ELECTRICAL SAFETY

COLLINS RADIO COMPANY

Cedar Rapids, Iowa

EFFECTS OF ELECTRICITY ON THE HUMAN BODY

HUMAN RESISTANCE TO ELECTRICAL CURRENT

Type of Resistance	Resistance Value
Dry Skin	100,000 to 600,000 Ohms
Wet Skin	1,000 Ohms
Internal Body - hand to foot	400 to 600 Ohms
Ear to Ear	about 100 Ohms

CURRENT VALUES* AFFECTING HUMAN BEINGS+

	Readings	Effects
SAFE CURRENT VALUES	1* milliampere or less	Causes no sensation - not felt.
	1 to 8 m.a.	Sensation of shock, not painful; individual can let go at will because muscular control is not lost.
UNSAFE CURRENT VALUES	8 to 15 m.a.	Painful shock; individual can let go at will because muscular control is not lost.
	15 to 20 m.a.	Painful shock; muscular control of adjacent muscles lost. Cannot let go.
	20 to 50 m.a.	Painful, severe muscular contractions; breathing is difficult.
	50 to 100 m.a. (Possible) 100 to 200 m.a. (Certain)	VENTRICULAR FIBRILLATION (A heart condition that results in instant death -- no known remedy)
	200 to over m.a.	Severe burns, severe muscular contractions -- so severe that chest muscles clamp heart and stop it during duration of shock. (This prevents ventricular fibrillation.)

* 1 milliampere is 1/1000 of an ampere.
+ values published by the National Safety Council.

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ELECTRICAL SAFETY

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Prepared by

Electronics Safety Committee
A. C. Victor, Chairman
A. Blank
K. Dawson
P. Piskel
A. Pyle
R. Titterington

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Section I

INTRODUCTION

1.1 PERSONAL SAFETY.

Nothing in Collins Radio Company can be more important to the individual than his own personal safety. In less than 1/100 of a second your carelessness can cause a fatal accident.

Electronic circuits are potentially dangerous even when the individual uses extreme caution in his work. The danger, however, varies inversely with the effectiveness of safety measures. Therefore, proven, recommended safety precautions must be used.

Watch what touches your body as well as your hands! Stop and think before you touch bare conductors!

1.2 SAFETY IS YOUR BUSINESS.

The Collins Radio Company is taking every step possible to provide safeguards for all its equipment to reduce or eliminate electrical shock hazards. Test methods and test equipment are being reviewed to achieve greater safety. Your suggestions for improvements are always welcome. Success in accident prevention can be achieved only through cooperation and individual participation by every employee.

It is important that every employee know and practice all safety rules. Violation of the rules may bring irreparable injury or death to you or to others.

1.3 EXTINGUISHING ELECTRICAL FIRES.

Remove all electrical power before attempting to extinguish an electrical fire. Most fires in the testing section are caused by short circuits or overloading, and can be put out easily by the use of fire extinguishers. Use only carbon dioxide, carbon tetrachloride, or dry chemical-type fire extinguishers. If it appears that the fire cannot be controlled, the fire department must be called at once.

Do not use carbon tetrachloride in confined areas because of the poisonous fumes that arise.

1.4 FIRST AID TREATMENT TO SHOCK VICTIM.

THE WELFARE OF THE VICTIM IS OF PRIMARY IMPORTANCE. A co-worker should notify the first aid department and the employee's supervisor as soon as possible. Your first responsibility will be to kill the circuit immediately or, if unable, carefully remove the patient from contact with the circuit, using insulation to protect yourself. Do not touch the victim's body. During the confusion and excitement, you may have turned off the wrong switch. DO NOT MOVE PATIENT FARTHER THAN ABSOLUTELY NECESSARY.

1.5 RESUSCITATION.

Do not stop to loosen the patient's clothing, but begin actual resuscitation immediately. A life may be lost if a minute is wasted. As soon as possible, feel in the patient's mouth and throat to remove any foreign substance, such as tobacco, false teeth, gum, etc. If the mouth is shut tightly, artificial respiration may be applied through the nose. See section V for instructions.

Section II

SAFETY RULES FOR THE ELECTRONICS TECHNICIAN AND ELECTRICAL ENGINEER

2.1 SAFETY RULES.

2.1.1 DO'S.

(1) When Power is not Needed, Turn it Off.

This is a basic safety rule. Make every move a safe one.

(2) Discharge Capacitors.

Before you touch a capacitor which is connected to a de-energized circuit or which is disconnected entirely, short circuit the terminals to make sure the capacitor is completely discharged. A well-insulated lead or a shorting or grounding bar should be used for this purpose. Remember, capacitors are not discharged instantly when they are a part of an RC filter network.

(3) Consider all Bare Wiring as Live.

If you must work in close proximity to bare wiring, use extreme care.

(4) Beware of High Voltage.

Work with one hand in your rear pants pocket, grasping a billfold, a comb, or a handkerchief. You must consult your foreman if two hands are required. Stay clear of all grounding surfaces. An insulated floor mat may be necessary. Tell a co-worker what to do should you have an accident. It is too late to tell him afterward.

(5) Always be Alert.

New job assignments will require the full use of alert thinking and safe habits. Don't relax after you know the job.

(6) Develop Safe Habits.

Make adherence to safety rules a habit. Observance of all safety rules will enable you to do your work efficiently and safely.

(7) Know Your Job.

Study your equipment; have complete information about the work to be performed.

(8) Think Safety.

Report any hazard to your foreman. Reports should be made immediately; your life or your co-worker's life might be at stake. Promote safety on the job and at home. Make safety a habit.

(9) Learn Artificial Respiration.

If you know it, it may save your co-worker's life; if he knows it, it may save your life.

(10) Report All Electrical Shocks to Your Supervisor.

It is his responsibility to provide you with a safe place to work. If your equipment is faulty or your thinking is perplexed, the need exists for you and your supervisor to correct it. If you are sick, don't stay on the job.

2.1.2 DON'TS.

(1) Don't Use Faulty Test Equipment.

Report to your supervisor all equipment having frayed or worn cord sets, broken or damaged insulators, damaged or worn connectors, intermittent switches, and loose connecting terminals. They must be repaired. Their use in production shall be discontinued until repaired.

(2) Don't Work on High-Voltage Equipment When You Are Overtired, Dizzy, Nauseated, Feverish, or Under the Influence of Drugs Which Cause Drowsiness.

(3) Don't Work on High-Voltage Alone.

Have someone within sight who is qualified to render artificial respiration. Tell him what to do in case of trouble.

(4) Don't Assume a Circuit is Dead.

Use a voltmeter or other suitable indicating device to check for the presence of high-voltage. Turning the switch off is not sufficient reason to assume the circuit is dead. Relays and switches can be inoperative. Fusing can be wired incorrectly. Interlocks may be jumpered or defective.

(5) Don't Wear Jewelry.

Before you start work, remove your rings, wrist watches, bracelets and other similar items. One out of every five technicians has been a victim of electric shock or flesh burns because of jewelry.

(6) Don't Assume Your Equipment is Grounded.

Check all ground connections, making sure they are secure and are attached to a clean surface. INSPECT THEM WITH A VOLTMETER IF THE POWER IS ON. An ohmmeter should be used when the power is switched off.

Clear synthetic lacquer, or chemical finishes will prevent or reduce the effectiveness of an apparently good ground connection. Don't rely on a VISUAL INSPECTION; it can be misleading.

(7) Don't Be Careless.

A careless worker is a potential hazard to his fellow workers as well as to himself. Most electrical shocks are received because someone was careless. Don't take electrical shocks deliberately; injury to yourself or your friends may be the result.

(8) Don't Perpetrate Jokes.

Jokes involving human life are not funny.

(9) Don't Short-Out Interlocks Without Proper Authority.

They are provided to protect others from electric shock as well as yourself.

Section III

THE NATURE AND EFFECTS OF ELECTRIC SHOCK

3.1 EFFECTS OF ELECTRIC SHOCK.

Death from electric shock may result from any one or a combination of the following causes:

(1) Paralysis of the respiratory muscles; producing death by asphyxia (deficiency of oxygen and excess of carbon dioxide in the blood).

(2) Hemorrhage; produced by increasing blood pressure during the passage of electric current.

(3) Heart failure; resulting from ventricular fibrillation. In this condition, the fibers of the heart muscles contract in an uncoordinated manner, blood circulation ceases, and death ensues.

(4) Respiratory failure; due to nervous inhibitions or actual damage to the nervous system.

(5) Skin and flesh burns with resultant complications.

3.1.1 PARALYSIS OF RESPIRATORY MUSCLES.

The first of these causes, while it in itself may be responsible for death, is in most cases associated with one of the other causes. It is a condition that results from continuous contraction of the respiratory muscles. In this condition, the normal functioning of the lungs is impossible and the victim suffocates.

3.1.2 HEMORRHAGE.

As the current passes through the blood stream, it raises the temperature of the blood and increases the pressure which makes the walls of the blood vessels break. This condition partially accounts for the usually severe hemorrhage following a serious electric shock.

3.1.3 HEART FAILURE.

This is of chief concern since death can result from contact with low-voltage circuits, which cause only a relatively low value of current to pass through the victim. Ventricular fibrillation is a condition in which the heart loses it rhythm; muscles quiver in an uncoordinated manner, even after the current is stopped, and the heart cannot regain rhythm.

Hence, the victim is sure to die unless he is given immediate medical aid that only a fully informed and competent physician is qualified to administer. Artificial respiration does nothing to restore heart rhythm.

Scientific groups have estimated that the passage of current in excess of ten milliamperes through the body can cause ventricular fibrillation or result in severe shock or both. To some extent, the longer the contact, the lower the current required for fibrillation.

3.1.4 RESPIRATORY FAILURE DUE TO NERVOUS INHIBITIONS OR DAMAGE TO THE NERVOUS SYSTEM.

These results usually are associated with higher potentials which will cause the passage of larger amounts of current through the body. When the body contacts a circuit and receives a high-intensity electric shock, the nervous system in the current path is paralyzed temporarily. The most common cause of this paralysis is respiratory failure. Breathing may be initiated by the use of artificial respiration or the application of a bodily jolt or jar. Paralysis of other parts of the body is sometimes involved and may persist for considerable periods after the current has been interrupted.

3.1.5 SKIN AND FLESH BURNS.

Aside from the fact that electric burns are apt to be deeper and therefore more serious than they appear outwardly, they are not different from other burns. They usually occur at the point of contact with the electrical circuit and are the result of passage of current through an extremely high-resistance contact.

3.2 REMEDIAL ACTION IS REQUIRED URGENTLY.

Since a layman cannot distinguish between the various possibilities, outlined previously, he should attempt resuscitation immediately if the victim is not breathing. This should be continued until the victim revives, death is diagnosed by a physician, or until rigor mortis sets in.

