QUADRATURE DOWN CONVERTER
EC2.103 ANALOG ELECTRONIC CIRCUITS

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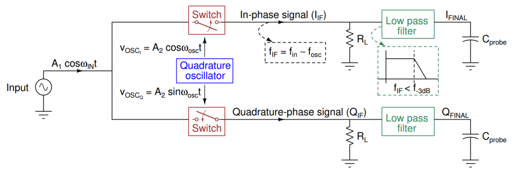
Abstract—This paper presents a comprehensive summary of a course project on quadrature down converter. The project delves into both LTspice simulations and real circuit implementations, providing a detailed analysis of each stage. The paper offers insights into the design, performance, and challenges encountered during the development process.

1.INTRODUCTION

A QDC is used to downconvert a high-frequency signal to a lower intermediate frequency signal which is used for further processing.

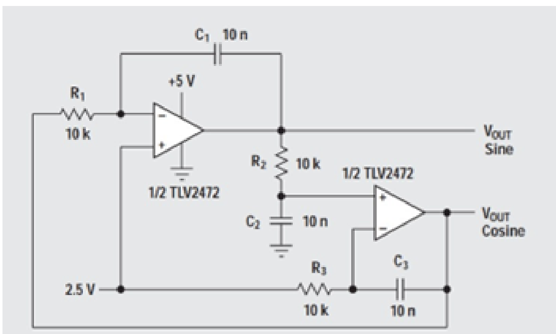
Parts of a QDC



1.Quadratic Oscillator
2.Switcher(Mixer)
3.LPF

2.QUADRATURE OSCILLATOR DESIGN

1.Aim: To generate sine and cosine wave (Amplitude 1 V_{PP} and frequency of 100kHz.
2.The initial idea of a quadrature oscillator is taken from the reference pdf.



3.Working
The three RC sections are configured such that each contributes to 90 ° phase shift.
The sine output is fed into an integrator inorder to generate a cosine output.
The outputs are labeled as sine and cosine because there is a 90 ° phase shift.

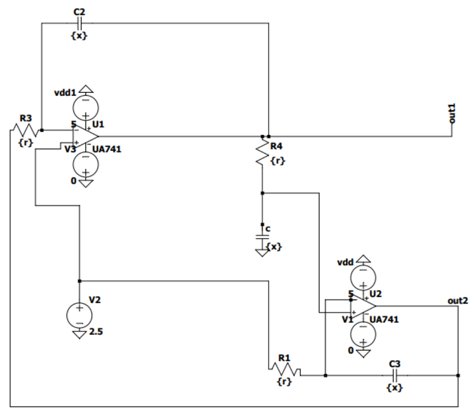
4.Calculations

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

$100kHz = \frac{1}{2\Pi RC}$

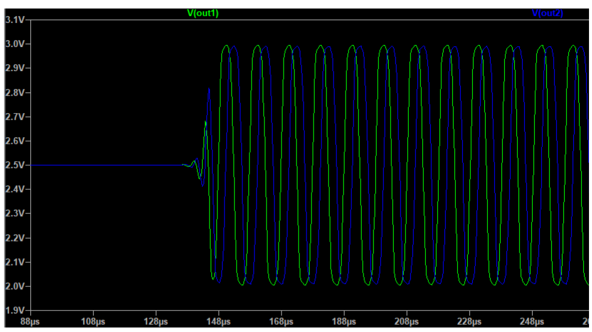
Fixing C=1 nF , we get R as 1591Ω.

5.LTspice

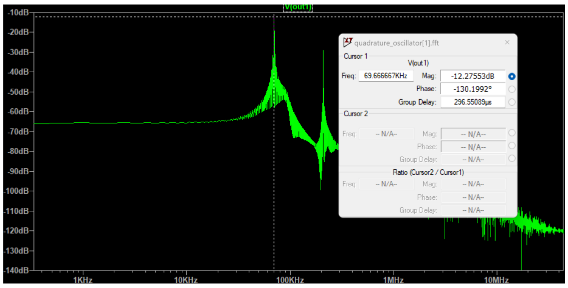


Observations
We obtain a sine and cosine wave of required Amplitude but of frequency less than 100kHz. Inorder to get 100kHz frequency, we decrease the resistance value and check the frequency again and again.

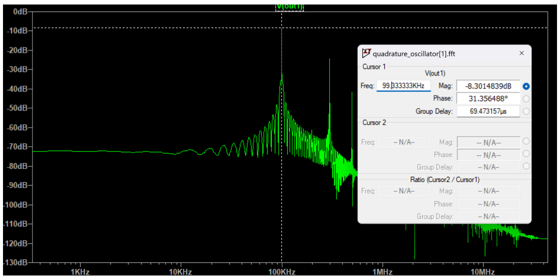
R	Freq
1591Ω	70kHz
1000Ω	81kHz
600Ω	90kHz
300Ω	100kHz



