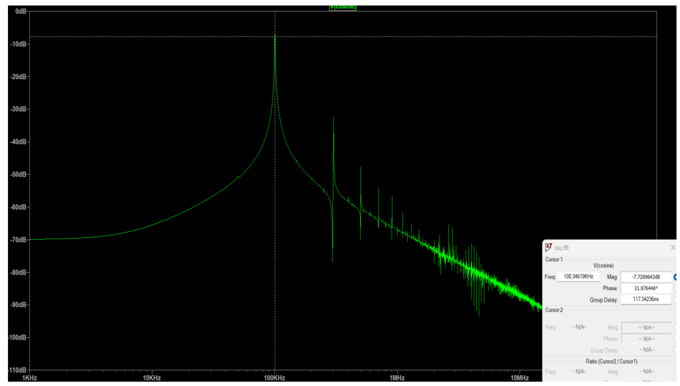




FFT For the sine wave obtained:



FFT For the cosine wave obtained:

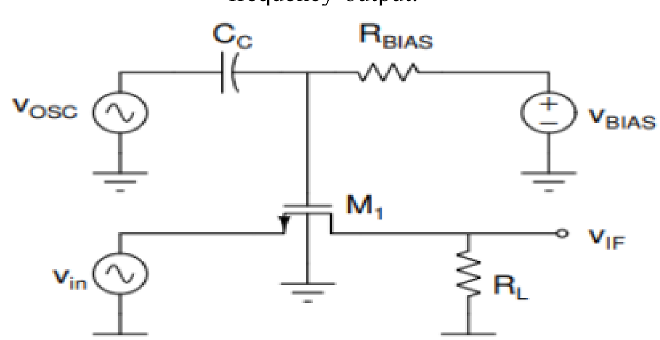


B. Mixer

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.

To ensure that the switch behaves as desired, it is important to ensure that the NMOS transistor remains in the saturation region throughout the entire swing of the oscillator input. In our circuit, we have set the threshold voltage of the NMOS transistor to 0.49V. Since the amplitude of the oscillator signal is 0.5V, we have chosen a bias voltage of 1.3V to guarantee that the NMOS transistor remains reliably in the saturation region.

This configuration ensures that the Mixer component effectively multiplies the received signal with the generated sine and cosine waves, producing the desired mixed frequency output.

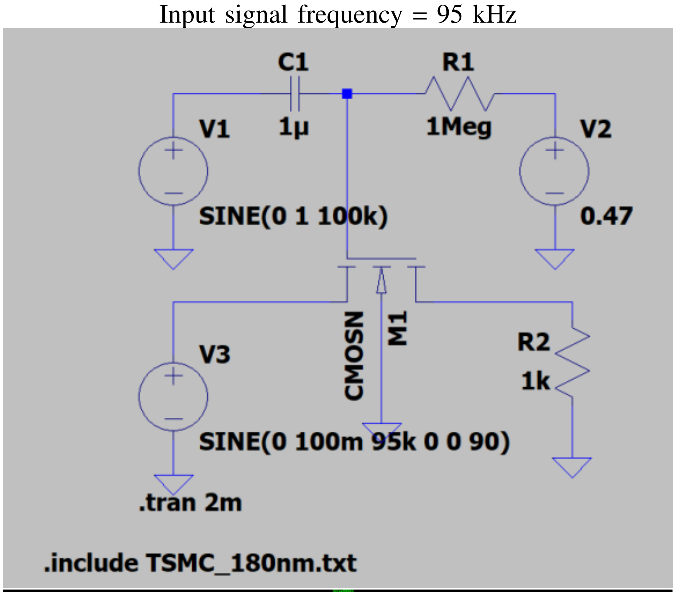


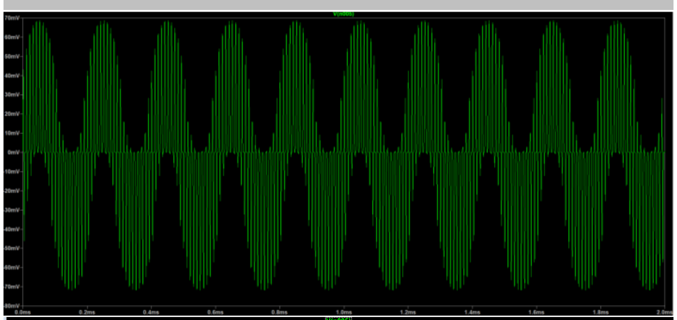
For LTspice simulation, RL=1 kOhm.; RBIAS= 1 MOhm.

