DEC STANDARD 186

Signal Integrity

TITLE: SIGNAL INTEGRITY

ABSTRACT: This document is intended as a standard by which DIGITAL systems should be designed, configured, and installed in order to maintain system signal integrity, and thereby preserve functionality and reliability. A philosophy of maintaining separate distributions for logic reference and earth, and connecting the two only when necessary to satisfy safety requirements, is persistent throughout the document.

The problem is approached by drawing 'concentric circles' around the system, and addressing the problems encountered at each level, including:

1. Site Preparation
2. System Installation
3. Cabinet Configuration
4. Inter-Enclosure Wiring
5. Box Design
6. Sub-assembly Design

The document is intended for use by all levels of engineering within the corporation, including box designers (electrical and mechanical), systems designers and configurers, and field service (site preparation and installation).

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NOTE

This is a preliminary document. It was prepared by a committee formed from representatives of the Power Supply, RFI, and Systems Interconnect Engineering groups, and represents the combined expertise of these groups in the subjects of signal integrity and referencing.

Chapters 1, 2 , 3 and 10 are of a general nature, and are therefore timeless.

Chapters 4, 5, 6 and 7 are intended to address the problems encountered in installing and configuring systems today, with currently available DIGITAL hardware. In that regard, the guidelines presented are the best known compromise between what is desirable, what is available, and what is practical.

Chapters 8 and 9 are intended as a pointer or bridge to future DIGITAL systems design. However, since extensive systems modeling and evaluation cannot be performed without great time and expense, the exact direction and philosophy for all future design cannot be determined at this time. Therefore, while these chapters do provide insight into the known problems and offer acceptable solutions, these solutions have not been experimentally verified, nor have they been proven to be the only, or the most effective solutions available.

It should not be construed to imply that the rigid implementation of all the rules and design guidelines presented here is necessary in all cases. The engineer must necessarily make tradeoffs between cost, reliability, performance, and manufacturability to insure a marketable product.

In no case should it be implied that rigid conformance to these rules will guarantee ideal system performance.

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1.0 REFERENCES

DEC STD 002 -- AC Power Wiring and Receptacles

DEC STD 102 (Sec. 7) -- Electromagnetic Inteference

DEC STD 119 -- DIGITAL Policy and Practices Relative to Product Safety

DEC STD 123 -- Power Control Bus Standard

Antenna Engineering Handbook, Henry Jasik, editor, McGraw Hill, 1961

Noise Reduction Techniques in Electronic Systems, Henry W. Ott, John Wiley Sons, 1976

2.0 DEFINITIONS

Ground: The term 'ground' has received widespread misuse throughout electronics. Its use by different branches of electronics has led to ambiguous definitions. Since the precise categorization of the different reference planes within a system is the essence of this document, the term 'ground' is reserved to denote that substance in which potatoes and carrots thrive. Those terms defined in this section which are often considered to be 'ground' by others, but which must be individualized in this document, are labeled '(G)' next to their respective definitions.

System: The set of all electronic equipment, including both DIGITAL supplied and non-DIGITAL supplied, which communicate with at least one DIGITAL supplied component, at a DIGITAL customer's location.

Primary Power Source: A source of system power, external to the system, from which system operating power/voltages are derived. Examples are 50 or 60 Hz AC commercial mains power, UPS, 48 VDC telephone power (specific to TELCO systems), and external batteries. (See Figs. 1,2, and 3.)

Primary Power Earth Reference (G): The earth connection provided from the primary power source. It is usually a wire (or bus bar) located at the system distribution panel. (See Figs. 1,2, and 3.)

System Earth Reference (G): The point from which the system is con sidered to be safety referenced. This point, being the local implementation of an earth reference for the system, is the unique root node of the system earth reference distribution tree. (See Figs. 1, 2, and 3.)

System Distribution Panel: The point in the primary power source and earth reference distribution system electrically closest to the system, from which all system power is derived. This panel also contains the primary power earth reference.

It is important to draw the distinction between an electrician's definition of distribution panel and ours. While our system distribution panel may also be an electrician's distribution panel (most likely in a larger system), it may also be a single outlet or outlet cluster (for smaller systems), or a single strip of power bus ducting. In any case, one should look at the power and earth reference inputs to every device in the system and trace them back to the first common source point for all. This point should be considered the system distribution panel. Power derived from this point and entering the system domain is reserved for exclusive use by the system. (See Figs. 1, 2, and 3.)

System Earth Return (G): The electrical connection from the system earth reference to earth. It is normally a connection at the system distribution panel between the system earth reference and the primary power earth reference. (See Figs. 1, 2, and 3.) It should be a single link, removable for testing purposes. (Refer to para. 4.1.4.)

System Logic Reference (G): The point from which all logic voltages are referenced. Although a structure implementing this philosophy (one point in the system from which all logic voltages are referenced) could be developed, it would be difficult (and impractical) to implement. For these reasons, therefore, the system logic reference does not exist as a single point (as in the case of system earth reference, which does exist as described). The system logic reference is distributed, and established by the plane of interconnecting signal cables between boxes and/or enclosures in the system.

Logic Paths: The network of communication interconnects between logic elements (boxes, backplanes, modules, etc.) in a system. A logic path includes both the signal and logic reference (return) connections in cables or backplanes.

Logic Power Reference (G): The point from which active logic elements derive their power to function. This point should be designed to be physically next to the active element through the use of local storage elements (capacitors) which typically derive their energy from a remote power supply. The remote power supply delivers its energy through D.C. supply and return wires carrying equal currents, guaranteed to be so by prohibiting connections which provide alternate paths for current flow.

Box: A device performing a logical function in the system, and being the lowest level of equipment having its own primary power and earth reference entry (power cord).

Cabinet: A mechanical structure which can house one or more boxes. Examples are: H950, H9500, LA36 cabinet, VT52 cabinet, etc.

Enclosure: A cabinet or group of cabinets whose frames are suitably bonded around their peripheries. Bolting (electrically bonding) two enclosures together in this manner yields one larger enclosure.

NOTE

This is not always possible for every enclosure, for mechanical reasons.

NOTE

It should not be implied that the definitions of box, cabinet, enclosure, and system are mutually exclusive. It is possible (even likely) that these definitions will overlap in practical applications, i.e., a box may qualify as a cabinet, or a cabinet may also be classified as an enclosure, dependent upon function and configuration of the device.

3.0 GENERAL

Proper layout of a reference distribution system involves these fundamental concepts:

1. One and only one point in the system will be identified as system earth reference. This point is normally connected to the primary power earth reference at the system distribution panel.

2. A logic reference shall be established for the system, independent of the earth reference.

3. Connections between the logic and earth references are made solely for safety reasons, and are usually in conflict with signal integrity requirements. When these conflicts arise, however, the safety requirements cannot be compromised.

4. The physical loop area between the logic paths and earth returns should be minimized, to reduce magnetic field antenna effects.

5. Reduce electric field antenna effects by minimizing lengths of external signal cables, or through proper use of shielding.

4.0 SITE PREPARATION

With respect to this document, site preparation is defined as the planning, prior to installation, of the customer's premises to insure that his facilities, i.e., his primary power and earth reference distribution, meet DIGITAL requirements for reliable system performance as outlined in this document. Site preparation also includes the proper implementation of this plan. This section describes the means of acheiving these goals.

4.1 PRIMARY POWER DISTRIBUTION

4.1.1 Primary Power Source

The primary power source (feeder) for the entire system (including any logically connected components such as terminals, other systems in direct communication, laboratory data collection equipment, etc.) should be unique to the system. Stated differently, all power for system related components should be derived from the same system distribution panel. (See Figs. 1, 2, and 3.) Although more than one physical panel (as described in para. 4.1.1.1 and 4.1.1.2) may be employed, when properly configured they are concep.ually one panel.

4.1.1.1 Allowable Variances from Single Distribution Panel

It is understood that in some cases it may not be possible to implement a physically unique system distribution panel. Valid reasons for not using a unique system primary power source include:

1. The system requires more power than one feeder could possibly deliver.
2. The system must communicate with another existing system whose feeder does not have enough reserve to power the new system, or the power is incompatible (incorrect voltage/frequency).
3. The system is distributed over a very large area such that branching from a single system distribution panel is impractical.

4.1.1.2 Acceptable Solutions for Multiple Distribution Panels

In each of these cases, a means must be provided to break the current path between the earth references of the separate feeders. One (or a combination of both) of the following should be implemented:

1. Isolation transformers on all of the primary power sources the system requires (except one, denoted the master), or individual isolation transformers in each of the system components not deriving their power from the master. These transformers must be either safety types (shield between primary and secondary windings) or double insulated, to insure that a primary-to-secondary failure requires a double fault. The devices powered from the secondaries of these transformers must be referenced to the system earth reference at the system distribution panel of the master primary power source. (See Fig. 4.)

2. Special signal interface handling whenever a communication path goes between two devices being powered from different feeders. Special signal interface handling may include opto-isolation, optical coupling, differential drivers/receivers, or any means of communicating which can maintain logic reference isolation between the communicating components. The impedance between any conductor in a logic path on one side of the isolation to any conductor in a logic path on the isolated side should be 300 ohms minimum, measured from D.C. to 30 MHz. The interconnect means employed must also meet applicable safety requirements. (Refer to para. 6.2 for a discussion of signal types.)

4.1.2 Convenience Outlets

A convenience outlet contains receptacles providing primary power for devices not used during the normal operation of the system.

4.1.2.1 Customer Convenience Outlets

It is required that any customer convenience devices, eg., coffee pots, vacuum cleaners, electric typewriters, etc., receive their powerfrom a branch circuit independent from that powering the system. This branch circuit may be taken from the same primary power source as the system without adverse effects. The intent is to insure that the system earth return carries only earth return currents unique to the system and not those from any customer convenience devices.

4.1.2.2 Field Service Convenience Outlets

Outlets should be provided for the field service engineer's test equipment (eg., oscilloscopes and soldering irons). Since the field service engineer must often measure voltages with respect to earth reference as used by the system, these convenience outlets must receive their power from the system distribution panel. However since devices such as soldering irons, heat-shrink guns, etc., may introduce considerable noise onto their power inputs, the outlets used should not be located within any system enclosure (i.e., do not use available receptacles on a system power controller). The outlets used should be located such that the power line filters at the enclosure boundaries isolate the system from the noise generated by the field service equipment. (Refer to para. 6.1.)

4.1.3 Primary Power Earth Reference

All electrical receptacles providing primary power for a system shall provide a connection from the earth reference (safety) wire of the power cable to the system earth reference point. (See Figs. 1, 2, and 3.) There shall be only one such system earth reference point per system, and the distribution of this reference shall be in a tree structure, i.e., all of the earth reference wires for the system shall be traceable to the system earth reference point (original node of tree) in one and only one path.

