EE 331 Devices and Circuits I

Lecture 1

March 31, 2014

Four Main Topics
(Welcome to the Real World!)

- Physics of conduction in semiconductors (Chap 2)
- Solid-state diodes – physics, applications, and analysis (Chap 3)
- Field effect transistors (FETs) – physics, applications and analysis (Chap 4)
- Logic circuit design (Chap 6,7)

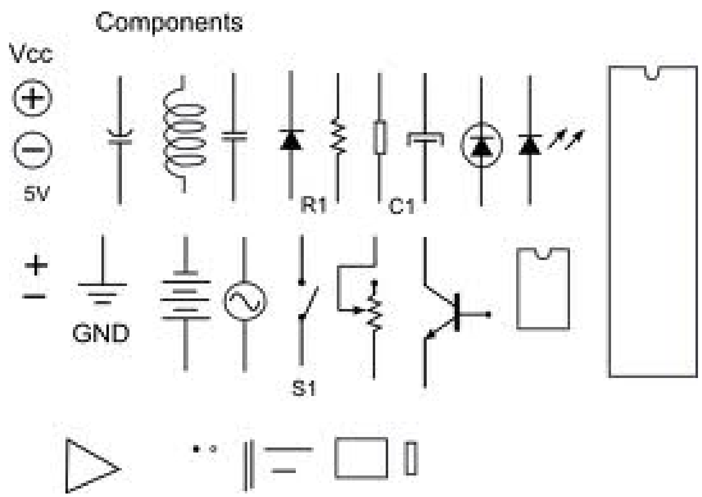
Links

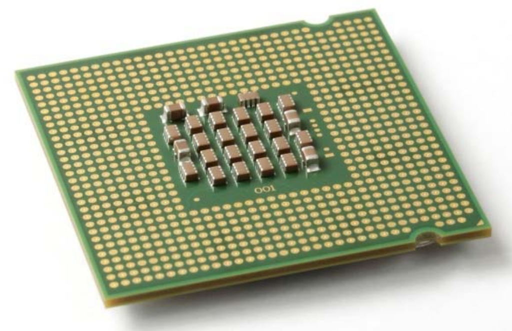
- Class Webpage: http://dunham.ee.washington.edu/ee331/
- Class discussion board: https://catalyst.uw.edu/gopost/board/dunham/36452/

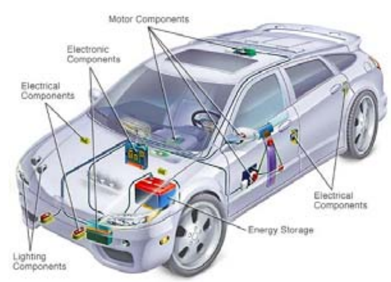
Announcements

- No lab in this week!
- HW0 to be posted online this afternoon.
- Multisim tutorial this week (see GoPost)

What is electronics?



