Amateur Radio Technician Exam Preparation Course

ARRL
The National Association for Amateur Radio®

Amateur Radio Technician Exam Prep Course

Module 9

Safety

9.1 Electrical Safety
9.2 Managing RF in Your Station
9.3 RF Interference (RFI)
9.4 RF Exposure
9.5 Mechanical Safety

Electrical Injuries

- Electrical current through the body can disrupt the electrical function of cells
  - Can cause involuntary muscle contractions
  - Large currents can burn the skin and heat tissue

Table 9.1
Effects of Electric Current in the Human Body

Current	*Reaction*
Below 1 milliampere	Generally not perceptible
1 milliampere	Faint tingle
5 milliamperes	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6-25 milliamperes (women) 9-30 milliamperes (men)	Painful shock, loss of muscular control*; the freezing current or "can't let-go" range.
50-150 milliamperes	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1000-4300 milliamperes	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10,000 milliamperes	Cardiac arrest, severe burns; death probable

Avoiding Electrical Hazards

- Safety tips for working with power **ON**
  - Keep one hand in your pocket
  - Wear insulating shoes
  - Never bypass a safety interlock during testing
  - Make sure capacitors are discharged
  - Keep metal objects clear of storage battery terminals
  - Avoid working on equipment with the battery connected
  - Remove unnecessary jewelry from your hands
  - Avoid working alone

AC Safety Grounding

- The *safety ground* is a connection to the power system's ground reference connection in your main electrical service box
- The ground connection causes a fuse or circuit breaker to remove power from the equipment
- Grounding guidelines …
  - Use three-wire power cords and plugs
  - Make sure all equipment has a connection to the ground
  - Use ground fault circuit interrupter (GFCI) circuit breakers/outlets
  - Verify AC wiring is done properly
  - Never replace a fuse or circuit breaker with one of a larger size
  - Don't overload single outlets

AC Safety Grounding (cont.)

- When wiring circuits, be sure to follow the US standard …
  - Hot — black wire (occasionally red)
  - Neutral — white wire
  - Safety or equipment ground — green
- Use cable and wire sufficiently rated for the expected current load
- Use the proper size fuses and circuit breakers
- Be sure fuses or circuit breakers are installed in series with the hot conductor or conductors

Table 9.2
Current-Carrying Capability of Some Common Wire Sizes

Copper Wire Size (AWG)	*Allowable Current (A)*	*Max Fuse or Circuit Breaker (A)*
6	55	50
8	40	40
10	30	30
12	25 (20)[1]	20
14	20 (15)[1]	15

[1]The National Electrical Code limits the fuse or circuit breaker size (and as such, the maximum allowable circuit load current) to 15 A for #14 AWG copper wire and to 20 A for #12 AWG copper wire conductors.

Lightning Protection

- Lightning protection is intended to provide fire protection for your home
- Starting at your antennas, all towers, masts, and antenna mounts should be grounded according to local building and electrical codes
- Connections are made at the tower base though a large-diameter wire to a ground rod
- Ground connections should be as short and direct as possible — avoid sharp bends
- Use lightning arrestors grounded to a common plate that is in turn connected to a nearby external ground
- All ground rods and earth connections must be bonded together with heavy wire

PRACTICE QUESTIONS

What health hazard is presented by electrical current flowing through the body?

A. It may cause injury by heating tissue
B. It may disrupt the electrical functions of cells
C. It may cause involuntary muscle contractions
D. All these choices are correct

T0A02 D 9-2

What hazard exists in a power supply immediately after turning it off?

A. Circulating currents in the dc filter
B. Leakage flux in the power transformer
C. Voltage transients from kickback diodes
D. Charge stored in filter capacitors

T0A11 D 9-2

In the United States, what circuit does black wire insulation indicate in a three-wire 120 V cable?

A. Neutral
B. Hot
C. Equipment ground
D. Black insulation is never used

T0A03 B 9-4

What is a good way to guard against electrical shock at your station?

A. Use three-wire cords and plugs for all AC powered equipment
B. Connect all AC powered station equipment to a common safety ground
C. Install mechanical interlocks in high-voltage circuits
D. All these choices are correct

T0A06 D 9-4

Where should a fuse or circuit breaker be installed in a 120V AC power circuit?

A. In series with the hot conductor only
B. In series with the hot and neutral conductors
C. In parallel with the hot conductor only
D. In parallel with the hot and neutral conductors

T0A08 A 9-4

Where should a lightning arrester be installed in a coaxial feed line?