3.3 NATURE OF AN ELECTRIC SHOCK.

Investigations of low-voltage electrical shocks have proven that their causes can be traced to failure of the employee to understand the hazards involved. Here at Collins Radio Company, after many personnel interviews conducted as a part of the electronics safety program, it became apparent that most personnel do not know or understand the hazards of their jobs. In addition, they contribute further to the likelihood of electrical injury to themselves because of their carelessness or indifference.

Electricity works for you twenty-four hours every day of the year. It is your slave, but if it is carelessly handled for just 1/100 of a second, you, a member of your family, or some friend may be it's next victim.

The facts concerning the nature of an electric shock are listed in the following paragraph. Study them with the idea that you want to keep electricity your faithful servant and slave and not your executioner.

Generally speaking, the factors which determine the seriousness of an electrical shock are:

(1) Body resistance.

(2) Magnitude of current.

(3) Frequency of current.

(4) Path of current through body.

(5) Duration of current (contact time).

(6) Element of anticipation.

Each of these factors has been investigated thoroughly and reviewed separately by various organizations. It is hoped that their findings, which are summarized here, can be used by you to help establish safer operating practices, whether you are at home or on the job.

3.3.1 BODY RESISTANCE.

Resistance to current flow is to be found mainly in the skin surface. Calloused or dry skin has a fairly high resistance, but a sharp decrease in resistance takes place when the skin is moist. Once the skin resistance is broken down, the current flows through the blood and through the body tissues.

You will find that resistance during accidental live contact on dry skin is very dependent on the condition of the skin. For instance, the back of the hand, while apparently having much thinner skin than the palm, is often very dry, somewhat hairy, and can give very high resistance. Another part of the body, for example, the neck is not usually so dry as the back of the hand. High voltages may cause puncturing of the skin, for example, through a pore on the back of the hand. Hence, at high voltage, the momentary contact resistance may be several thousand ohms, but a fraction of a second later, if the skin is punctured, it may go as low as 400 ohms.

TABLE 3-1. HUMAN RESISTANCE TO ELECTRICAL CURRENT

SKIN CONDITION*	RESISTANCE
(a) Dry skin	100,000 to 600,000 ohms
(b) Wet skin	1,000 ohms
(c) Internal body - hand to foot	400 to 600 ohms
(d) Ear to ear	100 ohms
*Conditions (a) and (b) assume no skin puncture. Conditions (c) and (d) are for punctured skin.	

3.3.1.1 Summary.

For exposure to weather or locations where dampness is prevalent and where large areas of contact are involved, a body resistance of 500 ohms must be considered. For exposure indoors under dry conditions with limited area contact and where puncture of the skin is not assumed, this value may be raised to 1500 ohms. When conditions of high humidity and temperature exist indoors, the increased probability of low contact resistance, which results from wet clothing and standing perspiration, makes the 500-ohm value preferable.

3.3.2 FREQUENCY OF CURRENT.

The chief difference in the physical effect of direct current, as opposed to alternating current, is that the direct current does not cause contraction of the muscles to the extent associated with alternating current. Laboratory tests indicate that an individual can withstand a decidedly higher value of direct current and still maintain control of his muscles. At higher voltages, the contraction of the muscles at the moment of contact is so violent that it has the effect of a repelling blow. The contraction associated with a d-c shock differs from that associated with an a-c shock in that the direct-current contraction occurs chiefly at the time of making and breaking of the circuit.

The violent shock on interruption of d-c actually is a forerunner to the results obtained when using waveforms of various shapes, for it is found that the peak of the current wave actually governs the physiological effects. When there is a mixture of d-c to a-c, (occurring with some welding machines or power supplies) there is an appreciable reduction in the let-go d-c current value. For example, a 6-percent a-c component allows only 28 ma d-c as compared to 65 ma for pure d-c.

Frequency tests have been performed by electrical engineering groups at the University of California, who have published to date many papers on electric shock. They have confirmed the results of earlier workers that the 60-cycle wave is a very dangerous wave. (See figure 3-1.) Note that most hazardous shock frequencies occur in a range between 10 cps and 1000 cps.

In figure 3-1, values for women are about 66 percent of those for men. Current values become progressively dangerous to an increasing number of people as indicated by percentiles on right-hand side of curves.

The lowest curve of figure 3-1 represents the let-go current for 99-1/2 percent of the group and generally is regarded as the highest uninterrupted alternating current reasonably safe for all personnel.

There is a continuing decrease in muscular response as the frequency is increased beyond 10 kc; at 2.0 megacycles and above, it is negligible. Dielectric heating effects are increasingly important as the frequency rises; at 100 kc and above, the heating sensation predominates.

3.3.2.1 Summary.

Since practically all a-c primary power is generated at frequencies within the 10- to 1000-cps frequency range, it must be considered especially dangerous to handle compared

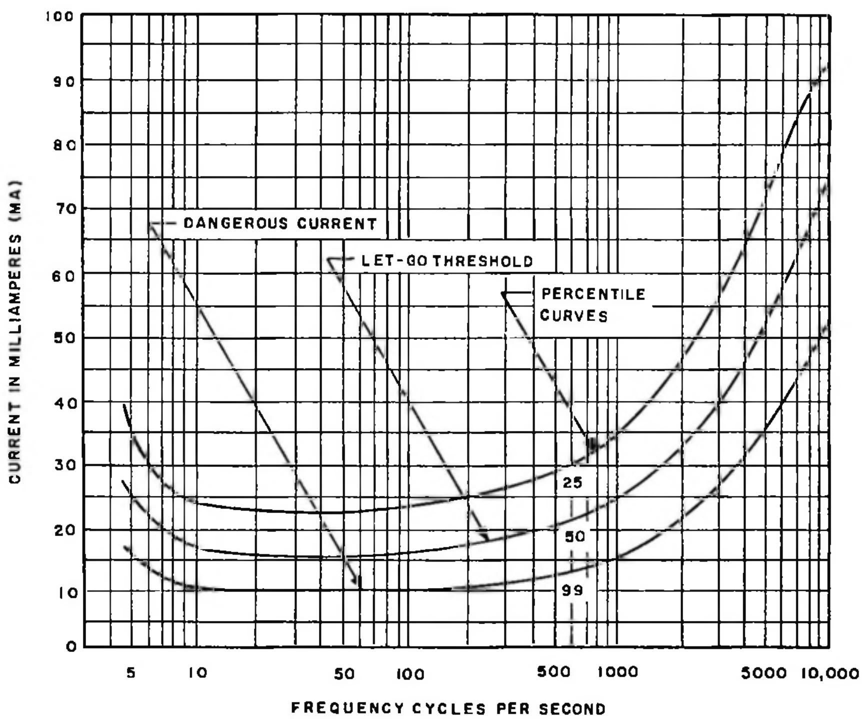

Figure 3-1. Effect of Frequency on Let-Go Current for Men

to d-c power. While work with d-c power is comparatively safer because the let-go current value is higher, it must be remembered that the uncontrollable and violent muscular reactions can cause innumerable accidents either involving oneself or innocent bystanders.

3.3.3 MAGNITUDE OF CURRENT.

A safe value of electric current is one that can be taken indefinitely, causes no bodily injury, and permits the individual to free himself voluntarily from contact with the circuit.

In 1930, a series of tests were conducted at Underwriter's Laboratories in an effort to determine the maximum current that an individual could withstand for a short time and still have voluntary control of his muscles. In these tests, members of the staff were used as subjects. Electrodes consisted of pliers held in each hand while the tests were recorded for 60 cycles alternating current. Tests with direct current indicated that slightly higher values could be withstood for a short period of time until a hot spot occurred at the point of contact.

In these tests, conducted on a mixed group of men and women, the voltage as well as the current was recorded. The results of these tests are detailed in table 3-2. Note the variation and magnitude of body resistance under normal conditions.

TABLE 3-2. UNDERWRITER'S LABORATORIES TESTS

SUBJECT	A-C VOLTAGE	CURRENT IN MILLIAMPERES	CALCULATED BODY RESISTANCE IN OHMS
A	40	6.0	6,670
B	32	7.5	4,260
C	25	6.0	4,170
D	20	8.0	2,500
E	20	8.0	2,500
F	33	9.5	3,470
G	21	6.0	3,500
H	30	10.0	3,000
I	29	8.0	3,620
J	31	6.0	5,160
K	30	10.0	3,000
L	21	9.0	2,330
M	30	8.0	3,750
Maximum	40	10.0	6,670
Minimum	20	6.0	2,330
Average	27.8	7.8	3,560

In similar tests on men only at the University of California, a greater magnitude of current, approximately 22 milliamperes, was withstood by some individuals. The average for their group was 16 milliamperes, while the low was 9 milliamperes.

In figure 3-2, Dalziel, Professor of electrical engineering, University of California, defines let-go current as that which 99-1/2 percent of the healthy adult male population can tolerate safely without loss of ability to voluntarily let go of the conductor which is held in the hand. Women can stand about 2/3 the current that men can withstand.

Hence, 7 ma forms the let-go value for women as compared to 9 ma for men. Children can stand about one-half the current that men can withstand.

There are no exact limits or even known values which show the exact injury for any given amperage, except in one instance. In criminal electrocutions, a current flow of 8 to 10 amperes through the victim has been recorded. A potential of approximately 2000 volts was applied between the electrodes. An average body temperature of approximately 138 degrees Fahrenheit was noted, forty degrees higher than the normal body temperature.

3.3.3.1 Summary.

It should be noted that the information on current magnitude generally concerns the effects of 60 cycles alternating current on men. Looking at figure 3-2, it will be noted that a difference of only 25 milliamperes exists between current which can just be perceived and current which can be fatal. The initial skin resistance may allow only a few milliamperes to flow through the body, but the instant the skin resistance breaks down, high current values will predominate.

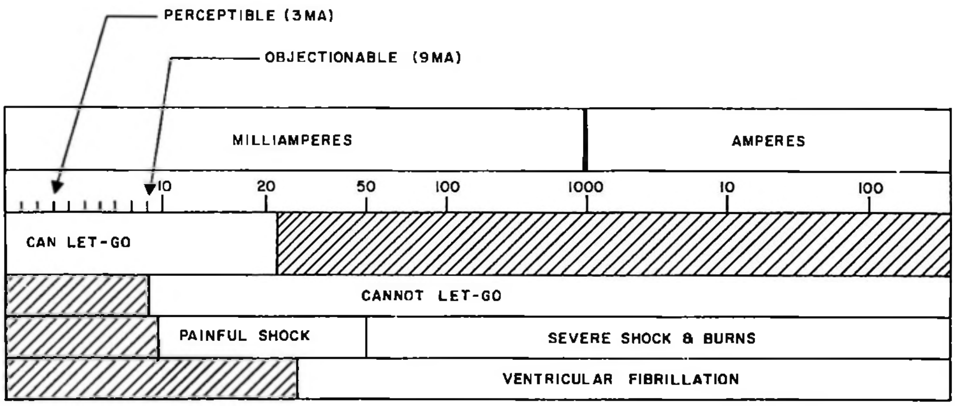

Figure 3-2. Effects of 60-Cycle Current on Men

Assuming the heart and lungs lay in the direct path of the current flow, scientific researchers state the maximum safe current flow would be 5 milliamperes. Currents between 5 and 25 milliamperes are dangerous, possibly fatal because they may lead to a state of exhaustion, loss of consciousness and inability to breathe. The muscular convulsions will cease when the current is removed, but the inability to breathe may persist, requiring artificial respiration.

