Chapter 6
Electronic Circuits

Amplifiers

- Any circuit that increases the strength of a signal – voltage, current, or power.
  - Input voltages from microvolts to hundreds of volts.
  - Output powers from billionths of a watt to thousands of watts.

Amplifiers

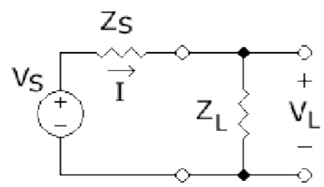
- Definitions.
  - Driver: Circuit that supplies the input signal to the amplifier.
  - Load: Circuit that receives the amplifier's output signal.
  - Final Amplifier: Last amplifier stage in a transmitter.

Amplifiers

- Amplifier Gain.
  - Ratio of output signal to input signal.
    - Voltage gain = V_{OUT} / V_{IN}
    - Current gain = I_{OUT} / I_{IN}
    - Power gain = P_{OUT} / P_{IN}
  - Can be expressed as simple ratio.
    - e.g. – Voltage gain = 10
  - Can be expressed in decibels.
    - e.g. – Power gain = 10 dB

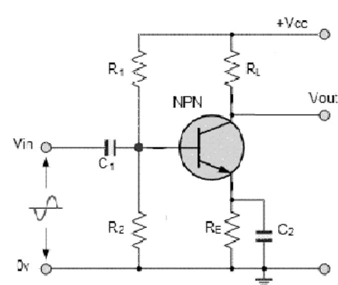
Amplifiers

- Input and Output Impedances.
  - Input impedance is load seen by driver.
  - Output Impedance is source impedance.
  - Maximum power transfer occurs when the load impedance equals the source impedance.



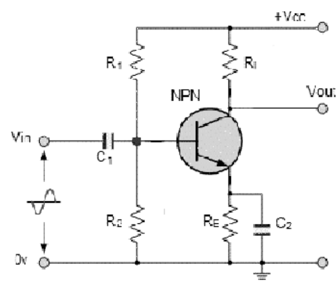
Amplifiers

- Discrete Device Amplifiers
  - Common emitter.
    - Most common amplifier type.
    - Provides both voltage gain and current gain.
    - Input & output voltages 180° out of phase.
    - Fairly high input impedance.
    - Output impedance depends on R_L.



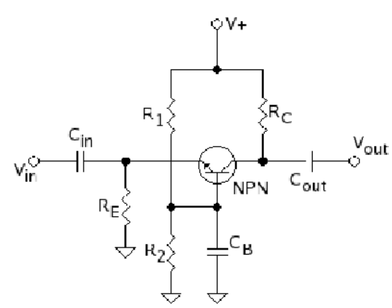
Amplifiers

- Discrete Device Amplifiers
  - Common emitter.
    - R_1 & R_2 provide fixed bias.
    - R_E provides bias point stability.
      - a.k.a. – Self-bias.
      - Thermal runaway.
    - C_2 allows maximum AC signal gain.



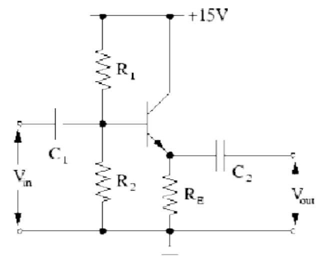
Amplifiers

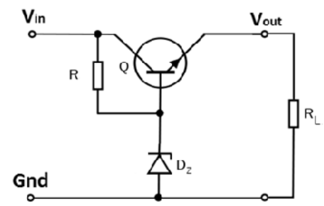
- Discrete Device Amplifiers
  - Common base.
    - Provides voltage gain.
    - Current gain < 1.
    - Input & output voltages in phase.
    - Low input impedance.
    - High output impedance.



Amplifiers

- Discrete Device Amplifiers
  - Common collector.
    - a.k.a. - Emitter follower.
    - Provides current gain.
    - Voltage gain < 1.
    - Input & output voltages in phase.
    - Fairly high input impedance.
    - Low output impedance.
    - Linear voltage regulator.

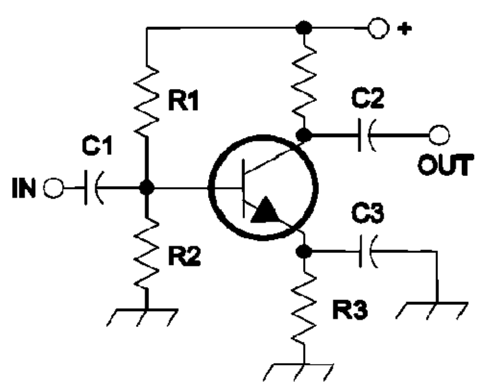




E7B10 -- In Figure E7-1, what is the purpose of R1 and R2?

A. Load resistors
B. Fixed bias
C. Self bias
D. Feedback

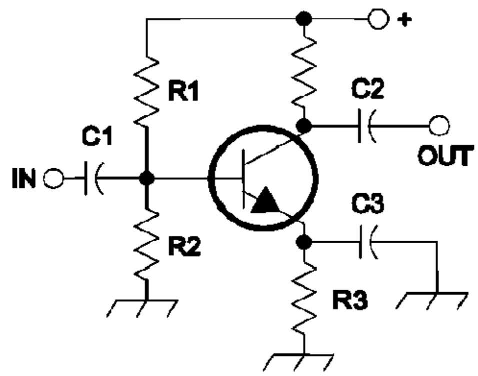
Figure E7-1



E7B11 -- In Figure E7-1, what is the purpose of R3?

A. Fixed bias
B. Emitter bypass
C. Output load resistor
➡ D. Self bias

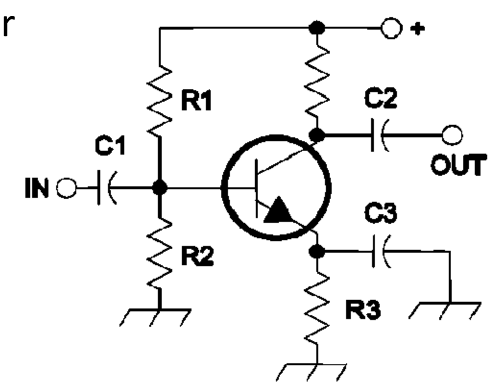
Figure E7-1



E7B12 -- What type of amplifier circuit is shown in Figure E7-1?

A. Common base
B. Common collector
➡ C. Common emitter
D. Emitter follower

Figure E7-1



E7B13 -- In Figure E7-2, what is the purpose of R?

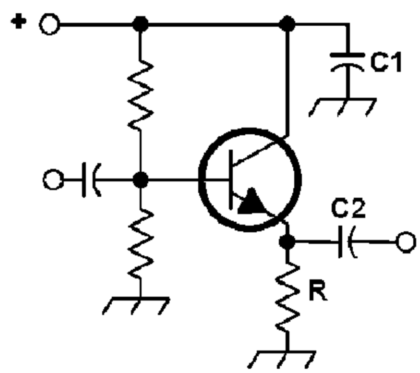
➡A. Emitter load

B. Fixed bias

C. Collector load

D. Voltage regulation

Figure E7-2



E7B15 -- What is one way to prevent thermal runaway in a bipolar transistor amplifier?

A. Neutralization

B. Select transistors with high beta

➡C. Use a resistor in series with the emitter

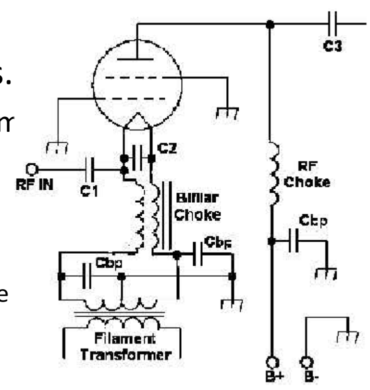
D. All of these choices are correct

Amplifiers

- Vacuum Tube Amplifiers
  - Each type of transistor amplifier circuit has a corresponding vacuum tube amplifier circuit.
    - Common-Emitter ←→ Common-Cathode.
    - Common-Base ←→ Grounded-Grid.
    - Common-Collector ←→ Common-Anode.
      - Emitter Follower ←→ Cathode Follower.

Amplifiers

- Vacuum Tube Amplifiers.
  - Grounded-Grid Amplifiers.
    - Most common RF power am
    - Stable.
      - Easier to neutralize.
    - Low input impedance.
      - Little or no input impedance



E7B18 -- Which of the following is a characteristic of a grounded-grid amplifier?

A. High power gain

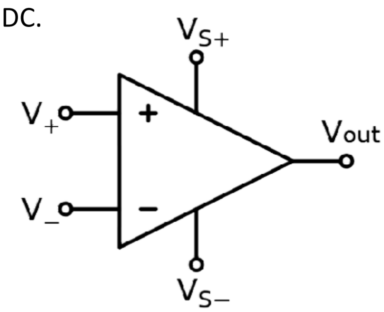
B. High filament voltage

➡ C. Low input impedance

D. Low bandwidth

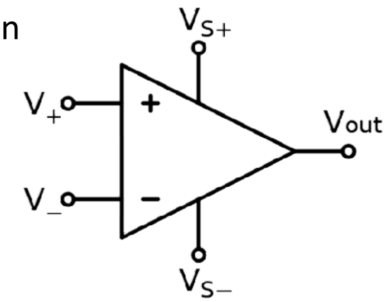
Amplifiers

- Operational Amplifier (Op-Amp)
  - High-gain, direct-coupled, differential amplifier.
    - Differential input → Input signal is difference between inverting & non-inverting inputs.
    - Direct-coupled → Will amplify DC.
  - Ideal operational amplifier
    - Infinite input impedance.
    - Zero output impedance.
    - Infinite gain.
    - Flat frequency response.
    - Zero offset voltage.
      - 0 V_{IN} → 0 V_{OUT}



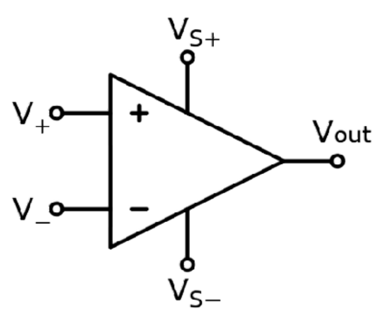
Amplifiers

- Operational Amplifier (Op-Amp)
  - Circuit characteristics totally determined by external components.
  - In closed-loop configuration
    - Input voltage = 0.
    - Input current = 0.



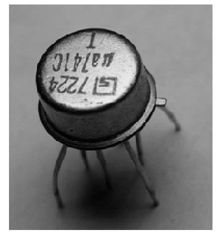
Amplifiers

- Operational Amplifier (Op-Amp)
  - Operational amplifier specifications.
    - Open-loop gain.
    - Gain-Bandwidth.
    - Slew rate.
    - Input offset voltage.
      - Input voltage in closed-loop.
    - Input impedance.
    - Output impedance.



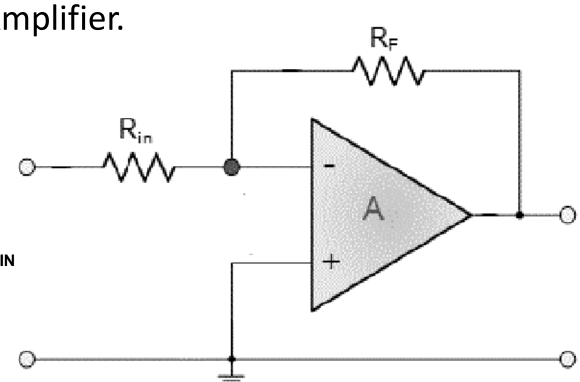
Amplifiers

- Operational Amplifier (Op-Amp)
  - Practical operational amplifier.
    - Differential input.
    - Direct-coupled.
    - Very high input impedance.
    - Very low output impedance.
    - Very high voltage gain.
      - Up to 120 dB.
    - Wide bandwidth.



Amplifiers

- Operational Amplifier (Op-Amp)
  - Inverting Amplifier.

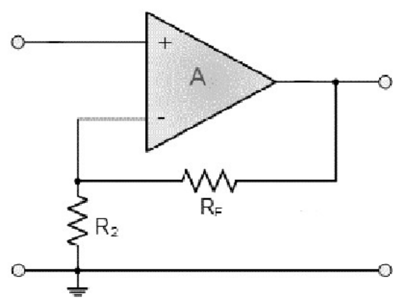


Gain = - R_F / R_{IN}

Amplifiers

- Operational Amplifier (Op-Amp)
  - Non-inverting Amplifier.

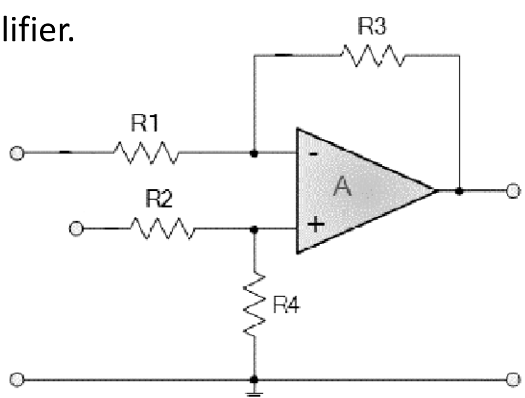
Gain = $(R_F + R_2) / R_2$



Amplifiers

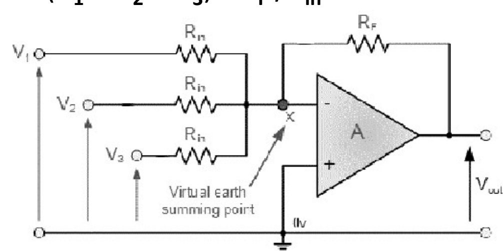
- Operational Amplifier (Op-Amp)
  - Differential Amplifier.

