PERSONAL SAFETY CONSIDERATIONS WITH BROADCAST TRANSMITTERS

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INTRODUCTION

Most people are concerned with safety one way or another in our daily lives and are generally safety conscious. This is particularly true in the broadcast industry. Yet sometimes safety is taken for granted. The question of safety gets little or no attention until the occurrence of a major safety related accident. Much of the responsibility related to safety rests in the hands of broadcast station engineers.

Personal safety must be a very important consideration in the design, operation, and maintenance of broadcast transmitter equipment containing high voltages, currents and large amounts of energy storage. The equipment should incorporate adequate safety protection against accidental direct exposure to dangerous potentials. More importantly, the broadcast engineering staff should be aware of the possible hazards and follow good electrical safety practices. This is especially important in today's highly competitive radio station environment where technical expertise is depleting at an alarming rate. This paper discusses the various hazards which may be encountered, the safety requirements for transmitting equipment including standards and the protective circuits, devices, and methods used in a typical broadcast transmitter to achieve the desired safety level.

SAFETY HAZARDS

The safety hazards which are of primary concern to broadcast staff are described below.

Electrical Shock

Current rather than voltage is the most important parameter which affects the intensity of electric shock. Three factors that determine the severity of electric shock are: (1) amount of current flowing through the body; (2) path of current through the body; and (3) duration of time the current flows through the body.

The voltage necessary to produce a current dangerous to life is dependent upon the resistance of the body, contact conditions, and the path through the body [1]. The resistance of the human body varies with the amount of moisture on the skin, the muscular structure of the body and the voltage to which it is subjected.

Studies of adult human body resistance have indicated that under normal dry skin conditions hand-to-hand resistance varied typically from 6,600 ohms to 18,000 ohms and hands-to-feet resistance varied from 1,550 ohms to 13,500 ohms [2]. The body resistances of children were found to be generally higher. Higher voltages have the capability to breakdown the outer layers of the skin thereby reducing the resistance. In judging a product for safety against electric shock, Underwriters Laboratories (UL) uses a resistance value of 1,500 ohms under normal dry contact conditions and a resistance value of 500 ohms under wet conditions [2,3]. Based on research of Charles F. Dalziel, Professor Emeritus, University of California, Berkeley, the effects of 60 Hz AC (alternating current) on the human body, are illustrated in Table 1 [4]. The safe "let-go" currents generally accepted for 0.5 percent of population are approximately 9 and 6 mA for men and women repectively [5]. The "let-go" current is the maximum current at which a person is still capable of releasing a live conductor by using muscles directly stimulated by that current. Currents only slightly in excess of one's let-go current are said to "freeze" the victim to the circuit. The maximum safe current specified by the International Electrotechnical Commission (IEC) is 2 mA DC (direct current) and 0.7 mA peak AC measured in a non-inductive resistor of 2,000 ohms connected between the part containing voltage in excess of 72 volts peak and ground [6].

Sufficient current passing through any part of the body will cause severe burns and hemorrhages. However, relatively small current can be lethal if the path includes a vital part of the body such as the heart or the lungs. The duration of current flow also affects the severity of injury. The effects of electrical current and time duration on the human body is illustrated in Figure 1 [4]. The current range previously noted in Table 1 which causes "freezing" to the circuit is also illustrated. It is obvious from Figure 1 that a 100 mA current flowing for 2 seconds through a human adult body will cause death by electrocution. Considering a minimum value of hands-to-feet resistance of 1,500 ohms, a current of 80 mA can flow if both hands are in contact with a 120V AC source and both feet are grounded. If this condition persists for more than 2 seconds, it may cause electrocution. The above data provides insight into the hazards of electrical shock.

Electrical and Radio Frequency Burns

Electrical burns are usually of two types, those produced by heat of the arc which occurs when the body touches a high voltage circuit, and those caused by passage of high current through the skin and tissue. In the latter case even the low voltage source(s) containing large amounts of energy can cause severe arcing or overheating if accidentally short-circuited with the possibility of injury to personnel and the risk of fire.

TABLE 1. THE EFFECTS OF 60 Hz ALTERNATING CURRENT ON THE HUMAN BODY

1 milliamp or less	-	No sensation, not felt.
More than 3 mA	-	Painful shock.
More than 10 mA	-	Local muscle contractions, sufficient to cause "freezing" to the circuit for 2.5 percent of the population.
More than 15 mA	-	Local muscle contractions, sufficient to cause "freezing" to the circuit for 50 percent of the population.
More than 30 mA	-	Breathing difficult, can cause unconsciousness.
50 to 100 mA	-	Possible ventricular fibrillation* of the heart.
100 to 200 mA	-	Certain ventricular fibrillation* of the heart.
Over 200 mA	-	Severe burns and muscular contractions; heart more apt to stop than fibrillate.
Over a few amperes	-	Irreparable damage to body tissues.

*NOTE: Ventricular fibrillation is defined as "very rapid uncoordinated contractions of the ventricles of theheart resulting in loss of synchronization between heartbeat and pulse beat". Once ventricular fibrillation occurs, it will continue and death will ensue within a few minutes. Resuscitation techniques, if applied immediately, may save the victim.

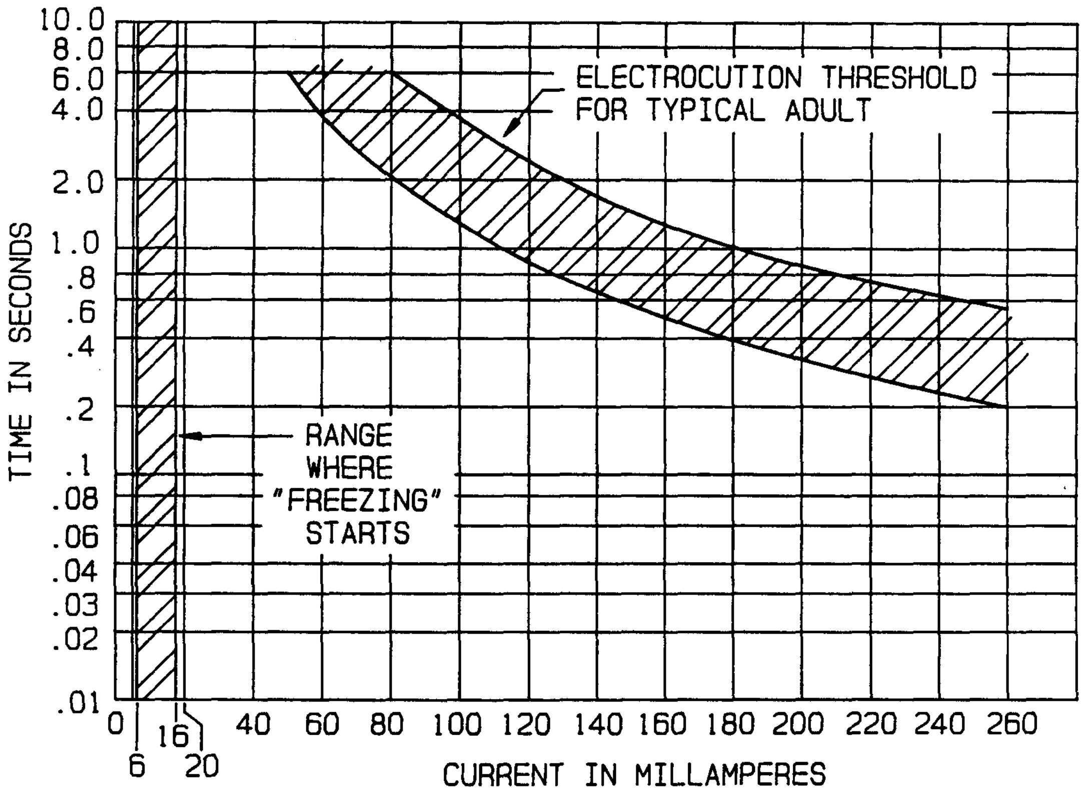


FIGURE 1. THE EFFECTS OF ELECTRICAL CURRENT AND TIME ON THE HUMAN BODY

This can occur when a metal part in contact with the skin such as jewelry or tool provides path for high short-circuit currents.

