# Quadrature Down Converter

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***Abstract*—In modern day wireless receivers such as Bluetooth, Wi-Fi and WLAN we use Quadrature down converters which helps in interference mitigation and improving the quality of communication**

***Index Terms*—opamps, quadrature oscillator, mixer**

## I. Use of Quadrature Down Converter

To decrease the frequency of the transmitted signal from the source that was received in order to isolate the message signal from the carrier signal.

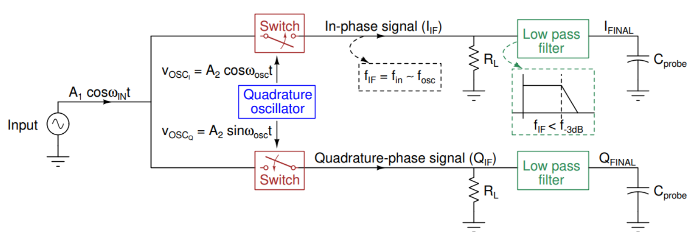



Fig. 1: Quadrature Down Converter.

## II. Quadrature Oscillator Design

The quadrature oscillator was realized in simulations using UA741 opamps to produce two sinusoidal signals at 100 kHz with phase difference of 90°with oscillation amplitude of 1 $V_{p-p}$.

The circuit below is based on Bark Hausen principles. We configured the loop gain to be $\geq 1$ and the target frequency's phase shift to 360°. The oscillator amplifies noise it gathers up from the environment. The frequency of interest has a phase shift across the loop of 360°, which undergoes constructive interference with the preceding signal to maintain the desired oscillation. If the amplified noise returns at a frequency other than the frequency of interest, destructive interference occurs and the oscillation dies down.

In this particular oscillator, the output of one opamp is fed to the other opamp while receiving an appropriate phase shift from an impedance. The phase shift should be set up so that the total phase shifts from the opamp and impedance add up to 90 degrees, giving us two sinusoidal signals with that phase shift. To match the Bark Hausen requirements for the required frequency, the output of the second opamp is once more given a phase shift and fed back to the input of the first opamp.

By applying circuit short and KCL we obtained the following equations

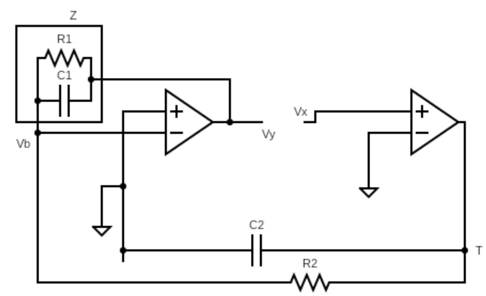



Fig. 2: Circuit for open loop gain

### 1) *For phase shift condition:*

$$\frac{V_{in}}{R_1} = \frac{-V_{out}(1 + SC_1R_2)}{R_2} \tag{1}$$

$$\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}\frac{1}{(1 + SC_1R_2)} \tag{2}$$

$$\text{Phase shift} = -\tan \text{inverse}(\omega C R_1) \tag{3}$$

### 2) *For loop gain condition:* Applying KCL at node T

$$I = \frac{AV_x - V_b}{R_2} = \frac{V_y - V_b}{Z} \tag{4}$$

where

$$Z = \frac{R_1}{1 + j\omega R_1 C_1} \tag{5}$$

$$V_b = V_y - V_z \tag{6}$$

$$I = \frac{AV_x - V_y}{R_2 - Z} \tag{7}$$

$$\frac{AV_x}{\frac{1}{SC_2}} + \frac{AV_x - V_y}{R_z - Z} = 0 \tag{8}$$

$$\frac{A}{\frac{1}{SC_2}} + \frac{A - loopgain}{R_2 - Z} = 0 \tag{9}$$

The output of the second opamp was fed to the inverting terminal of the first opamp in this case. Because of the parasitic capacitance, the opamp produces a phase shift of 90°. When the output of the first opamp is passed through the second opamp, the phase shift is 90°. The output is routed to the inverting terminal. With the opamp's phase shift of 90°and the inverting terminal's phase shift of 180°, we have a total phase shift of 270°, and the signal at the desired frequency has a phase shift of 360°around the loop.

### A. LTSpice Simulations

By building the circuit in LTSpice (Fig. 3.), we obtained two signals of amplitude $1V_{p-p}$ and frequency 100 kHz with a phase shift of 90°(fig. 4.).

