EE 521: Instrumentation and Measurements

Aly El-Osery

Electrical Engineering Department, New Mexico Tech
Socorro, New Mexico, USA

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Handbook of Operational Amplifier
http://focus.ti.com/lit/an/sboa092a/sboa092a.pdf

Overview

- Used for a wide variety of applications.
- Responds to the use difference in the input signals.
- Discriminates against changes in the dc power supply voltage.

DA Basics

Given two inputs $v_{i,1}$ and $v_{i,2}$ define *difference mode* and *common-mode* input and output signals as

$$v_{id} = (v_{i,1} - v_{i,2})/2, \qquad v_{ic} = (v_{i,1} + v_{i,2})/2 \tag{1}$$

$$v_{od} = (v_{o,1} - v_{o,2})/2, \qquad v_{oc} = (v_{o,1} + v_{o,2})/2 \tag{2}$$

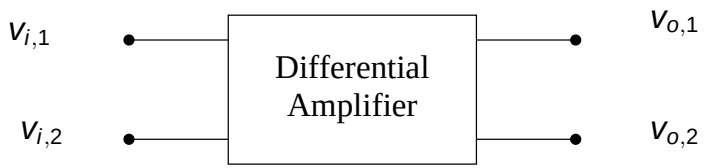

Figure: Differential amplifier block

Middlebrook Equations

$$v_{od} = A_{dd} v_{id} + A_{dc} v_{ic}, \qquad v_{oc} = A_{cd} v_{id} + A_{cc} v_{ic} \tag{3}$$

Output Equations

For single output $v_o = v_{o,1}$

$$\begin{aligned} v_o &= \frac{A_{dd} + A_{cd} + A_{dc} + A_{cc}}{2} v_{i,1} + \frac{A_{cc} + A_{dc} - A_{dd} - A_{cd}}{2} v_{i,2} \\ &= A_D v_{id} + A_C v_{ic} \end{aligned} \tag{4}$$

Ideal DA

$$A_{cc} = A_{cd} = A_{dc} = 0 \tag{5}$$

$$A_C = 0, \qquad A_D = A_{dd} \tag{6}$$

Common-Mode Rejection Ratio (CMRR)

How close is the real differential amplifier close to an ideal one?

$$CMRR \equiv \frac{(|v_{ic}| \text{ to } \textit{give a certain } v_o)}{(|v_{id}| \text{ to } \textit{give the same } v_o)} \tag{7}$$

$$CMRR = \left|\frac{A_{dd}}{A_{cc}}\right| = \left|\frac{A_D}{A_C}\right| \tag{8}$$

Measurement of A_D and A_C

- First case, connect both inputs to v_{s1} generating a common mode input signal which results in an output v_o.
- Second Case, connect the + input to v_{s2} and negative input to ground.

$$v_{id} = v_{s2}/2, \quad v_{ic} = v_{s2}/2$$

- Adjust v_{s2} such that the output is equal to v_o generated in the common mode input.

$$A_C = v_o/v_{ic} = v_o/v_{s1}$$

also

$$v_o = A_D v_{s2}/2 + A_C v_{s2}/2$$

consequently,

$$A_D = v_o(2/v_{s2} - 1/v_{s1}) \tag{9}$$

and

$$CMRR = A_D/A_C = (2v_{s1}/v_{s2} - 1) \tag{10}$$

DC Equivalent Input Circuit

Most frequently, common-mode input resistance, R_{ic}, measured between one input to ground using common mode input, and a difference-mode input resistance, R_{id}, measured using difference mode input from either inputs to ground, are provided by the manufacturer.

