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TENTH EDITION

GENERAL CLASS

LICENSE COURSE FOR HAM RADIO

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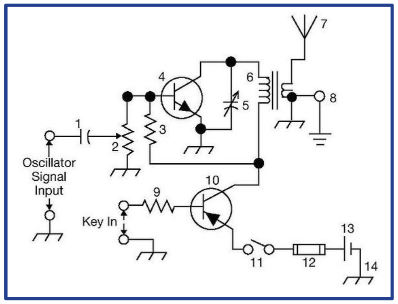

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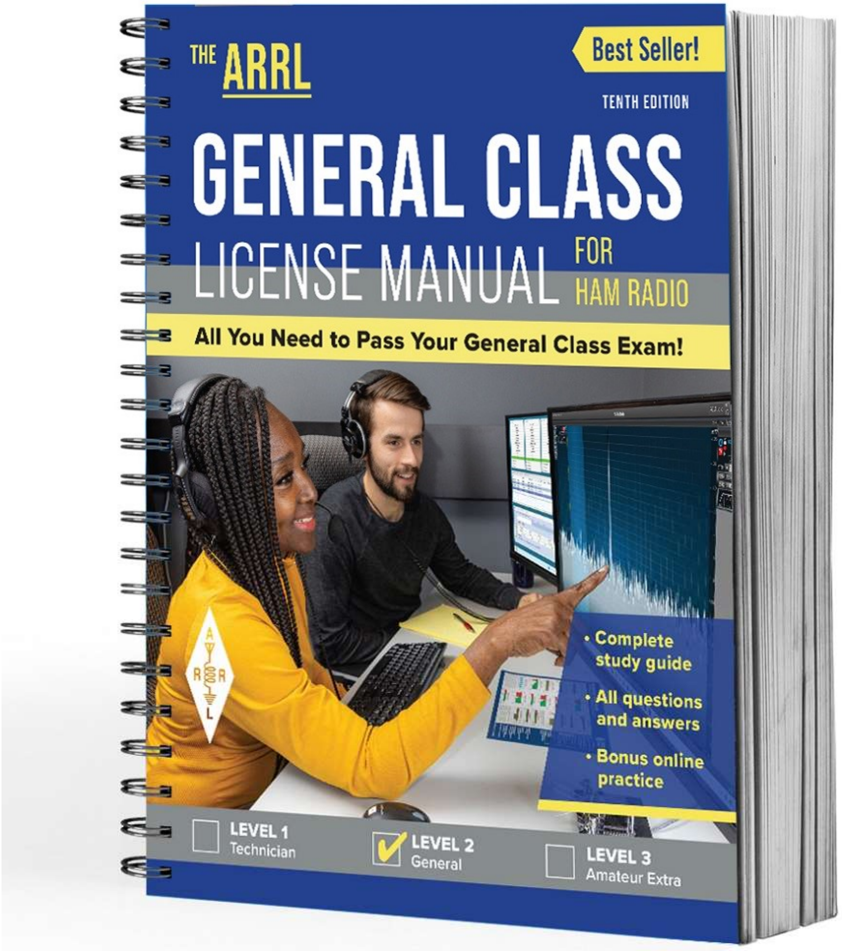

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Chapter 9 Part 1 of 1

ARRL General Class
Electrical and RF Safety
Sections 9.1, 9.2, 9.3

Electrical Safety, RF Exposure, Outdoor Safety

Section 9.1: Electrical 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

Figure 9.1: Diagram of a Grounding Stick

A grounding stick is touched to all circuitry inside an enclosure to insure that no high voltage is present. The alligator clip is attached to an electrical ground and the eyebolt is put in contact with the circuitry.

