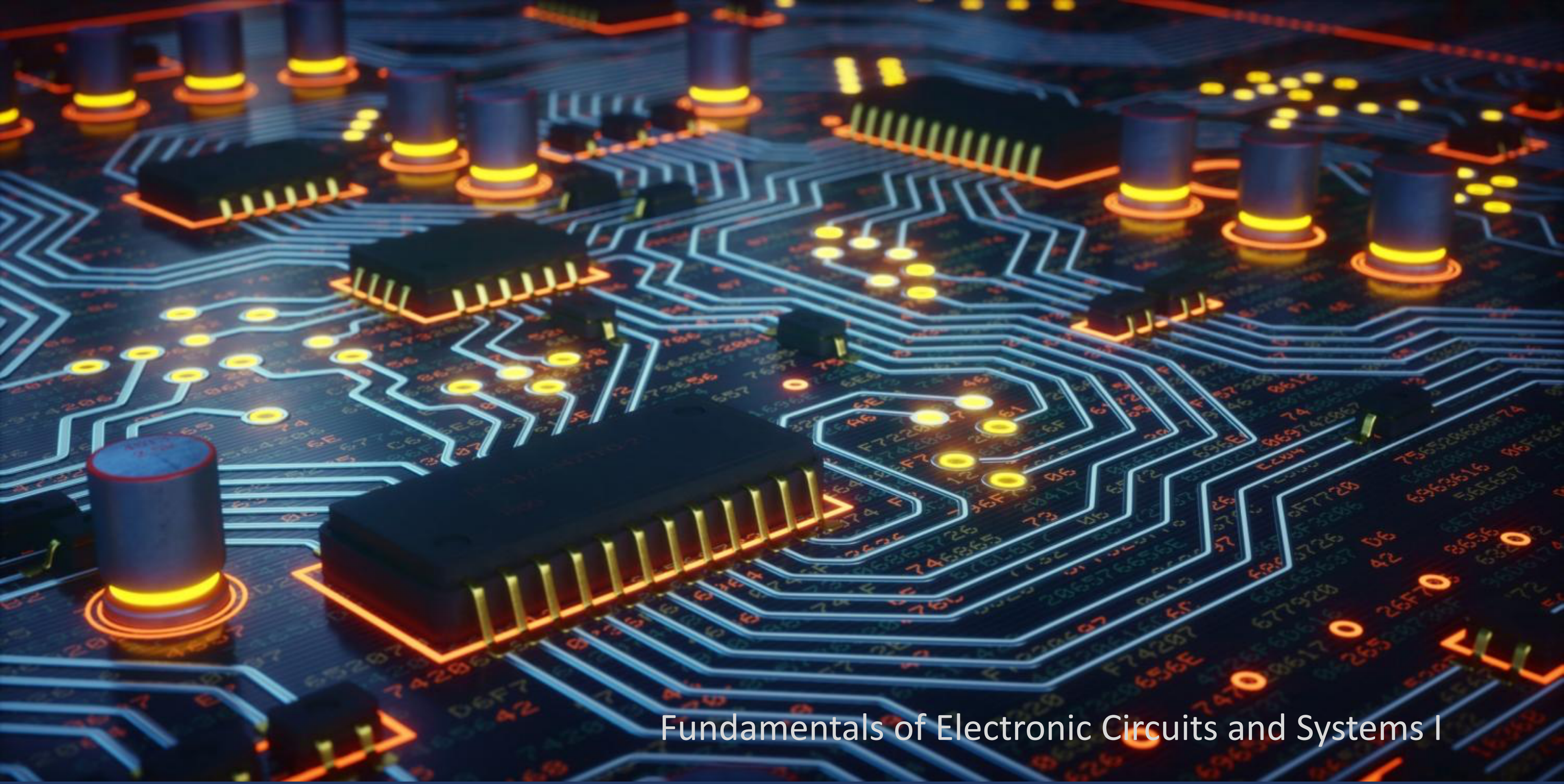


Fundamentals of Electronic Circuits and Systems I

Introduction & Basic Concept

Milin Zhang
Dept of EE, Tsinghua University

Welcome

- Instructor: Milin Zhang
  - Email: zhangmilin [at] tsinghua [dot] edu [dot] cn
  - Office location: Rm716, Rohm BLDG
  - Office hour: by email appointment
- TAs
  - Jiaxin Lei (leijx19[at] mails [dot] tsinghua [dot] edu [dot] cn)
  - Yang Liu (liuy-19[at] mails [dot] tsinghua [dot] edu [dot] cn)
  - Chao Zhang (zc20[at] mails [dot] tsinghua [dot] edu [dot] cn)
  - Hongzhuo Liu (liu-hz20[at] mails [dot] tsinghua [dot] edu [dot] cn)
  - Office hour: Sat 7-10pm, Rm 715, Rohm BLDG
- Textbook
  - "Basic Engineering Circuit Analysis" by J. D. Irwin & R. M. Nelms
  - "Microelectronic Circuits" by A. S. Sedra & K. C. Smith

Office hours are your friends, we get to know you better when you come to see us

Calendar

Week 1 / Feb 26	Lecture 1: Introduction & Basic Concept
Week 2 / Mar 5	Lecture 2: Resistive Circuits
Week 3 / Mar 12	Lecture 3: Circuit Analysis Techniques
Week 4	Tutorial 1: HW 1-3 (optional)
Week 5 / Mar 26	Lecture 4: Capacitors & Inductors
Week 6 / Apr 2	Lecture 5: Transient circuit analysis
Week 7	Tutorial 2: HW 4-5 (optional)
Week 8 / Apr 16	Midterm Exam
Week 9 / Apr 23	Lecture 6: AC steady-state analysis
Week 11 / May 7	Lecture 7: Frequency domain analysis
Week 12	Tutorial 3: HW 6-7 (optional)
Week 13 / May 21	Lecture 8: Two-port network
Week 14 / May 28	Lecture 9: Operational amplifier & Feedback
Week 15 / Jun 4	Wrap up
Week 16	Tutorial 4: HW 8-9 (optional)

3 classes per lecture session

Attendance & Quiz

- Attendance
  - Optional
  - Slides posted online
- Quiz
  - 5-10min Quiz by the end of every lecture session
  - Lowest 3 quizzes dropped in final grading

Review the slides RIGHT AFTER every lecture
DO NOT wait until one week before the exams

Homework

- Assigned every week after lecture
- Due one week afterwards
- HW submission after due can get 50% score
- Discussion between classmates are encouraged
- Zero tolerance to cheating/plagiarism. Penalty for cheating/plagiarism is failure of the course, and will be turned over to the department

Grading

- Homework & Quiz – 20%
- Middle exam – 35%
    - No makeup
    - Absences: 0
- Final exam – 45%

General philosophy

- Practice makes master
  - Circuit is difficult
  - The only way to get good is by practicing

- Self learning is important
  - Not everything you need for homework is covered by my lecture
  - Your teacher is a guide, not a spoon feeder

- You get what you put into this course
  - I have no desire to force you to study

Who study circuit and systems?

Fundamentals of Electronic Circuits and Systems

CAS

IEEE Circuit and System Society

IEEE Solid-State Circuit Society

International societies are where you find your peers

The Prologue of CAS History

Fundamentals of Electronic Circuits and Systems

CAS

A. Volta

1800
Invention of
Voltaic Pile

The Prologue of CAS History

Fundamentals of Electronic Circuits and Systems

CAS

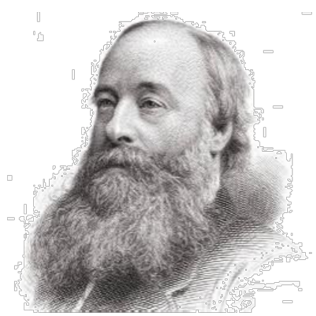
1800

Invention of Voltaic Pile

The Golden Epoch

Late 1800s to 1900s

A.-M. Ampere



J. P. Joule

C. A. Coulomb

M. Faraday

The Prologue of CAS History

Fundamentals of Electronic Circuits and Systems

CAS

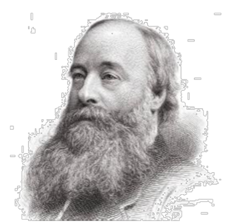
1800

Invention of Voltaic Pile

The Golden Epoch

Late 1800s to 1900s

A.-M. Ampere



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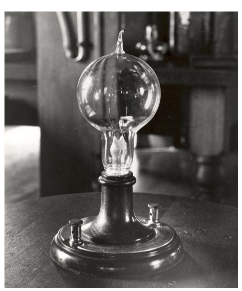