DA Input Circuit

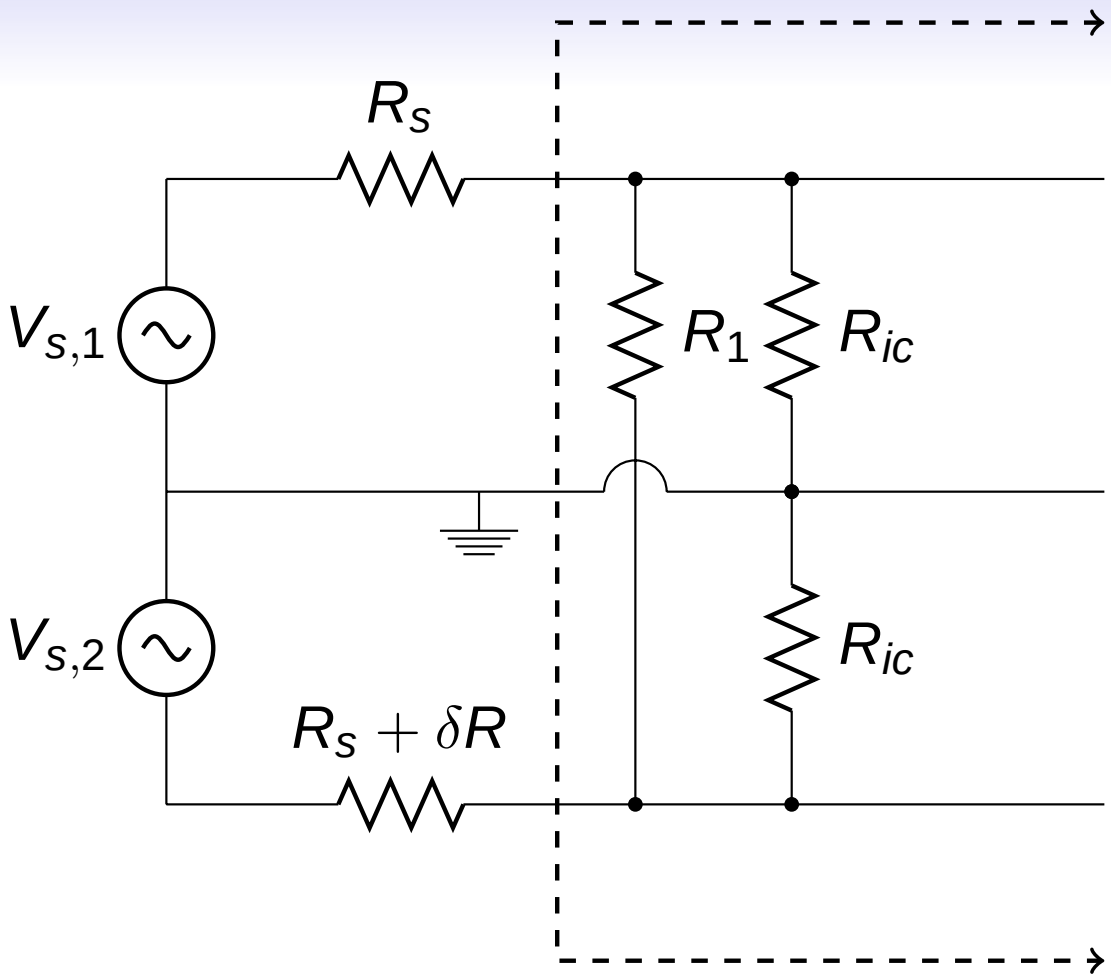

Figure: Differential amplifier input circuit at dc showing source resistance unbalance.

CMRR-Computation

$$
\begin{aligned}
CMRR_{sys} &= \frac{A_D/A_C + \delta R/[2(R_{ic} + R_s)]}{[A_D/A_C]\delta R/[2(R_{ic} + R_s)] + 1} \\
&\approx \frac{CMRR_A}{CMRR_A \delta R/[2(R_{ic} + R_s)] + 1}
\end{aligned}
\tag{11}
$$

