



GOVERNMENT COLLEGE OF TECHNOLOGY – COIMBATORE

Proposal: Design and Simulation of Dual Readout Analog Frontend for Silicon Photomultiplier Sensors

PRESENTED BY

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ABSTRACT

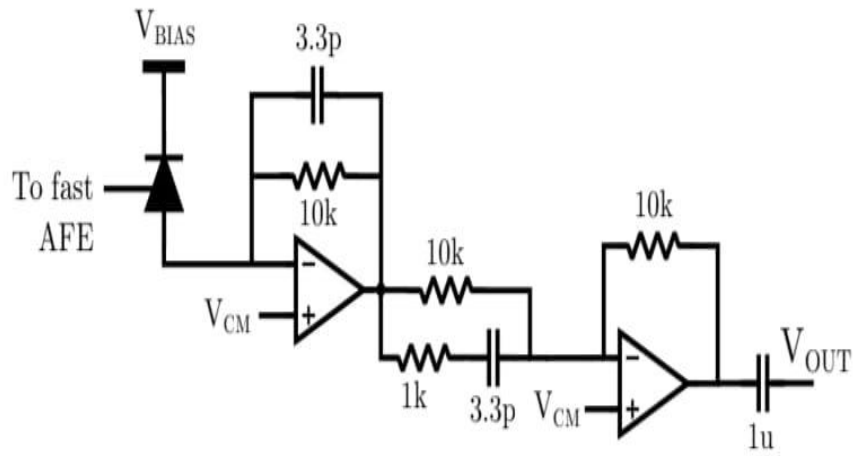
Silicon Photomultipliers (SiPMs) are highly sensitive solid-state photodetectors used in applications such as medical imaging, radiation detection, high-energy physics and LiDAR. This project focuses on the design and simulation of a dual-readout analog front-end (AFE) for SiPM sensors using the KiCad and eSim open-source EDA environment. The proposed AFE consists of two complementary signal-processing paths: a standard output path for amplitude-oriented processing and a fast output path for timing-oriented signal processing. Both circuits were implemented and evaluated using SPICE-based frequency-domain simulations. The obtained frequency responses demonstrate the frequency-dependent behavior of the two paths and provide a basis for further optimization of the circuit parameters. The work demonstrates the feasibility of implementing and analyzing a dual-readout SiPM AFE using an open-source simulation workflow.

INTRODUCTION

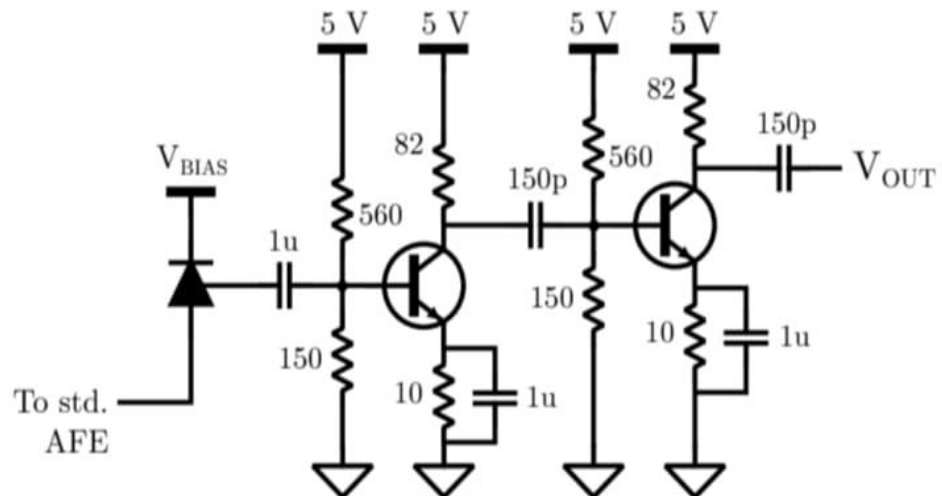
Silicon Photomultipliers (SiPMs) are solid-state photon detectors capable of producing electrical current pulses in response to very small optical signals. Their high sensitivity and fast response make them attractive for instrumentation where both the magnitude of a detected event and its arrival time are important. A single readout chain may be optimized mainly for amplitude accuracy or speed. A dual-readout architecture addresses this limitation by processing the same sensor signal through two complementary paths. The present work implements this concept using KiCad for schematic capture and eSim for SPICE-based simulation. The standard output path is intended for amplitude-oriented signal conditioning, while the fast output path is intended to retain rapid signal variations for timing analysis.

