

### 5.4.3 Selection of a Grounding Scheme

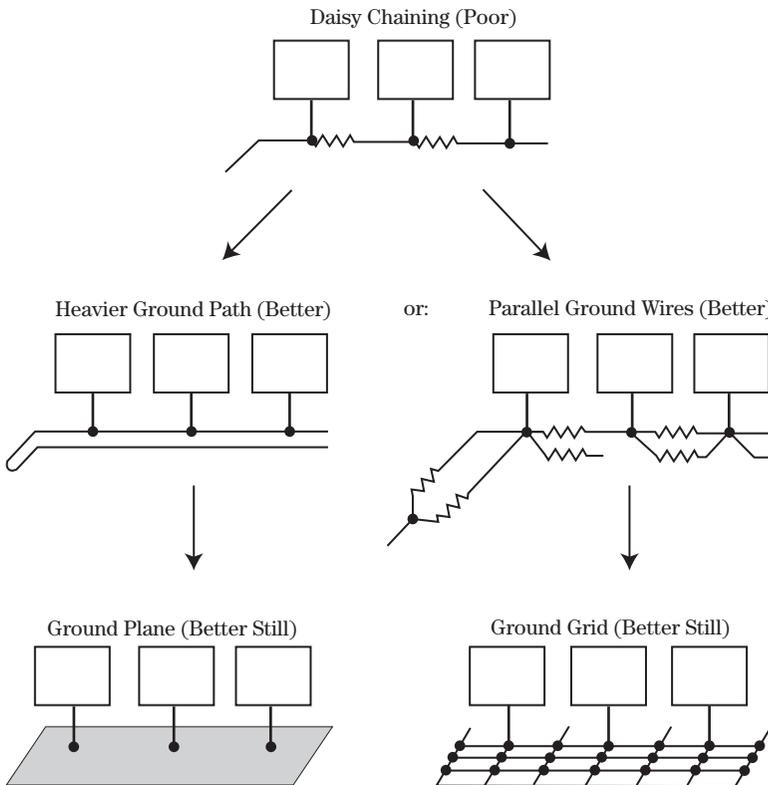
The facts are that a single-point grounding scheme operates better at low frequencies, and a multipoint ground behaves best at high frequencies. If the overall system, for example, is a network of audio equipment, with many low-level sensors and control circuits behaving as broadband transient noise sources, then the high-frequency performance is irrelevant, since no receptor responds above audio frequency. For this situation, a single-point ground would be effective. Conversely, if the overall system were a receiver complex of 30 to 1,000 MHz tuners, amplifiers, and displays, then low-level, low-frequency performance is irrelevant. Here, multipoint grounding applies, and interconnecting coaxial cables should be used.

The above comparison of audio versus VHF/UHF systems makes clear the selection of the correct approach. The problem then narrows down to one of defining where low- and high-frequency crossover exists for any given subsystem or equipment. The answer here in part involves the highest significant operating frequency of low-level circuits relative to the physical distance between the farthest located equipments. The determination of the crossover frequency region involves consideration of (1) magnetic versus electric field coupling problems and (2) ground-plane impedance problems due to separation. Hybrid single and multipoint grounding systems are often the best approach for crossover region applications.

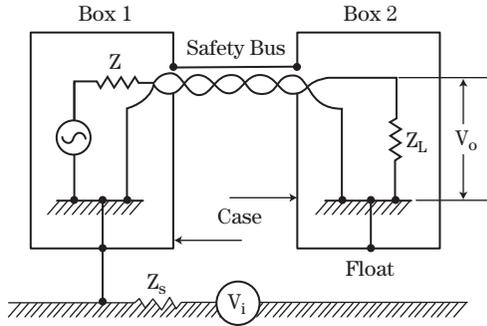
When printed circuits and ICs are used, network proximity is considerably closer. Thus, multipoint grounding is more economical and practical to produce per card, wafer, or chip. Interconnection of these components through wafer risers, motherboards, etc. should use a grounding scheme following the illustrations of previous paragraphs. This will likely still represent a multipoint or hybrid grounding approach in which any single-point grounding (for hybrid grounds), if used, would be to avoid low-frequency ground current loops and/or common-mode impedance coupling.