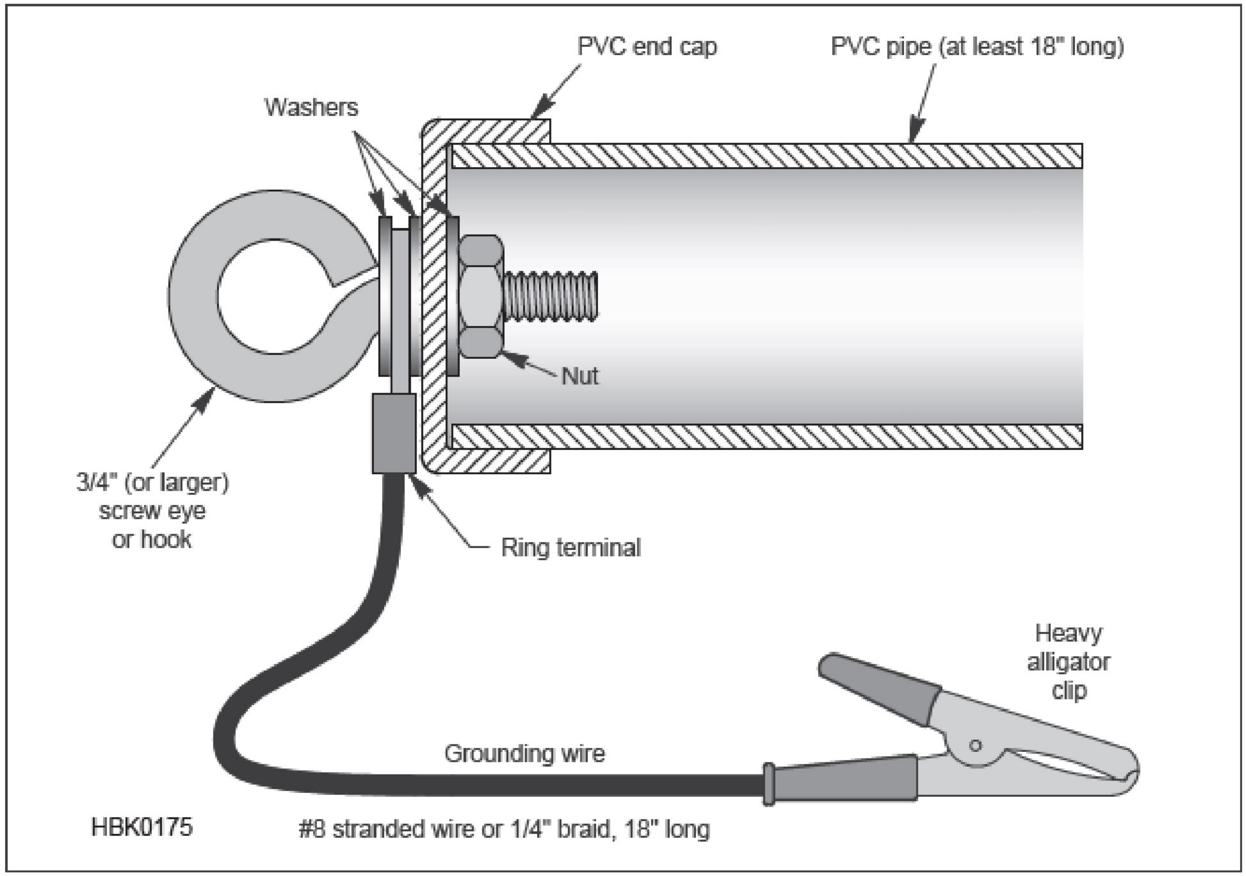


Table 9.1: Effects of Electric Current Through the Body of an Average Person

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
  - Rosin flux smoke likely not good for you in high doses
  - When finished, wash hands to remove solder or flux residue
- As of 2006, environmental regulations were passed for solder to eventually be lead-free (leaded solder still available)
  - Lead-free solder melts at significantly higher temperature than traditional “60/40” solder (60% tin / 40% lead) … greater risk of damaging heat-sensitive components

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

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

WARNING: Don't run antenna feed lines over power lines or service drops from a transformer to the house.

