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DSE4T (Experimental Techniques)

Topic – Shielding and Grounding

Introduction:

Historically, grounding requirements arose from the need to provide protection from electrical faults, lightning and industrially generated static electricity. Because most power-fault and lightning control relies on a low-impedance path to earth, all major components of an electrical power generation and transmission system were earth grounded to provide the required low-impedance path. As a result, strong emphasis was placed on earth grounding of electrical equipment and the overall philosophy was to ground without regard to other problems, such as electromagnetic interference, that may be created by this approach.

Safety, system protection and performance are the three main reasons to ground a system. Not all electronic equipment needs to be connected to earth to work, satellites are an example. Sometimes wrong grounding configurations, oriented to satisfy the special power and performance requirements of electronic loading equipment, can compromise safety rules generating dangerous situations for personnel and equipment. Personnel safety, equipment safety and performance grounding issues have to be analyzed together. In any case, safety rules must not be violated. All these concepts as well as the relations between ground issues need to be clarified before passing on to a higher level in the control of the electromagnetic emissions of the system.

The integrity of both the facility grounding and the proper equipment operation depends on the proper bonding of the grounding electrode system, proper system grounding of service equipment and separately derived sources and proper equipment grounding for operational frequencies (DC or AC-mains) as well as higher frequencies. It is recommended that the grounding design and installation be compliant to all applicable codes and standards. The grounding is not designed as an active component of the power supply (PS) distribution system, hence this path must be free of any operational current. Metal parts of equipment enclosures, racks, raceways and equipment grounding conductors susceptible of being energized by electrical currents (due to circuit faults, electrostatic discharge, and lightning), must be effectively grounded for reasons of personnel safety, fire hazard reduction, equipment protection and equipment performance. Grounding these metallic objects facilitates the operation of over-current protective devices during ground faults and permits return current from electromagnetic interference filters and surge protective devices, connecting line to ground or line to chassis, to flow in proper fashion. All metallic conduits and raceways in areas containing electronic load equipment have to be carefully bonded to form an electrically continuous conductor.

Standard Equipment Grounding:

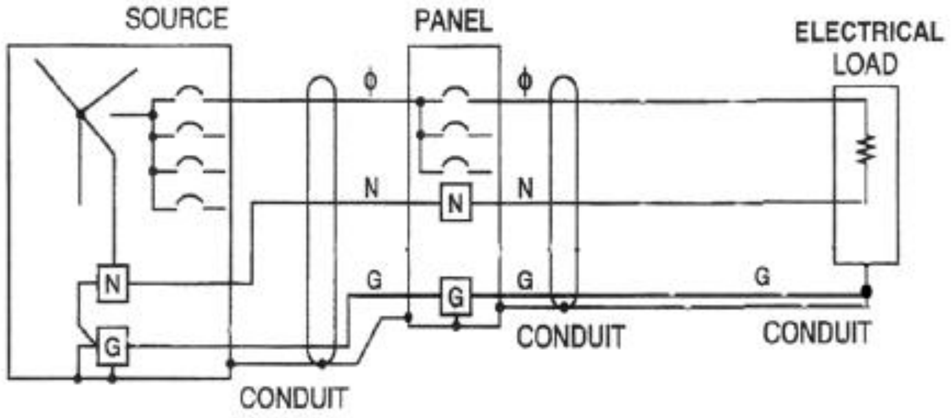

Fig. 1

The standard equipment ground configuration uses one equipment grounding conductor in green colour, running with the phase and neutral conductors to supplement grounded metal raceway and conduit. This configuration is shown in Fig. 1. The standard equipment grounding conductors are usually sized according to the table of standards for equipment grounding conductors and are properly connected and bonded to each metal enclosure that it passes through from the separately derived system or power service to the electronic load equipment. These metal enclosures include all distribution panel boards, safety switches, circuit breaker enclosures, transformers and branch circuit panel boards, as well as pull boxes, junction boxes and metal outlet boxes.

The conduit and raceway system may depend on the integrity of mechanical connections at conduit and raceways joints, panel boards, junction boxes and at the receptacles themselves. The non-uniformity and bad performance of the grounding paths can compromise personnel safety as well as the operation of surge suppressors and filters located in the electronic load equipment. In addition, currents flowing on grounded surfaces may take less desirable paths, such us through load equipment and associated data cables. The purpose of the installed equipment grounding conductor is to increase the reliability of the grounded metal conduit system.

