EARTHING AND GROUNDING FOR THE CONTROL OF EMI IN INDUSTRIAL INSTRUMENTATION AND CONTROL SYSTEMS

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A project report submitted to the Faculty of Engineering, in partial fulfilment of the requirements for the Degree of Master of Science in Engineering.

Declaration

I declare that this project report is my own, unaided work. It is being submitted for the Degree of Masters of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

(D. Ambelal)

13 day of JANUARY 1986

ABSTRACT

When earthing and grounding is installed for safety and protection purposes, the requirements are clear, and well developed standards and implementation methods exist. When installed to prevent interference, the requirements are unclear and no substantial standardisation or agreement on implementation methods exists.

This study investigates the various aspects, in theory and practice, of earthing and grounding for the control of EMI in industrial instrumentation and control systems. Practical engineering guidelines and principles are suggested for the correct design and implementation of earthing and grounding systems in order to ensure that correct electromagnetic interference reduction techniques have been incorporated.

Topics examined in this study include:

- The industrial EMI environment
- Ground circuit behaviour in all frequency regions
- Interference coupling mechanisms
- Signal and shield grounding
- Lightning protection grounding
- Integrated systematic engineering approach to grounding design
- The earth electrode system
- Computer control system grounding
- Measurement and testing

The main conclusion is that earthing and grounding system should also be designed like any other circuit and that a co-ordinated and systematic engineering approach is required to ensure noise free operation.

To my Grandfather

PREFACE

Based on their experience with a number of installed Distributed Computer Control Systems, the Industrial Products Group of Honeywell South Africa (Pty) Ltd. identified the need for a thorough and complete investigation of the problems of earthing and grounding in such systems. It was against this background that the study in this project report was undertaken with the objective of compiling a reference guide for practicing engineers.

This project report provides the necessary information relating to the many aspects of earthing and grounding in an industrial environment, with a particular emphasis on reduction of interference. To be effective as a guide, it was felt necessary to include all the information pertinent to all aspects of the subject; ranging from an examination of the electromagnetic industrial environment and the frequency dependent behaviour of ground circuits to plant-wide system grounding analysis methods - hence the voluminous nature of the document. Any omissions of any subject matter is, however, regretted and the only explanation offered is that of time which is a limiting factor in any study.

This subject area is of particular interest to me due to my early involvement with industrial instrumentation and control systems where the haphazard practices on site led me to realise that principles and practices are not so well established. Manufacturer's installation guides provided some guidelines but, in general, it was found that the process of adapting existing guidelines to the application at hand was subjective and in most cases the empirical on-site observations have been the dominating deciding factor. Hence, when the opportunity arose, I took it upon myself to provide a reference guide which would cover all the subject areas of practical concern to the engineer.

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DEFINITIONS AND TERMINOLOGY

In order to avoid misinterpretation and/or confusion and to clarify the meanings of terms commonly used in this study, the following terms are defined.

EARTH	Refers to the infinite conducting plane of mother earth, and is usually assigned a potential of zero, all other potentials being referenced to this zero potential.
EARTHING	Earthing is effected by means of connections made to earth rods or earth mats.
GROUND	Refers to the zero signal reference of a electronic system or for that of a group of such systems. A ground may be a large conductor serving as a reference element, and may or may not be ohmically connected to earth. However, for reasons of safety, static dissipation or to establish signal reference and return paths grounding conductors are interconnected and bonded to an earth connection.
GROUND PLANE	A metal sheet or plate used as a common reference point for circuit returns and electrical signal potentials
BONDING	Bonding is the process in which components or modules of an assembly, equipments, or subsystems are electrically connected by means of a low-impedance conductor. The purpose is to make the structure homogenous with respect to the flow of Radio Frequency (RF) currents.

INTERFERENCE This term will be used to mean any extraneous electrical or electromagnetic disturbance that:

1. tends to disturb the reception of desired signals, or

2. produce undesirable responses in a circuit or system.

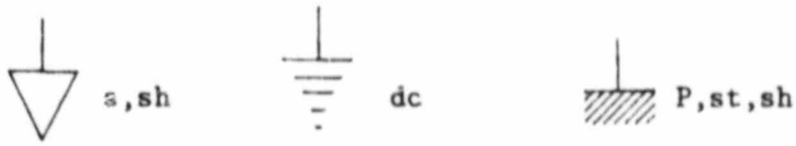
ELECTRICAL NOISE Unwanted electrical signals, which produce undesirable effects in the circuits of the control systems in which they occur.

