ARRL The national association for AMATEUR RADIO®

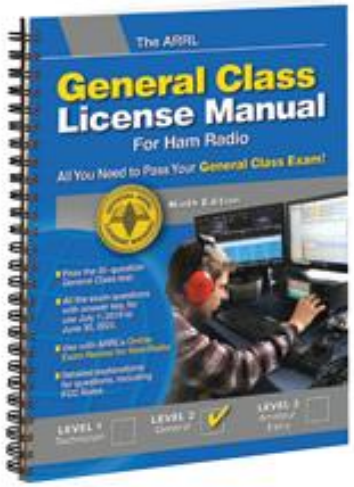
The ARRL General Class License Course

All You Need to Pass Your General Class Exam

LEVEL 2: General

For use with *The ARRL General Class License Manual*, Ninth Edition

General Class License Manual and other resources



http://www.arrl.org/shop/Licensing-Education-and-Training/

Module 9

ARRL General Class
Chapter 9 – Electrical and RF Safety
(9.1, 9.2, 9.3)

Electrical Safety, RF Exposure, Outdoor Safety

Preventing Electric Shock

- Have a master OFF/ON switch for station and workbench
  - Clearly labeled and somewhat away from the equipment
- Don’t put yourself in a position to be shocked
- When working inside equipment, remove, insulate, or secure loose wires and cables
- Use grounding stick to remove charge from capacitors

Table 9.1: Effects of Electric Current Through the Body of an Average Person

Current	*Effect (1 sec contact)*
Below 1 mA	Generally not perceptible.
1 mA	Faint tingle
5 mA	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6 – 25 milliamperes (women)	Painful shock, loss of muscular control*
9 – 30 milliamperes (men)	The freezing current or "let-go" range.* Individual cannot let go, but can be thrown away from the circuit if the extensor muscles are stimulated.
50 – 150 milliamperes	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1,000 – 4,300 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

*If the extensor muscles are excited by the shock, the person may be thrown away from the power source.

Source: W.B. Kouwenhoven, "Human Safety and Electric Shock," Electrical Safety Practices, Monograph, 112, Instrument Society of America, p. 93. November 1968.

Soldering Safety

- Primarily lead-based; tin added to lower melting point
  - Lead is a known toxin
  - Solder in a well-ventilated area
  - When finished, wash hands to remove solder or flux residue
- *As of 2006, environmental regulations require that solder become lead-free*

Wiring Practices

- *National Electrical Code Handbook* contains details for handling ac wiring in home and station
- Use local building codes to ensure home is properly wired to meet special local conditions
- Standard wire color conventions
  - Hot: **Red** or **Black** insulation, connect to brass terminal or screw
  - Neutral: **White** insulation, connect to silver terminal or screw
  - Ground: **Green** insulation or **bare** wire, connect to green or bare terminal or screw

