NO NOISE IS GOOD NOISE

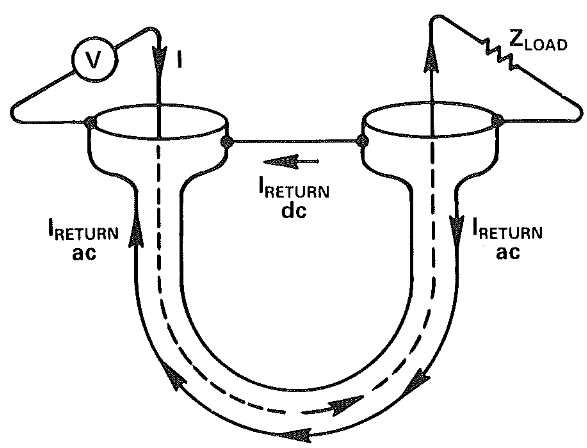
NO NOISE IS GOOD NOISE : A DOWN TO EARTH DISCUSSION OF GROUND AND NOISE MANAGEMENT

In precision analog circuits, noise management and ground management techniques must be rationally applied to obtain the desired signal to noise ratio. Problems arising from improper grounding or shielding become more critical at higher resolutions and wider bandwidths. When analyzing interference of this type, the designer must carefully consider where noise signals originate and what is the best return path for them.

....Principle: Think—Where will the currents flow?

This may seem fairly obvious, but all of us tend to think of the currents we're interested in as flowing "out" of some place, and "through" some other place, but often neglect to worry about how the current will find its way back to its original source.

Current will return to its source via the path of least impedance. Wiring impedance is a combination of resistance and inductance. As frequencies move away from dc, the inductance becomes the dominating factor. Minimum inductance means minimum area enclosed by current flow. For example, consider the cable shown below.



If V is a dc source, then the current will flow through the load and return to the source through the short wire connecting the two ends. This is the least resistive path. However, as V increases in frequency, more and more current will flow through the load and return via the outer conductor of the coaxial cable to the source. This is the least inductive path because the current encloses less area than if it had flowed from one cable end to the other.

Noise will continue to find its way into our circuits unless we understand the characteristics of both the noise and the circuit that it is invading. For a complete analysis, we could solve the loop and node equations of the circuit, including wire resistance, stray capacitance and mutual coupling. However, since this level of detail is either impractical or impossible for many circuits, we will examine some common situations to develop a few guidelines that will be useful in most applications.

SOURCES OF NOISE

- **Transmitted Noise**
- **Intrinsic Noise**
- **Interference Noise**

Any electronic system contains many sources of noise. Three basic forms in which it appears are: transmitted noise—recieved with the original signal and indistinguishable from it, intrinsic noise—such as thermal noise, shot noise, and popcorn noise (intrinsic noise is covered in section three under op amp specifications), and interference noise—picked up from outside the circuit. This last type of noise may be coupled in from other electrical systems such as switching power supplies, nearby digital circuits or even another segment of the same analog signal path. In this section we will concentrate on eliminating interference noise, since it is the only type that can be influenced by choices of wiring, layout and shielding.

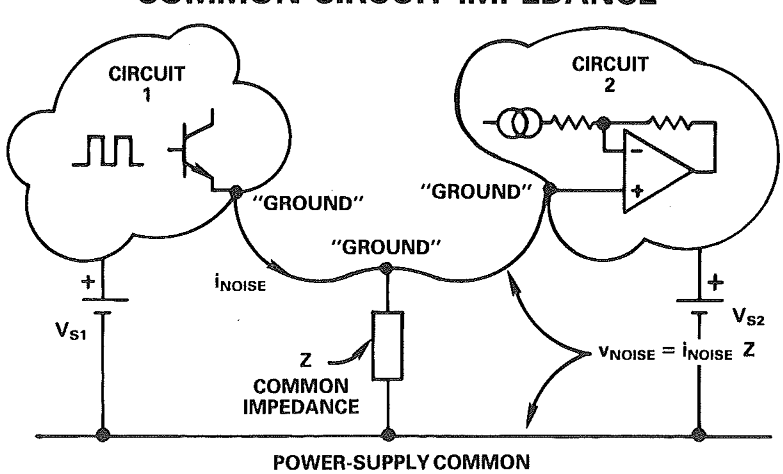
INTERFERENCE NOISE CAN BE COUPLED INTO A CIRCUIT IN SEVERAL DIFFERENT WAYS:

- **Conductive Coupling (Direct Contact)**
- **Capacitive Coupling (Electric)**
- **Inductive Coupling (Magnetic)**
- **Radiative Coupling (Electromagnetic)**

CONDUCTIVE COUPLING

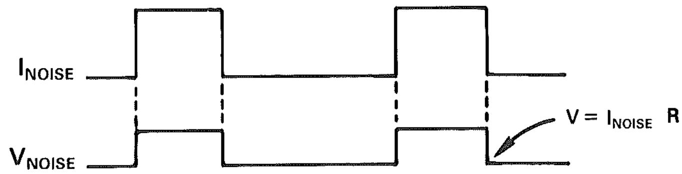
Conductively coupled noise occurs when a direct electrical contact, or leakage path, to an interference source is present. The diagram below shows the basic configuration which might occur when a digital logic circuit and an op amp's reference terminal are both connected to a "ground" point having tangible impedance to the power supply return terminal. The return current of circuit 1 will develop a voltage, Vnoise, across impedance Z which will appear as a noise signal to circuit 2.

HOW NOISE IS DEVELOPED BY A COMMON CIRCUIT IMPEDANCE



The characteristics of the noise are determined by both the noise source and the impedance of the return path Z. For example, if Z is purely resistive, the noise voltage will be proportional to the noise current and of similar shape.

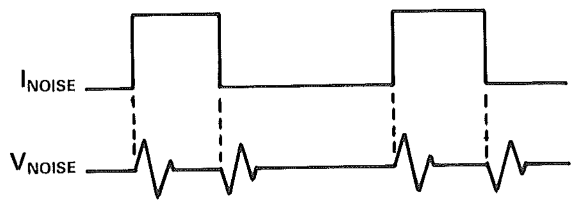
NOISE EFFECTS IN A COMMON IMPEDANCE



RESISTANCE

If Z is inductive and capacitive as well as resitive, the response is that of a damped second order system. That is, an impulse of current causes an exponentially decaying sinusoid of characteristic (resonant) frequency. An identifying characteristic of conductive, or common impedance, coupling is a non-zero average value for the noise waveform.

