AM 5-602

ELECTROMAGNETIC PULSE (EMP)

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- William P Hand

References:

The following references apply to this manual:

US Army FM/TM Manuals;

(1) TM 5-811-3 - Electrical Design, Lightning and Static Electricity Protection
(2) TM-664 – Basic Theory and Use of Electronic Test Equipment

MARS Technical Documents

(1) AM 5-203 Basic Electronics, Grounding and Bonding
(2) AM 5-303 Basic Propagation Theory

Acronyms and Abbreviations:

Abbreviations	Definition
AIS	automated information systems
AM	Amplitude Modulated
ANCS	Alternate Net Control Station
APC	Allied Communications Publication
AR	Army Regulation
BT	Break
C	Celsius
CCTV	Closed Circuit Television
CK	Check the count of words
CW	Continuous Wave (Morse Code)
D.I.R.T.	Data Interception by Remote Transmission
DoD	Department of Defense
DoT	U.S. Department of Transportation
DTG	Date Time Group
DVD	
ECOM	Emergency Communications
EM	electromagnetic
EMP	electromagnetic pulse
EMR	Electromagnetic Radiation
EMSEC	Emissions Security
EPA	Environmental Protection Agency
F	Fahrenheit
FBI	Federal Bureau of Investigation
EEC	European Economic Community
EMI	Electromagnetic Radiation
FCC	Federal Communications Commission
First Field	Magnetic Field
FOUO	Official Use Only
FM	1. Frequency modulated 2. From 3. Field Manual
GHz	Gigahertz 1,000,000 Hertz
HEMP	High altitude electromagnetic pulse
HM	Hazardous Materials
HVAC	High Voltage AC
Hz	Hertz, one cycle per second
IEC	International Electrotechnical Commission
KHz	Kilohertz, 1,000 Hertz
Km	Kilometer
L	Length
LAN	Local Area Network
MEV	Million electron volts
MF	Field Manual
MHz	Megahertz, 1,000,000 Hertz
MIL	Military

Abbreviations	Definition
MSDS	Material Safety Data Sheets
Abbreviations	**Definition**
NIST	National Institute of Standards and Technology
NSA	National Security Agency
RAID	Raster Analysis
SECOND FIELD	far-field - electrical field
TEMPEST	Telecommunications Electronics Material Protected From Emanating Spurious Transmissions
Third Field	Plane Wave
TRANSITION POINT	about 12-15 feet away
TSCM	1. Tempest Countermeasures 2. Technical surveillance countermeasures
SIGINT/COMINT	Signals or Communications Intelligence
VCR	Video Cassette Recorder
VHF	Very High Frequency

1 ELECTROMAGNETIC PULSE (EMP)

1.1 INTRODUCTION:

The focus in this section is on electromagnetic pulse (**EMP**) produced by nuclear explosions at high altitudes (high-altitude **EMP**, or **HEMP**). Herein, the terms **EMP** and **HEMP** are used synonymously. In many cases facilities are not targeted for other nuclear effects and a HEMP event is the worst-case scenario for ground-based facilities. Therefore, many protective measures described herein will also protect against some other electromagnetic environments.

1.1.1 Subjects Not Covered:

Specific protection methods for other types of EMP, such as source-region EMP and surface-burst EMP are not covered. In addition, this document does not cover protection against other effects of nuclear explosions (for example, blast overpressure & thermal / nuclear radiation).

1.1.2 TEMPEST Problem:

The TEMPEST problem is nearly the inverse of the HEMP event. TEMPEST is the unclassified name for the studies and investigation of compromising emanations. Equipment within the facility can be the source of electromagnetic waves and stray currents/voltages with characteristics which are related to the information content of signals being processed. If these unintentional emissions are intercepted and studied, the analyst can reconstruct the original data and could gain access to national security information. A proper TEMPEST design will preclude the presence of analyzable signals in uncontrolled areas.

1.1.3 Common Treatment:

Thus, each HEMP and TEMPEST protective measures must control electromagnetic energy, the former protecting system equipment from externally generated signals and the latter containing emissions from internal sources. The functional similarities imply that a common treatment can be employed for the two purposes. This may, or may not be the case, but the problems are similar.

1.1.4 Application:

Information in this document is applicable to engineers responsible for design, construction, and maintenance of mission-critical facilities, such as those supporting the command, control, communications and intelligence network. The information is relevant to new construction as well as to additions, upgrades, and retrofits to existing facilities.

1.1.5 References:

This document is intended to stand alone and, as such, no additional references should be required to understand the material herein. However, only a small sample of the material published on HEMP and TEMPEST can be highlighted here, most is classified and can thus not be presented. Further reference can be obtained by researching **Operation STARFISH PRIME**.

1.1.6 Reliance on Electronic Technology:

Facilities are becoming increasingly reliant on automated systems that take advantage of modern electrical and electronic technology. They have state-of the- art computerized systems for expeditious, reliable, and cost-effective operations. However, the electromagnetic (EM) properties of many electronic components can make entire systems susceptible to upset, or permanent damage, due to the environmental effects of EMP. Systems are also susceptible to the compromise of security information by the unintentional intelligence-bearing emanations of electromagnetic signals. Thus, with the benefits of automation has come an increased vulnerability.

1.1.7 Early Planning:

Techniques to protect a facility are usually accomplished during the early design phase. If it is anticipated that a facility may someday acquire equipment that must be protected, early planning can avoid costly retrofitting later. The decision to harden a facility will be based on the interaction of mission criticality, electromagnetic environment, security requirements, and costs.

HEMP is dangerous with far-reaching effects because this event has far reaching effects at distances where other nuclear environments are either nonexistent or inconsequential and because of its high level of broad spectral energy. However, the spectrum included under HEMP does not cover all EM environments. For example, the characteristic pulse rise-time and possible conducted current waveforms for lightning differ from those for HEMP; thus, hardening against HEMP does not necessarily protect against lightning.

