Analysis and Modeling of Frequency-Domain Compensation Techniques for High Bandwidth Shunt Resistors

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Abstract:

This report presents the migration and simulation of a high-frequency current shunt resistor model with RC compensation into the eSim environment. The objective is to study the effect of parasitic inductance and compensation resistance on the frequency response of the system. AC analysis was performed over a wide frequency range, and the output magnitude was observed for different values of compensation resistance. The results demonstrate the presence of gain peaking due to parasitic inductance and its suppression using an RC compensation network. The simulated behavior closely follows the trends reported in the reference research paper, validating the effectiveness of the compensation technique.

Introduction:

Current shunt resistors are widely used for current sensing in high-speed electronic systems. However, at high frequencies, parasitic inductance and capacitance significantly affect their performance, leading to inaccurate measurements. These parasitic elements introduce resonance effects, resulting in gain peaking and instability in the frequency response.

To overcome these issues, frequency-domain compensation techniques using RC networks are employed. These compensation circuits help reduce resonance and improve measurement bandwidth. The present project focuses on modeling such a compensated shunt resistor circuit and analyzing its behavior using the eSim simulation platform.

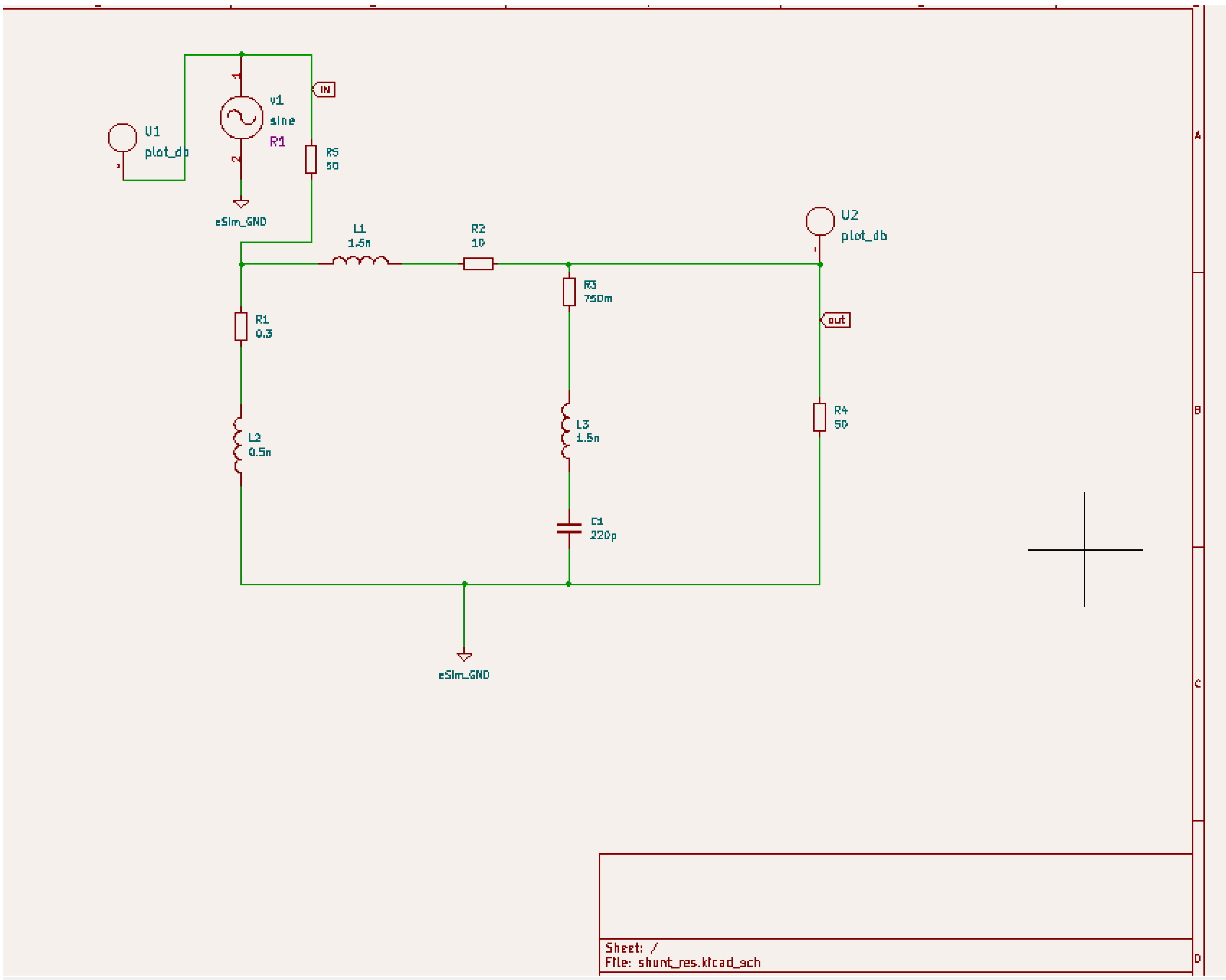
Objectives:

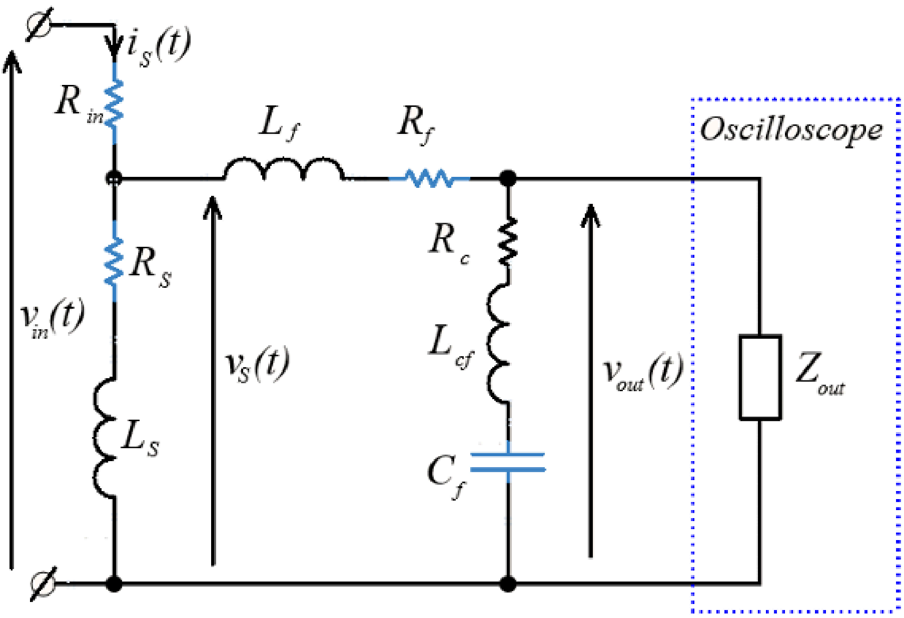
1. Implement the current shunt resistor model with parasitic elements in eSim.
2. Perform AC analysis to observe frequency response characteristics.
3. Study the effect of varying compensation resistance (R_f).
4. Compare simulated results with trends from the reference research paper.
5. Analyze the role of RC compensation in stabilizing the system.

Methodology:

1. The circuit was designed including parasitic elements such as inductance and resistance to model real-world behavior.
2. An RC compensation network was added to control high-frequency response.
3. A sinusoidal AC source was used as input, and AC analysis was performed over a wide frequency range.
4. Voltage probes were placed at input and output nodes to observe magnitude response.
5. Simulations were repeated for different values of compensation resistance (1Ω, 5Ω, 10Ω, 25Ω, 50Ω).
6. The output magnitude (in dB) was plotted and analyzed to study system behavior.