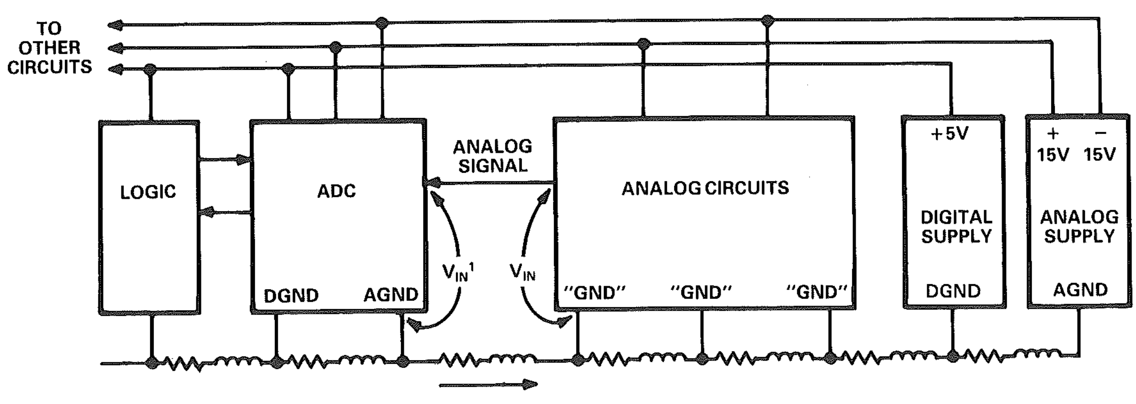
NOISE EFFECTS IN A COMMON IMPEDANCE



AN R-L-C CIRCUIT

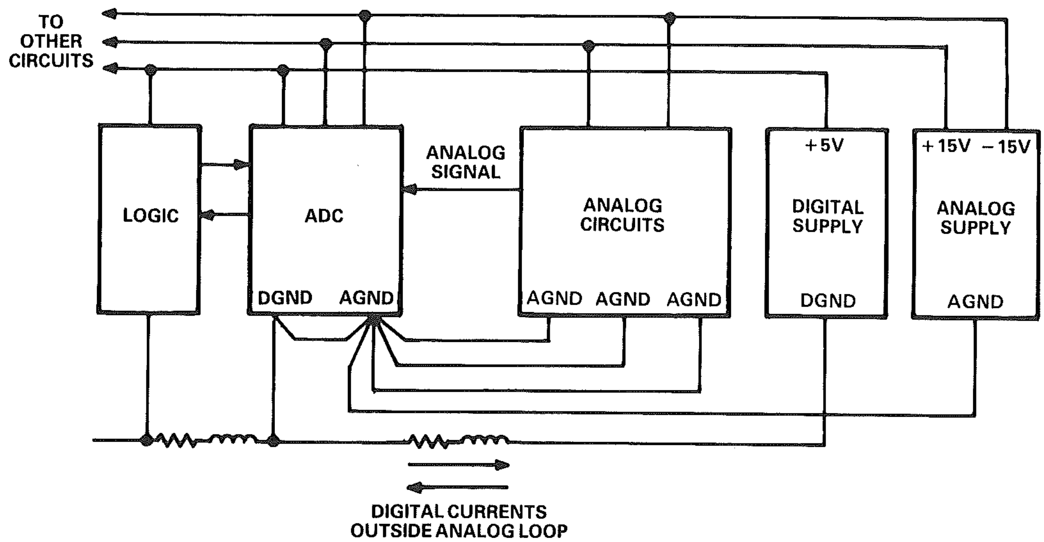
The example above is a simplified representation of the class of grounding problems that often occur in high resolution data acquisition systems. The figure below shows a typical arrangement of components in a single channel data acquisition system. The power and ground distribution systems are shown with their equivalent resistive and inductive components. This representation emphasises the complexity of the ground distribution network and its implications with respect to noise. Digital or other rapidly changing signals impressed on this "daisychain" ground will clearly affect the instantaneous potential of the separate ground nodes, and this causes errors.

A COMMON GROUND ARRANGEMENT



You can improve the situation greatly if a single analog reference is established. This arrangement is often called a star ground system. All analog signals should return to the ground reference via separate pc board tracks or wires. In small systems using only one converter, it is usually desirable to arrange circuit topology so that the analog ground reference point and the analog ground connection of the ADC are one and the same.

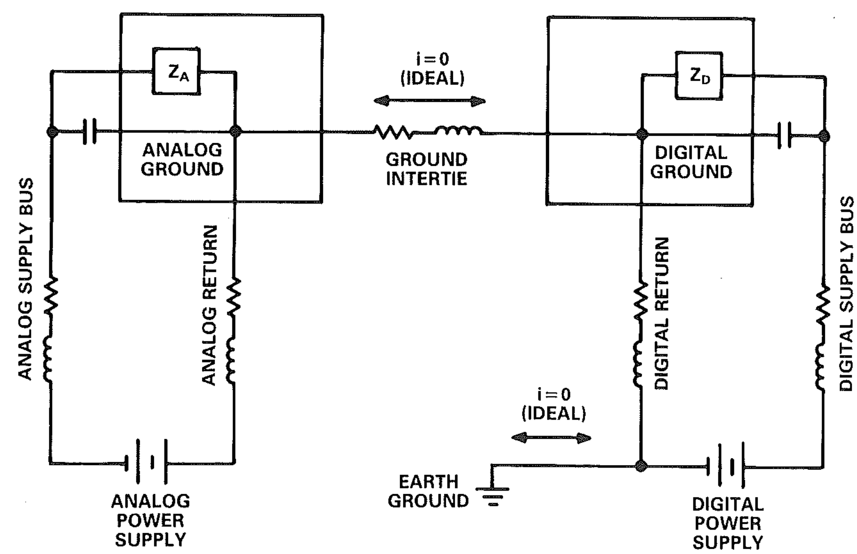
IMPROVED GROUND MANAGEMENT



EACH ANALOG SIGNAL HAS A SEPARATE RETURN PATH.
DIGITAL AND ANALOG GROUNDS ARE CONNECTED ONCE AT THE ADC.

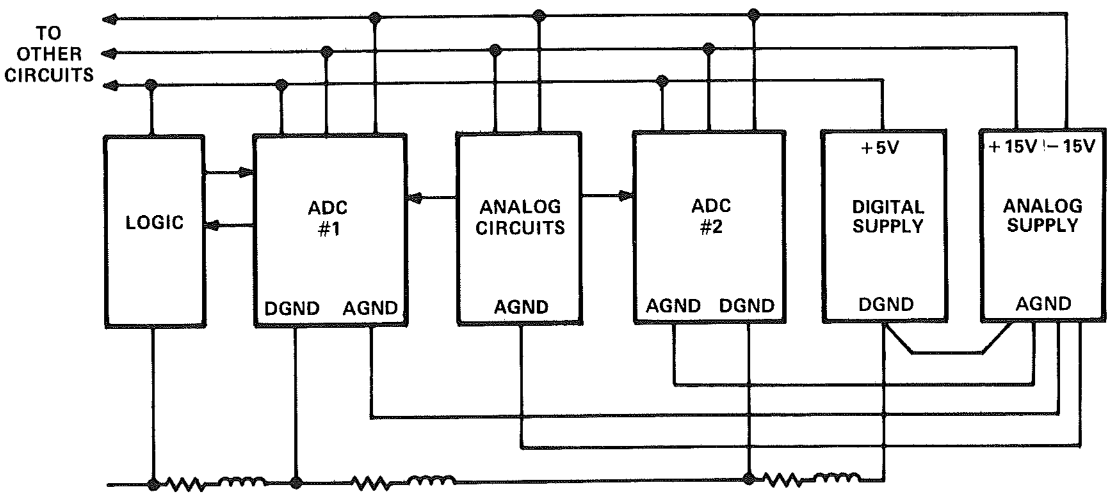
The most effective way to minimize conductive interference is to separate the analog signal return from the digital signal return. The figure below shows a system that has only one analog ground star point and one digital ground point. These two grounds are connected together via one heavy gauge connection that we shall refer to as a ground intertie. This limits the voltage difference between the two. The analog and digital supplies are NOT tied together at a common point in the supply rack. The only direct connection between the two grounds is the intertie. An additional connection would create a ground loop that would allow the noisy digital ground currents to flow through the analog system. Ideally, the analog and digital signal currents will flow through their returns to the appropriate source and no current will flow in the intertie or earth ground.

ISOLATED SUPPLIES ELIMINATE GROUND LOOPS



For a single converter system, the tie between analog and digital ground should occur right at the chip. In multiple converter systems, it is more difficult to arrange a single point ground. In such applications, the tie between analog and digital ground should occur once at the power supply common, not at each individual chip. If the power supply is located at an inconvenient or distant location, then another point may be chosen at which to connect the analog and digital grounds. The most important design rules to follow are: provide a separate return for each analog signal through the common analog ground; provide a return for each digital signal through the digital ground; connect the analog ground to the digital ground at only one point and reference everything to that point.

