

The No-Nonsense, General Class License Study Guide

(for tests given after July 1, 2007)

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NOT FOR SALE!!

What is amateur (ham) radio?

Amateur radio, also known as ham radio, is a hobby enjoyed by hundreds of thousands of Americans and millions around the world. They enjoy communicating with one another via two-way radios and experimenting with antennas and electronic circuits.

All kinds of people are amateur radio operators, also known as "hams." Hams are young, old, men, women, boys, and girls. Kids as young as seven years old have gotten amateur radio licenses and many hams are active into their 80s and beyond. You never know who you'll run into on the amateur radio bands: young and old, teachers and students, engineers and scientists, doctors and nurses, mechanics and technicians, kings and entertainers.

For example, did you know that most of the astronauts sent up to the International Space Station (ISS) in the last five to ten years have been licensed radio amateurs? They use the amateur radio station on board the ISS to communicate with school groups all over the world as they are flying over.

How do you get into amateur radio?

With just a little study, you can learn all you need to know to get a Technician Class license, which is the license most popular with beginners. To get a Technician Class license, you must take a test with 35 multiple-choice questions. The test, sometimes referred to as Element 2, covers basic regulations, operating practices, and electrical and electronics theory. Knowing Morse Code is not required to get this license, nor any other license as of February 2007. Technician Class licensees have all amateur radio privileges above 30 MHz, including the very popular 2-meter band. Also, as of February 2007, Technician Class licensees can operate CW on certain sub-bands in the 80m, 40m, 15m, and 10m bands, as well as phone in the 10m band.

The General Class license is the next step. When you pass the General Class license test, sometimes referred to as Element 3, you can operate phone and digital modes in parts of all the HF bands. The test is another 35-question, multiple-choice examination. The test is more difficult from a technical point of view than the Technician Class license. This study guide is designed to help you pass Element 3.

To get an Amateur Extra Class license, you must pass a 50-question examination, sometimes referred to as Element 4. This is an even more difficult test, and there are many questions in the question pool on topics that some might consider arcane.

Where do I take the test?

Amateur radio license examinations are given by Volunteer Examiners, or VEs. VEs are licensed radio amateurs who have been trained to administer amateur radio tests. To find out when the VEs in your area will be giving the test go to the American Radio Relay League's (ARRL). On the Exam Session Search page (<http://www.arrl.org/arrlvec/examsearch.phtml>), you will be able to search for test sessions that are close to you. If you do not have access to the Internet, you can phone the ARRL at 860-594-0200.

Can I really learn how to be an amateur radio operator from a simple manual like this?

Yes and no. This manual will help you get your license, but getting your license is only the beginning. There is still much to learn, and to get the most out of your General Class license, you will have to continually learn new things.

I am normally not a big fan of this type of approach to getting an amateur radio license. It will teach you the answers to the test questions, but not give you a deep understanding of electronics, radio, or the rules and regulations. That will be up to you after you get your license.

I hope that by helping you get your license that you'll be encouraged to become an active radio amateur and get on the air, participate in public service and emergency communications, join an amateur radio club, and experiment with radios, antennas, and circuits. These are the activities that will really help you learn about radio in depth, and in the end, help you be confident in your abilities as an amateur radio operator.

How do I use this manual?

Simply read through the manual and take some practice tests. You will find the answers to questions in **bold**. You can take practice tests online at

- QRZ.Com,
- AA9PW.Com, and
- HamTestOnline.Com.

You can use all three for free. HamTestOnline does, however, offer some features that the others don't, and you have to subscribe to use them.

Good luck and have fun!

I hope that you find this study guide useful and that you'll become a radio amateur. Remember that getting your license is just a start, and that you will be continually learning new things.

If you have any comments, questions, compliments or complaints, I want to hear from you. E-mail me at kb6nu@w8pgw.org. My goal is to continually refine this study guide and to continually make it better.

Acknowledgment

I would like to acknowledge Bruce Spratling, W8BBS for his support and his work on an earlier version of Technician Class study guide.

73!

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Subelement G1

Commission's Rules (5 groups, 5 exam questions)

G1A - General class control operator frequency privileges; primary and secondary allocations

When you get your General Class license you will have many more frequencies to use than when you were a Technician. On **160, 30, 17, 12, and 10 meters**, a General Class license holder is granted all amateur frequency privileges. **24.940 MHz** is in the 12 meter band.

On other bands, however, there are restrictions. For example, phone operation prohibited on **30 meters**. Image transmission is also prohibited on **30 meters**. **60 meters** is the amateur band that restricts communication to specific channels, using only USB voice, and prohibits all other modes, including CW and data.

When a General Class licensee is not permitted to use the entire voice portion of a particular band, **the upper end** of the voice segment is generally available to them. Here are some examples:

- **7.250 MHz** is in the General Class portion of the 40 meter band.
- **3900 kHz** is within the General class portion of the 75 meter phone band.
- **14305 kHz** is within the General Class portion of the 20 meter phone band.
- **21300 kHz** is within the General Class portion of the 15 meter band.

When a General Class licensee is not permitted to use the entire voice portion of a particular band, it is usually the lowest 25 kHz of a band that is not available to him or her. For example, 3520 kHz would not be available, but **3560 kHz** is within the General Class portion of the 80 meter band.

All of these answers are correct when talking about frequencies available to a control operator holding a General Class license: 28.020 MHz, 28.350 MHz, 28.550 MHz.

Some amateur radio bands are shared with other services. Be aware, however that **none** of the amateur band are shared with the Citizens Radio Service.

When the FCC rules designate the amateur service as a secondary user and another service as a primary user on a band, **amateur stations are allowed to use the frequency band only if they do not cause harmful interference to primary users**. For example, when operating on either the 30 or 60 meter bands, a station in the primary service interferes with your contact, you must **stop transmitting at once and/or move to a clear frequency**. Amateur radio stations are a secondary service in the 60 meter band, and **they must not cause harmful interference to stations operating in other radio services**.

G1B - Antenna structure limitations; good engineering and good amateur practice; beacon operation; restricted operation; retransmitting radio signals

In addition to the regulations regarding frequencies that you can use, there are a whole raft of regulations that determine what you can and cannot do. For example, you may wish to build a tower for your antenna system. If you do so, you must be aware that **200 feet** is the maximum height above ground to which an antenna structure may be erected without requiring notification to the FAA and registration with the FCC, provided it is not at or near a public-use airport.

You may also want to set up a beacon station. **Observation of propagation and reception, or other related activities** is a purpose of a beacon station as identified in the FCC Rules. One of the conditions with which beacon stations must comply is that **there must be no more than one beacon signal in the same band from a single location**. The power limit for beacon stations is **100 watts PEP output**.

You must also never use secret codes. The use of abbreviations or procedural signals in the amateur service are restricted, but **they may be used if they do not obscure the meaning of a message**. The only time an amateur station is permitted to transmit secret codes is **to control a space station**.

Before an amateur station may provide news information to the media during a disaster, **the information must directly relate to the immediate safety of human life or protection of property and there is no other means of communication available**.

The only time music may be transmitted by an amateur station is **when it is an incidental part of a space shuttle or ISS retransmission**.

All of these answers are correct when referring to transmissions prohibited by the FCC Rules for amateur radio stations:

- Transmission of music as the primary program material during a contact
- The use of obscene or indecent words
- Transmission of false or deceptive messages or signals

An amateur station may transmit communications in which the licensee or control operator has a pecuniary (monetary) interest **only when other amateurs are being notified of the sale of apparatus normally used in an amateur station and such activity is not done on a regular basis**.

For operations not explicitly covered by the Part 97 rules, the FCC requires an amateur station be operated **in conformance with good engineering and good amateur practice**. **The FCC** determines what “good engineering and good amateur practice” means as they apply to the operation of an amateur station. If an amateur station is causing interference to a broadcast receiver of good engineering design, the FCC may **restrict the amateur station op-**

eration to times other than 8 pm to 10:30 pm local time every day, as well as on Sundays from 10:30 am to 1 pm local time.

GIC - Transmitter power regulations; HF data emission standards

In general, 1500 watts PEP is the absolute maximum amount of power that amateur radio stations can use when transmitting. Other than the 1500 watt PEP limit, the only other restriction placed on transmitter power in the 14 MHz band (and all other bands for that matter) is that **only the minimum power necessary to carry out the desired communications should be used.**

1500 watts PEP output is the maximum transmitting power an amateur station may use on the 12 meter band. **1500 watts PEP output** is the maximum transmitting power a General class licensee may use when operating between 7025 and 7125 kHz. **1500 watts PEP output** is the maximum transmitting power a station with a General Class control operator may use on the 28 MHz band. **1500 watts PEP output** is the maximum transmitting power an amateur station may use on 1825 kHz.

On 30m and 60m, the power limit is much lower. **200 watts PEP output** is the maximum transmitting power an amateur station may use on 10.140 MHz. When a station is transmitting on the 60 meter band, **transmissions must not exceed an effective radiated power of 50 Watts PEP referred to a dipole antenna.**

There are also restrictions on how fast you can send digital data. For example, **300 baud** is the maximum symbol rate permitted for RTTY emissions transmitted on frequency bands below 28 MHz. **1200 baud** is the maximum symbol rate permitted for RTTY or data emission on the 10m band. **19.6 kilobaud** is the maximum symbol rate permitted for RTTY or data emission transmissions on the 6 and 2 meter bands. **19.6 kilobaud** is the maximum symbol rate permitted for packet emission transmissions on the 2 meter band.

There are also some bandwidth limitations that you need to know. **20 kHz** is the maximum authorized bandwidth for RTTY, data or multiplexed emissions using an unspecified digital code transmitted on the 6 and 2 meter bands. **2.8 kHz** is the maximum bandwidth permitted by FCC rules for amateur radio stations when operating on USB frequencies in the 60-meter band.