A. At the output connector of a transceiver
B. At the antenna feed point
C. At the ac power service panel
D. On a grounded panel near where feed lines enter the building

T0A07 D 9-5

What should be done to all external ground rods or earth connections?

A. Waterproof them with silicone caulk or electrical tape
B. Keep them as far apart as possible
C. Bond them together with heavy wire or conductive strap
D. Tune them for resonance on the lowest frequency of operation

T0A09 C 9-5

Which of the following is good practice when installing ground wires on a tower for lightning protection?

A. Put a drip loop in the ground connection to prevent water damage to the ground system
B. Make sure all ground wire bends are right angles
C. Ensure that connections are short and direct
D. All these choices are correct

T0B01 C 9-5

Which of the following is true when installing grounding conductors used for lightning protection?

A. Use only non-insulated wire
B. Wires must be carefully routed with precise right-angle bends
C. Sharp bends must be avoided
D. Common grounds must be avoided

T0B10 C 9-5

Which of the following establishes grounding requirements for an amateur radio tower or antenna?

A. FCC Part 97 rules
B. Local electrical codes
C. FAA tower lighting regulations
D. UL recommended practices

T0B11 B 9-5

Managing RF in Your Station

- Your station wiring, feed lines, power connections, and other cables all pick up RF from your transmitted signal
- It is not practical to “ground” RF current in the same way as for AC power and lightning protection
- Best approach is to *bond* all of the equipment together
  - Keeps all of your equipment at the same voltage so that RF current does not flow between the different pieces
- RF current on cables and enclosures can cause audio distortion, erratic operation of computer equipment, and even RF “burns”
- “RF feedback” via a microphone cable can cause distorted transmitted audio

Bonding Tips

- Bond all metal equipment enclosures to a common RF ground bus
- Use short, wide conductors such as copper flashing or strap or heavy solid wire
  - Solid strap is best because it presents the lowest impedance to RF
- Keep all connections, straps and wires as short and direct as possible
- Connect the ground bus to your AC safety ground and any earth connections
- See Figure 9.2 in text

RF Interference (RFI) and Filters

- Interference between appliances and ham radio is called *radio frequency interference* (RFI)
- Filters are used to …
  - Prevent unwanted signals from being radiated
  - Keep unwanted signals from being received
- AC power line filters keep RF signals from passing into or out of equipment via the hot and neutral conductors of the AC power connection
  - They reject all signals with frequencies greater than a few kHz
- Ferrite chokes are also used to reduce RF current on the outside of shielded audio, microphone, and computer cables.

Filters (cont.)

Ferrite — The RFI Buster

One of the most useful materials in dealing with RFI is the *ferrite core*. Ferrite is a ceramic magnetic material — you may have used ferrite magnets. The type of ferrite used for RFI suppression is specially designed to absorb RF energy over a broad frequency range, such as HF or VHF. Ferrite is available in many different *mixes* of slightly different composition that absorbs best in a particular range.

One popular form of ferrite is the snap-core shown in the figure. The actual ferrite is a rectangular block with a large hole in it, sawn in half. A plastic case with a snap holds the two pieces together. This allows cords or cables to be wound on the core even if they already have connectors attached, such as power cords or video cables.

Ferrite is available as round *cores* (toroids), rods and beads shown in **Figure 9.4**. Wires or cables are then wound on or passed through the ferrite forms. Beads are made large enough that they can be slipped over coaxial cables and secured with tape or a locking wire-tie. A wire or cable wound on such a ferrite core forms an RF choke.

Figure 9.4 — Ferrite is a ceramic magnetic material used to make choke filters for RFI suppression. It is available in many different forms: rings (toroids), rods, and beads. Cables can be passed through or wound on these cores to prevent RF signals from flowing along their outside surfaces.

Interference from Amateur Transmissions

- The most common causes of RFI from your transmissions are *fundamental overload*, *harmonics*, and *spurious emissions*
- Very strong signals may overwhelm a receiver's ability to reject them
  - This is called *fundamental overload*
- Consumer equipment is often unable to reject strong signals outside the bands it is intended to receive
- A *high-pass filter* can be connected at antenna input of FM & TV receivers to reject strong lower-frequency signals from amateur HF signals
- *Broadcast-reject filters* attenuate signals from nearby AM, FM, or TV broadcast stations