Fig 9.3

Standard Wiring Conventions

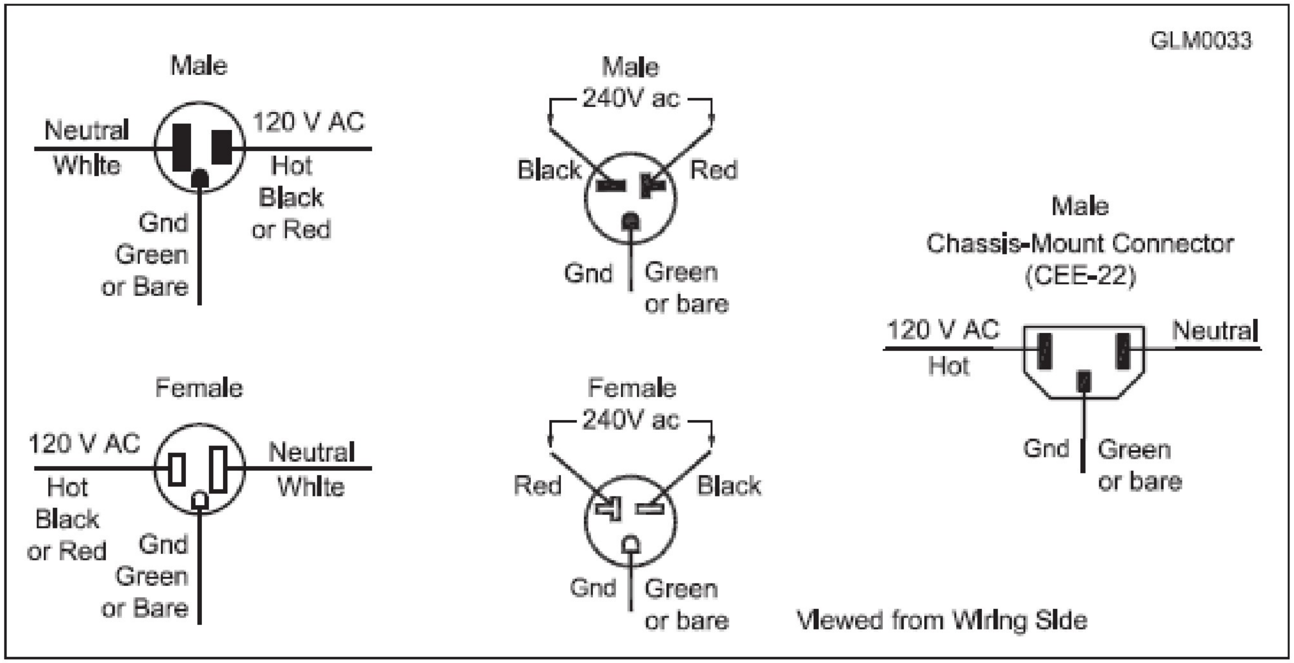


Figure 9.3 — Standard wiring conventions for 120-V and 240-V ac plugs and receptacles. It is critically important to follow the correct wiring techniques for ac power wiring. The white wire is neutral, the green wire is ground, and the black or red wire is the hot lead. Note that 240 V circuits have 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. See Table 9.2.

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.

Table 9.2

The rating of wire to carry current is called its ampacity.

When you are finished with the wiring job, verify that you have the connections correct by using an ac circuit tester.

Table 9.2
Current Carrying Capacity of Some Common Wire Sizes

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

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

Fuses and Circuit Breakers

- Interrupt excessive current flow
  - Fuses do so by melting a short length of metal
  - Circuit breakers act like fuses and “trip” when current overloads occur
- Use properly sized fuses and circuit breakers
- When installing fuses or circuit breakers in an ac wiring circuit, be sure to place them only in the correct lines (***never*** *in the neutral or ground*)
- Be sure there is a fuse or circuit breaker in the hot conductor for 120 V circuits or both hot conductors of a 240 V circuit

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 wire or wires in a four-conductor 240 VAC circuit should be attached to fuses or circuit breakers?

A. Only the hot wires
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 size of fuse or circuit breaker would be appropriate to use with a circuit that uses AWG number 14 wiring?

A. 30 amperes
B. 25 amperes
C. 20 amperes
D. 15 amperes

Which of the following conditions will cause a ground fault circuit interrupter (GFCI) to disconnect AC power?

A. Current flowing from one or more of the hot wires to the neutral wire
B. Current flowing from one or more of the hot wires directly to ground
C. Overvoltage on the hot 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 of the station
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

G0B12 (C) Page 9-6

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
- Generators should always be shut off when refueling to avoid igniting fumes or splashed liquid from the spark plug
- A fire extinguisher should be kept near the generator and separated from the fuel

PRACTICE QUESTIONS

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

A. The generator should be operated 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

G0B09 (A) Page 9-7

Lightning

- Goals of lightning protection:
  - Provide fire prevention for your home
  - Reduce or prevent electrical damage to your equipment
- Use metal entry panel where signal & control cables enter the house
  - Panel should be grounded nearby with a heavy, short metal strap
  - Ground rod must be bonded to the ac service entry ground rod outside the building with a heavy conductor
  - Lightning arrestors should be installed at the entry panel (where feed line enters)
- Grounding wires and straps should be as short and direct as possible
- Do not use solder to make ground connections (solder joints could melt if hit with a lightning-sized current -- use mechanical clamps, brazing, or welding)
- All towers, masts, and antennas should be grounded

PRACTICE QUESTIONS

Why should soldered joints not be used in lightning protection ground connections?

