What’s an Analog Signal?

- Derived from the word analogous (analogous to the original signal)
- Our most powerful electronic systems are digital systems, e.g. computers, however, analog signals are required to represent real world signals
- Most interfacing to/from electronic circuitry requires some analog circuitry

- With increasing clock frequencies (>1GHz) for digital microprocessors, the digital signals are beginning to look more “analog”
- There is an increased amount of analog circuitry on the microprocessor:

    -- Sense Amps

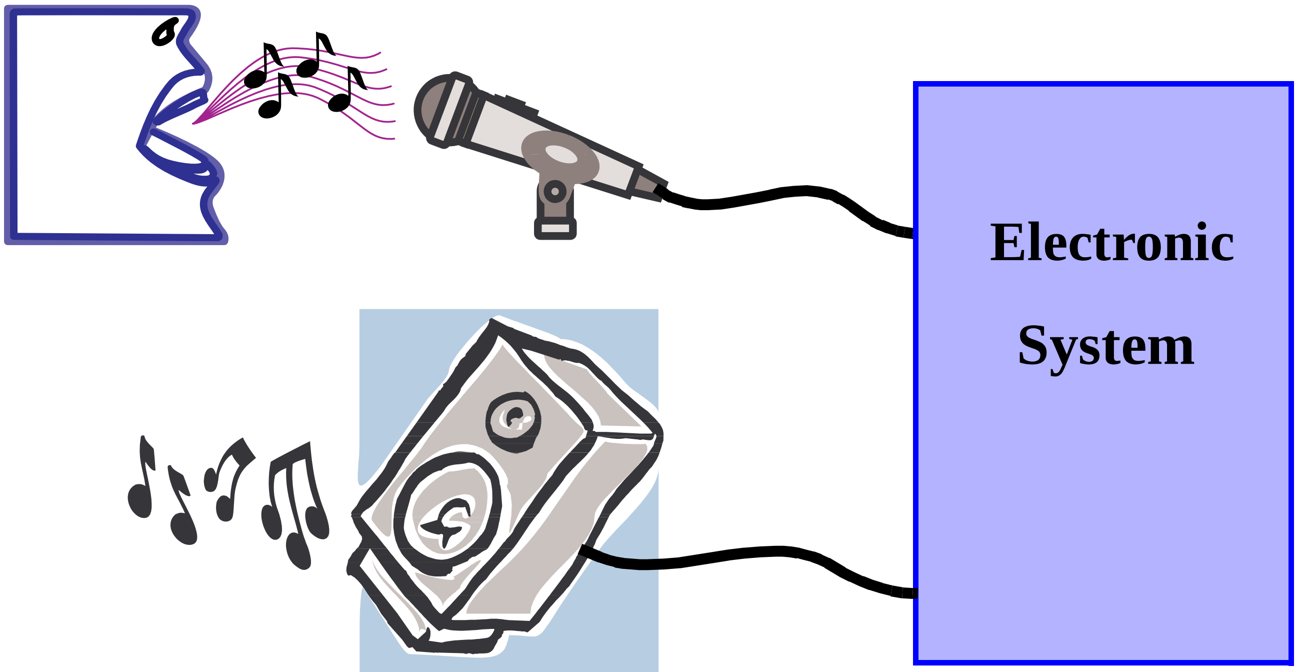
    -- Phase Lock Loops for Clocks

    -- Flash Memory Cells

    -- etc...

