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NIRSPEC

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NIRSPEC Electronics Design Note 09.00
Exterior Noise - Ground Noise

1. Introduction

Noise reduction is a significant design issue in most electronic systems. It is especially so, in NIRSPEC, because of the extremely high resolution requirement of less than ½bit of noise. At 16-bit resolution, the size ½bit of noise is only 76μVrms. It is therefore important to analyze all the possible noise sources especially ground noises.

Noise sources can break into two main groups. They are internal noise and external noises. The internal noise sometimes called "device noise" is caused by physics of the devices and materials that make up the electrical device. Therefore, we cannot eliminate this kind of noise from a circuit. It is the theoretical minimum noise level for any electrical system. The internal noise group has been treated in earlier design note, NEDN0600. The other noise group is called external noise. External noise may be caused by electrostatic or electromagnetic coupling between the circuit and the external sources. Some of the sources of interferences can be 60Hz power lines, radio transmitter, fluorescent lights, cross talk between adjacent circuits, dc power supplies. Or microphonics caused by the mechanical vibration of components. Most of these types of interferences can be often minimized or eliminated by adequate shielding, filtering, proper grounding or the layout of circuit components.

Noise sources, if not fully considered early in the design cycle, can adversely affect final performance and prevent the high-resolution potential of a system from being realized; at the very least, costly redesign and rework may be required. This design note will discuss ways of minimizing or preventing noise generated or coupled within the circuit or system from corrupting the signal of the system.

2. Noise Coupling Mechanisms:

There are four noise coupling mechanism paths:

1) Conductive (direct contact) - Metallic path
2) Capacitive (electric field) - Near Field dv/dt
3) Inductive (magnetic field) - Near field di/dt
4) Radiative (electromagnetic) - Far field $d>\lambda/(2\pi)$

These are also the four mechanisms for transferring electromagnetic energy.

Because all radiated electromagnetic energy must be conducted before any energy can be radiated. It is important in any design to reduce the conducted energy. If the conducted EMI sources could be eliminated, there would be no radiation. This is not possible, of course. We seek to develop design methods and techniques to reduce the conducted emissions to an acceptance level.

In the near-field radiation where the distance between noise source is less than the wavelength $\lambda/(2\pi)$, the noise coupling of the conductive (metallic path), capactive (electric field), and inductive(magnetic field) will be conducted energy. The wavelength, λ (meter) is equal to c/f where c is speed of light ($c=3.00x10^8$ meter/second) and f (hertz) is the frequency of the signal.

As an example, the current through a capacitor is conducted yet there is no metallic connection between the two capacitor leads. Alternating current passes through the field between the capacitor plates. This is near-field radiation because the distance between the plates is much less than the wavelength $\lambda/(2\pi)$. It is primarily an electrostatic field; the magnetic field strength is very small. Noise can be inducted capacitively or inductively (near-field radiation) or can be induced by far field electromagnetic radiation. In the near-field range, close to the source, the field is primarily electric. As the electric field propagates away from the source, the energy naturally converts to transverse electromagnetic waves. Some of the electrical energy is converted into a magnetic field that is perpendicular to the electric field. In the region close to the magnetic field source, the field is primarily magnetic. As the magnetic field propagates away from the source, the energy converts to a transverse electromagnetic wave with an electric field perpendicular to the magnetic field.

At a distance greater than $\lambda/(2\pi)$, far-field, the wave impedance converges to 377 ohms, the impedance of free space. The electric and magnetic fields are perpendicular to each other and the direction of propagation. Far-field electromagnetic energy is the same whether it is created from a magnetic source or an electric source.