Gain = $(R_3 + R_1) / R_1$
or
Gain = $(R_4 + R_2) / R_2$
where: $R_1 = R_2$ and $R_3 = R_4$



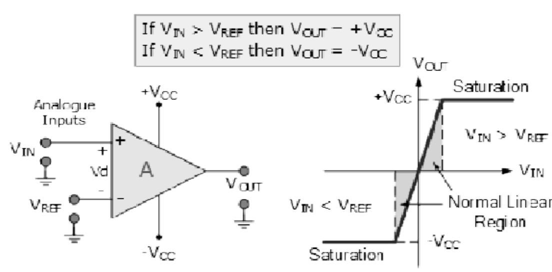
Amplifiers

- Operational Amplifier (Op-Amp)
  - Summing Amplifier.
    - $V_{out} = -((V_1 \times R_F / R_{in}) + (V_2 \times R_F / R_{in}) + (V_3 \times R_F / R_{in}))$
    - $V_{out} = -(V_1 + V_2 + V_3) \times R_F / R_{in}$



Amplifiers

- Operational Amplifier (Op-Amp)
  - Voltage Comparator.
    - Compares 2 voltages.
    - Apply reference voltage to one input.

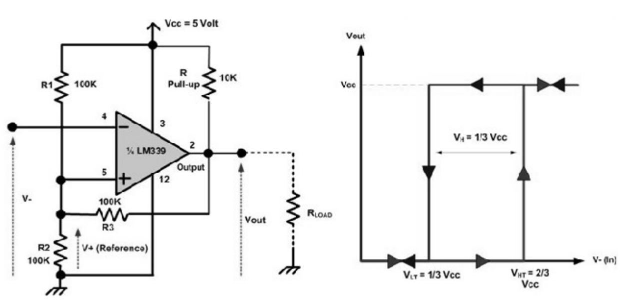


Amplifiers

- Operational Amplifier (Op-Amp)
  - Voltage Comparator.
    - If input voltage is close to the threshold, minor variations (noise) can cause output to rapidly & randomly change between states.
      - This is called “chattering”.
    - Adding “hysteresis” eliminates chattering.
      - Output changes state slightly above the threshold on the way up & slightly below the threshold on the way down.

Amplifiers

- Operational Amplifier (Op-Amp)
  - Voltage Comparator.
    - Adding feedback resistors provides hysteresis.



E6C01 -- What is the function of hysteresis in a comparator?

➡ A. To prevent input noise from causing unstable output signals

B. To allow the comparator to be used with AC input signal

C. To cause the output to change states continually

D. To increase the sensitivity

E6C02 -- What happens when the level of a comparator's input signal crosses the threshold?

A. The IC input can be damaged

➡ B. The comparator changes its output state

C. The comparator enters latch-up

D. The feedback loop becomes unstable

E7G01 -- What is the typical output impedance of an integrated circuit op-amp?

➡ A. Very low
B. Very high
C. 100 ohms
D. 1000 ohms

E7G03 -- What is the typical intput impedance of an integrated circuit op-amp?

A. 100 ohms
B. 1000 ohms
C. Very low
➡ D. Very high

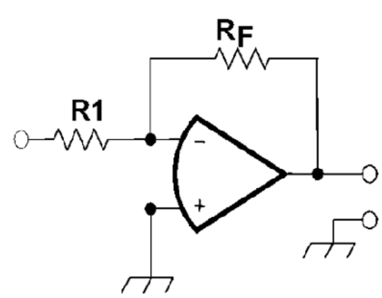
E7G04 -- What is meant by the term op-amp input offset voltage?

A. The output voltage of the op-amp minus its input voltage
B. The difference between the output voltage of the op-amp and the input voltage required in the immediately following stage
➡C. The differential input voltage needed to bring the open-loop output voltage to zero
D. The potential between the amplifier input terminals of the op-amp in an open-loop condition

E7G07 -- What magnitude of voltage gain can be expected from the circuit in Figure E7-4 when R1 is 10 ohms and RF is 470 ohms?

A. 0.21
B. 94
➡C. 47
D. 24

Figure E7-4



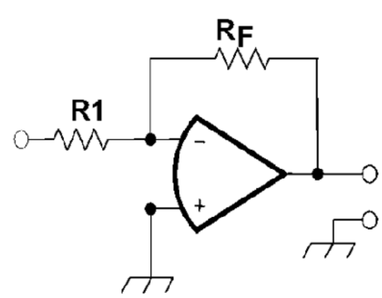
E7G08 -- How does the gain of an ideal operational amplifier vary with frequency?

A. It increases linearly with increasing frequency
B. It decreases linearly with increasing frequency
C. It decreases logarithmically with increasing frequency
➡ D. It does not vary with frequency

E7G09 -- What will be the output voltage of the circuit shown in Figure E7-4 if R1 is 1000 ohms, RF is 10,000 ohms, and 0.23 volts dc is applied to the input?

A. 0.23 volts
B. 2.3 volts
C. -0.23 volts
➡ D. -2.3 volts

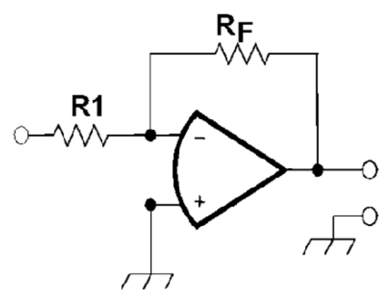
Figure E7-4



E7G10 -- What absolute voltage gain can be expected from the circuit in Figure E7-4 when R1 is 1800 ohms and RF is 68 kilohms?

A. 1
B. 0.03
➡C. 38
D. 76

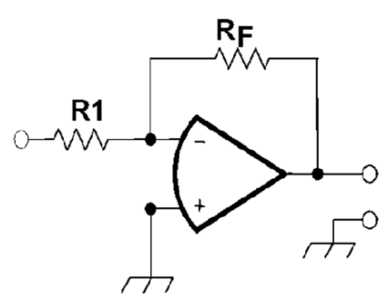
Figure E7-4



E7G11 -- What absolute voltage gain can be expected from the circuit in Figure E7-4 when R1 is 3300 ohms and RF is 47 kilohms?

A. 28
➡B. 14
C. 7
D. 0.07

Figure E7-4



E7G12 -- What is an integrated circuit operational amplifier?

➡ A. A high-gain, direct-coupled differential amplifier with very high input impedance and very low output impedance

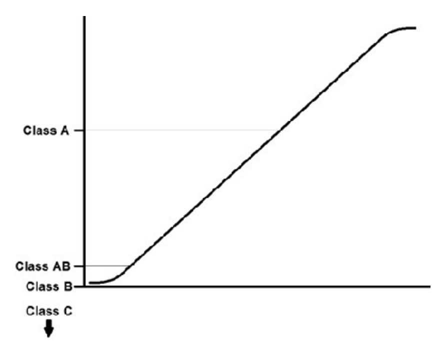
B. A digital audio amplifier whose characteristics are determined by components external to the amplifier

C. An amplifier used to increase the average output of frequency modulated amateur signals to the legal limit

D. A RF amplifier used in the UHF and microwave regions

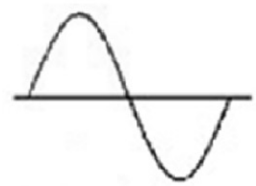
Amplifiers

- Amplifier Load Line.
  - Output vs Input
    - Cutoff Region
    - Linear Region.
    - Saturation Region.



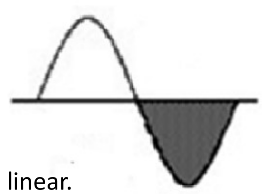
Amplifiers

- Amplifier Classes.
  - Class A
    - On for 360°
    - Best linearity.
    - Least efficient. (25%-30%)



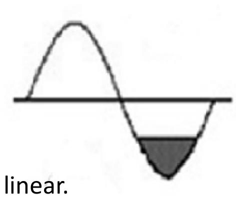
Amplifiers

- Amplifier Classes.
  - Class B
    - On for 180°
    - Non-Linear (if AF).
      - 2 devices in push-pull configuration is linear.
    - Linear (if RF).
      - Flywheel action of tank circuit provides other half of cycle.
    - More efficient. (Up to 60%)



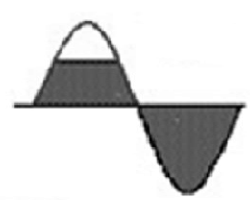
Amplifiers

- Amplifier Classes.
  - Class AB
    - On for >180° but < 360°
    - Non-Linear (if AF).
      - 2 devices in push-pull configuration is linear.
    - Linear (if RF).
      - Flywheel action of tank circuit provides other half of cycle.
    - Compromise between classes A & B



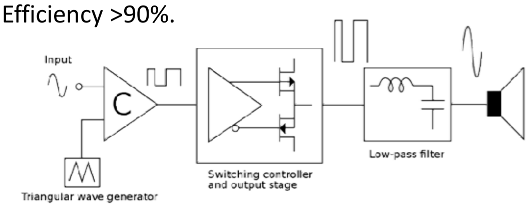
Amplifiers

- Amplifier Classes.
  - Class C
    - On for <180°
    - Highly non-linear.
    - Most efficient. (Up to 80%)



Amplifiers

- Amplifier Classes.
  - Class D (Switching or Switch Mode)
    - Used for audio amplifiers.
    - Uses switching techniques to achieve high efficiency.
      - Switching speed well above highest frequency to be amplified.
      - Efficiency >90%.



Amplifiers

- Distortion and Intermodulation.
  - Selecting amplifier class.
    - For audio, AM or SSB, a linear amplifier is required.
    - For CW or FM, a non-linear amplifier may be used.

Amplifiers

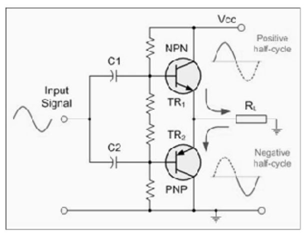
- Distortion and Intermodulation.
  - Selecting amplifier class.
    - For best linearity & lowest efficiency, use Class A.
      - Low-level stages.
    - For a good compromise between linearity & efficiency, use Class AB.
      - Power amplifiers.

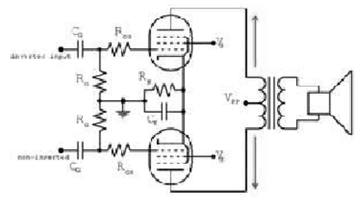
Amplifiers

- Distortion and Intermodulation.
  - Selecting amplifier class.
    - For highest efficiency or intentional harmonics, use Class C.
      - Frequency multiplier stages.
      - CW transmitters.
      - FM transmitters & receivers.

Amplifiers

- Distortion and Intermodulation.
  - Selecting amplifier class.
    - Class B push-pull circuits.
      - Audio power amplifiers.
      - Even harmonics are reduced.





Amplifiers

- Distortion and Intermodulation.
  - Distortion
    - Non-linearity results in distortion.
    - ALL physical components have non-linearity.
    - Distortion results in harmonics.
    - Can have low distortion or high efficiency, but not both.

Amplifiers

- Distortion and Intermodulation.
  - Intermodulation.
    - 2 or more signals mixing together to produce other frequencies.
      - $F_{IMD} = (A \times F_1) \pm (B \times F_2)$.
      - If A+B is odd, then odd-order intermodulation product.
        - F_{imd} is near fundamental or odd harmonics of F_1 & F_2.
      - If A+B is even then even-order intermodulation product.
        - F_{imd} is near even harmonics of F_1 & F_2.
    - Since odd-order IMD products are close to desired frequency, spurious signals can be transmitted.

Amplifiers

- Distortion and Intermodulation.
  - Tuned amplifiers.
    - Power amplifiers are a compromise between linearity & efficiency.
    - Tuned output circuit acts like a “flywheel”, minimizing effects of distortion.
      - Single-ended class B & AB amplifiers.

E7B01 -- For what portion of a signal cycle does a Class AB amplifier operate?

➡ A. More than 180 degrees but less than 360 degrees

B. Exactly 180 degrees

C. The entire cycle

D. Less than 180 degrees

E7B02 -- What is a Class D amplifier?

➡ A. A type of amplifier that uses switching technology to achieve high efficiency

B. A low power amplifier using a differential amplifier for improved linearity

C. An amplifier using drift-mode FETs for high efficiency

D. A frequency doubling amplifier

E7B03 -- Which of the following forms the output of a class D amplifier circuit?

➡ A. A low-pass filter to remove switching signal components
B. A high-pass filter to compensate for low gain at low frequencies
C. A matched load resistor to prevent damage by switching transients
D. A temperature compensating load resistor to improve linearity

E7B04 -- Where on the load line of a Class A common emitter amplifier would bias normally be set?

