

Compute The Input Impedances Of The Unweighted Voltage Subtractor Circuit. Keep The Other Input At V

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Understanding the input impedance of a voltage subtractor circuit is vital for designing reliable and accurate analog systems. In particular, the unweighted voltage subtractor circuit, often used in applications such as differential amplifiers, signal processing, and instrumentation, requires precise calculation of input impedances to ensure minimal signal loading and accurate voltage subtraction. When one input is held at a constant voltage V , analyzing the input impedance becomes a critical step in understanding how the circuit interacts with preceding stages.

This article provides a comprehensive guide to computing the input impedances of the unweighted voltage subtractor circuit with one input fixed at voltage V . We will explore the circuit configuration, derive the expressions for input impedances, and discuss practical considerations for circuit design and analysis.

Understanding the Unweighted Voltage Subtractor Circuit

Before delving into impedance calculations, it is important to understand the typical configuration of an unweighted voltage subtractor circuit.

Circuit Overview

An unweighted voltage subtractor generally consists of:

- Two input terminals: one for the variable input voltage (V_{in}) and the other for a fixed voltage (V) .
- A set of resistors arranged to subtract the voltages without involving specific weighting factors.
- An output node that provides the difference of the two voltages.

A common implementation uses operational amplifiers (op-amps) with resistors configured to perform the subtraction operation.

Typical Circuit Configuration

A standard unweighted voltage subtractor circuit might look like this:

- Input 1: (V_{in}) connected through resistor (R_1) to the summing node.
- Input 2: (V) connected through resistor (R_2) to the same summing node.
- The summing node is connected to the op-amp's inverting input.
- The non-inverting input is grounded or biased as needed.
- Feedback resistor (R_f) from the output to the inverting input.

In this configuration, the output voltage (V_{out}) is proportional to $(V_{in} - V)$.

Analyzing Input Impedances

Input impedance is a measure of how much a circuit resists the flow of current into its input terminals. It plays a crucial role in determining how the circuit interacts with signal sources.

Why Compute Input Impedances?

- To ensure minimal loading on the sources.
- To match impedance levels for maximum power transfer.
- To design circuits with predictable behavior.

In the context of the unweighted voltage subtractor, calculating the input impedance at each input terminal when the other input is held at voltage (V) helps in understanding the circuit's behavior and optimizing performance.

Considerations for the Analysis

- The op-amp is assumed ideal (infinite input impedance, zero output impedance, infinite gain).
- The circuit is in the linear region.
- The other input is held at a fixed voltage (V) .

Calculating Input Impedance at the Variable Input Terminal

When analyzing the input impedance at the (V_{in}) terminal with the other input held at (V) ,

the circuit simplifies based on the ideal op-amp assumptions.

Step 1: Model the Circuit

- The inverting input of the op-amp is a virtual ground (assuming negative feedback and ideal op-amp).
- The resistor (R_1) connects (V_{in}) to the inverting input.
- The resistor (R_2) connects the fixed voltage (V) to the same node.
- The non-inverting input is grounded.

Step 2: Replace the Fixed Input Source

Since (V) is held at a fixed voltage, it can be considered as a known bias point. For impedance calculation at (V_{in}) , treat (V) as an AC ground (if analyzing AC impedance) or as a fixed DC voltage source.

Step 3: Derive the Input Impedance at (V_{in})

Given the ideal op-amp:

- The inverting input node is at virtual ground (0 V).
- The current flowing into the (V_{in}) terminal is:

$$I_{in} = \frac{V_{in} - 0}{R_1} = \frac{V_{in}}{R_1}$$

- The resistor (R_2) connected to (V) creates a voltage at the node, but since the node is at virtual ground, the influence of (V) appears as an AC ground or bias.

Thus, the input impedance seen at (V_{in}) is primarily:

$$Z_{in(V_{in})} = R_1$$

Answer: The input impedance at the variable input (V_{in}) , with the other input held at (V) , equals (R_1) .

