The NATIONAL ELECTRICAL CODE (NFPA 70) as it Applies to Amateur Radio Stations. A Discussion and Interpretation.

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Preface

This work was presented as a talk to the Homebrew Special Interest Group (HB-SIG) of the Raleigh Amateur Radio Society (RARS), on 15 January, 1991 and was revised for another presentation on 26 January, 1994.

This document contains excerpts of the National Electrical Code (NFPA 70-1990) that, in the author's opinion, apply to the installation of amateur radio equipment as would commonly be found in most amateur radio stations. Direct excerpts from the Code are contained within inset quotations. Paraphrased excerpts from the Code are itemized. The author's interpretation and discussion of the Code is set full-width. The author's interpretation and discussion of various sections of the Code is not meant to be all-encompassing, nor the official interpretation of the National Fire Protection Association, nor of any offical governing body having legal authority of jurisdiction over electrical installations, but is meant to be used as a teaching tool for amateur radio operators.

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Contents

Historical Perspectives

The National Electrical Code began in 1881 from a proposal by the National Association of Fire Engineers. In 1895, it was initially formalized by the National Board of Fire Underwriters as a nationally recommended code. Subsequently, and using this first code as a basis, the first National Electrical Code (NEC) was drafted, in 1897. After 1911, the publication of the National Electrical Code (NEC) was sponsored by the National Fire Protection Association. It has remained in their care since that time. It has been endorsed, since 1920, by the American National Standards Institute, as ANSI Standards Committee C1.

The code was largely rewritten in 1923, and editorially revised for clarity in 1937. It was renumbered, sectionally, in 1959, and has remained, structurally the same since then.. During this time, the NEC has become established as "the most widely adopted code of standard practices in the U.S.A."

The Earliest Days

The earliest days of amateur radio were literally "by the breadboard". In those days, rigs were often hay-wired together by any and all possible means. Most rigs were marginally safe. Most met the code in a marginal way. Many did not. The wiring of most transmitters was open and flat, on a board of some sort (the "breadboard" construction form). At best, the situation was dangerous. Antennas and ground systems were simple, but usually satisfactory. Since little regulation was in effect, the possiblity of shock by the antenna coming into contact with the electrical service, or by the operator coming into contact with the transmitter was rather good. Many a ham was "bitten" not only by the hobby, but also by the rig.

Hamdom in the Roaring Twenties

The "roaring twenties" was a *great* time for amateur radio. The vacuum tube (i.e., electron valve) (i.e., self-heating transistor for you youngsters) was just becoming commonly available to the amateur. Prior to 1920, few hams had access to tubes. A few were available from WWI surplus, or, if you lived in a large city on the east coast, you might find a few, but, they were horribly expensive. In the “twenties” they became commonplace. This prompted a revolution in amateur radio equipment. One major development in equipment design was non-direct coupling of the transmitter to the antenna. This kept the possibility of B+ getting on the antenna to a minimum. Although most transmitters were still of the breadboard design, many had insulating (e.g., bakelite) front panels that added a measure of safety to the rig. Regulatory practices were better, and most hams had some form of lightning protection and a basic ground. It was still not uncommon, though, to be as always, “bitten by the rig” as well as by the hobby.

Progress in the Thirties

Amateur radio in the thirties was characterized by a slow but steady progress in the technology and a significant change in the basic design of equipment. Gone were most of the battery sets, as well as most of the battery eliminators. “King Spark” was gone. Gone was the breadboard design, and the open high voltage wiring, except in experimental design development. Aluminum was the material of choice for chassis, and most rigs were being mounted in racks to facilitate wiring, and to increase safety. Enclosures around high voltage circuitry was becoming the standard. AC power was the standard. Safety was becoming a big issue. It is sad and unfortunate that one of the greatest minds in hands-on experimental amateur radio, Ross Hull (Technical Editor of QST), was killed by electrocution while undertaking design work on early amateur television. He made the unfortunate choice to change the high voltage transformer in an experimental television receiver from a small low current one to a 4400 volt pole peg transformer used backwards. He was wearing headphones and apparently reached across the set to adjust the power, when he was killed. One should pause for a moment and consider the 2000-4000 volts in the B+ of your amplifier power supply, if it uses vacuum tubes(s).

Technological Breakthroughs in WWII

The advent of World War II brought a tremendous advancement in the technology of radio — in a hurry. This revolutionized amateur radio. Everything was in aluminum or steel cabinets. Everything was grounded. Although RF burns were still commonplace, shock due to high voltage power was almost, but not entirely, a thing of the past. Many hams still built the rigs, but better care and more emphasis on safety was the norm. It was still the day of the KW AM rigs, and huge modulators that ran on thousands of volts on the plates (2000-4000 vdc being common). But, even in homebrew rigs, everything was enclosed, and with the advent of television, most everything became rf shielded, too. Antennas were mostly fed with good ol' open wire line. A few folks were experimenting with that newfangled coaxial line.

The commercial marketplace took off just after the war, using all of this new technology and it was like a shopping spree for hams. Most hams bought their recievers. Most built their first rigs, and many bought their later rigs instead of building them.

