Quadrature Down Converter

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Abstract: The goal of this project is to design and build a Quadrature down converter. A quadrature down converter is a critical component in modern communication systems that is used for frequency down-conversion and quadrature signal demodulation. To validate the performance of the quadrature down converter, the project will include system-level analysis, circuit design, simulation, and practical implementation.

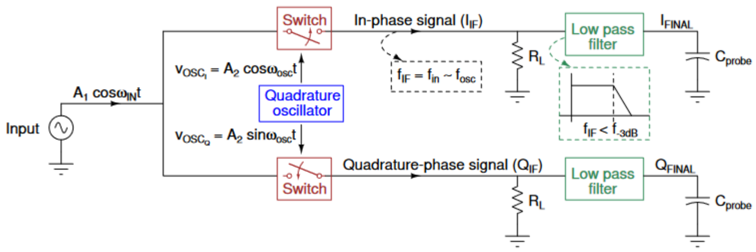

Fig. 1. Project Circuit Overview

I. INTRODUCTION:

The quadrature down converter is essential in modern communication systems because it allows high-frequency quadrature signals to be converted to baseband or intermediate frequency signals. It is a fundamental component in wireless communication since the down conversion process is required for demodulating and extracting information from received signals.

A quadrature down converter's principal function is to shift the frequency of the input signal while preserving the in-phase (I) and quadrature-phase (Q) components. This is commonly accomplished by combining mixing, filtering, and amplification stages. The quadrature down converter has various advantages, including increased signal quality, noise performance, and effective spectrum utilisation.

The project's goal is to develop and build a quadrature down converter that fits the stringent criteria of current communication networks. This includes selecting appropriate components like as mixers, filters, and amplifiers. The project aims to achieve high linearity, low noise, broad bandwidth, and outstanding dynamic range by carefully developing and optimising the various stages of the down converter.

To guarantee that the intended performance standards are reached, the project will include extensive system-level analysis and simulation. The project will also include actual implementation and testing to validate the concept and evaluate its performance in real-world circumstances.

The successful creation of a high-performance quadrature down converter will help to progress communication systems by allowing for greater data transfer, higher signal quality, and more spectrum efficiency. It will find use in a variety of sectors, including wireless communication, radar systems, and software-defined radios.

It has three main components in it:

- **Wein Bridge Oscillator :** This oscillator circuit generates two high-frequency signals characterized by a phase disparity of 90°.
- **Mixer Circuit (or) Switch:** This circuit (which includes MOSFET as an important component) performs signal mixing by combining two input signals, one sourced externally and the other derived from the oscillator, resulting in the generation of a mixed signal.
- **Low Pass Filter:** This filter selectively attenuates high-frequency signals while allowing low-frequency signals to pass through, based on its defined cut-off frequency.

II. CIRCUITS IN THE PROJECT

A. Wein Bridge Oscillator

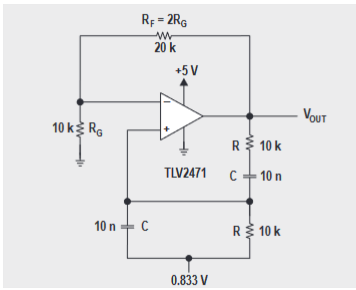

Fig. 2. Wein Bridge circuit

B. Mixer Circuit (Switch)

1) Charecterization of MOSFET: We Characterized the MOSFET such that it operates in Triode Region only,for which the proof is written below.

2) Working: This is used to produce a **sum of two Sinusoids**, one with high frequency and other with a low frequency.

The working of the circuit is as follows:

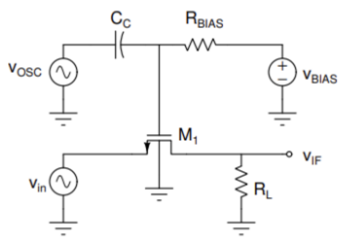

Fig. 3. Mixer Circuit

- voltage input from the oscilloscope $= V_{OSC} = A_1 sin(2\pi t \cdot 100k)$
- voltage input from the external source $= V_{IN} = A_2 sin(2\pi t \cdot 99k)$
- Biasing Voltage $= V_{BIAS}$

$$V_g = V_{BIAS} + V_{OSC}$$
$$V_s = V_{IN}$$
$$V_b = 0$$

Now,

$$V_{GS} = V_{BIAS} + V_{OSC} + V_{IN}$$

Let, V_{BIAS} be approximately equal to the Threshold Voltage of the MOSFET.

$$\therefore V_{GS} - V_{TH} = V_{OSC} - V_{IN}$$
$$\therefore \text{ if } V_{OSC} - V_{IN} < 0$$
$$\implies I_{DS} = 0$$
$$\implies \text{the MOSFET is in Cut-off Region.}$$
$$\text{if } V_{OSC} - V_{IN} > 0$$
$$\implies \text{the MOSFET is in Triode region.}$$

