Electro-Magnetic Interference in Robots and how to deal with it!

***Lack of range, poor reception, erratic movement, and sluggish response*.**

All of the above symptoms can be caused by poor attention to the causes of Electro-Magnetic Interference.

EMI can be generated in many ways, both intentional and unintentional.
Under the umbrella of intentional we have sources such as: - Mobile Phones, walkie-talkie, other Transmitters, TV broadcast equipment and even RADAR in some cases. But these are covered by emission regulations and are usually a long way off, so it would be extremely rare that they would cause any problems.

Unintentional sources however, are a different matter, these include: - Switch-mode drivers, un-suppressed motors, solenoids & relays, ICE ignition circuit, etc most of which will be inside your machine and generating: - Magnetic & Electric fields, Electrical noise, Current spikes, Voltage surges & dips

All of these potential sources are guaranteed to make life difficult for those unaware of the pitfalls.

Problems

1. The most common symptom is lack of range caused by poor reception. This is due primarily to the nature of the receiver, it being what is called a Super Heterodyne, but enough of the technical jargon. Its input is very sensitive to being overloaded by excessive amounts of RF energy *(It's like trying to listen to someone at a loud rock concert)*, when the receiver becomes deafened it can't hear the intended signal from the transmitter.

2. The next type of failure is sluggish performance associated with some makes of speed controller.

3. The third type is when the machine starts behaving erratically when certain systems are switched on or off.

A Few Concepts

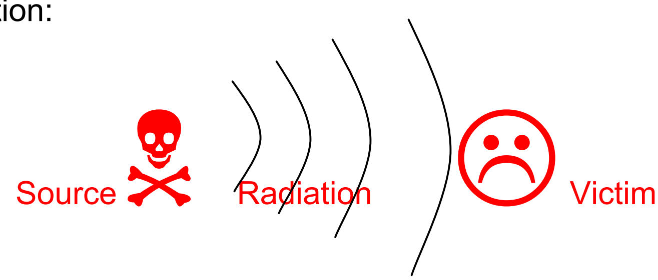
Everyone knows the fire triangle; well here we have a variation on it, the EMI triangle.

As with its predecessor, remove any of the 3 sides and the EMI problem goes away.

So how do you do that?

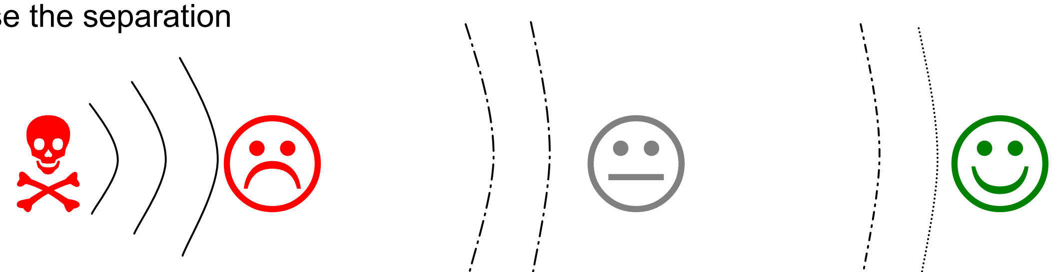
(For the purpose of this explanation I have used the radiated propagation method)

An unsatisfactory situation:



Improvement methods:

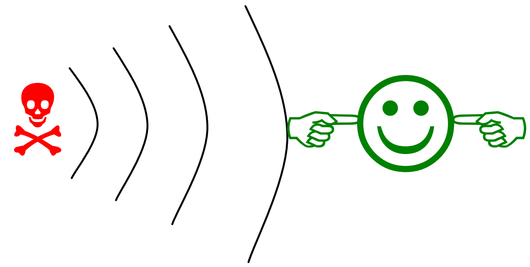
1: Increase the separation



(This is effectively reducing the transfer path.)

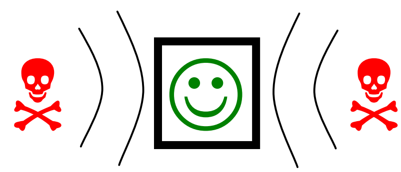
2: Attenuate the source

3: Desensitise the victim



4: Guard the source

5: Protect the victim



The problems arise in identifying what is the source, what it's affecting and how it's getting there, especially in a complex machine with lots of different systems and little or no test equipment.

Things get even more complicated when you realise that interference can be conducted as well as radiated, and even change from radiated to conducted, and back to radiated again.

To the untrained eye and with no test equipment, finding problem sources can be a black art. However, you can get a feeling for what is going on using an ordinary AM radio.

To do this set your robot up on blocks so it can't move, activate the electrical systems and operate the machine while someone else operates the AM radio, the radio will need to be scanned through the bands, listening for Buzzing, Hum, Fuzz, Whistles or Clicks whenever the different systems are being used, this not only means during constant use but also as they are switched on or off, This must be differentiated against the normal fuzz that you get from the AM radio when all systems are deactivated. Once you've identified a possible source you can then set about fixing it.

