Quadrature Down Converter

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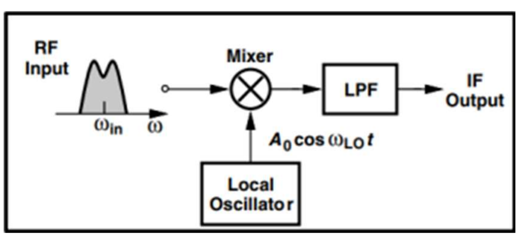
***Abstract*— This paper introduces a Quadrature Down Converter (QDC) that incorporates a quadrature oscillator, two mixers, and two low-pass filters. The Quadratic Down Converter (QDC) is a crucial component in modern communication systems, particularly in the field of wireless communication and signal processing. The primary objective of the QDC is to convert high-frequency signals to lower frequencies, enabling efficient processing and transmission.**

I. Introduction

Frequency-down converters are comprehensive units that facilitate the conversion of high-frequency RF (Radio Frequency) signals into lower-frequency IF (Intermediate Frequency) signals. When confronted with the challenge of channel-selection filtering at elevated carrier frequencies, a specialized device called a "mixer" comes into play.

To shift the center frequency downwards, a sinusoidal wave represented as $A_0\cos(\omega_{LO}t)$ is employed to multiply the incoming signal. This wave is generated by a local oscillator (LO). It is important to note that multiplication in the time domain corresponds to convolution in the frequency domain. Consequently, the impulses located at $\pm\omega_{LO}$ displace the desired channel to $\pm(\omega in \pm \omega_{LO})$.

The components positioned at $\pm(\omega in + \omega_{LO})$ are not relevant to our purpose and are effectively eliminated by means of a low-pass filter (LPF). Subsequently, the signal remains centered at a frequency of $(\omega in - \omega_{LO})$. This entire process is commonly referred to as "down conversion."



$$Acos(\omega_{IF}t) = Acos(\omega in - \omega_{LO}) \qquad (1)$$
$$Acos(\omega_{IF}t) = Acos(\omega_{LO} - \omega in) \qquad (2)$$

By analyzing equations (1) and (2), it becomes evident that regardless of whether ωin is positioned above ω_{LO} or below ωLO, the resulting IF remains the same. This implies that two spectra symmetrically located around ω_{LO} are both down-converted to the identical IF. This symmetrical relationship designates the component at ωim as the image of the desired signal.

Expressed mathematically, the value of ωim can be determined as follows:

$$\omega im = \omega in + 2\omega_{IF} = 2\omega_{LO} - \omega in \qquad (3)$$

Within various standards encompassing a wide range of frequencies, numerous users transmit signals, consequently generating multiple interferers. It is worth noting that if one of these interferers happens to fall precisely at $\omega im = 2\omega LO - 2\omega in$, it has the potential to corrupt the desired signal subsequent to the down-conversion process.

Converting an asymmetrically modulated signal to a zero intermediate frequency (IF) can result in self-corruption unless the baseband signals are separated based on their phases. To address this issue, a possible solution is the utilization of a Quadrature Down Converter.

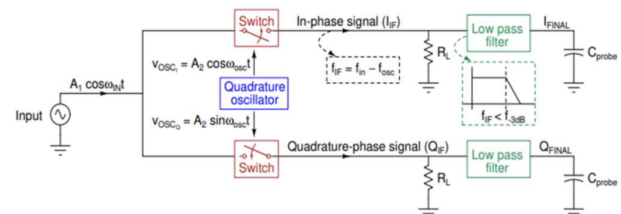


Figure 1

The Quadrature Down Converter generates two versions of the down converter signal, each with a phase difference of 90°. This approach involves the use of two mixers, where one is fed with a cosine wave and the other with a sine wave. Consequently, the RF data is split into two different paths, resulting in the generation of quadrature signals at the baseband level, which are denoted as BB.

The input signal, $vin = A1\cos(\omega_{in}t)$, is mixed with

$v_{OSCI} = A2\cos(\omega_{osc}t)$ and $v_{OSC}Q = A2\sin(\omega_{osc}t)$, leading to the production of in-phase (v_{IFI}) and quadrature-phase (v_{IFQ}) intermediate frequency (IF) signals, respectively.

The in-phase and quadrature-phase signals exhibit a phase difference of 90°. It is important to note that mixing two signals is mathematically equivalent to multiplying them together.

$$v_{IFI} = v_{in} \times v_{OSCI} = A_1A_2/2\,(\cos(\omega_{in}t - \omega_{OSC}t) + \cos(\omega_{in}t + \omega_{OSC}t)) \qquad (4)$$

$$v_{IFQ} = v_{in} \times v_{OSCQ} = A_1A_2/2\,(\sin(\omega_{in}t + \omega_{OSC}t) - SIN(\omega_{in}t - \omega_{OSC}t)) \qquad (5)$$

This produced mixed signal is passed to an LPF (Low Pass Filter) which passes only the IF signal with a low frequency of $\omega_{IF} = (\omega_{in} - \omega_{OSC})$, which is significantly lower than ωin and ωOSC.

II. QUADRATURE OSCILLATOR

An oscillator is a type of frequency generator that can produce a continuous waveform with a consistent frequency and amplitude. Oscillator circuits are designed to generate various periodic waveforms, including square, triangular, sawtooth, and sinusoidal waves. These waveforms serve different purposes in electronic systems.

