Noise Elimination Techniques In Electronics For Plasma Diagnostics

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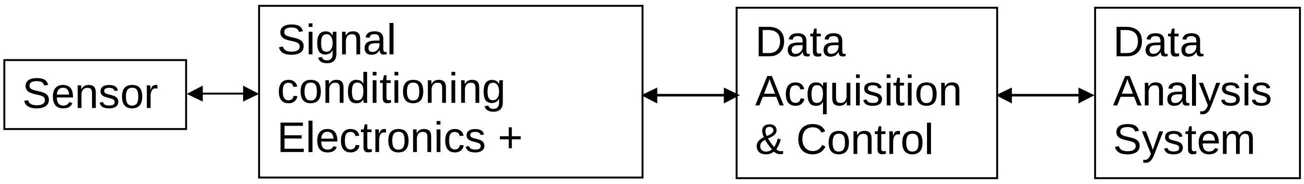
The concept of 'Noise' plays a crucial role in the statistical analysis of data. Whenever we try to make accurate measurements we discover that the quantities we are observing appear to fluctuate randomly by a small amount. This limits our ability to make quick, accurate measurements and ensures that the amount of information we can collect or communicate is always finite. These random fluctuations are called ***Noise.***

In some cases it's possible to improve a system by choosing a better design or using it in a different way. In other cases there are fundamental limits set by unavoidable noise effects.

Noise is generated because of poor workmanship for cable and connector, wiring, improper grounding, improper selection of components, improper PCB layout, improper laying of cables, improper shielding, impedance mismatch and so on..

Noise in Diagnostic System:

A Diagnostic system consists of Sensor, Signal Conditioning electronics, Data Acquisition and control and Data Analysis System.



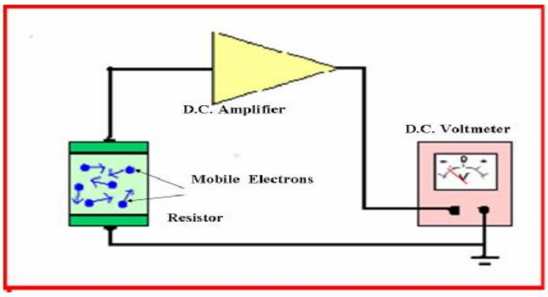
Noise is generated in all stages of the system. Electromagnetic diagnostic have Coil as sensor, Soft-X-Ray, Hard-X-Ray, Bolometer have Photo-diode as sensor, Thomson Scattering, Spectroscopy, NIM/GIM have PMT, Longmuir Probe has Probe and Microwave has Schottkey diode as detector.

Sensors may need biasing and controlling electronics for its operation. The output of the sensor must be conditioned using amplification/attenuation and filtering while data acquisition needs converter, memory and controlling electronics. Data is transmitted from one of system to another system using interfacing cables. Each stage of the system can invariably introduce noise in each stage.

Type of Noise: There are two main types of noise: Inherent and Generated.

Thermal, Shot, Flicker and Burst noise are considered as Inherent Noise, while noises due to grounding, interference, components etc are considered as Generated Noise.

Thermal noise, also known as "White Noise" contains noise signals of all frequencies and all these signals have the same average amplitude. It is created by the motion of electrons in a resistor. Because the resistor is at a temperature above absolute zero (-459 F), the electrons move randomly in the solid. This random, fluctuating movement of electrons produces a noise voltage at the terminals of the resistor **in the range of mV.** The internal resistance of transistors, diodes, and other active electronic components creates thermal noise. For capacitors and inductors, the internal resistances are negligible and they can be considered to be noiseless.



Shot noise is a noise produced in active devices such as transistors. The flow of current in a transistor is not a smooth steady flow. It is made of discrete current carriers, electrons, and the number of electrons leaving the collector of a transistor is not constant, but varies slightly from moment to moment. In bipolar transistors, the shot noise increases as the bias current is increased. In FET's, the shot noise is not affected by changes in bias.

Flicker noise, also known as 1/*f* noise, occurs in almost all electronic devices. Flicker noise is most troublesome at frequencies below 1 kHz and its amplitude is inversely proportional to frequency. It occurs in almost all electronic devices, and results from a variety of effects though always related to a direct current, such as impurities in a conductive channel, generation and recombination noise in a transistor due to base current, and so on. It is always related to a direct current.