Harmonics, Spurious Emissions & Leakage

- Every transmitter's RF output signal contains weak *harmonics* of the desired output signal and other *spurious emissions* that can cause interference to nearby equipment
- A *low-pass* or *band-pass filter* can be installed at the transmitter's connection to the antenna feed line to prevent harmonics
- *Leakage* is another source of interference
- The most common cause of leakage is faulty coaxial connectors on the cable feed line
  - Be sure the connectors are installed correctly and attached tightly

Good Practices in Your Station

- Regardless of the source, you can reduce or eliminate much interference by making sure your own station follows good amateur practices for grounding and filtering
  - Make sure your station is in good working order with appropriate grounding, filtering, and good quality connections
  - Use shielded wire and shielded cables to prevent coupling with unwanted signals and undesired radiation … be sure to connect the shield properly
  - Eliminate interference to your own home appliances and televisions first

RFI and Neighbors

- Start by making sure it's really your transmissions that are causing the problem
- Offer to help determine the nature of interference

- If you're the recipient of the RFI …
  - Make sure your station meets the standards of good amateur practices
  - Offer to help determine the source of interference
  - You may have to politely explain to the neighbor that FCC rules prohibit them from using a device that causes harmful interference
  - Be diplomatic in dealing with your neighbors

PRACTICE QUESTIONS

Which of the following conductors is preferred for bonding at RF?

A. Copper braid removed from coaxial cable
B. Steel wire
C. Twisted-pair cable
D. Flat copper strap

T4A08 D 9-6

What is a symptom of RF feedback in a transmitter or transceiver?

A. Excessive SWR at the antenna connection
B. The transmitter will not stay on the desired frequency
C. Reports of garbled, distorted, or unintelligible voice transmissions
D. Frequent blowing of power supply fuses

T7B11 C 9-6

Which of the following could you use to cure distorted audio caused by RF current on the shield of a microphone cable?

A. Band-pass filter
B. Low-pass filter
C. Preamplifier
D. Ferrite choke

T7B04 D 9-7

Which of the following can cause radio frequency interference?

A. Fundamental overload
B. Harmonics
C. Spurious emissions
D. All these choices are correct

T7B03 D 9-8

What would cause a broadcast AM or FM radio to receive an amateur radio transmission unintentionally?

A. The receiver is unable to reject strong signals outside the AM or FM band
B. The microphone gain of the transmitter is turned up too high
C. The audio amplifier of the transmitter is overloaded
D. The deviation of an FM transmitter is set too low

T7B02 A 9-8

How can fundamental overload of a non-amateur radio or TV receiver by an amateur signal be reduced or eliminated?

A. Block the amateur signal with a filter at the antenna input of the affected receiver

B. Block the interfering signal with a filter on the amateur transmitter

C. Switch the transmitter from FM to SSB

D. Switch the transmitter to a narrow-band mode

T7B05 A 9-8

Which of the following can reduce overload of a VHF transceiver by a nearby commercial FM station?

A. Installing an RF preamplifier
B. Using double-shielded coaxial cable
C. Installing bypass capacitors on the microphone cable
D. Installing a band-reject filter

T7B07 D 9-8

What should be the first step to resolve non-fiber optic cable TV interference caused by your amateur radio transmission?

A. Add a low-pass filter to the TV antenna input
B. Add a high-pass filter to the TV antenna input
C. Add a preamplifier to the TV antenna input
D. Be sure all TV feed line coaxial connectors are installed properly

T7B09 D 9-10

Which of the following is a reason to use shielded wire?

A. To decrease the resistance of DC power connections
B. To increase the current carrying capability of the wire
C. To prevent coupling of unwanted signals to or from the wire
D. To couple the wire to other signals

T6D03 C 9-9

Which of the following actions should you take if a neighbor tells you that your station's transmissions are interfering with their radio or TV reception?

A. Make sure that your station is functioning properly and that it does not cause interference to your own radio or television when it is tuned to the same channel

B. Immediately turn off your transmitter and contact the nearest FCC office for assistance

C. Install a harmonic doubler on the output of your transmitter and tune it until the interference is eliminated

D. All these choices are correct

T7B06 A 9-9

What should you do if something in a neighbor's home is causing harmful interference to your amateur station?

