Quadrature Down Converter

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***Abstract*—This document aims to explain the fabrication of a simple prototype of Quadrature Down Converter**

***Index Terms*—operational amplifier, filter, MOSFET, oscillator, switch**

I. INTRODUCTION

Quadrature down converters have important widespread applications in low-voltage CMOS technologies and radio communications. QDC is commonly used in modern day wireless receivers (RX) such as Bluetooth, Wi-Fi and WLAN.

QDC helps in improving the quality of communication.
This paper analyzes the design and the fabrication process of the QDC.
The QDC consists of three components: quadrature oscillator, MOSFET based switch(mixer) and RC low pass filter. Mixer is designed using dual gate MOSFET(CD4007be).
Quadrature oscillator is designed using 2 op-amps.
Design and fabrication have been described briefly for each of the three components.

II. QUADRATURE OSCILLATOR

A. Components

Component	Quantity
Op-amp	2
Capacitor-27pF	3
Resistor-22kΩ	3

B. *Working*

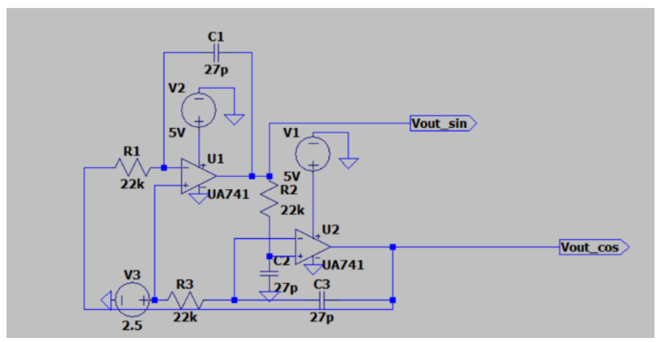
A quadrature oscillator is made using operational amplifiers. The noise present in the circuit is fed back into the amplifier circuit and the oscillating signal is amplified to a certain value which resembles a sine wave.

The op-amp integrator is used to create a 90° phase shift. The 2 waves resemble sine and cosine waves which are given to the mixer.

C. *Design*

Oscillation occurs in the given circuit because the magnitude of loop gain > 1.
The signal at the first op-amp is fed into the other op-amp to generate 90-degree phase shift.
A very high amplitude of the output signal leads to distortion on the waveform itself and thus, it is necessary to maintain the amplitude of output signal regulated using regulator circuits. But, if the loop gain is very small, this may lead to slowing down resulting in undesirable waveform at the output. The circuit oscillates correctly only at a certain frequency which is:

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



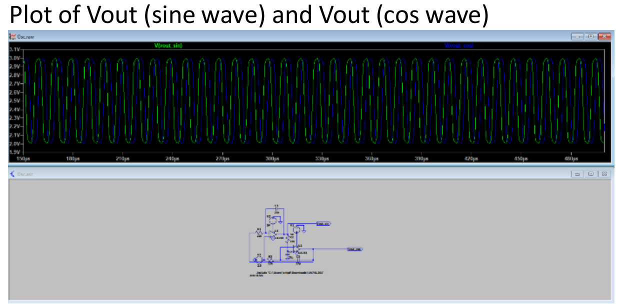
The necessary condition for proper working if this circuit is:

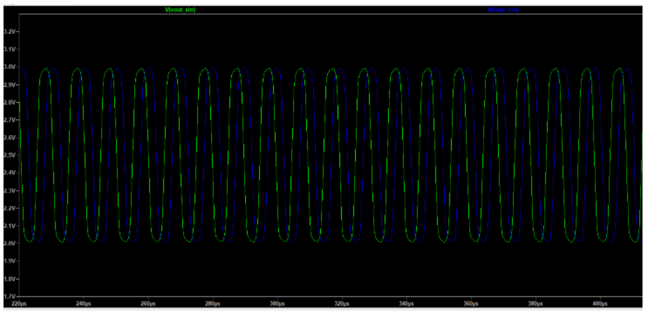
$$R_1C_1 = R_2C_2 = R_3C_3 = RC$$

Chosen values: R=22kΩ
C=27pF

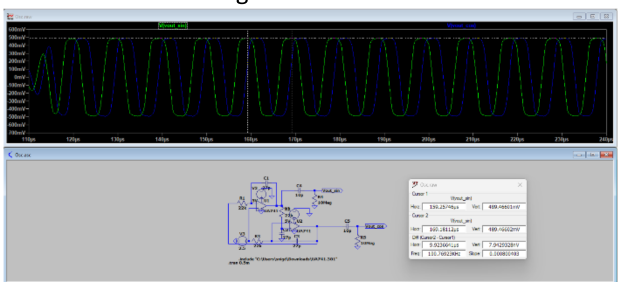
D. Simulation

Plot of Vout (sine wave) and Vout (cos wave)



