Power Amplifier

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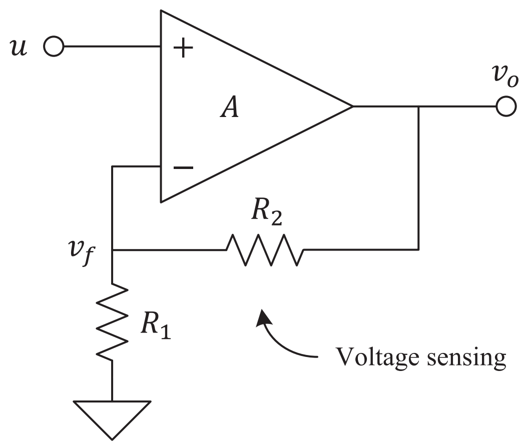
1 Voltage Amplifier

How can we make a controlled current source?

Recall how we made a voltage amplifier → **Feedback**



We measure the voltage and feed it back.

The voltage sensing circuit has large input resistance to minimally affect the *measurand*.

Figure 1: Voltage amplifier.

2 Transconductance Amplifier

We take the same strategy as the voltage amplifier.

That is, we measure the current and feed it back.

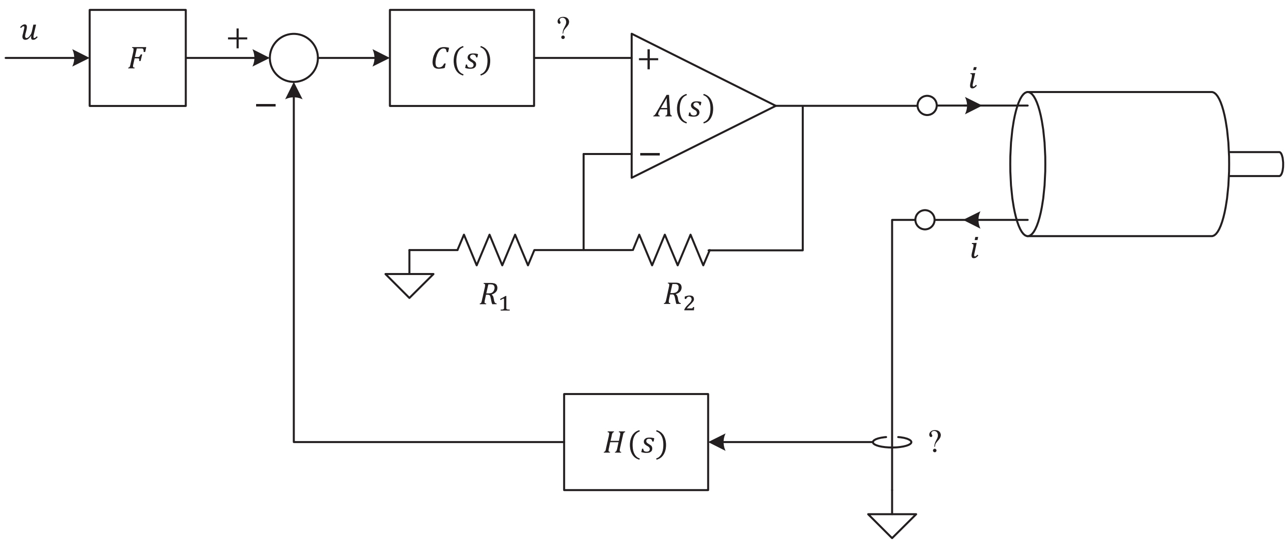


Figure 2: Transconductance amplifier concept.

Three design questions:

(1) How to measure the output current?

(2) How to implement the controller (realize the block diagram)?

(3) How to design the controller?

2.1 Current sensing

Design requirements:

(1) Minimal effect on the output current (measurand).

(2) High bandwidth

(3) Low noise

(4) Low interference (e.g, temperature, EMI, etc.)

(5) Low cost

Two most common solutions:

(1) (Current-sensing) shunt resistor

(2) Hall-effect sensor

Shunt resistor is the most popular option for motor current control. There exist special resistors for current sensing (e.g., 4-terminal resistors).

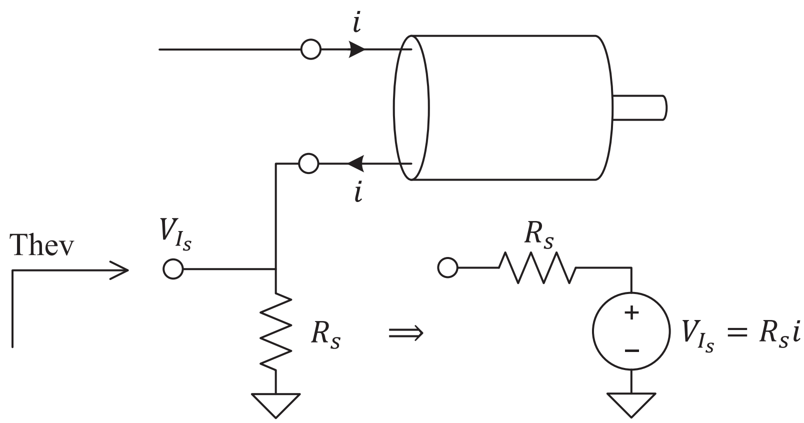


Figure 3: Shunt resistor and the Thevenin equivalent circuit.