Flicker noise is **found in carbon composition resistors**, where it is referred to as *excess noise*, since it increases the overall noise level above the thermal noise level, which is present in all resistors. In contrast, wire-wound resistors have the least amount of flicker noise.

Burst noise consists of sudden step-like transitions between two or more levels as high as several hundred millivolts, at random and unpredictable times. Each shift in offset voltage or current lasts for several milliseconds, and the intervals between pulses tend to be in the audio range (less than 100 Hz), leading to the term popcorn noise for the popping or crackling sounds it produces in audio circuits.

Man-made Noise and its elimination:

Noise is generated in electronics system by various reasons; **at system level** because of grounding and interference and **at component level** because of temperature, PCB layout and component mounting, grounding, interference, component selection etc.

Grounding: Grounding is very crucial component in noise generation.

Electrical circuits are connected to ground (earth) for several reasons:

1) Safety of personnel and other systems from hazardous voltage
2) Limits the building of static electricity while repairing and maintenance of different equipment
3) Used as return path
4) Reference potential for measurement
5) "ground" is usually idealized as an infinite source or sink for charge, which can absorb an unlimited amount of current without changing its potential.

Problems due to improper grounding:

Ground loop: When two or more interconnected system grounded by more than one ground, it will result in ground loop problem. The duplicate path forms the equivalent of a loop antenna and pick up current from the changing magnetic field around it. Lead resistance transforms these currents into voltage fluctuations. As a consequence of ground-loop induced voltages, the ground reference in the system is no longer a stable potential, so signals ride on the noise. The noise becomes part of the actual signal. It will generate 50Hz noise.

Easiest way to check for Ground Loop is to connect speaker to the output, it gives humming sound for the 50Hz noise.

Solution: To prevent ground loops, all signal grounds need to go to one common point and when two grounding points cannot be avoided, one side must isolate the signal and grounds from the other.

Leakage current between line and neutral and line and ground can cause current in ground wires and ground loops. It can generate Humming noise in audio signal, interference bar in video signal, noise in analog signal and transmission error in network signal. Higher currents can cause sparking in connection or damage in equipment.

In real life system there is always some leakage in ground, so if neutral and ground shared on same wire, the current flowing on neutral wire would easily cause a large diff on diff outlets grounds. The ground potential on any outlet depends on the load current, neutral wire resistance and the mains phase it is connected to.

Solution: Separate ground and neutral conductor is required to provide good electrical wiring security and minimizing ground potential diff between outlets.

Cable shield connections are very crucial. To avoid ground loop the shield should be grounded to only one end, at the receiving end and to avoid interference, both ends should be grounded.

Solution: Practically it is observed that shield should be connected to ground at the receiving end for low frequency signal, while for RF signal, it should be grounded at transmission ends.

If there is a mix of circuit types, Analog, TTL, CMOS, etc., then the analog grounds must be separate from the digital ground returns. And, sometimes if there is a large concentration of fast TTL, and some CMOS logic: thought should be given to separate supplies and, of course, separate ground returns. The reason for the latter is that TTL, by its very nature, puts large amounts of noise into its supply rail, and though CMOS is robust, its merely a matter of degree to what it takes to corrupt it.

Solution: The analog ground must be separated from the digital ground returns.

Earth Ground can be improved by following:
1) Increasing the surface area of the electrode in contact with the earth
2) Increasing the depth to which it is driven
3) Connecting several ground rods
4) Increasing the moisture of the soil
5) Improving the conductive mineral content of the soil(add salt in soil)

6) Signal ground must be connected to earth by shortest possible path.
7) Ground mats are used for repair and for fuel trucks (or flammable material carrier)

Grounding can be improved by following:

1) To prevent ground loops, all signal grounds need to go to one common point and when two grounding points cannot be avoided, one side must isolate the signal and grounds from the other. Signal ground must be separated from Safety ground.
2) Use proper shielded cable and shield connection must be done properly.
3) The equipments which have metal case have typically grounded power connectors. In this case the metal enclosure is grounded to the Safety ground.

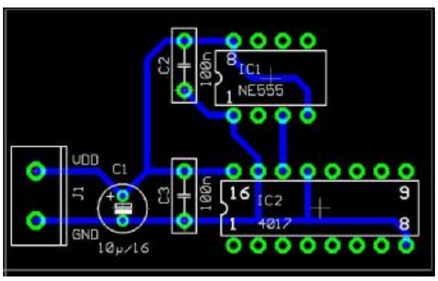
Decoupling: The choke offers a high impedance path to any noise between stages, while offering a very low resistance path to the DC power, this is known as decoupling.