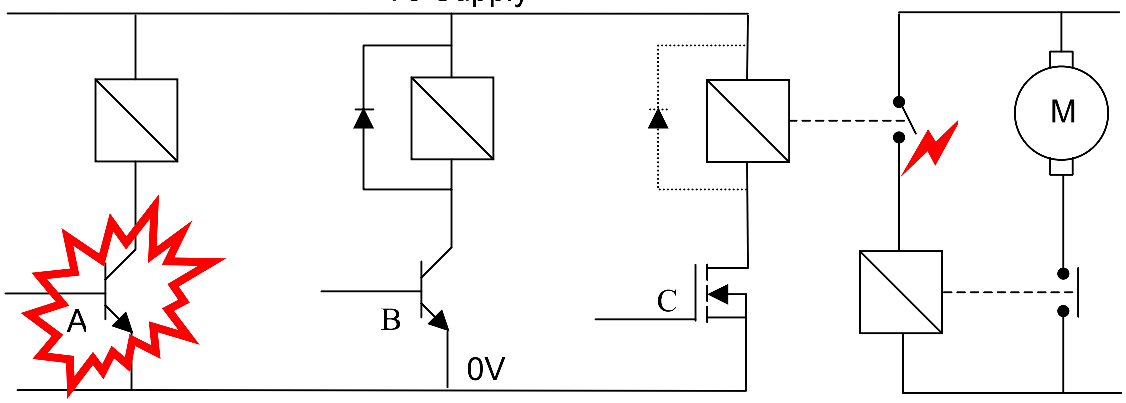
For the different types of interference source, there are different methods of dealing with them, some more effective than others.

Solutions

Prevention is usually better than cure, so for the following list the first will potentially give the most improvement, and the last can be used for mopping up.

1. Suppression.

Make sure all relays and solenoids have some form of fly-back protection.



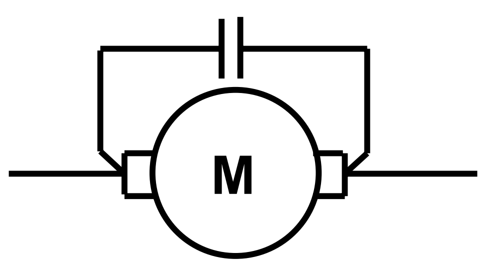
Circuit A; has no fly-back protection, as a result the relay will switch on once only, because when it switches off the fly-back voltage of the relay (or solenoid) will destroy the transistor.

Circuit B; has a simple fly-back diode fitted, so that when the circuit switches off the current generated by the relay will re-circulate and discharge safely (the diode must be able to withstand the relay current).

Circuit C; this is a commonly seen method of using a transistor to drive a relay, in order to activate a bigger solenoid. The MOSFET power transistor has internal protection built in, so the fly-back diode is not needed (but can be included for belt and braces); the solenoid however has no such protection, as a result an arc will strike across the relay contacts when it switches off. This will eventually destroy the relay contacts, but will also emit enough noise to seriously interfere with the radio reception and even wipe out the settings on a PCM set.

Motor Suppression

DC Motor commutators will generate spark noise as they get old and worn, or contaminated (very possible after a few battles).
The way to solve this is to fix a small value capacitor across the brushes preventing the noise getting out of the motor.

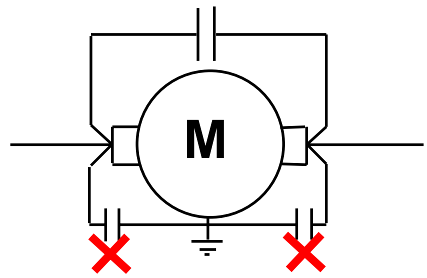


At this point you may be thinking… BIG IS GOOD **WRONG.**

The capacitor should be the **minimum** size to eliminate the commutation noise (10nF should be as large as you will ever need). If you make the capacitor too big it will look like a short circuit to the speed controller. This is because the switch mode technique that speed controller's use will be trying to charge and discharge the capacitor at its switching frequency, creating a large inrush current through the controller each time it switches. This will either: - create higher heat dissipation in the output transistors, or if the controller has a current limit protection system, cause it to think that the motor is stalled/ faulty, and limit the current. This in turn will lead to a sluggish response. The large current spikes can also radiate energy from the motor leads, more on this later.

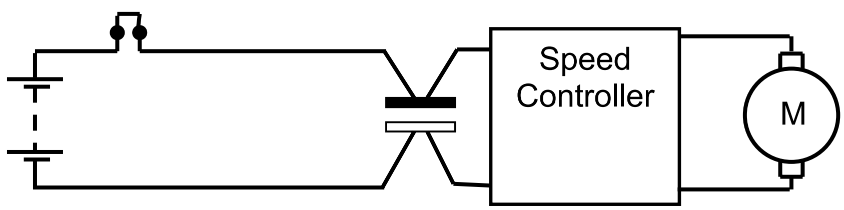
Some commutation suppresser circuits have extra capacitors connected from the brushes to the motor case.

Fitting these is a **bad idea**, as it will only serve to inject noise onto your chassis, and from there into anything else.



Supply Decoupling

This is a type of suppression that can reduce conducted noise spikes and surges. Most commercially available speed controllers already have them fitted, but it doesn't hurt to give them a helping hand, especially if the battery wires are long.



The capacitor is essentially a small reservoir, its purpose is to supply current when needed, absorb small surges from re-gen braking and soak up high frequency noise.