➡ A. Approximately half-way between saturation and cutoff
B. Where the load line intersects the voltage axis
C. At a point where the bias resistor equals the load resistor
D. At a point where the load line intersects the zero bias current curve

E7B06 -- Which of the following amplifier types reduces or eliminates even-order harmonics?

A. Push-push
➡ B. Push-pull
C. Class C
D. Class AB

E7B07 -- Which of the following is a likely result when a Class C amplifier is used to amplify a single-sideband phone signal?

A. Reduced intermodulation products
B. Increased overall intelligibility
C. Signal inversion
➡ D. Signal distortion and excessive bandwidth

E7B14 -- Why are switching amplifiers more efficient than linear amplifiers?

A. Switching amplifiers operate at higher voltages
B. The power transistor is at saturation or cut off most of the time, resulting in low power dissipation
C. Linear amplifiers have high gain resulting in higher harmonic content
D. Switching amplifiers use push-pull circuits

E7B16 -- What is the effect of intermodulation products in a linear power amplifier?

A. Transmission of spurious signals
B. Creation of parasitic oscillations
C. Low efficiency
D. All of these choices are correct

E7B17 -- Why are odd-order rather than even-order intermodulation distortion products of concern in linear power amplifiers?

➡ A. Because they are relatively close in frequency to the desired signal
B. Because they are relatively far in frequency from the desired signal
C. Because they invert the sidebands causing distortion
D. Because they maintain the sidebands, thus causing multiple duplicate signals

Amplifiers

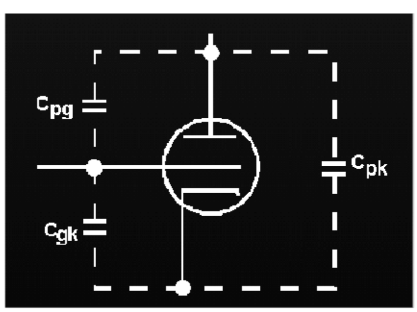
- Instability and Parasitic Oscillation.
  - Amplifier stability.
    - Excessive gain or undesired positive feedback can cause an amplifier to oscillate.
    - Can occur in any amplifier stage, not just power amplifiers.
    - Can result in:
      - Increased noise figure in receiver.
      - Spurious radiations.
      - Excessive heating.

Amplifiers

- Instability and Parasitic Oscillation.
  - Neutralization.
    - Inter-electrode capacitances in amplifying device and/or stray capacitances in associated circuitry can cause an amplifier to oscillate at the frequency of operation.
    - Oscillation can be prevented by “neutralizing” the amplifier.
      - Feed small amount of signal back to input out-of-phase.

Amplifiers

- Instability and Parasitic Oscillation.
  - Neutralization.

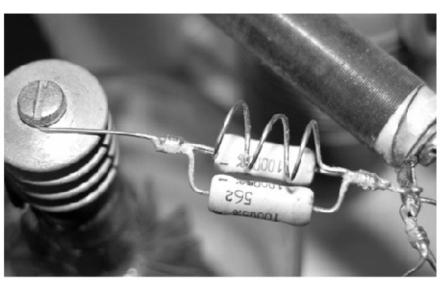


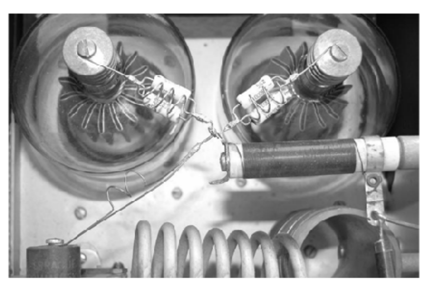
Amplifiers

- Instability and Parasitic Oscillation.
  - Parasitic oscillation.
    - Not related to operating frequency.
    - Caused by resonances in surrounding circuitry.
    - Typically at VHF or UHF frequencies.
    - Parasitic oscillations in HF vacuum tube amplifiers are eliminated by adding parasitic suppressors to the plate or grid leads.
      - Coil in parallel with resistor.

Amplifiers

- Instability and Parasitic Oscillation.
  - Parasitic suppressor.





Amplifiers

- Instability and Parasitic Oscillation.
  - Parasitic suppressor.

E7B05 -- What can be done to prevent unwanted oscillations in an RF power amplifier?

A. Tune the stage for maximum SWR

B. Tune both the input and output for maximum power

➡ C. Install parasitic suppressors and/or neutralize the stage

D. Use a phase inverter in the output filter

E7B08 -- How can an RF power amplifier be neutralized?

A. By increasing the driving power

B. By reducing the driving power

➡ C. By feeding a 180-degree out-of-phase portion of the output back to the input

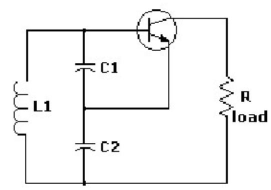
D. By feeding an in-phase component of the output back to the input

Signal Processing

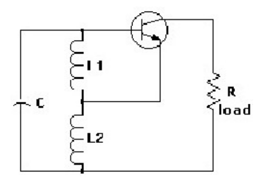
- Oscillator Circuits & Characteristics.
  - Generates sine wave.
  - Amplifier with positive feedback.
    - A_V = Amplifier voltage gain.
    - β = Feedback ratio.
    - Loop Gain = $A_V \times \beta$
    - If loop gain > 1 and feedback signal is in phase, circuit will oscillate.
    - L-C circuit acts as a filter, restricting feedback to resonant frequency.

Signal Processing

- Oscillator Circuits & Characteristics.
  - Colpitts oscillator.
    - Tapped capacitance.

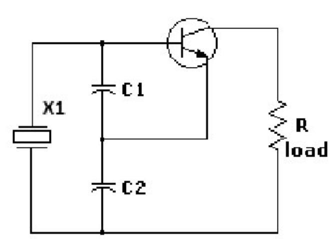


  - Hartley oscillator.
    - Tapped inductance.



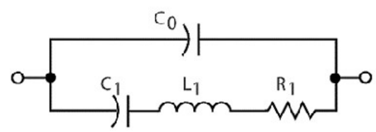
Signal Processing

- Oscillator Circuits & Characteristics.
  - Pierce oscillator.
    - Colpitts oscillator with inductor replaced with a quartz crystal.



Signal Processing

- Oscillator Circuits & Characteristics.
  - Crystals.
    - Equivalent circuit.
      - C_1 = Motional capacitance
      - L_1 = Motional inductance
      - R_1 = Loss resistance
      - C_0 = Electrode & stray capacitance
    - Designed to operate with a specified parallel capacitance.



Signal Processing

- Oscillator Circuits & Characteristics.
  - Variable-frequency oscillator.
    - Make either L or C adjustable.
      - Usually a Colpitts oscillator with adjustable capacitor.
    - Not as stable.

Signal Processing

- Oscillator Circuits & Characteristics.
  - Oscillator stability.
    - Oscillator frequency can change with variations in power supply voltage, loading, temperature, and other factors.
    - Increased stability can be achieved by using:
      - GPS signals.
      - Rubidium oscillators.
      - Temperature-stabilized dielectric resonators.

Signal Processing

- Oscillator Circuits & Characteristics
  - Microphonics & Thermal Drift.
    - Physical changes in the arrangement of the components of an oscillator can effect frequency.
      - Moving components changes stray capacitances.
      - Vibrations, such as the impact of sound waves, can cause changes in physical arrangement of components.
      - Effect is known as “microphonics”.
      - Reduce microphonics by mechanically isolating oscillator from rest of equipment.
        - Shock absorbers, etc.

Signal Processing

- Oscillator Circuits & Characteristics
  - Microphonics & Thermal Drift.
    - Changes in ambient temperature can cause frequency to change.
      - Use components that are not susceptible to value changes with changes in temperature.
        - NPO capacitors, etc.
      - Provide oscillator (or crystal) with a non-changing temperature.
        - Crystal ovens.

E6D02 -- What is the equivalent circuit of a quartz crystal?

➡ A. Motional capacitance, motional inductance, and loss resistance in series, all in parallel with a shunt capacitor representing electrode and stray capacitance

B. Motional capacitance, motional inductance, loss resistance, and a capacitor representing electrode and stray capacitance all in parallel

C. Motional capacitance, motional inductance, loss resistance, and a capacitor representing electrode and stray capacitance all in series

D. Motional inductance and loss resistance in series, paralleled with motional capacitance and a capacitor representing electrode and stray capacitance

E6E03 -- Which of the following is an aspect of the piezoelectric effect?

➡ A. Mechanical deformation of material by the application of a voltage

B. Mechanical deformation of material by the application of a magnetic field

C. Generation of electrical energy in the presence of light

D. Increased conductivity in the presence of light

E7H01 -- What are three oscillator circuits used in Amateur Radio equipment?

A. Taft, Pierce and negative feedback

B. Pierce, Fenner and Beane

C. Taft, Hartley and Pierce

➡ D. Colpitts, Hartley and Pierce

E7H02 -- Which describes a microphonic?

A. An IC used for amplifying microphone signals
B. Distortion caused by RF pickup on the microphone cable
➡ C. Changes in oscillator frequency due to mechanical vibration
D. Excess loading of the microphone by an oscillator

E7H03 -- How is positive feedback supplied in a Hartley oscillator?

➡ A. Through a tapped coil
B. Through a capacitive divider
C. Through link coupling
D. Through a neutralizing capacitor

E7H04 -- How is positive feedback supplied in a Colpitts oscillator?

A. Through a tapped coil
B. Through link coupling
➡ C. Through a capacitive divider
D. Through a neutralizing capacitor

E7H05 -- How is positive feedback supplied in a Pierce oscillator?

A. Through a tapped coil
B. Through link coupling
C. Through a neutralizing capacitor
➡ D. Through a quartz crystal

E7H06 -- Which of the following oscillator circuits are commonly used in VFOs?

A. Pierce and Zener
➡ B. Colpitts and Hartley
C. Armstrong and deForest
D. Negative feedback and balanced feedback

E7H07 -- How can an oscillator's microphonic responses be reduced?

A. Use of NP0 capacitors
B. Eliminating noise on the oscillator's power supply
C. Using the oscillator only for CW and digital signals
➡ D. Mechanically isolating the oscillator circuitry from its enclosure

E7H08 -- Which of the following components can be used to reduce thermal drift in crystal oscillators?

➡ A. NP0 capacitors
B. Toroidal inductors
C. Wirewound resistors
D. Non-inductive resistors

E7H12 -- Which of the following must be done to insure that a crystal oscillator provides the frequency specified by the crystal manufacturer?

A. Provide the crystal with a specified parallel inductance
➡ B. Provide the crystal with a specified parallel capacitance
C. Bias the crystal at a specified voltage
D. Bias the crystal at a specified current

E7H13 -- Which of the following is a technique for providing highly accurate and stable oscillators needed for microwave transmission and reception?

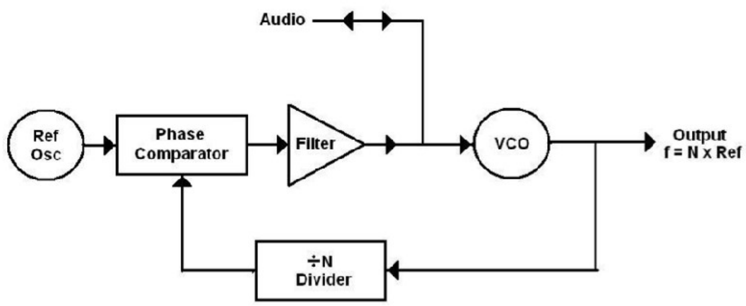
A. Use a GPS signal reference
B. Use a rubidium stabilized reference oscillator
C. Use a temperature-controlled high Q dielectric resonator
➡ D. All of these choices are correct

Signal Processing

- Frequency Synthesis
  - The use of frequency synthesis provides the capabilities of a variable frequency oscillator (VFO) but with the stability of a crystal oscillator (XO).
    - Virtually **ALL** modern equipment uses frequency synthesizers rather than VFO's to determine operating frequency.
  - Two primary types of frequency synthesizers:
    - Phase-locked loop (PLL).
    - Direct digital synthesis (DDS).

Signal Processing

- Frequency Synthesis
  - Phase-Locked Loop (PLL).

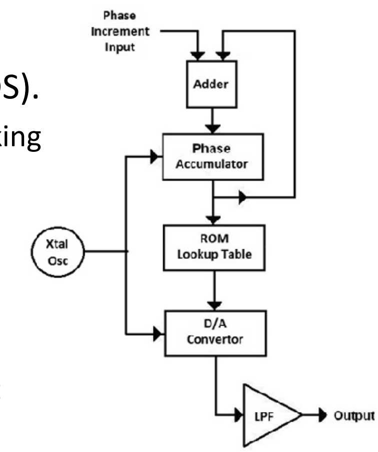


Signal Processing

- Frequency Synthesis
  - Phase-Locked Loop (PLL).
    - Servo loop
      - Error-detecting circuit with negative feedback.
    - Can do FM modulation & demodulation.
    - Capture range – Range of frequencies over which PLL can achieve lock.
    - Spectral impurities are mainly broadband phase noise.
    - PLL has been replaced in modern designs by direct digital synthesis.

