Quadrature Down Converter

Design and Simulation

Anushka Agrawal, Arya Marda, Pabba Ananya Vaibhavi

IIIT Hyderabad

***Abstract*—This paper presents the design, simulation results and working of a quadrature down converter. It briefly explains the uses of down conversion and elaborates upon the working of the down converter by segregating it into different parts and elucidating in detail the usage of each component, finally integrating them all into a single circuit. This paper also shows the comparative analysis of the practical and theoretical simulation results thus verifying the working of the device.**

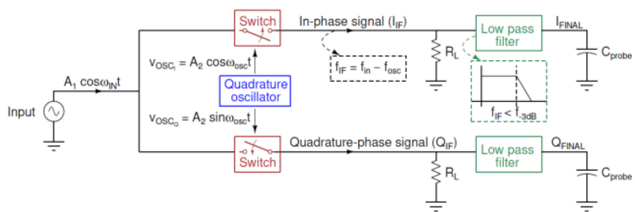
Keywords—quadrature, oscillator, down conversion, mixer, filter, frequency

I. INTRODUCTION

A quadrature down converter (QDC) is commonly used in modern day wireless receivers (RX) such as Bluetooth, Wi-Fi and WLAN. Quadrature down conversion helps in interference mitigation and improves the quality of communication. Signals are generally frequency modulated before transmitting because of practical complications. The height of the antenna that transmits signals is directly proportional to the wavelength of the signal and we know that as frequency increases wavelength decreases so antenna size decreases, decreasing the cost of transmission. So, once they are frequency modulated, there can be interference of other waves during transmission and this quadrature converter helps in mitigation of that interference and converting the high frequency modulated signal which comprises of addition of carrier frequency and original message frequency to its baseband frequency in the form of its two quadrature components.

This quadrature down conversion uses two mixers, one fed with a cosine wave and the other with sine wave generated by the quadrature oscillator. So, the same IF data will go to two different paths to be changed to quadrature signals.

II. PARTS OF A QUADRATURE DOWN CONVERTER



(Fig.1) Schematic's of Quadrature down converter circuit.

The given quadrature converter design in Fig.1 comprises of primarily three major parts:

- QUADRATURE OSCILLATOR

  It produces two sinusoidal signals with a phase difference of 90° to be fed to the mixer/switch.

- MIXER/SWITCH:

  Two mixers are used, one fed with a cosine wave and the other with sine wave. It's function is to multiply/superimpose/mix our input signal with the signal fed to it from the quadrature oscillator.

- LOW PASS FILTER:

  The mixed signal is fed to a low pass filter to pass only the IF signals with frequency less than or equal to w_{IF}

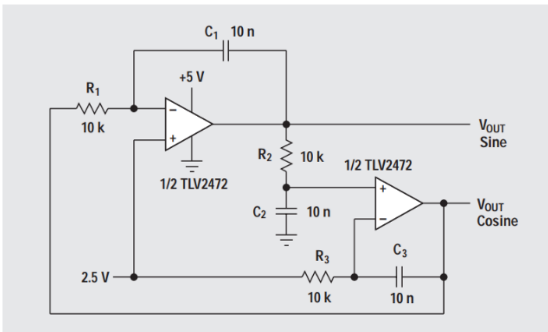
$$w_{IF} = w_{IN} - wOSC$$

Where,

w_{IN} = Frequency of input signal

w_{OSC} = Frequency of quadrature oscillator

III. QUADRATURE OSCILLATOR



(Fig.2) Schematic's of Quadrature oscillator.

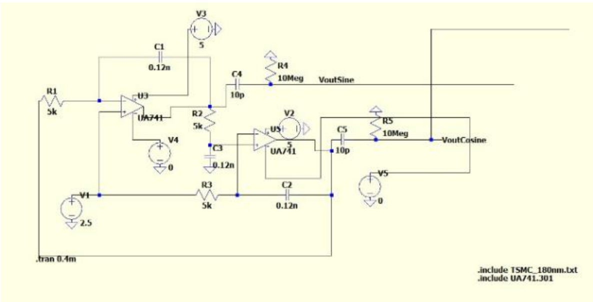
Quadrature oscillator is used to produce two sinusoidal signals with a phase difference of 90°. The topology we used requires two opamps both of which produces two sinusoidal signals with a phase shift 90°.

The topology of the quadrature oscillator is given in Fig.2. To understand the working of the oscillator we analyze the circuit in two halves. In the first half of the circuit, we consider the 1st opamp. It can be seen that the opamp acts as integrator as the output of that opamp is feedback to the input terminal using capacitor. If we provide a sinusoidal input (say, cosine signal) to the input of this opamp, we get a 90° phase shift (sine wave) at the output. Now, in the second half of the circuit, this output of the 1st opamp is fed to RC filter to filter out the higher frequency components. The output of this filter is fed as input to the other opamp which also acts as an integrator. So, if the input signal is sine wave, we get a cosine wave at the output of this opamp which was initially fed as input to the 1st opamp.

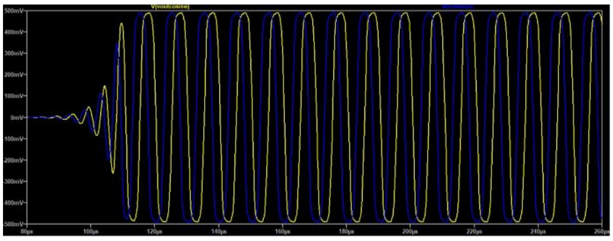
The frequency of the sinusoidal signal obtained is decided by the values of resistance and capacitance we choose. If we take the same values of all R and C. The frequency of the signal is given by:

$$f_{osc} = \frac{1}{2\pi RC}$$

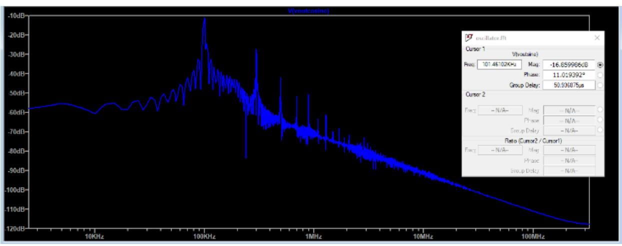
To obtain the sinusoidal signals of frequency 100kHz we take the values of R and C as 5kΩ and 0.19nF respectively.



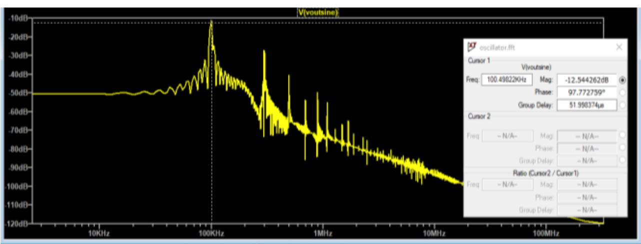
(Fig.3) Realizing oscillator on LTSPICE.



(Fig.4) Simulation results: 2 Sine waves at a phase difference of 90^0, with Vpp 1V and frequency 100KHz.



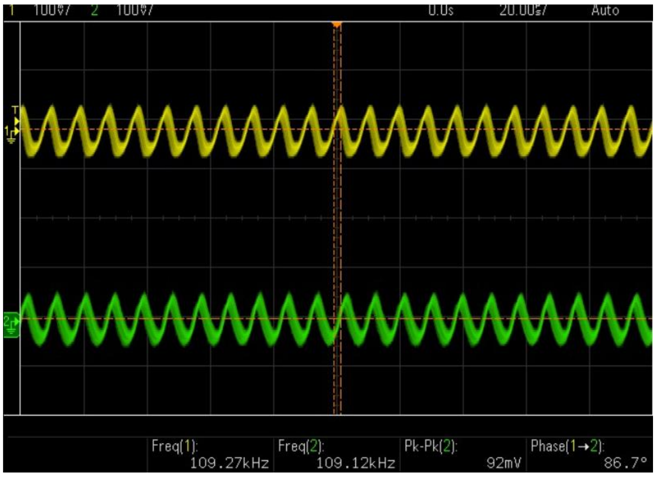
(Fig.5) FFT plot of Cosine wave which is output of our simulation: We get a prominent peek at 100.46102 kHz frequency.



