AEC PROJECT

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***Abstract*—We look at the working of a wien bridge, which is followed by the design, simulation and implementation of a wien bridge, single-gate MOSFET mixer, and a low-pass filter to make a quadrature down converter.**

***Index Terms*—wien bridge oscillator, single-gate mixer, low-pass filter**

I. Introduction to Quadrature Down Converter

A quadrature down converter (QDC) is a circuit that takes a band-limited signal, and converts it into two waves with a phase shift of $90°$ which are at a lower frequency, whilst preserving the information contained in the signal. This helps simplify processing in further stages

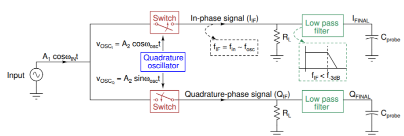

Fig. 1. Schematic of QDC circuit.

A. Components of a QDC

- Oscillator
- Single-Gate MOSFET Mixer
- Low-Pass RC Filter

II. Oscillator

An oscillator is a device that generates a sine wave and a cosine wave, ideally of equal amplitude and frequency.

It works by combining circuits built using op-amps. Since real-world resistors have noise,so we filter a particular frequency of noise and amplifiy it.

A. Working

We use a Wein-bridge oscillator in our circuit. The wein-bridge oscillator is built using a negative-feedback op-amp amplifier with high-pass and low-pass filters, as shown in Fig. 2.

The high-pass and low-pass filters act together to allow only a particular frequency f to pass through (the resonant frequency), given by

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} \tag{1}$$

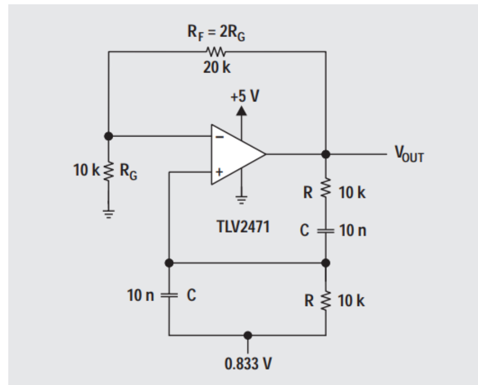

Fig. 2. Schematic of the oscillator circuit.

where R_1, C_1 represent the RC values of the high-pass filter, and R_2, C_2 represent the RC values of the low-pass filter.

Since a DC signal can be thought of as being made of multiple frequencies combined together, we can utilise the noise, amplify it till it reaches a stable value dependent on V_{DD} and pass it through the filter mechanism to get our desired sine wave with desired frequency.

The voltage gain equation of the Wein-bridge can be written as:

$$\frac{v_o}{v_{in}} = \frac{j\omega R_2C_1}{1-\omega^2R_1R_2C_1C_2 + j\omega[R_1C_1 + R_2C_2 + R_2C_1]} \tag{2}$$

Since $\omega = 2\pi f$, substituting eqn. 1 in eqn. 2,

$$\frac{v_o}{v_{in}} = \frac{R_2C_1}{R_1C_1 + R_2C_2 + R_2C_1} \tag{3}$$

This is then passed through an op-amp integrator circuit to obtain a cosine wave.

The voltage gain (A) equation of the integrator can be written as:

$$A = \frac{R_2}{R_1} \times \frac{1}{2\pi f R_2 C} \tag{4}$$

B. LTspice Simulation

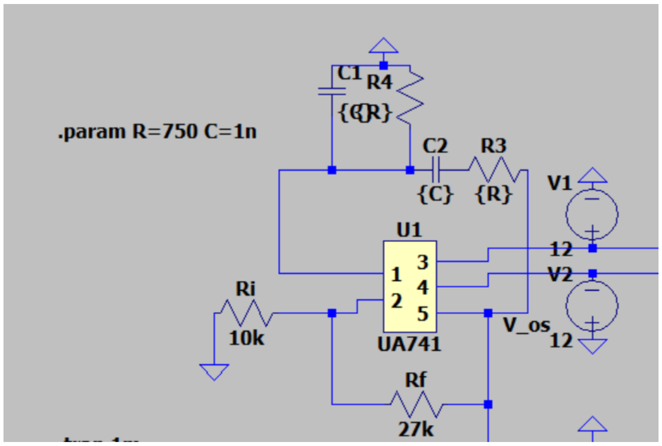

Fig. 3. LTspice oscillator.

By taking the values of circuit elements as shown in above we can get the output as shown in Fig. 4 of amplitude of roughly 1 V_{pp} and frequency of 100 kHz.

