Quadrature Down Convertor

Project

Analog Electronic Circuits

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***Abstract*—This electronic document is a report based on Quadrature Down Convertor Circuit designed using Operational Amplifiers and MOSFETs.**

Keywords—Quadrature Down Convertor, Operational Amplifiers, MOSFETS

I. Introduction

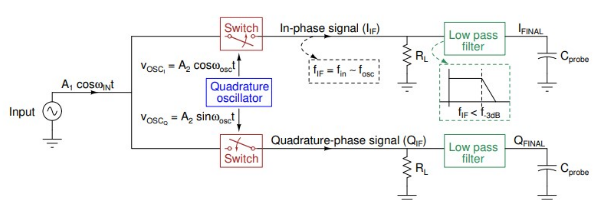
QUADRATURE DOWN CONVERTOR (QDC), as its name suggests is a model that converts a signal with high frequency to low frequency (“Down Convertor”) with the help of a sine and a cosine wave, which means 2 signals with 90° phase shift (“Quadrature”).

This model is commonly used in wireless Receivers (Wi-Fi, WLAN, etc.) Thus, Down Conversion helps in transmission and reduction of inaccuracy, which enhances the quality of communications.

This circuit is designed in 3 phases.

1. *Quadrature Oscillator*: Generating Quadrature signal.
2. *Mixer or Switch*: Multiplying/Mixing input signal with Quadrature Signal.
3. *Low Pass Filter*: Seperating out higher frequencies which aren’t required.

II. Circuit Design and Structure



As introduced earlier, the prototype we are following consists of the above 3 circuital models.

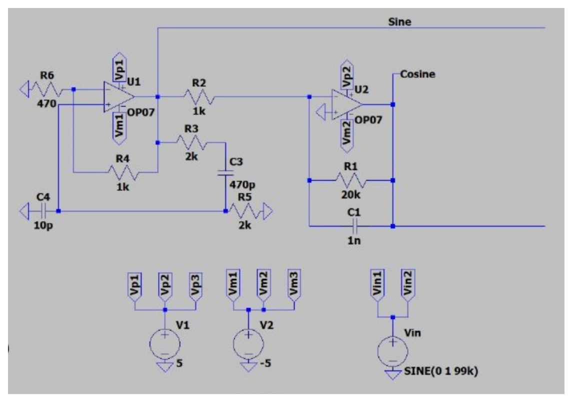
The Quadrature Oscillator generates 2 signals with 90° phase shift. This is done by combining an oscillator and an Integrator circuit. We consider the oscillator to generate a sine wave, and integrator to convert it into a cosine wave. Both these circuits are designed using Operational Amplifiers and certain Resistors and Capacitors.

Next, we send both the waves to switch along with the input signal to the mixer, that actually multiplies both the signals, and output is obtained based om the frequency difference between both the signals. The MOSFET used gets a DC cutoff voltage point based on the biased voltage and resistor. Thus, it converts the circuit into a switch based on the Gate voltage.

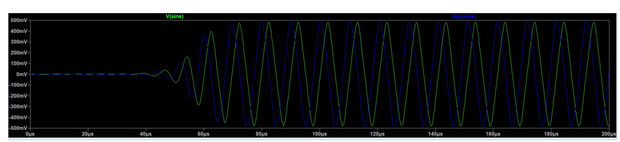
But this multiplication causes many unwanted high frequency signal along with the required output acting as a noise. Thus, we pass the output through Low Pass Filter, and set it’s cutoff according to the frequency difference of input waves. At last we get our input signal in low frequency form suitable for transmission.

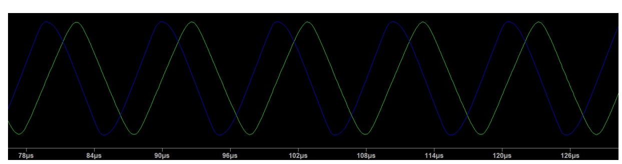
III. Quadrature Oscillator

The Quadrature Oscillator is divided into 2 phases, The Oscillator and the Integrator.