Radio Frequency (RF) burns are caused by the flow of RF currents through the skin when it is exposed to an RF energy source. The energy is absorbed by the resistance of the skin. The severity of burns will depend on the area of exposed surface, the amount of current flow, the voltage level, the frequency and the time duration.

Harmful Radiation

The two types of harmful radiation which may be encountered in and near the transmitting equipment are: (1) Non-ionizing Radiation and (2) Ionizing Radiation.

Non-ionizing radiation may exist due to poor shielding of the transmitter equipment operating at high power levels or due to the proximity of antenna. Exposure to excessive non-ionizing radiation of radio frequency electromagnetic fields in the frequency range from 300 kHz to 100 GHz will cause heating of the body which in turn may have adverse biological effects. Studies have shown that whole-body-averaged absorption rates approach maximum values when the long axis of a body is parallel to the E-field vector and is four tenths of a wavelength of the incident field. At a frequency near whole-body resonance, which is about 70 MHz for the Standard Man, the absorption of RF energy is maximum [7]. Under 3 MHz, most of the energy will pass completely through the human body with little attenuation or heating effect. The dangers of non-ionizing RF radiation are most severe at UHF and microwave frequencies. Human eyes are particularly vulnerable to low-energy microwave radiation and blindness can result from overexposure. Cardiac pacemakers may also be affected by RF radiation.

Ionizing X-ray radiation may exist near high power tube transmitters depending on the work-function of the materials that the tube is constructed with. Typically X-rays are emitted from the copper anode at high voltages. As operating voltages increase beyond 15 kilovolts, power tubes are capable of producing progressively dangerous X-ray radiation [8]. X-ray levels should be checked at regular intervals for possible changes due to tube aging. Exposure to excessive ionizing X-ray radiation may damage human body cells with resultant biological changes due to dissipation of energy in body tissues. The levels of radiation, the exposure rate, and the length of time over which exposure occurs are closely connected with the nature and extent of any damage. The effect of ionizing radiation on matter is to release charge either by direct ionization or by the liberation of ionizing particles [9].

High Temperatures and Fire

The transmitting equipment parts may attain high temperatures under normal conditions. The external surface of power tubes operates at high temperatures (up to 200 degrees to 300 degrees centigrade).

All hot surfaces may remain hot for an extended time after the the transmitter is switched off [8]. Thermal burns may result if the body skin comes in contact with hot surfaces. Hot water lines used for tube cooling in some transmitters may present a similar hazard. The temperature rise of some components under fault conditions may be excessive so as to cause injury to personnel. Staff should keep away from hot surfaces and should be aware of any possibility of fire or its spread and take necessary precautionary measures.

Other Hazards

Personnel should be aware of components which may cause danger due to implosion or explosion. These apply to components such as cathode-ray tubes, vacuum power tubes, electrolytic capacitors or glass fuses. Accidental breakage of vacuum tube glass envelope can cause an implosion, which will result in an explosive scattering of flying glass particles and fragments. This may cause serious personal injury [8].

Beryllium oxide ceramic material (BeO) is used as a thermal link to dissipate heat away from a tube or transistor. BeO dust or fumes are highly toxic and breathing them may result in serious injury endangering the life [8]. Polychlorinated biphenyls (PCBs) used in older oil-filled power transformers and high voltage capacitors are also hazardous. The Environmental Protection Agency (EPA) has established regulations (40 CFR Part 761) regarding the use and disposal of electrical components containing PCBs.

Care should be taken to prevent injury due to contact with moving mechanical parts such as fans, gears. Sharp projections or edges should be avoided to protect from cuts or abrasions. Exposure to excessive noise can cause damage to hearing and to the nervous system.

SAFETY REQUIREMENTS FOR TRANSMITTING EQUIPMENT

Safety Standards

Safety standards related to broadcast transmitter installations are found in the following publications:

a) International Electrotechnical Commission (IEC) Publication 215 contains the safety standard for radio transmitting equipment [6]. This is the only standard which specifically addresses the safety requirements for transmitting equipment.

b) The general safety standard used widely for reference purposes is the Military Standards, "MIL-STD-454K: General Requirements for Electronic Equipment, Requirement 1, Safety Design Criteria - Personnel Hazard" [1]. This standard establishes safety design criteria and provides guidelines for personnel protection.

c) Safety Standard which deals with permissible levels of human exposure to RF electromagnetic fields is contained in the American National Standards Institute document ANSI C95.1-1982 [7].

d) The National Electrical Code (NEC) is a comprehensive document that details safety requirements for all types of electrical installations. The National Electric Code or The National Electrical Code Handbook is published by the National Fire Protection Association (NFPA) [10].

e) Another NFPA publication titled "NFPA 79: Electrical Standard for Industrial Machinery 1987" provides detailed information for the application of electrical/electronic equipment, apparatus, or systems supplied as part of industrial machinery which will promote safety to life and property [11].

f) U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Safety and Health Standards 29 CFR 1910 contains design safety standards for electrical systems, safety-related work practices, safety-related maintenance requirements and safety requirements for special equipment [12].

Other publications related to safety are given in the reference section of this paper including the addresses to order any of the publications listed.

Safety Requirements

The principal design and construction requirements for safety of personnel during the installation, operation and maintenance of broadcast transmitters are discussed below. Major differences between existing standards are also highlighted.

(a) Protection against electrical shock and burns, including RF skin-burns.

(1) An effective grounding system is essential to prevent the possibility of electric shock. The equipment grounding is necessary to insure that all the external metal parts, surfaces, shields are bonded together and then connected to a safety ground by a low-impedance conductor of sufficient capacity to carry operating and fault currents. System grounding is required to connect one of the primary AC conductor and service equipment to ground, which then completes the ground-fault loop. Proper grounding also protects equipment from damage caused by AC line disturbances.

(2) A reliable main power disconnect switch for cutting off all power to the transmitter should be provided. The switch should plainly indicate whether it is in the open (off) or closed (on) position. Live conductors shall be protected against accidental contact. A fused type disconnect is preferred over circuit breakers by some broadcast engineers.

(3) Type of protection required to prevent accidental contact with different voltage levels is given in Table 2. Protection requirements specified by NFPA 79, MIL-STD-454K, and IEC 215 are also shown in the table. Voltages in excess of 30 volts (per MIL-STD-454K and NEC) or 50 volts (per IEC 215) should not be directly accessible under normal operating conditions.

