EMI/EMC

EMI is an acronym for **E**lectro **M**agnetic **I**nterference. This term is often applied to the adverse effects caused by unwanted electromagnetic fields. EMI can be generated by many devices, wiring, and circuits. The adverse effects can cause mis-operation or faults in affected equipment.

EMC is an acronym for **E**lectro **M**agnetic **C**ompatibility. This term describes a characteristic of devices that may generate EMI or be susceptible to it. A device that generates low amounts of EMI may be said to have good EMC, as may a device with good immunity from EMI.

It isn't possible **nor necessary** to completely eliminate EMI. However, it is necessary to reduce the effects of EMI sufficiently that the overall electronic system *functions as intended*. When this is achieved, the system is said to have "good EMC behavior." It is easier to "design in" good EMC performance from the beginning than to struggle to work around it later.

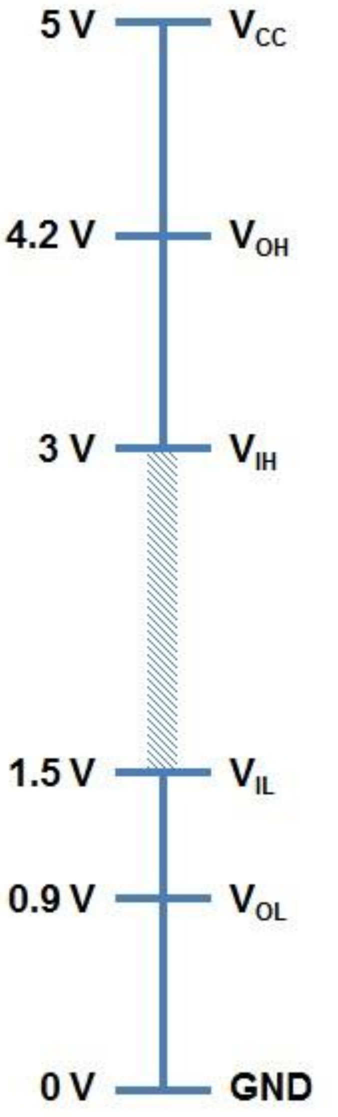
The science behind EMI mitigation techniques is complex. But the techniques themselves are mostly simple, practical methods that any builder can apply successfully without knowing the science behind the magic. The explanation of *why* something works against EMI is intentionally brief, but the technique itself will be described sufficiently for practical use. Step away from your calculator and forget your calculus because we're not doing that here.

EMI is cumulative in nature. EMI appears at many frequencies across the RF spectrum. Sometimes it takes the form of a single frequency signal but it can also be broadband in nature or extend periodically through the spectrum. A spectrum analyzer will often display EMI as a broad swath of noise. When multiple EMI sources are present these signals mix in unpredictable ways. These signals tend to be cumulative in their effect on susceptible devices. It is possible to have several devices which produce low amounts of EMI individually but when operated simultaneously they produce severe EMI issues because of the cumulative effect.

The objective is to improve the margin against EMI. The chart on the next page illustrates the logic levels of a typical 5 volt logic family. We will use this for our examples. There are three main areas depicted on this chart. (1) The amplitudes for valid input and output HIGH logic states, (2) the amplitudes for valid input and output LOW logic states, and (3) the amplitude range of INVALID logic states.

Logic design must guarantee that the amplitudes for HIGH and LOW logic states fall within the limits shown on the chart. Normally this results in a noise margin of about 1.2 volts for HIGH logic states and 1.5 volts for LOW logic states when driving outputs to inputs. (Sharp-eyed readers will observe that this is greater than typical TTL logic families, but is valid for CMOS families with TTL compatible inputs and outputs.) However, when driving logic inputs from mechanical switches, a different set of margins applies.

