EN1012 Electronic Devices and Circuits
Topic 5 - Amplifier Circuits and Applications

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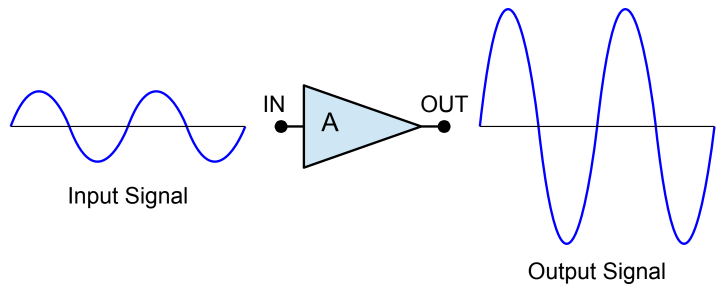
Outline

Introduction

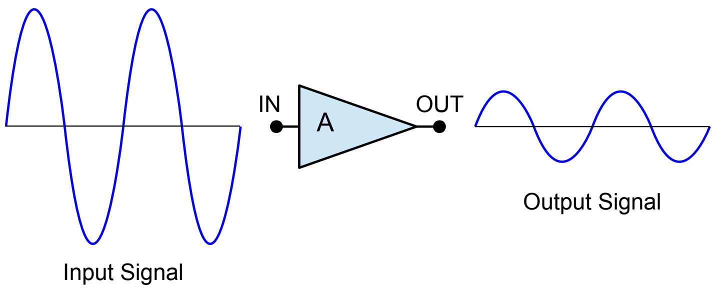
Amplification

- Increasing the amplitude of a signal
  - Increasing the voltage, current or power of a signal



Attenuation

- Decreasing the amplitude of a signal
  - Filtering of signals (e.g. removing 50 Hz AC line noise)



Nature of the Amplifier

- Voltage (Pre) amplifiers
  - Provide voltage gain
  - Suitable for amplifying weak signals
- Current (Power) amplifiers
  - Provide current gain to a large amplitude voltage signals, resulting in power gain
  - Suitable for driving loads such as speakers and radio transmitters

Amplifier Parameters

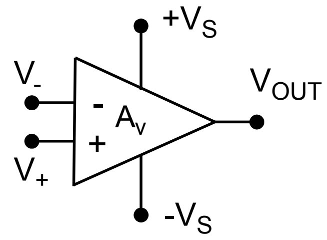
- Input impedance
  - Made as large as possible to prevent current loading and maximize voltage transfer
- Output impedance
  - Often made as small as possible to maximize power output
- Gain of the amplifier
  - Limited by the saturation of the device
  - Optimal at the bandwidth of the amplifier
  - Typical ranges: 20-20000 Hz for an audio amplifier, 0.1-100 Hz for a seismic signal amplifier

Voltage Amplifiers

Operational Amplifiers

- The main device for voltage amplification
- A *monolithic* amplifier implemented on a single chip
  - The basic building blocks are transistor amplifiers
- Unlike discrete BJT or FET amplifiers it is convenient to use
  - The gain of an op-amp amplifier can be conveniently set
- It has a number of other applications
  - Comparators
  - Hysteresis comparators
  - High impedance buffers etc.
- Generally needs a *dual supply* for amplification
- Suitable for low frequency use

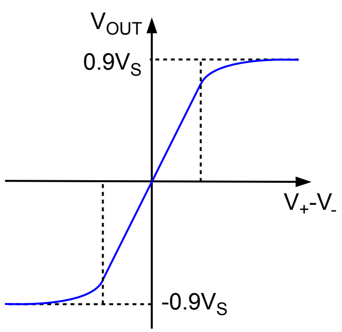
Op-Amp Model



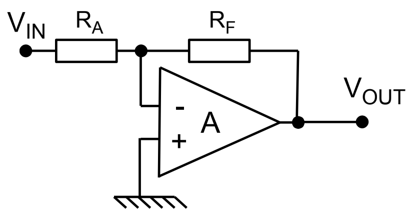
- Two inputs V_+ (non-inverting input) and V_- (inverting input)
- Has a very high voltage gain A_V (typically 10^5 to 10^6)
- The difference $\Delta V = V_+ - V_- \approx 0$ (considered to be very small)

Op-Amp Model (Contd..)