Note that the MOSFET never goes to saturation, because:

$$V_{OUT} << V_{IN} << V_{OSC}$$
$$V_{DS} - V_{GS} = V_{OUT} - V_{IN} - V_{BIAS} - V_{OSC} + V_{IN}$$
$$V_{DS} - V_{GS} = V_{OUT} - V_{BIAS} - V_{OSC}$$
$$V_{DS} - V_{GS} < -V_{BIAS}$$

for a triode to be in saturation,

$$V_{DS} > V_{GS} - V_{TH}$$

which is not getting satisfied in the above circuit.
Continuing with the proof for the MOSFET being in Triode Region,

$$I_{DS} = \mu_n C_{OX} \frac{W}{L}((V_{GS} - V_{TH})V_{DS} - \frac{V_{DS}^2}{2})$$

let, $\mu_n C_{OX} \frac{W}{L}$ = k

$$V_{OUT} = I_{DS} R_L$$
$$V_{OUT} = R_L k((V_{OSC} - V_{IN})(V_{OUT} + V_{IN}) - \frac{(V_{OUT}+V_{IN})^2}{2})$$

after neglecting few terms, based on our above consederations,

$$V_{OUT} = R_L k V_{OSC} V_{IN}$$
$$V_{OUT} = R_L k A_1 sin(2\pi t \cdot f_1) A_2 sin(2\pi t \cdot f_2)$$
$$V_{OUT} = \frac{R_L k A_1 A_2}{2}(cos(2\pi t(f_1 - f_2)) - cos(2\pi t(f_1 + f_2)))$$
$$V_{OUT} = \frac{R_L k A_1 A_2}{2}(sin(2\pi t(f_1 + f_2)) + sin(2\pi t(f_1 - f_2)))$$

C. Low pass filter

A low-pass filter is designed to attenuate or suppress high-frequency components while allowing low-frequency signals to pass through relatively unaltered. The cutoff frequency, denoted as f_C, determines the point at which the filter starts attenuating the higher frequencies. The roll-off characteristic defines the rate at which the attenuation increases beyond the cutoff frequency. The filter's transfer function can be described using various mathematical representations, including the Laplace transform or transfer function in the s-domain. for a low pass filter with R and

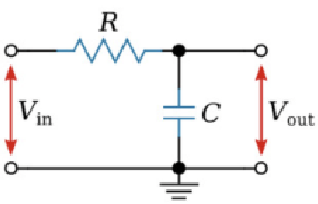

Fig. 4. Low Pass Filter

C as its resistance and capacitance,

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

D. Amplifier and AC Coupling

1) Amplifier: An amplifier is generally used to Amplify the signal which doesn't have sufficient signal strength.Here, we have used an Non - Inverting Operational Amplifier to amplify the signal outcome from the Low pass filter of the Quadrature Down Converter.

2) AC Coupling:

E. Working of the Circuit

- V_{IF_I}
  $= v_{in} \cdot v_{OSC_I}$
  $= \frac{A_1 A_2}{2} \cdot (cos(\omega_{in} t - \omega_{OSC} t) + cos(\omega_{in} t + \omega_{OSC} t))$
- V_{IF_Q}
  $= v_{in} \cdot v_{OSC_Q}$
  $= \frac{A_1 A_2}{2} \cdot (sin(\omega_{in} t + \omega_{OSC} t) - sin(\omega_{in} t - \omega_{OSC} t))$