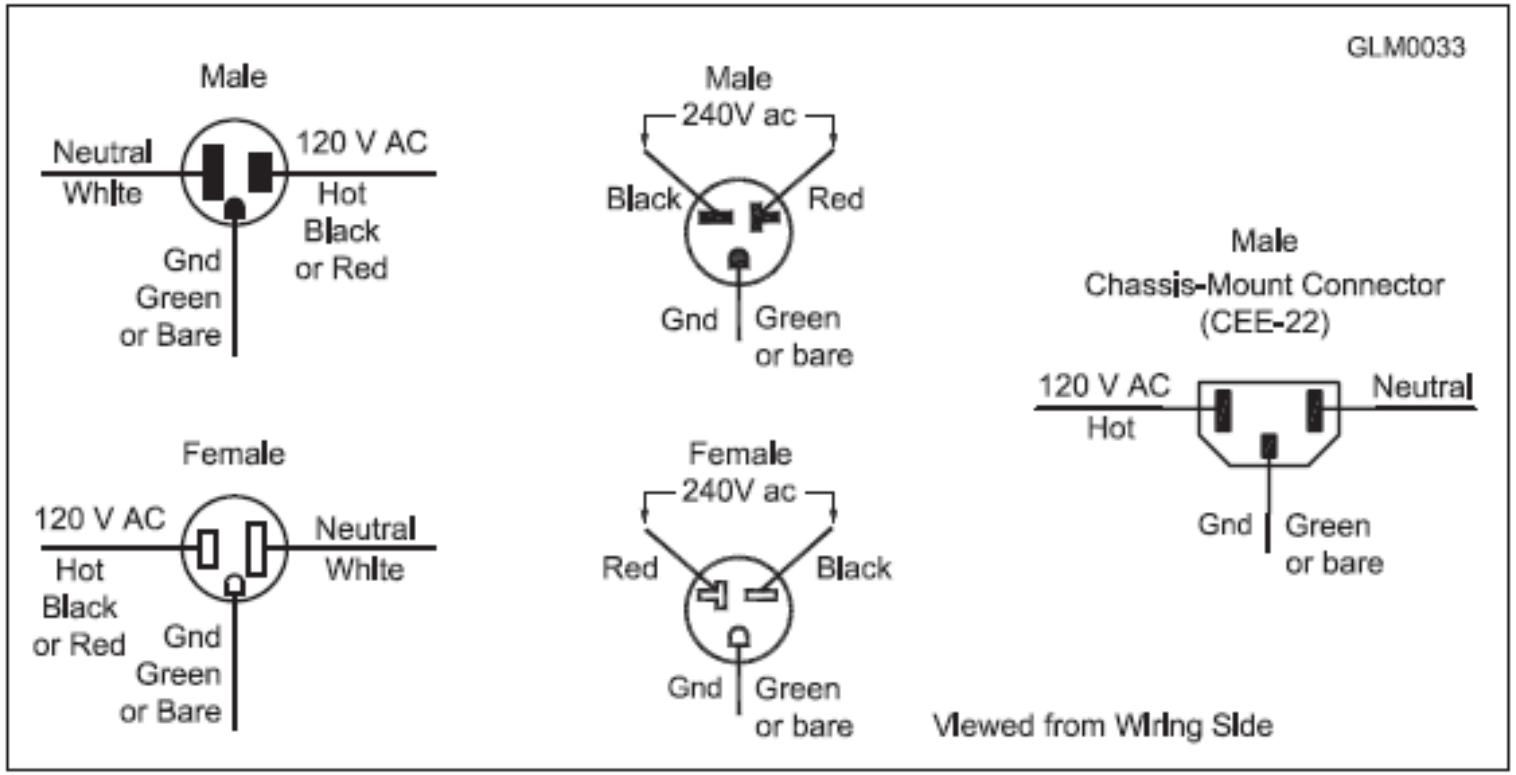


Figure 9.3 — Standard wiring conventions for 120-V and 240-V ac plugs and receptacles. It is critically important to follow the correct wiring techniques for ac power wiring. The white wire is neutral, the green wire is ground, and the black or red wire is the hot lead. Note that 240 V circuits have two hot wires and a ground.

House ac wiring, most common sizes are #12 AWG for 20 A circuits and #14 AWG for 15 A circuits.

Use fuse or circuit breaker in the hot conductor for 120 V circuits or both hot conductors of a 240 V circuit using three or four wires.

Ground fault circuit interrupter (GFCI) circuit breakers

- Used in ac power circuits to prevent shock hazards
- Trips if imbalance is sensed in currents carried by hot and neutral conductors
- Sensitive to just a few milliamperes (mA) of imbalance between hot and neutral, well below threshold for electrical injury

Safety Interlock

- Switch that prevents dangerous voltages or intense RF from being present when a cabinet or enclosure is opened
- Several types …
  - Physically disconnects high voltage (HV) or RF when activated
  - Shorts or grounds HV circuit when activated, possibly blowing a circuit breaker or fuse in a power supply

PRACTICE QUESTIONS

Which of the following is a danger from lead-tin solder?

A. Lead can contaminate food if hands are not washed carefully after handling the solder
B. High voltages can cause lead-tin solder to disintegrate suddenly
C. Tin in the solder can “cold flow,” causing shorts in the circuit
D. RF energy can convert the lead into a poisonous gas

Which wire or wires in a four-conductor connection should be attached to fuses or circuit breakers in a device operated from a 240 VAC single phase source?

