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TENTH EDITION

GENERAL CLASS

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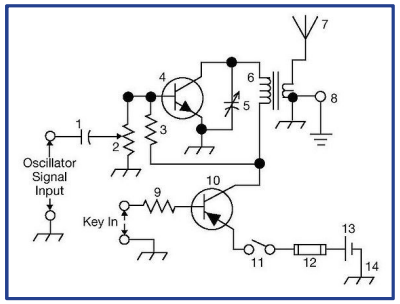

Resource & Reference

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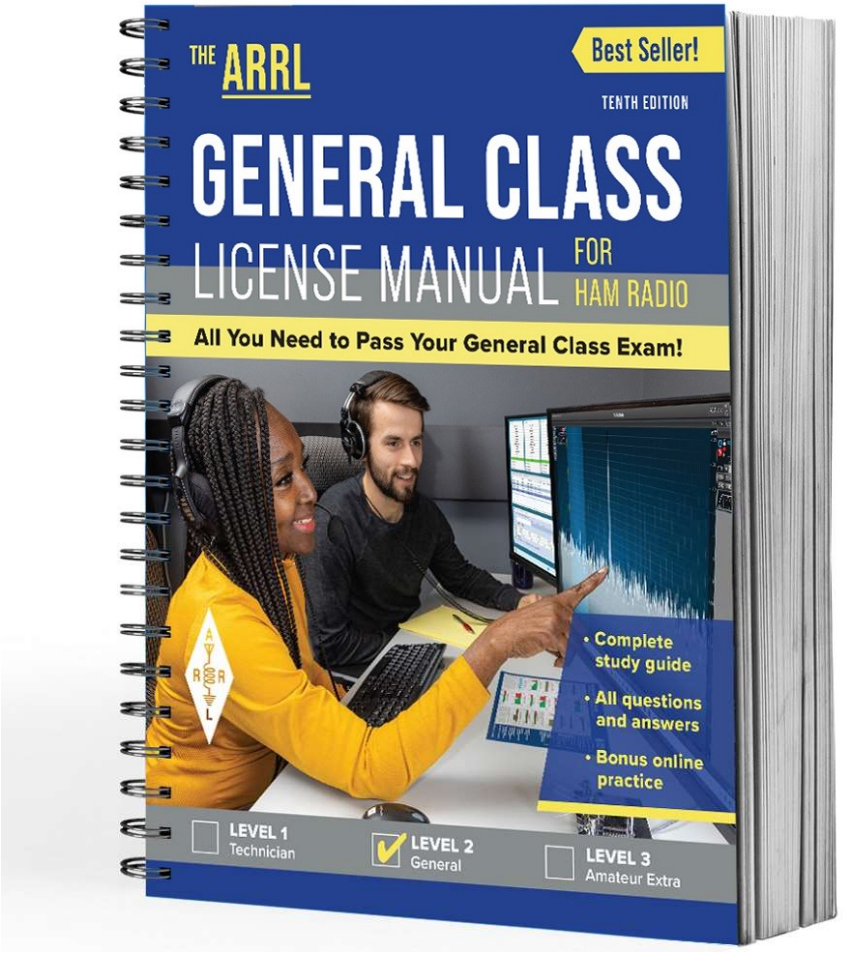


Chapter 4 Part 2 of 3

ARRL General Class
Components and Circuits
Sections 4.4, 4.5

Reactance, Impedance & Resonance, Active Components

Section 4.4
Reactance

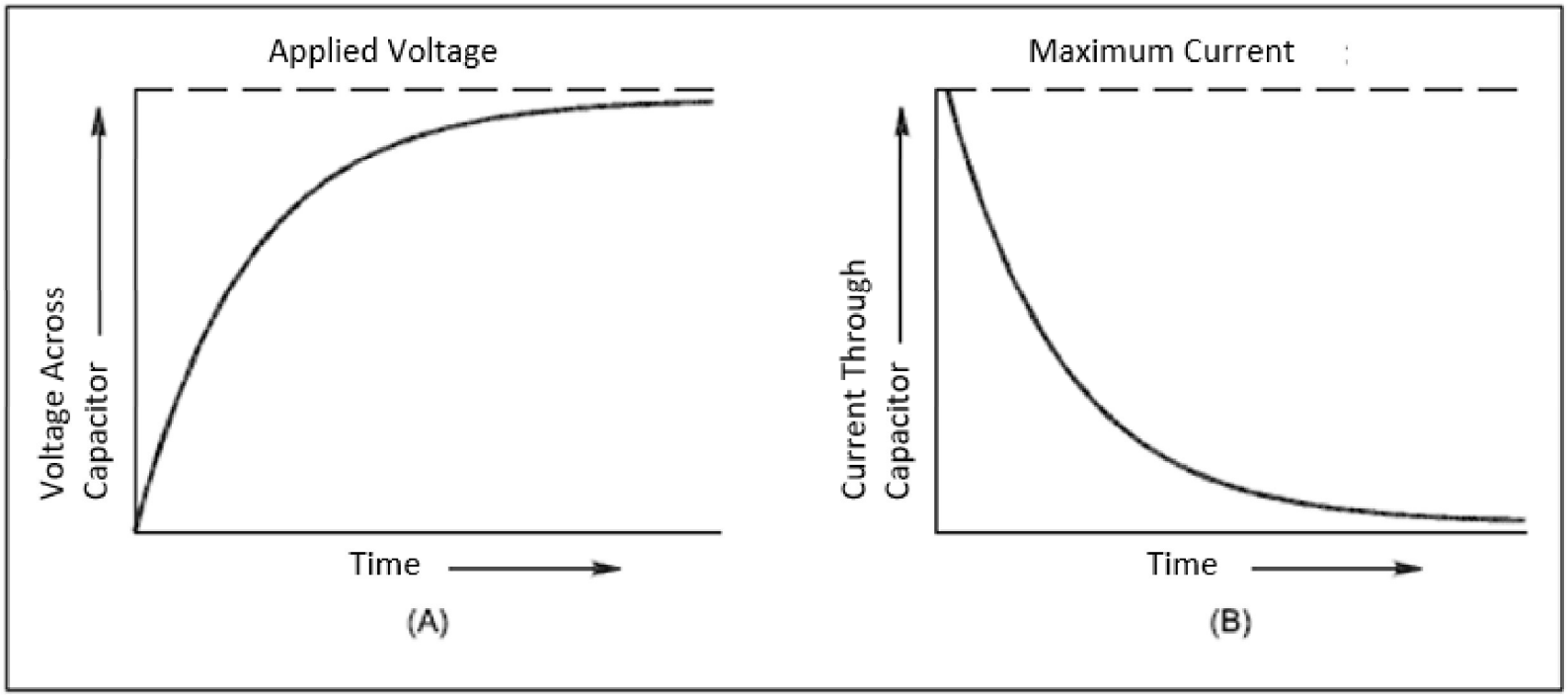
- Reactance: Resistance to the flow of ac current caused by capacitance or inductance. Denoted by X. Measured in ohms (Ω), like resistance.
- Capacitive Reactance: Opposition to ac current flow from the stored energy in a capacitor. Denoted by X_C (see next slide).
- Capacitors behave differently with ac and dc current. With dc, when voltage is initially applied, capacitor looks like a short circuit. After charging, it looks like an open circuit. This is how it blocks dc signals. AC behavior depends upon voltage frequency.

Capacitive Reactance

$$X_C = \frac{1}{2\pi f C}$$

f = frequency (Hz)
C = capacitance (farads)

As the frequency (**f**) of the applied signal increases, X_C decreases, and vice versa.



When a circuit containing a capacitor is first energized, the voltage across the capacitor is zero and the current is very large. As time passes, the voltage across the capacitor increases, as shown at **A**, and the current drops toward zero, as shown at **B**.

Capacitive Reactance (cont.)

Example: What is the reactance of a 1 nF capacitor at 2 MHz?

First convert MHz to Hz and nF to F … (everything in *base* units)

$2\ \text{MHz} = 2{,}000{,}000\ \text{Hz} = 2 \times 10^{6}\ \text{Hz}$

$1\ \text{nF} = 1/1{,}000{,}000{,}000\ \text{F} = 1 \times 10^{-9}\ \text{F}$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.14 \times (2 \times 10^{6}) \times (1 \times 10^{-9})} = \frac{1}{0.01256} = 79.6\ \Omega$$

Reactance (cont.)