If a mechanical switch provides any voltage to an input that is between 5.0 and 3.0 volts, it will be recognized as a valid logic HIGH input signal. That is a 2.0 volt margin. If a mechanical switch provides any voltage to an input that is between 1.5 and 0.0 volts, it will be recognized as a valid logic LOW input signal. That is a 1.5 volt margin. This is good news because nearly all of the mechanical switches in our sims drive a logic input directly and the extra margin helps to resist EMI.



ATMega328
DC Characteristics

5 volts is the amplitude of the +DC power source.

4.2 volts is the nominal amplitude of a logic output in the HIGH state.

3 volts is the minimum amplitude of a logic input for a valid HIGH state.

Amplitudes between 1.5 and 3.0 volts are INVALID.

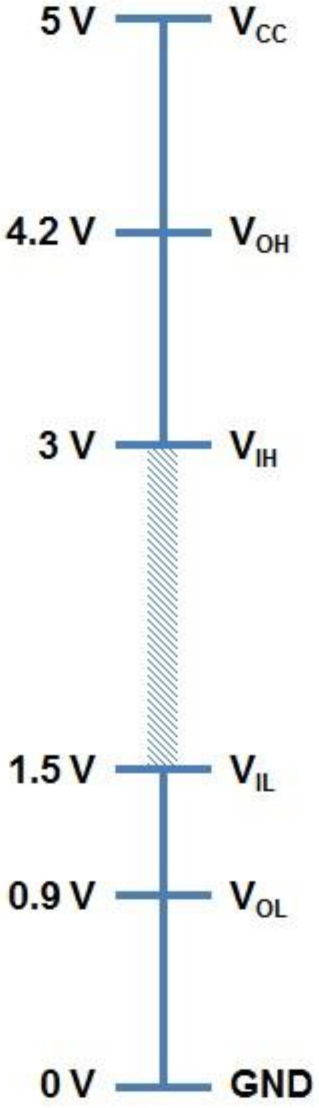
1.5 volts is the maximum amplitude of a logic input for a valid LOW state.

0.9 volts is the nominal amplitude of a logic output for a valid LOW state.

0 volts is circuit common, or “ground”.

Now consider the logic states with EMI present. The chart below illustrates how a logic input may be fooled into thinking a mechanical switch is not in the position intended.

Suppose we have a mechanical switch driving a logic input. The switch is in the “open” position. The signal that arrives at the logic card input has 4 volts of EMI impressed upon it. How does that affect what the logic card “sees” at the input? In this example the logic card would be completely incapable of detecting a VALID high or low signal from the switch.