III. SPICE SIMULATIONS

A. Wein Bridge Oscillator

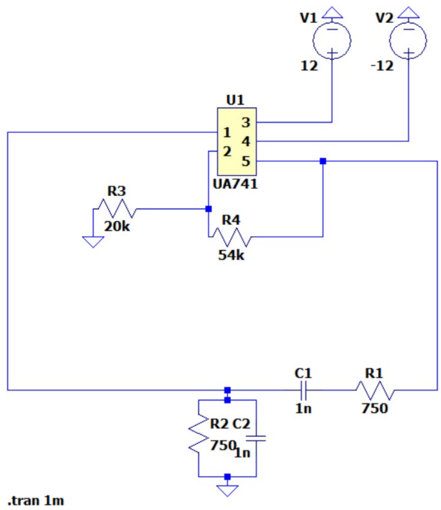

Fig. 5. Wein Bridge

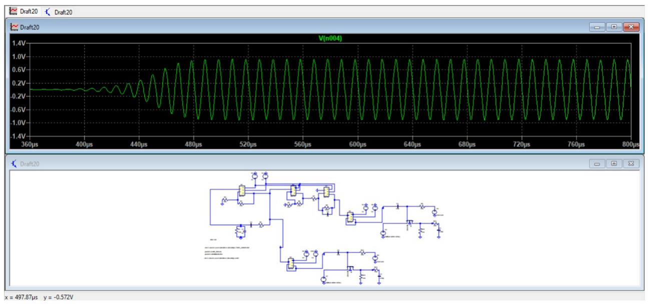

Fig. 6. Wein Bridge Output

B. Mixer Circuit (Switch)

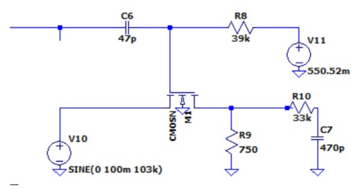

Fig. 7. Mixer

C. Low pass filter

D. Complete Circuit

IV. HARDWARE DEMONSTRATION

A. Wein Bridge Oscillator

B. Mixer Circuit (Switch)

C. Total CirCuit

V. SPICE VERSUS HARDWARE

VI. CONTRIBUTIONS

Modampuri Radheshyam

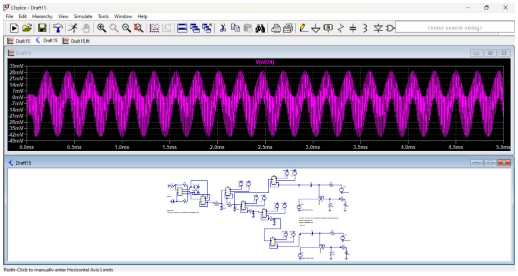

Fig. 8. Mixer Circuit Output for sine wave

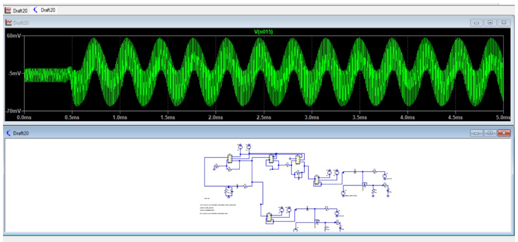

Fig. 9. Mixer Circuit Output for Cos wave

- Lt spice simulations
- Oscialltor
- LPF

Eswar kumar Anantha

- Mixer Circuit
- Amplifier
- Report and PPT

REFERENCES

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

[2] Chapter 3 and 4 from 'RF Microelectronics' (2nd edition) by Behzad Razavi.)