SUSCEPTIBILITY Is used to quantify the degree to which a device is sensitive to EMI noise.

EMI Electromagnetic Interference, sometimes called Radio Frequency Interference (RFI), is a form of interference, periodic or random, which may have a disturbing influence on devices exposed or coupled to it. In this study EMI is distinguished from junction or thermal noise common to components.

EMC Electromagnetic Compatibility will be used to mean the ability of an electrical system to perform its specified function in the presence of EMI generated, either internally or externally, by other systems without degradation in operation. This means that equipment should neither radiate nor conduct EMI, nor be susceptible to such energy from other equipment or the environment locally.

The following symbols are often used to denote various types of grounds



P = single-point ground

dc = dc power ground

s = signal or secondary power ground

sh = shield ground

st = structure ground

Note, no strict adherence to this symbol convention is applied in this document. Hence, where applicable, the type of ground suggested would be explained.

CHAPTER 1

1.0 INTRODUCTION TO EARTHING AND GROUNDING

The modern industrial plant is increasingly characterised by sophisticated microprocessor-based electronic instrumentation and process control systems. Due to the complexity of these systems, total malfunction and/or varying degrees of performance degradation are likely to result unless the design of the system earthing and grounding is approached methodically and from a total system perspective.

Many grounding systems are totally unstructured and the reason why some systems work and others do not, is never quite clear. It is wishful thinking to expect a grounding system to work well if no thought is given to its design. A grounding rule which is valid for shock or fire protection at power frequencies may not be valid for the control of Electromagnetic Interference (EMI) in a strong Ultra High Frequency (UHF) environment. As with any circuit, a good ground system must be designed. Thus a set of guidelines to assist in the design and installation of earthing and grounding systems for industrial instrumentation and control systems is required.

1.1 GOALS

The goal of this study is to establish a proper perspective of the functions of various earthing and grounding systems for electronic installations and to present the scientific principles governing the performance of grounding networks in all frequency regions. A set of guidelines are to be developed to facilitate the correct analysis and design of earthing and grounding networks for industrial instrumentation and control installations where the prime objective is control of Electromagnetic Interference (EMI).

Too often, the situation exists, in large installations where building service engineers design and install the lightning protection, while other contractors put in power supply facilities and earthing for these systems, and separate earthing for the building protection. Later, the electronics and instrument engineers install various additional earthing and grounding systems for lightning protection and separate signal and computer references, and there is very little co-ordination between these different systems. From a total systems operation point of view, it is certainly one of the most essential requirements to integrate the different earthing and grounding systems throughout the whole installation. Thus, in this study, a strong emphasis is placed on the need for a co-ordinated and systematic approach to the design and installation of earth ground systems for large industrial facilities.

1.2 HISTORY OF EARTHING AND GROUNDING

Historically, earthing and grounding requirements arose from the need to provide protection against lightning stroke and industrially generated static electricity. Building structures, as well as electrical equipment, were connected to earth to provide a path necessary for lightning and static discharges. As utility power systems developed, grounding to earth was found necessary for personnel and equipment safety. All major components of a transmission system such as generating stations, substations, and distribution elements had to be earth grounded to provide for a path back to the generator for the fault currents in case of line trouble. The rationale was a low impedance path to earth for lightning discharge and power fault clearance. In one sense this was strange, since the reactive component of such impedances (due to the dielectric nature of the earth and inductance in conductors) exceeds the resistance above a few kHz, where most of the lightning energy exists.

With the development of electronics the legacy of ground all metallic items for safety and a low impedance to ground remained and subsequently became synonymous with good EMI control. Thus, in addition to fire protection and mechanical reasons, not EMI reasons, metal became the usual choice for structural parts surrounding the electrical and electronic circuitry. This is a significant fact, for much of the cause for grounding mystique (and dilemma) can be related to the presence of metal. The ready availability of something to ground to has obscured the real reason why a ground is needed. In addition, the closeness of the metal to electrical circuitry poses a possible shock hazard and EMI (when poorly bonded). This leads to arguments about earthing the metal which obscures the prior fact that the part should perhaps not have been metallic in the first place(12). Thus it can be said that a thorough understanding of the principles of grounding for purposes other than meeting the minimum requirements of the electrical safety code has been lacking and that the true function of signal grounding networks for the reduction of EMI has been obscured.