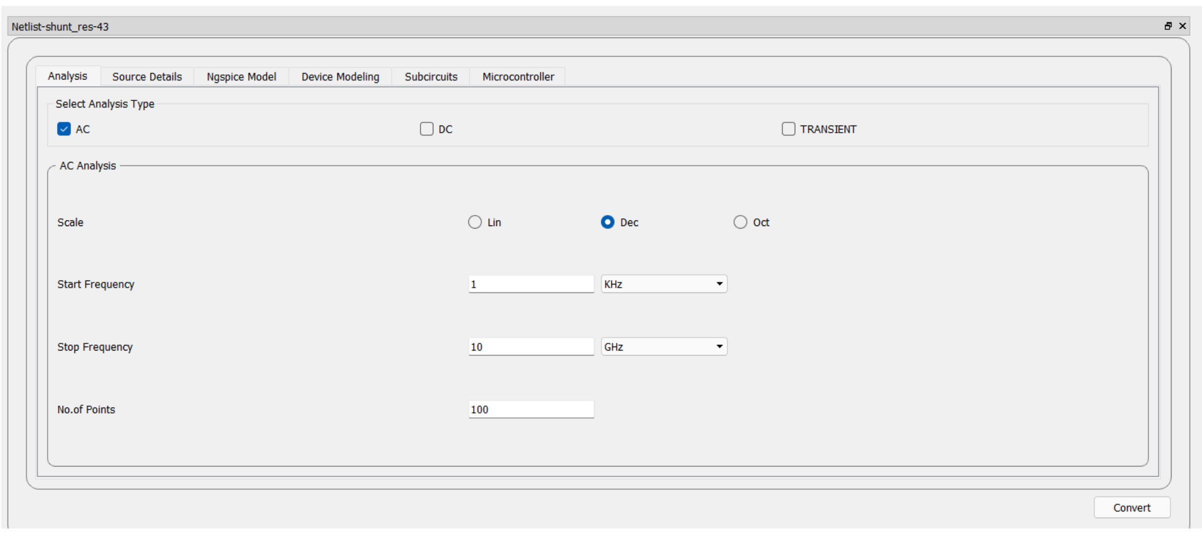
Circuit Diagram

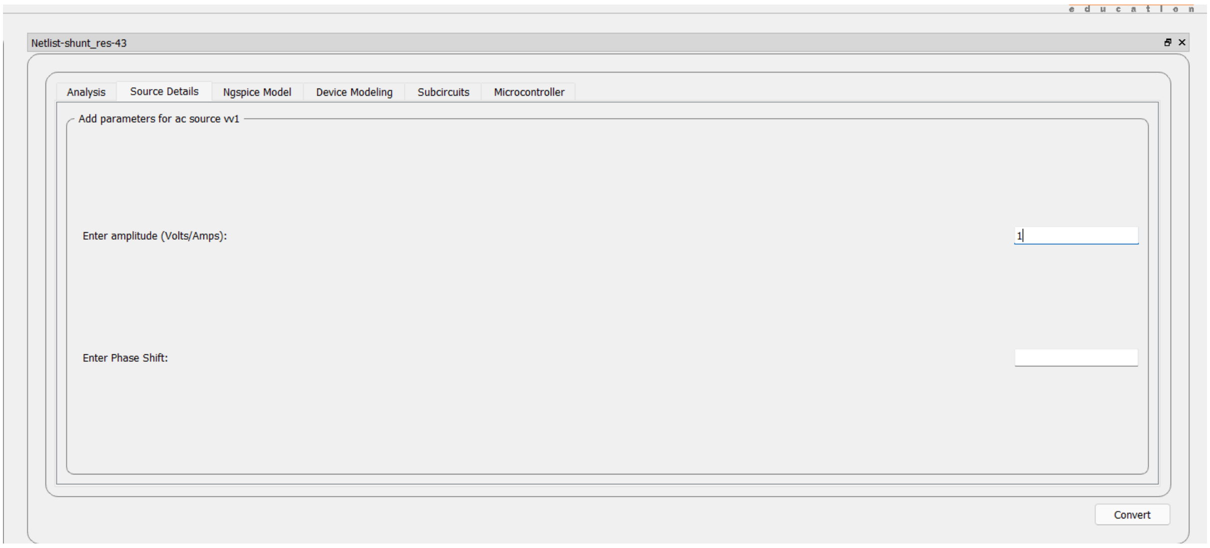




Input Parameters (for analysis):

- Input source: AC voltage source
- Frequency range: (10^3) Hz to (10^9) Hz
- Capacitance (C_f): 220 pF
- Compensation resistance (R_f): 1Ω, 5Ω, 10Ω, 25Ω, 50Ω
- Parasitic inductance: nH range (as per model)





Expected Result:

1. The circuit should show a flat response at low frequencies.
2. Gain peaking is expected due to parasitic inductance.
3. A dip should appear due to the RC compensation network.
4. Increasing (R_f) should reduce peaking and smooth the response.