A. Work with your neighbor to identify the offending device
B. Politely inform your neighbor that FCC rules prohibit the use of devices that cause interference
C. Make sure your station meets the standards of good amateur practice
D. All these choices are correct

T7B08 D 9-10

RF Exposure

- With its relatively low frequency, RF energy is *non-ionizing radiation*
- RF radiation is not the same as ionizing radiation from radioactivity because the energy in signals at radio frequencies is far too low to cause an electron to leave an atom (can't cause genetic damage)
- Per FCC rules the station licensee is responsible for ensuring that no one is exposed to RF energy above the FCC exposure limits
- Heating as a result of exposure to RF fields is caused by the body absorbing RF energy
- Absorption varies with frequency because the body absorbs more RF energy at some frequencies than others
- RF burns can be eliminated by proper bonding techniques or by preventing access to an antenna

Exposure Limits

Controlled Exposure (6-Minute Average)

Frequency Range (MHz)	*Power Density (mW/cm^2)*
0.3-3.0	(100)*
3.0-30	($900/f^2$)*
30-300	1.0
300-1500	f/300
1500-100,000	5

Uncontrolled Exposure (30-Minute Average)

Frequency Range (MHz)	*Magnetic Field Power Density (mW/cm^2)*
0.3-1.34	(100)*
1.34-30	($180/f^2$)*
30-300	0.2
300-1500	f/1500
1500-100,000	1.0

f = frequency in MHz
* = Plane-wave equivalent power density

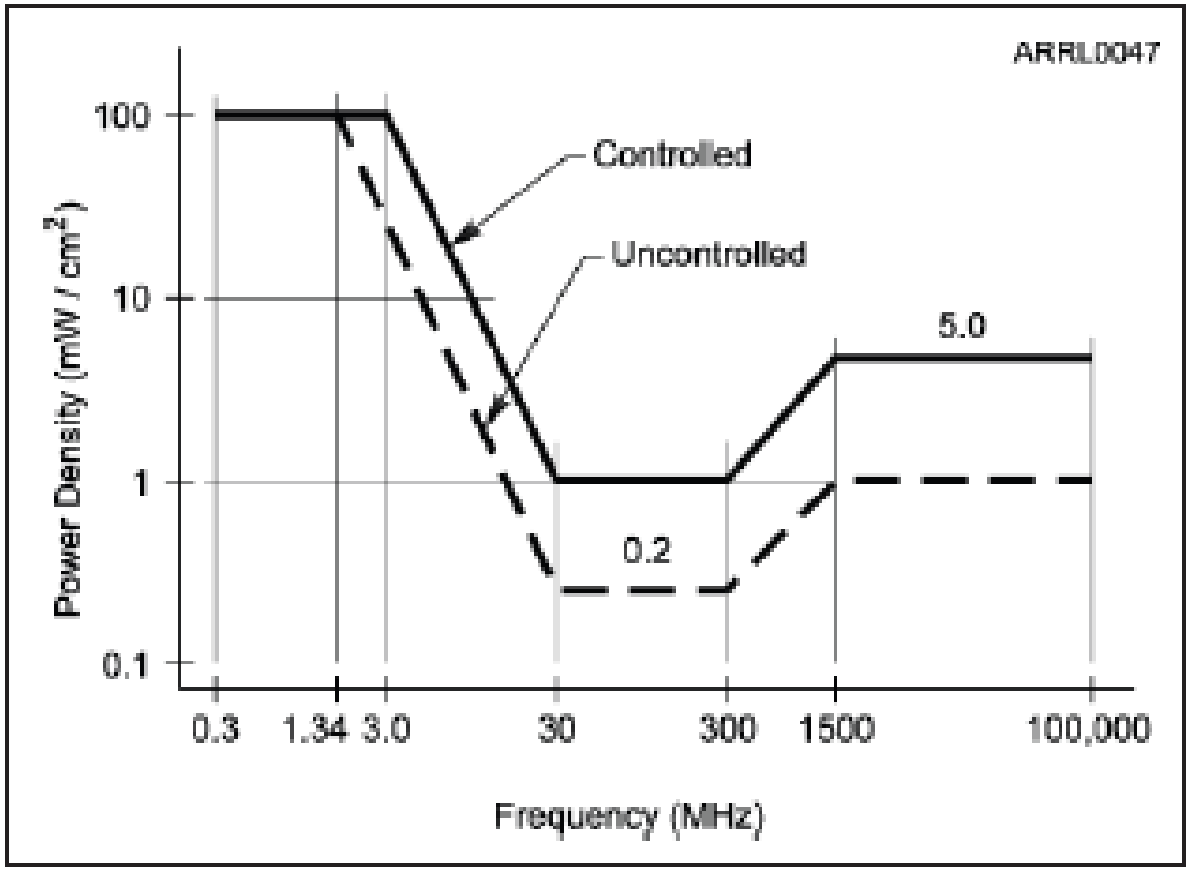

Figure 9.5 — Maximum Permissible Exposure (MPE) limits vary with frequency because the body responds differently to energy at different frequencies. The controlled and uncontrolled limits refer to the environment in which people are exposed to the RF energy.