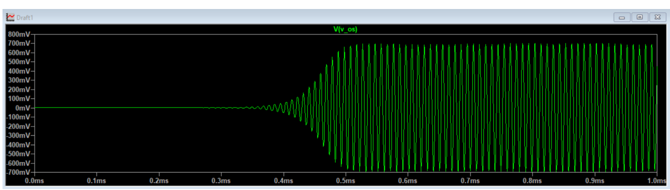

Fig. 4. LTspice oscillator circuit and its output.

Fig. 5 shows that the phase difference is 90° and Fig. 6 shows the frequency of the simulated circuit.

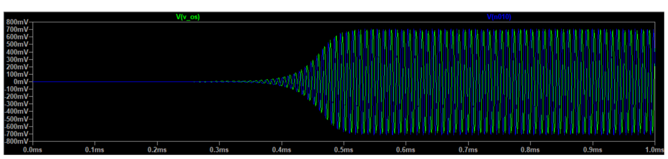

Fig. 5. When sine is zero, cos is at its maxima.

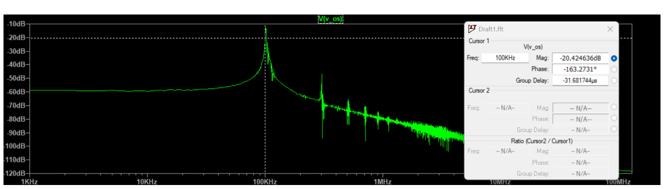

Fig. 6. LTspice oscillator circuit's frequency.

C. Hardware Implementation

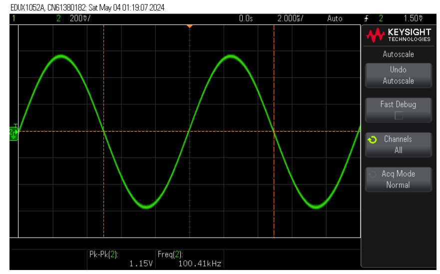

Fig. 7. Hardware implementation oscillator circuit's output.

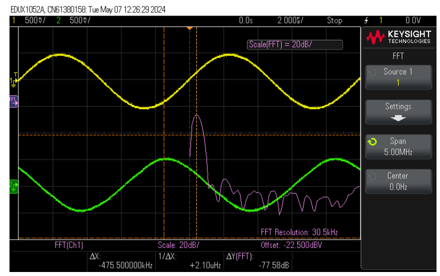

Fig. 8. Hardware implementation oscillator circuit's output fft.

III. Single-Gate MOSFET Mixer

A single-gate MOSFET mixer is used for each of the generated sine and cosine waveforms from the Wein-bridge oscillator (here-on referred to as oscillator waves) to act as a switch.

A. Working

The output wave of the oscillator and the input signal are connected to the Gate and Source terminals of the MOSFET respectively.

As shown in Fig. 9, the Gate terminal is biased to the MOSFET's threshold voltage (V_{TH}) such that the MOSFET is in cut-off region whenever the amplitude of the oscillator wave is negative, and mixes the input signal with the oscillator wave whenever the amplitude of the oscillator wave is positive, thereby acting as a switch.

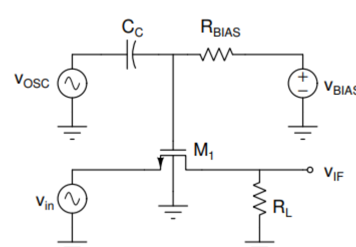

Fig. 9. Schematic of the mixer circuit.

If the input signal is $v_{in} = A_{in}sin(\omega_{in}t)$, and the oscillator waves being $v_{osc_Q} = A_{osc}sin(\omega_{osc}t)$ and $v_{osc_I} = A_{osc}cos(\omega_{osc}t)$, then the intermediate in-phase (v_{IF_I}) and quadrature-phase (v_{IF_Q}) signals are as follows:

$$
\begin{aligned}
v_{IF_I} &= v_{in} \times v_{osc_I} \\
&= A_{in}A_{osc} \left(sin(\omega_{in}t)cos(\omega_{osc}t) \right) \\
&= \frac{A_{in}A_{osc}}{2} \left(sin(\omega_{in}t + \omega_{osc}t) + sin(\omega_{in}t - \omega_{osc}t) \right)
\end{aligned} \tag{5}
$$

$$
\begin{aligned}
v_{IF_Q} &= v_{in} \times v_{osc_Q} \\
&= A_{in}A_{osc} \left(sin(\omega_{in}t)sin(\omega_{osc}t) \right) \\
&= \frac{A_{in}A_{osc}}{2} \left(cos(\omega_{in}t - \omega_{osc}t) - cos(\omega_{in}t + \omega_{osc}t) \right)
\end{aligned} \tag{6}
$$

A sufficiently large C_C is used so that the DC bias input (V_{BIAS}) doesn't affect the source of the AC signal, and a large R_{BIAS} is used so that the AC signal doesn't flow through V_{BIAS}, since the DC source acts as an AC ground.

