AEC PROJECT MID EVAL

Team Name: Non-Operational Amplifiers

Team Members:

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Team Project : Quadrature Down Converter

Project Workflow

1. LT SPICE Simulations for :

Switch (mixer)

Low Pass Filter (LPF)

Combined Circuit of switch and LPF

2. The working principles for the above two blocks(How? and why? they work in the way they should)

Project Description and working

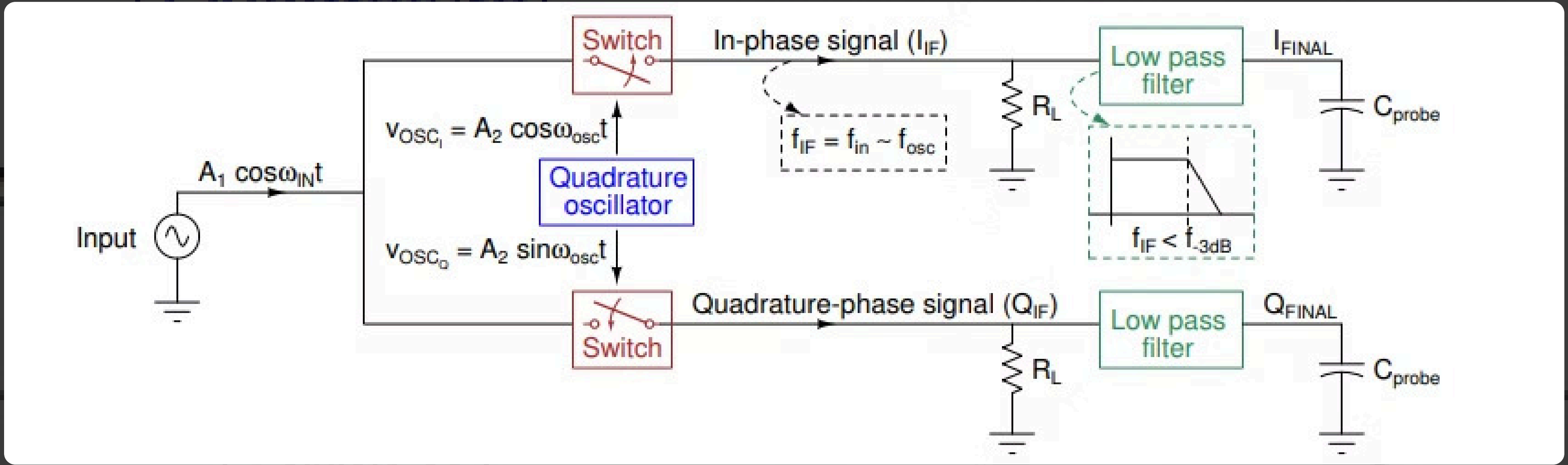
This project is about the workings of a Quadrature Down Converter , along with the 3 blocks which are involved.(LPF,QO and Mixer)

Working of a Quadrature Down Converter:

1. A quadrature downconverter is used to translate high-frequency radio signals (RF) to a lower intermediate frequency (IF) . Its operation relies on the principle of mixing and phase sensitive detection to preserve both amplitude and phase information of the input signal.
2. First, the quadrature downconverter receives an RF signal from the host device.At the same time, the local oscillator generates a reference signal at a frequency close to the RF signal's carrier frequency. This Local Oscillator(LO) signal is split into two components: one in-phase (I) and one phase-shifted by 90 degrees (quadrature, Q).
3. The RF signal is mixed with both the in-phase (I) and quadrature (Q) components of the LO signal using two mixers. This process produces intermediate frequency (IF) signals by subtracting or adding the LO frequency from the RF frequency, depending on the mixer configuration.
4. The I mixer output contains the real part of the downconverted signal, while the Q mixer output contains the imaginary part, shifted by 90 degrees. This relationship between the outputs , helps to preserve the phase information of the RF signal.
5. The outputs from the I and Q mixers are passed through low-pass filters to remove high-frequency components and retain the desired IF or baseband signals.

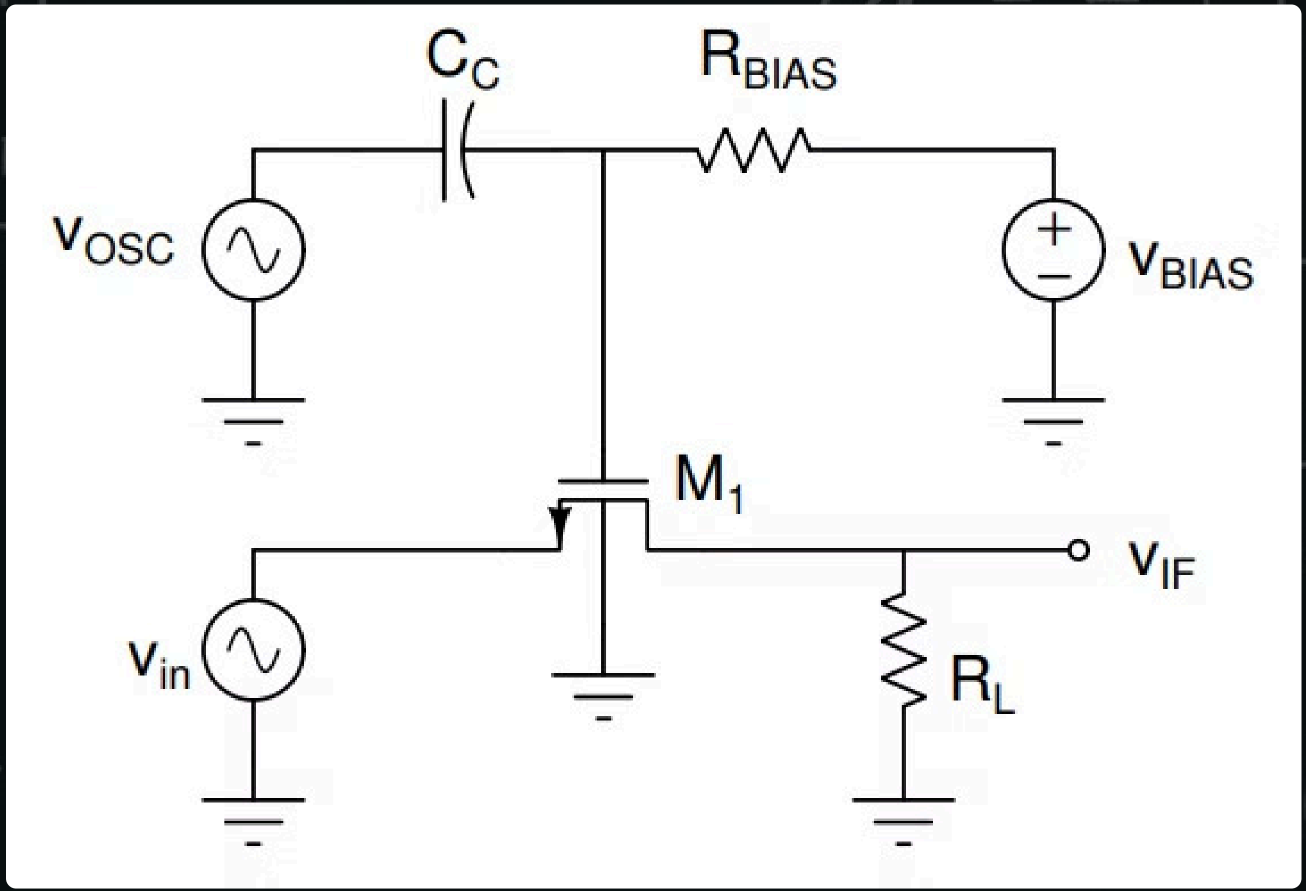
Quadrature downconverters are widely used in software-defined radios, wireless receivers, and radar systems.

Full Circuit



Block 1 - Mixer

A switch mixer modulates an input signal by rapidly switching it with a local oscillator signal, effectively performing frequency translation through a series of on-off operations.



Inputs Given to the block:

- V_{osc} and V_{in}

Outputs from the block:

- V_{IF}

Working of a mixer

- Mixer circuits function by multiplying two input signals, with the output being the product of these inputs.
- The NMOS device operates effectively as a mixer when it is in the linear region, where the input signals are applied to the gate and source, and the output is extracted from the drain.
- Visualize the NMOS as a water tap: when off ($V_{gs} < V_{TH}$), no current (water) flows; when fully open ($V_{gs} \gg V_{TH}$), current (water) flows freely with minimal variation from small pressure (signal) changes; when slightly open, small pressure changes (signals) result in significant flow changes, which is ideal for mixing.
- To achieve this behavior, V_{bias} is set close to but not equal to V_{th} at the gate, compensating for the V_{gs} - V_{TH} term in the drain current equation.
- With V_{bias} appropriately set, the expression V_{gs} - V_{TH} can be approximated as V_{osc} - V_{in} , enabling effective signal mixing.

Calcuations for Mixer:

V_{th} was calculated to be 0.57 V from LT Spice Simulations

Coupling capacitance C_c is just used to block the dc component of the output from the quadrature oscillator. So, we took a value of 100 pF. Impedance due to this capacitance (X_{Cc}) = 1/2π*f*C which is nearly 15.9 kΩ. To ensure minimal signal loss through R_{bias} (so most AC goes into NMOS): Rbias >= 10 * (X_{Cc}). So, we take R_{bias} to be a value greater than 159 kΩ. Hence, we took 200 kΩ.