With any suppression device where you put them is going to effect on how well they perform. Generally they should be as close to the source as possible and any leads at so that the potential interference is taken out before it has the chance to radiate from the wires.

There are more methods of suppression that can be used, but are too numerous to mention in this article.

2. Segregation.

Within your machine you are going to have different systems doing different things: -

Battery, Speed controller, Motor, Receiver, Servos, Solenoids, ICE Ignition, etc.

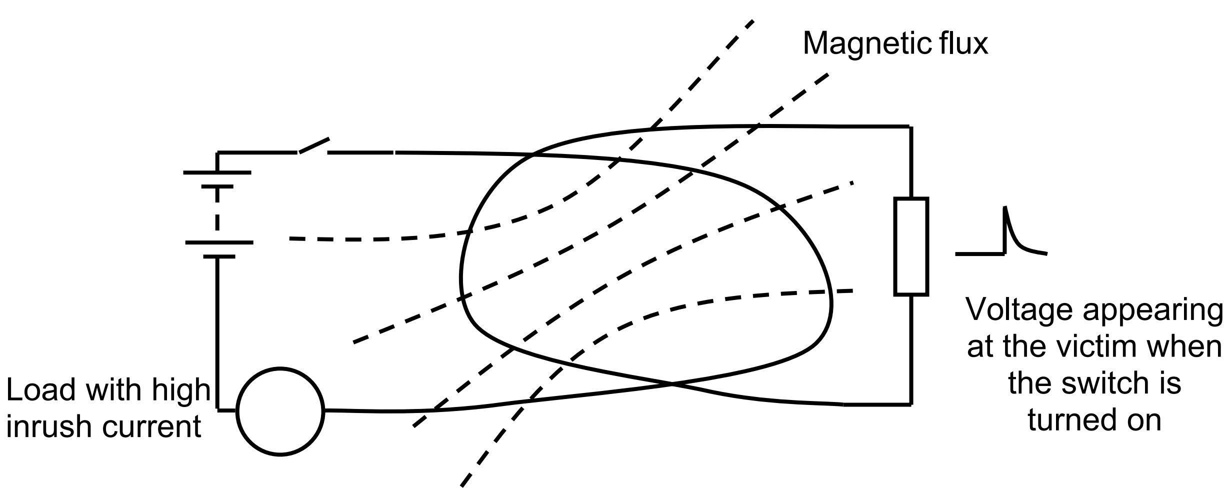
Each of these elements is going to have associated wiring, and if you're not careful how you install them, all hell could break loose.

The best way of looking at segregation is to group them by function: -

Class 1	Sensitive.	Receiver aerial, Servo leads.
Class 2	Neutral.	Switch Inputs/ Outputs.
Class 3	Interfering.	Battery, Motor leads.
Class 4	High Voltage.	ICE Ignition

Starting with the easiest, Engine ignition circuits, these are in a class of their own (4). Due to the nature of the ignition pulse (High voltage with a fast rise time), it has the ability to interfere with a whole host of systems, and if not installed correctly, sparks will fly, sometimes quite literally.
Ensure that the contact breaker has a suitable suppression capacitor fitted, that you use suppressed plug leads, and that the earth return path from the coil is adequate or else it can cause trouble; the best solution is to bolt the coil to the engine if possible.

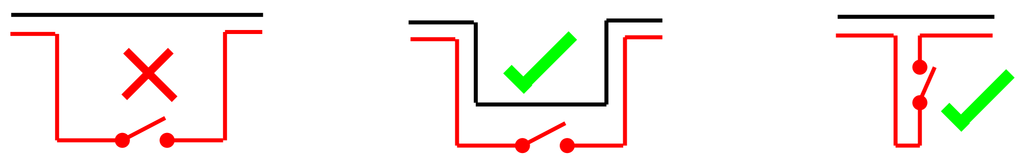
Drive motors, motion or weaponry, are going to demand the most current out of the batteries, sometimes the current delivery is quite smooth, but mostly it won't be, Huge surges in demand and re-gen braking can and do create current in the 100's of amps.
This current passes along the wires creating a magnetic field; this energy is easily transferred from one system to another thanks to a method that is similar to the windings in a transformer.



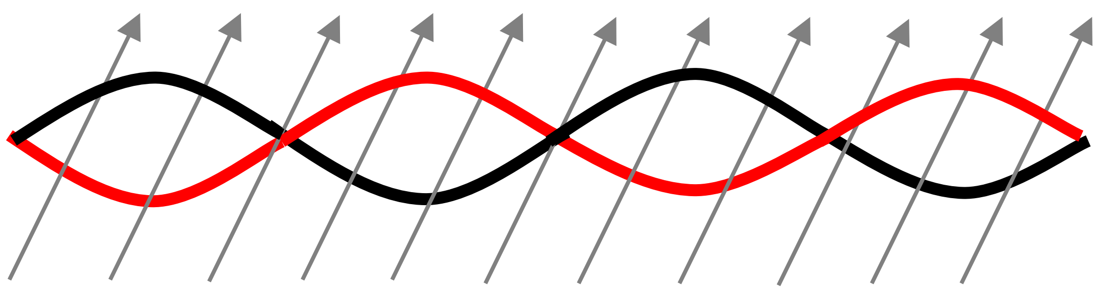
The amount of energy involved with this type of interference in particularly bad installations can destroy sensitive electronics.
Fortunately dealing with this type of interference is easy, since the loop area determines the amount of coupling. Reducing the area will correspondingly reduce the problem.