- Very high input impedance
  - Negligible current flows into the device
- Very low output impedance
- The output is given by
  - $V_{OUT} = A_V(V_+ - V_-)$
  - It saturates when $V_{OUT} \approx 0.9V_S$



Inverting Amplifier

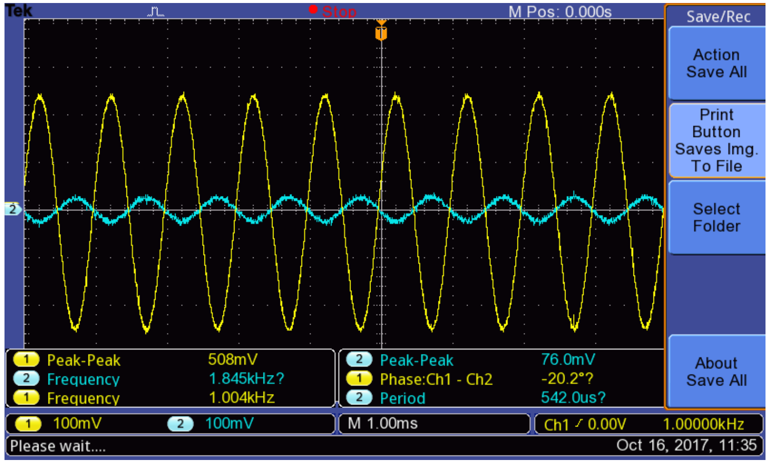


$V_+ - V_- \approx 0 \Rightarrow V_- \approx 0$ A *virtual* ground

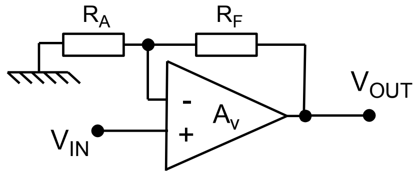
Therefore,

$$G \approx \frac{V_{OUT}}{V_{IN}} = \frac{-I_F R_F}{I_F R_A} = -\frac{R_F}{R_A}$$

Inverting Amplifier Output



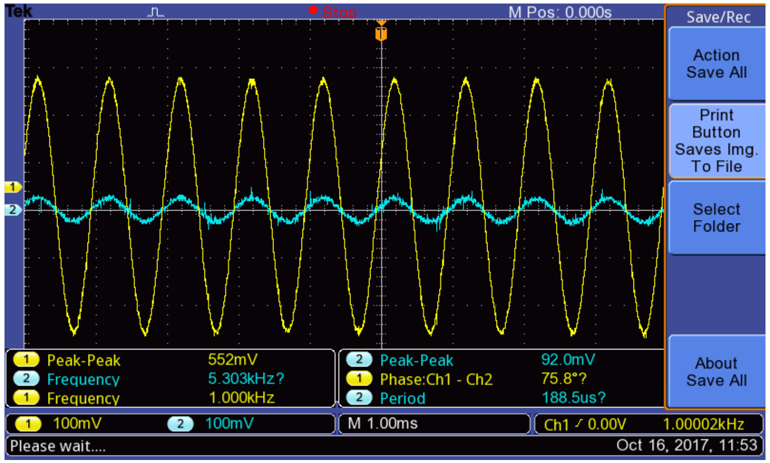
Non-Inverting Amplifier



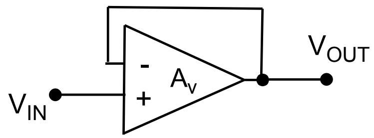
$$V_{OUT} = A_V\left[V_+ - V_-\right] = A_V\left[V_+ - \frac{R_A}{(R_A+R_F)}V_{OUT}\right]$$

$$\frac{V_{OUT}}{A_V} = \left[V_{IN} - \frac{R_A}{(R_A+R_F)}V_{OUT}\right] \approx 0 \Rightarrow G = \frac{R_F}{R_A} + 1$$