It is important to have small resistance for R_s ($R_s \ll R_m$) so that it minimally impede the output current.

Shunt resistor has power rating.

$$P_{\max} = R_s I_{\max}^2.$$

Should check the maximum permissible rms current.

More topics, such as 4-wire (Kelvin) measurement, will be covered later when we study instrumentation amplifier.

Should account for temperature effect, such as temperature coefficient of resistance (T.C.R.) and thermal emf (thermocouple effect).

$$\text{T.C.R. } [\mathrm{K}^{-1}] \quad \triangleq \quad \frac{\mathrm{d}R}{\mathrm{d}T}\frac{1}{R} \quad \approx \quad \frac{R_2 - R_1}{T_2 - T_1}\frac{1}{R_1}$$

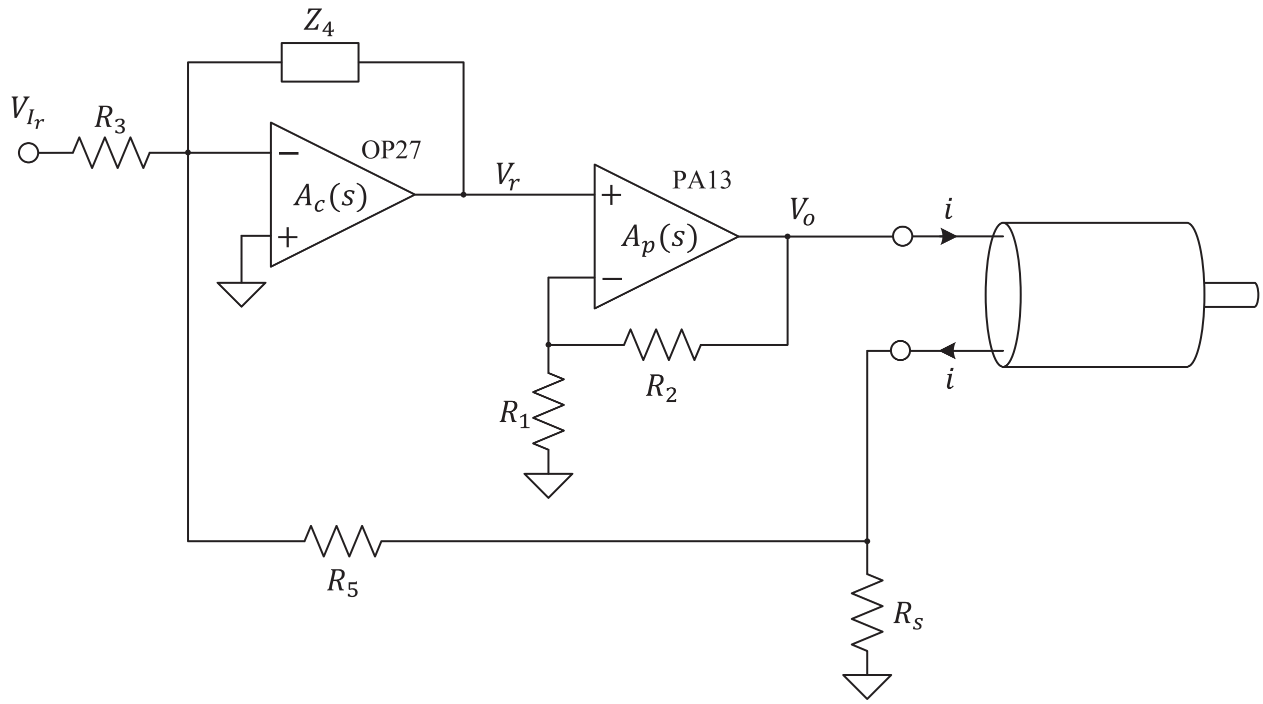
2.2 Controller implementation

We will implement the controller with analog circuit elements.

Analog implementation allows for higher bandwidth and lower noise than digital implementation (e.g., micro-controllers and switching power electronics).

That being said, there exist high-speed digital processors, such as field programmable gate arrays (FPGA) and digital signal processors (DSP), which can implement decent high-bandwidth current control.

One possible analog circuit is as follows.



<u>Key ideas</u>

- Summing junction is implemented via KCL at the op-amp inverting terminal.
- Controller transfer function $C(s)$ is implemented via feedback impedance $Z_4(s)$.

Approximate circuit analysis

Let us focus on the analysis of the following circuit section.

