Chapter 17

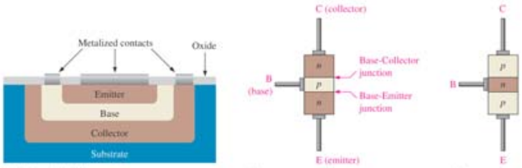
Transistors and Applications

Objectives

- Describe the basic structure and operation of bipolar junction transistors
- Explain the operation of a BJT class A amplifier
- Analyze class B amplifiers
- Analyze a transistor switching circuit
- Describe the basic structure and operation of JFETs and MOSFETs
- Analyze two types of FET amplifier configurations
- Discuss the theory and analyze the operation of several types of oscillators

DC Operation of Bipolar Junction Transistors (BJTs)

- The bipolar junction transistor (BJT) is constructed with three doped semiconductor regions separated by two *pn* junctions
- Regions are called **emitter**, **base** and **collector**



(a) Basic epitaxial planar structure (b) *npn* (c) *pnp*

DC Operation of Bipolar Junction Transistors (BJTs)

- There are two types of BJTs, the *npn* and *pnp*
- The two junctions are termed the *base-emitter* junction and the *base-collector* junction
- The term bipolar refers to the use of both holes and electrons as charge carriers in the transistor structure
- In order for the transistor to operate properly, the two junctions must have the correct dc bias voltages
  - the base-emitter (BE) junction is forward biased
  - the base-collector (BC) junction is reverse biased

DC Operation of Bipolar Junction Transistors (BJTs)

- Transistor Currents:

$$I_E = I_C + I_B$$

- **alpha** (α_{DC})

$$I_C = \alpha_{DC} I_E$$

- **beta** (β_{DC})

$$I_C = \beta_{DC} I_B$$

  – β_{DC} typically has a value between 20 and 200

DC Operation of Bipolar Junction Transistors (BJTs)

- DC voltages for the biased transistor:
- Collector voltage

$$V_C = V_{CC} - I_C R_C$$

- Base voltage

$$V_B = V_E + V_{BE}$$

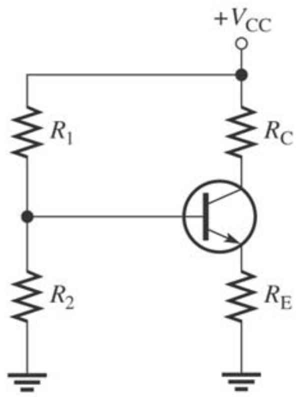
  – for silicon transistors, $V_{BE} = 0.7$ V

DC Operation of Bipolar Junction Transistors (BJTs)

- The voltage divider biasing is widely used
- Input resistance is:

  $R_{IN} \cong \beta_{DC} R_E$
- The base voltage is approximately:

  $V_B \cong V_{CC} R_2 / (R_1 + R_2)$

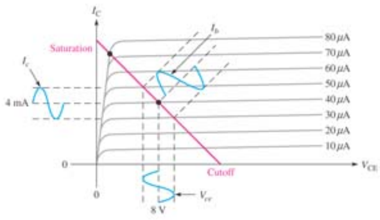


BJT Class A Amplifiers

- In a class A amplifier, the transistor conducts for the full cycle of the input signal (360°)
  - used in low-power applications
- The transistor is operated in the active region, between saturation and cutoff
  - saturation is when both junctions are forward biased
  - the transistor is in cutoff when $I_B = 0$
- The *load line* is drawn on the collector curves between saturation and cutoff

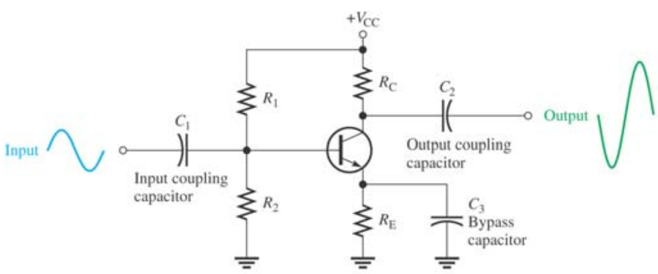
DC Operation of Bipolar Junction Transistors (BJTs)

- The base current, I_B, is established by the base bias
- The point at which the base current curve intersects the dc load line is the quiescent or Q-point for the circuit



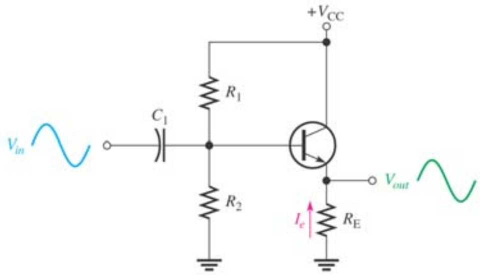
DC Operation of Bipolar Junction Transistors (BJTs)

