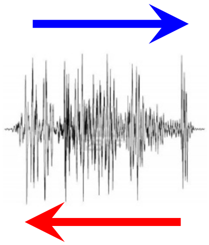
EE2021
Devices and Circuits

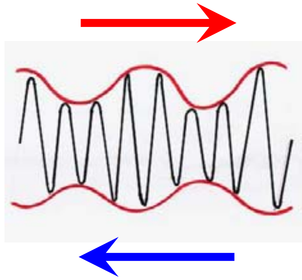
Fundamentals

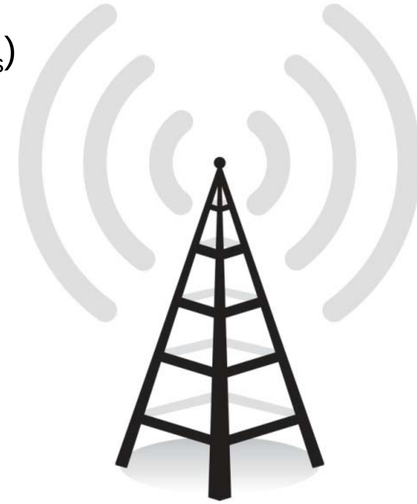
World of Signals

Audio:20~20kHz
Mic: 5~50mV
Earphone: 0.316V_{rms} (nominal)

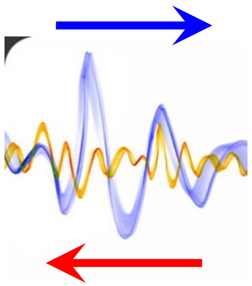
Radio: 850, 900, 1800, 1900, 2100MHz
Transmit: +33dBm (10V)
Receive: -104dBm (1.4μV_{rms})







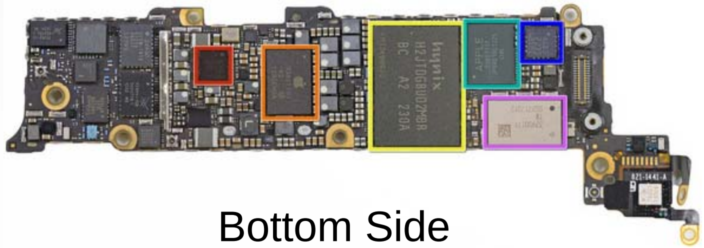
Motion:
Vibration: 50Hz@5V
Movement: ±8g, 12-bit



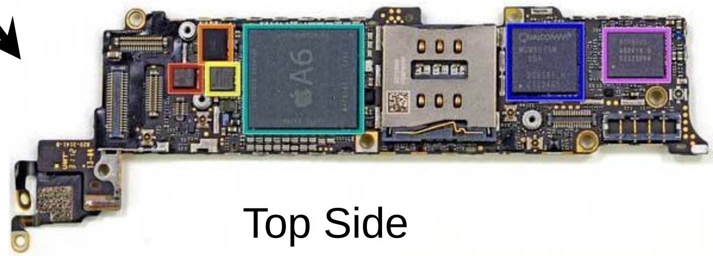
Camera:
Picture: 8 Megapixel
Video: HD, 30fps