GID - Volunteer Examiners and Volunteer Examiner Coordinators; temporary identification

Amateur radio license examinations are given by amateur radio operators who have volunteered to perform this service and have been accredited to do so. They are called volunteer examiners (VEs), and volunteer examiners are accredited by a **Volunteer Examiner Coordinator**. To gain accreditation, VEs must meet several requirements.

For example, to be accredited, **the person must hold a U.S. amateur radio license of General class or above**. You may participate as a VE in administering an amateur radio license examination **once you have been granted your General class license and received your VEC accreditation. 18 years** is the minimum age that one must be to qualify as an accredited Volunteer Examiner. A non U.S. citizen may be an accredited Volunteer Examiner.

When you are an accredited VE holding a General Class operator license, you may only administer the **Technician** license examination. **A FCC General class or higher license and VEC accreditation** is sufficient for you to be an administering VE for a Technician Class operator license examination. **At Least three VEC-accredited General Class or higher VEs must be present** for administering a Technician Class operator examination.

The administering VEs are responsible at a Volunteer Exam Session for determining the correctness of the answers on the exam. VEs must issue a **CSCE** document to a person that passes an exam element. A Certificate of Successful Completion of Examination (CSCE) is valid for exam element credit for **365 days** after successfully completed that exam element.

If you are a Technician Class operator and have a CSCE for General Class privileges, you may operate **on any General Class band segment**. You do, however, have to identify in a special way until your upgrade appears in the FCC ULS database. The proper way to identify when transmitting on General class frequencies if you have a CSCE for the required elements but your upgrade from Technician has not appeared in the ULS database is to **give your call sign followed by the words "temporary AG."**

You must add the special identifier "AG" after your call sign if you are a Technician Class licensee and have a CSCE for General Class operator privileges **whenever you operate using General class frequency privileges**. Whenever you operate on frequencies allocated to Technician Class licensees, you do not have to use the special identifier.

GIE - Control categories; repeater regulations; harmful interference; third party rules; ITU regions

A **repeater station** is the kind of amateur station simultaneously retransmits the signals of other stations on another channel. Some repeaters are cross-band repeaters. That is, they receive a signal on one band and repeat it on another. When this happens, it is important to know the license class of the control operator. A 10 meter repeater may retransmit the 2 meter signal from a station having a Technician Class control operator **only if the 10 meter control operator holds at least a General class license.**

Because repeater stations may cover a wide area, it is necessary to coordinate their input and output frequencies to avoid interference. The power to assign frequencies has been given to coordinating bodies in particular regions. A repeater station may operate on frequencies that have not been assigned to it, but will have to cease operation if it causes any interference. **The licensee of the non-coordinated repeater has primary responsibility to resolve the interference** in the event of interference between a coordinated repeater and an uncoordinated repeater.

Third-party traffic has always been a hot topic for radio amateurs. Third-party traffic is any message sent by someone who is not an amateur radio operator over an amateur radio link. **Only messages relating to amateur radio or remarks of a personal character, or messages relating to emergencies or disaster relief** may be transmitted by an amateur station for a third party in another country. If **the third party is a person previously licensed in the amateur service whose license had been revoked**, that party is disqualified from participating in stating a message over an amateur station.

Third-party traffic is prohibited with **any country other than the United States, unless there is a third-party agreement in effect with that country**, except for messages directly involving emergencies or disaster relief communications. For a non-licensed person to communicate with a foreign amateur radio station from a US amateur station at which a licensed control operator is present, **the foreign amateur station must be in a country with which the United States has a third party agreement. Sending a message to a third party through a foreign station** is a permissible third party communication during routine amateur radio operations **as long as that person is a licensed amateur radio operator.**

Another cardinal rule of amateur radio is to never willfully cause interference to other amateur radio operators or other services. **All of these answers are correct** when considering which of the following conditions require an amateur radio station to take specific steps to avoid harmful interference to other users or facilities:

- When operating within one mile of an FCC Monitoring Station
- When using a band where the amateur service is secondary
- When a station is transmitting spread spectrum emissions

It is also important to properly identify your station. You must use **English** when identifying your station if you are using a language other than English in making a contact.

Subelement G2

Operating Procedures (6 groups, 6 exam questions)

G2A - Phone operating procedures; USB/LSB utilization conventions; procedural signals; breaking into a QSO in progress; VOX operation

SSB is the mode of voice communication most commonly used on the High Frequency Amateur bands. Single sideband (SSB) is **a form of amplitude modulation in which one sideband and the carrier are suppressed**. When using the single sideband (SSB) voice mode, **only one sideband is transmitted; the other sideband and carrier are suppressed**. When compared to other voice modes on the HF amateur bands, using single sideband is an advantage because of **less bandwidth used and high power efficiency**.

Lower Sideband is the sideband most commonly used on the 160, 75, and 40 meter bands. The reason most amateur stations use lower sideband on the 160, 75 and 40 meter bands is because it is **current amateur practice is to use lower sideband on these frequency bands**.

Upper Sideband is the sideband most commonly used for phone communications on the bands above 20 meters. **Upper Sideband is the** sideband most commonly used in the VHF and UHF bands. **Upper Sideband** is the mode most commonly used for voice communications on the 17 and 12 meter bands.

VOX is short for voice-operated transmission. **VOX allows "hands free" operation. All of these choices are correct** when talking about user adjustable controls that are usually associated with VOX circuitry:

- Anti-VOX
- VOX Delay
- VOX Sensitivity

Here are a couple of operating procedures to keep in mind when operating phone. The recommended way to break into a conversation when using phone is to **say your call sign during a break between transmissions from the other stations**. When an operator uses the expression "CQ DX," it usually indicates that **the caller is looking for any station outside their own country**. If you are in the same country as the calling station, do not answer this call.

G2B - Operating courtesy; band plans

The amateur radio bands are often congested. To make this situation as pleasant as possible, please be courteous to other operators. This will help minimize interference.

A practical way to avoid harmful interference when selecting a frequency to call CQ using phone is to **ask if the frequency is in use, say your callsign, and listen for a response**. A practical way to avoid harmful interference when calling CQ using Morse code or CW is to **send "QRL? de" followed by your callsign and listen for a response**.

Another way to be courteous is to keep enough space between your transmissions and transmissions of other amateurs. **Approximately 3 kHz** is the minimum frequency separation between SSB signals should be allowed to minimize interference. **150 to 500 Hz** is the minimum frequency separation between CW signals should be allowed to minimize interference. **250 to 500 Hz** is the minimum frequency separation between 170 Hz shift RTTY signals should be allowed to minimize interference. If you notice increasing interference from other activity on a frequency you are using, **move your contact to another frequency**.

Many amateurs like to meet on a single frequency. This is called a "net." If a net is about to begin on a frequency you and another station are using, **move to a different frequency as a courtesy to the net**. If the frequency on which a net normally meets is in use just before the net begins, **ask the stations if the net may use the frequency, or move the net to a nearby clear frequency if necessary**.

Another way amateurs attempt to minimize interference is by publishing band plans. A band plan is **a voluntary guideline for band use beyond the divisions established by the FCC**. In order to comply with good amateur practice when choosing a frequency for Slow-Scan TV (SSTV) operation, **follow generally accepted band plans for SSTV operation**. In order to comply with good amateur practice when choosing a frequency for radio-teletype (RTTY) operation, **follow generally accepted band plans for RTTY operation**. In order to comply with good amateur practice when choosing a frequency for HF PSK operation, **follow generally accepted band plans for PSK operation**. The "DX window" in a voluntary band plan is **a portion of the band that should not be used for contacts between stations within the 48 contiguous United States**.

G2C - Emergencies, including drills and emergency communications

One of the purposes of amateur radio is to aid emergency communications. The first thing you should do if you are communicating with another amateur station and hear a station in distress break in is to **acknowledge the station in distress and determine what assistance may be needed. The location and nature of the emergency** should be given to a station answering a distress transmission.

An amateur station is **never** prevented from using any means at its disposal to assist another station in distress. When normal communications systems are not available, an amateur station may use **any means of radiocommunication at its disposal** to provide essential communications when there is an immediate threat to the safety of human life or the protection of property.

You are never prohibited from helping any station in distress from helping a station in distress. **Whatever frequency has the best chance of communicating the distress message** is the frequency should be used to send a distress call. An amateur station may make **transmissions necessary to meet essential communications needs and to facilitate relief actions** during a disaster. **Any mode** can be used to obtain assistance during a disaster. **Any frequency authorized to the control operator** may be used by an amateur station to obtain assistance when in distress.

When helping out in an emergency or making a distress call, always be sure to identify your station properly. A control operator is making **an unidentified transmission** when transmitting out of the amateur band without station identification during a life threatening emergency.

RACES stands for Radio Amateur Civil Emergency Service. When operating RACES events, certain restrictions apply. **Only a person holding an FCC issued amateur operator license** may be the control operator of an amateur station transmitting in RACES to assist relief operations during a disaster. The FCC may restrict normal frequency operations of amateur stations participating in RACES **when the President's War Emergency Powers have been invoked.**

G2D - Amateur auxiliary; minimizing interference; HF operations

The Amateur Auxiliary are **amateur volunteers who are formally enlisted to monitor the airwaves for rules violations**. The objectives of the Amateur Auxiliary are **to encourage amateur self-regulation and compliance with the rules**.

Amateurs in the Amateur Auxiliary hone their skills to help them in their job. For example, many take part in “fox hunts,” in which they attempt to find a low-power transmitter. During “Fox Hunts,” Amateur Auxiliary members learn **direction-finding skills used to locate stations violating FCC Rules**.