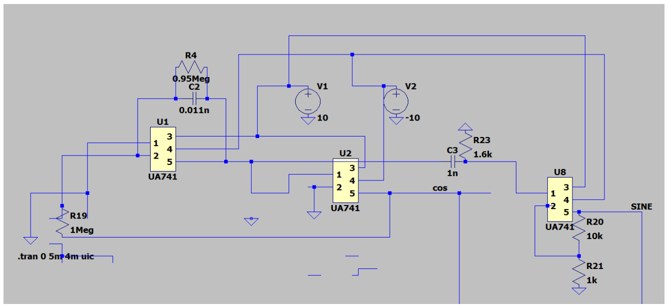



Fig. 3: Circuit schematic of Oscillator

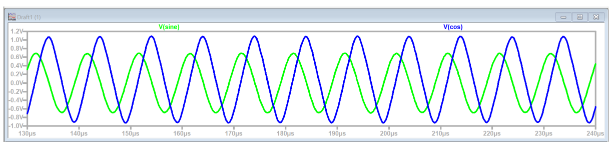



Fig. 4: Outputs of the Quadrature oscillator in LTSpice

### B. Circuit realization in lab

After realizing the same circuit in lab we observed two signals of frequency almost 100 kHz with phase difference between then as 85°.

We carefully adjusted the value of resistance and capacitances as a trade-off to amplitude in order to obtain the needed frequency on hardware.

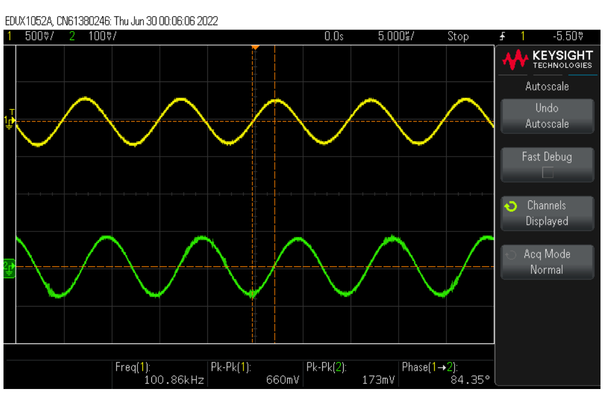



Fig. 5: Outputs of the Quadrature oscillator in Oscilloscope

## III. Mixer Design

In design of mixer we use an NMOS to combine the given signals.

A mixer is just a sinusoidal wave multiplied by a square wave. The square wave we are creating has a frequency of $f_{OSC} = 100kHz$ and many frequency harmonics. When this square wave is multiplied by the sinusoidal input signal, we have a range of output frequencies from which we may select the required frequencies. The equation below (eq .10) elaborates on this process.

$$v_{IF} = v_{in} \times v_{OSC} = \frac{A_1 A_2}{2}(cos(\omega_{in}t - \omega_{OSC}t) + cos(\omega_{in}t + \omega_{OSC}t)) \tag{10}$$

Now, in the given circuit when looked from the side of $V_{OSC}$, the $C_C$ acts as a high pass filter whereas when looked from the side of $V_{BIAS}$ the $R_{BIAS}$ acts as a low pass filter.

Here the $V_{BIAS}$ should be barely less than the value of the threshold voltage of the MOSFET so that the MOSFET is on the edge of turning on.

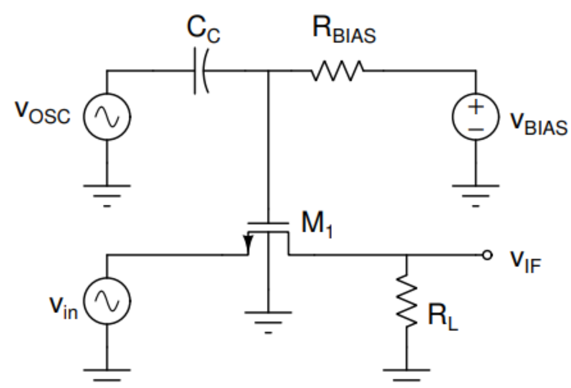



Fig. 6: Circuit diagram of mixer

When simulating the circuit in LTSpice we obtained the value of threshold voltage of the MOSFET to be 0.47 V.