2.1 Output Sine and Cosine



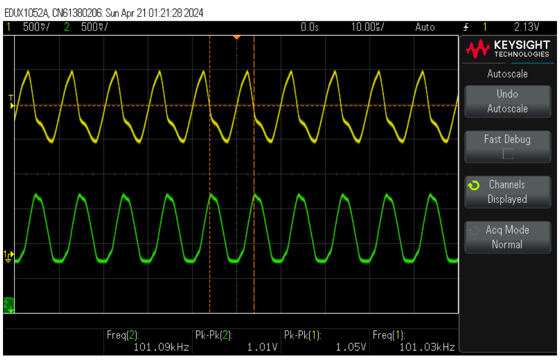
2.2 FFT at 1591Ω : Freq is 70 kHz



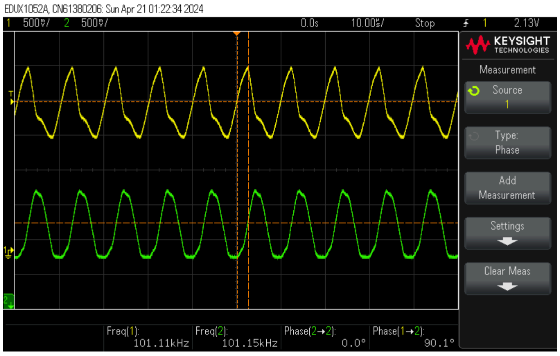
2.3 FFT at 300Ω : Freq is 100 kHz

6.<u>Lab simulations</u>

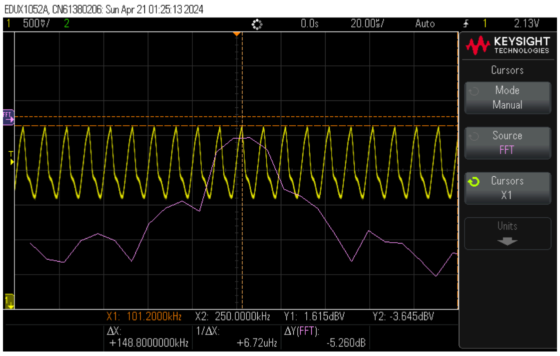
Value	Real	LTspice
$Freq_1$	101.11kHz	100kHz
$Freq_2$	101.15kHz	100kHz
Amp_1	1.05V	1V
Phase diff	90.1°	90°
Amp_2	1.01V	1V
V_{DD}	7.2V	5V
V_{IN}	2.1V	2.5V



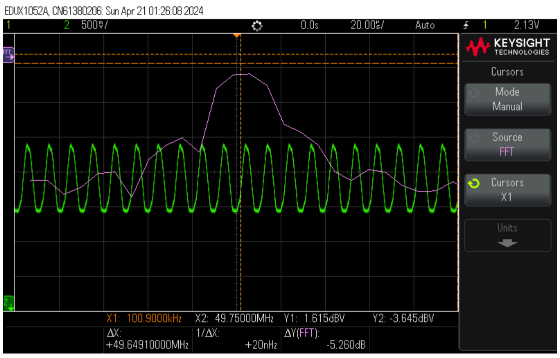
2.4.a Frequencies and Amplitude



2.4.b Phase difference

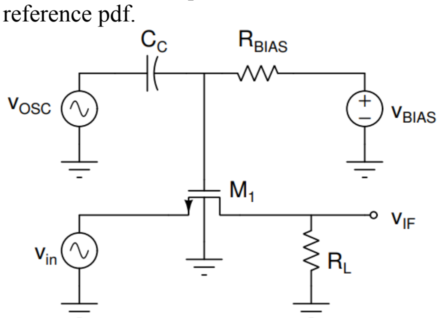


2.4.c FFT Sine



2.4.d FFT Cosine**3.MIXER**

1.<u>Aim</u>:To mix 2 signals V_{IN} and V_{OSC} to achieve a multiplied Signal with frequency less than both the input signals.
2.The initial idea of a quadrature oscillator is taken from the reference pdf.



3.<u>Working</u>
The oscillator frequency (V_{OSC}) is equal to the carrier frequency, and we set V_{BIAS} value nearly equal to the

threshold frequency of the MOSFET.
When we look at the Gate side of the MOSFET from V_{IN} we see that C_c and R_{BIAS} as a High Pass Filter (HPF),and only Allows AC signal to pass blocking any DC signal. When we look at the Gate side of the MOSFET from V_{BIAS} side it acts as a Low Pass Filter (LPF),allowing only DC signal.

The Final Signal that enters the Gate side of the MOSFET is an AC signal with DC offset V_{BIAS}. When the $V_{OSC} > 0$ the MOSFET operates in linear mode,where signal multiplication occur in a mixer. When the oscillator signal is $V_{OSC} < 0$, MOSFET operates in cutoff mode,the MOSFET is essentially turned off, and very little current flows between its source and drain terminals.In short,we get output when $V_{OSC}>0$ and no output when $V_{OSC}<0$. This action represents the multiplicative action of two signals.

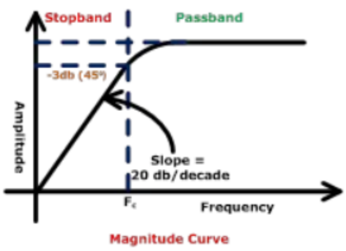
We can imagine the rapid switching of MOSFET similar to generating a square wave.The Fourier series of a square wave includes odd harmonics such as 1ω, 3ω, 5ω, and so on, where ω represents the fundamental frequency of the square wave.When the square wave (with its odd harmonics) is multiplied with an input signal in a mixer, the mixer's nonlinear operation causes frequency mixing.Multiplication in the time domain corresponds to convolution in the frequency domain, leading to the generation of sum and difference frequencies.When the square wave, along with its odd harmonic frequencies, is multiplied by the input signal, we observe peaks of high amplitude at various frequencies. These frequencies include the odd harmonic frequencies added and subtracted to the input frequency (f_{IN}) Consequently, the output of the mixer exhibits peaks at different frequencies, with **prominent peaks occurring at f_{IN}, $f_{OSC} + f_{IN}$, $f_{OSC} - f_{IN}$, and $2f_{OSC}$,these frequencies can be clearly observed in DSO FFT.**

4.<u>Calculations</u>

$f_{osc} > \frac{1}{2\Pi RC}$

$100kHz > \frac{1}{2\Pi RC}$

Fixing C=1 nF , we also take a random R as 10MΩ which satisfies our required equation of the Filter.



