GROUNDING OF ELECTRONIC SYSTEMS

Historically, grounding requirements arose from the need to protect personnel, equipment, and facilities from lightning strokes and from industrially generated static electricity. Structures, as well as electrical equipment, were connected to earth, i.e., grounded, to provide the path necessary for lightning and static discharges. As utility power systems developed, grounding to earth was found to be necessary for safety. All major components of the system such as generating stations, substations, and distribution systems needed to be earth grounded to provide a path back to the generator for the fault currents in case of line trouble. As electronic equipments became complicated and complex, the role of grounding in the reduction of electromagnetic interference also became important.

Signal grounding is frequently spoken of as "black magic" because of the lack of a thorough understanding of the principles of grounding for purposes other than meeting the minimum requirements of the National Electrical Code (NEC). As a consequence, the true function of signal grounding networks in the reduction of EMI is obscured.

Ideally, the signal ground should provide:

(1) an equipotential reference plane to prevent unwanted coupling between circuits,
(2) a return path between circuits for signal currents,
(3) a low impedance network to control static charge and stray capacitance effect, and
(4) fault protection for signal circuits.

In practical applications, where complex electronic systems extend throughout a large facility, the first of these objectives, i.e., an equipotential reference plane, cannot be achieved. However, the other three objectives must still be accomplished. The signal ground system must be designed to provide a "low" impedance network in the facility to minimize unwanted coupling between equipments while controlling static buildup and achieving adequate fault protection.

National Electrical Code

Metal is the usual choice for structural parts surrounding electrical and electrnics circuitry. This "electrical structure" is metallic in the interest of providing fire protection, mechanical strength, and EMI control. The metal housings or supports pose a very definite personnel hazard if they happen to become electrically energized. To ensure that the unsuspecting public is not exposed to such lethal hazards, the National Electrical Code (NEC) has been evolved.

The NEC has the two major objectives of (1) protection of personnel against electrical shock hazards, and (2) protection of the facility from fire hazards produced by electrical short circuits. There is little doubt that these objectives are adequately achieved by the NEC. However, the objectives of the NEC do not include the control of EMI between equipments located in a facility. In order to achieve some measure of EMI control, it is necessary to go beyond the stipulations of the NEC. Thus several requirements must be met that are not related to the protection against power line faults.

Electronic Grounding

Much of the mystique of grounding is perhaps related to the existence of the metal environment. The ready availability of something to "ground" to tends to obscure the real reason why a ground is needed. The closeness of metal poses a possible shock hazard which leads to arguments about earthing the metal for an electronic ground when perhaps the parts should not have been metallic in the first place.

The grounding of electronic systems is more concerned with minimizing the potential difference of one part of the system with respect to another part of the system rather than establishing a low absolute potential with respect to earth. Consider for example the ideal energy transfer system shown in Figure 1. Even if non-ideal

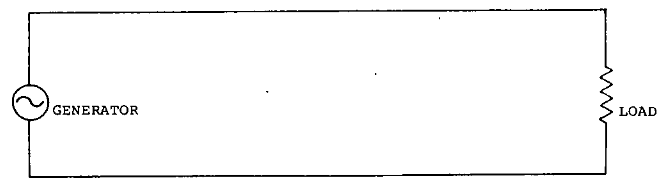

Figure 1. Idealized Energy Transfer Loop.

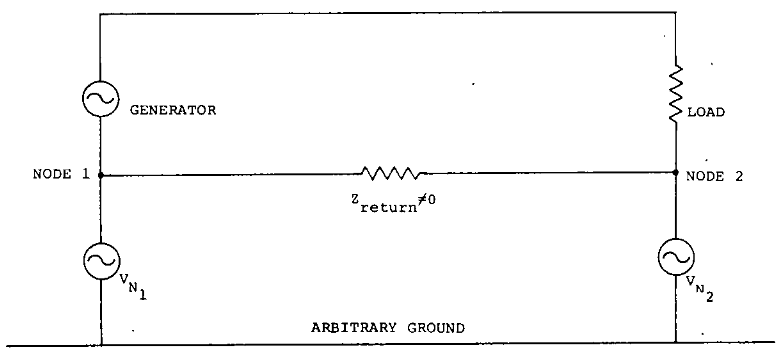

Figure 2. Energy Transfer Loop With Noise Sources in Ground System.

conductors are assumed, the currents available from the generator will be delivered to the load. (Obviously, the less ideal the transmission path the greater will be the alteration of the signal as it travels from the generator to the load.) With no extraneous voltages present within the loop, then by definition this simple isolated pair is interference free. It may be concluded, then, that each set of directly coupled circuits well isolated from an environment can within limits operate at any potential, steady or varying, with respect to that environment.