GROUND MANAGEMENT FOR MULTI-CONVERTER SYSTEMS

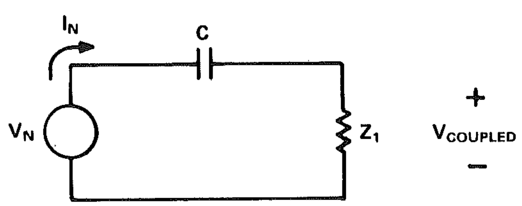


EACH ANALOG SIGNAL HAS A SEPARATE RETURN TO THE SUPPLY. DIGITAL AND ANALOG GROUNDS ARE CONNECTED ONCE AT THE SUPPLIES.

CAPACITIVE COUPLING

Capacitive coupling of noise occurs when an electric field couples a noise source to the desired signal. All capacitive coupling may be represented by a voltage noise source, a coupling capacitor, and a circuit impedance.

CAPACITIVE COUPLING EQUIVALENT CIRCUIT

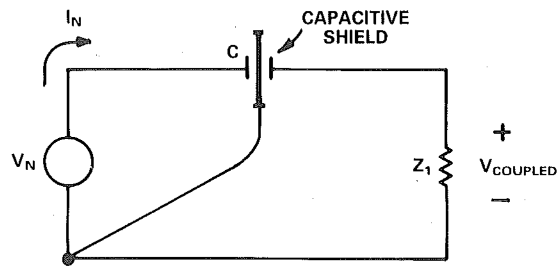


Z_1 = CIRCUIT IMPEDANCE
Z_2 = 1/JWC

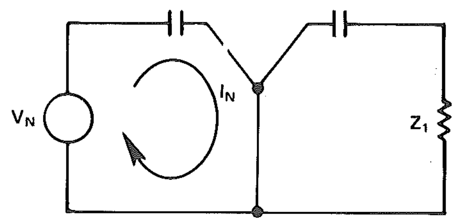
$$V_{COUPLED} = V_N \left(\frac{Z_1}{Z_1 + Z_2}\right)$$

Several steps may be taken to reduce the coupled voltage. Reducing the capacitance (C), the noise voltage (Vn), the frequency of the noise (Fn), or the circuit impedance (Z1) will all result in a smaller coupled voltage. Unfortunately, some of these options may not be possible. Another possibility is to filter the noise at the load. This is only practical if the frequency of the noise is substantially different than that of the signal. Possibly the best solution is to use a capacitive shield.

CAPACITIVE SHIELD INTERRUPTS THE COUPLING ELECTRIC FIELD

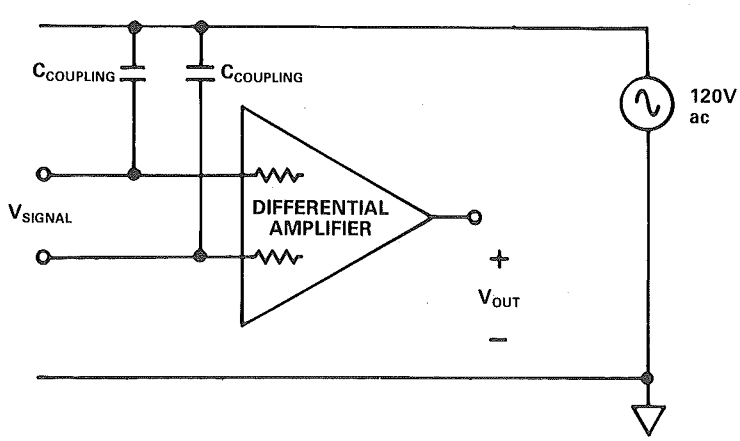


EQUIVALENT CIRCUIT ILLUSTRATES HOW A CAPACITIVE SHIELD CAUSES THE NOISE CURRENTS TO RETURN TO THEIR SOURCE WITHOUT FLOWING THROUGH Z_1



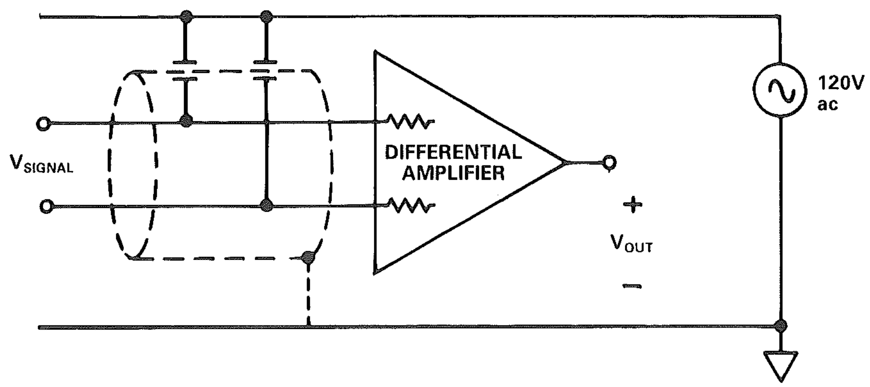
For a capacitive shield to be effective, the shield must be placed in the proper location and be connected correctly. Shields should be located between the two coupled surfaces so as to interrupt the coupling electric field. They should be connected at only one point to allow the noise currents to bypass the signal circuit as they return to their source. Capacitive shields should never be connected to more than one node, nor should they ever be left floating. An incorrectly implemented shield can be worse than no shield at all.

CAPACITIVE COUPLING



One example of capacitive coupling is crosstalk. If the signal cable is twisted pair, then the two coupling capacitances should be equivalent. Balanced capacitance makes the interference common mode. Unbalanced capacitance results in both normal and common mode interference. Using twisted pair will greatly improve the situation by taking advantage of the differential amplifier's common mode rejection.

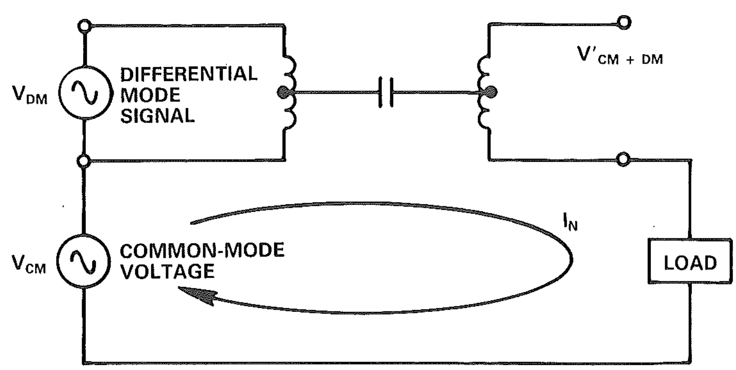
CAPACITIVE SHIELD INTERCEPTS NOISE CURRENTS AND RETURNS THEM TO THEIR SOURCE



Further improvement is obtained by using a shield. Note that the shield doesn't eliminate the noise current, it simply re-routes it so as not to interfere with the signal.

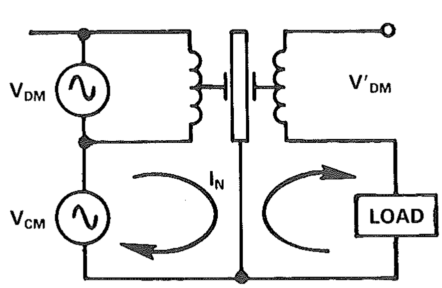
Effective shielding may be further illustrated by considering a typical transformer. Capacitive coupling may occur between the coils unless the exposed metal between primary and secondary is shielded.

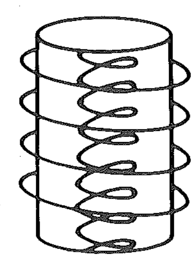
CAPACITIVE COUPLING OF TRANSFORMERS



The desired differential signal is magnetically coupled by the transformer. However, the parasitic capacitance allows the common mode signal to pass from the primary to the secondary. Consider an isolation amplifier that uses transformers to isolate a patient from a potentially dangerous voltage. Coupling of this voltage could result in serious consequences. Note how a shield may be used effectively to intercept the coupled signal and return it to its source.