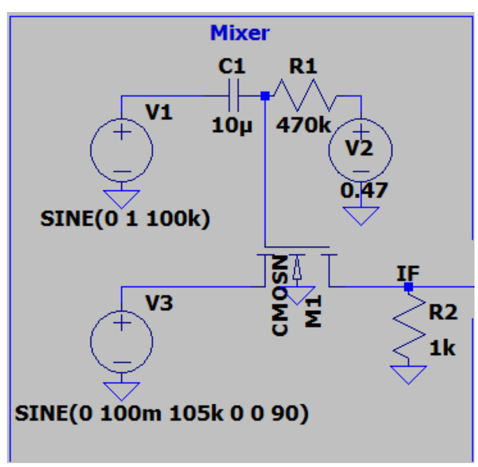
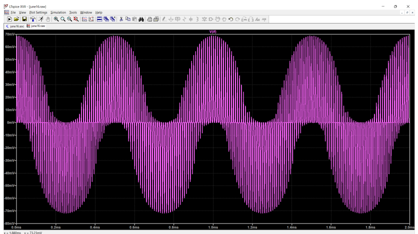


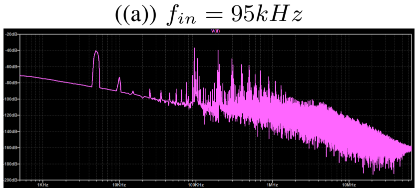

Fig. 7: Circuit schematic of mixer

### A. Circuit realization in LTSpice

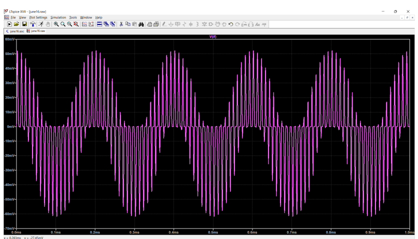
When we applied a signal of 100 mV amplitude and different frequencies the obtained transient plots and corresponding FFT plots are as follows



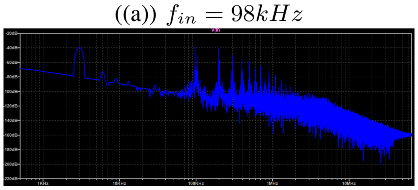
((a)) $f_{in} = 95kHz$



((b)) FFT when$f_{in} = 95kHz$



((a)) $f_{in} = 98kHz$



((b)) FFT when$f_{in} = 98kHz$

For all of the simulated frequencies we observed first peak in FFT at difference of the input and the oscillator frequency.

### B. Circuit realization in lab

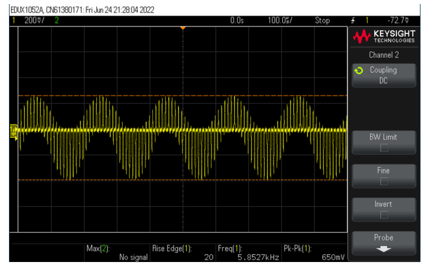
When we realized the same circuit in lab, we used hef4007UBP whose threshold voltage is 1.3 V and the following results were observed.

And when we applied $v_{OSC}$ of 100 kHz frequency and 1 $1V_{p-p}$ and $v_{IN}$ of 98 kHz frequency the observed outputs and corresponding FFT are as of in the following figures.

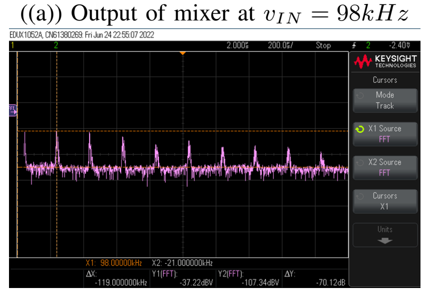
## IV. RC Circuit Design

In design of a Low Pass Filter with -3dB cut off frequency of 2 kHz the desired values of the capacitance and resistance were obtained by the relation $f = \frac{1}{2\pi RC}$. The obtained value of R is $1k\Omega$ and value of C is $80nF$.

The transient response from AC analysis in LTSpice simulations is depicted in Fig. 14.