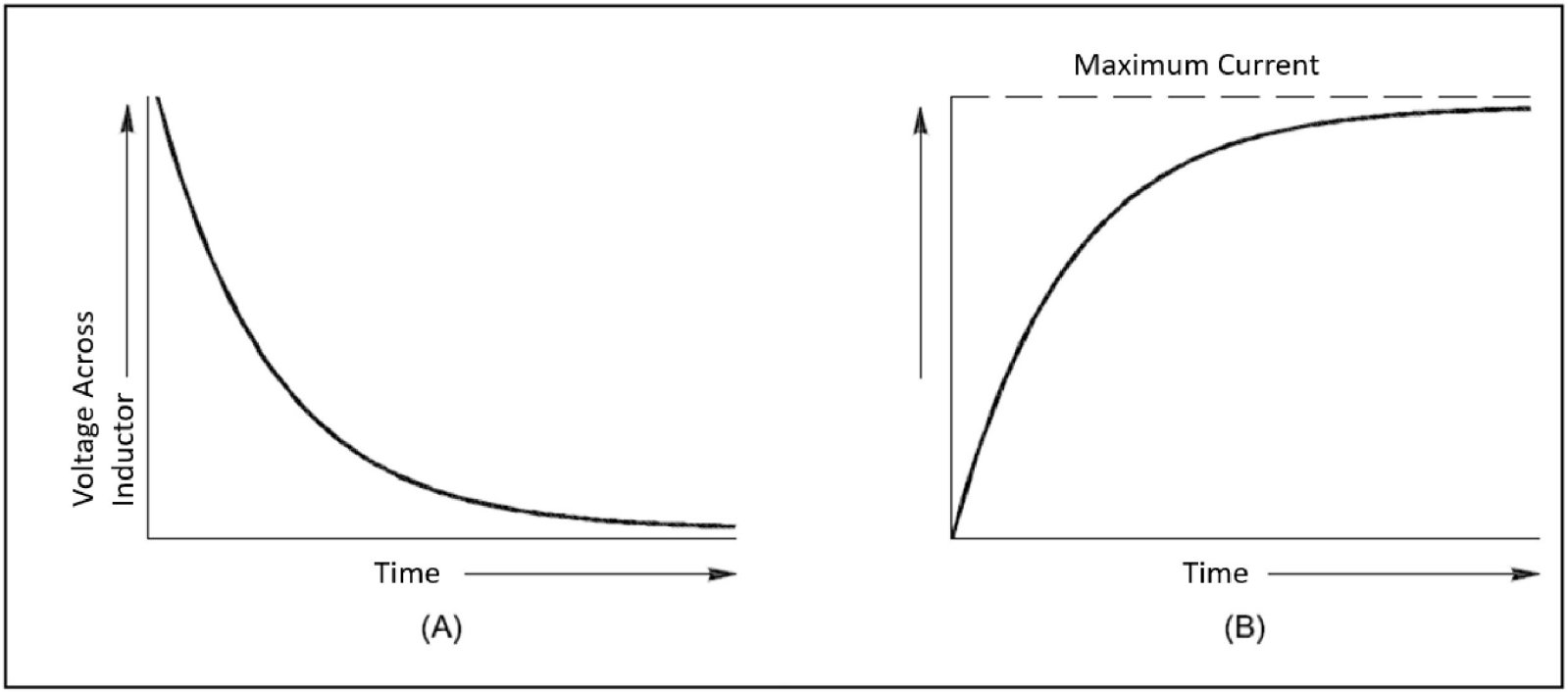
- Inductive Reactance is the opposition to ac current flow from the stored energy in a inductor and is denoted by X_L
- Behavior with frequency is described by:

$$X_L = 2\pi f L$$

f = frequency (Hz)
L = inductance (henrys)

Inductive Reactance

As the frequency (**f**) of the applied signal increases, X_L increases, and vice versa



When a circuit containing an inductor is first energized the initial current is zero and the full applied voltage appears across the inductor. As time passes, the voltage drops toward zero as shown at A, and the current increases, as shown at B.

Inductive Reactance (cont.)

Example: What is the reactance of a 10 µH inductor at 5 MHz?

First convert µH to H and MHz to Hz (everything to same base units)

$5\ \text{MHz} = 5{,}000{,}000\ \text{Hz} = 5 \times 10^6\ \text{Hz}$

$10\ \mu\text{H} = 10/1{,}000{,}000\ \text{H} = 1 \times 10^{-5}\ \text{H}$

$$X_L = 2\pi f L = 2 \times 3.14 \times (5 \times 10^6) \times (1 \times 10^{-5}) = 314\ \Omega$$

Parasitic Inductance

- Parasitic: an unwanted characteristic resulting from the component's physical construction. Examples:
  - The coils in wire-wound resistors (coils create parasitic inductance)
  - Wire leads of components
  - In inductors, each pair of turns creates *parasitic capacitance* in series with the inductance
- Often significant enough to disrupt circuit's operation or affect tuning in radios

Parasitic Inductance (cont.)

- Some capacitors made of thin foils are rolled up – the rolled up construction creates parasitic inductance – *very high in electrolytic capacitors*
  - This limits their use to relatively low frequencies
- Tantalum and ceramic capacitors have little parasitic inductance – can be used up to microwave frequencies

PRACTICE QUESTIONS

What is reactance?

A. Opposition to the flow of direct current caused by resistance
B. Opposition to the flow of alternating current caused by capacitance or inductance
C. Reinforcement of the flow of direct current caused by resistance
D. Reinforcement of the flow of alternating current caused by capacitance or inductance

Which of the following causes opposition to the flow of alternating current in an inductor?

A. Conductance
B. Reluctance
C. Admittance
D. Reactance

G5A03 (D) Page 4-20

Which of the following causes opposition to the flow of alternating current in a capacitor?

A. Conductance
B. Reluctance
C. Reactance
D. Admittance

G5A04 (C) Page 4-20

How does an inductor react to AC?

A. As the frequency of the applied AC increases, the reactance decreases
B. As the amplitude of the applied AC increases, the reactance increases
C. As the amplitude of the applied AC increases, the reactance decreases
D. As the frequency of the applied AC increases, the reactance increases

G5A05 (D) Page 4-22

How does a capacitor react to AC?

A. As the frequency of the applied AC increases, the reactance decreases
B. As the frequency of the applied AC increases, the reactance increases
C. As the amplitude of the applied AC increases, the reactance increases
D. As the amplitude of the applied AC increases, the reactance decreases

What unit is used to measure reactance?

A. Farad
B. Ohm
C. Ampere
D. Siemens

G5A09 (B) Page 4-20

Why should wire-wound resistors not be used in RF circuits?

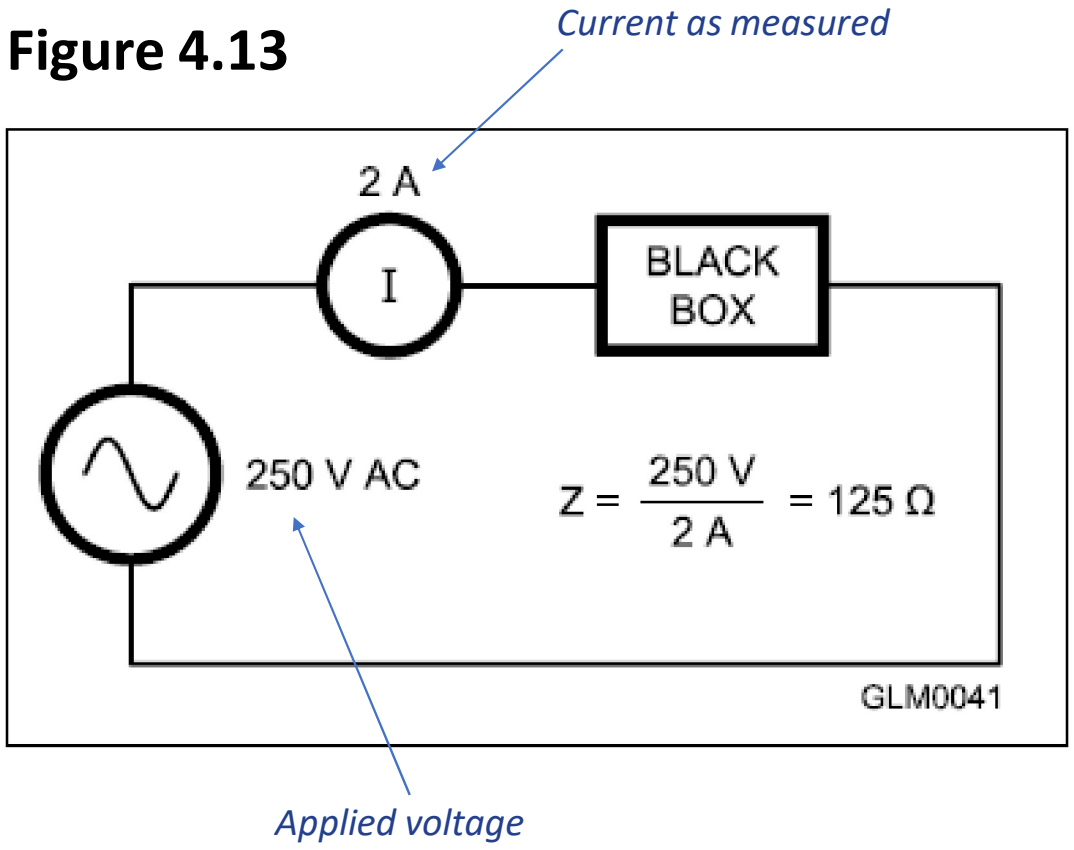
A. The resistor’s tolerance value would not be adequate
B. The resistor’s inductance could make circuit performance unpredictable
C. The resistor could overheat
D. The resistor’s internal capacitance would detune the circuit