(4) A grounding stick with an insulated handle and a rigid conducting hook connected to ground by means of a flexible stranded copper wire (covered with transparent sleeving) should be provided as an additional safety measure.

TABLE 2. TYPE OF PROTECTION RECOMMENDED TO PREVENT ELECTRICAL SHOCK

VOLTAGE RANGE (rms or dc)	TYPE OF PROTECTION		
	NFPA 79	MIL-STD-454K	IEC 215
0-30	None		
> 30-50 Volts	Provide doors or covers to protect from direct accidental contact under normal operating conditions.		
> 50-70 Volts	Doors permitting access to voltages 50 volts or more should be interlocked to disconnect power when opened. Exposed voltages should be discharged to 50 volts within one minute after disconnecting power.	Exposed high voltage circuits and capacitors should be discharged to 30 volts or less within 2 seconds after disconnecting power.	Protective covers not removable by hand.
> 70-250 Volts		Parts exposed to dc, ac or rf voltages should be guarded from accidental contact with a "CAUTION" sign. Bypassable interlocks required.	
> 250-500 Volts			Current limit in a 2K ohm test resistor connected to ground is 2mA dc or 0.5mA ac.
> 500-700 Volts		Exposed parts should be completely enclosed with a "DANGER" sign. Access door or cover should be interlocked to remove power when opened.	
> 700 Volts			Exposed parts should be grounded by "fail-safe" grounding switch when access door or cover is opened.

(5) Transmitter output terminals or transmission lines with RF voltages should be protected from accidental contact by guards or screens. MIL Standards require protection against RF voltages in the same manner as for AC voltages in the 70 to 500 volt range. IEC 215 Standard requires that RF output connection has provision to drain off any static charge build up. It should also be protected against RF voltages pick-up due to coupling from other transmitters operating on the same site.

(6) Low voltage/high current parts such as tube filament supplies, large filter capacitors, and high-capacity batteries should be protected against accidental short-circuits. This may be accomplished by the use of mechanical guards with warning signs or safety devices. MIL Standards require protection for all power busses supplying 25 amperes or more.

(b) Protection against harmful radiation.

The transmitter construction should have adequate shielding so that there is no danger to personnel from any stray or cabinet radiation.

(1) Non-ionizing radiation at radio frequencies: MIL-STD-454K specifies the requirements of the American National Standards Institute (ANSI) C95.1-1982 Standard with respect to human exposure to RF electromagnetic fields in the frequency range from 300 kHz to 100 GHz. ANSI Standard recommends specific absorption rate (SAR) below 0.40 watts per kilogram as averaged over the whole body over any 0.1 hour period. "SAR" is the time rate at which RF energy is imparted to an element of mass of a biological body. Radio frequency protection guide for whole-body exposure of human beings in terms of the equivalent plane-wave free space power density measured at a distance of 5 cm or greater from the transmitter part as a function of frequency is illustrated in Figure 2. The limit on the power density between 30 to 300 MHz is 1 mW/cm^2 (milliwatts per square centimeter). A 10 mW/cm^2 per 0.1 hour average level has been adopted by OSHA as the radiation protection guide in the frequency range of 10 MHz to 100 GHz [12]. The IEC 215 Standard recommends a power density limit of 10 mW/cm^2 over the frequency range 30 MHz to 30 GHz.

MIL-STD-454K requires that shields, covers, doors, which when opened or removed allow microwave and RF radiation to exceed the above, should be provided with non-bypassable interlocks.

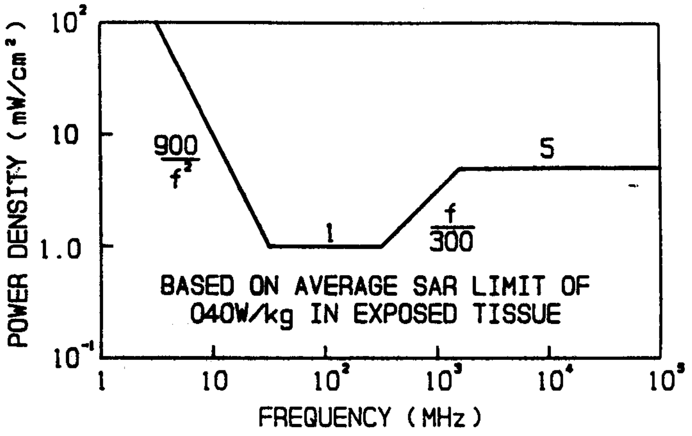


FIGURE 2. RADIO FREQUENCY PROTECTION GUIDE FOR WHOLE-BODY EXPOSURE OF HUMAN BEINGS

(2) Ionizing radiation of X-rays: For X-rays an exposure that releases a charge of 0.258 coulomb per gram of dry air is defined as one roentgen. MIL-STD-454K specifies limit of radiation levels to less than 2 mR (milliroentgens) in any one hour and 100 mR in any consecutive 7 days. Shields, covers, doors which allow X-ray radiation to exceed the limit when removed should be provided with non-bypassable interlocks. The IEC 215 Standard specifies a limit of radiation level to less than 0.5 mR per hour per kilogram.

(c) Protection against high temperatures and fire.

MIL-STD-454K specifies the temperature rise limit to exposed parts including enclosure of the equipment to 35°C (degrees centigrade) maximum and those of front panels and controls to 24°C rise at 25°C ambient. The IEC 215 Standard requires that temperature rise of accessible parts be limited to 30°C under normal operation and 65°C under fault conditions at 35°C ambient temperature, to prevent injury to personnel [13].

The electrical insulation or mechanical strength of equipment parts should not be impaired by the temperature rise. No part of the equipment shall reach high temperature so as to cause danger or fire or the release of flammable or toxic gases. The use of flammable material should be avoided and the possibility of fire and its spread should also be minimized.

(d) Other Hazards.

Components prone to implosion or explosion under fault conditions should be protected against danger to personnel. The safety valve of the components such as electrolytic capacitors should be clearly marked and oriented so as not to endanger the personnel in the event of its operating.

Moving parts such as blowers, motors, fans, gears should be adequately guarded to prevent possible injury. Mechanical design should minimize the possibility of injury from sharp edges, protruding corners, release of springs or accidental pulling out of drawers or assemblies. Attention should also be paid to minimize the generation of acoustic noise.

Permissible noise exposure limit specified by OSHA regulations in a full work day of 8 hours is 90 dB(A) of sound level when measured by a precision sound-level meter [14].