1. $V_g = V_{BIAS} + V_{OSC}$

2. $V_s = V_{in}$

3. $V_{gs} - V_{TH} = V_{BIAS} + V_{OSC} - V_{in} - V_{TH}$

4. Considering $V_{BIAS} = V_{TH} \Rightarrow V_{gs} - V_{TH} = V_{OSC} - V_{in}$

5. If $V_{OSC} - V_{in} < 0 \Rightarrow I_{DS} = 0 \Rightarrow$ MOSFET in Cut-off

6. If $V_{OSC} - V_{in} > 0 \Rightarrow$ MOSFET in Triode

Here, MOSFET never enters Saturation since:

7. $V_{DS} = V_{out} - V_{BIAS} - V_{OSC}$

8. For the MOSFET to be in Saturation: $V_{DS} > V_{gs} - V_{TH}$ (not satisfied)

9. $I_{DS} = \mu_n C_{OX} \frac{W}{L} \left[(V_{gs} - V_{TH}) V_{DS} \right]$

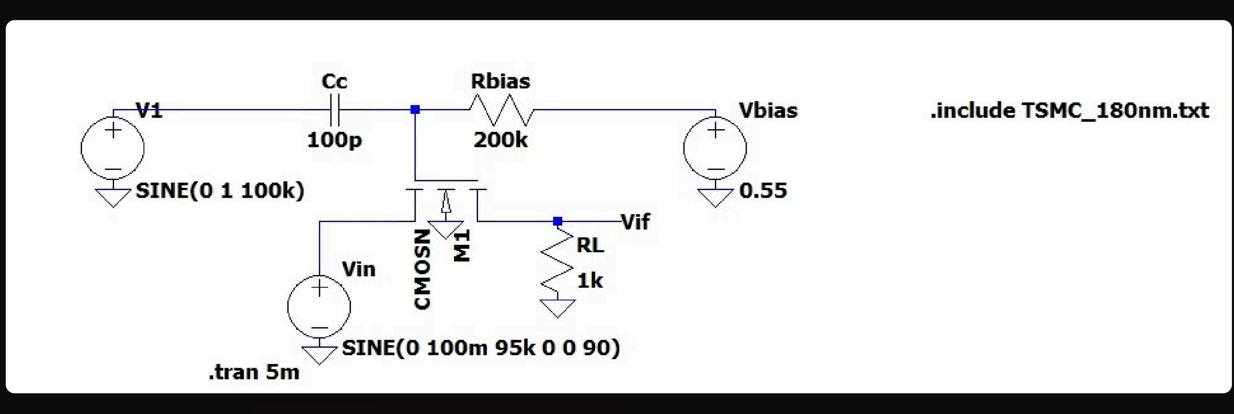
10. $V_{out} = I_{DS} R_L = k_n R_L \left[(V_{gs} - V_{TH}) V_{DS} \right]$

11. $V_{gs} - V_{TH} = V_{OSC} - V_{in}, \quad V_{DS} = V_{out} - V_{in}$

12. $V_{out} = k_n R_L \left[(V_{OSC} - V_{in})(V_{out} - V_{in}) \right]$

14. Assuming $V_{OSC} \gg V_{in} \gg V_{out} \Rightarrow V_{out} \approx k_n R_L V_{OSC} V_{in}$

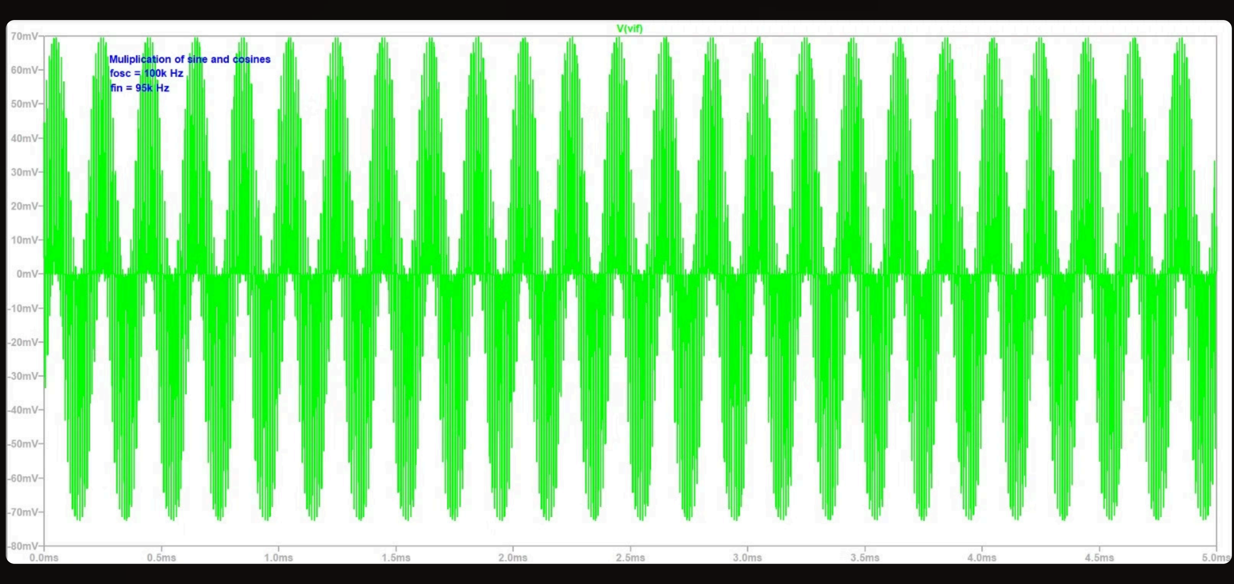
LT SPICE SIMULATIONS FOR THE MIXER



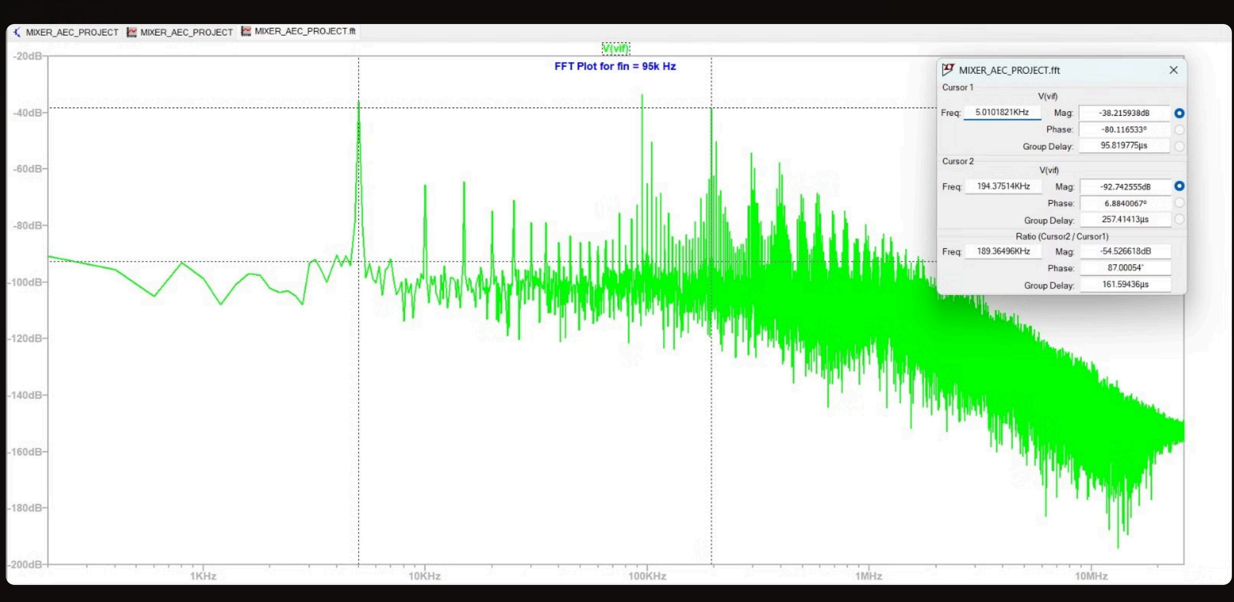
The below simualtions show the outputs of the above circuit for different fin :