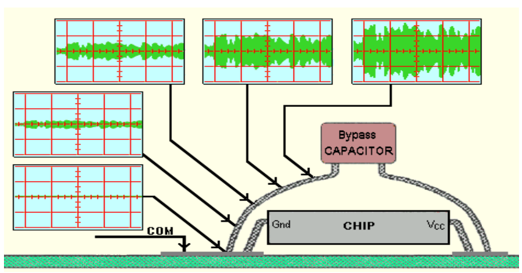
Uses of decoupling capacitors:

1) Bypass capacitors smooth out voltage spikes
2) It coupled the two circuits and so save the load circuit from switching effect of source circuit.
3) The bypass capacitor gets charged when supply is available and released enough energy, quickly enough, that the current required by the chip does not have to come from the main power supply in a short pulse.

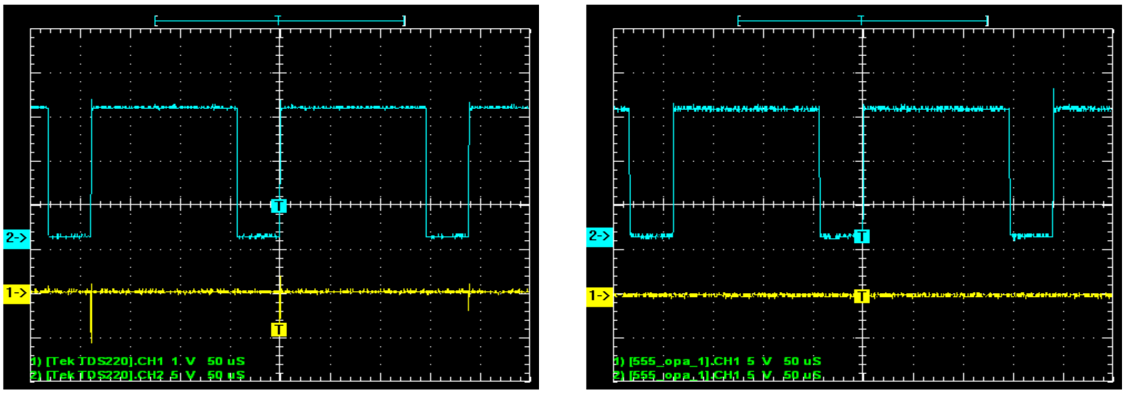
Type of Capacitors used for coupling:

1) General purpose bypass capacitors are surface mount thin film caps. They have no leads to speak of, and low series inductance. Theoretically, the impedance of a capacitor, at a given frequency, goes down as the capacitor value is increased. This is true, but also, it's internal inductance and resistance rise. So, for any given value of capacitor, there is actually a band of frequencies where it will perform best.
As a rule-of-thumb: 0.1uF at 3 MHz, 0.01uF at 30 MHz, 0.001uF at 300 MHz
2) Two capacitors are connected in Parallel for decoupling. Instead of parallel effect of the capacitor, small capacitor prevent small glitches while large capacitor being big and clunky as they are somewhat slower, they can't catch those fast glitches, but in one fell swoop they can swallow one fat slow glitch. So little caps fasts glitches and noise, big fat caps for big glitches and slow noise.
3) A power supply decoupling bypass capacitor should be placed as close to the voltage/current source as possible. The idea is to minimize the line inductance and series resistance between the capacitor and the supplied devices.
4) When two high frequency signal lines are close together they can couple due to their capacitances and mutual inductance. Signal lines can effectively act like antennas emitting electromagnetic waves. Decoupling capacitors of the power and ground planes can be used to short circuit or filter noise.





An illustration of the **effects of Inductance in Excessive Lead Length**



Effect of De-coupling

Noise generated in power supply lines comes from current spikes caused by switching logic or instantaneous current requests from devices down the line. When a load is suddenly applied to a voltage source, the circuit tries to suddenly increase its current, but the inductance in the power supply line acts to oppose that increase. It opposes it by lowering the voltage the power line supplies. This is not just the voltage that the load in question sees, but the voltage that every other sub-circuit that shares that power supply line sees. This is only temporary; the inductance ultimately loses the battle and the voltage comes back to normal. But even a temporary reduction in voltage can disturb other sub-circuits.