Signal Processing

- Frequency Synthesis
  - Direct Digital Synthesis (DDS).
    - Generates sine wave by looking up values in a table.
    - Changing phase increment changes frequency.
    - Increase tuning range by adding PLL.
    - No phase noise, but spurs at discrete frequencies.



E7H09 -- What type of frequency synthesizer circuit uses a phase accumulator, lookup table, digital to analog converter and a low-pass anti-alias filter?

A. A direct digital synthesizer

B. A hybrid synthesizer

C. A phase locked loop synthesizer

D. A diode-switching matrix synthesizer

E7H10 -- What information is contained in the lookup table of a direct digital frequency synthesizer?

A. The phase relationship between a reference oscillator and the output waveform

➡ B. The amplitude values that represent a sine-wave output

C. The phase relationship between a voltage-controlled oscillator and the output waveform

D. The synthesizer frequency limits and frequency values stored in the radio memories

E7H11 -- What are the major spectral impurity components of direct digital synthesizers?

A. Broadband noise

B. Digital conversion noise

➡ C. Spurious signals at discrete frequencies

D. Nyquist limit noise

E7H14 -- What is a phase-locked loop circuit?

A. An electronic servo loop consisting of a ratio detector, reactance modulator, and voltage-controlled oscillator
B. An electronic circuit also known as a monostable multivibrator
➡ C. An electronic servo loop consisting of a phase detector, a low-pass filter, a voltage-controlled oscillator, and a stable reference oscillator
D. An electronic circuit consisting of a precision push-pull amplifier with a differential input

E7H15 -- Which of these functions can be performed by a phase-locked loop?

A. Wide-band AF and RF power amplification
B. Comparison of two digital input signals, digital pulse counter
C. Photovoltaic conversion, optical coupling
➡ D. Frequency synthesis, FM demodulation

Signal Processing

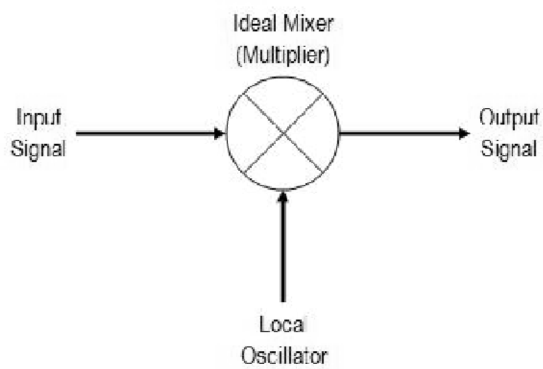
- Mixers
  - Used to change the frequency of a signal.
  - Mathematically multiplies 2 frequencies together, generating 4 output frequencies.
    - $f_1 \times f_2 \rightarrow f_1,\ f_2,\ f_1+f_2,\ f_1-f_2$
  - Superheterodyne receiver.
    - $f_{RF} \times f_{LO} \rightarrow f_{LO} - f_{RF} = f_{IF}$

Signal Processing

- Mixers
  - Only enough pre-amp gain should be used to overcome mixer losses.
  - Excessive input signal can:
    - Overload mixer circuit.
    - Distort signal.
    - Generate spurious mixer products.
  - Operation of a mixer is similar to operation of product detectors & modulators.

Signal Processing

- Mixers

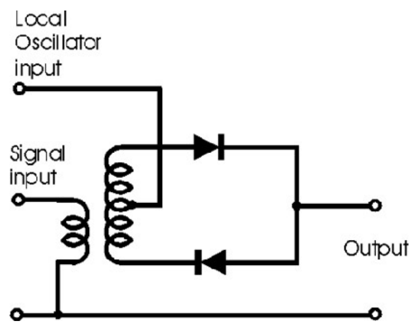


Signal Processing

- Mixers
  - Passive mixers.
    - Uses passive components such as diodes.
    - No amplification.
    - Some conversion loss.
    - Require strong LO signal.
    - Generate noise.

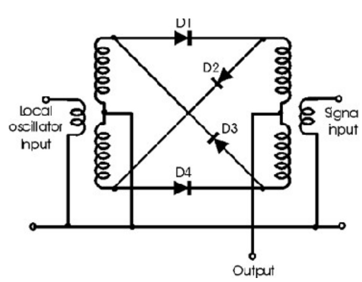
Signal Processing

- Mixers
  - Single-balanced mixer.



Signal Processing

- Mixers
  - Double-balanced mixer.
    - f_{RF} & f_{LO} are suppressed leaving only sum & difference frequencies.

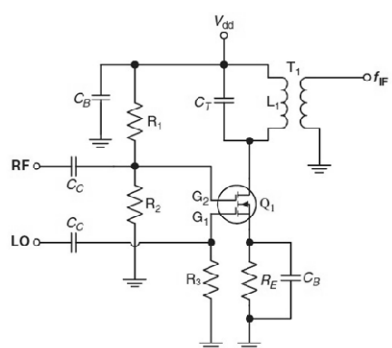


Signal Processing

- Mixers
  - Active mixers.
    - Uses active components such as transistors or FET's.
    - Amplification possible.
    - No conversion loss.
    - Less LO signal needed.
    - Generate less noise.
    - Strong signal handling capability not as good as passive mixers.

Signal Processing

- Mixers
  - Dual-gate MOSFET mixer.



E7E08 -- What are the principal frequencies that appear at the output of a mixer circuit?

A. Two and four times the original frequency
B. The sum, difference and square root of the input frequencies
➡ C. The two input frequencies along with their sum and difference frequencies
D. 1.414 and 0.707 times the input frequency

E7E09 -- What occurs when an excessive amount of signal energy reaches a mixer circuit?

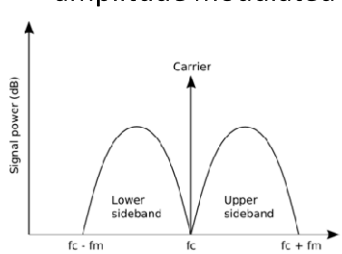
➡ A. Spurious mixer products are generated
B. Mixer blanking occurs
C. Automatic limiting occurs
D. A beat frequency is generated

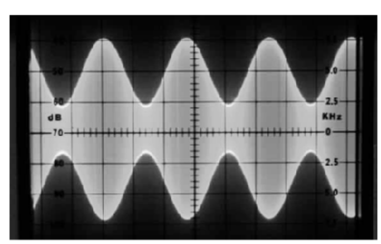
Signal Processing

- Modulation
  - Combining a modulating signal with an RF signal resulting in a signal that can be transmitted.
    - Modulating signal also known as the “baseband” signal.
    - Varying the amplitude of the signal is called amplitude modulation (AM).
    - Varying the frequency or phase of the signal is called angle modulation.
      - Frequency modulation (FM).
      - Phase modulation (PM).

Signal Processing

- Modulators
  - Amplitude modulation.
    - Multiplying (mixing) AF signal & carrier produces amplitude modulated signal.





Signal Processing

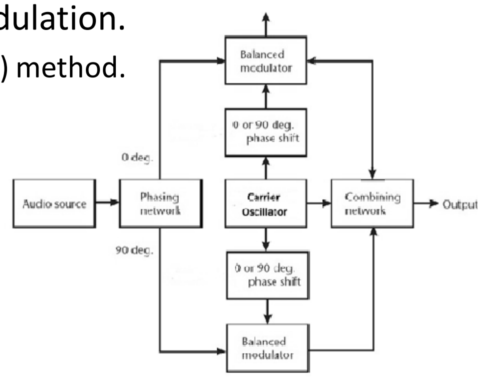
- Modulators
  - Single-sideband modulation.
    - Filter method.
      - Start with AM double-sideband signal & use filters to remove one sideband & the carrier.
      - Better idea – use a balanced modulator (double-balanced mixer) to generate a double-sideband suppressed carrier signal. Then all you have to filter out is the unwanted sideband.

Signal Processing

- Modulators
  - Single-sideband modulation.
    - Phasing (quadrature) method.
      - Generate 2 identical carrier signals, 90° out of phase.
      - Generate 2 identical audio signals, 90° out of phase.
      - Mix these together in a pair of balanced modulators & result is that the carrier & one sideband are canceled out leaving only one sideband.
      - 90° phase shift of a band of audio frequencies difficult to accomplish in hardware, but relatively easy in software.
        - Hilbert-transform filters.
      - Most SDR transmitters use the phasing or quadrature method to generate SSB mathematically.

Signal Processing

- Modulators
  - Single-sideband modulation.
    - Phasing (quadrature) method.



E7E04 -- What is one way a single-sideband phone signal can be generated?

A. By using a balanced modulator followed by a filter

B. By using a reactance modulator followed by a mixer

C. By using a loop modulator followed by a mixer

D. By driving a product detector with a DSB signal

E7E07 -- What is meant by the term baseband in radio communications?

A. The lowest frequency band that the transmitter or receiver covers

➡B. The frequency components present in the modulating signal

C. The unmodulated bandwidth of the transmitted signal

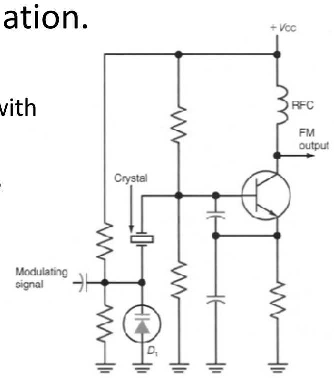
D. The basic oscillator frequency in an FM transmitter that is multiplied to increase the deviation and carrier frequency

Signal Processing

- Modulators
  - Reactance Modulator.
    - A circuit that modulates a signal by varying the reactance of a circuit.
      - Usually by varying the bias voltage of a variable-capacitance diode (varicap).

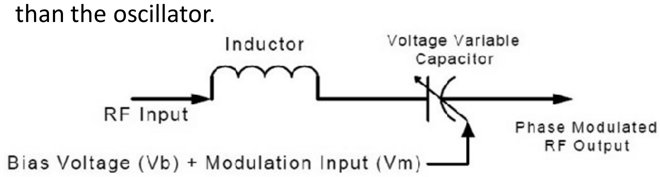
Signal Processing

- Modulators
  - Frequency and phase modulation.
    - Direct FM
      - Frequency deviation constant with modulating frequency.
      - Generated by adding reactance modulator to oscillator circuit.



Signal Processing

- Modulators
  - Frequency and phase modulation.
    - Indirect FM (phase modulation).
      - Frequency deviation increases with increasing modulating frequency.
      - Generated by adding reactance modulator to any stage other than the oscillator.



Signal Processing

- Modulators
  - Pre-Emphasis and De-Emphasis.
    - With FM, deviation is constant regardless of modulating frequency.
    - With PM, deviation increases as modulating frequency increases.
    - In the transmitter, if we amplify the higher frequencies in the modulating signal more than the lower frequencies, we can make an FM signal “look like” a PM signal.
    - This is called “pre-emphasis”.

Signal Processing

- Modulators
  - Pre-Emphasis and De-Emphasis.
    - In the receiver, if we attenuate the higher frequencies in the de-modulated signal with respect to the lower frequencies, we can make a received PM signal “look like” an FM signal.
    - This is called “de-emphasis”.

Signal Processing

- Modulators
  - Pre-Emphasis and De-Emphasis.
    - Using pre-emphasis & de-emphasis yields a better signal-to-noise ratio.
    - A PM transmitter does not need pre-emphasis.
    - An FM receiver with de-emphasis can receive both FM & PM signals.

E7E01 -- Which of the following can be used to generate FM phone emissions?

A. A balanced modulator on the audio amplifier

➡ B. A reactance modulator on the oscillator

C. A reactance modulator on the final amplifier

D. A balanced modulator on the oscillator

E7E02 -- What is the function of a reactance modulator?

A. To produce PM signals by using an electrically variable resistance
B. To produce AM signals by using an electrically variable inductance or capacitance
C. To produce AM signals by using an electrically variable resistance
➡ D. To produce PM signals by using an electrically variable inductance or capacitance

E7E03 -- How does an analog phase modulator function?

A. By varying the tuning of a microphone preamplifier to produce PM signals
B. By varying the tuning of an amplifier tank circuit to produce AM signals
➡ C. By varying the tuning of an amplifier tank circuit to produce PM signals
D. By varying the tuning of a microphone preamplifier to produce AM signals

E7E05 -- What circuit is added to an FM transmitter to boost the higher audio frequencies?

A. A de-emphasis network

B. A heterodyne suppressor

C. An audio prescaler

➡ D. A pre-emphasis network

E7E06 -- Why is de-emphasis commonly used in FM communications receivers?

➡ A. For compatibility with transmitters using phase modulation

B. To reduce impulse noise reception

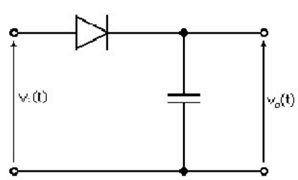
C. For higher efficiency

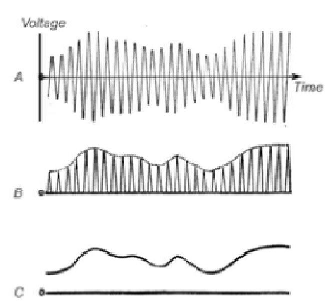
D. To remove third-order distortion products

Break

Signal Processing

- Detectors and Demodulators
  - Detectors.
    - Simplest detector is the diode detector.
      - a.k.a. – Envelope detector.
      - Rectifies & filters RF signal.
      - Demodulates AM signals.