Exposure Limits (refer to previous slide)

- People in *controlled environments* are aware of their exposure and can take the necessary steps to minimize it
- People in *uncontrolled environments* are not aware of their exposure, (areas open to the general public or your neighbor's property)
- Frequencies at which the body has the highest absorption rate are from 30 to 1500 MHz (see graph)

Averaging and Duty Cycle

- MPE limits are based on averages, not peak exposure, allowing exposure to be averaged over fixed time intervals
- Transmitters only generate RF for a fraction of the time they operate (only when transmitting … they receive or sit idle the remaining time)
  - This lowers the *duty cycle* of the emissions … the ratio of the transmitted signal's on-the-air time to the total operating time
- Duty cycle must be considered when evaluating exposure
- *Because the signal is only present for about ½ the time (50% duty cycle), the signal power can be twice as high and still have the same average power as transmitting continuously with a duty cycle of 100%*

Evaluating Exposure

- All fixed stations must perform an exposure evaluation … three ways of making this evaluation …
  - Use the techniques outlined in the FCC's OET (Office of Engineering Technology) Bulletin 65
  - Measure the power density of your transmissions
  - Make computer models of your station
- You only need to re-evaluate if you change equipment in your station that affects average output power
- The following web page lists resources that make the job a lot easier (http://www.arrl.org/fcc-rf-exposure-regulations-the-station-evaluation)
  - You'll need information on the RF signal's frequency and power level, distance
  - from the antenna and the antenna's radiation pattern

Exposure Safety Measures

- Locate antennas away from where people can get close to them
- Raise the antenna
- Avoid pointing beam antennas where people are likely to be
- Use a lower gain antenna to reduce radiated power density or reduce transmitter power
- Limit the average power of your transmissions
- Place mobile antennas on the roof or trunk of the car (maximizes shielding)
- Use a remote microphone to hold a handheld transceiver away from your head

PRACTICE QUESTIONS

What type of radiation are radio signals?

A. Gamma radiation
B. Ionizing radiation
C. Alpha radiation
D. Non-ionizing radiation

T0C01 D 9-11

Why do exposure limits vary with frequency?

A. Lower frequency RF fields have more energy than higher frequency fields
B. Lower frequency RF fields do not penetrate the human body
C. Higher frequency RF fields are transient in nature
D. The human body absorbs more RF energy at some frequencies than at others

T0C05 D 9-11

What hazard is created by touching an antenna during a transmission?

A. Electrocution
B. RF burn to skin
C. Radiation poisoning
D. All these choices are correct

T0C07 B 9-11

How does RF radiation differ from ionizing radiation (radioactivity)?

A. RF radiation does not have sufficient energy to cause chemical changes in cells and damage DNA
B. RF radiation can only be detected with an RF dosimeter
C. RF radiation is limited in range to a few feet
D. RF radiation is perfectly safe

T0C12 A 9-11

Who is responsible for ensuring that no person is exposed to RF energy above the FCC exposure limits?

A. The FCC
B. The station licensee
C. Anyone who is near an antenna
D. The local zoning board

T0C13 B 9-11

At which of the following frequencies does maximum permissible exposure have the lowest value?

A. 3.5 MHz
B. 50 MHz
C. 440 MHz
D. 1296 MHz

T0C02 B 9-12

How does the allowable power density for RF safety change if duty cycle changes from 100 percent to 50 percent?

A. It increases by a factor of 3
B. It decreases by 50 percent
C. It increases by a factor of 2
D. There is no adjustment allowed for lower duty cycle

T0C03 C 9-13

Why is duty cycle one of the factors used to determine safe RF radiation exposure levels?

A. It affects the average exposure to radiation
B. It affects the peak exposure to radiation
C. It takes into account the antenna feed line loss
D. It takes into account the thermal effects of the final amplifier

T0C10 A 9-13

What is the definition of duty cycle during the averaging time for RF exposure?

A. The difference between the lowest power output and the highest power output of a transmitter
B. The difference between the PEP and average power output of a transmitter
C. The percentage of time that a transmitter is transmitting
D. The percentage of time that a transmitter is not transmitting

T0C11 C 9-13

What factors affect the RF exposure of people near an amateur station antenna?