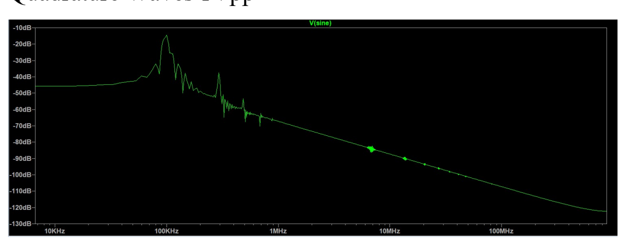


LT Spice Simulation





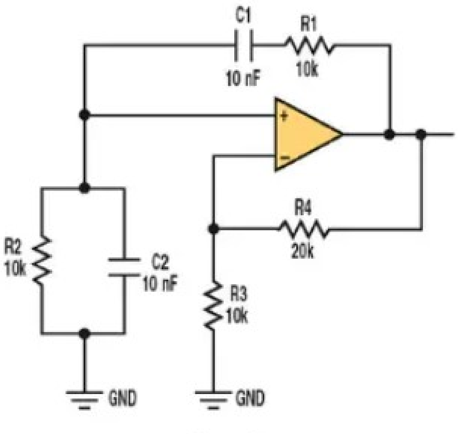
Quadrature Waves 1Vpp



Frequency approx 100kHz (FFT)

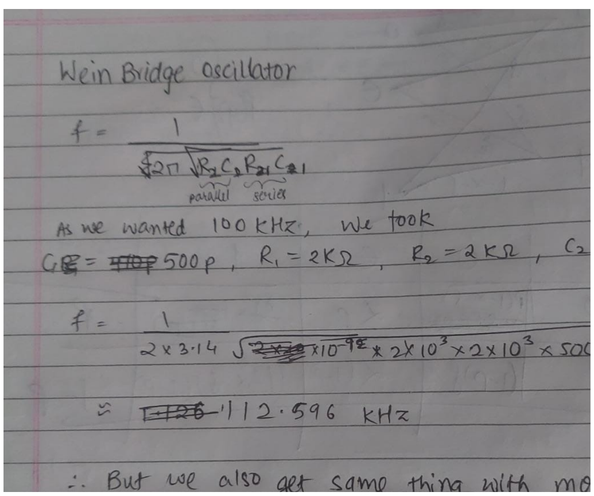
A. Wein Bridge Oscillator:

We have assembled Wein Bridge Oscillator to generate a sine wave through Operational Amplifiers



Ref:https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.electrical4u.com%2Fwien-bridge-oscillator%2F&psig=AOvVaw1t_ITCOomT7EB5cE4ZKVN-&ust=1687413838446000&source=images&cd=vfe&ved=0CA4QjRxqFwoTCODYvMnY0_8CFQAAAAAdAAAAABAP

This Wein Bridge oscillator is based on the main principle of Oscillator, where the noise present in the circuit due to non-ideal conditions. This noise is again sent to the amplifier, and we get an amplified signal with frequency according to our R and C values. Here, the 2 RC impedences decides the frequency and R3, R4 amplifies the signal.



Wein Bridge oscillator

$$f = \frac{1}{2\pi\sqrt{\underbrace{R_2 C_2}_{\text{parallel}}\,\underbrace{R_1 C_1}_{\text{series}}}}$$

As we wanted 100 kHz, we took

$C = 500p$, $R_1 = 2K\Omega$, $R_2 = 2K\Omega$, C_2

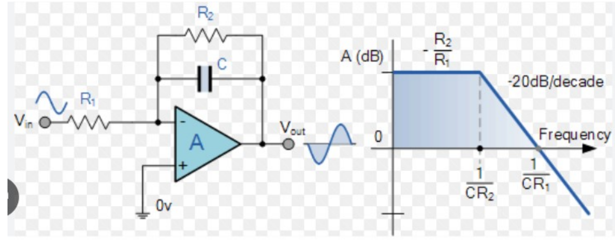
$$f = \frac{1}{2 \times 3.14\sqrt{\times 10^{-12} \times 2 \times 10^3 \times 2 \times 10^3 \times 50}}$$