PROTECTIVE CIRCUITS, DEVICES, AND METHODS USED IN A TYPICAL RADIO BROADCAST TRANSMITTER TO ACHIEVE DESIRED SAFETY LEVEL

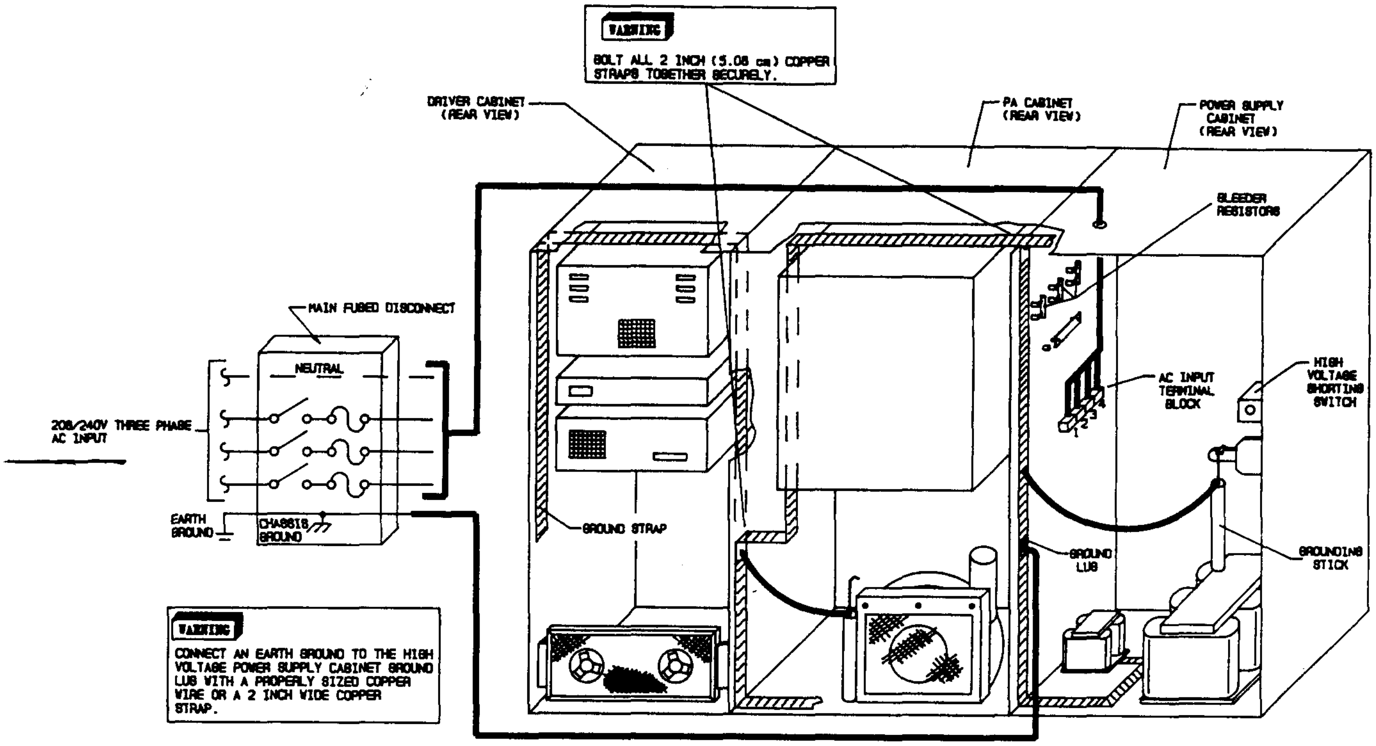
The protective circuits and safety devices typically used in radio broadcast transmitters manufactured in the United States will be discussed to illustrate safety design considerations.

Protective Circuits

Incoming AC primary power source should be connected to the transmitter through a fused main disconnect switch so that all power may be cut off quickly and reliably, either before working on the equipment, or in case of a fault condition or an accident.

The equipment enclosures, chassis, or frames, including ground terminals of power supplies, are connected to the cabinet or rack ground strap. Typically, a two-inch wide copper strap is routed inside each transmitter rack or cabinet. Straps of individual racks are then bolted together and connected to the ground terminal as shown in Figure 3. The ground terminal is provided for connection to the station earth ground and the system ground. The ground strap has sufficient current carrying capacity and provides a low impedance path for equipment ground fault currents.

A simplified primary AC control diagram of a Broadcast Electronics FM transmitter is shown in Figure 4. The primary AC input to the transmitter is distributed to the low voltage and high voltage supplies through separate properly rated circuit breakers and contactors. The transmitter design incorporates a safety interlock circuit to disconnect primary power from contactors when access doors or panels are opened. Contactor coils are de-energized by specially designed optically coupled relays (OCR) which are in turn operated by the transmitter controller logic level commands. The contactors cannot be re-energized to restore the power without first closing the interlock circuit and then manually resetting the transmitter turn-on sequence.



BOLT ALL 2 INCH (5.08 cm) COPPER STRAPS TOGETHER SECURELY.

CONNECT AN EARTH GROUND TO THE HIGH VOLTAGE POWER SUPPLY CABINET GROUND LUG WITH A PROPERLY SIZED COPPER WIRE OR A 2 INCH WIDE COPPER STRAP.

FIGURE 3. TRANSMITTER CABINET GROUND STRAP CONNECTIONS

This feature eliminates the possibility of turning on the transmitter due to accidental closing of doors during maintenance. An external interlock circuit such as for a test load or remote control fail-safe connection is also provided to disable the high voltage supply when opened. A positive going control voltage of +15 volts DC is required to complete the interlock circuit in the transmitter controller. This is a "fail-safe" feature because any ground fault in the interlock circuit wiring will make the circuit fail in the "safe" condition, thereby eliminating the possibility of turning on the high voltage.

Grounding sticks and high voltage shorting switches are also interlocked to prevent the transmitter from turning on if these safety devices are not in the normal operating position. The transmitter control circuit design allows the blower to run for few minutes after turning off the filament supply so that the tube may cool down. This safety measure will help prevent accidental burns, if the tube anode radiator is touched by maintenance personnel after the cool-down period.