(Fig.6) FFT plot of Sine wave which is output of our simulation: We get a prominent peek at 100.49822 kHz frequency.

Components	Simulation values	Practical values
R2=R1=R3	5K	4.7K
C2=C3= C1	0.12nf	0.2nF
C5=C4	10pf	10pF
R5=R4	10Mega	10.2Mega

Practical plots:



(Fig.7) Output of practically realized oscillator, the output gives two Sine waves at phase difference of 86.7^0 and amplitude 92Mv, the frequency produced by the oscillator is 109.2KHz.

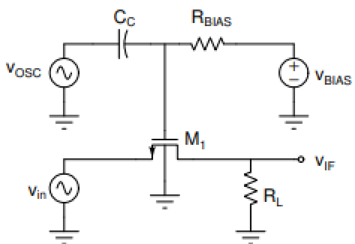
IV. SWITCH(MIXER).

A. *Introduction*

The main objective of our project is to convert high input frequency to low output frequency, i.e.to convert the input signal which comprises of addition of carrier frequency and original message frequency to a signal having frequency same as original message frequency. This can be achieved, if we somehow create high amplitude signal of required output frequency and filter all the other frequencies.

The separation of the message frequency to different frequencies is achieved using a device called mixer, which uses message signal and the signal developed by quadrature oscillator, this device mixes these frequencies to produces desired frequencies.

B. *Circuit Topology and Working of a Mixer*

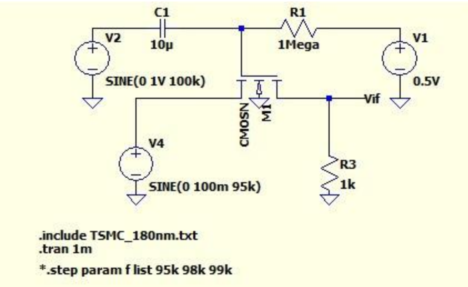


(Fig.8) Schematic's of Switch (Mixer).

The oscillator frequency (V_{OSC}) is equal to the carrier frequency, and we set V_{BIAS} value nearly equal to threshold frequency of the MOSFET. Looking from the oscillator side the configuration behaves as high pass filter, only passing ac signal and blocking any DC signal. If we look from the V_{BIAS} side the system behaves as a low pass filter, therefore blocking any ac signal from V_{BIAS} and only passing DC signal.

Therefore, the signal at gate of MOSFET is a signal with DC offset V_{BIAS} and ac amplitude and frequency equal to V_{OSC}. When the $V_{OSC} > 0$ the MOSFET is in linear mode, and when oscillator signal is $V_{OSC} < 0$, MOSFET is in cutoff mode. On and off action due to oscillator signal can be thought as a switch with frequency equal to that of oscillator frequency. We get output when $V_{OSC}>0$ and no output when $V_{OSC}<0$. This action represents multiplicative action of two signals.

Thinking of Fourier series of a square wave, we get all the odd harmonics from 1, w, 3w, 5w and so on with decreasing amplitude. On multiplying this signal with input signal, we get high amplitude at different frequencies, which are odd harmonic frequencies + f_{IN}, and odd harmonics – f_{IN}. So at output of mixer we get peaks at different frequencies, among which high amplitude peeks are F_{iIN} ,$F_{carrier}$ + F_{IN} ,$F_{carrier}$ – f_{IN} and $2F_{carrier}$.



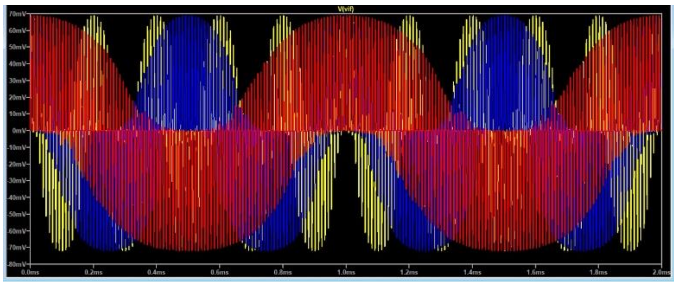
(Fig.9) Realizing Mixer on LTSPICE. R_{BIAS} is equal to 1MegaΩ and value of capacitor C_C equal to 10uF.

Amplitude of V_{IF} can be found by multiplying V2 and V4 signal (refer Fig.8)

Amplitude is given as:

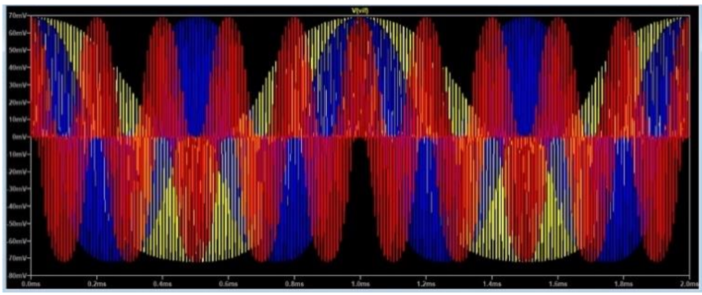
$$v_{IF_I} = v_{in} \times v_{OSC_I} = \frac{A_1A_2}{2}\left(cos(\omega_{in}t - \omega_{OSC}t) + cos(\omega_{in}t + \omega_{OSC}t)\right)$$

$$v_{IF_Q} = v_{in} \times v_{OSC_Q} = \frac{A_1A_2}{2}\left(sin(\omega_{in}t + \omega_{OSC}t) - sin(\omega_{in}t - \omega_{OSC}t)\right)$$



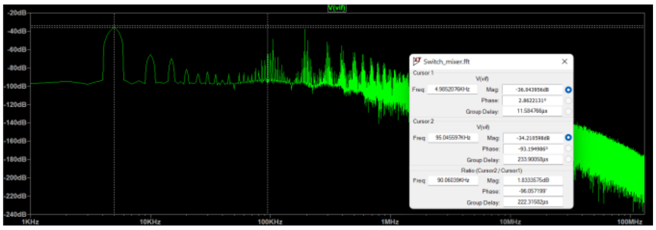
(Fig.10.a) V_{IF} at input signal with frequencies: 95kHz, 98kHz, 99kHz.

Color	F_{IN}
Red	95KHz
Blue	98KHz
Yellow	99KHz

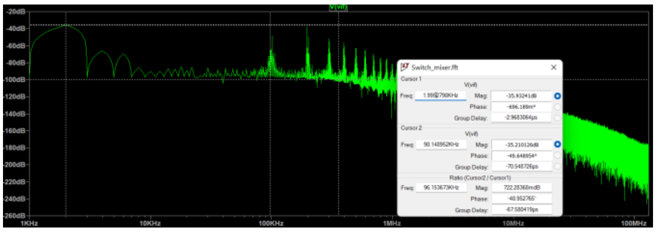


(Fig.10.b) V_{IF} at input signal with frequencies: 101kHz 102kHz 105kHz.

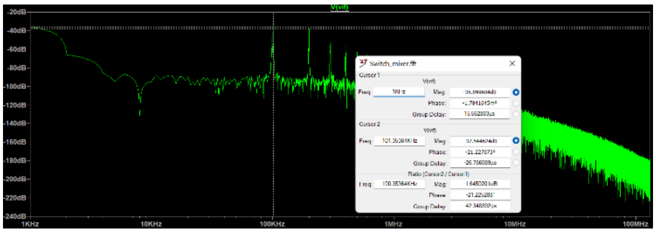
Color	F_{IN}
Red	105KHz
Blue	102KHz
Yellow	101KHz



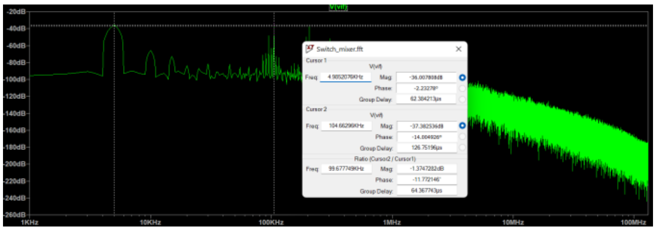
(Fig.11) Frequency response at F_{IN} = 95KHz, we get peaks at 5KHz, 95KHz, and 195KHz.