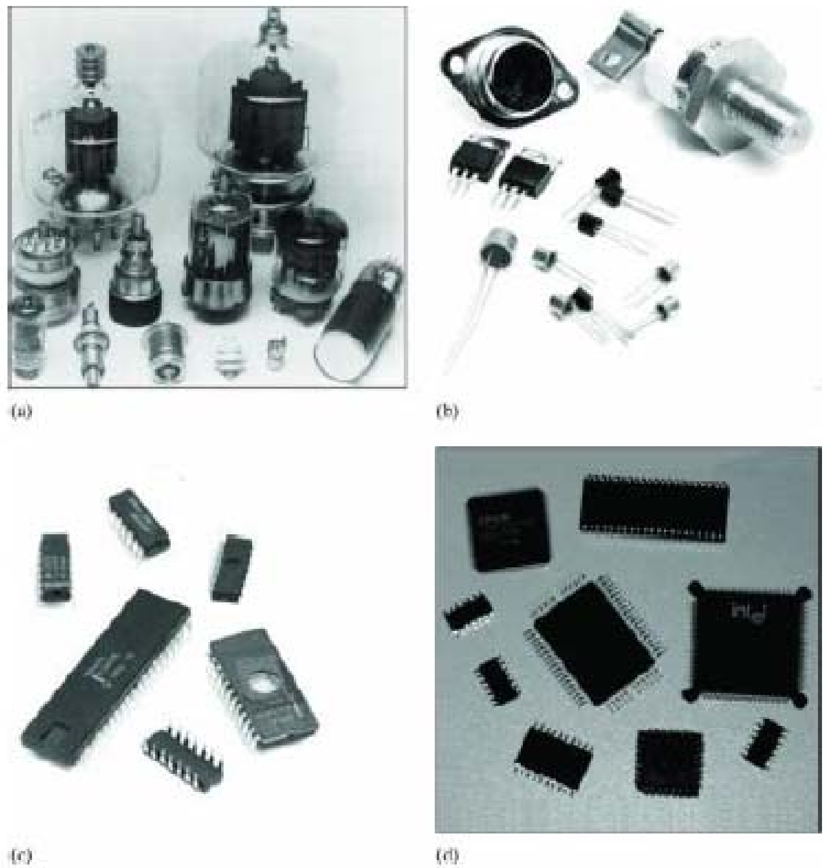




Evolution of Electronic Devices

Vacuum Tubes

Discrete Transistors



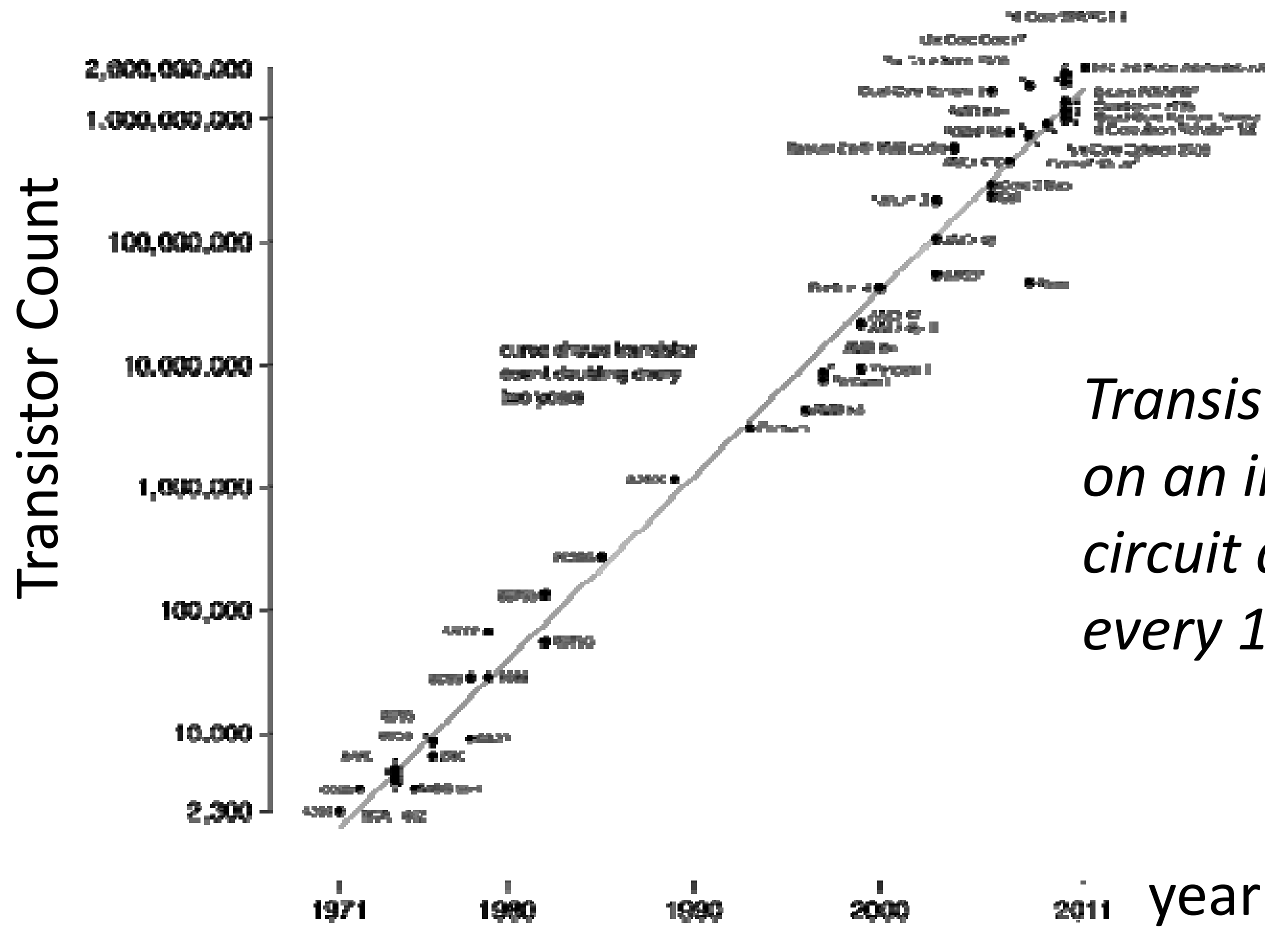
Integrated Circuits

Surface-Mount Circuits

Transistors and Moore's Law

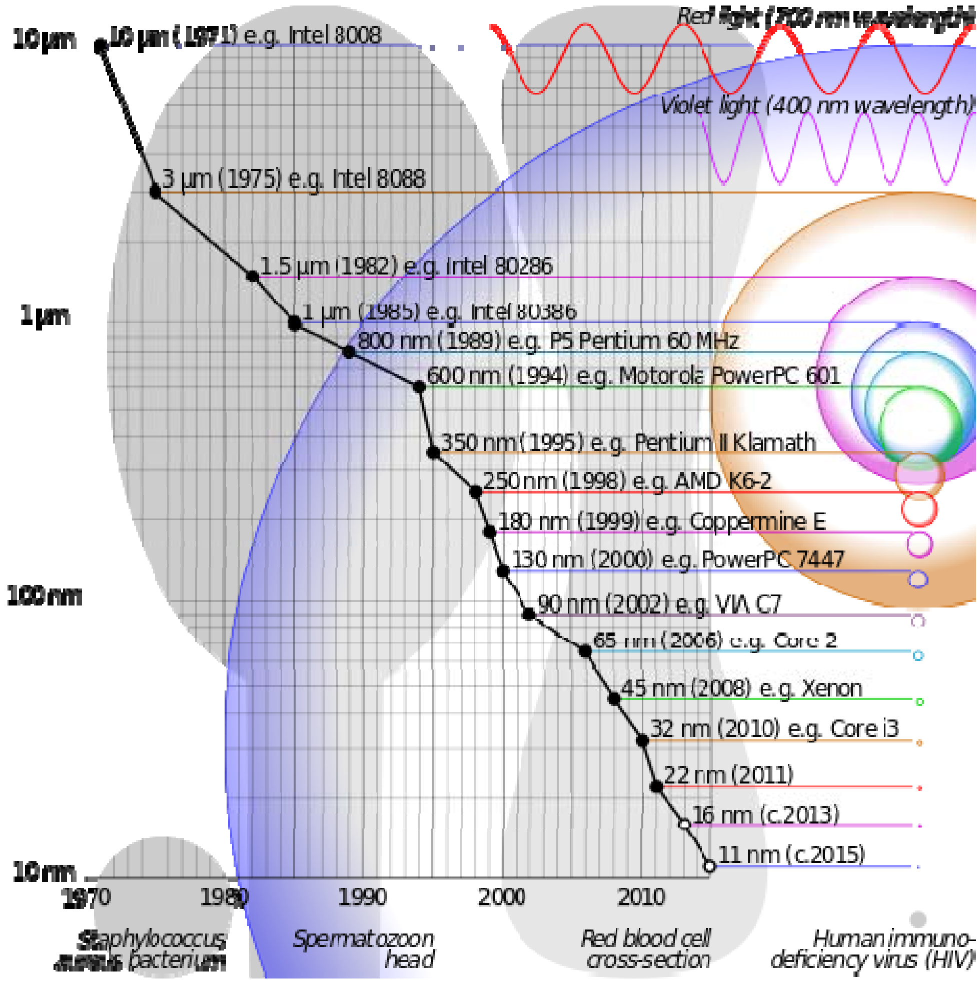