Sometime in the late forties, there arose the idea of a non-self-heating electron valve — the transistor. A couple o' fellas even got a patent on the thing. It just couldn't seem to do much, though. It had a hard time amplifying anything, and couldn't even oscillate above the broadcast band. Oh well, maybe later ..... thought "T.O.M".

The New Age of Electronics

That later time came, slowly through the fifties, but with a great flood in the sixties. That little piece of germanium and its relatives heralded a new age of electronics..., and it is a new age for amateur radio. Everything has become transistorized. Excepting the occasional use of vacuum tubes in the homebrewing of gear, that means that nearly all new amateur radio equipment does not use voltages in excess of 50 volts dc. What does this mean? It means that the age of being "bitten" by the rig instead of the hobby, is coming to a close. The major electrical shock item in the new age amateur radio station *is the 110/120 VAC electrical system power coming in the power line.* If you are into anything using video display units (VDU's for short), you can still get a shock, though, from the 10,000-20,000 VDC on the display tube. Other than that, there are few items in the new age hamshack to generate high voltages. A few commercial linear amplifiers are still using vacuum tubes, but that will change quickly. If you are homebrewing transmitters or especially amplifiers, you will probably still be using power tubes and high voltages for a few years yet to come. So remember *safety, always,* in such cases.

Aside from the power line potential for shock, the remaining source is the antenna and its lead-in. Most hams are using coaxial line fed antennas. This has greatly standardized getting the rf power from the rig to the antenna. It has also simplified making your station compliant with the NEC, as long as you *ground* the outer conductor of the coaxial cable.

Scope of the National Electrical Code

General Purpose and Concepts

The purpose of the NEC is "the practical safeguarding of persons and property from hazards arising from the use of electricity."

The NEC is basically considered to be the minimum adequate set of critera by which an electrical installation should be judged. Many local and regional authorities use the NEC as a standard for their requirements in electrical installations. As it represents the minimum, many local and regional authorities have have gone further and use more stringent sets of critera than the NEC.

It is fundamental to the NEC that the code is "not intended as a design specification nor an instruction manual for untrained persons." Since you are trained amateur radio operators, I *will* make the assumption that you are trained persons regarding the basic installation and operation of amateur radio equipment. You are most likely *untrained* regarding general electrical matters. As such *this* document should be considered as useful for informational purposes only, and not as absolute. The NEC is the absolute, and it is specifically stated in the NEC that ...

> "**Enforcement.** This Code is intended to be suitable for manditory application by governmental bodies excercising legal jurisdiction over electrical installations and for use by insurance inspectors. The *authority having jurisdiction of enforcement of the Code* will have the responsibility for making interpretations of the rules, for deciding upon the approval of equipment and materials, and for granting the special permission contemplated in a number of the rules.
>
> The authority having jurisdiction may waive specific requirements in this Code or permit alternate methods, where it is assured that equivalent objectives can be achieved by establishing and maintaining effective safety.
>
> This Code may require new products constructions, or materials which may not yet be available at the time the Code is adopted. In such event, the authority having jurisdiction may permit the use of the products, constructions, or materials which comply with the most recent previous edition of this Code adopted

by the jurisdiction. "

It will be noted from the above quotation that 1) the "authority having jurisdiction" (e.g., your local city/county/state building inspectors) has the final say-so in the matter regarding interpretation of the Code, 2) such authority may waive specific requirements of the Code for a given installation, and 3) such authority may waive new Code requirements for a given installation until such time as the materials necessary are available.

The NEC specifically covers installations of:

1. "electric conductors and equipment within or on public or private buildings or other structures, including mobile homes, recreational vehicles, and floating buildings; and other premises such as yards, carnival, parking and other lots, and industrial substations"
2. "conductors that connect to the supply of electricity"
3. "other outside conductors on the premises"
4. "optical fiber cable"

The NEC specifically does *not* cover installations:

1. "in ships, watercraft other than floating buildings, railway rolling stock, aircraft, or automotive vehicles other than mobile homes and recreational vehicles"
2. "underground in mines"
3. "of railways for generation, transformation, transmission, or distribution of power used exclusively for operation of rolling stock or installations used exclusively for signalling and communication purposes"
4. "of communication equipment under the exclusive control of communication utilites, located outdoors or in building spaces used exclusively for such installations"
5. "under the exclusive control of electric utilities for the purpose of communication, or metering; or for the generation, control, transformation, transmission, and distribution of electric energy located in buildings used exclusively by utilities for such purposes or located outdoors on property owned or leased by the utility or on public highways, streets, roads, etc., or by established rights on private property"

As can be gleaned from the above, if your amateur station is in your *home*, or in your *yard*, or in your *mobile home*, or in your *recreational vehicle*, its installation is covered by the NEC.