There are two primary categories of oscillators: relaxation oscillators and sinusoidal oscillators. Relaxation oscillators are capable of generating waveforms such as triangular and sawtooth waves, which are not purely sinusoidal. On the other hand, sinusoidal oscillators specialize in producing sinusoidal waveforms, which are smooth and continuous.

Another type of sinusoidal oscillator is the quadrature oscillator. Quadrature oscillators are designed to generate two sinusoidal signals with the same frequency and amplitude, but with different phase angles. When represented as a rectangular waveform, the quadrature signal exhibits a phase shift of 90 degrees.

By using distinct phasing techniques, quadrature generators provide a means to create multiple sinusoidal signals with a precise phase relationship, offering valuable applications in various fields of electronics and signal processing.

A) Design Considerations:

When considering the design of oscillators, a configuration involving two integrator stages connected in series with an inverter proves to be effective. This setup facilitates a feedback loop where the output of the inverter is fed back to the input of the first stage.

Op-Amp oscillators play a significant role in this design. These oscillators are intentionally engineered to remain in an unstable or oscillatory state, serving as self-sustaining systems. Remarkably, Op-Amp sine wave oscillators operate without the need for an externally applied input signal. Instead, a combination of positive and negative feedback is utilized to drive the Op-Amp into an unstable state, thereby causing the output to continuously oscillate back and forth between the supply rails.

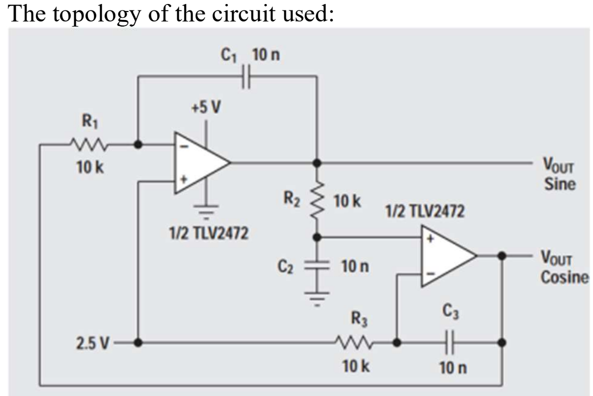
The frequency and amplitude of oscillation are determined by the arrangement of passive and active components surrounding a central Op-Amp. By carefully selecting and configuring these components, precise control over the oscillation characteristics can be achieved, enabling the generation of desired sine wave signals.

B) Working of a Quadrature Oscillator:

Within a quadrature oscillator, a sine wave undergoes a phase shift of 180 degrees. This particular phase shift occurs as a result of the double integration of the original sine wave. Through this process, the sine wave transforms into a negative sine wave with the same frequency and phase.

To induce oscillation, the phase of the second integrator is inverted, effectively reversing its polarity. This inverted phase is then applied as positive feedback within the system. By incorporating this positive feedback, the quadrature oscillator initiates and sustains oscillation, generating the desired waveform.

The topology of the circuit used:



From the following equation, LOOP GAIN is calculated,

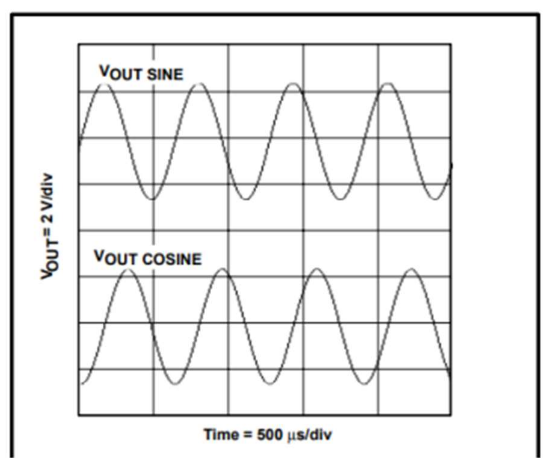
$$A\beta = A\,(1/R1C1s)\,[\,R3C3s{+}1/R3C3s(R2C2s{+}1)] \quad (8)$$

When R1C1 = R2C2 = R3C3, the equation becomes,

$$A\beta = A\,(1/RCs)^2 \quad (9)$$

When $\omega = 1/RC$, the equation reduces to $1\angle{-180}$, so oscillation occurs at $\omega = 2\pi f = 1/RC$.

Adjusting the gain can increase the amplitude. But as a trade-off, we would have reduced bandwidth.



C) <u>Requirements for the Quadrature Oscillator:</u>

Amplitude of cos and sine wave = 1Vpp
Frequency = 100kHz
Phase difference = 90^0

Phase difference is calculated by:

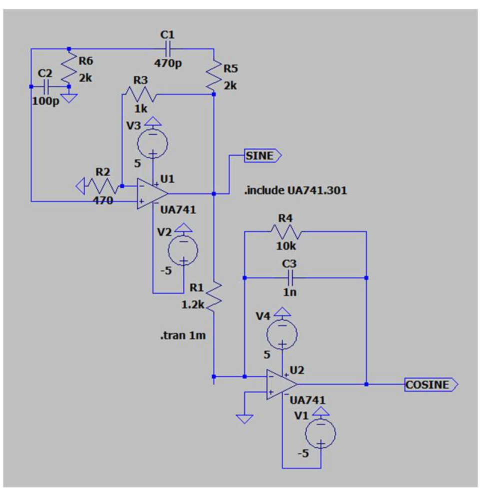
$$\Phi = tan^{-1}(-wRc) - tan^{-1}\left(\frac{1}{wrC}\right) + \frac{\pi}{2} \qquad (11)$$