G6A06 (B) Page 4-22

Impedance

- Impedance is the opposition to current flow in an ac circuit caused by resistance, reactance, or any combination of the two. Denoted by *Z*. Measured in ohms.
- Like resistance, it's the ratio of voltage to current (Fig. 4.13).
- The inverse of impedance is *admittance*

Figure 4.13

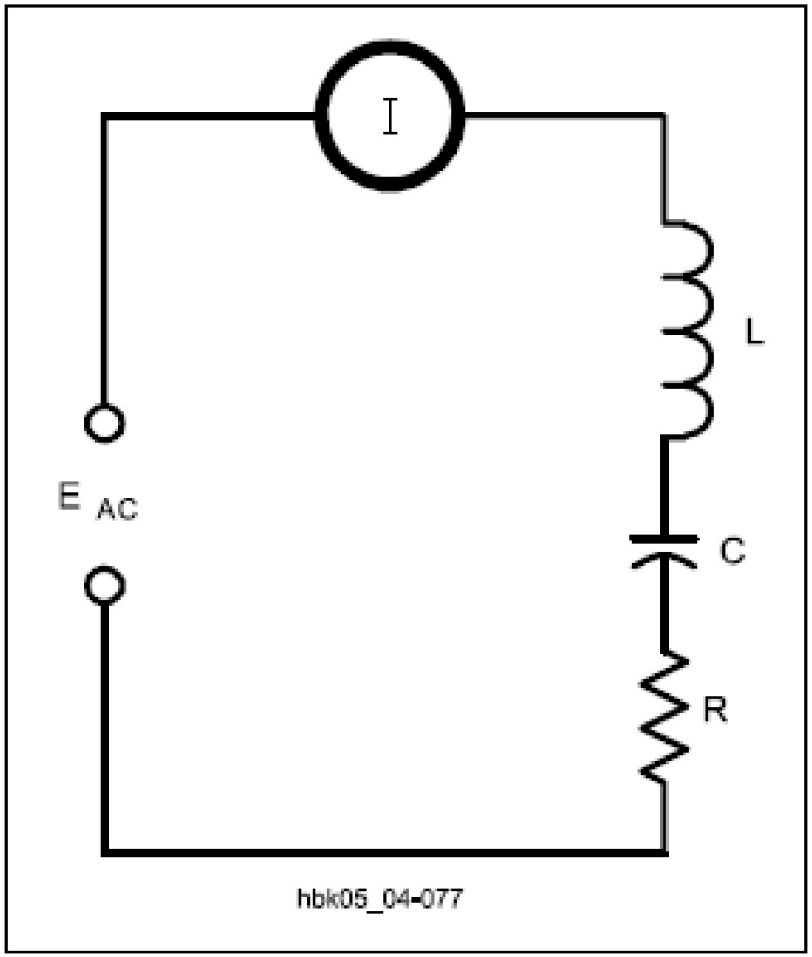


Resonance

- Resonance indicates a match between the frequency at which a circuit or antenna naturally responds to the frequency of an applied signal
- Occurs when … *capacitive reactance = inductive reactance*
- In a resonant series circuit, reactance of ***L*** and ***C*** cancel, making a short circuit, leaving only the resistance (***R***) as the circuit's impedance
- Used in filters & tuned circuits to pass or reject specific frequencies

Resonant Series Circuit

In a resonant series circuit, the reactance of L and the reactance of C cancel, making a short circuit. This leaves only the resistance (R) as the circuit's impedance.



Self-Resonance

- Resonance can occur when a component's expected reactance equals the reactance of it's parasitic reactance (called *self-resonance*)
- Results in a component that appears to be a short or open circuit at the self-resonant frequency
- Above this frequency, the component's reactance switches type, making an inductor capacitive and a capacitor inductive!

Impedance Transformation

- A transformer can change the combination of voltage and current while transferring energy
- The transformer also changes impedance between the primary and secondary circuits (by changing the ratio of voltage and current between the primary and secondary circuits)
- The turns ratio controls the transformation in the same way as the ratio of gear teeth in a mechanical transmission

Impedance Transformation Examples

$$Z_P = Z_S \left[\frac{N_P}{N_S} \right]^2 \quad \text{or} \quad \sqrt{\frac{Z_P}{Z_S}} = \frac{N_P}{N_S}$$

What is the primary impedance if a 200 Ω load is connected to the secondary of a transformer with a 5:1 secondary-to-primary turns ratio?

$$Z_P = Z_S \left[\frac{N_P}{N_S} \right]^2 = 200 \left[\frac{1}{5} \right]^2 = 8\ \Omega$$

Impedance Transformation Examples (cont.)

What turns ratio is required to change a 600 Ω impedance to a 50 Ω impedance?

$$Turns\ Ratio = \frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}} = \sqrt{\frac{600}{50}} = \sqrt{12} = 3.46$$

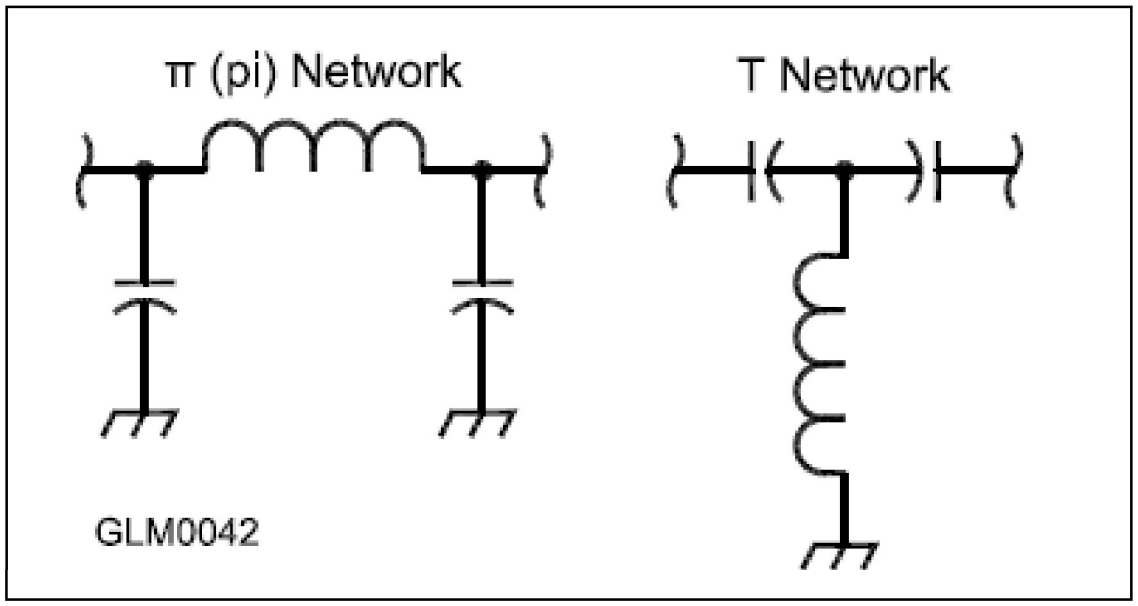
Note that the impedance to be changed (in this case 600 Ω) can be connected to the primary or secondary, but turns ratios are always stated with the larger number first. (3.46:1 not 1:3.46)

Impedance Matching

- An energy source's ability to deliver power to a load is limited by its *internal impedance*
- Amateur transmitting equipment is designed so that the internal impedance of its output circuits is **50 Ω**
- If the difference between the antenna system impedance and transmitter's out impedance is great enough, the transmitter may reduce output power to avoid damage (solution is an *impedance-matching circuit*)

Impedance Matching (cont.)