Bode Plot of a HPF

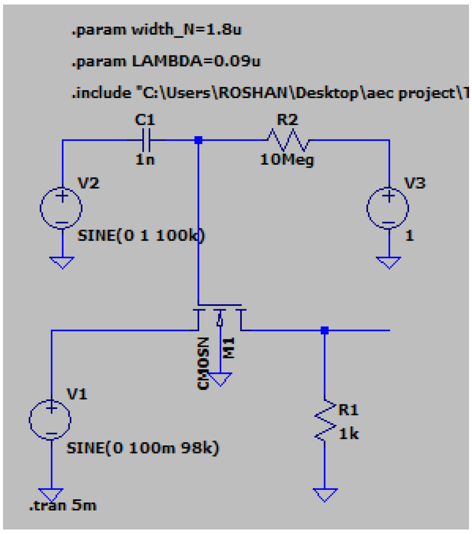
Amplitude of the mixed signals:

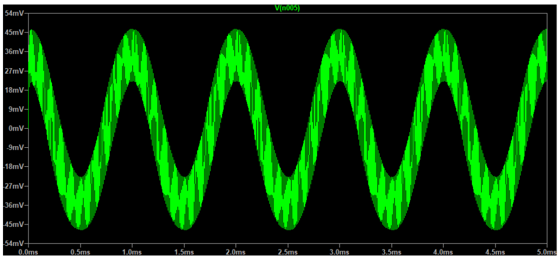
$$v_{IF_I} = v_{in} \times v_{OSC_I} = \frac{A_1 A_2}{2}\left(cos(\omega_{in}t - \omega_{OSC}t) + cos(\omega_{in}t + \omega_{OSC}t)\right)$$

$$v_{IF_Q} = v_{in} \times v_{OSC_Q} = \frac{A_1 A_2}{2}\left(sin(\omega_{in}t + \omega_{OSC}t) - sin(\omega_{in}t - \omega_{OSC}t)\right)$$

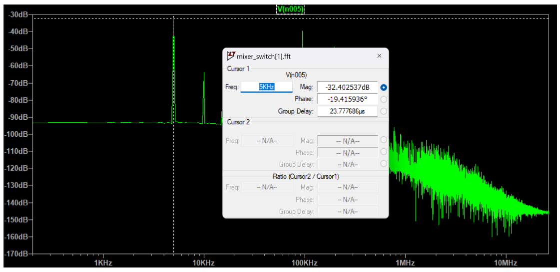
5.<u>LTspice and Lab simulations</u>

R_{BIAS} and C_c are the same in LTspice and Lab.

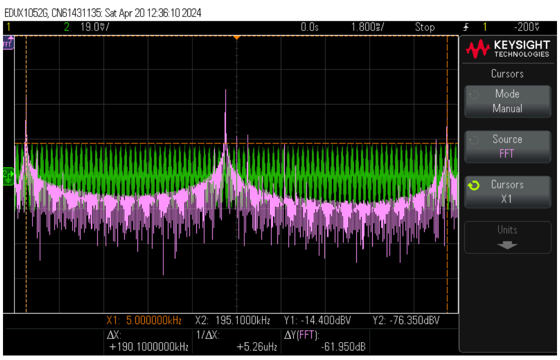




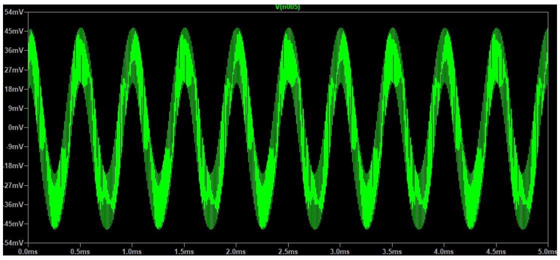
3.1.a Output at f_{IN}=95kHz



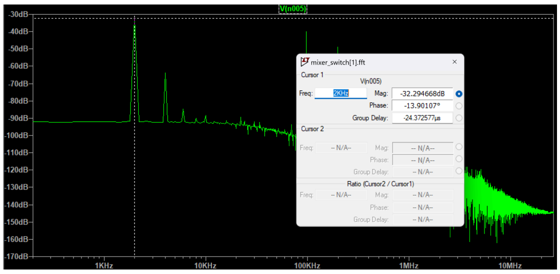
3.1.b FFT at f_{IN}=95kHz,peaks are observed at 5kHz,195kHz



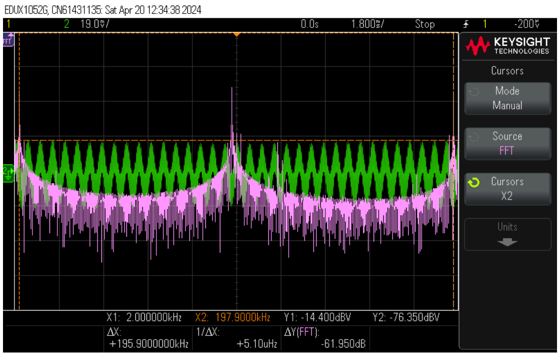
3.1.c Peaks are observed at 5.1kHz, 195.1kHz



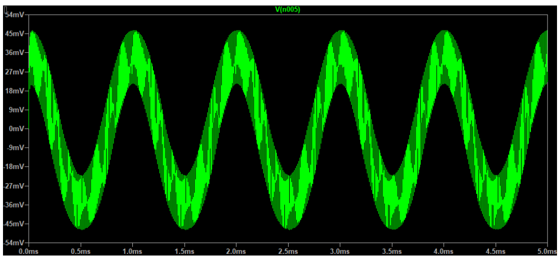
3.2.a Output at f_{IN}=98kHz



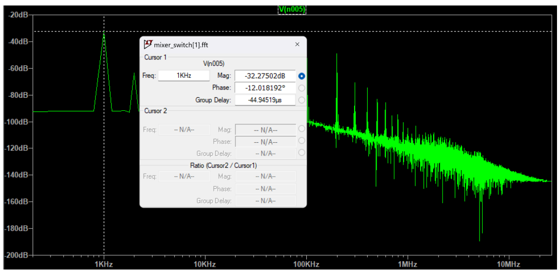
3.2.b FFT at f_{IN}=98kHz,peaks are observed at 2kHz,198kHz