The only times it would not be covered by the NEC, would then be, in mobile operation (not in your recreational vehicle) and in portable or emergency operation (not in a building or on a premises where you are connected to permanent elecrical systems or portable generation systems). Portable generation systems, i.e., engine driven electrical generators, are covered by grounding and cordage requirements of the NEC. In other words, you are probably covered by the requirements of the NEC at all times except where in mobile operation or self-contained battery portable operation. This could be intepreted to include such typical amateur radio operations as field days, picnics where stations are set up, etc., but would not include your car or your yacht (other Codes *may apply* in these instances).

Reference Materials of Note

There are three good references relative to the NEC. The first two are from the National Fire Protection Association (NFPA) (they who write/revise the Code) and the last is by the American Radio Relay League (ARRL).

1. Anonymous. 1989. NFPA 70 National Electrical Code — 1990. ANSI/NFPA 70, An American National Standard, August 7, 1989. National Fire Protection Association, Battery Park, Quincy, MA 02269.

2. Early, Mark W., ed. 1989. The National Electrical Code — 1990 Handbook. National Fire Protection Association, Battery Park, Quincy, MA 02269.

3. Wilson, M.J. 1986. The 1987 ARRL Handbook for the Radio Amateur. 64th ed. American Radio Relay League, Newington, CT 06111. (See Chapter 37 — Assembling a Station).

There is also a booklet, referenced in the ARRL Handbook, published by the NFPA, listed as NFPA 78-1983 "Lightning Protection Code" that is of interest. You might write the NFPA to obtain copies of the NEC Handbook, and the Lightning Protection Codes. The cost of the Handbook is approximately $50.00, which is a bit exhorbitant for the average ham, but well worth it if you ever *need* it. It should be possible to find copies of these documents in any well-stocked public library. Since the sections of the Code pertaining to amateur radio are relatively stable, you might find out of date editions for reference at electrical contractors, or even used book stores.

There are several other guides and study books covering the NEC. But most do not *completely* cover the Code. They often leave out the sections that are applicable to amateur radio and merely have a small paragraph that says, in effect, *go read* the "real" Code. Beware of those guides, manuals, etc. They are not worth *your* money.

Sections of the NEC Applicable to Amateur Radio

Articles That May Apply

The articles of the NEC that apply directly to amateur radio are:

1. Article 810 — Radio and Television Equipment.
2. Chapter 1 — General. (e.g., general definitions and requirements)
3. Chapter 2 — Wiring and Protection.
4. Chapter 3 — Wiring Methods and Materials.
5. Chapter 4 — Equipment for General Use.
6. Article 640 — Sound Recording and Similar Equipment.

These articles and chapters of the NEC are specifically cited as requiring compliance *where there is "wiring from the source of power to and between devices connect[d] to the interior wiring system."* Note that where an installation *DOES NOT* connect *in any way* to the "interior wiring system" some of these sections of the code may not apply. (Such installation will be rare, except in portable or emergency amateur radio operations.)

Because of the rapid advancement of the state of the art in amateur radio, the current (1990) form of the NEC may not cover some newly developing practices. In this particular case, certain additional sections of the NEC *may* apply or will be of use for reference purposes. These particular sections are:

1. Article 480 — Storage Batteries.
2. Article 551 — Recreational Vehicles, Parks.
3. Article 645 — Electronic Computer/Data Processing Equipment.

4. Article 670 — Industrial Machinery.
5. Article 690 — Solar Photovoltaic Systems.
6. Article 702 — Optional Standby Systems.
7. Article 720 — Circuits and Equipment Operating at Less than 50 Volts.
8. Article 820 — Community Antenna Television and Radio Distribution Systems.

The Main Article that DOES Apply

Article 810 — Radio and Television Equipment is the main article that applies to amateur radio. There are several additional specific articles (Chapters 1-4 and Article 640) that cover general wiring requirements not specifically superceded by Article 810. These form the basic core of of the Code affecting amateur radio installations. There is some coverage of coaxial cable installations in Article 820, that is of potential application to amateur radio stations.

Some hams may need to comply with additional aspects of the Code because of their installation of such equipment as solar charging panels, standby generators, or battery power supplies. Also, if your station is contained in a recreational vehicle, there are sections of the Code that apply. If you operate any of these additional units, check the sections of the Code that apply (as enumerated above).

Amateur Radio Installations

Scope

Amateur radio installations are covered by Article 810 — Radio and Television Equipment. Most of this article will apply, plus some additional articles. If the installation is only a receiving installation, sections A — General, and B — Receiving Equipment — Antenna Systems, will apply. Generally, the receiving installations will be such stations as SWL stations, or special receive only installations, or your general purpose boat anchor household radio, from the crystal set up (if it uses an exterior antenna). If the installation is a receiving and transmitting installation (as are esssentially all amateur radio stations) then sections A, B, C — Amateur Transmitting and Receiving Stations — Antenna Systems, and D — Interior Installation — Transmitting Stations, will apply. For the purposes of this document, I will make the assumption that all readers are interested in amateur installations of transmitting and receiving equipment.

If your amateur radio station is comprised of entirely manufactured commercially available equipment, then much of the following as regards specifics of wiring, fusing, etc., will not apply. It will apply to the amateur experimenter who builds his own equipment.