- Transistor: The fundamental building block of modern electronic devices.
- Moore's Law: the number of transistor that can be placed inexpensively on an integrated circuit die doubles every 18 months.

Transistors and Moore's Law



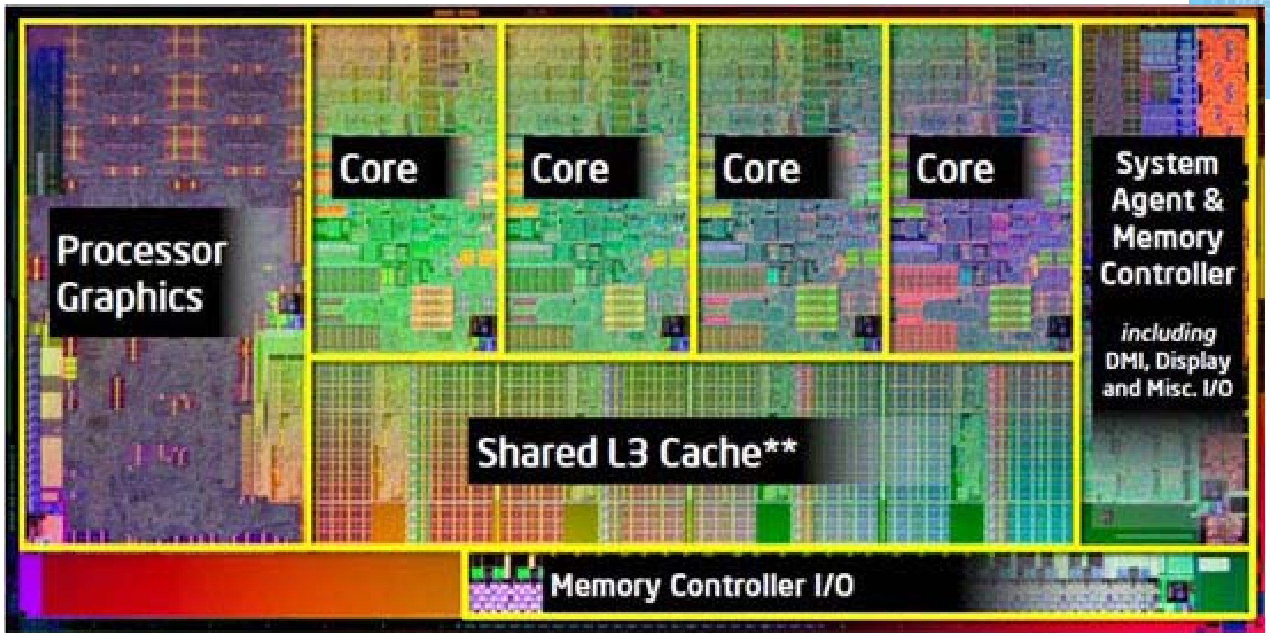
Transistor count on an integrated circuit doubles every 18 months.