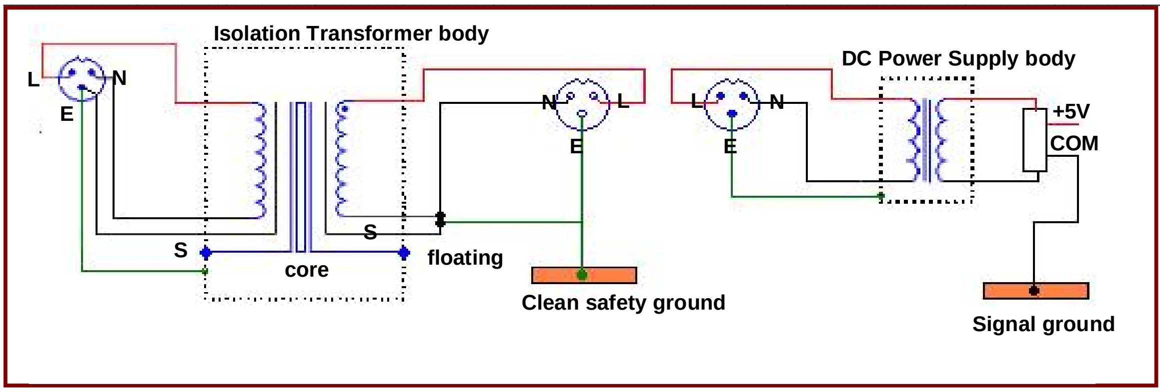
Solution: To decouple other sub-circuits from the effect of the sudden current demand, a decoupling capacitor can be placed between the supply voltage line and its reference (ground) next to the switched load. The required extra current can be supplied by the decoupling capacitor.

Isolation Transformer:

An **isolation transformer** is a transformer, often with symmetrical windings.

Uses of Isolation Transformer:

1) It is used to decouple two circuits. An isolation transformer allows an AC signal or power to be taken from one device and fed into another without electrically connecting the two circuits.
2) It blocks transmission of DC signals from one circuit to the other, but allow AC signals to pass.
3) It also blocks interference caused by ground loops. Isolation transformers with electrostatic shields are used for power supplies for sensitive equipment such as computers or laboratory instruments.
4) Isolation transformer physically and electrically separates two parts of a circuit, while allowing for the two parts to interact.
5) It improves common-mode voltage and noise rejection
6) It permits the two parts of the circuit to be at different voltage levels, which means one can be safe while the other side is at hazardous voltage levels
7) Many industrial applications require isolation to protect the electronics from transient voltage spikes and provide greater common mode noise rejection in electrically noisy environments containing machinery and inductive loads.



Isolation Transformer and Rack Power supply configuration

Shielding:

Electromagnetic shielding is the process of limiting the penetration of electromagnetic fields into a space, by blocking them with a barrier made of conductive material. Typically it is applied to enclosures, separating electrical devices from the 'outside world', and to cables, separating wires from the environment the cable runs through.

Use of Shielding:
It protects the circuit by shielding it from outside noise or unwanted signals; and conversely, it contains its own signals and thus protects the outside world from interference of its own making.

Reason:
One important requirement for a shield to be effective is that there must be no currents flowing through the shield itself. This is best accomplished by connecting the reference or common, at only one point on the shield, thus preventing any flow of current.

A **conductive enclosure** used to block electrostatic fields is also known as a **Faraday cage**. The amount of reduction depends very much upon the material used, its thickness, the size of the shielded volume and the frequency of the fields of interest and the size, shape and orientation of apertures in a shield to an incident electromagnetic field.
Typical materials used for electromagnetic shielding include **sheet metal, wood, metal foam, and plasma (ionized gas).** Any holes in the shield or mesh must be significantly smaller than the wavelength of the radiation that is being kept out, or the enclosure will not effectively approximate an unbroken conducting surface. Electronic goods housed in plastic enclosures, is to coat the inside of the enclosure with a metallic ink or similar material. Wire mesh around the cable is use for shielding.
For ***varying magnetic field*** (below about 100 KHz) the Faraday shielding is ineffective. For that shields made of high magnetic permeability metal alloys such as Permalloy and Mu-metal is used. These materials don't block the magnetic field, as with electric shielding, but rather draw the field into themselves, providing a path for the magnetic field lines around the shielded volume. At very low magnetic field strengths, and at high field strengths the material becomes saturated.
Solution: To achieve low residual fields, magnetic shields often consist of several enclosures one inside the other, each of which successively reduces the field inside it.