General

There are three general points to be noted concerning amateur installations. They are:

1. "Wiring from the source of power to and between devices connected to the interior wiring system shall comply with Chapters 1 through 4 other than as modified by Sections 640-3, 640-4, and 640-5."

2. "Wiring for radio-frequency and audio-frequency equipment and loud speakers shall comply with Article 640."

3. "Radio interference eliminators, interference capacitors, or noise supressors connected to power-supply leads shall be of a listed type. They shall not be exposed to physical

damage."

The first point means that *all* wiring of power TO and BETWEEN any amateur equipment *connected to the interior wiring system* shall be properly installed. Chapters 1-4 and Article 640 cover in great detail what is required. The most important considerations are that 1) your power cable running the 110 volt (or maybe also 220 volt) wiring will meet the code requirements. Probably this just will mean that your wall receptacle plug and the power cord needs to be in good shape and of the *proper* type of cable. Since most power cords are built in for AC powered rigs, this is usually not a problem. You need to be sure that any extension cord or power strip that you might use is listed, or is or approved construction if you homebrew your own. Also, any interconnecting cords will have to be in good shape, and of the proper type. If your rig is recent, the manufacturers power cord should suffice. If you are wiring your own power cord, then it will have to comply with appropriate sections of the NEC.

The second point merely requires that RF and AUDIO wiring you might use meets the requirements of Article 640. The scope of Article 640 covers equipment and wiring for "sound recording and reproduction, centralized distribution of sound, public address, speech-input systems, and electronic organs". So, the article applies in a general way to amateur installations. Basically the requirements from Article 640 are as follows:

1. Power supply conductors need to be properly identified, and will not be mixed with RF or AUDIO wiring.

2. Leads to motor generators (dynamotors) or rotary converters will be separated (input leads from output leads).

3. Flexible cords and cables will be of types S, SJ, ST, SJO, SJT, or other approved types. Note that terminals will be marked to show their proper connections.

4. Power supply terminals will be separated from non-power supply terminals by a distance equal to at least the spacing between power supply terminals of the opposite polarity.

5. Storage battery installations will have to comply with Article 480. Conductors for storage batteries shall be rubber-covered or thermoplastic covered.

6. Overcurrent protection shall be as follows — a) filament circuits (not to 15 amperes except for storage batteries not to exceed 20 amperes), b) plate circuits (not to exceed 1.0 ampere), and control grid circuits (not to exceed 1.0 ampere). Note that overcurrent devices will be placed as near as practicable to the source of power.

The third point requires that all devices added to power supply leads for filtering will be listed, and that they will be installed so as to be protected from damage. This *appears to* *apply* to external devices only. For devices that an amateur experimenter would ordinarily install for filtering in the course of building, for example, an amplifier and its associated power supply, internally to the enclosure containing the amplifier or power supply circuitry, this may not apply. But, it would be up to the builder to insure that the components installed would be of sufficient rating so as to *not* be prone to failure.

Amateur Radio Transmitting Equipment

There are specific requirements for amateur radio transmitting equipment as relates to interior installation. These requirements are specifically covered by Article 810, section D (Interior Installation — Transmitting Stations).

First, there must be a clearance of at least 4 inches between any transmitter conductor inside the building and normal interior electrical lines.

> "**810-70. Clearance from Other Conductors.** All conductors inside the building shall be separated at least 4 inches (102mm) from the conductors of any electric light, power, or signaling circuit.
>
> *Exception No. 1: As provided in Article 640.*
>
> *Exception No. 2: Where separated from other conductors by raceway or some firmly fixed non-conductor such as porcelain tubes or flexible tubing.*"

The exceptions appear to allow for placement in raceways, wireways or auxilliary gutters, with certain specific additional requirements. (see Article 640), or for spaced placement by firmly fixed non-conductors. Most amateur installations will *not* have such exotic wiring adaptations, unless the shack was designed from the ground up, as if, for example, you were building your own shack in a separate building in your yard, and could have it designed from scratch.

Second, certain requirements must be met regarding the actual construction of the transmitting equipment.

> "**810-71. General.** Transmitters shall comply with (a) through (c) below.
>
> **(a) Enclosing.** The transmitter shall be enclosed in a metal frame or grille, or separated from the operating space by a barrier or other equivalent means, all metallic parts of which are effectively connected to ground.
>
> **(b) Grounding of Controls.** All external metal handles and controls accessible to the operating personnel shall be effectively grounded.

> **(c) Interlocks on Doors.** All access doors shall be provieded with interlocks that will disconnect all voltages over 350 volts between conductors when any access door is opened."

In the first requirement, that of enclosing, it is important to have the transmitter contained in a metal frame or cabinet, *or* have it spatially removed from potential shock to the operator by placement behind a barrier of some sort.

In the second requirement, that of grounding of controls, it is necessary to make sure that any control available to the operator is grounded at all points exterior to the cabinet, where the operator might be able to get a shock. This probably would also include RF burns, but is not specifically so stated.