This leads us to an overall installation principal: -

Ensure that all send and return wires are close together at all times



Better still, twist the send and return wires together and the net magnetic flux through adjacent turns will cancel each other (provided the twists are even); it will also even out the charge on the wires if subject to an electric field. The intention of this is to reduce the interference between the lines. The tighter the twists the better.



This technique also works for emissions.

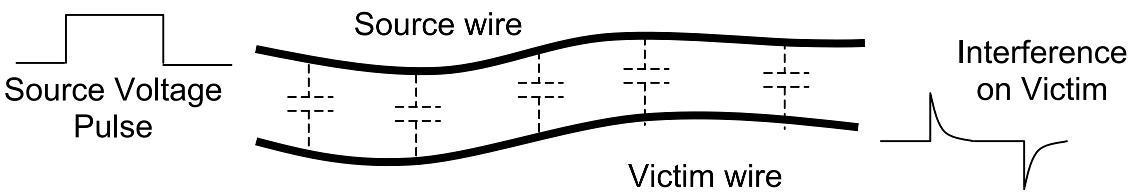
Neutral circuits are those that are neither susceptible nor interfering. However, they can transfer noise from one system to another using cross talk; so take care not to route the cables such that interference could pass from disturbing to sensitive systems.

You will notice that the Servo leads are listed as sensitive, and although they are delivering power and signal to the servo's they can still pick up interference and transfer it directly to the receiver.
The +Ve supply and the signal are pretty immune but not many people realise that the negative supply is also a second aerial. In fact it's the opposite pole of the main aerial lead, so there are a few precautions that need to be taken (more on this later).

As an aside, if you want 2 aerials one on the topside and one on the flip side of your machine, wiring directly from the receiver negative is as good a way as any to achieve it.

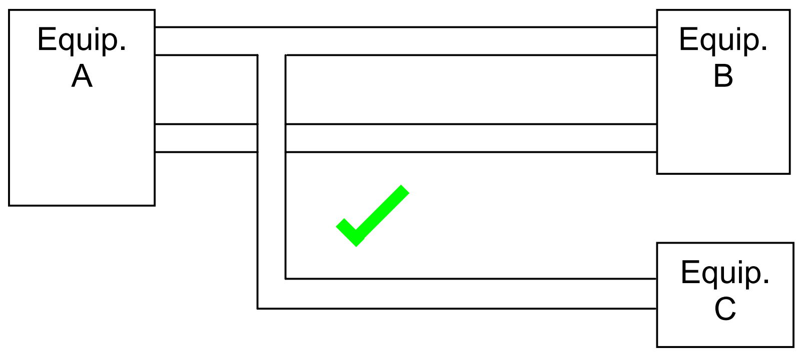
3a. Separation.

Radiated interference is not just radio waves; a signal can couple onto adjacent wires quite easily by using phantom capacitance.



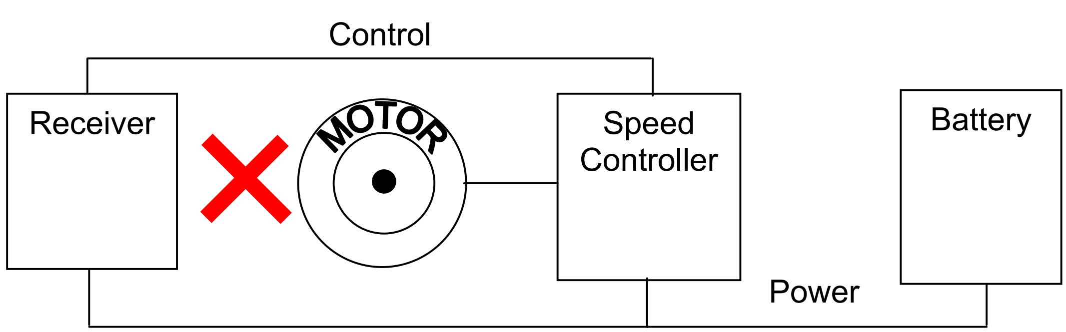
This type of coupling reduces with the square of the distance between them.

If different cable groups are running parallel between 2 or more components, then separating them will reduce the interference transferred from one to the other.
If cable groups need to cross over each other, try to ensure that they do so at 90°.



However, whilst maintaining separation, try to ensure that wiring between the same pieces of equipment follows a common route; else you could be in danger of creating a loop that could pick up noise.

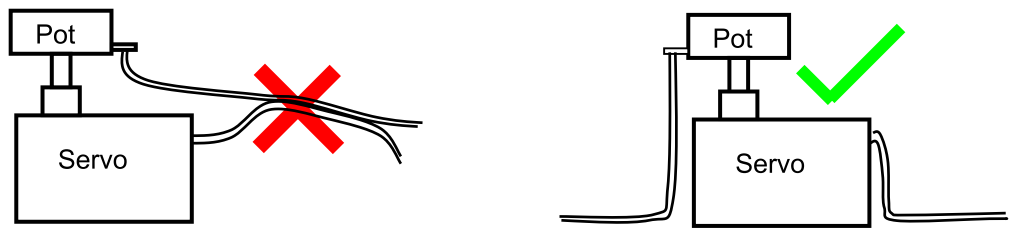
In this example there is a loop created by the power and control lines, between the receiver and speed controller.