A. A soldered joint will likely be destroyed by the heat of a lightning strike
B. Solder flux will prevent a low conductivity connection
C. Solder has too high a dielectric constant to provide adequate lightning protection
D. All these choices are correct

Where should the station's lightning protection ground system be located?

A. As close to the station equipment as possible
B. Outside the building
C. Next to the closest power pole
D. Parallel to the water supply line

G0B04 (B) Page 9-8

Which of the following is required for lightning protection ground rods?

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

G0B11 (D) Page 9-8

Where should lightning arrestors be located?

A. Where the feed lines enter the building
B. On the antenna, opposite the feed point
C. In series with each ground lead
D. At the closest power pole ground electrode

G0B13 (A) Page 9-8

Section 9.2
RF Exposure

- At high power levels, for some frequencies, the amount of energy that the body absorbs can be a problem
- *Maximum permissible exposure* (MPE): Maximum intensity of RF radiation to which a human being may be exposed
- Factors to consider when estimating MPE: transmitted power level or density, frequency, average exposure time, and duty cycle of the transmission (*power density* & *frequency* are primary ones)
- Stations with a time-averaged transmission of more than one milliwatt are subject to the FCC's RF exposure rules; if your station exceeds the exemption criteria, you will need to evaluate it according to the FCC OET Bulletin 65

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 also 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), and vice versa