Signal Processing

- Detectors and Demodulators
  - Product Detectors.
    - Actually, a mixer circuit.
    - Multiplies signal with a local oscillator to retrieve the modulating signal.
      - $f_{RF} \times f_{LO} \rightarrow f_{RF} - f_{LO} \rightarrow f_{AF}$
    - Local oscillator sometimes called a "beat frequency oscillator".
      - Simulates the original carrier.
    - Demodulates AM, SSB. & CW signals.

Signal Processing

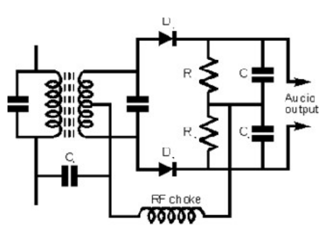
- Detectors and Demodulators
  - Product Detectors.
    - For AM, local oscillator frequency & phase must precisely match AM signal carrier.
    - For SSB, local oscillator frequency must match carrier frequency of suppressed carrier.
    - For CW, local oscillator frequency is offset from signal frequency to produce a sidetone.

Signal Processing

- Detectors and Demodulators
  - Direct Conversion.
    - Local oscillator is at the frequency of the received signal.
    - Requires very stable local oscillator.
    - Many software-defined radios (SDR) typically use a modified direct-conversion technique.
      - Signal is converted to a baseband AF signal for A-to-D conversion & processing.

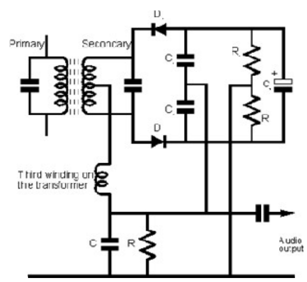
Signal Processing

- Detectors and Demodulators
  - Detecting FM signals.
    - Frequency discriminator.
      - a.k.a. – Foster-Seeley Detector.



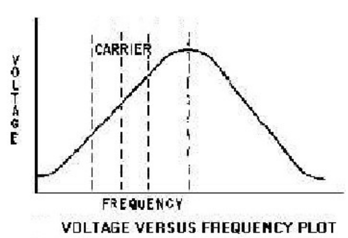
Signal Processing

- Detectors and Demodulators
  - Detecting FM signals.
    - Ratio detector.



Signal Processing

- Detectors and Demodulators
  - Detecting FM signals.
    - Slope detector.
      - Use AM receiver’s selectivity curve to detect FM.



E7E10 -- How does a diode detector function?

➡ A. By rectification and filtering of RF signals
B. By breakdown of the Zener voltage
C. By mixing signals with noise in the transition region of the diode
D. By sensing the change of reactance in the diode with respect to frequency

E7E11 -- Which of the following type of detector is used for demodulating SSB signals?

A. Discriminator
B. Phase detector
➡ C. Product detector
D. Phase comparator

E7E12 -- What is a frequency discriminator stage in a FM receiver?

A. An FM generator circuit
B. A circuit for filtering two closely adjacent signals
C. An automatic band-switching circuit
➡ D. A circuit for detecting FM signals

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Part of virtually all modern transceivers.
  - Allows signal processing difficult or impossible to obtain by analog methods.
  - Digital signals can be regenerated (duplicated) many times without error.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

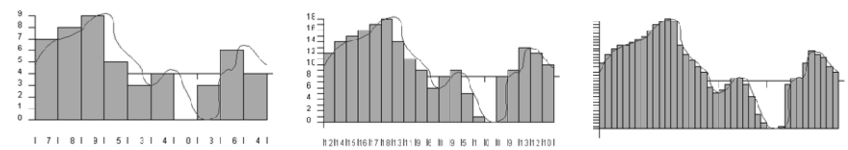
- Digital Signal Processing (DSP)
  - Representation of Numbers.
    - Floating Point.
      - Similar to scientific notation.
      - Greater range of numbers can be handled.
      - Not necessary for DSP since range of numbers limited by precision of ADC.
      - Used in computers.
    - Fixed Point.
      - Fraction <1.
      - Used for most DSP in amateur equipment

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Procedure:
    - Convert analog signal to series of numbers.
    - Process series of numbers mathematically.
    - Convert resulting series of numbers back to analog signal.

Digital Signal Processing (DSP)
Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Analog-to-digital conversion.
    - Sequential sampling.
      - Sample signal at regular intervals (sequential sampling).
      - Convert signal value to a number.
      - Higher sampling rates yields higher accuracy.
      - More “bits” in the number yields higher accuracy



Digital Signal Processing (DSP)
Software-Defined Radio (SDR)

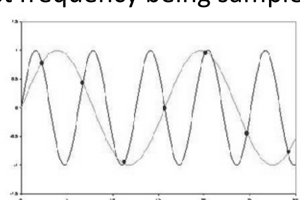
- Digital Signal Processing (DSP)
  - Sine wave, alias sine wave, harmonic sampling.
    - If sample rate is less than frequency of signal being sampled, result does not match input signal.
      - Retains general shape of sine wave but at lower frequency.
      - Downward frequency translation can be useful.
      - Longer time between samples results in more processing time.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Sine wave, alias sine wave, harmonic sampling.
    - Harmonic sampling.
      - If frequency of signal being sampled is about twice the sampling rate, result is exactly same as if frequency is equal to sampling rate.
        - Must limit bandwidth of signal being sampled.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Sine wave, alias sine wave, harmonic sampling.
    - Aliasing.
      - Nyquist sampling theorem.
        - To avoid aliasing, sampling rate must be ≥ 2x highest frequency being sampled.



Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Data converters.
    - Analog-to-digital converter (ADC).
      - Device that performs analog-to-digital conversion.
      - Produces a binary number that is directly proportional to value of the input voltage.
      - More bits in binary number → higher resolution.
        - 8 bits → 256 steps.
        - 10 bits → 1024 steps.
        - 16 bits → 65,536 steps.
        - 24 bits → 16,777,216 steps.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

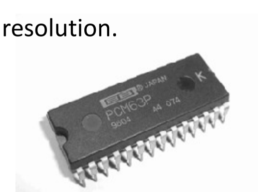
- Digital Signal Processing (DSP)
  - Data converters.
    - Analog-to-digital converter (ADC).
      - When used in an SDR receiver, the minimum detectable signal level (MDS) of the receiver is determined by:
        - Voltage corresponding to largest voltage (reference voltage).
        - Number of bits (sample width).

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Data converters.
    - Analog-to-digital converter (ADC).
      - Dithering – Adding a small amount of noise to the input signal can improve

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Data converters.
    - Digital-to-analog converter (DAC).
      - Device that performs digital-to-analog conversion.
      - Produces an output voltage that is directly proportional to value of a binary number.
      - More bits in binary number → higher resolution.
        - 8 bits → 256 steps.
        - 16 bits → 65,536 steps.
        - 24 bits → 16,777,216 steps.



Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Fourier Analysis and Fast Fourier Transform (FFT).
    - Fourier Analysis – Process of breaking a complex signal down into the individual frequencies that compose the signal.
      - e.g. – Fourier analysis of a square wave shows that it is composed of a fundamental frequency and all odd harmonics.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Fourier Analysis and Fast Fourier Transform (FFT).
    - Fourier Transform – A series of mathematical computations used to perform a Fourier analysis.
      - Mathematical equivalent of a spectrum analyzer.
        - Input is a signal in the time domain.
        - Output represents a signal in the frequency domain.
      - Requires a **LARGE** number of calculations.
      - FFT is a modern algorithm that reduces the number of calculations required by a factor of 100 or more.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Decimation and Interpolation.
    - DSP can perform functions impossible to do with analog circuitry.
      - e.g. – By using techniques called decimation & interpolation can shift the frequency of a signal by a non-integer amount.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Decimation and Interpolation.
    - Decimation – by removing samples, we can reduce the effective sample rate.
      - Decimation factor = ratio of input sampling rate to output sampling rate.
      - Must add an anti-aliasing filter to avoid interpreting high-frequency frequencies as lower frequency signals.

Digital Signal Processing (DSP)
Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Decimation and Interpolation.
    - Interpolation – by adding samples, we can increase the effective sample rate.
      - Interpolation factor = ratio of input sampling rate to output sampling rate.
      - No anti-aliasing filter needed.

Digital Signal Processing (DSP)
Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Decimation and Interpolation.
    - For example, to shift the sampling rate by ¾, we would:
      - Apply an interpolation factor of 3, then
      - Apply a decimation factor of 4

E7F05 -- How frequently must an analog signal be sampled by an analog-to-digital converter so that the signal can be accurately reproduced?

A. At half the rate of the highest frequency component of the signal

➡ B. At twice the rate of the highest frequency component of the signal

C. At the same rate as the highest frequency component of the signal

D. At four times the rate of the highest frequency component of the signal

E7F06 -- What is the minimum number of bits required for an analog-to-digital converter to sample a signal with a range of 1 volt at a resolution of 1 millivolt?

A. 4 bits

B. 6 bits

C. 8 bits

➡ D. 10 bits

E7F07 -- What function can a Fast Fourier Transform perform?

A. Converting analog signals to digital form
B. Converting digital signals to analog form
➡ C. Converting digital signals from the time domain to the frequency domain
D. Converting 8-bit data to 16 bit data

E7F08 -- What is the function of decimation with regard to digital filters?

A. Converting data to binary code decimal form
➡ B. Reducing the effective sample rate by removing samples
C. Attenuating the signal
D. Removing unnecessary significant digits

E7F09 -- Why is an anti-aliasing digital filter required in a digital decimator?

➡ A. It removes high-frequency signal components which would otherwise be reproduced as lower frequency components

B. It peaks the response of the decimator, improving bandwidth

C. It removes low frequency signal components to eliminate the need for DC restoration

D. It notches out the sampling frequency to avoid sampling errors

E7F11 -- What sets the minimum detectable signal level for an SDR in the absence of atmospheric or thermal noise?

A. Sample clock phase noise

➡ B. Reference voltage level and sample width in bits

C. Data storage transfer rate

D. Missing codes and jitter

E7F16 -- How might the sampling rate of an existing digital signal be adjusted by a factor of 3/4?

A. Change the gain by a factor of ¾
B. Multiply each sample value by a factor of ¾
C. Add 3 to each input value and subtract 4 from each output value
➡ D. Interpolate by a factor of three, then decimate by a factor of four

E8A01 -- What is the name of the process that shows that a square wave is made up of a sine wave plus all of its odd harmonics?

➡ A. Fourier analysis
B. Vector analysis
C. Numerical analysis
D. Differential analysis

E8A04 -- What is "dither" with respect to analog to digital converters?

A. An abnormal condition where the converter cannot settle on a value to represent the signal

➡ B. A small amount of noise added to the input signal to allow more precise representation of a signal over time

C. An error caused by irregular quantization step size

D. A method of decimation by randomly skipping samples

E8A09 -- How many levels can an analog-to-digital converter with 8 bit resolution encode?

A. 8

B. 8 multiplied by the gain of the input amplifier

C. 256 divided by the gain of the input amplifier

➡ D. 256

E8A10 -- What is the purpose of a low pass filter used in conjunction with a digital-to-analog converter?

A. Lower the input bandwidth to increase the effective resolution

B. Improve accuracy by removing out of sequence codes from the input

C. Remove harmonics from the output caused by the discrete analog levels generated

D. All of these choices are correct

E8A11 -- What type of information can be conveyed using digital waveforms?

A. Human speech

B. Video signals

C. Data

D. All of these choices are correct

E8A12 -- What is an advantage of using digital signals instead of analog signals to convey the same information?

A. Less complex circuitry is required for digital signal generation and detection

B. Digital signals always occupy a narrower bandwidth

➡ C. Digital signals can be regenerated multiple times without error

D. All of these choices are correct

E8A13 -- Which of these methods is commonly used to convert analog signals to digital signals?

➡ A. Sequential sampling

B. Harmonic regeneration

C. Level shifting

D. Phase reversal

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Software-Defined Radio (SDR) Systems
  - A software-defined radio (SDR) system is a radio communication system where components that have been typically implemented in hardware (e.g. mixers, filters, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a computer or embedded computing devices.
  - Operation of radio can be changed simply by loading new software.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- Software-Defined Radio (SDR) Systems
  - The ideal SDR receiver would be to attach an antenna to an analog-to-digital converter (ADC).
  - Similarly, the ideal SDR transmitter would be to attach a digital-to-analog converter (DAC) to an antenna.
  - Not feasible with current technology, so some compromise is necessary.

Digital Signal Processing (DSP)
Software-Defined Radio (SDR)

- Digital Signal Processing (DSP)
  - Software-Defined Radio (SDR).
    - Some analog processing still required.
    - Future is an all-digital radio.
    - Commercial SDR transceivers now available for amateur use.