Cabling:

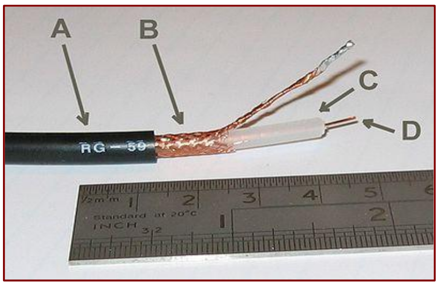
Coaxial, Twisted Pair, Ribbon cable and Fiber optic cable are the different cables used for different application.

Coaxial Cable:

If an ordinary wire is used to carry high frequency currents, the wire acts as an antenna, and the high frequency currents radiate off the wire as radio waves, causing power losses. To prevent this, in coaxial cable one of the conductors is formed into a tube and encloses the other conductor. This confines the radio waves from the central conductor to the space inside the tube. To prevent the outer conductor, or shield, from radiating, it is connected to electrical ground, keeping it at a constant potential.

Coaxial cable design choices affect physical size, frequency performance, attenuation, power handling capabilities, flexibility, strength and cost.

The term **coaxial** comes from the inner conductor and the outer shield sharing the same geometric axis. Manufacturers specify a minimum bend radius, to prevent kinks that would cause reflections. In an ideal coaxial cable the electromagnetic field carrying the signal exists only in the space between the inner and outer conductors. This allows coaxial cable runs to be installed next to metal objects without the power losses that occur in other transmission lines, and provides protection of the signal from external electromagnetic interference. The dimensions and spacing of the conductors are uniform. Any abrupt change in the spacing of the two conductors along the cable tends to reflect radio frequency power back toward the source, causing a condition called standing waves. This acts as a bottleneck, reducing the amount and quality of the transmitted power. To hold the shield at a uniform distance from the central conductor, the space between the two is filled with a plastic dielectric**.**



RG-59(Registered-Jack) flexible coaxial cable

***A:** outer plastic sheath **B:** copper screen*

***C:** inner dielectric insulator **D:** copper core*

Advantages of Co-axial Cable:

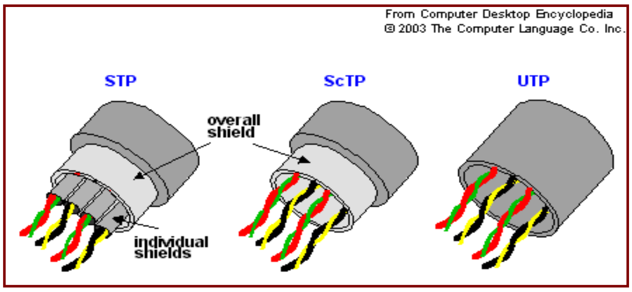
1) Braided metal shield over the single copper conductor blocks interference.
2) It supports longer lengths than twisted pair.
3) Insulated plastic layer over the center conductor keep moisture out.

Disadvantages of Co-axial Cable:

1) Because of the braided metal shield over the centre copper conductor it is hard to install.

Twisted Pair:

Twisted pair cabling is a form of wiring in which two conductors (the forward and return conductors of a single circuit) are twisted together for the purposes of canceling out electromagnetic interference (EMI) from external sources.

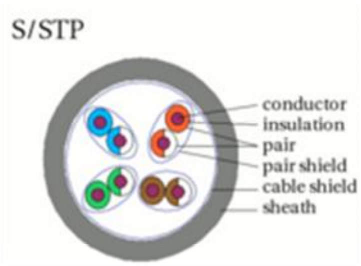


Type of Twisted Pair Cable:

1) UTP: Unshielded Twisted Pair Cable, used for telephone, television and networking due to the high flexibility and improved bandwidth to match base band of TV of the cable. UTP cables are connected with the RJ(Registered Jack)-45 connector.

2) STP: Shielded Twisted Pair Cable, used in noisy environments where the shields around each of the wire pairs, plus an overall shield, protect against excessive electromagnetic interference.