- Most impedance-matching circuits are *LC* circuits (inductors and capacitors), called π and T networks … see figure below:



Impedance matching can also be performed by special lengths and connections of transmission line.

PRACTICE QUESTIONS

What happens when inductive and capacitive reactance are equal in a series LC circuit?

A. Resonance causes impedance to be very high
B. Impedance is equal to the geometric mean of the inductance and capacitance
C. Resonance causes impedance to be very low
D. Impedance is equal to the arithmetic mean of the inductance and capacitance

G5A01 (C) Page 4-23

What is the term for the inverse of impedance?

A. Conductance
B. Susceptance
C. Reluctance
D. Admittance

What is impedance?

A. The ratio of current to voltage
B. The product of current and voltage
C. The ratio of voltage to current
D. The product of current and reactance

Which of the following devices can be used for impedance matching at radio frequencies?

A. A transformer
B. A Pi-network
C. A length of transmission line
D. All these choices are correct

G5A10 (D) Page 4-25

What letter is used to represent reactance?

A. Z
B. X
C. B
D. Y

G5A11 (B) Page 4-23

What occurs in an LC circuit at resonance?

A. Current and voltage are equal
B. Resistance is cancelled
C. The circuit radiates all its energy in the form of radio waves
D. Inductive reactance and capacitive reactance cancel

G5A12 (D) Page 4-24

What transformer turns ratio matches an antenna's 600-ohm feed point impedance to a 50-ohm coaxial cable?

A. 3.5 to 1
B. 12 to 1
C. 24 to 1
D. 144 to 1

What happens when an inductor is operated above its self-resonant frequency?

A. Its reactance increases
B. Harmonics are generated
C. It becomes capacitive
D. Catastrophic failure is likely

G6A11 (C) Page 4-24

What is one reason to use an impedance matching transformer at a transmitter output?

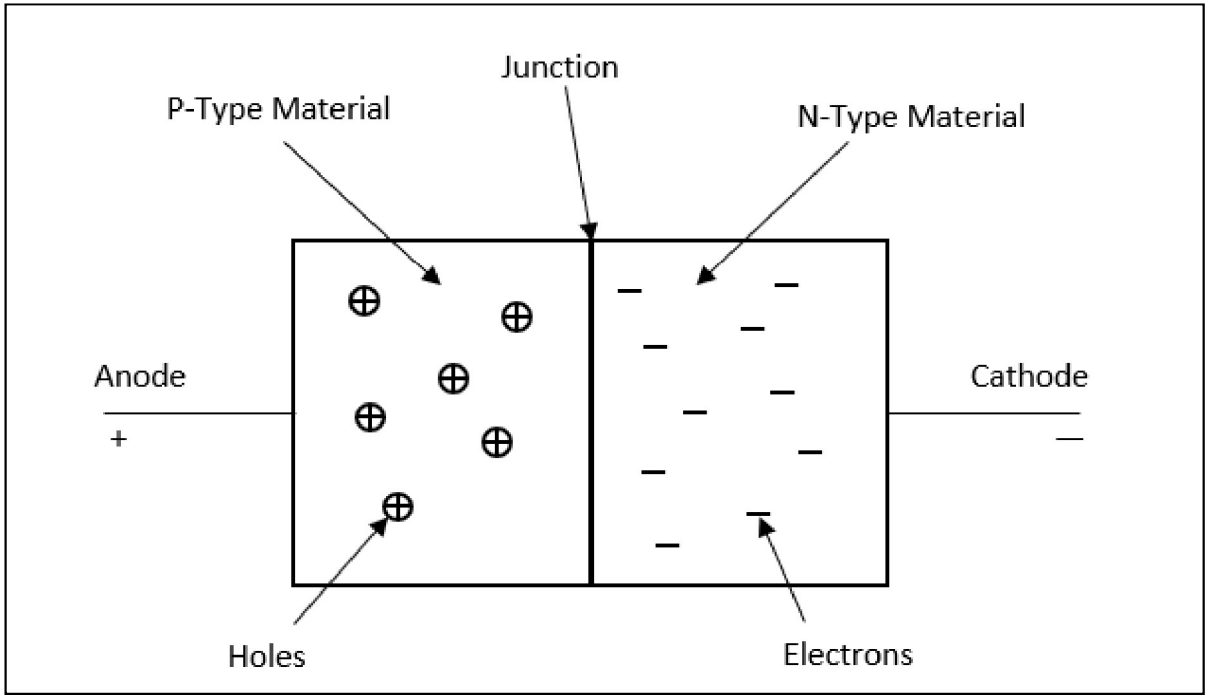
A. To minimize transmitter power output
B. To present the desired impedance to the transmitter and feed line
C. To reduce power supply ripple
D. To minimize radiation resistance

Section 4.5
Semiconductor Components

- The most common active components are made of semiconductors
- Most are made of silicon and germanium
- Electrical properties can be controlled by addition of small amounts of *dopants* (impurities) such as indium and phosphorus
- If the impurity creates an excess of electrons, the result is an *N-type* material. The opposite is *P-type* (a deficit of electrons).
- Where N-type and P-type are in contact is a *PN junction*

Diodes & Rectifiers

- A semiconductor junction diode uses a PN junction to block current flow in one direction
- Wire leads are attached to each layer
- Current flows when positive voltage is applied from P-type to N-type material (*forward bias*)



Diodes & Rectifiers (cont.)

- Voltage applied in opposite direction is *reverse bias*
  - Pulls electrons away from junction so no current flows
- Voltage required to force electrons across junction is the *forward voltage* or *junction threshold voltage* (V_F)
  - For silicon diodes, $V_F \cong 0.7$ V
  - For germanium diodes, $V_F \cong 0.3$ V

Types of Diodes

- Light Emitting
- Laser
- Avalanche
- Zener
- Schottky
- Photodiode
- PN junction
- Transient Voltage Suppression
- Gold Doped
- Constant Current
- Peltier
- Silicon Controlled Rectifier
- PIN
- Varactor

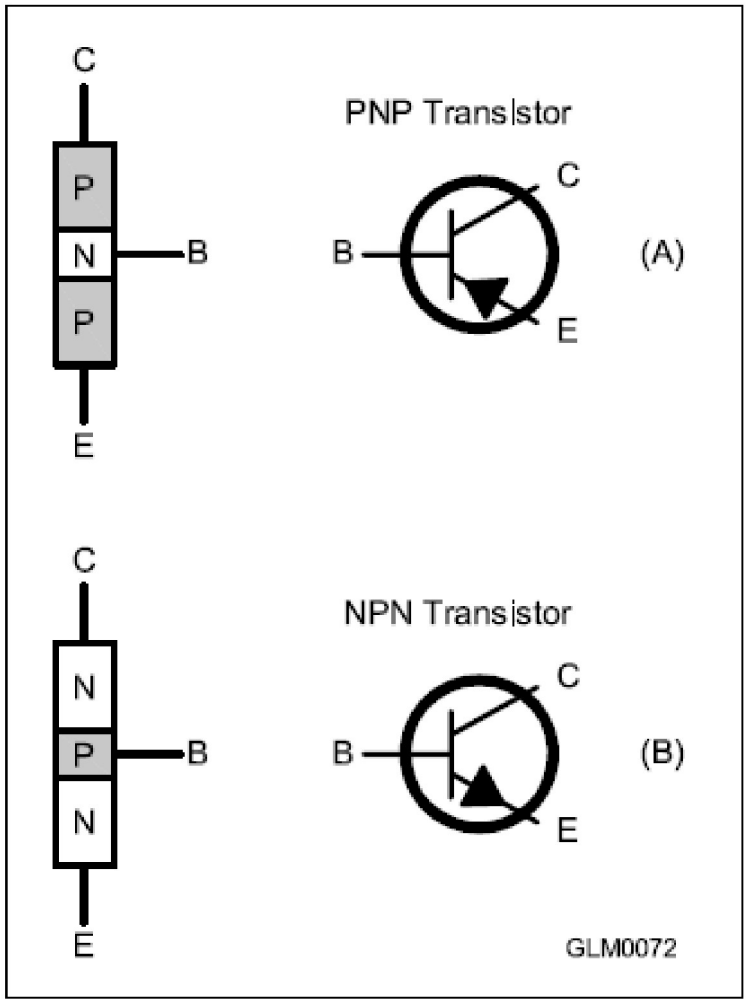
Diode Ratings

- Peak inverse voltage (PIV): Maximum reverse voltage before breakdown occurs (allowing current to flow in reverse direction)
- Average forward current (I_F): Exceeding diode's rating will destroy the diode's internal structure
- Junction capacitance (C_J): When reverse biased, layers of P- and N-type material act like capacitor plates. The larger the C_J the longer it takes to switch to conducting forward current.