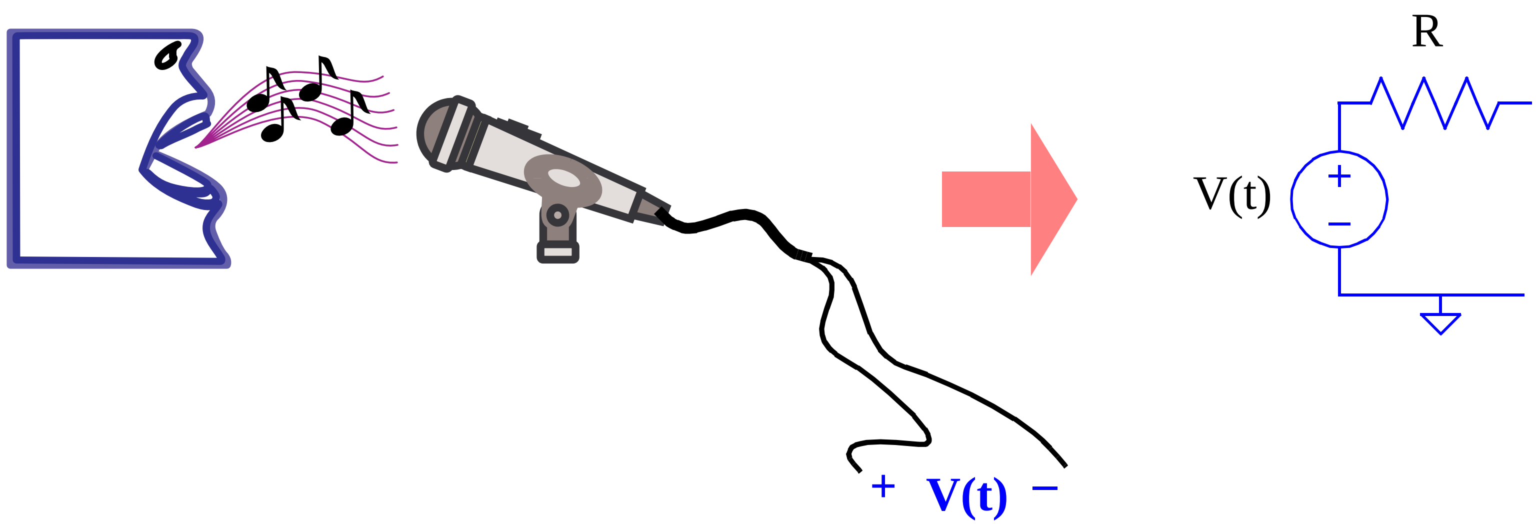
Transducers

- Many real-world analog electronic signals come via transducers
- Transducers also convert electrical analog signals into other types of responses
- Example: Accoustic transducers



Electrical Models of Transducers

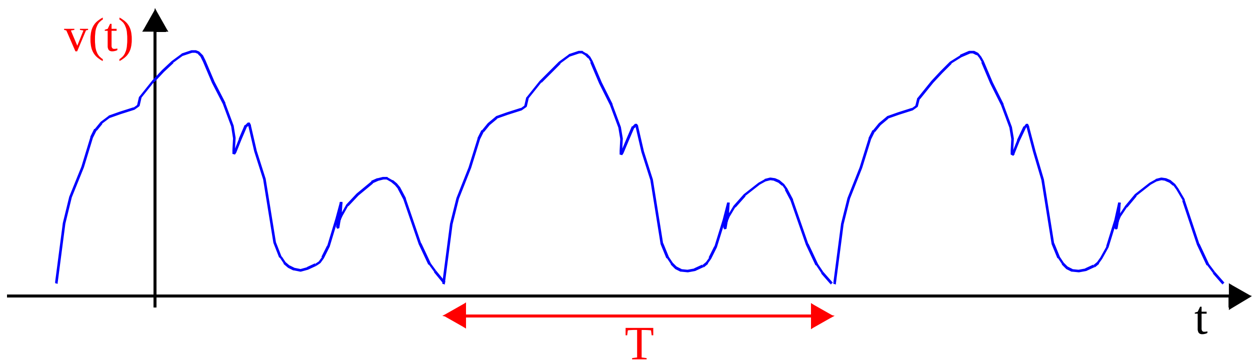
- For our purposes, we often can consider that the transducers are generating a perfect analog (analogous) signal for us from the real world signal
- A perfect transducer does not distort the signal in any way
- But it still has nonidealities that we must model:



- What does the Thevenin equivalent resistance model?

Analog Signals and the Frequency Domain

- Since the purpose of analog circuits is to process and generate analogous signals, analog circuits primarily behave linearly
- Linear systems are most effectively analyzed in the frequency domain
- Our analyses will be focused on frequency domain analysis and phasors
- Many signals will be periodic, hence represented in terms of their Fourier Series

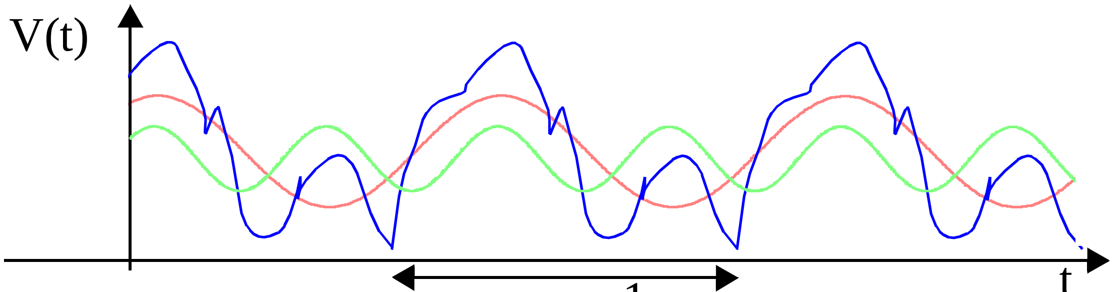


- Non-periodic signals can be represented in a similar way in terms of their Fourier Transform (18-396)
- Both methods rely on a frequency domain analysis of the circuit