3. Power Supply:

Switching power supplies are major noise producers. It contains both conducted and radiated noise up to 30Mhz. For this reason, we will not use switching power supplies anywhere within our electronic system. However, linear power supplies have other problems. They may have 60-Hz sawtooth noise. Another problem is poor input-output isolation, which lets power-line noise enter the electronic system through the power supplies. High frequency noise is extremely common on most AC power lines. Therefore, the power lines should be filtered on the primary side of power supply. In additional, the power supply should use a double-shielded Faraday transformer to reduce the common-mode voltage coupling between circuit ground and power ground or earth. The primary Faraday electrostatic shield should be attached to earth ground and the secondary's shield should be attached to DC ground. Figure 1 shows noise suppression at the primary side and a Faraday shield connection. To further reduce the ripple noise from a commercial power supply, an additional regulator will be provided.

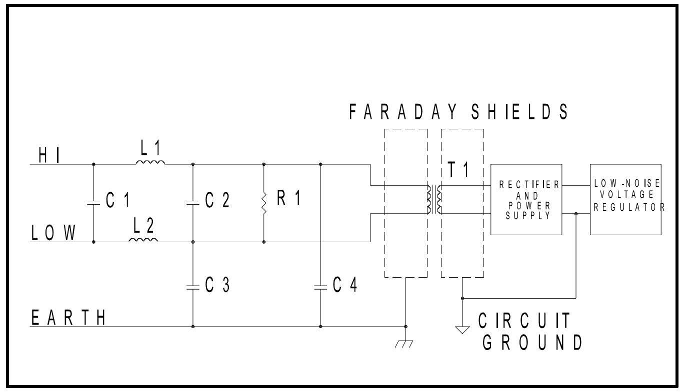

Figure 1 POWER SUPPLY

For isolation between different electronic circuits, separate power supplies will be used according to their functions, for example, between digital and analog; high and low power circuits and high and low frequency circuits.

3.1 Power Supply De-Coupling:

Figure 2 shows the recommended decoupling for preamplifier and postamplifier. R1 and R2 help keep power-line noise from coupling into the first stage. The power input is close to the output stage in order to decrease power-line noise into the input stage. The ideal layout for a multistage amplifier is a straight line, keeping the input stage and the output stage as far apart as possible.

It is generally wise to power the opamp from the power available at the load side of the circuit, and to decouple it with respect the load common. The reason for this can be deduced from the circuit architecture of the most-common types of opamps.

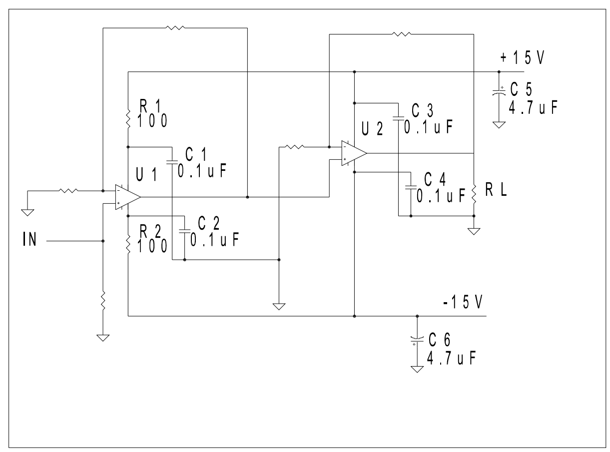

Figure 2 Power Supply De-Coupling

Digital IC's tend to be both producers and victims of electrical noise spike. Whenever a digital signal toggle, it generates significant noise from DC up to 55Mhz. To reduce noise emissions from digital logic, keep signals slow (i.e., increase the rise and fall times), and use good grounding and bypassing techniques. Bypass capacitors supply the transient current needed by digital ICs, reduce voltage drops in the Vcc and ground nets, and help filter out power /ground noise. A series resistor at the driver will work if the receivers are all at the far end of the line.