Minimum Feature Size



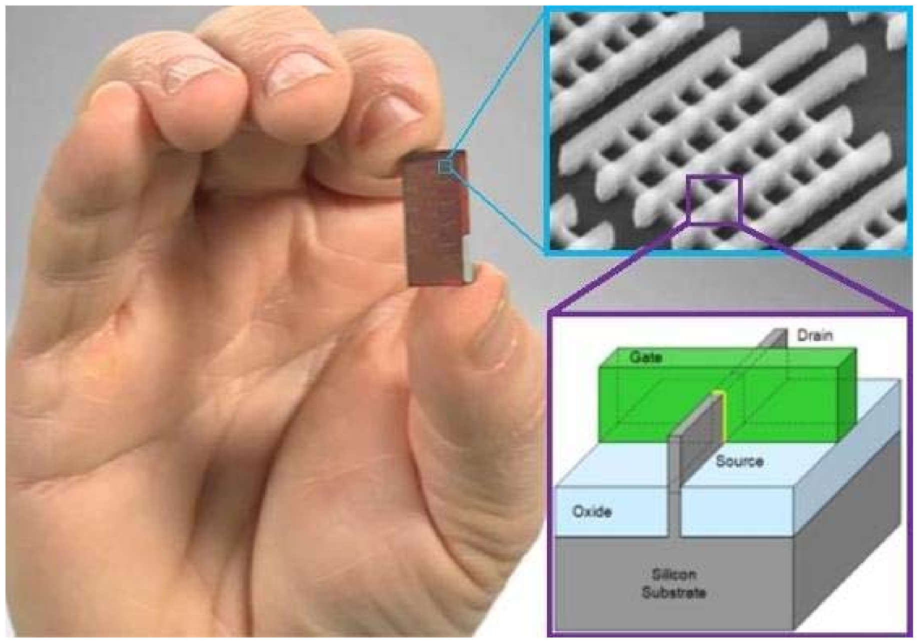
32 nm technology (2010)

- Intel's Core i3, i5, i7 processors



22/14 nm technology (2011/14)

- Intel's 3D Tri-gate transistor



- Check this video:

http://www.youtube.com/watch?v=7xaNivRKuGI

About electronics …

- Electronics is everywhere
- A field at the leading edge of technology, with rapid rate of progress
- Pushes the limits in speed, degree of integration, automation …

Where do we start?

- Materials => Devices => Circuits
- We already know about passive linear components: resistors, capacitors, inductors
- We will learn about new nonlinear components: diodes, field effect transistors
- We will use them to design and build circuits

After this course, you'll be able to …

- Calculate conduction properties of materials and simple device structures
- Explain the operating principles of semiconductor diodes and FETs
- Determine the in-circuit operating state of diodes and FETs
- Perform large signal analysis of circuits containing diodes and FETs
- Use a modern schematic capture and computer-aided circuit analysis program (SPICE)
- Calculate the performance parameters for different MOS logic families to design and build circuits

EE 331 Devices and Circuits I

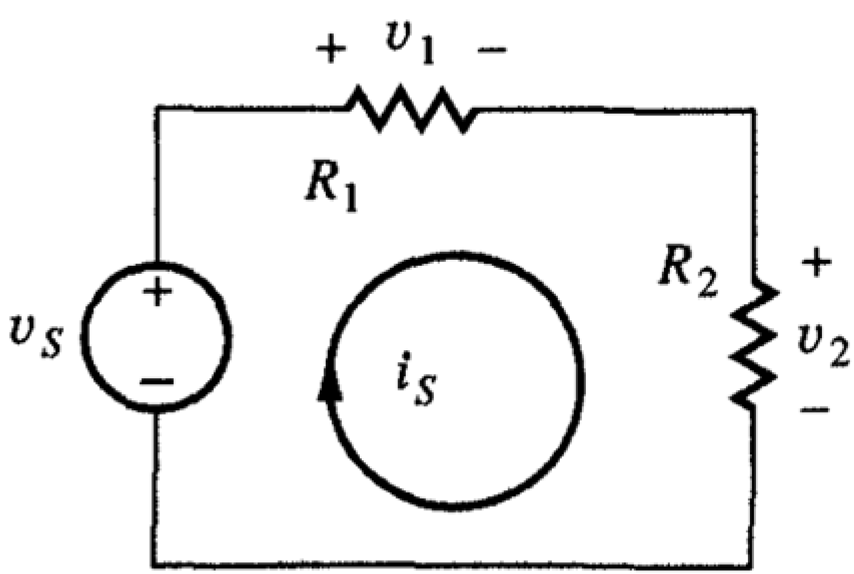
Chapter 1

Circuit Review

Circuit Theory Review

- Starting point:
  - Ohm's Law (OL)
  - Kirchhoff's voltage law (KVL)
  - Kirchhoff's current law (KCL)
- Derive:
  - Voltage Division
  - Current Division
  - Thevenin Equivalent Circuits
  - Norton Equivalent Circuits