A suitable R_L is chosen to load the circuit and receive a proper output v_{IF}.

B. LTspice Simulation

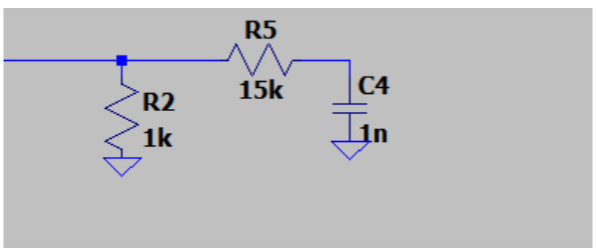

Fig. 10. LTspice mixer circuit.

Taking the values of parameters as shown in Table I, we get the output shown in Fig. 11. The red wave is the output wave after mixing, the blue wave being the input signal, and the green wave being the oscillator wave.

TABLE I
VALUES OF DIFFERENT PARAMETERS

Parameter	Value
Width of Transistor	1.8 μm
Length of Transistor	180 nm
Drain Area of Transistor	0.81 pm
Source Area of Transistor	0.81 pm
Drain Perimeter of Transistor	4.5 μm
Source Perimeter of Transistor	4.5 μm
A_{osc}	1 V_{pp}
A_{in}	100 mV_{pp}
ω_{osc}	100 kHz
ω_{in}	103 kHz
V_{BIAS}	700 mV
R_{BIAS}	1 $M\Omega$
C_C	10 pF
R_{Load}	1 $k\Omega$

Varying f_{in} as 95 kHz, 98 kHz, 99 kHz, 101 kHz, 102 kHz and 105 kHz we observe the output and its FFT as shown in Fig. 12 and Fig. 13 respectively.

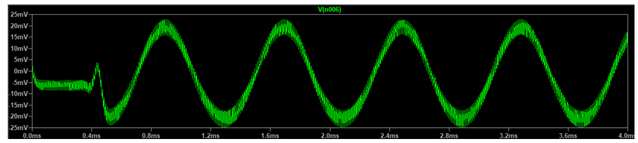

Fig. 11. LTspice mixer output.

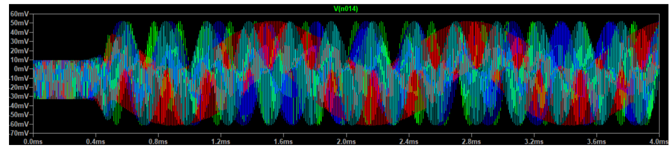

Fig. 12. LTspice mixer output for varying input frequencies.

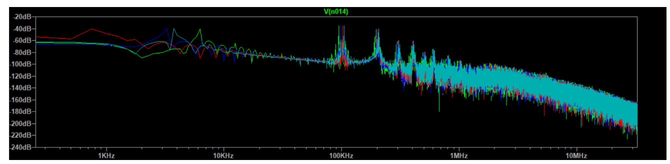

Fig. 13. LTspice mixer output's FFT.

C. Hardware Implementation

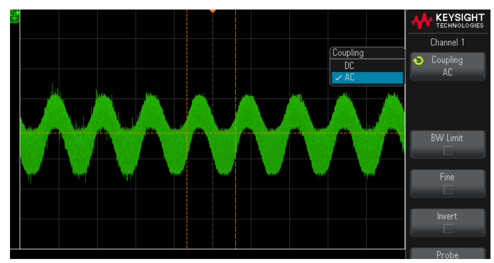

Fig. 14. Hardware implementation mixer output.

As seen in Fig. 15, for an input signal of 95 kHz we observe peaks primarily at $\omega_{in} - \omega_{osc}$, ω_{in}, ω_{osc} and $\omega_{in} + \omega_{osc}$ in the FFT, which is in accordance with eqn. 6.

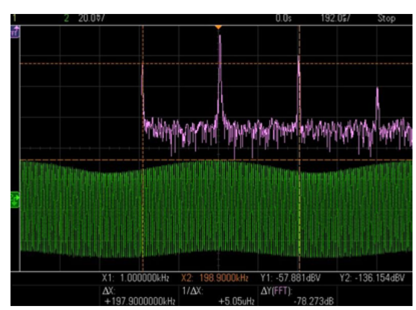

Fig. 15. Hardware implementation mixer output with FFT.