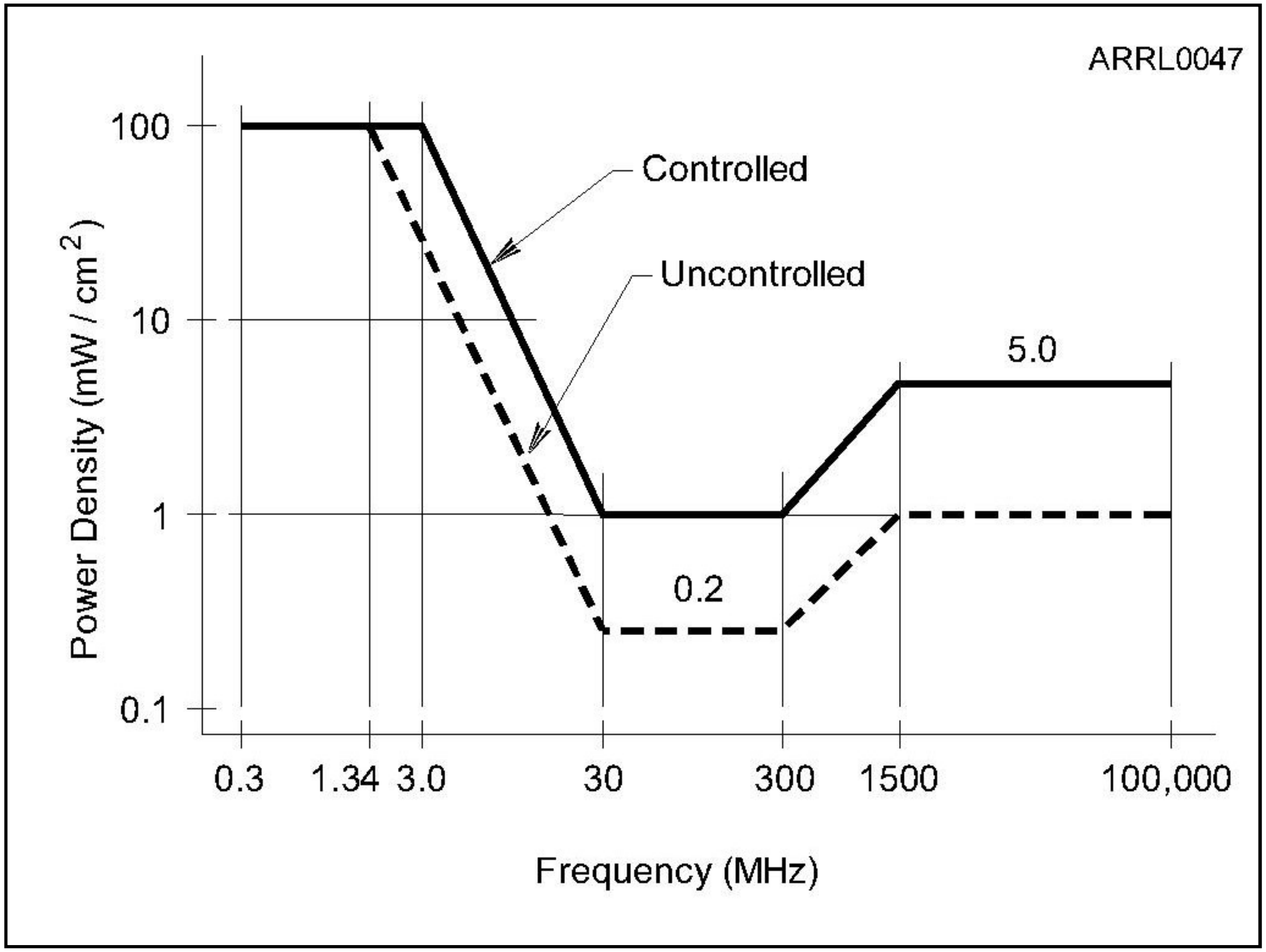
Absorption and Limits

- SAR (*specific absorption rate*): Rate at which energy is absorbed from the power to which the body is exposed
  - Best measure of RF exposure, but difficult to measure
  - 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).



Limits for Occupational/Controlled Exposure

(Combined Table 9.3A & 9.3B)

Controlled Exposure (6-Minute Average)		*Uncontrolled Exposure (30-Minute Average)*	
Frequency Range (MHz)	*Power Density (mW/cm^2)*	*Frequency Range (MHz)*	*Magnetic Field Power Density (mW/cm^2)*
0.3-3.0	(100)*		
3.0-30	$(900/f^2)$*	0.3-1.34	(100)*
30-300	1.0	1.34-30	$(180/f^2)$*
300-1500	f/300	30-300	0.2
1500-100,000	5	300-1500	f/1500
		1500-100,000	1.0

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

Controlled Exposure Limits apply to individuals trained in RF exposure (such as licensed amateurs)

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Table 9.3B
Limits for General Population/Uncontrolled Exposure

Frequency Range (MHz)	*Electric Field Strength (V/m)*	*Magnetic Field Strength (A/m)*	*Power Density (mW/cm²)*	*Averaging Time (minutes)*
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	(180/f2)*	30
30-300	27.5	0.073	0.2	30
300-1500	—	—	f/1500	30
1500-100,000	—	—	1.0	30

f = frequency in MHz
* = Plane-wave equivalent power density (see Notes 1 and 2).

Note 1: This means the equivalent far-field strength that would have the E or H-field component calculated or measured. It does not apply well in the near field of an antenna. The equivalent far-field power density can be found in the near or far field regions from the relationships:

Pd = |Etotal|2 / 3770 mW/cm² or from $P_d = |H_{total}|^2 \times 37.7$ mW/cm².
Note 2: $|E_{total}|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2$, and $|H_{total}|^2 = |H_x|^2 + |H_y|^2 + |H_z|^2$

Uncontrolled Exposure Limits apply to individuals NOT trained in RF exposure (general public)

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%)
- Same as *duty factor*, but duty factor is expressed as a fraction (0.25 instead of 25%)
- A lower transmission duty cycle permits greater short-term exposure levels for a given average exposure (*called operational duty cycle*)
- The less time the transmitter is ON, the lower the average exposure, permitting greater short-term exposure levels for a given average exposure
- 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.

Calculating Average Duty Cycle Power

A station is using SSB without speech processing, transmitting and listening for equal amounts of time and with transmitted power of 150 W. Calculate the average power output.

Average Duty Cycle Power =

Transmitted Power × Emission Duty Cycle × Operating Duty Cycle

Transmitted Power = 150 W (given in the problem statement)

See Table 9.4 for Emission Duty Cycle. For conversational SSB without speech processing = 20%

Operating Duty Cycle = 50% (half time transmitting, half receiving)

Average Duty Cycle Power = 150 W × 20% × 50% = 15 W

Estimating Exposure & Station Evaluation

(ERP = Effective Radiated Power)

- All *fixed* amateur stations must evaluate their capability to cause RF exposure, no matter whether they use high or low power
- Limits vary with frequency and PEP
- Required to perform the evaluation if your power exceeds the levels shown for any band (Table 9.5A)
- Table 9.5B gives the minimum distances from the antenna for which the FCC exemptions can be used for most amateur bands
- Exposure evaluation is performed by 3 different methods:
  - Measuring RF field strength with calibrated meters and calibrated antennas, or
  - Use computer modeling/calculation per FCC OET Bulletin 65, or
  - Easiest way … ARRL's online calculator … www.arrl.org/rf-exposure-calculator

Table 9.5A

Maximum Exempt ERP

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

	Frequency (MHz)	*Maximum ERP (Watts)*
VLF	0.3 – 1.34	$1920 \times R^2$
HF	1.34 – 30	$3450 \times R^2 / f^2$
VHF	30 – 300	$3.83 \times R^2$
UHF	300 – 1500	$0.0128 \times R^2 \times f$
MW	1500 – 100,000	$19.2 \times R^2$

Note: R is distance in meters and f is frequency in MHz.