A. Frequency and power level of the RF field
B. Distance from the antenna to a person
C. Radiation pattern of the antenna
D. All these choices are correct

T0C04 D 9-14

Which of the following is an acceptable method to determine whether your station complies with FCC RF exposure regulations?

A. By calculation based on FCC OET Bulletin 65
B. By calculation based on computer modeling
C. By measurement of field strength using calibrated equipment
D. All these choices are correct

T0C06 D 9-14

How can you make sure your station stays in compliance with RF safety regulations?

A. By informing the FCC of any changes made in your station
B. By re-evaluating the station whenever an item in the transmitter or antenna system is changed
C. By making sure your antennas have low SWR
D. All these choices are correct

T0C09 B 9-14

Which of the following actions can reduce exposure to RF radiation?

A. Relocate antennas
B. Relocate the transmitter
C. Increase the duty cycle
D. All these choices are correct

T0C08 A 9-14

Mechanical Safety … Antennas & Supports

- Make sure your plans satisfy any local zoning codes or covenants or restrictions in your deed or lease
- Place all antennas and feed lines well clear of power lines
- A good guideline is to separate the antenna from the nearest power line by 150% of total height of tower or mast plus antenna
  - A minimum of 10 feet of clearance during a fall is required
- Never attach an antenna or guy wire to a utility pole
- Grounding rules for antennas and supports must be followed according to your local electrical code
- Towers should be grounded with separate 8-foot long ground rods for each tower leg, bonded to the tower and each other
- Place a safety wire through any turnbuckles used to tension guy lines (prevents loosening due to vibration and twisting)

Tower Work and Climbing Safety

- Climbers and ground crew should wear appropriate protective gear any time work is under way on the tower
- Be sure to get sufficient training on safe tower climbing techniques before beginning, use appropriate tie-off to the tower at all times, and always wear an approved climbing harness
- Never climb a crank-up tower supported only by the cable that supports the sections
- Double-check all climbing belts and lanyards before climbing
- Make sure all ropes and load-bearing hardware are in good condition before placing them in service
- Use a gin pole so that you do not have to hoist things directly
- Double-check the latest weather report
- Avoid climbing alone

PRACTICE QUESTIONS

Which of the following is an important safety precaution to observe when putting up an antenna tower?

A. Wear a ground strap connected to your wrist at all times
B. Insulate the base of the tower to avoid lightning strikes
C. Look for and stay clear of any overhead electrical wires
D. All these choices are correct

T0B04 C 9-17

What is the purpose of a safety wire through a turnbuckle used to tension guy lines?

A. Secure the guy line if the turnbuckle breaks
B. Prevent loosening of the turnbuckle from vibration
C. Provide a ground path for lightning strikes
D. Provide an ability to measure for proper tensioning

T0B05 B 9-17

What is the minimum safe distance from a power line to allow when installing an antenna?

A. Add the height of the antenna to the height of the power line and multiply by a factor of 1.5
B. The height of the power line above ground
C. 1/2 wavelength at the operating frequency
D. Enough so that if the antenna falls, no part of it can come closer than 10 feet to the power wires

T0B06 D 9-17

Which is a proper grounding method for a tower?

A. A single four-foot ground rod, driven into the ground no more than 12 inches from the base

B. A ferrite-core RF choke connected between the tower and ground

C. A connection between the tower base and a cold water pipe

D. Separate eight-foot ground rods for each tower leg, bonded to the tower and each other

T0B08 D 9-17

Why should you avoid attaching an antenna to a utility pole?

A. The antenna will not work properly because of induced voltages
B. The 60 Hz radiations from the feed line may increase the SWR
C. The antenna could contact high-voltage power lines
D. All these choices are correct

T0B09 C 9-17

What is required when climbing an antenna tower?

A. Have sufficient training on safe tower climbing techniques
B. Use appropriate tie-off to the tower at all times
C. Always wear an approved climbing harness
D. All these choices are correct

T0B02 D 9-19

Under what circumstances is it safe to climb a tower without a helper or observer?

A. When no electrical work is being performed
B. When no mechanical work is being performed
C. When the work being done is not more than 20 feet above the ground
D. Never

T0B03 D 9-19

Which of the following is an important safety rule to remember when using a crank-up tower?

A. This type of tower must never be painted
B. This type of tower must never be grounded
C. This type of tower must not be climbed unless it is retracted, or mechanical safety locking devices have been installed
D. All these choices are correct

T0B07 C 9-19

END OF MODULE 9