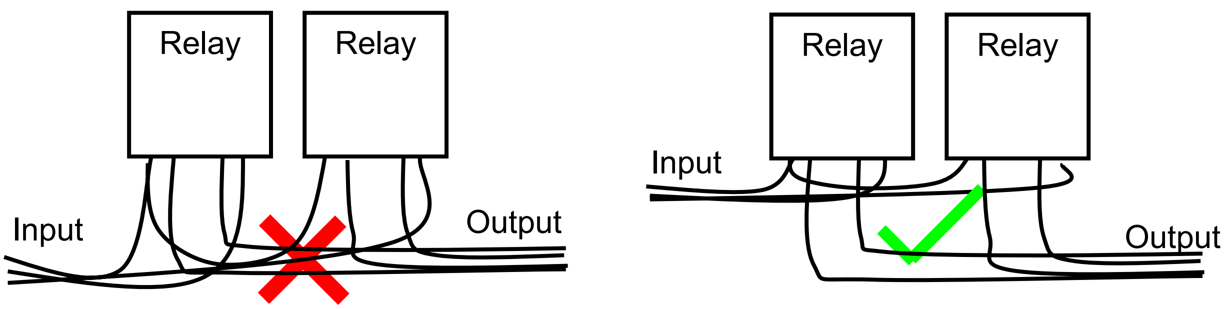
A word of caution, Do not be tempted to loom cables together just because they "Look Neat", provided that the send and return cables run together a "Rats' Nest" arrangement can work well, it's just harder to maintain.

3b. Isolation.

Isolation is a good method of preventing conducted interference getting from one system to another via the direct route and preventing loops from forming. However, as previously explained interference can jump gaps,
So do not run the servo wires from your receiver close to potentially noisy cables,



And don't mix the inputs and outputs of relays in the same loom.



3c. Earthing Practice.

Some people think "earth the battery negative like they do in cars". But the reason motor manufacturers' do this is to – a) reduce the cost of the wiring, and b) reduce the corrosion of the earth connections.
If you earth your battery, then there is the possibility that a single fault or lucky damage could short out the positive to chassis, It will also inject electrical noise directly onto the chassis and then into everything else.
It is best to keep the battery isolated from the chassis.
The chassis will still be picking up any stray EMI from inside the machine or externally, so don't earth the receiver to the chassis, otherwise reception could suffer.

With the chassis isolated from both battery and receiver it can be used for screening purposes.

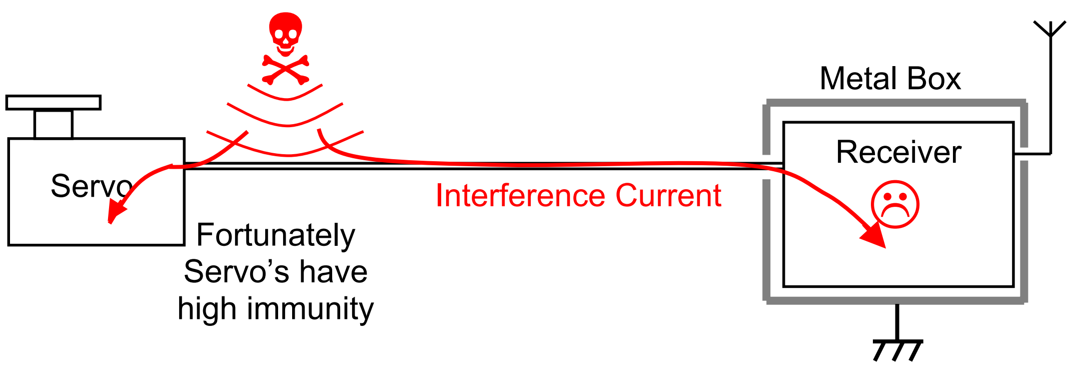
4. Protection.

In close proximity EMI can radiate as either a magnetic or electric field.
Magnetic fields couple onto wires by inducing a circulating current in loops; an electric field on the other hand will couple capacitively onto anything in the vacinity.

We have already seen that the best way of avoiding this is to segregate and separate your wiring appropriately; but what if that's impossible, or just not adequate?

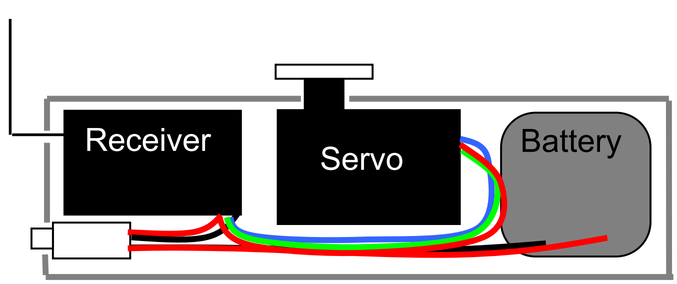
4a. Screening.