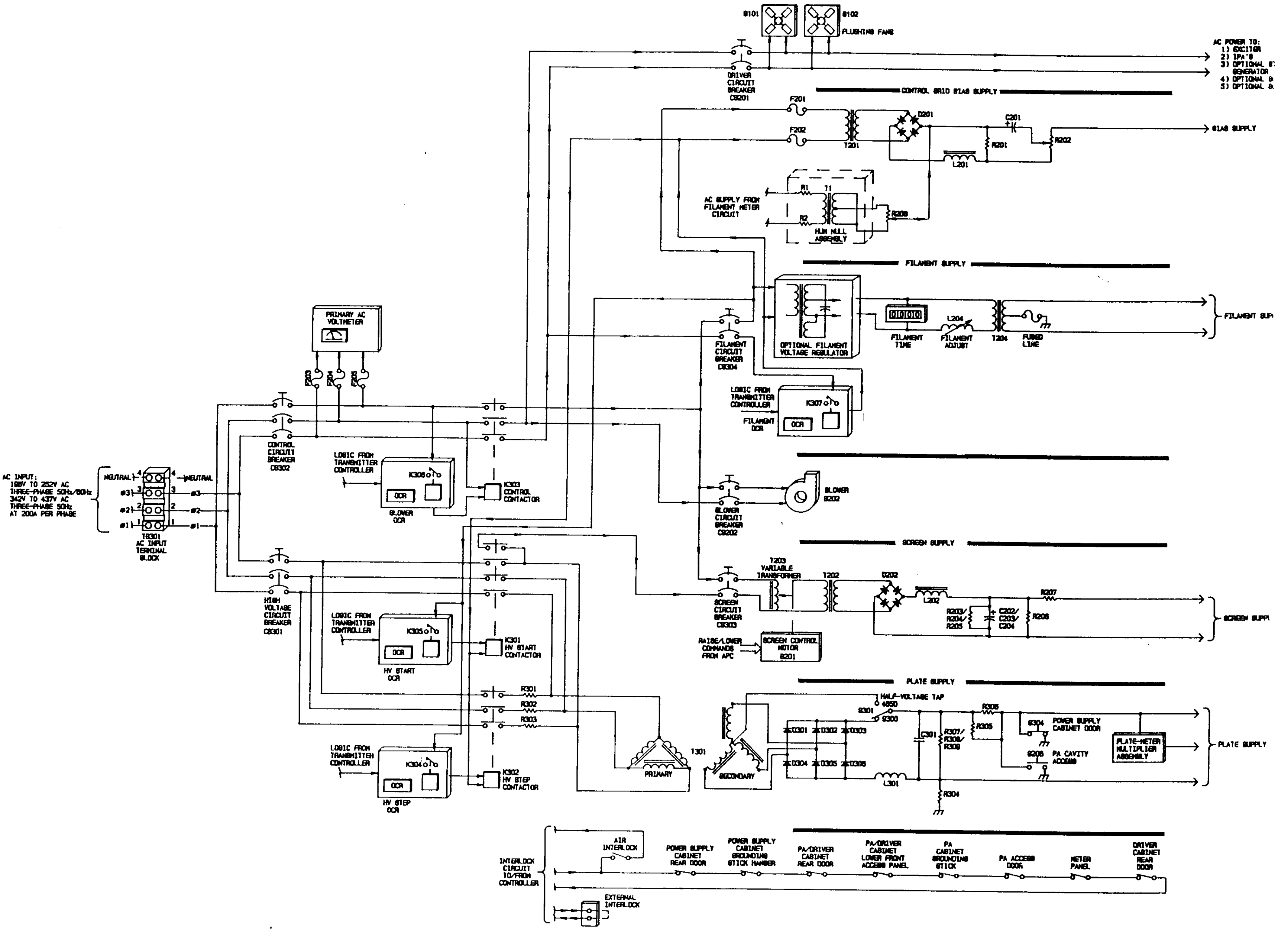


FIGURE 4. SIMPLIFIED PRIMARY AC CONTROL DIAGRAM OF A BROADCAST ELECTRONICS FM TRANSMITTER

In addition to personal safety devices, the following additional circuits are provided to protect the equipment and its parts:

(a) Component stress at power-on is reduced by a step-start circuit which limits inrush current in the high voltage power supply.

(b) An air interlock circuit to insure adequate differential air pressure and flow for the tube before the filament voltage is applied.

(c) The step/start circuit is interlocked through contacts of filament contactor to assure that the filament voltage is applied to the tube before a high-voltage-on sequence can be initiated.

(d) The RF drive to the tube cannot be applied without turning on the high voltage.

(e) Any fault condition causing circuit overloads due to high plate current, screen current, grid current, or high VSWR will be interrupted to protect the equipment from possible damage.

(f) Solid-state intermediate power amplifiers have built-in temperature sensors to shut down the transmitter when the heat-sink temperature exceeds the maximum limit.

Protective Devices

(a) Bleeder Resistors.

Bleeder resistors provided in all power supplies function as the first level of protection against dangerous voltages. The bleeder resistors discharge residual voltages from all components with stored energy when the primary power is switched off. The rate at which the voltage discharges depends upon the nominal voltage and the R-C time constant of the power supply. The resistor values should be chosen to allow the voltages to decay to a safe level within the specified time interval after turning off the power. The voltage drops to 0.37 times the initial or nominal voltage in one time constant interval (RC seconds, where R is in ohms and C is in farads). This is shown in Figure 5.

(b) Safety Interlock Switches.

Safety interlock switches typically used in broadcast transmitters and their construction are shown in Figure 6. Figure 6A shows switches with an activating lever which closes the interlock contacts when the grounding stick is properly secured. This type of switch is also used to insure that the high voltage shorting switch remains in the open state when the access door to the RF enclosure is closed.

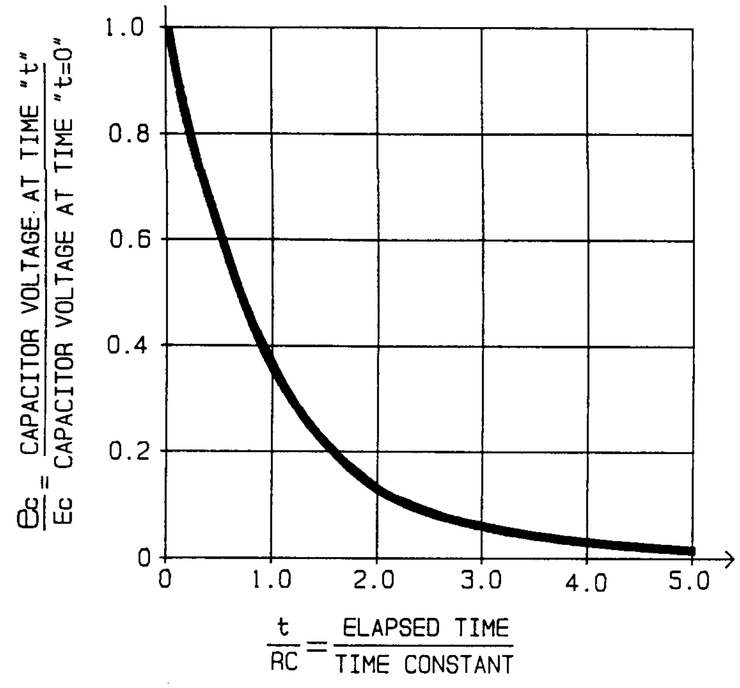


FIGURE 5. CAPACITOR VOLTAGE DISCHARGE WITH TIME

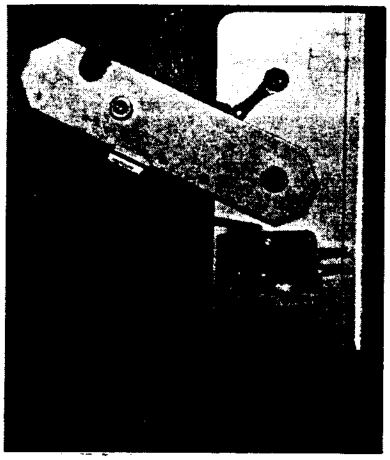


FIGURE 6A

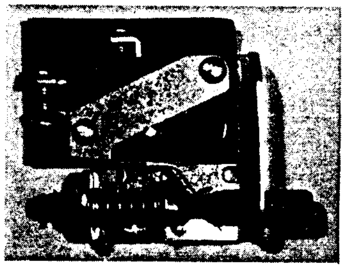


FIGURE 6B

SAFETY INTERLOCK SWITCHES

The switch shown in Figure 6B is used extensively to interlock cabinet doors, enclosure access doors, panels, or covers. The switch is designed in accordance with the "fail-safe" principle to keep the contacts open when the mechanical spring is expanded in its natural state.

(c) High Voltage Shorting Switches.

High voltage shorting switches provide a back-up system to the safety interlock switches described in "(b)" above. This philosophy provides two independent safety systems to protect personnel from accidental exposure to high voltages.