Calculating Input Impedance at the Fixed Voltage Input (V)

Similarly, to find the input impedance at the (V) terminal:

Step 1: Model the Circuit

- The resistor (R_2) connects (V) to the inverting input.
- The resistor (R_1) connects (V_{in}) to the same node.
- The inverting node is at virtual ground (0 V).

Step 2: Treat the Variable Input (V_{in}) as a Source

- When calculating the impedance at (V) , consider (V_{in}) as an independent voltage source with its own impedance or as a test source.

Step 3: Derive the Input Impedance at (V)

- The current flowing into (V) is:

$$I_V = \frac{V - 0}{R_2} = \frac{V}{R_2}$$

- The equivalent impedance looking into the (V) terminal, with the other side at virtual ground, is:

$$Z_{in(V)} = R_2$$

Answer: The input impedance at the fixed voltage terminal (V) is (R_2) .

Summary of Input Impedances

The analysis yields straightforward expressions:

- Impedance at the variable input (V_{in}) :

$$Z_{in(V_{in})} = R_1$$

$$Z_{in(V_{in})} = R_1 \parallel$$

- Impedance at the fixed input (V_-) :

$$Z_{in(V_-)} = R_2 \parallel$$

These simplified results assume ideal op-amp conditions and that the other input is held at voltage (V_-) .

Practical Considerations in Impedance Calculation

While the ideal calculations provide fundamental insight, real-world circuits require consideration of additional factors:

Non-Ideal Op-Amp Parameters

- Finite input impedance.
- Input bias currents.
- Offset voltages.
- Bandwidth limitations.

Effect of Circuit Layout and Component Tolerances

- Resistor tolerances impact impedance values.
- Parasitic capacitances may influence AC impedance at high frequencies.

Impact on Circuit Design

- Ensuring input impedances are sufficiently high to avoid loading sources.
- Matching impedances where necessary for optimal performance.
- Selecting resistor values considering the desired impedance and signal integrity.

Conclusion

Calculating the input impedances of an unweighted voltage subtractor circuit with one input held at voltage (V) is straightforward under ideal conditions. The key results demonstrate that:

- The impedance at the variable input (V_{in}) is simply (R_1) .
- The impedance at the fixed input (V) is (R_2) .

Understanding these values helps engineers design circuits with optimal performance, ensuring minimal signal loading and accurate voltage subtraction. When implementing these circuits in practical applications, always consider non-idealities and component tolerances to achieve the desired system behavior.

References

- Sedra, A. S., & Smith, K. C. (2015). Microelectronic Circuits. Oxford University Press.
- Horowitz, P., & Hill, W. (2015). The Art of Electronics. Cambridge University Press.
- Operational Amplifier datasheets and application notes.

For further assistance with circuit analysis or design, consult technical resources or reach out to experienced electronics engineers.

Frequently Asked Questions

What is the significance of input impedance in an unweighted voltage subtractor circuit?

The input impedance determines how much the circuit loads the input sources, affecting signal integrity and accuracy in voltage subtraction. High input impedance minimizes loading effects on the input signals.

How do you compute the input impedance of the unweighted voltage subtractor circuit when one input is held at voltage V ?

The input impedance can be calculated by analyzing the resistor network connected to the input node, considering the feedback and input resistor configurations, and treating the other input as a fixed voltage source.

Why is it important to keep one input at a fixed voltage V when calculating input impedance?

Keeping one input at a fixed voltage V simplifies the analysis by providing a reference point, allowing the calculation of the input impedance seen at the other input without the influence of the varying voltage.

What effect does the value of the resistors have on the input impedance of the voltage subtractor circuit?

The resistor values directly influence the input impedance; higher resistor values increase the impedance, leading to less loading of the input source, while lower resistor values decrease impedance, potentially affecting signal fidelity.

Can the input impedance of the voltage subtractor circuit be approximated as infinite? Why or why not?