Isolated Grounding:

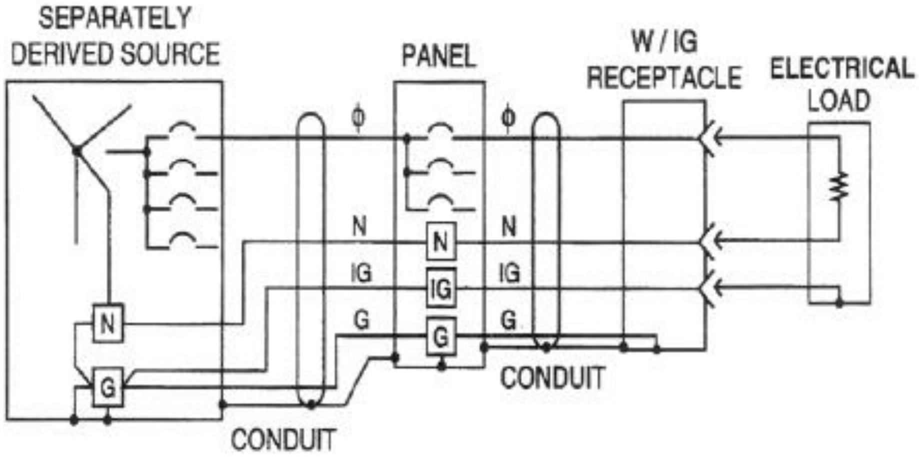

Fig. 2

The isolated grounding configuration uses an insulated equipment grounding conductor, typically green colour with yellow stripe, running with the phase, neutral and PE conductors from the electronic load equipment to the equipment grounding terminal of the power system or separately derived system. As opposed to the standard equipment grounding configuration, this additional insulated equipment grounding conductor typically connects the isolated ground receptacle only to the equipment grounding terminal or bus of the power system source or separately derived system. This equipment grounding conductor extends radially downstream to the chassis of the electronic load equipment without contacting any grounded metal surfaces such as metal conduits and race ways, panel boards, and outlet boxes for receptacles. This configuration is shown in Fig. 2.

The isolated equipment grounding conductors are sized according the table of standards for equipment grounding conductors and are properly connected and bonded to the metal enclosure at load level as explained in the standard equipment grounding. This type of equipment grounding configuration is only intended to be used for reducing the common mode (CM) electrical noise on the electronic load equipment circuit.

Circuit and System Grounding:

At this point, it should be obvious that grounding is very important from the stand-point of minimizing and controlling electromagnetic interference or EMI. However, grounding is one of the least understood and most significant culprits in many system-level EMI problems. The grounding scheme of a system must perform the following functions:

(a) Analog, low-level and low-frequency circuits must have noise-free dedicated returns. Due to the low frequencies involved, wires are generally used (more or less dictating a single-point or star ground system).

(b) Analog high-frequency circuits such as radio, video etc. must have low impedance, noise-free return circuits, generally in form of planes or coaxial cables.

(c) Returns of logic circuits, especially high-speed logic, must have low impedances over the whole bandwidth (dictated by the fastest rise times), since power and signal returns share the same paths.

(d) Returns of powerful loads (solenoids, motors, lamps etc.) should be distinct from any of the above, even though they may end up in the same terminal of the power supply regulator.

(e) Return paths to chassis of cable shields, transformer shields, filters etc. must not interfere with functional returns.

(f) When the electrical reference is distinct from the chassis ground, provision and accessibility must exist to connect and disconnect one from the other.

(g) More generally, for signals that communicate within the equipment or between parts of a system, the grounding scheme must provide a common reference with minimum ground shift (unless these links are balanced, optically isolated etc.). Minimum ground shift means that the common-mode voltage must stay below the sensitivity threshold of the most susceptible device in the link.