In summary, many system-level EMI problems can be avoided by paying careful attention to the grounding scheme used. Common-mode, common-ground impedance problems may be reduced by application of one or more of the following techniques.

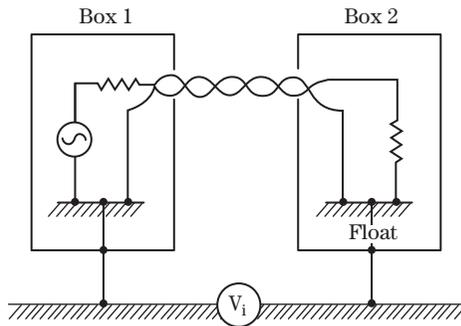
- Eliminate common impedance by using a single point ground (Fig. 5.11) if possible. This configuration is usually optimal for power frequencies and signal frequencies below 300 kHz.
- Separate and isolate grounds on the basis of signal type, level, and frequency as illustrated in Fig. 5.10.
- Minimize ground impedance as illustrated in Fig. 5.14 by using ground bus, ground plane, or ground grid.
- Float circuits or equipments if practical from a safety standpoint as illustrated in Fig. 5.15. The effectiveness of floating circuits or equipments depends on their physical isolation from other conductors. In large facilities, it is difficult to achieve a floating system.
- Use an inductor or capacitor in the ground connection to provide high- or low-frequency isolation, respectively, as illustrated in Figs. 5.16 and 5.17.



**Figure 5.14** Means of decreasing common-impedance coupling by decreasing ground path impedance. From the bad practice of daisy-chain (top), the improvement evolves toward a plane (left) or a grid (right).



(a) Float Equipment Enclosures



(b) Float Circuits and Boards

Figure 5.15 Float circuits or equipments.

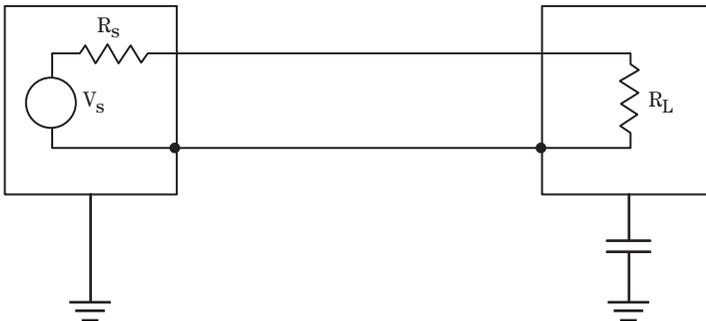


Figure 5.16 Capacitive grounding.

- Use filters or ferrites in ground loops to limit common-mode currents or provide a common-mode voltage drop.
- Use a common-mode choke as illustrated in Fig. 5.18 or a common-mode isolation transformer as illustrated in Fig. 5.19 to suppress ground-loop EMI. These devices may provide on the order of 60 dB

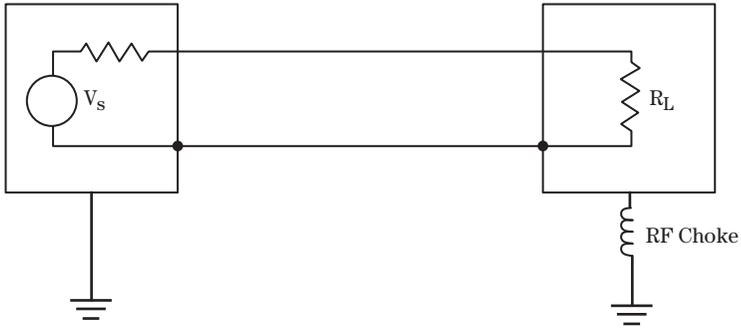


Figure 5.17 Inductive grounding.