Periodic Analog Signals: Fourier Series

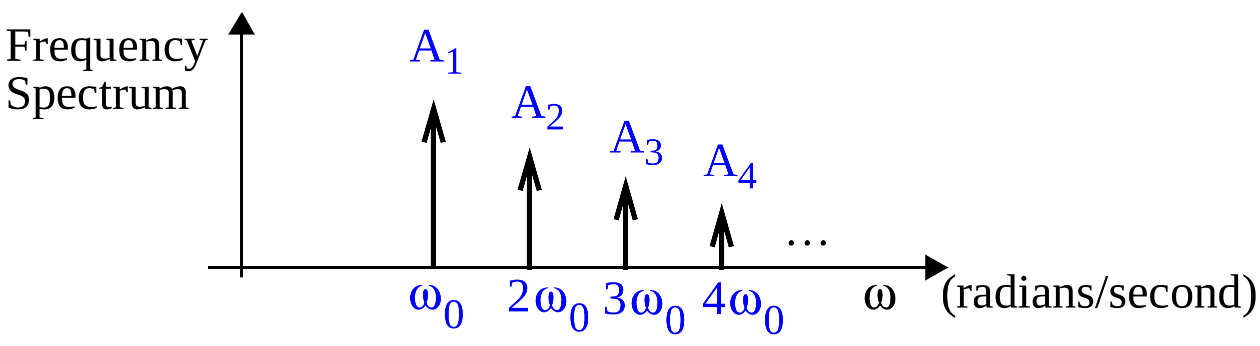
- Can represent any periodic signal as an infinite sum of sinusoids with frequencies that are integer multiples of the fundamental frequency

$$V(t) = a_{avg} + \sum_{n=1}^{\infty} A_n \cos(n\omega_o t - \theta_n)$$



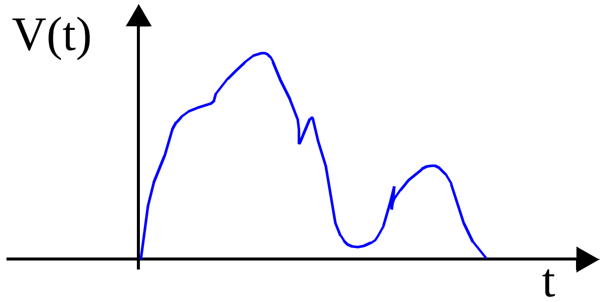
$$T_o = \frac{1}{f_o}$$

- The frequency spectrum of a periodic signal is represented as:

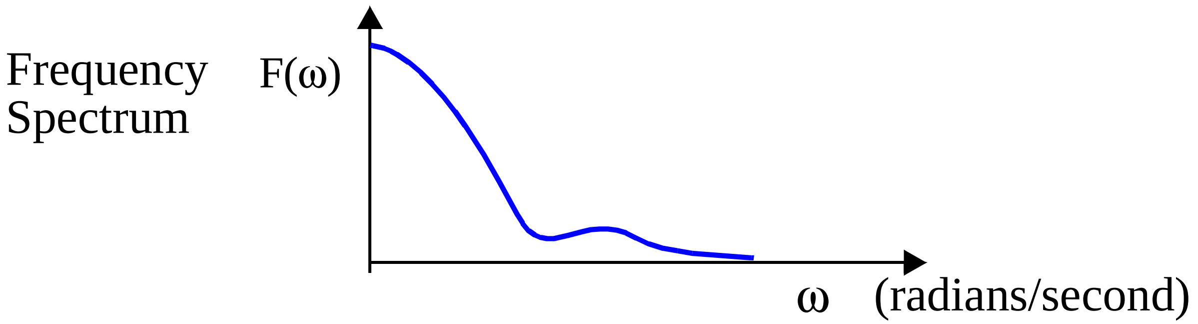


Non-Periodic Analog Signals: Fourier Transform

- Think of the Fourier Transform as a Fourier Series when the period is infinite



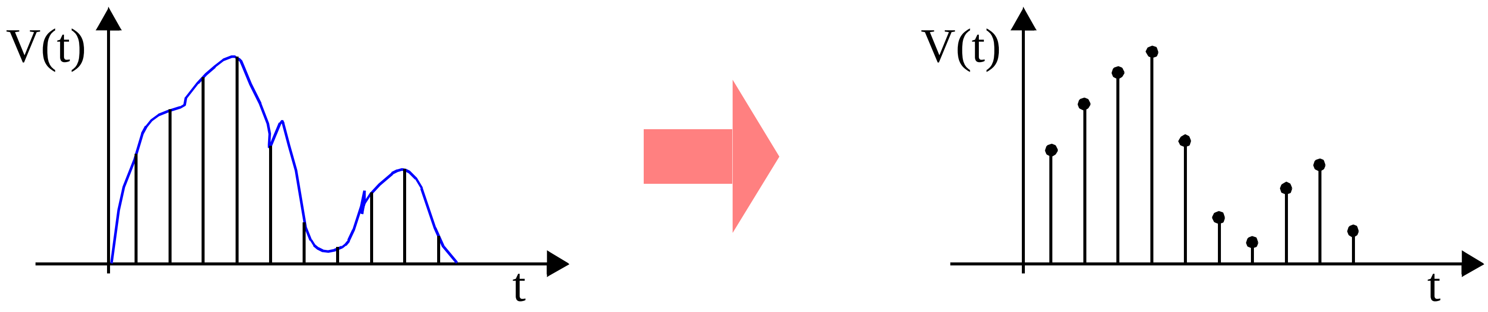
- The frequency spectrum is now continuous (18-396); All frequency components are present



- We can analyze circuits in the frequency domain and observe the frequency content of both periodic and non-periodic signals

Analog vs. Digital Signals

- We often want to convert analog signals to digital signals for more effective signal processing ---- e.g. DSP (digital signal processing)



- However, “some” analog circuitry is always present because:

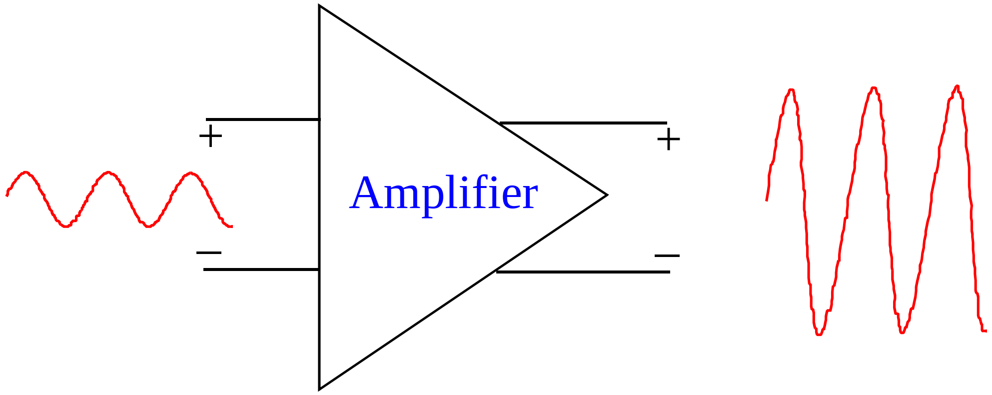
  1) of input/output interface requirements

  2) some tasks are best performed using analog circuits

- Amplification is one of the most obvious examples of something that is best handled by analog circuits

Amplifier Example

- Signals from transducers may be on the order of micro- or milli-volts
- Requires a voltage amplifier circuit that is perfectly linear (no distortion)
- Example: preamplifier for the microphone output

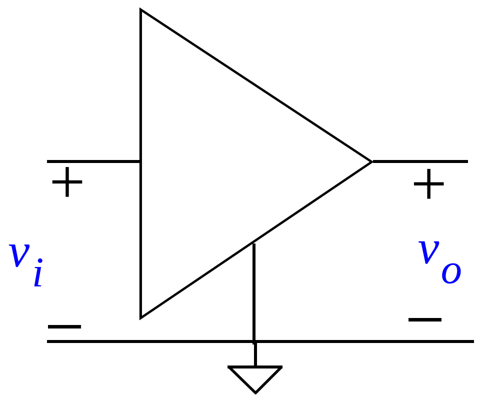


$$A_v = \frac{v_o}{v_i}$$

- Need more than one amplifier because it is difficult to design a high gain amplifier that includes all of the other properties of a preamplifier, such as:

Signal Reference

- Two lines are required to carry a signal, but often the reference wire is the common or ground for the entire circuit, and not always shown explicitly