The neutral conductor from the primary power source shall not be connected to earth reference at any point other than the building service entrance for the primary power. Specifically, this connection shall not be made at the system distribution panel, nor anywhere within the system itself.

There are a number of methods of distributing the earth reference from the system distribution panel to the receptacles providing power for the system. In some cases the installer has control over the type of wiring used, while in other cases the installer must use what has been already provided. The following sections give guidelines for the distribution of the earth reference from the system distribution panel to the receptacles.

4.1.3.1 Earth Reference Distribution to Non-isolated Outlet Boxes

Any outlet box or cluster of outlet boxes using metallic conduit or cable sheaths to cover the power and/or earth reference wires from the system distribution panel to the outlet box(es) shall be considered a non-isolated outlet box. Furthermore, even if conduit or sheaths are not used as described, if the outlet box is mounted such that it forms an electrical connection with any metalwork, such as building structure, air conditioning or electrical ductwork, etc., it shall also be considered a non-isolated box.

Any non-isolated outlet boxes providing system power must have the earth reference wire connection in the receptacle(s) isolated from the box frame and the conduit feeding the box. Note that the conventional receptacles (three wire duplex, etc.) used by electricians do not normally have the reference wire isolated from the mounting hardware. This standard type of outlet is not acceptable in this application.

The installer should remember that an earth reference wire must still be connected to the isolated earth conductor provided on the receptacle, and must be brought back to the system distribution panel by an insulated wire, independently from any such connection provided by the conduit or sheath.

Note that these rules only apply to outlets remote from the system distribution panel. If the entire system is powered from one outlet (or one cluster of outlets), then that outlet is considered to be the system distribution panel, and these rules do not apply. (See Fig. 1.)

4.1.3.2 Earth Reference Distribution to Isolated Outlet Boxes

An isolated outlet (or cluster of outlets) is an outlet isolated from any earth reference except for an insulated wire specifically provided for this purpose, connected to the system earth reference. (eg., the outlet box is mounted so as to provide electrical isolation from building metal, and is fed by non-metallic sheathed cable, such as Romex.)

If any outlets providing system power conform to these requirements then the isolated reference wire receptacles described in para. 4.1.3.1 are not necessary. Conventional receptacles may be used. The earth reference wire must still be brought back to the system earth reference point. (This is the wire specifically provided for, decribed above.)

4.1.3.3 Earth Reference Distribution to Power Bus Ducts

Power bus ducts are an inexpensive means of distibuting a large amount of power over a large area. They generally distribute 3 phase, 'Y' connected power, using four wires in an overhead mounted structure. The earth reference connection to the outlets plugged into the bus is provided by the metal duct structure. A wire is not provided in the duct for this purpose.

If it is deemed desirable to use power bus duct, the following should be considered:

1. The entire system should be powered from one strip of the power bus ducting, if possible. In this way, the bus duct strip can be considered the system distribution panel, and the earth reference wiring from service entrance up to the strip need not be considered. The installer should realize, however, that using this procedure renders it difficult to test the system earth reference as described in para. 4.1.4, since there is no single link available from the system earth reference to the primary power earth reference.

2. If it is not possible to power the entire system from one power bus duct strip, the minimum number of strips necessary to provide system power should be employed. The strips used should be physically as close as practicable, and the earth reference connections (power bus duct frames) tied together with a low impedance connection.

In all cases, the power bus duct mounting hardware (and the duct itself) must be electrically isolated from building structure. (See Fig. 5.)

Once the primary power source and earth reference points are chosen, and any required actions taken as described above, the actual physical layout of the power system from the system distribution panel to the system enclosures must be considered. It is desirable to minimize the area of any physical (not electrical) loop formed by the logic paths and earth return wiring, in order to reduce any magnetic loop antenna effects. This can be accomplished by routing signal cables between enclosures parallel to, but spaced away from, power cable paths. For a further discussion of magnetic loop antennas, refer to the Antenna Engineering Handbook, Chapter 6 (pp. 6-1 to 6-3). (See Sec. 1.0 for a detailed list of references.)

4.1.4 Testing the System Earth Reference

A means should be provided to verify that the entire system is indeed referenced to earth at one and only one point (the system earth reference point). It is necessary that this point be well defined, and labeled. It should additionally have a means of disconnection (single stud/lug) whereby this reference can be lifted and the system tested to determine if there is any point other than this point at which the system is referenced to earth.

Two simple tests can be performed which will verify the proper distribution of the system earth reference point.

Test 1: With power applied to the system, measure the current in the system earth return wire. (See Figs. 1, 2, 3, and 4.) Preferably, this measurement should be made with a device which can measure current without disconnection of the wire (a clamp-on ammeter). The maximum current in the system earth return should be 3.5 mA for each line cord exiting a cabinet in the system. This represents the total earth leakage current of the system. Current in excess of this amount indicates improper primary power/earth reference distribution, and should be investigated before continuing. (Note that conventional clamp-on ammeters (calibrated in amperes) are inappropriate here. Use one calibrated in milliamps.)

NOTE

If the system is hard-wired into the primary power source and earth reference (the power cords to the enclosures are not removable), the 3.5 mA restriction on leakage current per cabinet power cord no longer applies. However, the field engineer should still check the current in the system earth return wire, as excessive currents indicate improper wiring of the primary power and/or earth reference.

Test 2: TO BE PERFORMED ONLY BY A QUALIFIED ELECTRICIAN IN THE PRESENCE OF DIGITAL FIELD PERSONNEL, AFTER TEST 1 (ABOVE) VERIFIES THAT THE SYSTEM EARTH RETURN CURRENT IS NOT EXCESSIVE.

**** WARNING ****

WHEN THE SYSTEM EARTH RETURN IS REMOVED FROM THE PRIMARY POWER EARTH REFERENCE THERE MAY EXIST HAZARDOUS VOLTAGES BETWEEN THE EARTH RETURN WIRE AND THE EARTH REFERENCE. THIS WIRE SHOULD THUS BE HANDLED ACCORDINGLY. BEFORE ANY RESISTANCE MEASUREMENTS ARE MADE WHICH REQUIRE THE DISCONNECTION OF THIS RETURN WIRE, THE PERSON PERFORMING THE TEST SHOULD FIRST MEASURE THE VOLTAGE BETWEEN THE LIFTED RETURN WIRE AND THE EARTH REFERENCE TO DETERMINE IF A HAZARDOUS CONDITION EXISTS.

Disconnect system primary power at the system distribution panel. (Disconnect ONLY system primary power, not primary power from other, non-system devices which derive their power from the same physical panel as the system.) (See Fig. 3.)

When the system earth return is now disconnected from the primary power earth reference there should be a minimum of 100 ohms resistance between the system earth return wire and the earth reference, measured at D.C. Make sure that the earth reference configuration is returned to its original state after this test has been completed.

4.2 FALSE FLOORS/GRIDS

The large conducting plane of a false floor grid can sometimes be used to enhance the impedance characteristics of the system earth reference distribution system. In order to use a floor grid, the field engineer must insure that the grid is electrically homogenous, i.e., good electrical conductivity is guaranteed across the entire plane and any subsection of it, under working stress (human and equipment load and load shift conditions). Means of providing this homogeneity include a welded construction, or use of bonding straps across each mechanically separate (bolted together) member of the structure. A bolted-together structure without these electrical bonding straps cannot be used for a system earth reference distribution plane. Unless the installer is absolutely sure that the floor grid is constructed in this manner, and additionally, that the grid is 100% isolated (minimum 100 ohms measured at D.C.) from building structure, electrical conduit, cable troughs or conduits, air-conditioning duct, etc., there should be no connection made between the floor grid and the system earth or logic references. In fact, the installer should take pains to insure that at no point are the system earth or logic references connected to the floor grid. This includes isolating:

1. Cabinet frames
2. Signal cable ducts
3. Inter-enclosure braids/wires

If, however the floor grid is constructed and installed as described above, then it is not only allowable, but desirable to connect cabinet frames and cable ducts to the grid wherever possible. The grid in this case can provide an excellent low impedance earth reference plane for the system.

4.3 LIGHTNING AND HIGH ENERGY ELECTRICAL DISCHARGE PROTECTION

This section is included as an alert that this form of protection and its impact on the system should be considered when preparing a site.

The sources of high energy electrical discharge can be separated into two classes, natural and man-made. The most common natural source is lightning. Man-made sources include, but are not limited to, high tension wires, arc welders, and high energy physics installations.

Lightning is the electrical discharge between clouds or between clouds and earth. It is characterized by a high electrical potential causing a dielectric breakdown of the air, resulting in a high current for an extremely short time. If lightning strikes a power line, this high energy may follow the line into the building housing the system. The building power distribution system may propagate this energy in both differential and common mode form, causing dramatic and/or catastrophic system failures. The normal protection against this is to have surge arrestors installed at the power service entrance to the building. These arrestors should protect for both the differential and common mode components, and must be installed as close to physical and electrical earth as possible. The field engineer and the user should realize that these surge arrestors are intended to prevent destructive equipment failures only, and will not prevent system crashes (hardware or software) from occurring as a result of the electrical discharge.

Lightning may also strike the building structure. When this happens, the energy causes the structural steel and anything referenced (connected) to it to assume a new electrical potential. It is for this and other (refer to para. 3.0 and 4.1.) reasons that the use of building metalwork (including piping, air-conditioning duct, etc.) as a distributed system reference is expressly prohibited. It is also good practice to maintain adequate (1 meter) spacing between any system enclosures/cables and building metal to minimize the electrical coupling and to prevent possible arcing in the event building metal is not homogeneous, or not properly connected to earth.

Protection from man-made sources can best be acheived by knowing the source of the energy and understanding the possible failure mechanisms. If a high energy discharge could be impressed on the power source (feeder) serving the system distribution panel, then surge arrestors properly installed, located near and dedicated to the system distribution panel could be effective. If high energy electromagnetic radiation is possible, a shielded room may be required. Most of these problems can be solved by preparing a detailed site plan, then properly locating the system and installing the necessary fixtures.

5.0 SYSTEM INSTALLATION

System installation guidelines follow the same pattern as site preparation guidelines, on a smaller scale. The same philosophy of removing redundant earth and logic paths by utilizing tree-structured earth and logic reference distributions, and minimization of physical loop area between the earth returns and logic paths should be followed. This section describes the implementation of these ideas at the system installation level.

5.1 PRIMARY POWER CABLE ROUTING

Primary power cables (and their associated reference wires) should be routed in a well-defined tree structure, i.e., the primary power and earth reference wires at any device should be insulated and traceable all the way back to the system distribution panel (and hence the system primary power source and system earth reference point) in only one possible path.

Primary power cables should be dressed neatly between system enclosures, and isolated from signal cable routing by a minimum of .25 meter, and a maximum of .5 meter. Primary power cables between system components should follow a parallel but separate path with respect to any data (signal) cables running between the same system components. Note that while it is important that signal and primary power cables should be separated by this minimum .25 meter spacing, this should not be construed to mean that extremely large spacing between primary power and signal distribution paths is desirable, as this violates the rule of maintaining minimum loop area in the system return distributions. (Refer to para. 3.0, item 4.)