TRANSFORMER CAPACITIVE SHIELDING





UNDESIRED, CAPACITIVELY COUPLED SIGNALS ARE ONE OF THE MOST COMMON SOURCES OF INTERFERENCE.

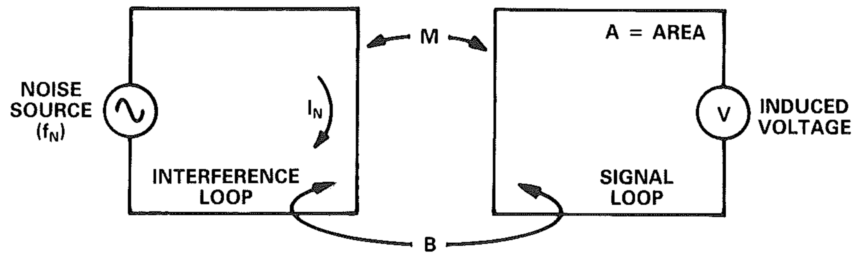
SOME IDENTIFYING CHARACTERISTICS TO LOOK FOR ARE:

- Metal surfaces which are unshielded or electrically floating.
- High noise voltage relative to signal voltage
- High impedance signal circuit
- If the noise is affected by the location of nonmagnetic materials such as cable or people, then it is more than likely capacitively coupled.

INDUCTIVE COUPLING

Magnetic flux can couple between a signal circuit and an interference circuit and cause an undesired voltage to be induced in the signal circuit. This is inductive coupling. The figure below illustrates the basic principles.

BASIC PRINCIPLES OF INDUCTIVE COUPLING

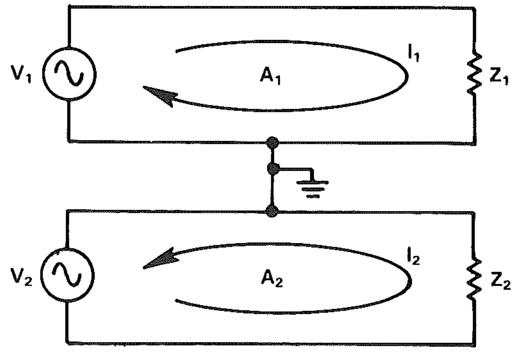


M = MUTUAL INDUCTANCE
B = MAGNETIC FLUX DENSITY
A = AREA OF SIGNAL LOOP
ω_N = $2\pi f_N$ = FREQUENCY OF NOISE SOURCE

V = INDUCED VOLTAGE = $\omega_N M I_N = \omega AB$

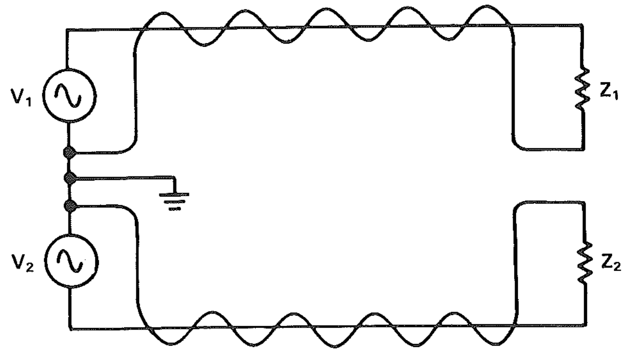
The induced voltage may be decreased by reducing any of the terms in the above equations, namely: Fn, M, B, I, or A. As with any coupling, minimizing ALL of the contributing factors is not possible. In some cases the noise frequency can be reduced. For example, if the interference is digital, increasing the pulse rise time will decrease the noise bandwidth. If this is not practical, another alternative is to decrease the magnetic flux density or mutual inductance. This may be accomplished by increasing the separation between the two loops or by using magnetic sheilding. Running the loops perpendicular to each other will also help eliminate magnetic coupling. One of the best, and often easiest to implement, solutions is to reduce the loop areas.

SINGLE POINT GROUND AND POOR LAYOUT RESULTS IN EXCESSIVE LOOP AREAS



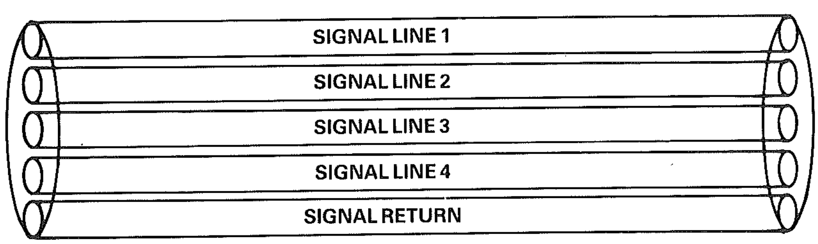
This simple circuit illustrates a poorly designed, single point grounding scheme. Note the two loop areas enclosed by the current flow. These large areas cause an excessive amount of inductive coupling between the circuits.

PROPER SIGNAL ROUTING REDUCES LOOP AREA



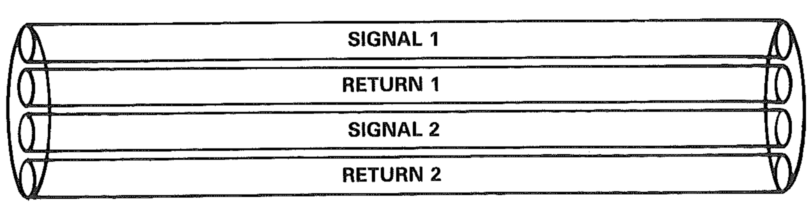
By properly routing the signal, the areas are greatly reduced, as is any inductively coupled interference. Twisting the signal and return leads will also help significantly. The equal and opposite currents produce magnetic fields that tend to cancel each other and the benefits can be significant. In comparison to running the two leads side by side, two twists per foot will reduce the voltage induced by approximately 15dB. Three twists in a foot will reduce it by 23dB and twelve twists per foot will reduce the coupled noise by about 43dB. This is an easy way to enhance the signal to noise ratio of your system.

FLAT RIBBON CABLE WITH A SINGLE RETURN RESULTS IN UNEQUAL LOOP AREAS

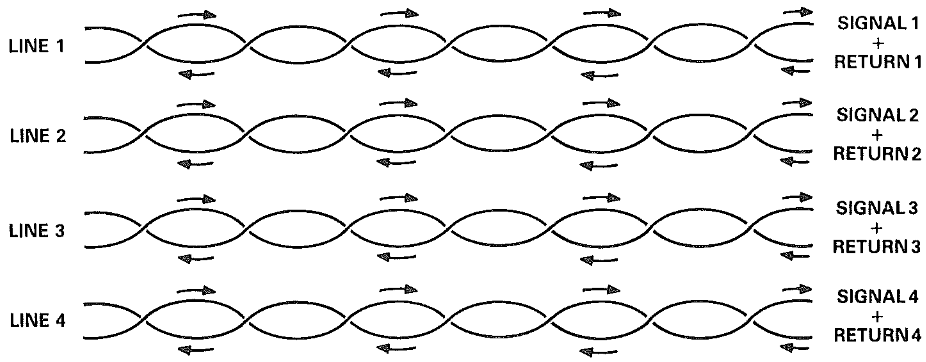


The ribbon cable shown above does not equally minimize signal loop areas. The signal through line one encloses the largest loop area, through line 4 the smallest. If this was a digital data bus which line should be assigned to the LSB? Since the LSB changes state most frequently, one could argue that it should be assigned to line 4. But what about the MSB? If it is assigned to line 1, then it is the most susceptable to noise. This could result in a half scale error if it is toggled by loop noise.