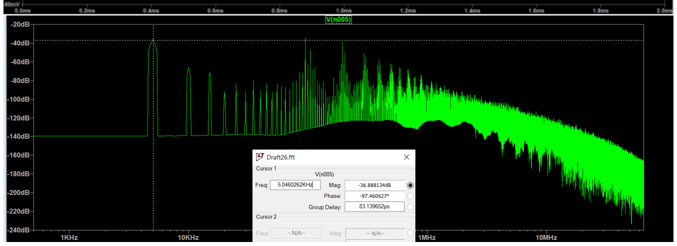
VBIAS = 0.47V. Taking Vin as 100 mVpp Sine wave, frequency 102kHz and Vosc as 1Vpp Sine wave, frequency 100 kHz

LTspice simulation result:

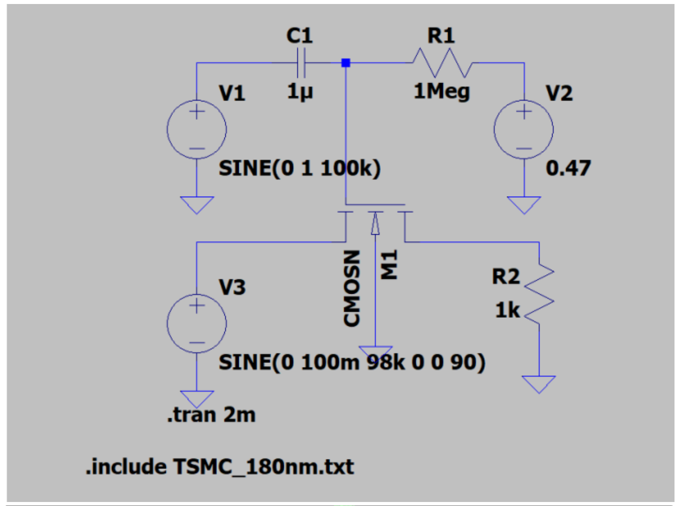
Input signal frequency = 95 kHz

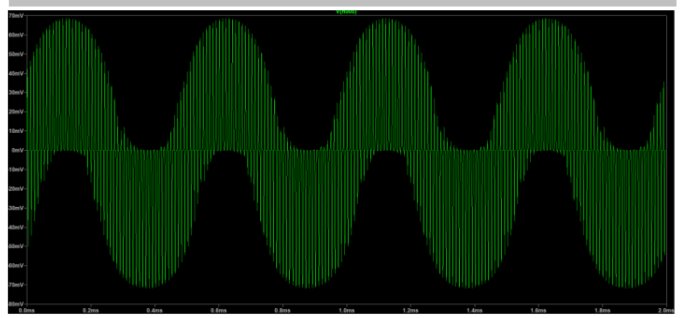