4. Partitioning:

We can reduce noise and interference problems by isolating the sensitive circuits from the noisy ones through control of common-impedance coupling, inductive coupling, capacitive coupling, and electromagnetic radiation effects. That is we need to keep low-power sensitive circuits, such as preamplifier close to the signal sources. Keep high power noisy circuits, such as motor close to the loads. Separate low-power and high power circuits as much as possible. Keep wires as short as possible, and keeps current loops as small as possible. Keep sensitive circuits and their cables away from the other circuits, using the system's support structure to provide free shielding. Tie the subassembly ground systems together at only one point and put grounded shields around high-impedance circuits and high-voltage circuits.

5. Cables:

DC power returns should not be used as chassis grounds or signal return. The DC power wire and return wire will be twisted together to minimize the noise. For multistage amplifiers, bring power in at the output stage. Shield the power cables going to noisy circuits, bonding the shields to the chassis at the ends of the cables and every 0.2λ in-between.

Terminate each signal return at the signal source and at the load. Provide ground wires in the signal cables for switches and controls - do not connect them to chassis ground. Mount DC power cables close to chassis members and away from AC power cables, transformers, and motors. Mount signal cables close to chassis members and away from AC power cables, DC power cables, transforms, and motors. Keep signal cables at least 12" away from power cables. Separate digital-signal cables and AC power. Shield all exterior signal cables going to high-speed devices. Sensitive signals may need individual shields. Insulate these shields to prevent accidental grounding, and run the signals and their shield through adjacent connector pins. Ground the shield at only one point if shield current would affect the signal. Ground the source end to reduce noise emissions, and ground the load end to reduce noise pickup.

6. Grounding

Every grounding system is a compromise between conflicting requirements. The definition of a ground is a low-impedance connection that minimizes the voltage difference between parts of a system for signal voltage referencing or safety. Three major functions generally called groundings are:

1) voltage-reference for system signals,
2) safety for people and equipment from lighting and power-line faults,
3) signal and power current return ("current return").

A grounding system must be carefully designed to meet all these requirements, while minimizing the unwanted coupling between signals that causes noise problems.

The first two items in the list generally called grounding, fit the definition of grounding. The third in the list, "current return", does not fit and is technically not grounding. Calling a "current return" a ground is probably the most confusion thing. This misconception has complicated the concept of grounding.

It is important to note that grounds conduct <u>no current</u> in ideal circuits. In real circuits there is always some amount of radiation and current (different potentials) due to exterior or internal influences. We want to have the ground paths as low an impedance as possible so that the unavoidable interference currents cause as little difference in potential between the circuit references as possible. Ground and current returns are clearly two different functions.

The purposes for grounding are:

1) Increase safety of personnel and equipment
2) Reduce noise
3) Provide a signal voltage reference

All three purposes require minimizing the voltage difference between different parts of a system. The primary purpose of safety grounding is to protect personnel, equipment, and wiring from excessive voltage differences.

We can isolate signal-return, DC power-return, and AC-power return currents from one another by building the system with three independent ground networks, tied together at only one point. This lets us optimize each ground system without worrying about the others. Signal grounds, for example, must have low impedance from DC to megahertz but do not carry much current. DC-power grounds need low impedance from DC to kilohertz but must carry much higher currents, while AC-power/chassis grounds need low impedance in the 100Hz range and may carry many amperes.

6.1 Ground planes:

Ground planes are low-impedance, low-inductance reference planes. A ground plane should be designed to be an equal potential surface. This means that there is to be virtually no current flowing in the ground plane. In circuits where the currents are <u>relatively small</u>, a conductive plane can be used for both a reference plane and a return plane. For example, relatively high current dc motor drive must be routed on a separate trace to a single-point ground located on the ground plane where it connects to the main ground reference usually at the connector of the pc board. The normal IC current returns can be grounded directly to the ground plane because they are of relatively low current levels. This method of layout will isolate the high current circuits from the relatively lower-current circuits to reduce the effects of shared common ground impedance. Also, the reference to the ground plane potential in the high current ground is not as important as in the low current grounds.