BLOCK DIAGRAM

STANDARD PATH:



FAST PATH:



WORKING PRINCIPLE

Standard Output Path

1. The input signal representing the SiPM output is applied to the **first op-amp stage**.
2. The input signal is processed by the op-amp through its **feedback network**, which provides signal conditioning and frequency-dependent response.
3. The output of the first stage is transferred to the **second op-amp stage** through an intermediate coupling and conditioning network.
4. The second op-amp further processes the signal and provides additional signal conditioning.
5. The processed signal is **AC-coupled to the output**, removing the unwanted DC component before the final output.
6. The resulting signal is obtained at **VOUT** as the standard readout signal.

Fast Output Path

1. The input signal is applied to the **first transistor amplifier stage** through an input coupling network.
2. The coupling network allows the varying detector signal to enter the amplifier while isolating the DC component.
3. The transistor biasing network establishes the required **operating point** for the first amplifier stage.
4. The first transistor amplifies the input signal, with the emitter network providing the required AC response.
5. The amplified signal is transferred to the **second transistor stage** through an inter-stage coupling network.
6. The second transistor further amplifies and processes the signal, particularly preserving the rapid variations of the input signal.
7. The processed signal is coupled to the output through the output coupling network.
8. The resulting signal is obtained at **VOUT** as the fast readout signal.

Overall Operation

1. The detector signal is processed simultaneously through **two independent readout paths**.
2. The **standard path** uses cascaded op-amp stages for signal conditioning and amplitude-oriented readout.
3. The **fast path** uses cascaded transistor stages to process rapid signal variations for timing-oriented readout.
4. The two outputs can be analyzed independently to obtain **complementary information about the detected SiPM signal**.

DESIGN OF DUAL READOUT ANALOG FRONTEND SILICON PHOTO MULTIPLIER SENSORS

1. Define the SiPM input signal

An AC input source is used to represent the electrical signal generated by the SiPM.

2. Design the Standard Readout Path

Two cascaded **LM741 op-amp stages** are used for signal conditioning and amplification.

3. Set the Standard-Path Parameters

The feedback and signal-conditioning networks are selected as:

- $R1 = 10\text{ k}\Omega$, $C1 = 3.3\text{ pF}$
- $R2 = 10\text{ k}\Omega$
- $R3 = 1\text{ k}\Omega$, $C2 = 3.3\text{ pF}$
- $R4 = 10\text{ k}\Omega$
- Output capacitor $C3 = 1\text{ }\mu\text{F}$
- Load resistance = $100\text{ }\Omega$
- Op-amp bias/reference = 2.5 V
- Op-amp supply = $\pm 15\text{ V}$

4. Design the Fast Readout Path

Two cascaded **transistor amplifier stages** are used to process the rapid variations of the SiPM signal.

5. Set the Fast-Path Parameters

The transistor stages are implemented with:

- Collector resistors = $560\text{ }\Omega$ and $82\text{ }\Omega$
- Bias resistors = $150\text{ }\Omega$
- Emitter resistors = $10\text{ }\Omega$
- Input coupling capacitor = $1\text{ }\mu\text{F}$
- Inter-stage coupling capacitor = 150 pF
- Output coupling capacitor = 150 pF
- Emitter bypass capacitors = $1\text{ }\mu\text{F}$
- Supply voltage = 5 V

6. Implement the Circuits in KiCad/eSim

The selected components, sources, biasing networks and ground connections are assembled according to the designed schematics.