1. fin = 95kHz

Transient Analysis of Circuit

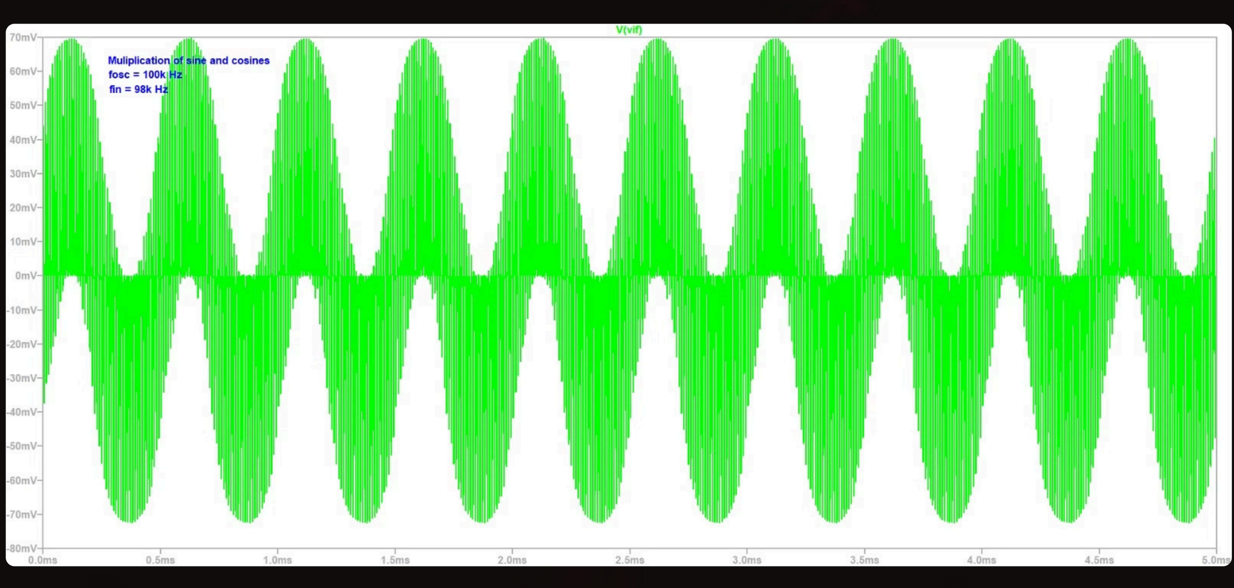


FFT



2. fin = 98kHz

Transient Analysis of Circuit



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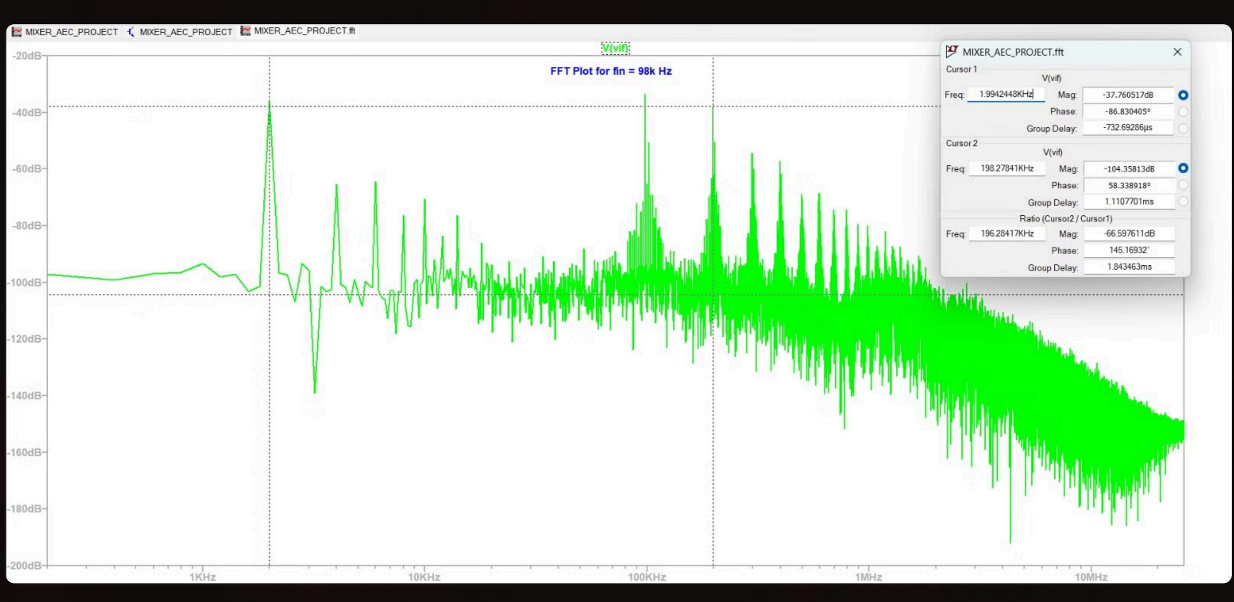
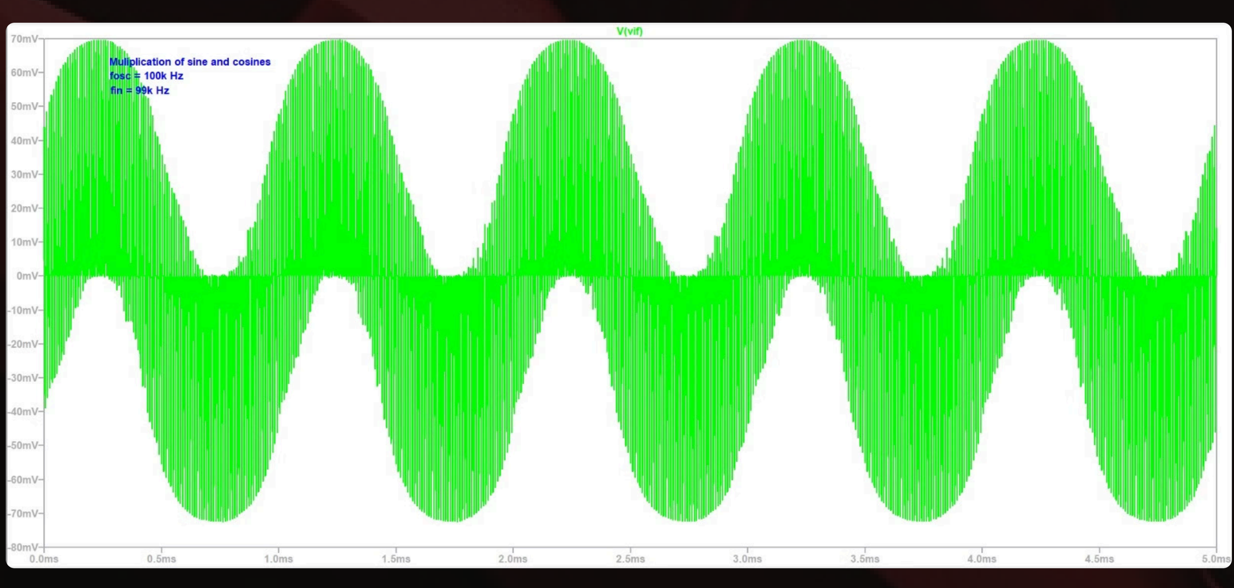


3.fin = 99kHz

Transient Analysis of Circuit



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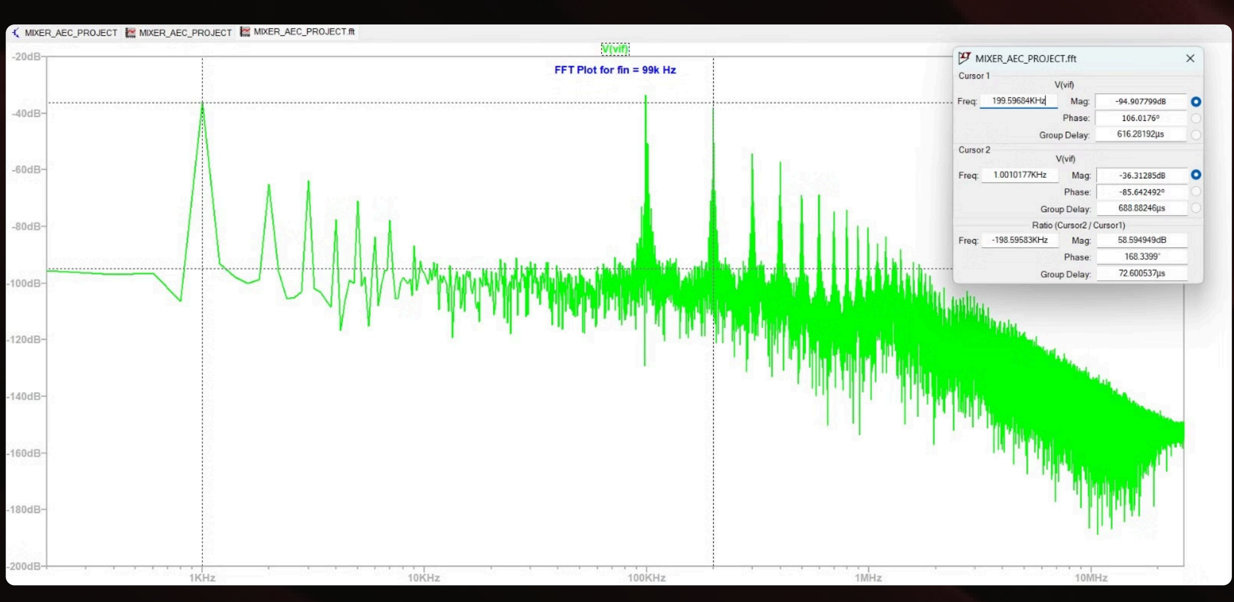
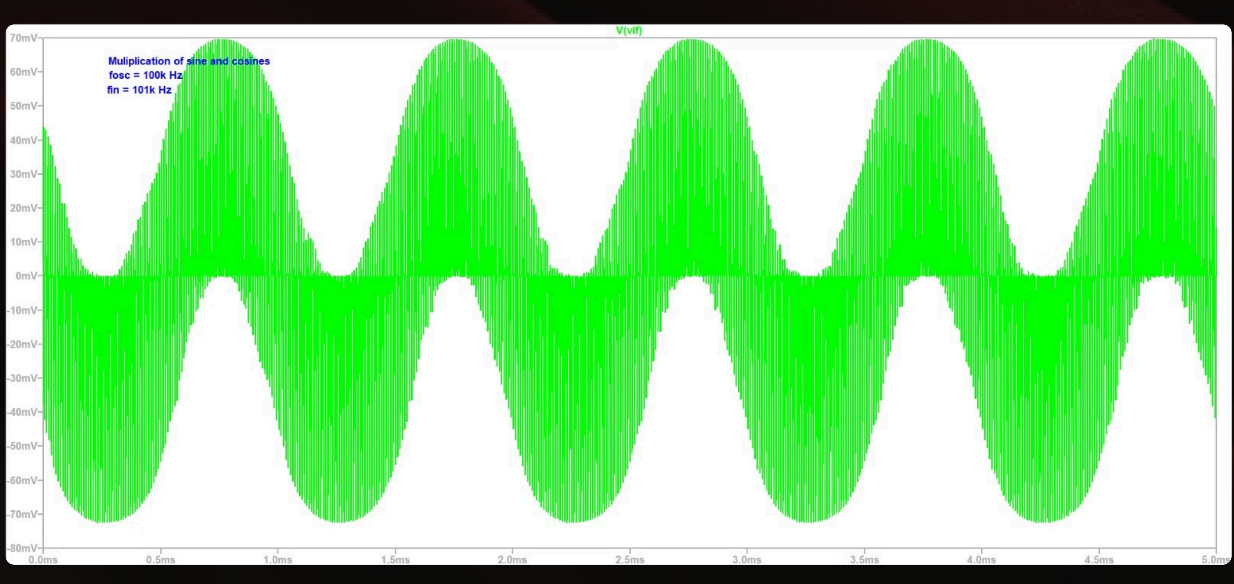