An azimuthal projection map is **a world map projection centered on a particular location**. An **azimuthal projection** map is the most useful type of map to use when orienting a directional HF antenna toward a distant station. When making a “long-path” contact with another station, a directional antenna is pointed **180 degrees from its short-path heading**.

While it is not necessary to log contacts, there are some records that you must keep. For example, a licensee must retain as part of their station records **antenna gain calculations or manufacturer's data for antennas used on 60 meters**. FCC rules require, when operating in the 60 meter band, that, **if you are using other than a dipole antenna, you must keep a record of the gain of your antenna**.

Many amateurs will, however, keep a log even though the FCC doesn't require it. One reason to do so is **to help with a reply if the FCC requests information on who was control operator of your station at a given date and time**. **All of these choices are correct** when discussing what information is traditionally contained in a station log:

- Date and time of contact
- Band and/or frequency of the contact
- Call sign of station contacted and the signal report given

One aspect of the hobby that has become quite popular is QRP operation. QRP operation is **low power transmit operation, typically about 5 watts**. One of the reasons for its popularity is that low-power operation can substantially minimize the interference you cause.

There are other ways to minimize interference, such as your choice of antennas. **A unidirectional antenna** would be the best HF antenna to use for minimizing interference.

G2E - Digital operating: procedures, procedural signals and common abbreviations

Now that computers are widely used in amateur radio, digital modes, such as RTTY, have become quite popular. The abbreviation "RTTY" stands for **Radio-Teletype**.

You need to know how to set up your equipment to use them properly. For example, you should select the **LSB** mode when using a SSB transmitter with an Audio Frequency Shift Keying (AFSK) RTTY signal. **170 Hz** is the most common frequency shift for RTTY emissions in the amateur HF bands.

Messages sent via RTTY most often use the Baudot code. The Baudot code is a **5-bit code, with additional start and stop bits**.

PSK31 is also a very popular mode because it allows you to communicate with low power even in adverse conditions. One of the reasons for this is that **the number** of data bits **varies** in a single PSK31 character.

PSK31 is only one of a number of recently-developed digital modes. Another is MFSK16. The abbreviation "MFSK" stands for **Multi (or Multiple) Frequency Shift Keying**. A major advantage of MFSK16 compared to other digital modes is that **it offers good performance in weak signal environment without error correction**.

Stations using packet radio communicate in much the same way that computer communicate over the internet. Stations decompose a message into "packets" of data which are sent out over the air and are then re-assembled at the receiving station. Because the message may pass through several relay stations, the packets contain routing and handling information so that they get sent to the appropriate receiving station. The part of a data packet contains the routing and handling information is called the **header**.

Digital communications can take place on the VHF bands or the HF bands. The 20 meter band segment most often used for most data is **14.070 - 14.100 MHz**. On the 20 meter band, PSK signals generally found **around 14.070 MHz. 3570 - 3600 kHz** is the segment of the 80 meter band is most commonly used for data transmissions.

G2F - CW operating procedures and procedural signals, Q signals and common abbreviations; full break in

Even though a Morse Code test is no longer required to obtain a General Class license, it remains a popular mode. There are a number of things to keep in mind when making CW contacts. These considerations will make operating CW much for fun for all operators.

CW operators pride themselves on the courtesy they show to other operators. For example, it is courteous not to send faster than the other station is capable of receiving. With that in mind, the best speed to use answering a CQ in Morse Code is **the speed at which the CQ was sent**. It is also courteous to slow down when requested to do so. **Send slower** if a CW station sends "QRS" when using Morse code.

To help ensure that a station you are calling can hear you, you should try to transmit on a frequency as close to the other station's frequency as possible. We say that you should "zero beat" the other station. In CW operation, the term "zero beat" means **matching the frequency of the transmitting station**.

In a CW contact, one of the first things sent is a signal report, often called an RST report. It consists of three numbers denoting: readability (1-5), strength (1-9), and tone (1-9). When a "C" is added to the RST report, it means that the sending station has a **chirpy or unstable signal**.

Amateur operators in contact using CW have a form of shorthand, called Q-signals, that they use to reduce the number of characters they must send. Q-signals are three-letter signals all beginning with the letter "Q." For example, the Q signal "QSL" means "**I acknowledge receipt**." The Q signal "QRQ" means "**send faster**." The Q signal "QRV" means "**I am ready to receive messages**."

When using Morse code, operators also use a variety of "prosigns," which are meant to inform other operators of certain things. For example, when a CW operator sends "KN" at the end of a transmission, it means that he or she is **listening only for a specific station or stations**. When a CW operator sends "CL" at the end of a transmission, it means **closing station**, or in other words, going off the air. **AR** is the prosign sent to indicate the end of a formal message.

A station is operating with full break-in telegraphy (QSK) when **incoming signals are received between transmitted code character elements**.

Subelement G3

Radio Wave Propagation (3 groups, 3 exam questions)

G3A - Sunspots and solar radiation; ionospheric disturbances; propagation forecasting and indices

Amateur radio communications is subject to the whims of nature. Many different phenomena affect amateur radio communications, and it behooves us to know a little something about the phenomena. Doing so, will make you a more effective amateur radio communicator.

The phenomenon that most affects amateur radio communication is the sunspot cycle. The typical sunspot cycle is **approximately 11 years**. The sunspot number is **a measure of solar activity based on counting sunspots and sunspot groups. Long-distance communication in the upper HF and lower VHF range is enhanced** when sunspot numbers are high.

The sunspot cycle is a long-term phenomenon. There are other phenomenon which are short-term that also deserve consideration. For example, the solar flux index is a measure of **the radio energy emitted by the sun**. In particular, it is the **measure of solar activity at 10.7 cm**. The K-index is **a measure of the short term stability of the Earth's magnetic field**. The A-index is **an indicator of the long term stability of the Earth's geomagnetic field**.

At any point in the solar cycle, the 20 meter band usually supports worldwide propagation during daylight hours. **Frequencies above 20 MHz** are the frequencies are least reliable for long distance communications during periods of low solar activity. If the HF radio-wave propagation (skip) is generally good on the 24-MHz and 28-MHz bands for several days, you might expect a similar condition to occur **28 days later**.

A Sudden Ionospheric Disturbance (SID) will have an effect on the daytime ionospheric propagation of HF radio waves. In particular, **it disrupts signals on lower frequencies more than those on higher frequencies**. To continue communications during a sudden ionospheric disturbance **try a higher frequency**.

During an SID, the sun emits a great deal of ultraviolet and X-ray radiation. The increased ultraviolet and X-ray radiation from solar flares takes **approximately 8 minutes** to affect radio-wave propagation on the Earth.

Also, **HF communications are disturbed** by the charged particles that reach the Earth from solar coronal holes. It takes **20 to 40 hours** for charged particles from Coronal Mass Ejections to affect radio-wave propagation on the Earth.

Geomagnetic disturbances also cause disruptions in HF propagation. A geomagnetic disturbance is **a significant change in the Earth's magnetic field over a short period of**

time. Latitudes **greater than 45 degrees North or South latitude** have propagation paths that are more sensitive to geomagnetic disturbances. **Degraded high-latitude HF propagation** is an effect of a geomagnetic storm on radio-wave propagation.

One possible benefit to radio communications resulting from periods of high geomagnetic activity is an **aurora that can reflect VHF signals.**

G3B - Maximum Usable Frequency; Lowest Usable Frequency; propagation "hops"

The two most important parameters for predicting the propagation between two locations are the MUF and LUF. MUF stands for the **Maximum Usable Frequency for communications between two points**. LUF stand for the **Lowest Usable Frequency for communications between two points**.

Radio waves with frequencies below the maximum usable frequency (MUF) **are bent back to the Earth** when they are sent into the ionosphere. Radio waves with frequencies below the lowest usable frequency (LUF) **are completely absorbed by the ionosphere**. When the lowest usable frequency (LUF) exceeds the maximum usable frequency (MUF), **no HF radio frequency will support communications over the path**.

Select a frequency just below the MUF is the guideline that one should use when deciding on a frequency that will give the lowest attenuation when transmitting on HF. For example, **15 meters** is the band should offer the best chance for a successful contact if the maximum usable frequency (MUF) between the two stations is 22 MHz. **20 meters** is the band that should offer the best chance for a successful contact if the maximum usable frequency (MUF) between the two stations is 16 MHz.

How do you determine the MUF? Well, one reliable way to determine if the maximum usable frequency (MUF) is high enough to support 28-MHz propagation between your station and Western Europe is to **listen for signals on a 28 MHz international beacon**. **All of these choices are correct** when talking about factors that affect the maximum usable frequency (MUF):

- Path distance and location
- Time of day and season
- Solar radiation and ionospheric disturbance

2,500 miles is the maximum distance along the Earth's surface that is normally covered in one hop using the F2 region. **1,200 miles** the maximum distance along the Earth's surface that is normally covered in one hop using the E region.

If a sky-wave signal sound arrives at your receiver by both short path and long path propagation, **a well-defined echo can be heard**.

Sometimes you can use conditions on one band to predict propagation conditions on another band. For example, **short hop sky-wave propagation on the 10 meter band** is a good indicator of the possibility of sky-wave propagation on the 6 meter band.

G3C - Ionospheric layers; critical angle and frequency; HF scatter; Near Vertical Incidence Sky waves

The D layer is the ionospheric layer closest to the surface of the Earth. **The D layer** is the ionospheric layer is the most absorbent of long skip signals during daylight hours on frequencies below 10 MHz. Long distance communication on the 40, 60, 80 and 160 meter bands more difficult during the day because **the D layer absorbs these frequencies during daylight hours. Absorption will be minimum** near the maximum usable frequency (MUF).