$CMRR_A$ is specified by the manufacturer

CMRR - Special Cases

- If the thevenin source resistance are matched

$$CMRR_{sys} = CMRR_A \tag{12}$$

- When

$$\delta R/R_s = -2(R_{ic}/R_s + 1)/CMRR_A$$

then

$$CMRR_{sys} \rightarrow \infty$$

Source Resistance Asymmetry

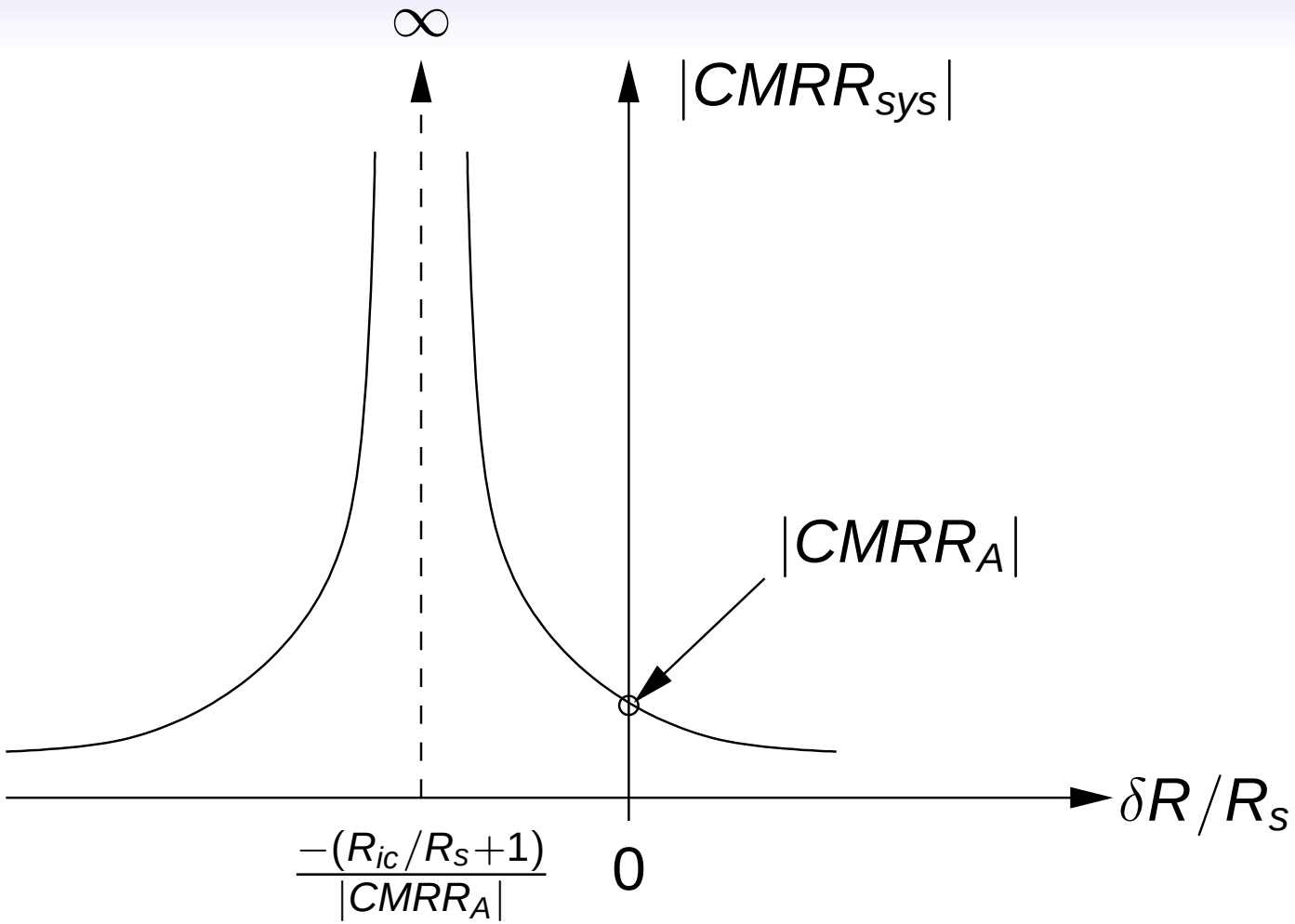

Figure: Differential amplifier CMRR magnitude vs fractional unbalance in source resistance.

Typical Op-Amp

Open-loop Transfer Function

$$A_D = \frac{v_o}{v_i - v_i'} = \frac{k_{ov}}{(\tau_1 s + 1)(\tau_2 s + 1)} \tag{13}$$

- $f_1 = 1/(2\pi\tau_1)$ and $f_2 = 1/(2\pi\tau_2)$.
- To ensure stability $|A_D(jf_2)| \ll 1$.
- f_1 occurs at a relatively low value.
- Small-signal gain $\times$ bandwidth product

$$GBWP \approx k_{ov}/(2\pi\tau_1) \tag{14}$$

- The unity gain of 0dB frequency of the open loop, f_T, is approximately equal to the $GBWP$.
- Slew rate η.

Notes

- Two pieces of information define are required to define the op-amp's open-loop characteristics.
  - DC open-loop gain k_{ov}, and
  - 0dB frequency, f_T.
- Closed-loop gain is limited by the open-loop gain.
- The higher the closed-loop gain is the smaller the bandwidth.
- To overcome this problem, it is better to cascade identical amplification stages rather than having one op-amp with a high gain.