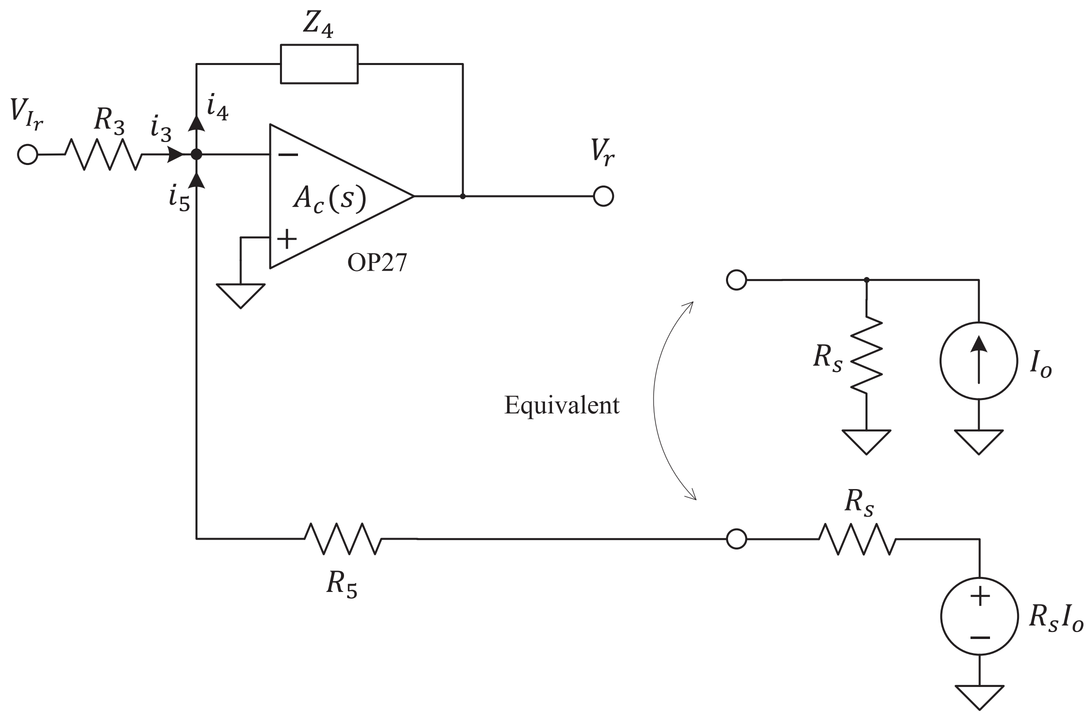


Figure 4: Circuit analysis with the virtual short approximation.

Virtual short approximation: $V_{-} \approx 0$.

KCL at the inverting terminal: $i_4 = i_3 + i_5$ (Summing junction)

Therefore, the output voltage V_r is

$$
\begin{aligned}
V_r &\approx -Z_4\ i_4 && \text{Virtual short} \\
&= -Z_4(i_3 + i_5) \\
&= -Z_4 \left(\frac{1}{R_3} V_{I_r} + \frac{R_s}{R_5 + R_s} I_o \right) \\
&\approx -Z_4 \left(\frac{1}{R_3} V_{I_r} + \frac{R_s}{R_5} I_o \right) && R_s \ll R_5
\end{aligned}
$$

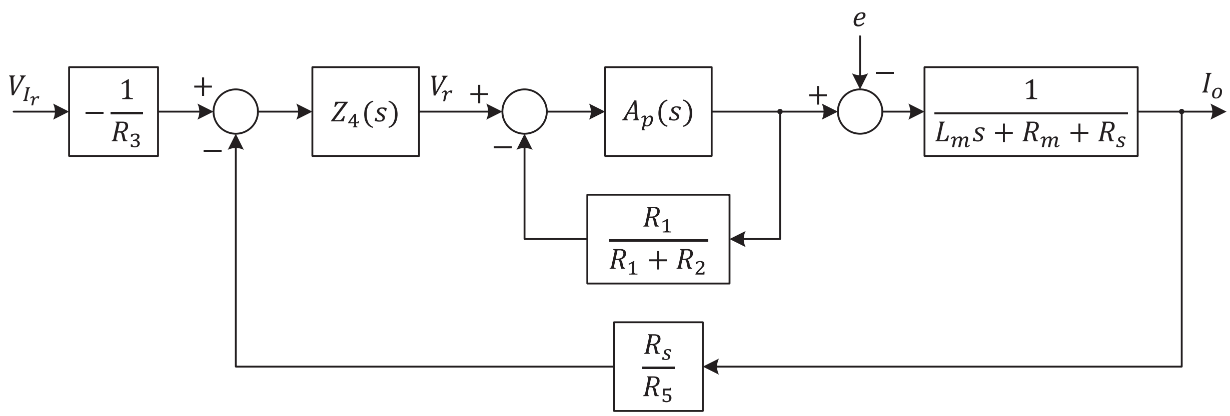


Figure 5: Approximate block diagram.

Back emf is modeled as a low-frequency disturbance.

Note the nested loop structure. The outer-loop bandwidth cannot be higher than the inner-loop bandwidth.