The F2 region can be expected to reach its maximum height at your location **at noon during the summer**. The F2 region mainly responsible for the longest distance radio wave propagation **because it is the highest ionospheric region**.

The term 'critical angle,' as used in radio wave propagation, means **the highest takeoff angle that will return a radio wave to the Earth under specific ionospheric conditions**.

Scatter propagation is a phenomenon often observed when using the HF bands. **Scatter** radio wave propagation allows a signal to be detected at a distance too far for ground wave propagation but too near for normal sky wave propagation. An indication that signals heard on the HF bands are being received via scatter propagation is when **the signal is heard on a frequency above the maximum usable frequency**.

A characteristic of HF scatter signals is that **they have a wavering sound**. HF scatter signals often sound distorted because **energy is scattered into the skip zone through several radio wave paths**. HF scatter signals in the skip zone are usually weak because **only a small part of the signal energy is scattered into the skip zone**.

Short distance HF propagation using high elevation angles is called Near Vertical Incidence Sky-wave (NVIS) propagation. **A horizontal dipole placed between 1/8 and 1/4 wavelength above the ground** is the type of antenna that will be most effective for skip communications on 40 meters during the day.

Subelement G4

Amateur Radio Practices (5 groups, 5 exam questions)

G4A - Two-tone Test; amplifier tuning and neutralization; DSP

Digital signal processing (DSP) is a common feature of modern amateur radio transceivers. DSP filtering is accomplished **by converting the signal from analog to digital and using digital processing. All of the these answers are correct** when talking about what is needed for a DSP IF filter:

- An Analog to Digital Converter
- Digital to Analog Converter
- A Digital Processor Chip

An advantage of a receiver IF filter created with a DSP as compared to an analog filter is that **a wide range of filter bandwidths and shapes can be created**. One use for a DSP in an amateur station is **to remove noise from received signals. A DSP filter** performs automatic notching of interfering carriers.

A two-tone test analyzes a transmitter's **linearity. Two non-harmonically related audio signals** are used to conduct a two-tone test. **An oscilloscope** is an instrument that may be used to measure the output of a single sideband transmitter when performing a two-tone test of amplitude linearity.

When using a linear amplifier that uses vacuum tubes, pay special attention to tuning procedures. **A pronounced dip** on the plate current meter of a vacuum tube RF power amplifier indicates correct adjustment of the plate tuning control. The correct adjustment for the "Load" or "Coupling" control of a vacuum tube RF power amplifier is **maximum power output without exceeding maximum allowable plate current**.

Negative feedback is used to neutralize an RF amplifier. The reason for neutralizing the final amplifier stage of a transmitter is **to eliminate self oscillations**. A neutralizing circuit in an RF amplifier **cancels the effects of positive feedback**.

G4B - Test and monitoring equipment

When you set up your amateur radio station, sometimes called your “shack,” you’ll not only want to acquire radios, but also some test equipment. The most basic piece of test equipment is the voltmeter. Voltmeters may be either analog or digital.

Significantly better precision for most uses is an advantage of a digital voltmeter as compared to an analog voltmeter. Digital voltmeters usually have higher input impedances than analog meters. High input impedance is desirable for a voltmeter because **it decreases the loading on circuits being measured**.

An oscilloscope is another handy piece of test equipment to have in your shack. With an oscilloscope, you can view waveforms of signals. An advantage of an oscilloscope versus a digital voltmeter is that **complex waveforms can be measured**. An **oscilloscope** is an item of test equipment contains horizontal and vertical channel amplifiers.

A monitoring oscilloscope is the best instrument to use to check the keying waveform of a CW transmitter. **The attenuated RF output of the transmitter** is the signal source connected to the vertical input of a monitoring oscilloscope when checking the quality of a transmitted signal.

Sometimes when troubleshooting, you need a signal source to provide an input for a circuit. To troubleshoot receiver circuits, you might want to use a signal tracer. You would normally use a signal tracer **to identify an inoperative stage in a receiver**.

A noise bridge is a device that you can use to measure the impedance of an antenna system. **Pre-tuning an antenna tuner** is one way a noise bridge might be used. When someone uses a noise bridge, **it is connected between a receiver and an antenna of unknown impedance and is adjusted for minimum noise**.

A similar piece of test equipment is the antenna analyzer. One advantage that an antenna analyzer has over a noise bridge is that it can measure SWR directly. An **antenna and feedline** must be connected to an antenna analyzer when it is being used for SWR measurements.

Another instrument that is sometimes used to measure the resonant frequency of an antenna is the dip meter. Determining **the resonant frequency of a circuit** is one measurement that can be made with a dip meter.

A field-strength meter is an instrument that may be used to monitor relative RF output when making antenna and transmitter adjustments. **The radiation pattern** of an antenna can be determined with a field strength meter. **Close-in radio direction-finding** is another use for a field strength meter.

For measuring the output power of your transmitter, you would use a wattmeter. **Standing Wave Ratio** (SWR) can be measured with a directional wattmeter. This is done by making

two measurements—the power being sent to the antenna and the power reflected by the antenna—and then calculating the SWR.

Nearly all commercial receivers have an “S” meter to indicate relative signal strength. Each digit on an S-meter corresponds to an increase or decrease of about 6 dB. This means that power output of a transmitter must be raised **approximately 4 times** to change the "S" meter reading on a distant receiver from S8 to S9.

G4C - Interference with consumer electronics; grounding

At some point or another, your amateur radio station will interfere with a radio, television set, or telephone. Sometimes this may be your fault, other times it may be the fault of the device. In either case, you should do everything you can to eliminate this interference.

Public-address (PA) systems are often the targets of interference. **Distorted speech** is the sound is heard from a public-address system if there is interference from a nearby single-sideband phone transmitter. **On-and-off humming or clicking** is the effect on a public-address system if there is interference from nearby CW transmitter.

There are many things that you can do. For example, a **bypass capacitor** might be useful in reducing RF interference to audio-frequency devices. One reason to place ferrite beads around audio cables to reduce common mode RF interference is that **they act as a series inductor**. **An RFI filter at the affected telephone** should be installed if a properly operating amateur station is interfering with a nearby telephone.

One of the most basic things you can do to eliminate interference is to ensure that your station is properly grounded. **All of these answers are correct** when considering important reasons to have a good station ground:

- To reduce the likelihood of RF burns
- To reduce the likelihood of electrical shock
- To reduce interference

A good practice is to keep the wire from your equipment to the ground rod as short as possible. One good way to avoid stray RF energy in an amateur station is to **keep the station's ground wire as short as possible**.

Keeping the ground wire short will prevent the wire from being resonant on a frequency that you are likely to operate. When the ground wire is resonant, it may actually present a high impedance to the RF energy, making it relatively useless as a ground. It might be that **the ground wire is resonant** if you receive an RF burn when touching your equipment while transmitting on a HF band, assuming the equipment is connected to a ground rod. **RF hot spots can occur in a station located above the ground floor if the equipment is grounded by a long ground wire**.

When grounding your station, make sure that all conductors make good electrical contact. **Induced currents in conductors that are in poor electrical contact** can cause unintended rectification of RF signal energy and can result in interference to your station as well as nearby radio and TV receivers. **Arcing at a poor electrical connection** is one cause of broadband radio frequency interference at an amateur radio station. **Connect all ground conductors to a single point** to avoid a ground loop.

While grounding equipment, you should also consider electrical safety. **Electrical safety inside the ham shack** is one topic covered in the National Electrical Code.

G4D - Speech processors; S meters; common connectors

Speech processors can be very useful when operating SSB. The reason for using a properly adjusted speech processor with a single sideband phone transmitter is that **it improves signal intelligibility at the receiver. It increases the average power** of a transmitted single sideband signal.

When using a speech compressor, it is important to adjust it properly. **All of these answers are correct** when talking about the result of using an incorrectly adjusted speech processor:

- Distorted speech
- Splatter
- Excessive background pickup

On the receive side, a useful device is the S-meter. An S-meter measures **received signal strength**. An S-meter generally found **in a receiver**.

The S-meter uses a logarithmic scale, with each S-unit 6 dB greater than the previous one, assuming a properly calibrated S meter. A signal with an S-meter reading of 20 dB over S-9 **is 100 times stronger** than an S-9 signal, assuming a properly calibrated S meter.

In amateur radio, you will use many different types of connectors. A **UHF** connector is commonly used for RF service at frequencies up to 150 MHz. A Type-N connector is **a moisture resistant RF connector useful to 10 GHz**. A **DB-9** would be a good choice for a serial data port connector. An **RCA Phono** connector is commonly used for audio signals in amateur radio stations.

Some connectors are keyed, while others are not. The main reason to use keyed connectors over non-keyed types is the **reduced chance of damage due to incorrect mating**.

G4E - HF mobile radio installations; emergency and battery powered operation

Operating mobile, that is from a car or boat, is an activity enjoyed by many radio amateurs. And amateurs can do almost everything from a mobile station that they can do at a fixed station. **All of these choices are correct** when discussing transmission types that are permissible while operating HF mobile:

- CW
- SSB
- FM

When setting up your mobile station, it is important to consider how you are going to supply power to your radios. **A direct, fused connection to the battery using heavy gauge wire** is the best power connection for a 100-watt HF mobile installation. One reason that it is best NOT to draw the DC power for a 100-watt HF transceiver from an automobile's cigarette lighter socket is that **the socket's wiring may be inadequate for the current being drawn by the transceiver.**

A commonly encountered problem when operating from an automobile with alternator whine. Alternator whine is **a tone or buzz in transmitted or received audio that varies with engine speed.**

As you can imagine, mobile antennas are always a compromise. **The HF mobile antenna system** is the factor that most limits the effectiveness of an HF mobile transceiver operating in the 75 meter band.