1.1.8 Evolving Technology:

It is important to note that this field is relatively new and technical expertise is evolving very rapidly. Therefore, it is the designer’s responsibility to stay current with new developments to assure the most cost-effective reliable configuration EMP operation.

1.2 NUCLEAR ELECTROMAGNETIC PULSE (NUCLER EMP):

A nuclear electromagnetic pulse differs from other kinds of electromagnetic pulse (EMP) in being a complex electromagnetic multi-pulse. The complex multi-pulse is usually described in terms of three components, and these three components have been defined as such by the international standards commission called the International Electrotechnical Commission (IEC). The three components of nuclear EMP, as defined by the IEC, are called **E1**, **E2** and **E3**.

1.2.1 E1 Component:

The **E1** component is a very fast component of nuclear EMP. The **E1** component is a very brief but very intense electromagnetic field that can quickly induce very high voltages in electrical conductors. The **E1** component causes most of its damage by causing electrical breakdown voltages to be exceeded. **E1** is the component that can destroy computers and communications equipment and it changes too fast for ordinary lightning protectors to provide effective protection against it. Even consumer transient protectors are becoming increasingly able to handle faster rise-time pulses, though. There are special transient protectors that are fast enough to suppress nuclear EMP.

The **E1** component is produced when gamma radiation from the nuclear detonation knocks electrons out of the atoms in the upper atmosphere. Electrons begin to travel in a generally downward direction at relativistic speeds (more than 90 percent of the speed of light). In the absence of a magnetic field, this would produce a large pulse of electric current vertically in the upper atmosphere over the entire affected area. The Earth's magnetic field acts on these electrons to change the direction of electron flow to a right angle to the geomagnetic field. This interaction of Earth's magnetic field and downward electron flow produces a very large, and very brief, electromagnetic pulse over the affected area.

Numerical values for a typical case of **E1** pulse produced by a second-generation nuclear weapon such as those used in high altitude tests of Operation Fishbowl in 1962. Typical gamma rays given off by the weapon have energy of about **2 MEV** (million electron volts). When these gamma rays collide with atoms in mid-stratosphere, gamma rays knock out electrons. This is known as the Compton Effect, and resulting electrons produce an electric current that is known as Compton current. Gamma rays transfer about half of their energy to the electrons, so these initial electrons have energy of about **1 MEV**. This causes electrons to begin to travel in a generally downward direction at about 94 percent of the speed of light. Relativistic effects cause the mass of these high energy electrons to increase to about 3 times their normal rest mass.

If there were no geomagnetic field and no additional atoms in the lower atmosphere for additional collisions, electrons would continue to travel downward with an average current density of about 48 amperes per square meter in the stratosphere.

This downward tilt of Earth's magnetic field at high latitudes causes the area of peak field strength to be a U-shaped region to the equatorial side of the nuclear detonation. For nuclear detonations over the continental United States, this U-shaped region is south of the detonation point. Near the equator, where the Earth's magnetic field is more nearly horizontal, the **E1** field strength is more nearly symmetrical around the burst location.

Earth's magnetic field quickly deflects the electrons at right angles to the geomagnetic field, and the extent of deflection depends upon the magnetic field strength. At geomagnetic field strengths typical of central United States, central Europe or Australia, these initial electrons spiral around magnetic field lines in a circle with a typical radius of about 85 meters (about 280 feet). These initial electrons are stopped by collisions with other air molecules at an average distance of about 170 meters (a little less than 580 feet). This means that most of the electrons are stopped by collisions with air molecules before the electron can complete one full circle of its spiral around the Earth's magnetic field lines.

This interaction of the very rapidly moving negatively charged electrons with the magnetic field radiates a pulse of electromagnetic energy. The pulse typically rises to its peak value in about 5 nanoseconds. The magnitude of this pulse typically decays to half of its peak value within 200 nanoseconds. (By the IEC definition, this **E1** pulse is ended at one microsecond (1000 nanoseconds) after it begins.) This process occurs simultaneously with about 10^{25} other electrons.

There are a number of secondary collisions thus causing subsequent electrons to lose energy before reaching ground level. The electrons generated by these subsequent collisions have reduced energy that does not contribute significantly to the E1 pulse.

These 2 MEV gamma rays will normally produce an **E1** pulse near ground level at moderately high latitudes that peaks at about 50,000 volts per meter. This is a peak power density of 6.6 megawatts per square meter.

The process of gamma rays knocking electrons out of atoms in mid-stratosphere causes this region of the atmosphere to become an electrical conductor due to ionization, a process that blocks production of further electromagnetic signals and causes the field strength to saturate at about 50,000 volts per meter. The strength of the **E1** pulse depends upon number and intensity of gamma rays produced by the weapon and upon rapidity of the gamma ray burst from the weapon. This strength of the **E1** pulse is also somewhat dependent upon the detonation altitude.

There are many reports of super EMP nuclear weapons that overcome the 50,000 volt per meter limit by the very nearly instantaneous release of a burst of gamma radiation of much higher energy levels produced by second-generation nuclear weapons. The construction details of these weapons are classified, and therefore cannot be confirmed.

1.2.2 E2 Component:

The **E2** component is generated by scattered gamma rays and inelastic gammas produced by weapon neutrons. This **E2** component is an "*intermediate time*" pulse that, by IEC definition, lasts from about one microsecond to one second after the beginning of the electromagnetic pulse. The **E2** component of the pulse has many similarities to the electromagnetic pulses produced by lightning, although electromagnetic pulse induced by a very close lightning strike may be considerably larger than the **E2** component of a nuclear EMP. Because of the similarities to lightning-caused pulses and the widespread use of lightning protection technology, the **E2** pulse is generally considered to be the easiest to protect against.

According to the EMP Commission, the main potential problem with **E2** component is that it immediately follows the **E1** component, which may have already damaged the devices that would normally protect against **E2**.

According to the EMP Commission Executive Report of 2004, "In general, it would not be an issue for critical infrastructure systems since they have existing protective measures for defense against occasional lightning strikes. The most significant risk is synergistic, because the **E2** component follows a small fraction of a second after the first component's insult, which can impair, or destroy many protective and control features. Energy associated with the second component thus may be allowed to pass into and damage systems."

