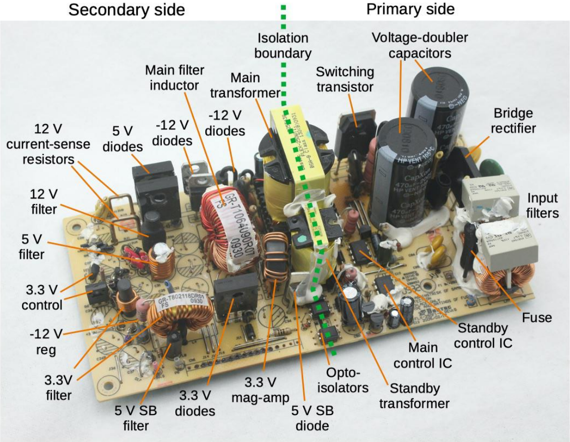


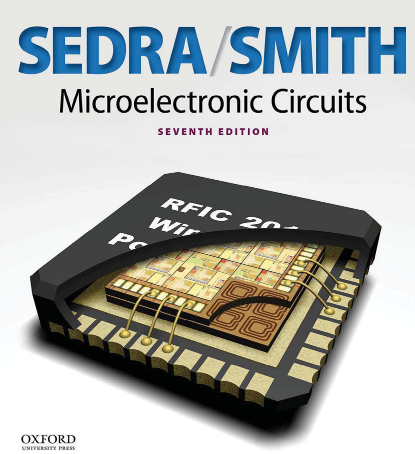
https://qiriro.com/epe2165/

Amplifiers

Kizito NKURIKIYEYEZU, Ph.D.

Readings

- **Section 1.4 (page 15-25)**
- Example 1.2 on page 20



[1] Readings are based on Sedra & Smith (2014), Microelectronic Circuits 7th edition.
[2] Bold reading section are mandatory. Other sections are suggested but not required readings

Why signal amplification?

- Many transducers yield output at low power and have little energy (Fig. 1).
- Such signals are too small for reliable processing, and processing is much easier if the signal magnitude is made larger.
- An amplifier is a circuitry that can increase the power of a signal[1]

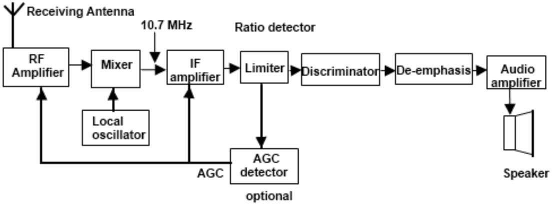


FIG 1. Principles of an FM radio receiver[2]
A radio receiver's antenna get very low power level, on the order of picowatts or femtowatts. To produce an audible signal, this signal to be amplified a trillion-fold (i.e., the gain $A > 10^{12}$)

[1] https://en.wikipedia.org/wiki/Amplifier

[2] https://www.daenotes.com/electronics/communication-system/superheterodyne-fm-receiver

Linearity and distortion

- An amplifier should not change nor introduce new information in the signal
- linearity —is property of an amplifier which ensures a signal is not “altered” from amplification
- distortion—is any unintended change in output
- The “wiggles” in the output waveform must be identical to those in the input waveform. Any change in waveform is distortion and undesirable.

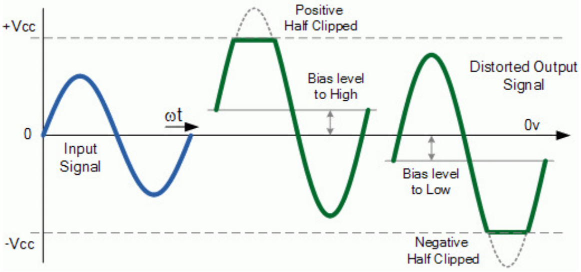


FIG 2. Non-linear amplitude distortion due to incorrect biasing[1]
The amplitude of the original signal is distorted because amplification cannot take place over the whole signal cycle due to the shift in the Q-point.

[1] https://www.electronics-tutorials.ws/amplifier/amp_4.html

Signal Amplification

- An amplifier that preserves the details of the signal waveform is characterized by Equation (1)

$$v_o(t) = Av_i(t) \tag{1}$$

  where v_i and v_o are the input and output signals, respectively, and A is the amplifier gain.
- Voltage amplifier —boost voltage levels for increased resolution.
- Power amplifier —boost current levels for increased “intensity”.