Non-Inverting Amplifier Output



High Impedance Buffer



$$V_{OUT} = A_V\left[V_+ - V_-\right] = A_V\left[V_{IN} - V_{OUT}\right]$$

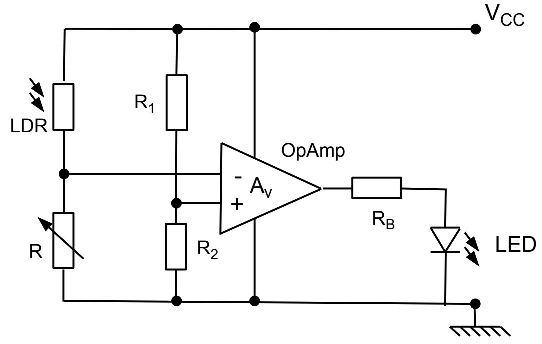
$$\frac{V_{OUT}}{A_V} = \left[V_{IN} - V_{OUT}\right] \approx 0 \Rightarrow G = 1$$

- Can match a high impedance source to a low impedance load

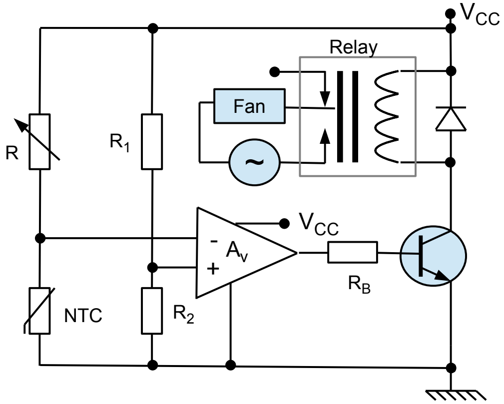
Comparator

- In the comparator the op-amp is used in open-loop
  - Maximum gain
  - Will saturate for a low difference
  - For example: $A_V = 10^5$ and $V_S = \pm 12$ V and $V_{SAT} = 0.9V_S$ results in maximum signal amplitude (δ) of $108\ \mu$V
- Therefore, by comparing V_+ and V_- it is possible to compare the two and switch a device on and off.
  - If $V_+ - V_- > \delta$ then $V_{OUT} = +V_{SAT}$
  - If $V_- - V_+ > \delta$ then $V_{OUT} = -V_{SAT}$

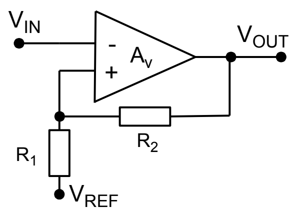
LDR Comparator Circuit

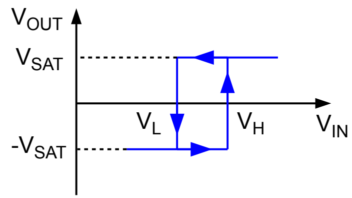


Thermistor Comparator Circuit



Hysteresis Comparator





$$
\begin{aligned}
V_H &= \frac{R_2 V_{REF} + R_1 V_{SAT}}{R_1 + R_2} \\
V_L &= \frac{R_2 V_{REF} - R_1 V_{SAT}}{R_1 + R_2}
\end{aligned}
$$

Hysteresis Comparator (Contd..)

Obtained using the *Superposition theorem* because $(+)$-input is considered as $I_{IN} \neq 0$ due to saturation.