Frequency = $(1/2\pi)RC$
$\omega = 1/RC$
$\omega = 2\pi f$
Since, amplitude is very low, therefore it is amplified by using amplifier circuits.
Gain = 1+R2/R1 FFT of SINE wave

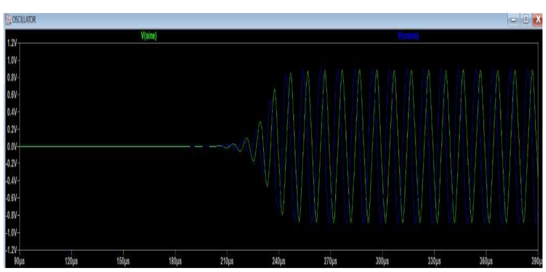
In accordance with the design requirements, the following values have been taken for the quadrature oscillator:

a) R1=1.2K R2=470 R3=1K R4=10K
b) R5=2K R6=2K
c) C1=470p C2=100p C3= 1n
d) Vss (oscillator) = -5V , VDD (oscillator) = 5V
e) Vss (amplifier) = -5V , VDD (amplifier) = 5V
f) OP-AMP UA741

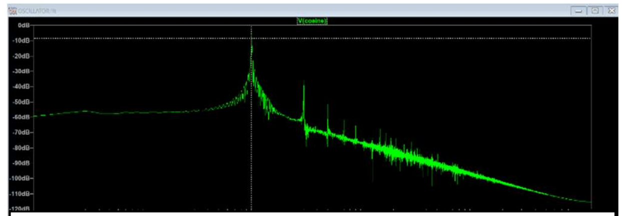
D) <u>Observations on LTspice:</u>



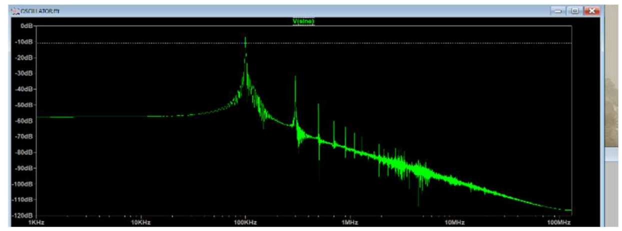
Sine and cos Wave generated by the quadrature oscillator:



WAVES differ by a phase of 90°

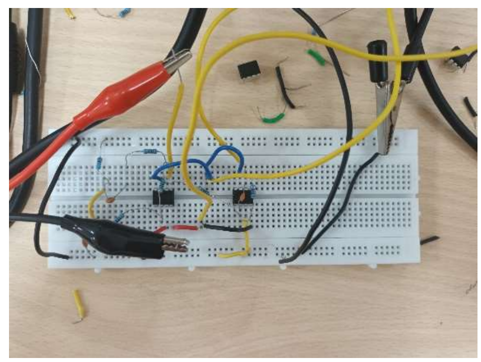


FFT of SINE wave

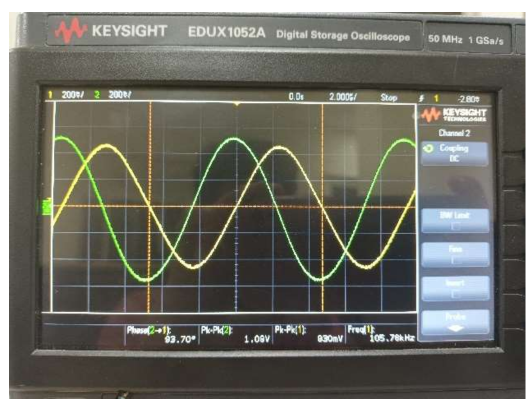


FFT of COSINE wave

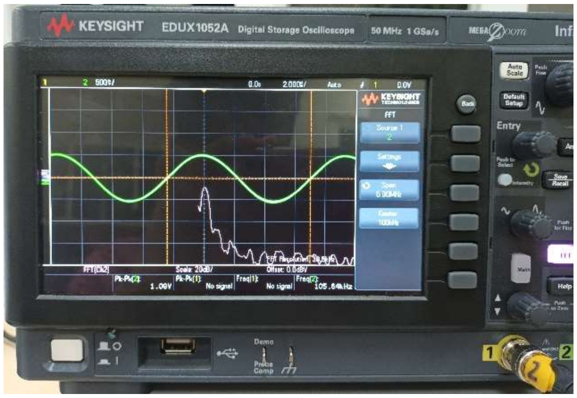
CIRCUIT:



The SIN and COSINE wave produced by our circuit on DSO:



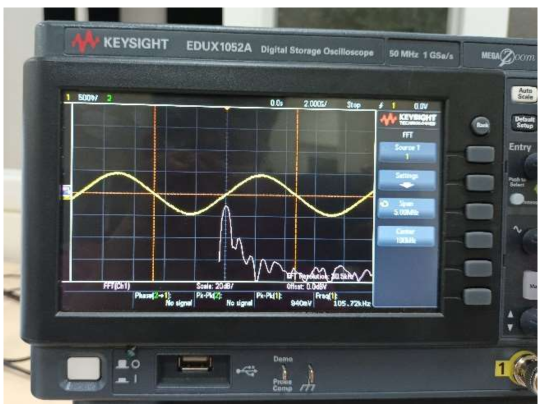
FFT of SINE wavez



Amplitude= 1.02v, frequency= 106KHz

In the FFT plot the first peak is seen at around 100KHz

FFT of COSINE wave:



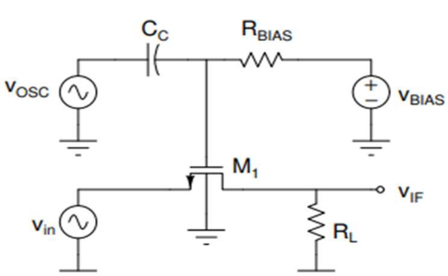
Amplitude=940 mv, frequency= 106KHz

In the FFT plot the first peak is seen at around 100KHz

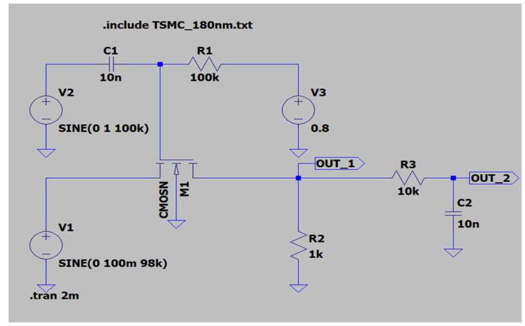
III. SWITCH (MIXER):

We use a simple MOSFET as a switch, The output of switch behaves as if a square wave has been multiplied by the input signal giving rapid on/offs.

The topology used to make the circuit is as follows :-

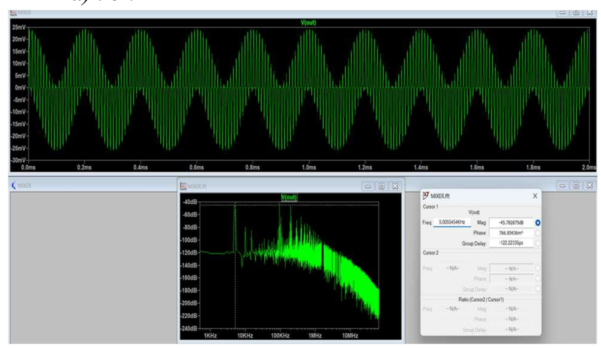


LTSpice schematic:

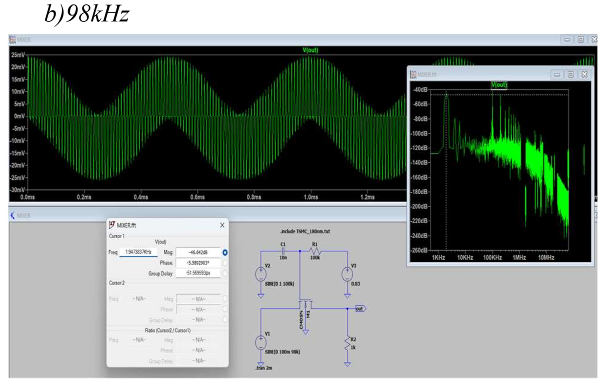


Transient plots of vin, vIF for fIN = {95, 98 kHz, 99 kHz, 101 kHz, 102, 105 kHz}. with corresponding FFT plots for vIF .