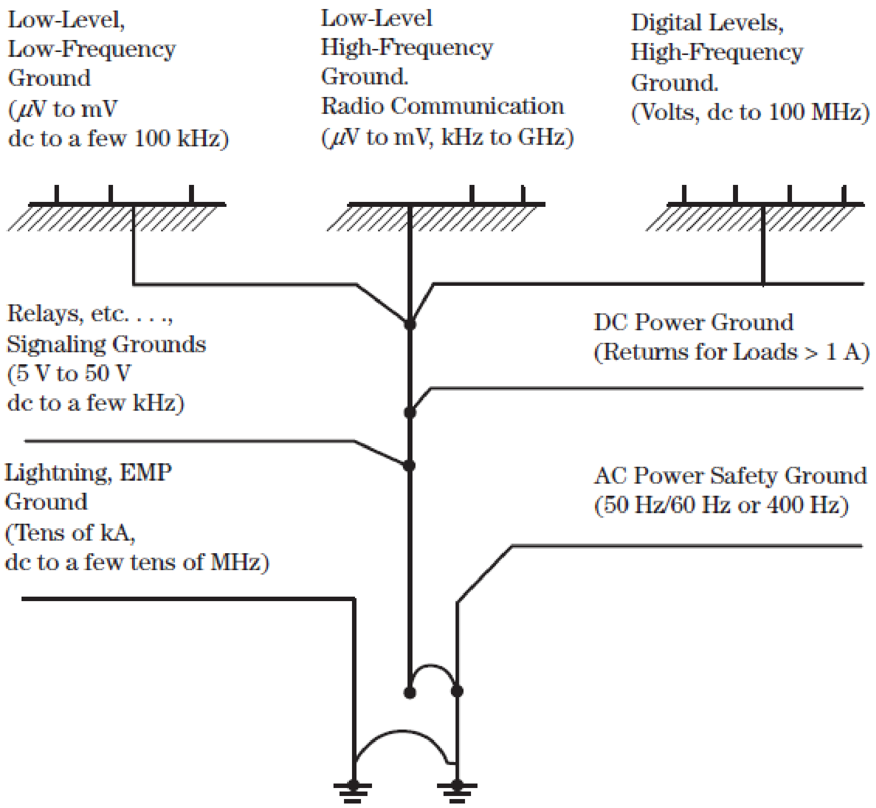

Fig. 3

All the above constraints can be accommodated if their functional returns and protective grounds are integrated into a grounding system hierarchy as shown in Fig. 3. The application of this concept is the subject of the following discussion.

Single-Point Grounding or Star Grounding Scheme. Modern electronic systems seldom have only one ground. To mitigate interference, such as due to common-mode impedance coupling, as many separate grounds as possible are used. Separate grounds in each subsystem for structural grounds, signal grounds, shield grounds, and primary and secondary power grounds are desirable if economically and logistically practical. These individual grounds from each subsystem are finally connected by the shortest route back to the system ground point, where they form an overall system potential reference. This method is known as a *single-point ground* or *star ground* and is illustrated in Fig. 4.

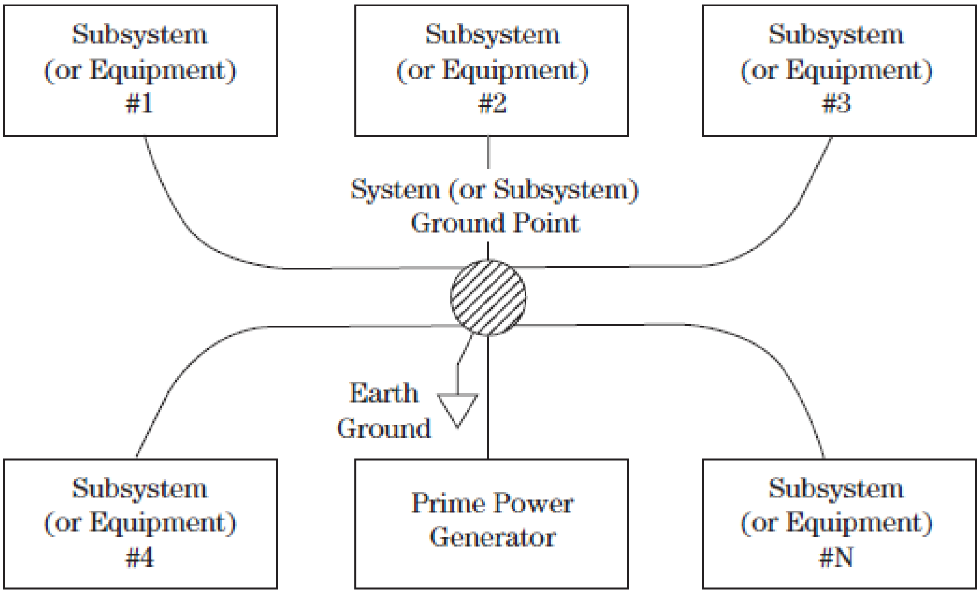

Fig. 4

The single-point or star type of grounding scheme shown in the figure avoids problems of common-mode impedance coupling. The only common path is in the earth ground (for earth-based structures), but this usually consists of a substantial conductor of very-low impedance. Thus, as long as no or low ground currents flow in any low-impedance common paths, all subsystems or equipments are maintained at essentially the same reference potential.