However, consider what happens when sources of noise are present between the low or reference side of the generator and the load and some arbitrary ground, as shown in Figure 2. (This arbitrary ground may be an equipment chassis, the building frame, or the earth.) Unless noise source V_{N1} is identical to noise source V_{N2} in both phase and amplitude, a voltage difference will exist between the low side of the generator (Node 1) and the low side of the load (Node 2). This voltage difference effectively appears in the signal transfer loop as a noise source in series with the signal generator as shown in Figure 3. Consequently, the currents developed in the load from this source appear as interference. Thus, it is evident that the reference points within a directly coupled set should be maintained at a common potential. The "relativity" of electronic grounding is immediately accepted in air and space systems, but in ground installations there is an unfortunate tendency to require a connection to earth simply because the earth is accessible.

Noise Minimization

There are four fundamental ways of combating the noise effect illustrated in Figure 2. One way is to isolate the source-load pair from the world containing the noise sources, i.e., float the system and provide the necessary shielding and filtering to prevent coupling into the loop via other means. The second way to prevent the noise source from appearing within the loop is to connect the low side of the loop to the reference plane at either Node 1 or Node 2 but not at both. The third way of minimizing the loop noise is to reduce its magnitude by lowering the impedance of the path (i.e., the current return) connecting the two noise sources. The fourth way of combating this noise is to reduce the magnitudes of V_{N1} and V_{N2} through the control of the currents producing them or the reduction of the impedances through which these currents flow.

Isolation

If the generator-load pair does not have to interact with other generator-load pairs and if it can be operated from its own self-contained power source (such as a battery), it can be floated without any electrical contact with its surroundings. Most systems, however, derive their power from the commercial power system and consequently must have their exposed metallic parts grounded to provide adequate fault protection. In a large system, the floating ground concept suffers from a number of additional practical disadvantages. For example, static charge build-up on the isolated components is likely and may present shock and spark hazards. In particular, if elements of the systems are near high voltage power lines, such build-up is quite likely. Another danger with the floating system is that power faults to the signal system would cause the entire system to rise to hazardous voltage levels. A third danger is the threat of flash-over between the structure or cabinet and the signal system in the event of a lightning stroke to the facility. Not being conductively coupled together, the structure could be elevated to a high voltage relative to the signal ground and possibly produce flashover. (Note that none of these reasons has anything to do with the elimination of interference.)

Single-Point Grounding

To provide the necessary protection against power system faults and to provide a discharge path for static build-up, only Node 1 or Node 2 needs to be connected to the earth or to a locally established ground within the facility. Connecting only one of the nodes is the basis of single-point grounding.

An ideal single-point signal ground system would be one in which separate ground risers extend from a single point on the earth counterpoise to the signal return side of each of the numerous circuits located throughout a facility. This type of ground system, however, would contain a very large number of conductors and thus generally is not economically feasible in a large facility. Since this ideal configuration is not practicable, various degrees of approximation to single-point grounding are usually used.

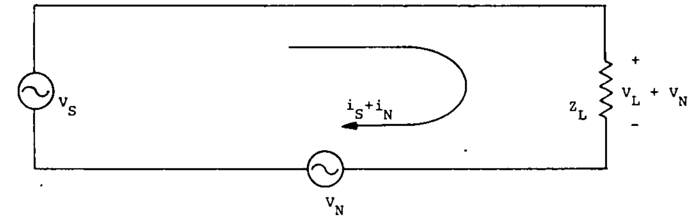

Figure 3. Equivalent Circuit of Non-Ideal Energy Transfer Loop.