Excess primary power cable should be dressed outside the enclosures; it is NOT acceptable to coil it up in the base of the cabinet.

Preferably, primary power cables should not be run in metal troughs or conduits. (Note that this is for system installation purposes only, and should not be taken to mean that the primary power distribution from the service entrance to the system distribution panel cannot be run in metal conduit.) If metal troughs or conduits are mandated by other factors (local ordinances, existing system configurations, etc.), these troughs or conduits should be electrically isolated from the system components and enclosures, as well as any building metalwork. They should also be isolated from any metal ducts carrying system signal distribution. (Refer to para. 5.2.) The primary power wiring troughs or conduits, if used, should be connected to the primary power earth reference. The rules given in para. 4.1 for primary power distribution also apply here.

5.2 SIGNAL CABLE (LOGIC PATH) ROUTING

There are a number of approved schemes for routing signal cables between cabinets of a system. They are enumerated here in order of preference.

1. Bond together the cabinets between which the signal cable is being routed such that they form a single enclosure. The cable may then be run inside the enclosure confines with no special treatment, other than that described in para. 7.3.

2. If the cabinets must be separate, i.e., the cabinets are separate enclosures, then cables should be routed between the enclosures in metallic cable ducts. Only one such duct is desirable between any two enclosures. These ducts should have a closeable metal cover to provide both shielding and service accessability. They should form a good electrical connection between enclosures, and thus be bonded along their length and at both ends to the enclosures they are interconnecting, and isolated from any building metal, such as floor grids (except as noted in para. 4.2), outlet boxes, or other non-system cable troughs, conduits, or ducts. (See Fig. 7.) See Appendix A for a list of cable duct suppliers.

3. If a single duct between enclosures to house all cables between those enclosures cannot be provided, then the cables between those enclosures should be individually shielded, with the shields connected to the enclosures at the point of entry. The shields provide a form of individual duct for each cable. Multiple, individually shielded cables between two enclosures should be routed over the same path, and may be closely spaced. The shielded cable design should follow the recommendations of para. 6.2.3.

4. If neither ducts nor shielded cables can be provided, an insulated braided conductor should be run over the same path as (and grouped with) all signal cables between enclosures. Only one braid should be run between any two enclosures. The braid should be treated exactly as a cable duct with respect to insulation and connections. The braid should be such that its cross-sectional area is at least that of a 4 ga. wire conductor. In addition, the larger the surface area of the braid (the lower the length/width ratio) the better the braid is as a bonding conductor, as its inductance (and therefore, its impedance) is lower.

Indiscriminate routing of cables between separate enclosures without ducts, shields, or parallel braid wires is expressly discouraged. The designer should also refer to para. 6.2.2 for a discussion of preferred signal types for interfacing across the enclosure boundary.

5.3 POWER CONTROL BUS ROUTING OUTSIDE THE ENCLOSURE

The power control bus is a 3 wire bus used for the switching of primary power to individual units in a system. The specifications and uses for this bus are given in DEC Standard 123.

5.3.1 Power Control Bus Route Planning Considerations

There are a number of significant factors concerning this bus that must be taken into account when its routing is planned.

1. The power control bus is referenced to earth at the chassis of the power controller. This earth reference is carried in the third wire of the bus to all devices the bus interconnects. Therefore, since it is desired to eliminate redundant earth return paths, there must be no connection between the earth return wire of the bus and any logic reference points.

2. Current practice typically allows the routing of this bus cable external to the enclosures with no shielding or filtering. This tends to make this bus relatively noise prone. Therefore, it is necessary to reduce the coupling between the logic and the power control bus in order to minimize the introduction of this noise into the system logic.

3. Since the power control bus must often be routed in the same area as logic components to make connection to power switches, thermal sensors, etc., it is necessary to reduce the coupling between the power control bus and the primary power distribution.

The power control bus must be treated as a separate entity; it is neither a power cable nor a signal cable.

5.3.2 Power Control Bus Installation Procedures

For the purposes of system installation, the following are guidelines for the routing of this cable between cabinets.

1. If the bus cable is being routed between two cabinets which are part of the same enclosure (cabinets bonded together as defined in para. 2.0), then the bus cable should be routed internal to the enclosure, with the minimum length necessary for connection and servicing. No length of the power control bus cable may be routed outside the enclosure in this instance.

2. If all power control bus wiring internal to the cabinet is shielded as specified in para. 7.4 and 8.6, then inter-enclosure power control bus cable routing should be done external to any cable ducts provided for logic signal cables, but separated from the primary power distribution by a minimum of .15 meter.

3. If the power control bus wiring internal to the cabinets is not shielded as specified in para. 7.4 and 8.6, then any inter-enclosure power control bus cable should be routed inside the cable ducts provided for signal cable distribution, but the installer should provide a minimum 7 mm spacing between the power control bus cable and any signal cables in the duct. No length of the power control bus cable may be routed outside the extended enclosure (including ducts) in this instance.

4. If neither shielding is provided for the power control bus, nor ducts for the signal cable distribution, the power control bus between enclosures should be routed parallel to both the primary power and signal cable distributions, but separated from either by a minimum .15 meter.

5.4 MODEM (TELEPHONE) CONSIDERATIONS

The system must often communicate to remote peripherals (terminals) through telephone interconnects. The most common method of telephone interconnect is through a modem/DAA (modulator-demodulator/Data Access Arrangement) supplied by the local telephone company. (eg., Bell 103) In order that the signal integrity of the system not be compromised by the telephone interconnect, certain rules must be followed regarding interfacing the modem/DAA to the system.

Primary power for the modem/DAA should be derived from the system distribution panel, but under no conditions should this primary power cable cross a system enclosure boundary. The modem/DAA should be considered a peripheral device of the system in this respect.

The DAA must be designed so that isolation is maintained between the telephone network and the user-available connection. This isolation must insure both electrical discontinuity from the telephone network, and minimum capacitive coupling between the network and the user. Both FCC (Federal Communications Commission) and BSP (Bell System Practices) requirements for DAA's generally meet these criteria.

It is common in interconnect schemes (RS232, etc.) to provide separate connection points (and wires) for equipment chassis and logic reference. The designer of the interface logic (at both the computer and telephone ends) and the cabling must insure that these two entities remain separate, except as mandated by safety factors in the equipment. Unnecessary and redundant connections between the logic reference and chassis for the modem interconnect must be avoided.

The interconnecting cable from the DAA (or modem/DAA) external to the system to the interface within the system must enter the appropriate enclosure at the I/O interface bulkhead, and must be either shielded or filtered with respect to that bulkhead, as is the case for any cable crossing an enclosure boundary.

6.0 INTER-ENCLOSURE WIRING

6.1 INTERFACING PRIMARY POWER ACROSS AN ENCLOSURE BOUNDARY

6.1.1 Primary Power Interfacing Requirements

Primary power shall not be allowed to cross an enclosure boundary unless one of the following conditions is met:

1. The primary power is filtered at the enclosure boundary by an approved filter, which has been mounted and connected in a proper fashion, or

2. Any primary power cable used is of a shielded construction with the shield extending the full length of the cable and connected only to the enclosure bulkhead(s). (Ref. Fig. 13.)

The mounting surface for the filter or the shield connection shall be the same as, or an extension of, the I/O interface bulkhead described in para. 6.2.1, and shall conform to the rules described there. (See Fig. 6.)

6.1.2 R.F. Isolation Inductor

For all primary power crossing an enclosure boundary there must be an R.F. isolation inductance in the earth return for the enclosure. This inductor performs a number of important functions, including isolating high frequency transients on the incoming power cable from appearing on the equipment chassis and preventing high frequency computer signals from being coupled onto the power lines. This inductance must meet certain criteria as follows:

1. Minimum impedance must be 100 ohms when measured at any frequency between 150 KHz and 30 MHz, at maximum rated leakage current.

2. Maximum D.C. resistance is 5 milliohms.

3. Current handling capability must be such that it does not impair the performance of any overcurrent protection devices.

4. The inductor shall be connected in series between the earth reference wire of the incoming power cable and the enclosure I/O interface bulkhead. (Refer to para. 6.2.1.)

5. The inductance terminal identification shall be as shown in Fig. 10.

This R.F. isolation inductance is commonly located within the filter for the power entrance. This filter/inductor combination is often located within a power controller. (See para. 9.1.)

Primary power cables crossing an enclosure boundary must still meet applicable safety requirements.

6.2 INTERFACING SIGNAL CABLES ACROSS AN ENCLOSURE BOUNDARY

The rules for interfacing signal cables across an enclosure boundary are similar to those for primary power cables.

All signal cables which cross an enclosure boundary must do so at the I/O interface bulkhead (See para. 6.2.1). In addition, these signal cables must be either filtered or shielded, with the filter or shield referenced to the I/O bulkhead. The decision on whether to shield or filter is dependent upon the bandwidth of the signals carried in the cable. Typically, low frequency (bandlimited to 500 KHz) signals can be filtered without disturbing the signal characteristics, while high frequency (frequency components greater than 500 KHz) signals cannot tolerate the capacitance introduced by the filter. Optical filtering (isolation) may be appropriate, however. High frequency signals should generally be shielded.

6.2.1 I/O Interface Bulkhead

It is desirable to provide a single, common entry/exit point (per enclosure) for all cables that must cross enclosure boundaries. This common point shall be designated the I/O interface bulkhead for the enclosure. There should be only one (if any) I/O interface bulkhead per enclosure. This bulkhead shall provide a common reference plane. This plane shall be the reference for any signal or power cable filtering or shielding. No other enclosure reference for cable shields or filters shall be acceptable. (See Fig. 6.)

It is always desirable (from a signal integrity standpoint) to have only one I/O interface bulkhead per enclosure. However, it is recognized that this may be an undue restriction on some large systems. It may be acceptable for the designer to implement the I/O bulkhead using two or more physical panels to form one electrical bulkhead in these cases. There are some restrictions in the design of the I/O interface bulkhead:

1. The effective length/width ratio of the bulkhead assembly dimensions must not exceed 10:1, in order to minimize the bulkhead inductance, and allow the entire bulkhead to be considered a single point.

2. The material used for the bulkhead and all connections between multiple physical panels in a single bulkhead should have a surface resistivity (measured in ohms/square) less than or equal to that of aluminum. Steel, or plated steel may be acceptable as an I/O bulkhead material for physically small systems.

Care must be taken in the layout and positioning of any holes (cut-outs) so as not to impair the effectiveness of the bulkhead. The integrity of the panel can be maintained by insuring that where connectors are mounted on the bulkhead, they are appropriately bonded to the bulkhead. Also, any unused connector cut-outs should be covered with a blank, electrically conductive filler panel.