Digital Signal Processing (DSP)
Software-Defined Radio (SDR)


Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- SDR Hardware
  - Early SDR designs for amateur radio used the following design concept:
    - A segment of RF spectrum is converted to an audio IF which is digitized & processed.
      - Can use lower speed A/D & D/A chips.
      - Possible to use the computer soundcard for the A/D & D/A functions.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- SDR Hardware
  - Current SDR designs for amateur radio use the following design concept:
    - A segment of the RF spectrum itself is digitized & processed.
      - Called “Direct Digital Conversion”.
      - Requires high-speed A/D & D/A chips.
        - Direct conversion or flash conversion chips.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- SDR Hardware
  - Currently there are 4 types of SDR architecture:
    - Most processing is done in a computer, & the computer soundcard is used for A/D & D/A functions.
    - Most processing done in a computer, but the A/D & D/A functions are done in radio.
    - Most processing is done in the radio with a computer providing the user interface.
    - All processing done in the radio with conventional knobs & buttons for the user interface.

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- DSP Modulation
  - Any sinusiodal signal may be represented by adding a cosine (cos) wave and a sine (sin) wave.
    - The cosine wave is called the I (in-phase) signal.
    - The sine wave is called the Q (quadrature) signal.
  - For DSP it is convenient to consider the I & Q signals separately.
  - The I & Q signals can be represented mathematically as a complex number:
    - X = I +jQ

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- DSP Modulation
  - Given the I & Q signals of the modulating waveform & 2 identical RF carriers 90° out of phase, **ANY** type of modulated signal can be generated.
    - AM
    - DSB
    - SSB
    - FM
    - PM

Digital Signal Processing (DSP) Software-Defined Radio (SDR)

- DSP Modulation
  - Using I/Q modulation to generate a SSB signal is the mathematical equivalent of the quadrature method of SSB generation.
    - Generating an audio signal shifted by 90° requires a special type of DSP filter.
      - Hilbert transform filter.

E7F01 -- What is meant by direct digital conversion as applied to software defined radios?

A. Software is converted from source code to object code during operation of the receiver
B. Incoming RF is converted to a control voltage for a voltage controlled oscillator
➡ C. Incoming RF is digitized by an analog-to-digital converter without being mixed with a local oscillator signal
D. A switching mixer is used to generate I and Q signals directly from the RF input

E7F03 -- What type of digital signal processing filter is used to generate an SSB signal?

A. An adaptive filter
B. A notch filter
➡ C. A Hilbert-transform filter
D. An elliptical filter

E7F04 -- What is a common method of generating an SSB signal using digital signal processing?

A. Mixing products are converted to voltages and subtracted by adder circuits

B. A frequency synthesizer removes the unwanted sidebands

C. Emulation of quartz crystal filter characteristics

➡ D. Combine signals with a quadrature phase relationship

E7F10 -- What aspect of receiver analog-to-digital conversion determines the maximum receive bandwidth of a Direct Digital Conversion SDR?

➡ A. Sample rate

B. Sample width in bits

C. Sample clock phase noise

D. Processor latency

E7F12 -- What digital process is applied to I and Q signals in order to recover the baseband modulation information?

➡ A. Fast Fourier Transform

B. Decimation

C. Signal conditioning

D. Quadrature mixing

E7F17 -- What do the letters I and Q in I/Q Modulation represent?

A. Inactive and Quiescent

B. Instantaneous and Quasi-stable

C. Instantaneous and Quenched

➡ D. In-phase and Quadrature

E8A08 -- Why would a direct or flash conversion analog-to-digital converter be useful for a software defined radio?

A. Very low power consumption decreases frequency drift

B. Immunity to out of sequence coding reduces spurious responses

➡ C. Very high speed allows digitizing high frequencies

D. All of these choices are correct

Filters and Impedance Matching

- Filter Families and Response Types
  - Filters are circuits designed to pass certain frequencies and reject others.
    - R-C circuits.
    - R-L circuits.
    - R-L-C circuits.
  - A resonant circuit is a simple filter.
    - Most filters normally pass a wider range of frequencies than a simple resonant circuit.

Filters and Impedance Matching

- Filter Families and Response Types
  - Passive filters.
    - Constructed using only passive components.
      - Capacitors.
      - Inductors.
      - Resistors.
    - Other types.
      - Crystal.
      - Mechanical.
      - Cavity.
    - Always have insertion loss.

Filters and Impedance Matching

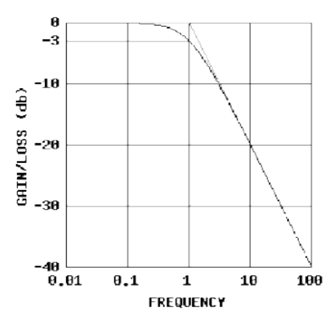
- Filter Families and Response Types
  - Cavity Filters
    - Cavity filters use the resonant properties of a conductive tube or box to act as a filter.
    - Cavity filters have an extremely narrow bandwidth (extremely high Q) and very low loss.
    - Cavity filters are often used in repeater duplexers.

Filters and Impedance Matching

- Filter Families and Response Types
  - Active filters.
    - Include an amplifying device.
      - No insertion loss.
      - Can have gain.
    - Some type of filters can ONLY be built using active components.

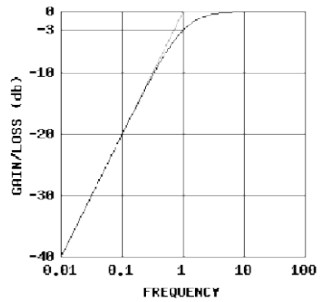
Filters and Impedance Matching

- Filter Classification
  - Low-pass filter.
    - Passes all frequencies below the cut-off frequency.
    - Attenuates all frequencies above the cut-off frequency.
    - Cut-off frequency is the frequency where the response falls to 3 dB below the maximum level.



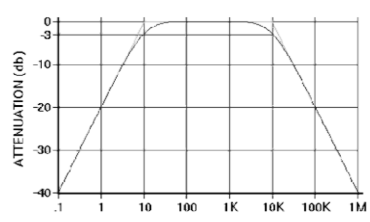
Filters and Impedance Matching

- Filter Classification
  - High-pass filter.
    - Attenuates all frequencies below the cut-off frequency.
    - Passes all frequencies above the cut-off frequency.
    - Cut-off frequency is the frequency where the response rises to 3 dB below the maximum level.



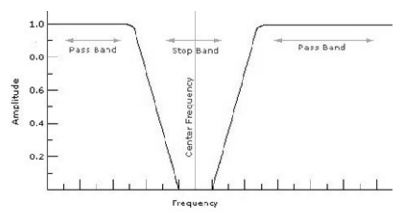
Filters and Impedance Matching

- Filter Classification
  - Band-pass filter.
    - 2 cut-off frequencies.
      - Cut-off frequencies are frequencies where response is 3dB below maximum.
    - Passes all frequencies between the cut-off frequencies.
    - Attenuates all frequencies outside of the cut-off frequencies.



Filters and Impedance Matching

- Filter Classification
  - Band-reject filter.
    - If the passband is narrow, it is called a notch filter.
    - 2 cut-off frequencies.
    - Attenuates all frequencies between the cut-off frequencies.
    - Passes all frequencies outside of the cut-off frequencies.



Filters and Impedance Matching

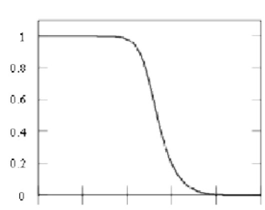
- Filter Design
  - Definitions.
    - Response curve.
      - Output signal level vs. frequency.
      - Cut-off frequency = -3 dB point.
      - Cut-off transition.
        - Steepness of curve in transition region.
        - Steep transition curve → sharp filter.
      - Ripple.
        - Variations of response curve in passband or outside of passband.

Filters and Impedance Matching

- Filter Design
  - Definitions.
    - Phase response.
      - Shift of signal phase vs. frequency.
      - Higher attenuation → more phase shift.
      - Linear phase shift means phase shift is smooth with no ripple as frequency changes.
      - Non-linear phase response can distort digital signals.
    - Ringing.
      - Oscillations continue after signal is removed.

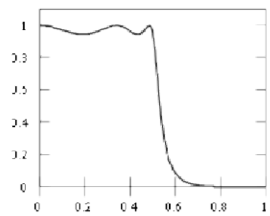
Filters and Impedance Matching

- Filter Design
  - Butterworth
    - Minimum ripple in both pass band & stop band.
    - Cutoff transition smooth but not steep.
    - Smoothly varying phase response.



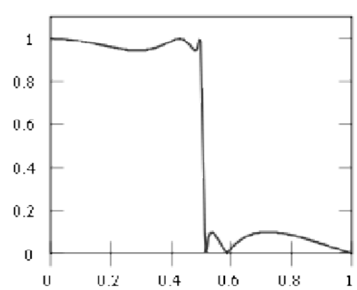
Filters and Impedance Matching

- Filter Design
  - Chebyshev
    - Ripple in pass band.
    - Sharper cutoff transition.
    - Significant phase shift in pass band.



Filters and Impedance Matching

- Filter Design
  - Elliptical
    - Ripple in both pass band & stop band.
    - Sharpest cutoff transition.
    - Notches are positioned at specific frequencies in stopband to make transition as sharp as possible.

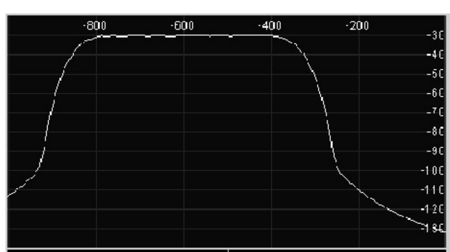


Filters and Impedance Matching

- Filter Design
  - Shape factor.
    - Measurement of “sharpness” of filter.
    - Ratio of -60dB bandwidth to -6dB bandwidth.
      - SF = BW_{60dB} / BW_{6dB}
    - The closer the ratio is to 1.0, the sharper the filter.
      - An ideal filter would have a shape factor of 1.0.

Filters and Impedance Matching

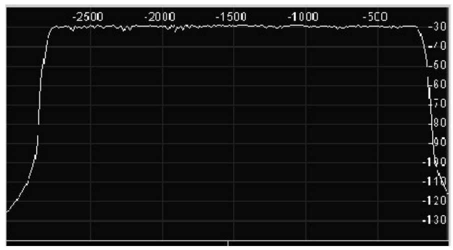
- Filter Design
  - Shape factor.



Filter Characteristics
6dB Bandwidth 487 Hz,
60dB Bandwidth 660 Hz
Shape Factor ~1.36

Filters and Impedance Matching

- Filter Design
  - Shape factor.



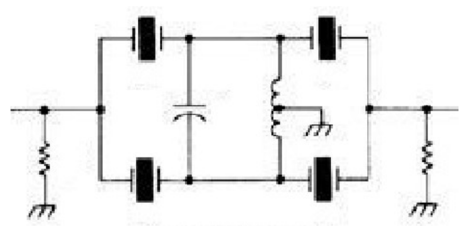
Filter Characteristics
6dB Bandwidth 2587 Hz,
60dB Bandwidth 2756 Hz
Shape Factor ~1.06

Filters and Impedance Matching

- Crystal filters.
  - IF stages of a receiver require very narrow bandwidth (high Q) filters with sharp transitions to filter out adjacent signals.
    - Cannot be achieved with L-C filters.
  - SSB transmitters require very narrow bandwidth (high Q) filters with sharp transitions to filter out unwanted sideband.
    - Cannot be achieved with L-C filters.

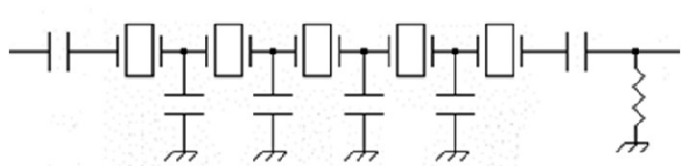
Filters and Impedance Matching

- Crystal filters.
  - Lattice filter.
    - Typically used in SSB transmitters to remove unwanted sideband.



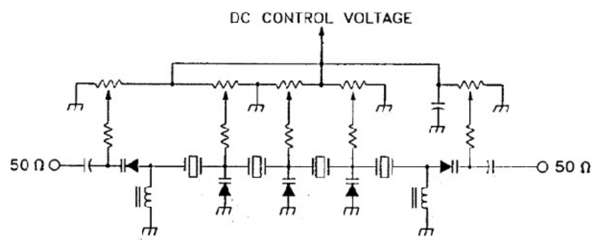
Filters and Impedance Matching

- Crystal filters.
  - Ladder filter.
    - Bandwidth & response determined by frequencies of individual crystals.



Filters and Impedance Matching

- Crystal filters.
  - Jones filter.
    - Variable-bandwidth crystal ladder filter.
    - Invented by Lee J. Jones, WB4JTR, of Ten-Tec.



Filters and Impedance Matching

- Crystal filters.
  - Jones filter.

NOTE: Both the book and the question pool (E7C09) mistakenly refer to the Jones filter as a crystal lattice filter when in fact, it is a crystal ladder filter.

E7C05 -- Which filter type is described as having ripple in the passband and a sharp cutoff?

A. A Butterworth filter
B. An active LC filter
C. A passive op-amp filter
➡ D. A Chebyshev filter

E7C06 -- What are the distinguishing features of an elliptical filter?

A. Gradual passband rolloff with minimal stop band ripple
B. Extremely flat response over its pass band with gradually rounded stop band corners
➡ C. Extremely sharp cutoff with one or more notches in the stop band
D. Gradual passband rolloff with extreme stop band ripple

E7C07 -- What kind of filter would you use to attenuate an interfering carrier signal while receiving an SSB transmission?