$\simeq$ 112.596 kHz

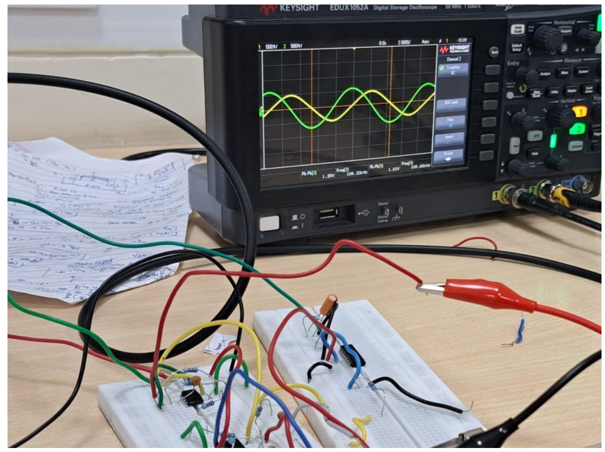
∴ But we also get same thing with mo

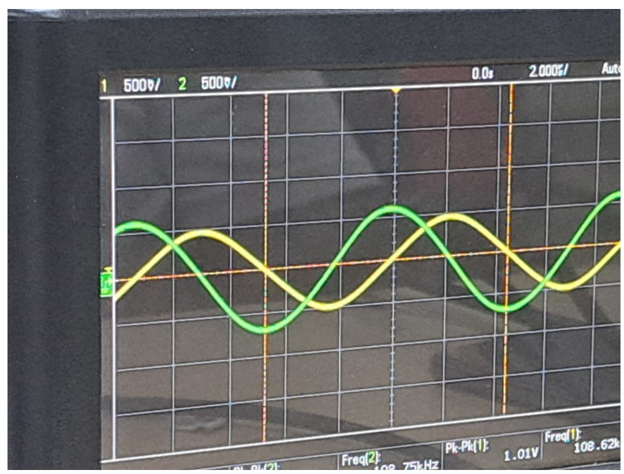
B. Integrator:

Then we connect the Integrator circuit to the oscillator output, and we obtain a cosine wave through it.



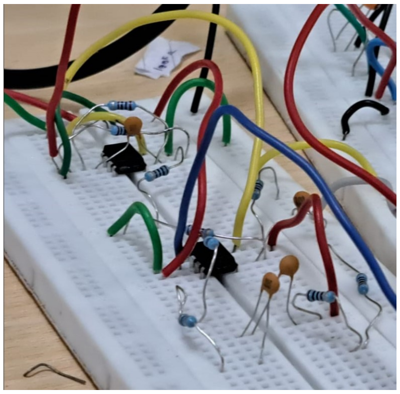
Keeping RC values accordingly, the Quadrature signals are obtained.



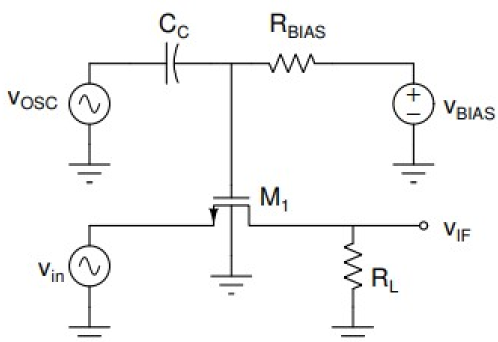


Frequency approx. 100kHz,

Amplitude can be adjusted by Voltage Divider Circuit.