6.2.2 Signal Types and Placement

The type of signals used in a cable crossing an enclosure boundary will have a large effect on the ability of the logic using those signals to withstand electrical and environmental stress. The following are some common signal schemes in order of ability to tolerate external electrical interference.

1. Current loop with optical isolation. This is the most preferred signal type due to its inherent high common mode noise rejection. In addition, if the optical isolation is located at the enclosure boundary, it may also provide the necessary 'filtering' for the signal. This method can also constitute the necessary special signal interface handling required by para. 4.1.1 for the use of multiple primary power sources.

2. Current loop without optical isolation. Because of the low impedance of the receiver in this scheme, it is difficult to develop significant noise voltages. However, without optical isolation, it is still necessary to provide either filtering or shielding at the I/O bulkhead.

3. True differential drivers/receivers (wide common mode range, typically 10 V or better, or transformer coupled). For all signals in the cable, the transformers should be located at the same physical point (either the driver or receiver end, or some other selected point). A truly differential drive scheme can provide considerable immunity against common mode noise. This is especially useful for high frequency signals, due to the wide allowable bandwidths. This method can also constitute the necessary special signal interface handling required by para. 4.1.1 for the use of multiple primary power sources.

4. Limited range differential drivers/receivers (eg., SN75113, SN75118, etc.). This non-transformer coupled, limited range differential scheme can provide some immunity against common mode noise, but the limit is typically less than one volt common mode. This is much worse than the transformer coupled differential drive, but may be sufficient in many instances where the number of signals, and therefore the cost of transformers may be great.

5. Single-Ended drive. This is not an acceptable medium for signals outside the extended enclosure (i.e., not outside of enclosures or ducts). Refer to para. 5.2 for further information.

The decision on which signal type to use should be based on the bandwidth of the signals, the length of cable to be expected, the critical nature of the signals, and the operating environment.

6.2.3 Shielded Cables

Shields on cables are used to provide a virtual extension of the enclosure around the cable as it leaves the physical boundaries of the enclosure. The design of the cable and the reference selected for the shield should keep this idea in mind.

A cable shield which is to be used for the purpose of providing an extension of the enclosure should be designed to minimize the coupling between the shield and the signals it is protecting. As the spacing between the shield and the internal wires is increased, the coupling decreases. Shielded cables must have an insulated covering to prevent unwanted, accidental connections to earth reference.

When a shielded cable enters an enclosure, the insulation covering the shield should be removed at the point where it passes through the I/O bulkhead and the shield clamped to the reference plane provided by this bulkhead. The shielded cable can then continue to its destination (or source) in the enclosure. The shield should NOT be connected to any other point within the enclosure. Only the bulkhead should be used for the enclosure reference. The shielded cable should be connected to the enclosure bulkheads at both ends of the inter-enclosure cable run.

NOTE

It is important to provide good R.F. continuity between the shield and the enclosures it traverses. However, if the enclosures traversed are powered from separate primary power sources (as described in para. 4.1.1), then low-frequency (50/60 Hz) connections should be avoided to prevent loop currents from flowing in the shield. An acceptable solution is to connect the shield to one (either one will do) of the enclosures traversed through a capacitor (0.5 uf typical). This capacitor should provide low impedance at high frequency.

Where connectors are used for the cable termination at the enclosure bulkhead, provisions must be made for terminating the cable shield, either through a connector pin or by a stud near the connector.

6.2.4 Non-Shielded Cables

It is recommended that no unshielded cables be allowed to cross an enclosure boundary unless a filter is provided for the cable at the enclosure bulkheads of both the source and destination enclosure.

These filters utilize L-C networks. Because of their inherent delay and impedance characteristics, their use is in general restricted to low speed signal cables. High speed (bus) signals typically cannot tolerate the capacitance associated with these filters, and therefore must be shielded. (See para. 6.2.)

If metal cable ducts used are in accordance with para. 5.2 then the cable does not leave the enclosure (and no filtering is necessary) unless the cable leaves both the enclosure and the duct. That is, the duct is considered to be an extension of the enclosure, and the interface between an enclosure and a duct (properly bonded to the enclosure) does not constitute crossing an enclosure boundary.

7.0 CABINET CONFIGURATION RULES

Configuring the cabinet is similar to configuring a miniature system whose boundaries are restricted to the cabinet. The same rules about signal and primary power cable separation apply, as well as controlling the distribution of cabinet earth reference to the individual box earth references.

7.1 SEPARATION OF CABLE ROUTING WITHIN A CABINET

Primary power cables must be separated from signal cables within a cabinet by a minimum of .15 meter. To provide a uniform cable routing scheme which can maintain this separation criterion, the following configuration suggestion is given:

1. All primary power wiring within a cabinet should be routed near the edges of the cabinet (either the right edge or the left edge, whichever is more convenient on a unit-by-unit basis). Primary power wiring should not be routed in the center of the cabinet.

2. All signal wiring within a cabinet should be run in the center area of the cabinet, maintaining a minimum .15 meter spacing from primary power wiring at the edges of the cabinet.

Figure 9 gives a pictorial display of this wiring convention.

7.2 CABINET FANS

Cabinet fans must be considered when configuring a cabinet, as they pose a potential electrical noise threat to the system. This threat appears in two forms:

1. Inductive transients (spikes) placed on the primary power lines when fan power is disconnected. This can occur during either a failure in the fan circuit, or during normal power down sequencing. Note that the system must maintain its reliability even after the fans stop, as a powerfail sequence may be incurred. For example, the cabinet may be only one part of a multi-processor system.

2. Running (normal operation) noise from commutator-type motors with brushes. Note that induction motors do not constitute an appreciable noise source.

In either case, steps must be taken to suppress the noise. A capacitor placed across the primary power input to the fan, and located at the fan, is usually sufficient. A typical value for this capacitor is 1 uf for a 200-400 cfm fan.

** WARNING **

This voltage rating of this capacitor should be such as to withstand the induced transient voltage. (Typically 1 kV transient rating.) Rating this capacitor for the nominal operating voltage is not sufficient.

7.3 SIGNAL CABLE ROUTING WITHIN A CABINET

As stated in para. 7.1, signal cables shall be routed through the center area of the cabinet. Additionally, a spacing must be maintained between all signal cables and any metal cabinet surface of at least 20 mm. This implies spacing signal cables away from skins, cabinet framework, back doors, etc. The 20 mm figure was chosen to reduce the impact on impedance and crosstalk of the cables, to maintain the isolation of logic reference from the enclosure, and to insure that there will be no breakdown of the isolating medium during a 15 kV static discharge. (See Figs. 8 and 9.)

In practice, some proximity between primary power and signal cables must be tolerated. However, these should be minimized. Also, any physical crossings of primary power and signal cabling should be done at an angle of no less than 45 degrees, with a minimum amount of parallel overlap between cables. This last statement should not be taken as a liberty to cross cables an excessive number of times, even though the crossings are done as prescribed. In all cases the number of crossings between, and the proximities of signal and primary power cables should be minimized.

Note that the impedance characteristics of cables need only be considered when the cable used must be treated as a transmission line. A signal cable must be considered a transmission line whenever the electrical round trip time on the cable exceeds one-half the response time of the receiving circuitry.

7.3.1 Flat, Multi-Conductor Cables

There are four main types of flat, multi-conductor cables in common use within DIGITAL. These are:

1. Cables with neither a shield nor a reference plane provided.

2. Cables with a reference plane provided (generally a fine wire mesh grid), but no provisions for connecting the reference plane to a logic reference point at the source or destination.

NOTE

This type of cable (unconnected reference) is not recommended for use in new design, because of undefinable impedance and crosstalk characteristics.

3. Cables with a reference plane provided, and the reference plane connected to one or more wires in the cable (internal connection). This reference plane in the cable must be connected at its terminations to the logic reference for the signals the cable carries. Note that this connected reference plane in no way constitutes a shield for the cable, as discussed in para. 5.2, 6.2 and 6.2.3.

4. Multiple, individual coaxial cables. Note that the outer conductor of a coaxial cable does not constitute a shield as discussed in para. 5.2, 6.2, and 6.2.3.

Each type of cable has certain properties which will affect how it can be properly routed to provide maximum signal integrity. The cable properties will also generally determine the types of signals each cable is capable of transmitting successfully.

7.3.1.1 Flat Cable Stacking

In long (greater than .1 meter) cable runs, where multiple flat cables must follow the same general path, it is common practice to stack the flat cables to provide a neat, easy to handle group, with very high conductor densities. In fact, this is one of the major advantages of using flat cables. But the designer must realize that stacking of two or more cables will affect the characteristics of both cables, unless cert- precautions are taken. Each type of cable listed above reacts differently to stacking.

In the first and second types (no reference plane or unconnected reference plane), cable impedance will decrease with stacking, while crosstalk will increase with stacking. The cable impedance reduction may be undesirable, however the crosstalk increase is always undesirable. Note that unconnected reference plane cables are not recommended for use in new designs.

In the third type (connected reference plane), both cable impedance and crosstalk will be decreased by cable stacking. Lowering the cable impedance, however, may not be a desired effect.

The fourth type of cable (multiple coaxial) is not affected at all by stacking. No impedance or crosstalk changes will occur.

In any of these cases, if these crosstalk and impedance problems incurred will affect design requirements, separation of stacked layers by approximately 7 mm (1/4 inch) of foam (or other appropriate separator) over the entire length of the cable run solves virtually all of the aforementioned problems. It reduces the crosstalk coupling coefficients and restores the characteristic impedance of the cable to its nominal value. (See Fig. 8.)

This 7 mm spacing should not be construed as a restriction on close proximity between cables for short distances (such as box entrances, and cable clamps). A good rule is that any tight coupling (less than 7 mm spacing) should be limited to a maximum length of .1 meter of parallel cable run. This limit is based on a signal rise time greater than or equal to 5 ns.

7.3.1.2 Flat Cable Routing

All types of flat cables (including coaxial) routed near metal surfaces affect system signal integrity. Care should be taken so that no close coupling is allowed between cable runs and metal frame hardware. This is especially important for the reduction of susceptibility of the system to static discharge. Separation of cables from metal surfaces by 20 mm will virtually eliminate any coupling from cable to the metal surface, as well as prevent any breakdown of the insulating medium by a 15 kV static discharge. Again, if close coupling (clamping at entrances/exits, strain relief points) is required, it may be done satisfactorily over a maximum of .1 meter of the cable run. Any such clamping should be done internal to the enclosure, away from outside surfaces.

7.3.2 Round, Multi-Conductor Cables

Round, multi-conductor cables at DEC can generally be grouped into two classes; controlled impedance and uncontrolled impedance types.

There is an advantage in the use of round cables (as opposed to flat cables) with respect to cable routing. In round cables, the internal lay of the wires (their spiral rotation within the cable jacket) does not allow any individual wire to be close to any structural metal the cable is routed near for any appreciable continuous length. Thus separation from structural hardware becomes less critical.