4.fin = 101kHz

Transient Analysis of Circuit



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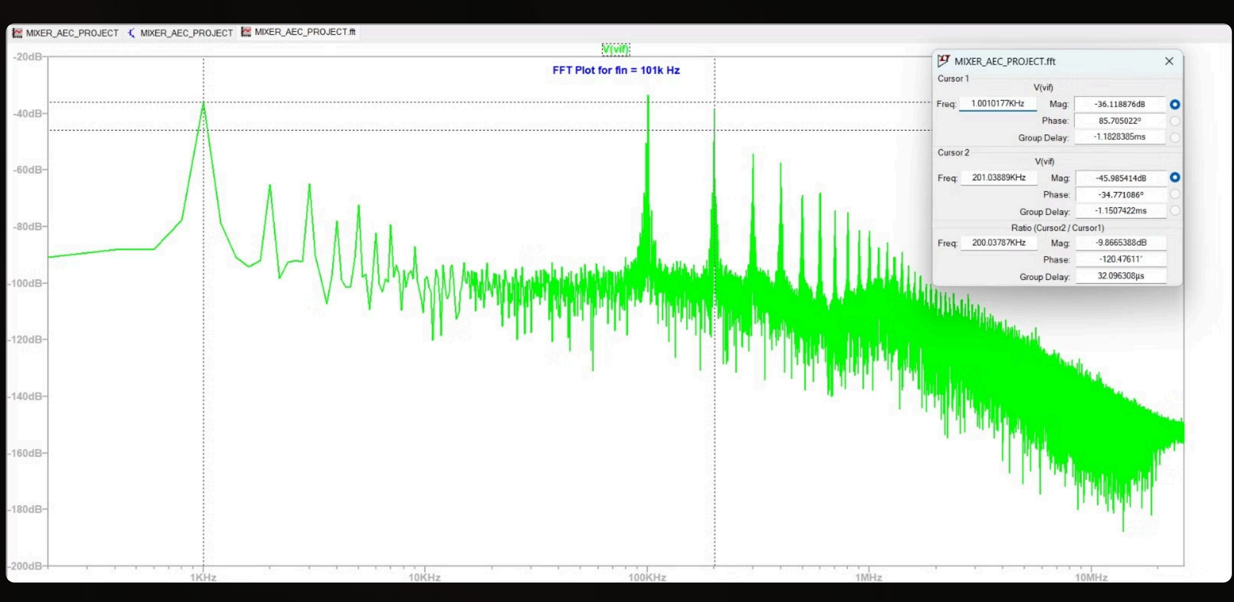
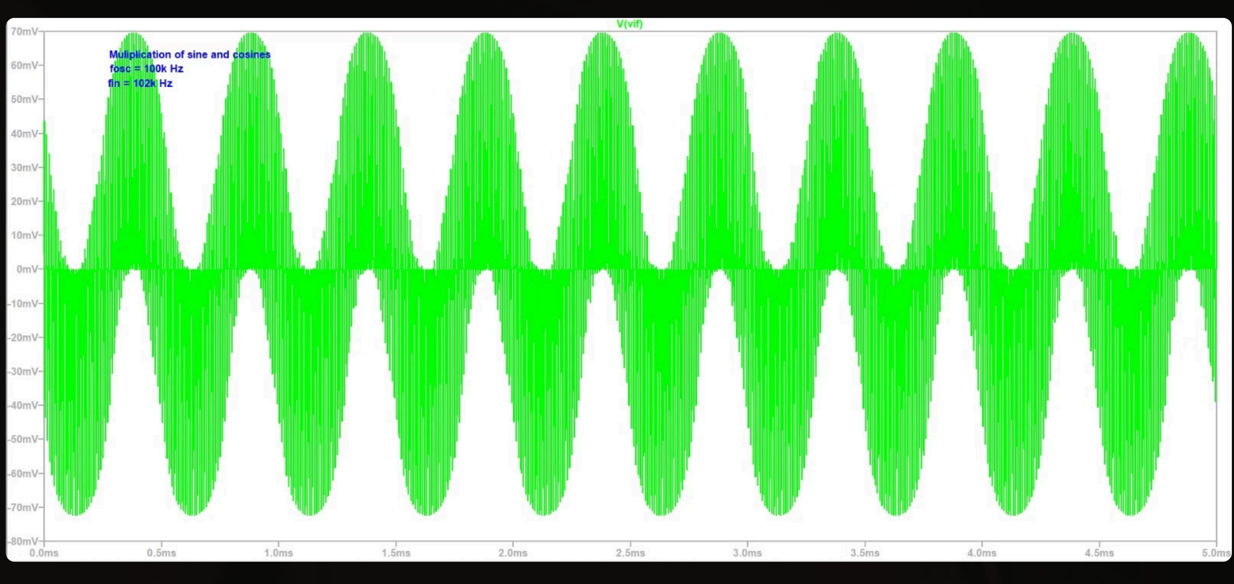
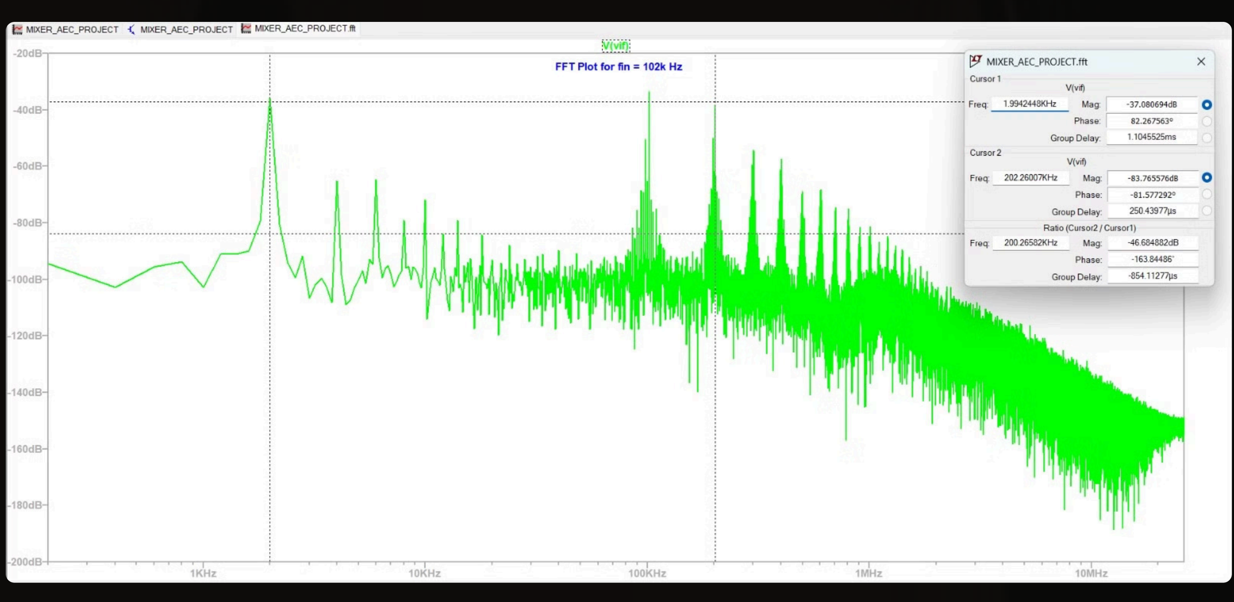