(Fig.12) Frequency response at F_{IN} = 98KHz, we get peaks at 1.99KHz, 98.14KHz, and 198.14KHz.



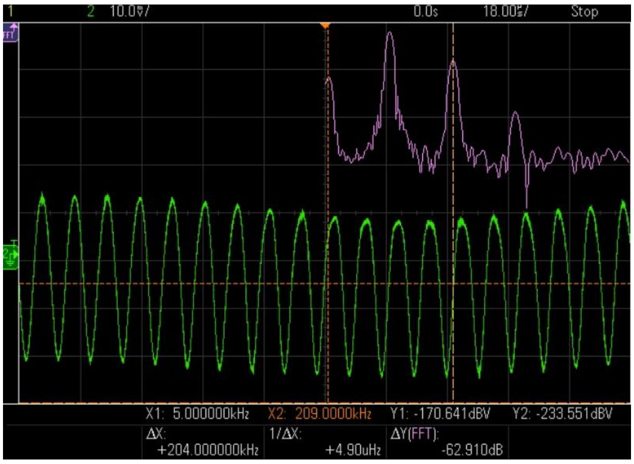
(Fig.13) Frequency response at F_{IN} = 101KHz, we get peaks at 1 kHz, 101.35 kHz, and 201.35KHz.



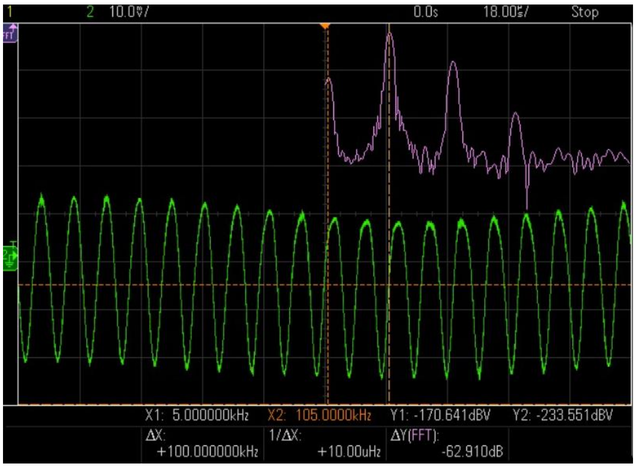
(Fig.14) Frequency response at F_{IN} = 105KHz, we get peaks at 4.9016 kHz, 104.66.35 kHz, and 204.65KHz.

Components	Simulation values	Practical values
V_{BIAS}	0.5V	1.8V
R_{BIAS}	1 Mega	470KΩ
C_C	10uF	0.1uF

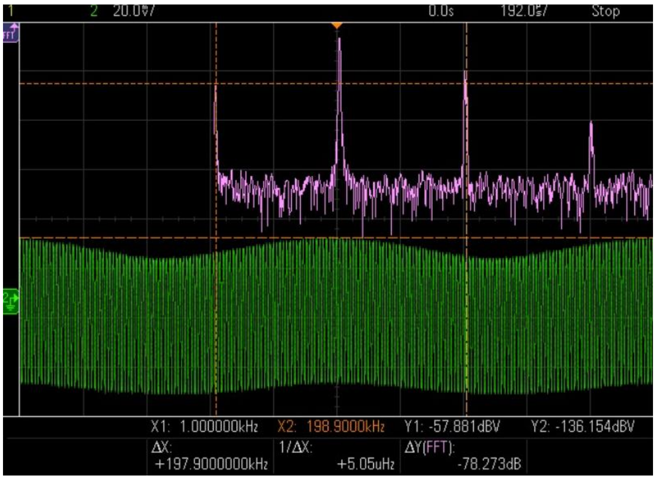
Practical outputs:



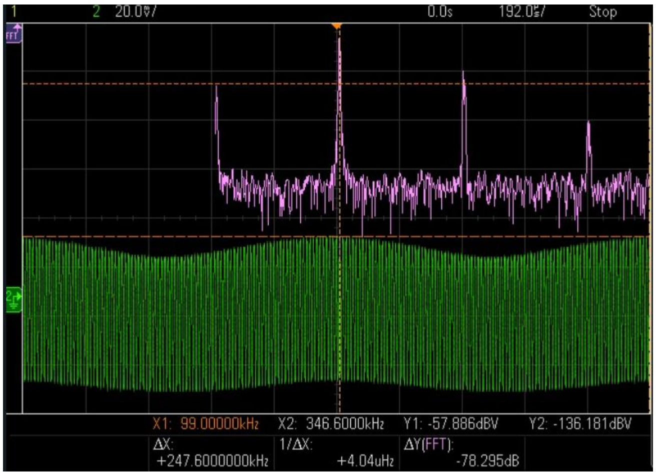
(Fig.15.a) FFT plot and output of mixer on OSC when F_{OSC} is 100KHz and F_{IN} 105KHz. We see that we get peaks on FFT at 5KHz, 209KHz.



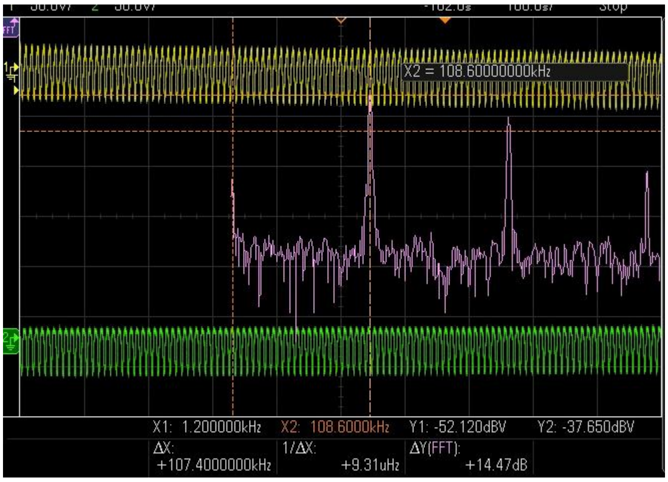
(Fig.15.B) FFT plot and output of mixer on OSC when F_{OSC} is 100KHz and F_{IN} 105KHz. We see that we get peaks on FFT at 5KHz, 105KHz.



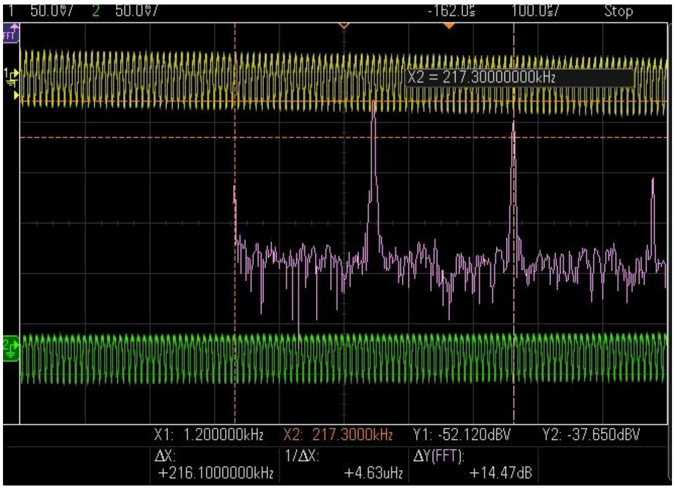
(Fig.16.a) FFT plot and output of mixer on OSC when F_{OSC} is 100KHz and F_{IN} 99KHz. We see that we get peaks on FFT at 1KHz, 198KHz.