1870s

2nd industrial revolution

Course Objectives

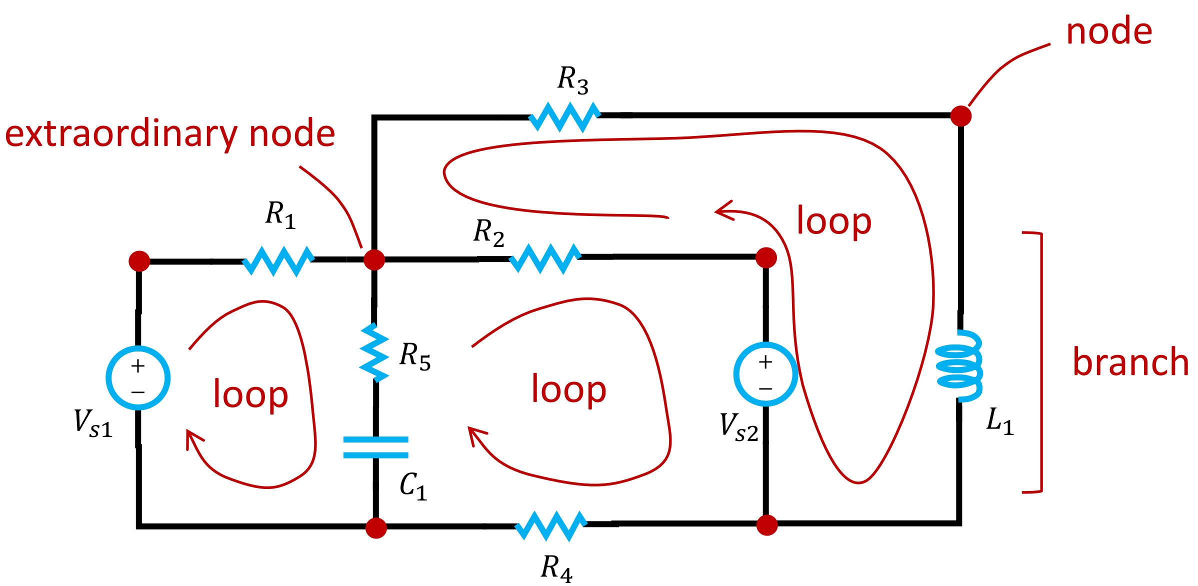
Fundamentals of Electronic Circuits and Systems

- Devices: Individual circuit elements
  - R/L/C/Diode/Transistors
  - Well understand and use the I-V relationship
- Circuits: can be considered as subsystems
  - Know the function of some classical circuits
  - Well understand the analysis skill
- Systems
  - Know some important systems

To learn how to analyze the I-V relationship of a device / a circuit / a system

Circuit Topology

- **Branch**: signal element, such as a resistor or source
- **Node**: connection point between two or more branches
- **Extraordinary node**: connection point between at least 3 branches
- **Loop**: closed path in a circuit



Common circuit elements

Connections

Conductor

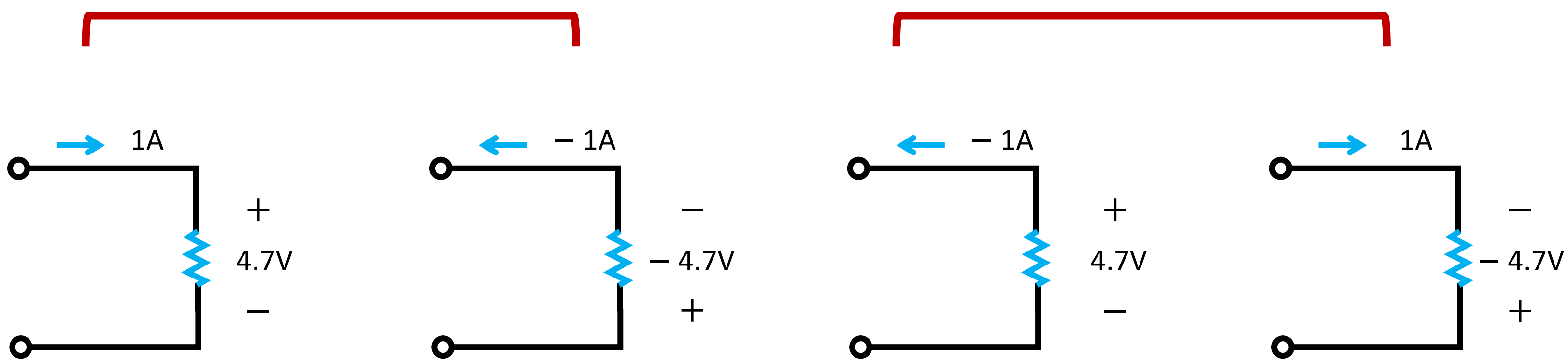
Two conductors electrically joined at node A

Two conductors not joined electrically

Switch

Associated variables convention

Positive current flow | **Negative current flow**

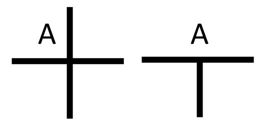


Associated Variables Convention define current to flow in at the device terminal assigned to be positive in voltage

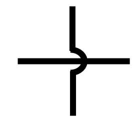
Common circuit elements

Connections

Conductor



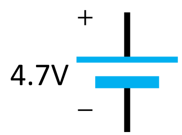
Two conductors electrically joined at node A



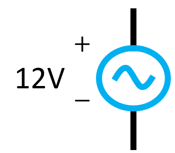
Two conductors not joined electrically

Switch

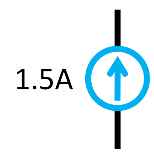
Supplies



4.7V DC



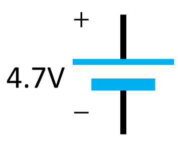
12V AC



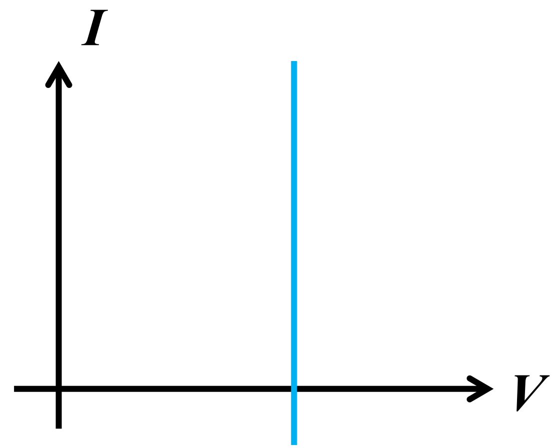
1.5A current

I-V relationships of a voltage source

Ideal linear independent voltage source



4.7V DC

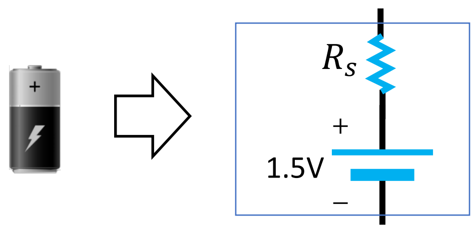


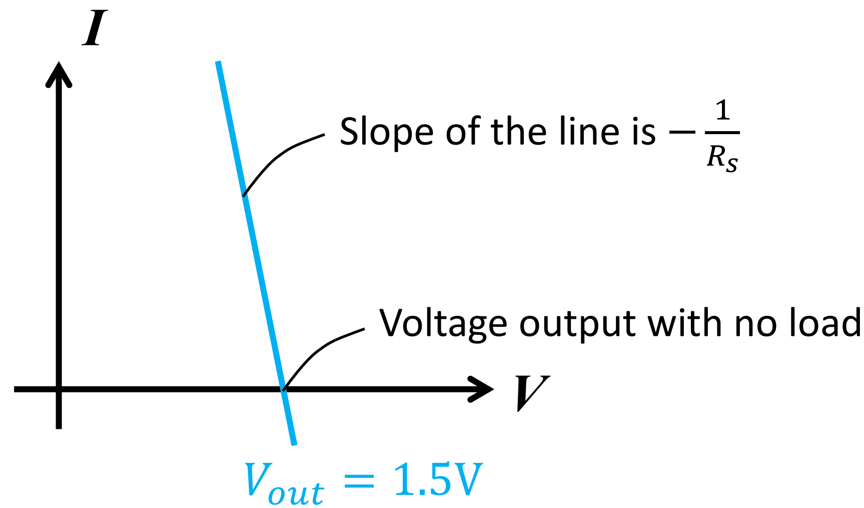
$V_{out} = 4.7\text{V}$

- Provide a FIXED voltage output
- Provide UNLIMITED current output

I-V relationships of a voltage source

Practical voltage source

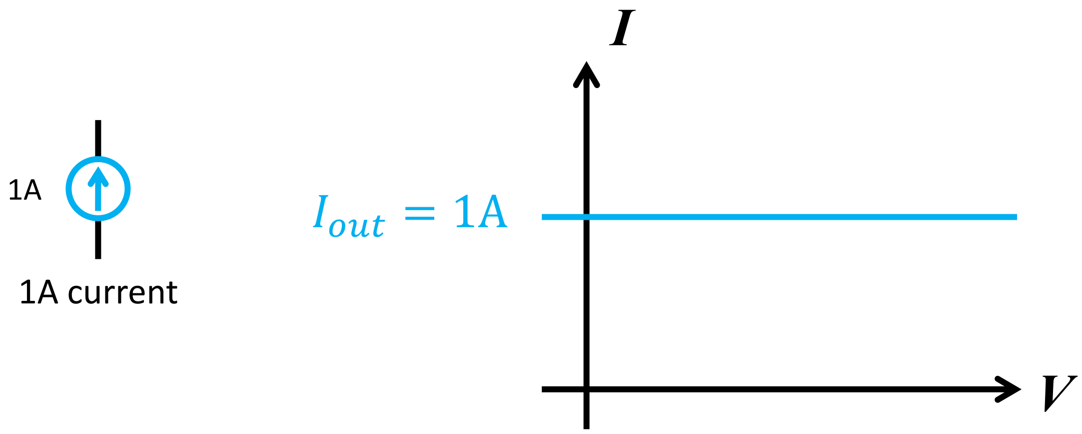




- Can NOT Provide a fixed voltage output
- There is an internal resistance in the model