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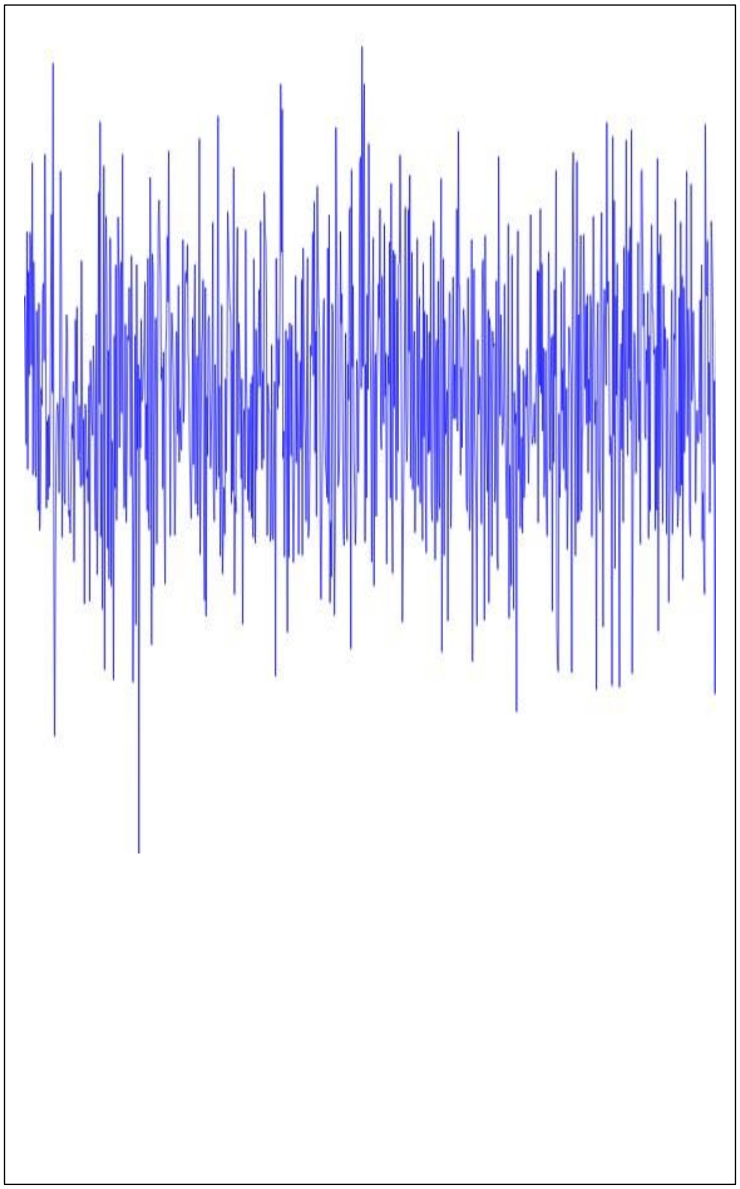