1.3 WHY GROUND?

The terms "earthing" and "grounding" are very often confused or are used to describe the wrong practice in electronics. Throughout the study, a distinction is drawn between these two terms. "Grounding" is intended to relate to those measures or principles whereby electrical circuits are interconnected and bonded to an earth connection, while, "Earthing" will relate to the means of establishing an electrical connection to the mass of the earth.

A situation commonly encountered is that of multiple electronic circuits and equipment sharing common metallic paths which, in turn, may also serve as power returns, lightning discharge paths, or an integral portion of an electromagnetic shield (Figure 1.1). In such cases numerous currents from various sources may be present in the common impedance path which frequently leads to undesired EMI coupling. Hence, it can be said that effective grounding should be the realisation of an appropriate reference network serving multiple roles without producing EMI between user circuits and equipment.

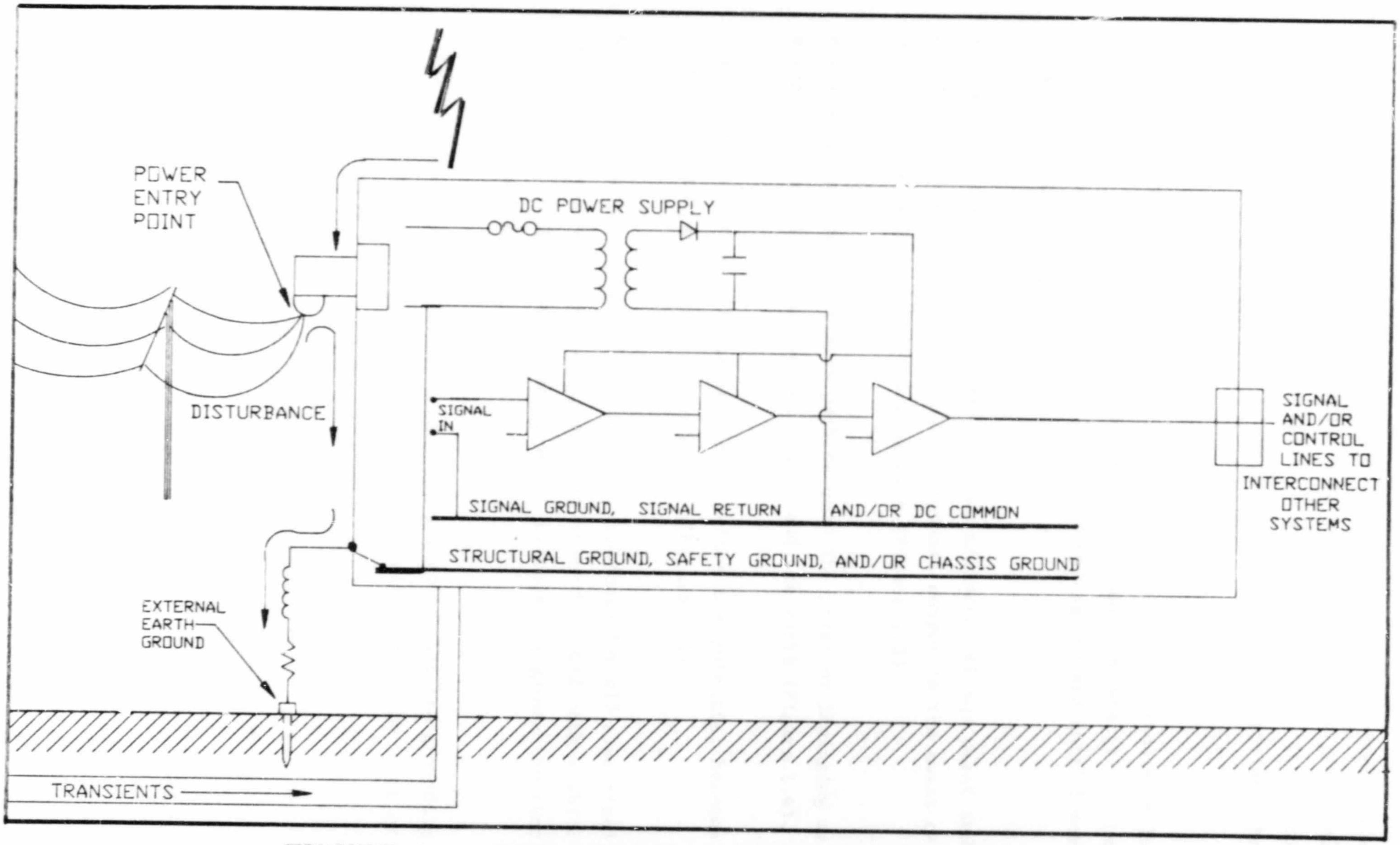


FIGURE 1.1 THE MULTIPLE FUNCTIONS OF GROUND

The main purpose of grounding is to electrically interconnect conductive or charged objects with a low impedance so as to minimise the potential differences between them and to establish a reference plane. Thus from a functional point of view a grounding system should provide the following[1]:

1. A low resistance connection with earth so that a low resistance fault return path is created between the fault and the energy source (usually a transformer) so as to lessen the voltage hazard until fuses blow or breakers trips (Figure 1.2).

2. A low resistance path between electronic/electrical equipment and nearby metallic objects to minimise personnel danger in the event of an electrical fault within the equipment (Figure 1.3).

3. A preferential low resistance path between the point of impinging of a lightning stroke on an exposed object and the earth (Figure 1.4).

4. A path for bleeding off static charge before the potential becomes high enough to produce a spark or an arc (Figure 1.5).

5. A common reference plane of low relative impedance for all electrical or electronic systems and equipments in order to avoid both a shift in operating voltage levels and prevent circulating ground current loops (Figure 1.6).

6. A low impedance connection to an earthing system so that the grounding system can act as a "sink" for noise from circuitry, lightning or other sources.