When using round cables, the placement of the conductors in the cable must be considered. The relationship of any wire to any other wire in the cable must be specified. Also, the direction of the lay of the cable, and the lay pitch, must be such that this relationship is maintained throughout the cable length.

7.3.2.1 Controlled Impedance Types

In the case of controlled impedance cables care must be taken in cable stacking and grouping, and to some lesser degree (as described above) in routing.

For non-shielded, controlled impedance round cables, the rules given in para. 7.3.1 for flat cables with no reference plane are applicable.

For shielded, controlled impedance round cables, the rules given in para. 7.3.1 for multiple coaxial cables are applicable.

7.3.2.2 Non-Controlled Impedance Types

Since these cables do not have a specified characteristic impedance, they should not be used for the distribution of high-speed signals. However, to preserve system signal integrity, the rules outlined in para. 7.3.1 and 7.3.2 should be followed.

7.4 POWER CONTROL BUS ROUTING WITHIN THE CABINET

It is important for the individual responsible for cabinet configuration to realize that power control bus cables are to be treated as neither power cables nor signal cables. They exist in a category by themselves, and must be treated as such.

It should be understood that the current configuration and utilization of the power control bus presents a paradox in terms of signal integrity. On the one hand, the bus is referenced to earth and couples to the primary power earth reference wiring at the power control. On the other hand, the sensors (overtemperature, etc.) and switches (power on/off) that the bus interfaces with are generally located close to logic. Additionally, current practice allows the power control bus to be routed between enclosures with no shielding or filtering, rendering it highly susceptible to noise pickup.

In the future, it will become necessary to isolate the power control bus from logic, thereby allowing future configurations to couple the power control bus to the primary power distribution wiring with no adverse effects. Until then, intermediate measures must be taken to help alleviate the problems induced by coupling the power control bus to both the primary power and logic signal distributions. The following should be considered:

1. All power control bus routing within a cabinet (typically from the power control to the sensors/switches) should use cables with an insulated shield covering. The shield should be connected to the cabinet chassis at both ends of the cable. In order to fully realize the effectiveness of this treatment, the cable shielding should be maintained inside any box it enters within the cabinet. This will provide a minimal opportunity for exposure of this cable within the box. The length of any unshielded cable run should be minimized.

2. If shielded cable cannot be provided, the designer should maintain a minimum .15 meter spacing from signal cables, and a minimum 7 mm spacing from primary power cables when routing the power control bus within a cabinet. No care need be exercised in isolating the power control bus from the cabinet chassis.

When it is necessary for the power control bus to be routed between enclosures, the decision must be made as to whether or not to dress the cable in any available signal cable ducts. If the power control bus is not shielded for all cable runs within the cabinets, the cable should be routed in the available ducts. However, any power control bus cables run inside these ducts must be separated from signal cables in the same duct by a minimum of 7 mm. If the bus cable is shielded for all cable runs within the cabinets, any cable routing external to the enclosures should be done outside of any available signal cable ducts. (Refer to para. 5.3)

7.5 CABINET DESIGN FOR IMPROVED TOLERANCE TO HARSH ENVIRONMENTS

The cabinet (and therefore, the enclosure) should provide protection against incident electromagnetic energy. To do so requires that the structure surround (shield) the internal electronics as much as practicable with an electromagnetic barrier. The degree to which this is acheived is the degree to which the enclosure will reduce the incident energy.

Cabinets have historically been fabricated from sheet steel, which as a material is very effective against both electric and magnetic fields (both are always present in a radiated wave). Although the choice of material is appropriate, the cabinet design is typically not, since earlier design goals emphasized low cost (therefore wide tolerance), mechanically rugged structures. Cabinet design goals must now consider electrical (signal integrity) requirements.

One approach to reaching this added design goal would be to introduce the equivalent of an EMI shielded cabinet. However, this would represent a high cost to many less critical installations which do not require it. Another approach would be to design a separate line of EMI shielded cabinetry for special applications. The cost of design and the impact on manufacturing control would make this unattractive. The recommended approach is to design the cabinet with the necessary 'hooks' to allow the electrical hardening to be included as an added cost option to the basic cabinet. These hooks include:

1. Providing adequate space for the installation of conductive finger stock or gasketing, to form an R.F. tight seal around the edges of the cabinet.

2. Use of plated or non-corrosive metals where electrical conductivity may be important. This includes the areas described above for the installation of finger stock or gasketing. Dress panels should be designed to make good electrical contact with the cabinet frame structure. Painted cabinetry does not allow easy addition of electrically conductive materials to the cabinet frame later on. Use of non-painted cabinets also increases the probability of low impedances across the cabinet structure, thereby improving safety performance. Plastic cabinetry requires special consideration.

3. Proper selection of airflow (vent) hole size and patterns. The ability of a perforated metal to shield against electromagnetic energy is a function of the largest dimension of any apertures. By properly selecting the vent aperture size and shape, effective shielding can be achieved while still maintaining required airflow characteristics. (As a rule of thumb, the largest dimension of any vent holes should be less than 25 mm.)

8.0 FUNCTIONAL UNIT (BOX LEVEL) CONSIDERATIONS

Within a functional unit (box), it should be considered a design goal to effectively isolate the unit's logic reference from the chassis of the unit and thereby reduce the coupling between the two. The beneficial effects of this procedure will become realizable as more interconnected units provide this isolation.

The designer must be aware that there is a conflict of interest between the needs of the box chassis and the logic reference. Ideally, logic should be totally isolated from chassis (no connection made at all) to optimize signal integrity. Unfortunately, present and near-future designs will require logic to be connected to chassis at one point, for safety reasons. Consequently, control over how this logic-chassis connection is made must be maintained. Note that the use of double insulated power systems will remove the requirement for a logic reference to chassis connection since the safety requirements will have been met.

A rule of thumb is to limit the coupling between logic reference and accomplished while still maintaining the required safety connection by using a low-Q inductor as the connection between logic reference and chassis.

8.1 SAFETY WIRE CONNECTIONS

The primary power cable entering a box shall have a wire provided for a safety connection. The design engineer should refer to DEC Standard 119 for information on equipment safety.

8.2 BOX LEVEL SIGNAL REFERENCING

The isolation between logic reference and chassis should be designed into all boxes (and therefore all subassemblies within boxes). There are two general considerations:

1. Do not use the chassis as a distribution plane for logic reference. All boxes should function properly whether the logic is referenced to chassis or not.

2. Minimize parasitic coupling capacitance between logic and chassis through proper hardware layout. The greater the physical separation between logic components and chassis, the less the capacitance. Circuit boards parallel to a metal box surface should be spaced a minimum of 15 mm from that surface.

The unit's logic reference, if connected to the earth reference, should be connected at only one point, and this point should provide a convenient means by which this connection can be removed. This allows for the installation of an R.F. isolating inductor between logic reference and the earth reference, or the complete removal of the wire, where it can be determined that the connection is unnecessary.

If a box is designed to also be an enclosure, then additional spacing of logic components from chassis may be necessary to avoid the possibility of breakdown during an electrostatic discharge. A spacing of 20 mm is sufficient ro protect against a 15 kV discharge.

8.3 SIGNAL DISTRIBUTION

Every logic path must have a unique, expressly designed return path. Any given cable, either flat, round or simply harnessed wires should carry only one family of signals. Logic families (TTL, ECL, analog, etc) should NOT be combined in any cable or harness unless the designer is prepared to take specific care with respect to the coupling coefficients between conductors in the cable.

8.3.1 Cable Distribution

The rules and information given in para. 7.3.1 and 7.3.2 for cable stacking and routing within a cabinet are also generally applicable within a box. Long cable runs are less likely within a box because of the physical size. Close coupling between cables or between cables and chassis should be avoided in cable runs in excess of .1 meter.

8.3.2 Wire Harnesses (Non-Jacketed Cables)

Harnesses are not an exception to the general rule given in para. 8.3. Harnesses should not contain signal wires from more than one logic or signal family, unless the designer has taken care of the coupling problems.

Because of this restriction, the use of harnesses (as opposed to cables) for signal distribution should be avoided.

8.3.3 Individual Wires

One single wire does not constitute an acceptable logic path, since the return path is poorly defined. Every signal wire must have a well defined, expressly designed return path associated with it, which is closely coupled to the signal wire.

8.4 PRIMARY POWER WITHIN A BOX

8.4.1 Primary Power Entry and Distribution

The location of the primary power entry, and its distribution within the box, should be well-defined. A corner of the box should be selected for the primary power cable entrance. This will allow for conformance with the convention for primary power and signal cable placement in a cabinet, as outlined in para. 7.1. Selecting a corner for primary power ent:_ will also make it a relatively simple matter to isolate the primary power distribution from the signal and D.C. distributions in the box. Separation of primary power from signal cables must be maintained at a minimum of .15 meter, as specified in para. 7.1.

Contrary to the rules for signal cable distribution, primary power should be routed as closely to the edges of the box as possible. This will provide a good, high-frequency distributed capacitance from the primary power to chassis, which will help reduce noise conducted in and out of the box on the primary power cable. It will also increase the isolation from primary power to signal cables, since signal cables should be routed away from the edges and surfaces of the box.

NOTE

> The previous discussion assumes that the box chassis is at earth reference, as is common in DEC equipment. If the chassis of a box is not referenced to earth (it may be at logic reference, eg., the BA11-P as used in the 11/60) then it is not desirable to route the primary power distribution close to the chassis. In this case, care should be taken to isolate the primary power distribution from the chassis, since this would imply coupling to the logic reference.

Unneccessary distribution of primary power within a box should be minimized. For example, it is usually ill-advised to route primary power to a front panel power switch.

8.4.2 Power Line Filters

Power line filters are not always required. For example, if the box under consideration can never be its own enclosure (there is always some superstructure housing it), then filtering will always be provided at the enclosure (or cabinet) level. Intra-enclosure EMI considerations, however, may mandate the use of a power line filter at the box level. The engineer responsible for the box should investigate the need (or lack of need) for a power line filter, taking into account the emissions and susceptibility characteristics of the subassemblies in the box, and the manner in which the box is configured in a system.

If a power line filter is called for, care should be taken in its installation to insure its effectiveness. Specifically, the following criteria must be met:

1. Any filter having common mode insertion loss (component(s) connected from primary power to chassis) must be securely bonded to the chassis with a low impedance connection. This implies mounting a metal-cased filter on a plated surface (no paint). In general, a wire from the filter case to a chassis stud does not suffice for a low impedance connection at high frequency.

2. Input and output leads from the filter should be routed as close as possible to the chassis, in order to provide a good, high-frequency distributed capacitance.

3. Input leads to the filter must be isolated from the filter's output leads. The preferred situation is a metal bulkhead on which the filter is mounted, with the input leads on one side, and the output leads on the other side of the bulkhead. Under no conditions should the filter's input and output leads be harnessed in the same bundle.