Voltage Division

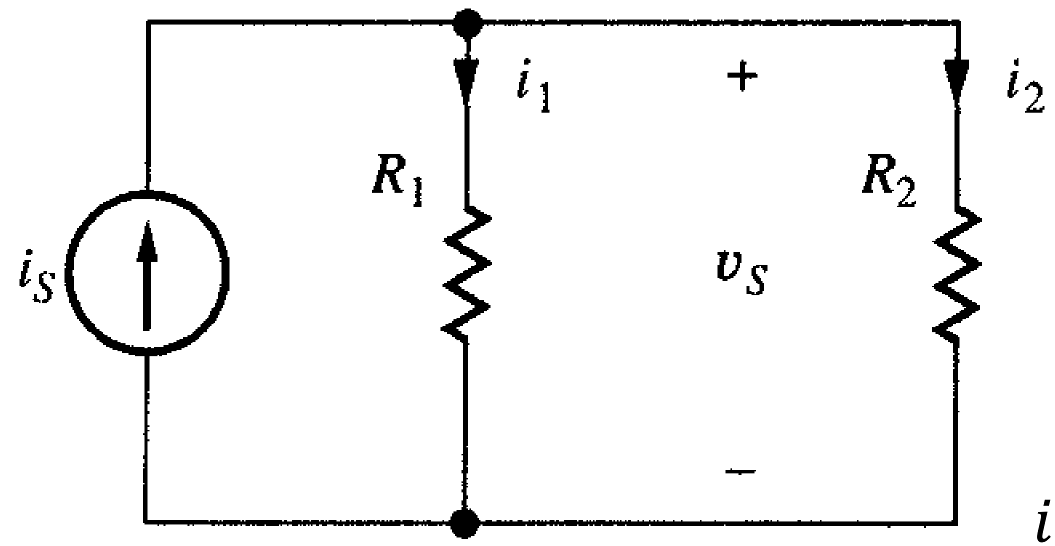


OL: $v_1 = i_S R_1$
OL: $v_2 = i_S R_1$
KVL: $v_s = v_1 + v_2$
$= i_S(R_1 + R_2)$

$$v_1 = v_s \frac{R_1}{R_1 + R_2}$$

$$v_2 = v_s \frac{R_2}{R_1 + R_2}$$

Current Division



OL: $i_1 = \frac{v_S}{R_1}$

OL: $i_2 = \frac{v_S}{R_2}$

KCL: $i_s = i_1 + i_2$

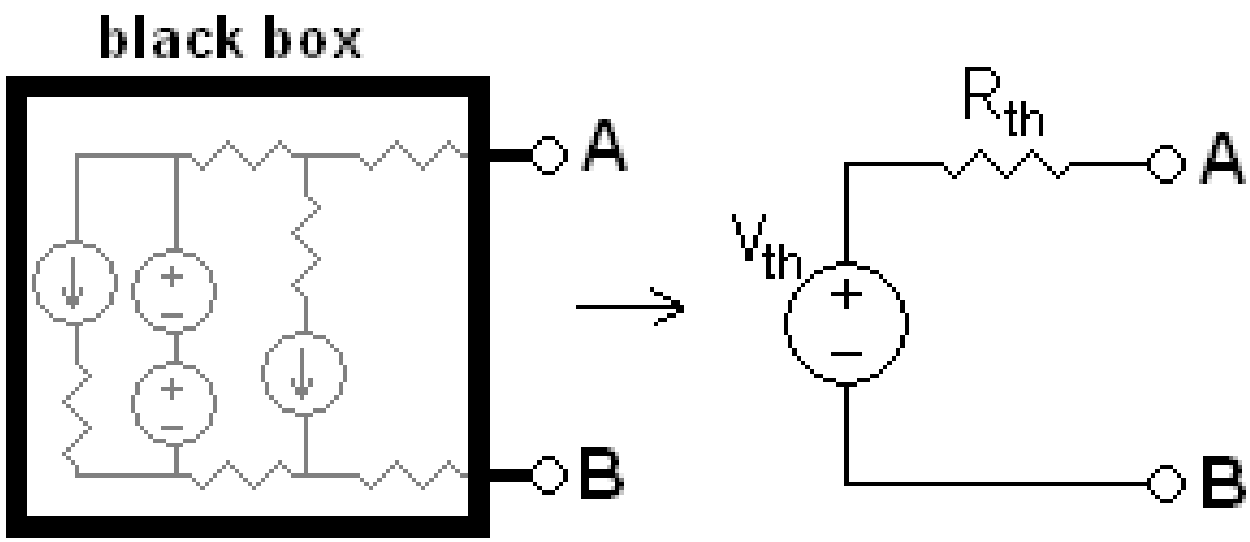
$= \frac{v_S}{R_1} + \frac{v_S}{R_2} = \frac{v_S}{(R_1 || R_2)}$

$$i_1 = i_s \frac{R_1 || R_2}{R_1} = i_s \frac{R_2}{R_1 + R_2}$$

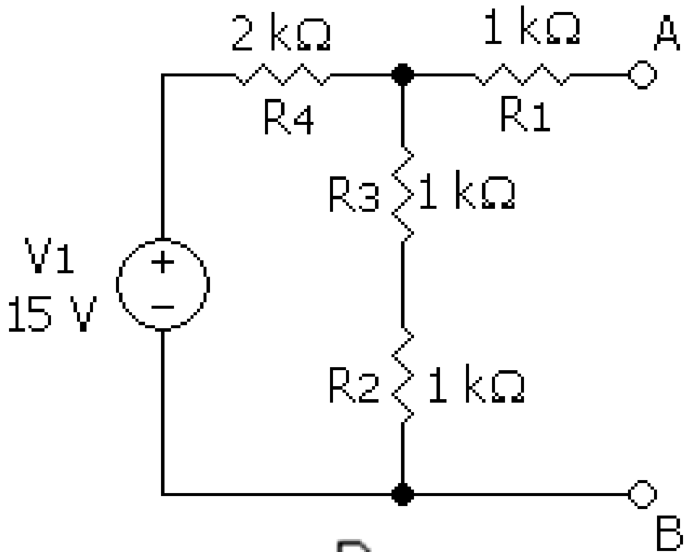
$$i_2 = i_s \frac{R_1 || R_2}{R_2} = i_s \frac{R_1}{R_1 + R_2}$$