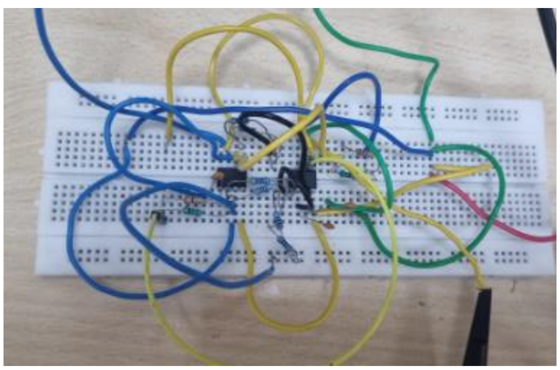


Phase shift of 90-degrees is observed



Frequency of each of the waves is 100kHz

E. Circuit



F. Observations

III. SWITCH(MIXER)

A. Components

Component	Quantity
MOSFET	1
Capacitor-10µF	1
Resistor-1MΩ	1
Resistor 1kΩ	1

B. Working

The purpose of a mixer is to multiply two signals. Here, MOSFET is used to act as a switch, the oscillator signal is applied to the gate of the device. Input is applied at the source and the intermediate frequency output Is taken at the drain. The in-phase and quadrature shifted waveforms are given as inputs to 2 separate MOSFET based mixers.

At the gate of the MOSFET, we maintain $V_{threshold}$ by V_{bias} and we send Vosc after passing it through a coupling capacitor. Coupling capacitor removes any DC bias if present in V_{osc}. When V_{osc} reaches the junction at the gate, it combines with V_{bias} such that the positive cycles of the oscillation signal increase the gate voltage above the threshold voltage which allows the signal to pass through (MOSFET working as a closed switch). Now, during the negative cycles of the oscillating signal the Vgate is reduced below the threshold voltage, and signal is restricted from passing through (MOSFET acting as an open switch). Here a resistor called Rbias is used, and its value is set to extremely high (in order of mega ohms). Its significance is that it restricts the oscillating signal from entering the right branch of the circuit, so that the Vosc completely reaches the gate of the MOSFET. At the source of the MOSFET we apply Vin directly so that it is allowed to mix with the oscillating signal. The drain of the transistor is where we obtain the output (multiplied signal) which is measured across the load resistance RL. If in-phase and quadrature components of the quadrature oscillator is given by:

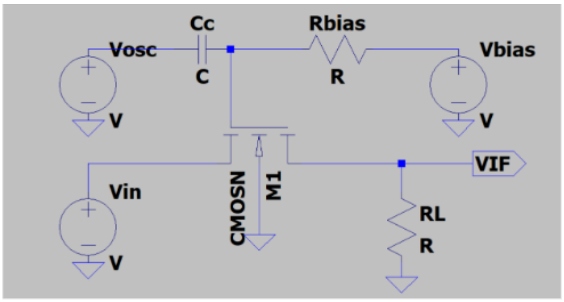
$$V_{OSC_1} = A_2 \cos(\omega_{OSC} t) \; V_{OSC_Q} = A_2 \sin(\omega_{OSC} t)$$

Then, mixing of 2 signals is equivalent to their multiplication:

$$v_{\text{IFI}} = \text{vin} \times \text{v}_{\text{OSCI}} = \frac{\text{A1A2}}{2} \times (\cos(\omega_{\text{int}} - \omega_{\text{OSC}} t) + \cos(\omega_{\text{int}} + \omega_{\text{OSC}} t))$$

$$v_{\text{IFQ}} = \text{vin} \times \text{v}_{\text{OSCQ}} = \frac{\text{A1A2}}{2} \times (\sin(\omega_{\text{int}} + \omega_{\text{OSC}} t) - \sin(\omega_{\text{int}} - \omega_{\text{OSC}} t))$$