8.4.3 Primary Power Outputs

If primary power outputs (receptacles) are provided on a box, then that portion of the box which performs this function should follow the same rules as for a power controller. These rules are given in para. 9.1.

8.5 D.C. POWER DISTRIBUTION

This section refers to distribution of D.C. outputs from power supplies, and any associated power signals (eg., remote sense). It does not refer to power control signals, or power supply logic signals (eg.,AC/DC LO).

The functional element to which the D.C. power is being supplied establishes the logic power reference for that D.C. power. If two or more functional elements communicating via logic paths derive their D.C. power from a single source, then special care must be taken to insure that the power wires do not form an alternate path nor become a source for introducing D.C. power related noise into the logic paths. In no way should the D.C. power source attempt to provide a logic reference for the functional elements.

D.C. return leads should follow the same path as the D.C. power leads, to reduce the possibility of forming a magnetic loop antenna which can efficiently radiate noise into the system.

D.C. power distribution should be isolated from primary power distribution (para. 8.4.1), as well as any signal distributions (para. 8.3). This is in line with providing isolation between earth and logic references.

Remote sense leads, if required, should be routed using twisted pair or shielded cable, and should in addition be routed over the same path as the power supply outputs it senses. They should be sufficiently isolated from the power leads to reduce positive feedback and resulting instability of the power supply.

Within a box, any unregulated D.C. distribution should be isolated from regulated D.C. Close coupling between the two should be avoided in cable runs in excess of .1 meter.

Special consideration must be given to D.C. power distribution systems which require a portion of the output of a common power supply to be switched (on or off) while the remaining portion must still supply power to an operational element. If not handled properly, the transient created by the switching action could cause a failure of the operational element.

8.6 POWER CONTROL BUS DISTRIBUTION IN A BOX

Power control bus routing within a box must be compatible with the routing of this bus at the cabinet and system levels (refer to para. 5.3 and 7.4). The box designer must take care not to allow excessive coupling between the power control signals and either the logic or the primary power distributions in the box. Specifically, no power control bus signals should be coupled either conductively or capacitively (parasitically) to any logic signals. In order to acheive these ends, the designer should implement one of the following:

1. The power control bus should be distributed using cable having an insulated shield covering. The shield should be connected to the box chassis at both ends of the cable run. This applies only to boxes whose chassis are at earth reference, as in current DEC boxes. If the box chassis is not at earth reference, the shield should not be connected at both ends to the box. Alternative shielding means must be employed. Any length of unshielded cable must be minimized.

   It is understood that often the power control bus must be routed via printed circuit etch (eg., console keyswitches). The designer should plan the printed circuit so as to minimize the length of unshielded power control bus run that this circuit etch represents. A minimum of 7 mm spacing between power control and logic signal distribution on the circuit board is required.

2. If shielded cable is not provided, the designer must maintain a minimum .15 meter spacing between the power control bus and any logic or primary power distribution within the box.

It must be understood that choosing unshielded cable inside the box is undesirable. This forces the cabinet configurer and the system installer to use shielding in their respective cable routings. The proper use of shielded cable in the box is the preferred choice.

8.7 FANS

Fan wiring in a box is generally considered to be primary power distribution, and the rules given in para. [8.4.1] are also applicable to fan wiring in the box.

The possibility of D.C. fans and the distribution of their wiring will be considered for a future release of this document.

There may be long term benefits in isolating fans from chassis (at both D.C. and R.F.), either by appropriate mounting hardware, or specifying proper isolation from the fan winding to the fan frame in the purchase specifications for the fans. This issue will be decided after acquiring a better understanding of the benefits of increased decoupling of primary power from the enclosure.

8.8 POWER SUPPLY/LOGIC INTERFACE SIGNALS

Power supplies must often provide logic signals to the devices they power. The most common of these are powerfail signals (AC/DC LO), and the 50/60 Hz line clock. Because the power supply is the location where these logic signals must interface with primary and D.C. power, care must be taken to provide necessary decoupling and isolation between the different families of signals. The designer must realize that, even though they are located in a power supply, the logic signals cannot be treated the same as primary power or D.C. distributions. (Refer to para. 8.3 for logic signal distribution guidelines.) The following general guidelines should be followed:

1. Minimize wire lead and etch run lengths of logic signals in power supplies. The shorter the lengths of these wires, the less susceptible they are to the noise influences of the power supply.

2. Isolate power supply logic signal distribution from primary power and unfiltered D.C. distributions by a minimum of 7 mm. This is to minimize capacitive coupling between the different families. This rule should be adhered to both in wire harnesses and printed circuit etch.

3. Isolate power supply logic returns from D.C. power returns. The reference for the logic signals should be derived from the logic that uses the signals, not from the power supply. Indiscriminate connections between the power supply reference and the logic reference should be avoided.

4. Use twisted pair wires to connect the logic signals from the power supply to the backplane or other termination. This twisted pair should not normally be harnessed in the same bundle as the D.C. power outputs of the power supply, even though they may have the same destination. Minimum 7 mm spacing should be maintained. If this is not possible, it may be necessary to use shielded twisted pair for the logic connection.

5. Filter the power supply logic signals as close as possible to the logic which utilizes it. Typically the power supply logic signals are not high speed nor do they require fast rise times. Therefore, filtering is an excellent means of further protecting the logic from power supply noise coupled through the power supply logic signals. Filtering may consist of common mode capacitance or other more elaborate networks.

   It is important to realize that this filtering may cause rise times to be slowed down enough to cause the signal receiver to oscillate. The use of local bypass capacitors is the recommended solution for this problem. The engineer must consider this in the design.

9.0 SUB-ASSEMBLIES

A subassembly is any logic element or component which is a subdivision of a logic box.

The designer of a subassembly should insure that the satisfactory operation of his device does not depend upon the referencing of logic to earth at any point. The equipment should operate whether or not an earth reference is provided at the box, cabinet, enclosure, or system level.

If it is determined logic will be referenced to earth at some point in the box, no designer of a subassembly for that box should assume that their subassembly will contain the logic-to-earth connection. That function should be provided by the box, not by a subassembly. The intent of this is that each subassembly should be a functional device unto itself, operating with or without an earth reference provided at the box, cabinet, enclosure or system level. If an earth connection is to be provided, it is a system consideration, not to be assumed by any subassembly designer.

9.1 POWER CONTROLLERS

A power controller is a device which has the ability to control the application and removal of primary power by means of electrical or electronic control. Often, many other functions can be performed within this same device, including:

1. Power line filtering
2. Overcurrent protection
3. Implementation of the DEC Power Control Bus
4. Power switching and/or sequencing
5. Distribution point for primary power within the enclosure although these are not required in any given power controller.

Commonly, power controllers use a contactor to connect/disconnect primary power on demand. Because of problems due to transients generated by opening and closing of contacts, transient suppression should be included. This suppression should be sufficient to limit the transient voltage to 125% of the peak voltage at nominal line.

If the power controller contains a transformer to derive the voltages necessary to implement the DEC power control bus, this transformer should insure that the only coupling between the primary and secondary is magnetic, not capacitive. A split bobbin transformer is suitable. Double insulation of this transformer is also desirable, to allow the future implementation of a power control bus which is not referenced to chassis at the transformer secondary.

Since the power control bus is often routed near sensitive logic components, it is necessary to minimize the capacitive coupling from the bus lines to the primary power.

9.2 POWER SUPPLIES

Power supplies, like any subassembly, should not provide a connection from logic reference to earth. The presence and location of that connection is a system issue.

For power supplies with inductive inputs (eg., ferroresonant transformers), the designer must provide input transient suppression to insure that inductive transients (spikes) are not generated on the primary power input when power is disconnected. This transient suppression must guarantee that any transient presented to the primary power line has an amplitude no greater that 200 V above the peak voltage at nominal line, and a rise time not more that 1 V/us.

The common mode (any output to earth) impedance looking back into the D.C. outputs of any power supply should be 100 ohms minimum, measured at any frequency from D.C. to 30 MHz.

9.3 BACKPLANES

9.3.1 Interfacing Across the Backplane Boundary

A unique location on the backplane should be defined and reserved for D.C. power entry and the backplane logic return.

In addition, power and power return leads should enter the backplane at the most centralized location possible, in order to minimize the voltage drop seen by the logic using the backplane.

Signal connections, when made to the backplane, should be located no more than 50 mm from the edge connector finger used for the signal interconnection to the circuit board. Logic reference conductors in the cable must be kept separate from D.C. power return distribution at least until connection is made with the circuit board edge connector (source/destination), unless the backplane logic reference distribution is a contiguous etch plane.

9.3.2 Backplane Logic Reference

The backplane should provide a contiguous, uninterrupted logic reference plane (not broken up by power or signal runs, etc.). This will reduce the possibility of voltages appearing across logic returns, which appear as noise in the system.

There should be a single point identified on the backplane, known as the backplane logic reference, from which this logic reference plane is derived. This should be the only point on the backplane where an external (non-backplane) connection to logic reference is made. (This may be to a common reference point in the box, or earth.) The backplane is a leaf of the tree-structured logic reference distribution system discussed throughout this document. THE TREE STRUCTURE DOES NOT APPLY BELOW THIS LEVEL. It is not necessary to design against logic reference loops on the backplane. A matrix or planar logic reference distribution system is desirable.

The logic reference plane should be electrically isolated from any mechanical mounting of the backplane. This isolation should be such as to provide both D.C. isolation and a minimum capacitive coupling in order to maximize isolation at high frequencies. If the backplane is to be mounted directly on an enclosure structure, then separation sufficient to prevent breakdown during an electrostatic discharge must be provided. A spacing of 20 mm is sufficiant to protect against a 15 kV discharge, as required by DEC STD. 102, Section 7.

9.3.3 Backplane Signal Integrity

Care should be taken so that the integrity of critical signals is not diminished on the backplane. These include fast rise-time clocks and all edge sensitive signals. Of extreme importance in this regard are signals which perform system (or sub-system) initialization functions, as improper assertion of initializing signals may cause the system to require manual intervention (with possibly severe data losses) to bring the system back to its normal state. Critical signals should preferably be run in backplane etch. These critical etch runs must be isolated from other logic signals by appropriate spacing (at least twice the minimum etch spacing required), or by providing a logic reference etch on both sides of the critical path. Barring the use of backplane etch, twisted pair wire should be used when using wire-wrap technology for these critical signal connections. It is important to control the placement of all wiring in order to acheive consistency and predictability of effects due to crosstalk.

If there are to be signal connections (of any type) across a segmented backplane, there should be at least as many return connections as signal wires, and these return connections should follow the same paths as the signals. Twisted pair wire is excellent for this purpose, as its use insures meeting this requirement.

9.4 CONSOLES

This section outlines the signal integrity considerations to be made when designing an operator's console. This should not be confused with a console terminal, whose guidelines are the same as for any other terminal (or any other peripheral, for that matter).