IV. LOW-PASS RC FILTER

When a resistor and capacitor are connected in series, with the non-joined end of the resistor connected to an input signal, and of the capacitor connected to ground, we can realise a filter circuit that only allows lower values of frequencies to pass through.

A. Working

This works on the principle of rate of change of voltage across a capacitor's terminals. Since voltage across a capacitor develops with the accumulation of charges on the capacitor gates, there is a finite rate at which voltage across the capacitor can change.

Thus at higher frequencies, this voltage difference cannot appear rapidly on par with the frequency, hence we see a highly reduced output. While at lower frequencies, the capacitor can easily adjust its voltage and hence is able to allow the signal to pass through with minimal interference.

When R is the resistance used and C is the capacitor used, with input signal's angular frequency as ω, then the cut-off frequency f_c is given by

$$f_c = \frac{1}{2\pi RC} \tag{7}$$

beyond which the output amplitude starts to decrease. This frequency is also represented in a Bode plot as the -3dB frequency.

B. LTspice Simulations

1) Filter: Since the -3dB cut-off frequency is 2kHz, replacing it in eqn. 7, we get

$$\begin{aligned} 2 \times 10^3 &= \frac{1}{2\pi RC} \\ RC &= \frac{1}{2\pi \times 2 \times 10^3}\ s \\ &= \frac{1}{4\pi}\ ms \\ &= 0.0796\ ms \\ &\approx 80\ \mu s \end{aligned} \tag{8}$$

To achieve this, we can choose a resistor of 80 Ω and a capacitor of 1 μF. The desired frequency response is observed as shown in Fig. **??**.

When given an input signal with frequency below 2 kHz (such as 1 kHz), the filter allows the signal to pass through with minimal effect, and for signals with frequency greater than 2 kHz (such as 10 kHz) the signal is highly attenuated, as observed in the transient analysis shown in Fig. 17. The blue wave is the output for 10 kHz and the green wave is for 1 kHz.

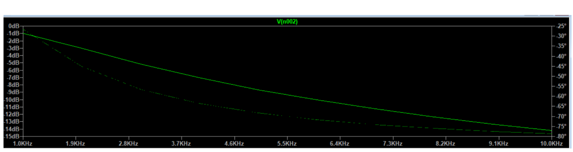

Fig. 16. LTspice filter output for ac analysis.

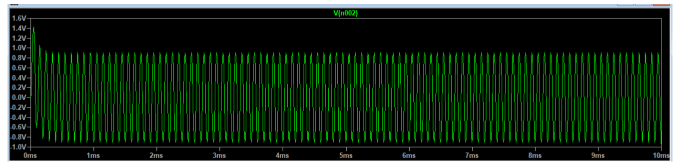

Fig. 17. LTspice filter output for transient analysis.

2) Filter with Switch: The switch/mixer output is a sinusoidal wave with multiple high-frequency peaks. Passing this output through a filter attenuates the higher frequencies of the signal and results in a smoother waveform.

We see that the output is not affected much when $\omega_{in} - \omega_{osc}$ is less than 2 kHz, such as in Fig. 18, while the output is highly attenuated otherwise, as in Fig. 19.

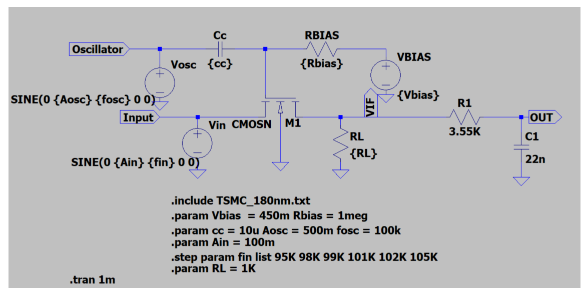

Fig. 18. LTspice mixer with filter output for $f_{in} = 99\ kHz$.

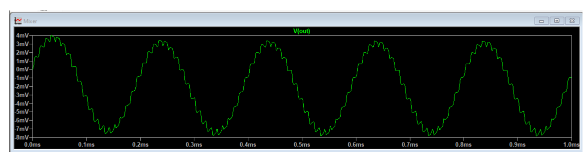

Fig. 19. LTspice mixer with filter output for $f_{in} = 99\ kHz$.