I-V relationships of a current source

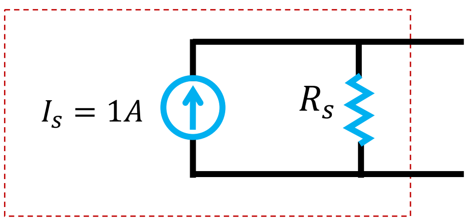
Ideal linear independent current source

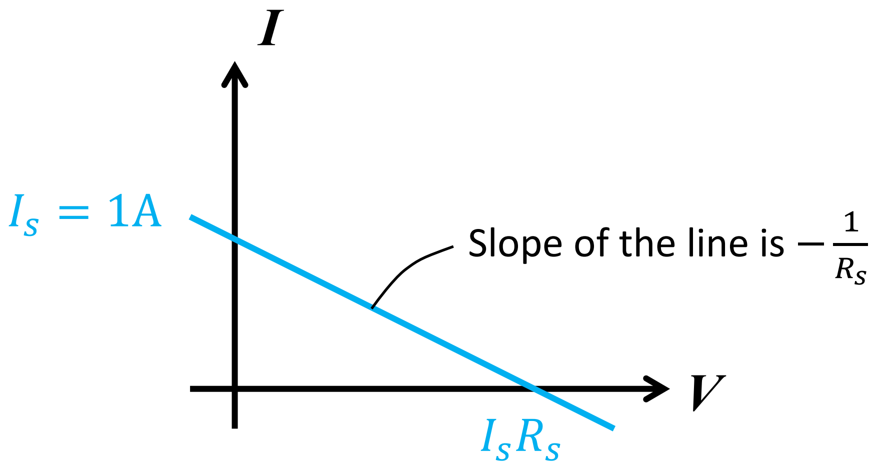


- Provide a FIXED current output
- Provide UNLIMITED voltage output

I-V relationships of a current source

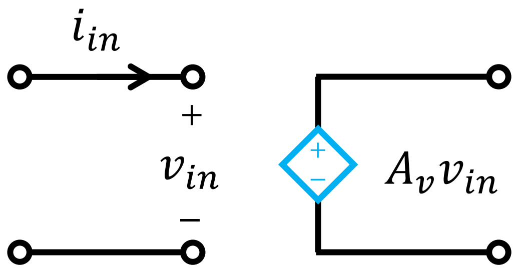
Practical current source



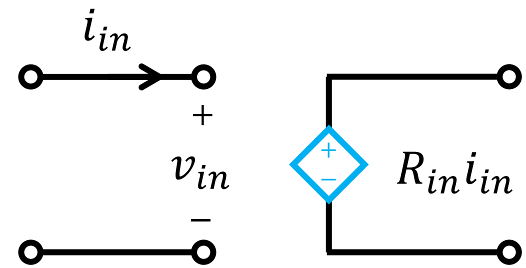


- Can NOT Provide a fixed current output
- There is an internal resistance in the model

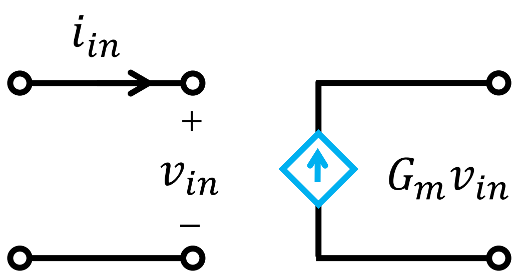
Linear **dependent** sources



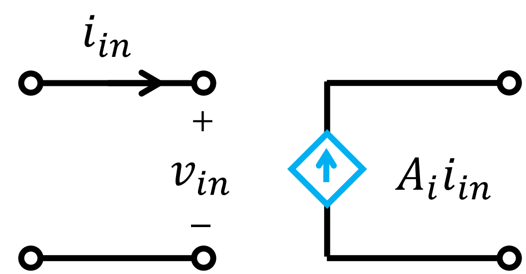
Voltage-controlled voltage source (VCVS)



Current-controlled voltage source (CCVS)



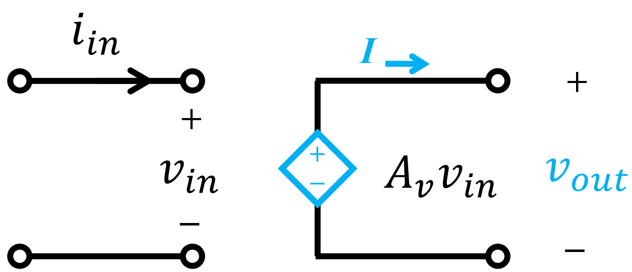
Voltage-controlled current source (VCCS)



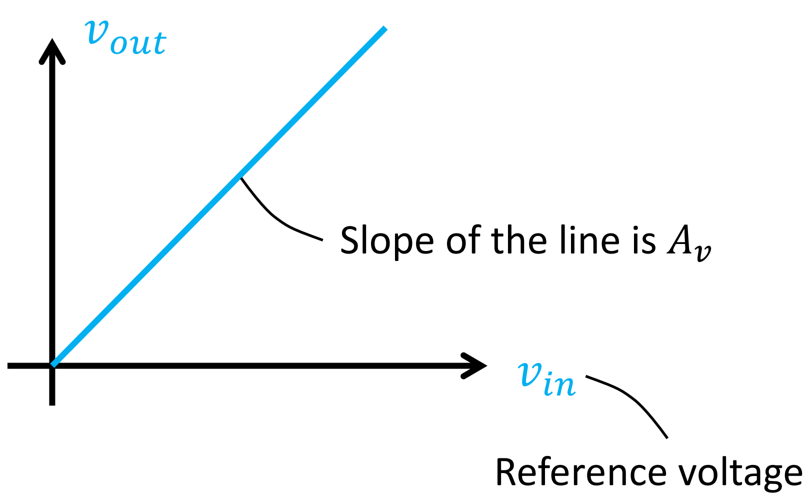
Current-controlled current source (CCCS)

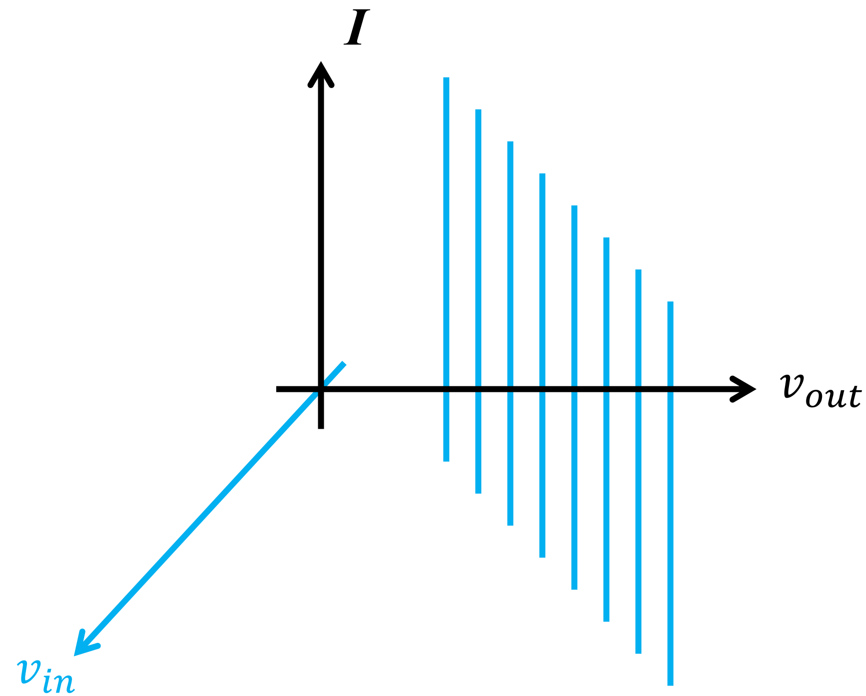
The source voltage/current **DEPENDS** on a voltage/current elsewhere in the circuit

I-V relationship of dependent source



Voltage-controlled voltage source (VCVS)

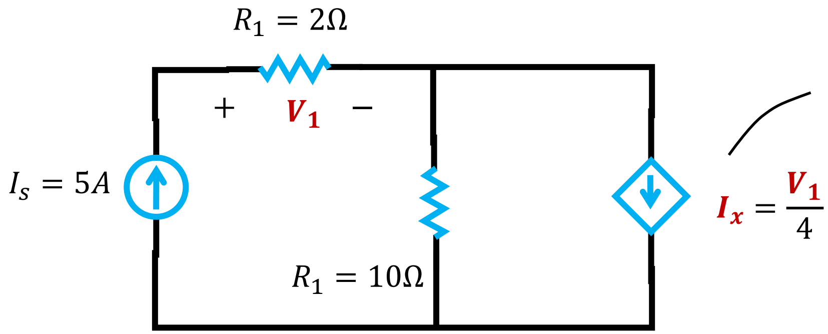




Dependent source output varies with the reference voltage/current

Example 1

QUESTION: Find $\boldsymbol{I_x}$ in the circuit below:



$\boldsymbol{I_x}$ depends on the voltage across $\boldsymbol{R_1}$

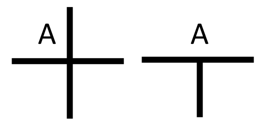
SOLUTION:

- According to **Ohm's Law** $\quad V_1 = I_s R_1 = 10V$
- $I_x = \frac{V_1}{4} = \mathbf{2.5A}$

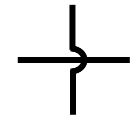
Common circuit elements

Connections

Conductor



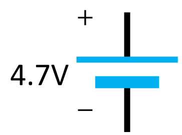
Two conductors electrically joined at node A