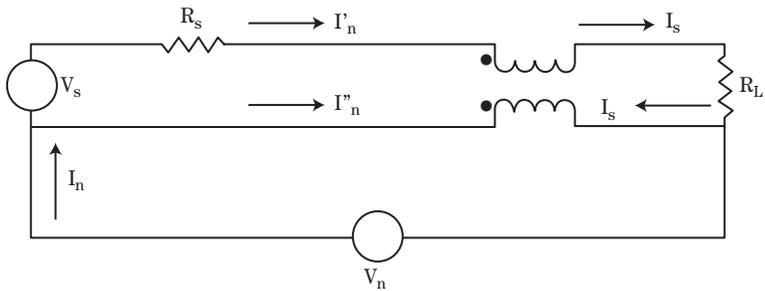


Figure 5.18 Common-mode chokes.

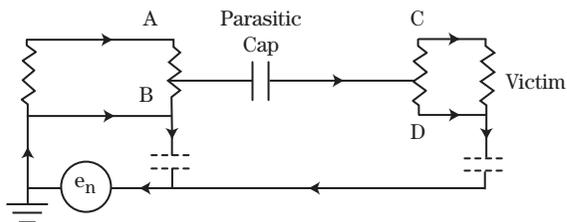
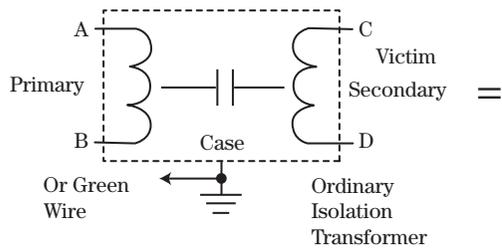


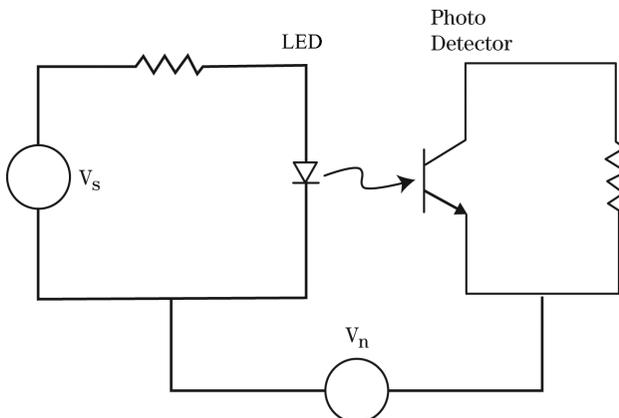
Figure 5.19 Common-mode isolation transformer.

of common-mode rejection at frequencies up to several hundred kilohertz.