5.fin = 102KHz

Transient Analysis of Circuit

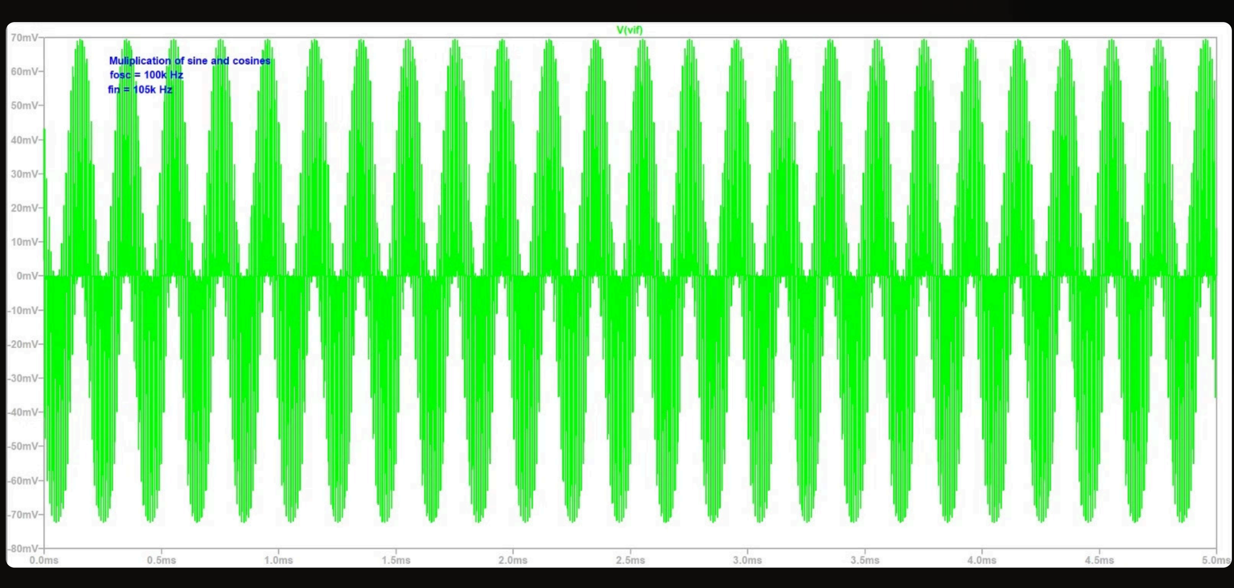


FFT

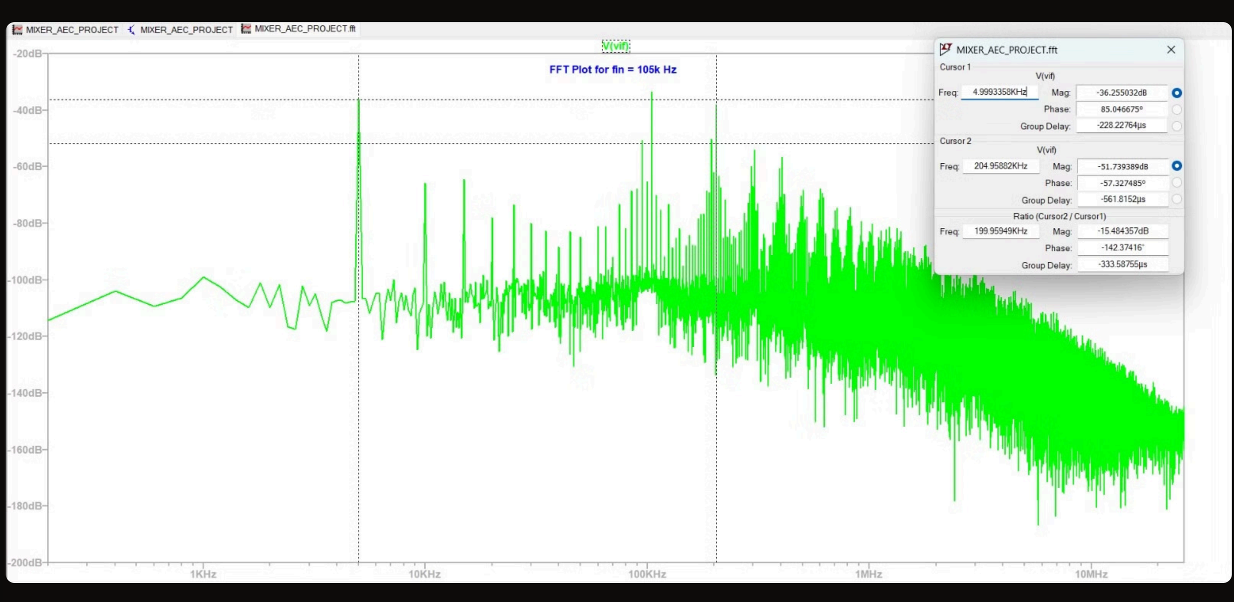


6.fin = 105KHz

Transient Analysis of Circuit



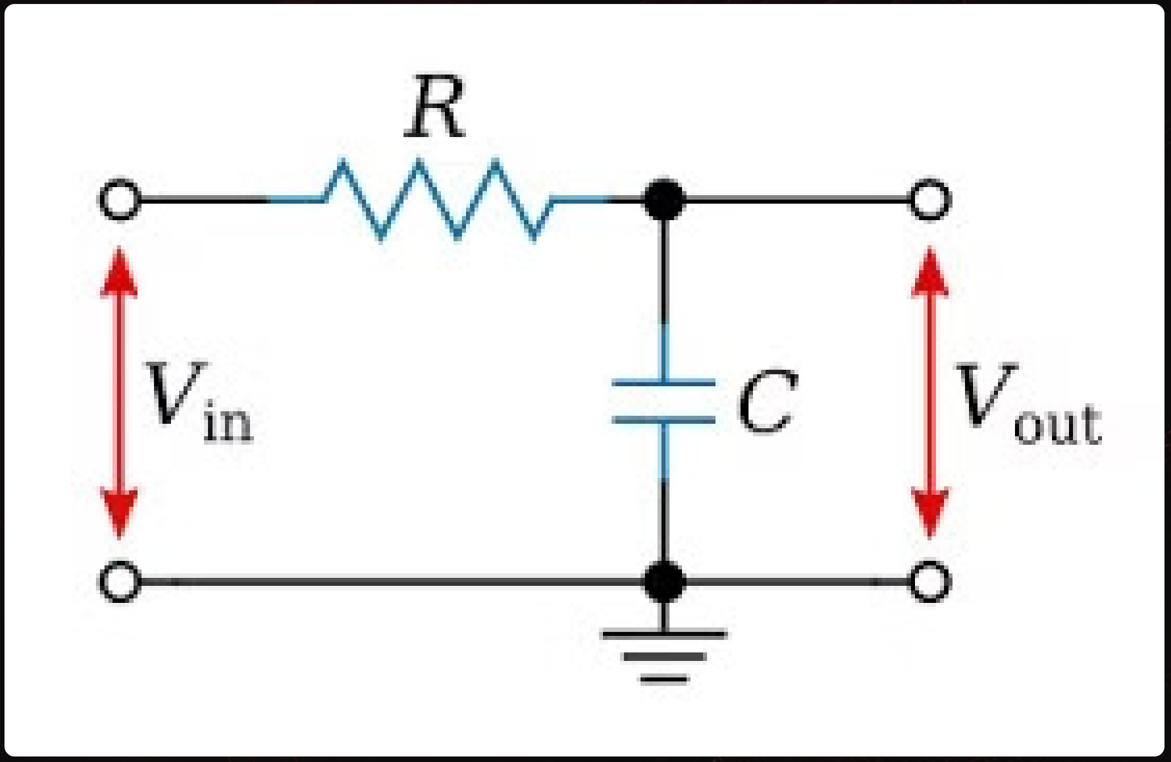
FFT



The other frequencies in the FFT plot are due to non-linearity of the mos and the many approximations we took which are valid for transient analysis, but cannot be ignored in FFT because it gives the frequencies which have that frequency component in the signal.

Block 2 -Low Pass Filter

A low pass filter allows signals with a frequency lower than a specified cutoff frequency to pass through while attenuating higher frequencies. It's commonly used to remove noise or smooth signals in electronic circuits.



Inputs Given to the block:

- V_{IF}

Outputs from the block:

- V_{IFinal}

Working of a Low Pass Filter

In the context of the project, the low pass filter is assigned a specific bandwidth to allow only the required signal to pass through it. The below is the working mechanism for the above cirucit block:

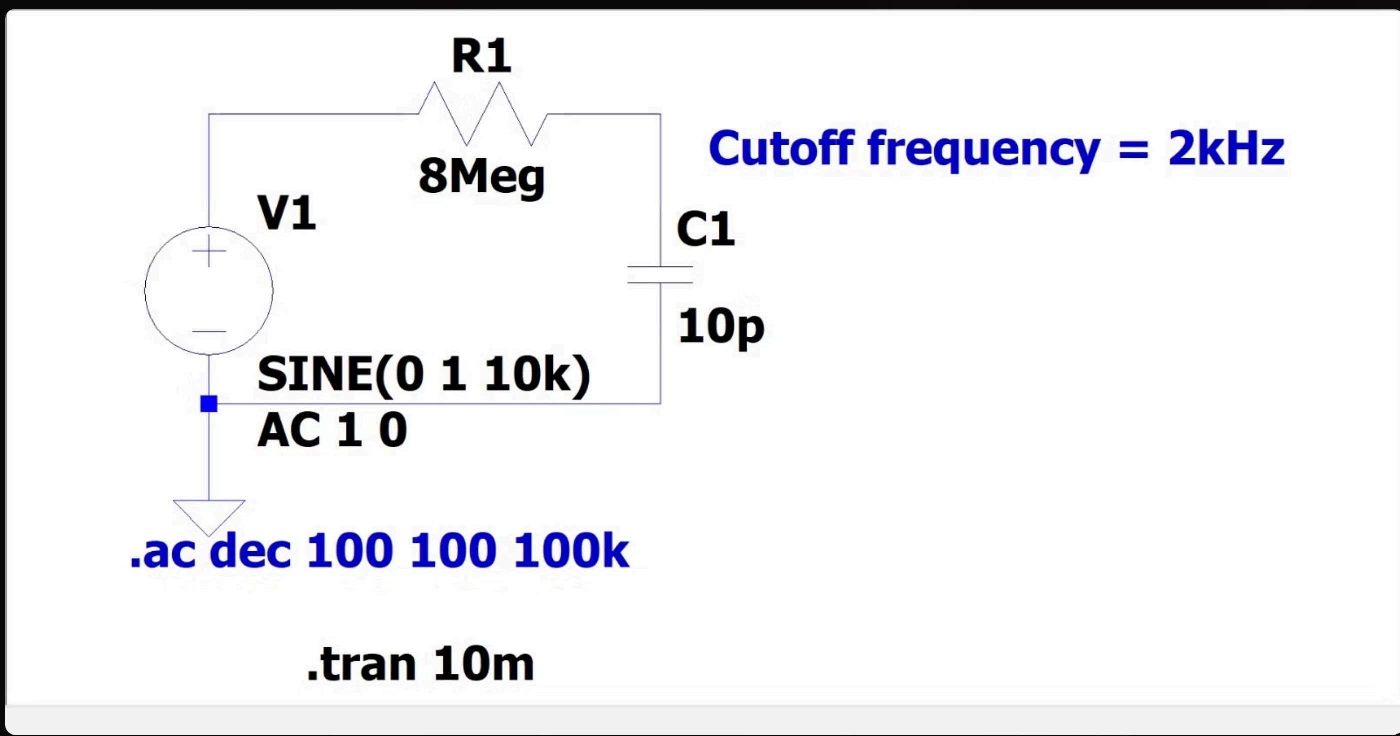
1. The LPF is used after the mixing stage to filter out unwanted high-frequency signals, such as the sum frequency components generated during the multiplication of the input signal with the local oscillator (LO).
2. The cutoff frequency of the LPF determines the bandwidth of the down-converted signal. In a quadrature down-converter project.In our project , since it is a down converter, we need the required signal to have the difference in frequencies , whereas in other applications , the LPF can also be used to segregate other signals from the mixer based on requirements.
3. By limiting the frequency content before any subsequent sampling, the LPF helps prevent aliasing, which is the misinterpretation of the signals, which can often lead to signal reconstruction errors which in our case happens in the I and Q signals.
4. The LPF is also used to increase the amount of signal obtained , even after the introduction of noise from external sources.