A high voltage shorting switch design based on the "fail-safe" principle, is shown in Figure 7. The insulated rod with a built-in spring mechanism and the block for mounting contact plates are all integral parts of the switch which remain in or go to a "safe" condition to provide protection to personnel in the event of a fault within the device. These positive acting, highly reliable devices are actuated by mechanical release when the door is opened. High voltage is short-circuited to ground due to the closure of contact plates. The insulating rod and housing material has been chosen such as to allow smooth, unrestricted movement from "safe" to "unsafe" position or vice versa. The switch cannot be bypassed without deliberate action violating the safety rules. The high voltage shorting switch shown in the above-mentioned figure is used for short-circuiting the high voltage when the RF enclosure access door is opened. The built-in interlock switch contacts open first to remove primary power just before grounding the high voltage.

The switch is designed such as to prevent any corona discharge under normal operating conditions and to withstand breakdown voltage at least twice the nominal high voltage level.

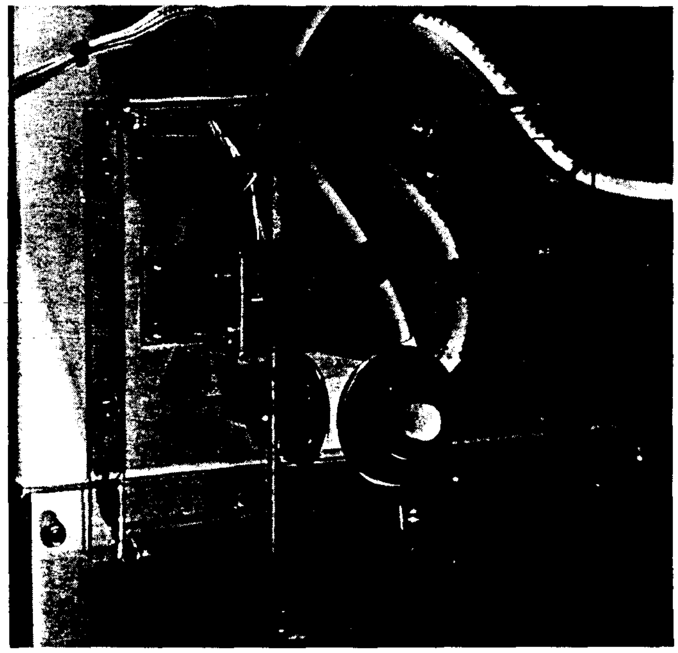


FIGURE 7. HIGH VOLTAGE SHORTING SWITCH

(d) Fail-Safe Solenoid.

The fail-safe solenoid shorts the high voltage circuits to ground and provides a back-up system to the safety interlock switches described in "(b)" above. This philosophy provides two independent safety systems to protect personnel from accidental exposure to high voltages.

A fail-safe solenoid is shown in Figure 8. This safety device is actuated by an electrical solenoid such that the plunger drops to short the high voltage terminal to ground when the transmitter cabinet door is opened. In addition, this device will short the high voltage circuits whenever power is removed from the blower and cabinet flushing fans.

The solenoid design, as the name implies, is based on the "fail-safe" principle. It will remain in or go to a condition which provides protection to personnel in the event of a fault within the device. As soon as the door is opened, the power to the solenoid coil is interrupted and the plunger will drop due to its weight and the mechanical release of spring, thereby shorting the high voltage. This device cannot be disabled without deliberately violating the safety rules. The spacing between the contacts is selected to eliminate possibility of any corona discharge or dielectric breakdown.

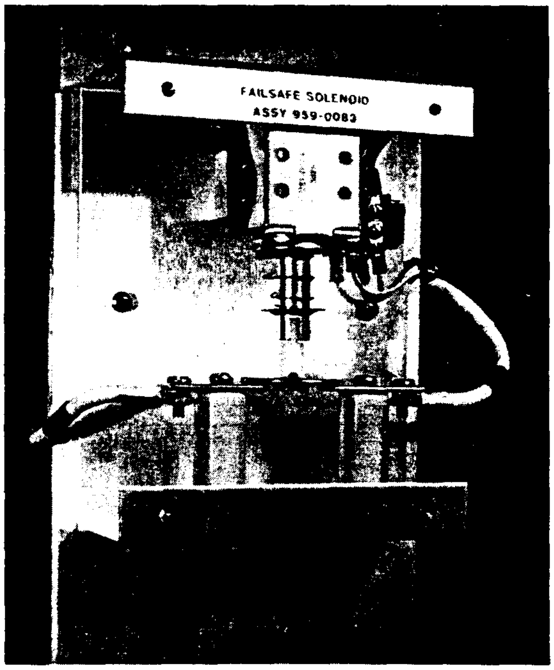


FIGURE 8. FAIL-SAFE SOLENOID (WITHOUT COVER)

(e) Grounding Sticks.

The purpose of a grounding stick is to remove residual voltages from exposed parts of the transmitter before working on it. It is essential to discharge voltages remaining in the equipment after turning off the transmitter, because residual voltages in the energy storage components may be dangerous to personnel safety, particularly if the other safety devices did not function properly. The grounding stick is a mandatory safety device in all transmitters containing dangerous voltages.

A typical grounding stick is shown in Figure 9. It consists of an insulated handle appropriate for the voltages in the equipment, with a rigid metal hook at one end. A flexible stranded copper wire of adequate size connects the hook to the cabinet ground strap. A transparent sleeving is used as an insulation for the wire to allow visual verification of the ground wire integrity. The grounding stick is permanently secured in the transmitter to make it readily visible and accessible by means of either a ground stick hanger or a pair of clamps with built-in interlock switch to insure its correct placement as shown in Figures 9 and 10.