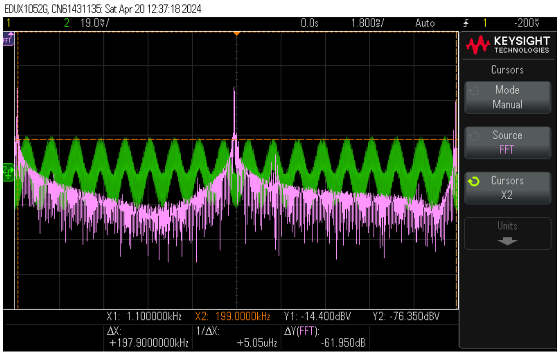
3.2.c Peaks are observed at 2kHz, 197.9.1kHz



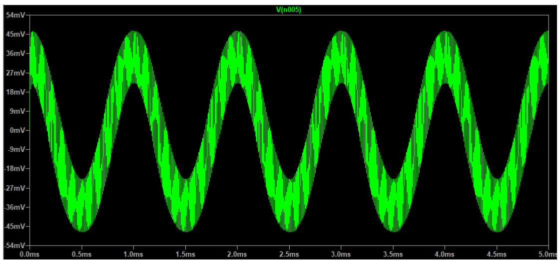
3.3.a Output at f_{IN}=99kHz



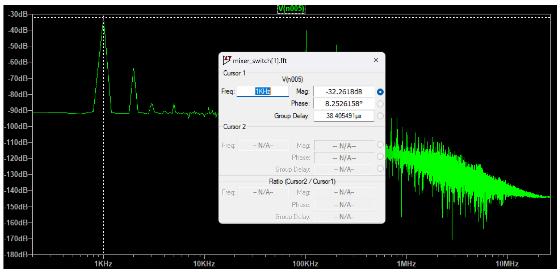
3.3.b FFT at f_{IN}=99kHz,peaks are observed at 1kHz,199kHz



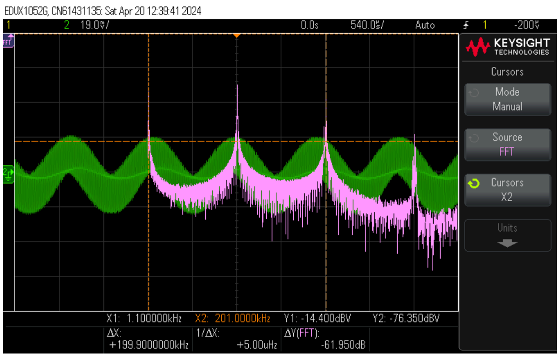
3.3.c Peaks are observed at 1.1kHz, 199kHz



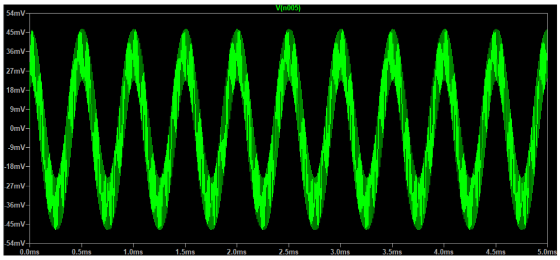
3.4.a Output at f_{IN}=101kHz



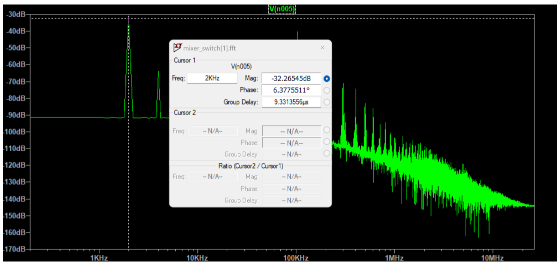
3.4.b FFT at f_{IN}=101kHz,peaks are observed at 1kHz,201kHz



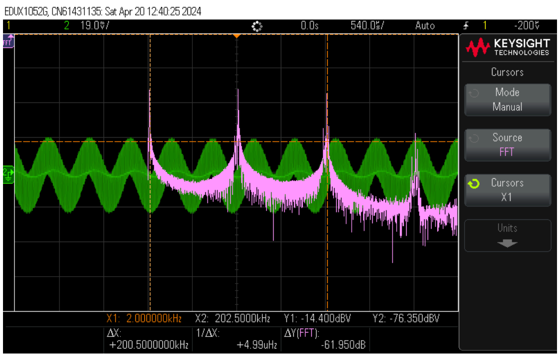
3.4.c Peaks are observed at 1.1kHz,201.1kHz



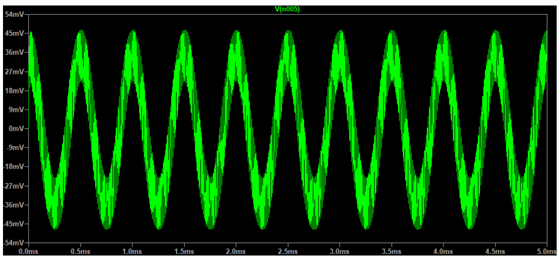
3.5.a Output at f_{IN}=102kHz



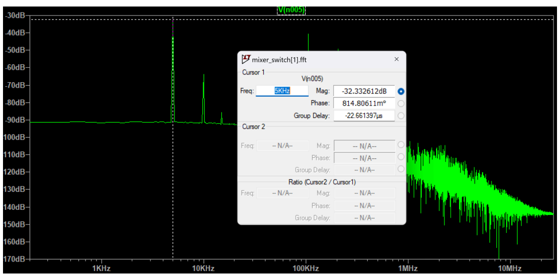
3.5.b FFT at f_{IN}=102kHz,peaks are observed at 2kHz,202kHz