- A **common-emitter** (CE) amplifier
  - capacitors are used for coupling ac without disturbing dc levels



DC Operation of Bipolar Junction Transistors (BJTs)

- A **common-collector** (CC) amplifier
  - voltage gain is approximately 1, but current gain is greater than 1



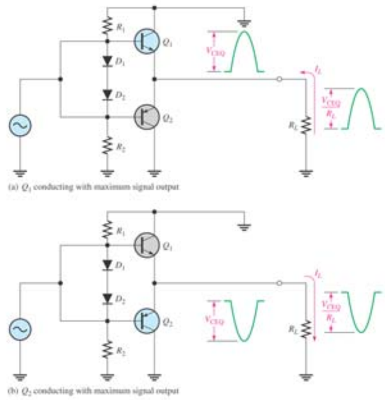
DC Operation of Bipolar Junction Transistors (BJTs)

- The third configuration is the **common-base** (CB)
  - the base is the grounded (common) terminal
  - the input signal is applied to the emitter
  - output signal is taken off the collector
  - output is in-phase with the input
  - voltage gain is greater than 1
  - current gain is always less than 1

BJT Class B Amplifiers

- When an amplifier is biased such that it operates in the linear region for 180° of the input cycle and is in cutoff for 180°, it is a class B amplifier
  - A class B amplifier is more efficient than a class A
- In order to get a linear reproduction of the input waveform, the class B amplifier is configured in a push-pull arrangement
  - The transistors in a class B amplifier must be biased above cutoff to eliminate crossover distortion

BJT Class B Amplifiers



The BJT as a Switch

- When used as an electronic switch, a transistor normally is operated alternately in cutoff and saturation
  - A transistor is in cutoff when the base-emitter junction is not forward-biased. V_{CE} is approximately equal to V_{CC}
  - When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated

DC Operation of Field-Effect Transistors (FETs)

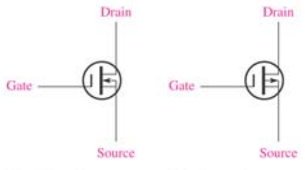
- The junction **field-effect transistor (JFET)** is operated with a reverse biased junction to control current in a channel
  - the device is identified by the material in the channel, either n-channel or p-channel
- When shown in a drawing, the **drain** is at the upper end and the **source** is at the lower end
- The channel is formed between the gate regions
  - controlling the reverse biasing voltage on the gate-to-source junction controls the channel size and the drain current, I_D

DC Operation of Field-Effect Transistors (FETs)

- The **metal-oxide semiconductor field-effect transistor (MOSFET)** differs from the JFET in that it has no *pn* junction; instead, the gate is insulated from the channel by a silicon dioxide (SiO_2) layer
- MOSFETs may be depletion type (D-MOSFET) or enhancement type (E-MOSFET)
  - D-MOSFETs have a physical channel between Drain and Source, with no voltage applied to the Gate
  - E-MOSFETS have no physical Drain-Source channel

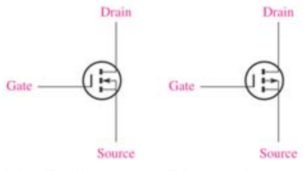
DC Operation of Field-Effect Transistors (FETs)

- D-MOSFET
  - Channel may be enhanced or restricted by gate voltage



(a) *n* channel (b) *p* channel

- E-MOSFET
  - Channel is created by gate voltage



(a) *n* channel (b) *p* channel

FET Amplifiers

- Voltage gain of a FET is determined by the **transconductance** (g_m) with units of Siemens (S)

$$g_m = I_d / V_g$$

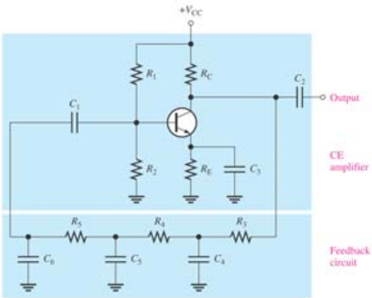
- Common source (CS) JFET amplifiers may be self-biased, with a gate voltage at 0 V dc
- The D-MOSFET may also be zero-biased
- The E-MOSFET requires a voltage-divider-bias
- All FET's provide extremely high input resistance

Feedback Oscillators

- An oscillator is a circuit that produces a repetitive waveform on its output with only the dc supply voltage as an input
- Feedback Oscillator operation is based on the principle of positive feedback
  - The phase shift around the feedback loop must be 0°
  - Stead-state closed loop gain must be 1 (**unity gain**)
  - For oscillation to begin, the voltage gain around the positive feedback loop must be greater than 1, so the amplitude can build to the desired level