7. A reference plane for long wave antennae systems.

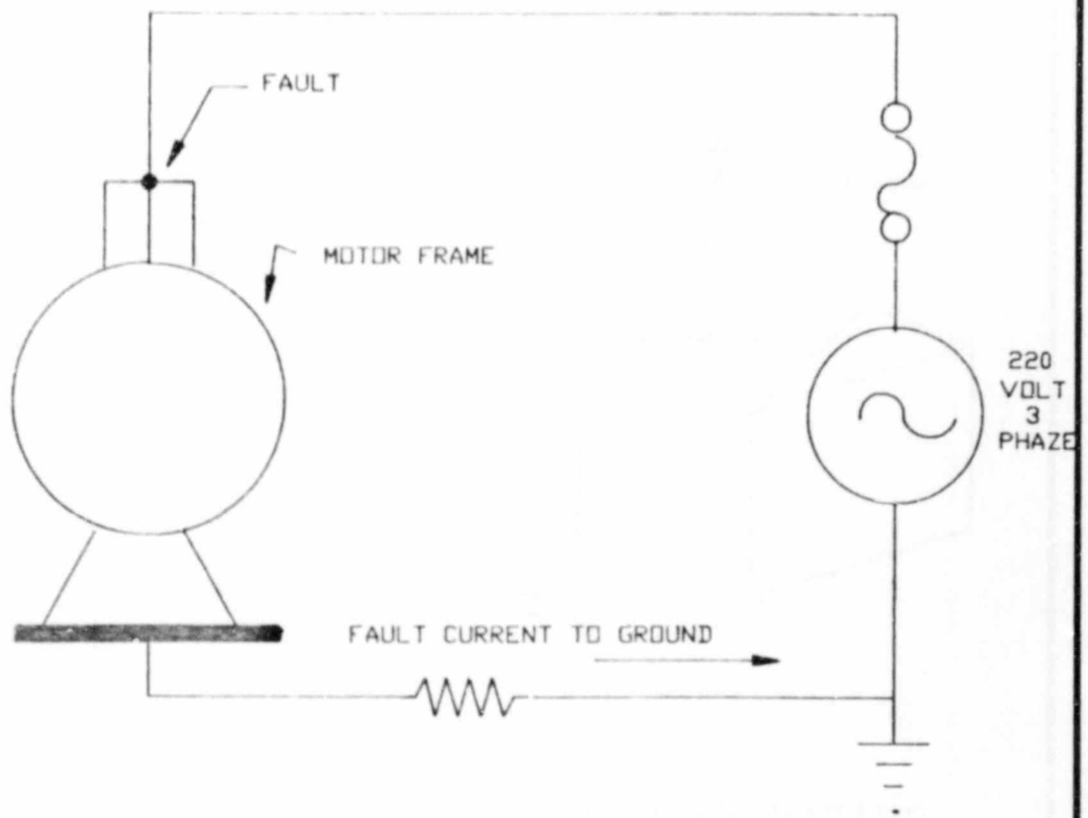


FIGURE 1.2 GROUNDING FOR FAULT PROTECTION

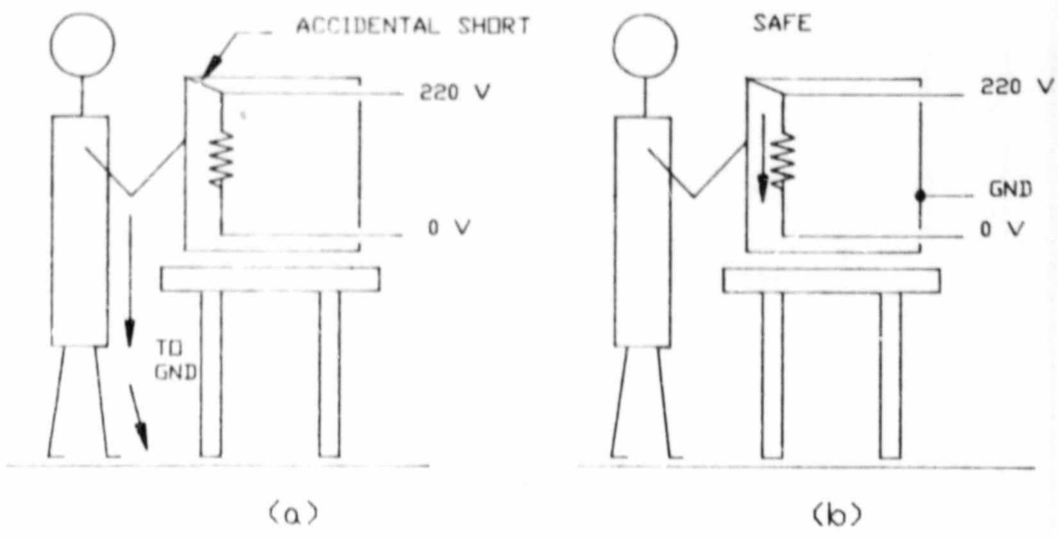


FIGURE 1.3 SAFETY AND SHOCK HAZARD

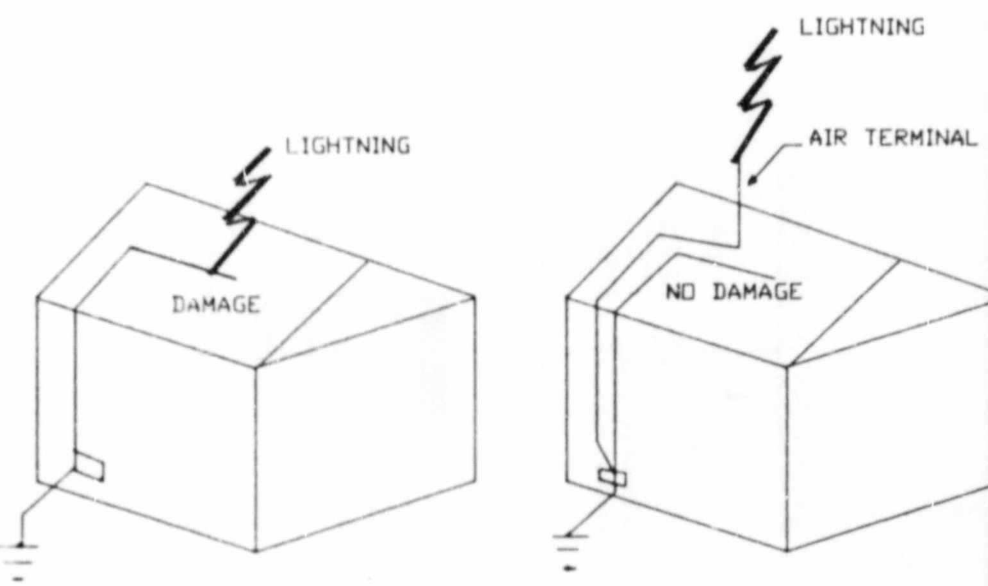


FIGURE 1.4 LIGHTNING STROKE HAZARD

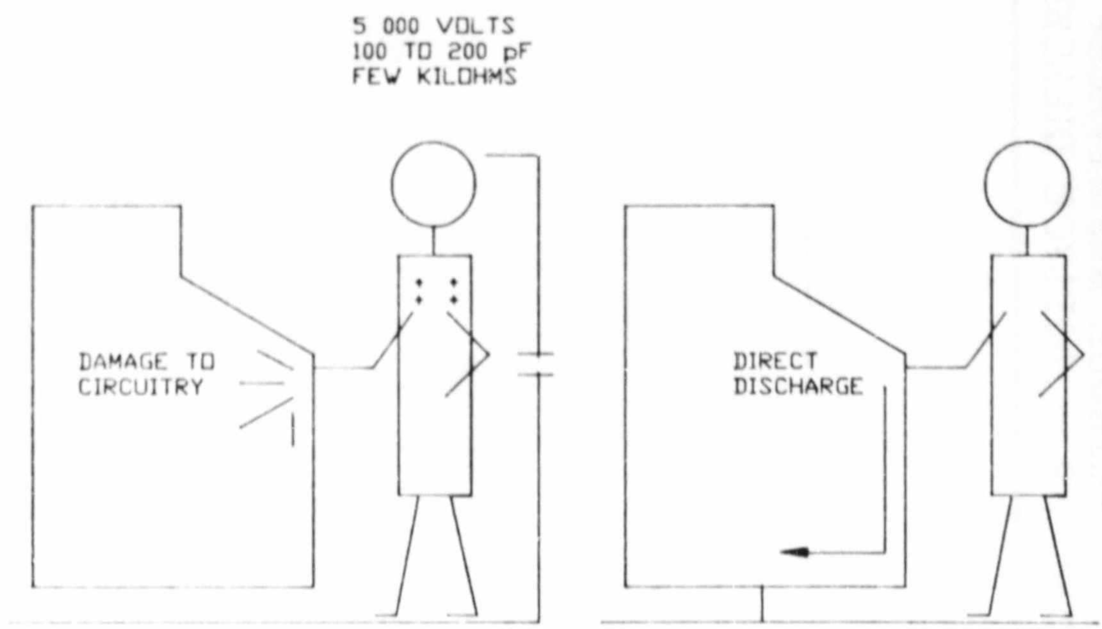


FIGURE 1.5 STATIC HAZARD

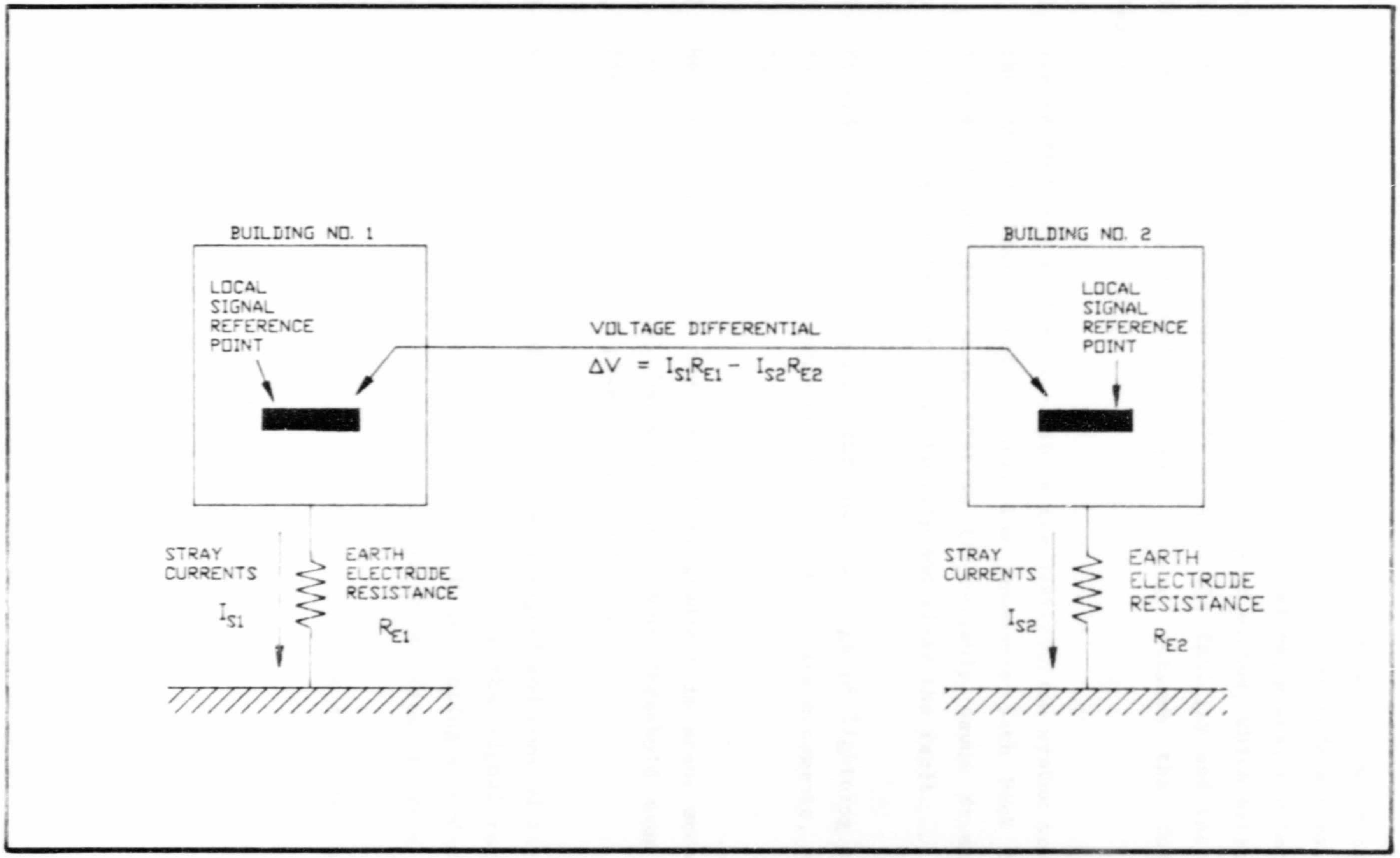


FIGURE 1.6 – VOLTAGE DIFFERENTIAL ARISING FROM UNEQUAL EARTH ELECTRODE RESISTANCES AND UNEQUAL STRAY CURRENTS

1.4 WHY EARTH?

Earthing, as already defined, is the process by which an electrical connection is made to earth by means of