1.2.3 E3 Component:

The **E3** component is very different from the other two major components of nuclear EMP. The E3 component of the pulse is a very slow pulse, lasting tens to hundreds of seconds, that is caused by the nuclear detonation heaving Earth's magnetic field out of the way, followed by the restoration of the magnetic field to its natural place. The **E3** component has similarities to a geomagnetic storm caused by a very severe solar flare. Like a geomagnetic storm, **E3** can produce geomagnetically induced currents in long electrical conductors, which can damage or destroy components such as power line transformers.

This similarity between solar-induced geomagnetic storms and nuclear E3, it has become common to refer to solar-induced geomagnetic storms as "solar EMP."

NOTE:

At ground level, "solar EMP" is NOT known to produce an E1 or E2 component.

NOTES:

2 NUCLEAR EFFECTS

2.1 HF:

HF radio using ionospheric propagation is more susceptible to the disrupting effects of nuclear explosions in the atmosphere and is like any other radio propagation mechanism in any other frequency band. This is due primarily to catastrophic changes in the structure of the ionosphere. Such changes occur minutes after any explosion and last for several minutes to several days. When explosions occur on the day side of the earth, continuing ionization by the sun can restore ionosphere layers in as little as ten minutes. When explosions occur on the night side, the earth blocks this major ionization source and effects last until daylight. Decaying effects of the explosion, however, may reappear each night for several nights. The primary effects on skywaves are:

1. Loss of F-layer propagation paths, due to depletion of electrons in the layer
2. Anomalous propagation modes caused by irregular ionization enhancement
3. Greatly increased attenuation through absorption in the D layer

For nuclear explosions below about 100 km in altitude, the predominant effect is signal absorption. Above about 100 km, the major effects are refraction and dispersion.

2.2 KILOTON-YIELD BURSTS:

A Kiloton-yield burst below about 30-km altitude has little appreciable effect on ionospheric propagation. Megaton yields either form a gamma-ray-induced D layer or augment an existing D layer, leading to increased signal absorption. Moreover, a shock driven acoustic wave distorts the structure of the F layer, in turn distorting the refraction geometry and possibly causing loss of propagation path. Both effects occur within about five minutes of the explosion. The effects of low-altitude bursts are illustrated in Figure 2-1.

At intermediate altitudes of 30 to 100 km, yields near a megaton are important. The effects just described for low-altitude bursts are magnified and four major new effects are produced:

1. X-rays from burst increase D-layer absorption
2. Free electrons from burst increase D-layer absorption
3. F layer electrons are depleted
4. A fireball-driven acoustic gravity wave distorts ionospheric structure

These effects are illustrated in Figure 2-2.

2.3 OTHER EFFECTS:

Three other effects are sometimes troublesome (reference Figure 1-2**).**

1. Wave-reflection from the fireball, setting up new radio paths

2. A conjugate 11 layer being formed at some distance from the explosion. (Electrons kicked upward from the D layer in the vicinity of burst travel along geomagnetic field to another location, where they form conjugate D layer.)

3. A short-lived plume of plasma (gas made up of charged particles, in this case electrons) emanating from the fireball and aligned with geomagnetic field produces a refracting/ reflecting layer at a very high altitude, producing anomalous propagation paths.