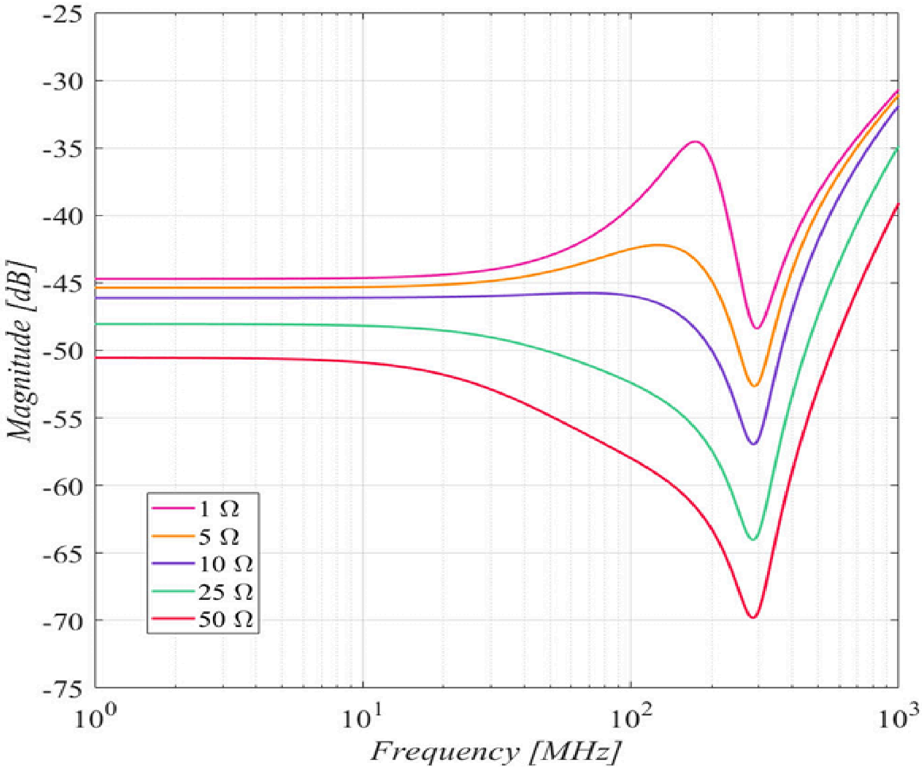
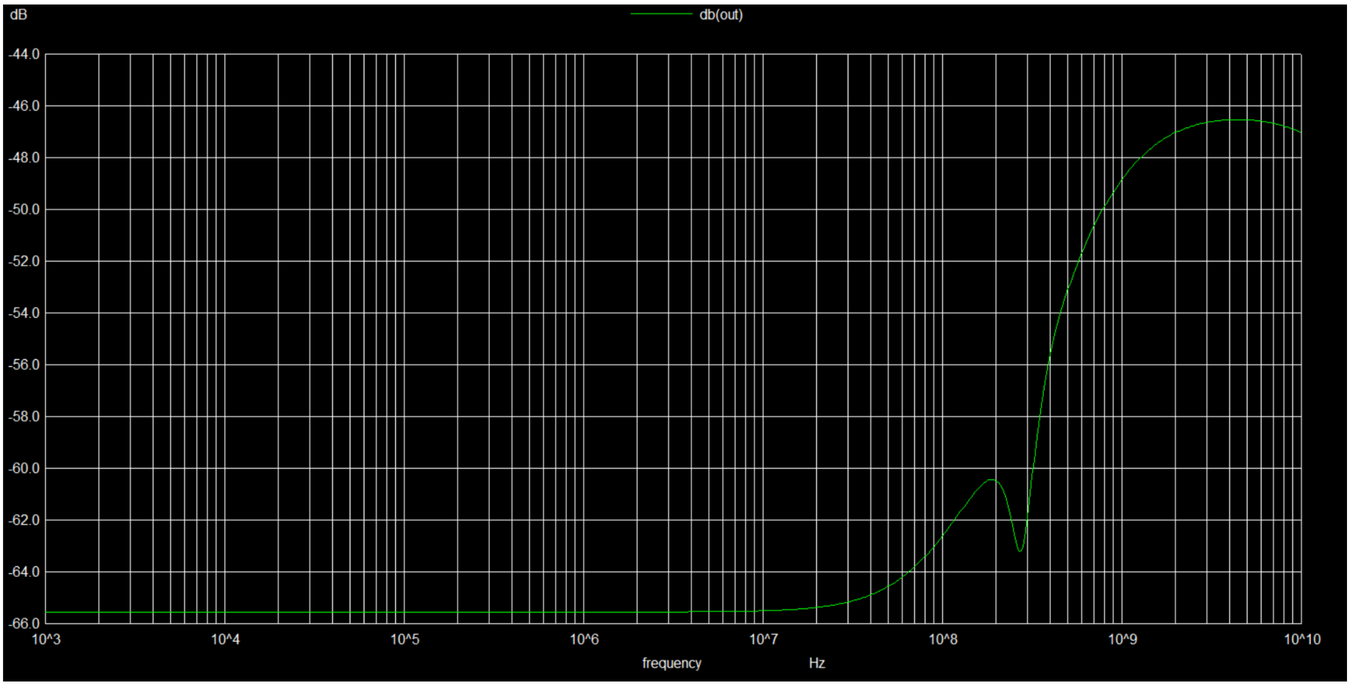