Required Cutoff Frequency = 2KHz

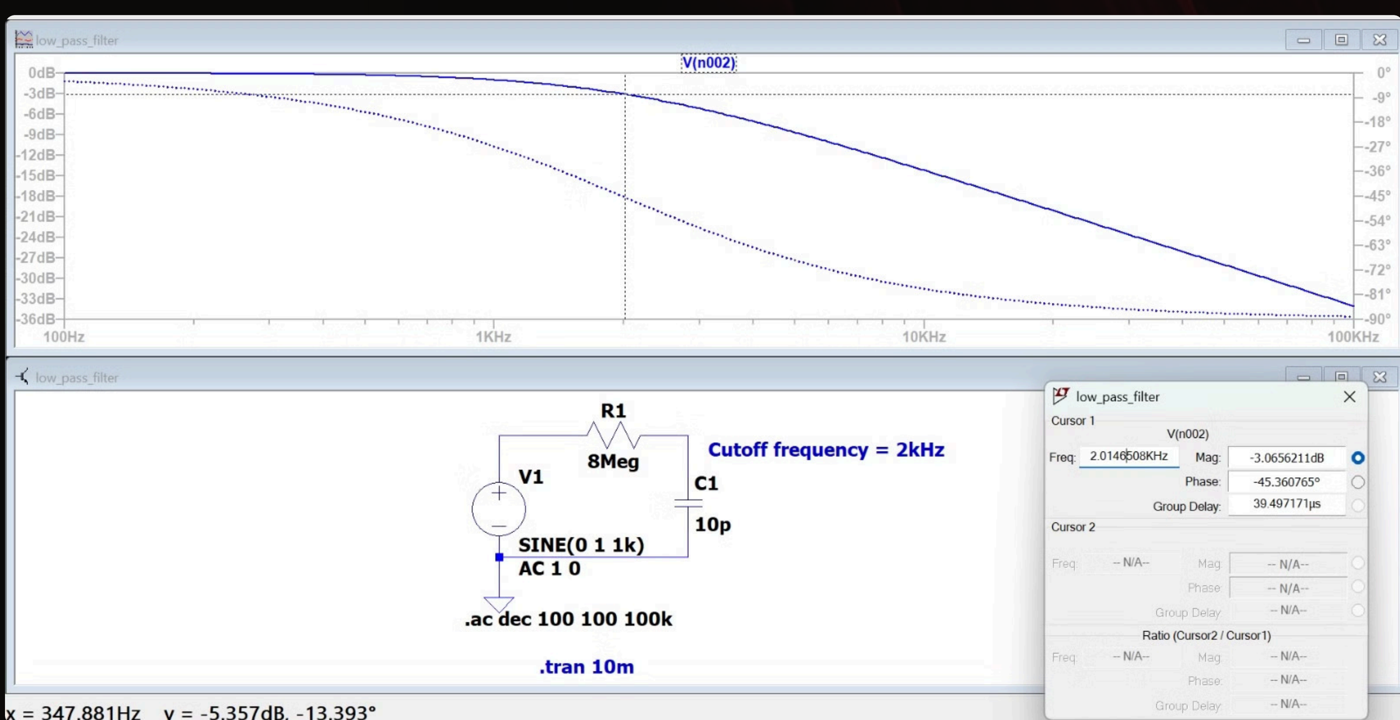
Formual fo Cutoff Frequency = $\frac{1}{2\pi RC}$