Bipolar Transistors

- Adding a 3rd layer of semiconducting material creates a device that can amplify signals is called the *transistor*
- Figure here is a *bipolar junction transistor* (BJT)
- Requires power to function
- 3 electrodes
  - Collector (C)
  - Base (B)
  - Emitter (E)

Controlled by current flow between base and emitter

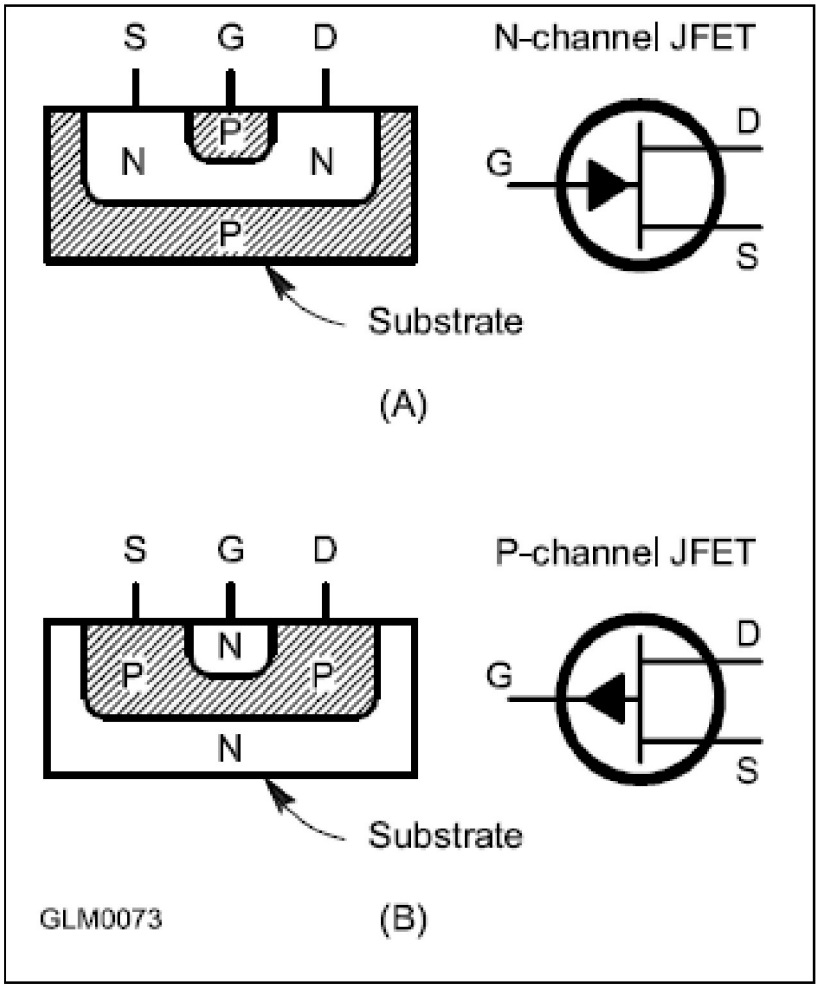


Bipolar Transistors (cont.)

- Very little base-emitter current is required for collector-emitter current to flow
- The control of a large current by a smaller current is *amplification*
- Ratio of collector-emitter current to base-emitter current is *current gain*
  - Current gain for dc signals is *ß*
  - Current gain for ac signals is h_{fe}

Field Effect Transistors (FET)

- 3 electrodes: Drain (D), Source (S), and Gate (G)
- Instead of controlling drain-source current with gate-source current, the voltage between gate and source is used
- Instead of current gain, FET has *transconductance* (g_m) which is the ratio of source-drain current to gate voltage
- MOSFETs (metal-oxide semiconductor FET) use oxide layer to insulate the gate



Additional Transistor Notes

- FETs are very sensitive … require only small amounts of voltage to control the source-drain current
- High amplification makes them ideal for use as switches (both voltage and current)
- With enough voltage, transistors can be driven into *saturation* where further increases in input result in NO change in output
- High enough input signals can reduce output current to zero called *cutoff*
- Saturation and cutoff conditions are excellent representation of digital ON/OFF signals in logic circuits

PRACTICE QUESTIONS

What is the approximate junction threshold voltage of a germanium diode?

A. 0.1 volt
B. 0.3 volts
C. 0.7 volts
D. 1.0 volts

G6A03 (B) Page 4-26

What is the approximate forward threshold voltage of a silicon junction diode?

A. 0.1 volt
B. 0.3 volts
C. 0.7 volts
D. 1.0 volts

G6A05 (C) Page 4-26

What are the operating points for a bipolar transistor used as a switch?

A. Saturation and cutoff
B. The active region (between cutoff and saturation)
C. Peak and valley current points
D. Enhancement and depletion modes

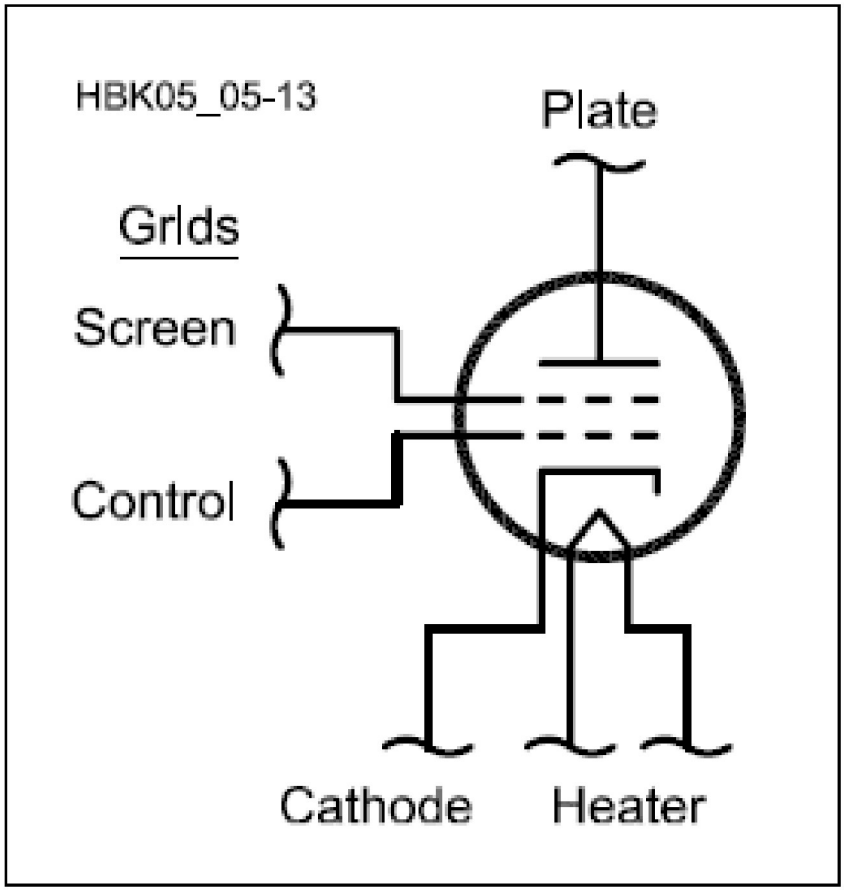
Which of the following describes MOSFET construction?

A. The gate is formed by a back-biased junction
B. The gate is separated from the channel by a thin insulating layer
C. The source is separated from the drain by a thin insulating layer
D. The source is formed by depositing metal on silicon

G6A09 (B) Page 4-27

Vacuum Tubes

- Have at least 3 electrodes called *elements*
- 3 basic parts:
  - A source of electrons
  - Electrode to collect electrons
  - Intervening electrodes that control electrons traveling from source to collector
- Compared to transistors, most like the FET
- Operate at high (hazardous) voltages (2000-3000 V). **Exercise caution!**



Tube Terminology

- Filament or heater – heats the cathode, causing it to emit electrons
- Cathode – source of electrons
- Control grid – grid closest to cathode, used to regulate electron travel between cathode and plate
- Screen grid – electrode that reduces grid-to-plate capacitance
- Suppressor grid – prevents electrons from traveling from plate to control or screen grid
- Plate – collects electrons, called *plate current*

PRACTICE QUESTIONS

Which element of a vacuum tube regulates the flow of electrons between cathode and plate?