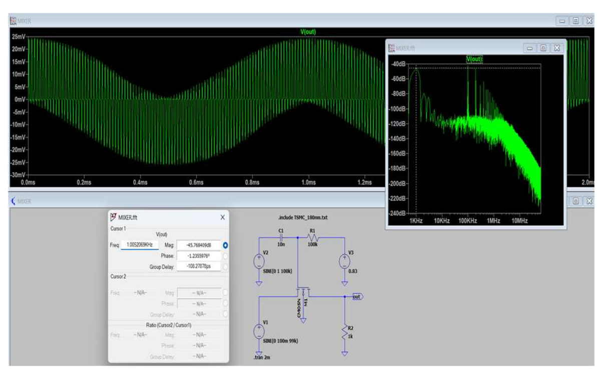
a) 95kHz



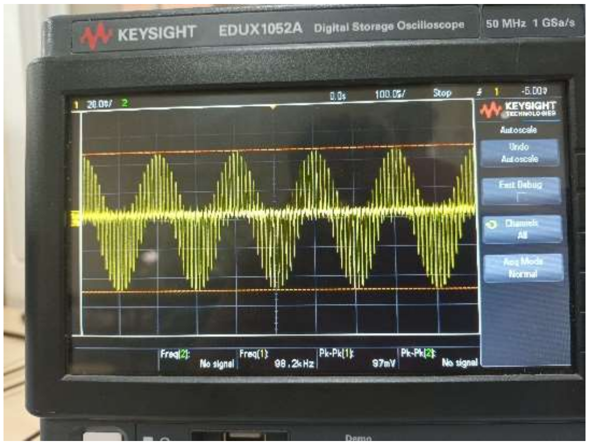
b)98kHz

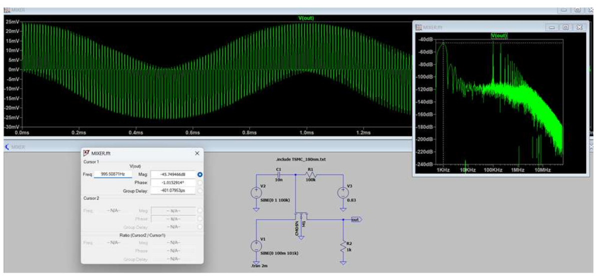


c)99kHz

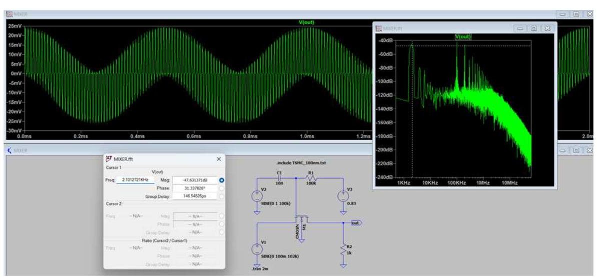


d)101kHz

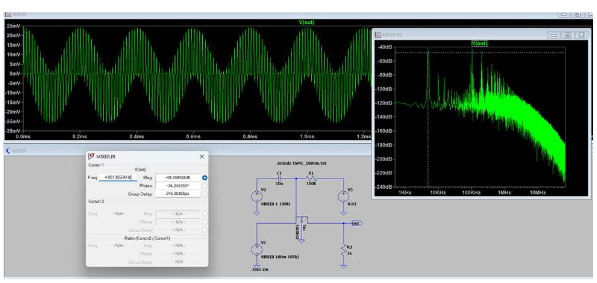




e)102kHz



f)105kHz



IV. LOW PASS FILTER

A Low Pass Filter is an electrical circuit designed to selectively modify or eliminate high-frequency components of a signal, while allowing the desired low-frequency components to pass through. It effectively acts as a gatekeeper, permitting only the signals desired by the circuit's designer.

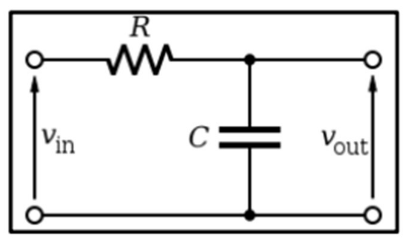
To put it simply, a low pass filter distinguishes between low and high frequencies. It allows signals with frequencies lower than a specific threshold, known as the cut-off frequency, to pass through, while attenuating or blocking signals with frequencies above the cut-off frequency.

In practice, for low-frequency applications up to 100kHz, passive filters are commonly employed. These filters utilize simple RC (Resistor-Capacitor) networks to achieve the desired filtering effect. On the other hand, for higher frequency applications above 100kHz, RLC (Resistor-Inductor-Capacitor) components are often used to construct the filters.

Passive filters are composed of passive elements such as resistors, capacitors, and inductors. They do not incorporate amplifying components like transistors or op-amps, resulting in no signal amplification. Therefore, the output level of passive filters is always lower than the input level.

RC LOW PASS FILTER:

A Low Pass Filter is a circuit that can be designed to reject all unwanted high frequencies. The calculated cut-off for a low pass filter is We take the desired value of frequency and accordingly chose the practical values of R and C such that we are able to realise the circuit practically. The topology used to make the circuit is as follows :-



The reactance of a capacitor varies inversely with frequency, while the value of the resistor remains constant as the frequency changes. The capacitor allows a high-frequency signal and blocks low-frequency signal.

$XC = 1/2\pi fC$

$VC = Vin \times XC/R{+}XC$

$VC = Vin \times 1/2\pi fC/(R{+}\ 1/2\pi fC)$

$VC = Vin \times 1/1{+}2\pi fRC$

$VR = Vin \times R/R{+}XC$

$VR = Vin \times 2\pi fRC/1{+}2\pi fRC$

At low frequencies the capacitive reactance, (XC) of the capacitor is very large as compared to the resistive value of the resistor (R). So, the capacitor acts as an open circuit and the signal will appear across its terminal, which will eventually flow out as output.

A) FREQUENCY RESPONSE:

$$V_{out} = V_{in} \times \frac{X_C}{R+X_C}$$

$$V_{out} = V_{in} \times \frac{1}{1+j2\pi fRC}$$

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{1}{\sqrt{1+(2\pi fRC)^2}}$$

B) CUT-OFF FREQUENCY:

Cut-off frequency, also known as corner frequency, denoted by fc is the selected frequency point where the output signal's power becomes -3db or 70.7% of the input signal.

At this the capacitive reactance and resistor resistance becomes equal.

The LPF allows only the frequency below the cut-off frequency to pass through it.

Cut-off frequency is:

$$20log\left|\frac{V_{out}}{V_{in}}\right| = -3dB$$

$$20\log\left(\frac{1}{\sqrt{1+(2\pi fRC)^2}}\right) = -3$$

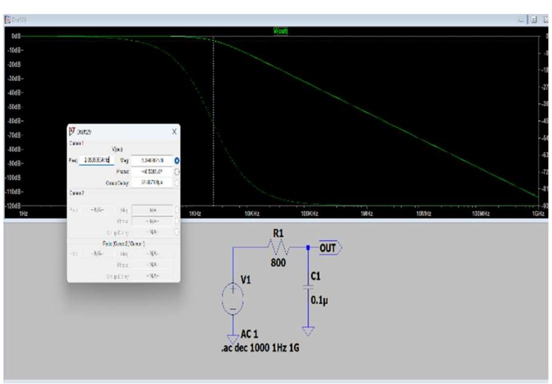
$$f_c = \frac{1}{2\pi RC}$$

Now, to design a low pass filter with -3db cut-off frequency of 2khz, R & C are calculated by:

$$2 \times 10^3 = \frac{1}{2\pi RC}$$

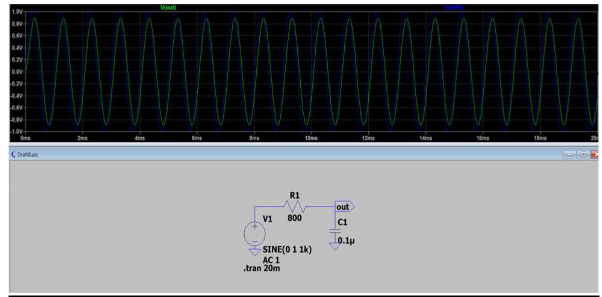
$$RC = 75 \times 10^{-6}$$

We take R= 800 ohm and C=0.1 uF.

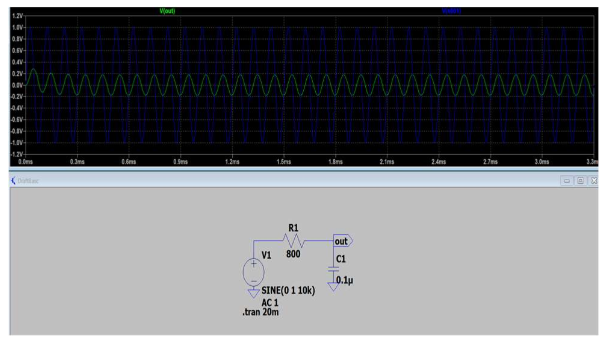


OBSERVATIONS:

Transient Response for f=1kHz:

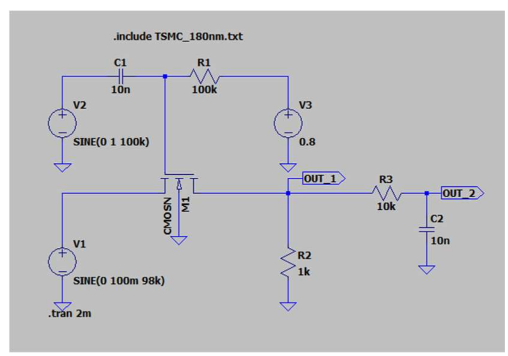


Transient Response for f=10kHz:

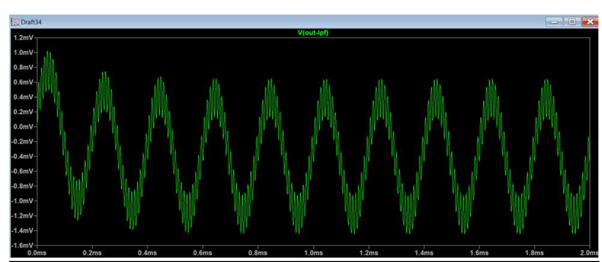


E) MIXER with LPF:

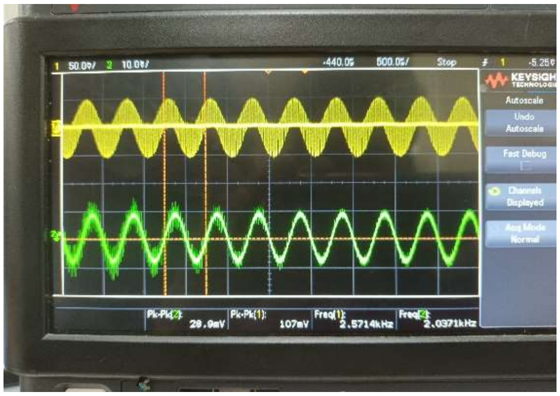
CIRCUIT:



LTspice simulations:



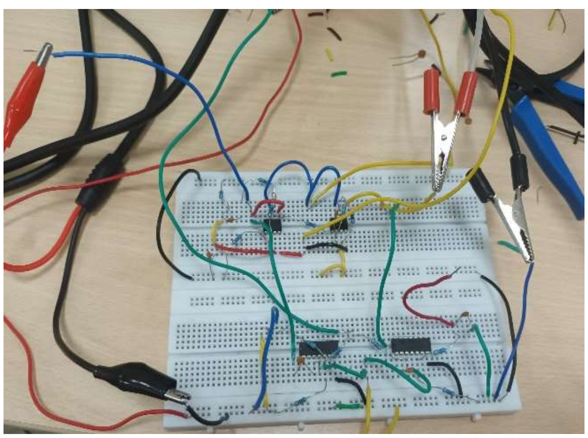
OUTPUT IN DSO:



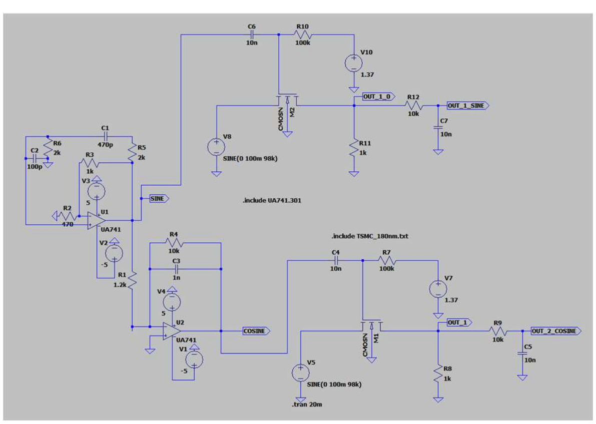
V. COMPLETE CIRCUIT PROTOTYPE DESIGN:

Connecting all the building blocks – Oscillator, Mixer and Filter, the final circuit is implemented. The final circuit will produce two waves IFI and IFQ which are the in-phase and the quadrature-phase components of the IF signal. These signals have a phase difference of 90°.