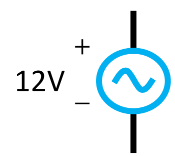
Two conductors not joined electrically

Switch

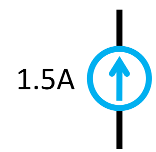
Supplies



4.7V DC



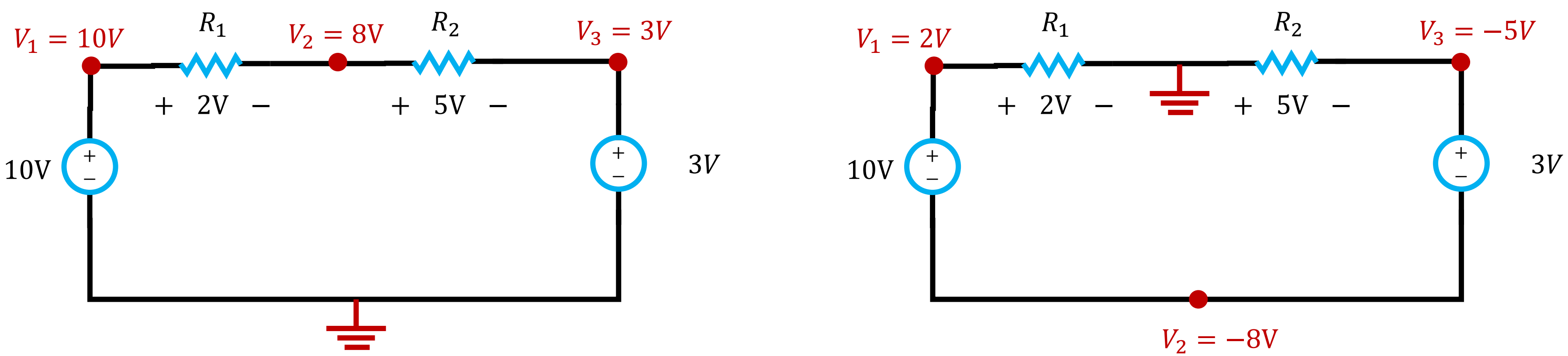
12V AC



1.5A current

Voltage reference (ground)

Reference / Ground



- Choose REFERENCE point for all the potentials
- Assign the potential at reference equals 0, called GROUND
- All potentials are relative to ground terminal

Common circuit elements

Connections

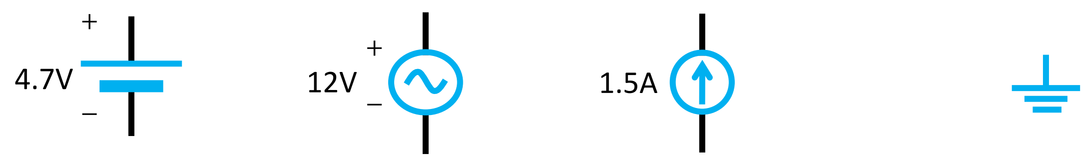
Conductor

Two conductors electrically joined at node A

Two conductors not joined electrically

Switch

Supplies



4.7V DC

12V AC

1.5A current

Voltage reference (ground)

Passive devices

Fixed value resistor

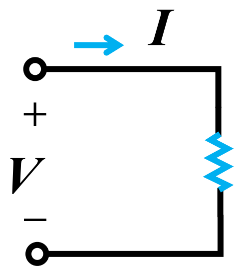
Variable resistor

Capacitor

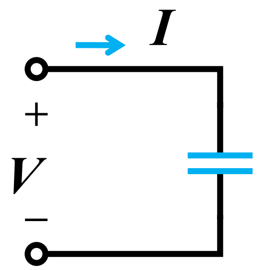
Inductor

I-V relationship of passive devices

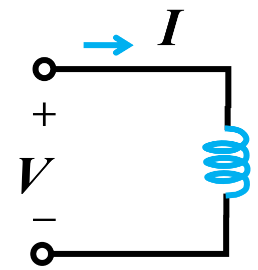
Resistor



Capacitor



Inductor



$$v(t) = R \cdot i(t)$$

$$i(t) = C \cdot \frac{dv(t)}{dt}$$

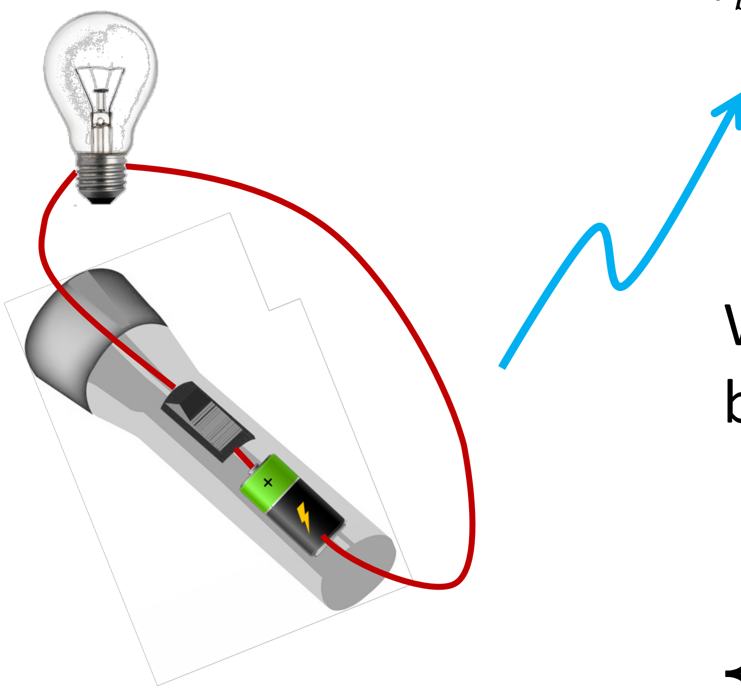
$$v(t) = L \cdot \frac{di(t)}{dt}$$

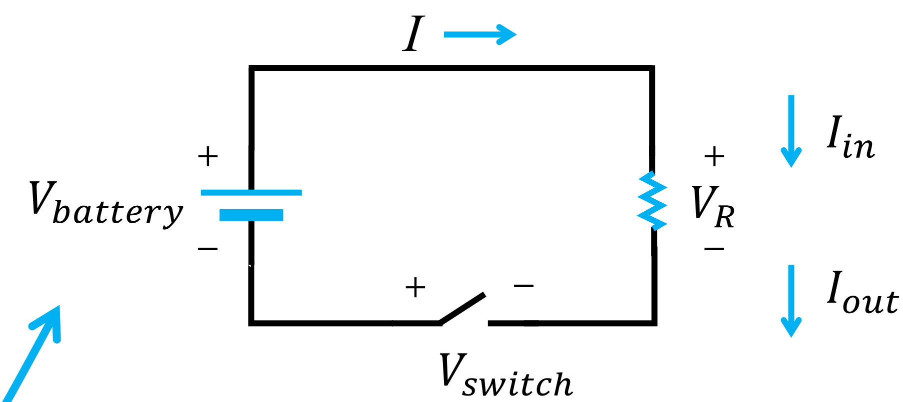
More details will be introduced in this semester

Outlines

- Welcome & course logistics/policies
- Course objectives
  - To learn how to analyze the I-V relationship
- Common circuit elements
  - A quick review
  - Dependent voltage/current sources
  - I-V relationship of voltage/current sources
  - I-V relationship of passive devices
- An example of circuit

An example of circuit

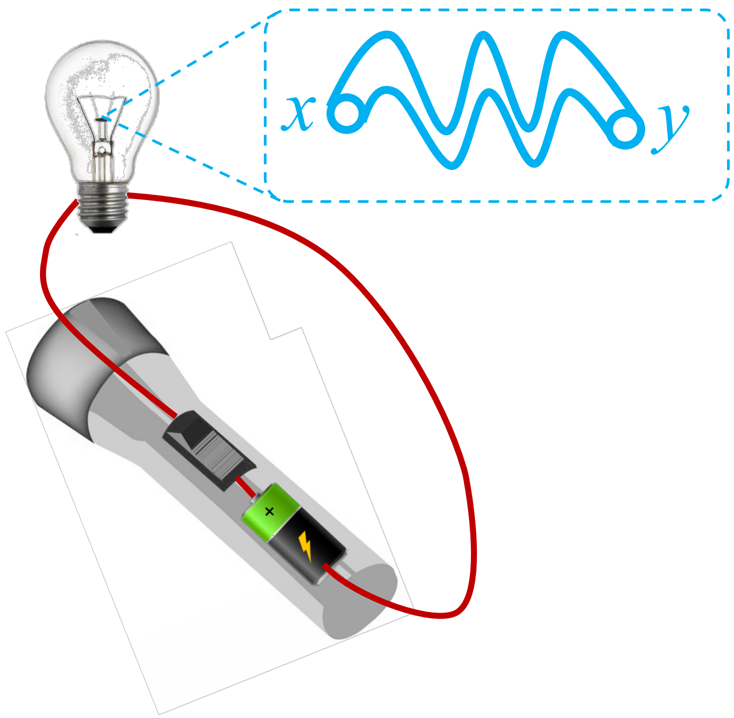




What is the relationship between I and V_R?

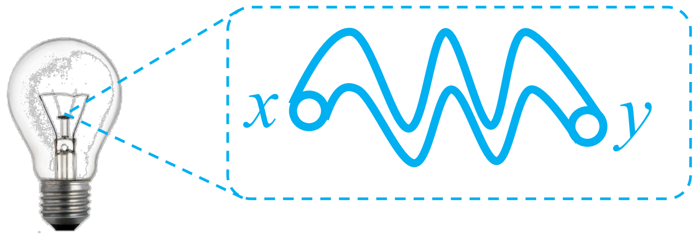
$$
\begin{cases}
V_R = IR \\
V_R + V_{switch} = V_{battery} \\
I_{in} = I_{out}
\end{cases}
$$

According to Maxwell's equations



$$\begin{cases} \int_{S_x} J \cdot dS - \int_{S_y} J \cdot dS = \dfrac{\partial q}{\partial t} \\ \oint E \cdot dl = -\dfrac{\partial \Phi_B}{\partial t} \end{cases}$$

Lumped circuit elements



Real world scenario

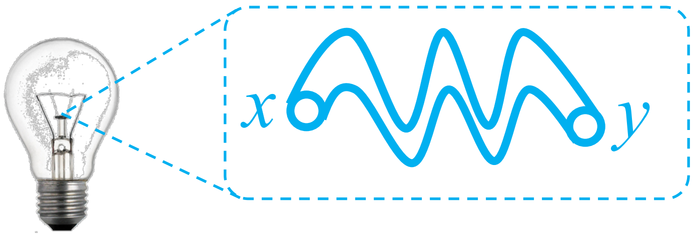
Lumped circuit elements

$$\begin{cases} \int_{S_x} J \cdot dS - \int_{S_y} J \cdot dS = \frac{\partial q}{\partial t} \\ \oint E \cdot dl = -\frac{\partial \Phi_B}{\partial t} \end{cases}$$

$$\begin{cases} I_{in} = I_{out} \\ V_R + V_{switch} = V_{battery} \end{cases}$$

Are they the same?