A. Control grid
B. Suppressor grid
C. Screen grid
D. Trigger electrode

G6A10 (A) Page 4-28

What is the primary purpose of a screen grid in a vacuum tube?

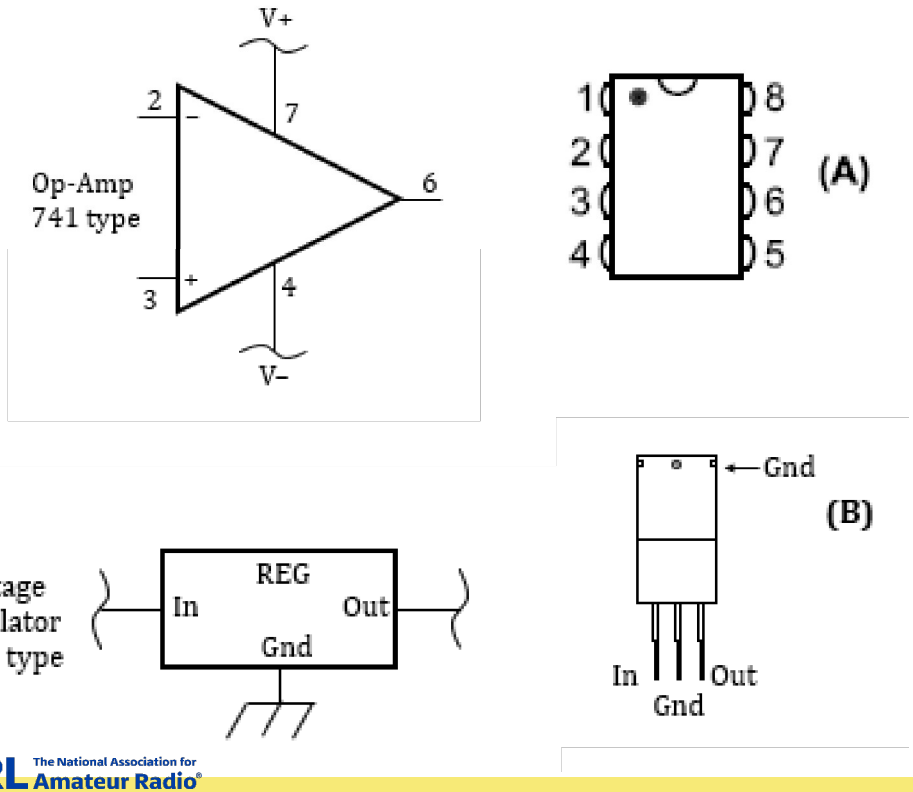
A. To reduce grid-to-plate capacitance
B. To increase efficiency
C. To increase the control grid resistance
D. To decrease plate resistance

G6A12 (A) Page 4-28

Analog Integrated Circuits (IC's)

- IC Definition: An electronic circuit formed on a small piece of semiconducting material, performing the same function as a larger circuit made from discrete components (aka, CHIP)
- Operate over a continuous range of voltages and currents
- Used for amplification, filtering, measurement, voltage regulation, and power control
- Most common analog IC's: operational amplifier and linear voltage regulator
  - Op amps are used for dc and audio circuits … inexpensive source of gain
  - Linear voltage regulators maintain power supply output at constant voltage over a wide range of currents

Figure 4.22



The popular 741 op-amp symbol and dual in-line package (DIP) connections are shown at (**A**). A common 3-terminal voltage regulator, the 7800-series, is shown in the TO-220 package at (**B**).

Digital Integrated Circuits

- Digital IC's operate with discrete values of voltage and current representing the binary numbers system values 0 and 1 (representing OFF and ON)
- Used for performing computations or controlling functions
- The most popular logic family in use is *CMOS* (complementary metal-oxide semiconductors) technology (known for high speed and low power consumption)

Table 4.4: Logic Family Characteristics

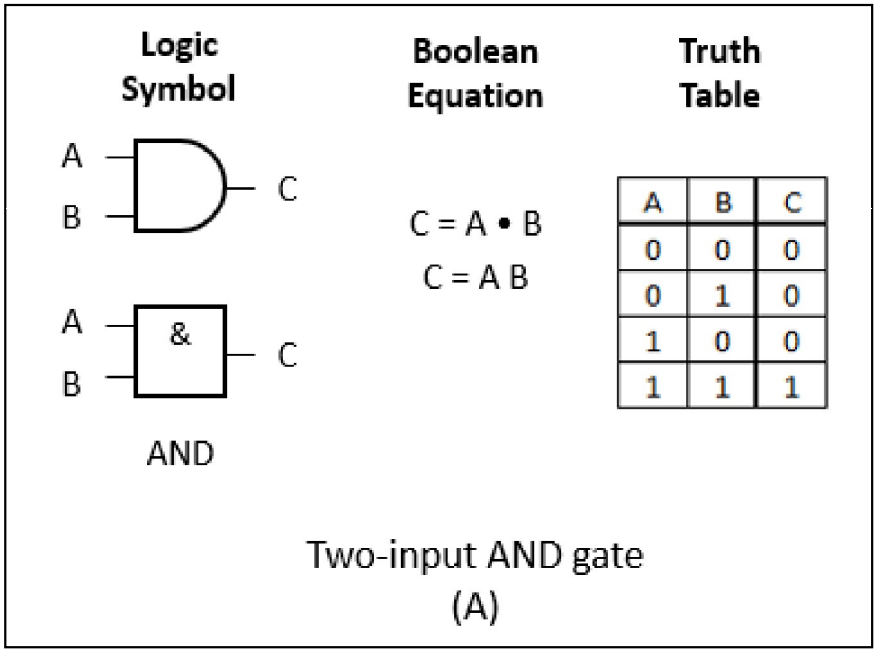
FAMILY NAME	MAX OPERATION FREQUENCY	POWER CONSUMPTION	POWER SUPPLY
TTL	100 MHz	High	5 V
CMOS	1 GHz	Low	3-5 V
CMOS (CD4000)	1 MHz	Very Low	3-15 V

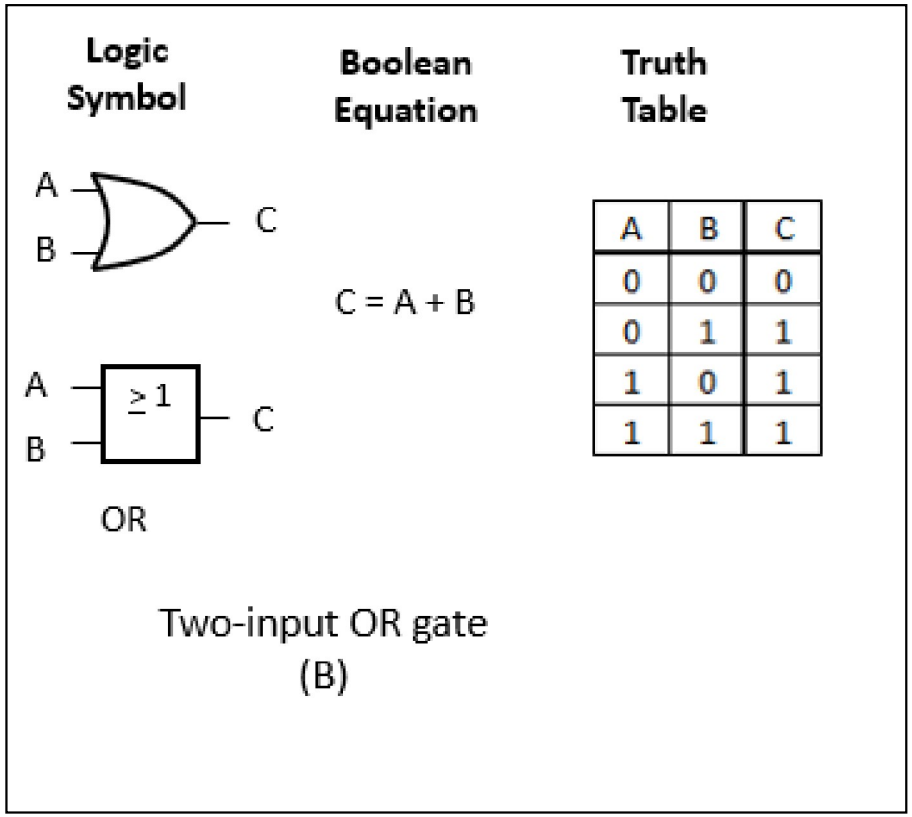
Digital Logic Basics

- The basic building block of digital circuits are called *gates* that perform *inversion* (changing 1 to 0 and vice versa) and the OR and AND functions
- The most common gates in use are the inverter, NAND and NOR
- More complex functions (e.g., microprocessors, signal processors, etc.) are constructed from combinations of these functions
- Circuits that use gates to combine binary inputs to generate a binary output or combination of binary outputs are called *combinational logic*

See Figure 4.23 for details

Figure 4.23: Schematic symbols for the basic digital logic functions with the logic equations and truth tables that describe their operation.