LT SPICE Simulations for the LPF

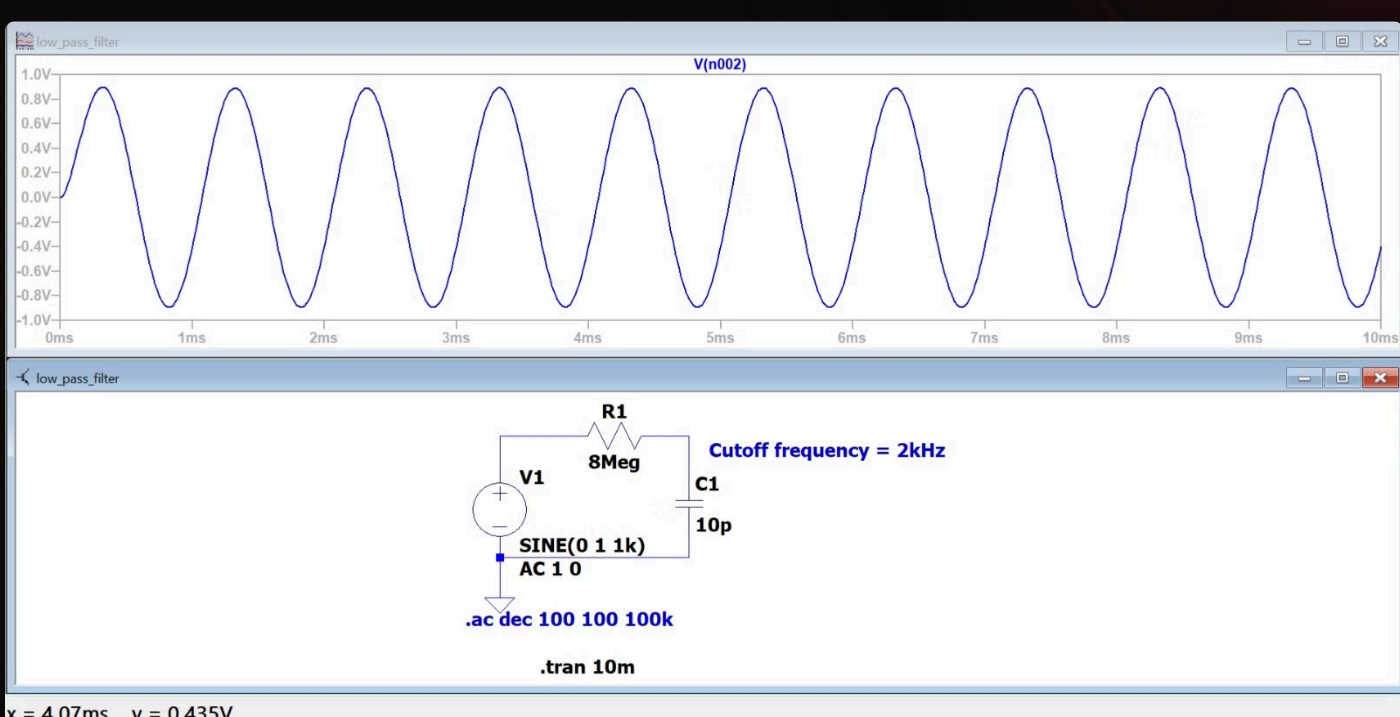
1. Circuit Diagram



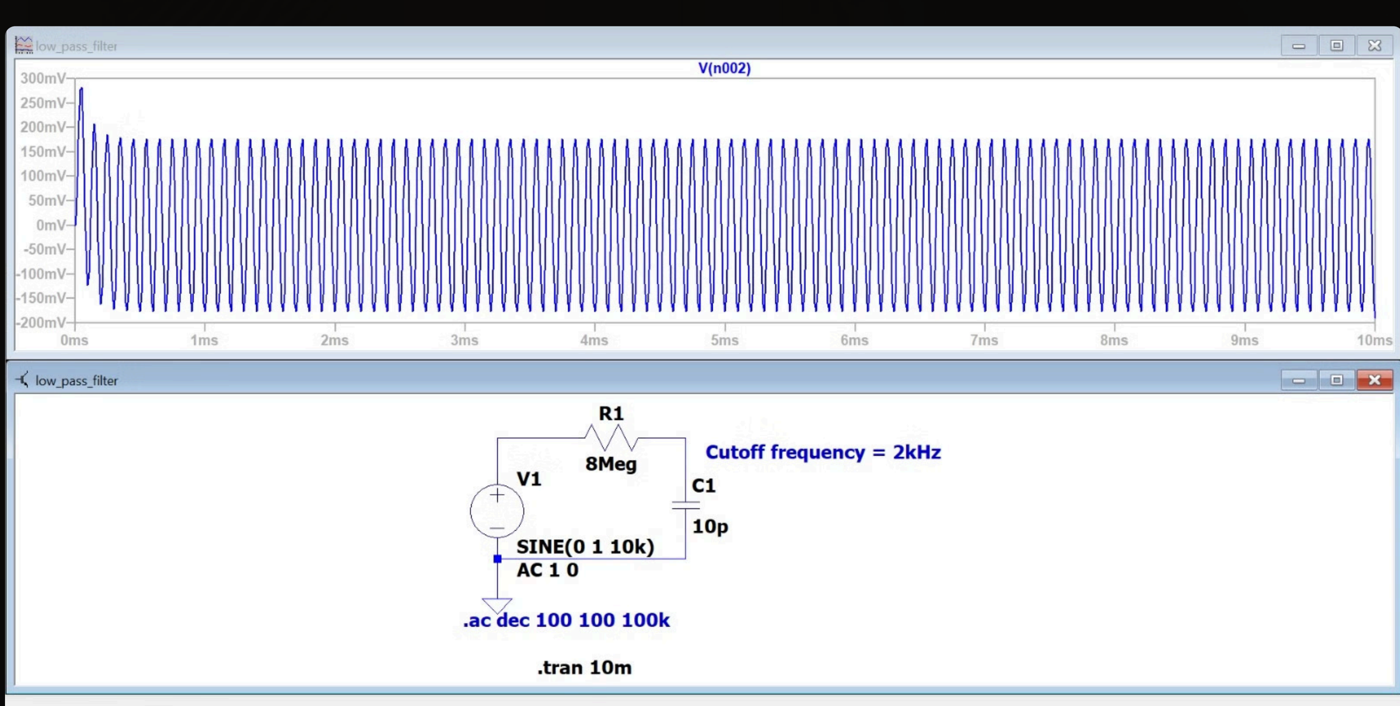
2. AC- Analysis of Low Pass Filter



3. Transient Analysis at 1KHz



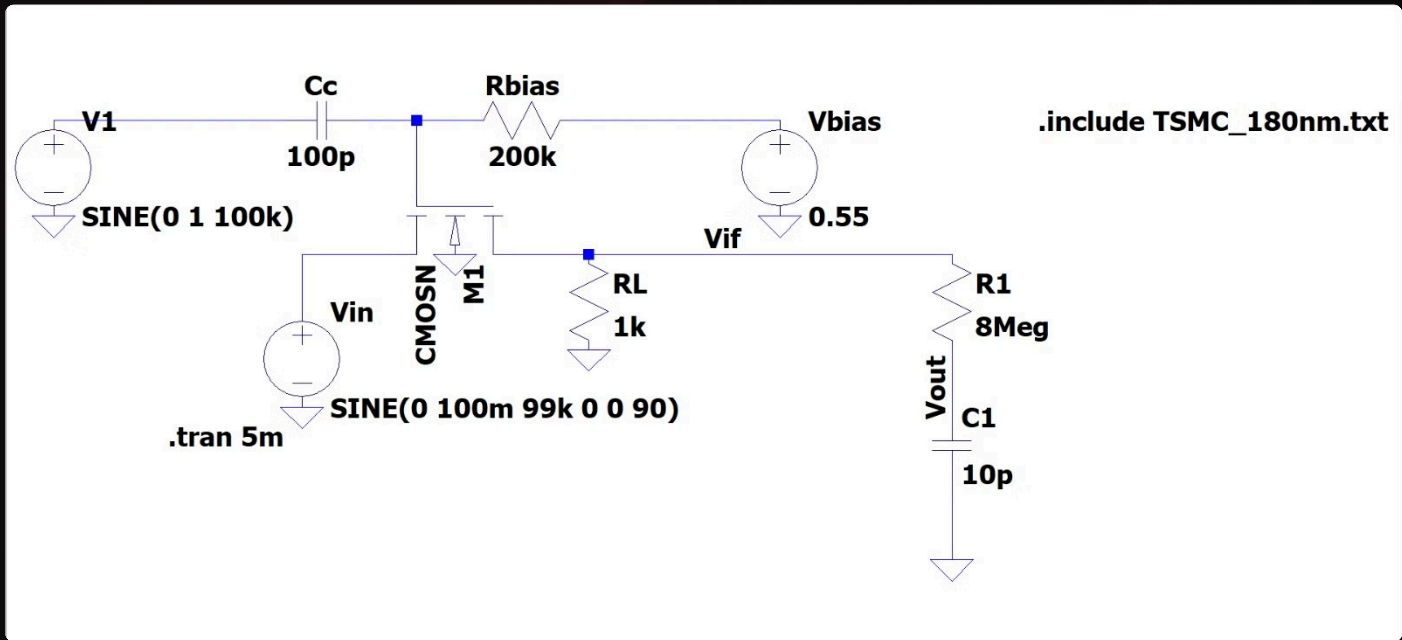
4. Transient Analysis at 10KHz



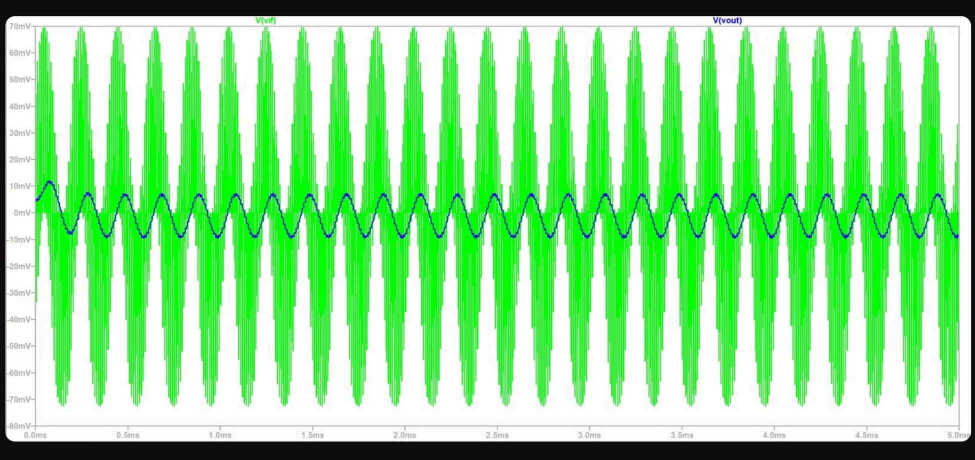
Combined Circuit of LPF and Mixer

LT SPICE Simulations

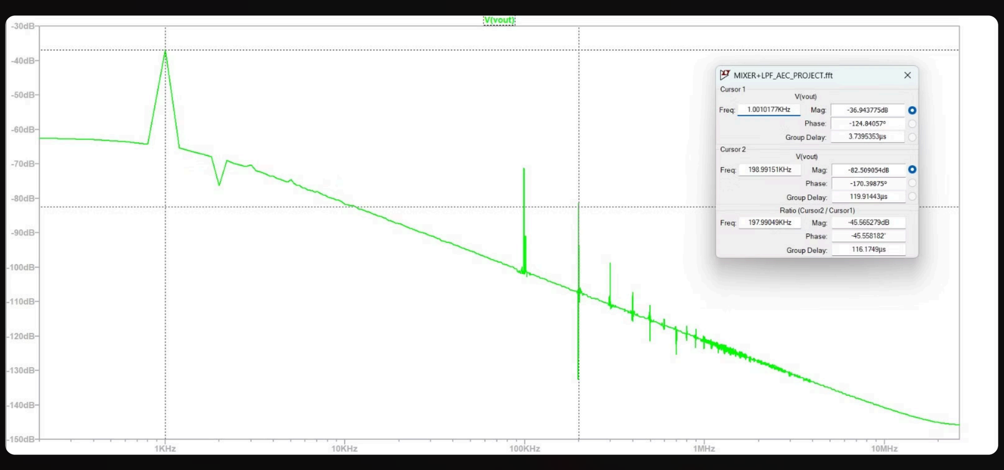
Circuit Made



For fin = 95KHz

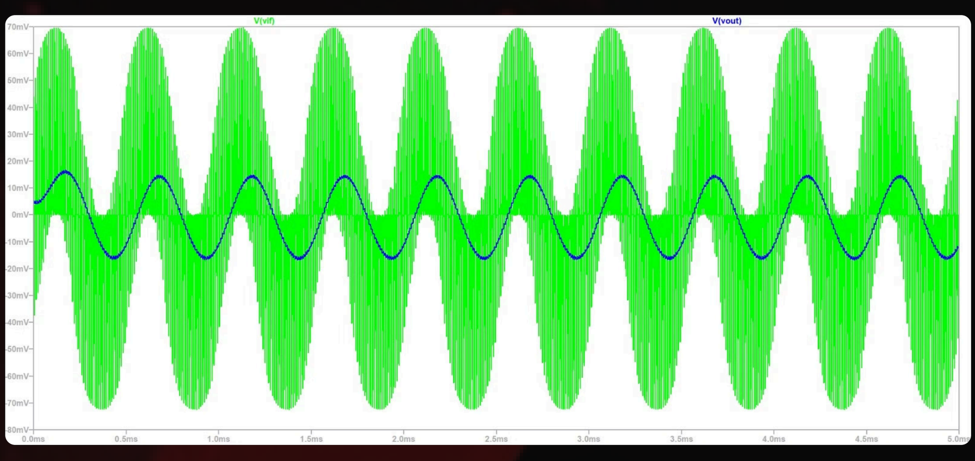


Transient Analysis of the Circuit

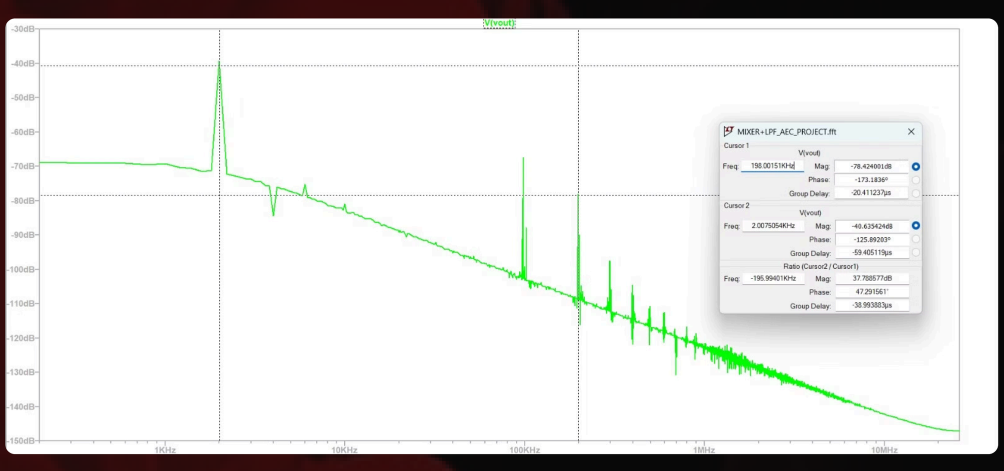


FFT of the above analysis

For fin = 98KHz

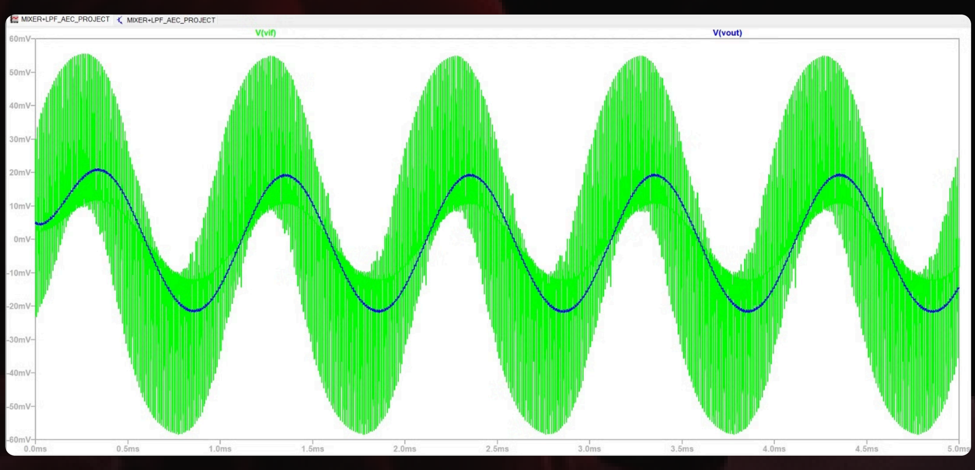


Transient Analysis of the Circuit

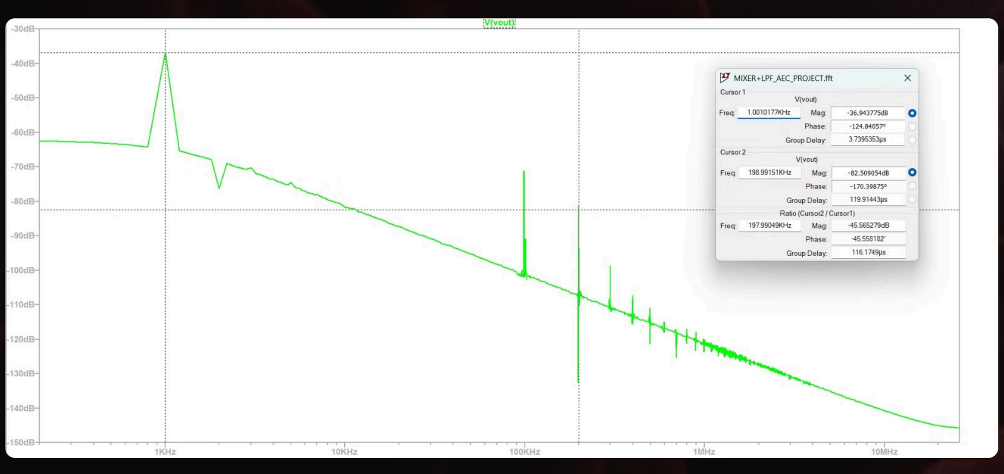


FFT of the above analysis

For fin = 99KHz

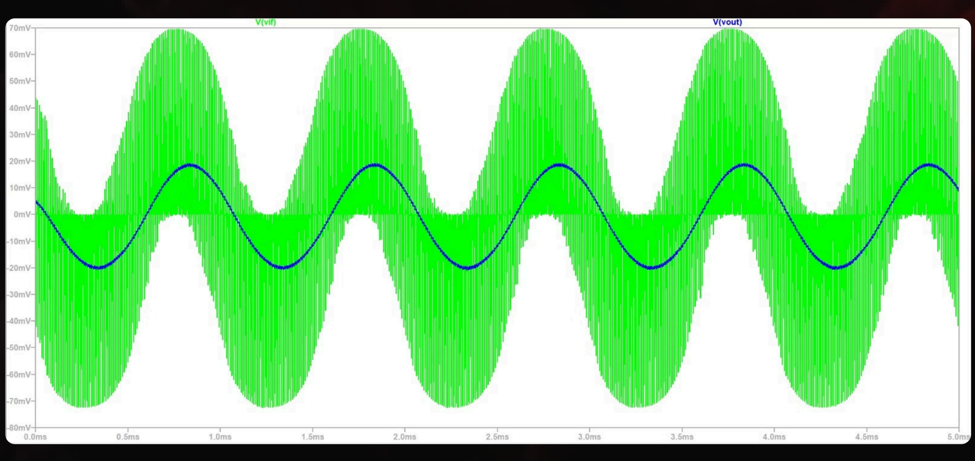


Transient Analysis of the Circuit

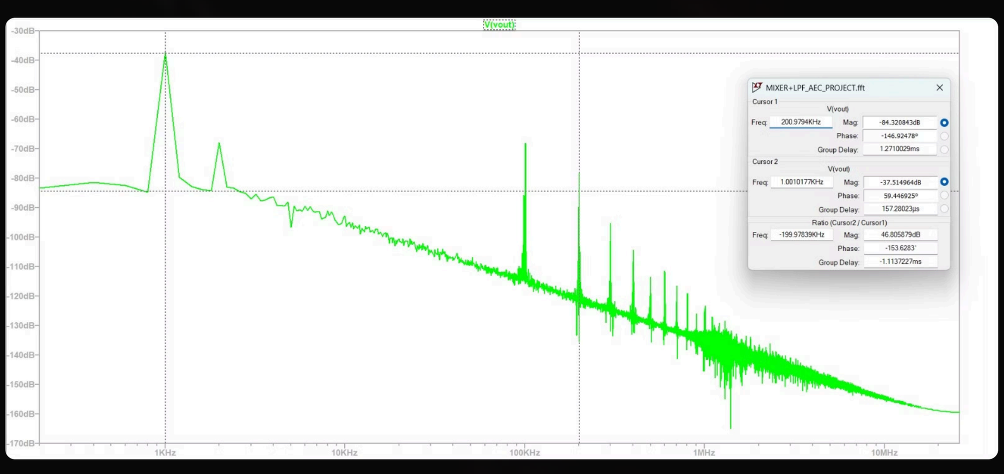