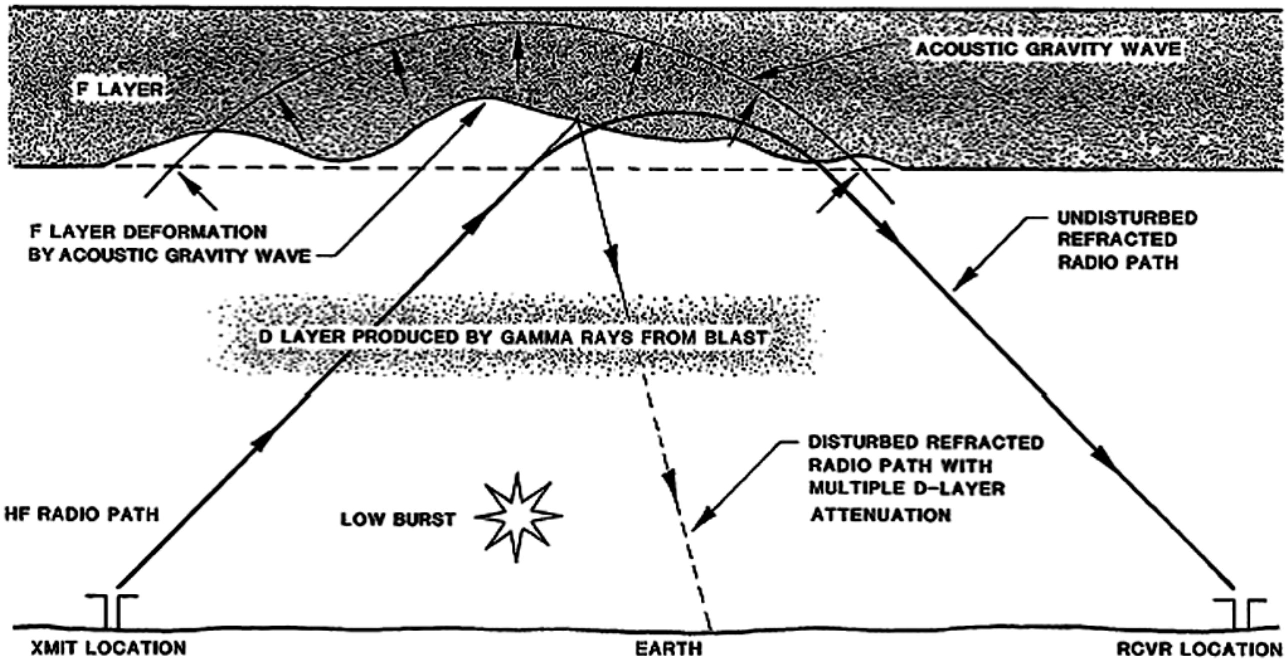

Figure 2-1,
Low Altitude Burst

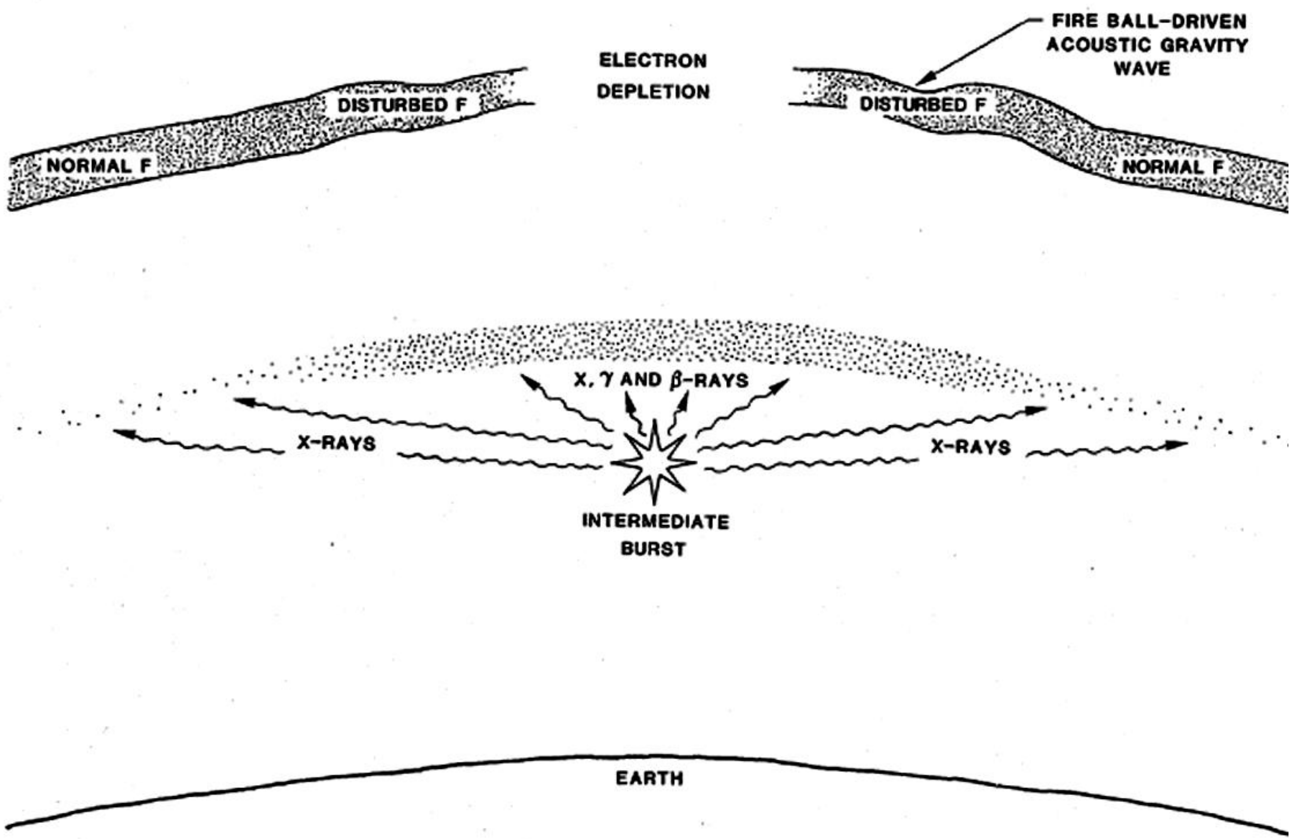

Figure 2-2
Intermediate Burst

2.4 HIGH ALTITUDE EXPLOSION:

A high-altitude explosion, above about 100 km, exacerbates all the effects mentioned above, as well as two other important effects:

1. An extensive, long-lasting, structured plasma plume at a very high altitude produces **anomalous propagation paths**.

2. A debris patch near and below the explosion plus a conjugate debris path formed by debris streaming along the geomagnetic field. This increases **signal absorption** in the area and **produces scattering**.

These effects are illustrated in Figure 2-3.