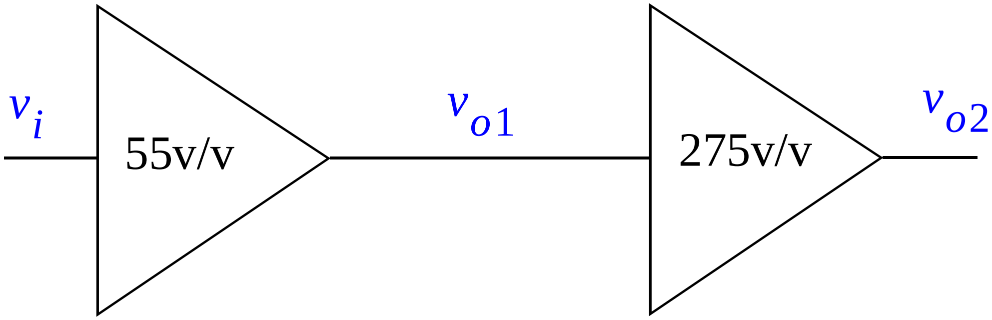


$$A_v = \frac{v_o}{v_i}$$

Gain

- What is the overall gain of the two amplifiers cascaded together?

$$A_v = \frac{v_{o2}}{v_i}$$

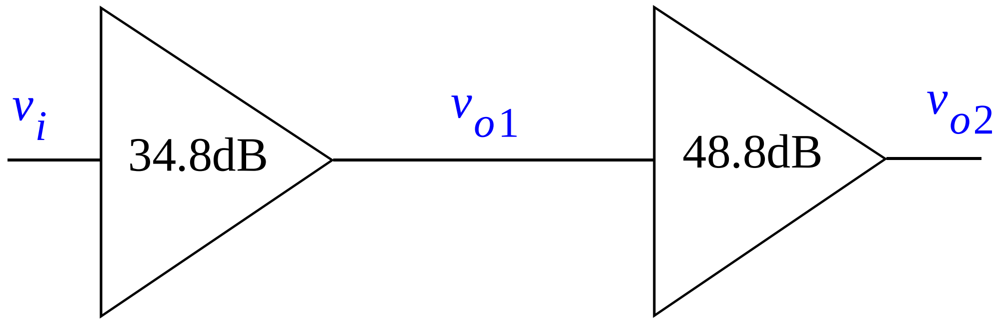


decibels (dB)

- Mainly for historical reasons, the magnitude of the amplifier gain is often represented in the units of decibels

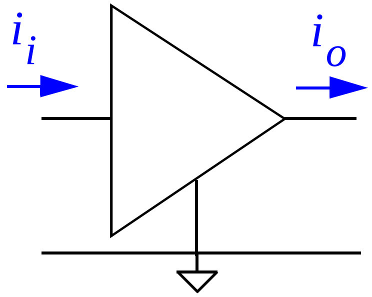
$$dB \equiv 20\log(|A_V|)$$

- Bell Telephone invented the "Bel" unit so that gain products could be calculated more readily
- At the time, engineers had slide rules instead of palm pilots
- What's the gain in dB's?



decibels (dB)

- Current gain would be described similarly



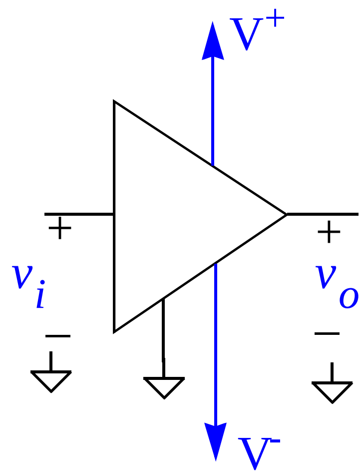
$$A_i = \frac{i_o}{i_i} \qquad dB \equiv 20\log(|A_i|)$$

- The deci prefix for decibels is derived from it's application to power gain:

$$A_p = \frac{v_o i_o}{v_i i_i} = A_v A_i \qquad dB \equiv 10\log(|A_p|)$$

Amplifier Power Connections

- The power supply connections are not always explicitly shown

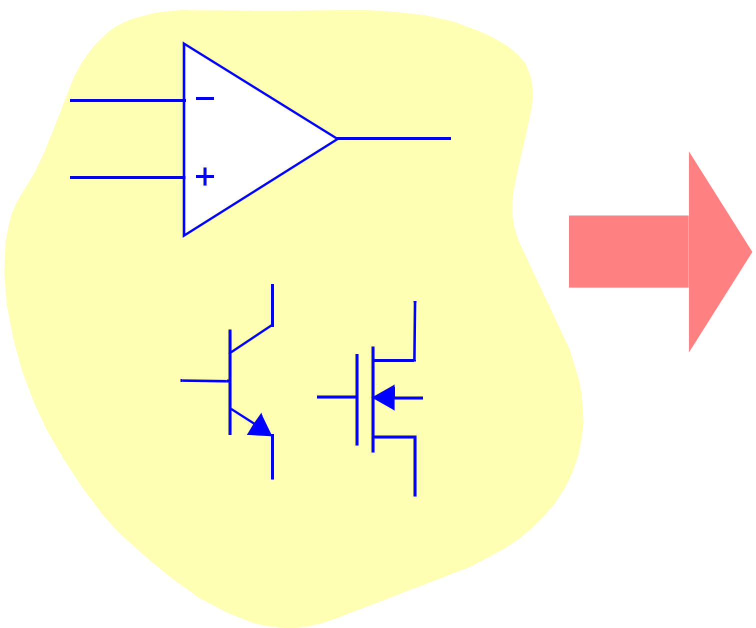


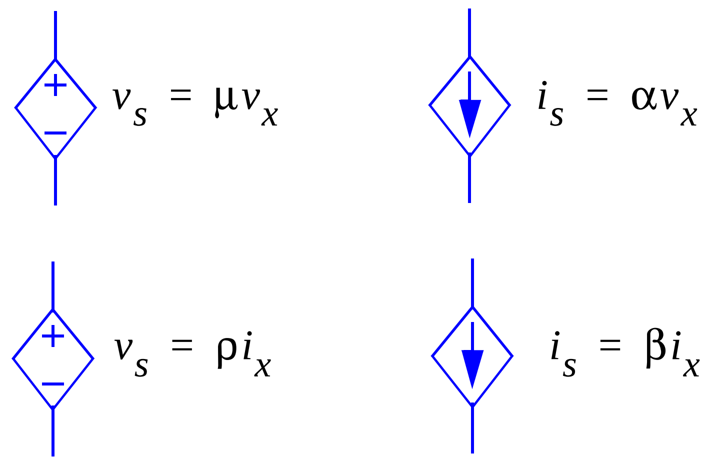
$$A_p = \frac{v_o i_o}{v_i i_i} = A_v A_i$$

- Most amplifiers require positive and negative supply voltages
- The output voltage range is limited by the supply voltages
- Operating the amplifier so that the output voltage is near the supply voltages can also result in distortion --- transmission function is no longer linear

Amplifier Circuit Models

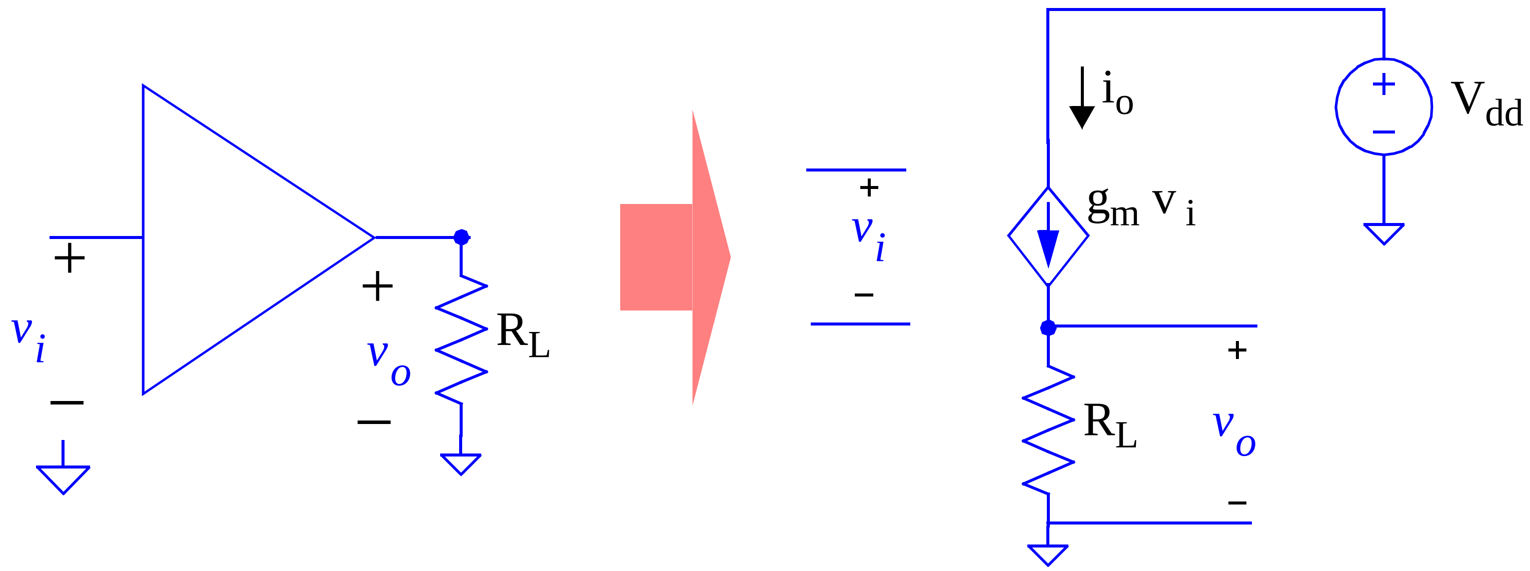
- Some distortion (from the transistors) is inevitable
- We will sometimes model and analyze this distortion using models of the transistors or macromodels of the amplifiers
- Linear amplifiers and transistors behaving linearly are modeled in terms of basic circuit elements: R’s, L’s, C’s, etc., and linear controlled sources