6.2 Ground Plane, High Frequency Current Path:

The ground plane layer is often advocated as the best return for low power and signal current, while providing a reference node for converters and references. However, even extensive use of a ground plane does not ensure a high quality ground reference for ac circuits. For example, the simple circuit built on a two-layer printed circuit board, has an ac and dc current source on the top layer connected to feedthrough #1 at one end and to a single U-shaped copper trace connected to feedthrough #2. Both feedthroughs go through the circuit board and connect to the ground plane underneath. Ideally, impedance is zero and the voltage appearing across the current source should be zero. The dc current flows directly across feedthrough #1 to feedthrough #2 which is path of least resistance. In contrast, the ac current does not take the path of least resistance; but it takes the path of least impedance, which in turn depends on inductance.

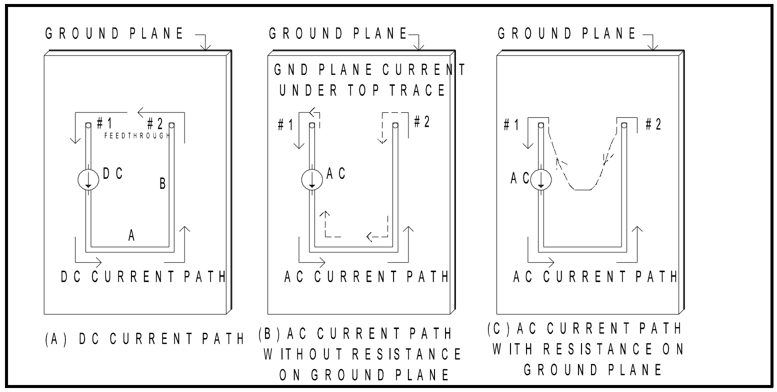

Figure 3 AC and DC Current Paths

Inductance is proportional to the area of the loop made by the current flow. By applying the Faraday's law the relationship between the inductance can be illustrated by the right-hand rule on the magnetic fields. Inside the loop, current along all parts of the loop produces magnetic field lines that add constructively. Away from the loop, however, field lines from different parts add destructively. Thus, the field is confined principally within the loop. Therefore, a larger loop has greater inductance. This means that, for a given current level, it has more stored magnetic energy (Li^2), greater impedance ($X_L = j\omega L$), and therefore will develop more voltage at a given frequency.

Which path will the ac current choose in the ground plane? Naturally the lowest-impedance path. Considering the loop formed by the U-shaped surface lead and the ground plane, and neglecting resistance, high-frequency ac current will follow the path with least inductance, therefore the least area. In the simple example show, the loop with the least area is quite evidently formed by the U-shaped top trace and the portion of the ground plane directly underneath it. So, while Figure 3a shows the dc current path, Figure 3b shows that the path that most of the ac current takes in the ground plane, where if finds minimum area, directly under the U-shaped top conductor. In practice, the resistance in the ground plane causes the current flow at low-and mid-frequencies to be somewhere between straight back and directly under the top conductor, Figure 3c. However, the return path is nearly under the top trace even at frequencies as low as 1 Mhz. Once the return current paths in the ground-plane are understood, common layout trouble spots can be identified and corrected.

6.3 Shared Return Common Impedance ("Single Point Ground"):

Common mode currents are present in nearly all systems. Common impedance ground currents are one source of common mode currents. The proper use of single-point grounds can reduce the common current caused by potentials created by shared ground paths. Each separate ground conductive path should be come to a single point called the "ground reference" point as opposed to "daisy chaining," as shown in Figure 4B. An example of the common impedance problem is shown in Figure 4C. The two grounds G_1 and G_2 should be all the same potential but they are separated by some distance. The grounds' G_1 and G_2 could be two different points on the chassis. The impedances' Z_1 and Z_2 represent the characteristic impedance of wire or circuit traces or could be a filter designed to reject unwanted frequency components. The impedance between G_1 and G_2 is represented by Z_C. The current source I_{GC} represents a current flow in a totally separate electrical circuit from the one under investigation. No matter how small Z_C is, there will be a potential V_g between G_1 and G_2 caused by the shared ground impedance and current I_{GC}. A differential EMI voltage, resulting from the common mode currents and the unbalance of the circuit impedances, will be impressed across the load ZL. We must keep these potential problems in mind when designing with any electronic circuitry.