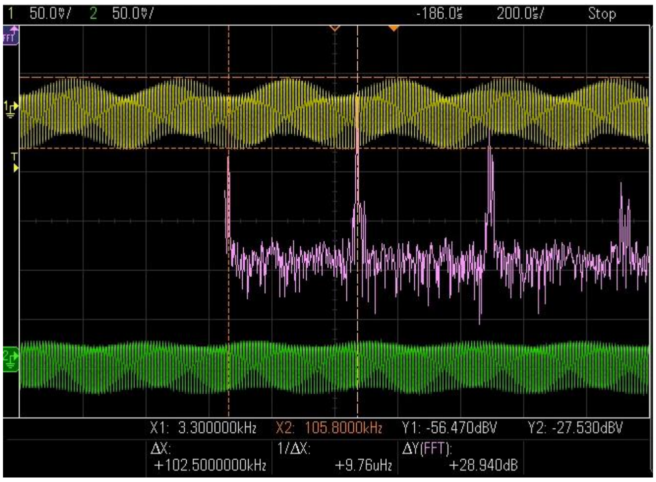
(Fig.16.b) FFT plot and output of mixer on OSC when F_{OSC} is 100KHz and F_{IN} 99KHz. We see that we get peaks on FFT at 99KHz



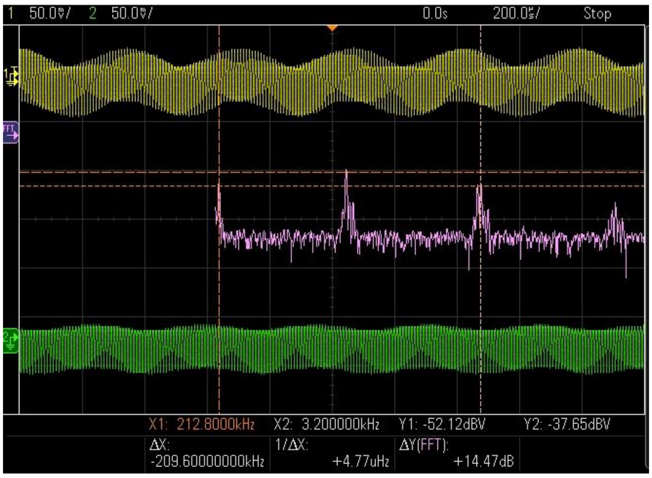
(Fig.17.a) FFT plot and output of mixer on OSC when F_{OSC} is 109kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 1.2kHz and 108.6kHz



(Fig.17.b) FFT plot and output of mixer on OSC when F_{OSC} is 109kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 1.2kHz and 217.3kHz



(Fig.18.a) FFT plot and output of mixer on OSC when F_{OSC} is 105kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 3.3kHz and 105.8kHz



(Fig.18.b) FFT plot and output of mixer on OSC when F_{OSC} is 105kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 3.2kHz and 105.8kHz

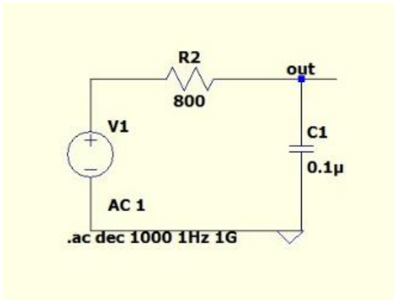
V. LOW PASS FILTER

A. *Introduction and Objective*

We use a simple RC circuit design to fulfil the objective of a low pass filter as shown in Fig. The output of the mixer still has higher frequencies which must be toned down to convert it to its baseband frequency and this job is done by our RC low pass filter.

We keep the -3dB cut-off frequency of the low pass filter as 2kHz so that the high frequency component of the output signal gets filtered out. This 2kHz is the frequency of our original signal before frequency modulation with the carrier wave.

B. *Working*

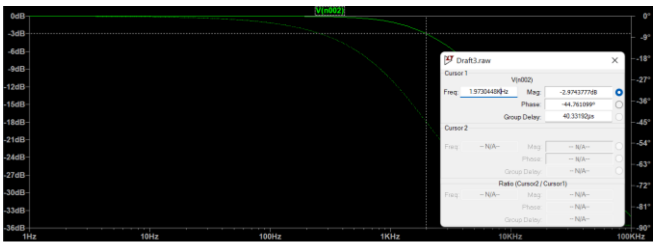


(Fig.19) Realizing RC low pass filter with cut off frequency 2KHz on LTSPICE.

The circuit topology is just a resistor and capacitor in series with an input voltage and out voltage is measured across the capacitor. When the frequency of V_{IN} is high, the input voltage changes very fast but the capacitor is in series with a resistor so it cannot change its voltage immediately, so it charges slowly, and so output voltage frequency attenuates. So, when the input frequency is low, it has enough time to charge slowly and it outputs same frequency output as that of input and thus, it filters out the higher frequencies depending on the R and C value specifications.

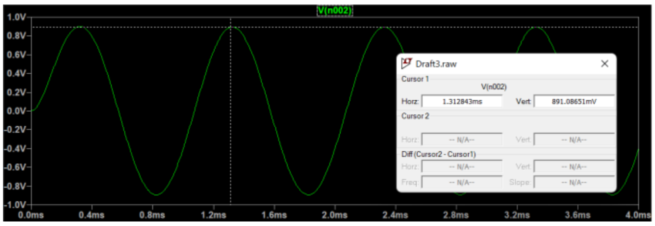
- The cut-off frequency of the RC filter is given by:

$$f_{cut\text{-}off} = 1/2\pi RC$$

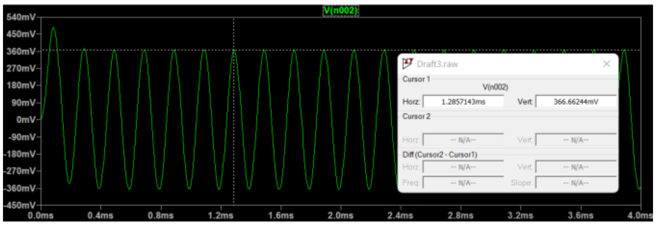


(Fig.20) Frequency response of RC low pass filter, we get -3dB frequency at 1.97KHz.

We can see from the above frequency response of the RC low pass filter that the cut-off frequency or –3dB frequency is 2kHz. Thus, it lower frequencies lesser than 2kHz to pass but attenuates the higher frequencies.



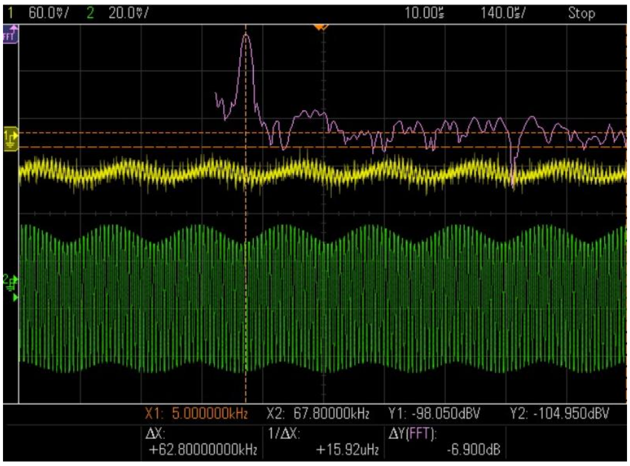
(Fig.21) Output of low pass filter when input signal has amplitude 1V and frequency 1KHz. Amplitude of output signal is 891mv.