For providing emergency power, amateurs will often use a gasoline-powered generator. **The generator should be located in a well ventilated area** in an emergency generator installation. **Danger of carbon monoxide poisoning** is a primary reason for not placing a gasoline-fueled generator inside an occupied area. It would be unwise to power your station by back feeding the output of a gasoline generator into your house wiring by connecting the generator through an AC wall outlet because **it might present a hazard for electric company workers.**

Some amateurs use photovoltaic cells to provide emergency power. **Photovoltaic conversion** is the name of the process by which sunlight is changed directly into electricity. **0.5 VDC** is the approximate open-circuit voltage from a modern, well illuminated photovoltaic cell. **Doped Silicon** is a material used as the active element of a solar cell.

Some amateurs use solar cells to charge batteries. You must be careful when using lead-acid batteries in this application. A lead-acid storage battery might give off explosive hydrogen gas **when being charged.**

Finally, some amateurs even use wind power as an emergency power source. A disadvantage to using wind power as the primary source of power for an emergency station is that **a large**

energy storage system is needed to supply power when the wind is not blowing.

Subelement G5

Electrical Principles (3 groups, 3 exam questions)

G5A - Resistance; reactance; inductance; capacitance; impedance; impedance matching

Reactance is the **opposition to the flow of alternating current caused by capacitance or inductance**. **Reactance** causes opposition to the flow of alternating current in an inductor. **Reactance** causes opposition to the flow of alternating current in a capacitor. The **Ohm** is the unit used to measure reactance.

A coil reacts to AC in this way: **as the frequency of the applied AC increases, the reactance increases**. A capacitor reacts to AC in the opposite way. **As the frequency of the applied AC increases, the reactance decreases**.

Impedance is **the opposition to the flow of current in an AC circuit**. It is the combination of the capacitive reactance, the inductive reactance, and the resistance in a circuit. The **Ohm** is also used to measure impedance.

The source can deliver maximum power to the load when the impedance of an electrical load is equal to the internal impedance of the power source. Impedance matching is important **so the source can deliver maximum power to the load**.

To maximize the transfer of power, use an impedance matching transformer. Core saturation of a conventional impedance matching transformer should be avoided because **harmonics and distortion could result**.

One method of impedance matching between two AC circuits is to **insert an LC network between the two circuits**. **All of these choices are correct** devices when talking about devices that can be used for impedance matching at radio frequencies:

- A transformer
- A Pi-network
- A length of transmission line

G5B - The Decibel; current and voltage dividers; electrical power calculations; sine wave root-mean-square (RMS) values; PEP calculations

The RMS value is the measurement of an AC signal that is equivalent to a DC voltage of the same value. For an AC signal with a sine wave shape, the RMS value is .707 times the peak value.

12 volts is the RMS voltage of sine wave with a value of 17 volts peak.

Conversely, the peak-to-peak value is twice the peak value, or $2 \times 1.414 \times$ the RMS value. Accordingly, **339.4 volts** is the peak-to-peak voltage of a sine wave that has an RMS voltage of 120 volts.

The square root of the average of the sum of the squares of each voltage waveform would be the RMS voltage if you combined two or more sine wave voltages.

Power is equal to the RMS voltage times the current, or

$$P \text{ (watts)} = V_{\text{RMS}} \times I$$

Using Ohm's Law, we can show that:

$$P = V_{\text{RMS}}^2 / R$$

$$P = I^2 \times R$$

Using these formulas, you can see that **200 watts** of electrical power are used if 400VDC is supplied to an 800-ohm load. **2.4 watts** of electrical power are used by a 12-VDC light bulb that draws 0.2 amperes. **Approximately 61 milliwatts** are being dissipated when a current of 7.0 milliamperes flows through 1.25 kilohms.

These formulas can also be used to calculate RF power and RF voltages and currents. **245 volts** would be the voltage across a 50-ohm dummy load dissipating 1200 watts.

A term sometimes used in phone work is peak envelope power (PEP). This is the maximum instantaneous power achieved when transmitting a phone signal. Since the amplitude of a phone signal varies with time, the average power may be considerably less. **1060 watts** is the output PEP of an unmodulated carrier if an average reading wattmeter connected to the transmitter output indicates 1060 watts. **1.00** is the ratio of peak envelope power to average power for an unmodulated carrier.

The output PEP from a transmitter is **100 watts** if an oscilloscope measures 200 volts peak-to-peak across a 50-ohm dummy load connected to the transmitter output. **625 watts** is the output PEP from a transmitter if an oscilloscope measures 500 volts peak-to-peak across a 50-ohm resistor connected to the transmitter output.

Often, we're not concerned with the actual power, but with the ratio of power input to power output. For example, if an amplifier has a gain of 10, we know that if we input a 1 W signal, we'll get 10 W out. Quite often, you'll see this ratio specified in decibels, or dB.

The formula for calculating power ratios in dB is:

$$A(\text{dB}) = 10 \times \log_{10}(P2/P1)$$

Using this formula, you can see that a two-times increase or decrease in power results in a change of **3 dB**. By rearranging the terms of this equation, you would calculate that **20.5 %** is the percentage of power loss would that result from a transmission line loss of 1 dB.

The total current **equals the sum of the currents through each branch** of a parallel circuit.

G5C: Resistors, capacitors, and inductors in series and parallel; transformers

Connecting components in series and in parallel will affect their effective values. For example, if you connect resistors in series, the effective resistance is the sum of the individual resistances.

A resistor in series should be added to an existing resistor in a circuit to increase circuit resistance.

Connecting resistors in parallel will decrease the circuit resistance. For example, the total resistance of three 100-ohm resistors in parallel is **33.3 ohms**. **5.9 ohms** is the total resistance of a 10 ohm, a 20 ohm, and a 50 ohm resistor in parallel. **150 ohms** is the value of each resistor, which when three of them are connected in parallel produce 50 ohms of resistance, and the same three resistors in series produce 450 ohms.

Inductors work the same way. **An inductor in series** should be added to an inductor in a circuit to increase the circuit inductance. The inductance of a 20 millihenry inductor in series with a 50 millihenry inductor is **70 millihenrys**, but the inductance of three 10 millihenry inductors connected in parallel is **3.3 millihenrys**.

Capacitors, however, are quite the opposite. **A capacitor in parallel** should be added to a capacitor in a circuit to increase the circuit capacitance, while connecting capacitors in series will decrease circuit capacitance. The capacitance of a 20 microfarad capacitor in series with a 50 microfarad capacitor is **14.3 microfarads**. The capacitance of three 100 microfarad capacitors connected in series **33.3 microfarads**. The equivalent capacitance of two 5000 picofarad capacitors and one 750 picofarad capacitor connected in parallel is **10750 picofarads**.

Inductors exhibit a behavior called mutual inductance. Mutual inductance occurs when a current flowing through one inductor induces a current in a nearby inductor. We use this behavior to create components called transformers.

The simplest transformer has two windings: a primary winding and a secondary winding. The source of energy is normally connected **to the primary winding** in a transformer. **Mutual inductance** causes a voltage to appear across the secondary winding of a transformer when an AC voltage source is connected across its primary winding.

The voltage across the secondary winding will be equal to the ratio of the number of turns in the secondary to the number of turns in the primary. For example, the voltage across a 500-turn secondary winding of a transformer is **26.7 volts** if the 2250-turn primary is connected to 120 VA.

Transformers are also used to transform impedances. The impedance ratio is also related to the turns ratio. The turns ratio of a transformer used to match an audio amplifier having a 600-ohm output impedance to a speaker having a 4-ohm impedance is **12.2 to 1**.

Transformers are not 100% efficient. That is, they will draw current and consume power even when no load is attached to the secondary winding. The current in the primary winding of a transformer when no load is attached to the secondary is called **magnetizing current**.

Subelement G6

Circuit Components (3 groups, 3 exam questions)

G6A - Resistors; capacitors; inductors

There are a number of practical considerations you must make when using electronic components in circuits. For example, the resistance of a carbon resistor **will change depending on the resistor's temperature coefficient rating** if the temperature is increased. In some cases, we can use this characteristic to our advantage. For example, A thermistor is **a device having a controlled change in resistance with temperature variations**.

One type of resistor that's commonly used is the wire-wound resistor. Its main advantage is that its value can be set very precisely. The main disadvantage of using a conventional wire-wound resistor in a resonant circuit is that **the resistor's inductance could detune the circuit** that it is used in.

It's also important to choose capacitors wisely. For example, **comparatively low cost** is the primary advantage of ceramic capacitors, but they may have a high temperature coefficient.

High capacitance for given volume is an advantage of an electrolytic capacitor. For this reason, an **electrolytic** capacitor is often used in power-supply circuits to filter the rectified AC.

The leads of a capacitor are inductive, and at some frequencies, this is significant. One effect of lead inductance in a capacitor used at VHF and above is that the **effective capacitance may be reduced**.

A popular choice for inductors is the ferrite core inductor. **All of these choices are correct** when talking about the advantages of using a ferrite core with a toroidal inductor:

- Large values of inductance may be obtained
- The magnetic properties of the core may be optimized for a specific range of frequencies
- Most of the magnetic field is contained in the core

As noted earlier, placing two inductors closely together may cause unwanted mutual inductance. One reason why it might be important to minimize the mutual inductance between two inductors is **to reduce or eliminate unwanted coupling**. Two solenoid inductors should be placed **with their winding axes at right angles to each another** so as to minimize their mutual inductance.

Another unwanted characteristic of inductors is the capacitance between windings of the inductor. One effect of inter-turn capacitance in an inductor is that **the inductor may become self resonant at some frequencies**.

Many times, components are made with specific characteristics for particular applications. For example, **suppressor capacitor** is the common name for a capacitor connected across a transformer secondary that is used to absorb transient voltage spikes. **Filter choke** is the common name for an inductor used to help smooth the DC output from the rectifier in a conventional power supply.

