Floating Voltage Sources

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Introduction

This note discusses some issues that occur when differential amplifiers are connected to floating input transducers.

A floating voltage is a voltage that is not referenced to the system ground. The voltage may be referenced to the ground of a different system with the voltage between the two system grounds undefined. The problem of floating voltage sources frequently occurs when differential input amplifiers are used to process signals from input transducers. The input transducer may either be a voltage source in of itself (thermocouple, solar cells, microphone, etc.), have battery operated electronics, or be powered from an isolated power supply. In each case the input voltage is floating unless there is a connection between the electrical grounds of the transducer system and amplifier system. Connecting the two grounds is not always practical or desirable.

Understand that a floating voltage is not a problem that must be eliminated but rather a system issue (like any system issue) that must be dealt with appropriately. There are situations (ion collectors for example) where a transducer must be floated at several hundred volts relative to system ground for practical reasons. Issues with floating voltage sources occur often enough in instrumentation so that a number of manufactures sell what is known as isolation amplifiers. An isolation amplifier permits signals to be coupled from one system to another where the impedance between the two grounds is essentially infinite. The voltage between the two system grounds may also be large (perhaps several thousand volts). Inductive or optical methods are frequently used.

Circuit Analysis

Often it is possible to make a mathematical circuit transformation that converts the floating voltage to an equivalent ground based voltage. This transformation is the trivial replacement of the single input voltage with the difference of two voltages relative to system ground. If this transformation is valid then conventional nodal analysis can be performed to determine circuit function. Nodal analysis can be used if both of the following rules apply to the circuit.

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Rule 1. There must be a definite and finite resistance (DC) or impedance (AC) between the electrical grounds of the two systems.

Rule 2. The finite value from Rule 1 must result in negligibly small effects when the differential input amplifier input characteristics such as impedance, bias current, etc. are considered.

There are two reasons why it is desirable to be able to mathematically handle floating voltage sources without resorting to simplifying circuit transformations.

1. The circuit transformations are not always valid as an example will show. Not understanding the problem or incorrectly applying the rules results in an invalid transformation.

2. Even when the transformation seems valid there will always be people who are not convinced (perhaps rightly so) and will only believe an analysis that does not depend on any connection of the input voltage to system ground.

For the mathematics to be convincing the input voltage must <u>not</u> be converted to a ground based voltage such as Vin = V1 - V2. This transformation is so simple and obvious that it is difficult to avoid inadvertently doing it. The urge to do nodal analysis using ground based voltages must be avoided. Only loop analysis can be used for any equation involving the floating input voltage. Other equations can be nodal.

If the loop analysis works then you end up proving that the amplifier output is identical to the result of modeling the input voltage as V1 - V2 and using nodal analysis (i.e. the easy way). So what is the point? Note that I implied that the loop analysis might not work. It is possible to get stuck with a current being two different values at the same time or just not defined at all. In this case it is not possible to predict what the amplifier will do. This is a real problem that must be solved – the electronics can not be proved to work even if it produces the correct output for some test cases. Either an isolation amplifier must be used or an impedance must be placed between the two system grounds. Note that nodal analysis using the transformation would not have revealed this problem. If a problem exists you want to know about it. *Solving the circuit in a way that hides the problem does not make the problem go away*.

The attached hand notes show the analysis of a floating voltage source (i.e. a battery) connected to a standard 4-resistor differential amplifier and a standard instrumentation amplifier. In the first case both rules clearly apply because of the connections via the resistors. In the second case the rules do not apply and the loop analysis also fails to work.

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The problem in the second case is resolved by placing an appropriate impedance between the two system grounds. Why not just make this impedance zero as in a wire? Sometimes this is fine but doing so could introduce what is known as a ground loop and defeat the purpose of using an instrumentation amplifier – to remove common mode interference signals. The impedance should be as large as possible consistent with Rule 2.