Lumped Matter Discipline (LMD)



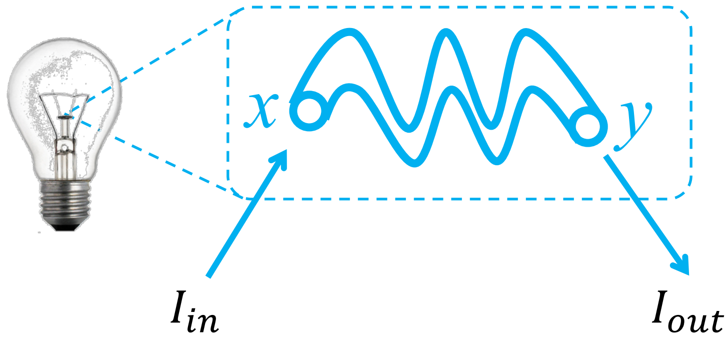
- The rate of change of magnetic flux linked with any portion of the circuit must be zero for all time.

$$\oint E \cdot dl = -\frac{\partial \Phi_B}{\partial t} = \mathbf{0} \quad \Rightarrow \quad V_R + V_{switch} = V_{battery}$$

- The rate of change of the charge at any node in the circuit must be zero for all time. A node is any point in the circuit at which two or more element terminals are connected using wires.

$$\int_{S_x} J \cdot dS - \int_{S_y} J \cdot dS = \frac{\partial q}{\partial t} = \mathbf{0} \quad \Rightarrow \quad I_{in} = I_{out}$$

Size issue



$$I_{in} = I_{out}$$

$$I_{in}(t) \overset{?}{=} I_{out}(t + \Delta t)$$

- What if the wire is very long?
- What if Δt is very large?

The signal timescales must be much larger than the propagation delay of electromagnetic waves through the circuit.

Examples of size issue

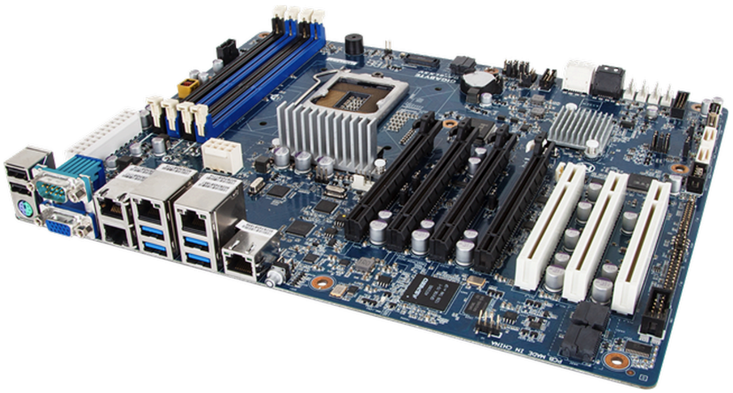
- @60Hz

$$\lambda = \frac{c}{f} = \frac{3\times10^8 m/s}{60Hz} = 5000km$$

The resistance on the power line cannot be ignored

- @1GHz

$$\lambda = \frac{c}{f} = \frac{3\times10^8 m/s}{1GHz} = 300mm$$



LMD cannot be simply applied for 30cm motherboard with 1GHz frequency

Examples of size issue

4004	8008	8080	8085	8086	80286	Intel386	Intel486
108kHz	200kHz	2MHz	2MHz	10MHz	12MHz	33MHz	50MHz
10um	10um	6um	3um	3um	1.5um	1.5um	1um
2.3kT	3.5kT	6kT	6.5kT	29kT	134kT	275kT	1.2MT
1971	72	74	76	78	82	85	89

93	98	99	02	04	06
Pentium	P-II	P-III	P-4	P-M	P-D
66MHz	266MHz	1GHz	1.7GHz	2.13GHz	3.40GHz
0.8um	0.25um	0.18um	0.13um	90nm	65nm
3.1MT	7.5MT	28MT	55MT	140MT	376MT

$$\lambda = \frac{c}{f} = \frac{3\times 10^8 m/s}{108kHz} = 2.78km$$

$$\lambda = \frac{c}{f} = \frac{3\times 10^8 m/s}{3.4GHz} = 88.2mm$$

Lumped Matter Discipline (LMD)

- **The rate of change of magnetic flux linked with any portion of the circuit must be zero for all time.**

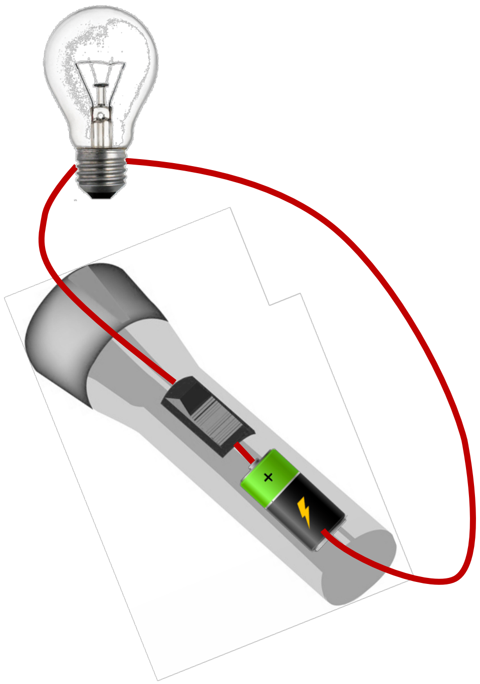
$$\oint E \cdot dl = -\frac{\partial \Phi_B}{\partial t} = 0 \quad \Rightarrow \quad V_R + V_{switch} = V_{battery}$$

- **The rate of change of the charge at any node in the circuit must be zero for all time. A node is any point in the circuit at which two or more element terminals are connected using wires.**

$$\int_{S_x} J \cdot dS - \int_{S_y} J \cdot dS = \frac{\partial q}{\partial t} = 0 \quad \Rightarrow \quad I_{in} = I_{out}$$

- **The signal timescales must be much larger than the propagation delay of electromagnetic waves through the circuit.**

WHY LMD?



- **According to Maxwell's equations**

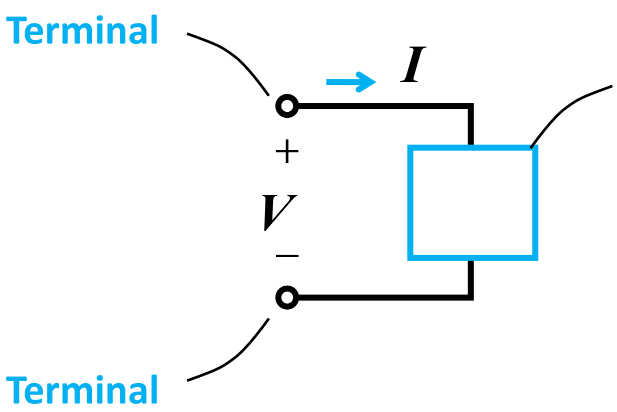
$$\begin{cases} \int_{S_x} J \cdot dS - \int_{S_y} J \cdot dS = \frac{\partial q}{\partial t} \\ \oint E \cdot dl = -\frac{\partial \Phi_B}{\partial t} \end{cases}$$