A. A band-pass filter
➡ B. A notch filter
C. A Pi-network filter
D. An all-pass filter

E7C08 -- Which of the following factors has the greatest effect in helping determine the bandwidth and response shape of a crystal ladder filter?

➡ A. The relative frequencies of the individual crystals
B. The DC voltage applied to the quartz crystal
C. The gain of the RF stage preceding the filter
D. The amplitude of the signals passing through the filter

E7C09 -- What is a Jones filter as used as part of a HF receiver IF stage?

A. An automatic notch filter

➡B. A variable bandwidth crystal lattice filter

C. A special filter that emphasizes image responses

D. A filter that removes impulse noise

E7C10 -- Which of the following filters would be the best choice for use in a 2 meter repeater duplexer?

A. A crystal filter

➡B. A cavity filter

C. A DSP filter

D. An L-C filter

E7C14 -- Which mode is most affected by non-linear phase response in a receiver IF filter?

A. Meteor Scatter
B. Single-Sideband voice
➡ C. Digital
D. Video

E7C15 -- What is a crystal lattice filter?

A. A power supply filter made with interlaced quartz crystals
B. An audio filter made with four quartz crystals that resonate at 1-kHz intervals
C. A filter with wide bandwidth and shallow skirts made using quartz crystals
➡ D. A filter with narrow bandwidth and steep skirts made using quartz crystals

E7G02 -- What is the effect of ringing in a filter?

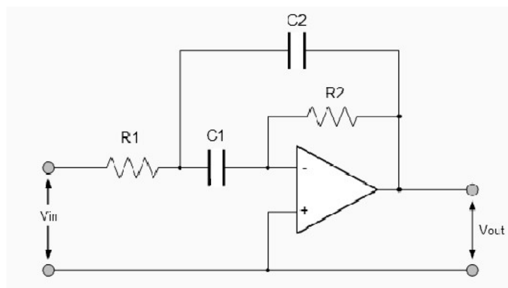
A. An echo caused by a long time delay
B. A reduction in high frequency response
C. Partial cancellation of the signal over a range of frequencies
➡ D. Undesired oscillations added to the desired signal

Filters and Impedance Matching

- Active filters.
  - Active audio filters
    - Can be built without inductors.
    - Smaller & lighter.
    - No insertion loss & can have gain.
    - Op-amps.
      - Filter characteristics determined by external components.
      - Ringing can result if gain and/or Q are too high.
    - Best suited for audio filtering in receivers.

Filters and Impedance Matching

- Active filters.
  - Active audio filters.
    - An active band-pass filter.



Filters and Impedance Matching

- Active filters.
  - Active audio filters
    - Pick standard value capacitors.
      - Low-loss
      - Temperature stable.
      - Polystyrene (?)
    - Calculate resistors.

E7G05 -- How can unwanted ringing and audio instability be prevented in a multi-section op-amp RC audio filter circuit?

➡ A. Restrict both gain and Q
B. Restrict gain, but increase Q
C. Restrict Q, but increase gain
D. Increase both gain and Q

E7G06 -- Which of the following is the most appropriate use of an op-amp active filter?

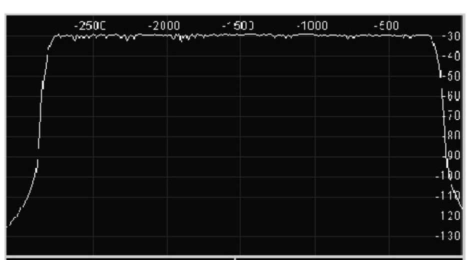
A. As a high-pass filter used to block RFI at the input to receivers
B. As a low-pass filter used between a transmitter and a transmission line
C. For smoothing power-supply output
➡ D. As an audio filter in a receiver

Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - No tuning required.
  - No worry about selecting standard component values.
  - Adaptive processing.
    - Software can recognize & adapt to different signals & conditions to remove noise.
  - Requires computing hardware.

Filters and Impedance Matching

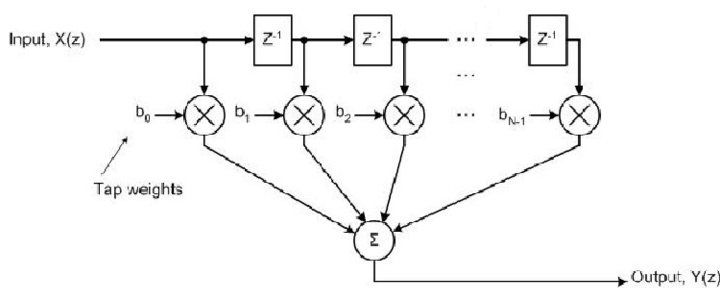
- Digital Signal Processing (DSP) Filters.
  - Can build filters impossible to achieve with hardware.
    - "Brick wall" filters approach shape factors of 1.0.



Filter Characteristics
6dB Bandwidth 2587 Hz,
60dB Bandwidth 2756 Hz
Shape Factor ~1.06

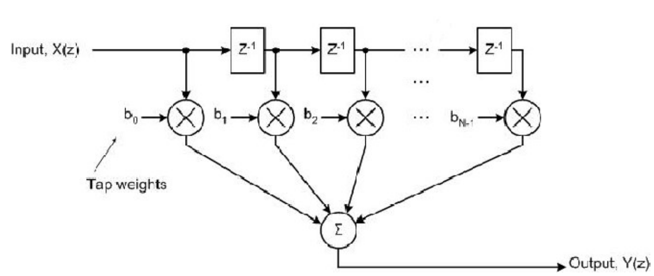
Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - Finite Impulse Response (FIR) filters.



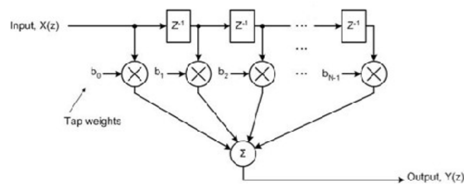
Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - Finite Impulse Response (FIR) filters.
    - Output ceases finite time after input is removed.



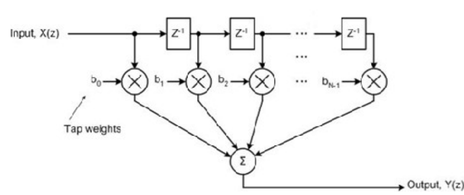
Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - Finite Impulse Response (FIR) filters.
    - Input is fed to a shift register.
      - Each stage in shift register is called a "tap".
    - Input & outputs of each tap are scaled & added together to create the output signal.



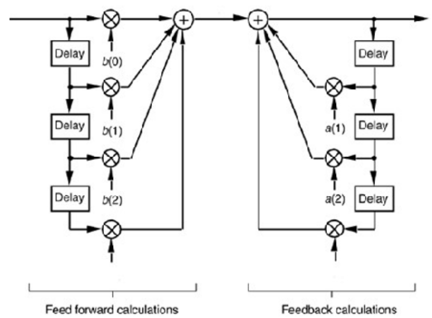
Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - Finite Impulse Response (FIR) filters.
    - Taps provide incremental signal delays used to create the filter function.
      - More taps → sharper filter.
      - More taps → longer delay.



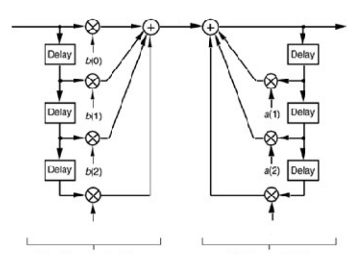
Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - Infinite Impulse Response (IIR) filters.



Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - Infinite Impulse Response (IIR) filters.
    - Output continues long after input is removed.
    - Feed-forward & feedback loops are used to create the filter function.



Filters and Impedance Matching

- Digital Signal Processing (DSP) Filters.
  - FIR vs IIR filters.
    - FIR filters have linear phase response.
      - All frequency components are delayed by the same amount.

        NOTE: Book is wrong!
    - FIR filters are easier to design.
    - IIR filters require fewer software components.
      - Less computational power needed.

E7F02 -- What kind of digital signal processing audio filter might be used to remove unwanted noise from a received SSB signal?

➡ A. An adaptive filter

B. A crystal-lattice filter

C. A Hilbert-transform filter

D. A phase-inverting filter

E7F13 -- What is the function of taps in a digital signal processing filter?

A. To reduce excess signal pressure levels
B. Provide access for debugging software
C. Select the point at which baseband signals are generated
➡ D. Provide incremental signal delays for filter algorithms

E7F14 -- Which of the following would allow a digital signal processing filter to create a sharper filter response?

A. Higher data rate
➡ B. More taps
C. Complex phasor representations
D. Double-precision math routines

E7F15 -- Which of the following is an advantage of a Finite Impulse Response (FIR) filter vs an Infinite Impulse Response (IIR) digital filter?

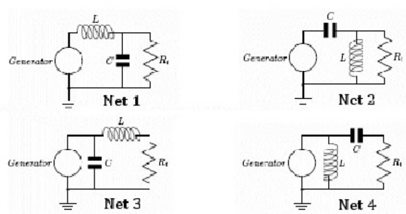
A. FIR filters delay all frequency components of the signal by the same amount
B. FIR filters are easier to implement for a given set of passband rolloff requirements
C. FIR filters can respond faster to impulses
D. All of these choices are correct

Filters and Impedance Matching

- Impedance Matching.
  - If load & source impedances are not equal, an impedance matching network is needed for maximum power transfer.
  - Assuming a source impedance of 50Ω, the matching network must:
    - Cancel the reactive portion of the load impedance.
    - Transform the resistive component to 50Ω.

Filters and Impedance Matching

- Impedance Matching.
  - L Networks.
    - Can match virtually any 2 impedances.
    - Q is fixed.
    - Usually only designed to work on a single band.

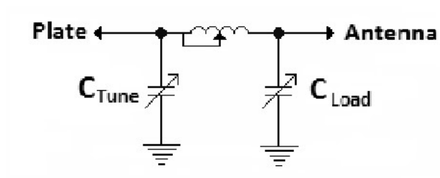


Filters and Impedance Matching

- Impedance Matching.
  - Pi-Networks.
    - Equivalent to 2 L-networks connected back-to-back.
    - Matches wide range of load impedances.
    - Q can be varied depending on component values chosen.
    - Used in most tube amplifiers.

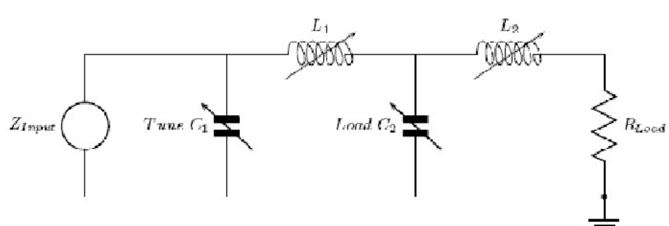
Filters and Impedance Matching

- Impedance Matching.
  - Pi-Networks.
    - Adjust $C_{\textbf{Tune}}$ for minimum plate current.
    - Adjust $C_{\textbf{Load}}$ for maximum plate current.
    - Repeat until maximum power output is achieved **without** exceeding maximum tube plate current rating.



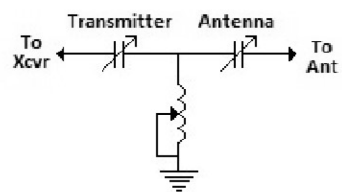
Filters and Impedance Matching

- Impedance Matching.
  - Pi-L networks.
    - Add inductor to output of Pi network
    - More harmonic reduction.



Filters and Impedance Matching

- Impedance Matching.
  - T-Networks.
    - Can match wide range of impedances.
    - Lower loss than pi-network.
    - Used in most antenna tuners.
    - High-pass filter
      - Does **not** provide harmonic suppression.



E7B09 -- Which of the following describes how the loading and tuning capacitors are to be adjusted when tuning a vacuum tube RF power amplifier that employs a pi-network output circuit?

A. The loading capacitor is set to maximum capacitance and the tuning capacitor is adjusted for minimum allowable plate current
B. The tuning capacitor is set to maximum capacitance and the loading capacitor is adjusted for minimum plate permissible current
C. The loading capacitor is adjusted to minimum plate current while alternately adjusting the tuning capacitor for maximum allowable plate current
D. The tuning capacitor is adjusted for minimum plate current, while the loading capacitor is adjusted for maximum permissible plate current

E7C01 -- How are the capacitors and inductors of a low-pass filter Pi-network arranged between the network's input and output?

A. Two inductors are in series between the input and output, and a capacitor is connected between the two inductors and ground
B. Two capacitors are in series between the input and output and an inductor is connected between the two capacitors and ground
C. An inductor is connected between the input and ground, another inductor is connected between the output and ground, and a capacitor is connected between the input and output
➡ D. A capacitor is connected between the input and ground, another capacitor is connected between the output and ground, and an inductor is connected between input and output

E7C02 -- Which of the following is a property of a T-network with series capacitors and a parallel shunt inductor?

A. It is a low-pass filter
B. It is a band-pass filter
➡ C. It is a high-pass filter
D. It is a notch filter

E7C03 -- What advantage does a Pi-L-network have over a Pi-network for impedance matching between the final amplifier of a vacuum-tube transmitter and an antenna?