A configurataon that closely approximates the ideal single-point ground system uses separate ground buses extending from a single point on the earth counterpoise to each individual electronic system. In each system, the various electronic subsystems are connected at only one point to this ground bus. This single-point ground configuration is illustrated in Figure 4. A second approximation is illustrated in Figure 5. Here the bus network assumes the form of a tree wherein the various electronic subsystems are single-point grounded at the system level, and these single points are then connected to the ground bus.

Multiple-Point Grounding

The third way of reducing the interference noise voltage is to reduce the impedance of the return path--in other words, strive for a zero impedance reference plane. If a truly zero impedance ground reference plane or bus could be realized, it could be utilized as the return path for all currents--power, control, audio, and RF--present within the system or complex. The closest approximation to an ideal reference plane for a system would be an extremely large sheet of a good conductor such as copper, aluminum, or silver underlying the entire facility with large risers extending up to individual equipments. Material costs and installation practicalities usually prohibit this kind of approach. A more conventional approach is to utilize a network of wires, tubes or pipes, and bars of copper or aluminum multiply interconnected to provide several paths between any two points within the system.

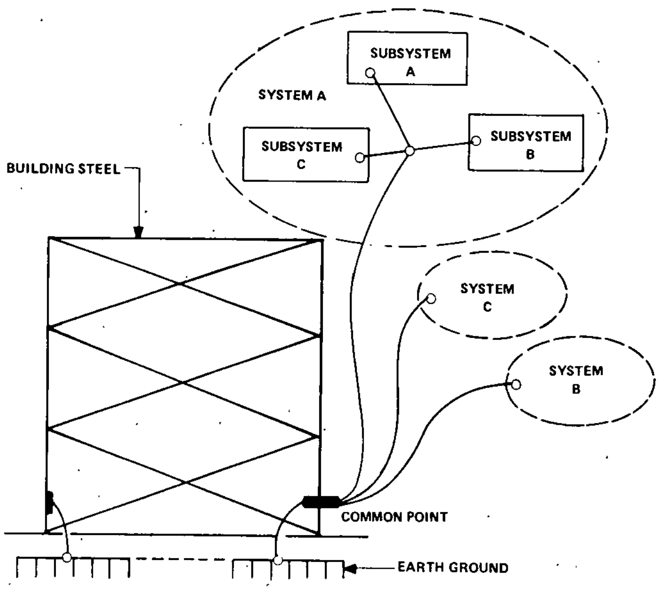

Figure 4. Single-Point Ground Bus System Using Separate Risers.

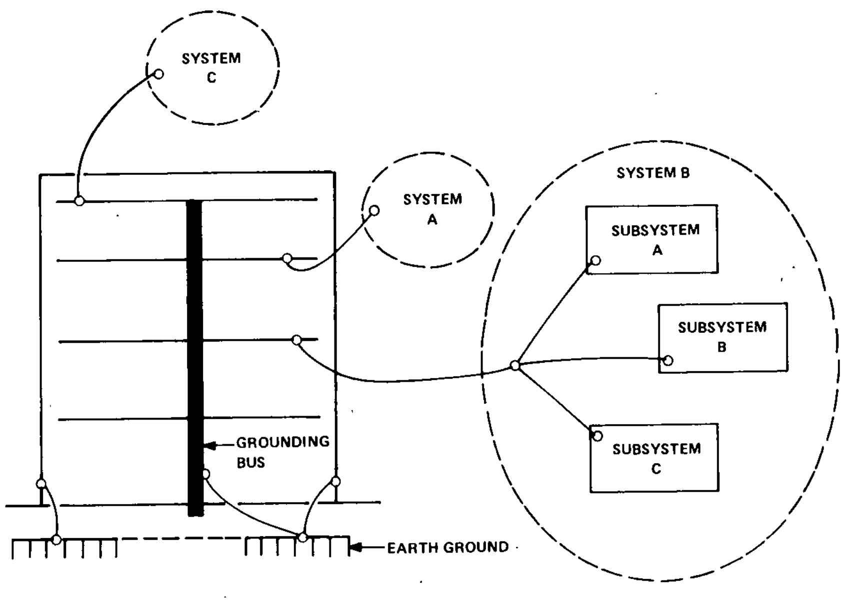

Figure 5. Single-Point Ground Bus System Using a Common Bus.