- **After applying LMD**

$$\begin{cases} I_{in} = I_{out} \\ V_R + V_{switch} = V_{battery} \end{cases}$$

A dramatic reduction on computational load

Lumped circuit abstraction

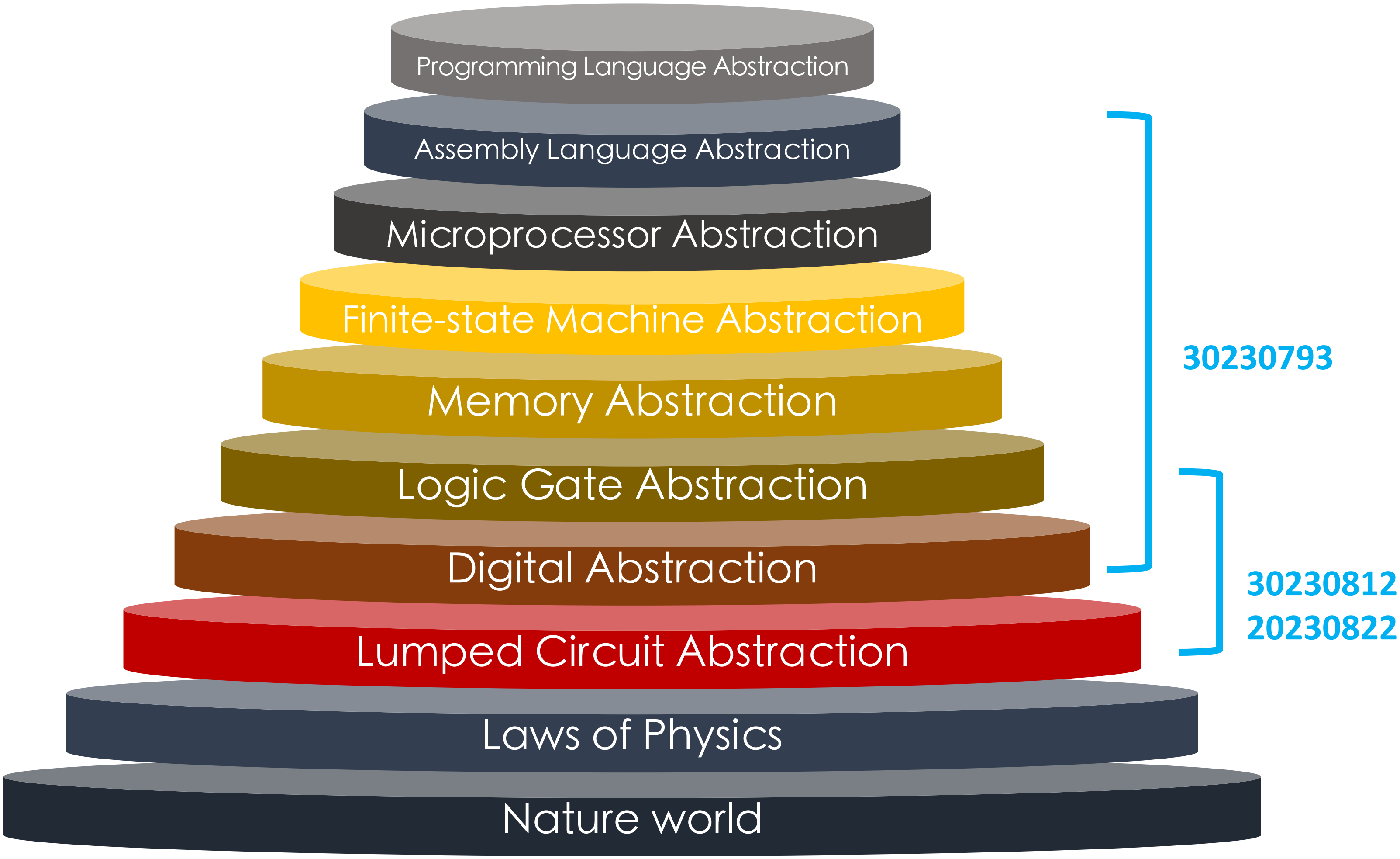


A lumped element

- An abstraction of the real element
- Behavior at the terminals is more important

The lumped circuit abstraction capped a set of lumped elements that obey the lumped matter discipline (LMD) using ideal wires to form an assembly that performs a specific function results in the lumped circuit abstraction.

Why Abstraction?

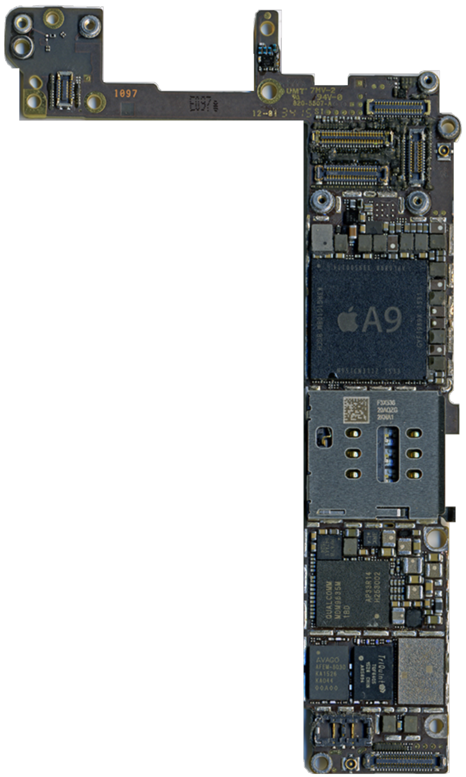


Abstraction is a pathway from the real world to engineering world

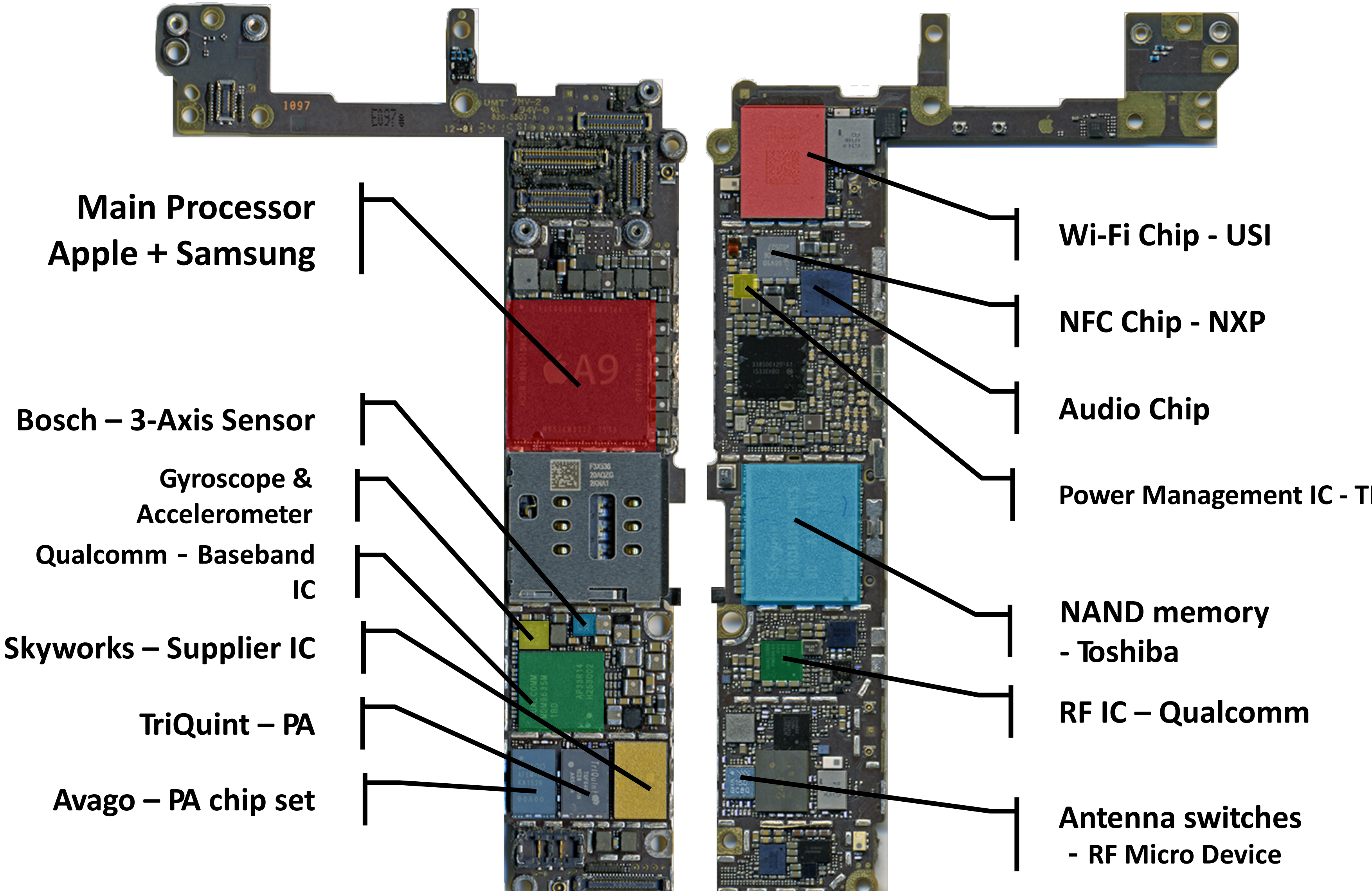
Outlines

- Welcome & course logistics/policies
- Course objectives
  - To learn how to analyze the I-V relationship
- Common circuit elements
  - A quick review
  - Dependent voltage/current sources
  - I-V relationship of voltage/current sources
  - I-V relationship of passive devices
- An example of circuit
  - Lumped Matter Discipline (LMD)
- An example of system