In the third requirement, that of interlocks when any panel is removed from the transmitter and the plate voltage is in excess of 350 volts, is one that is essentially unheard of in amateur radio equipment. But, it is a requirement. Most commercial amateur transmitters *do not* have interlocks. Most military surplus transmitters that are likely to be found in the amateur stations, when they are in the 100-1000 watt category *will* have interlocks, unless previously removed by a ham. Technically, if your transmitter uses any high voltage in excess of 350 volts, there are *supposed to be* interlocks on all access panels. The way that manufacturers get around this is to use screws to hold the panels on, instead of latches or thumbnuts. In that way, they can claim that the transmitter was *not designed* to be operated with the covers off. Since most amateur equipment of recent vintage is transistorized (except for the final stages of some relatively recent rigs) this requirement will most likely not apply much in the future, unless you are running a tube linear amplifier.

Grounds and Grounding

Grounding of an amateur radio station is *the* most important consideration when installing the station. Although many people think that almost any ol' metal stake/rod/pipe or whatever driven into the ground is a "ground", the requirements of the NEC are *much* more specific and detailed.

A ground is " a conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth." Hopefully all of the grounds that you ever will use are intentional, and not accidental, as the accidental ones are sometimes *permanent* to the amateur operator, rendering him a silent key. For the purposes of this document, the ground in an amateur radio station is covered by Articles 810 and 250. Article 250 is a *very extensive* section that covers all possible grounds in residential/industrial/other applications. But, certain points should be noted from Article 250. They are:

> "Rod and pipe electrodes shall not be less than 8 feet (2.44 m) in length and shall consist of the following materials, and shall be installed in the following manner:
>
> 1. Electrodes of pipe or conduit shall not be smaller than 3/4-inch trade size and, where of iron or steel, shall have the outer surface galvanized or otherwise metal coated for corrosion protection.
> 2. Electrodes of rods of iron or steel shall be at least 5/8 inch (15.87 mm) in diameter. Nonferrous or stainless steel rods or their equivalent less than 5/8 inch (15.87 mm) shall be listed and shall not be less than 1/2 inch (12.7 mm) in diameter.
> 3. The electrode shall be installed such that at least 8 feet (2.44 m) is in contact with the soil. It shall be driven to a depth of not less than 8 feet (2.44 m) except that where rock bottom is encountered, the electrode shall be driven at an oblique angle not to exceed 45 degrees from the vertical or shall be buried in a trench that is at least 2-1/2 feet (762 mm) deep. The upper end of the electrode shall be flush with or below ground level unless the above-

ground end and the grounding grounding electrode conductor attachment are protected against physical damage as specified in Section 250-117.

> 250-117. Protection of Attachment. Ground clamps or other fittings shall be approved for general use without protection or shall be protected from ordinary physical damage as indicated in (a) or (b) below.
>
> (a) Not Likely to be Damaged. Installations where they are not likely to be damaged.
>
> (b) Protective Covering. Enclosing in metal, wood, or equivalent protective covering."

If your house or shack electrical system is a 3-wire grounded system, using one of the above grounding electrodes, then, technically, all you have to do is to connect via a standard approved 3-wire plug to your equipment, and your shack is grounded. This is the minimum, and in older houses, cannot be counted on to be valid. Therefore, you must take it upon yourself in your own amateur radio station installation to install a proper ground per the above Article 250 requirements and the following Article 810 requirements.

1. "Material. The grounding conductor shall be of copper, aluminum, copper-clad steel, bronze, or similar corrosion-resistant material."

2. "Inslulation. Insulation on grounding conductors shall not be required."

3. "Supports. The grounding conductors shall be securely fastened in place and shall be permitted to be directly attached to the surface wired wired over without the use of insulating supports. *Exception: Where proper support cannot be provided, the size of the grounding conductors shall be increased proportionately.*"

4. "Mechanical Protection. The grounding conductor shall be protected where exposed to physical damage, or the size of the grounding conductors shall be increased proportionately to compensate for the lack of protection."

5. "Run in Straight Line. The grounding conductor for an antenna mast or antenna discharge unit shall be run in as straight a line as practicable from the mast or discharge unit to the grounding electrode."

6. "Electrode. The grounding conductor shall be connected as follows:

   (a) To the nearest accessible location on (1) the building or structure grounding electrode system as covered in Section 250-81, ... or (6) the grounding electrode conductor or the grounding electrode conductor metal enclosures; or

   (b) If the building or structure served has no grounding means as described in [the previous item], to any one of the individual electrodes described in Section 250-81; or

   (c) If the building or structure served has no grounding means as described in [the second previous item], to: (1) an effectively grounded metal structure, or (2) to any of the individual electrodes described in Section 250-83." (Note: this means connected to your station ground rod.)

7. "Inside or Outside Building. The grounding conductor shall be permitted to be run either inside or outside the building."

8. "Size. The grounding conductor shall not be smaller than No. 10 copper or No. 8 aluminum or No. 17 copper-clad steel or bronze."