FIGURE 6. Magnitude vs frequency - fixed parameter of capacitance 220 pF and variable value of R_f .

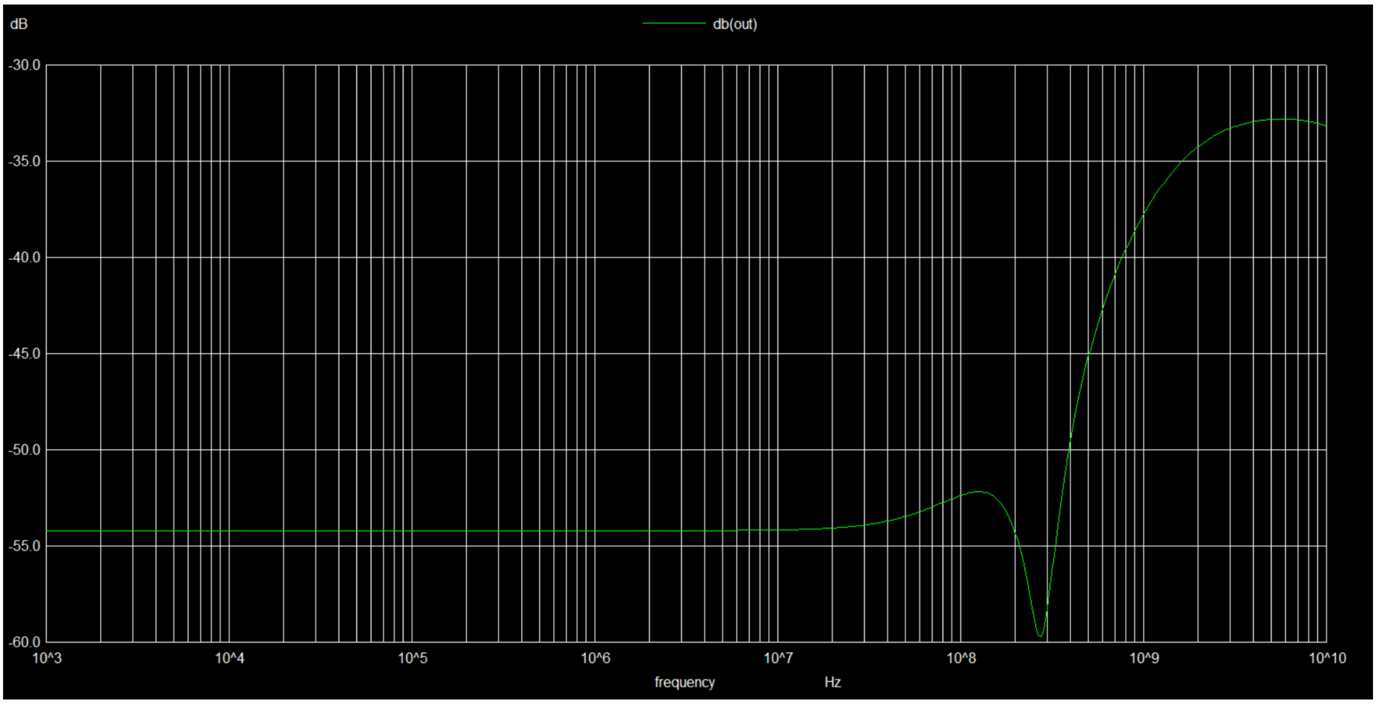
Observed Result:

1. AC analysis successfully produced frequency response curves for all values of (R_f).
2. At low frequencies, the output remained stable and flat.
3. At higher frequencies, a gain peak followed by a dip was observed.
4. For low (R_f), strong resonance effects were seen.
5. As (R_f) increased, the response became smoother and more stable.
6. For higher (R_f), the system showed overdamped behavior with minimal peaking.
7. The overall trend closely matched the reference research paper, with minor deviations due to modeling simplifications.

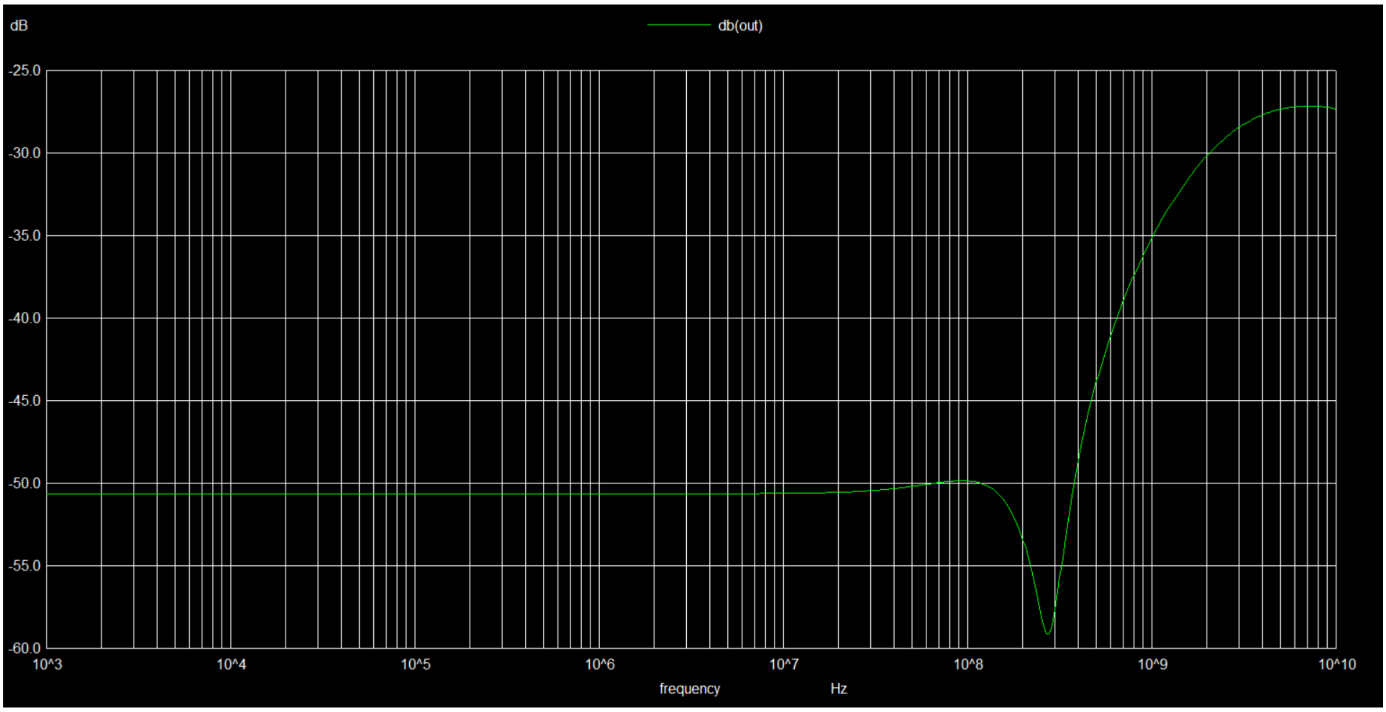
FOR 1 OHM



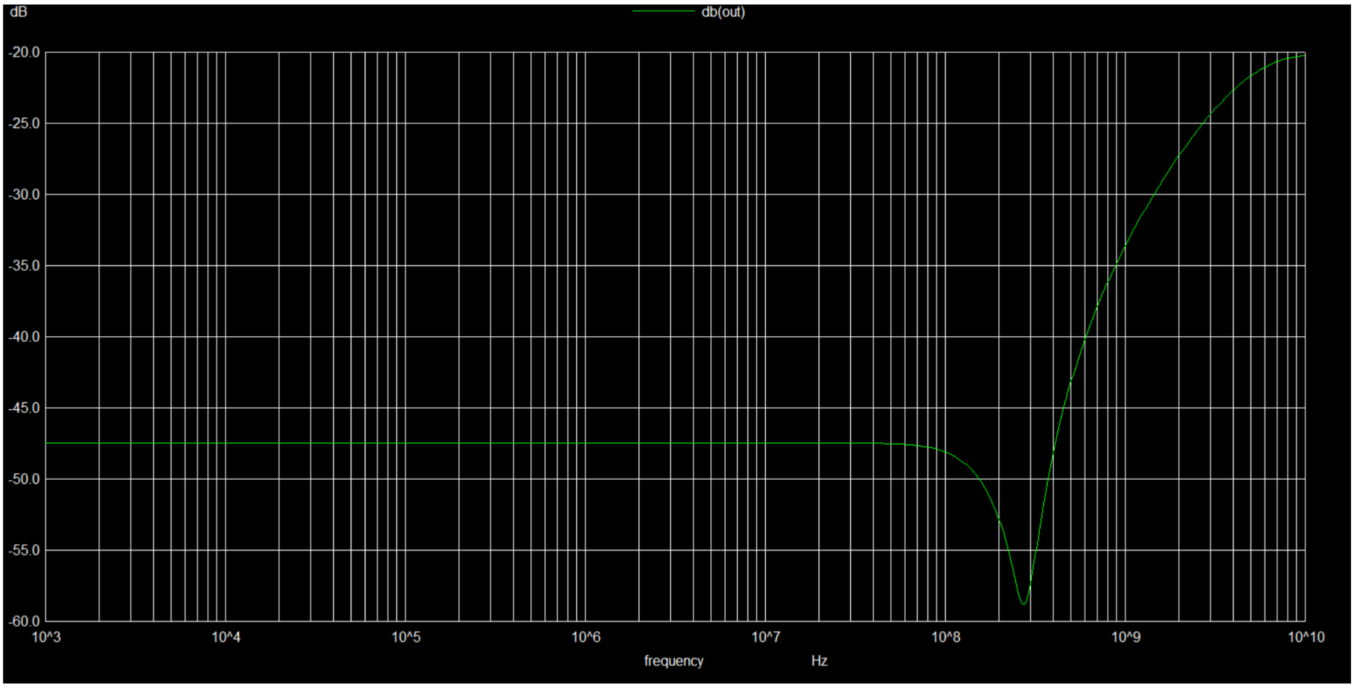