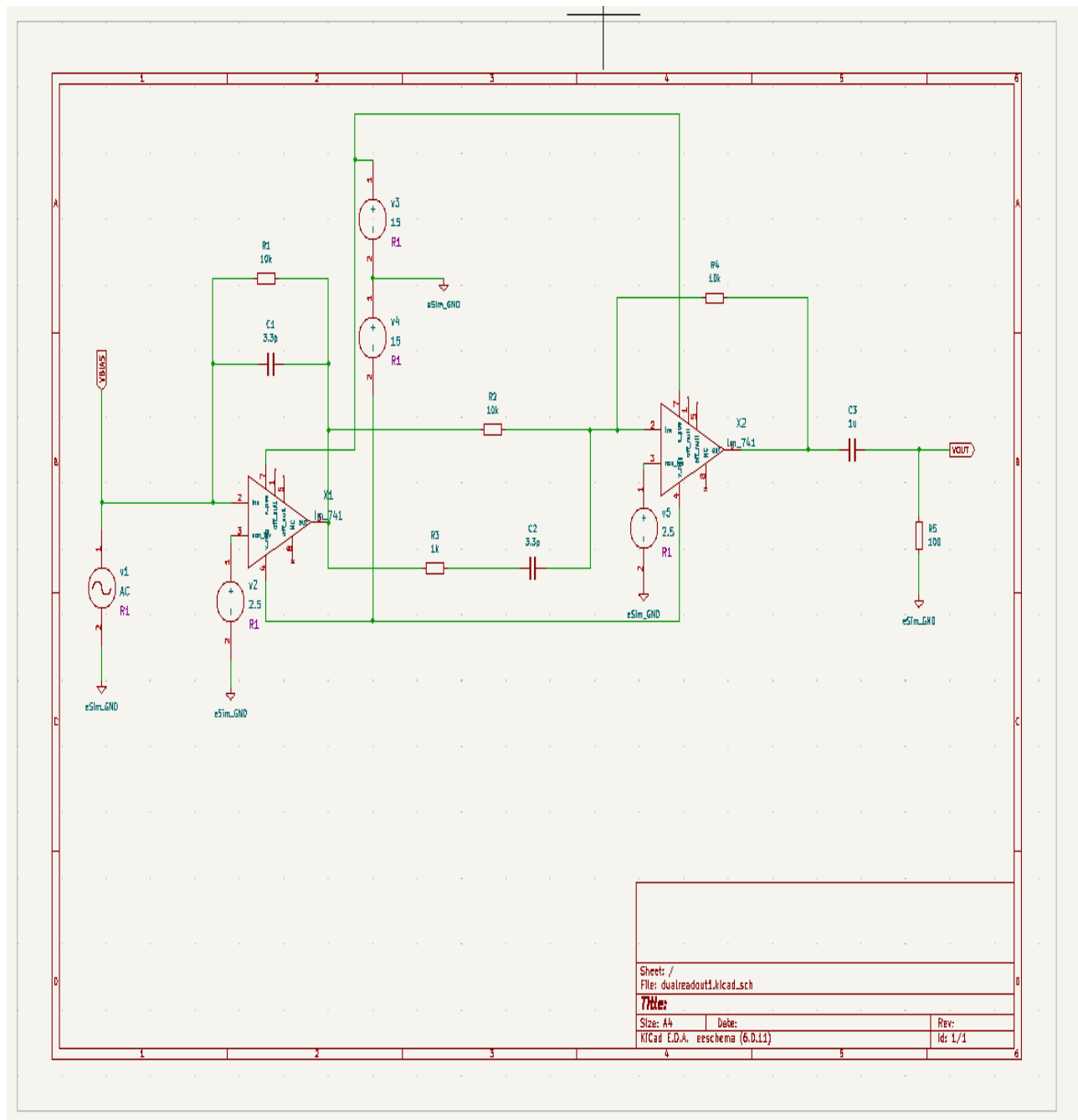
7. Perform AC Simulation

Both circuits are simulated over the selected frequency range to obtain the **VOUT frequency response**.