3) ScTP: ScTP has only outer shield while STP has individual as well as overall shield.



S/STP Screened Shielded Twisted Pair

S/UTP, also known as FTP, Foiled Unshielded Twisted Pair

This shielding can be applied to individual pairs, or to the collection of pairs. When shielding is applied to the collection of pairs, this is referred to as screening.

Points to consider:

1) Twisted pair's susceptibility to the electromagnetic interference greatly depends on the pair twisting schemes (usually patented by the manufacturers) staying intact during the installation. This relative fragility of twisted pair cables makes the installation practices an important part of ensuring the cable's performance.

2) In video applications twisted pair cabling can introduce signaling delays known as **skew** which results in subtle color defects and ghosting. The skew occurs because twisted pairs within the same cable often use a **different number of twists per meter** so as to prevent common-mode crosstalk between pairs with identical numbers of twists.

3) To reduce crosstalk or electromagnetic induction between pairs of wires, two insulated copper wires are twisted around each other. Each signal on twisted pair requires both wires.

4) An ideal shield would be a perfect conductor with no holes, gaps or bumps connected to a perfect ground. However, a smooth solid copper shield would be heavy, inflexible, and expensive. Practical cables must make compromises between shield efficacy, flexibility and cost, such as the corrugated surface of hardline, flexible braid, or foil shields.

Advantages of Unshielded Cable:

1) It is a thin, flexible cable that is easy to string between walls.
2) Because UTP is small, it does not quickly fill up wiring ducts.
3) UTP costs less per meter/foot than any other type of LAN cable.

Disadvantages of Unshielded Cable:

1) It can be affected by cross talk when laying multiple cables in parallel.
Solution: The individual cable can be twisted with insulated copper conductor.
2) UTP cables are vulnerable to radio and electrical frequencies.

Solution: Use Shielded Cable

Advantages of twisted pair cable:

1) It reduces the cross talk between the signals.
2) Good protection against Electrical Interference.
3) Twisted pair is now frequently installed with two pairs to the home, with the extra pair making it possible to add another line (perhaps for modem use) when needed.
4) Installed for LAN connection as it is cheaper than Co-axial.

Disadvantages of twisted cable:

1) Twisted pair cabling can introduce signaling delays known as skew.
2) Shield makes cable bulky, heavy and rigid.

Ribbon Cable:

A **ribbon cable** (also known as multi-wire planar cable) is a cable with many conducting wires running parallel to each other on the same flat plane. As a result the cable is wide and flat. Its name comes from the resemblance of the cable to a piece of ribbon (which is likewise wide and flat). It is used for data and control signal transmission. They are two types: Straight Flat cable and Twisted and straight Flat cable.

20 way Grey Ribbon cable, rainbow cable with IDC 16 connector

Fiber Optic Cable:

Fiber optic cable is made of a glass center with many protective layers. It's designed to transmit light, not electronic signal, so there is no problem with electrical interference. It can transmit signals further than coaxial and twisted cable, and at faster speeds. It is often used for video conferencing. 10BaseF is the standard for Fiber Optic Cable carrying Ethernet. Connections are made with an ST connector, which is similar to a BNC connector. There are various grades of fiber, but 50 micron laser optimized is the most widely used today.

<u>Connector:</u>

Characteristic Impedance:

Each type of coaxial cable has characteristic impedance (resistance) depending on its dimensions and construction, which is **the ratio of the voltage to the current in the cable**. To prevent reflections, the connector is designed to have the same impedance as the attached cable.

BNC (Bayonet Neill-Concelman) connectors used normally **for Co-axial cable** are manufactured with 50 and 75 ohm impedance capability, with the 50 ohm impedance good for frequencies of up to 4 GHz and the 75 ohm impedance for up to 2 GHz. The best coaxial cable impedances in high-power, high-voltage, and low-attenuation applications were experimentally determined in 1929 at Bell Laboratories to be 30, 60, and 77 Ω respectively. The arithmetic mean between 30 ohms and 77 ohms is 53.5, the geometric mean is 48 ohms. The selection of 50 ohms as a compromise between power handling capability and attenuation is generally cited as the reason for the number.

LEMO: LEMO type connector is used for Twisted pair cable. It is available

for single pin, two pin or multi pin configuration.

D type connector: It is used for Ribbon cable connector. It is available for 9pin, 15pin, 25 pin and so on..