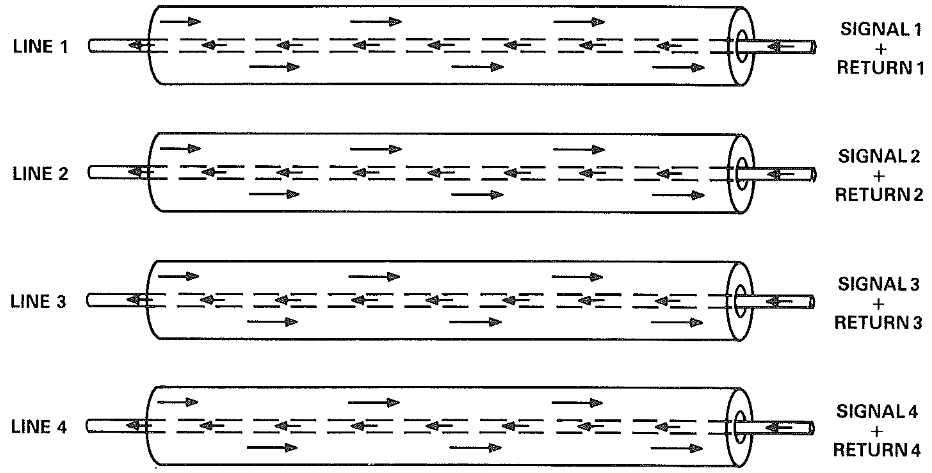
ALTERNATE SIGNAL AND RETURN LINES IMPROVE SIGNAL INTEGRITY



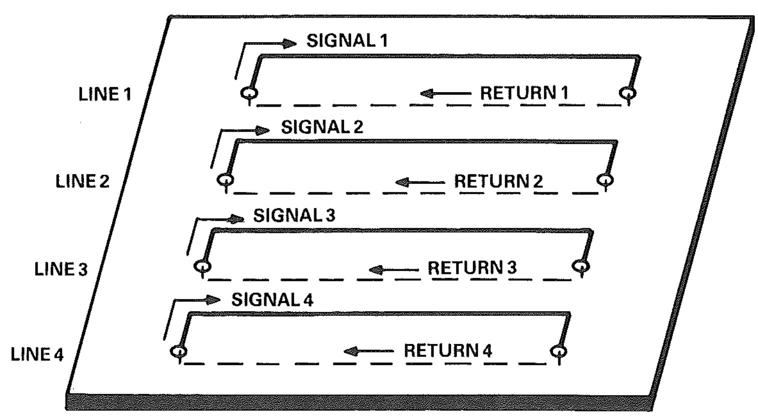
TWISTED PAIR PROVIDES A SIGNAL AND RETURN PATH FOR ALL LINES



COAXIAL CABLE PROVIDES INDIVIDUAL SIGNAL AND RETURN LINES



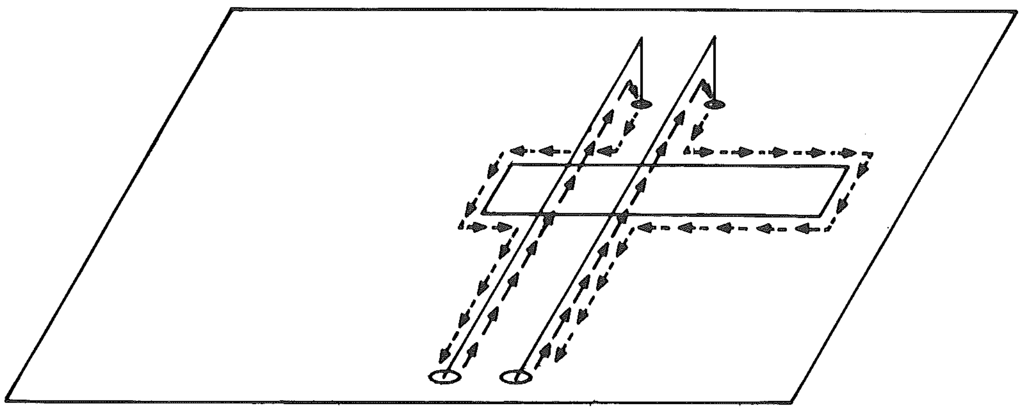
TWO LAYER PRINTED CIRCUIT BOARD PROVIDES A TRACE FOR EACH SIGNAL AND A GROUND PLANE FOR THE RETURN PATHS



A preferred solution is to provide multiple return paths, ideally one return for each signal. This may be accomplished by dedicating every other line of the ribbon cable as a signal return. Another option is to use twisted pair. Each pair should be composed of a signal path and a return for that signal. Coaxial cable could accomplish the same result. An alternative approach is to use a ground plane. Each signal will automatically return via a minimum area (minimum inductance) path through the plane.

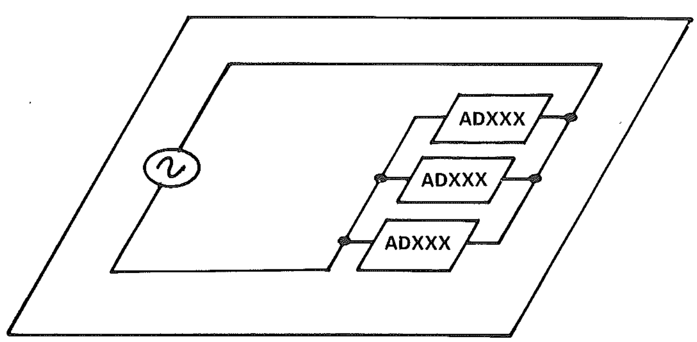
This leads to the subject of current flow patterns and associated noise problems on printed circuit boards. When laying out a PC board, it is very important to consider where the currents will flow. Again, the same arguement applies: current will chose the path of least impedance. This generally means least area. Unfortunately, we sometimes prevent this from happening by the way we lay out our board.

OPENING IN 2 LAYER PC BOARD CAN RESULT IN CURRENTS TAKING A NONOPTIMUM PATH

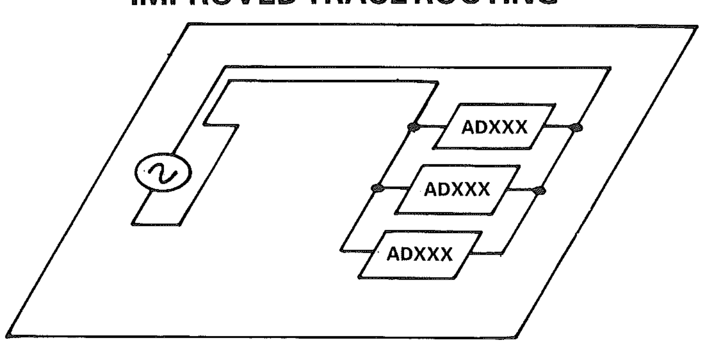


Often on a two layer PC board, an opening is cut around a device. This opening can get in the way of current selecting the least inductive path. In the figure above, the signal follows its path on the top layer, goes through the board, and tries to return to its source through the metal plane below. If the opening weren't there, the current would flow directly underneath its original path, minimizing the loop area. With the opening cut away in the plane, this path is impossible and another one is chosen which results in a larger enclosed area. This, of course, increases the magnetic coupling between the traces.

NONIDEAL SIGNAL TRACE ROUTING



IMPROVED TRACE ROUTING



We not only prevent current from selecting the best path in a ground plane, but we may also force it to take an excessively inductive path by routing it that way. The figure above illustrates this point. Proper trace routing to minimize the area enclosed by the signal path significantly reduces inductive coupling of noise. This principle should be followed as much as possible when designing PC boards, or any boards for that matter. It is important for low level analog signals, power supply busses, digital signals—all signals.

Another means of decreasing magnetic coupling is through shielding. The capacitive shield discussed previously intercepts the electric field and reroutes the noise currents back to their source. A magnetic shield redirects the magnetic flux by providing a path of higher permeability.

Permeability is a measure of how easily magnetic flux can be established in a material. For non-magnetic materials such as copper, aluminum, wood, or glass the permeability is, practically speaking, the same as that for air. For magnetic materials, the permeability is a hundred or a thousand times that of air.