G6B - Rectifiers; solid state diodes and transistors; solar cells; vacuum tubes; batteries

The diode is one of the most versatile components. They are used to rectify AC voltages, regulate DC voltages, switch RF voltages, and demodulate radio signals. One of the most important parameters of a diode used for rectification is the peak inverse voltage (PIV). The peak-inverse-voltage rating of a rectifier is **the maximum voltage the rectifier will handle in the non-conducting direction.**

The two major ratings that must not be exceeded for silicon-diode rectifiers are **peak inverse voltage; average forward current.** Average forward current is the maximum amount of current that the diode can handle when it is forward biased and conducting. If the average forward current is greater than this value, there is a good chance that the diode will “burn out.”

Another important diode parameter is the junction threshold voltage. This voltage will be different for different types of diodes. The approximate junction threshold voltage of a germanium diode is **0.3 volts.** The approximate junction threshold voltage of a silicon diode is **0.7 volts.** Like resistors, you can connect two or more diodes in parallel to increase the current handling capacity. When doing so, connect a small resistor in parallel with each of the diodes. When two or more diodes are connected in parallel to increase current handling capacity, the purpose of the resistor connected in series with each diode is so that **the resistors ensure that one diode doesn't carry most of the current.**

A type of diode often used in RF circuits is the Schottky diode. **Lower capacitance** is an advantage of using a Schottky diode in an RF switching circuit as compared to a standard silicon diode. The lower capacitance allows it to switch faster than other types of diodes.

There are two main types of transistors, bipolar transistors and field effect transistors (FETs). **An FET** is the solid state device most like a vacuum tube in its general characteristics. The following describes the construction of a MOSFET: **the gate is separated from the channel with a thin insulating layer.**

Transistors are often used in amateur radio circuits as amplifiers and switches. The stable operating points for a bipolar transistor that is used as a switch in a logic circuit are **its saturation and cut-off regions.** When used as an amplifier or a power supply pass transistor, it is often necessary to insulate the case of a large power transistor **to avoid shorting the collector or drain voltage to ground.**

Some amateur radio equipment, most notably linear amplifiers, still uses vacuum tubes. The simplest vacuum is the triode, which has three elements: the cathode, the control grid, and the plate. The **control grid** is the element of a triode vacuum tube is used to regulate the flow of electrons between cathode and plate.

A pentode is a tube with five elements, one of which is called the screen grid. The primary purpose of a screen grid in a vacuum tube is **to reduce grid-to-plate capacitance**.

Batteries are often used to power amateur radio equipment, so it's important to know their characteristics and how to use them. Some batteries can be used only once, while others are rechargeable. For example, **Nickel Metal Hydride** is a type of rechargeable battery, but it is **never** acceptable to recharge a carbon-zinc primary cell.

Nickel Cadmium batteries, sometimes called "Ni-Cads," are another type of rechargeable battery. **High discharge current** is an advantage of the low internal resistance of Nickel Cadmium batteries.

For applications that require long battery life, 12 volt lead acid batteries, often car batteries or deep cycle marine batteries are used. When using these batteries, it's important to not discharge them all the way. **10.5 volts** is the minimum allowable discharge voltage for maximum life of a standard 12 volt lead acid battery.

G6C - Analog and digital integrated circuits (ICs); microprocessors; memory; I/O devices; microwave ICs (MMICs); display devices

Most amateur radio devices today contain integrated circuits (ICs). On a single piece of silicon, manufacturers can put thousands of transistors, implementing very complex circuit functions. ICs may contain analog circuits, digital circuits, or a combination of both. A simple example is the **linear voltage regulator**, which is most often provided as an analog integrated circuit. Another commonly used **analog** IC is an operational amplifier.

A more sophisticated analog IC is the MMIC. The term MMIC means **Monolithic Microwave Integrated Circuit**.

Digital ICs are often described by the technology used to create the transistors. One type, or “family,” of digital IC uses complementary, metal-oxide semiconductor, or CMOS, transistors. **CMOS** is the most commonly used digital logic family of integrated circuits. CMOS has several advantages over other IC technologies, such as transistor-transistor logic (TTL). **Low power consumption**, for example, is an advantage of CMOS Logic integrated circuits compared to TTL logic circuits.

Memories are an important type of digital IC. The term ROM refers to **Read Only Memory**, which is a type of memory often used to store microprocessor programs. ROM is “non-volatile,” meaning **the stored information is maintained even if power is removed**.

ROMs are often used to store programs that run microprocessors. A microprocessor is a **miniature computer on a single integrated circuit chip**. Modern amateur radio transceivers usually have one or more microprocessors to control their operation.

These transceivers use light-emitting diodes (LEDs) or liquid crystal displays (LCDs) to display operating status, such as frequency. An LED is **forward biased** when emitting light. Older radios often used incandescent bulbs instead of LEDs. **High power consumption** is one disadvantage of an incandescent indicator compared to a LED.

LCDs do not emit light. Therefore, one characteristic of a liquid crystal display is that **it requires ambient or back lighting**.

Most modern transceivers can now be controlled by a computer. A common way to connect a computer to a transceiver is with a USB interface. A **computer and transceiver** are two devices in an amateur radio station that might be connected using a USB interface.

Subelement G7

Practical Circuits (2 groups, 2 exam questions)

G7A - Power supplies; transmitters and receivers; filters, schematic drawing symbols

Power supplies are devices that convert AC power to the DC voltages needed to power amateur radio equipment. There are two main types of power supplies available: linear power supplies and switching power supplies.

Linear supplies use a transformer to transform the voltage up or down, a rectifier to convert the AC voltage to a DC voltage, and capacitors and inductors to smooth the output voltage. The rectifier in a linear supply may be a half-wave rectifier, a full-wave rectifier, or bridge rectifier.

180 degrees is the portion of the AC cycle is converted to DC by a half-wave rectifier. **360 degrees** portion of the AC cycle is converted to DC by a full-wave rectifier. **A series of DC pulses at twice the frequency of the AC input** is the output waveform of an unfiltered full-wave rectifier connected to a resistive load.

The minimum peak-inverse-voltage rating of the rectifier in a full-wave power supply is **double the normal peak output voltage of the power supply**. The approximate minimum peak-inverse-voltage rating of the rectifier in a half-wave power supply is **two times the normal peak output voltage of the power supply**.

The output of a rectifier connects to a filter made up of capacitors and inductors. **Capacitors and inductors** are used in a power-supply filter network. **Low equivalent series resistance** is a desirable characteristic for capacitors used to filter the DC output of a switching power supply.

A safety feature found on many linear power supplies is the bleeder resistor. **It discharges the filter capacitors** once the power supply is turned off.

Switching, or switched-mode power supplies are now being sold by many vendors. One advantage of a switched-mode power supply as compared to a linear power supply is that **high frequency operation allows the use of smaller components**. One disadvantage is that the circuits are much more complex than linear power supply circuits.

Filters are an important part of amateur radio equipment. For example, a filter might be used to process signals from the balanced modulator and send them to the mixer in a single-sideband phone transmitter.

You might also use a filter, called a low-pass filter because it's designed to pass all frequencies below a "cutoff frequency," to avoid causing interference to nearby television sets. You connect the low-pass filter between your transceiver and your antenna. The impedance of a low-pass

filter as compared to the impedance of the transmission line into which it is inserted should be **about the same**.

Balanced modulators is a type of circuit found in amateur radio transmitters. A **balanced modulator** is used to combine signals from the carrier oscillator and speech amplifier and send the result to the filter in a typical single-sideband phone transmitter. Most amateur radio transmitters use variable frequency oscillators to set the output frequency, but some still use the fixed-frequency crystal oscillator. **Stable output frequency** is an advantage of a crystal controlled transmitter.

The superheterodyne receiver is the most popular type of amateur radio receiver. Superheterodyne receivers convert the received frequency to an intermediate frequency (IF) and then process that IF signal. A **mixer** is used to process signals from the RF amplifier and local oscillator and send the result to the IF filter in a superheterodyne receiver. A **product detector** is used to process signals from the IF amplifier and BFO and send the result to the AF amplifier in a single-sideband phone superheterodyne receiver. The combination of an **HF oscillator, mixer, and detector** is the simplest combination of stages that can be combined to implement a superheterodyne receiver.

Another type of receiver is the direct conversion receiver. A **direct conversion receiver** is a type of receiver suitable for CW and SSB reception but does not require a mixer stage or an IF amplifier. While simpler, direct conversion receivers often do not perform as well as superheterodyne receivers.

The **discriminator** is a type of circuit is used in many FM receivers to convert signals coming from the IF amplifier to audio.

When designing or troubleshooting radios, amateur radio operators use schematic diagrams to describe circuits. Various symbols represent the different types of components. A typical schematic is shown in Figure G7-1.