FFT of the above analysis

For fin = 101KHz

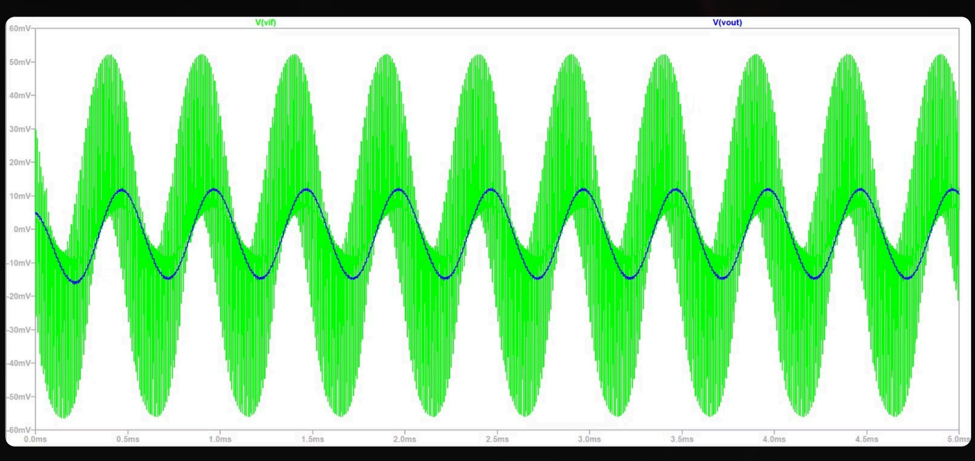


Transient Analysis of the Circuit

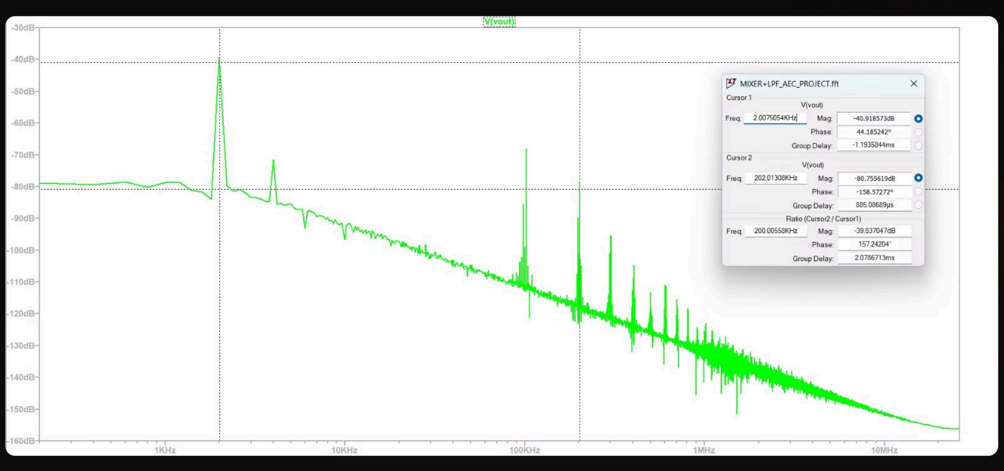


FFT of the above analysis

For fin = 102KHz

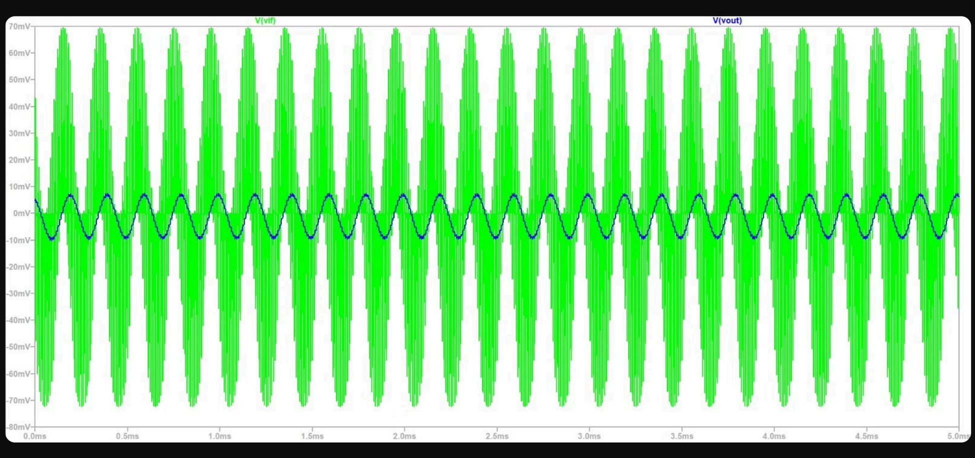


Transient Analysis of the Circuit

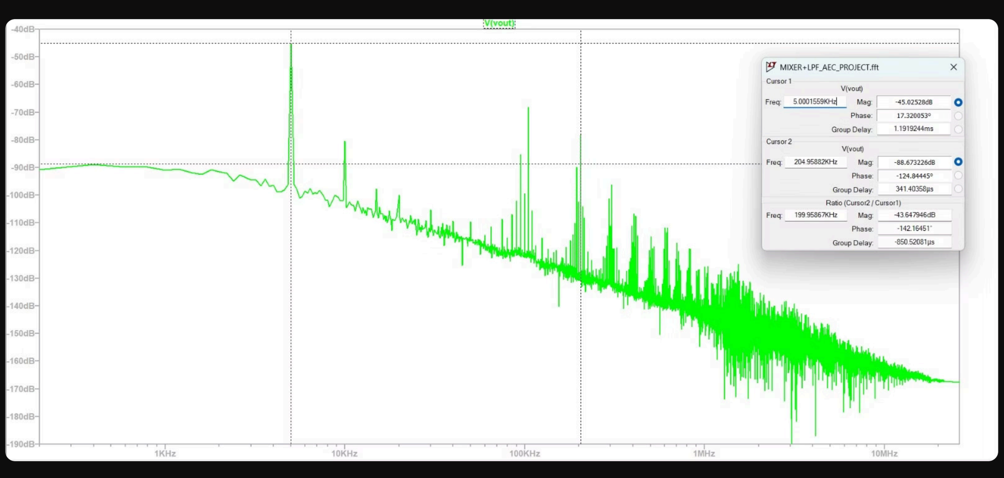


FFT of the above analysis

For fin = 105KHz



Transient Analysis of the Circuit



FFT of the above analysis

Future Goals

1. Understanding the working of an op amp upto some extent to build the third block.
2. Completing the remaining circuit block of the project(Quadrature Oscillator)
3. Making the full circuit with the three circuit blocks and testing its working.

References

1. **Basic concept of RF mixer:** https://youtu.be/rL6tc5SF-_8?si=hECQSO_6w8Plp3NB
2. **Frequency Mixer:** https://www.youtube.com/watch?v=locK_caODik