PERMEABILITY (μ) IS A MEASURE OF HOW EASILY MAGNETIC FLUX CAN BE ESTABLISHED IN A MATERIAL

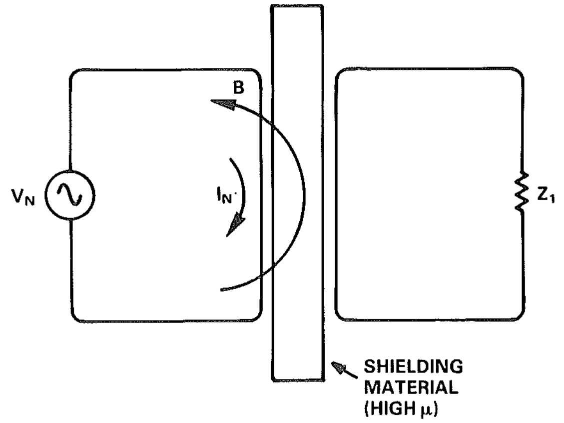
PERMEABILITY OF FREE SPACE = $\mu_O = 4\pi \times 10^{-7}$ H/M

RELATIVE PERMEABILITY OF A MATERIAL = $\mu_R = \frac{\text{PERMEABILITY OF MATERIAL}}{\text{PERMEABILITY OF FREE SPACE}} = \frac{\mu}{\mu_O}$

MATERIAL	μ_R
BISMUTH	0.9999986
PARAFFIN	0.99999942
WOOD	0.9999995
SILVER	0.99999981
ALUMINUM	1.00000065
BERYLLIUM	1.00000079
NICKEL CHLORIDE	1.00004
MAGNESIUM SULFATE	1.0001
NICKEL	50
CAST IRON	60
COBALT	60
POWDERED IRON	100
MACHINE STEEL	300
FERRITE (TYPICAL)	1,000
PERMALLOY 45	2,500
TRANSFORMER IRON	3,000
SILICON IRON	3,500
IRON (PURE)	4,000
MUMETAL	20,000
SENDUST	30,000
SUPERMALLOY	100,000

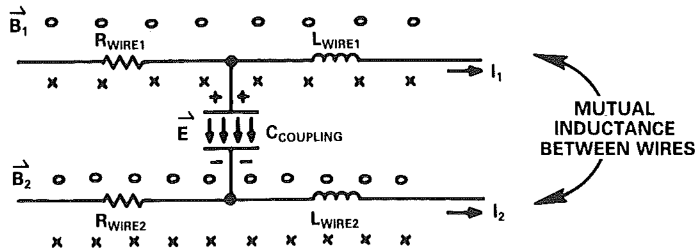
Magnetic flux will take a path of most permeability. This is the principle upon which the magnetic shield is based. The shield must be made out of a magnetic material with a high relative permeability. This shield will then contain most of the flux. The magnetic field remains the same strength as it was before the shield was added, however, the flux pattern changes.

REDIRECTING MAGNETIC FLUX BY SHIELDING

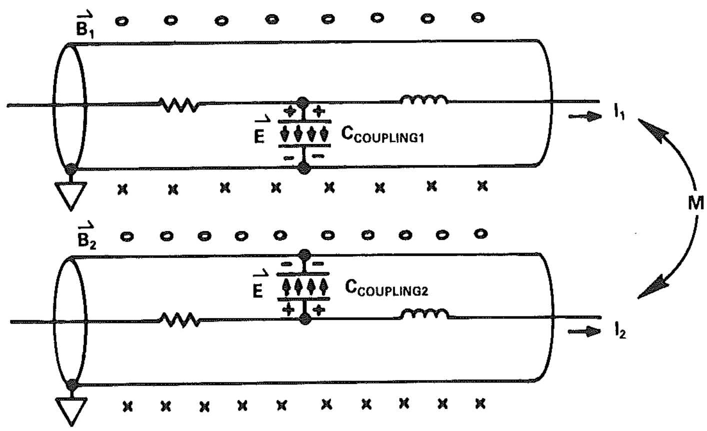


To illustrate the difference between magnetic and capacitive shields, consider current flowing in two wires. They have no shield. If we replace the exposed wire with coaxial cable, we have provided a capacitive shield. The outer conductor of the cable will intercept the electric field and a carefully chosen connection will provide a return path for the noise currents. However, the coaxial cable does not act as an effective magnetic shield. The outer conductor is not a magnetic material and therefore has a permeability practically equivalent to air. This does not help contain the flux. An additional shield made of iron, or some other highly permeable material, will provide a means to contain the magnetic flux.

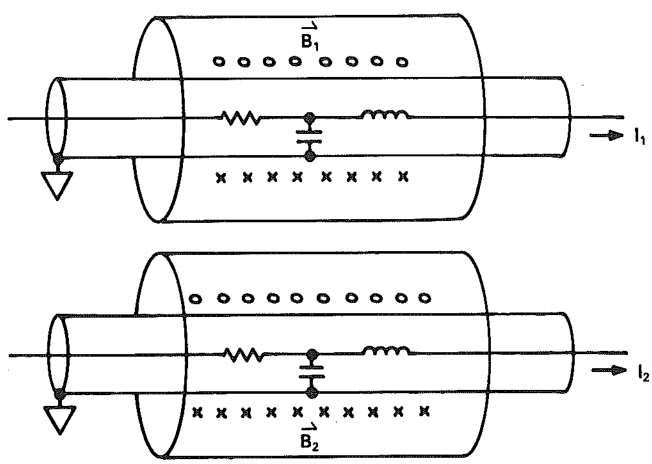
CURRENT IN UNSHIELDED WIRE IS EXPOSED TO BOTH CAPACITIVE AND MAGNETIC COUPLING



COAXIAL CABLE ACTS AS CAPACITIVE SHIELD BUT IS NOT EFFECTIVE AS A MAGNETIC SHIELD



MAGNETIC SHIELDS WITH HIGH RELATIVE PERMEABILITY CONTAIN MAGNETIC FLUX, REDUCE MUTUAL INDUCTANCE AND ARE EFFECTIVE AT ELIMINATING INDUCTIVELY COUPLED INTERFERENCE



SOME IDENTIFYING CHARACTERISTICS OF INDUCTIVELY COUPLED NOISE ARE:

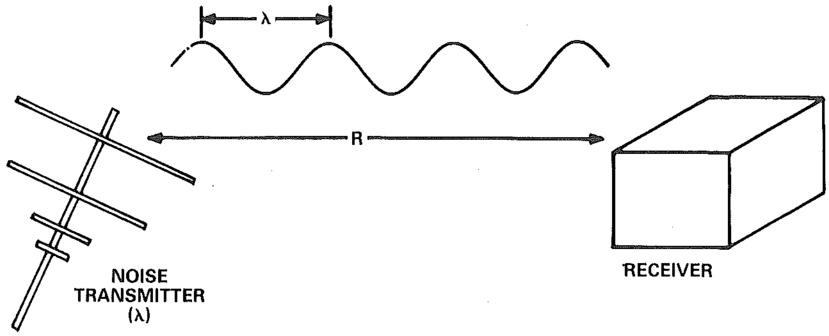
- Excessive wiring inductance due to unnecessary loop areas.
- Unaffected by materials which are nonconducting or nonmagnetic, such as people.
- The shield effectiveness is not influenced by different grounding schemes.
- High noise current.
- High frequency noise.

Logic signals are often magnetically coupled, as suggested by the last two characteristics.

RADIATIVE COUPLING

Radiative coupling is the reception or transmission of propagating electromagnetic energy. It is a far field effect, as opposed to capacitive and inductive coupling, which are near field effects, and direct conductive coupling.