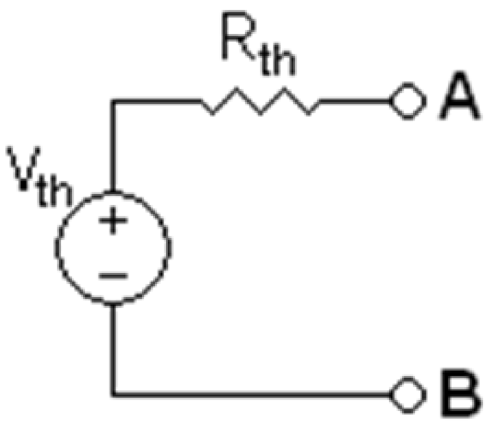
Thevenin Equivalent Circuits

- Voltage source V_{Th} is the open circuit voltage at the output terminals
- R_{Th} : equivalent resistance present at the output terminals with all independent sources set to zero



Thevenin Equivalent Circuits (e.g. 1)





Open circuit voltage:

$V_{Th} = V_{23}$

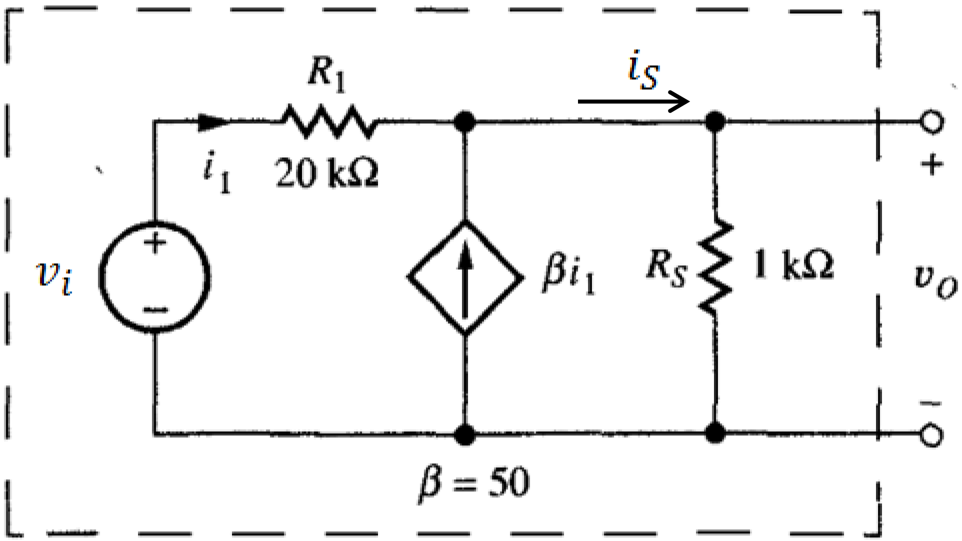
voltage division

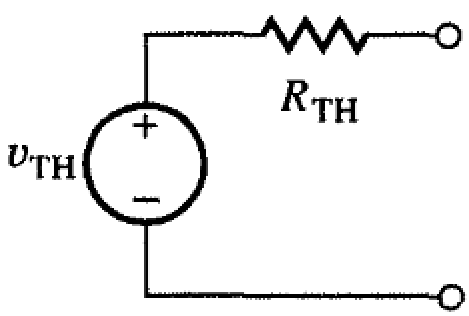
$$= V_1 \frac{R_4}{R_4 + R_2 + R_3} = 7.5 \text{ V}$$

Set V_1 to zero.

$$R_{Th} = R_1 + R_4 || (R_2 + R_3)$$
$$= 1 \text{ k}\Omega + 2 \text{ k}\Omega || 2 \text{ k}\Omega = 2 \text{ k}\Omega$$

Thevenin Equivalent Circuits (e.g. 2)





$$V_{Th} = i_S R_S$$

KCL: $i_S = (1 + \beta) i_1$

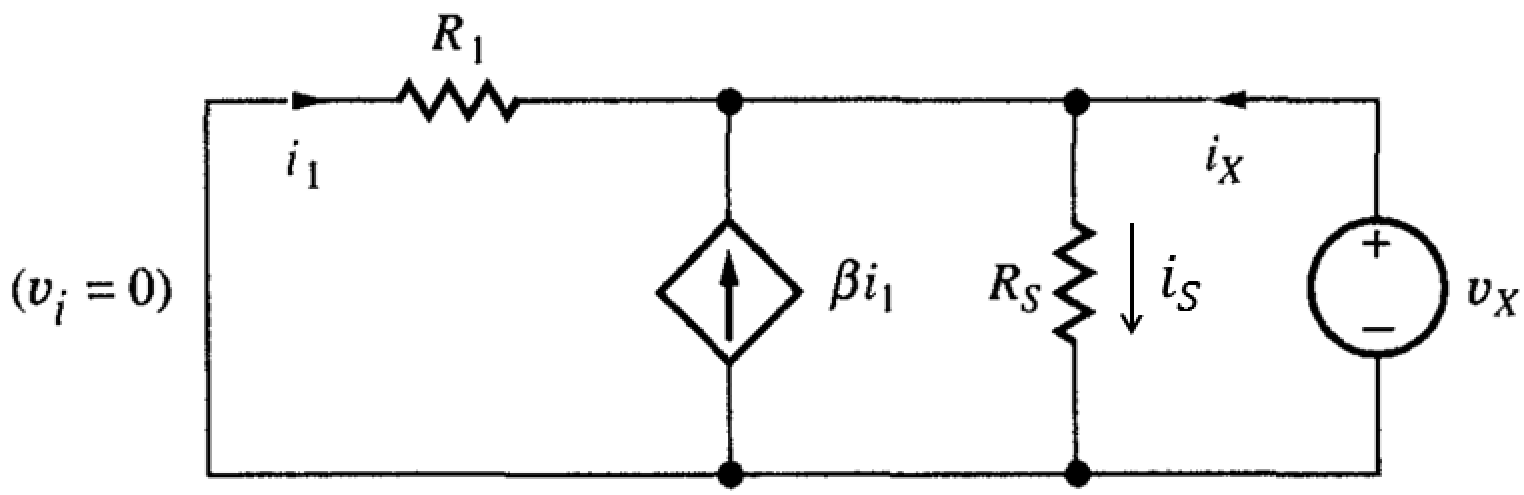
$$\Rightarrow V_{Th} = (1 + \beta) i_1 R_S$$