Electromagnetic interference (or **EMI**, also called **radio frequency interference** or **RFI**) is a disturbance that affects an electrical circuit due to either electromagnetic conduction or electromagnetic radiation emitted from an external source. The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit.
The main sources of noise in embedded systems come from switching power supplies, common mode current, noisy ground islands, high frequency switching signals, oscillators, phase-locked loop circuits, crosstalk between signals, the transmission line effect, and from hardware sources like disk drives.

Magnetic fields from transformers can cause humming
Mains transformers typically cause an AC magnetic field around them. This magnetic field can be coupled to wiring, electronics or signal transformers and cause humming. The effect of low frequency magnetic field can be reduced by **enclosing the circuit with steel case**.
Sometime the power transformer leak heavy magnetic field due to use of cheap core material or improper design. The effect can be reduced by **leaving blank spaces between the equipment** from that leaky transformer. Effect can be checked by moving the object from the transformer to different distance.

Magnetic fields from distribution panels
Main power distribution panels have high current carrying wires, relays and contactors in them and they can cause quite strong magnetic fields around then. It is not advisable to put any computer monitors or audio equipments near them. **Few meters clearance from mains distribution panel** is usually enough to stop any magnetic interference.

Magnetic fields from electrical motors
Electrical motors, air conditioners, vacuum pumps etc generate strong magnetic fields inside them, create 50Hz noise in electronics circuit. **Leaving blank spaces between the equipment can reduce the effect.**

Radio interference
Radio interference can cause serious noise problems to the audio system which is not properly shielded. Some strong radio transmitters and industrial systems which use radio frequency signals can sometimes be modulated with mains frequency humming (for example because of poor power supply). If this kind of modulated radio frequency signal enters to your equipments it can cause mains humming like interference which is very hard to get rid of.

Main voltage quality problems
If mains voltage is not nice sine wave then it contains harmonics which can usually more easily enter to the circuit than 50 Hz mains. Typical sources for this kind of power quality problems are high frequency interference caused by dimmers. Computer power supplies and fluorescent lighting can cause harmonics to the power and thus interference to sensitive equipments. Some cheapest UPS equipments put out very low quality main voltage which will generate all kinds of noise.
Mains quality problems are usually solved by using mains filters and isolation

transformer. High quality on-line UPS equipments can improve power problems. This UPS will filter out any problems from the incoming power and also useful protection against short mains power breaks.

Practical example On integrated circuits, important means of reducing EMI are:

1) The use of bypass or "decoupling" capacitors on each active device (connected across the power supply, as close to the device as possible), rise time control of high-speed signals using series resistors, and VCC filtering. Shielding is usually a last resort after other techniques have failed because of the added expense of RF gaskets and the like.

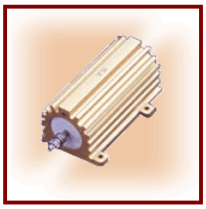
2) At lower frequencies, such as 133 MHz, radiation is almost exclusively via I/O cables; RF noise gets onto the power planes and is coupled to the line drivers via the VCC and ground pins. The RF is then coupled to the cable through the line driver as common-mode noise. Since the noise is common-mode, shielding has very little effect, even with differential pairs. The RF energy is capacitively coupled from the signal pair to the shield and the shield itself does the radiating. One cure for this is to use a braid-breaker or choke to reduce the common-mode signal.

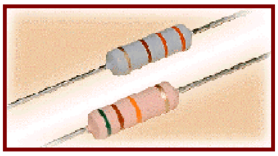
3) Switching inductive loads, such as electric motors, often cause interference, but it is easily suppressed by connecting a snubber network, a resistor in series with a capacitor, across the switch. Exact values can be optimised for each case, but 100 ohms in series with 100 nanofarads is usually satisfactory.

Selection of Components:

Points to consider while selection of components: Main active components are transistor, diode, ICs etc while passive components are resistor, capacitors, cable, connectors etc

Resister :Wire wound has good accuracy (0.005%) but is highly expensive. Carbon film resistors are very general purpose resistor with accuracy of (5%) but have better frequency response than Wire wound resistor. For low noise application Metal Film Resistors are used. It has 1% accuracy and has better frequency response than Carbon film resistor.





Capacitors: Tantalum capacitors are used for Low frequency; Large Ceramic capacitors (e.g., 0.1 ufd) for the higher frequencies and Small Ceramic, RF capacitors (~1nfd) are used for the much higher frequencies.