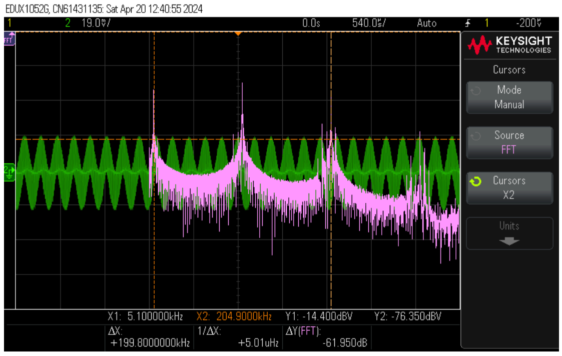
3.5.c Peaks are observed at 2kHz, 202.5kHz



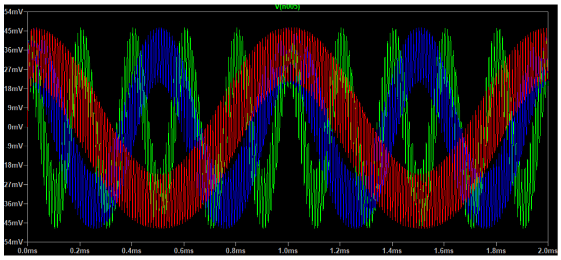
3.6.a Output at f_{IN}=105kHz



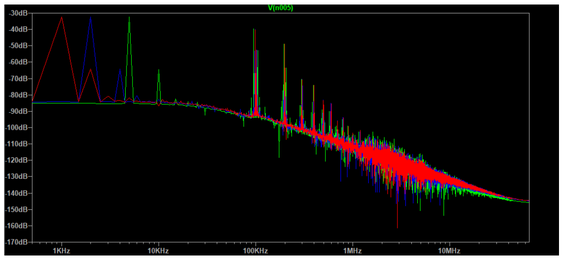
3.6.b FFT at f_{IN}=105kHz,peaks are observed at 5kHz,205kHz



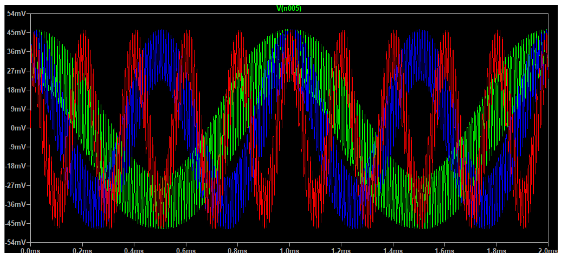
3.6.c Peaks are observed at 5.1kHz, 205.1kHz



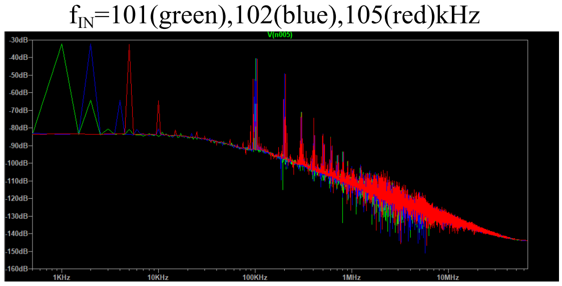
3.7.a Output at f_{IN}=95(green),98(blue),99(red)kHz



3.7.b FFT at f_{IN}=95(green),98(blue),99(red)kHz,peaks are observed at their respective f_{IN}-f_{OSC} and f_{IN}+f_{OSC}



3.8.a Output at f_{IN}=101(green),102(blue),105(red)kHz

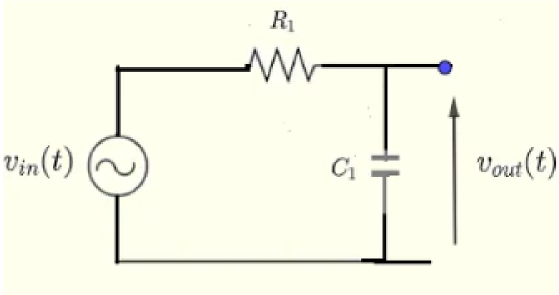


3.8.b FFT at f_{IN}=101(green),102(blue),105(red)kHz,peaks are observed at their respective f_{IN}-f_{OSC} and f_{IN}+f_{OSC}

4.LOW PASS FILTER.

1.<u>Aim:</u> To Design a Low Pass Filter (LPF) with RC values such that we achieve -3dB frequency of 2kHz.

2.Circuit



3.<u>Working</u>

Low pass filter is a simple circuit used in electronics to allow low-frequency signals to pass through while attenuating or blocking high-frequency signals.

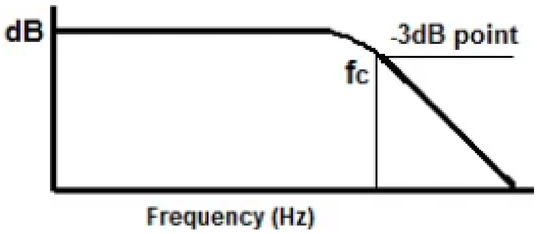
LPF helps us filter the high frequency that we get at Mixer Output.

4.<u>Calculations</u>

$f_C = \frac{1}{2\Pi RC}$

$2kHz = \frac{1}{2\Pi RC}$

Fixing C=0.1µF , we satisfy in above equation and get R as 800Ω.