Example Calculations:

On 14.1 MHz at 10 meters from the antenna, the maximum exempt ERP is $3450 \times 10^2 / 14.1^2 = 1735$ W.

On 22.2 MHz at 10 meters from the antenna, the maximum exempt ERP is $3450 \times 10^2 / 22.2^2 = 433$ W.

On 50.1 MHz at 5 meters from the antenna, the maximum exempt ERP is $3.83 \times 5^2 = 96$ W.

On 146 MHz at 0.5 meters from the antenna, the maximum exempt ERP is $3.83 \times 0.5^2 = 0.96$ W.

Table 9.5B

Minimum Exemption Distances ($\lambda/2\pi$)

Band (MHz)	*Distance*	*Band (MHz)*	*Distance*
1.8	87.0 ft	24.9	6.3 ft
3.6	43.5 ft	28.2	5.6 ft
3.9	40.2 ft	50.1	3.1 ft
7.1	22.1 ft	146	1.1 ft
10.1	15.5 ft	223	8.4 in
14.1	11.1 ft	440	4.3 in
18.1	8.7 ft	902	2.1 in
21.2	7.4 ft	1296	1.5 in

Exposure Safety Measures / Good Practices

- 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

G0A01 (A) Page 9-9

Which of the following is used to determine RF exposure from a transmitted signal?

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

G0A02 (D) Page 9-9

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

G0A03 (D) [97.13(c)(1)] Page 9-13

What does “time averaging” mean when evaluating 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 period

What must you do if an evaluation of your station shows that the RF energy radiated by your station exceeds permissible limits for possible human absorption?

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

G0A05 (A) [97.13(c)(2), 1.1307(b)] Page 9-13

What must you do if your station fails to meet the FCC RF exposure exemption criteria?

A. Perform an RF Exposure Evaluation in accordance with FCC OET Bulletin 65

B. Contact the FCC for permission to transmit

C. Perform an RF exposure evaluation in accordance with World Meteorological Organization guidelines

D. Use an FCC-approved band-pass filter

G0A06 (A) [97.13(c)(2), 1.1307(1)(b)(3)(i)] Page 9-9

What is the effect of modulation duty cycle on RF exposure?

A. A lower duty cycle permits greater power levels to be transmitted
B. A higher duty cycle permits greater power levels to be transmitted
C. Low duty cycle transmitters are exempt from RF exposure evaluation requirements
D. High duty cycle transmitters are exempt from RF exposure requirements

G0A07 (A) Page 9-11

Which of the following steps must an amateur operator take to ensure compliance with RF safety regulations?

A. Post a copy of FCC Part 97.13 in the station
B. Notify neighbors within a 100-foot radius of the antenna of the existence of the station and power levels
C. Perform a routine RF exposure evaluation and prevent access to any identified high exposure areas
D. All these choices are correct

G0A08 (C) [97.13(c)(2)] Page 9-12

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

A. receiver with digital signal processing (DSP) noise reduction
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

G0A09 (B) Page 9-13

What should be done if evaluation shows that a neighbor might experience 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. Use an antenna with a higher front-to-back ratio
C. Take precautions to ensure that the antenna cannot be pointed in their direction when they are present
D. All these choices are correct

G0A10 (C) Page 9-13

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

G0A11 (C) Page 9-14

What stations are subject to the FCC rules on RF exposure?

A. All commercial stations; amateur radio stations are exempt
B. Only stations with antennas lower than one wavelength above the ground
C. Only stations transmitting more than 500 watts PEP
D. All stations with a time-averaged transmission of more than one milliwatt

G0A12 (D) [1.1307(1)(b)(3)(i)(A)] Page 9-9

Section 9.3: 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
- Belts and harnesses must be within their service life and adequately rated for weight
- Check the weather report!
- Take your time

PRACTICE QUESTIONS

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

A. Always hold on to the tower with one hand

B. Confirm that the harness 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 harness

D. All these choices are correct

G0B07 (B) Page 9-16

What should be done before climbing 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

G0B08 (B) Page 9-16

END OF CHAPTER 9 PART 1 OF 1

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