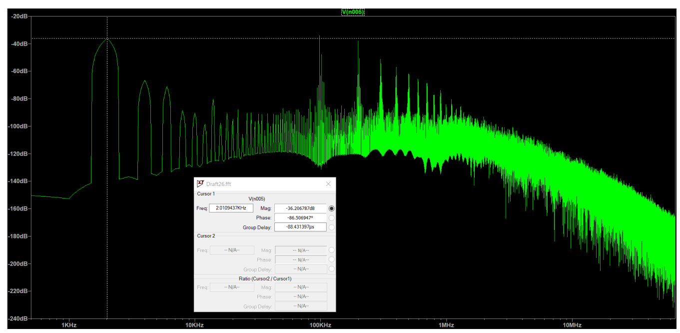




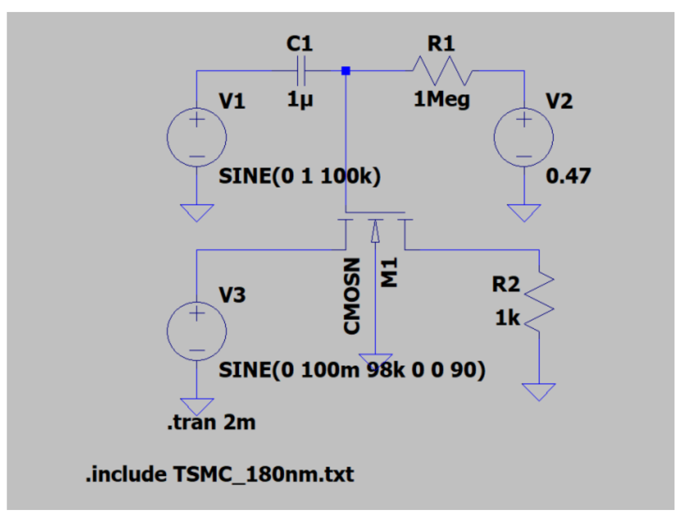
Input signal frequency = 98 kHz

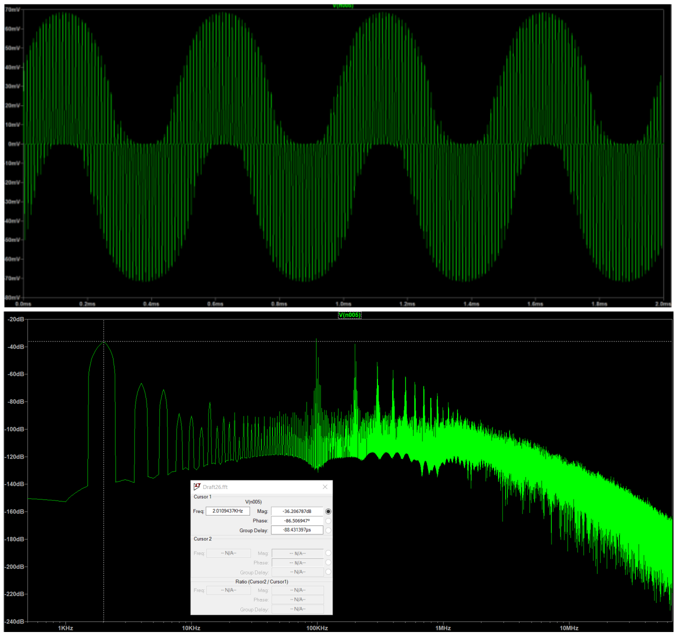




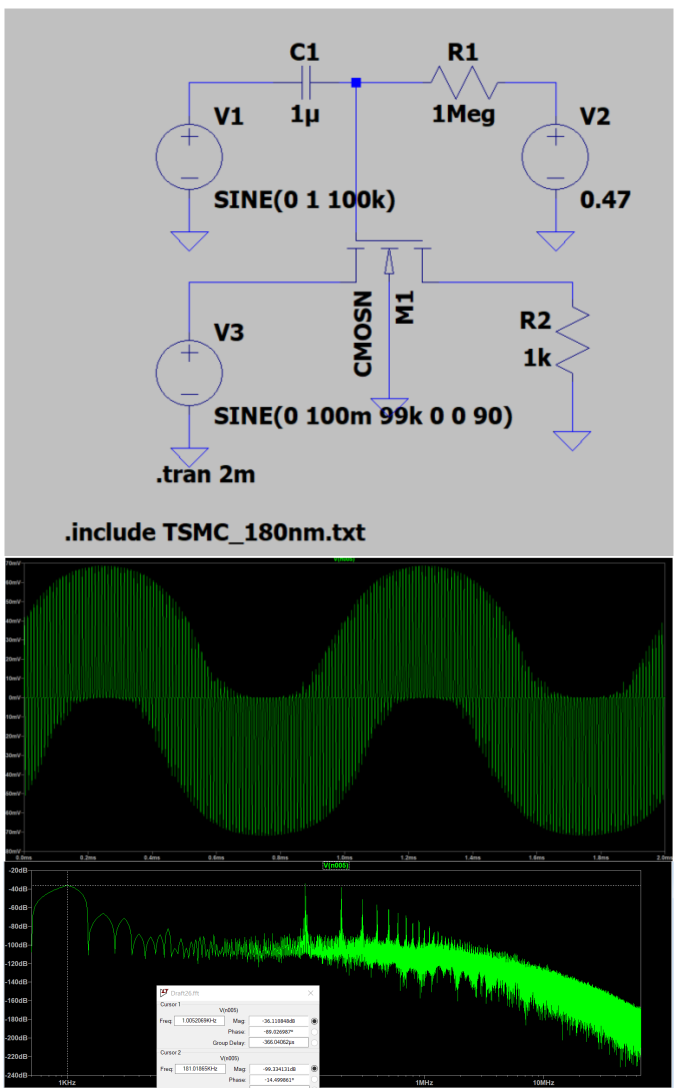


Input signal frequency = 99 kHz

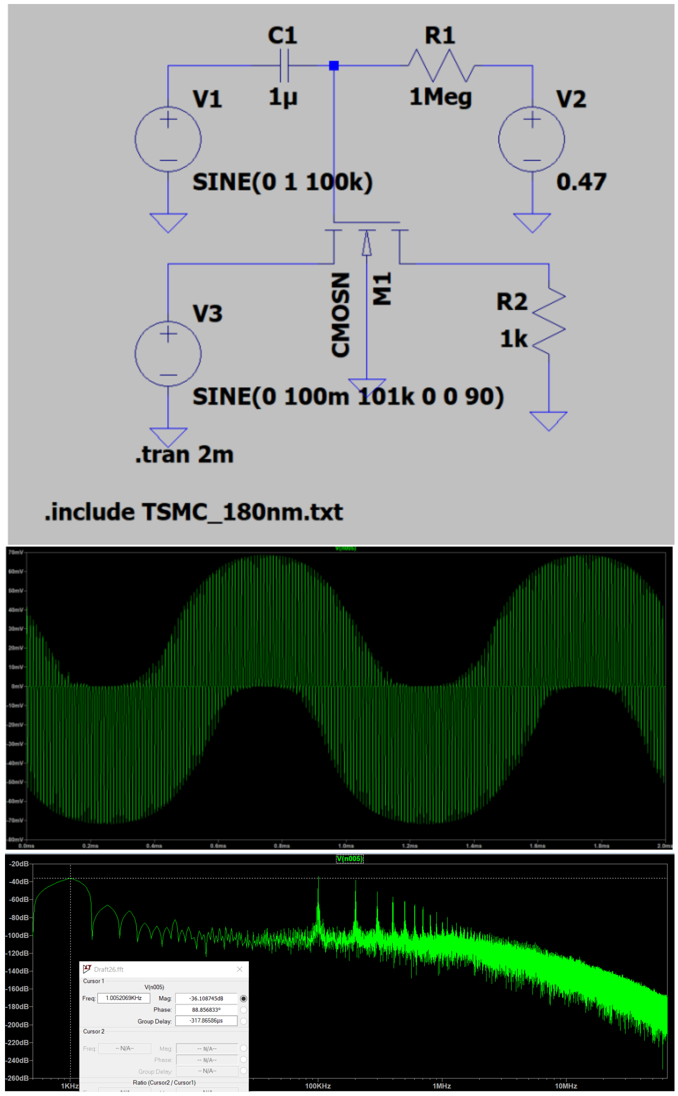




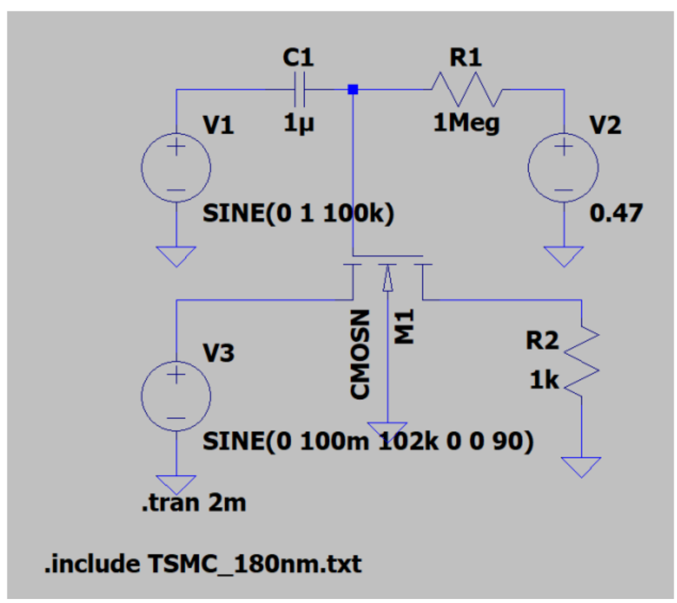