C. Design



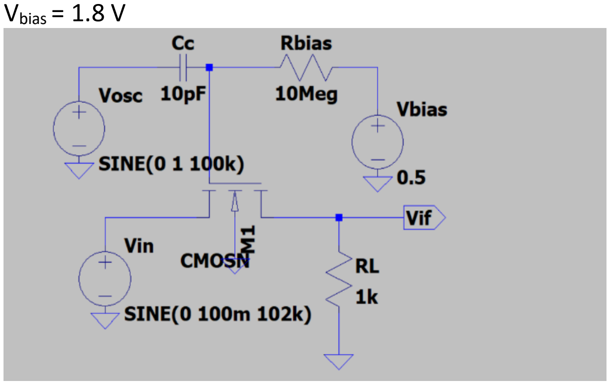
Here we will be using a very high value resistor:

R_{bias} = 1Meg Ω

C_C = 10pF

R_L = 1k

V_{bias} = 1.8 V



All the simulations use

The following MOSFET parameters

L=0.18u

W=1.8u

Drain Area (AD)= 0.81p

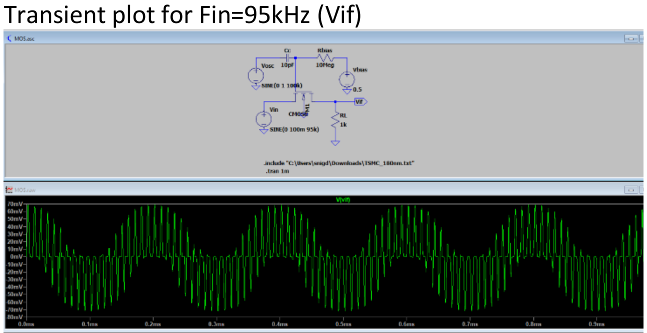
Source Area (AS)=0.81p

Drain Perimeter (PD)=4.5u

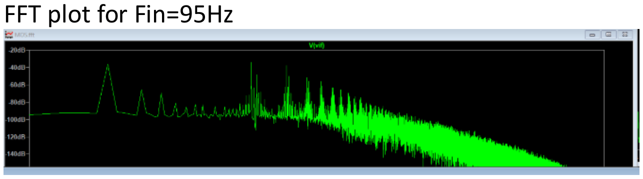
Source Perimeter (PS)=4.5u

D. *Simulation*

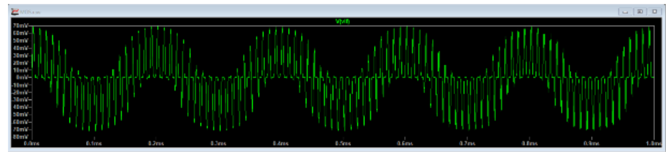
Transient plot for Fin=95kHz (Vif)



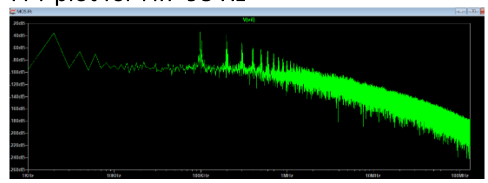
FFT plot for Fin=95Hz



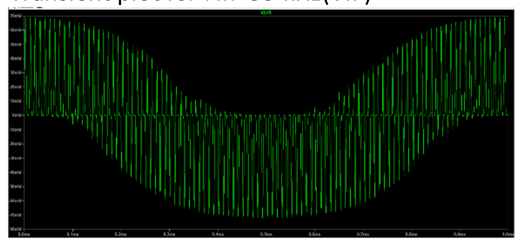
Transient plot for Fin=98 kHz (VIF)



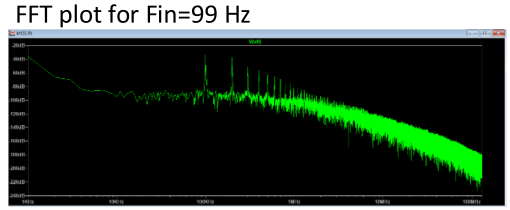
FFT plot for Fin=98 Hz



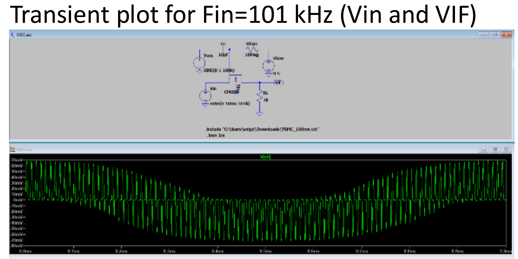
Transient plot for Fin=99 kHz(VIF)