KVL:

$$v_i = i_1 R_1 + (1 + \beta) i_1 R_S$$

$$V_{Th} = v_S \frac{(1 + \beta) R_S}{R_1 + (1 + \beta) R_S}$$

Thevenin Equivalent Circuits (e.g. 2)



KVL: $v_X = -i_1 R_1; v_X = i_S R_S$

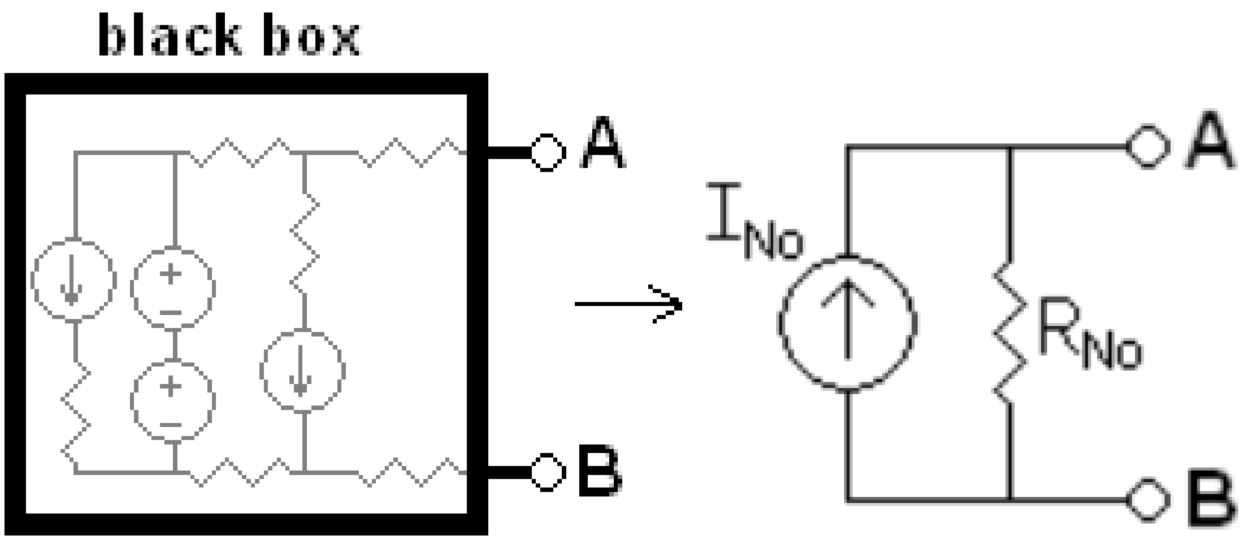
KCL: $i_S = i_X + (1+\beta) i_1$

$\Rightarrow v_X = [i_X + (1+\beta) i_1] R_S = \left[i_X - (1+\beta)\frac{v_X}{R_1}\right] R_S$

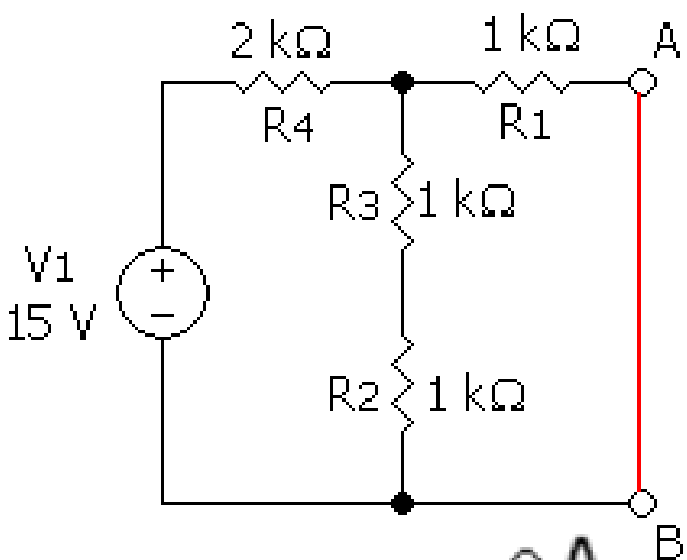
$\Rightarrow R_{Th} = \frac{v_X}{i_X} = v_S \frac{R_S}{1+(1+\beta)R_S/R_1}$