Input signal frequency = 101 kHz

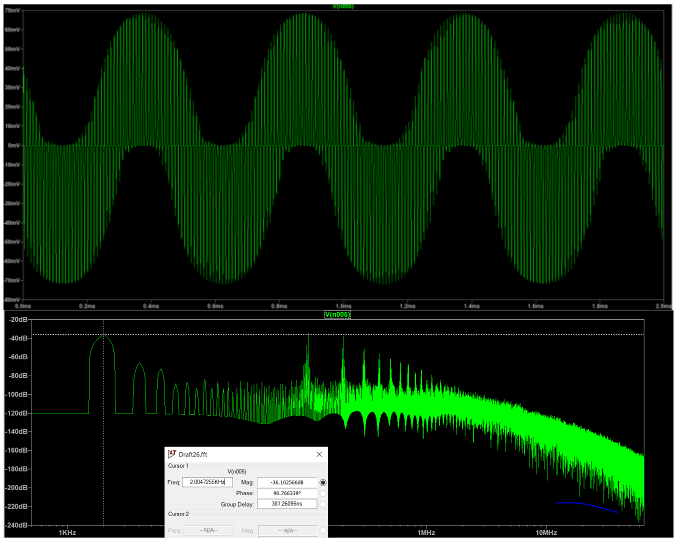


Input signal frequency = 102 kHz

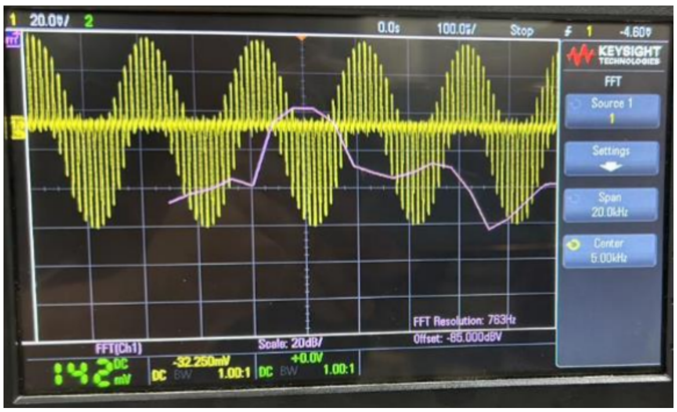


Input signal frequency = 105 kHz

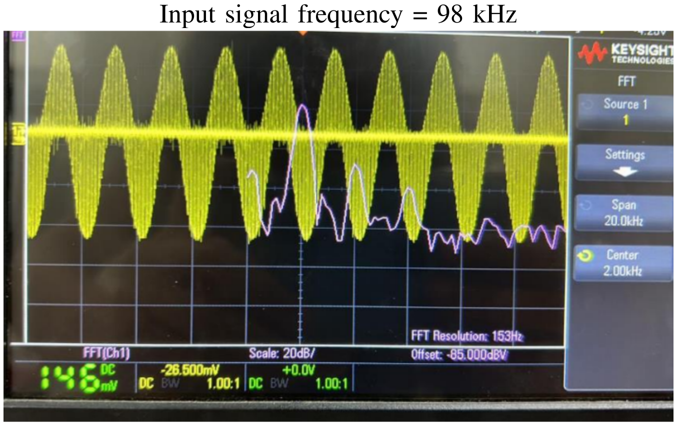




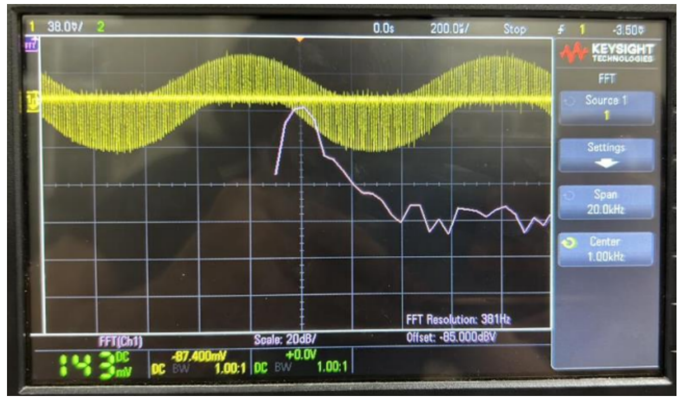
Oscilloscope Results: Input signal frequency = 95 kHz