In practical circuits, the input impedance can be very high but not truly infinite. It is often approximated as infinite when resistor values are very large compared to other circuit components, minimizing loading effects.

How does the presence of feedback in the voltage subtractor circuit influence its input impedance?

Feedback typically increases the input impedance by reducing the loading effect on the input source, making the circuit more ideal for precise voltage subtraction.

What is the formula for calculating the input impedance of an unweighted voltage subtractor with one input at voltage V ?

The input impedance (Z_{in}) can be calculated using the resistors connected to the input node, often expressed as $Z_{in} = R_{in} \parallel (R_{feedback} + \text{other resistances})$, depending on the specific configuration of the circuit.

Additional Resources

Input Impedance of the Unweighted Voltage Subtractor Circuit

Understanding the input impedance of a circuit is fundamental when designing and analyzing analog systems, especially those involving precise voltage subtraction. The unweighted voltage subtractor circuit, a variation of the classic difference amplifier, has unique characteristics when it comes to input impedance, particularly when one input is held at a fixed voltage V . In this article, we delve deep into the intricacies of calculating the input impedances of this circuit configuration, exploring theoretical foundations, practical considerations, and implications for circuit design.

Introduction to the Unweighted Voltage Subtractor Circuit

The unweighted voltage subtractor circuit is a variation of the difference amplifier setup, designed to subtract one input voltage from another. Unlike weighted subtractors, which assign different gains or weights to inputs, the unweighted version maintains equal or normalized contributions from each input, simplifying analysis and implementation.

Typical Configuration:

- Two input voltages: V_1 and V_2 .
- An operational amplifier (op-amp) with negative feedback.
- Resistors arranged to facilitate voltage subtraction.
- One input is held at a fixed voltage V (which can be ground or any reference level).

The key focus is on understanding the input impedance seen at each voltage source when the other is held at V , especially considering the impact of the resistor network and the op-amp's properties.

Fundamentals of Input Impedance

What is Input Impedance?

Input impedance is the measure of how much a circuit resists or allows current flow at its input terminal when a voltage is applied. High input impedance is desirable, as it minimizes the loading effect on the source, preserving signal integrity.

Why Is Input Impedance Important?

- Ensures minimal signal distortion.
- Prevents excessive loading of preceding stages.
- Influences the stability and frequency response of the circuit.

In the case of the voltage subtractor, precise knowledge of input impedance is crucial for applications like sensor interfacing, where sources have limited current-driving capability.

Analyzing the Circuit Configuration

Before calculating the input impedance, it's essential to understand the typical unweighted voltage subtractor circuit structure:

- Resistors:
- R_1 connected from V_1 to the inverting input node of the op-amp.
- R_2 connected from V_2 to the same node.
- Feedback resistor R_f from the op-amp output to the inverting input.

- Non-inverting input is usually grounded or connected to a reference voltage (V) .
- Op-Amp Assumptions:
 - Infinite open-loop gain.
 - Infinite input impedance at input terminals.
 - Zero input bias current.
 - Zero output impedance.

Note: For simplicity and clarity, the initial analysis assumes ideal op-amp conditions.

Setting One Input at Voltage (V)

In this specific scenario, we keep one input, say (V_2) , fixed at a voltage (V) . The goal is to determine the input impedance seen at the other input, (V_1) , under this condition.

Key considerations include:

- How the fixed voltage (V) influences the circuit's behavior.
- The effect of the resistor network on the impedance seen by (V_1) .
- The interaction through the op-amp's feedback and input characteristics.

By fixing $(V_2 = V)$, the circuit effectively becomes a voltage-controlled impedance environment from the perspective of (V_1) .

Calculating the Input Impedance at (V_1)

Step 1: Simplify the Circuit

Given $(V_2 = V)$, the circuit reduces to a configuration where the node connected to (R_1) sees a specific voltage source fixed at (V) . The input impedance at (V_1) is the ratio of the voltage applied at (V_1) to the current flowing into the network at that node.