V. Complete Circuit

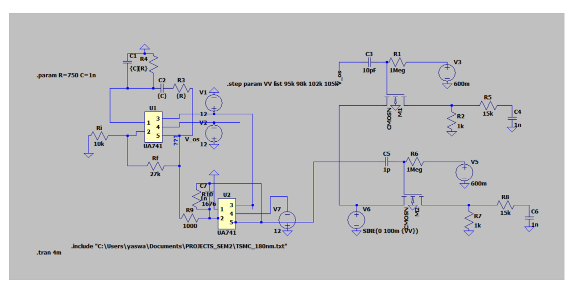

Fig. 20. Final circuit in Lt Spice.

A. LTspice simulations

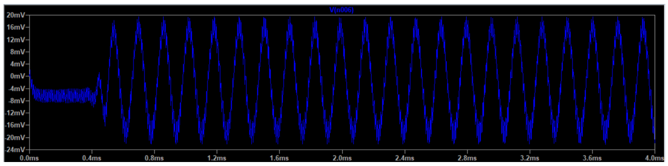

Fig. 21. LTspice transient analysis of the final circuit.

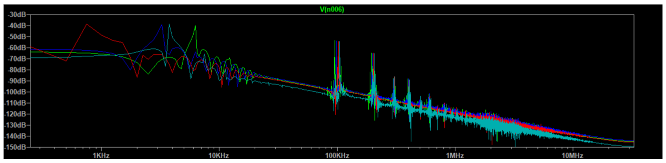

Fig. 22. LTspice FFT of the final circuit's $v_{IF_{FINAL_I}}$ and $v_{IF_{FINAL_Q}}$.

B. Hardware Implementation

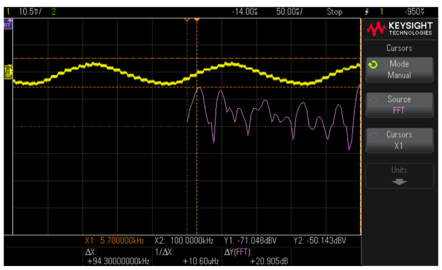

Fig. 23. Output of Oscillator + Mixer + LPF.

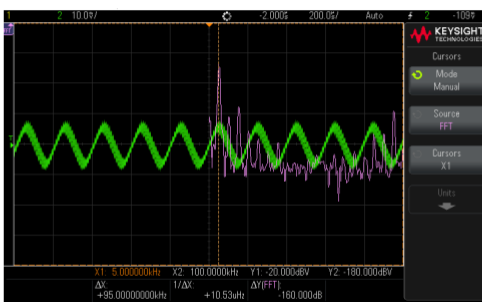

Fig. 24. Hardware implementation output of $v_{IF_{FINAL_Q}}$ and its FFT.

TABLE II
COMPARISON OF VALUES BETWEEN SIMULATION AND HARDWARE

Parameters*	**Simulated**	**Measured**
Oscillator Frequency	110 kHz	99.8 kHz
Oscillator Amplitude (I-phase)	930 mV_{pp}	1.01 V_{pp}
Oscillator Amplitude (Q-phase)	930 mV_{pp}	1.05 V_{pp}
Input frequency	109 kHz	98kHz
V_{BIAS}	0.5 V	1.6 V

*Parameters not mentioned here are almost similar between the simulation and the hardware.

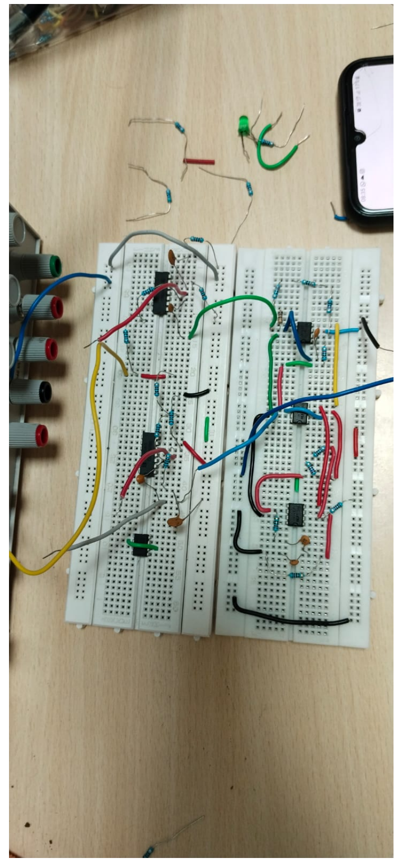

Fig. 25. Hardware implementation circuit.

REFERENCES

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[2] Ron Mancini, "Design of op amp sine wave oscillators", Analog Applications Journal, August 2000.

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