When $V_{REF} = 0$, $V_+ = V_1 = \frac{R_1}{R_1+R_2} V_{OUT} = \pm \frac{R_1}{R_1+R_2} V_S$

When $V_{OUT} = 0$, $V_+ = V_2 = \frac{R_1}{R_1+R_2} V_{REF}$

From the Superposition Theorem (since R_1 and R_2 are linear)

$$V_+ = V_1 + V_2 = \underbrace{\pm\frac{R_1}{R_1+R_2} V_S}_{\text{positive feedback}} + \underbrace{\frac{R_2}{R_1+R_2} V_{REF}}_{\text{offset}}$$

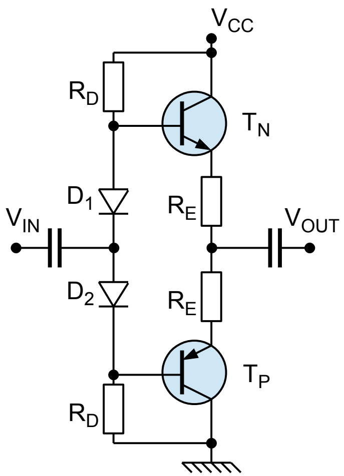
Therefore V_+ can either be V_H or V_L.

Current Amplifiers

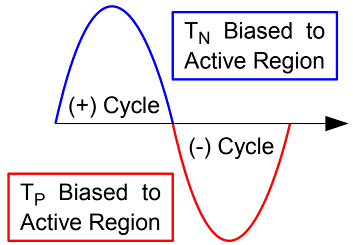
Transistor Power Amplifiers

- Generally op-amps are not capable of driving large loads
  - Have to use transistor amplifiers instead
- Signal amplitiude is large enough to affect the bias point of the transistors used
- Example circuit is the Class AB power amplifier
  - Has two complementary BJTs (one for each half cycle)

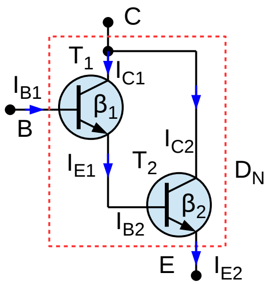
Class AB Power Amplifier



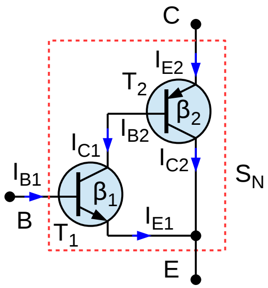
- R_E prevents thermal runaway
- Diode AC resistance is considered negligible
- $R_D \approx 1k\Omega$



Further Current Amplification

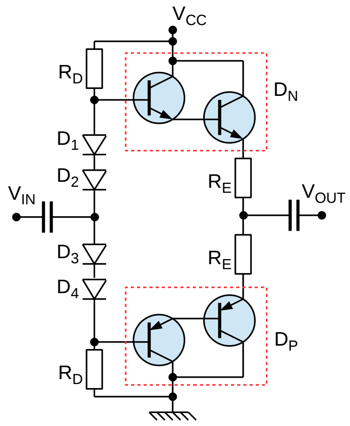


Darlington Configuration

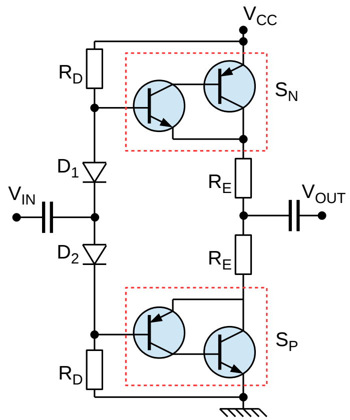


Sziklai Configuration

Further Current Amplification (Contd..)



Darlington



Sziklai

Conclusion

Summary

- Transistors can be used for switching and amplification
- Swiching circuits are simple to design
- Amplifier circuits are more complex
  - Simple amplifier bias circuits have many drawbacks
  - Robust amplifier bias circuits are difficult to design
- Op-amps are general purpose amplifiers that are convenient to implement
  - Even these devices have circuits that are complex to design
- What are the limitations of analog electronics?
  - For example, can a *Turing Machine* be built using analog components?

Next Lecture...

Introduction to Digital Electronics