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

[4] Lecture notes, tutorials and labs conducted in this course

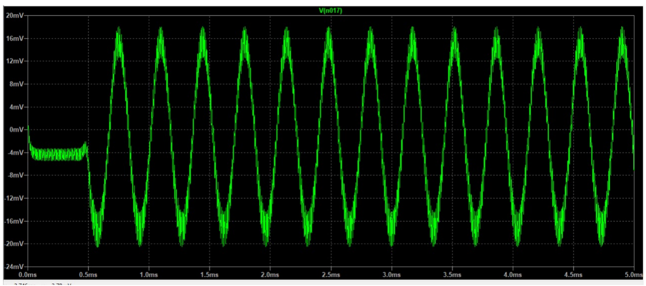

Fig. 10. LowPass Output for Sin wave

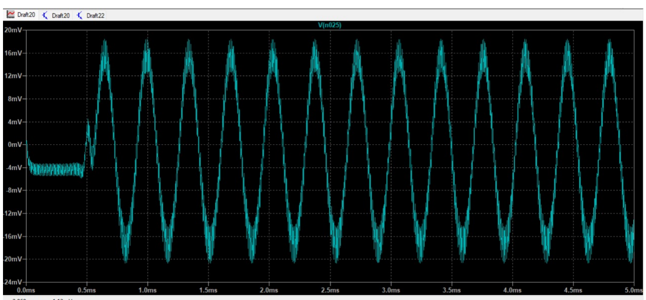

Fig. 11. LowPass Output for Cos wave

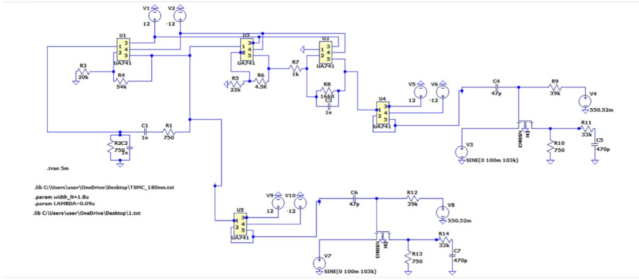

Fig. 12. Total Circuit

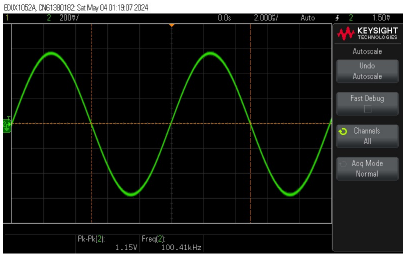

Fig. 13. output for sin wave

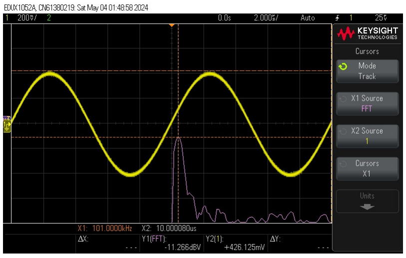

Fig. 14. output for cos Wave

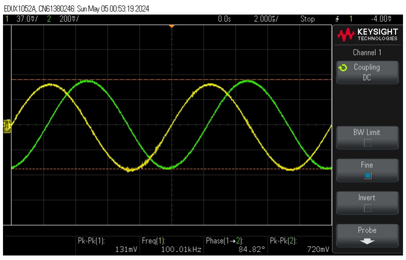

Fig. 15. Comparing outputs for cos Wave and sin wave

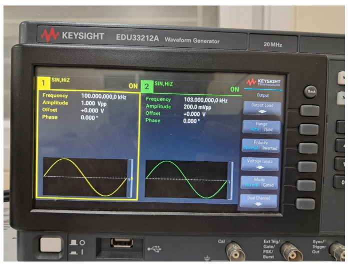

Fig. 16. Generating both sin waves

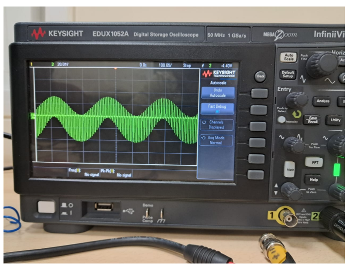

Fig. 17. output for generated waves

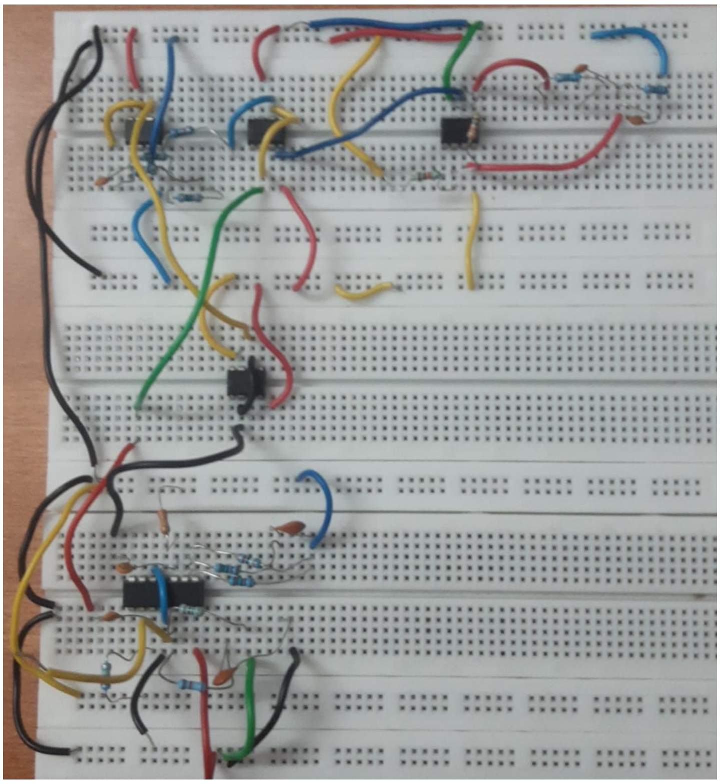

Fig. 18. Circuit

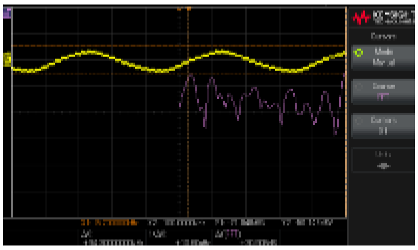

Fig. 19. Output of Oscillator+Mixer+LPF

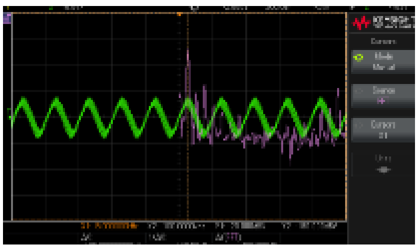

Fig. 20. FT of Final output

TABLE I
PERFORMANCE SUMMARY AND COMPARISON

Paramertes	Simulated	Measured
Oscilator frequency for sin	100 KHz	104 Khz
Oscilator frequency for cos	100 KHz	104 Khz
Oscillator Amplitude for sin	1.5	0.9
Oscillator Amplitude cos	1	0.1
V_{DD}	12	5.9
V_{DD}	12	5.9
V_{SS}	-12	5.9
V_{BIAS}	2.5	1.09
C_C	10nF	10nF