A. Only the two wires carrying voltage
B. Only the neutral wire
C. Only the ground wire
D. All wires

According the National Electrical Code, what is the minimum wire size that may be used safely for wiring with a 20 ampere circuit breaker?

A. AWG number 20
B. AWG number 16
C. AWG number 12
D. AWG number 8

Which of the following conditions will cause a Ground Fault Circuit Interrupter (GFCI) to disconnect the 120 or 240 Volt AC line power to a device?

A. Current flowing from one or more of the voltage-carrying wires to the neutral wire
B. Current flowing from one or more of the voltage-carrying wires directly to ground
C. Overvoltage on the voltage-carrying wires
D. All these choices are correct

Which of the following is covered by the National Electrical Code?

A. Acceptable bandwidth limits
B. Acceptable modulation limits
C. Electrical safety inside the ham shack
D. RF exposure limits of the human body

What is the purpose of a power supply interlock?

A. To prevent unauthorized changes to the circuit that would void the manufacturer's warranty
B. To shut down the unit if it becomes too hot
C. To ensure that dangerous voltages are removed if the cabinet is opened
D. To shut off the power supply if too much voltage is produced

Generator Safety

- Fueling and ventilation problems cause more injuries associated with generators than from any other cause
- Install generators outdoors
  - Carbon monoxide (CO) in exhaust can quickly build up to toxic levels
- When using generators regularly, install CO detector alarms in living and working areas
- Generator output connected directly to a home's wiring system must have the ability to disconnect power service from utility lines

PRACTICE QUESTIONS

Which of the following is a primary reason for not placing a gasoline-fueled generator inside an occupied area?

A. Danger of carbon monoxide poisoning
B. Danger of engine over torque
C. Lack of oxygen for adequate combustion
D. Lack of nitrogen for adequate combustion

Which of the following is true of an emergency generator installation?

A. The generator should be located in a well-ventilated area
B. The generator must be insulated from ground
C. Fuel should be stored near the generator for rapid refueling in case of an emergency
D. All these choices are correct

What must you do when powering your house from an emergency generator?

A. Disconnect the incoming utility power feed
B. Insure that the generator is not grounded
C. Insure that all lightning grounds are disconnected
D. All these choices are correct

Lightning

- Lightning protection goals: Provide fire prevention and reduce or prevent electrical damage to equipment
- A metal entry panel where signal and control cables enter the house is a good place to provide a lightning ground
  - Panel should be grounded to a nearby ground rod
- Towers should be grounded with separate 8-foot ground rods for each tower leg
- Grounding wires and straps should be as short and direct as possible
- All towers, masts and antenna mounts should be grounded
- Lightning grounds should be bonded to other safety grounds
- Do not solder connections since solder joints would likely melt and be destroyed if hit with a lightning-sized current

PRACTICE QUESTIONS

Why should soldered joints not be used with the wires that connect the base of a tower to a system of ground rods?

A. The resistance of solder is too high
B. Solder flux will prevent a low conductivity connection
C. Solder has too high a dielectric constant to provide adequate lightning protection
D. A soldered joint will likely be destroyed by the heat of a lightning strike

Which of the following is good practice for lightning protection grounds?

A. They must be bonded to all buried water and gas lines
B. Bends in ground wires must be made as close as possible to a right angle
C. Lightning grounds must be connected to all ungrounded wiring
D. They must be bonded together with all other grounds

RF Exposure

- At high power levels, for some frequencies, the amount of energy that the body absorbs can be a problem
- The *maximum permissible exposure* (MPE): Maximum intensity of RF radiation to which a human being may be exposed
- Factors to consider when estimating MPE: power level or density, frequency, average exposure time, and duty cycle of the transmission (*power density* & *frequency* are primary ones)

Power Density

- Heating from exposure to RF signals is caused by the body tissue absorbing RF energy
- Measured in mW/cm^2 (milliwatts per square centimeter)
- RF field strengths can be measured in V/m and A/m, (mW/cm^2 is the most useful for amateur requirements)
- Power density is highest near antennas and in the directions in which antennas have the most gain
- Decreasing transmitter power and increasing distance from an antenna lowers power density (lowers RF energy)

Absorption and Limits

- SAR (*specific absorption rate*): Rate at which energy is absorbed from the power to which the body is exposed
  - Best measure of RF exposure
  - Varies with frequency, power density, average amount of exposure, and duty cycle of transmission
  - Depends on frequency and size of the body or body part affected; highest where the body and body parts are naturally resonant
- Safe levels of SAR based on demonstrated hazards have been established for by the FCC in the form of maximum permissible exposure (MPE) limits

Fig 9.9

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.