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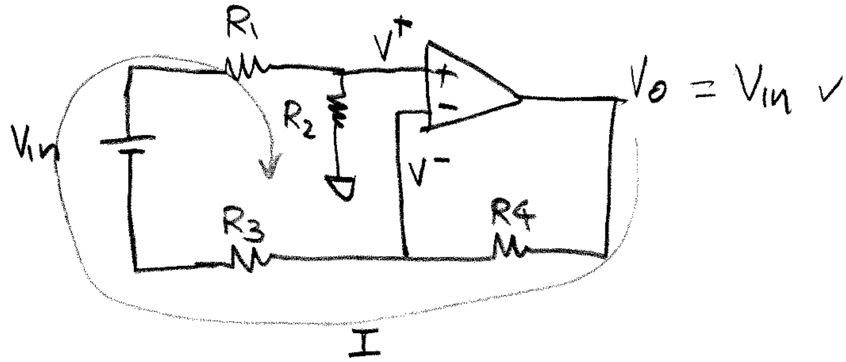
FLOATING VOLTAGES



NOTE CURRENT LOOP

$$I = \frac{V^+}{R_2}$$

SUM VOLTAGES FROM V^- TO V^+ (LOOP ANALYSIS)

$$V^+ = V^- - IR_3 + V_{in} - IR_1$$

NOTE: $V^+ = V^-$

$$\cancel{V^+} = \cancel{V^+} - \frac{V^+R_3}{R_2} + V_{in} - \frac{V^+R_1}{R_2}$$

(V_{in} IS NOT REFERENCED TO GROUND)

$$V^+\left(\frac{R_1+R_3}{R_2}\right) = V_{in}$$

$$V^+ = V_{in}\left[\frac{R_2}{R_1+R_3}\right]$$

NOTE THAT $V_o = V^- + IR_4 = V^+ + \frac{V^+R_4}{R_2} = V^+\left(1+\frac{R_4}{R_2}\right)$

THUS $$\boxed{V_o = V_{in}\left(\frac{R_2}{R_1+R_3}\right)\left(1+\frac{R_4}{R_2}\right)}$$

IF $R_1 = R_2 = R_3 = R_4$ THEN $\underline{V_o = V_{in}}$

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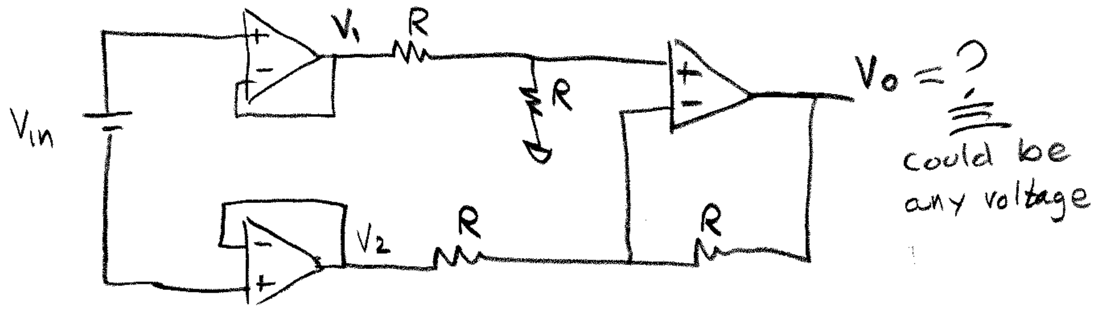
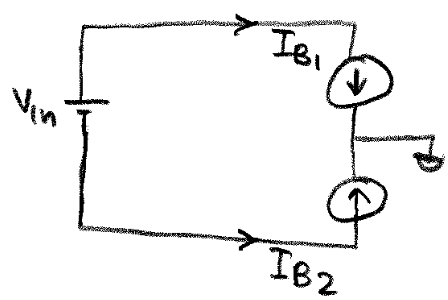
INSTRUMENTATION AMPLIFIER WILL NOT WORK WITH FLOATING SOURCE



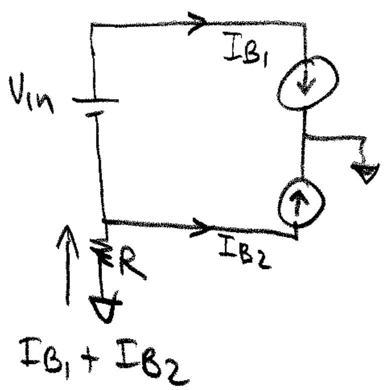
WE KNOW FROM PRIOR ANALYSIS THAT $V_O = V_1 - V_2$.
GIVEN V_{in}, WHAT IS V_1, WHAT IS V_2?

CONSIDER INPUT CIRCUIT WITH OP AMP BIAS CURRENTS.



THIS CIRCUIT HAS NO SOLUTION

WE NOW ADD A RESISTOR TO PROVIDE A PATH FOR THE TWO BIAS CURRENTS.



R IS CHOSEN SMALL ENOUGH SO THAT $(I_{B_1} + I_{B_2})R$ PRODUCES NO MORE THAN A VOLT OR SO. NOW $V_2 \simeq 0$ AND
$V_1 = V_2 + V_{in}$.