Most people think of screening as "stick the receiver in a metal box", but this will only protect the receiver from direct radiation.
The problem is that the biggest part of any system is the wiring, and this acts as an aerial, picking up any interference going.
The Metal Box or to give it its proper term "Faraday Cage" will only work properly if **ALL** of the electronics being protected and their wiring is inside the box. If any wires are outside, then they can pick up interference and conduct it through the side and into the protected zone as if the box wasn't there.



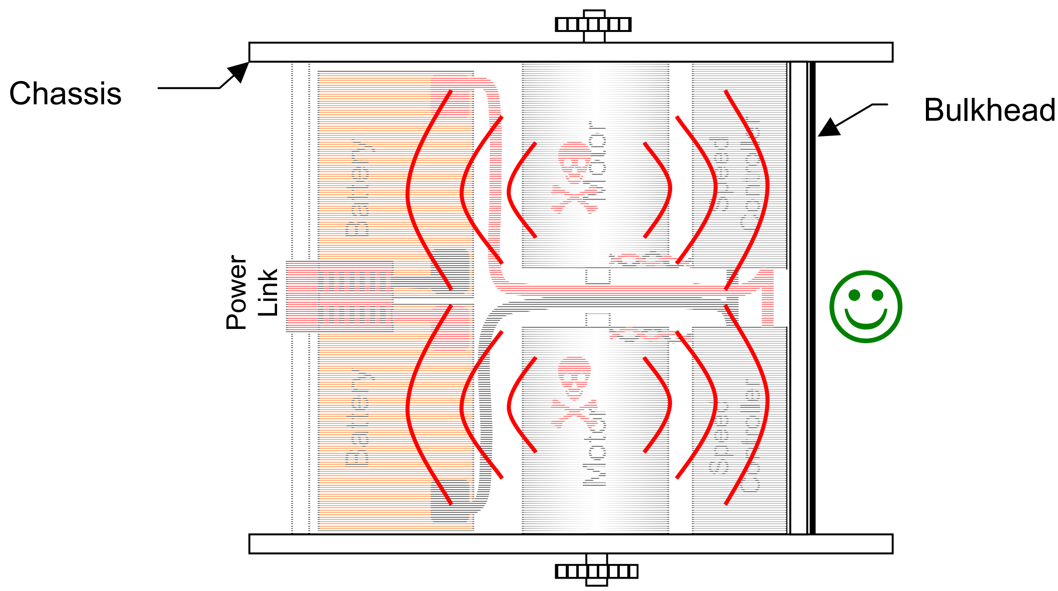
So what can you do?

One possible solution is to put your receiver, its servos and battery in a sealed metal box, the only things left poking out should be the servo mechanical drives a switch for the battery and an aerial lead; however, the aerial can still pick up interference.

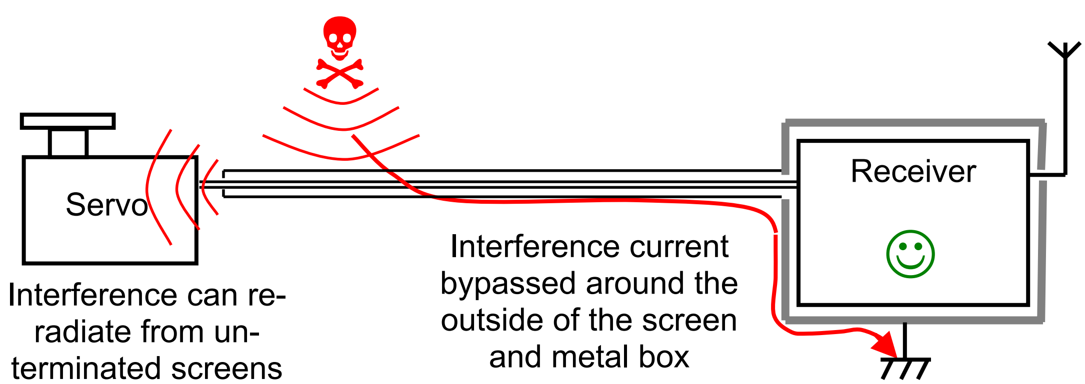


This however may not be convenient for your application!

Another approach is if your machine has a convenient structural metal plate that can be used as a bulkhead to partition the noisy equipment from the sensitive, creating a "Quiet Zone".



If you can't avoid running the sensitive cables past the nasty stuff, then they will probably need screening; this is effectively an extension of the Faraday cage.
The screen will need to cover as much of the cable as possible.



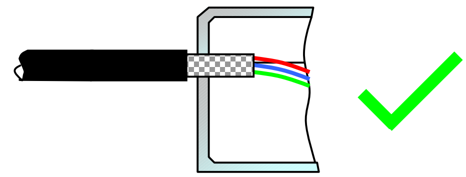
The above diagram shows a screen earthed at one end and free at the other; this runs the risk of letting the interference re-radiated onto the system and wiring at that end, then being conducted back along the signal wires to the receiver.

It is better to earth the screen at both ends.

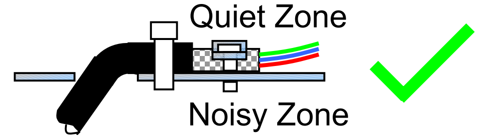
Screen Termination Do's & Don'ts

Good Methods

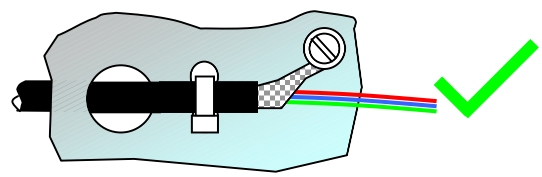
1. If using a metal box, trap the screen in a slot under the lid. Take care not to trap the screen too tightly or else it could result in cable damage. The cable will require strain relief.