Important things:
1. Signal level
2. Signal frequency

Teardown



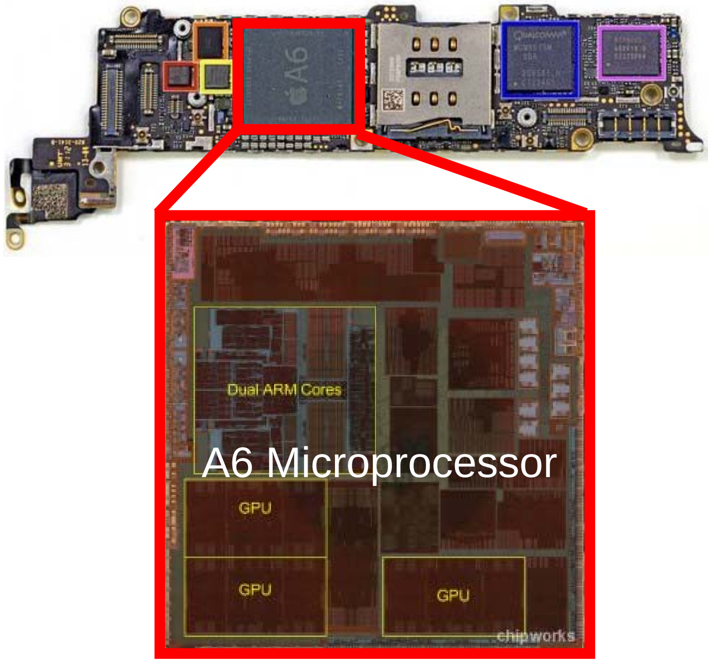
Bottom Side



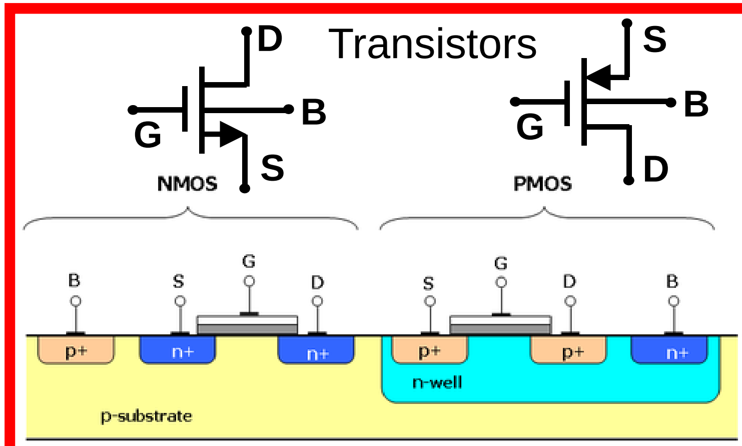
Top Side

http://www.ifixit.com/Teardown/iPhone+5+Teardown/10525/1

Microprocessor

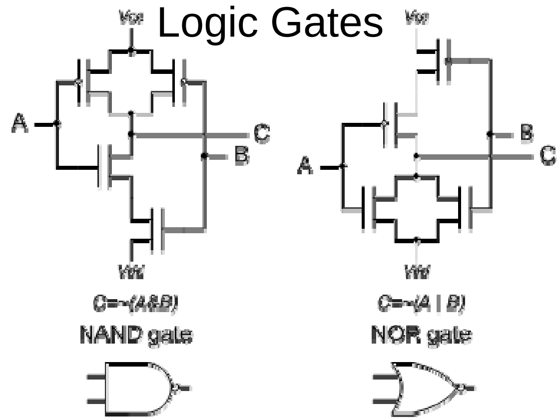


Transistors



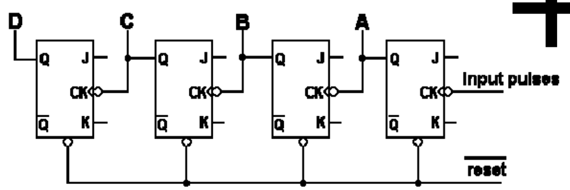
Lecture on MOSFET and semiconductor physics