Currents in excess of 25 milliamperes are extremely dangerous. Since it is doubtful if one can let-go, death is very possible.

3.3.4 PATH OF CURRENT.

It is obvious that shocks likely to produce ventricular fibrillation cannot be performed on man, and the only recourse is to project results obtained from animal experimentation to man.

Through years of laboratory experimentations, physiologists have substantiated the fact that the response of the heart of the dog and sheep to a given stimulus is the same as that of a human.

Basing their work upon this fact, tests were conducted to determine the effect of various current paths. Tests were conducted using 60 cycles alternating current, and the period of shock was 3 seconds. The results of these tests are tabulated in table 3-3.

TABLE 3-3. VENTRICULAR FIBRILLATION IN ANIMALS

ELECTRODE POSITION	NO. OF ANIMALS	CURRENT IN MILLIAMPERES		
		MINIMUM FIBRILLATING		MAXIMUM NONFIBRILLATING
		AVERAGE	RANGE	AVERAGE
Right front leg and left hind leg	20	250	160-390	240
Right front leg and left front leg	10	390	300-730	360
Head and left hind leg	10	300	120-430	260
Left front leg and right chest	10	240	140-390	200
Right and left chest	11	260	170-410	240
Right and left hind leg	5	No fibrillation up to 12.4 amperes		

3.3.4.1 Summary.

Injuries from electric shock are not as likely to be fatal when the current does not pass through or near nerve centers and vital organs. Results of scientific tests conducted on small animals would tend to substantiate the statement. In the majority of electrical accidents, the current flows from hand to feet or hand to hand. Since such a path involves both the heart and the lungs, there is great probability of a serious shock.

3.3.5 DURATION OF CURRENT (Contact Time).

In general, the longer the current flows through the body, the more serious may be the result. On high-voltage sources, considerable current is likely to flow, and generally if the victim is to be revived, only a very short exposure can be tolerated.

Time is of the utmost importance with respect to the severity of bodily tissue burns. Burns which break down the skin resistance allow a greater current flow, thus creating a more severe shock situation. Internally large amounts of current, 10 amperes or more, even though fibrillation of the heart is not present, will cause severe burning of tissue and organs, poisoning by combustion products, plus possible hemorrhage.

Continued contact with low-voltage circuit (the victim is unable to free himself) will result in a rapid decrease in muscular strength due to pain and fatigue associated with the accompanying severe involuntary muscular contractions.

Therefore, the ability to let-go rapidly decreases with prolonged contact. Prolonged exposure to currents only slightly in excess of ones let-go limit may produce exhaustion, asphyxia, and unconsciousness followed by death.

In the September 1961 issue of National Safety News, Charles F. Dalziel listed "the quantitive values of various electrical quantities controlling the danger of electric shock." They are listed here to help you in your evaluation of a potential shock hazard and to help eliminate the confusion about what constitutes an electric shock hazard.

3.3.5.1 Lethal Shock Hazard.

Those a-c and d-c circuits capable of passing through a 500-ohm resistor an uninterrupted alternating current in excess of 100 milliamperes, an interrupted direct current in excess of 500 milliamperes, or an impulse discharge in excess of 50 joules*; for complex output waveforms, such as d-c power supplies, a total of 50 or more joules through a 500-ohm resistor for one second.

*One joule is equivalent to the work required to force a current of one ampere flowing through a resistance of one ohm for one second (equals one watt-second).

3.3.5.2 Shock Hazard.

Those a-c and d-c circuits capable of passing through a 500-ohm resistor: an uninterrupted alternating current in excess of 9 milliamperes, an uninterrupted direct current in excess of 60 milliamperes, or an impulse discharge in excess of 1/4 joule.

3.3.5.3 Negligible Shock Hazard.

Shocks of an intensity less than those producing shock hazard, previously defined, from equipment and circuits operating at 25 volts or less are negligible.

NOTE: While shock hazards are negligible at 25 volts, a power source of as low as 6 volts can be dangerous. Approximately 20 percent of the people who received safety lectures in our plant were at some time in serious trouble with rings or watch bands shorting across low-voltage, high-current transformer windings, or storage batteries. In most cases, a ring had caused the short circuit and had become excruciatingly hot. In several extreme cases, part of the ring melted.

3.3.5.4 Summary.

It has been pointed out repeatedly that the longer the duration of the current, the more severe the shock. Therefore, prompt removal of the victim from the electric circuit is of paramount importance, but not to the extent that the rescuer forgets his own personal safety. Removal in a safe manner means pulling the victim free without coming in contact with the circuit or victim's body. No part of the victim's body must be touched with the unprotected hands as long as he is electrified.

3.3.6 ELEMENT OF ANTICIPATION.

The element of anticipation may or may not be present in every shock accident. Anticipation of a shock means that the victim is prepared to handle his muscular reactions to the limit of his ability. Shock under controlled conditions can be minor.

Many people feel they can absorb an electrical shock through electrical paths which do not involve the vital organs. Such practices are foolish and dangerous. Muscular reactions are uncontrollable momentarily and during this time, any equipment held in the hand may be flung in any direction endangering the lives of other people. A momentary loss of balance has caused death in many instances where a fall from a roof, ladder, pole, or scaffold has occurred. Absorbing a shock of a duration of 1/100 of a second can be fatal.

Section IV

COMMON SAFETY DEVICES IN ELECTRONIC EQUIPMENT

4.1 COMMON SAFETY FEATURES IN ELECTRONIC EQUIPMENT.

The Collins technician should be aware of safety features that generally are included in electronic equipment. There is a tendency on the part of design people to pay more attention to safety features when the equipment is intended for use by unskilled persons than when it is used by skilled persons and to minimize safety features on low-voltage equipment. Therefore, there is always a possibility that an accident will happen to the skilled, but negligent person. This is a matter to keep in mind; the technician must remember that safety devices cannot be counted on to function at all times.

Some of the common safety features are interlock switches, bleeder resistors, current-limiting resistors, insulated controls, and power-line safety devices. If your equipment is in need of any of these safety features, consult your supervisor.

4.1.1 AUTOMATIC GROUNDING.

Most electronic equipment now is equipped with a three-conductor cord and safety plug, which, when connected to the proper mating receptacle, automatically connects the equipment enclosure to a positive ground. The resistance from the equipment enclosure to the ground will not exceed a small fraction of an ohm.

Ungrounded electronic equipment cases create an unnecessary hazard and frequently produce electronic interference. A missing ground should be replaced. All ground connections should be checked using an ohmmeter.

Where a direct ground on equipment is not acceptable for certain tests, your supervisor can provide an adapter plug. Under no circumstances shall the grounding pin of the line-cord plug be removed. When such tests are completed, the adapter plug should be removed and the three-cord connector inserted into the grounding receptacle.

4.1.2 INSULATED CONTROLS.

Metal knobs, dials, switches, and adjustment screws generally are used in equipment of the cold-chassis type.

When insulated knobs are used, short setscrews, which do not extend beyond the recessed opening in the knob, are used to prevent the operator's fingers from coming in contact with a possible live circuit.

Rheostats and potentiometers in high-voltage circuits are placed far enough back to permit an insulated shaft coupling between the device and the control knob. Common examples are the focus, intensity, and beam-centering controls of oscilloscopes.

4.1.3 CURRENT-LIMITING RESISTORS.

A current-limiting resistor sometimes is connected in series with the output lead of a high-voltage circuit to limit the current (actually, the terminal voltage) to a safe value when a short circuit or an accidental contact occurs. One example is the limiting resistor in the output circuit of high-voltage power supplies which are a part of hi-pot. and continuity testers.

Accidental contact loads the circuit in series with the resistor, and most of the high voltage is developed across the resistor instead of the person making the accidental contact. Bear in mind that a very small current through the body may be fatal. Extreme caution should be exercised at all times when working on live circuits, regardless of the magnitude of voltage.

4.1.4 BLEEDER RESISTORS.

A bleeder resistor generally is connected across the output terminals of high-voltage d-c supplies. It is used to bleed the dangerous charges off filter capacitors because a high-grade filter capacitor can maintain its charge for a long period of time.

The bleeder current is an added drain on the power supply, but the system is designed to withstand this additional burden.

In some equipments where large, high-voltage capacitors cannot be shunted by bleeder resistors effectively, the technician must discharge these capacitors before working on the high-voltage circuits. For this purpose, special shorting sticks are available. Contact your supervisor.

The technician must keep in mind the possibility that the bleeder resistor may burn out and thus become useless as a protective device. On equipment being tested for the first time, a possibility exists that the bleeder may not be wired properly. Where modular construction is employed, the bleeder may be installed in another module and will give absolutely no protection against capacitor charges until connected.

Filter capacitors must be discharged as a matter of routine when repair work is done. Do not depend on the bleeder; it is merely an added protection.

4.1.5 INTERLOCK SWITCHES.

An interlock is ordinarily wired in series with power-line leads to the electronic power supply unit and is installed on the lid or door of the enclosure to break the circuit when the lid or door is opened. A shorting interlock (one that shorts the voltage to ground) frequently is employed to protect against high-voltage shocks and is installed on the cover or guard over the parts operating at voltages in excess of 250 volts. Interlocks are entirely automatic in action, therefore, the operator does not manipulate them.

Multiple interlock switches, connected in series, may be used for increased safety. One switch may be installed on the access door of a transmitter, and another on the cover of the power-supply section, and yet another on the r-f power amplifier enclosure. Complex interlock systems are provided when several separate circuits must be opened for safety.

Occasionally you will be required to deactivate interlock switches to perform certain tests. On such occasions you must consult your supervisor and receive his permission to bypass the interlocks.

4.2 EMERGENCY-OFF POWER SWITCHES.

During the normal test effort, there are occasions when a technician may have an equipment under test that is defective. It may cause a fire or, because of wiring errors, cause the technician to be the victim of a severe shock. In either case, removal of electric power must be accomplished as quickly as possible. To fulfill this need, new test consoles are being provided with emergency-off power switches. All power inputs to the console are disconnected when the emergency-off switch is depressed.

4.3 AREA SWITCHES.

In most test areas, a master switch for each power service is available. Locate and memorize the location of the switches. If there is not a switch available within easy reach during an emergency, find the method of disconnecting a cable or removing fuses to disable a live circuit. Your co-worker will appreciate the interest in his welfare.

Section V

ARTIFICIAL RESPIRATION

Artificial respiration must be applied immediately if an electric shock victim is not breathing. Do not stop to loosen the victim's clothing. Every second of delay is serious.