These take into account the variations in the body's sensitivity to RF energy at different frequencies. Also see Table 9.3 (next slide).

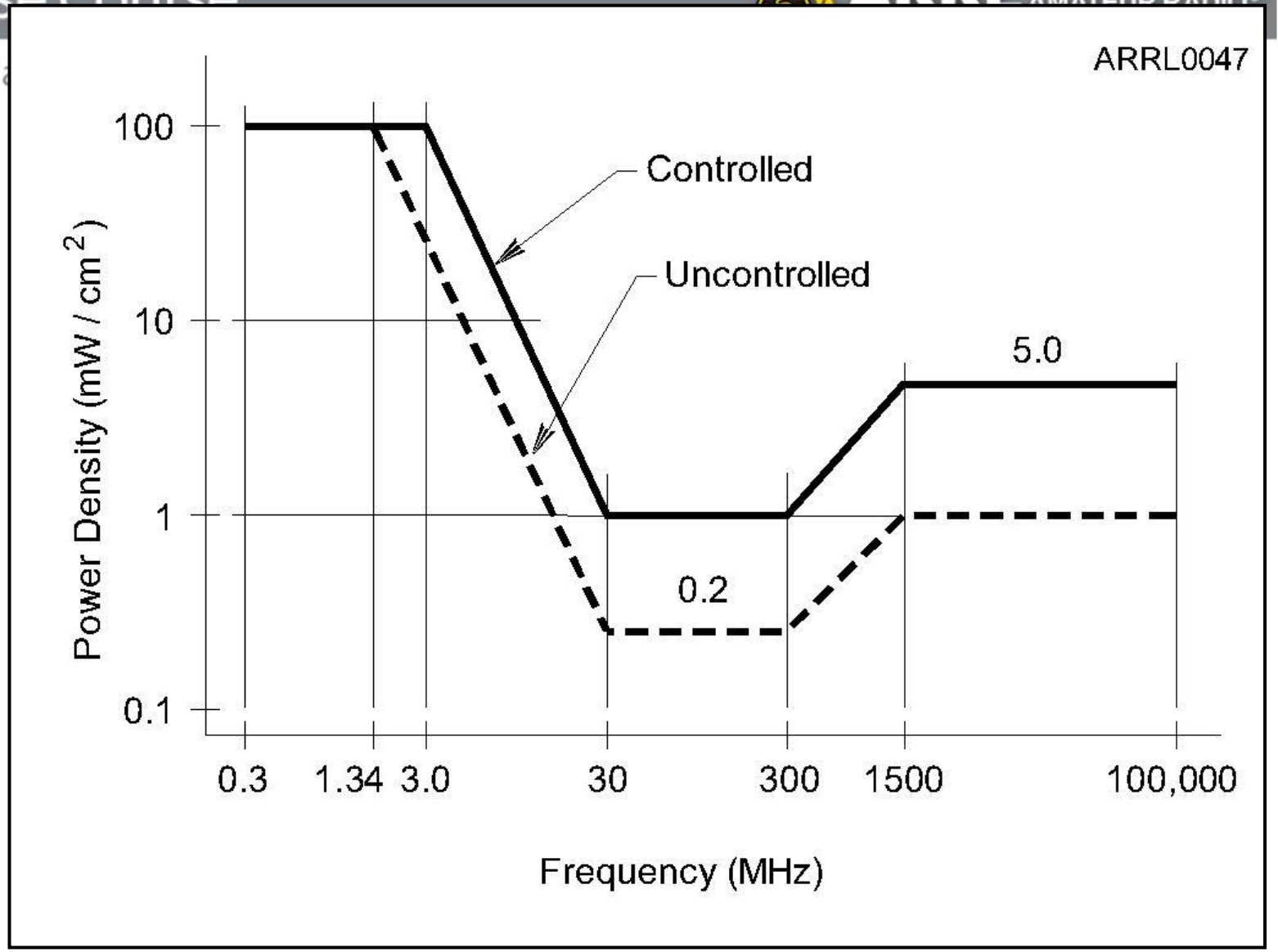


Table 9.3
Maximum Permissible Exposure (MPE) Limits

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

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

Duty Cycle & Controlled/Uncontrolled Environments

- Exposure to RF energy is averaged over fixed time intervals
- Time-averaging evaluates total RF exposure over a fixed time interval
- Two types of averaging periods: Controlled & uncontrolled
- Controlled = You're aware of your exposure and are expected to take reasonable steps to minimize
- Controlled Environment Examples: Transmitting facilities, near antennas
- Uncontrolled environments: General public has access
  - People in uncontrolled environments are not aware of their exposure, but are much less likely to receive continuous exposure

Duty Cycle

- Ratio of the time the transmitter is ON to the total time during the exposure (max = 100%)
- A lower transmission duty cycle permits greater short-term exposure levels for a given average exposure (*called operating duty cycle*)
- Along with operational duty cycle, the different modes themselves have different *emission duty cycles* (see Table 9.4)

Table 9.4

Operating Duty Factor of Modes Commonly Used by Amateurs

For most amateurs operating, listening and transmitting time are about the same, so operating duty cycle is rarely higher than 50%.

Mode	*Duty Cycle*	*Notes*
Conversational SSB	20%	1
Conversational SSB	40%	2
SSB AFSK data	100%	
SSB SSTV	100%	
Voice AM, 50% modulation	50%	3
Voice AM, 100% modulation	25%	
Voice AM, no modulation	100%	
Voice FM	100%	
Digital FM	100%	
ATV, video portion, image	60%	
ATV, video portion, black screen	80%	
Conversational CW	40%	
Carrier	100%	4

Notes
1) Includes voice characteristics and syllabic duty factor. No speech processing.