FAR FIELD EFFECTS OCCUR AT DISTANCES GREATER THAN ONE INTERFERENCE WAVELENGTH



FAR-FIELD DISTANCE: $R \geq \lambda$

The possibility that noise is electromagnetically, or radiatively, coupled can be disregarded unless the transmitter and receiver are at least one wavelength apart. A list of common interference wavelengths is given below

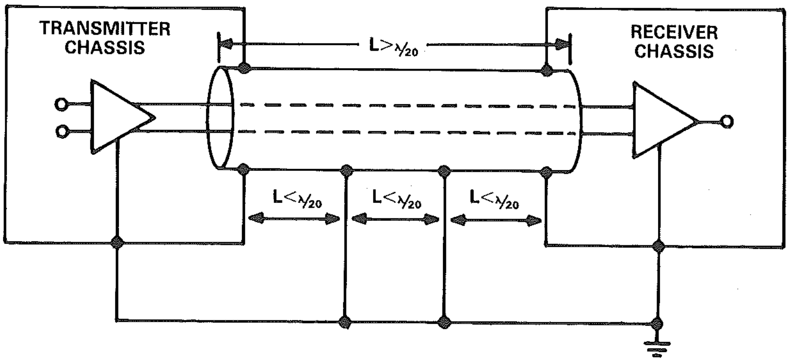
INTERFERENCE SOURCE	FREQUENCY (F_N)	WAVELENGTH (λ)
U.S. Power	60Hz	5,000km
European Power	50Hz	6,000km
Aircraft Power	400Hz	750km
Switching	20kHz	15km
Power Supplies	40kHz	7.5km
FM Radio	88MHz–108MHz	2.7m–3.4m
AM Radio	550kHz–1600kHz	188m–545m
Microwaves	1.5GHz–600GHz	0.5mm–200mm
X-Rays	15×10^{15}Hz–6×10^{24}Hz	0.05fm–20nm
TV	56MHz–16Hz	300mm–5.4m
Amateur Band	3MHz–36MHz	8.3m–100m
Cellular Phones	800MHz	375mm

C = SPEED OF LIGHT = $\lambda f_n \approx 3 \times 10^8$m/s

fm	=	10^{-15}m
pm	=	10^{-12}m
nm	=	10^{-9}m
μm	=	10^{-6}m
mm	=	10^{-3}m
km	=	10^{3}m
kHz	=	10^{3}Hz
MHz	=	10^{6}Hz
GHz	=	10^{9}Hz

The best way to reduce radiatively coupled noise is by shielding.

USING A SHIELD TO REDUCE RADIATIVE COUPLING



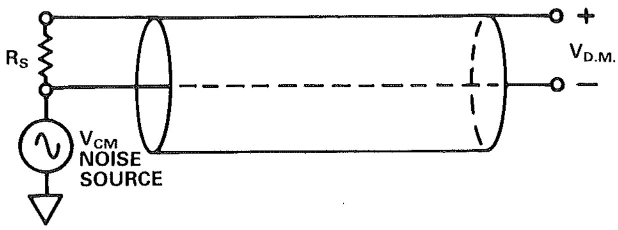
Electromagnetic shields must make a tight bond, both mechanically and electrically, at each end. They should never be terminated inside the receiver as this would provide a path via which the high frequency currents could penetrate. If the shield has a length greater than λ/20, then it may act as an antenna. This effect can be reduced by connecting the shield to ground along its length at distances less than λ/20, making it appear electrically shorter than it is.

When evaluating electomagnetic susceptibility, remember that if a system can transmit energy at a certain frequency then it can also receive at that frequency and vice-versa.

BALANCED VS. UNBALANCED SYSTEMS

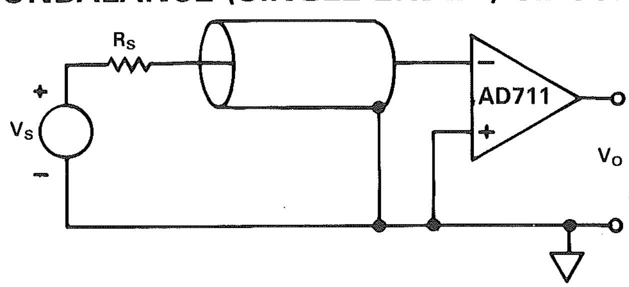
An unbalanced circuit can cause a common mode noise to become differential.

CIRCUIT UNBALANCE CAUSES COMMON MODE TO DIFFERENTIAL MODE CONVERSION

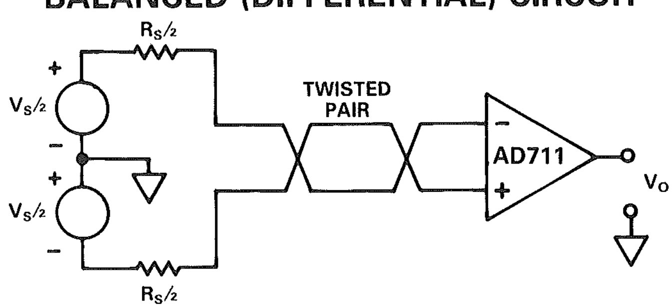


Desired signals are differential. Noise can be either differential or common mode. A conversion of common mode noise to differential will cause it to interfere with the desired signal. A balanced circuit helps to minimize this conversion.

UNBALANCE (SINGLE ENDED) CIRCUIT



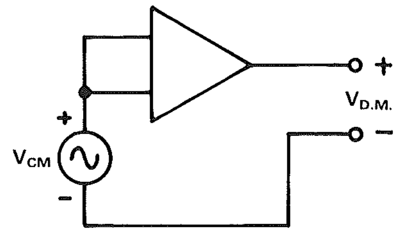
BALANCED (DIFFERENTIAL) CIRCUIT



A balanced circuit is one whose current signal path is electrically identical to the current return path. For a system to be balanced, every component must be balanced, including the source, the cable, and the receiver.

Devices with good common-mode rejection help to control noise by improving the circuit balance.

DEFINITION OF COMMON-MODE REJECTION

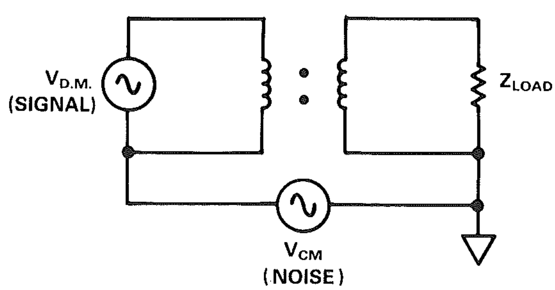


$$\left(\text{COMMON-MODE REJECTION}\right) = \text{CMR} = \left(\frac{V_{CM} \text{ AT INPUT}}{V_{DM} \text{ AT OUTPUT}}\right)$$

$$\text{IDEALLY} \quad V_{DM} = 0 \quad \text{CMR} = \infty$$

Differential amplifiers, instrumentation amplifiers, and isolation amplifiers are examples of good common-mode rejection devices.

SIMPLIFIED MODEL OF ISOLATION AMPLIFIER ILLUSTRATES COMMON-MODE REJECTION



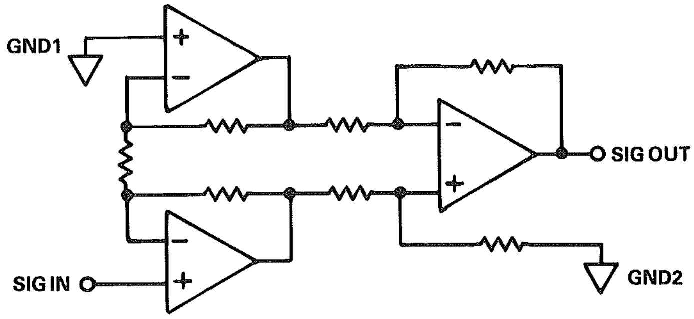
To minimize the conversion of common-mode noise to differential mode noise, electrically balance the system and use devices with high common-mode rejection.