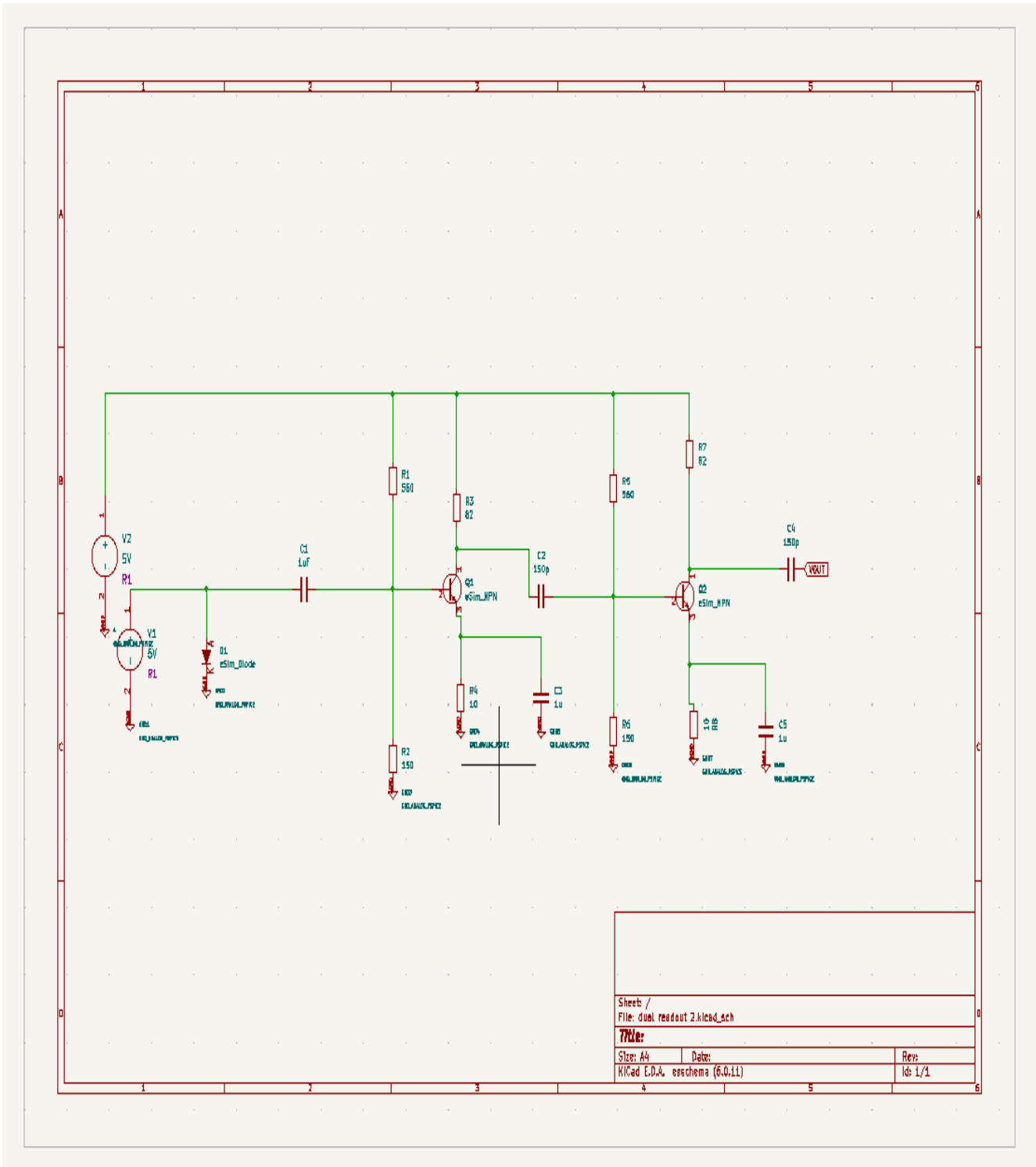
8. Analyze and Compare the Results

The simulated standard and fast responses are plotted and compared to evaluate their complementary **amplitude-oriented and timing-oriented characteristics**.