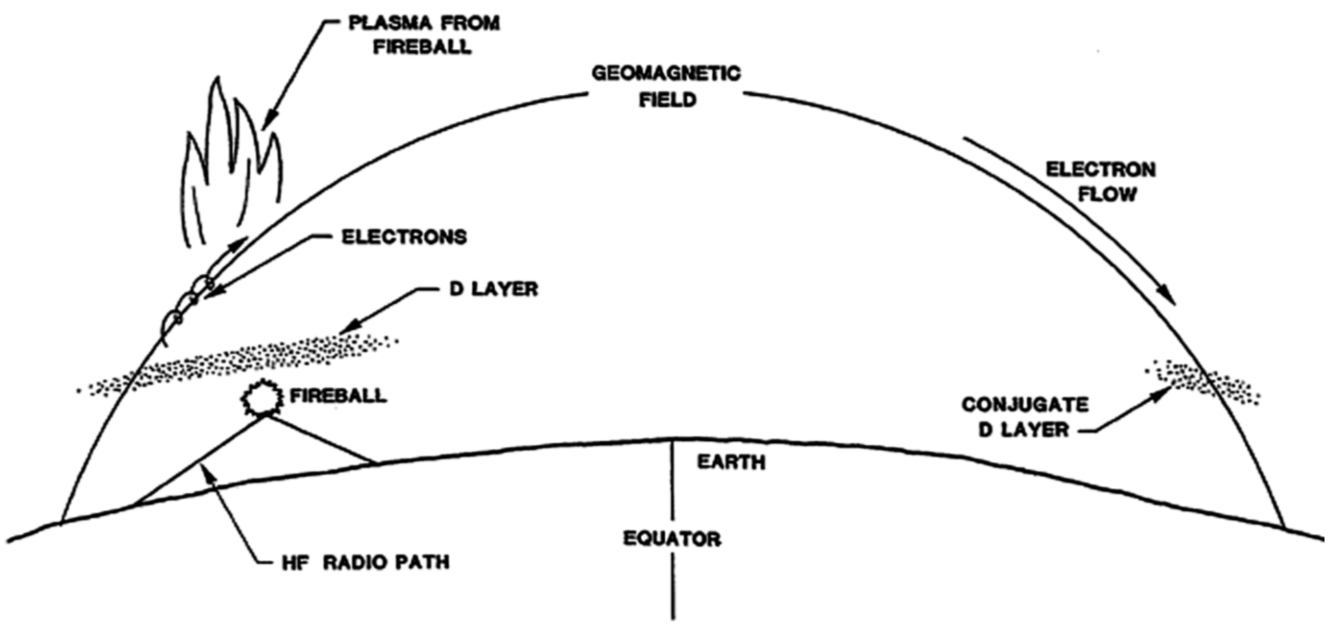

Figure 2-3
High Altitude Burst effects

NOTES:

3 PROTECTION FROM EMP

3.1 GENERAL:

Some of protection you establish for lightning is suitable for protection you can do for EMP. If you are very close to the source there is likely no protection that would be enough to keep your equipment in working order. It will be fried and there is little that can be done, however if there is a little distance then there are methods to protect equipment. The further from the source the more that can be done at lesser cost. Close to the source protection can be achieved, but costs would be excessive and only in the realm of the Government to acheive.

3.2 BASIC CONSIDERATIONS:

If you are at a great distance from the source of a nuculear EMP most equipment would survive if it is isolated from the outside world. Not connected to a power line, or antenna. But since there is no way to know where an EMP pulse occurs then there needs to be some way to give equipment connected to the outside world some protection. If the source is Lightning no equipment can defend from a direct hit, but if it is not a direct hit then there is some defense from surges and EMP caused by the strike. There are minimums that should be done in all cases. I will present three stages for consideration. All stations should have at least stage one protection as a minimum. Additional steps to inprove protection can then be taken as time and money allow.

3.2.1 Grounds:

A good solid ground system is critical to protection of equipment. No matter what else you do, a poor ground will negate all your effort at protection.The following diagram (Figure 3-1) is a good typical ground system for EMP and Lightning protection of a Radio station and antenna system. This system will likely be beyond what the average MARS member can do. The more you protect the safer you are. The Grounds should be a combination of 8 foot ground rods and UFER grounds.
Reference AM 5-203 Basic Electronics, Grounding and Bonding.

3.2.2 Building:

Good practice dictates that all buildings should have good ground systems. The more complete the system the better protected building, equipment and personnel inside will be from lightning and EMP pulses. There is nothing that will protect from a direct ligntning srike or a nuculear EMP pulse if it is close to the building. A major EMP pulse will likely totally overwhelm a shielding and grounding system if the pulse is local. However that does not preclude protection from close lightning strikes or EMP pulses from a nuculear explosion at a resonable distance.

Reference AM 5-203, Basic Electronics - Grounding, Bonding and Lightning, for details on grounding of the Main Switch box.