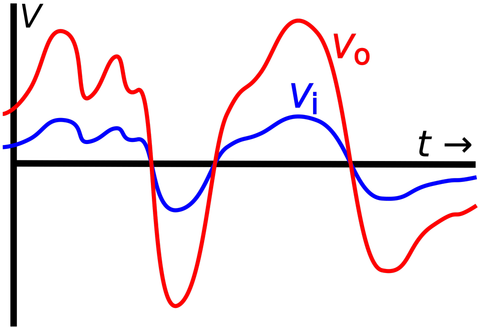


FIG 3. Signal amplification[1]
The input $v_i(t)$ is amplified with a gain $A = 3$. The output signal $v_o(t)$ is a linear representation of the original signal $v_o(t) = 3 \cdot v_i(t)$

[1] https://en.wikipedia.org/wiki/Amplifier

Amplifier circuit symbols

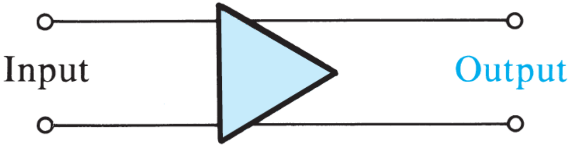


FIG 4. Circuit symbol for amplifier
This symbol clearly distinguishes the input and output ports and indicates the direction of signal flow. In general, an amplifier symbol must have two input terminals that are distinct from the two output terminals

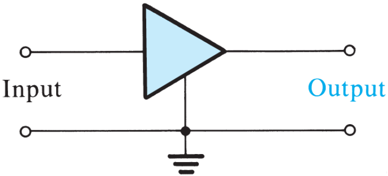


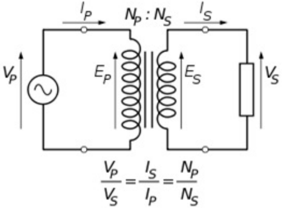
FIG 5. An amplifier with a common terminal
An amplifier is often depicted with a common terminal between the input and output ports of the amplifier. This common terminal is used as a reference point and is called the circuit ground.

Power and Current Gain

- An amplifier increases the signal power —an important feature that distinguishes an amplifier from a transformer (Equation (2))

$$A_p = \frac{load\ power(P_l)}{input\ power(P_i)} = \frac{v_o i_o}{v_i i_i} \quad (2)$$

- A transformer can deliver a voltage greater its input voltage. However, **the power delivered is always less than or at most equal to the power supplied by the signal source.**



Expressing gain in decibels

- Log scale allows to represent very small and large number with small figures. For example:
  - $10,000,000,000,000W = 130dBW$.
  - A voltage gain of $A = 0.0000001$ is $A = -140dB$
- The gain is expressed in decibels as shown in Equation (3)[1] [2]

$$
\begin{aligned}
A_{v_dB} &= 10 \cdot log\frac{V_o^2}{V_i^2} \\
&= 10 \cdot log\left(\frac{V_o}{V_i}\right)^2 \\
&= 20 \cdot log\left(\frac{V_o}{V_i}\right)
\end{aligned}
\tag{3}
$$

- voltage gain in decibels $= 20\log_{10}|A_v|dB$
- current gain in decibels $= 20\log_{10}|A_i|dB$
- power gain in decibels $= 10\log_{10}|A_p|dB$

[1] Note that the power gain equation use a coefficient of 10 unlike the other two. By convention, decibels refer to power. In the other cases, the the coefficient of 20 is a result of the fact that power is proportional to voltage squared and current squared.

[2] The absolute values of the voltage and current gains are used because in some cases A_v or A_i will be a negative number.

The amplifier power supplies

- An amplifier needs external power supply to function. This ensure that it can deliver a power greater than the power drawn from the signal source
- An amplifier has two power supplies as shown in Fig. 6[1]:
  - V_{CC} is positive, current I_{CC} is drawn
  - V_{EE} is negative, current I_{EE} is drawn
- Thus, the power drawn from an amplifier can be expressed by Equation (4)

$$P_{dc} = V_{CC} I_{CC} + V_{EE} I_{EE} \tag{4}$$

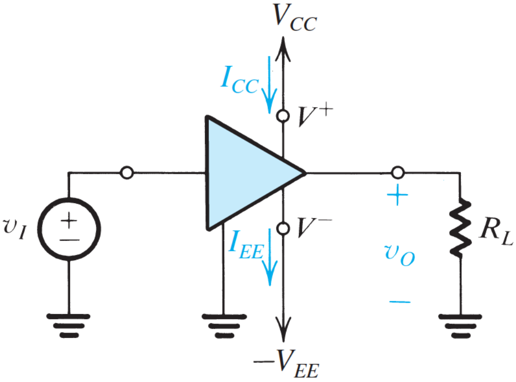


FIG 6

[1] See IC power-supply pin naming conventions at https://en.wikipedia.org/wiki/IC_power-supply_pin