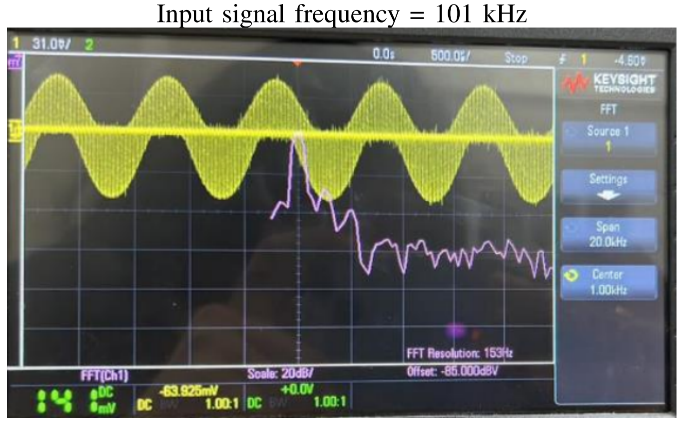
Input signal frequency = 98 kHz



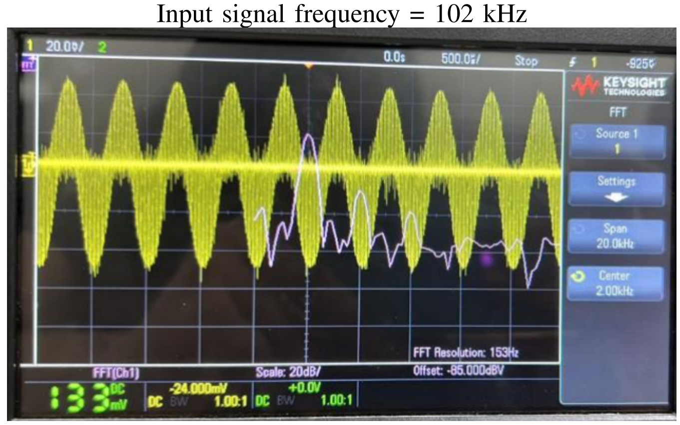
Input signal frequency = 99 kHz



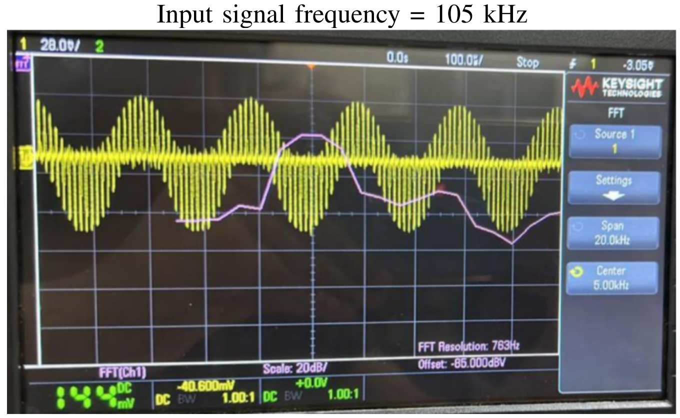
Input signal frequency = 101 kHz



Input signal frequency = 102 kHz



Input signal frequency = 105 kHz



Observation Table:

Input Frequency	1st Peak	2 nd Peak	3 rd Peak
95 kHz	5 kHz	95 kHz	195 kHz
98 kHz	2 kHz	98 kHz	198 kHz
99 kHz	1 kHz	99 kHz	199 kHz
101 kHz	1 kHz	101 kHz	201 kHz
102 kHz	2 kHz	102 kHz	202 kHz
105 kHz	5 kHz	105 kHz	205 kHz

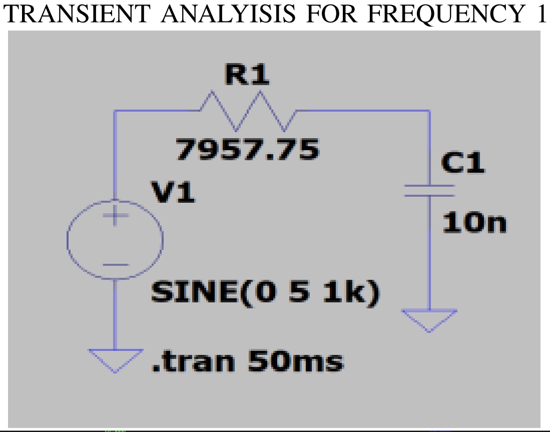
1st peak occurs at $|f_{osc} - f_{in}|$. 2nd peak occurs fin. 3rd peak always occurs at fosc + fin. Frequency of the required component (in phase or quadrature phase) = $|f_{osc} - f_{in}|$.