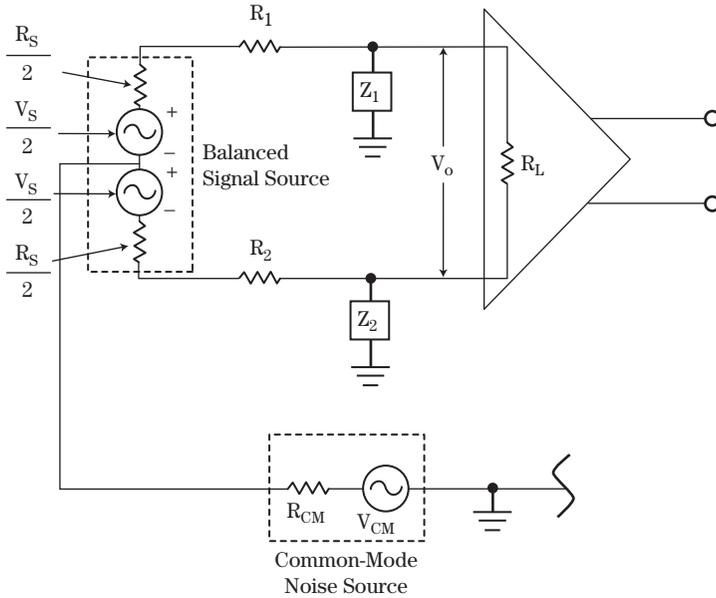
- Use optical isolators and/or fiber optics to block common-mode EMI effects as illustrated in Fig. 5.20. Optical isolators provide a high degree of common-mode rejection at frequencies up to and including the HF band (i.e., 3 to 30 MHz). Optical isolators are usually limited to digital applications (they are not applicable to low-level analog circuits).
- Use balanced circuits to minimize effects of common-mode EMI in the ground loop as illustrated in Fig. 5.21. With a perfectly balanced circuit, the currents flowing in the two parts of the circuit will produce equal and opposite voltages across the load, so the resulting voltage across the load is zero. Balanced circuits can provide significant (greater than 20 dB) common-mode reduction for low-frequency conditions. However, at higher frequencies (above 30 MHz), other effects start to predominate, and the effectiveness of balanced circuits diminishes.

Common-mode radiated EMI effects resulting from emissions that are radiated or picked up by a ground loop may be reduced by the application of one or more of the following techniques:

- Minimize the common-mode ground loop area by routing interconnecting wires or cable close to the ground.
- Reduce the common-mode ground loop currents by floating circuits or equipments; using optical isolators; or inserting common-mode filters, chokes, or isolation transformers.
- Use balanced circuits or balanced drivers and receivers.



**Figure 5.20** Use of optical isolation to combat common-mode impedance.



**Figure 5.21** Balanced configuration with respect to common-mode voltage.

## 5.5 Ground System Configurations

The ground system for a collection of circuits within a system or facility can assume any one of several different configurations. Each of these configurations tends to be optimal under certain conditions and may contribute to EMI problems under other conditions. In general, the ground configurations will involve either a floating ground, a single-point ground, a multipoint ground, or some hybrid combination of these.

A floating ground configuration is illustrated in Fig. 5.22. This type of signal ground system is electrically isolated from the ground and other conductive objects. Hence, noise currents present in the ground system will not be conductively coupled to the signal circuits. The floating ground system concept is also employed in equipment design to isolate signal returns from equipment cabinets and thus prevent unwanted currents in cabinets from coupling directly to signal circuits.

Effectiveness of floating ground systems depends on their true isolation from other nearby conductors; floating ground systems must really float. In large facilities, it is often difficult to achieve and maintain an effective floating system. Such a floating system is most practical if a few circuits or a few pieces of equipment are involved and power is applied from either batteries or dc-to-dc converters.

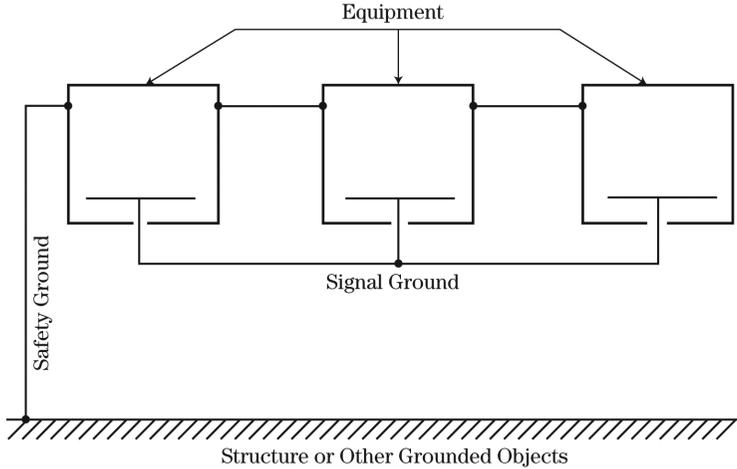


Figure 5.22 Floating Signal Ground.