Examine the following illustrations and memorize the instructions. Your ability to apply artificial respiration immediately, without waiting for help or getting instructions, can be the deciding factor in saving a man's life.

5.1 ARTIFICIAL RESPIRATION INSTRUCTIONS.

FOLLOW THESE INSTRUCTIONS EVEN THOUGH THE VICTIM APPEARS TO BE DEAD

(1) Turn Off the Power.

Immediately kill the circuit or, if you are unable to do so, carefully remove the victim from contact with the circuit using insulation to protect yourself. A dry stick, an insulated tool, dry clothing, or any nonconductor can be used to separate the victim from the energized conductor. This must be done PROMPTLY and SAFELY. If someone is available, send him for medical help while you render aid to the victim.

(2) Place the Victim on His Back.

Do not waste time moving the victim to a more convenient location unless it is physically impossible to apply artificial respiration or you are endangering your own life. Loosening of clothing or keeping the victim warm is desirable but unnecessary at the moment. Your first responsibility is giving artificial respiration to the victim.

(3) Clear the Throat.

If there is foreign matter visible in the mouth, wipe it out quickly, using your fingers or a cloth wrapped around your fingers.

If a foreign body is suspected after failure of mouth-to-mouth resuscitation to move air into the lungs, the victim should be placed on his side and a sharp blow administered between the shoulders to jar the obstructing material free. Then sweep your fingers through the victim's mouth to remove such material.

(4) Apply Mouth-to-Mouth Artificial Respiration.

Step 1. TILT THE HEAD BACKWARD AND DISPLACE THE LOWER JAW FORWARD TO CLEAR THE AIRWAY. Using one hand only, grasp the lower jaw with the thumb hooked over the teeth and the fingers under the chin. Then pull the lower jaw forward and upward to tilt the head back as far as possible. See figures 5-1 and 5-2.

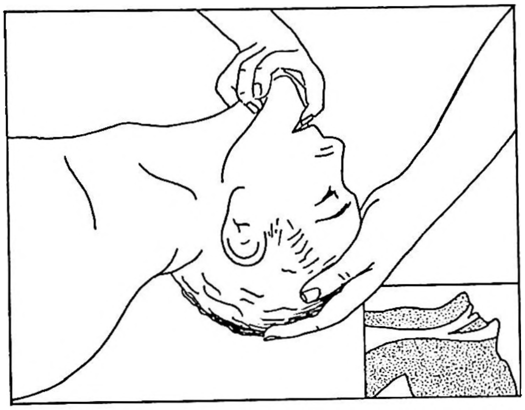

Figure 5-1. Full Extreme Tilt is Necessary

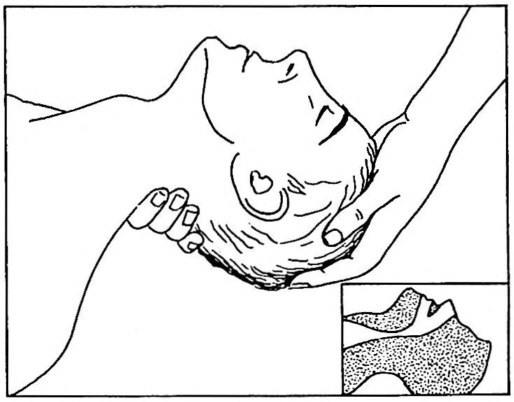

Figure 5-2. Halfway Tilt is not Enough

Step 2. USING YOUR OTHER HAND, PINCH THE VICTIM'S NOSTRILS AND PLACE YOUR MOUTH OVER HIS. The victim's nostrils must be closed to prevent air leakage while you breathe into his mouth. See figure 5-3.

Step 3. BLOW AIR INTO THE VICTIM'S MOUTH UNTIL YOU SEE THE CHEST RISE. Avoid over distention; the lungs should not be inflated beyond the point where the rescuer sees the victim's chest or abdomen expand. The first blowing effort will determine whether or not an obstruction exists in the mouth or throat. If the airway is clear, your breath will provide the urgently needed oxygen.

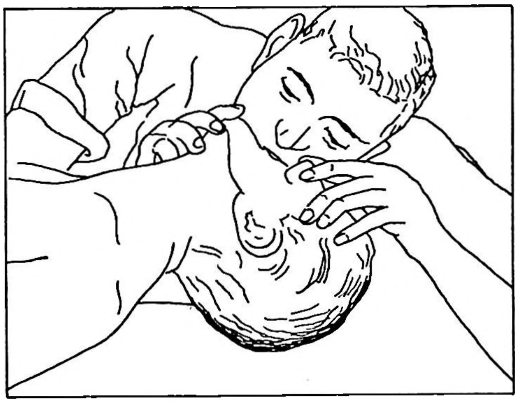

Figure 5-3. Blow Through Mouth

Step 4. REMOVE YOUR MOUTH TO LET HIM EXHALE. (See figure 5-4.) Some victims accept inflation easily through the nose but must breathe out through the mouth. While you listen to the sound of the victim's exhalation, take a deep breath, and reinflate his lungs again as soon as the victim has exhaled. Continue inflations at a rate of about 12 times per minute. Resuscitation should be continued without interruption until the victim revives, until rigor mortis sets in, or until the case is pronounced hopeless by a physician.

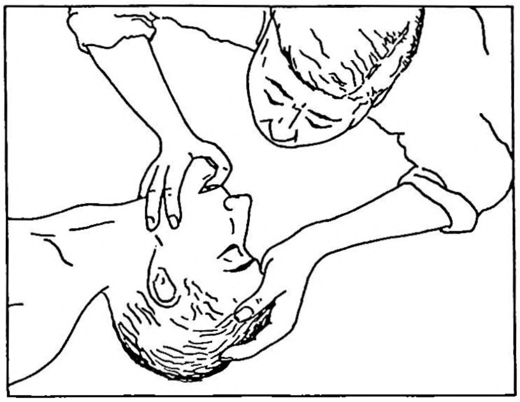

Figure 5-4. Victim May Breathe Out Better Through Mouth

Should it be necessary, because of adverse conditions, to move the victim before he is breathing normally, resuscitation should be continued while he is being moved.

A brief return of normal breathing does not necessarily indicate that resuscitation should be discontinued. Sometimes, the victim, after temporarily recovering, stops breathing again. He must be watched, and if normal breathing stops, artificial respiration must be resumed at once.

5.2 FIRST AID AFTER VICTIM REVIVES.

To avoid strain on the victim's heart when he revives, keep him lying down. If he revives before a doctor arrives, he should be given a stimulant, such as inhalation of ammonia, or a hot drink, such as coffee or tea. The victim should be kept warm.

5.3 WHY USE MOUTH-TO-MOUTH OR MOUTH-TO-NOSE TECHNIQUE OF ARTIFICIAL RESPIRATION?

The following statements are a portion of a report reviewing the data obtained from research projects, which were supported by the Department of the Army, the American Red Cross, and others. It was presented by the National Academy of Sciences, National Research Council AD HOC Committee on Artificial Respiration at its meeting of 3 November 1958:

"It was UNANIMOUSLY AGREED BY MEMBERS OF THE AD HOC GROUP THAT THE MOUTH-TO-MOUTH (OR MOUTH-TO-NOSE)

TECHNIQUE OF ARTIFICIAL RESPIRATION IS THE MOST PRACTICAL METHOD FOR EMERGENCY VENTILATION OF AN APNEIC INDIVIDUAL OF ANY AGE, in the absence of equipment or of help from a second person, regardless of the cause of apnea. This method has the advantage of providing pressure to inflate the victim's lungs immediately and allowing the rescuer to gain some information on the pressure, volume, and duration of each blowing effort. For adults, a rate of about twelve breaths per minute of twice the normal volume was recommended, and for children, relatively shallow breaths, appropriate for their size, at a rate of about twenty per minute. For infants, only shallow puffs should be used.

"The most important single factor contributing to the rescuer's success by any method is the immediate introduction of air into the victim's lungs. This can be accomplished only through an open airway. Mouth-to-mouth artificial respiration should be started at the earliest possible moment. The victim should be placed in a supine position with his head tilted backward and the lower jaw displaced forward. These two maneuvers relieve obstruction of the airway by the tongue by moving the tongue away from the back of the throat.

"If obstructing foreign material is obviously present, such as food particles, secretions, false teeth, blood or blood clots, or chewing gum, it must be removed immediately with the fingers or by any other means possible. The first blowing effort will determine whether or not obstruction exists and, in the absence of obstruction, will provide the urgently needed oxygen.

"If aspiration of a foreign body is suspected in an adult after failure of mouth-to-mouth ventilation to move air into the lungs, the victim should be placed on his side and a sharp blow administered between the shoulders to jar the obstructing material free. Again, the rescuer's fingers should sweep through the victim's mouth to remove such material."

Section VI

ELECTRICAL SAFETY AND YOUR JOB

6.1 ARE YOU COMPLACENT?

Electrical safety concerns every individual who is in direct contact with any equipment carrying an electric current. Ironically, the more you know about it, the more complacent your attitude becomes. You assume that with your knowledge and experience, you will never be the victim of an electrical shock.

Remember that there are as many people killed who know what it's all about as those who are uninformed. The electrical engineer working with breadboard layouts and hasty connections with little or no guards is more susceptible to electric shock than the people who service or operate the equipment. Unfortunately our schools teach practically nothing concerning the nature and the effects of electric shock. In addition, no effort has been made to teach the student how to avoid the hazards of electrical shock.

There are those who consider an electric shock part of their jobs and will make no effort to eliminate the condition which caused it. An electric shock is a warning that something is wrong, that your thinking is disordered or the equipment is defective, and that it is time to do something about it.

Electrical safety is for everyone. Don't let one careless act make you a newspaper headline.

6.2 HOW MUCH CURRENT IS DANGEROUS?

People who know very little of the nature and the effects of an electric shock usually will ask the question, "What is a dangerous voltage?" If you have studied the nature of an electric shock, the question should be, "What is a dangerous current?" Any voltage which will cause a current flow through the body in excess of five milliamperes is dangerous.

Scientific studies have confirmed the fact that some people will freeze with as little as 7 ma current through the body. The individual will be perfectly aware of what has happened, but because his muscles are paralyzed, he is unable to free himself. Prolonged exposure, even though the current is low, eventually will bring on serious body effects, such as respiratory failure.

Skin resistance is a variable that cannot be predetermined and yet, many persons will take electrical shocks deliberately, hoping that the current flow is within safe limits and that their heart cycle won't be caught at the wrong phase, which, if it is, will result in ventricular fibrillation.

Ohm's law can be stated as follows:

$$\text{Current through body} = \frac{\text{Contact voltage}}{\text{Body resistance plus skin resistance}}$$

As a matter of interest, here are a few examples of how much current will pass through the body if the initial skin resistance is broken down.