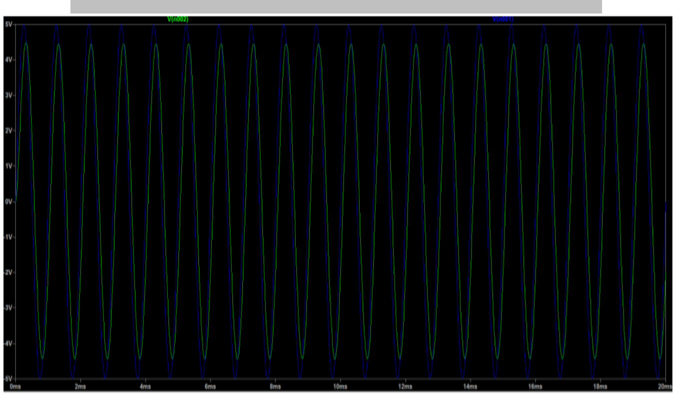
LOW PASS FILTER

- 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.
- Since from our signal we receive a signal which has both low frequencies and high frequencies. But our required signal has low frequency.
- 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/ 2πRC
- we have selected -3dB frequency to be 2 kHz, we take R and C values as

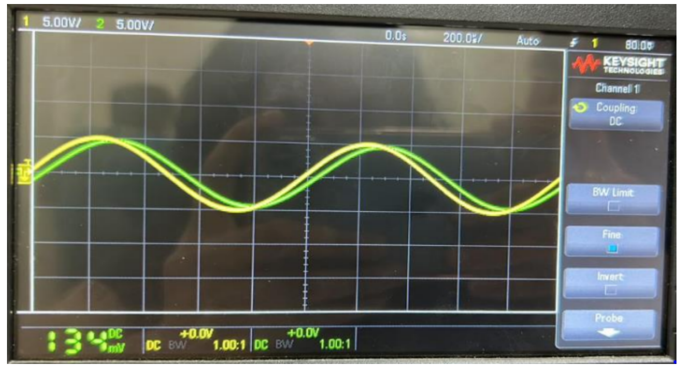
R = 7957.75 Ohm and C = 10nF.

TRANSIENT ANALIYSIS FOR FREQUENCY 1K:

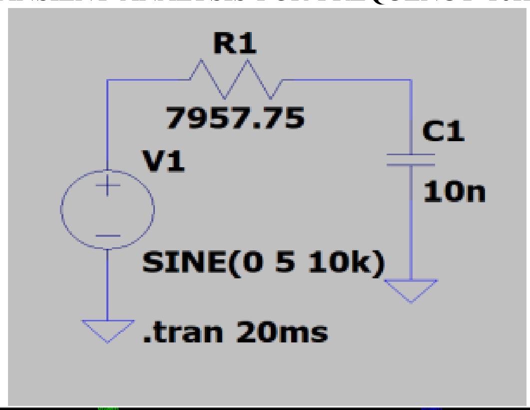


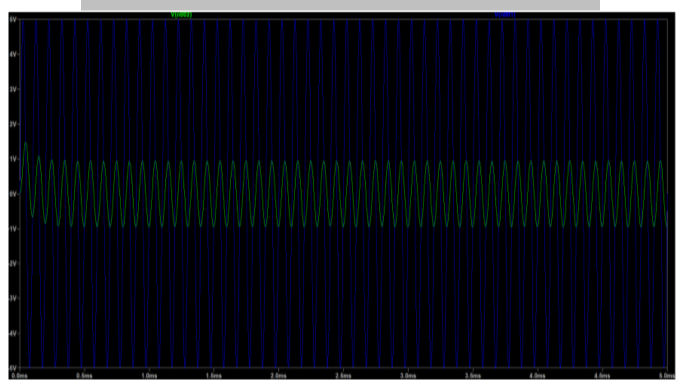


Output on DSO:

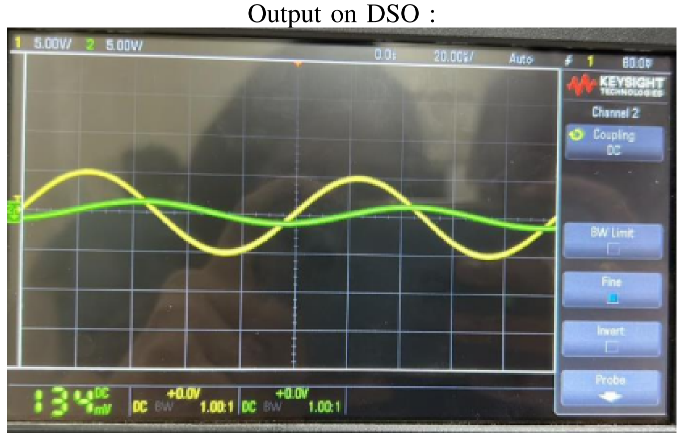


TRANSIENT ANALYSIS FOR FREQUENCY 10KHZ:

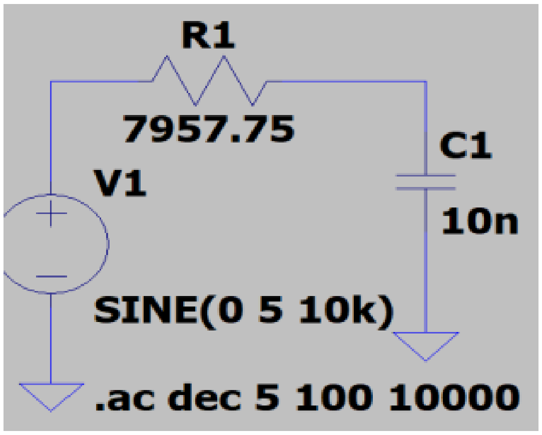


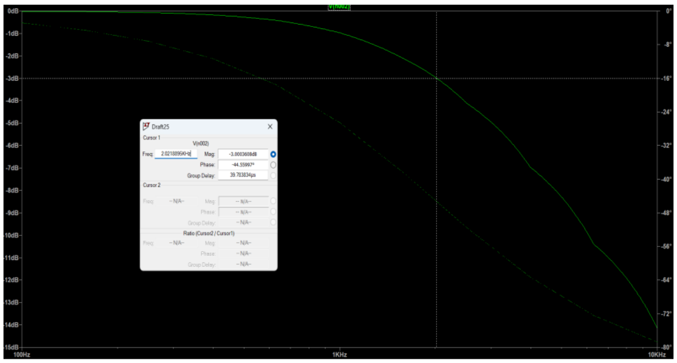


Output on DSO :

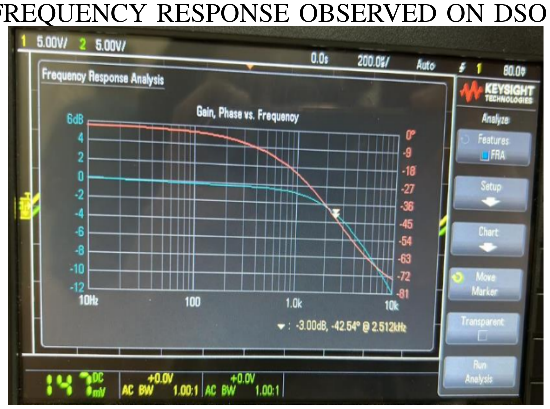


AC ANALYSIS :

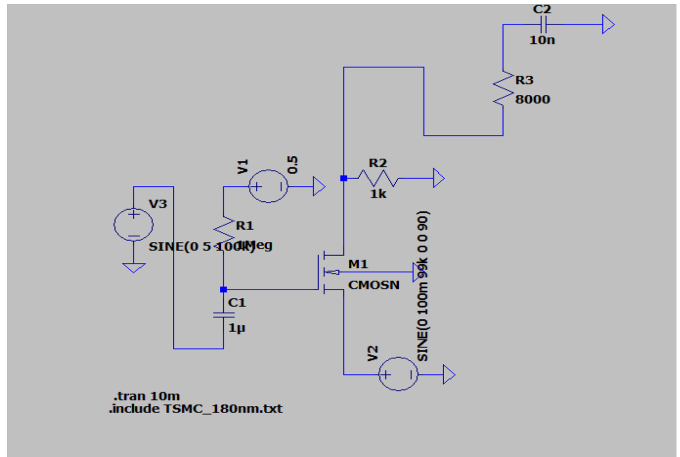


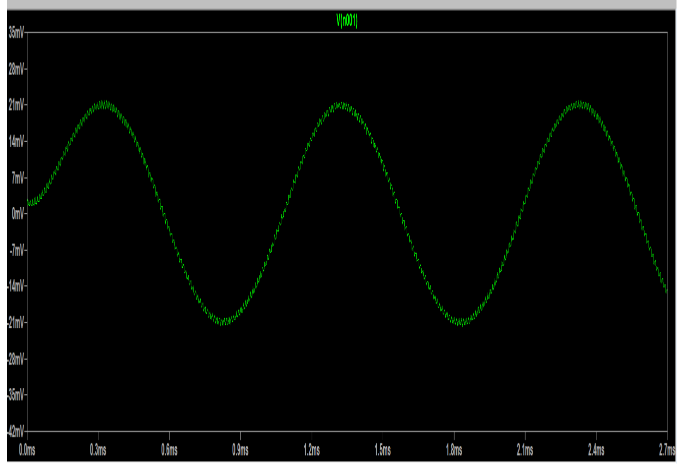


FREQUENCY RESPONSE OBSERVED ON DSO :



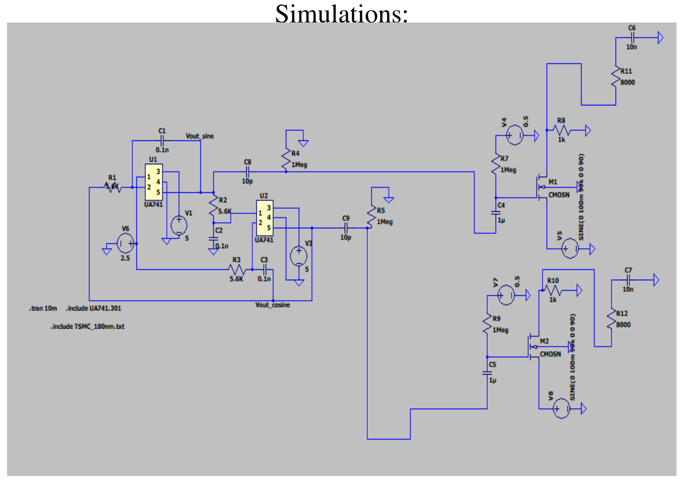
• The frequency response at -3dB refers to the point at which the output signal of a filter is attenuated by 3 decibels (dB) relative to its maximum amplitude. In the context of a low pass filter, the -3dB frequency represents the cutoff frequency, which separates the range of frequencies that are allowed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