A single-point ground for an equipment complex is illustrated in Fig. 5.23. With this configuration, the signal circuits are referenced to a single point, and this single point is then connected to the facility ground. The ideal single-point signal ground network is one in which separate ground conductors extend from one point on the facility ground to the return side of each of the numerous circuits located throughout a facility. This type of ground network requires an extremely large number of conductors and is not generally economically feasible. In lieu of the ideal, various degrees of approximation to single-point grounding are employed.

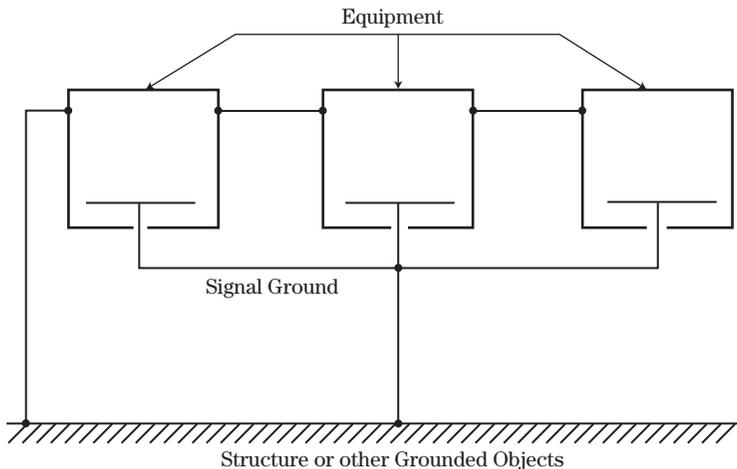


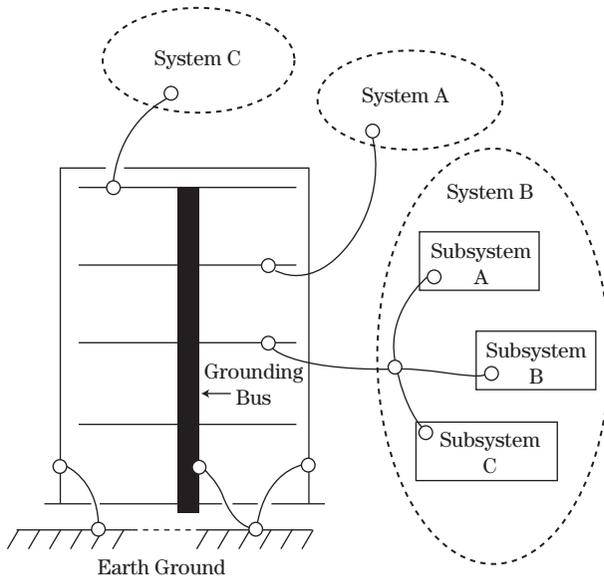
Figure 5.23 Single-point signal ground.

The configuration illustrated in Fig. 5.24 represents a ground bus arrangement that is often used to provide an approximation to the single-point grounding concept. The ground bus system illustrated in Fig. 5.24 assumes the form of a tree. Within each system, the individual subsystems are single-point grounded. Each of the system ground points is then connected to the tree ground bus with a single insulated conductor.

The single-point ground accomplishes each of the three functions of signal circuit grounding. That is, a signal reference is established in each unit or piece of equipment, and these individual references are connected together. These, in turn, are connected to the facility ground at least at one point, which provides fault protection for the circuits and provides control over static charge buildup.

An important advantage of the single-point configuration is that it helps control conductively coupled interference. As illustrated in Fig. 5.23, closed paths for noise currents in the signal ground network are avoided, and the interference currents, or voltages in the facility ground system, are not conductively coupled into the signal circuits via the signal ground network. Therefore, the single-point signal ground network minimizes the effects of any noise currents that may be flowing in the facility ground.