9. "Common Ground. A single grounding conductor shall be permitted for both protective and operating purposes."

10. "Bonding of Electrodes. A bonding jumper not smaller than No. 6 copper or equivalent shall be connected between the radio and television equipment ground and the power grounding electrodes where the requirements of [Electrode section] above result in the use of separate electrodes. Bonding together of all separate electrodes shall be permitted."

11. "Size of Protective Grounding Conductor. The protective grounding conductor for transmitting stations shall be as large as the lead-in, but not smaller than No. 10 copper, bronze or copper-clad steel."

12. "Size of Operating Grounding Conductor. The operating grounding conductor for transmitting stations shall not be less than No. 14 copper or its equivalent."

Although the requirements seem stringent, they are relatively simple to meet. You must use an 8 foot or longer approved ground rod, separated at least 6 feet from the house ground rod, and connected to it by No. 6 wire. The ground rod must be in the ground at least 8 feet (i.e., all of it). The ground wire from your ground rod to the station must be at least the size of the antenna lead in wire or at least No. 10 copper in size. Connect all equipment to the ground wire with No. 10 size or larger copper wire. The antenna must be grounded in as straight a run to the ground rod, as practicable.

From an RF point of view, the ground conductor should be as short as possible, and effectively be as big as possible, to keep it low in impedance for RF. The ARRL has a good recommendation (see Chapter 37 — Assembling a Station, of the ARRL Handbook) for a low impedance amateur radio station ground. It uses a piece of 1/2 inch copper water pipe as a ground bus bar, connected to the grounding electrode with a length of RG-8 coaxial cable braid. Each piece of equipment is connected to the ground bus bar with a short piece of the same braid. This is a *very good and practical ground system.* The only additional requirement would be to bond the station ground rod to the house ground rod with No. 6 wire (or more or the RG-8 braid). (NOTE: The coaxial cable types with a double braid rather than a single braid work better, if you can find some.)

Once your ground system is in place, you can begin to think about your antenna system and making it meet the NEC.

Antennas

The requirements of the NEC as relates to amateur radio transmitting and receiveing station antennas are relatively simple. It is *very* simplified if you are using coaxial line antenna feed *and* the outer braid of the coaxial cable is grounded. If you are using an "old fashioned" open wire line fed antenna, single wire fed antenna, or end fed antenna (basically any high impedance, non-coaxial-line-fed antenna), then the requirements are somewhat more complex.

Antenna Construction

The antenna itself must meet certain requirements. These requirements have not changed greatly since approximately 1920, and their specifications are well proven.

The NEC requirements for antenna construction basically are:

1. The material from which antennas or lead-ins are constructed shall be hard-drawn copper, bronze, aluminum alloy, copper-clad steel or other high-strength, corrosion-resistant material. *Exception: Soft or medium-drawn copper shall be permitted for lead-in conductors where the maximum span between points of support is less than 35 feet (10.67 m).*

2. Outdoor antennas and lead-in conductors shall be securely supported. No attachment shall be made to an electric service mast, or to poles or structures carrying open power wires of over 250 volts between conductors. Insulators shall have sufficient strength to safely support the antenna. Lead-in conductors shall be securely attached to the antenna.

3. Outdoor antennas and lead-in conductors shall NOT cross OVER open conductors of electric power, and shall be kept well away from such circuits so as to avoid the possiblity of accidental contact. A clearance of at least 2 feet (610 mm) must be maintained between antennas and lead-in conductors and any such circuits. Where possible, the antenna conductors shall NOT cross UNDER open elctric light or power conductors.

4. Splices and joints in antenna spans shall be made mechanically secure with approved splicing devices or by such other means as will not appreciably weaken the conductors.

5. Masts and metal structures supporting antennas shall be grounded in accordance with [the grounding section above]. (Note: this also means that these grounds, if using separate electrodes from the main operating ground or house ground, shall be bonded to the main operating ground with at least No. 6 copper wire.)

6. The size of antenna wire depends upon the open span length between antenna supports. If the maximum open span length is less than 150 feet, then the size antenna wire shall be not less than No. 14 hard-drawn copper, copper-clad steel, bronze or *other high-strength material.* If the maximum open span length is 150 feet or greater, then the size antenna wire shall be not less than No. 10 hard-drawn copper, or No. 12 copper-clad steel, bronze or *other high-strength material.*

7. The size of antenna lead-in wire for transmitting stations shall be of a size at least as great as that of the antenna conductors.

Antenna and Lead-In Clearances

Certain clearances must be maintained between the antenna or antenna lead-in conductors and any building to which they are attached, per NEC requirements.

1. Antenna conductors for transmitting stations, attached to buildings, shall be firmly mounted at least 3 inches (76 mm) clear of the surface of the building, on nonabsorbent insulating support, such as treated pins or brackets equipped with insulators having not less than 3-inch (76 mm) creepage and airgap distances.