Because of the construction practicalities which are usually observed in high frequency systems, equipment chassis frequently serve as the signal reference. Two reasons for the use of the chassis as the signal reference are (1) the mass of metal offers a lower impedance between two points than any bus or wire, and (2) it is more convenient to ground the unbalanced transmission lines normally used for high frequency signals directly to the chassis. Since the exposed parts of the equipments must be grounded for fault protection, stray currents in the fault protection system present an interference threat to any system whose operating range extends down into the power and low frequency range. Where such problems exist, the only practical approach is to attempt to reduce the impedance of the reference plane as much as possible. Usually the approach employed is to establish as many parallel paths as possible between all points of the ground system. It should be recognized that because of the inductance and capacitance associated with the network conductors, such multiple-point ground systems offer a low impedance only to the low frequency noise currents; however, these currents can be the most troublesome.

Noise Source Reduction

The final way of minimizing the noise in the system is to decrease the magnitudes of the contributing sources. Although this step would appear to be intuitively obvious, frequently this alternative tends to be overlooked.

If, in a complex facility, a single ground system is used for both the safety ground and the signal ground, noise can be generated by large 60 Hz power currents flowing in the ground system conductors. There are a number of reasons why such large currents may be present. One is that during installation of the wiring, the ac return (the white wire) may be interchanged with or connected to the safety wire (the green wire).[1] When this happens, the ac supply current to the equipment may return through the safety ground back to the transformer. Because of the interference threat that these power-related currents pose to audio, digital, and control systems, or to any other system whose operating bandwidth extends down to 60 Hz or below, steps must be taken to isolate these large currents from signal return paths. (Note that the same rationale applies to large unwanted signals of any frequency.)

One way of lessening the effects of large power currents is to configure the signal ground system such that the signal return path does not share a path in common with a power return. The first step, therefore, in the development of an interference-free signal reference system is to assure that the ac primary power return lines are not connected to the safety ground at any point other than the service disconnect.

Isolation of ac return signals from the signal reference system will go a long way toward reducing many of the noise problems frequently encountered in facilities. However, other ac signals may be present in the ground system: signals arising from use of power line filters, from insulation leakage, etc. Large capacitors in power line filters can shunt a significant amount of 60 Hz current to ground. If several of these filters are used in an installation or complex, the net shunt impedance across the 60 Hz power line can become low enough to cause several amperes of current to flow through the ground system back to the transformer. One way of limiting these currents is to minimize the number of filter capacitors in an installation. This can be done if several equipments or subsystems can share a common filtered line.

System Grounding

A hybrid approach that implements the single-point principle at low frequencies and the multiple-point principle at high frequencies is frequently desirable in complex installations. With a composite configuration for signal grounding throughout the facility as illustrated in Figure 6, the signal reference in each piece of low frequency equipment is isolated from the equipment enclosure and connected back to the facility central ground point through a single isolated path. In the same facility, the signal references in high frequency equipments are multiply grounded to enclosures. The high frequency enclosures are then multiply connected together and to the safety ground (the building structural steel) thus providing multiple paths to the facility central ground point. In order to maintain this dual signal ground configuration, the low frequency signal ground network must be isolated from the high frequency signal reference ground and from the structural ground network. Some unwanted currents will unavoidably be present in the low frequency signal ground network and the network will present some non-zero impedance; therefore, this ground bus tree should not be used as the signal return path between equipments or systems. Instead, interfaces, i.e. cabling, between low frequency equipments and between low frequency and RF equipments should be balanced configurations. The interfaces should be twisted and shielded to the extent necessary to prevent unwanted signals from coupling to the signal line via capacitive and inductive means. The twisting reduces the cross-sectional area of the loop formed by the signal conductors and hence reduces magnetic pickup by the conductors. The use of balanced lines provides a high degree of common-mode rejection against the noise currents in the signal ground system. Also the use of the balanced lines allows low frequency equipment to be interfaced without compromising the single-point ground network. It should be noted that balanced-line interfaces require all low frequency drivers to have balanced outputs, and the receptors must have balanced inputs; however, the reduction in interference through the use of this technique justifies these requirements.