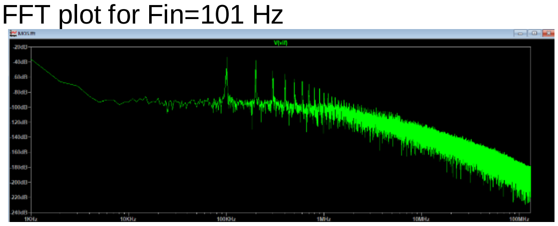
FFT plot for Fin=99 Hz



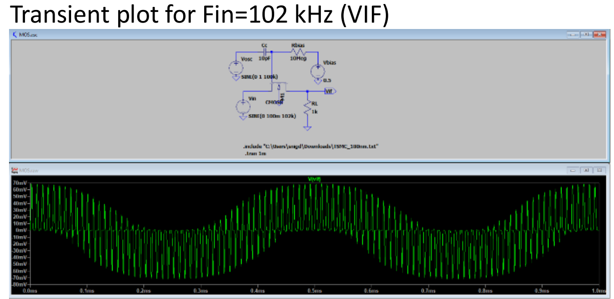
Transient plot for Fin=101 kHz (Vin and VIF)



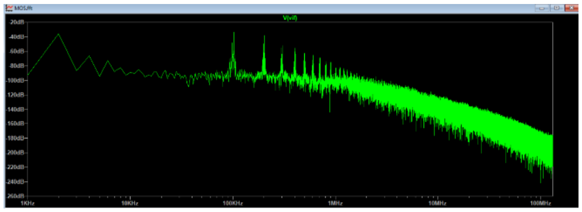
FFT plot for Fin=101 Hz



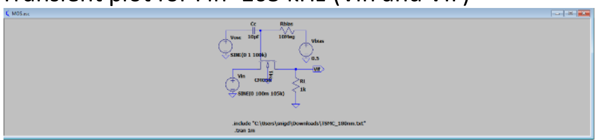
Transient plot for Fin=102 kHz (VIF)

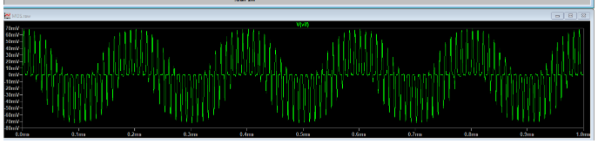


FFT plot for Fin=102 Hz

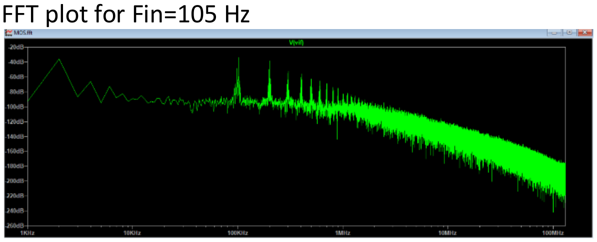


Transient plot for Fin=105 kHz (Vin and VIF)