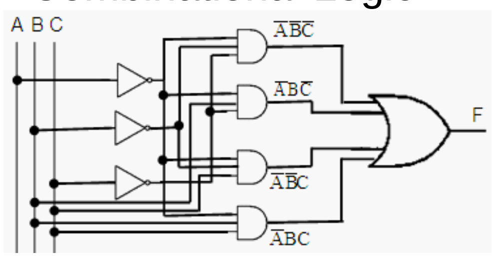
Logic Gates



Lecture on logic synthesis

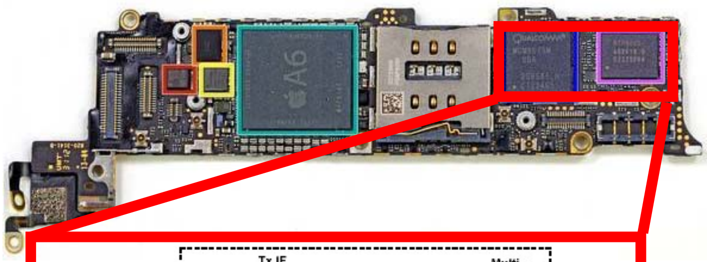
Sequential Logic + Combinational Logic

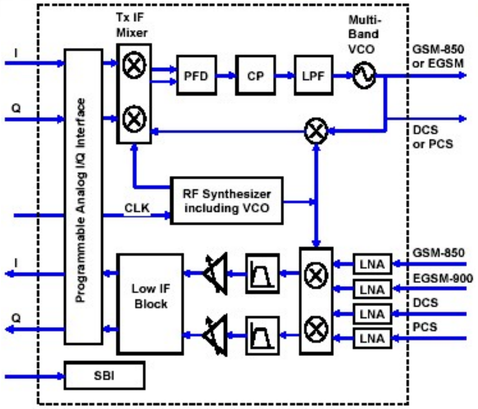


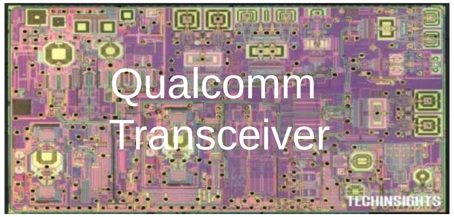


EE2020 Digital Fundamentals

Transceiver

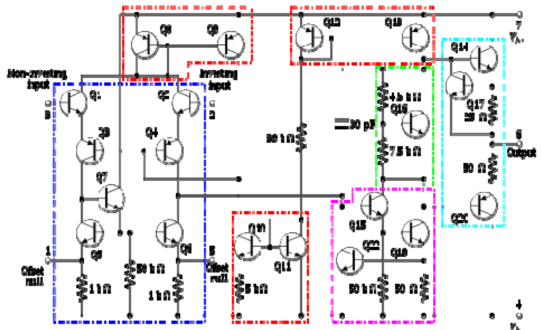




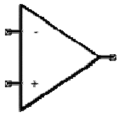


Mixer, Filter, LNA, Oscillator, VGA, ADC, DAC, etc.

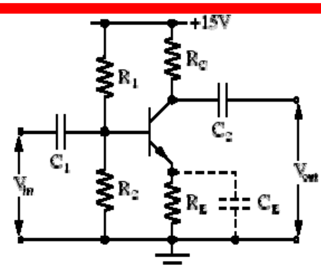
EE3407 Analog Electronics
EE5303 Microwave Electronics
EE6301 RF Transceivers
EE6506 Advanced IC Design



Opamp is built with current mirror and multistage amplifier

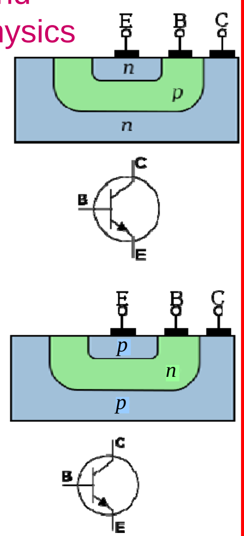


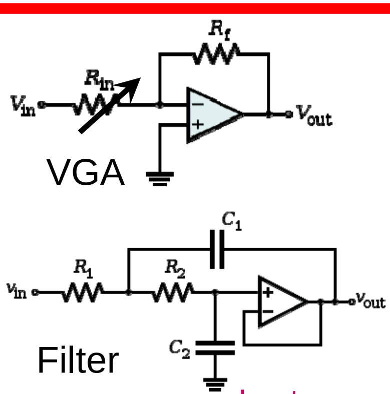
EE3408 Integrated Analog Design
Lecture on multi-stage amplifier