2. Saddle-clamp the screen to a bulkhead immediately inside the "Quiet Zone".

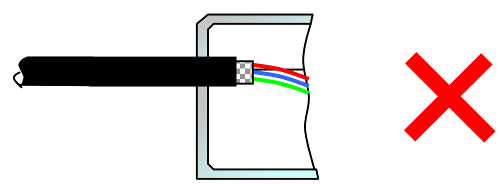


3. "Pigtail" the screen to a suitable earth point. Ensure the pigtail length is as short as possible.

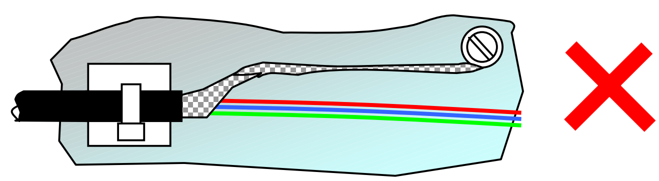


Poor Methods

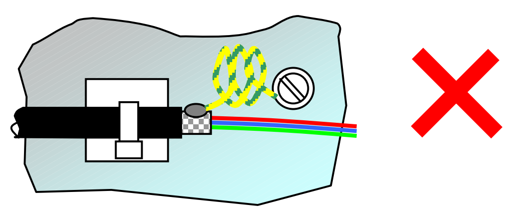
4. Screen left unterminated in the quiet zone. This will re-radiate any noise it has picked up.



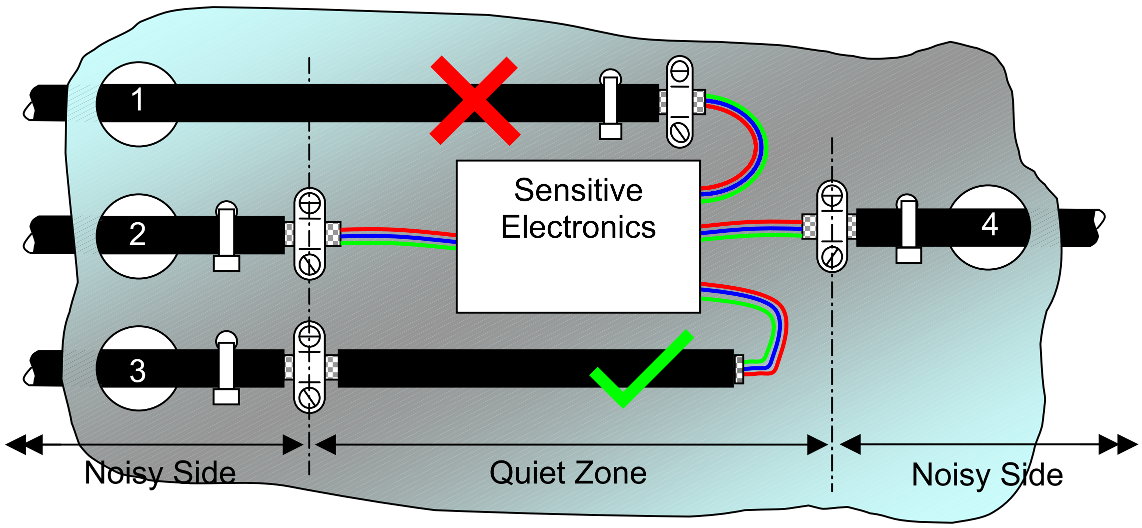
5. Pigtail termination too long. Ideally the pigtail should be no longer than 5 times its width.



6. Long pigtail coiled up.



How to create a “Quiet Zone” on a bulkhead.



In the above diagram;
Cables 2 & 4 are correctly installed creating a “quiet zone” inside which the sensitive electronics are protected.
Cable 1 allows its potentially noisy screen into the quiet zone, contaminating it.
Cable 3 has its screen terminated at the edge of the quiet zone preventing contamination. The screen extension inside the quiet zone is optional.

These methods of screening will only reduce the effects of electric fields getting onto the signal wires; magnetic fields on the other hand can still induce interference, and if the screen is earthed to the chassis at both ends it will create a loop. To prevent this from becoming a problem run the cable close to the chassis as this will reduce the loop area.

4b. Ferrites.