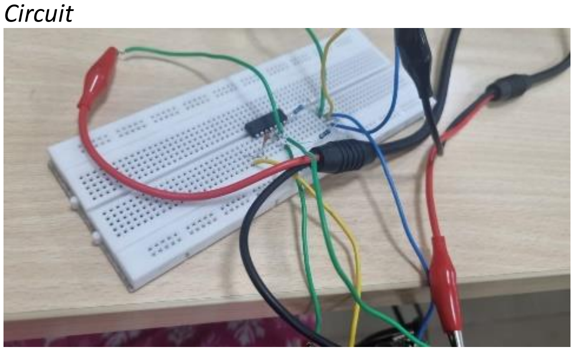




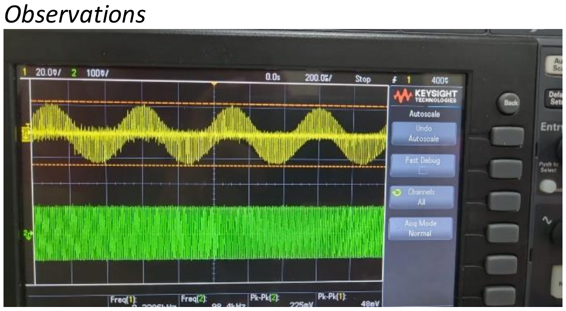
FFT plot for Fin=105 Hz

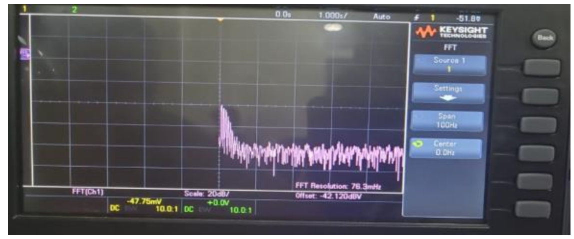


E. Circuit



F. Observations





IV. LOW-PASS FILTER

A. Components

Component	Number required
820 Ω resistor	2
0.1 µ capacitor	2

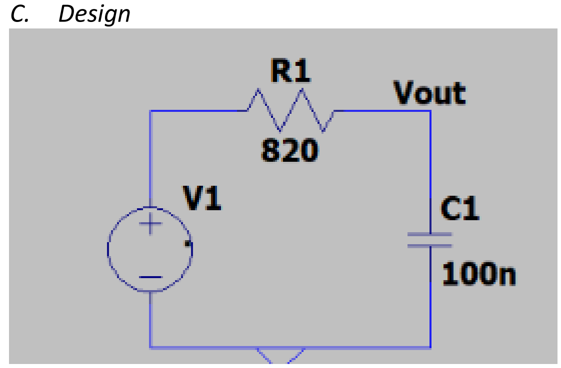
B. Working

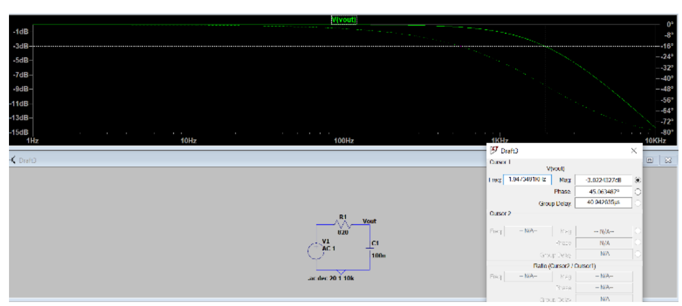
It is a device which only allows low frequency signals to pass through it. It restricts the passage of high frequency signals (high frequency signals get attenuated). The filter is made out of a capacitor and a resistor connected in series and the output is taken from the capacitor. The capacitor is a reactive device which has a capacitance of

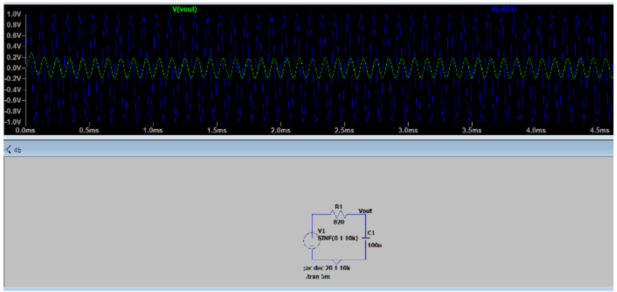
$$X_c = \frac{1}{2\pi RC}$$

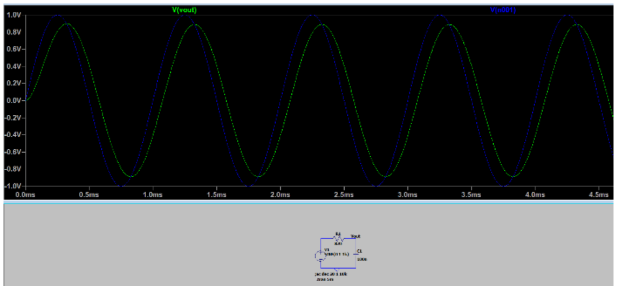
The capacitor offers differing resistance to signals of different frequencies entering through it. It offers very high resistance to low-frequency signals. And it offers low resistance to high-frequency signals.