Multipoint Grounding Scheme. The problem of implementing the above single-point grounding scheme comes about when (1) interconnecting cables are used, especially ones having cable shields that have lengths on the order of a tenth of a wavelength or greater and (2) parasitic capacitance exists between subsystem or equipment housings or between subsystems and the grounds of other subsystems. This situation is illustrated in Fig. 5. Here, cable shields connect some of the subsystems together so that more than one grounding path from a particular subsystem to the ground point exists. Unless precautions are taken, common-impedance ground currents could flow. At high frequencies, the parasitic capacitive reactance represents low-impedance paths, and the bond inductance of a subsystem-to-ground point results in higher impedances. Thus common-mode currents may flow or unequal potentials may develop between subsystems.

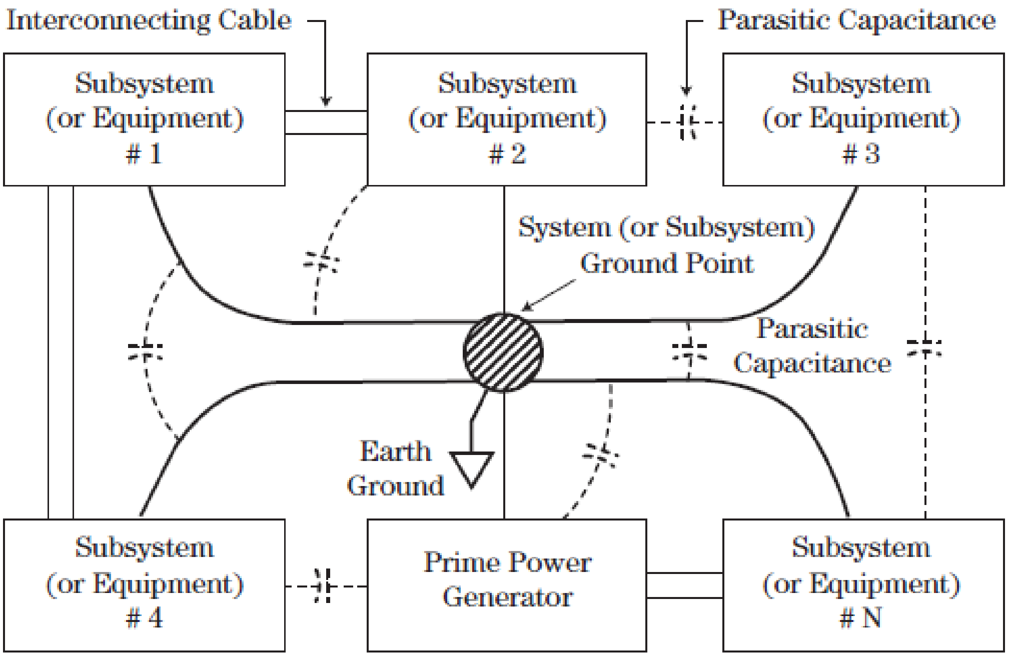

Fig. 5

Rather than have an uncontrolled situation as shown in Fig. 5, the other grounding alternative is *multipoint grounding* as illustrated in Fig. 6. Here each equipment or subsystem is bonded as directly as possible to a common low-impedance ground plane to form a homogeneous, low-impedance path. Thus, common-mode currents and other EMI problems will be minimized. The ground plane then is earthed for safety purposes.

The facts are that a single-point grounding scheme operates better at low frequencies, and a multipoint ground behaves best at high frequencies. If the overall system, for example, is a network of audio equipment, with many low-level sensors and control circuits behaving as broadband transient noise sources, then the high-frequency performance is irrelevant, since no receptor responds above audio frequency. For this situation, a single-point ground would be effective. Conversely, if the overall system were a receiver complex of 30 to 1000 MHz tuners, amplifiers and displays, then low-level, low-frequency performance is irrelevant. Here, multipoint grounding applies, and interconnecting coaxial cables should be used.