2) Includes voice characteristics and syllabic duty factor. Heavy speech processing.
3) Full-carrier, double-sideband modulation, referenced to PEP. Typical for voice speech. Can range from 25% to 100% depending on modulation.
4) A full carrier is commonly used for tune-up purposes.

Estimating Exposure & Station Evaluation

- All fixed amateur stations must evaluate their capability to cause RF exposure, no matter whether they use high or low power
  - Mobile and handheld transceivers are exempt
- Limits vary with frequency and PEP
- You are required to perform the evaluation only if your output power exceeds the levels shown for any band (Table 9.5)
- Evaluation is performed by measuring the RF field strength with calibrated field strength meters and calibrated antennas

Table 9.5

Power Thresholds for RF Exposure Evaluation

Band	Power (W)
160 meters	500
80	500
60	500
40	500
30	425
20	225
17	125
15	100
12	75
10	50
6	50
2	50
1.25	50
70 cm	70
33	150
23	200
13	250
SHF (all bands)	250
EHF (all bands)	250

What you need to calculate RF exposure …

- Power at the antenna, including adjustments for duty cycle and feed line loss
- Antenna type (or gain)
- Antenna height above ground
- Operating frequency

Exposure Safety Measures

- Locate or move antennas away from where people can be exposed to excessive RF fields … locate antenna away from property lines and place fence around base of ground-mounted antennas
- Don’t point gain antennas where people are likely to be
- Use beam antennas to direct RF energy away from people
- When using stealth, attic, or other indoor antennas, make sure MPE limits are not exceeded in living quarters
- On VHF and UHF, place mobile antennas on roof or trunk of car to maximize shielding of passengers
- Use dummy load or dummy antenna when testing a transmitter
- Reduce the power and duty cycle of your transmissions

PRACTICE QUESTIONS

What is one way that RF energy can affect human body tissue?