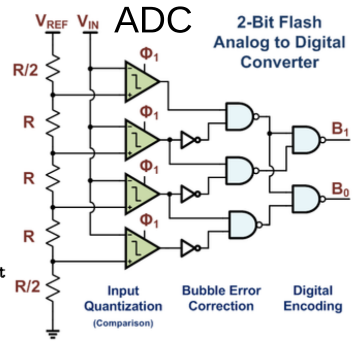


Single Stage Amplifier: CE/CS, CB/CG, CC/CD
Lecture on single stage amp

Transistors
Lecture on BJT and semiconductor physics

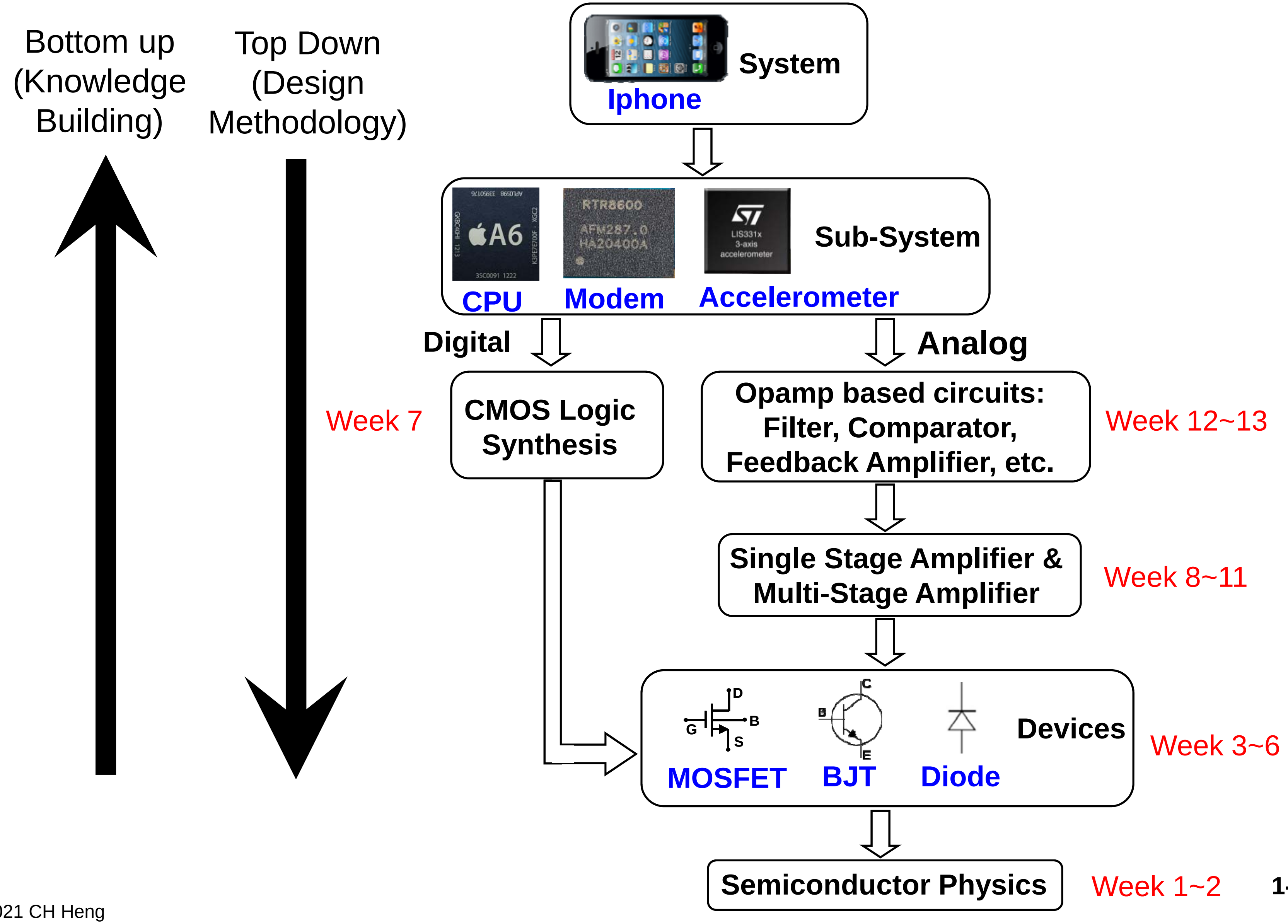






Lecture on opamp-based circuits

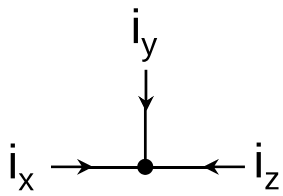
Overview


Bottom up (Knowledge Building)
Top Down (Design Methodology)
System
Iphone
Sub-System
CPU
Modem
Accelerometer
Digital
Analog
Week 7
CMOS Logic Synthesis
Opamp based circuits: Filter, Comparator, Feedback Amplifier, etc.
Week 12~13
Single Stage Amplifier & Multi-Stage Amplifier
Week 8~11
Devices
MOSFET
BJT
Diode
Week 3~6
Semiconductor Physics
Week 1~2

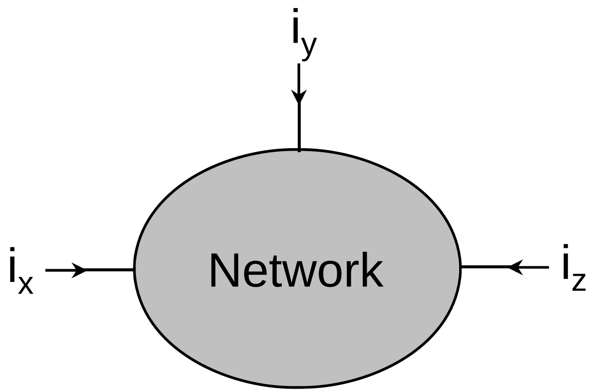
Refresh

- KCL and KVL
- Thevenin and Norton Equivalent
- Linear Superposition
- Definition on Decibel
- Maximum Power Transfer