ICs: The most important parameter in low-noise design is the source impedance.

1) When the **signal source has low impedance**, current noise has little effect, so choose an amplifier that has a low voltage noise. The lowest-voltage-noise amplifiers have bipolar-transistor input stages.

2) When the **signal source has high impedance**, current noise has a big effect, so choose an amplifier that has low current noise. The lowest current-noise amplifiers have JFET-input stages.

3) Select the voltage and current noises for optimal overall noise performance when the **signal source impedance is 1 kΩ to 1 MΩ**. This situation is the hardest one to tackle, but a low-power bipolar-transistor input stage usually does the job.

4) An insulated-gate CMOS-transistor stage offers **extremely low bias current**, but it has more voltage noise than its JFET counterpart. CMOS amplifiers have good noise performance at frequencies greater than 10 kHz, but, because poor 1/f performance handicaps them.

5) All things being equal—currents, device geometry, second-stage contribution, and so on—the JFET is still a better choice for low-noise performance in the 20-Hz to 20-kHz frequency range.

Solution:

1) Low source impedance dictates selection of a low-voltage-noise amplifier.
2) Medium source impedance means that the amplifier selection is a compromise between voltage- and current-noise performance.
3) High source impedance dictates selection of a low-current-noise amplifier.

Conclusion:

1. Un-terminated Cables can radiate. Properly terminated, differentially driven Shielded Twisted pair offer the best performance.
2. Bypass all active devices using two capacitors in parallel combination with smallest lead with a capacitor values as a rule-of-thumb, is this: 0.1uF at 3 MHz, 0.01uF at 30 MHz, 0.001uF at 300 MHz
3. Every signal should have return path. Analog and Digital ground should be separate.
4. Shields have No current flowing thru them, and they must be "Grounded," or referenced, at only one point. Openings or Apertures in Enclosures Appear as Point Sources, and Radiate extensively.
5. Shield and twist Noisy cable leads.
6. Restrict bandwidth by feedback capacitor
7. Shielded cables used to protect low frequency. Low-level signal leads should be grounded at one end only (coaxial cable may be used at high frequencies with shield grounded at both ends).
8. When low-level signal leads and noisy leads are in the same connector, separate them and place the ground leads between them.
9. Avoid common ground leads between high-voltage and low voltage equipment.
10. Keep equipment or safety grounds separate from circuit or signal grounds.
11. Ground the cable shield accordingly, for low frequency at receiving end while for RF on transmitting end.
12. Keep ground leads as short as possible.
13. Avoid ground loops in low frequency, low-level circuits.
14. Consider using the following devices for breaking ground loops:
    Isolation transformers
    Optical couplers
    Differential amplifiers
    Guarded amplifiers
15. Use conductive coatings in place of nonconductive coatings for protection of metallic surfaces.
16. Filter or decouple any leads entering enclosures containing sensitive equipment.
17. Keep ground and other leads separate.
18. Use low impedance power distribution lines.
19. Use Filters when applicable
20. Provide proper power supply decoupling
21. Use Shielded Enclosure
22. Minimize Ground inductance by using Ground Grid
23. Use smallest capacitor value that do the job
24. Use bulk decoupling capacitor to ‘recharge’ the individual IC decoupling capacitors
25. All unused inputs on logic gates should be connected to either power or ground.

26. I/O drivers should be located near where the cables leave the system.
27. Use the lowest frequency clock, and slowest rise time that will do the job.
28. Keep clock circuits and leads away from the I/O cables.
29. Switching inductive loads, such as electric motors, often cause interference, can be suppressed by connecting a resister in series with a capacitor across switch. Generally 100ohms in series with 100nanofarads can do the job.
30. All the traces should be kept as short as possible cutting down on the effective area of the loops that act as antennas.
31. All unused areas can be plated with copper and connected to ground at several points, adding extra shielding.
32. To keep phase-locked loops clean and unaffected by noise, the best solution is to isolate the loops from the actual power supply. This can be accomplished by adding a low drop out voltage regulator to the circuit.
33. Impedance matching and proper signal termination are required to cut back on crosstalk and transmission line effects.
34. A multilayer PCB with separate power and ground layers is useful to achieve the necessary isolation and shielding required for high gain and wide bandwidth device.