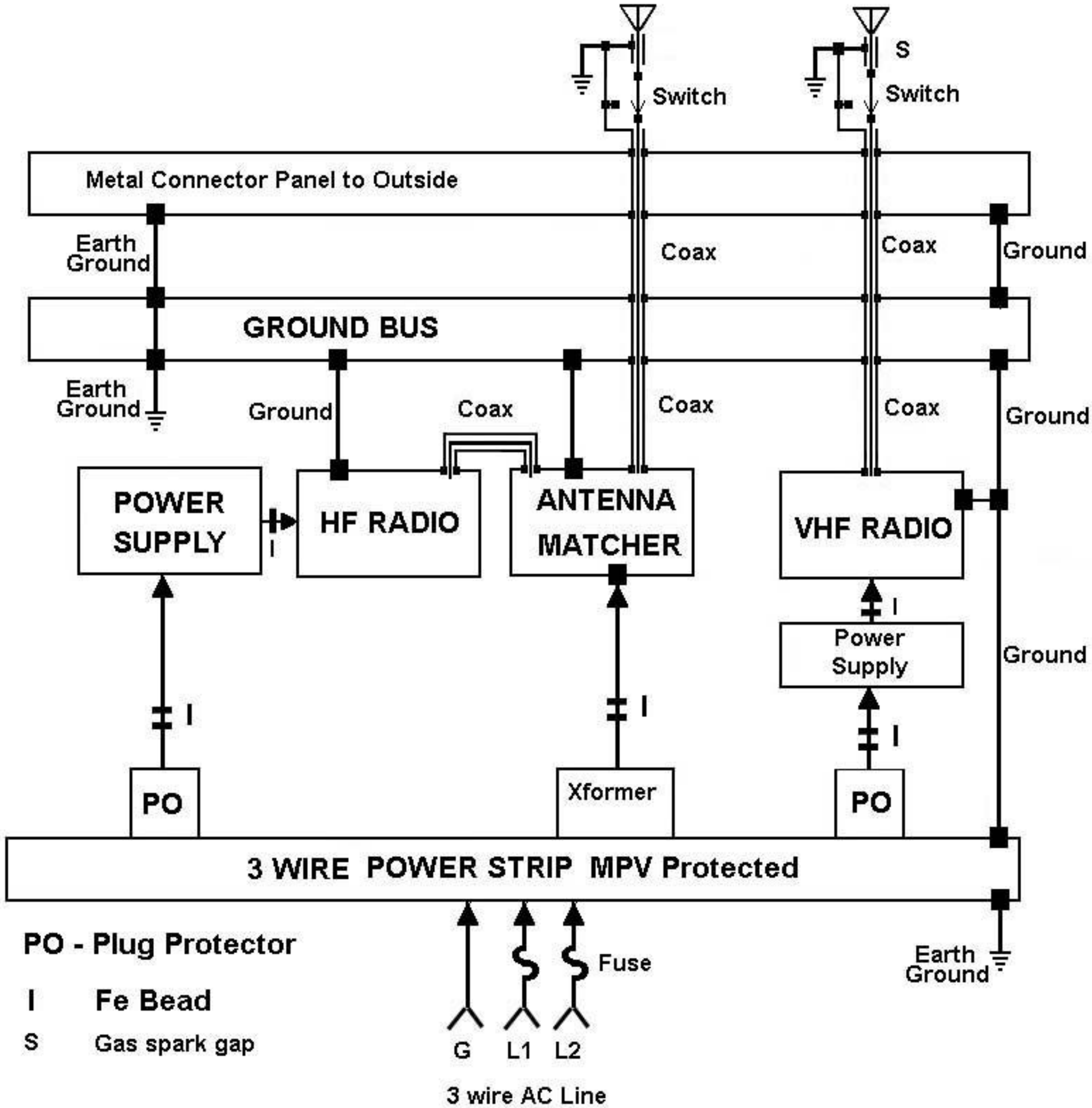

Figure 3-1
Basic EMP Protection

3.2.2.1 Electrical Wiring:

1. **Main Distribution Panel:**
   The main Power distribution panel **MUST** be protected.

NOTE

Be sure and check local Wiring regulations for differences in color, wire sizes or other requirements. Some local codes require special grounds.

2. **Outlet Boxes:**
Each outlet box should be protected in itself. A sample of a protected socket that can be built is shown in Figure 3-3.

NOTE

Be sure and check local Wiring regulations and laws for differences in color of the wires, or other requirements. In many areas the white is designated as hot and the Black is Neutral.

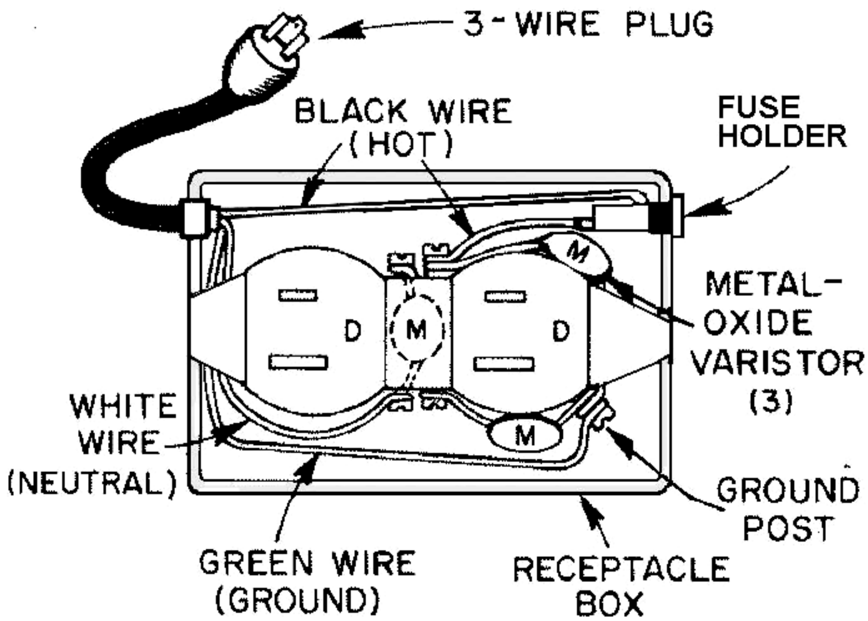

Figure 3-3
Protected Power Outlet

NOTES:

4 NUCLEAR EFFECTS ON RADIO

4.1 INTRODUCTION:

HF radio is more susceptible to disrupting effects of nuclear explosions in the atmosphere than is any other frequency band. This is primarily due to catastrophic changes in the ionosphere. Such changes occur rapidly after the explosion and last for several minutes to several days. When explosions occur on the day side of the earth, continuing ionization by the sun can restore ionospheric layers in as little as ten minutes. When explosions occur on the night side, this major ionization source is blocked by the earth and effects last until daylight. Decaying effects of the explosion, however, may reappear each night for several nights. The primary effects are:

1. Greatly increased attenuation through absorption in the D layer
2. Loss of F-layer propagation paths, due to depletion of electrons in the layer
3. Anomalous propagation modes caused by irregular ionization enhancement

4.2 LOW ALTITUDE EXPLOSIONS:

For nuclear explosions below about 100 km in altitude, the predominant effect is signal absorption. Above about 100 km, the major effects are refraction and dispersion.

Kiloton-yield bursts below about 30-km have no appreciable effect on ionospheric propagation. Megaton yields, on the other hand, either form a gamma-ray-induced D layer or augment an existing D layer, leading to increased signal absorption. The shock driven acoustic wave distorts the structure of the F layer, in turn distorting refraction geometry and possibly causing loss of propagation path. Both effects occur within about five minutes of the explosion. The effects of low-altitude bursts are illustrated in Figure 4-1.

4.3 INTERMEDIATE ALTITUDE EXPLOSIONS:

At intermediate altitudes of 30 to 100 km, yields near a megaton are important. Effects just described for low-altitude bursts are greatly magnified and four major new effects are produced:

1. X-RAYS FROM THE BURST INCREASE D-LAYER ABSORPTION

2. FREE ELECTRONS FROM THE BURST INCREASE D-LAYER ABSORPTION

3. ELECTRONS IN THE F LAYER ARE DEPLETED

4. A FIREBALL-DRIVEN ACOUSTIC GRAVITY WAVE DISTORTS THE IONOSPHERIC STRUCTURE

In addition, three other effects are sometimes troublesome (reference Figure 4-2).

1. Wave-reflection from the fireball, setting up new radio paths

2. A conjugate D layer being formed at some distance from the explosion. (Electrons kicked upward from the D layer in the vicinity of the burst travel along the geomagnetic field to another location, where they form the conjugate D layer.).