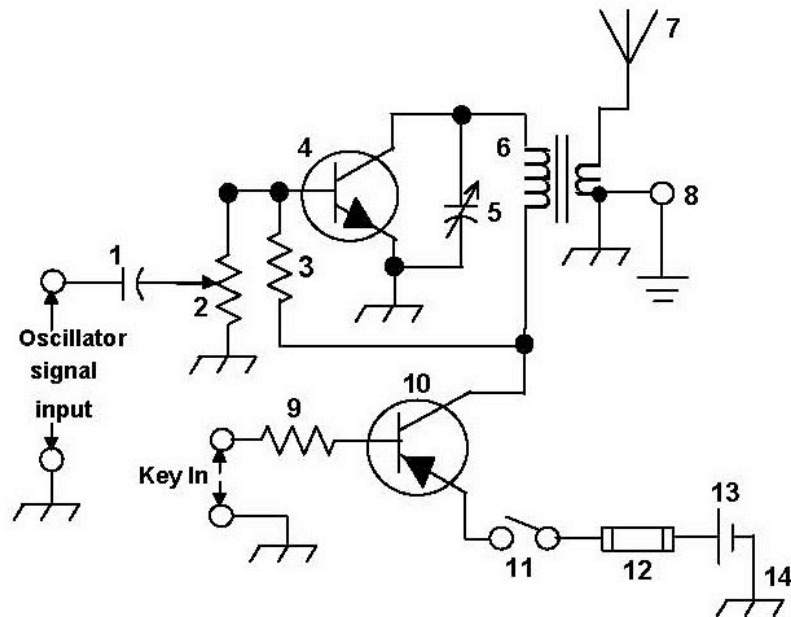


Figure G7-1. Common Schematic Symbols

Symbol 3 symbol in figure G7-1 represents a fixed resistor.

Symbol 13 in figure G7-1 represents a single cell battery.

Symbol 4 in figure G7-1 represents a NPN transistor.

Symbol 5 in figure G7-1 represents a variable capacitor.

Symbol 6 in figure G7-1 represents a transformer.

Symbol 11 in figure G7-1 represents a single pole switch.

G7B - Digital circuits (gates, flip-flops, shift registers); amplifiers and oscillators

Digital circuits are circuits whose outputs are one of two voltages - either “on” or “off” or “one” or “zero.” Digital circuits use the binary number system because **binary "ones" and "zeros" are easy to represent with an "on" or "off" state.**

We use digital circuits to implement logic functions, and there are many integrated circuits that implement specific logic functions, such as the NAND function or NOR function. **Zero** is the output of a two-input NAND gate, given both inputs are “one.” **One** is the output of a NOR gate given that both inputs are “zero.”

More complex logic functions, such as flip-flops, counters, and shift registers, are also available. A “flip-flop” circuit **a digital circuit with two stable states.** There are **8** states are in a 3-bit binary counter. A shift register is **a clocked array of circuits that passes data in steps along the array.**

An oscillator is a circuit that generates an AC signal output. **A filter and an amplifier operating in a feedback loop** are the basic components of virtually all oscillators. Some oscillators use and RC circuit for feedback. **The phase shift of the RC feedback circuit** determines the frequency of an RC oscillator. Other oscillators use and LC circuit for feedback. **The inductance and capacitance in the tank circuit** determines the frequency of an LC oscillator.

There are many different types of amplifiers. A linear amplifier, sometimes called a Class A amplifier, is **an amplifier whose output preserves the input waveform. Low distortion** is a characteristic of a Class A amplifier.

The Class C amplifier is not linear. An advantage of a Class C amplifier **high efficiency. CW** is the mode for which a Class C power stage is appropriate. To determine the efficiency of an RF power amplifier, **divide the RF output power by the DC input power.**

Subelement G8

Signals and Emissions (2 groups, 2 exam questions)

G8A - Carriers and modulation: AM; FM; single and double sideband; modulation envelope; deviation; overmodulation

Amplitude modulation is the name of the process that changes the envelope of an RF wave to convey information. **Amplitude modulation** is the type of transmission that varies the instantaneous power level of the RF signal to convey information.

Single sideband, or SSB, is a type of amplitude modulation (AM). A conventional AM signal has three components, the carrier and two sidebands. An SSB transmitter uses a balanced modulator to eliminate the carrier signal. **Both upper and lower sidebands** signal(s) would be found at the output of a properly adjusted balanced modulator. A filter is then used to eliminate one of the sidebands.

One advantage of carrier suppression in a single-sideband phone transmission is that **more transmitter power can be put into the remaining sidebands**. Another advantage is that **single sideband** phone emissions use the narrowest frequency bandwidth.

You must be careful when setting the audio level used to modulate a phone signal. If you set the level too high, the signal will be over-modulated, and an over-modulated single-sideband phone transmitter signal **becomes distorted and occupies more bandwidth**. This distortion is sometimes called flat-topping. Flat-topping of a single-sideband phone transmission is **signal distortion caused by excessive drive**.

To set the appropriate level, you use the radio's ALC meter. The **audio or microphone gain** is the control typically adjusted for proper ALC setting on an amateur single sideband transceiver.

Frequency modulation is the name of the process which changes the frequency of an RF wave to convey information. When a modulating audio signal is applied to an FM transmitter, **the carrier frequency changes proportionally to the instantaneous amplitude of the modulating signal**.

Phase modulation is the name of the process that changes the phase angle of an RF wave to convey information. **Phase modulation** is also the type of emission produced by a reactance modulator connected to an RF power amplifier.

G8B - Frequency mixing; multiplication; HF data communications; bandwidths of various modes

One of the most important circuits found in amateur radio equipment is the mixer. A mixer takes two input signals and outputs the sum and difference of the two input signals. **Heterodyning** is another term for the mixing of two RF signals.

The **mixer** is the receiver stage that combines a 14.250 MHz input signal with a 13.795 MHz oscillator signal to produce a 455 kHz intermediate frequency (IF) signal. If a receiver mixes a 13.800 MHz VFO with a 14.255 MHz received signal to produce a 455 kHz intermediate frequency (IF) signal, a 13.345 MHz signal produced will produce an unwanted **image response** in the receiver.

Mixers are also used in transmitters. **A mixer** in a transmitter would change a 5.3 MHz input signal to 14.3 MHz.

FM transmitters use multipliers to produce the VHF signal. The **multiplier** is the name of the stage in a VHF FM transmitter that selects a harmonic of an HF signal to reach the desired operating frequency.

On the VHF bands, we frequently use frequency-modulated (FM) phone. Two important parameters of an FM signal are bandwidth and deviation. Frequency modulated (FM) phone is not used below 29.5 MHz because **the bandwidth would exceed FCC limits**. The total bandwidth of an FM-phone transmission having a 5 kHz deviation and a 3 kHz modulating frequency is **16 kHz**. **416.7 Hz** is the frequency deviation for a 12.21-MHz reactance-modulated oscillator in a 5-kHz deviation, 146.52-MHz FM-phone transmitter.

Digital modes are now quite popular. RTTY, Morse code, PSK31 and packet communications **are digital modes**. An RTTY signal shifts between two set frequencies. This is sometimes called frequency-shift keying, or FSK. In an FSK signal, frequency shift is related to keying speed. In particular, **greater keying speeds require greater frequency shifts**. When transmitting a digital, or data mode, it is important to know the duty cycle of the mode you are using **to prevent damage to your transmitter's final output stage**.

The part of the 20 meter band most commonly used for PSK31 operation is **below the RTTY segment, near 14.070 MHz**.

Subelement G9

Antennas and Feedlines (4 groups, 4 exam questions)

G9A - Antenna feedlines: characteristic impedance, and attenuation; SWR calculation, measurement and effects; matching networks

Feedlines are the cables used to connect antennas to receivers and transmitters. Perhaps the most important characteristic of a feedline is its characteristic impedance. **50 and 75 ohms** are the typical characteristic impedance of coaxial cables used for antenna feedlines at amateur stations. **300 ohms** is the characteristic impedance of flat ribbon TV type twin lead. **The distance between the centers of the conductors and the radius of the conductors** are factors that determine the characteristic impedance of a parallel conductor antenna feedline.

A difference between feedline impedance and antenna feed point impedance is a common reason for the occurrence of reflected power at the point where a feedline connects to an antenna. A measure of this mismatch is the standing-wave-ratio, or SWR. The SWR is the ratio of the impedances.

A standing-wave-ratio of **4:1** will result from the connection of a 50-ohm feed line to a non-reactive load having a 200-ohm impedance. A standing-wave-ratio of **5:1** will result from the connection of a 50-ohm feed line to a non-reactive load having a 10-ohm impedance. A standing-wave-ratio of **1:1** will result from the connection of a 50-ohm feed line to a non-reactive load having a 50-ohm impedance.

The SWR will be **2:1** if you feed a vertical antenna that has a 25-ohm feed-point impedance with 50-ohm coaxial cable. The SWR will be **6:1** if you feed a folded dipole antenna that has a 300-ohm feedpoint impedance with 50-ohm coaxial cable. If the SWR on an antenna feedline is 5 to 1, and a matching network at the transmitter end of the feedline is adjusted to 1 to 1 SWR, the resulting SWR on the feedline will be **5 to 1**.

To prevent standing waves on an antenna feedline, **the antenna feed point impedance must be matched to the characteristic impedance of the feedline**. One reason for using an inductively coupled matching network between the transmitter and parallel conductor feed line feeding an antenna is **to match the unbalanced transmitter output to the balanced parallel conductor feedline**.

The attenuation of coaxial cable **increases** as the frequency of the signal it is carrying increases. RF feed line losses are usually expressed in **dB per 100 ft**.

G9B - Basic antennas

There are many different types of antennas, including:

- random-wire antennas,
- dipole antennas, and
- vertical antennas - including ground-plane antennas.

One disadvantage of a directly fed random-wire antenna is that **you may experience RF burns when touching metal objects in your station.**

A vertical antenna is quarter wavelength long and operates against ground or a set of radials. The radial wires of a ground-mounted vertical antenna system should be placed **on the surface or buried a few inches below the ground.**

When mounted above ground, the vertical antenna is often called a ground-plane antenna. The natural feedpoint impedance of the ground-plane antenna is 35 ohms, but the feed-point impedance of a ground-plane antenna **increases** when its radials are changed from horizontal to downward-sloping. An advantage of downward sloping radials on a ground-plane antenna is that **they can be adjusted to bring the feed-point impedance closer to 50 ohms.**

The half-wavelength dipole antenna is perhaps the most common amateur radio antenna. The approximate length for a 1/2-wave dipole antenna cut for 14.250 MHz is **32.8 feet**. The approximate length for a 1/2-wave dipole antenna cut for 3.550 MHz is **131.8 feet**. The approximate length for a 1/4-wave vertical antenna cut for 28.5 MHz is **8.2 feet**.