Reading TRUTH Tables

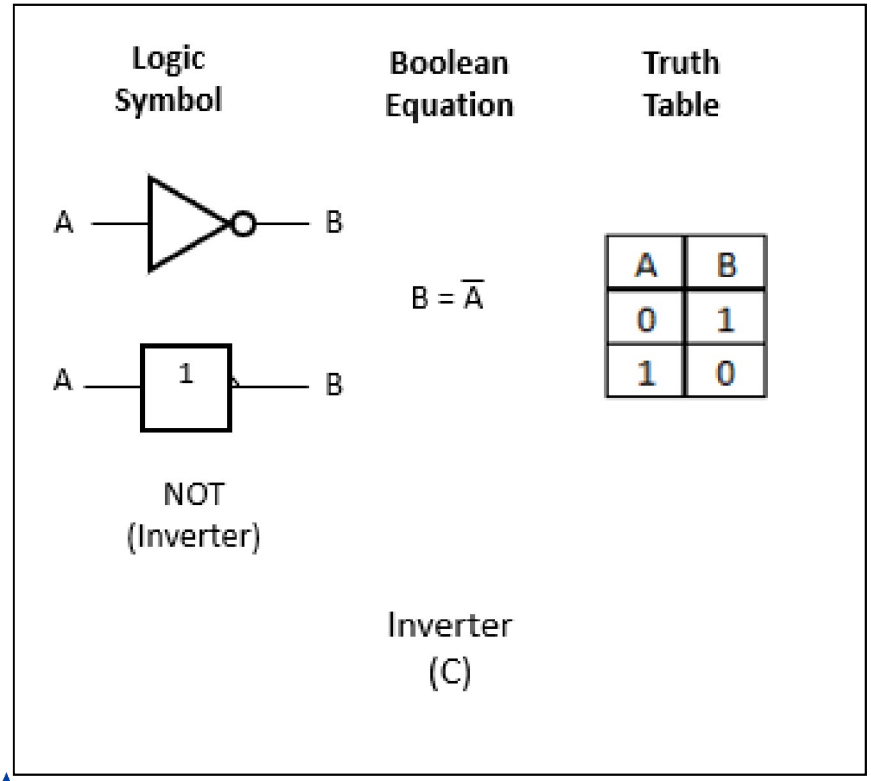
- Refer to previous slide
- Two-input AND gate
  - If EITHER A or B are OFF, the gate is OFF
  - Both have to be ON for the gate to be ON
- Two-input OR gate
  - If EITHER A or B are ON, the gate is ON
  - Both have to be OFF for the gate to be OFF

Can you think of examples where these might be used?

AND: Gumball machine – need to insert coin AND press button to dispense.

OR: Intrusion detection – alarm sounds for intrusion at front door OR bedroom window.

Figure 4.23: Schematic symbols for the basic digital logic functions with the logic equations and truth tables that describe their operation (cont.).



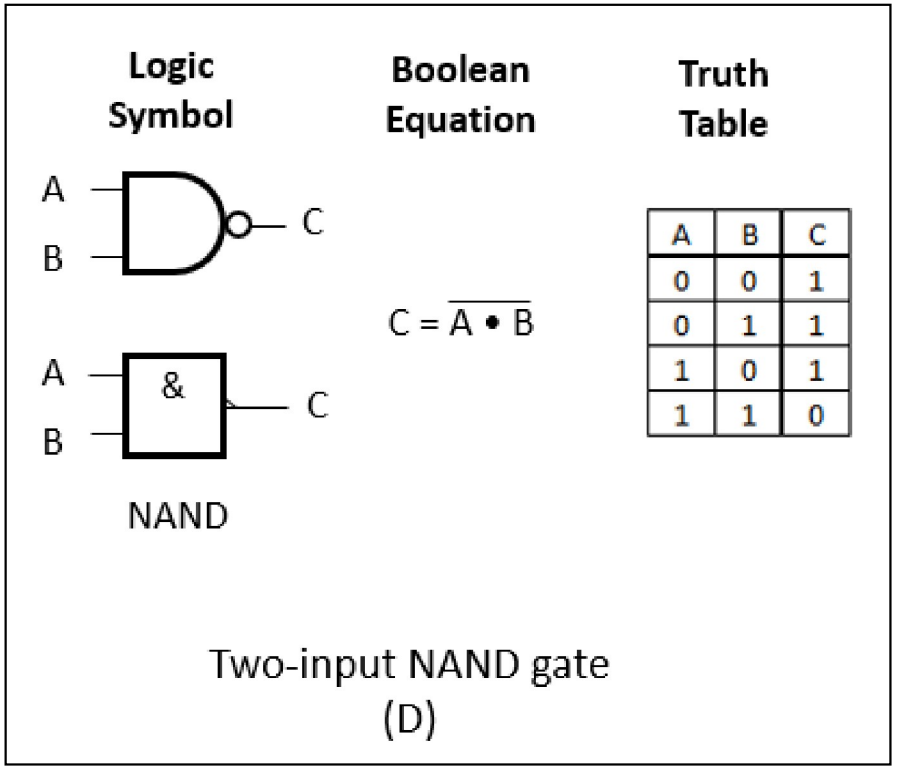
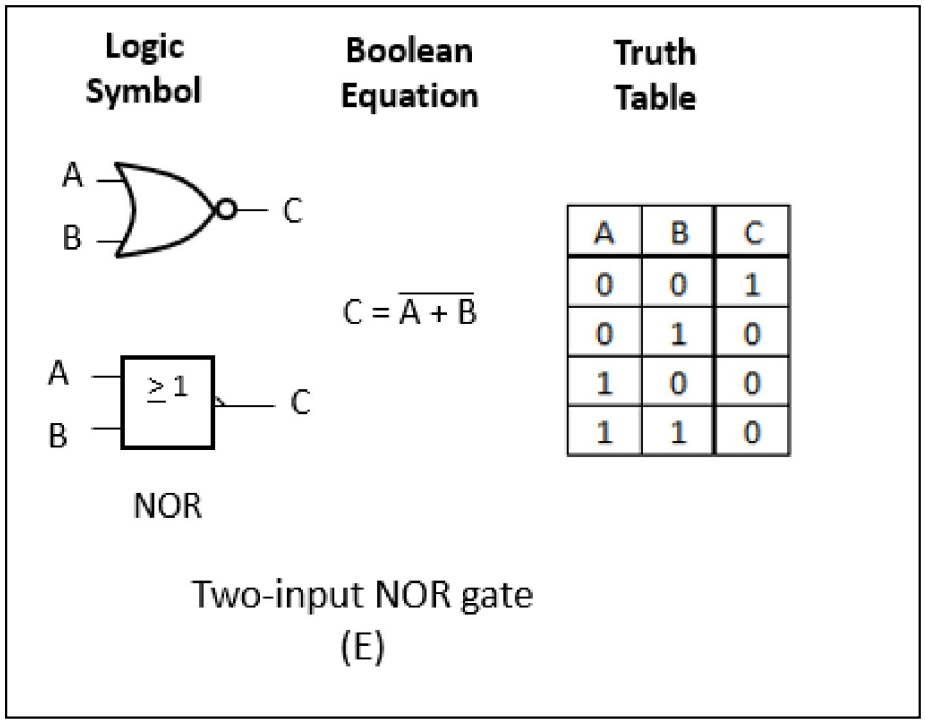
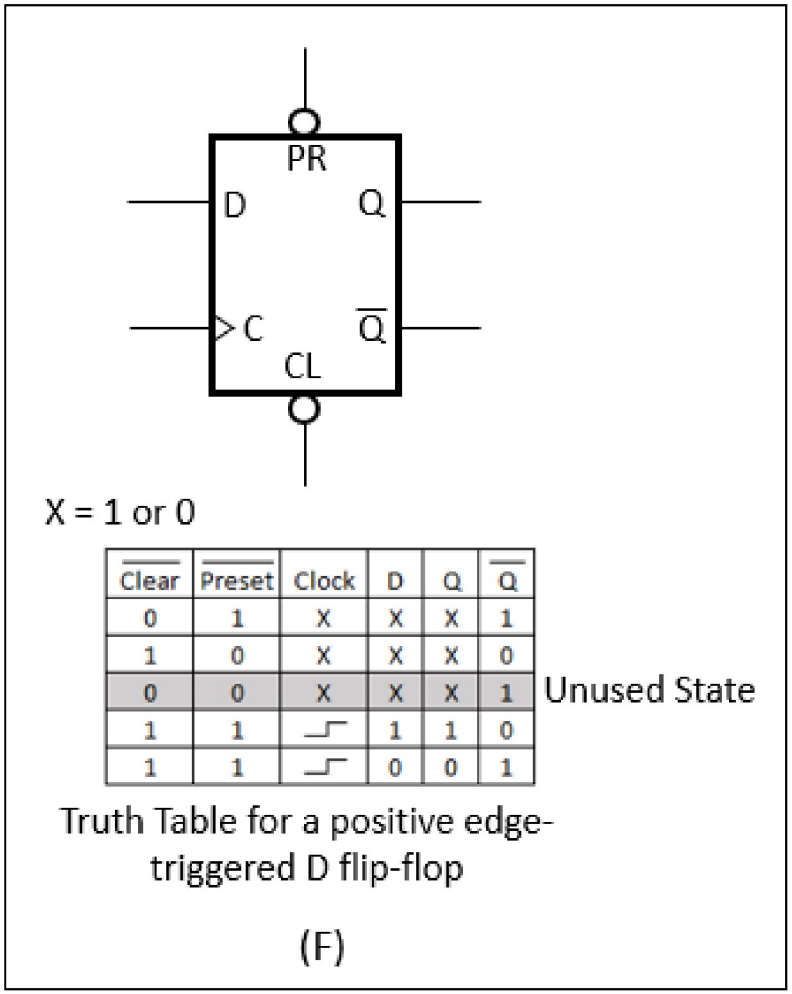