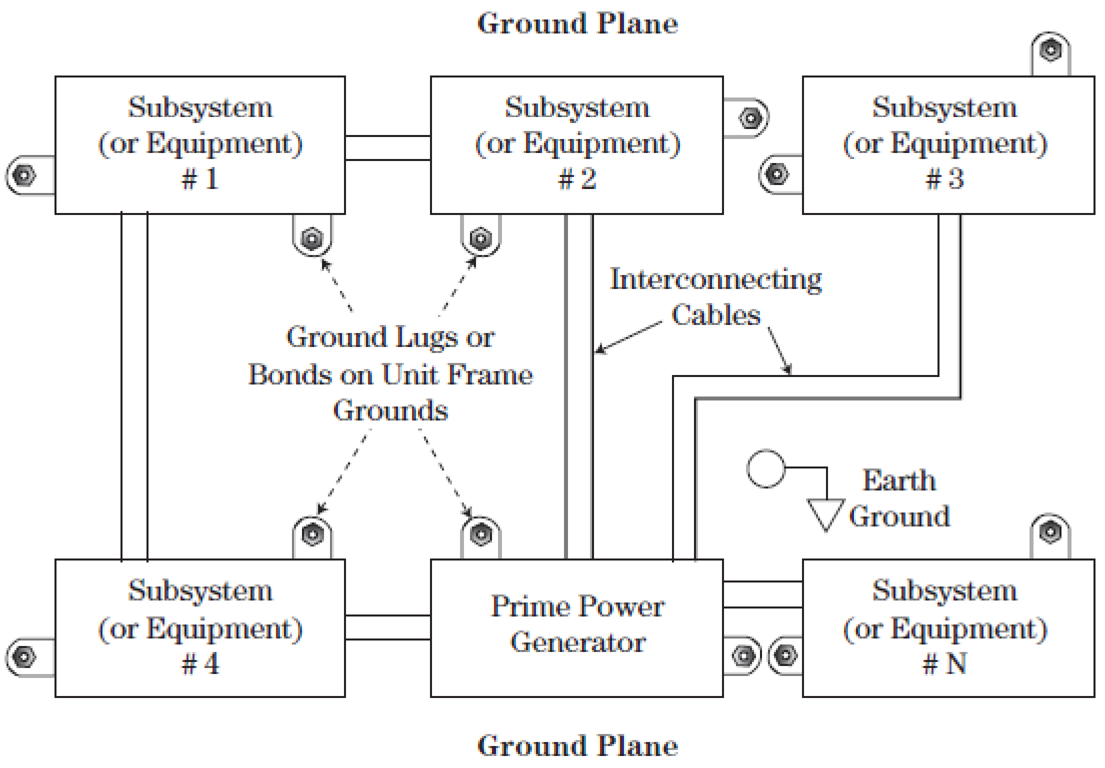

Fig. 6

Shielding:

The objective of electromagnetic, electric and magnetic shielding is to provide a significant reduction or elimination of incident fields that can affect sensitive circuits as well as to prevent the emission of components of the system from radiating outside the boundaries limited by the shield. The basic approach is to interpose between the field source and the circuit a barrier of conducting or magnetic material. Shielding effectiveness can be defined as the reduction in magnetic, electric or electromagnetic field magnitude caused by the shield. The effectiveness of a shield depends on the shield material as well as the characteristics of the incident field (far or near field), which is defined by the distance between the source and the victim. So, it is found that techniques for shielding depend on the type of source, whether the source is a magnetic field, electric field or electromagnetic field source. The shielding effectiveness (S) in dB, can basically be calculated as the sum of three components, namely, reflection loss (R), absorption loss (A) and a correction factor (C) used in special cases to consider multiple reflections in the shield, so that

$$S = R + A + C$$

Each component has a different expression and value depending on whether the incident wave is magnetic, electric or electromagnetic field.

EM Field Shielding. Although any radiated wave is an electromagnetic wave, the term electromagnetic wave is generally used to describe a far-field, plane wave, where the ratio between the electric field and the magnetic field is defined by the characteristic impedance of the free space ($Z_0 \approx 377\ \Omega$). When an electromagnetic wave passes through a medium, two phenomena, known as absorption and reflection losses, are present.

In the former, induced currents generate Ohmic loss, heating the material, and producing an exponential attenuation of the amplitude in the direction of the wave propagation. In the latter, when a field arrives at an interface between two media, part of the field can be reflected, introducing new losses. Basically the total loss is a combination of these two losses. The multiple reflection correction term is normally not considered for this type of waves as the reflection loss is high and the correction term is small.