2. Lead-in conductors for transmitting stations, attached to buildings, shall also comply with these requirements. *Exception: Where the lead-in conductors are enclosed in a continuous metalic shield that is permanently and effectively grounded, they shall not be required to comply with these requirements. Where grounded, the metallic shield shall also be permitted to be used as a conductor.*

3. Lead-in conductors to radio transmitters shall be so located or installed as to make accidental contact with them difficult.

Note: Creepage distance is that distance that represents the total length of travel of the shortest electrical path over the surface of the insulator from the conductor to the mounting surface. Airgap distance is the shortest distance in the air, not along the surface of the insulator, from the conductor to the nearest mounting surface.

What this means is that if you are using coaxial line feed to the antenna, and the outer braid of the coax is "permanently and effectively grounded" then that is all you have to do for grounding your antenna, and for lead-in clearances. If you are not using grounded outer braid coaxial line feed to the antenna, then you must maintain the lead-in clearances prescribed.

Although it is not stated exactly where the coaxial line fed antenna outer braid is to be grounded, relative to where it enters the building or where it connects to the station, there are some indications from Article 820 — Community Antenna Television and Radio Distribution Systems, as to where such grounding should occur. Specifically, " where coaxial cable is exposed to lightning or to accidental contact with lightning arrester conductors or power conductors operating at a voltage of over 300 volts to ground, the outer conductive shield of the coaxial cable shall be grounded at the building premises as close to the point of cable entry as practicable." Although this specifically applies to cable television installations, this writers opinion is that it *will also apply* to amateur coaxial cable antenna installations, because they also are exposed to lightning.

Entrance of the Antenna or Lead-in to the Building

The entrance of the antenna or antenna lead-in to the building must meet certain NEC requirements. The requirements are minimal for coaxial line fed antennas, and more complex for high impedance open line fed antennas.

> "Except where protected with a continuous metallic shield that is permanently and effectively grounded, lead-in conductors for transmitting stations shall enter buildings by one of the following methods: (1) through a rigid, noncombustible, nonabsorbent insulating tube or bushing; (2) through an opening provided for the purpose in which the entrance conductors are firmly secured so as to provide a clearance of at least 2 inches (50.8 mm); or (3) through a drilled window pane.

Most hams prefer the window pane approach (method 3) either by drilling a pane or by removing a pane and replacing it with and insulating board, or they prefer to leave a window partially open with an insulating board under the window (well sealed against weather and burglars). Few hams cut a 4 inch hole in the wall (method 2). Some hams use the insulating bushing (method 1), especially for coaxial cable entry.

Antenna Discharge Units and Antenna Grounding

ALL antenna and antenna lead-in conductors that enter a building need to be protected against static buildup or lightning on the conductors. This is done through the use of an antenna discharge unit (hams call them lightning arresters). Both receiving and transmitting stations require such units on conductors entering a building.

Receiving Installations

The requirements of the NEC for receiving antenna discharge units are relatively simple. Basically they are:

1. Each conductor of a lead-in from an outdoor antenna shall be provided with an antenna discharge unit. *Exception: Where the lead-in conductors are enclosed in a continuous metallic shield that is either permanently and effectively grounded, or is protected by an antenna discharge unit.*
2. Antenna discharge units shall be located outside the building or inside the building between the point of entrance of the lead-in and the radio set or transformers, and as near as practicable to the entrance of the conductors to the building. The antenna discharge unit shall not be located near combustible material nor in a hazardous (classifed) location as defined in Article 500.
3. The antenna discharge unit shall be grounded in accordance with [the grounding section above].

Note: a lightning arrester is not required where the lead-in conductors are enclosed in a continuous metallic shield (read good ol' coaxial cable). This is because a lightning discharge will jump from the inner conductor to the grounded braid *before* it gets into the receiving set. Remember — the assumption is that the outer braid is *grounded.*

Transmitting Installations

The requirements for transmitting installations are very similar to that for receiving installations, but the units are structurally larger, with higher breakdown voltages,

> "Antenna Discharge Units — Transmitting Stations. Each conductor of a lead-in for outdoor antennas shall be provided with an antenna discharge unit *or other suitable means* that will drain static charges from the antenna system."

It is key to note here that the "other suitable means" allows the use of a grounding switch or a grounding clip instead of a lightning arrester. It is still a good idea to have a transmitting sized lightning arrester present in the line, in addition to an antenna grounding switch or an antenna grounding clip.

The antenna grounding switch is a large double throw, single or double pole, knife switch with at least a 3 inch leakage path (creepage and airgap). Such switches are *not* common at the present time, but they can be found at hamfests, or can be constructed if the standoffs and knife switch blade parts are available or can be fashioned. The knife blade should have at least a 3 inch throw, and should be 1/8 inch thick and 1/2 inch wide minimally. Occasionally, such switch parts can be found in old auditoriums or theatres that are being torn down or renovated, since they are often found on old stage lighting electrical panels.