➡ A. Greater harmonic suppression
B. Higher efficiency
C. Lower losses
D. Greater transformation range

E7C04 -- How does an impedance-matching circuit transform a complex impedance to a resistive impedance?

A. It introduces negative resistance to cancel the resistive part of impedance
B. It introduces transconductance to cancel the reactive part of impedance
➡ C. It cancels the reactive part of the impedance and changes the resistive part to a desired value
D. Network resistances are substituted for load resistances and reactances are matched to the resistances

E7C11 -- Which of the following is the common name for a filter network which is equivalent to two L networks connected back-to-back with the inductors in series and the capacitors in shunt at the input and output?

A. Pi-L

B. Cascode

C. Omega

➡ D. Pi

E7C12 -- Which of the following describes a Pi-L network used for matching a vacuum-tube final amplifier to a 50-ohm unbalanced output?

A. A Phase Inverter Load network

➡ B. A Pi network with an additional series inductor on the output

C. A network with only three discrete parts

D. A matching network in which all components are isolated from ground

E7C13 -- What is one advantage of a Pi-matching network over an L-matching network consisting of a single inductor and a single capacitor?

A. The Q of Pi networks can be varied depending on the component values chosen

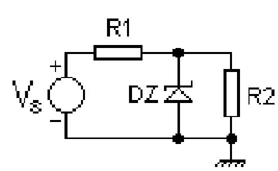
B. L networks can not perform impedance transformation

C. Pi networks have fewer components

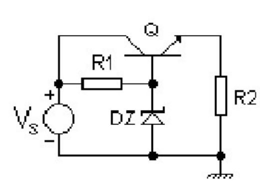
D. Pi networks are designed for balanced input and output

Power Supplies

- Linear Voltage Regulators.
  - Shunt Regulators.
    - Lousy efficiency.
    - Constant current drawn from source.
    - Maximum current flows all the time.

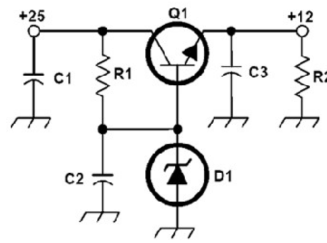


  - Series Regulators.
    - Good efficiency.
    - Only the current required by the load flows.



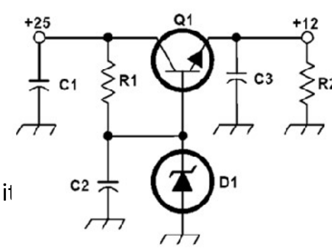
Power Supplies

- Linear Voltage Regulators.
  - Basic series regulator circuit.
    - C1 -- Input by-pass capacitor.
      - Filters supply voltage.
    - C2 – Hum-filter capacitor.
      - Bypasses hum around D1.
    - C3 – Output by-pass capacitor.
      - Often 2 capacitors in parallel.
        - Large value capacitor to filter output.
        - Small value capacitor to prevent self-oscillation.



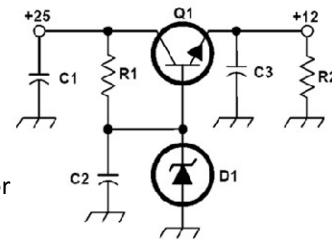
Power Supplies

- Linear Voltage Regulators.
  - Basic series regulator circuit.
    - D1 – Zener diode.
      - Provides voltage reference.
    - Q1 – Series pass transistor.
      - Increases current handling capabilit



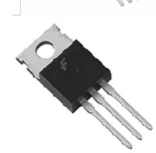
Power Supplies

- Linear Voltage Regulators.
  - Basic series regulator circuit.
    - R1 – Bias resistor.
      - Provides bias current to D1 & Q1.
    - R2 – Load resistor.
      - Provides minimum load current for



Power Supplies

- Linear Voltage Regulators.
  - IC "3-Terminal" Regulators.
    - Thermal shutdown.
    - Overvoltage protection.
    - Foldback current limiting.
    - LM78Lxx -- 100 mA.
    - LM78xx -- 1 Amp.
    - LM78Hxx -- 3 Amps.



Power Supplies

- Linear Voltage Regulators.
  - Drop-out point.
    - A minimum voltage must be maintained across the pass transistor (V_{in} - V_{Out}) to provide regulation.
    - Drop-out point = minimum value of (V_{in} - V_{Out}) for regulation to be maintained.

Power Supplies

- Linear Voltage Regulators.
  - Efficiency.
    - Both shunt & series regulators dissipate a significant amount of power as heat.
      - Series regulators are more efficient because only current required by the load is drawn.
    - Efficiency = 100% x P_{Out} / P_{in}
    - Power lost as heat in pass transistor = (V_{in} - V_{Out}) x I_L

Power Supplies

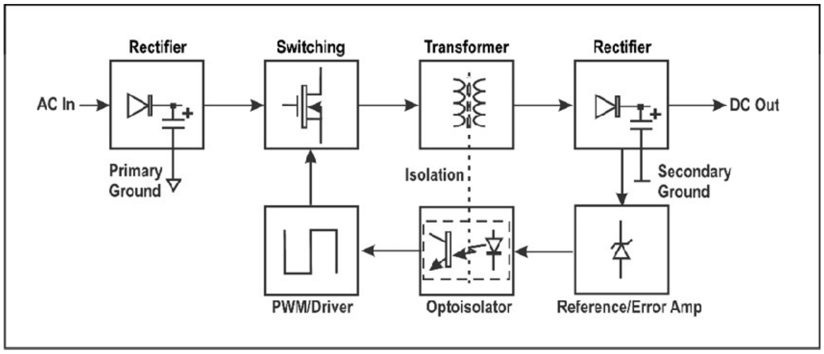
- Battery Charging Regulators.
  - Special types of regulators called “charge controllers” are used to charge re-chargeable batteries.
    - Required to prevent over-charging or damaging the battery being charged.
    - Type of regulator depends on chemistry of battery being charged.
      - Voltage regulator – Lead-Acid.
      - Current regulator – Ni-Cd, NiMh.

Power Supplies

- Switching Regulators
  - AC input is rectified & switched on/off at a high frequency.
    - Pulse width is varied to maintain constant average voltage.
  - A transformer changes the voltage level.
  - Output from transformer is rectified & filtered.
  - Output is sampled & compared to a reference.
  - Difference is used to control the pulse width.

Power Supplies

- Switching Regulators



Power Supplies

- Switching Regulators
  - More efficient than linear regulators.
    - Regulation accomplished by varying duty-cycle of input power rather than by dissipating excess power as heat.
  - Smaller, lighter, & less expensive than linear regulators.
    - High switching rate allows use of smaller transformers & filter components.

E7D01 -- What is one characteristic of a linear electronic voltage regulator?

A. It has a ramp voltage as its output
B. It eliminates the need for a pass transistor
C. The control element duty cycle is proportional to the line or load conditions
➡ D. The conduction of a control element is varied to maintain a constant output voltage

E7D02 -- What is one characteristic of a switching electronic voltage regulator?

A. The resistance of a control element is varied in direct proportion to the line voltage or load current
B. It is generally less efficient than a linear regulator
➡ C. The control device's duty cycle is controlled to produce a constant average output voltage
D. It gives a ramp voltage at its output

E7D03 -- What device is typically used as a stable reference voltage in a linear voltage regulator?

➡ A. A Zener diode
B. A tunnel diode
C. An SCR
D. A varactor diode

E7D04 -- Which of the following types of linear voltage regulator usually make the most efficient use of the primary power source?

A. A series current source
➡ B. A series regulator
C. A shunt regulator
D. A shunt current source

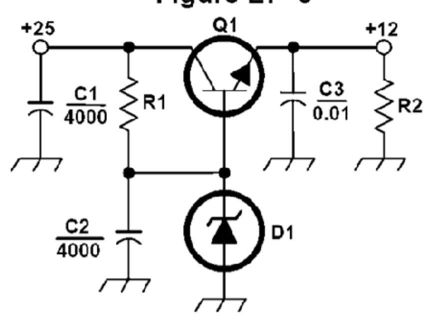
E7D05 -- Which of the following types of linear voltage regulator places a constant load on the unregulated voltage source?

A. A constant current source
B. A series regulator
C. A shunt current source
➡ D. A shunt regulator

E7D06 -- What is the purpose of Q1 in the circuit shown in Figure E7-3?

A. It provides negative feedback to improve regulation
B. It provides a constant load for the voltage source
➡ C. It increases the current-handling capability of the regulator
D. It provides D1 with current

Figure E7- 3



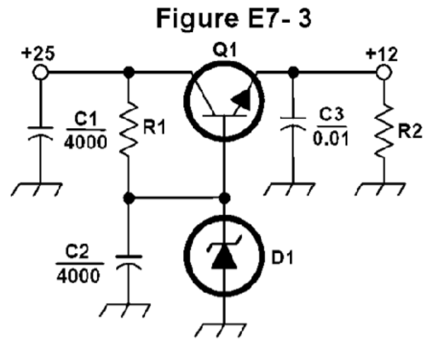
E7D07 -- What is the purpose of C2 in the circuit shown in Figure E7-3?

➡ A. It bypasses hum around D1

B. It is a brute force filter for the output

C. To self-resonate at the hum frequency

D. To provide fixed DC bias for Q1



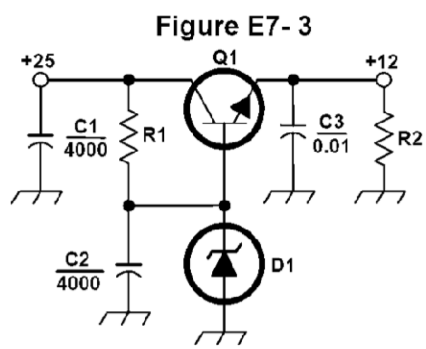
E7D08 -- What type of circuit is shown in Figure E7-3?

A. Switching voltage regulator

B. Grounded emitter amplifier

➡ C. Linear voltage regulator

D. Emitter follower



E7D09 -- What is the main reason to use a charge controller with a solar power system?

A. Prevention of battery undercharge
B. Control of electrolyte levels during battery discharge
➡ C. Prevention of battery damage due to overcharge
D. Matching of day and night charge rates

E7D10 -- What is the primary reason that a high-frequency switching type high voltage power supply can be both less expensive and lighter in weight than a conventional power supply?

A. The inverter design does not require any output filtering
B. It uses a diode bridge rectifier for increased output
➡ C. The high frequency inverter design uses much smaller transformers and filter components for an equivalent power output
D. It uses a large power factor compensation capacitor to create free power from the unused portion of the AC cycle

E7D11 -- What circuit element is controlled by a series analog voltage regulator to maintain a constant output voltage?

A. Reference voltage
B. Switching inductance
C. Error amplifier
➡ D. Pass transistor

E7D12 -- What is the drop-out voltage of an analog voltage regulator?

A. Minimum input voltage for rated power dissipation
B. Maximum amount that the output voltage drops when the input voltage is varied over its specified range
➡ C. Minimum input-to-output voltage required to maintain regulation
D. Maximum amount that the output voltage may decrease at rated load

E7D13 -- What is the equation for calculating power dissipation by a series connected linear voltage regulator?

A. Input voltage multiplied by input current

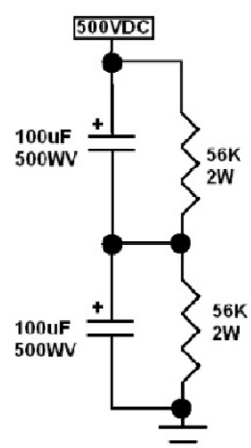
B. Input voltage divided by output current

➡ C. Voltage difference from input to output multiplied by output current

D. Output voltage multiplied by output current

Power Supplies

- High Voltage Techniques.
  - Bleeder resistor.
    - Discharges capacitors when power is turned off.
    - Improves voltage regulation by providing a minimum load current.
  - Voltage equalizing resistors.
    - Equalizes voltages across filter capacitors in series.



Power Supplies

- High Voltage Techniques.
  - Step-start.
    - Resistor in series with transformer primary.
    - Relay shorts resistor after specified time.
    - Limits in-rush current.
    - Reduces stress on rectifiers & filter capacitors by limiting in-rush current.
      - Capacitors charge more slowly.

E7D14 -- What is one purpose of a "bleeder" resistor in a conventional unregulated power supply?

A. To cut down on waste heat generated by the power supply

B. To balance the low-voltage filament windings

➡ C. To improve output voltage regulation

D. To boost the amount of output current

E7D15 -- What is the purpose of a "step-start" circuit in a high-voltage power supply?

A. To provide a dual-voltage output for reduced power applications
B. To compensate for variations of the incoming line voltage
C. To allow for remote control of the power supply
➡ D. To allow the filter capacitors to charge gradually

E7D16 -- When several electrolytic filter capacitors are connected in series to increase the operating voltage of a power supply filter circuit, why should resistors be connected across each capacitor?

A. To equalize, as much as possible, the voltage drop across each capacitor
B. To provide a safety bleeder to discharge the capacitors when the supply is off
C. To provide a minimum load current to reduce voltage excursions at light loads
➡ D. All of these choices are correct

Questions?