((a)) Output of mixer at $v_{IN} = 98kHz$



((b)) FFT of the observed output of mixer when$f_{in} = 98kHz$

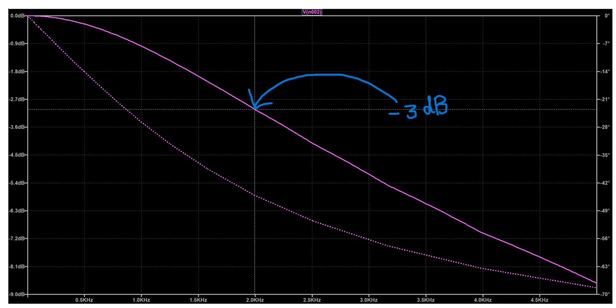



Fig. 11: Frequency response of RC filter

The transient response for 1 kHz and 10 kHz response is depicted in Fig. 15.

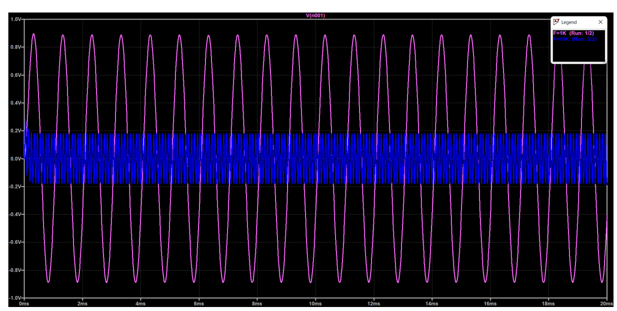
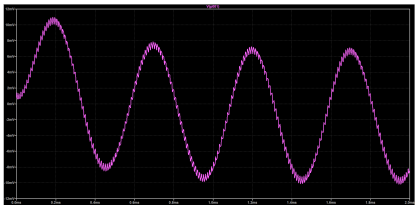


Fig. 12: Transient response of RC filter

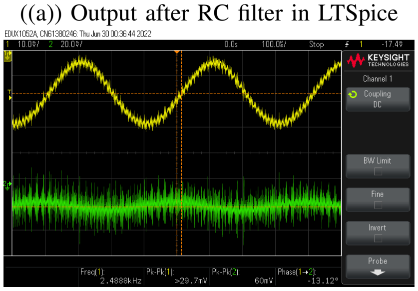
After connecting the mixer setup in the previous part and LPF the results obtained are depicted in the following figures.

## V. Complete Circuit Prototype Design

The circuit starts from the quadrature oscillator which is a self driven component which generates which generates sinusoidal waves of required frequency based on resistance and capacitance values as mentioned above. These signals are



((a)) Output after RC filter in LTSpice




((b)) Output after RC filter in DSO

then fed to the mixer where they form a square wave using an electric switch implemented using NMOS. The resultant signal after this step would contain multiple frequencies. This signal then goes to an RC filter which separates out some unwanted high frequencies and gives us the required frequency.

The ultimate circuit's LTSpice schematic is shown in Fig. 14 after all the circuit blocks have been connected.

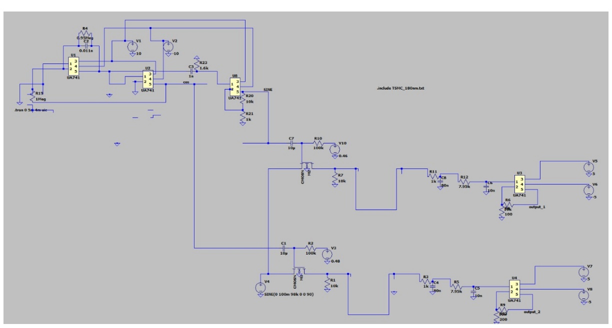


Fig. 14: Final circuit prototype

The results seen after modelling the final circuit in LTSpice are shown in the following figures.

The IF and final IF waveforms are shown in the following figures.

The final output as observed in DSO is shown in the following figures.

| **Parameters** | **Simulated** | **Measured** |
|---|---|---|
| Oscillator Frequency | 100 kHz | 101.5 kHz |
| Oscillator Amplitude (I-phase) | $1V_{p-p}$ | $1.2V_{p-p}$ |
| Oscillator Amplitude (Q-phase) | $800mV_{p-p}$ | $750mV_{p-p}$ |
| Input frequency | 98 kHz | 98 kHz |
| IF | 2, 98, 198 kHz | 2, 98, 198 kHz |
| Supply | 3.15 V | 4.3 V |
| $V_{BIAS}$ | 0.47 V | 1.4 V |
| $C_C$ | $10\mu F$ | $10\mu F$ |
| $R_{BIAS}$ | $470k\Omega$ | $470k\Omega$ |
| $V_{Final}$ frequency | 2 kHz | 2.43 kHz |
| $V_{Final}$ amplitude | 10 mV | 10 mV |
| $R_{Filter}$ | $1k\Omega$ | $1k\Omega$ |
| $C_{Filter}$ | $80nF$ | $104nF$ |

## REFERENCES

[1] Chapter 2 and 14 from 'Microelectronic Circuits' (7th edition) by Sedra and Smith.