The console is in a particularly high susceptibility location, since it typically must interface intimately with internal system logic (processor registers, etc.) not available in other locations. Unfortunately, it is also a prime human interface, and therefore must often be exposed both physically and electrically to the environment.

A general consideration for all types of consoles is that if the console is designed to support more than one host (eg., a multi-processor console), the logic necessary for the support of each individual host should be independent of the logic for the other hosts. No unnecessary connections should be made between the logic paths of the multiple hosts.

Console cables (from console to host) should follow the same rules as for any signal interconnecting cable. These are outlined in para. 5.2, 6.2, 7.3, and 8.3. Console circuit boards should follow the same rules given for all circuit boards in para. 9.6.

Console designs have historically taken many different forms, and promise to change even more in the future. However, the forms can be grouped into 4 generic types, discussed individually below.

9.4.1 Consoles Electrically Exposed to the Environment and Mechanically Separated from the Host

This implies a console which is not within the enclosure of the host, and which is electrically exposed (i.e., not in a shielded structure). Consoles of this type must be treated similarly to the treatment of external peripheral devices. Because of the sensitive nature of the host, these consoles should:

1. Use only switch contacts and/or indicator light functionality. If this is not possible, then

2. The console should utilize slow data rates for active transmission to allow for the implementation of electrical or logical filtering at the host.

The console signal cable(s) should enter the host's enclosure at the I/O interface bulkhead, and should be adequately filtered at that bulkhead. Optical interconnect provides excellent filtering, and should be considered seriously for this type of console. In addition, logical filtering (eg., time discriminant circuitry) should be provided that can allow the host to discriminate against noise.

9.4.2 Consoles Electrically Exposed to the Environment and Mechanically Within the Host Enclosure

Typical of this type of console is the PDP 11/45 style console. The console is exposed both to external electromagnetic fields and electrostatic discharges, but is contained within the enclosure of the host processor.

Guidelines with respect to signal types and speeds are identical to those in para. 9.4.1. In addition, the interface cable between the console and the host must be shielded, with the shield connected to both the enclosure frame at the console end, and the I/O interface bulkhead. This is done to prevent radiation from the unfiltered console cable from affecting other logic within the enclosure. Note that this shielded cable from the console to the I/O bulkhead is routed inside the enclosure. The cable must additionally be filtered at the I/O interface bulkhead, to eliminate noise picked up due to the electrically exposed nature of the console.

9.4.3 Consoles Electrically Protected from the Environment and Mechanically Separated from the Host

An electrically protected console implies that the structure of the console provides sufficient isolation from the environment. This means that the human access (if any) to the console must be via electrically insulated means, across an electrical and mechanical barrier. An example of this would be making switch contact closures by pressing a plastic coated (outside) metallic sheet, which contacted another conductor on the other side of the sheet. The metallic sheet would provide an electrically protected structure, while the plastic coating would provide insulation between operator and logic.

The mechanical separation of this console from the host should be in such a way so that the console is housed in a physicaly extension of the host enclosure, that is, although physically separated from the host, the console is in the same electrical enclosure. No interconnecting cables of any kind (signal, power, etc.) may cross the extended enclosure boundary. In addition, no console logic may be referenced (connected) to this enclosure extension. All referencing of signals should be with respect to the logic reference of the host, provided by interconnecting cables.

Note that this enclosure extension may be connected to the host enclosure at any appropriate point, that point not necessarily being the I/O interface bulkhead.

For electrostatic discharge protection, the breakdown voltage from the enclosure extension to the console logic or interconnecting cables should be 15 kV minimum (20 mm spacing).

9.4.4 Consoles Electrically Protected From the Environment and Mechanically Within the Host Enclosure

This implies a console which has the electrical characteristics of the console described in para. 9.4.3, but is housed in the same enclosure as the host, i.e., there is no enclosure extension. This is the preferred method for new consoles.

As in para. 9.4.3, access to the human interface should be through insulated means only. Breakdown voltage for electrostatic discharge protection is again 15 kV (20 mm spacing) from the enclosure to any console logic or console cables.

Console logic should be referenced solely through interconnecting cables with the host, and not connected to the enclosure in any way.

9.5 BATTERY BACK-UPS

Battery backup units are provided to allow for maintenance of some (or all) system activity in the event of loss of primary power. Batteries contained internally to system enclosures often do not have sufficient capacity to provide the necessary system functions for an appreciable length of time. Often, it is necessary to have larger batteries external to the enclosures to provide the needed backup.

External batteries, however, must be treated as sources of primary power. In this respect, the following guidelines are recommended:

1. If external battery inputs are provided by a battery backup unit in a system enclosure, these input terminals must appear on the I/O interface bulkhead for the enclosure, and must be adequately filtered at that interface bulkhead.

2. If external batteries are normally charged from another source of primary power (eg., A.C. mains), that primary power must be derived from the system distribution panel in the same manner as any system device receives its power.

9.6 CIRCUIT BOARDS

9.6.1 Logic Reference Distribution

The choice of a circuit board logic reference distribution system is heavily dependent upon the type of logic (family) employed, and the inherent speed of the logic.

ECL, being extremely high speed and highly sensitive to noise and impedance variations, mandates the use of a contiguous logic reference plane (separate layer of circuit board) for distribution of its logic reference.

The high speed Schottky, low power Schottky, and high power TTL logic families also require special care in their logic reference distributions. The minimum requirement is a matrix of logic reference connections, with each logic component's reference directly connected to each of its nearest neighbors on the circuit board. The contiguous logic reference plane described for ECL is also suitable, and in addition is required if etch lengths exceed .3 meter. (See Fig. 11.)

MOS, CMOS, and low power TTL do not require as much special attention. The logic reference for 6 or fewer adjacent logic components (I.C.'s) may be daisy chained together, with the daisy chained groups being interconnected in a matrix fashion. This is a relaxation of the Schottky distribution which requires each component to be in the matrix.

Regular TTL (7400 series) logic reference distribution should follow the same rules as for low power TTL (above), however the daisy chained groups should not exceed 3 in one chain.

Refer to para. 9.6.3 for a discussion of multiple logic families on a single component (eg., MOS-TTL level shifter).

The extension of the circuit board logic reference to the mating backplane must be done using multiple contacts (pins) distributed evenly along the connecting interface (edge connector). Doing this provides a low impedance signal reference to the backplane. Where logic reference appears at multiple points on an edge connector, these points must be interconnected on the circuit board to insure that all the logic reference connections are at the same potential. (See Fig. 11.)

The designer must insure that the logic reference connections have sufficient current carrying capacity to handle the total requirement of the circuit board.

9.6.2 Transient Decoupling

9.6.2.1 Circuit Board Level

The D.C. power supply voltages should be decoupled at the circuit board level by capacitors located near the power entrance to the board. An appropriate value for the capacitance is 30 uf per ampere of current drawn by the board. This capacitance should be distributed across the area where the power enters the board.

9.6.2.2 Component Level

Signal integrity demands adequate decoupling of D.C. power at the component level. The minimum requirement for multilayer (contiguous logic reference plane) circuit boards is to have one .047 uf decoupling capacitor for each 4 logic components (I.C.'s) on the board, with no component more than 25 mm from its associated decoupling capacitor. For non-multilayer boards (single or double-sided), .01 uf capacitor is required for each I.C. on the board, with the capacitor located no more than 1 cm from the decoupled I.C. Minimum lead lengths should be maintained on decoupling capacitors.

Where power and power returns are daisy chained, the chaining should be done at the decoupling capacitor and not at the component.

High current circuits must be designed with sufficient local decoupling and minimum circ etch length in order to keep these high current transients away om the reference of sensitive logic circuits.

9.6.3 Multiple Logic Families On a Circuit Board

When using more than one logic family (TTL, MOS, ECL, linear) on one circuit board, special care must be taken to insure that the different logic families do not interfere with each other.

Logic designers must be aware of the differences in the logic families they use; how one type might affect the other when used in close proximity. Some guidelines to follow to minimize the interaction of different logic families are:

1. Divide the circuit board into appropriate segments and use only one logic family in each segment.

2. Lay out the logic reference and D.C. power distribution etch unique to each segment first, then tie the separate segments to each other and to the supply points (edge connector) by wide, short etch runs. These etch runs should form a power distribution bus.

3. Communication between the separate logic families should be done by components located adjacent and directly connected to this power distribution bus etch.

4. Etch carrying signals from different logic families should be grouped by family, with liberal space between the groups from different families. Separating the groups of etch by logic reference etch is often useful.

In cases where multiple logic families exist on a single component, (I.C.) the component should be located so as to bridge the boundary between the logic families interfaced. The power supply decoupling and logic reference distribution must be chosen appropriately for the most sensitive logic family employed.

These guidelines serve to decrease proximity between differing logic families, eliminate power supply 'glitch' currents from one logic family from passing through board segments containing other logic family components, and minimize logic reference offsets over communication paths between segments.

9.6.4 Interfacing Signal Cables to Circuit Boards

Signal cables whose signal round-trip time exceeds one-half the response time of the receiving circuitry must be considered transmission lines. In this regard, the interfacing components (drivers and receivers) must be chosen with certain criteria in mind.

9.6.4.1 Signal Cable Drivers

When selecting signal cable drivers the following characteristics should be considered:

1. Current sufficient to drive the characteristic impedance of the cable, including allowance for a certain amount of mismatch. (A rule of thumb is to require the drivers to be able to source/sink 170% of the nominal line current calculated by dividing the output voltage by the line impedance.) This enables drivers to operate correctly during the dynamics of transmission line reflections.

2. Controlled rise/fall times. Crosstalk is reduced by long rise and fall times, depending on cable length.

9.6.4.2 Signal Cable Receivers

Signal cable receivers should provide:

1. Logic thresholds symmetrical about their active voltage swing, giving a balanced noise margin. This can be acheived either by selecting the receiver with the necessary characteristic, or by adjusting (biasing) the drive signal to move the voltage swing until symmetry is acheived.

2. A.C. (glitch) noise immunity.

3. High input impedance, with low input capacitance. (This is especially important in multi-drop bus signals.)

Logic reference lines in the cable must be directly connected to the interfacing component for the associated signal line by an etch length equal to that of the signal connection. (See Fig. 12.) There should ideally be as many returns provided as signal wires. Practically, the designer should provide as many returns as there are simultaneous active signals, distributed uniformly over the desired connector area.

Interfacing components should be physically near the signal cable entrance to the circuit board (connector). The maximum allowable distance is 50 mm. Etch run lengths from interfacing components to the cable connector must be minimized. (See Fig. 12.)

The logic reference of all interfacing components for a particular cable must be interconnected to insure that no dynamic potential differences can be developed. This is typically done by a matrix of logic reference interconnections. It is not necessary to tightly couple the logic reference matrix of the interfacing components to the logic reference for the rest of the circuit board. It is more important to insure tight coupling between the interfacing components' logic reference and that of the signal cable.