(1) $\frac{\text{6 volts d-c}}{\text{500 ohms}} = \text{12 milliamperes}$

(2) $\frac{\text{27.5 volts d-c}}{\text{500 ohms}} = \text{55 milliamperes}$

(3) $\frac{\text{115 volts a-c}}{\text{500 ohms}} = \text{230 milliamperes}$

It may seem a little strange that six volts can give a victim a severe shock, but it can happen under the right conditions.

A local doctor reported that he received a jolting shock from a six-volt battery. He was quite surprised but proceeded to investigate the cause rather than ignore it. He discovered that several strands of steel wool were embedded in his fingers from the evening before when he had been using steel wool on a home project. Since the steel wool had penetrated the skin, only a body resistance of approximately 500 ohms limited the current flow. Cuts or broken blisters could create similar conditions. Metal chips often are embedded in the skin for long periods of time.

A Collins engineer related how a man was killed aboard a ship while fighting a fire. He was handling and directing a hose at an open distribution box carrying 28 volts d-c. The direct path of a 28-volt d-c circuit consisted of the salt water being sprayed on the open box, the tightly held brass fire nozzle, his body, and the metal deck.

One need only to read the daily newspapers to be aware of the tragic results when contact is made with a 115-volt a-c power source. In a recent newspaper report from Chicago, three children were killed in a bath tub when a small radio fell into the water.

In your job, there are many instances where safety first will pay off. In the ensuing paragraphs we will try to cover as many rules or situations as practical.

6.3 GROUNDS.

Proper grounding is extremely important. An equipment properly grounded can save your life. However, an equipment grounded through your body can take your life.

6.3.1 WHAT IS WRONG WITH VISUAL INSPECTION OF GROUNDS?

Many people will assume a ground is satisfactory merely by making a visual inspection. This is a risky habit for the following reasons:

(1) Metal panels frequently are coated with a protective chemical finish that is transparent and is an insulator. An example of such a finish is anodizing which, when placed on aluminum, is invisible to the naked eye and yet it makes an excellent insulator.

(2) Metal panels may be spray-coated with lacquers or synthetic varnishes. They are very clear when applied thinly and insulating properties are good.

(3) Connections which have been in use for some time frequently are poor because the nut and bolt assembly has loosened. A lock washer should be employed whenever making electrical connections.

(4) Connections to ground may have rusted away in such a manner that they are concealed from the eye. Salt water corrosion is common in certain areas.

(5) Insulated wire used to make a grounding connection may have a concealed break under the wire insulation. Equipment which has been vibrated is frequently subject to such failures.

(6) Much too often, the individual who made the connections gave no thought to removing paint, lacquer, rust etc., before attaching a grounding wire. In fact, he may have expected the wire or lug to break through the protective coating when the grounding connector was bolted or riveted in place. Holes for grounding wires should be spot-faced to remove all nonconductive protective finishes.

A visual ground inspection is obviously poor practice when one realizes how ineffective it can be. Make a continuity check using a multimeter. As a word of caution, turn off the power to the equipment under test. If it is not turned off, an ohmmeter may be ruined when an open ground is discovered. When possible, a slight movement of the wire connections during the test may expose an intermittent connection. If you must inspect with the power on, check for voltage rather than resistance.

6.3.2 RESISTANCE TO ENCLOSURE GROUND.

Resistance through a proper mechanical ground connection will be zero ohms for all practical purposes.

6.3.3 RESISTANCE TO EARTH GROUND.

The combined resistance of the grounding wire, connection, and earth ground should not exceed three ohms when connected to a water pipe, and should be not greater than 25 ohms when using an artificial ground. Use a heavy current conducting wire to provide good low-resistance connections to earth grounds. Primary power supply grounds must carry considerable current under short-circuit conditions. Signal return grounds can be exempted from heavy wire if they are not part of the primary power circuitry.

6.3.4 WHY IS THE WATER PIPE SYSTEM PREFERABLE FOR GROUNDING AS COMPARED TO AN ARTIFICIAL GROUND SYSTEM?

The water pipe system comes in direct contact with an immense amount of soil under all conditions of moisture and chemistry. Metal framework of buildings, well casings, or other metal structures also will provide a low-resistance path in direct contact with the earth and are, therefore, equally satisfactory. The water pipe ground, the most common grounding system, offers good conductance to the flow of current directly into the earth. Although only a few branches of a water pipe system may come in contact with the wet soil, the extensiveness of the system brings the resistance down to a value of less than three ohms.

A word of caution is necessary at this point. Water pipe joints may be connected using insulating materials or connected to nonconductive piping. The water pipe system may be interrupted to avoid damage to the water meter by electrolysis. Water softener tank installations frequently are connected using rubber hosing. If a ground circuit cannot be attached to the street side of the water meter or water softener, a jumper wire can be installed to provide a current path around this equipment.

A fairly satisfactory ground can be provided using eight-foot grounding rods, spaced approximately six feet or more apart and located in damp soil. The ground resistance probably will be about 25 ohms. The National Electrical Code describes in detail the pipe, material, and spacing for such a grounding system in article 250. This article also details the proper size of grounding conductors for various current loads.

6.3.5 WHY IS UNGROUNDED EQUIPMENT EXTREMELY DANGEROUS?

In figure 6-1, the shock hazards are numerous. No ground is provided from the test equipment case to an earth ground. If it were, none of the following would be true:

(1) The power switch is effective in disconnecting the hot side of the line only when the connector is mated properly with the receptacle. Since the line cord connector is not polarized, there is no way of determining this without resorting to resistance measurements between the case and the earth ground.

(2) Power can never be removed from the fuse receptacle; therefore, it is possible to receive a shock when removing the fuse.

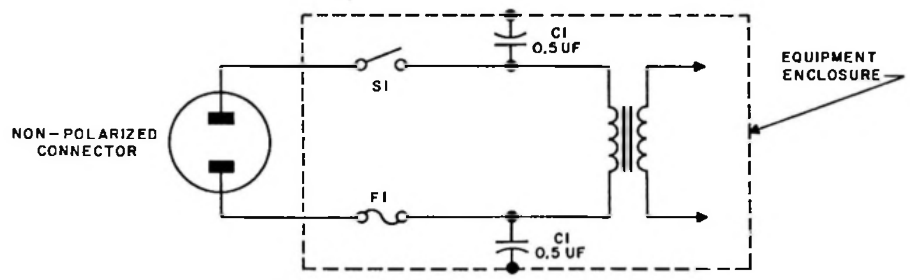

Figure 6-1. Ungrounded Equipment

(3) If the case should be grounded through your body, the line bypass capacitors, C1 and C2, will pass a current flow of approximately 20 milliamperes through the body, assuming a body resistance of 500 ohms.

Note: Capacitors C1 and C2 used on radio equipment having no grounding provisions must be limited to a maximum capacity of not more than 0.1 uf to avoid a current flow through the body in excess of 5 milliamperes.

(4) If capacitors C1 and C2 are in good condition, approximately 65 volts a-c may exist between the case and an earth ground whether the switch is in on or off position.

(5) If a short circuit occurs between the case and an electrical component, and the switch is in the on position, full line voltage might exist between the case and an earth ground, depending upon which way the connector is plugged into the receptacle. Normally a voltage of approximately 65 volts can be expected. Current flow during body contact would be limited by the reactance of the line bypass capacitors.

6.3.6 WHAT ADVANTAGES ARE GAINED WHEN EQUIPMENT IS GROUNDED?

Figure 6-2 shows the proper method of connecting equipment to the power line. Note the line cord connector is polarized and is provided with a separate contact for making connection with the ground circuit. The advantages of properly grounding radio equipment are:

(1) A short to the enclosure from the hot side of the input line will not create a hot radio but will blow a fuse.

(2) Connecting the junction of capacitors C1 and C2 and the chassis to an earth ground will keep the chassis at ground potential, thus eliminating the hot chassis criticism prevalent with equipment connected to the power receptacle with nonpolarized connectors.

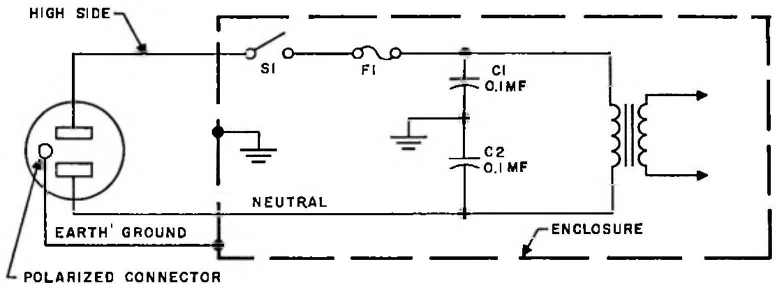

Figure 6-2. Grounded Equipment

(3) The three-conductor polarized connector always will connect the ground to the radio prior to application of power when mated to the receptacle and, conversely, is disconnected last when unplugged. In the design of a male connector with provisions for a separate ground wire, the ground terminal is longer than the neutral and hot terminals. If this safety feature were not provided, a person in contact with the defective equipment and ground would receive a shock each time the line cord connector was plugged or unplugged from the receptacle.

(4) While the location of fuse (F1) and switch (S1) has nothing to do with grounding, their installation in the circuit as shown in figure 6-2 will remove a shock hazard. The National Electrical Code states, "the switch shall be located between the power source and the fuse." When it becomes necessary to replace a fuse, all power will be disconnected when the switch is in the off position.

Figures 6-3 and 6-4 illustrate the correct way to connect a fuse receptacle. If the input power line were reversed with the output power line, and removal of the fuse were attempted with the switch on, the individual could come in contact with the hot line when he attempted to remove the fuse.