KCL



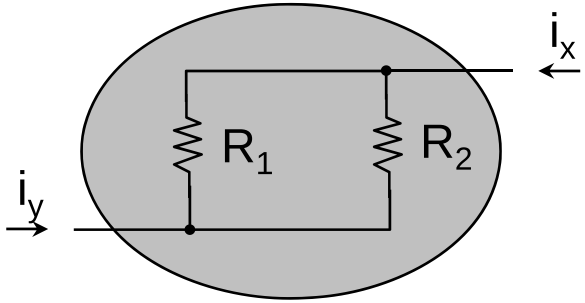
Conventional KCL:
Currents flowing into a node sum to zero



Generalized KCL:
Currents flowing into a network sum to zero

$$i_x + i_y + i_z = 0$$

Example:

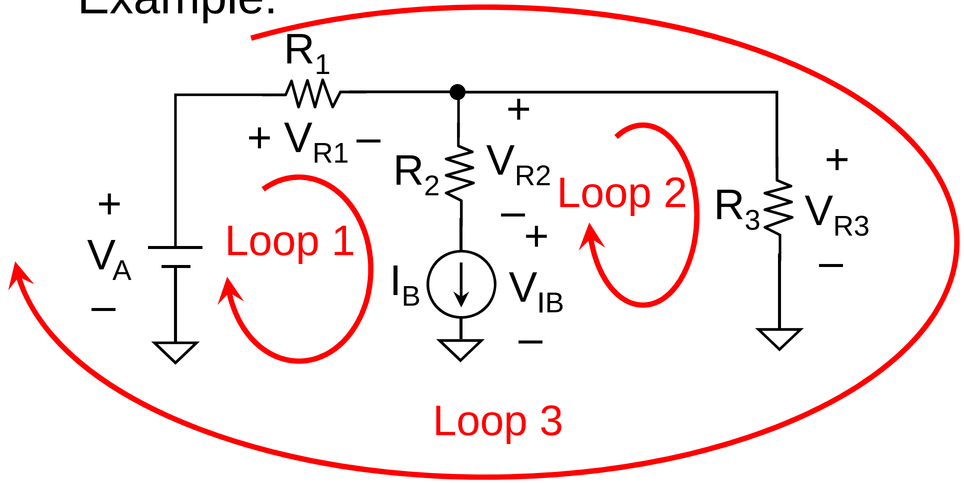


$$i_x + i_y = 0$$

KVL

KVL:
The sum of potential differences around any closed-loop is zero.

Example:



***Loop* 1:**

$$\boldsymbol{V_A} + (-\boldsymbol{V_{R1}}) + (-\boldsymbol{V_{R2}}) + (-\boldsymbol{V_{IB}}) = 0$$

***Loop* 2:**

$$\boldsymbol{V_{IB}} + \boldsymbol{V_{R2}} + (-\boldsymbol{V_{R3}}) = 0$$

***Loop* 3:**

$$\boldsymbol{V_A} + (-\boldsymbol{V_{R1}}) + (-\boldsymbol{V_{R3}}) = 0$$

Thevenin & Norton Equivalent

Thevenin:

Any linear network with one port output can be replaced with an equivalent Thevenin voltage source (V_{THV}) in series with a Thevenin resistance (R_{THV}).

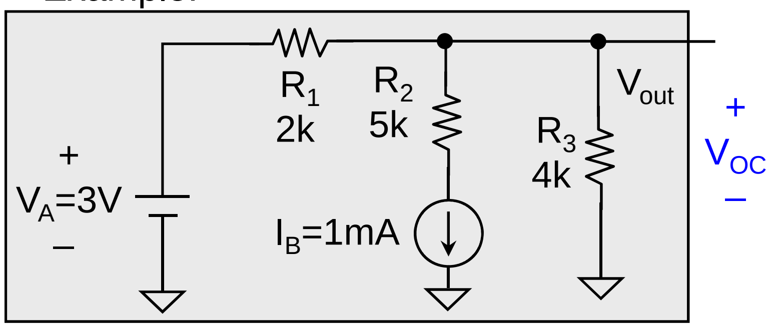
Norton:

Any linear network with one port output can be replaced with an equivalent Norton current source (I_{NOR}) in parallel with a Norton resistance (R_{NOR}) .

Notes:

1)The Thevenin voltage source (V_{THV}) is found by evaluating the open-circuit voltage at the port.
2)The Norton current source (I_{NOR}) is found by evaluating the short-circuit current at the port.
3)In finding the equivalent resistance looking into the port, kill the voltage sources with short circuit, and the current sources with open circuit.