10.0 SIGNAL INTEGRITY TOOLS

The designer can acquire confidence in his design through the use of various stress and analysis tools which now exist. The repertoire of such tools is never complete but in many instances the ones needed are not difficult to construct, and would provide a large return on investment. The items listed here are not intended to be a shopping list but a seed from which your particular tools grow.

10.1 NETWORK SIMULATION

The use of this tool should begin before the designer commits to building hardware. The Computer Aided Design (CAD) group at DIGITAL has available programs to simulate network electrical response at the I.C. design level, as well as at the wiring level. The use of these programs allow the designer to observe the electrical response of a complex network. Other programs are avaliable which simulate the network timing response. Logical race conditions are highlighted and analysis of system speed can be performed. Still other programs simulate the network logical response to test the validity of the network against the intended architecture design. These tools are valuable as designs can be evaluated for functionality over worst case limits even before the design is committed to hardware. It must be noted that once a complex piece of hardware is functioning, testing for worst care limits may be difficult or impossible.

10.2 MARGINING

Another confidence builder is the use of stress techniques to test the performance limits of a design. The stress parameters are typically voltage, timing, temperature, and mechanical, and each should be stressed to the non-destructive failing point of the design. Testing the combined effect of these variables on a device or system yields a plot of safe and unsafe operating regions known as a Schmoo plot. The stress tools may either be built in, (such as including a variable clock in the processor timing circuit) or may be separate (such as an external variable voltage D.C. power supply). Techniques which introduce controlled amounts of conducted or radiated signals into the system (EMI testing) have also proved to be very useful.

10.3 CONFIGURATION RULES

In working with the concepts developed so far (para. 10.1 and 10.2), some restrictions on the assembly and installation of a system or system element will be observed. These restrictions should be generalized, then included in the appropriate document as an aid to those building a system. For example, configuration rules which insure integrity of high speed bus signals (UNIBUS, QBUS, etc.) are currently being used by field service and manufacturing. It is also recommended that any system configuration rules be submitted to the DIGITAL Systems Integration group, under Computer Systems Development.

APPENDIX A — Cable Duct Suppliers

BURNDY/HUSKY -- Husky Products, Inc.
7405 Industrial Road
Florence Kentucky 41042
606-371-1900

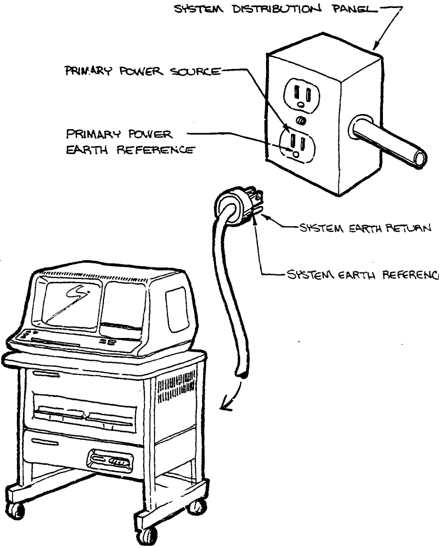

Figure 1 Typical Small Systems Configuration

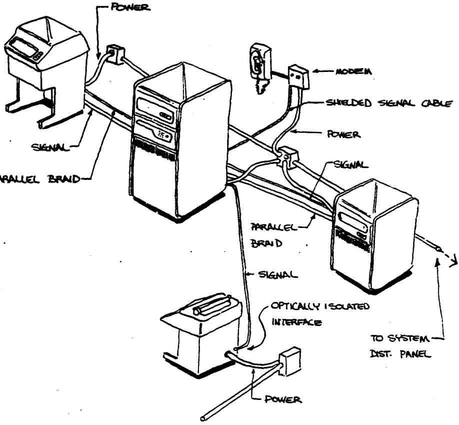

Figure 2 Typical Medium System Configuration

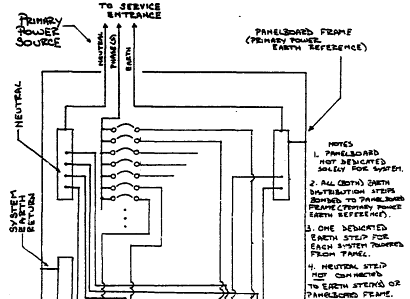

Figure 3 System Distribution Panel (medium/large system)

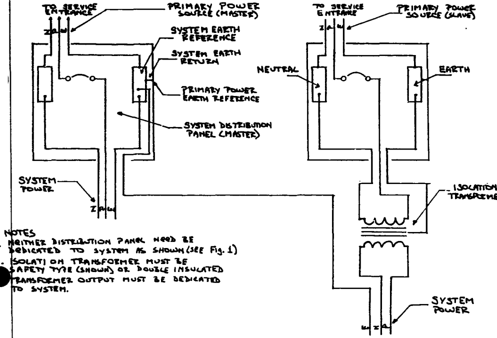

Figure 4 Multiple Primary Power Sources (with isolation transformer)

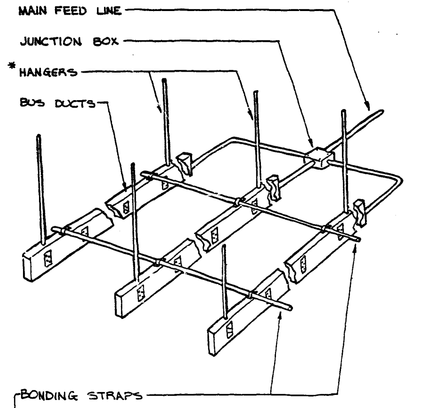

Figure 5 Power Bus Duct Configuration

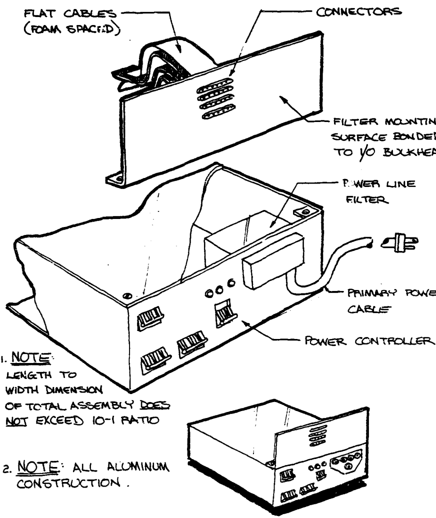

Figure 6 I/O Interface Bulkhead

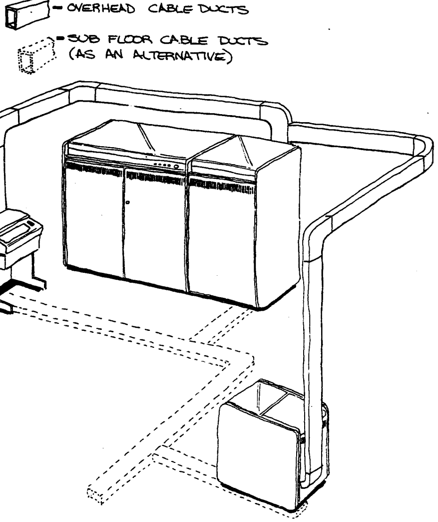

Figure 7 Signal Cable Ducts

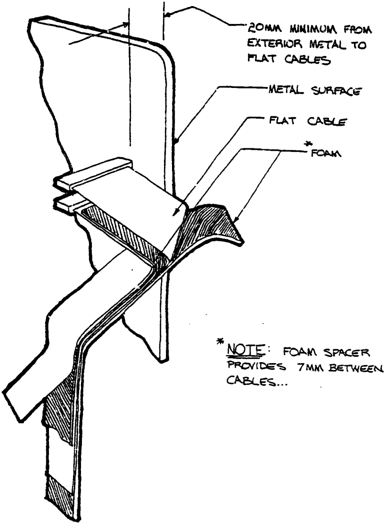

Figure 8 Flat Cable Stacking

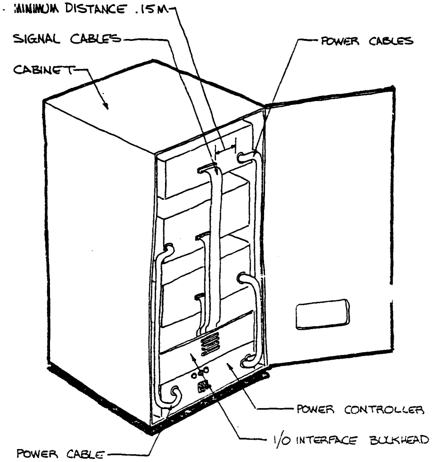

Figure 9 Cabinet Cable Configuration

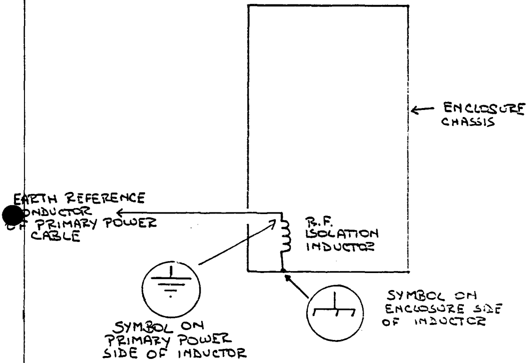

Figure 10 R. F. Isolation Inductor

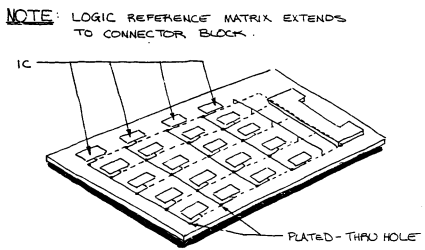

Figure 11 Matrix Type Logic Reference Distribution For Two Sided PC Board

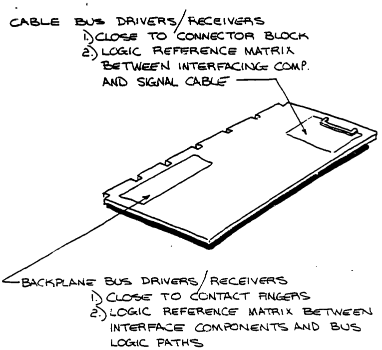

Figure 12 Interfacing Signal Cables to Circuit Board

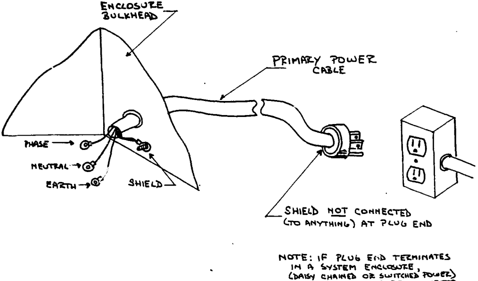

Figure 13 Primary Power Cable Shielding