an earth electrode system. Such a system typically includes a network of rods, wires, pipes, counterpoises or other configurations of metals (earth grid meshes) which establishes electrical contact between the elements of the facility and the earth. The earth system should, amongst others, achieve the following objectives[3]:

1. Insure that any faults to earth on the distribution system supplying the facility have a sufficiently low impedance path back to the substation or generating station to reliably cause transformer station high voltage breakers to trip and clear the fault.

2. Provide a low impedance path for the discharge of lightning strokes in such a manner that protects the structure, its occupants, and the equipment inside.

3. Restrict the step-and-touch potential gradient in areas accessible to persons to a level below the hazardous threshold even under lightning discharge or power fault conditions.

4. Assist in the control of interference in signal and control circuitry by minimising voltage differentials between the signal reference networks of separate facilities and also in preventing ground-current loops which result in common-mode impedance coupling. (Figure 1.6)

5. Form a natural "sink" from atmospheric lightning and other natural sources.

1.5 EARTHING AND GROUNDING ISSUES

Consider the situation depicted in Figure 1.1 where the resistance to earth may be of the order of 0.5 ohms (lthough resistances of tens or hundreds of ohms are not uncommon). During an electrical storm, a typical lightning stroke could result in a peak current amplitude of about 30 kA. The earth point could then suddenly be elevated to about 15 kVolts. Thus, if the earth resistance is not a minimum (about 1 ohm) and extensive cross-bonding of metallic items and power surge protectors not incorporated, many electrical and electronic equipment connected to power supplies or to field signal lines could be damaged.