In a large installation, a major disadvantage of a single-point ground configuration is the requirement for long conductors. In addition to



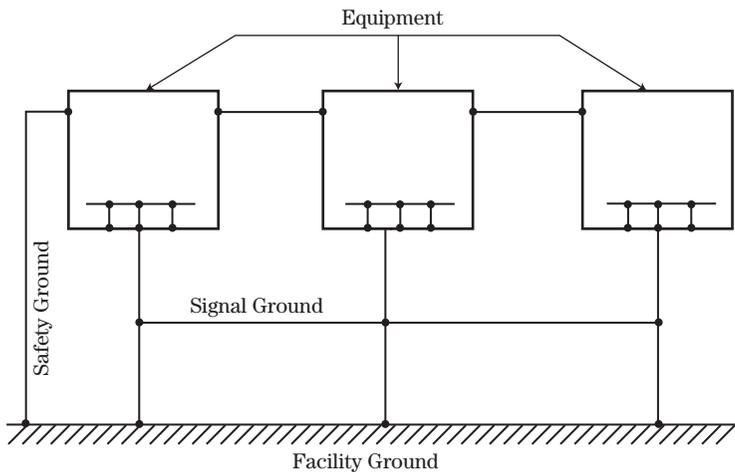
**Figure 5.24** Single-point ground bus system using a common bus.

being expensive, long conductors prevent realization of a satisfactory reference for higher frequencies because of large self-impedances. Furthermore, because of stray capacitance between conductors, single-point grounding essentially ceases to exist as the signal frequency is increased. In general, for typical equipments, systems, or facilities, single-point grounds tend to be optimum for frequencies below approximately 300 kHz.

The multiple-point ground illustrated in Fig. 5.25 is the third configuration frequently used for signal ground networks. This configuration establishes many conductive paths to various electronic systems or subsystems within a facility. Within each subsystem, circuits and networks have multiple connections to this ground network. Thus, in a facility, numerous parallel paths exist between any two points in the multiple-point ground network.

Multiple-point grounding frequently simplifies circuit construction inside complex equipment. It permits equipment employing coaxial cables to be interfaced more easily, since the outer conductor of the coaxial cable does not have to be floated relative to the equipment cabinet or enclosure.

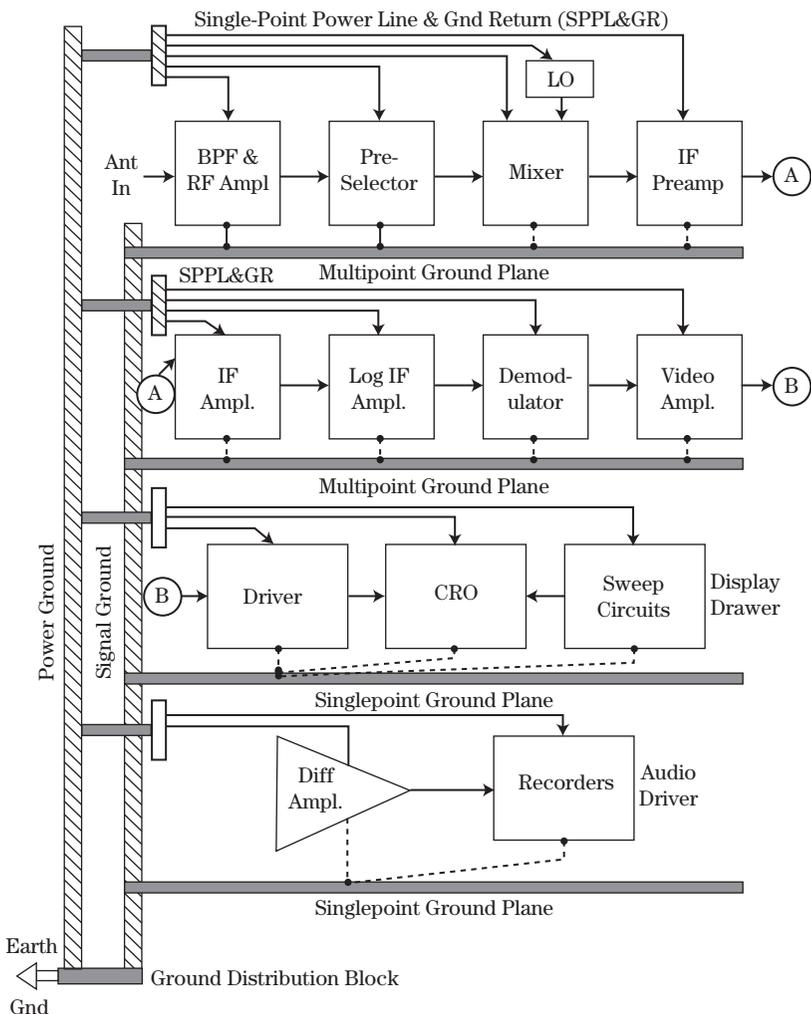
However, multiple-point grounding suffers from an important disadvantage. Power currents and other high-amplitude, low-frequency currents flowing through the facility ground system can conductively couple into signal circuits to create intolerable interference in susceptible low-frequency circuits. Also, multiple ground loops are created, and this makes it more difficult to control radiated emission or susceptibility resulting from the common-mode ground loop effects. In addition,