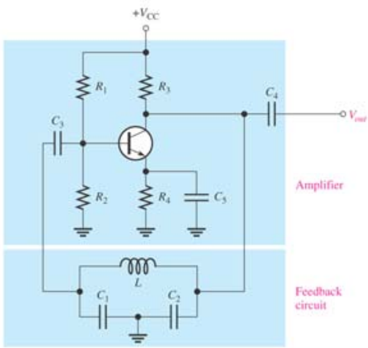
Feedback Oscillators

- The RC Oscillator
  - The three RC lag networks have a total phase shift of 180°
  - The CE transistor contributes another 180° phase shift
  - Overall gain of the circuit is 1 at the frequency of oscillation



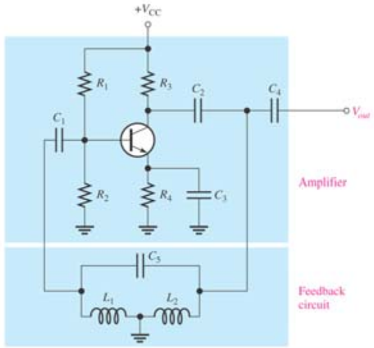
Feedback Oscillators

- The Colpitts Oscillator
  - Uses an LC in the feedback loop to provide the necessary phase shift, and to act as a filter that passes only the desired frequency of oscillation
  - Note the capacitive voltage divider



Feedback Oscillators

- The Hartley Oscillator
  - Similar to the Colpitts, except that the feedback circuit consists of two inductors and one capacitor
  - Note the inductive voltage divider

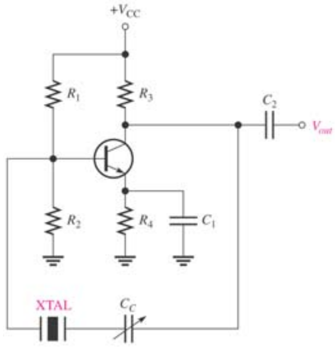


Feedback Oscillators

- The Crystal Oscillator uses a quartz crystal as the resonant tank circuit
  - Crystal oscillators offer excellent frequency stability compared to most other oscillators
- Quartz exhibits a property called the piezoelectric effect
  - When a changing mechanical stress is applied, a voltage is produced across the crystal
  - When a voltage is applied across the crystal, it vibrates at the frequency of the applied voltage

Feedback Oscillators

- In a series resonant tank circuit, the impedance of the crystal is a minimum at the series resonant frequency, thus providing maximum feedback
  - Capacitor C_C is used to "pull" the resonant frequency slightly



(a)

Summary

- A bipolar junction transistor (BJT) consists of three regions: emitter, base, and collector. A terminal is connected to each of the three regions
- The three regions of a BJT are separated by two *pn* junctions
- The two types of bipolar transistor are the *npn* and the *pnp*
- The term *bipolar* refers to two types of current: electron current and hole current

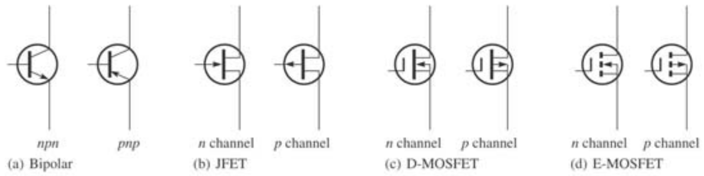
Summary

- A field-effect transistor (FET) has three regions: source, drain, and gate. A terminal is connected to each of the three regions
- A junction field-effect transistor (JFET) is operated with a reverse-biased gate-to-source *pn* junction
- JFET current between the drain and source is through a channel whose width is controlled by the amount of reverse bias on the gate-source junction

Summary

- The two types of JFETs are *n*-channel and *p*-channel
- Metal-oxide semiconductor field-effect transistors (MOSFETs) differ from JFETs in that the gate of a MOSFET is insulated from the channel
- The D-MOSFET has a physical channel between the drain and the source
- The E-MOSFET has no physical channel

Summary



- Two main types of BJT amplifier configurations are the common-emitter (CE) and common collector (CC). A third type is the common base
- Two main types of FET amplifier configurations are common-source (CS) and common-drain (CD)

Summary

- The class A amplifier conducts for the entire 360° of the input cycle and is normally used for low-power applications
- The class B amplifier conducts for 180° of the input cycle and is normally used for high-power applications
- Sinusoidal oscillators operate with positive feedback

Summary

- The two conditions for positive feedback are that the phase shift around the feedback loop must be 0° and the voltage gain around the feedback loop must be at least 1
- For initial start-up in a feedback oscillator, the voltage gain around the feedback loop must be greater than 1
- The feedback signal in a Colpitts oscillator is derived from a capacitive voltage divider in the LC circuit

Summary

- The feedback signal in a Hartley oscillator is derived from an inductive voltage divider in the LC circuit
- Crystal oscillators are the most stable type