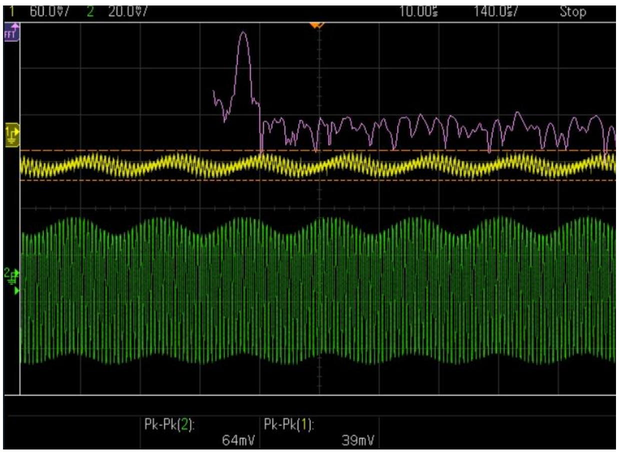
(Fig.22) Output of low pass filter when input signal has amplitude 1V and frequency 5KHz. Amplitude of output signal is 366mv.

Components	Simulation values	Practical values
R	800Ω	9.4K
C	0.1uF	0.1 uF

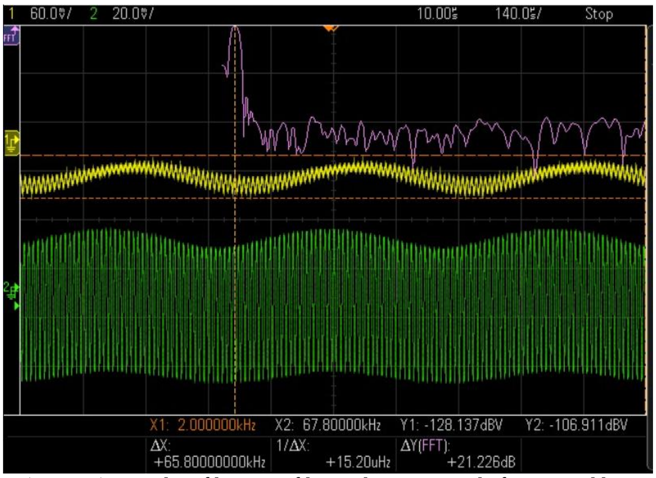
Practical output (all the output are after passing the output signal of mixer thriough low pass filter):



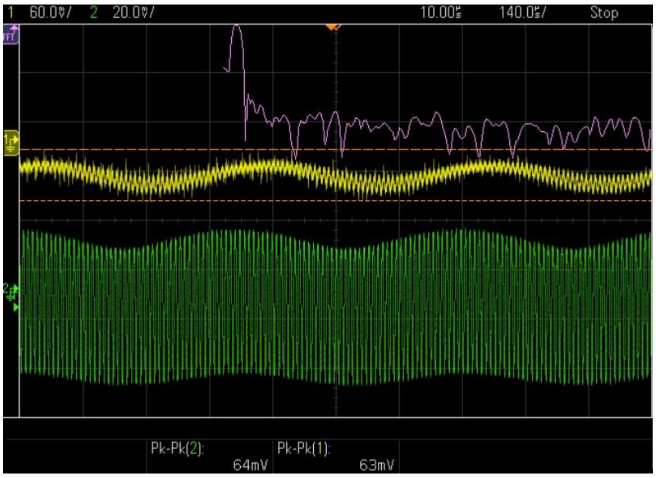
(Fig.23.a) FFT plot of low pass filter and output signal of mixer and low pass filter on OSC when F_{OSC} is 100KHz and F_{IN} 105KHz, and input of filter has high amplitude peaks at 100KHz, 105KHz, 205KHz. We get a peak in FFT of low pass filter at 5KHz.



(Fig.23.b) Amplitude of low pass filter is 39mV, when input signal has amplitude 64mV.



(Fig.24.a) FFT plot of low pass filter and output signal of mixer and low pass filter on OSC when F_{OSC} is 100KHz and F_{IN} 99KHz, and input of filter has high amplitude peaks at 100KHz, 99KHz, 199KHz. We get a peak in FFT of low pass filter at 2KHz.



(Fig.24.b) The amplitude of low pass filter is 63mV, when the input signal has an amplitude of 64mV.

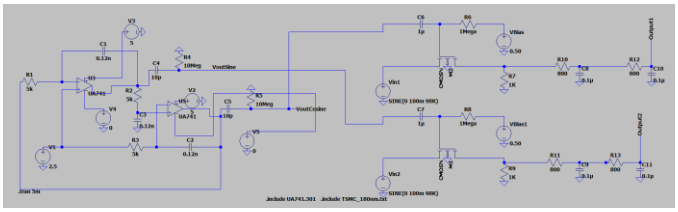
On comparig Fig.20.b and Fig.21.b we see the attenuation caused to the input signal when the input signal frequency for the filter is greater that 2KHz. The 5KHz input signal has high attunetion compared to 2KHz input signal.

VI. COMPLETE CIRCUIT

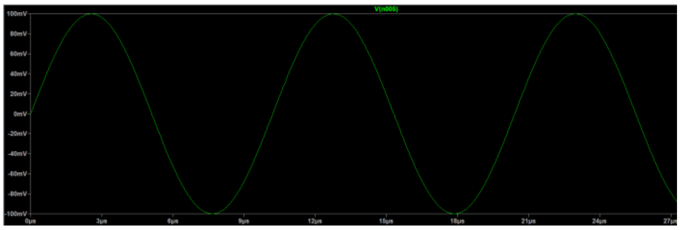
A. *Connecting all the components to get the final circuit:*

The first part of our circuit is oscillator, which takes DC voltage as input for V_{DD}, V_{SS} of Op-amps. The output of this oscillator consists of 2 signals, one sine and other cosine, both at a phase difference of 90^0. This signals act as oscillator signals in mixer, the cosine output wave is input for the In-phase mixer, and sine wave for quadrature-phase mixer. The input signal for the mixer's, are given from the wave generator. The output of the mixer is passed through the low pass filter to filter out any frequency greater than 2KHz. Finally, we have 2 output signals from the low pass filters, one in-phase component and other quadrature phase component.

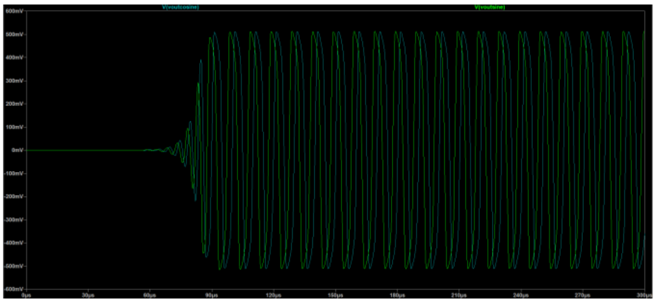
B. *Complete circuit realized on LTSPICE:*



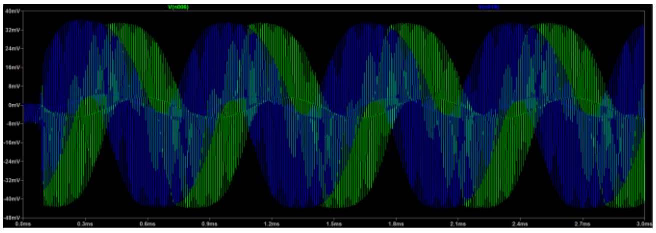
(Fig.25) Complete circuit on LTSPICE.



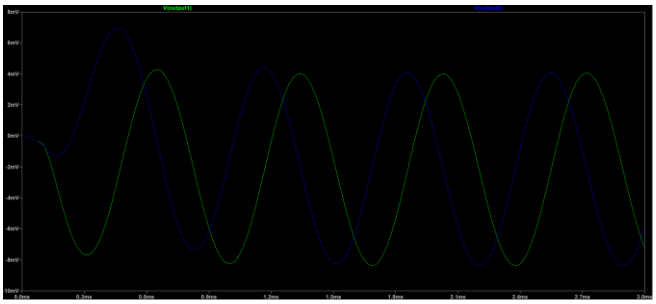
(Fig.26) Input signal with amplitude 100mV, frequency 98KHz.