Assuming the electromagnetic wave propagates perpendicular to the shield surface, the absorption and reflection losses (expressed in dB) can be calculated as

$$A \approx 131.4 \times t\sqrt{f\mu_r\sigma}$$

$$R \approx 168 - 10\log\left(\frac{f\mu_r}{\sigma}\right)$$

where t is the thickness of the shield, f the frequency, μ_r the relative permeability or dielectric constant and σ the conductivity. This equation is in close relation to the skin depth of the material. The reflection losses decrease with the frequency, whereas the absorption losses increase due to the skin effect. Based on these equations, it is possible to state that the reflection loss is the primary contributor to the shielding effectiveness at low frequencies. However, at higher frequencies the absorption loss is the primary contributor to the shielding effectiveness at high frequencies.

Electric Field Shielding. In the near-field, the relation between magnetic field and electric field is not determined by its characteristic impedance in free space ($Z_0 \approx 377\ \Omega$). The basic mechanisms of shielding observed for far-field sources are valid for near-field sources, but the type of source is critical for determining the shielding methodology to apply. For sources dominated by high voltages the predominant near-field is characterized by an electrical field, whereas for sources with high currents the dominant near-field is a magnetic field.

Basically, electric shielding consists of conductive barriers, metal enclosures, metal conduits or cable coverings around circuits. The spatial electric shield acts as a capacitive voltage divider between the field source and the circuit. As it was defined before, for a field propagating perpendicular to the shield surface, the effectiveness of the shield against an electric field is defined by the absorption and reflection losses, in which the absorption term is unaffected by the source, being equal to the previous equation for A. However, the reflection loss factor depends on the source and in the case of an electric field can be approximated by

$$R \approx 322 - 10\log\left(\frac{\sigma}{f^3\mu_r r^2}\right)$$

where r is the distance between the source and the shield. When the distance is undetermined, the equation showed for the far-field reflection could be used instead, as electric near-field reflection losses are always lower than, or equal to, the far-field reflection losses, hence introducing a certain safety margin. Based on those equations, conclusions for fields with dominant electric component are very similar to those attained for electromagnetic fields. The reflection loss is predominant at low frequencies, while absorption loss is predominant at higher frequencies.

Magnetic Field Shielding. In the case the magnetic component of the near-field is dominant, and the wave propagates perpendicular to the shield surface, the absorption losses are the same as those for far-field, defined by the first equation for A. However, the reflection losses are different and can be approximated as

$$R \approx 14.57 - 10 \log\left(\frac{\sigma f r^2}{\mu_r}\right)$$

Based on this equation, the reflection loss decreases for decreasing frequencies, and is lower than the reflection loss for the plane wave reflection. So, reflection losses are usually negligible for lower frequencies and absorption losses are small for low frequencies too. This fact forces the use of different shielding techniques against low frequency magnetic fields.

Basically, there exist two different ways for shielding against low frequency magnetic fields.

(a) Deviation of the magnetic flux with high permeability material.

(b) The shorted tuned method, which consists in the generation of opposing fluxes that cancel the magnetic field in the area of interest.

To deviate the magnetic flux, it is recommended the use of magnetic material instead of conductor material because it increases the absorption losses, hence improving the attenuation of the magnetic field (as it is the primary shielding mechanism at low frequency against magnetic fields). However, when a magnetic material is considered as material shield, two properties of this material, which introduce some limitations, have to be taken account,

(a) The permeability of a magnetic material decreases by increasing the frequency.

(b) The permeability of a magnetic material decreases by increasing the magnetic field strength.

The former depends only on the material, but the latter depends on the material and the section of the magnetic circuit. For example mu-metal material has a permeability of over 10000 from DC up to 1 kHz, however at 20 kHz the permeability is not larger than cold-rolled steel. The working condition of the shield is an important point as it has a serious impact in the selection of the shielding material.

As a summary a magnetic material such as steel or mu-metal makes a better magnetic field shield at low frequencies than does a good conductor such as aluminium or copper. However at high frequencies, good conductors provide better magnetic shielding. For non-magnetic material the shield effectiveness increases with the frequency, therefore, it is recommended to calculate the attenuation for the lowest frequency of interest. On the other hand, for magnetic materials the shield effectiveness may reduce due to the decrease of the permeability with the frequency.

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(All the figures have been collected from the above mentioned references)

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