Example:



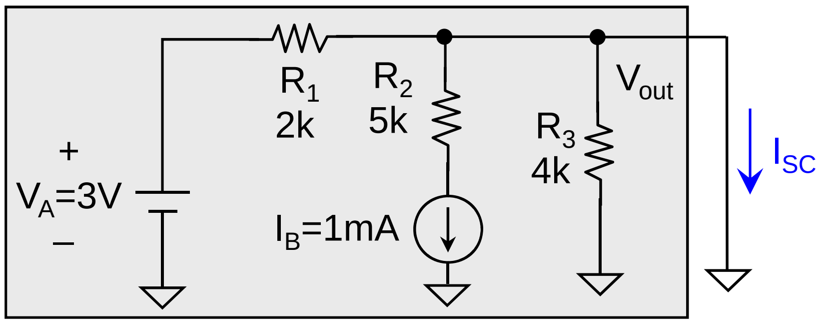
$$KCL:$$

$$\frac{V_A - V_{out}}{R_1} + \frac{0 - V_{out}}{R_3} + (-I_B) = 0$$

$$\Rightarrow 3V_{out} = 2V_A - I_B \times R_3 = 2V$$

$$\Rightarrow V_{out} = \frac{2}{3}V = V_{THV}$$

(Open-circuit voltage)



$$KCL:$$

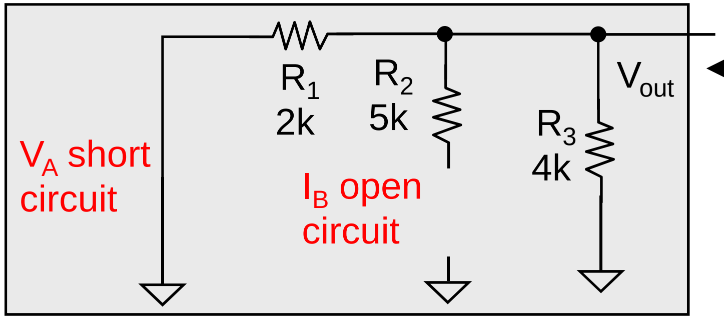
$$I_{R1} + (-I_B) + (-I_{R3}) + (-I_{SC}) = 0$$

$$I_{R1} = \frac{V_A}{R_1} = 1.5mA \quad I_{R3} = 0$$

$$\Rightarrow I_{SC} = I_{R1} - I_B = 0.5mA = I_{NOR}$$

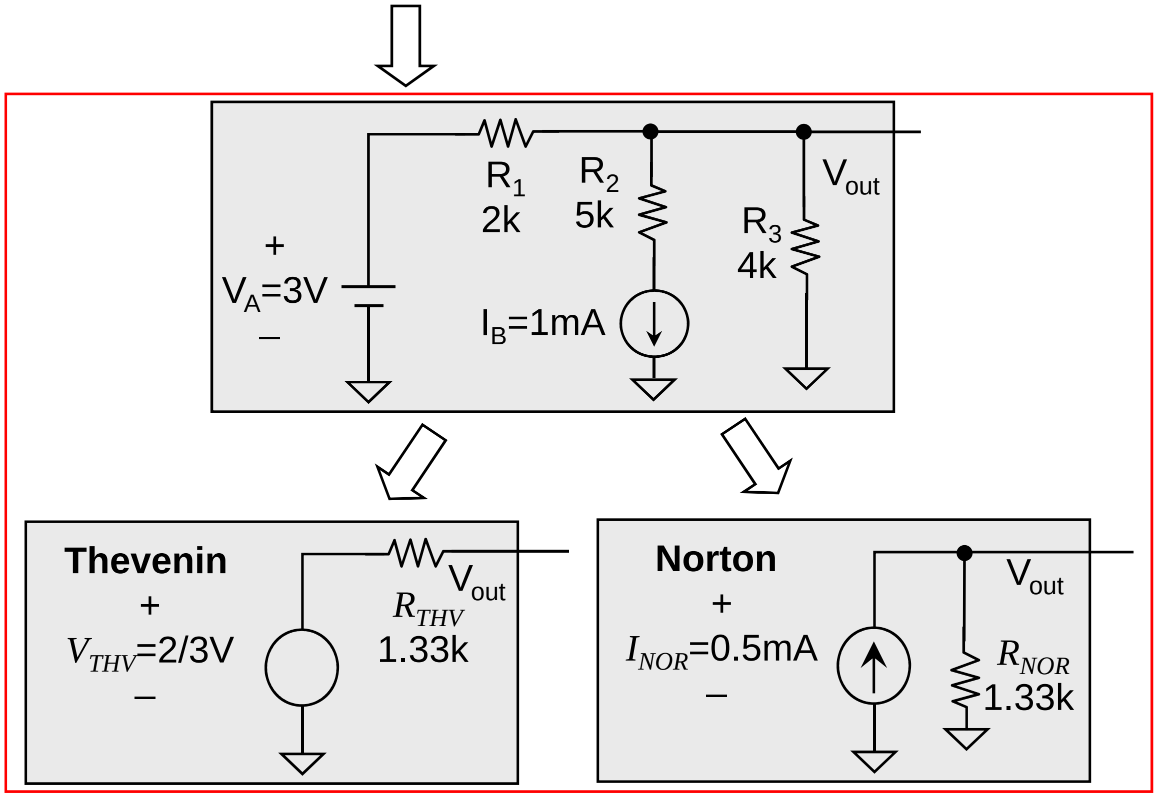
(Short-circuit current)