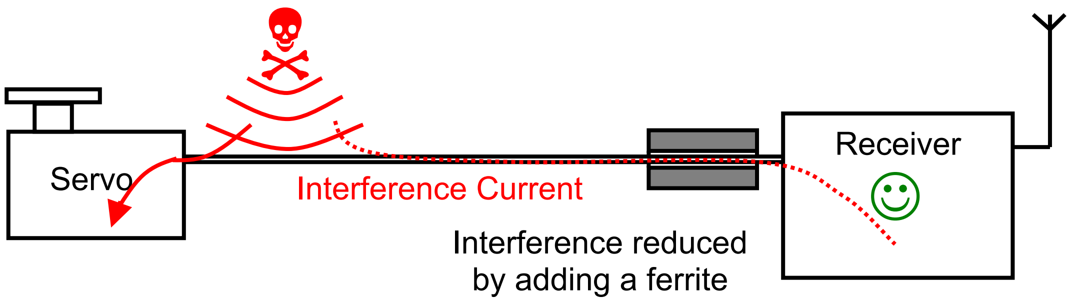
The most common application of a ferrite is as a sleeve over a cable to reduce interference currents on that cable. They’re available in a large variety of shapes & sizes, from a small bead to fit a single wire to larger donuts to fit cable bundles; they are even available to fit flat cables and inside multi-pin connectors.
A particularly useful type is the split tube in plastic ‘clip-on’ housing. They are easy to retro fit to a cable (and to remove when they are found not to do much).

As regards suitability for an application, there are 2 rules of thumb: -

- Where you have a choice of shape, longer is better than fatter;
- Maximum impedance demands the maximum material density.

So what do they do?

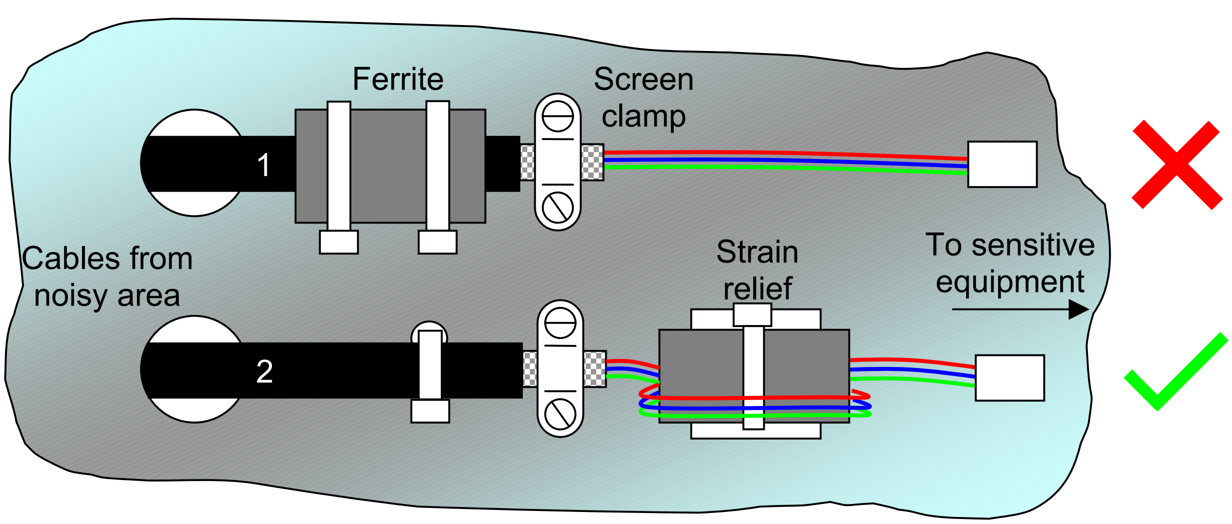
Adding a ferrite is effectively putting a resistor and inductor in the path of the interference signal, this will reduce high frequency currents' travelling along the wires it is attached to.



Notes:
1. In order to reduce the amount of unprotected wire; position the ferrite as close as possible to the device being protected.
2. The effectiveness of the ferrite (at low frequency) is proportional to the square of the number of turns the wire does through it.
3. A ferrite can only be used on a cable in this way if the current going out is equal to the current coming back (e.g. Servo lead).

Beware: ferrites are brittle and will shatter if dropped, so be careful how you handle them and make sure that they are adequately protected against shock.

How to combine screens & ferrites



In the above diagram;

Cable 1: has the ferrite applied to the cable and its screen; this will work but reduces the effectiveness of the screen.
Cable 2: has the ferrite applied to the cores; in this way the screen will be working at its maximum effectiveness and the ferrite will eliminate noise conducted along the signal wires. The single loop the wires do around the ferrite will improve its performance 9 fold; you also have the choice of using a smaller ferrite.

5. Maintenance.

Electro Static Discharge.

Believe it or not, but you can actually damage your electronics simply by touching them. The human body can build up static electricity to several thousand volts, you won't know about this until you get discharged to earth; this is when you might feel it.

You won't feel the ESD unless the voltage is quite high >1000V, the human body can be charged up to in excess of 15,000V, this you will definitely feel.

To the electronics all these levels are lethal, In fact anything above 50V can cause damage, and even if it doesn't stop working there and then, you have possibly caused it enough damage to weaken it so that it will fail sometime in the future.

When working with electronics take care to periodically discharge any static build-up, to do this earth yourself by touching something that is earthed, every 10 minutes or so, or before you handle the electronics.

When storing electronics, do not pack them away in polystyrene or anything that is a good insulator, as these can build up some very high voltages. If the electronics have no voltage sources on them, they can be packed in tin foil.

Welding.

When your machine gets damaged, it will need repairing, possibly welding. You **must** remove all the electronics before you weld, Induction from welding current can damage them, I have seen a Vantec destroyed because it was left in the chassis while the welding was being carried out… Ouch.

Author Tim Mann STINGER Dec 2003