A. It heats body tissue
B. It causes radiation poisoning
C. It causes the blood count to reach a dangerously low level
D. It cools body tissue

Which of the following properties is important in estimating whether an RF signal exceeds the maximum permissible exposure (MPE)?

A. Its duty cycle
B. Its frequency
C. Its power density
D. All these choices are correct

How can you determine that 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

What does “time averaging” mean in reference to RF radiation exposure?

A. The average amount of power developed by the transmitter over a specific 24-hour period
B. The average time it takes RF radiation to have any long-term effect on the body
C. The total time of the exposure
D. The total RF exposure averaged over a certain time

What must you do if an evaluation of your station shows RF energy radiated from your station exceeds permissible limits?

A. Take action to prevent human exposure to the excessive RF fields
B. File an Environmental Impact Statement (EIS-97) with the FCC
C. Secure written permission from your neighbors to operate above the controlled MPE limits
D. All these choices are correct

What precaution should be taken when installing a ground-mounted antenna?

A. It should not be installed higher than you can reach
B. It should not be installed in a wet area
C. It should be limited to 10 feet in height
D. It should be installed such that it is protected against unauthorized access

What effect does transmitter duty cycle have when evaluating RF exposure?

A. A lower transmitter duty cycle permits greater short-term exposure levels
B. A higher transmitter duty cycle permits greater short-term exposure levels
C. Low duty cycle transmitters are exempt from RF exposure evaluation requirements
D. High duty cycle transmitters are exempt from RF exposure requirements

Which of the following steps must an amateur operator take to ensure compliance with RF safety regulations when transmitter power exceeds levels specified in FCC Part 97.13?

A. Post a copy of FCC Part 97.13 in the station
B. Post a copy of OET Bulletin 65 in the station
C. Perform a routine RF exposure evaluation
D. Contact the FCC for a visit to conduct a station evaluation

What type of instrument can be used to accurately measure an RF field?

A. A receiver with an S meter
B. A calibrated field strength meter with a calibrated antenna
C. An SWR meter with a peak-reading function
D. An oscilloscope with a high-stability crystal marker generator

What is one thing that can be done if evaluation shows that a neighbor might receive more than the allowable limit of RF exposure from the main lobe of a directional antenna?

A. Change to a non-polarized antenna with higher gain
B. Post a warning sign that is clearly visible to the neighbor
C. Use an antenna with a higher front-to-back ratio
D. Take precautions to ensure that the antenna cannot be pointed in their direction

What precaution should you take if you install an indoor transmitting antenna?

A. Locate the antenna close to your operating position to minimize feed-line radiation
B. Position the antenna along the edge of a wall to reduce parasitic radiation
C. Make sure that MPE limits are not exceeded in occupied areas
D. Make sure the antenna is properly shielded

Outdoor Safety … Installing Antennas

- Place all antennas and feed lines well clear of power lines!
- No part of antenna system should be closer than 10 feet from power lines
- When working on roofs, trees, or towers, climbers and helpers should wear appropriate protective gear at all times … run through a safety checklist every time
- Turn off and unplug all ac equipment, locking circuits out and tagging them if possible
- Transmitters should be off and disconnected from feed line to avoid shock or excessive RF exposure
- Transmitters should be off and disconnected from feed line to avoid shock or excessive RF exposure
- Belts and harnesses must be within their service life and adequately rated for weight

PRACTICE QUESTIONS

Which of these choices should be observed when climbing a tower using a safety belt or harness?

A. Never lean back and rely on the belt alone to support your weight
B. Confirm that the belt is rated for the weight of the climber and that it is within its allowable service life
C. Ensure that all heavy tools are securely fastened to the belt D-ring
D. All these choices are correct

What should be done by any person preparing to climb a tower that supports electrically powered devices?

A. Notify the electric company that a person will be working on the tower
B. Make sure all circuits that supply power to the tower are locked out and tagged
C. Unground the base of the tower
D. All these choices are correct

What precaution should you take whenever you adjust or repair an antenna?

A. Ensure that you and the antenna structure are grounded
B. Turn off the transmitter and disconnect the feed line
C. Wear a radiation badge
D. All these choices are correct

END OF MODULE 9

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