IV. MIXER



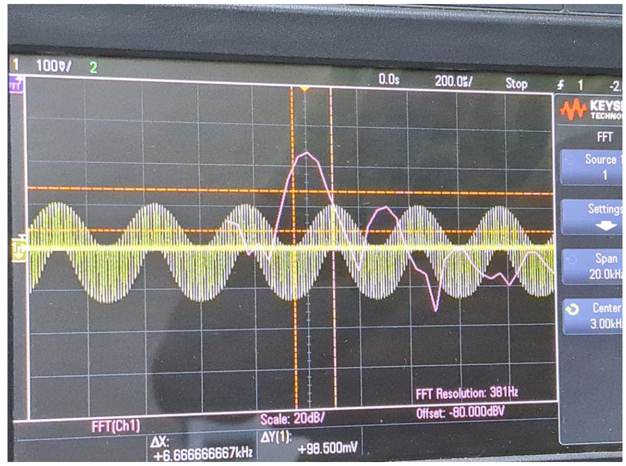
This design of a Mixer multiplies the oscillator and the input signal.

The Mixer, is mainly based on MOSFET. The biased voltage that we send to the Gate, which sets the Threshold voltage. The oscillator voltage is passed through the coupling capacitor to the Gate, so the DC part of voltage is blocked.

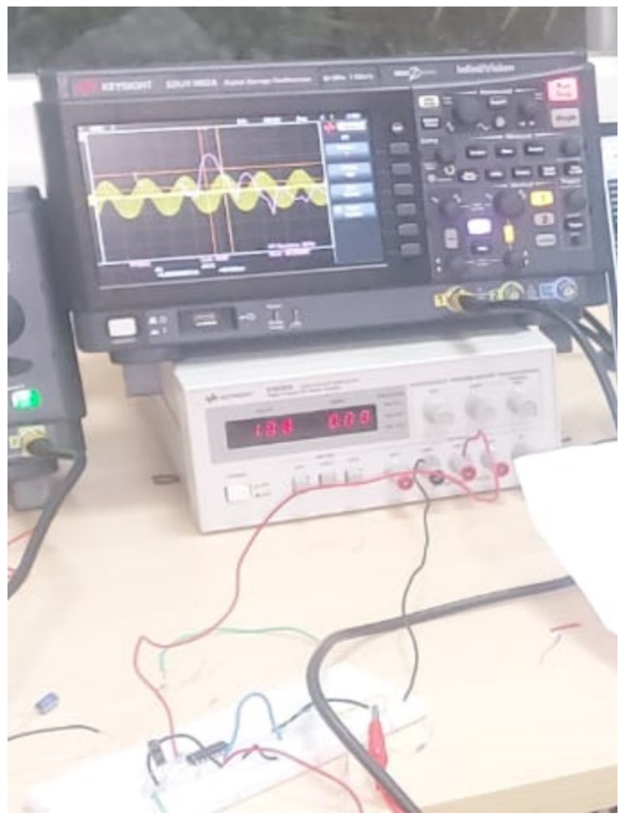
We keep resistance on the biased voltage side to be extremely high, so that it doesn't allow the oscillator signal to go towards the biased voltage.

Before entering into the MOSFET, it combines with the biased voltage. Due to this, the gate voltage has its positive cycles above the threshold voltage, hence passing through the MOSFET (Saturation Region), while the negative cycles go below the threshold voltage, thus get blocked (Cutoff Region). So MOSFET acts as a "Switch" for both cycles of the multiplied signal.

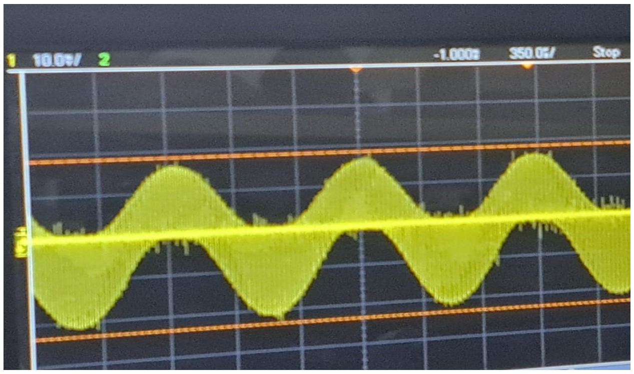
The input voltage is applied to the Source of MOSFET, so it is multiplied with the oscillated signal, and the final multiplied signal is obtained through the Drain. Also, the Body is grounded to avoid Body Effect over the signal.