Thevenin & Norton Equivalent



Equivalent resistance R_{THV} or R_{NOR} looking into the port

$$R_{THV} = R_{NOR} = R_1 // R_3 = 1.33k$$



Significance of Thevenin and Norton Equivalents:

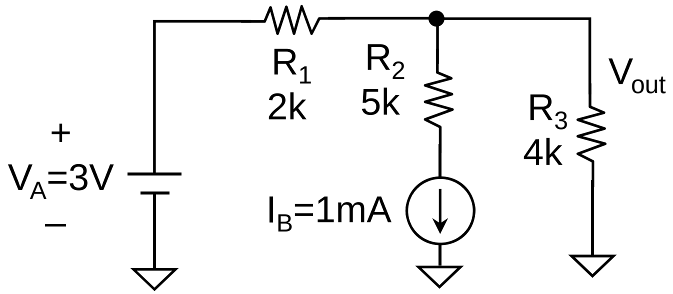
In reality, there is no need for you to open up the black box, determine the components and circuits, and work out the Thevenin or Norton equivalent. You just need multimeter, and measure open-circuit voltage (When multimeter is used to measure voltage, it actually behaves like open circuit) to get V_{THV}, and measure short-circuit current (When multimeter is used to measure current, it actually behaves like short circuit) to get I_{NOR}.

R_{THV} *and* R_{NOR} can be obtained from the expression V_{THV}/I_{NOR}.

Linear Superposition

The combined effect of various independent sources can be determined by summing the impact from various sources individually. When determining the impact of individual source, you can kill other voltage sources by short-circuit them, and current sources by open-circuit them.

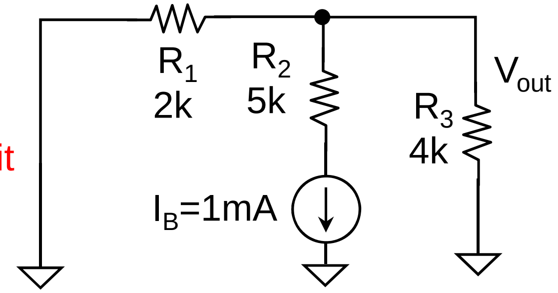
Example:
Determine I_{R3}



Superposition :

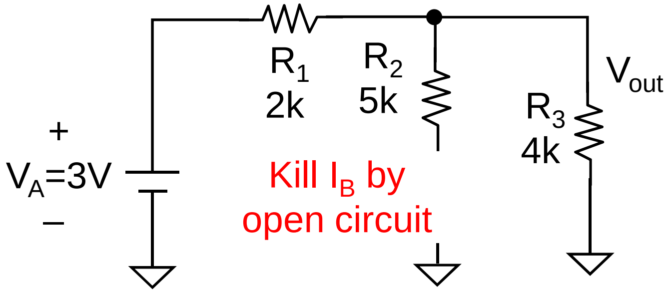
$$I_{R3} = I_{R3\_IB} + I_{R3\_VA} = 167\mu A$$

Kill V_A by short circuit



$$\frac{V_{out}}{R_3} + \frac{V_{out}}{R_1} = -I_B = -1mA$$

$$\Rightarrow V_{out} = -1.33V \Rightarrow I_{R3\_IB} = -333\mu A$$



$$I_{R3\_VA} = \frac{V_A}{R_1 + R_3} = 500\mu A$$

Definition of Decibel

$$\textit{Decibel (dB)}[\textit{Power Ratio}]$$

$$Y(dB) = 10 \times \log\left(\left|\frac{P_{out}}{P_{in}}\right|\right) = 10 \times \log(|\textit{Power Gain}|)$$

$$\Rightarrow$$

$$\textit{Power (dBm)}$$

$$P(dBm) = 10 \times \log\left(\frac{P_{out}}{1mW}\right)$$

Example :