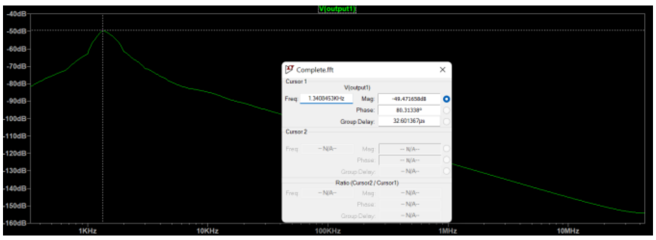
(Fig.27) Output of Oscillator when the complete circuit is connected. The Sine and Cosine components have a phase difference of 90^0 and we get amplitude of 1Vpp.



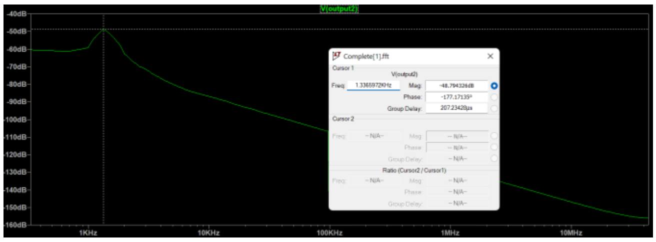
(Fig.28) Output of mixer when the above-mentioned output signals of oscillator and V_{IN} are given input to the mixer.



(Fig.29) Output of the complete circuit. 2 waves which are at phase difference of 90^0. The signals have 1.3408453KHz as output frequency.

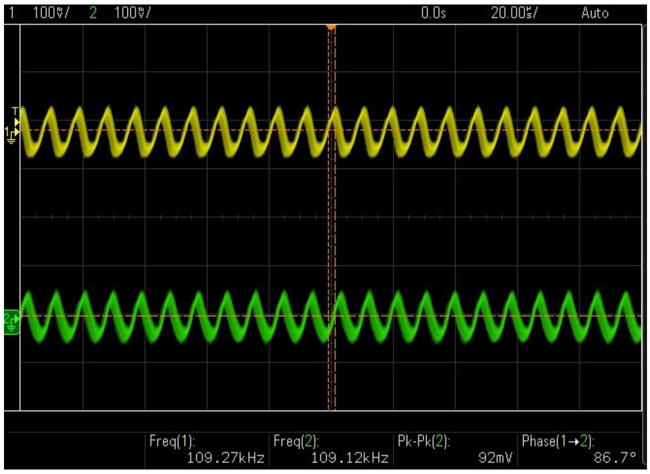


(Fig.30) FFT plot of in-phase output. We get a peak at 1.3408KHz frequency.



(Fig.31) FFT plot of Quadrature phase component. We get a peek at 1.3365KHz.

We can find the phase difference between the two outputs by adding the phase we get at the peak frequency values of their FFT plots. Here In-phase components phase at their peak frequency is 80.3^0 and that of Quadrature component is -177.71^0. On adding these two phases we see the phase difference is -94^0.

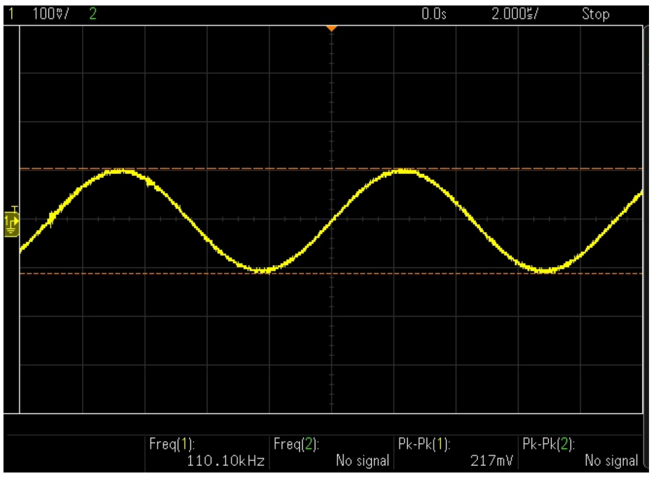


(Fig.32) Output of Quadrature Oscillator (in phase and quadrature components)

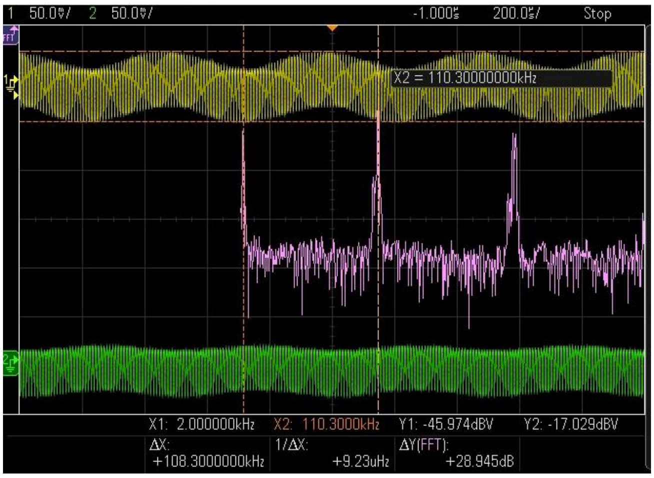
Practical output:

Given: Input Voltage frequency = 110kHz.

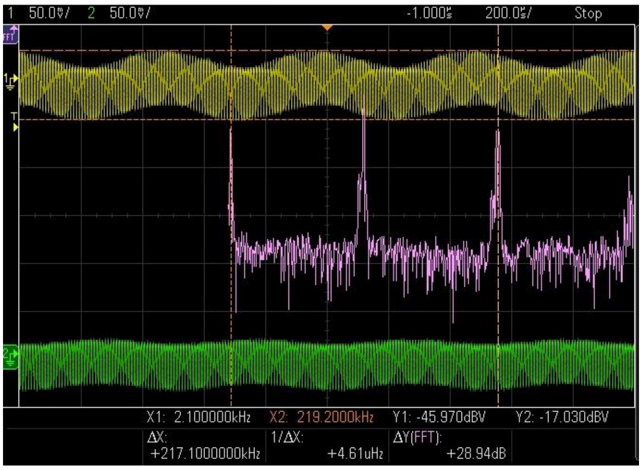
Input voltage amplitude = 100mV



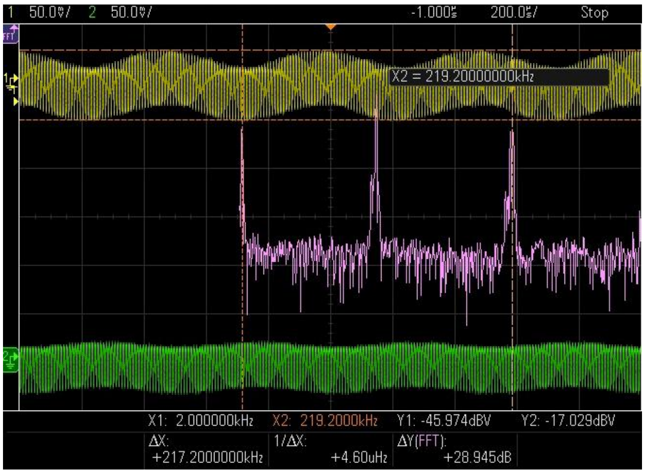
(Fig.33) Input Signal



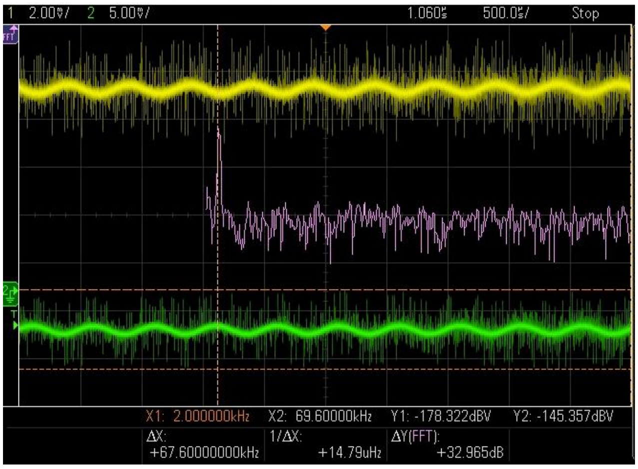
(Fig.34.a) FFT plot and output of in phase mixer on OSC when F_{OSC} is 108kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 2kHz and 110kHz