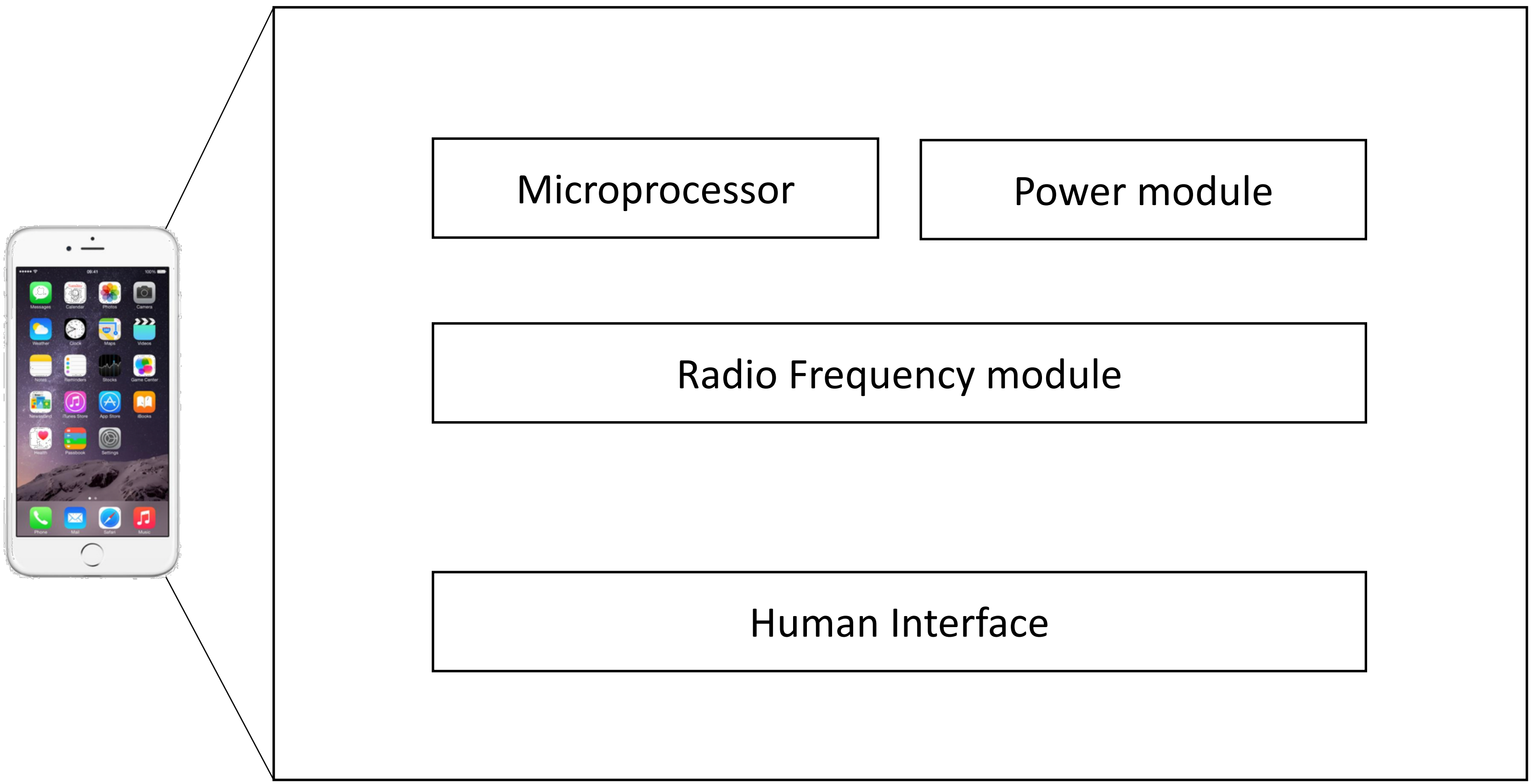
An example of system



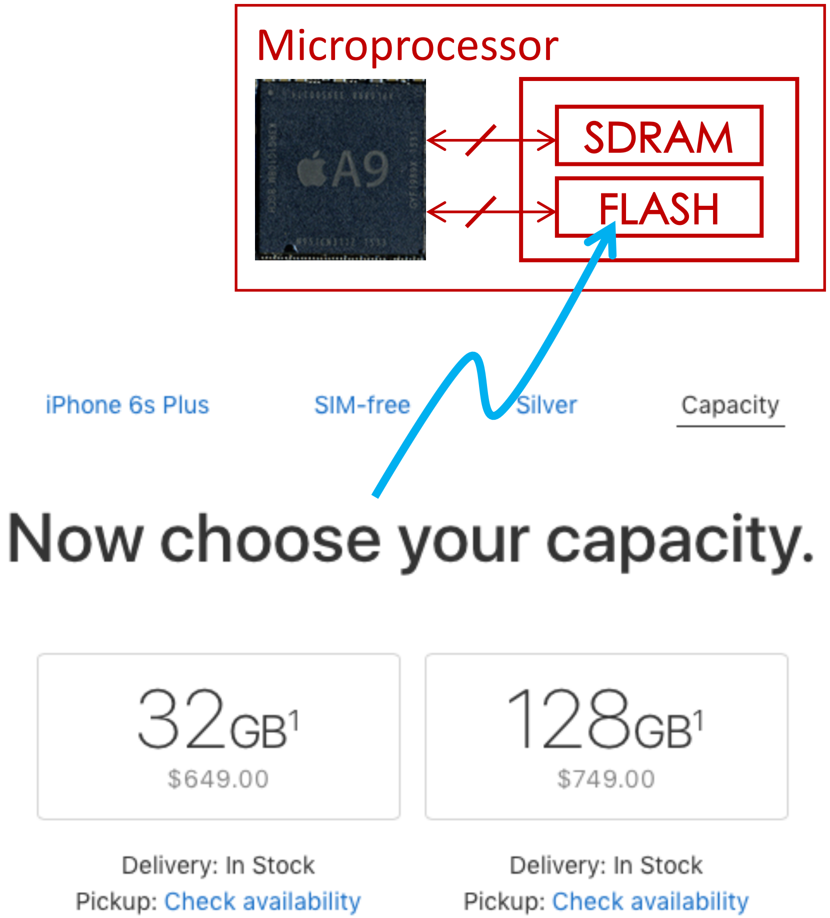
iPhone system



Architecture of an iPhone system

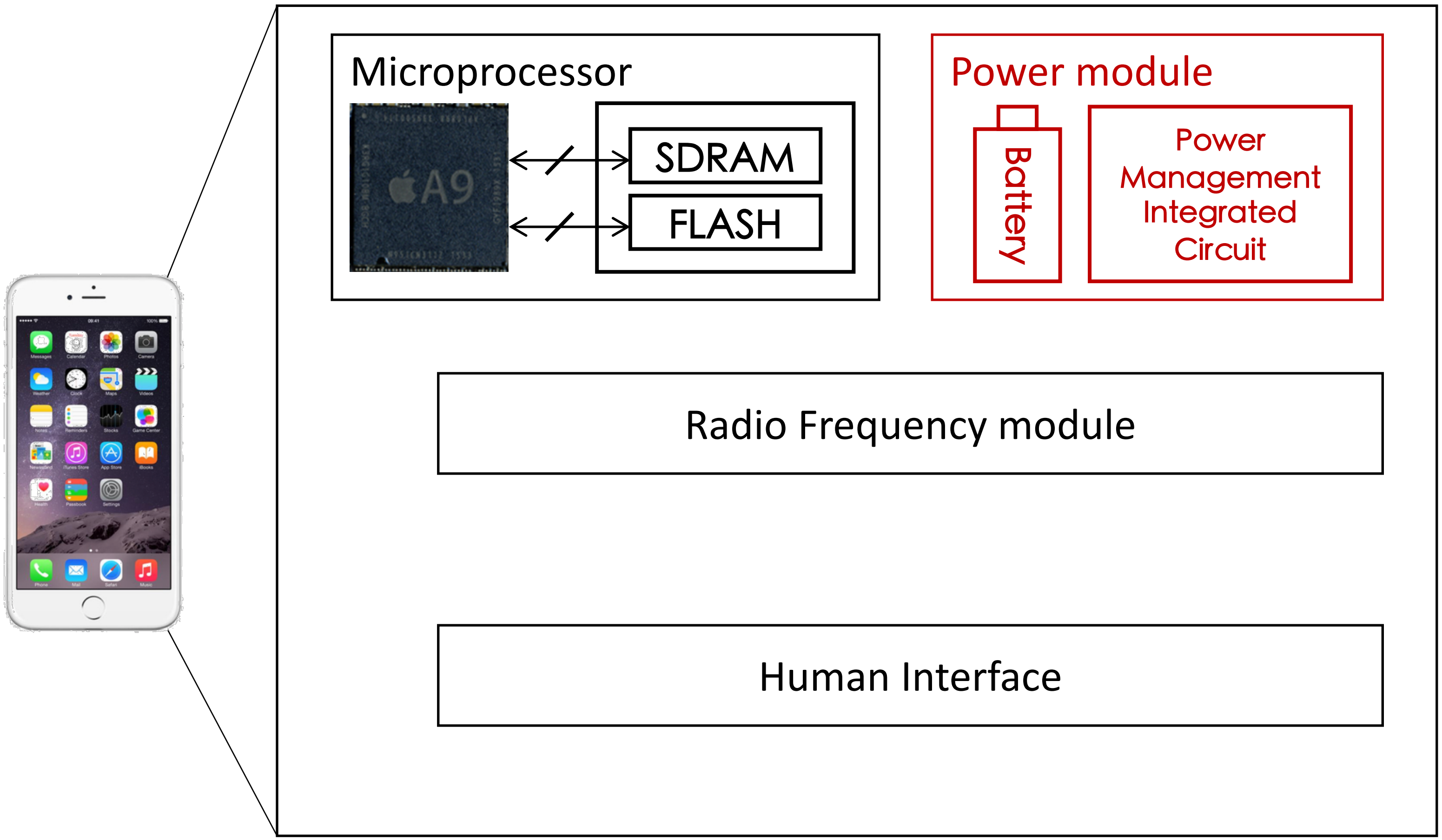


Architecture of an iPhone system



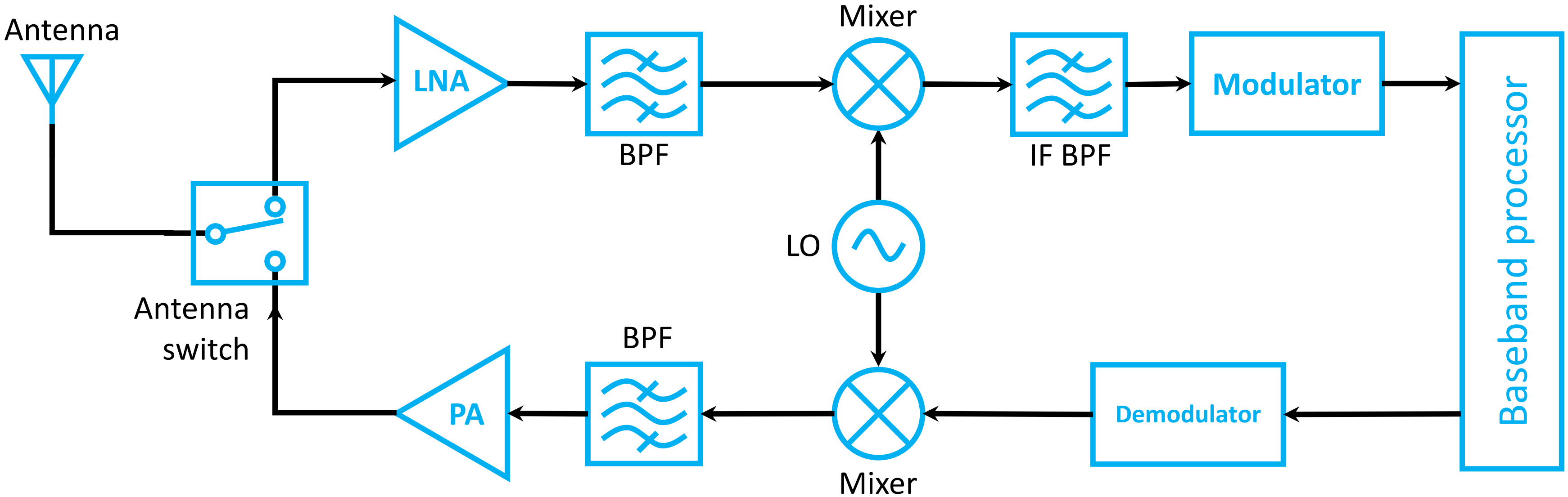
- SDRAM
  - i.e. DDR
- Flash
  - EPROM, EEPROM
  - NOR Flash, NAND Flash

Architecture of an iPhone system



Radio Frequency Module

Why we transfer signal at such a high frequency?



Human vocal speech frequency: 300Hz – 3.4kHz

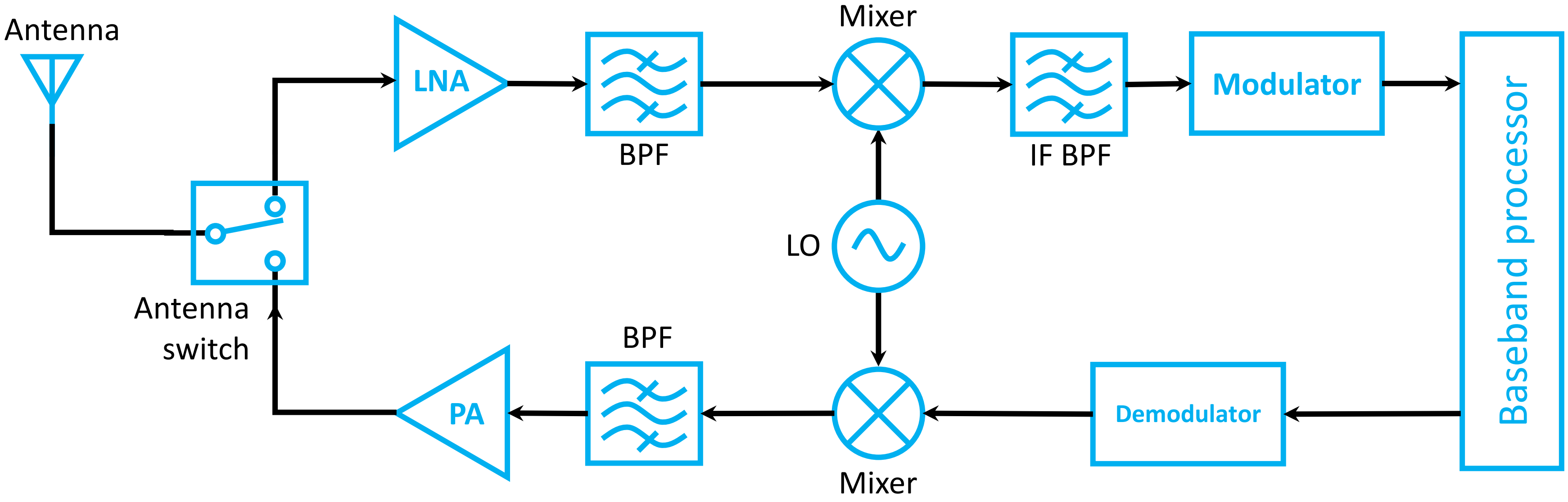
Frequency band for 4G

- China Mobile TDD-LTE: 2575MHz – 2635MHz
- China Unicom TDD-LTE: 2300MHz – 2320MHz
- China Telecom TDD-LTE: 2635MHz – 2655MHz
- China Unicom FDD-LTE: 1755 – 1765 / 1850 – 1860 MHz
- China Telecom FDD-LTE: 1765 – 1780 / 1860 – 1870 MHz

RF	Radio Frequency
BPF	Bandpass Filter
LNA	Low Noise Amplifier
PA	Power Amplifier
LO	Local Oscillator
Mixer	Frequency Up/Down Converter
IF	Intermediate Frequency
LTE	Telecommunication
TDD	Time Division Duplex