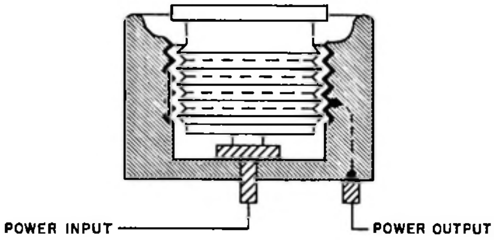

Figure 6-3. Conventional Fuse Holder

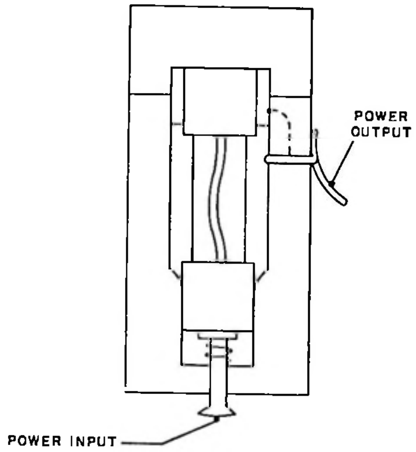

Figure 6-4. Cartridge Fuse
Holder

6.3.7 GROUNDING THE THREE-CONDUCTOR CORD TO EQUIPMENT ENCLOSURE.

The grounding lead should be connected directly to the chassis, making sure that paint, lacquer, etc., are removed first. Figure 6-5 shows a method of grounding equipment that is very unreliable. The terminal strip illustrated consists of a group of components all terminated for grounding purposes. When a grounding lead is attached to such a terminal

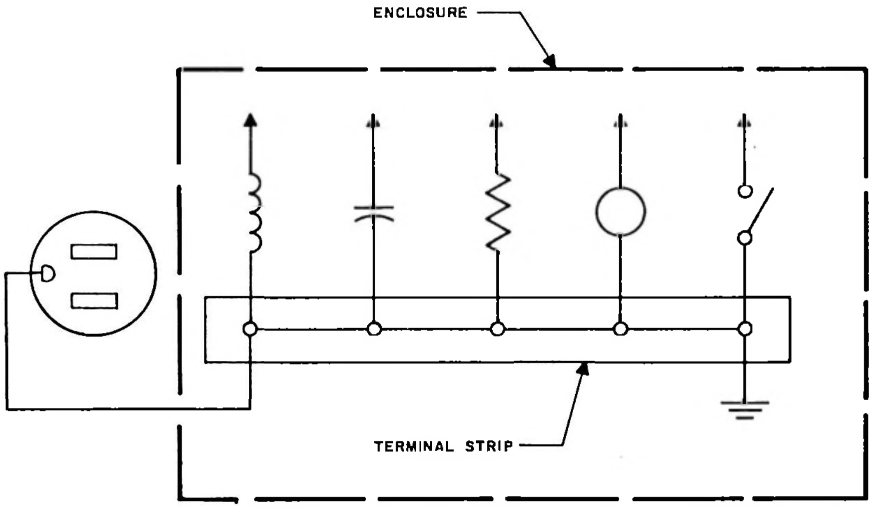

Figure 6-5. Unreliable Method of Grounding Equipment

strip and must depend on a series of connections as indicated, the safety ground connection is subject to cold soldering, no solder, wiring errors, undersized wiring, etc.

6.4 USE ONLY APPROVED CONNECTORS WHEN MAKING PRIMARY POWER CONNECTIONS.

There are many electrical connectors available for connecting a-c and d-c power to electrical equipment. The identified terminal should be connected to the line neutral using a white or natural gray colored wire. The grounding terminal of a connector shall be connected to an earth ground using a green wire. Color coding of wires is covered in section 210-5 of the National Electric Code. A list of standard power connectors has been compiled by the component standards group of Collins Radio Company and is available upon request.

6.5 ARE CAPACITORS DANGEROUS?

Probably the least suspected villian in the electronics safety program is the capacitor. It will maintain a charge for an indefinite period, and it actually will charge itself when setting on the shelf. Add to this the fact that the more quality you build into a capacitor, the greater the shock hazard becomes.

Many instances of severe shocks and fatalities have occurred when contacting capacitor terminals either directly or indirectly. For instance, a shipboard fatality occurred when a helper was asked to remove a transmitter filter capacitor. The helper, who was ignorant of any potential danger, removed each capacitor connection separately. Then, intending to lift the capacitor out, he grasped its terminals, one in each hand. He was killed instantly. Artificial respiration was applied but did no good. The current surge had been so great at the moment of contact that the thread marks were burned into the tissue of his hands. A residual charge still existed in the capacitor when an investigation was made shortly afterward.

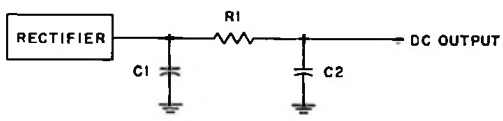

Figure 6-6. Typical D-C Power Supply Filter Network

The filter network in modern d-c power supplies is usually wired as shown in figure 6-6. Formerly resistance R1 was a filter choke whose d-c resistance was very low. Design engineers found the choke expensive and bulky. Capacitors C1 and C2 originally were limited to a capacitance not in excess of 8 microfarads. Now engineers have found that the choke usually can be replaced by a resistor if several high-capacity capacitors are used at C1 and C2. Thus, the modern power supply has become a greater shock hazard. The safety conscious technician will short the B+ line to ground and wait an appreciable length of time to allow the charge of C1 to drain off.

Capacitors can be made safe by proper engineering. A bleeder resistor should be connected across the output circuit of power supplies, filter networks, or d-c blocking circuits so that it will bleed off a dangerous charge automatically when the power is switched off. The bleeder resistance should be the lowest value practical which can discharge the capacitors quickly and yet avoid excessive loading when the d-c power is on. It is the responsibility of the design engineers to include a bleeder resistor and provide for the additional current drain on power supplies.

You may have noticed that capacitor manufacturers, who ship capacitors having sufficient storage capacity to be dangerous, usually assemble a shorting wire between the terminals. This is a safety precaution to prevent the capacitor from recharging, even though entirely disconnected from any d-c supply. Do not handle capacitors using the shorting wire as a handle, as it may damage the seal at the capacitor insulating bushings.

In some equipment, capacitors must be operated without bleeders. Therefore, it is a good safety habit to check for charged capacitors before working on such equipment. A grounding or shorting bar or hook must be used, equipped with a well-insulated handle. Where grounding or shorting bars are required, they should be attached permanently by cable to equipment, prominently displayed, and within easy reach of the operator.

Capacitors having high capacity and voltage ratings should be discharged through a current limiting resistor.

Because equipment is provided with a bleeder does not mean necessarily it is safe to handle when the power is switched off. In new production work, test personnel frequently will find ineffective bleeders. Either the bleeder resistor has burned out or assembly personnel have erred in wiring it into the circuit. For this reason, repair personnel must be careful to check for charged capacitors before proceeding with their work.

6.6 WHY SHOULD THE POWER BE TURNED OFF WHEN DISCONNECTING EQUIPMENT?

It is always a dangerous practice to separate electric equipment while the power is on. This is particularly true when working on modularized equipment or disconnecting cables.

Our military wants equipment which is serviced easily and to this end the modularized or subassembly-type equipment has been developed. This design technique is widely used now in all forms of equipment. Replacement of modules or subassemblies is easy, but frequently it is done with the power switched on. Test or maintenance personnel find it helps to get quicker performance data when comparing module performance. While some have discovered that disconnecting equipment with the power on is very dangerous, others have given no thought to it.

In figure 6-7 note that R1 will be connected between terminals 1 and 2 when the module is assembled to the chassis properly. Resistor R1 could be a bleeder resistor, voltage divider, motor winding, relay coil, or transformer winding. Assume that with the power switched on, one wished to switch modules. It would be natural to rest one hand or arm against the chassis while removing the module. If resistor R1 were disconnected on the ground side first and no metal contact existed between the chassis and module at this time, the operator would receive a shock, the severity of which would depend upon the magnitude of the current through the body. The current path would be through the heart region and, therefore, the effects of the shock could be very dangerous.

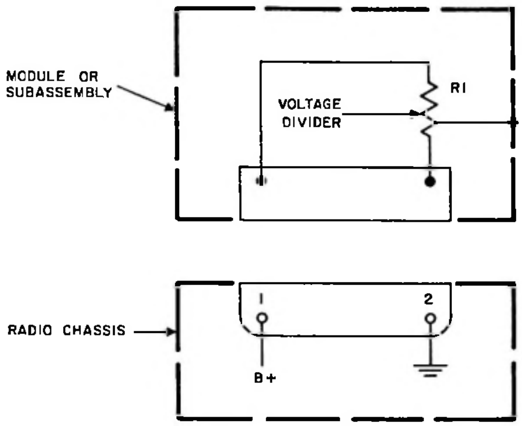

Figure 6-7. Modularized Equipment

In another version of this example, test personnel have found it convenient to operate modules on extension cables. The chances of getting a bad shock are even greater. If the negative return became disconnected in some manner, the operator would be caught between the chassis and the hot module. A separate grounding wire should be attached between the module and chassis whenever trouble shooting in this manner.

6.7 WHY TREAT NONINSULATED WIRING AS ALIVE?

Many times test personnel are required to work on equipment while it is operating; taking data, making adjustments, checking for defective components. Working in close proximity to exposed and noninsulated wiring and connections can be expected. Most technicians are aware of the danger that exists and act accordingly; but no precautions may be taken to prevent accidental contact. If one is careful, it would seem that this would not be necessary. Unfortunately, contact may happen during a moment of carelessness and the damage is done. Aside from carelessness, many technicians have received a pin prick sensation from foreign material, excess or frayed wiring, or static electrical discharges. Because of temporary fright and the reflex to move away quickly, they may make unexpected contact with dangerous potentials.

From a practical standpoint, any work performed near bare wiring, whether it carries a potential or not, must be regarded as potentially dangerous.

6.8 BEWARE OF HIGH VOLTAGES!

One basic safety rule when working on high voltage is never to make bodily contact with a ground. More than 80 percent of all electrical fatalities have occurred from contacts between grounds and live circuitry.

Much more could be said about the dangers of working near or on high-voltage circuits and the fatalities which have occurred. No amount of words will bring back the life of those who have died. No further explanation of the nature and the effects of electric shock will serve any purpose. To those who are still alive and are working with electricity, all the safety lectures, books, rules, precautions, or guards are absolutely necessary. Do not try to eliminate or ignore the safety precautions provided FOR YOU OR BY YOU TO PROTECT YOUR LIFE!

6.9 DEVELOP SAFE HABITS.

Everyone will admit that he or she is careless occasionally. Each person has sometimes felt dizzy, overtired, or been distracted while working on electrical equipment.

At such times, accidents will occur unless an individual has consistently developed safe working habits. For instance, one of the first habits one learns as a child is to look in both directions for cars before crossing a street. As an adult, one checks for cars as a result of early training and makes no conscious effort to do so.

Using good safety habits while working on electrical equipment is equally important. Know the safety rules and make observance of them a habit.

6.10 WHY SHOULD YOU KNOW YOUR JOB?

Ignorance of the presence of dangerous potentials on components can lead to a serious shock. For instance, many electric shocks have occurred when operators are unaware of the manner by which high-voltage circuits are switched on or off. Numerous radio equipments when operated in standby condition will have full operating potentials applied to certain connections of sockets, switches, or other parts. Many switches are labeled to inform the operator which function will occur, rather than to denote the control of operating voltages, such as the TRANSMIT-RECEIVE switch, SQUELCH ON-OFF switches, and others. Many power switches, while so labeled, may only break the center tap on a transformer or disconnect one side of the power line.

Under these conditions, adjustments or repairs by uninformed personnel can be extremely dangerous.

6.11 DO NOT USE FAULTY TEST EQUIPMENT.

Probably the biggest problem in any safety program is convincing test people that using defective equipment is extremely dangerous. Furthermore, if it were repaired promptly, it actually would save time. The popular attitude for most people is to let it go until it quits working or until it causes them personal injury; another group cares even less. They, simply stated, are too busy! And yet another group would be perfectly willing to return defective equipment for repair if their supervisor would tap them on the shoulder periodically and remind them.