[2] Ron Mancini, "Design of op amp sine wave oscillators", Texas Instruments, 2000.

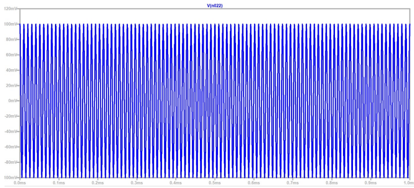
[3] Ralph Holzel, "A Simple Wide-Band Sine Wave Quadrature Oscillator", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 42, NO. 3, JUNE 1993.

[4] Asad A. Abidi, "Direct-Conversion Radio Transceivers for Digital Communications", IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 30, NO. 12, DECEMBER 1995.

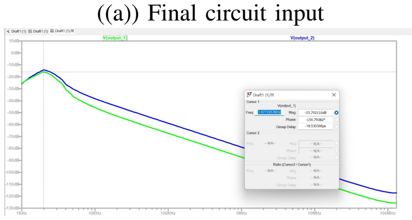
[5] Abhishek Srivastava, Lecture 24 in Analog Electronics Circuits Course Spring 2022, IIIT H.

## CONTRIBUTIONS

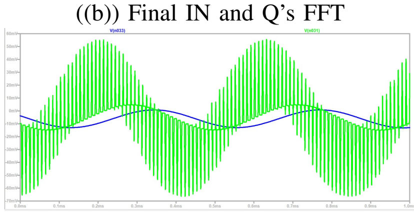
- Quadrature Oscillator analysis - Santrupta Singh
- Quadrature Oscillator Design and Realization - Santrupta Singh
- Mixer Design and Analysis - Nipun Goyal and Koundinya Varma
- Mixer Hardware realization - Koundinya Varma and Nipun Goyal
- RC Filter Analysis and realization - Nipun Goyal and Koundinya Varma
- Overall Hardware realization - Santrupta Singh, Nipun Goyal and Koundinya Varma



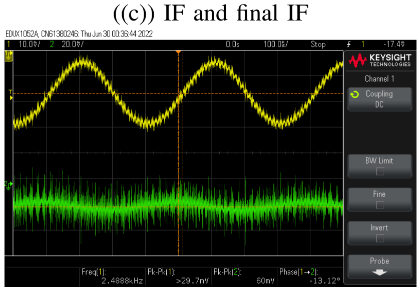
((a)) Final circuit input



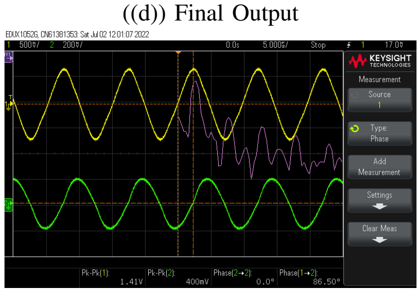
((b)) Final IN and Q's FFT



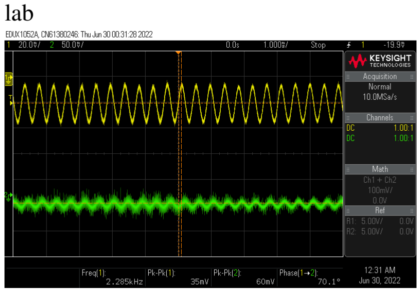
((c)) IF and final IF



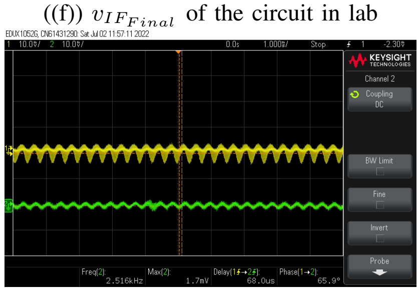

((d)) Final Output




((e)) $V_{OSC1}$ and $V_{OSC1}$ of the circuit in lab




((f)) $v_{IF_{Final}}$ of the circuit in lab




((g)) $v_{IF} v_{IF_{Final}}$ of the circuit in lab