Step 2: Derive the Equivalent Circuit

- The resistor (R_1) is connected between (V_1) and the inverting input node.
- The inverting input node is connected to the output through (R_f) and to (V) via (R_2) .
- The op-amp's inverting input node is a virtual ground (at approximately 0 V in the ideal case) due to the high gain and negative feedback.

Step 3: Apply Node Analysis

Assuming the inverting input node is at voltage (V_{-}) , which is close to the virtual ground:

$$V_{-} \approx 0, V$$

Since V_{-} is fixed at V , the current flowing through R_2 :

$$I_{R_2} = \frac{V - V_{-}}{R_2} \approx \frac{V}{R_2}$$

Similarly, the current through R_1 :

$$I_{R_1} = \frac{V_1 - V_{-}}{R_1} \approx \frac{V_1}{R_1}$$

The current into the op-amp input is negligible; thus, the sum of currents at the node:

$$I_{R_1} + I_{R_2} \approx 0$$

From this, the node voltage V_{-} can be expressed, and from the perspective of V_1 , the impedance is derived by analyzing the relationship between the applied voltage V_1 and the resulting current.

Step 4: Derive the Expression for Input Impedance

The input impedance Z_{in} at V_1 is:

$$Z_{in} = \frac{V_1}{I_{V_1}}$$

where I_{V_1} is the current flowing into the resistor R_1 .

Given the simplified analysis, the impedance can be approximated as:

$$Z_{in} \approx R_1 \left(1 + \frac{R_f}{R_2} \right)$$

This expression indicates that the input impedance at V_1 depends on the resistor values and the feedback network. The presence of the fixed voltage V effectively influences the current flow through R_2 , slightly modifying the impedance.

Impact of Circuit Parameters on Input Impedance

Resistor Values:

- Increasing R_1 increases the input impedance directly.
- Larger R_2 tends to decrease the influence of V on the impedance.
- The ratio R_f/R_2 significantly affects the impedance, especially in feedback configurations.

Feedback Resistor R_f :

- Higher R_f raises the input impedance at V_1 .
- The feedback network stabilizes the impedance, making it more predictable.

Fixed Voltage V :

- When V is at ground ($0V$), the impedance is primarily dictated by resistor ratios.
- When V is at a different potential, the current through R_2 alters the effective impedance seen at V_1 .

Op-Amp Non-idealities:

- Real-world op-amps have finite input impedances, bias currents, and bandwidth limitations, slightly affecting the theoretical calculations.
- These factors become more significant at high frequencies or with high-impedance sources.

Practical Considerations and Design Implications

Choosing Resistor Values:

- To maximize input impedance, select large resistor values, bearing in mind thermal noise and bandwidth limitations.
- Balance between high impedance and stability; very high resistances can introduce noise and parasitic effects.

Impact of Non-Idealities:

- Real op-amps will introduce small deviations from ideal behavior, slightly lowering the actual input impedance.
- Compensation techniques, such as buffering or using precision resistors, can improve accuracy.

Frequency Response:

- At higher frequencies, parasitic capacitances and op-amp bandwidth limitations can affect the impedance.
- Proper PCB layout and component selection are essential for high-frequency applications.

Application in Sensor Interfaces:

- High input impedance is crucial when interfacing with high-impedance sensors to prevent loading and signal distortion.
- The fixed voltage V can serve as a reference or bias point, stabilizing the circuit's operation.

Conclusion: Summary of Key Findings

The input impedance of the unweighted voltage subtractor circuit, when one input is held at a fixed voltage (V) , is primarily dictated by the resistor network and the feedback configuration. Under ideal op-amp assumptions, the impedance at the variable input (V_1) can be approximated by:

$$\boxed{Z_{in} \approx R_1 \left(1 + \frac{R_f}{R_2} \right)}$$

This expression highlights how resistor selection influences impedance characteristics, enabling designers to tailor the circuit for specific applications. Practical implementation requires careful

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