Amplifier power supply

- If the power dissipated in the amplifier circuit is denoted $P_{dissipated}$, the power-balance equation for the amplifier can be written by Equation (5)

$$P_{dc} + PI = P_L + P_{dissipated} \tag{5}$$

where,

  - P_I is the power drawn from the signal source
  - P_L is the power delivered to the load.
- The amplifier power efficiency, η is defined by Equation (6)

$$\eta = \frac{P_L}{P_I + P_{dc}} \tag{6}$$

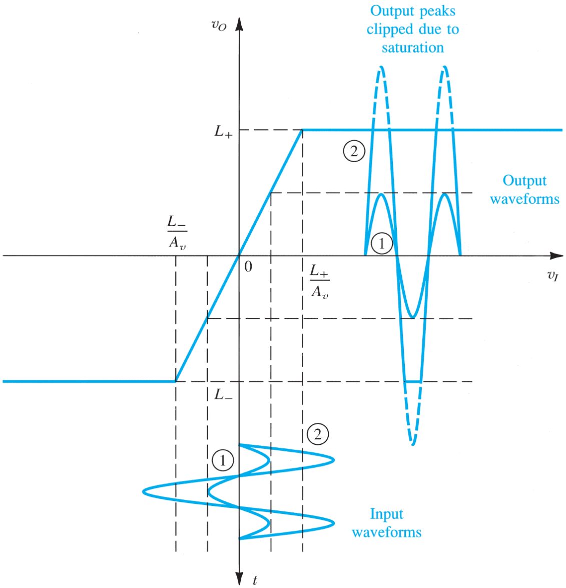
- Since the power drawn from the signal source is usually small, the amplifier power efficiency, η is expressed by Equation (7)

$$\eta = \frac{P_L}{P_{dc}} \tag{7}$$

Amplifier Saturation

- Limited linear range—practically, amplifier operation is linear over a limited input range.
- Saturation —beyond this range, saturation occurs. When there is saturation, the output remains constant as input varies
- To avoid distorting the output waveform, the input signal swing must stay within the linear range of operation, as shown in Equation (8)

$$\frac{L_-}{Av} \leq v_I \leq \frac{L_+}{Av} \qquad (8)$$



Example: Infrared emitter and detector

Working principle

- An infrared (IR) diode emits modulated signals at specific frequencies
- The signal is transmitted in pulses and modulated at around 38 kHz
- A phototransistor detects the signals and passes them through a series of analog circuits for processing.
- Modern remote TV remote controls are complex and involve programmable computers.

FIG 7. An infrared TV remote control

Detailed block diagram of the analogy circuit

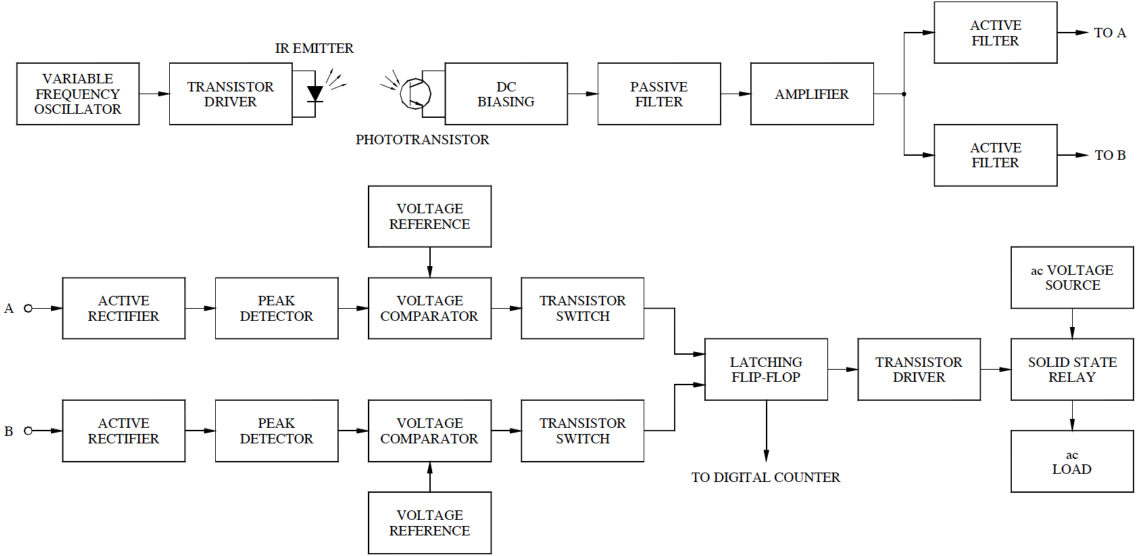


FIG 8. IR detector and emitter block diagram of the analog circuitry[3]

The end