3. A short-lived plume of plasma (gas made up of charged particles, in this case electrons) emanating from the fireball and aligned with the geomagnetic field produces a refracting / reflecting layer at a very high altitude, producing anomalous propagation paths

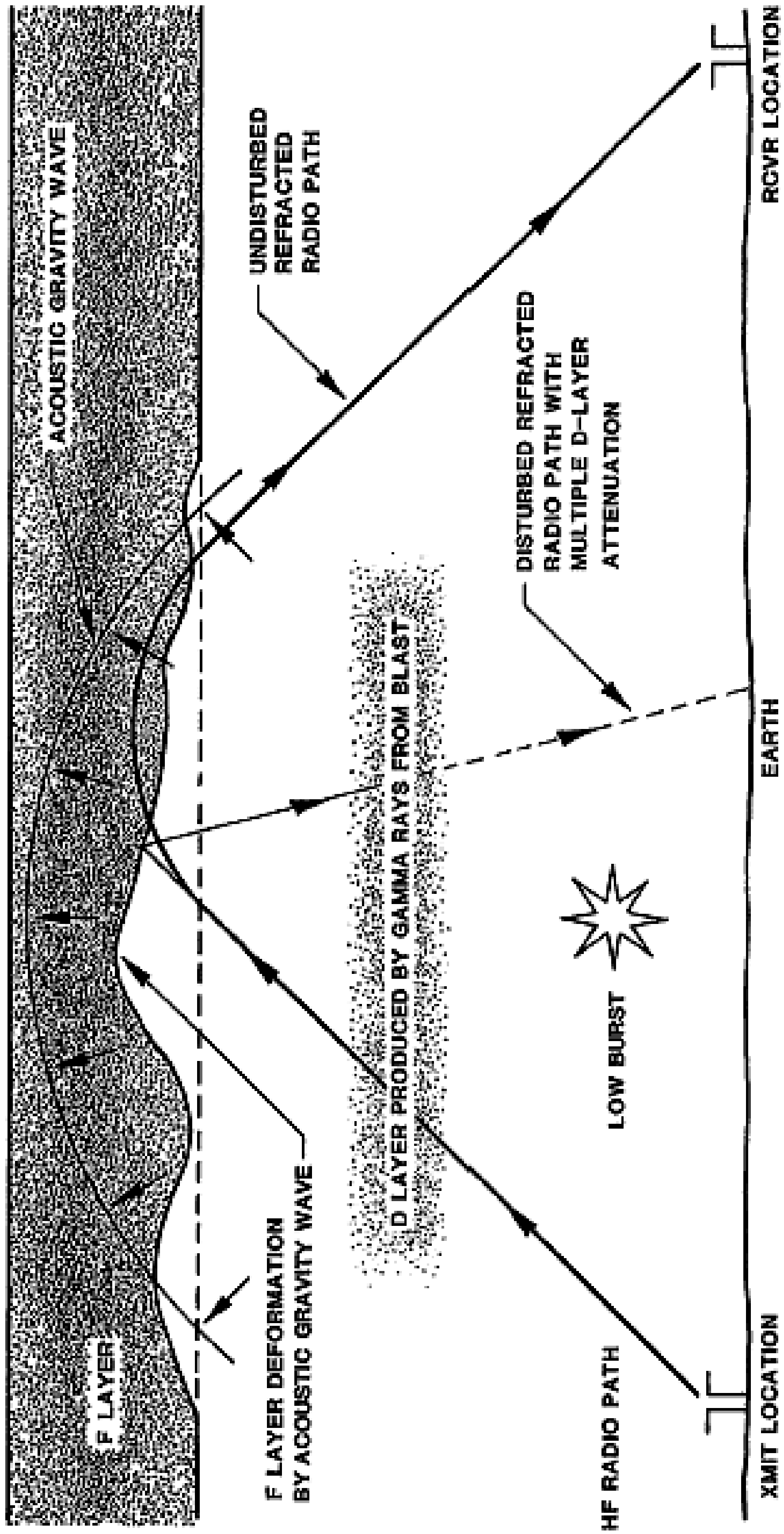

Figure 4-1
Low-Altitude Burst Effects

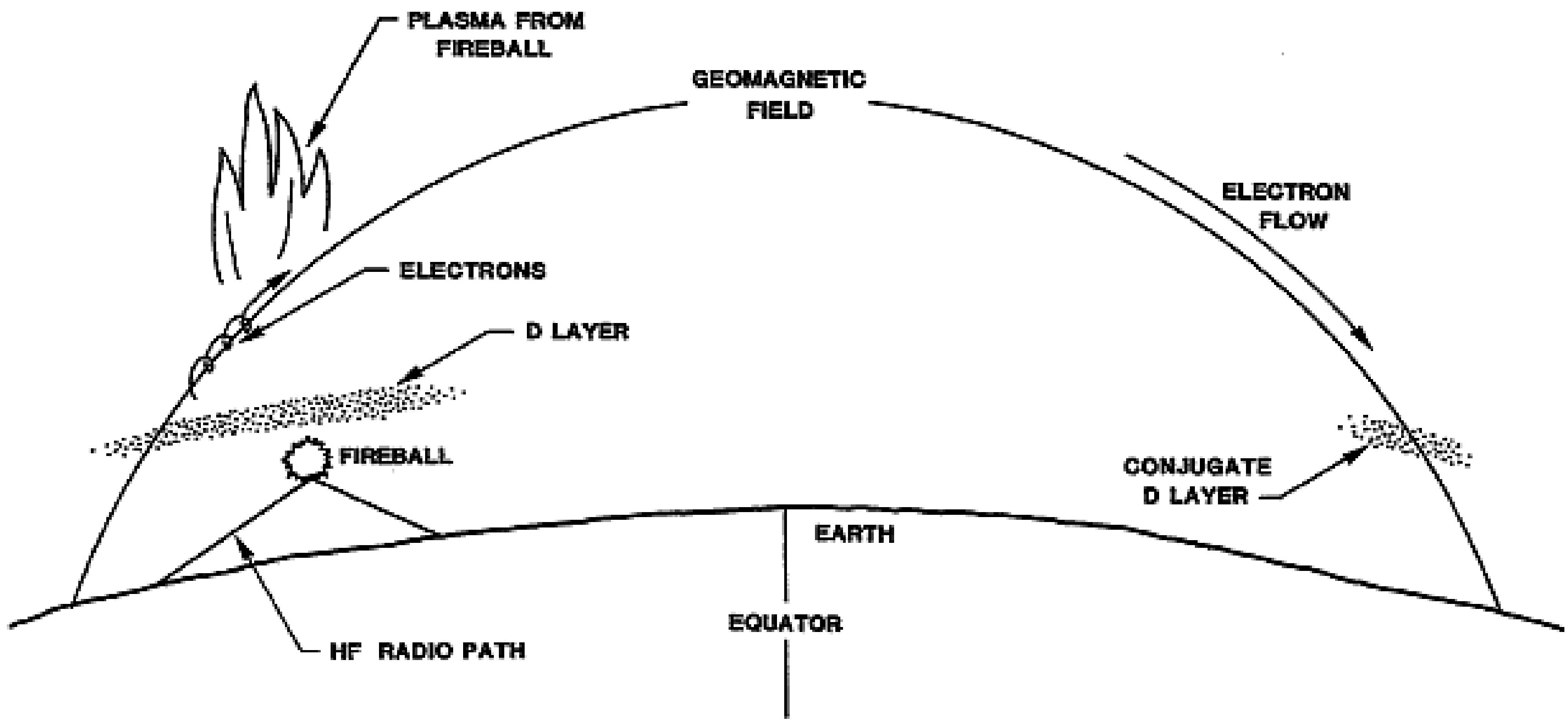

Figure 4-2
Medium Altitude Burst Effects

4.4 HIGH ALTITUDE EXPLOSIONS:

A high-altitude explosion, that is one above about 100 km, exacerbates all effects mentioned to this point, as well as two others:

1. An extensive, long-lasting, structured plasma plume at a very high altitude producing anomalous propagation paths

2. A debris, patch near and below the explosion, plus a conjugate debris path formed by debris streaming along the geomagnetic field. This increases signal absorption in the area and produces scattering.

These effects are illustrated in Figure 4-3.

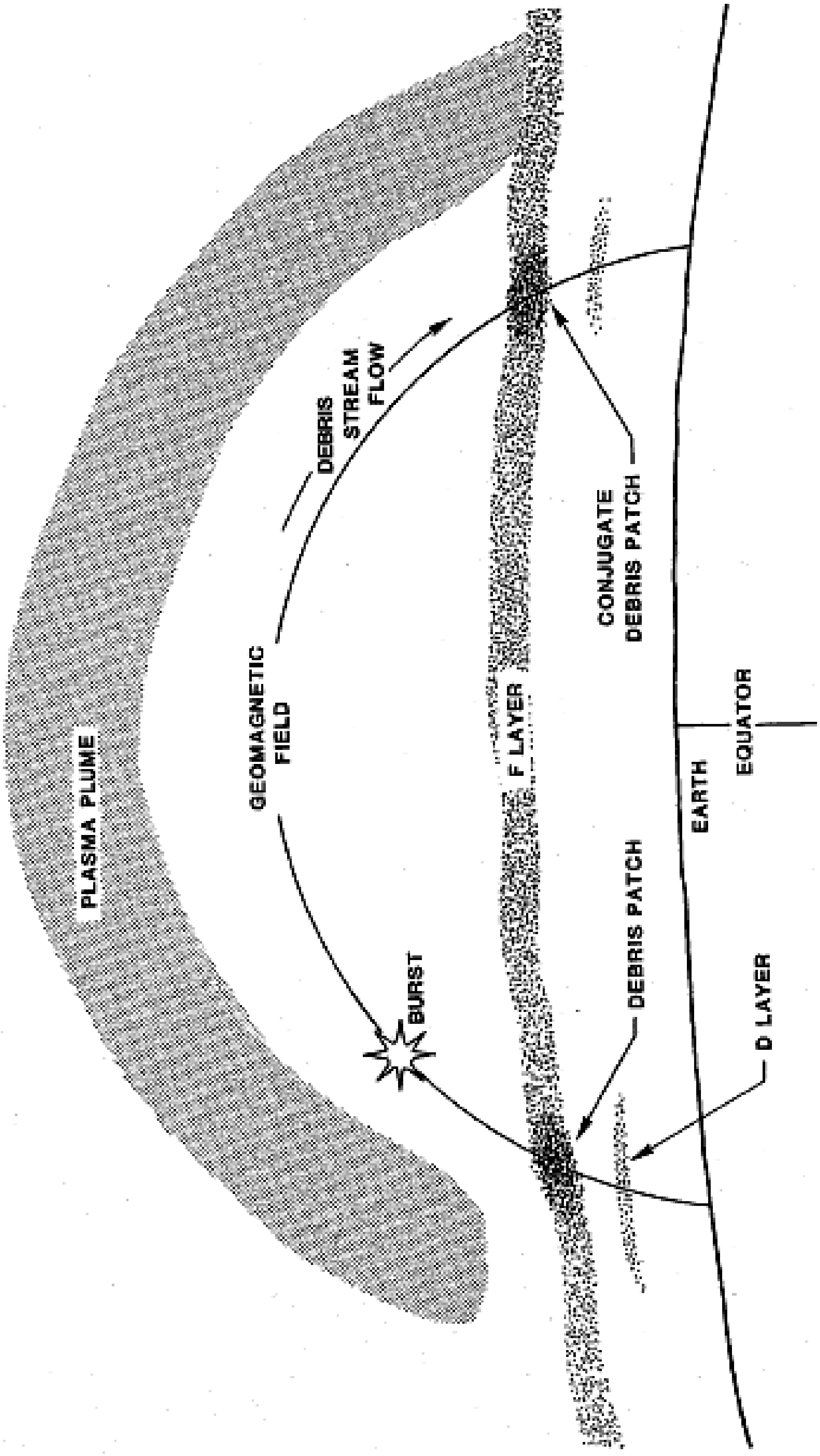

Figure 4-3
High-Altitude Burst Effects