The ground clip is perhaps the simplest approach to meeting the requirement. A large battery clip is attached to a flexible ground lead that can be clipped to the antenna where it enters the building. Alternatively, the entry lead and the ground lead can be mounted on large 3 inch standoffs and the clip attached to the antenna lead-in. Then the antenna can be clipped to the station or to the ground. Of the two means, the switch approach with a suitable lightning arrester is the best approach. Designs for transmitting rating lightning arresters are given in older ARRL Handbooks dating from the 1960's and earlier, since it was common in those days to use open wire feeders.

Once your antenna and ground systems are in place, your amateur radio station has basically met the requirements of the NEC. See the figures at the end of this document for illustrations of possible amateur radio station grounding systems, lightning arresters, and other related details.

The following sections of this document contain some additional information relating to other sections of the NEC that *might* be applicable to, or be useful for reference purposes concerning amateur radio installations.

Batteries and Battery Operation

Since recently manufactured amateur radio equipment is transistorized, and usually runs on 12 volts DC, it is not uncommon for amateur stations to be run entirely on battery power. When battery installations using batteries of a size larger than 10 Ah capacity (ten ampere hour capacity), then the installation must meet the requirements of the NEC.

Battery installations are covered by NEC Article 480 — Storage Batteries. The requirements are not particularly stringent, but require some thinking as to how they will be implemented. The main consideration is whether or not the battery installation is permanent or is temporary. Permanent in this case means that the battery installation is permanently in-line with the equipment. Temporary means that the battery is not permanently in-line with the equipment.

The minimal requirements for temporary installation as can be gleaned from all of the various sections of the Code that may apply are, (1) the conductors shall be No. 12 or larger copper, (2) overcurrent protection shall be provided, (3) a disconnecting means shall be provided, (4) the battery installation shall be grounded.

For most amateur transmitters, wire of No. 10 is used, and fuses are usually installed internally in the transmitter or in the line. An external circuit breaker in the line would be desirable. A plug and socket, or battery clips would provide disconnecting means. Grounding the negative battery lead would satisfy the grounding requirement. Additionally, the battery terminals should be protected so that they are not easily able to be shorted.

For permanent installations, there are no prescribed requirements, relating directly to amateur radio station installations. But, since the application is a voltage under 50 volts application, it could comply with Article 480 — Storage Batteries, Article 640 – Sound-recording and Similar Equipment, Article 690 — Solar Photovoltaic Installations, Article 650 — Organs, Article 551 — Recreational Vehicles and Recreational Vehicle Parks, Article 720 — Circuits and Equipment Operating at Less Than 50 Volts, or even Article 670 — Industrial Machinery, in addition to Chapters 1-4.

Which particular sections of the Code will apply, is mostly up to the whims of the authority having jurisdiction. It is this authors opinion that the most directly applicable sections of the Code are from Article 551. The other sections say essentially nothing directly applicable to low voltage battery operation of radio equipment. The only thing that comes close might be Article 690, since sections of that article apply to battery power installations.

Remember that if permanent installation is contemplated, then requirements for wiring, fusing, disconnecting, etc. will have to follow standard wiring practices as outlined in Chapters 1-4, plus whatever else is deemed applicable.

Useful Tidbits of Miscellaneous Information

The following pages contain diagrams, figures, and other sorts of information that might be useful in your setting up of an amateur radio station to meet the National Electrical Code. These tidbits of information have been excerpted from various sources, as noted.

Additionally, some pages contain examples illustrating various types of antenna standoffs, feed-throughs, insulators, etc., that might be sought at hamfests for use in an amateur radio station to meet compliance with the NEC.

Figure .1. ARRL suggested station grounding system (from the ARRL 1990 Radio Amateur Handbook). Note the use of *very heavy* conductors for low impedance.

Figure .2. ARRL suggested window or wall cable entry for low impedance coaxial, *insulated* twinlead, or antenna rotor cable (from the ARRL 1990 Radio Amateur Handbook).

Figure .3. Relative sizes and ampacity of wire — AWG American Wire Guage (from MWPS-28, Farm Building Wiring Handbook, 1986, Iowa State University, Ames).

Figure .4. Example ground systems (from MWPS-28, Farm Building Wiring Handbook, 1986, Iowa State University, Ames). Note: the NEC only requires 6 foot spacing between electrodes of the same or different systems.

Figure .5. ARRL suggested antenna discharge unit (lightning arrester) for use with high impedance fed antennas (from the ARRL 1978 Radio Amateur Handbook).

Figure .6. ARRL suggested antenna feedline entry methods for use with high impedance fed antennas (from the ARRL 1938 Radio Amateur Handbook).

Figure .7. General schematic representation summary of amateur radio requirements of the NEC (from Kenneth L. Gebert, National Electrical Code Blueprint Reading, 10th ed., 1986, American Technical Publishing Co.).

Figure .8. General simplistic schematic representation of an end fed antenna for amateur use (from an early Radio Amateur's Handbook by A. Collins.).

Figure .9. Example of a lightning switch used to ground an end fed antenna when not in use (from an early Radio Amateur's Handbook by A. Collins.).

Figure .10. Example of a feed through insulator used to bring the lead in from an end fed antenna into the radio room (from an early Signal Corps radio handbook from the Superintendent of Documents, Washington, DC).