The low angle azimuthal radiation pattern of an ideal half-wavelength dipole antenna **is a figure-eight at right angles to the antenna** when installed 1/2 wavelength high and parallel to the earth. **If the antenna is less than 1/2 wavelength high, the azimuthal pattern is almost omnidirectional.**

As the antenna is lowered from 1/4 wave above ground, the feed-point impedance of a 1/2 wave dipole antenna **steadily decreases**. As the feed-point location is moved from the center toward the ends, the feed-point impedance of a 1/2 wave dipole **steadily increases**.

Vertical antennas are vertically polarized, while dipole antennas are usually horizontally polarized. An advantage of a horizontally polarized as compared to vertically polarized HF antenna is **lower ground reflection losses.**

G9C - Directional antennas

To make their signals more effective, some amateurs use directional antennas. These antennas direct a transmitted signal in a particular direction and are more sensitive to signals coming from that direction.

The Yagi antenna is one type of directional antenna. One reason a Yagi antenna is often used for radio communications on the 20 meter band is that **it helps reduce interference from other stations to the side or behind the antenna.**

The Yagi antenna consists of a driven element, a reflector, and possibly one or more directors. The approximate length of the driven element of a Yagi antenna is **1/2 wavelength.**

A Yagi antenna consists of a driven element and some combination of parasitically excited reflector and/or director elements. A three-element Yagi would consist of one driven element, one reflector, and one director. The reflector is generally about 5% longer than the driven element, while the director is about 5% shorter. **The director is normally the shortest parasitic element. The reflector is normally the longest parasitic element.**

The "front-to-back ratio" of a Yagi antenna is **the power radiated in the major radiation lobe compared to the power radiated in exactly the opposite direction.** The approximate maximum theoretical forward gain of a 3 Element Yagi antenna is 9.7 dBi. The "main lobe" of a directive antenna is **the direction of maximum radiated field strength from the antenna.**

The purpose of a "gamma match" used with Yagi antennas is **to match the relatively low feed-point impedance to 50 ohms. No insulation is needed** when connecting the driven element of a Yagi antenna from the metal boom when using a gamma match.

By changing the characteristics of the elements you can change the characteristics of the antenna. **Use larger diameter elements** to increase the SWR bandwidth of a Yagi antenna. As you increase the boom length and adding directors to a Yagi antenna, **gain increases. All of these choices are correct** when talking about Yagi antenna design variables that could be adjusted to optimize forward gain, front-to-back ratio, or SWR bandwidth:

- the physical length of the boom,
- the number of elements on the boom, and
- the spacing of each element along the boom.

Cubical quads are another type of directional antenna. **A cubical quad antenna** is typically constructed from 2 square loops of wire each having a circumference of approximately one wavelength at the operating frequency and separated by approximately 0.2 wavelength. Each side of a cubical-quad antenna driven element is approximately **1/4 wavelength.** The forward gain of a 2-element cubical-quad antenna is **about the same** as the forward gain of a 3 element Yagi antenna. Each side of a cubical-quad antenna reflector element is **slightly more than 1/4 wavelength.**

The gain of a two element delta-loop beam is **about the same** as the gain of a two element cubical quad antenna. Each leg of a symmetrical delta-loop antenna driven element is approximately **1/3 wavelengths**.

The polarization of the radiated signal changes from vertical to horizontal when the feed-point of a cubical quad antenna is changed from the center of the lowest horizontal wire to the center of one of the vertical wires.

The reflector element must be approximately 5% longer than the driven element in a cubical-quad antenna must be used for the antenna to operate as a beam antenna, assuming one of the elements is used as a reflector.

G9D - Specialized antennas

The term "NVIS" means **near vertical incidence skywave** when talking about antennas. An NVIS antenna typically installed **between 1/10 and 1/4 wavelength** above ground. **High vertical angle radiation for short skip during the day** is an advantage of an NVIS antenna.

While a Yagi antenna is a great antenna, you can improve the performance of this antenna by stacking one on top of another. The gain of two 3-element horizontally polarized Yagi antennas spaced vertically 1/2 wave apart from each another is **approximately 3 dB higher** than the gain of a single 3-element Yagi. Vertical stacking of horizontally polarized Yagi antennas **narrows the main lobe in elevation**.

Another type of antenna sometimes used in amateur radio is the log periodic antenna. **Length and spacing of elements increases logarithmically from one end of the boom to the other** describes a log periodic antenna. **Wide bandwidth** is an advantage of a log periodic antenna.

A Beverage antenna generally not used for transmitting because **it has high losses compared to other types of antennas**. An application for a Beverage antenna is **directional receiving for low HF bands**. A Beverage antenna is **a very long and low receiving antenna that is highly directional**.

Many antennas are designed for a single band, but in many cases, putting up an antenna for each band you want to operate is impractical. So, many amateurs put up antennas that will work on more than one band. These are called multiband antennas. One disadvantage of multiband antennas is that **they have poor harmonic rejection**.

One type of multiband antenna is the trap vertical. The primary purpose of traps installed in antennas is **to permit multiband operation**.

Subelement G0

Electrical and RF Safety (2 groups, 2 exam questions)

G0A - RF safety principles, rules and guidelines; routine station evaluation

If you learn nothing else from this manual, I hope you'll learn to be safe when indulging in amateur radio. The first topic that we'll cover is RF safety.

One way that RF energy can affect human body tissue is that **it heats body tissue**. The effects take place over time. "Time averaging," in reference to RF radiation exposure, means **the total RF exposure averaged over a certain time**. This also means that when evaluating RF exposure **a lower transmitter duty cycle permits greater short-term exposure levels**.

The power level and frequency of the energy have the most direct effect on the permitted exposure level of RF radiation. **A calibrated field-strength meter with a calibrated antenna** can be used to accurately measure an RF field. One property that is NOT important in estimating if an RF signal exceeds the maximum permissible exposure (MPE) is **its critical angle**.

An amateur operator must **perform a routine RF exposure evaluation** to ensure compliance with RF safety regulations. **All of these choices are correct** when trying to determine if your station complies with FCC RF exposure regulations:

- by calculation based on FCC OET Bulletin 65,
- by calculation based on computer modeling, and
- by measurement of field strength using calibrated equipment.

If an evaluation of your station shows RF energy radiated from your station exceeds permissible limits, you must **take action to prevent human exposure to the excessive RF fields**. **No further action is required** when the maximum power output capability of an otherwise compliant station is reduced.

The amount of exposure depends greatly on the positioning of an antenna. For example, you should **make sure that MPE limits are not exceeded in occupied areas** if you install an indoor transmitting antenna. When installing a ground-mounted antenna, **it should be installed so no one can be exposed to RF radiation in excess of maximum permissible limits**. Whenever you make adjustments or repairs to an antenna, **turn off the transmitter and disconnect the feedline**.

An RF evaluation should take into account not only your house and property, but also your neighbors. 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 is **take precautions to ensure that the antenna cannot be pointed at their house**.

Some repeater stations may be located at a site with multiple transmitters. **Any transmitter that contributes 5% or more of the MPE** at a multiple user site is responsible for RF safety compliance.

G0B - Safety in the ham shack: electrical shock and treatment, grounding, fusing, interlocks, wiring, antenna and tower safety

When playing around with any radio gear, remember that electricity can be a dangerous thing. **60 cycle Alternating current** is the most hazardous type of electrical energy. **Current through the heart can cause the heart to stop pumping.** This is the mechanism by which electrical shock can be lethal. **50 microamperes** is the maximum amount of electrical current flow through the human body that can be tolerated safely.

When wiring a “shack,” pay special attention to the currents that the circuits will supply and use fuses with the appropriate ratings the appropriate wire sizes. For example, **15 amperes** is the size of fuse or circuit breaker would be appropriate to use with a circuit that uses AWG number 14 wiring. **AWG number 12** is the minimum wire size that may be safely used for a circuit that draws up to 20 amperes of continuous current.

For some devices, such as linear amplifiers, you may have to install a 240 VAC line. Remember, **only the “hot” (black and red) wires** wire(s) in a four-conductor line cord should be attached to fuses or circuit breakers in a device operated from a 240-VAC single-phase source. You can make your shack safer by using Ground Fault Circuit Interrupters (GFCIs). **Current flowing from the hot wire to ground** will cause a Ground Fault Circuit Interrupter (GFCI) to disconnect the 120 or 240 Volt AC line power to a device.

Another way to make the shack safer is to have the proper grounds. The metal chassis of every item of station equipment must be grounded (assuming the item has such a chassis) because **it ensures that hazardous voltages cannot appear on the chassis.**

It is also helpful if your equipment has safety features. For example, the purpose of a transmitter power supply interlock is **to ensure that dangerous voltages are removed if the cabinet is opened.**

Another hazard is the antenna tower. Any person preparing to climb a tower that supports electrically powered devices should **make sure all circuits that supply power to the tower are locked out and tagged.** Also, when climbing on a tower using a safety belt or harness, **always attach the belt safety hook to the belt “D” ring with the hook opening away from the tower.**

Because they can be hit by lightning, towers must be properly grounded. One good engineering practice for lightning protection grounds is that **they must be bonded together with all other grounds.** It is not safe to use soldered joints with the wires that connect the base of a tower to a system of ground rods because **a soldered joint will likely be destroyed by the heat of a lightning strike.**

Finally, be careful if you use lead-tin solder. One danger of using lead-tin solder is that **lead can contaminate food if hands are not washed carefully after handling.**