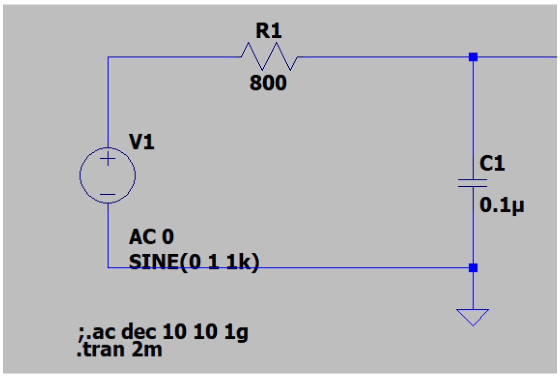


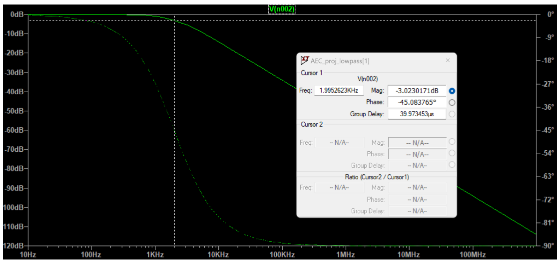
Bode Plot of a LPF

5.<u>LTspice and Lab Simulations</u>

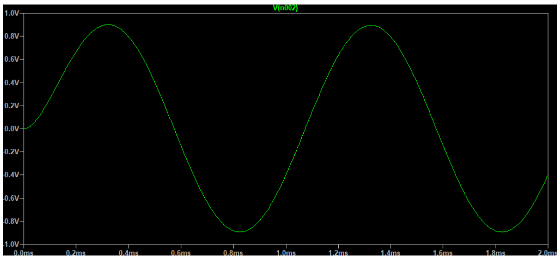
RC values used in Lab and LTspice are the same.

Circuit:

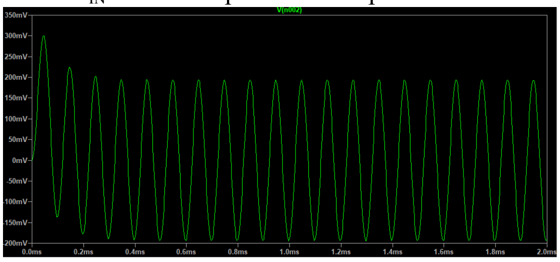




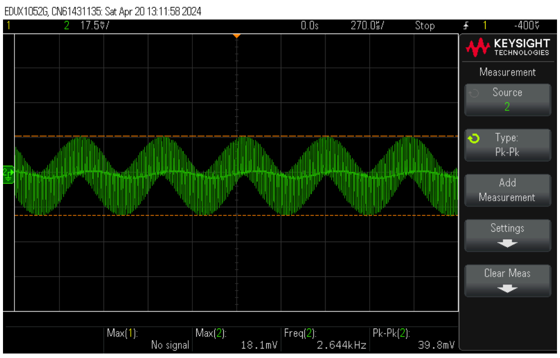
4.1.a Bode Plot of LPF



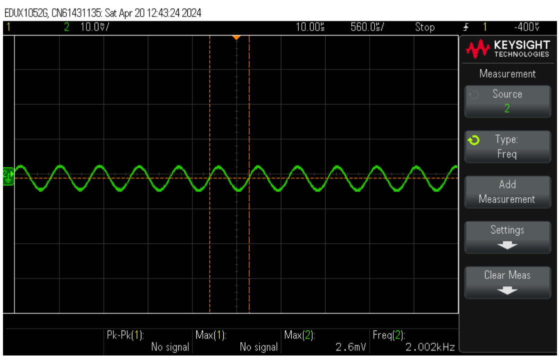
4.1.b Output of LPF at V_{IN}=1V and f_{IN}=1kHz.Amplitude of output is 1V



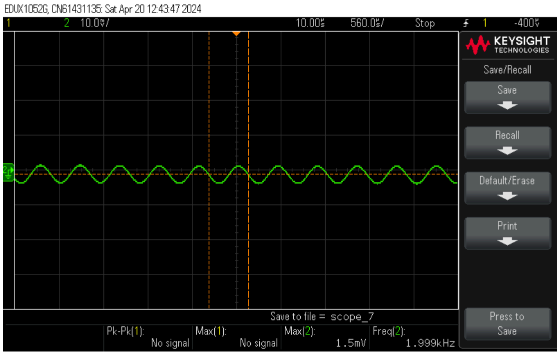
4.1.c Output of LPF at V_{IN}=1V and f_{IN}=10kHz.Amplitude of output is 200mV



4.2.a Mixer output



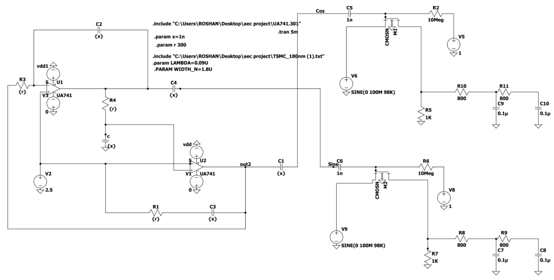
4.2.b Mixer Output after 1 Low Pass Filter

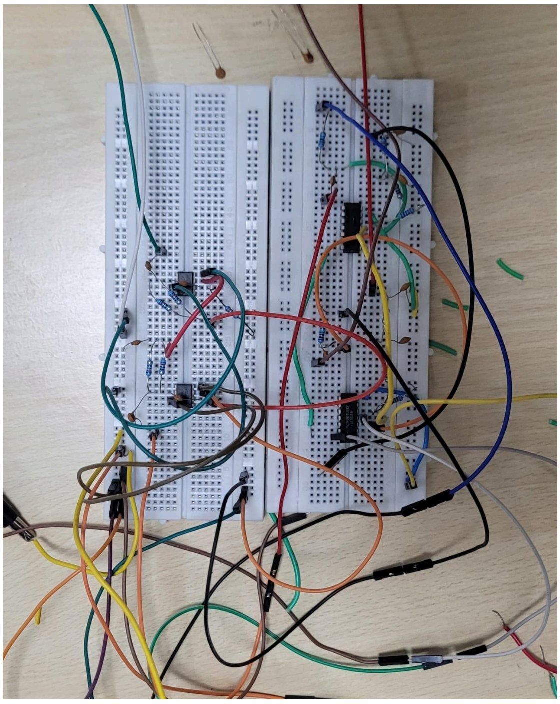


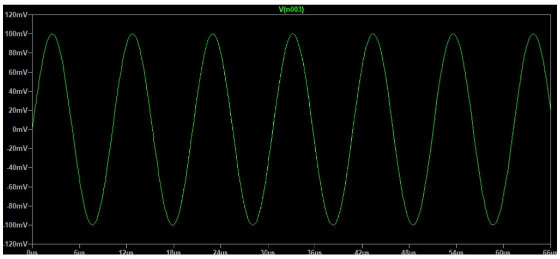
4.2.c Mixer Output after 2 Low Pass Filters