STANDARD PATH:

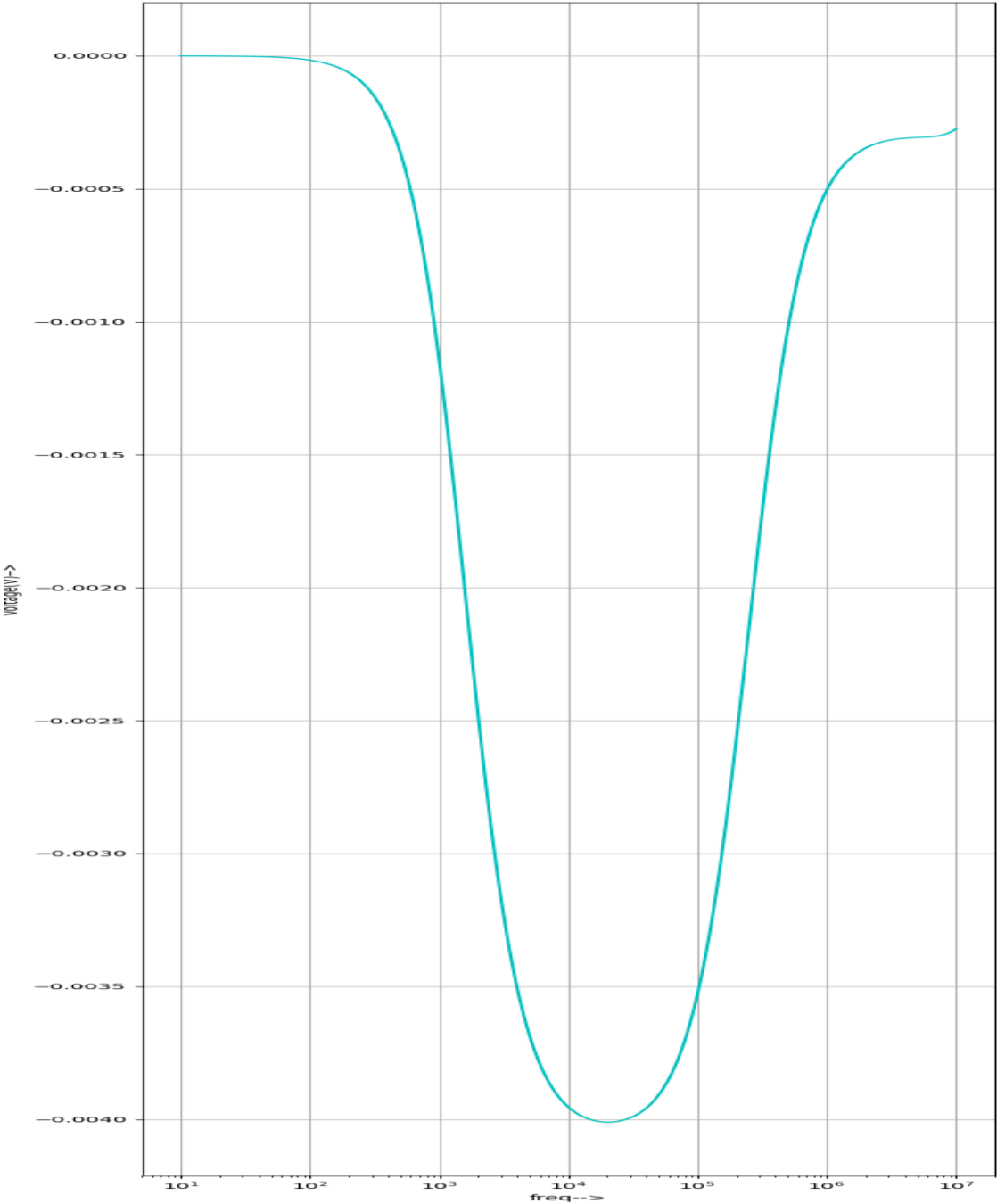


FAST PATH:

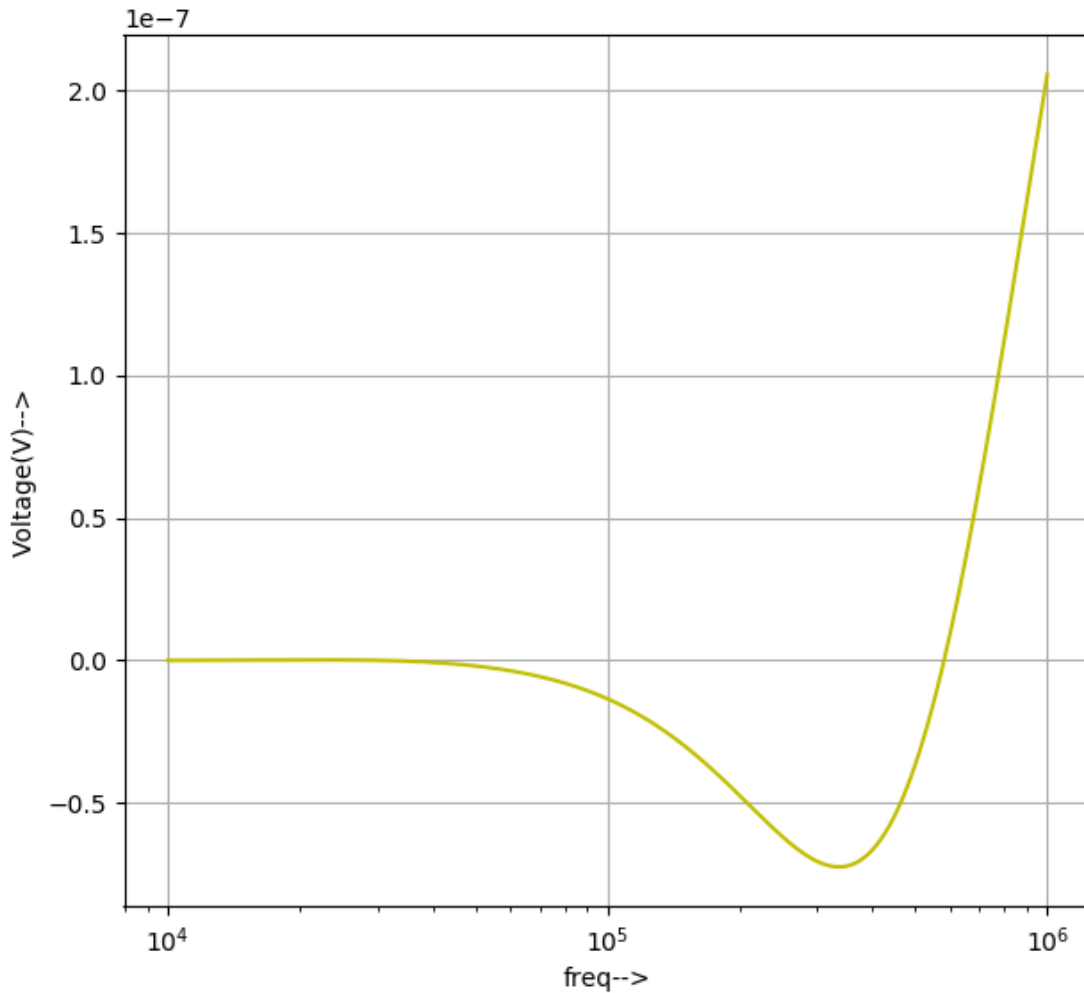


OUTPUT WAVEFORMS

STANDARD PATH:



FAST PATH:



Simulation Result

The standard and fast readout paths exhibit the expected frequency response. Although the input AC phase was set to 0° , the output appears inverted due to the inverting configuration of the amplifier stage, which introduces a 180° phase reversal. This confirms the proper operation of both readout paths.

CONCLUSION

The dual-readout analog front-end for SiPMs was successfully designed and simulated using the KiCad/eSim open-source EDA environment. The standard and fast readout paths were implemented to provide complementary signal characteristics for amplitude and timing analysis. The simulation results demonstrate the frequency-dependent operation of both paths, validating the feasibility of the proposed AFE design.

REFERENCES

<https://arxiv.org/pdf/2607.21339>

<https://cds.cern.ch/record/2738368>

<https://arxiv.org/abs/1606.02290>

<https://cds.cern.ch/record/2717126>