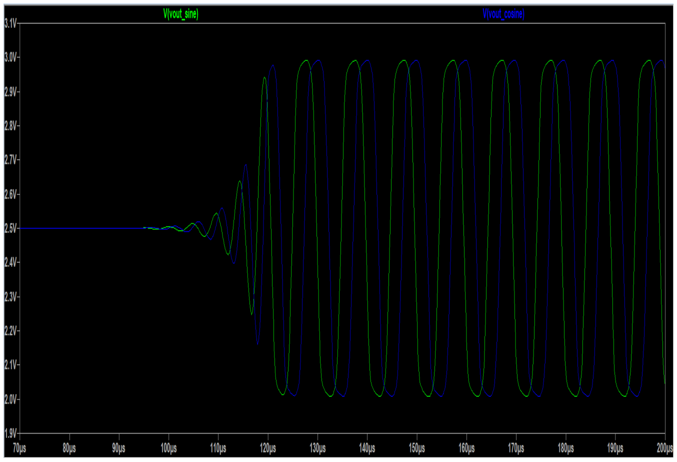
IV. COMPLETE CIRCUIT INTEGRATION

Now that we 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. LtSpice Simulations:

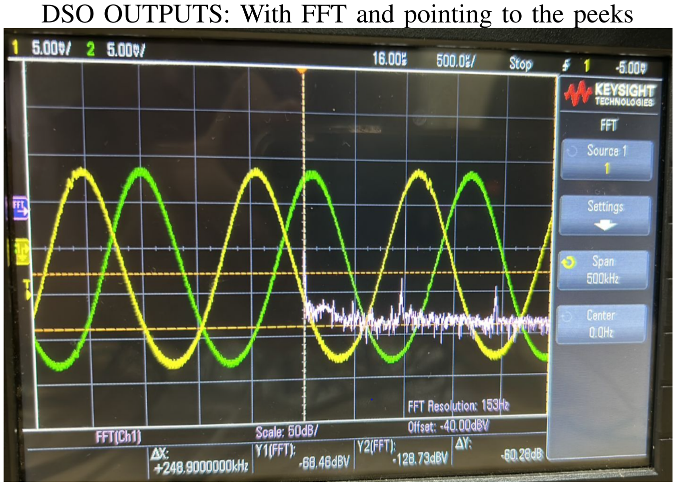


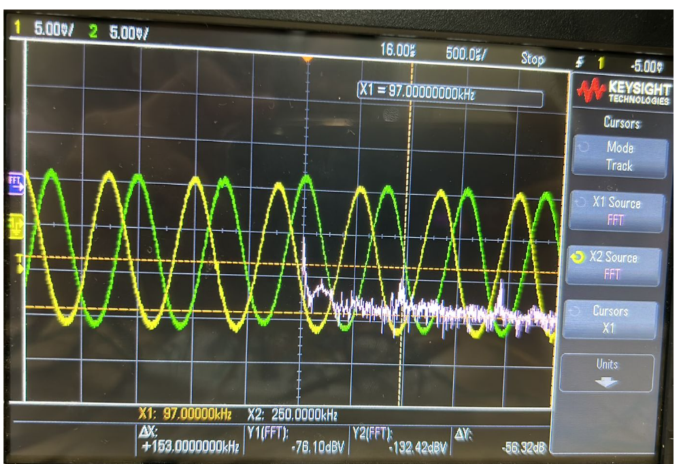
Output:

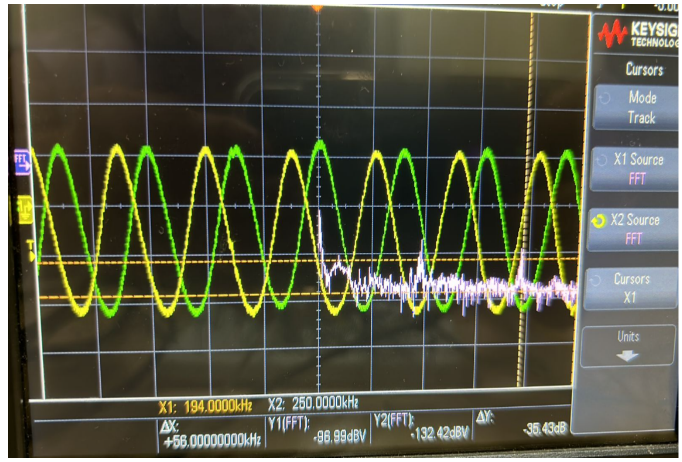
LTspice Simulation for mixer and low pass filter combined:



DSO OUTPUTS: With FFT and pointing to the peeks







RF Input: The high-frequency RF signal that needs to be downconverted.
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 ouput meeting above requirements