5.COMPLETE CIRCUIT

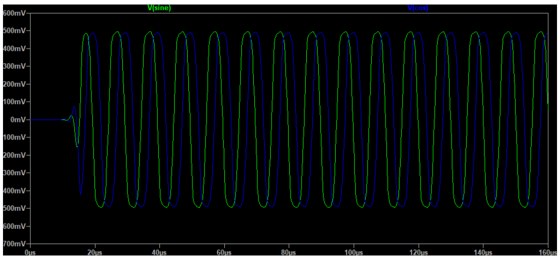
Connected Components.



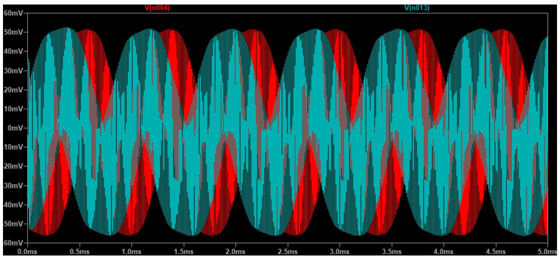




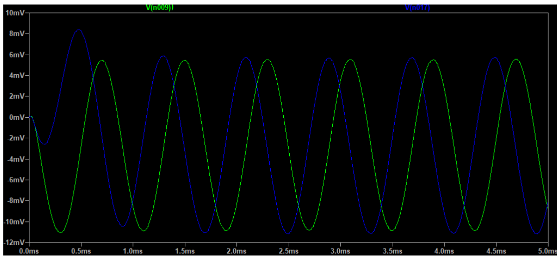
5.1 V_{IN} given to Mixer



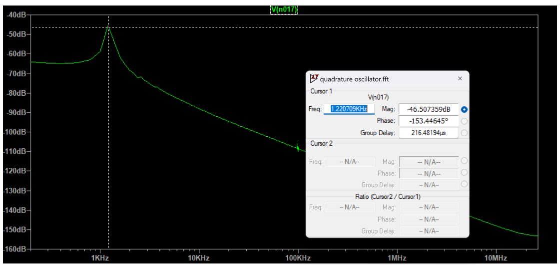
5.2 Oscillator Output



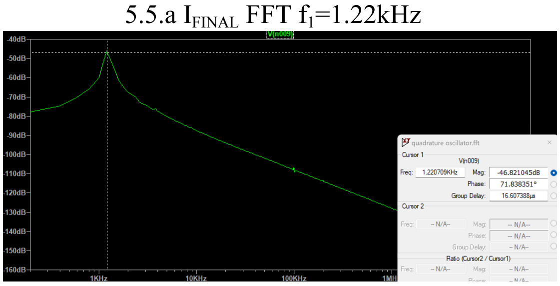
5.3 Mixer Output(I_{IF} and Q_{IF})



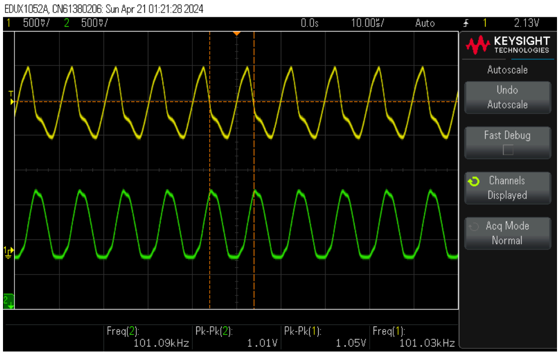
5.4 Final Output after LPF(I_{FINAL} and Q_{FINAL})