3 kHz frequency mixer wave for V_{osc} = 100kHz and V_{in} = 97kHz, having peak frequency at 3kHz in FFT.



We obtain a signal giving a frequency of 108.4 kHz through oscillator. Thus at 110 kHz, we get a multiplied wave with approx 1.1kHz. (exactly expected was 1.6kHz).



Theorotically, Multiplication of V_{osc} and V_{in} :

As shown in Fig. 1, the input signal $v_{in} = A_1\, cos\omega_{in}t$ is mixed with $v_{OSC_I} = A_2\, cos\omega_{OSC}t$ and $v_{OSC_Q} = A_2\, sin\omega_{OSC}t$ to produce in-phase (v_{IF_I}) and quadrature-phase (v_{IF_Q}) intermediate frequency (IF) signals, respectively. The in-phase and quadrature-phase signals have a phase difference of 90°. Mixing of two signals is equivalent to their multiplication as shown below.

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

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

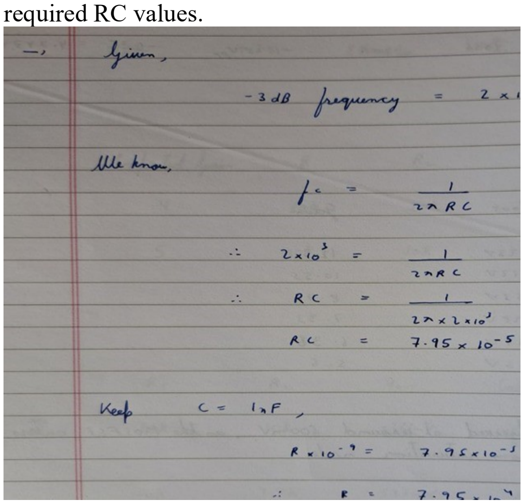
This is mix of high and low frequency waves.

V. LOW PASS FILTER AND FINAL CIRCUIT

From the multiplied signal, we only want the low frequency signal.

Thus, we obviously pass the output of mixer through Low Pass Filter and the high frequency unwanted signal is removed

The -3dB cutoff frequency is set to 2kHz for this experiment. Thus, through the calculation, we get the required RC values.



Given,

-3 dB frequency = 2 x

We know,

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

$$\therefore\ 2\times10^3 = \frac{1}{2\pi RC}$$

$$\therefore\ RC = \frac{1}{2\pi\times2\times10^3}$$

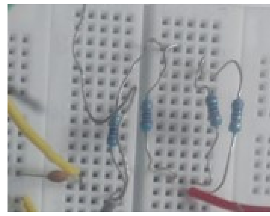
$$RC = 7.95\times10^{-5}$$

Keep C = 1nF,

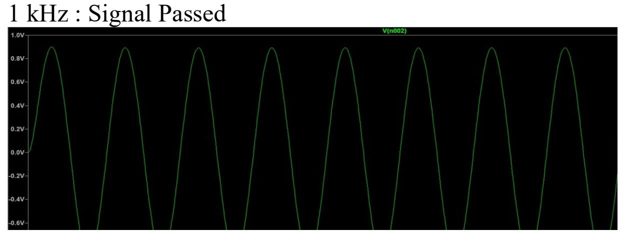
$$R\times10^{-9} = 7.95\times10^{-5}$$

$$\therefore\ R = 7.95\times10^{4}$$

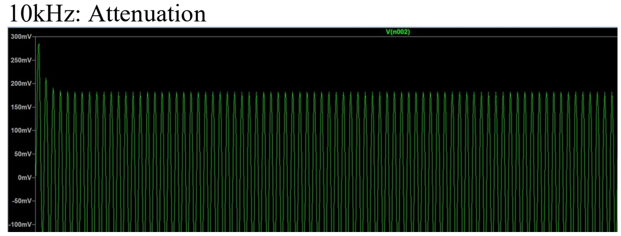
Thus we took 80k ohm and 1nF combination.