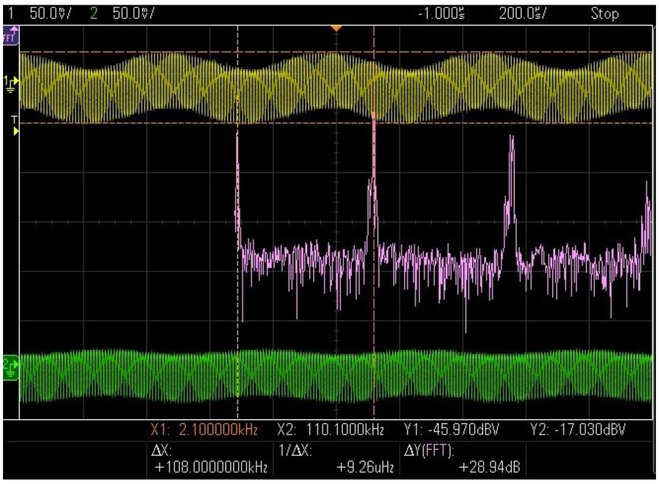
(Fig.35.b) FFT plot and output of in phase mixer on OSC when F_{OSC} is 108kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 2kHz and 219.2kHz



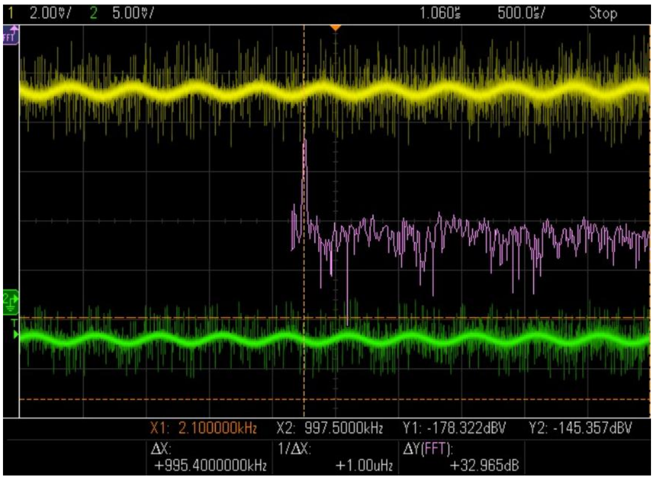
(Fig.34.b) FFT plot and output of in phase mixer on OSC when F_{OSC} is 108kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 2kHz and 219.2kHz



(Fig.36.a) Output and FFT plot of final In-phase output after passing through low pass filter. Peak is obtained at 2kHz

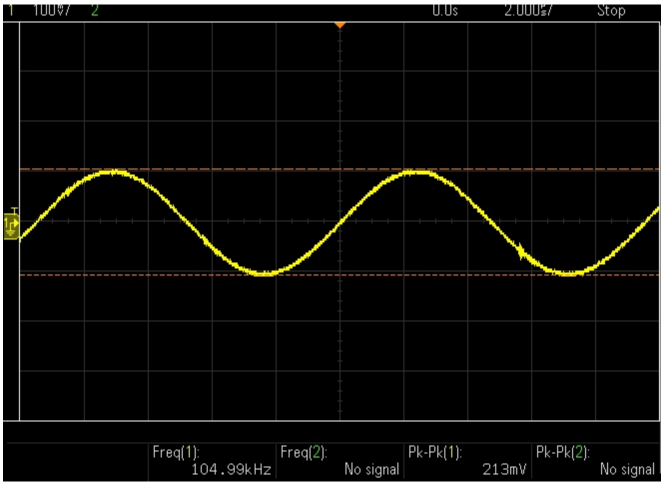


(Fig.35.a) FFT plot and output of quadrature phase mixer on OSC when F_{OSC} is 108kHz and F_{IN} 110KHz. We see that we get peaks on FFT at 2kHz and 110kHz

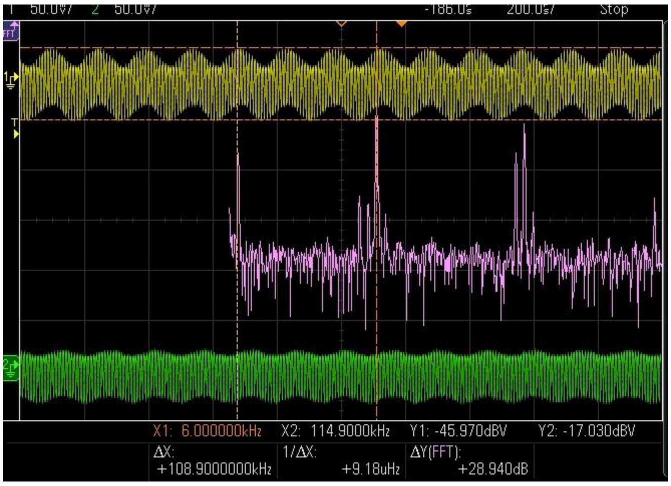


(Fig.36.b) Output and FFT plot of final quadrature-phase output after passing through low pass filter. Peak is obtained at 2.1kHz.

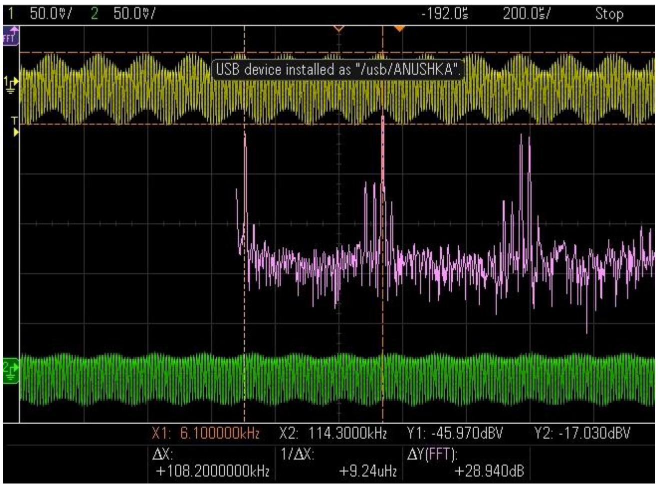
Given: Input voltage Frequency: 105kHz
Input voltage amplitude = 100mV.



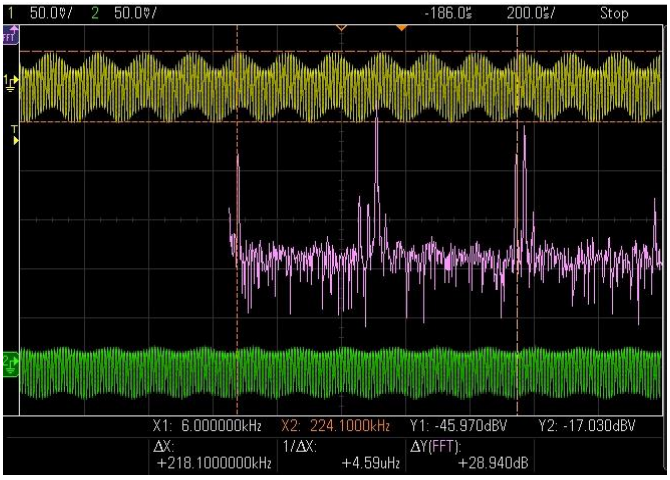
(Fig.37) Input Signal



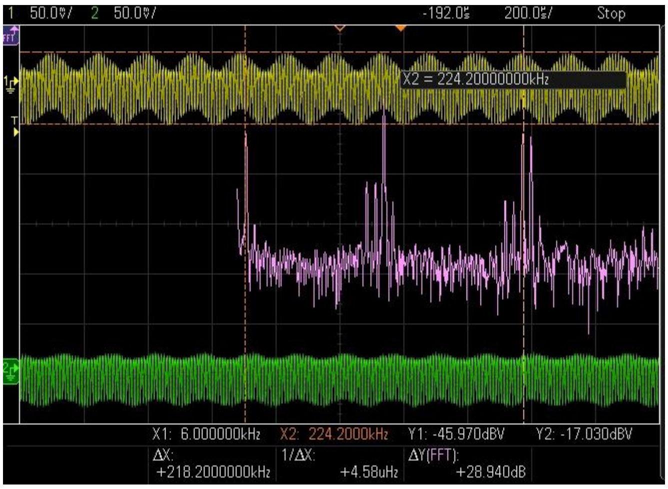
(Fig.39.a) FFT plot and output of quadrature phase mixer on OSC when F_{OSC} is 109kHz and F_{IN} 105KHz. We see that we get peaks on FFT at 6kHz and 114.2kHz