v_x and i_x are voltages and currents measured somewhere else in the circuit

Transconductance Amplifier Example



- The output signal is a voltage drop on the load impedance R_L:

$$v_o = R_L i_o = R_L g_m v_i$$

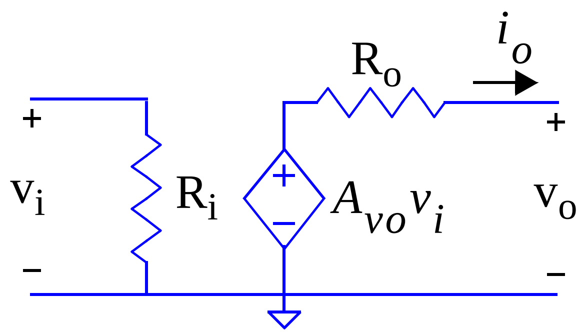
- The voltage gain in the circuit is

$$A_v = \frac{v_o}{v_i} = g_m R_L$$

- What is the current gain in this circuit?

Voltage Amplifiers

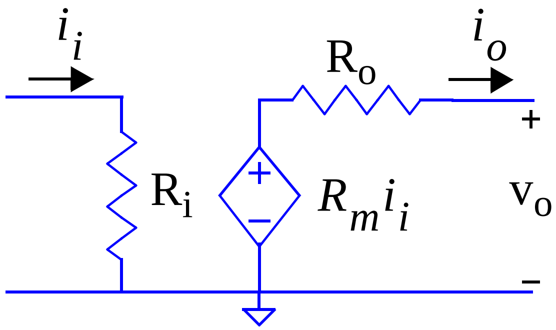
- A voltage preamplifier acts as a buffer, and should have a large input impedance, and a small output impedance
- Using linear circuit elements we can represent the amplifier and the impedances



- A_{vo} is the open circuit voltage gain
- What's the actual gain if the impedances are non-ideal?

Transresistance and Transconductance Amplifiers

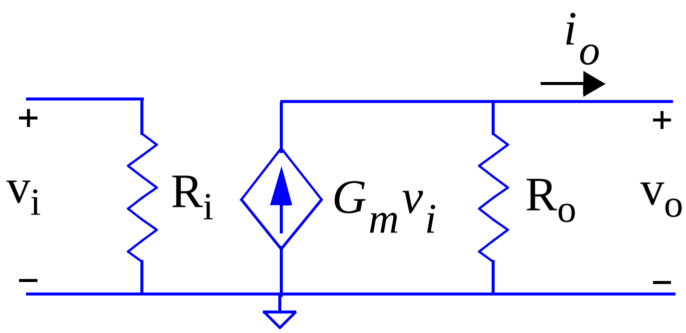
- In some applications the input signal may be a current, therefore, we would want a really low input impedance



Ideal: $R_o = 0$

$R_i = 0$

- While in other applications --- such as audio output drivers --- the output should be a current

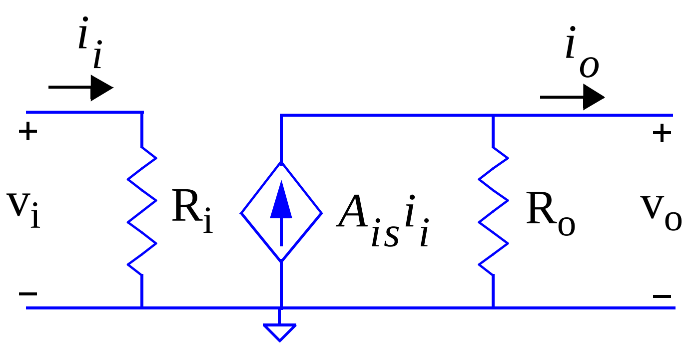


Ideal: R_o = infty

R_i = infty

Current Amplifiers

- A current amplifier should have a small input impedance, and a large output impedance