LPF

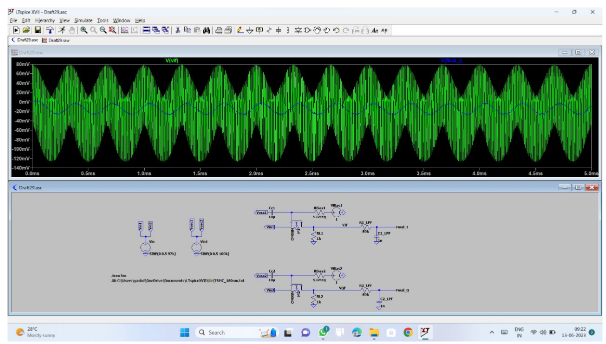
1 kHz : Signal Passed



10kHz: Attenuation



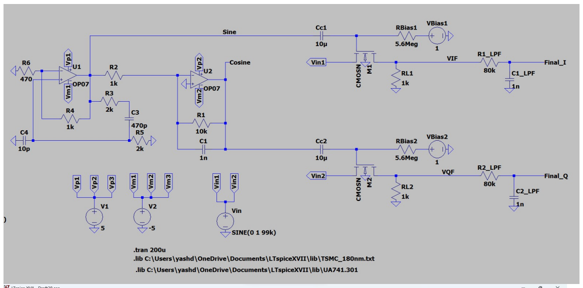
Final output of the circuit:

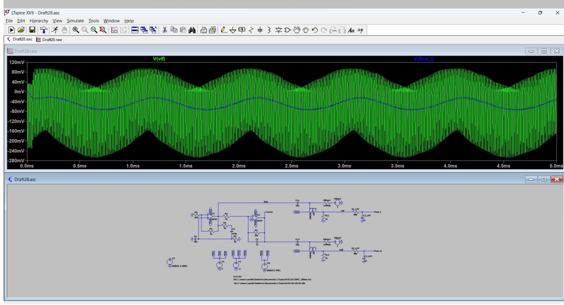


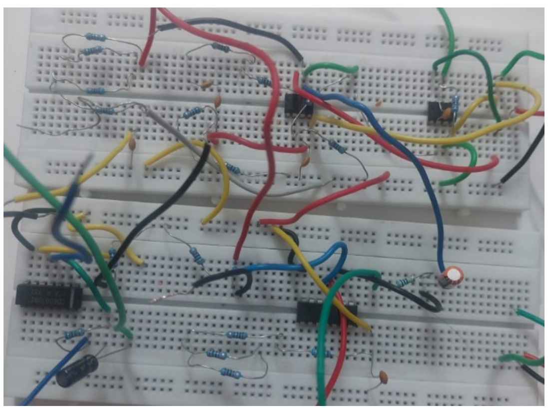
LT Spice simulation (Mixer + LPF)
Green for Mixer, Blue for switch

DSO output for both parts.
Here for 109.4kHz, we got the expected signal of 1kHz as a difference from the oscillator wave of 108.4KHz. Green signal is the mixer output, while yellow is the final output.

FINAL OBSERVATIONS:







REFERENCES

Dr Abhishek Srivastav's class notes
Sedra and Smith(low pass filter calculation)
Fundamentals of microelectronics(Behzad Razavi)(working of mosfet as switch)

Table 1: Performance summary and comparison

Parameters	Simulated	Measured
Oscillator Frequency	100 kHz	108.4 kHz
Oscillator Amplitude (I-phase)	1V	1.01 V
Oscillator Amplitude (Q-phase)	1V	1.35 V
Input frequency	101 kHz	109.4 kHz
IF		
Supply	5V	5.64 V
V_{BIAS}	1V	1.34 V
C_C	10 uF	10 uF
—		
—		
—		