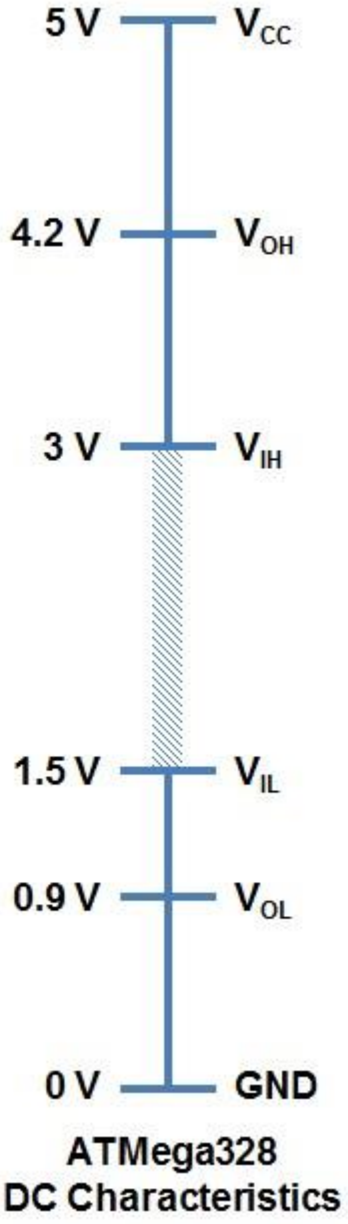
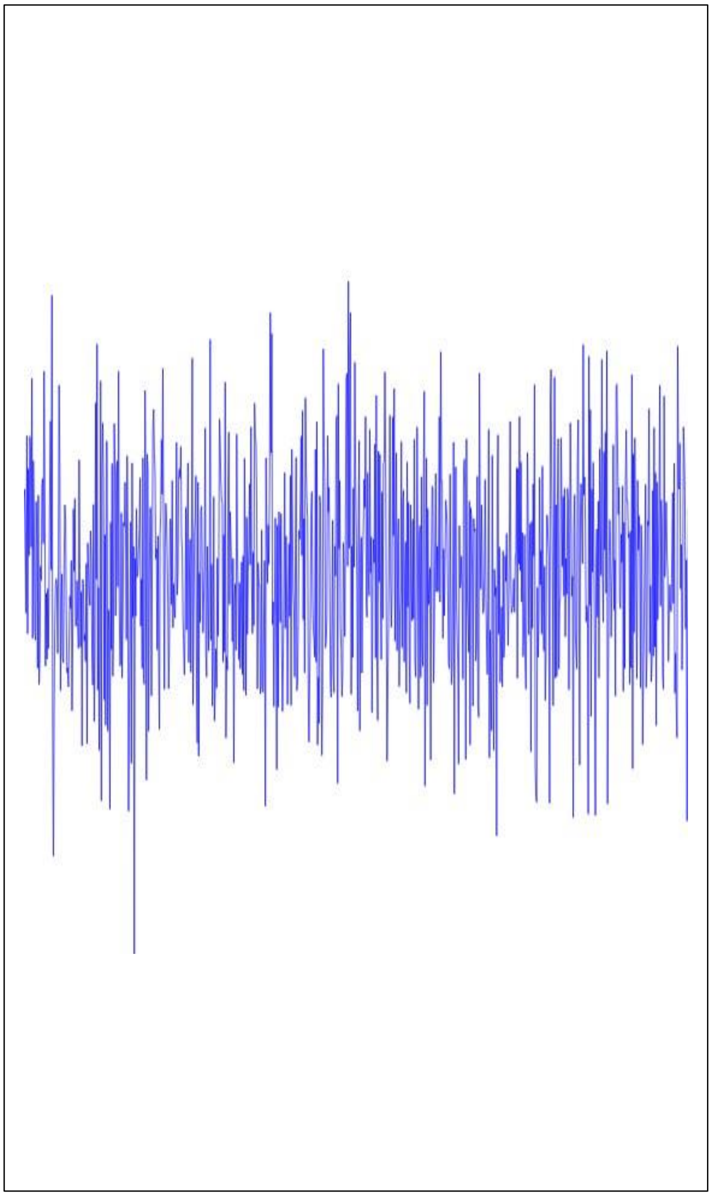
DC Characteristics

