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: Acoustic 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:

![Diagram of a transducer signal and an equivalent circuit model](image)

- 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

\[ V(t) = a_{avg} + \sum_{n=1}^{\infty} A_n \cos(n\omega_0 t - \theta_n) \]

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

![Diagram showing frequency spectrum](image-url)
Non-Periodic Analog Signals: Fourier Transform

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

\[ V(t) \]

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

\[ F(\omega) \]

- 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?

![Diagram showing signal gain in dB](image)
decibels (dB)

- Current gain would be described similarly

\[
A_i = \frac{i_o}{i_i} \quad dB \equiv 20\log(\|A_i\|)
\]

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

\[
A_p = \frac{v_o}{v_i} A_i = A_v A_i \quad dB \equiv 10\log(\|A_p\|)
\]
Amplifier Power Connections

- The power supply connections are not always explicitly shown

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

\[ A_p = \frac{v_o}{i_o} = A_v A_i \]
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**

\[
\begin{align*}
\text{v}_s &= \mu \text{v}_x \\
\text{i}_s &= \alpha \text{v}_x \\
\text{v}_s &= \rho \text{i}_x \\
\text{i}_s &= \beta \text{i}_x
\end{align*}
\]

\text{v}_x \text{ and } \text{i}_x \text{ are voltages and currents measured somewhere else in the circuit}
• 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.

\[ V_o = A_v o \times V_i \]

- \( A_v o \) 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

\[
\begin{align*}
R_i & \quad R_m i_i \\
+ & \quad + \quad + \\
R_o & \quad v_o \quad v_o \\
- & \quad - \quad -
\end{align*}
\]

Ideal: \( R_o = 0 \)
\( R_i = 0 \)

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

\[
\begin{align*}
+ & \quad + \\
R_i & \quad R_o \\
v_i & \quad G_m v_i \quad R_o \\
- & \quad - \quad -
\end{align*}
\]

Ideal: \( R_o = \text{infty} \)
\( R_i = \text{infty} \)
Current Amplifiers

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

\[
\begin{aligned}
&v_i & &R_i & &A_{is}i_i & &R_o & &v_o \\
&+ & & & & & & & &+
\end{aligned}
\]

Ideal: \( R_o = \infty \)

\( R_i = 0 \)

- \( A_{is} \) is the short circuit current gain
Example

Electronic System

pre-amp voltage amplifier

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

  \[ T(\omega) = \frac{V_o(\omega)}{V_i(\omega)} \quad \text{or} \quad H(\omega) = \frac{V_o(\omega)}{V_i(\omega)} \]

\[ v_i(t) = V_s \cos(\omega t + \phi) \]

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

\[ |T(\omega)| \]

\[ \omega_L \quad \text{Bandwidth} \quad \omega_H \]