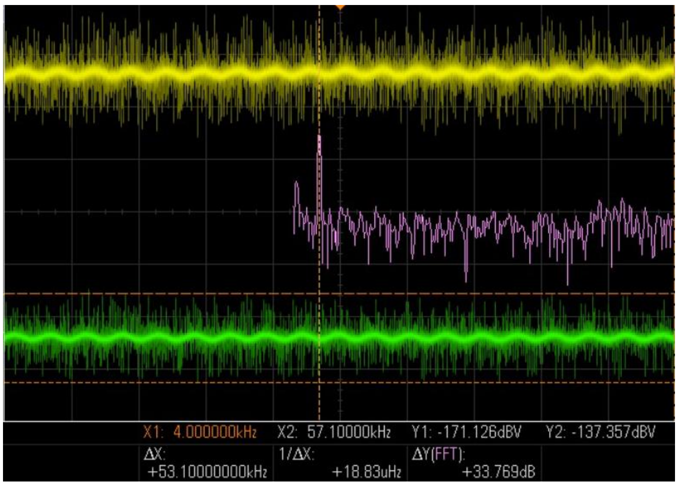
(Fig.38.a) FFT plot and output of in phase mixer on OSC when F_{OSC} is 109kHz and F_{IN} 105KHz. We see that we get peaks on FFT at 6kHz and 114.2kHz



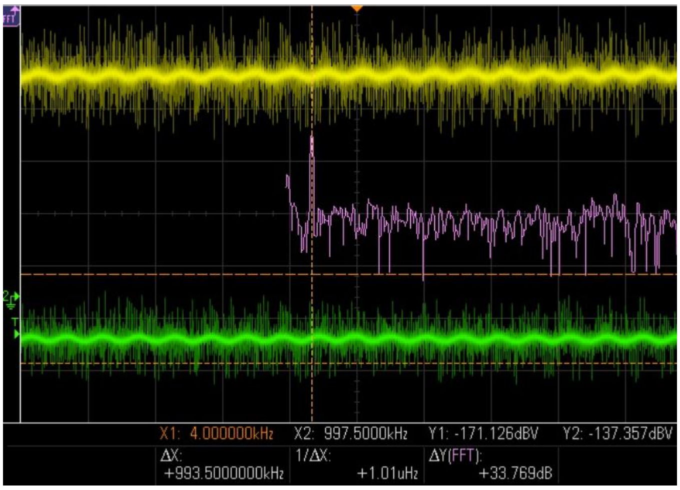
(Fig.39.b) FFT plot and output of quadrature phase mixer on OSC when F_{OSC} is 109kHz and F_{IN} 105KHz. We see that we get peaks on FFT at 6kHz and 224.2kHz



(Fig.38.b) FFT plot and output of in phase mixer on OSC when F_{OSC} is 109kHz and F_{IN} 105KHz. We see that we get peaks on FFT at 6kHz and 224.2kHz



(Fig.40.a) Output and FFT plot of final In-phase output after passing through low pass filter. Peak is obtained at 4kHz



(Fig.40.b) Output and FFT plot of final quadrature-phase output after passing through low pass filter. Peak is obtained at 4kHz

Circuit:

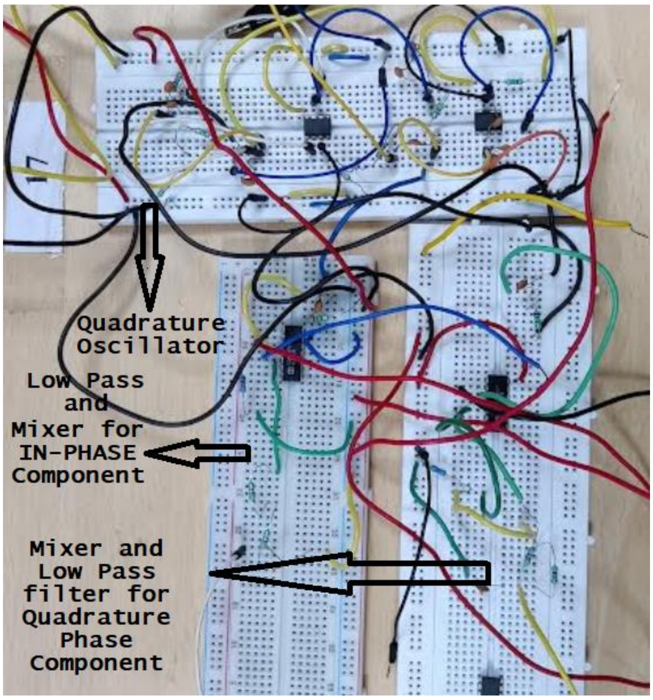
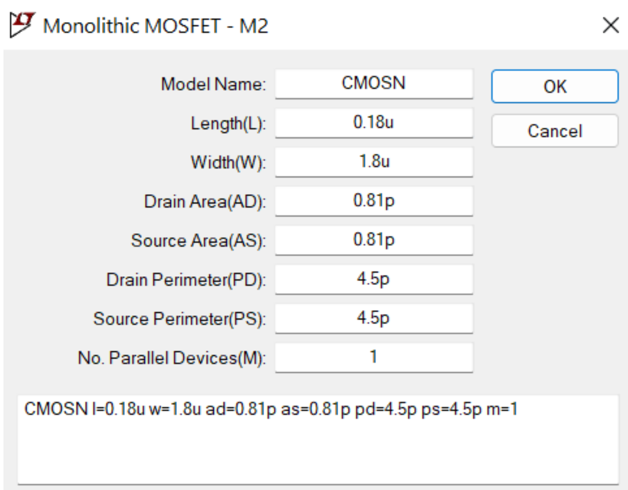


TABLE:

Parameters	Simulated	Measured
Oscillator frequency	100.498KHz	109.3KHz
Oscillator Amplitude (I-phase)	1Vpp	200mVpp
Oscillator Amplitude (Q-phase)	1Vpp	200mVpp
Input frequency	98KHz	105KHz and 110KHz
Supply	V_{DD}: 5V $V_{SS:}$ 0V	V_{DD}: 5V $V_{SS:}$ 0V
Bias	For OSC: 2.5V For Mixer:0.5V	For OSC: 1.9V Mixer:1.9V
Opamp used	UA741.301	741 Opamp IC



MOSFET parameters (Used in SPICE simulation's):

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 that aided in our study while simulating and designing the circuit. Thanks are given to Prof. Abhishek Srivastava for providing support and this platform to study, design and model this device The authors also give thanks to the teaching assistants of the course of the Institute for their help and useful comments on the paper.

REFERENCES

[1] Ralph Holzel "A Simple Wide-Band Sine Wave Quadrature Oscillator".

[2] TI_opamp_osc.pdf

[3] Rahsoft.com "Understanding Quadrature Down Conversion"