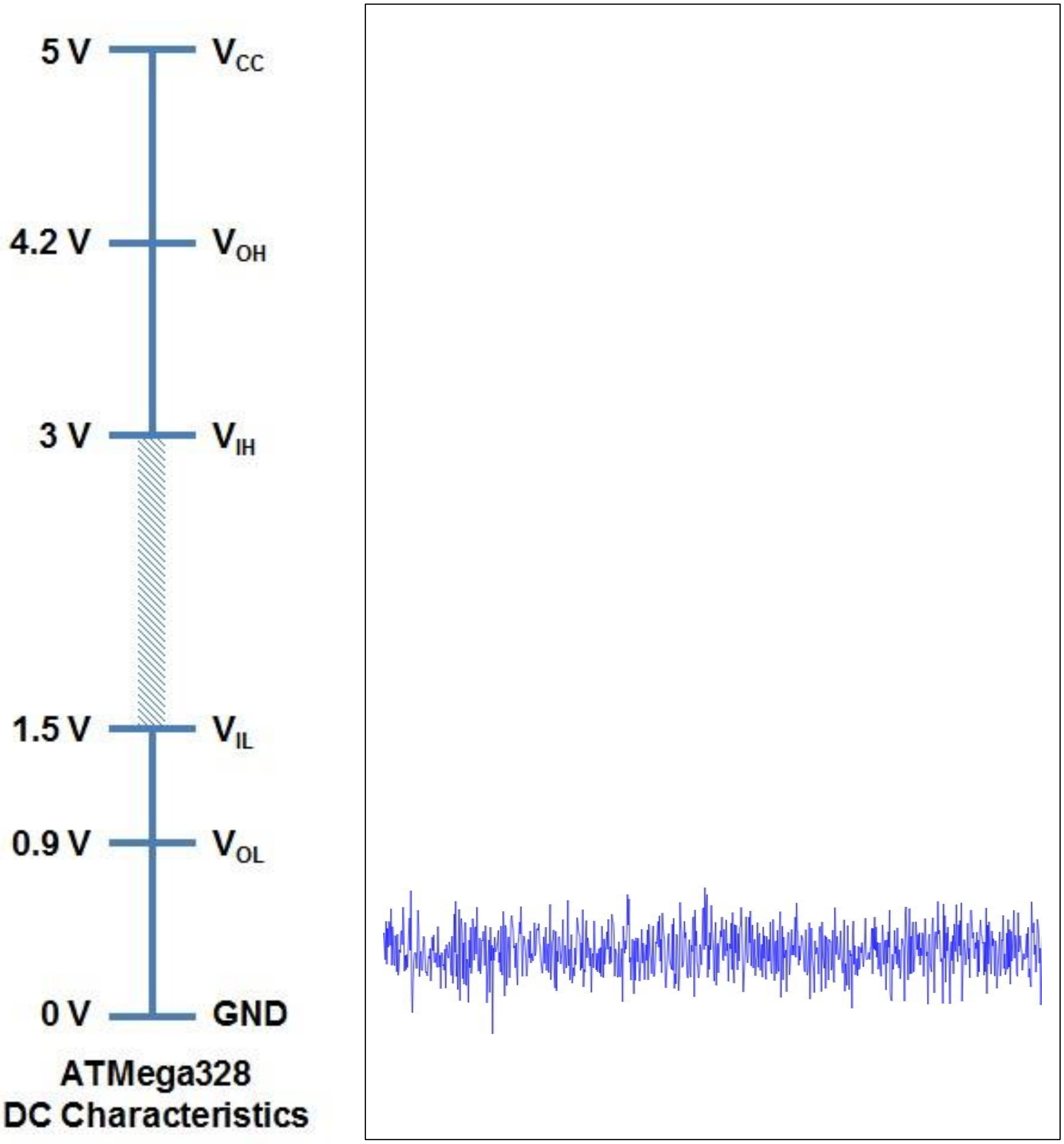


Here is the same example with the EMI signal lower in amplitude and at a different baseline. Notice that most of the EMI falls within the “Invalid” range of amplitudes. The logic card will not be able to accurately decode this input.





Now place the mechanical switch in the position to supply ground to the logic input. Here is the same chart with the same 4 volts of EMI impressed upon the signal arriving at the logic card input. It is obvious that something has improved the situation, but what? The logic card can easily decode this signal as a valid LOW even in the presence of EMI.



The difference in EMI noise margin between logic HIGH and logic LOW states is due to the respective impedances seen by the chipset inputs. When the mechanical switch is open, the input impedance is a function of the pull-up resistors in the chipset. The specification for the ATMega family of chipsets for the pull-up resistors is 20,000-50,000 ohms (typical). This is a high impedance. It is easier for EMI to cause issues in high impedance circuits than in low impedance circuits. The length and the type of wire attached to the logic input have a direct effect on susceptibility to EMI.

A mechanical switch in the closed position is essentially a short circuit to logic common. The typical resistance of a switch contact is less than 1 or 2 ohms. When the switch is closed EMI must work into a very low impedance circuit. It is FAR more difficult for EMI to achieve ingress into a low impedance circuit than a high impedance one. For this reason, in most logic families, logic "1" (the "true" condition) is defined as the LOW amplitude input signal. It is nearly impossible for EMI, or any other type of un-wanted signal, to cause a false input condition when the input is shorted to common.

Various techniques can be applied to improve noise margins against EMI. Almost all EMI suppression techniques are based on two principles: (1) Reduce the amplitude and/or quantity of the EMI, or (2) improve the ability of affected devices to reject it.

No single mitigation technique works for every EMI situation. Often, multiple techniques must be applied in a "layered defense" scheme to obtain the desired results. Here are some basic techniques that are useful. Apply them *in this order* for best results.

- **TEST – don't GUESS.** How do you know you have an EMI issue unless you test for it? You can't, of course, so the first thing to do is TEST circuits and devices to determine if EMI is the culprit.