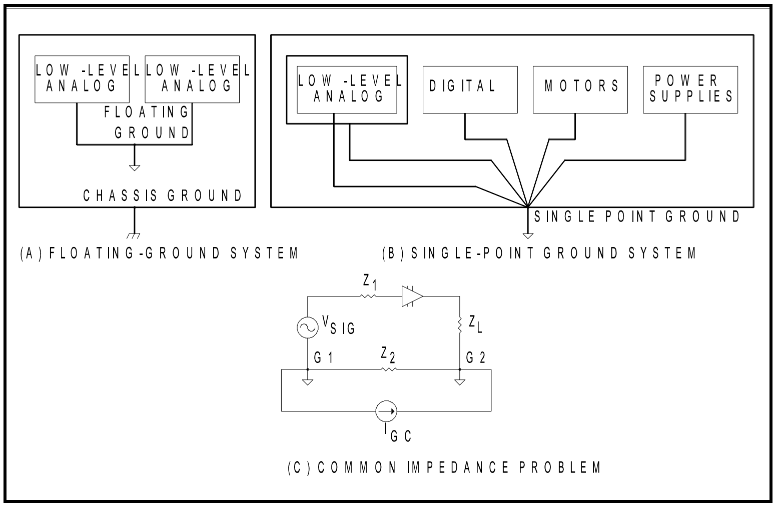

Figure 4 GROUND CONFIGURATION

6.4 Ground Design for Electronic Circuit:

The current returns should be consider first. The grounding scheme does not affect the the current returns. Routing current returns is the first priority. Grounding is the second. Current returns and grounds should not be mixed. Their separation should be well defined.

Current will flow in the lowest impedance path. The characteristic impedance of the ground path should be the lowest impedance path; otherwise the ground current will flow in unexpected parts of the system. Inductance usually determines the path of the lowest impedance in a ground circuit (see Sec 7.2).

The EMI filters must have a low impedance conductive path to the chassis to be effective. To be effective this capacitor component should be mounted to the chassis. One lead should be connected directly to the chassis, the other should be short, and the circuit should wire to and away from the ungrounded capacitor lead.

7. NIRSPEC Grounding Scheme:

The grounding scheme for NIRSPEC is shown in Figure 5. The design goal is to eliminate all possible noise sources especially ground loop. To eliminate all potential ground loop, we will have incorporating the following:

1) All power supplies will be the Faraday double shielded transformer type.

2) Separate power supplies will be used for each of following sections. They are (a) level shifter, (b) bias generator, (c) preamplifier, (d) postamplifier, filter, A/D converter, (e) logic, and (f) "data processor/transputer".
3) Used isolators for all interface between analog processor and the "data acquisition processor/transputer"

To reduce noise further, all power supplies will be low noise type. The AC lines to power supply will be filtered on the primary side and shielded from the system. In addition, all dc voltages will be filter and regulated by an IC regulator.

All power supplies cable will be twisted with its own return and finally a shield will be connected to both ends of the chassis return. Mount DC power cables close to chassis members and away from AC power cables.

All signal interface will be twist pair for each signal. Terminate each signal return at the signal source and at the load. Each cable will be consist of many twist pairs and the outside of cable will be shield. The shield will be terminated on the signal source end only. Mount signal cables close to chassis members and away from AC power cables at least 12". Insulate these outside shields to prevent accidental grounding, and run the signals and their shield through adjacent connector pins. Ground the shield at only one point. Ground the source end to reduce noise emissions, and ground the load end to reduce noise pickup.