C. Design









$$X_C = \frac{1}{j\omega C} = \frac{1}{SC}$$

S=jω

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

$$V_{out} = V_{in}\frac{\frac{1}{SC}}{\frac{1}{SC} + R}$$

$$V_{out} = V_{in} * \frac{1}{1 + SRC}$$

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

For -3dB frequency, we will perform the following steps:

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

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

$$\left|\frac{V_{out}}{V_{in}}\right| = 10^{\frac{-3}{20}}$$

$$\left|\frac{V_{out}}{V_{in}}\right| = 0.707 = \frac{1}{\sqrt{2}}$$

$$\frac{1}{\sqrt{1+(RC\omega)^2}} = \frac{1}{\sqrt{2}}$$

$$\sqrt{1+(RC\omega)^2} = \sqrt{2}$$

$$1 + (RC\omega)^2 = 2$$

$$(RC\omega)^2 = 1$$

RCω = 1

Given, frequency = 2kHz

$$\omega = 2 * \pi * 2k = \frac{1}{RC}$$

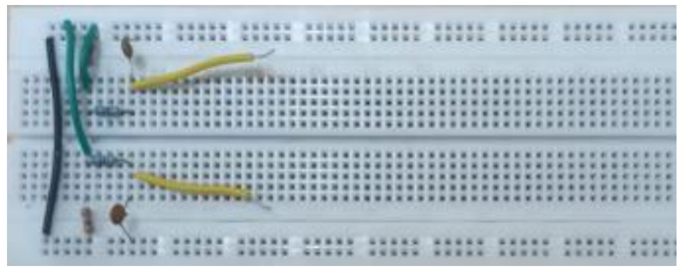
RC = 79.62$* 10^{-6}\ s$

In the experiment, we chose:

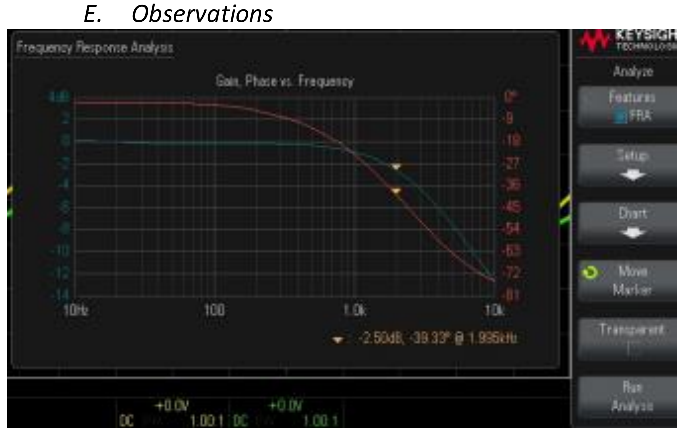
R= 820Ω

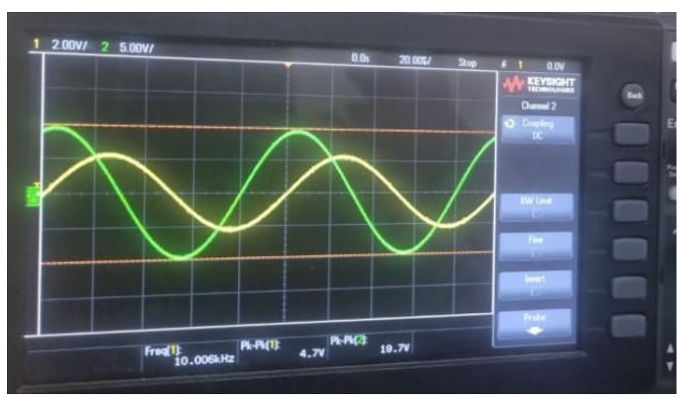
C=100nF

D. *Circuit*



E. *Observations*

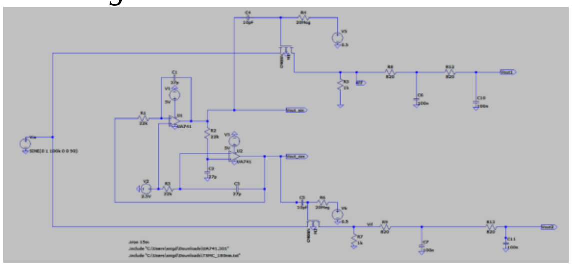




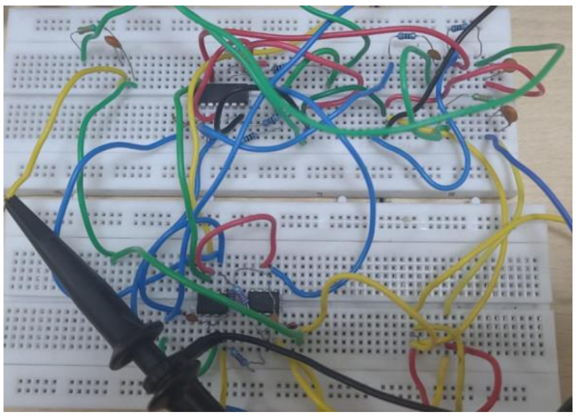
V. COMPLETE CIRCUIT PROTOTYPE

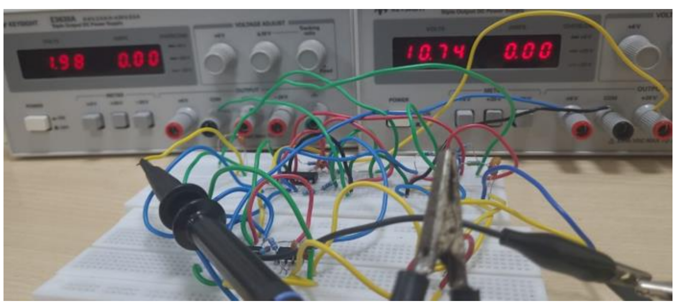
After connecting all the building blocks, Oscillator, mixer and the LPF, the final complete circuit is achieved. The final circuit will produce two waves IFI and IFQ which are the in-phase and the quadrature-phase components of the IF signal. These signals have a phase difference of 90°.

A. *Design*

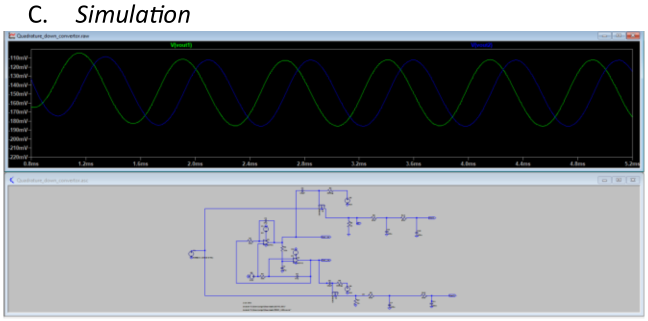


B. *Circuit*

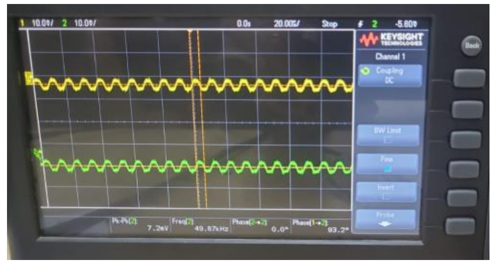




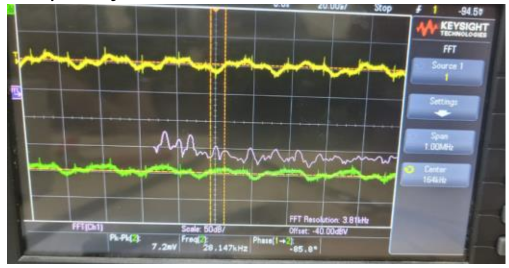
C. *Simulation*



D. *Observation*



FFT plot of the cos wave:



E. *Comparison table*

Parameter	*Simulated*	*Measured*
Oscillator frequency	*100KHz*	*107KHz*
Oscillator Amplitude(I-phase)	*1V*	1.3V
Oscillator Amplitude(Q-phase)	*1V*	*1.35V*
Input frequency	*100k*	*98k*
IF	*2K*	*2.32K*
Supply	*5V*	*10V*
Vbias	*0.5V*	*1.8V*
Cc	*10pF*	*10pF*

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CONTRIBUTION

Gandlur Valli-Project report, LTspice and analyzing the circuit.

Snigdha stp- Project report, Circuit design, LTspice.

REFERENCES

[1] Lecture notes, tutorials and labs conducted in the course Analog Electronic Circuits

[2] Sedra, A. S., & Smith, K. J. (2007). Microelectronic Circuits Revised Edition. In Oxford University Press eBooks. https://dl.acm.org/citation.cfm?id=1537213

[3] Razavi, B. (2011). RF Microelectronics (2nd Edition) (Prentice Hall Communications Engineering and Emerging Technologies Series). In Prentice Hall Press eBooks. https://dl.acm.org/citation.cfm?id=2132691