Typical WLAN / Bluetooth output power is $100mW$

$$\Rightarrow 10\log\left(\frac{100mW}{1mW}\right) = 20dBm$$

Typical mobile phone output power is $2W$

$$\Rightarrow 10\log\left(\frac{2W}{1mW}\right) = 33dBm$$

$$\Downarrow$$

$$\textit{Decibel (dB)}[\textit{Voltage Ratio}]$$

$$Y(dB) = 20 \times \log\left(\left|\frac{V_{out}}{V_{in}}\right|\right) = 20 \times \log(|Gain|)$$

Example :

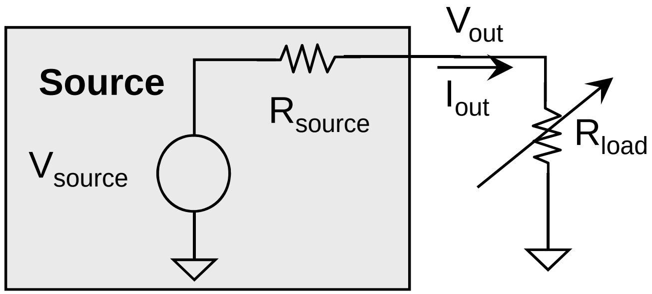
$$\textit{If } Gain = 1 \Rightarrow 20 \times \log(|Gain|) = 0dB$$

$$\textit{If } Gain = -100 \Rightarrow 20 \times \log(|Gain|) = 40dB$$

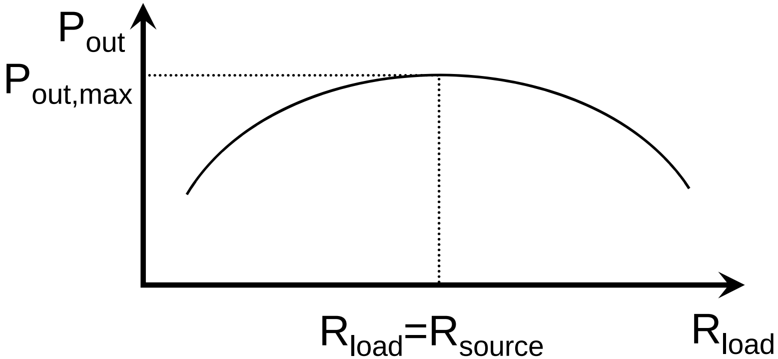
$$\textit{If } Gain = 0.001 \Rightarrow 20 \times \log(Gain) = -60dB$$

A negative gain in linear scale does not implies loss. But a negative gain in dB scale means loss

Maximum Power Transfer



What is R_{load} that will result in maximum power transfer from source to load?



1) When R_{load} is large, V_{out} is large but I_{out} is small $\Rightarrow$ $P_{out}=V_{out}\times I_{out}$ is small
2) When R_{load} is small, V_{out} is small but I_{out} is large $\Rightarrow$ $P_{out}=V_{out}\times I_{out}$ is small
3) There exists an optimum R_{load} with moderate V_{out} and I_{out} which gives rise to maximum $P_{out}=V_{out}\times I_{out}$

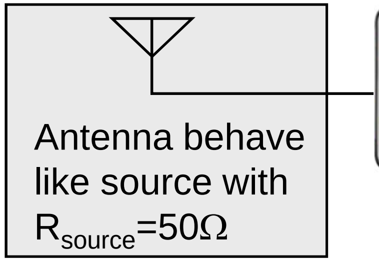
$$P_{out} = \frac{V_{source}}{R_{source}+R_{load}} \times \frac{R_{load}V_{source}}{R_{source}+R_{load}}$$

$$= \frac{R_{load}}{\left(R_{source}+R_{load}\right)^2} V_{source}^2$$

$$\frac{dP_{out}}{dR_{load}} = \frac{1}{\left(R_{source}+R_{load}\right)^2} - \frac{2R_{load}}{\left(R_{source}+R_{load}\right)^3} = 0$$

$$\Rightarrow R_{load} = R_{source}$$

Implications:



Cell phone should be designed to present $R_{load}=50\Omega$ when interface with antenna

Audio source should be designed to present $R_{source}=8\Omega$ when interface with speaker

Speaker behaves as $R_{load}=8\Omega$