Non-inverting Amplifier

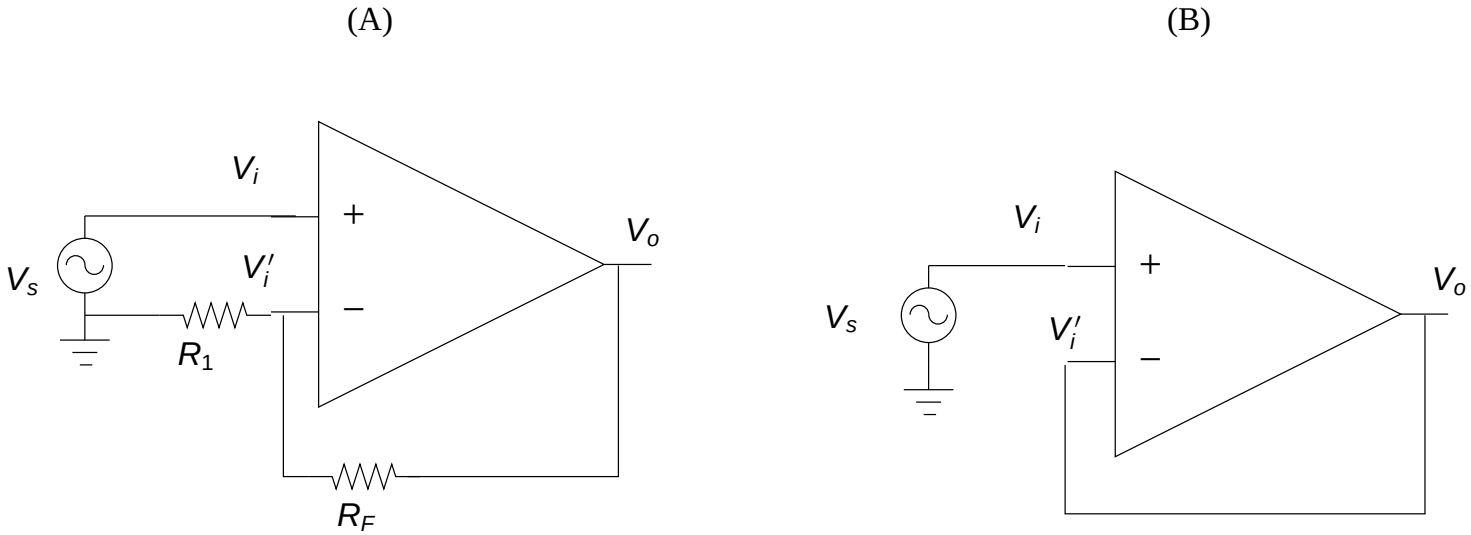

Figure: Non-inverting op-amp circuits

$$v_o/v_s = \frac{k_{ov}/(\tau s + 1)}{1 + \beta k_{ov}/(\tau s + 1)} \tag{15}$$

Inverting Amplifier and Summer

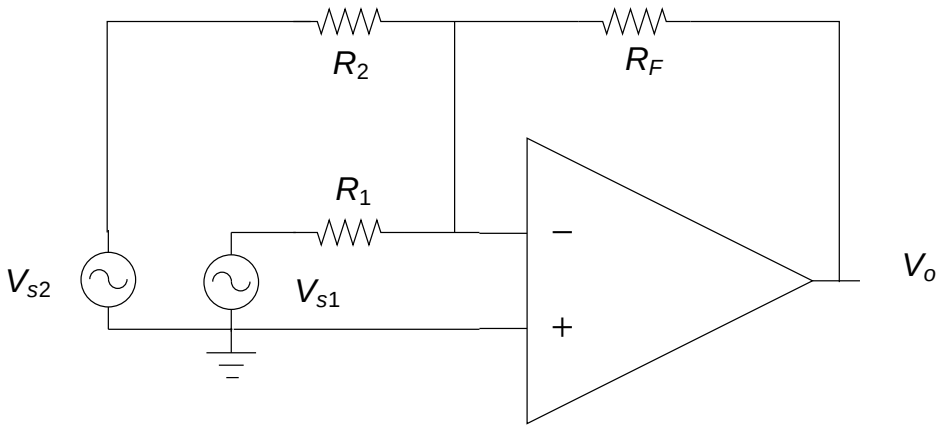

Figure: Summing op-amp