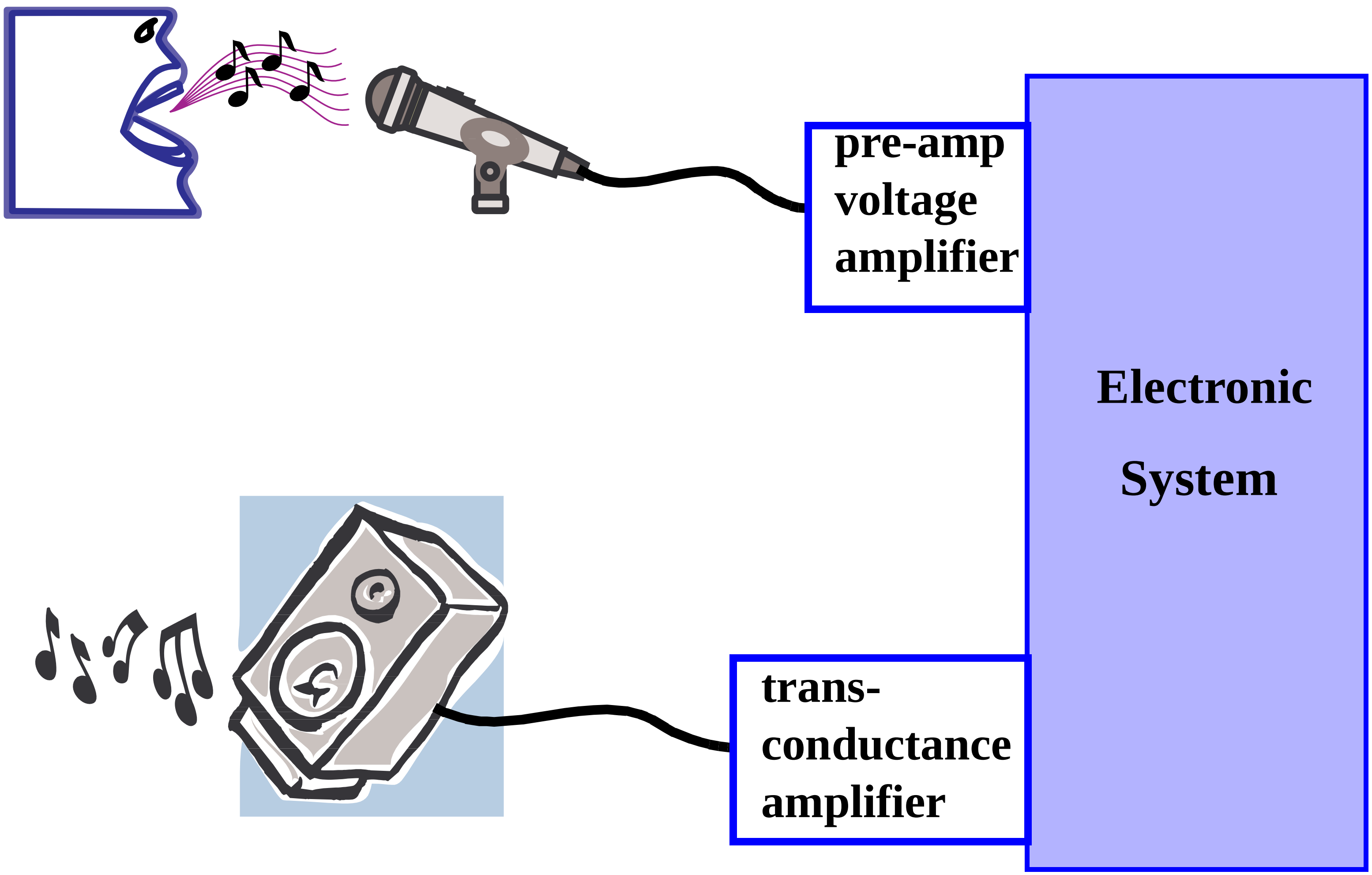


Ideal: R_o = infty

$R_i = 0$

- A_{is} is the short circuit current gain

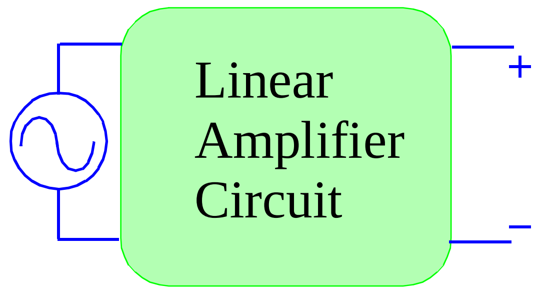
Example


pre-amp voltage amplifier
Electronic System
trans-conductance amplifier

Frequency Response

- The amplifier will not amplify signals at all frequencies by the same amount due to its limited bandwidth
- The signal transmission function, or transfer function for the circuit, is represented as $T(\omega) = \frac{V_o(\omega)}{V_i(\omega)}$ or $H(\omega) = \frac{V_o(\omega)}{V_i(\omega)}$

$v_i(t) = V_s \cos(\omega t + \phi)$



$v_o(t) = V_m \cos(\omega t + \phi + \theta)$