**Figure 5.25** Multiple-point ground configuration.

for multiple-point grounding to be effective, all ground conductors between the separate points must be less than 0.1 wavelength of the interference signal. Otherwise, common-ground impedance and ground-radiated effects will become significant. In general, multiple-point grounding configurations tend to be optimum at higher frequencies (i.e., above 30 MHz).

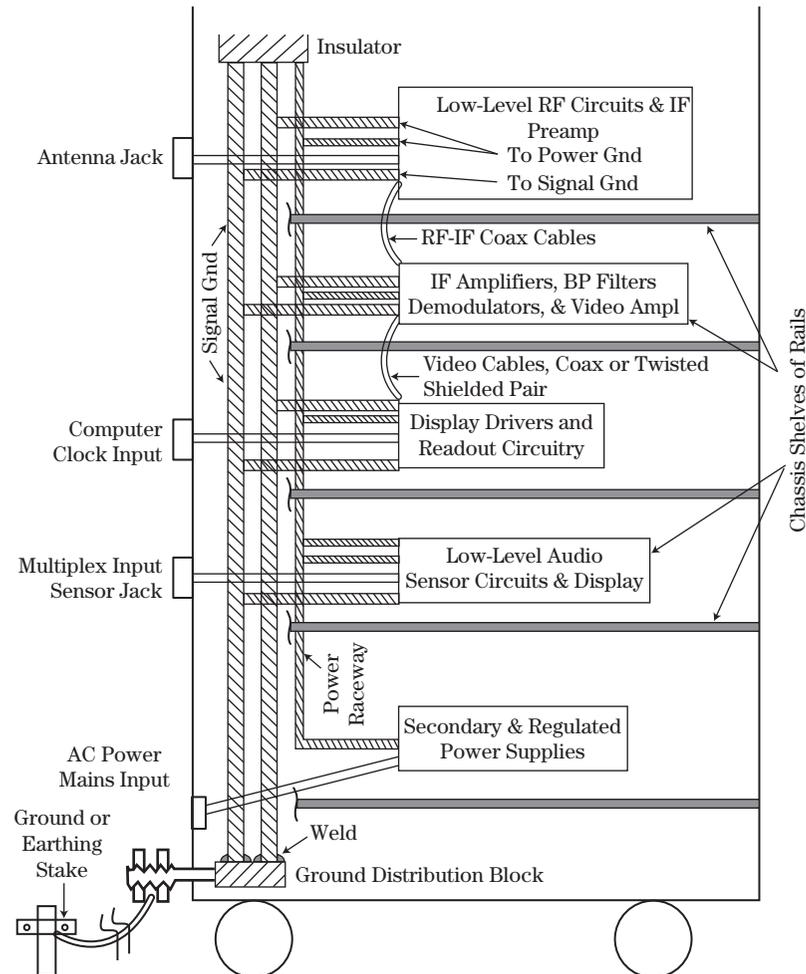
To illustrate one form of a hybrid-ground system, Fig. 5.26 shows a 19-in cabinet rack containing five separate sliding drawers. Each drawer contains a portion of the system (top to bottom): (1) RF and IF preamp circuitry for reception of microwave signals, (2) IF and video