A different approach to the same problem concerns the welfare of your co-workers. Allowing faulty equipment to be used by others without having the needed repairs attended to first can result in a serious shock to your co-worker due to his ignorance of hazard that, in one sense of the word, was a booby-trap.

Return defective equipment for repair immediately. Do not put it off! To the individual who has experienced one bad shock, reporting and returning defective equipment for repair is at the top of his activity list.

6.12 DO NOT WORK ON HIGH-VOLTAGE EQUIPMENT WHEN YOU ARE ILL.

All of us at some time may feel dizzy, nauseated, or have a high temperature. Taking certain medicines will cause drowsiness. Do not work on electronic equipment under these conditions.

It is equally important to be alert on the job instead of being sleepy or overtired. Regardless of which condition you may be experiencing, your thinking has been reduced to virtually a standstill. The company will only suffer the loss of production if you leave the job, while you as an individual may lose infinitely more. Do not gamble your life against such hazards.

6.13 DO NOT WORK ON HIGH VOLTAGE ALONE.

When one is the victim of a severe electric shock, or paralyzed and can't let go, one is, in either case, virtually helpless to summon aid. Immediate help can be given by those who recognize the problem, and then only if they can see you and know what to do. Therefore, keep a co-worker informed of your activities, and make a determined effort to stay in his sight. It takes less than 1/100 of a second to paralyze or kill. First aid must be rendered as quickly as possible. Every second or minute one waits for help reduces the chance of survival.

6.14 DO NOT ASSUME THAT A CIRCUIT IS DEAD.

In working with a co-worker, he may be asked to turn off the switch while needed adjustments or repairs are made. The co-worker may fail to hear the instructions, turn off the wrong switch, or, what is even worse, he may leave it on intentionally as a practical joke. There are times when the co-worker, not aware that the equipment is being worked on, will turn on the power. Relays and switches may not function. Interlocks may be defective or perhaps it has been decided to deactivate them deliberately.

Switch markings are sometimes confusing when operating and repairing radio equipment. Switch markings very often are intended to inform the regular operator of an operational feature, rather than to denote the switching on or off of a high-voltage circuit.

Wiring errors in new equipment often are responsible for a severe shock to the test technician who is handling it for the first time. Observe all safety rules. Check all known high-voltage circuits using a voltmeter.

While working on equipment, special precautions may be necessary if one is partially or totally concealed from co-workers. Place a shorting wire from ground to the high-voltage circuit. If there is a master switch which can be locked, do so and put the key in your pocket.

6.15 DO NOT BE CARELESS.

Carelessness by an electrician or technician cannot be excused. Failure to do his job properly affects his welfare as well as that of others who depend upon his knowledge and skill.

Defective wiring of equipment has resulted in numerous accidents because of failure of the equipment to do the job or because of fire and electrical shocks.

Your failure to warn other people who have very little or no knowledge of the potential danger involved in the use of defective electrical equipment or who may be misusing it, can be considered carelessness. A timely word of advice to these people certainly would be appreciated.

6.16 DO NOT WEAR JEWELRY.

When the first safety lectures were given at the Collins Radio Company, the technicians were invited to comment on experiences wherein they were the victims of electrical shock. Out of the experiences of more than 500 people, it became apparent that jewelry was responsible for many electrical shocks as well as serious burns.

Strangely enough, a fair percentage of these people were victims while in contact with low-voltage high-current power circuits. Working around car batteries, cigar lighters, starters, and generators of their own cars resulted in severe burns when the ring shorted the battery or generator circuit to the car chassis. Many of these people exhibited scarred ring fingers as evidence.

SEVERAL INDIVIDUALS RELATED PERSONAL EXPERIENCES OF HOW, IN AN URGENT ATTEMPT TO BACK AWAY FROM A MINOR SHOCK, THEY WERE CAUGHT BY WATCH BANDS HOOKING ON TO HIGH-VOLTAGE TERMINALS. Again these individuals exhibited scarred tissue on the wrist. Another man recounted the story of an Air Force man who dropped out of an aircraft and lost a finger when his ring hooked on the side of the escape hatch.

Investigations of comparable accidents by the United States Navy have long ago resulted in a rule that jewelry shall not be worn by their electricians and electronics technicians.

When a ring contact is made with an electric circuit, the initial skin resistance is considerably less because the area of contact is much greater. Also, the skin under the ring usually is very moist. Since the moisture on the skin consists of acids and salt in solution, the larger accumulation helps to reduce the initial skin resistance further. Wrist watches which cover a greater area of skin are even more hazardous because the skin resistance could be as low as 1000 ohms.

Another disadvantage of jewelry is caused by the fact that very little, if any, warning pressure will be felt when pressing against electrical wiring.

The right to wear jewelry, especially rings and watches, does not belong to any individual who services or tests electrical equipment. There is a possibility that one out of every five technicians sooner or later will be the victim of either a severe burn or shock or both if he continues to wear jewelry.

6.17 DO NOT BE A PRACTICAL JOKER.

While practical jokes involving electricity may be funny to the perpetrator, they are absolutely not funny to the victim. How far the joke can be carried and be safe is never known.

One of the most common tricks of the joker is to charge a capacitor and either allow the unsuspecting victim to pick it up or to toss it to him. For the sake of safety, don't do it.

One of the most serious types of jokes concerns the friend who is supposed to be helping you. This individual thinks it funny to leave the power switched on when you have specifically requested him to turn it off. In several actual cases the perpetrator informed his co-worker that he had turned the power off when, as a matter of fact, he did not. During one of these morbid jokes, a screwdriver was damaged beyond repair and the victim frightened so badly he was unable to work the rest of the day. Fortunately, he hadn't made bodily contact. The equipment on which he was making adjustments was a large broadcast transmitter where one mistake could have taken his life.

If you are inclined to having your little joke, don't use electricity to carry it out.

While the joker is never welcome, remember that, when working on high-voltage equipment, the only person you can trust is yourself. Sometimes your co-worker has no intentions of tricking you, but, because he misunderstood your instructions, the wrong switches or no switches were turned off. A good possibility exists that there are times when he didn't even hear your instructions.

6.18 WHY SHOULD I PROMOTE ELECTRICAL SAFETY?

You, as a technician, should be well informed of the potential hazards of electricity. Members of your family and a majority of your friends and co-workers are not well informed. Telling them to be careful when using or working near electrical equipment is practically meaningless. For instance, one of our industrial engineers related an experience of his friend who had been told that no harm would come to him if he contacted only one wire at a time.

His friend wished to disconnect the power transmission lines between the house and garage. He propped a metal ladder against the house under the wires, climbed up the ladder, and attempted to cut one line. Instead, he froze when he cut through the insulation and contacted the bare wire. He had used his body to complete the circuit to ground through the metal ladder.

In the home are many electrical appliances that can cause death or injury, especially in the kitchen and bathrooms. For instance, very recently a Wisconsin newspaper reported an electrocution caused by an ultra-violet ray lamp which fell into a bath tub. Authorities said there was a clamp on the lamp which had apparently been fastened above the bath tub. The clamp loosened and the lamp fell into the water, resulting in the electrocution of a young mother.

Another accident involved a young man erecting a television antenna tower. He was electrocuted when the television antenna tower came in contact with a 3,000-volt electrical transmission line. Three other men helping him guide the antenna tower in place, using the guy wires, were severely shocked and knocked to the ground.

Have you told your wife what to do if a member of your family should be a victim? Did you teach her what to do in an emergency? Above all things, did you teach her how to disconnect the circuit before she makes a rescue attempt?

Promote safety on a 24-hour basis. Repair defective equipment immediately. Help your neighbor to know the basic safety rules. Who knows, he might have to help you someday. Make safety a habit, not an unpleasant subject to avoid.

Section VII

CHARACTERISTICS OF ELECTRICAL ACCIDENTS

Most of the accidents traced to electrical factors have as their base the following three causes:

(1) I Didn't See.

(2) I Didn't Think.

(3) I Didn't Know.

Many engineers find it rather difficult to see the necessity for electrical safety. Therefore, the dangers are not always caused by the person who had the accident. The causes may find their origin in the design, application, and installation of electrical equipment, the responsibility of someone far removed from the scene. A reason that dulls their reaction to the need for electrical safety is that most of them have never experienced the disastrous results of real failure of equipment or an unsafe act leading to a bad accident. They are not every day occurrences, such as the automobile accidents reported in newspapers.

Statistics on electric work injuries show a high incidence of fatality. The ratio of deaths to injuries in the course of a year is approximately one in thirty. This is about fifty times the fatality rate in other injury classes combined. In a major number of cases, both an unsafe condition and an unsafe act existed simultaneously before an accident occurred.

Personal injuries are caused principally by the following:

(1) Arc and explosion: 30 to 35 percent.

(2) Contact with energized parts: 26 to 27 percent.

(3) Contact with parts normally de-energized: 23 to 26 percent.

The elements of the electric system or equipment design and operation which bear on these areas include the following:

(1) Adequate short circuit capability in company with appropriate protective relays.

(2) Metal enclosed construction.

(3) Design simplicity of electrical system.

(4) Appropriate interlocking.

(5) High quality components, correctly installed.

(6) Good equipment grounding.

(7) Effective maintenance.

(8) Proper operating practices.

Section VIII

DESIGNING FOR ELECTRICAL SAFETY

Safety devices and circuit arrangements can be included in electronic equipment at the design and construction stages. It is easier to build them into such apparatus than to add them later.

Shock and fire are the principal hazards which may accompany the operation of electrical equipment, including electronic apparatus. The first is dangerous to personnel only; the second to personnel, equipment, and surroundings. The causes often are related and sometimes are identical. Safety measures related to electronic equipment accordingly are directed toward reduction of shock and fire hazards.

Varied attitudes exist toward the potential dangers of electronic equipment. In general, the tendency is to pay little attention to such matters when apparatus is manned by skilled persons and to become concerned only when workers with limited training and experience are exposed. Unfortunately, a fatal or crippling shock or a destructive fire, either incident the fault of skilled but unalert persons, must occur to point up the need for more attention in this direction. All electronic equipment should be safe, regardless of the caliber of people assigned to its operation and maintenance. The laboratory should be no more hazardous than the assembly-line test position.

Safety measures may be applied effectively in three areas: design, installation, and operation. When apparatus is designed for maximum safety and is installed and operated with regard to the prevention of shock and fire, maximum freedom from danger usually is obtained. Concentration of precautionary steps in only one area imposes additional responsibility in each of the other two and jeopardizes life and property.

A survey of the most common safety devices will be discussed in the following paragraphs. Inclusion of any or all of them is the responsibility of the design engineer.

8.1 INTERLOCK SWITCH.

The interlock switch is one of the oldest electrical safety devices, but is one of the least used in modern equipment. Ordinarily, it is wired in series with one or both of the power-line leads to the electronic power supply unit, and is installed on the lid, cover, or door of the enclosure to break the circuit when the enclosure is entered. A true interlock switch is automatic in action. It does not depend upon manual manipulation by the operator.