For electronic systems to operate reliably in such an environment, the earthing and grounding must be designed so as to accommodate these wide fluctuations in building ground point potential and absorb the severe transients induced on external power lines and cables or impinging directly on the facility. In addition, continual power supply to the instrumentation and control systems must be ensured while still maintaining means of getting information into and out of these systems.

Another aspect of the earth-ground situation is to recognise that no local region has zero resistance to earth-ground and therefore between any two points a voltage differential exists, as illustrated in Figure 1.6. This is typically the case when thermocouples are grounded in the field close to the process and the corresponding input device is grounded to its "own ground". This could result in stray circulating currents (commonly referred to as ground loops) which causes potential drops between these points, leading to noise coupling in signal circuits.

Such situations pose particular interference problems - especially when high speed sampling systems found in data loggers, process computers and the like are used. Furthermore, apart from the soil resistance problem, a non-zero potential earth-ground, which is undesirable as a reference from the point of view of EMI control, results from earth pollution due to both AC (caused by improperly grounded AC systems, dielectric leakage, high resistance faults, etc) and DC (improperly returned DC) currents.

The above serves to illustrate that lightning (and power) earth grounds can conflict with EMI-control reference earth grounds (i.e. signal and instrumentation ground), either in terms of operational requirements or in terms of techniques of implementation. A basic intent of the remaining chapters is to foster an understanding of the electromagnetic properties of ground networks and of the various factors which affect the impedance of earth and ground systems such that designers can appropriately configure networks in facilities, control systems, equipment and signal circuits and have high degrees of confidence in their performance.

1.6 SURVEY OF SUCCEEDING CHAPTERS

The following chapters examine the various concepts, techniques and practices pertaining to earthing and grounding and the control of EMI. The breakdown of the chapters is as follows:

Chapter 2 - The Interference Environment

In this chapter, the electromagnetic environment is described to illustrate the wide range of frequencies and power levels associated with potential electromagnetic interference (EMI). Various EMI sources common to the industrial environment are identified; the means of coupling and the various victim receptor elements, particularly low level sensitive electronic systems, are presented. Wherever possible, graphical data have been included for purposes of an initial appraisal of the interference environment. In addition, the interference signal is characterised and examined in terms of narrow-band, broad-band, and transient EMI.

Chapter 3 - Characteristics of Ground Circuits

The behaviour of a ground circuit is described showing the frequency dependence due to resistive (R), inductive (L), and capacitive (C) elements present as distributed parameters throughout all circuit configurations. The problem of establishing common ground or reference planes as return paths for complex networks is described. Mathematical formulae and tables are provided which give values of the resistance and reactances per unit length of common gauge conductors and straps. Ground plane resonant behaviour is analysed and relationships developed to illustrate the non-ideal, high-frequency behaviour of grounding conductors.

Chapter 4 - Interference Coupling Mechanisms

In this chapter various coupling modes and mechanisms are identified and analysed. These include common-mode impedance coupling, capacitive coupling, inductive coupling and common-and-differential mode radiation coupling. How the extraneous signal causes interference in circuits is illustrated, with particular emphasis on the role of the ground circuit. Basic guidelines are established for interference reduction in ground circuits as well as forming the basis for grounding concepts developed in later chapters.

Chapter 5 - Effective Signal and Shield Grounding

Ground network configurations such as floating ground, single-point grounding, multiple-point grounding and hybrid grounding are discussed. Guidelines based on frequency and wavelength considerations are provided which aid in the selection of one of the methods. The problems of common impedance coupling (ground loops) in circuits are examined and techniques for reducing this coupling are presented. The question of where to ground shields is then addressed. Again rationale based on frequency and circuit sensitivity considerations provide guidelines for selecting either single-point or multi-point shield grounding. In addition, the aspects of preventing noise in grounded and ungrounded transducers through proper shield and signal grounding is also considered.

Chapter 6 - Lightning Characteristics and Protection

This chapter examines the characteristics of lightning and the effects thereof on electronic systems. The strike mechanism is reviewed with a