**Figure 5.26** Grounding arrangement used in cabinet racks.

signal amplifiers, (3) display drivers, displays, and control circuits, (4) low-level audio circuits and recorders for documenting sensitive multi-channel, hard-line telemetry sensor outputs, and (5) secondary and regulated power supplies. The hybrid aspect results from:

- The RF and IF video drawers are similar. Here, unit-level boxes or stages (interconnecting coaxial cables are grounded at both ends) are multipoint grounded to the drawer-chassis ground plane. The chassis is then grounded to the dagger pin, chassis ground bus as suggested in Fig. 5.27. The power ground to these drawers, on the other hand, is using a single-point ground from its bus in a manner identical to the audio drawer.



**Figure 5.27** Block diagram detail of hybrid grounding arrangement.

- The chassis or signal ground and power ground busses each constitute a multipoint grounding scheme to the drawer level. The individual ground busses are single-point grounded at the bottom ground distribution block. This avoids circulating common-mode current between chassis or signal ground and power grounds, since power ground current can vary due to transient surges in certain modes of equipment operation.
- Interconnecting cables between different drawer levels are run separately, and their shields, when used, are treated in the same grounding manner as at the drawer level.
- The audio and display drawers shown in Fig. 5.27 use single-point grounding throughout for both their unit-level boxes (interconnecting twisted cable is grounded at one end to its unit) and power leads. Cable and unit shields are all grounded together at the common dagger pin bus. Similarly, the outgoing power leads and twisted returns are separately bonded on their dagger pin busses.

To review the above scheme, the following is observed:

- The audio and display drawers have ground runs of about 0.6 m and an upper frequency of operation of about 1 MHz (driver and sweep circuits). Thus, single-point grounding to the strike pins is indicated.
- The RF and IF drawers process UHF and 30 MHz signals over a distance of a meter so that multipoint grounding is indicated.
- The regulated power supplies furnish equipment units having transient surge demands. The longest length is about 1.5 m, and significant transient frequency components may extend up in the HF region. Here, hybrid grounding is indicated: single-point within a drawer and multipoint from the power bus to all drawers.

## 5.6 EMI Control Devices and Techniques

The performance of some EMI control techniques or devices may be significantly influenced by grounding. In particular, cable shields; isolation transformers; EMI filters; ESD, lightning, and EMF protection techniques; and Faraday shields must be properly grounded so as to provide maximum EMI protection. A detailed discussion of specific grounding considerations associated with these EMI control techniques or devices is beyond the scope of this book. However, it is important to emphasize the importance of grounding on the performance of these techniques or devices, and details may be found in the references.

**Suggested Readings: Grounding**

- [1] Morrison, Ralph, and W. H. Lewis, *Grounding and Shielding in Facilities*, Hoboken, NJ: John Wiley & Sons, 1990.
- [1] Morrison, Ralph, *Grounding and Shielding Techniques in Instrumentation*, 3rd ed., Hoboken, NJ: John Wiley & Sons, 1990.
- [1] Denny, Hugh W., *Grounding for the Control of EMI*, Gainesville, VA, Interference Control Technologies, Inc.
- [1] Grounding, Bonding and Shielding for Electronic Equipment and Facilities, MIL-HDBK-419.