Primary ac power to low frequency circuits should be supplied through appropriately shielded transformers. All switches, controls, meters, etc., should be insulated from the enclosure or connected into the circuit so as to not electrically connect the low frequency circuit ground to the cabinet ground. In these equipments, the safety or power fault protection ground wire would be connected to the equipment case since this is the part with which human contact is likely. Faults to circuit ground are taken care of with the signal ground bus.

The question remaining concerns the frequency below which signals can be considered as low frequency. Certainly the dividing line between low and high frequency should be high enough to include all audio communication signals. Since digital systems employ frequencies which extend from the subaudio region to several magahertz, a decision based on pulsed-signal considerations is perhaps most appropriate. For example, assume a system utilizing pulses with rise and fall times of 1 microsecond. One microsecond corresponds to an upper frequency requirement of 1 MHz (λ = 300 meters in free space). To minimize the possibility that the ground bus conductors will form efficient antennas,[2] their lengths should not exceed 0.1 wavelength (approximately 100 feet at 1 MHz). Where the ground bus system extends beyond 100 feet, 1 MHz is the maximum frequency for which the single-point grounding system should be used. If the interequipment digital signals are at frequencies less than 100 kHz, conductor lengths up to 1000 feet can be approached without exceeding the 0.1 wavelength criteria. Other systems and studies have recommended different upper limits on the use of a single-point grounding system as shown below:

SUGGESTED UPPER FREQUENCY LIMITS ON THE USE OF THE SINGLE-POINT GROUNDING

Reference Number	Frequency Recommended (MHz)
1	2
3	1
4	0.15
5, 6	0.1
7, 8	0.05

Above the 2MHz the impedance presented by a 12-inch steel I-beam is less than 5 percent of the impedance of an equal length of 500,00 cmil cable[1] which suggests that the structure, i.e., the multiple-point ground, offers a better grounding system than the single-point ground network above 2MHz. In large systems and in buildings, single-point grounding for signal referencing purposes does not appear practical where the frequencies involved are in excess of 2 MHz.

The specific characteristics and requirements of a given system or facility should be carefully examined and the break point between low and high frequency chosen according to system needs.

SUMMARY

The grounding of electronic systems involves more than meeting the minimum requirements of the National Electrical Code. Electronic grounding must consider the specific needs and characteristics of a given system. In some situations, single-point grounding is preferred; in others, the multiple-point approach is necessary. Neither approach automatically solves all problems; grounding must be combined with other procedures such as shielding and stray current control in order to minimize the overall system noise leve.

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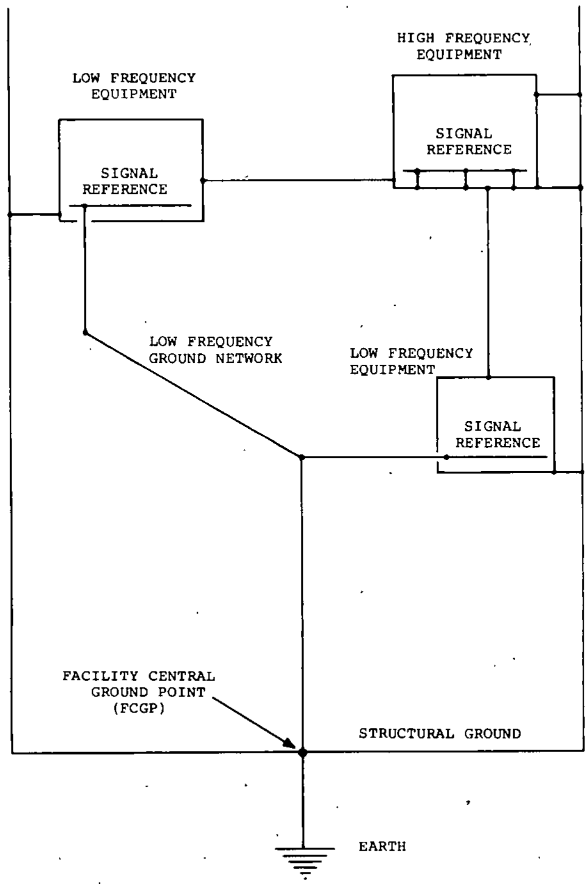

Figure 6. Composite Grounding System for Electronic Facility

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