Multiple interlock switches, wired in series, may be used for increased safety. Thus, one switch may be installed on the access door of a transmitter, and another on the dust cover of the power supply section.

Complex interlock systems are provided when separate circuits should be opened for safety. An example is the use of separate open-up switches for the a-c power line and the high-voltage d-c output of a power supply.

Since electronic equipment often must be serviced hot, interlock switches must be operable by responsible personnel when access doors are open. However, they should be located always in such a manner so that they make closure difficult and therefore attention-catching.

Interlock switches can be used to advantage on any equipment having lethal voltages present, such as transmitters, oscilloscopes, and high-voltage power supplies.

8.2 BLEEDER RESISTORS.

A bleeder resistor should be connected permanently across the output terminals of high-voltage d-c power supply. As its name implies, its purpose is to bleed the dangerous charges off the filter capacitors when the power is switched off.

No medium- or high-voltage power supply should be constructed without a bleeder, since high-grade filter capacitors can store murderous charges for long periods of time. The bleeder resistance must be the lowest value which can discharge the capacitors quickly without excessive loading after the power has been switched off. In power equipment, the resistor is chosen to give a discharge time constant of 1 minute.

The bleeder current is an additional load on the power supply, but the system should be designed with this slight additional burden in mind. Assurance is provided by the automatic charge-draining action of the bleeder resistor.

8.3 CURRENT-LIMITING RESISTOR.

A current-limiting resistor is an inexpensive safety device in a high-voltage power supply. It should be incorporated in every supply from which potential only, or small currents, will be required. Such a resistor is connected in series with the output and limits the current to a safe value during short-circuit or accidental contact. A familiar example is the high-resistance series resistor in the high-voltage power supply of television receivers or "hi-pot" continuity testers.

8.4 CAPACITOR-SHORTING DEVICES.

In some equipment (for example, high-voltage radar apparatus) where large, high-voltage capacitors must be operated without adequate bleeding, the operator must discharge these capacitors before working on the high-voltage circuits. For this purpose, metallic grounding or shorting rods with insulated handles should be cabled inside the equipment within easy reach of the operator. Short-circuiting rods, wands, or bars should be insulated beyond the voltage they will handle, in order to be grasped safely by the operator, and they should be nonremovable from the equipment.

NOTE: Do not discharge high-voltage capacitors with a low resistance bar. A large resistor of a 200-watt 10K-ohm rating should be used.

8.5 METER PROTECTION.

Old-style panel meters having metallic zero setscrews should be avoided in electronic equipment. Such setscrews run hot in high-voltage circuits and constitute both shock and fire hazards.

Metal-case meters should not be used except on grounded metal panels or chassis, since such instruments will, in the event of internal ground or short-circuit, have high potential on their cases and flanges.

For maximum safety, meters used in high-voltage circuits should be designed for high-voltage service or mounted behind a window of glass or thick plastic.

8.6 A-C/D-C CIRCUITRY.

Whenever possible, transformer-isolated power supplies should be used in preference to transformerless (a-c/d-c) circuits. Although the line-operated supply is simple and compact and furnishes sufficient power for many applications, its negative return is at power-line potential and therefore dangerous.

When there is no choice in the matter, design the circuit so that no connections are made directly to the chassis or metal panel. If the chassis must be included in the circuit, mount the completed equipment in a case or cabinet made of insulating material and use only insulated knobs, dials, and switches.

It is good practice also to polarize the power plug of a line-operated power supply so that the circuit returns always will be connected to the grounded side of the power line.

8.7 TEST POINTS.

Provide test point (tip jacks) for use on electronic equipment to avoid exposure to dangerous potentials. In many cases, the inclusion of test points at convenient circuit locations is very desirable to test personnel who wish to monitor performance during alignment or adjustment of the equipment.

The design requirements of such test points should include an insulated barrier to prevent accidental contact with the conductor. If an excessive amount of voltage is present at the test point, additional safety precautions should be provided, such as high-voltage warning signs or access covers.

8.8 BINDING POSTS.

Use binding posts which are insulated.

8.9 TERMINAL STRIPS.

The type of multiconnection terminal strip selected for use in electronic equipment is dependent on appearance, cost, and suitability. Unfortunately, very little thought has been given to the selection of this equipment with safety in mind.

Two things can be considered. First, select the terminal strip which provides protection against accidental contact, such as insulated barriers or covers. Second, locate the terminal strip in a position where it is readily accessible. If dangerous voltages are present, provide protective covers with HIGH-VOLTAGE warning stamped on them.

8.10 HIGH-VOLTAGE ENCLOSURES.

Enclosures are employed frequently by the design engineer to provide the extra margin of safety. Their use is recommended when persons, other than authorized personnel, can come in contact with high-voltage terminals. Covers of these enclosures should be labeled with HIGH-VOLTAGE warning stampings. In addition, removal of enclosure covers could actuate an interlock system to short out or disconnect the power supply.

8.11 INSULATED CONTROLS.

Use metallic knobs, dials, switches, and levers only in equipment known to be of the cold-chassis type. Never use such attachments with a-c/d-c devices. To avoid grounding an operator, short setscrews should be used in all insulated knobs, to prevent the operator's fingers contacting the tops of these screws. When this is not possible, cover the top of each screw with a spot of sealing wax or coil dope, after tightening.

The shafts of rheostats and potentiometers in high-voltage circuits should not be brought out directly to knobs or dials, but should be recessed far enough back of the panel or below the chassis to include an insulated shaft coupling and an ample length of insulated rod. Common examples of high-voltage components of this type are the intensity, focus, and beam-centering controls of an oscilloscope.

8.12 HIGH-VOLTAGE JACKS.

Jacks occasionally are employed in power circuits for the insertion of meters, keys, output lines, etc. Good practice is to connect such jacks in the grounded B-minus leg of the monitored circuit, rather than at any point in the B-plus sections.

When this method of connection is not practicable in a particular circuit, the jacks may be recessed behind the main panel, where they cannot be touched easily, and clearance holes provided for insertion of the plugs. This will prevent accidental contact by the operator and also accidental grounding and firing as a result of contact with wires or other metallic objects.

8.13 SWITCH FIRING.

Electronic circuits should be designed to minimize sparking, arcing, and firing in switches, relays, and similar make-and-break devices. Finished equipment must be inspected fully for verification of the design. In addition to shortening the life of the switching device, firing can touch off an explosion of combustible vapors in confined areas, such as in aircraft and boats.

Only explosion-proof switching devices should be employed when electrical equipment is to be used in an atmosphere of explosive gas or vapor. Certain commercial and military groups make the use of explosion-proof switching devices mandatory.

Mercury switches and other mercury-containing devices must be protected adequately against breakage of the glass containers. An additional precaution is to mount a mercury switch in such a location in the equipment that the mercury will not spill on a hot surface if the container should break. Mercury vapor is a pronounced health hazard, a factor which must be considered in addition to the electrical difficulties which might be caused by the free-flowing liquid metal.

8.14 POWER-LINE SAFETY.

Engineers and designers are inclined to confine their safety considerations to high-voltage apparatus. It is important to note, however, that considerable hazard lies in the power-line end of electronic equipment. Fires, bad shocks, and serious burns are known to result from personal contact, short circuit, and grounding at the a-c line. The danger is heightened when the supply is 220 or 440 volts.

Only 3-conductor line cords bearing Underwriter's Laboratories approval and in good physical condition should be employed. Such cords must pass through grommet-lined holes in chassis or panels, never through raw-edged metal.

Adequate fusing of the equipment should be provided, including information on fuse type and ampere rating. It is a form of negligence to assemble any complete radio or electronic apparatus without including one or more fuses in the equipment itself.

8.15 POSITIONING OF HIGH-POTENTIAL COMPONENTS.

Each component with exposed terminals, in medium or high-voltage portions of a circuit should be protected from short-circuit, grounding, or accidental contact by the operator.

Such parts include selenium rectifiers, bleeder resistors, capacitors with exposed terminals, switches, rheostats, and 115-volt pilot lights. Wherever possible, such components should be mounted under the chassis where they are not exposed. However, ventilation requirements do not always permit this. Therefore, when it is impracticable to conceal the components below chassis, protective housings with ventilating holes or louvers should be provided. When housing cannot be used, the exposed terminals of the components should be oriented away from the direction of easy contact. These expedients will lessen shock and firing.

8.16 INSTALLATION MEASURES.

All electronic equipment, whether designed for use in a laboratory or in a nontechnical environment, should meet the requirements of the National Electrical Code and local municipal rules and regulations as applied to wiring.

Some of the pitfalls to be avoided include: dangling, trailing, draped, or underrated power cords, overloaded power outlets, overheated or damp locations, overloaded power switches, unfused power lines or lack of circuit breakers, and use of multiple attachments (cubic taps).

Provide a safety ground at every installation. This consists of connecting with a heavy wire all of the metal panels, chassis, racks, cabinets, etc., and running this wire directly to a good ground. In most cases, the grounded electrical conduit is an adequate path to ground. Three-wire cords, with the third wire connected to the electrical conduit, are recommended because they connect the equipment automatically to earth ground whenever the power plug is inserted into the outlet.

Provide DANGER-HIGH VOLTAGE signs conspicuously both outside and inside the equipment at all important points where an operator should be reminded of the hazard. As an added precautionary measure, the actual potential present can be indicated.

A proposed location for a stationary electronic installation should be surveyed beforehand with respect to favorable temperature, humidity, vibration, power-line stability, magnetic fields, and traffic conditions to determine which elements should be removed or modified in the interest of safe operation.

8.17 FAILURE VERSUS SAFETY.

Electronic equipment breaks down in spite of the best engineering and maintenance. Failure is considered as falling into two categories. When the breakdown of a component causes dangerous overloads or voltage peaks or places high potentials in undesirable places, the failure is said to be unsafe. When breakdown places the system out of operation without in any way introducing trouble in the system or to the operator, the failure is said to be safe.

No blanket rule can be stated for designation of all cases. A particular failure must be viewed in terms of an analysis of the circuit or system in which it occurs in order to determine into which category it falls. Consider these examples: A bleeder resistor in a power supply fails leaving an unsafe condition because in burning open it allows a dangerous charge to be held by the filter capacitors. A short-circuited filter capacitor also fails leaving an unsafe condition because it draws excessive current which may destroy the rectifier (producing much heat), filter choke, or transformer. An open-circuited secondary winding in a power transformer in a simple power supply fails, leaving a safe condition because it removes the power automatically from the entire system. But the secondary would fail leaving an unsafe condition if the power supply furnished fixed bias voltage to high-power tubes, since these tubes would draw excessive plate current in absence of the bias.

The cautious designer of electronic equipment will take every possible precaution to cover fail-safe operation. For example, the inclusion of a fuse in series with a filter capacitor will change a fail-unsafe probability into a fail-safe situation, since the fuse will open if the capacitor short-circuits.