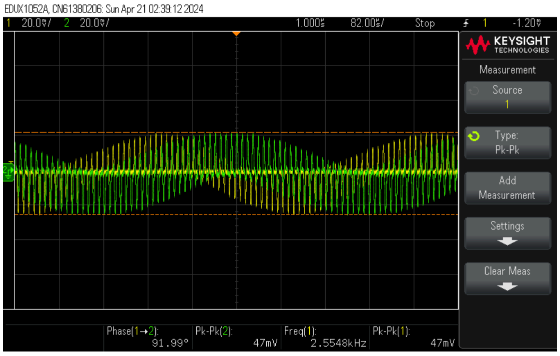
5.5.a I_{FINAL} FFT f_1=1.22kHz



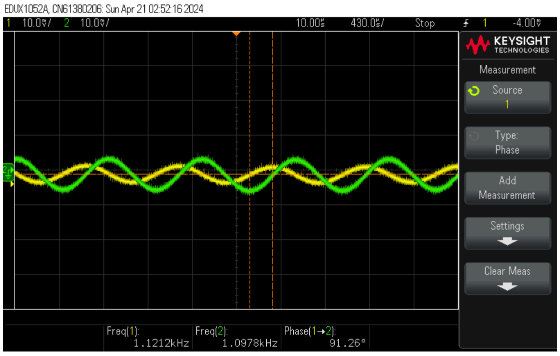
5.5.b Q_{FINAL} FFT f_2=1.22kHz



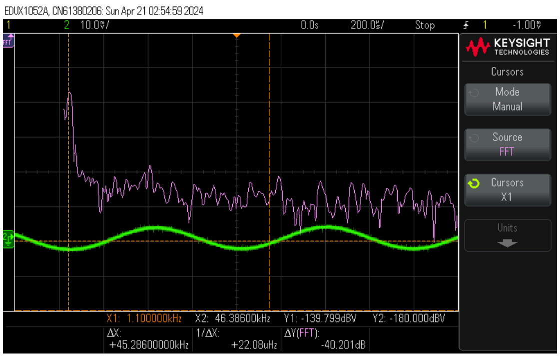
5.6 Oscillator Output



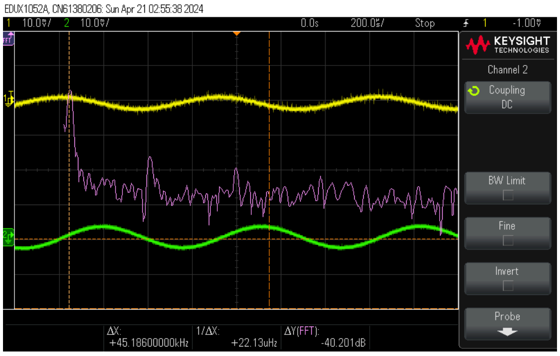
5.7 Mixer Output
Pk-Pk 47 mV,Phase diff. 91°,Freq 2.54 kHz



5.8 Final Output after LPF
Phase diff. is 91.26° , f_1=1.21kHz,f_2=1.09kHz



5.9.a FFT on DSO f_1=1.1kHz

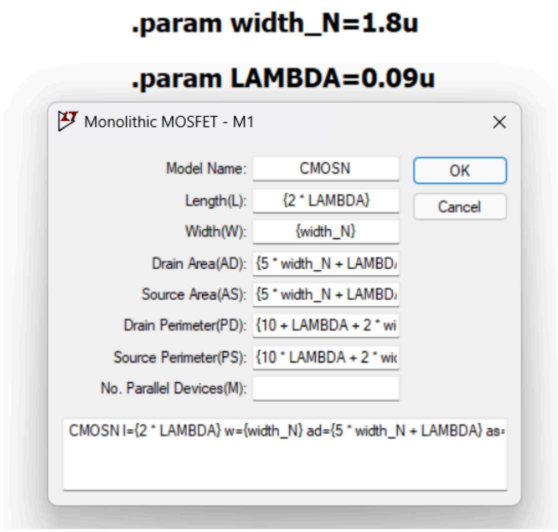


5.9.b FFT on DSO f_2=1.1kHz
Both have the same FFT

Table

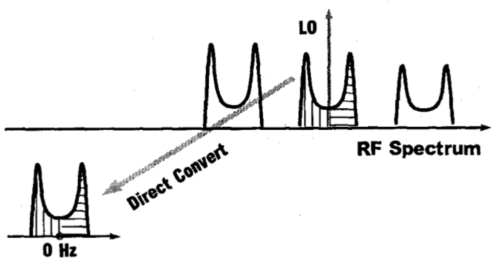
Parameters	LTspice	Lab
Frequency_{osc}	100kHz	101kHz
Amplitude_{osc}	$1V_{pp}$	$1.01V_{pp}$
Phase_{osc}	90°	90.1°
Frequency_{IF}	I_{IF}:2kHz Q_{IF}:2kHz	I_{IF}:1.98kHz Q_{IF}:2.55kHz
Amplitude_{IF}	I_{IF}:50mV_{pp} Q_{IF}:50mV_{pp}	I_{IF}:44mV_{pp} Q_{IF}:47mV_{pp}
$\text{Phase}_{IIF\text{-}QIF}$	90°	91.9°
Frequency_{FINAL}	I_{FINAL}:1.22kHz Q_{FINAL}:1.22kHz	I_{FINAL}:1.12kHz Q_{FINAL}:1.09kHz
Amplitude_{FINAL}	I_{FINAL}:5.5mV_{pp} Q_{FINAL}:5.5mV_{pp}	I_{FINAL}:8mV_{pp} Q_{FINAL}:12.2mV_{pp}
$\text{Phase}_{IF\text{-}QF}$	90°	91.26°
V_{IN}	$1V_{pp}$	$1V_{pp}$
V_{BIAS}	MOSFET_1:1V MOSFET_2:1V	MOSFET_1:2V MOSFET_2:1V
V_{DD}	OPAMP:5V	OPAMP:7.2V
V_{SS}	OPAMP:0V	OPAMP:0V

MOSFET Configuration:

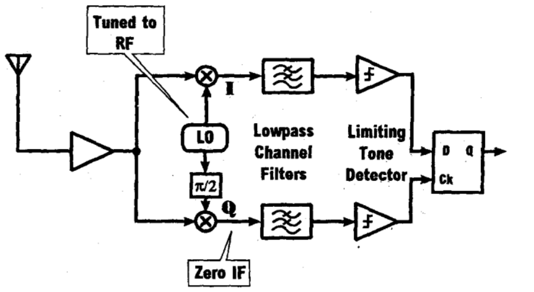


6.BONUS QUESTION

To maintain the phase and frequency information carried in a signal, it is necessary to change down a modulated radio frequency (RF) wave into a baseband. This is why modern wireless receivers require quadrature (I-Q) downconversion/mixing operation. Such requirement becomes important in digital communication systems that use modulation schemes like quadrature amplitude modulation (QAM) or quadrature phase-shift keying (QPSK), as both amplitude and phase of the transmitted signal carry information.



6(a) Note here that the -ve x axis part is an image of +ve x axis part



6(b)Block diagram of a direct-conversion FSK receiver

The mathematical expressions involved here are discussed in the respective subparts itself.

7.ACKNOWLEDGEMENT

We would like to express their gratitude to **Prof. Abhishek Srivastava** for his support throughout the course.We also extend our thanks to the **TAs** of the course for their helpful insights on the paper.

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9.PROJECT

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2.[LTspice]
3.[Mid _Eval PPT]
4.[End_Eval PPT]