FDD	Frequency Division Duplex

Radio Frequency Module

Antenna size: $\frac{\lambda}{4}$

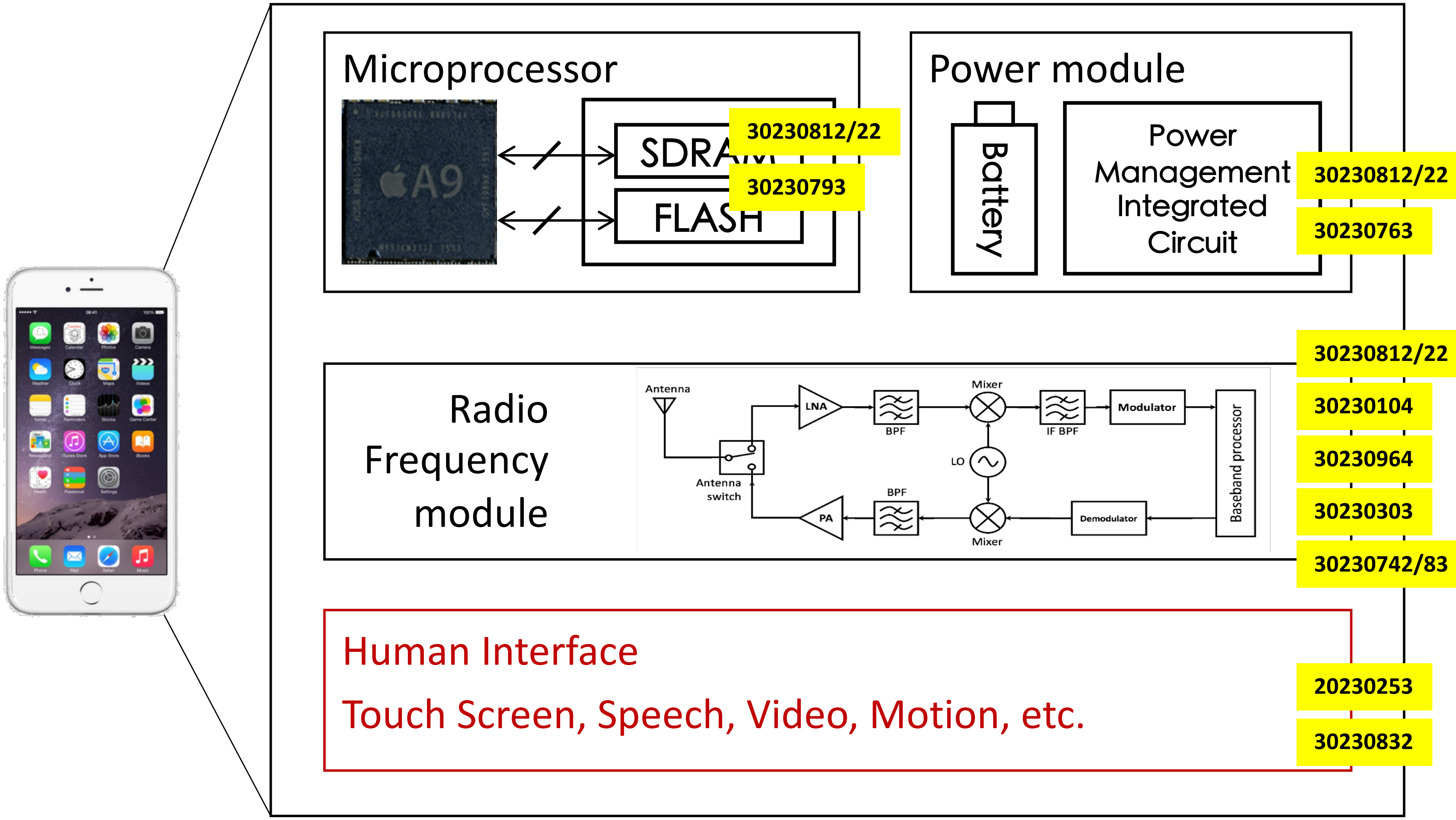


Wavelength of 1kHz Human vocal speech: $\lambda = \frac{c}{f} = \frac{3\times10^8 m/s}{1kHz} = 300km$

Wavelength of 2600MHz RF: $\lambda = \frac{c}{f} = \frac{3\times10^8 m/s}{2600MHz} = 11cm$

The RF module "moves" baseband signal to high frequency

Architecture of an iPhone system



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Reading tasks & learning goals

- Reading tasks
  - Basic Engineering Circuit Analysis
    - Chapter 1
  - Foundations of Analog and Digital Electronic Circuits
    - Chapter 1 (optional)
- Learning goals
  - Understand the key of this course: **I/V relationship**
  - Known the I/V relationship of the **power sources**
    - I/V relationship of the ideal linear independent voltage/current source
    - I/V relationship of the Practical voltage/current source
  - Understand the Lumped Matter Discipline (LMD)
  - Understand the lumped circuit abstraction