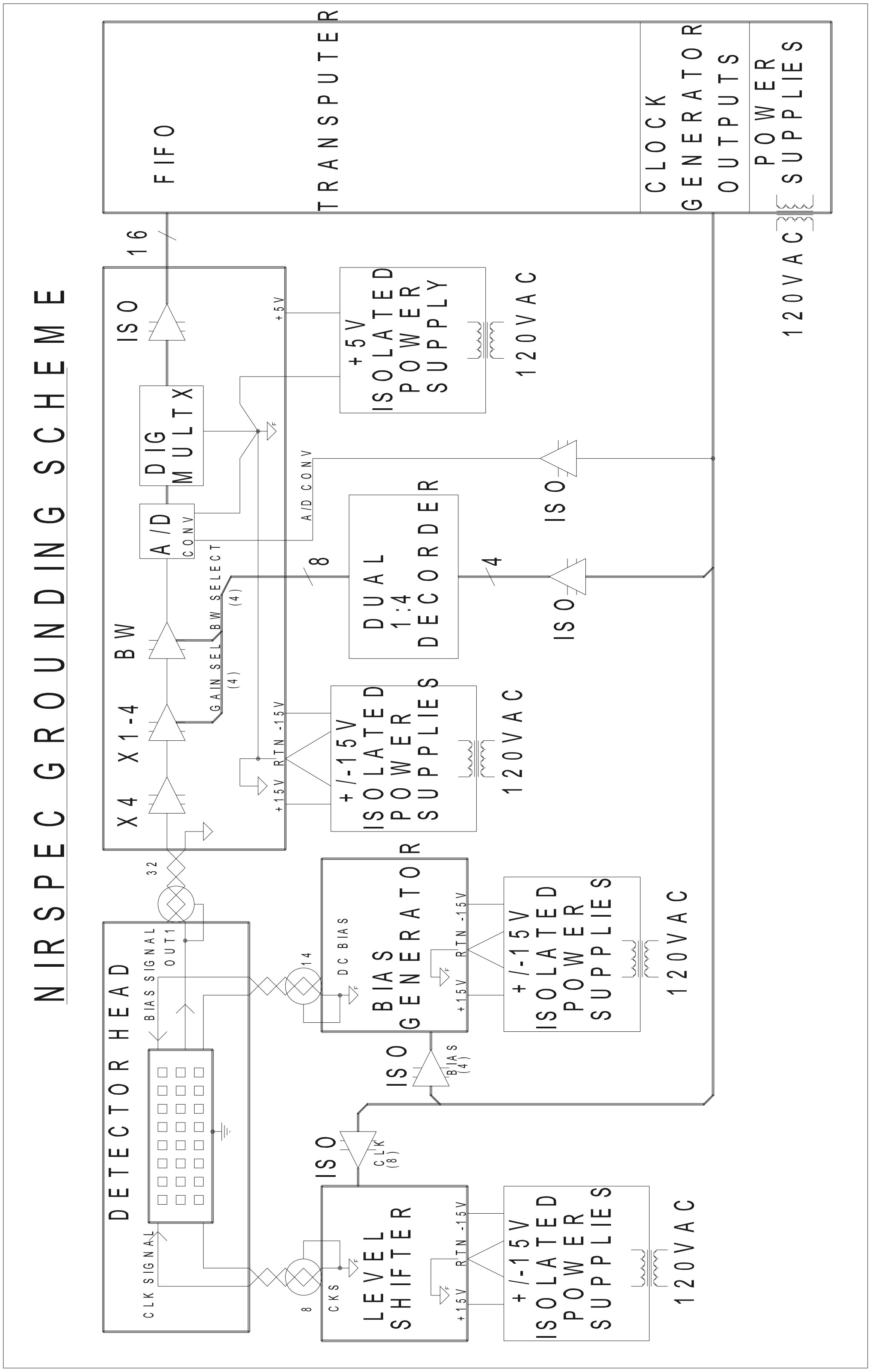

Figure 5 NIRSPEC Grounding Scheme