TRANSLATING GROUNDS

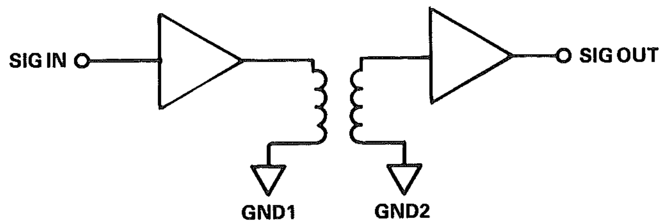
There will always be noise between different local grounds. These ground to ground noise voltages must be anticipated during system design so that an appropriate strategy can be developed to handle them. A voltage is meaningless if it is not referred to something. Therefore, when transferring signals from one ground to another, the signal must be translated from one ground reference to another.

The most common way to translate an analog signal to a board with a different ground reference is to use an electronic isolator such as an instrumentation amp, isolation amp, or differentially connected op amp.

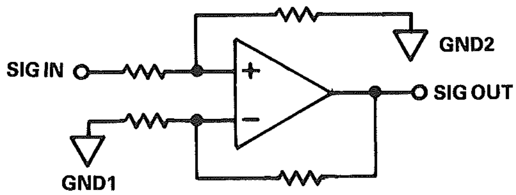
An isolation amp will cover ground differences as large as several thousand volts. They are suitable for transmitting low frequency (several kilohertz) signals between grounds that have very high levels of ground to ground noise. An inherent advantage of transformer coupling is that high frequency signals such as power supply glitches cannot readily pass through the transformer. The limited frequency response of the transformer core can be a disadvantage, however, because it limits the useable frequency of the signal being coupled through the isolation amplifier. In addition, isolation amplifiers are expensive; although modern manufacturing techniques have greatly lowered the price of some newer models.



INSTRUMENT AMP ISOLATION



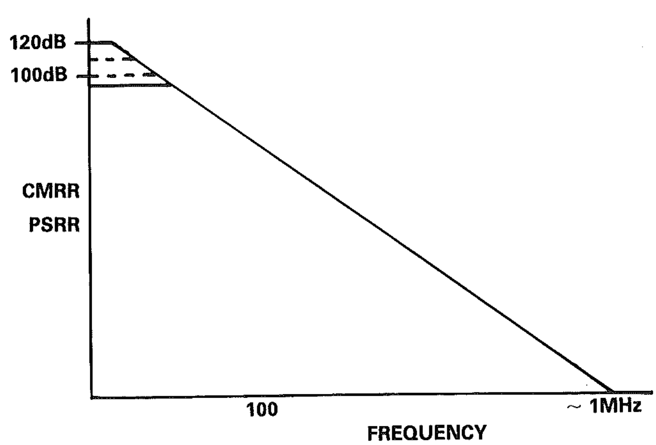
ISOLATION AMPLIFIER



DIFFERENTIAL OP AMP

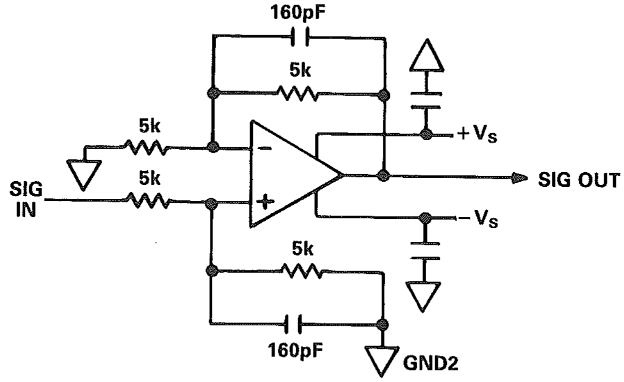
Instrumentation amplifiers and differentially connected amplifiers can provide the ground translation function at a much lower cost, althogh they are not without pitfalls. Obviously, the signals must stay within the power supply rails, but this is not necessarily a problem. Of far more importance is the high frequency performance of in-amps and differential connected op amps. In the data sheet for any amplifier, there are two specifications that are of special interest. They are PSRR and CMRR. Usually these specs are on the order of 100 to 120dB. However, THESE ARE DC SPECIFICATIONS. They do not mean that the amplifier has high rejection at the frequencies associated with glitches and other types of noise.

CMRR AND PSRR VS. FREQUENCY



Most amplifiers have CMRR and PSRR specifications that follow a single pole rolloff as shown in the plot above. They are quite good at eliminating dc errors, 60Hz interference, and even audio frequency interference, but are almost useless at stopping glitches caused by digital switching or other high slew rate transients. Therefore, the high frequency transients must be filtered out by passive means before or after the instrumentation amplifier.

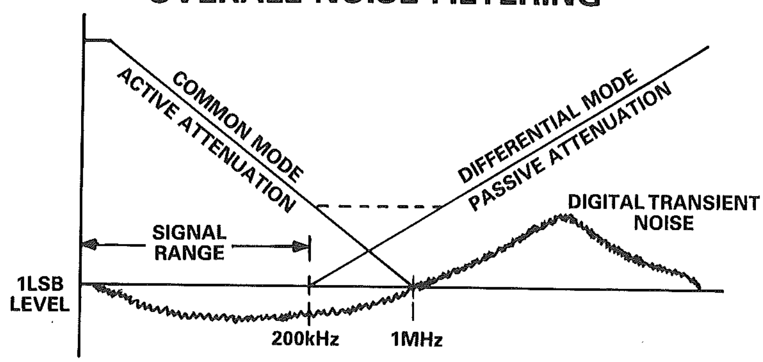
GROUND NOISE ISOLATOR
F_C = 200kHz



This figure shows a differential amplifier that has been modified by the addition of two capacitors so that it attenuates high frequency signals (glitches).

The 160pF capacitors causes attenuation of both differential and common mode signals above 200kHz. At that frequency, the common-mode noise attenuation is about a factor of five. This is shown graphically below. The power supplies in this configuration must be referred to ground 2 to avoid noise injection via the supplies.

OVERALL NOISE FILTERING



The total noise level should be kept below 1 LSB to preserve the accuracy of the system. This may be calculated by integrating the noise over the frequency range and multiplying the result by the attenuation factors of both the active common-mode attenuation (CMRR of the in-amp) and the differential mode attenuation (due to the R-C circuit) at higher frequencies. In the example shown and in many real life situations, most of the noise is at higher frequencies where the common-mode attenuation of the amplifier will not affect it. To compound the problem, high frequency noise is often rectified by both active and passive components resulting in a dc error. In these situations, it is absolutely necessary to provide some kind of passive filtering to eliminate noise. The filtering in this example limits the useful signal frequency to under 200kHz. However, it also eliminates most of the noise that would otherwise interfere. The bandwidth of a system need not exceed the required signal bandwidth. If the signal frequency range is much wider, it may be necessary to use more expensive high frequency amplifiers to translate signals from one ground level to another. Hybrid video amplifiers might be appropriate since they have at least a decade more CMRR than inexpensive monolithic amplifiers.

A FEW GENERAL RULES

Consider all signals to be differential signals requiring a path to and from their source. With proper attention to all applicable details, "ground" may serve as a return path.

Use separate signal and power return conductors.

Keep signal paths as short as possible. This will help to minimize voltage drops through the conductors as well as to minimize magnetic interference by controlling loop areas.

Using twisted pair cable is an easy way to improve the noise rejection of a system.

Provide separate analog and digital grounds and tie the two together only once.

Provide one connection from the system ground to the actual earth ground.

Connect capacitive shields once to provide a return path to the noise source.

Magnetic shields must be made out of a highly permeable material to be effective.

Metal should not be left electrically floating.

Maintain the balance of a system to prevent common mode signals from becoming differential.

Limit the bandwidth of the system to the required signal bandwidth

Last but not least: KEEP LOOP AREAS SMALL AND ALWAYS THINK – WHERE WILL THE CURRENTS FLOW?