Figure 4.23: Schematic symbols for the basic digital logic functions with the logic equations and truth tables that describe their operation (cont.).



A	B	C
0	0	1
0	1	0
1	0	0
1	1	0



$\overline{Clear}$	$\overline{Preset}$	Clock	D	Q	$\overline{Q}$
0	1	X	X	X	1
1	0	X	X	X	0
0	0	X	X	X	1
1	1	⎍	1	1	0
1	1	⎍	0	0	1

Digital Logic Basics (cont.)

- *Sequential logic circuits* combine binary signals in a way that depends on time and on the sequence of inputs to the circuits
- Basic building block of sequential logic is the *flip-flop*
  - Responds to clock signal that causes it outputs to change based on input
  - The 2 outputs (Q and Q-bar) are always in opposite states
  - Connecting flip-flops together so that one flip-flop's output feeds the next one's input creates 2 important circuits; *counters* and *shift registers*

Counter Logic

- The outputs of the chain of flip-flops make up a binary number or state representing the number of clock signals that have occurred
- Each flip-flop stores one bit of the total count
- Highest number a counter can represent is 2^N (N = number of flip-flops that make up the counter)
- A 3-bit counter (3 flip-flops) can count 2^3 (= 8) states, 4-bit (2^4) can count 16 states, 5-bit (2^5) counts 32 states, etc.

Shift Registers

- Connecting the array of flip-flops slightly differently results in a shift register
  - Stores a sequence of 1s and 0s from its input as the flip-flop outputs
  - Each clock signal causes the value at the shift register's input to pass or shift to the next flip-flop in the string
- Some shift registers circuits can be configured to shift up and down (or forward/backward)
- A simple form of digital memory

RF Integrated Circuits

- Designed for functions such as …
  - Low-level high-gain amplifiers, mixers, modulators/demodulators, filters
- Greatly reduce number of discrete devices require to build radio circuits
- Monolithic microwave integrated circuits (MMIC) are special types of RF IC's that work through microwave frequencies
  - Perform several functions
  - Enables construction of low-cost cell phones, GPS receivers, etc.

PRACTICE QUESTIONS

What is meant by the term MMIC?

A. Multi-Mode Integrated Circuit
B. Monolithic Microwave Integrated Circuit
C. Metal Monolayer Integrated Circuit
D. Mode Modulated Integrated Circuit

Which of the following is an advantage of CMOS integrated circuits compared to TTL integrated circuits?

A. Low power consumption
B. High power handling capability
C. Better suited for RF amplification
D. Better suited for power supply regulation

What kind of device is an integrated circuit operational amplifier?

A. Digital
B. MMIC
C. Programmable Logic
D. Analog

G6B06 (D) Page 4-30

Which of the following describes the function of a two-input AND gate?

A. Output is high when either or both inputs are low
B. Output is high only when both inputs are high
C. Output is low when either or both inputs are high
D. Output is low only when both inputs are high

G7B03 (B) Page 4-30

How many states does a 3-bit binary counter have?

A. 3
B. 6
C. 8
D. 16

What is a shift register?

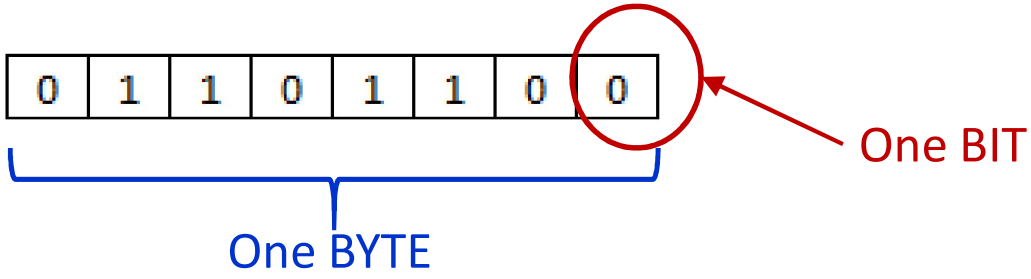
A. A clocked array of circuits that passes data in steps along the array
B. An array of operational amplifiers used for tri-state arithmetic operations
C. A digital mixer
D. An analog mixer

Microprocessors & Related Components: Memory

- Microprocessors are microcontroller ICs that are capable of performing millions of computing instructions per second
- Programs must be stored in *memory* devices so the microprocessor can read the instructions
  - *Volatile* memory loses data when power is removed
  - *Nonvolatile* memory stores data permanently, even without power
  - *Random-access memory* (RAM) can be read from or written to
  - *Read-only memory* (ROM) stores data permanently and cannot be changed

Data Interfaces

- Microprocessors communicate through data interfaces
  - Two types: Serial & Parallel
  - Serial transfers one *bit* of data in each transfer operation
  - Parallel transfers multiple bits in each operation



Visual Interfaces

- Amateur equipment uses two types of devices to present information visually; Indicators & displays
- Indicators: Presents ON/OFF information visually by the presence or absence of color or light
  - Common indicators: Incandescent light bulbs & light-emitting diodes (*LED*s)
- Displays: Presents text or graphics information in visual form

LEDs

- Have largely replaced incandescent light bulbs in amateur equipment
  - Last longer, can be turned on/off more quickly, use less power, generate less heat
- Available in many colors
- Made from special types of semiconductor material that emit light when the PN junction is *forward biased*

Liquid Crystal Displays (*LCD*)

- Most common type of display
- Created by sandwiching liquid crystal material between glass panels
- A pattern of electrodes is printed in a thin film on the front panel with a single electrode covering the rear panel
- Voltage applied to front panel causes the crystals to twist in a configuration that blocks light
- LCDs require ambient or back lighting (light source behind the crystal layer) since the crystal layer does not generate light on its own
  - Compared to LCDs, LEDs have higher contrast where there is high ambient light (sunny day)

PRACTICE QUESTIONS

How is an LED biased when emitting light?

A. In the tunnel-effect region
B. At the Zener voltage
C. Reverse biased
D. Forward biased

How does a liquid crystal display compare to an LED display?

A. Higher contrast in high ambient lighting
B. Wider dynamic range
C. Higher power consumption
D. Shorter lifetime

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END OF CHAPTER 4 PART 2 OF 3

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Feel free to contact me if you find errors or have suggestions for improvement.