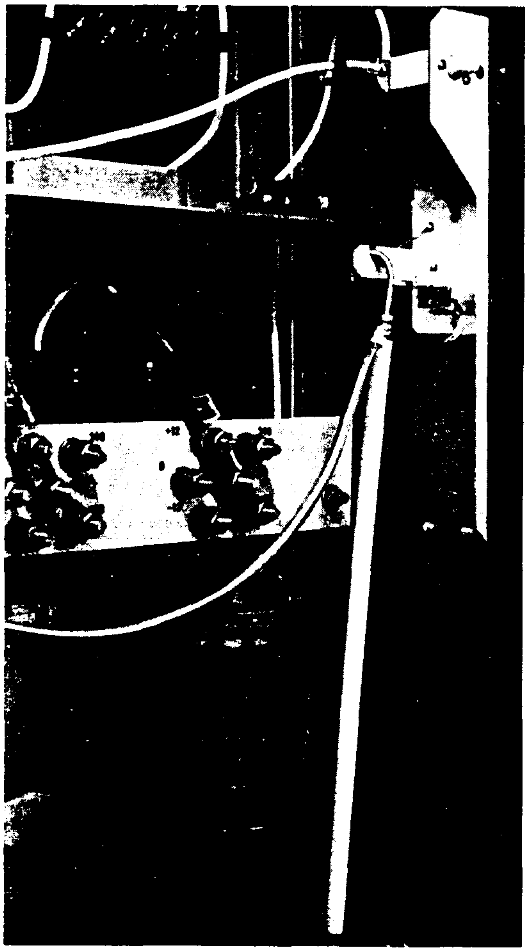


FIGURE 9. GROUNDING STICK

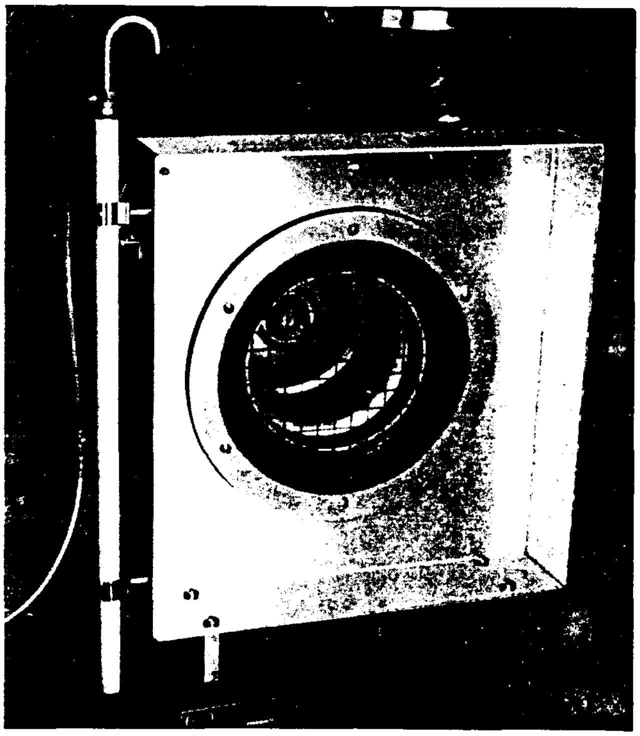


FIGURE 10. GROUNDING STICK
AND BLOWER SAFETY SHIELD

(f) Protective Covers, Guards, Shields and Markings.

All contacts, terminals, and conducting parts having voltages higher than 50 volts (per IEC 215 Standard) and 70 volts (per MIL Standards) with respect to ground when exposed and exhibit safety hazard are guarded from accidental contact by personnel. A guard for an AC terminal block is shown in Figure 11. High voltages are guarded by protective insulator or metal shields as shown in Figure 12. Low voltage components with large amounts of stored energy and conductors carrying high currents are also guarded where necessary by protective covers with proper markings. An example is shown in Figure 13.

FIGURE 11. GUARD FOR AC TERMINAL BLOCK

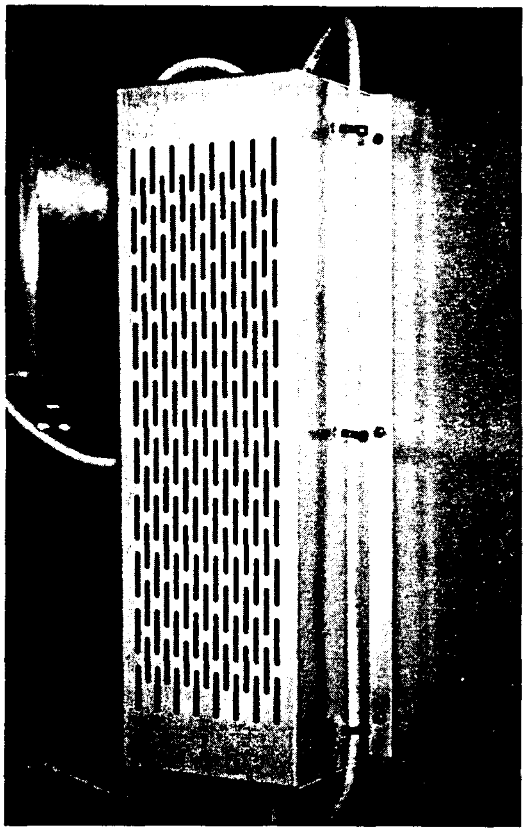


FIGURE 12. HIGH VOLTAGE METAL SHIELD

FIGURE 13. PROTECTIVE GUARD FOR CAPACITOR TERMINALS

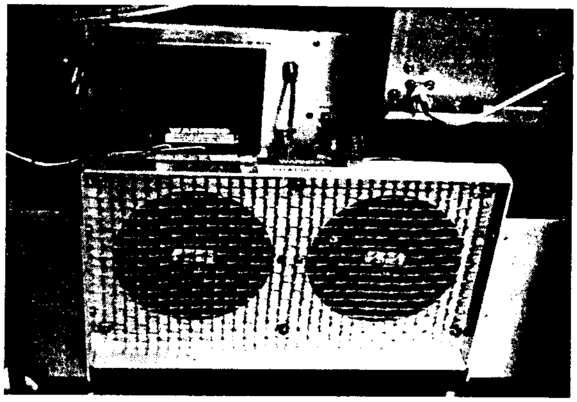


FIGURE 14. PROTECTIVE SHIELD FOR FANS WITH WARNING LABELS

Protective shields with warning signs are also provided to prevent contact with moving mechanical parts such as fans and blowers. Figure 14 shows a protective shield for fans with warning labels. Blower safety shield can be seen in Figure 10 mentioned above. The cabinet doors are provided with appropriate markings as shown in Figure 15.

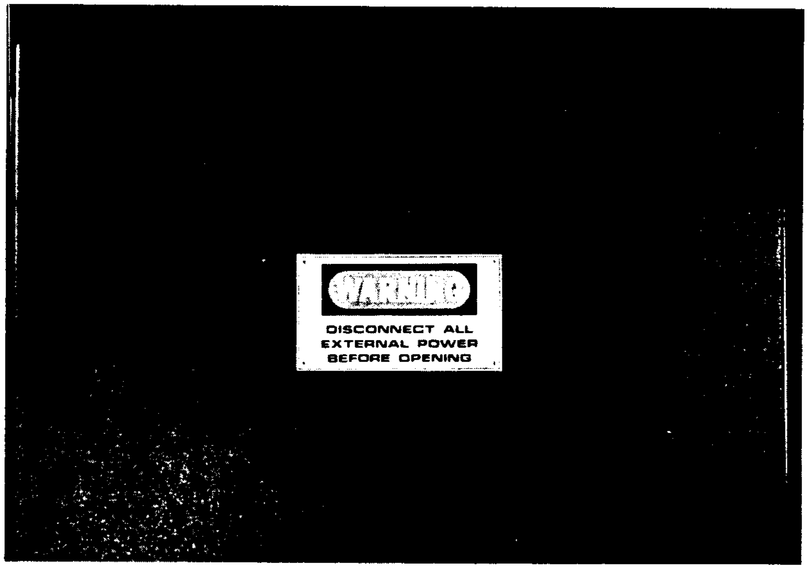


FIGURE 15. CABINET DOOR WARNING LABEL

Safety protection against RF radiation is provided by proper shielding to reduce RF leakage from doors, vent holes, air inlet and exhaust openings. Conductive finger stock and special aluminum shield cell honeycomb panels are used to provide adequate shielding as shown in Figures 16 and 17. An instrument for measuring the RF radiation levels to OSHA recommended limits is available from Holaday Industries, Inc. Broadcast Electronics uses this instrument to insure that the residual RF leakage from the transmitter is below the safe limit.