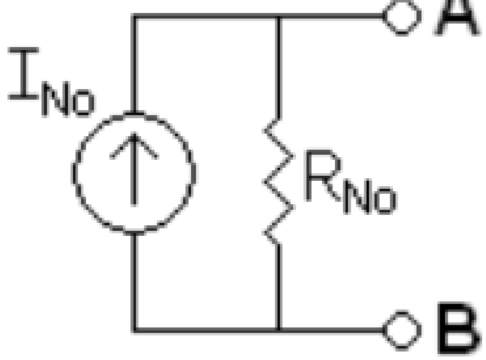
Norton Equivalent Circuits

- I_{No}: current coming out of the network when terminals are shorted
- R_{No} : equivalent resistance present at the output terminals with all independent sources set to zero ($R_{No} = R_{Th}$)



Norton Equivalent Circuits (e.g. 1)





$$i_{tot} = \frac{V_1}{R_{tot}} = \frac{V_1}{R_4 + R_1||(R_2 + R_3)} = 5.63 \text{ mA}$$

Short Circuit current:

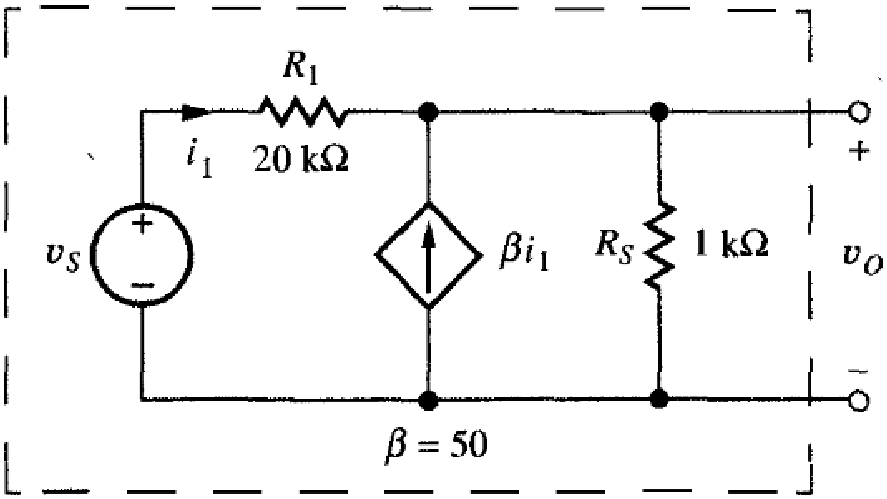
current division

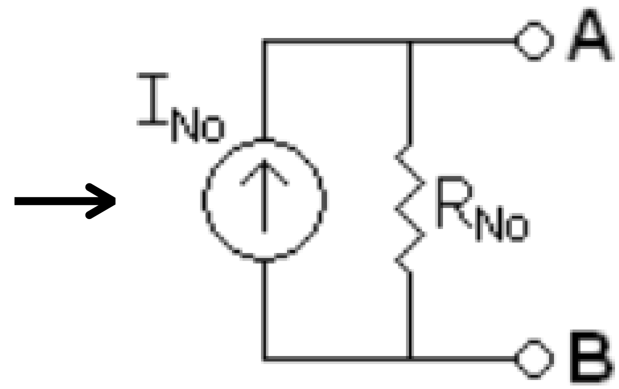
$$I_{No} = i_{tot} \frac{R_2 + R_3}{R_2 + R_3 + R_4} = 3.75 \text{ mA}$$

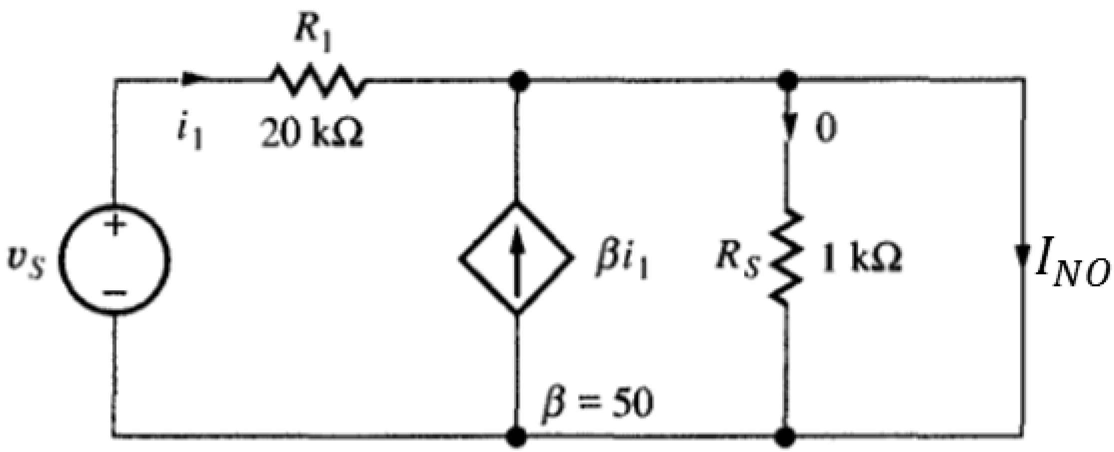
Set V_1 to zero.

$$R_{No} = R_1 + R_4||(R_2 + R_3)$$
$$= 1 \text{ k}\Omega + 2 \text{ k}\Omega||2 \text{ k}\Omega = 2 \text{ k}\Omega$$

Norton Equivalent Circuits (e.g. 2)







$$I_{No} = (1+\beta)i_1$$
$$= (1+\beta)v_S/R_1$$

R_{No} is the same as R_{Th} in Thevenin equivalent circuits

$$V_{Th} = I_{No}R_{Th}$$