CIRCUIT:

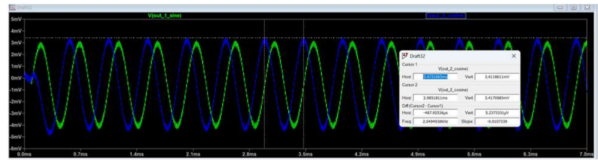


LTspice SIMULATION:

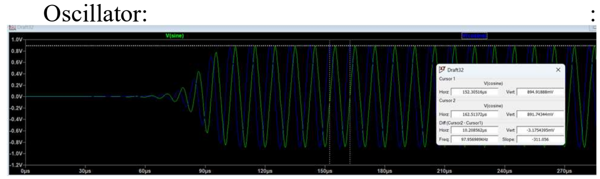


a) We are Running transient simulations and We can clearly see the waveforms of:

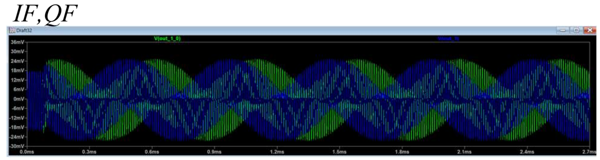
Output we get on LTSpice:



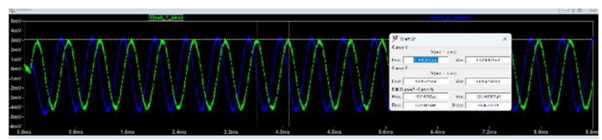
Oscillator: :



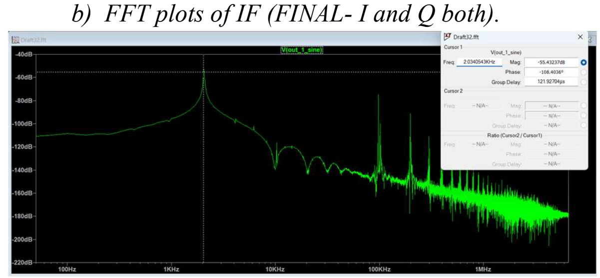
IF,QF



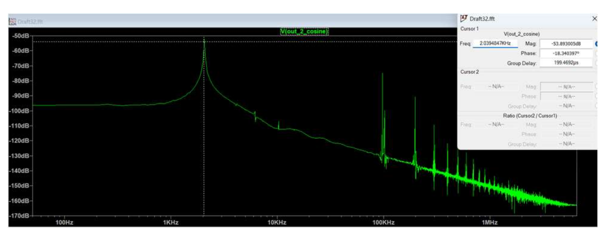
IF,QF (final) :



b) FFT plots of IF (FINAL- I and Q both).



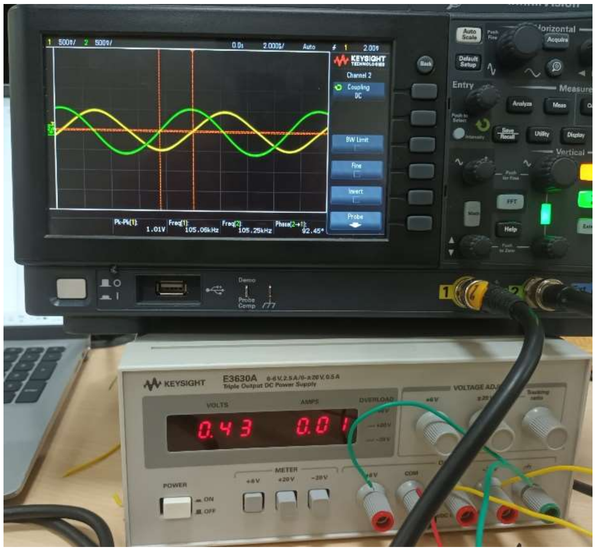
FFT of IF



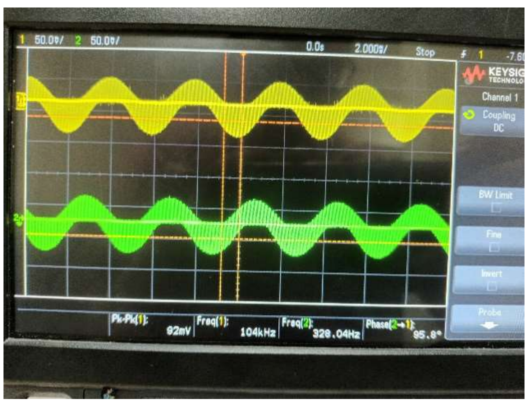
FFT of QF

c) After realizing the complete circuit in lab we are report transient plots of:

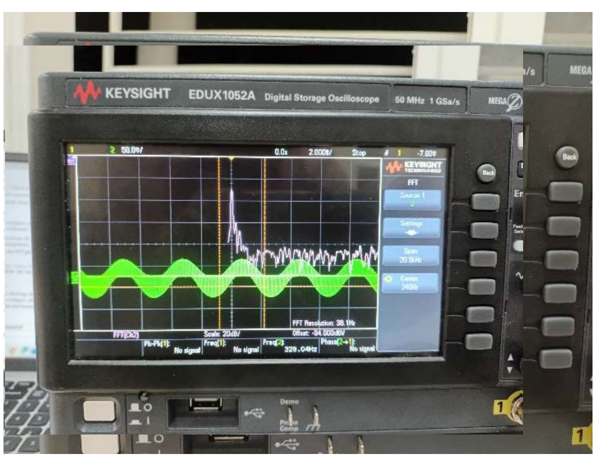
Vosc(I) and Vosc(Q)



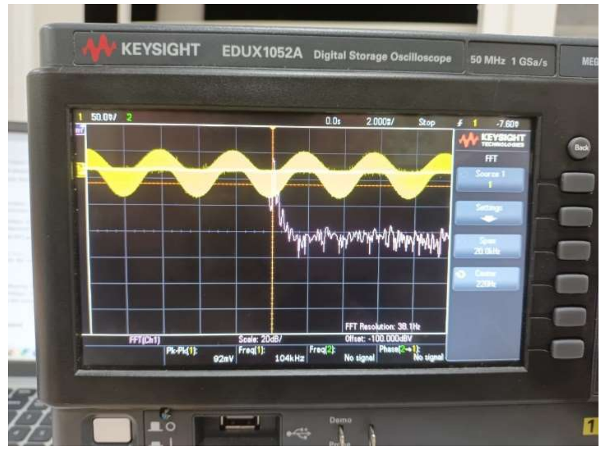
V(IF)I , V(IF) Q



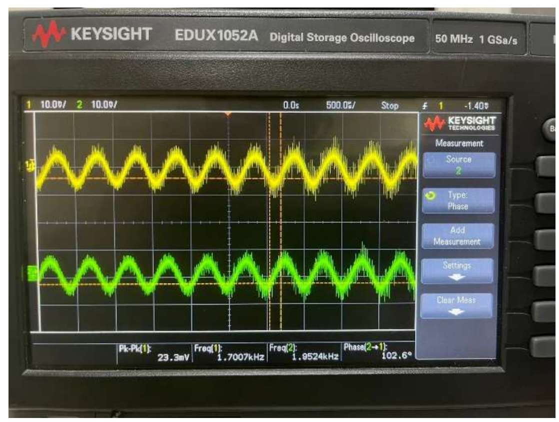
FFT of V(IF)Q

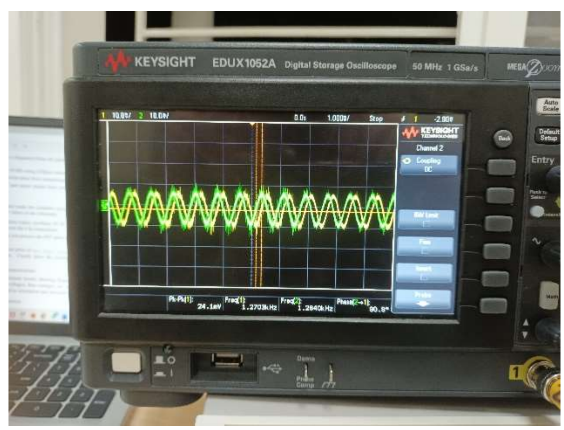


FFT of V(IF)I:



The final output of the complete circuit:

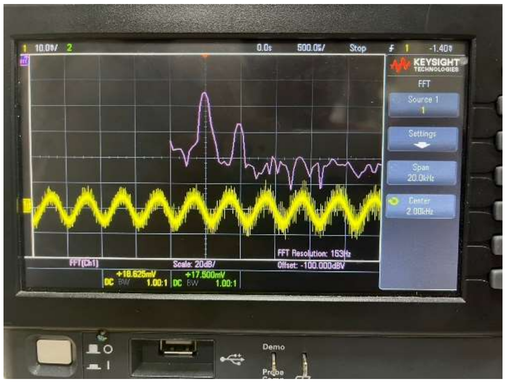




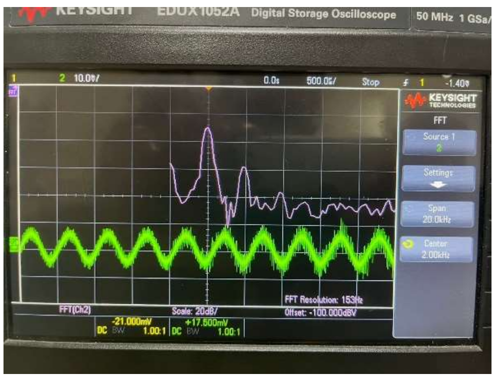
We can see the phase angle=90º and the frequency of both the waves is approx. 2kHz which was expected.

D)

FFT of V(IF) FINAL (I) output



FFT of V(IF) FINAL (Q) output



E) <u>comparison table for simulation and measurement results</u> :

PARAMETERS	SIMULATED	MEASURED
Oscillator Frequency	100KHz	106KHz
Oscillator Amplitude (i-phase)	1V	1.09V
Oscillator Amplitude (q-phase)	1V	0.96V
Input frequency	98KHz	98KHz
IF	2KHz	1.27KHz
SUPPLY	100mV	100mV
V_{bias}	0.5V	0.63V
C_C	10nF	10Nf
R_{BIAS}	100K	100K

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Project Report – ADITYA SINGH, PRAKHAR RAJ

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[7] CLASS NOTES.