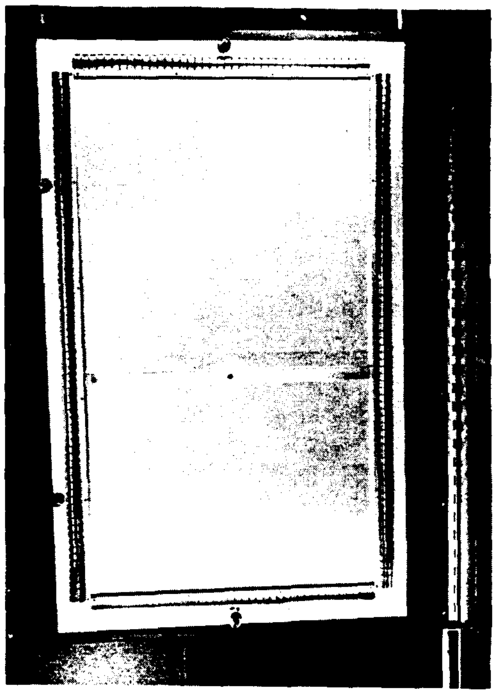


FIGURE 16. CONDUCTIVE FINGER STOCK TO REDUCE RF RADIATION

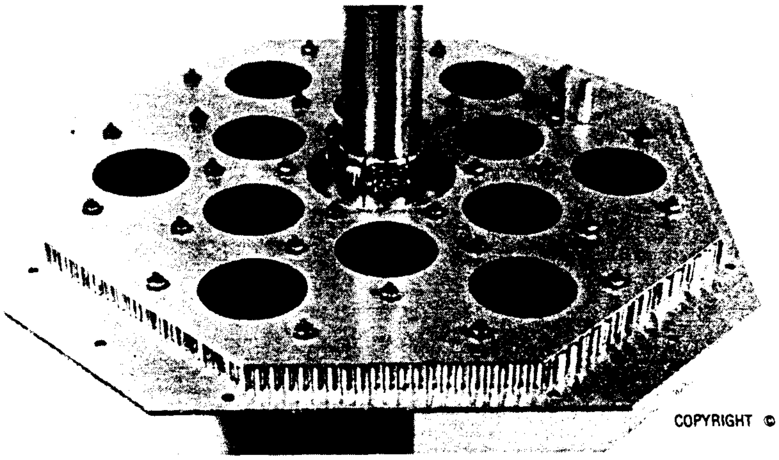


FIGURE 17. ALUMINUM SHIELD CELL HONEYCOMB TO REDUCE RF RADIATION

(g) Circuit Breakers, Fuses and Contactors.

Main primary circuit breakers used in the transmitters are equipped with a thermal as well as magnetic trip elements in each pole. Smaller size breakers have magnetic trip elements. The breakers used conform to applicable UL, National Electrical Manufacturers Association (NEMA), and IEC Standards. The circuit breakers have adequate making and breaking capacity and are selected to protect the equipment against excessive steady-state or instantaneous (less than one cycle) fault currents. The thermal trip protects against high temperature rise.

Circuits or assemblies which do not have individual breakers are protected by properly rated enclosed fuse elements. A fusible link in the center tap of the filament transformer secondary provides overload and safety protection for the filament supply wiring if a short-circuit to ground develops in either leg of the filament supply.

Contactors rated for maximum load and which have adequate making and breaking capacity are used for primary AC control of the transmitter in conjunction with the interlock circuits and the controller unit. The contactors remove the power from accessible areas when the interlock circuit is broken due to opening of doors, panels, or covers.

(h) Smoke Detectors, Fire Alarms, and Fire Extinguishers.

These devices are not part of the transmitter equipment and will not be discussed here. However, it seems prudent to note the following:

Appropriate type and number of smoke detecting devices and associated fire alarm circuits should be installed in the transmitting station. A reliable fire extinguishing system should also be provided to protect the personnel and equipment from fire hazards. Halon 1301 based systems are very effective and will not damage electronic equipment [16]. Automatic fire extinguisher systems should be interlocked with the transmitter control system to turn off the transmitter when the fire alarm system is activated.

Protective Methods

(a) Safety Protection Levels.

Protective methods used to provide different degrees of safety levels can be summed up as follows:

(1) Primary safety level is accomplished by providing doors, panels, and covers with warning signs or labels to avoid direct access to dangerous voltages. In addition, bleeder resistors are provided to discharge residual voltages from energy storage components such as capacitors which may be hazardous to safety even after the equipment is switched off.

(2) Secondary safety level is established by providing contactors together with mechanical and/or electrical interlock systems to insure that the primary power is removed when access doors, panels, or covers are opened without switching off the equipment.

(3) A third safety level is insured by providing shorting switches to short high voltages to ground when the door is opened and also by providing shields and guards which require tools for their removal.

(4) Ultimate safety level is achieved by providing good grounding system, by removing primary power from the equipment with a main disconnect switch, and by using a grounding stick to short out all residual voltages. An external voltage measuring instrument may be used to verify the absence of voltage. When the transmitter is equipped with primary AC metering, it may also be used for this purpose.

(b) Safety Protective Methods.

(1) Safety Program.

A good safety policy should be established by the station management and a comprehensive safety program should be developed and implemented as part of the regular business activity to insure that the facility is operating safely. Safety standards, rules, and guidelines should be developed and enforced. Safety hazards should be identified and necessary precautionary measures taken to eliminate or control them. All the broadcast staff and particularly those staff who have access to the transmitter facility should be properly trained in safety practices, including cardiopulmonary resuscitation (CPR) techniques and in the use of personal protective equipment if required. An adequate first aid kit with training should also be provided.

The United States Department of Labor, Occupational Safety and Health Administration (OSHA) regulations and guidelines contain safety requirements. Necessary information can be obtained from OSHA to start a safety program or to seek the services of a consultant [15].

(2) Safety Practices.

Basic electrical safety practices are described in various standards, regulations and other publications which are listed in the reference section of this paper. Some key personal safety precautions to be considered are highlighted below:

- Thinking safety and ensuring that the transmitter installation is safe in accordance with the OSHA regulations or National Electric Code.
- Taking time to be careful and using common sense.
- Turning off all power circuits before touching anything inside the transmitter.
- Eliminating the possibility of someone else turning on the equipment (by local or remote control methods) while working on equipment.
- Discharging all the voltages to ground, particularly from energy storage components.
- Avoiding bodily contact with any grounded object when working on the transmitter.
- Avoiding unnecessary exposure to RF radiation.
- Using safety tools and equipment.
- Ensuring that all the safety circuits and devices function correctly.
- Avoid working alone or when tired.

CONCLUSION

Safety is an important factor in the design and development of broadcast transmitters. However, it is not uncommon to find safety taken for granted in today's highly commercial broadcast station environment with fewer trained and experienced technical staff. The management and staff in the broadcasting business should give a high priority to the matter of personal safety because it concerns with the protection of personnel against injuries which may endanger the life. The cost of failure to recognize this fact may far exceed the small initial investment required in implementing a sound safety program.

Various hazards as well as the industry standards and the safety requirements related to transmitting equipment have been reviewed. Design considerations for numerous types of protective circuits, devices, and methods used in broadcast transmitters to achieve the desired safety level have also been discussed.

It is hoped that this paper will serve to stimulate greater awareness of personnel safety among broadcasters, equipment manufacturers, as well as equipment users at large and provide motivation to implement one or more positive action plans to make the broadcast station environment a "safer" place to be.

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