FOR 5 OHM



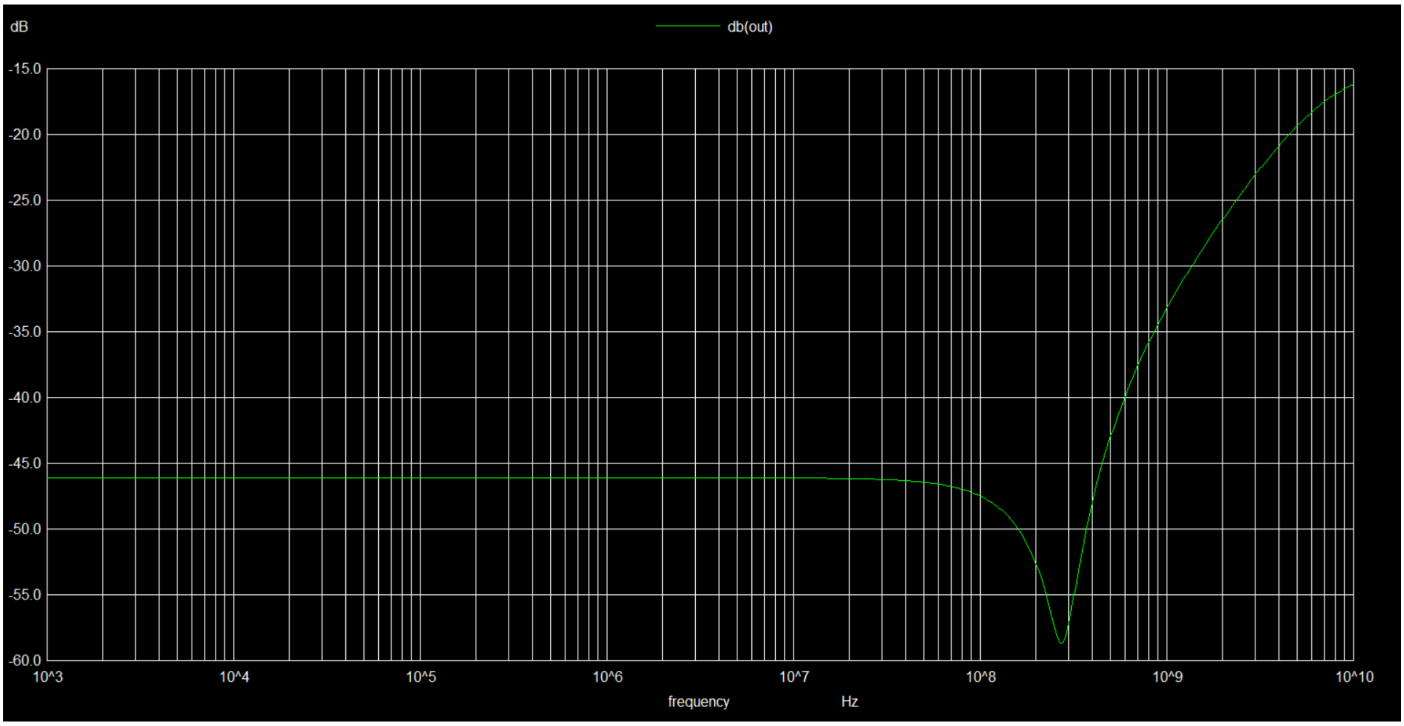
FOR 10 OHM



FOR 25 OHM



FOR 50 OHM



Inference:

1. Parasitic inductance introduces resonance and gain peaking at high frequencies.
2. The RC compensation network effectively suppresses this resonance.
3. Increasing compensation resistance increases damping in the system.
4. Proper selection of (R_f) is critical for achieving stable and accurate measurements.

Applications:

1. High-speed current sensing circuits.
2. Power electronics and switching systems.
3. Measurement systems requiring wide bandwidth.
4. Design of compensated analog circuits for improved stability.

Conclusion:

The current shunt resistor circuit with RC compensation was successfully implemented and simulated in eSim. The results confirmed that parasitic inductance introduces resonance effects, which can be effectively controlled using a compensation network. Increasing the compensation resistance improves stability by reducing gain peaking and smoothing the frequency response. The simulation results closely align with the trends reported in the reference study, demonstrating the effectiveness of frequency-domain compensation techniques in high-bandwidth measurement systems.