  Most builders do not have access to the specialized equipment needed for rigorous EMI testing nor the training needed to properly use it. But there are useful alternatives. Remember, we're after *practical results* here, not laboratory accuracy. A useful tool is a pocket AM radio receiver like those made in the 1970s and 1980s. If you don't have one, get one. It will quickly reveal sources of EMI. Tune the radio "off station" (where no station is broadcasting), turn the volume up about mid-range, then use the radio as a probe to identify sources of EMI. Good examples to start with are computers, laptop power adapters, or a CFL light bulb. Spend a bit of time walking around in your home testing for various EMI sources. Not everything the AM radio hears is a problem for our sims, but devices that produce LOUD noises from the radio speaker often are troublemakers. Practice a little and train your ear to discern the difference.

  How would you know, or suspect, that EMI is causing an issue? Look for these symptoms:

  - Intermittent operation of a circuit or device.
  - Phantom switch presses. The software sees a switch press when no switch was pressed.
  - Switch presses that previously worked suddenly stop working, then start working again.
  - Offsets that toggle (change state) for no apparent reason.
  - Things that stop working properly when other things (like a stick shaker) are activated.
  - Clicks, pops, or other odd noises in the audio from the simulation software (MSFS, P3D, X-Plane, etc.).
  - Can you correlate EMI you *hear on the AM radio* with false operation of sim functions? Does the radio "pop" or produce odd noises at the same time as failures occur?

- **Eliminate EMI at the source:** This is the single most effective tool in the box. If you can eliminate the EMI at the source – it's gone! There is no need for further suppression efforts. A builder may have a choice of two or three different model avionics fans. Any *brush-type* motor is an excellent interference generator, but a *"brushless"* motor has no brushes and does not generate brush noise. Choosing the brushless type fan over one that has brushes is an example of a design choice that eliminates EMI at the source. Similar choices exist for power supplies (particularly switching type), lighting dimmers, DC-DC converters, USB hubs, etc. Any solid-state device that switches at high speed will generate interference. The better ones generate *less* of it.

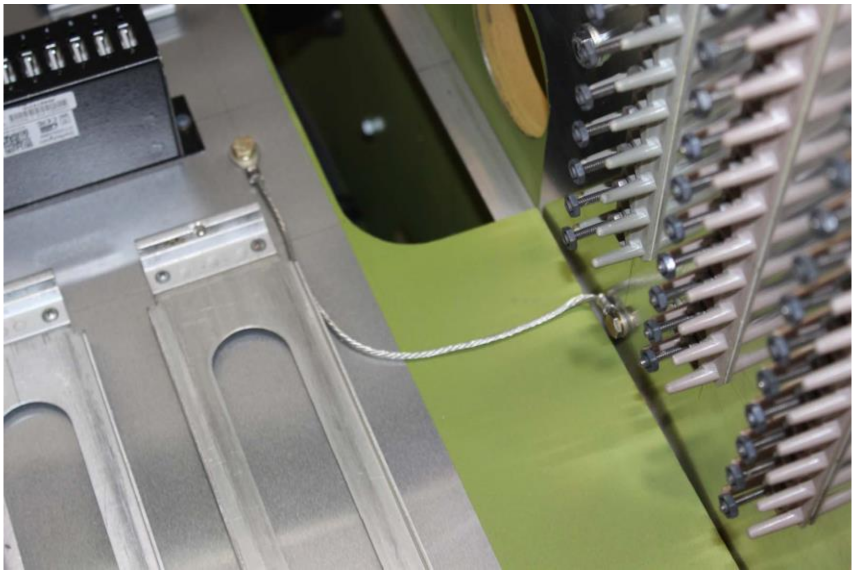
- **Contain the source of EMI:** Sometimes the only device that will do the job is the one that generates interference and we have no better choice. For example, stick shakers, DC-operated autopilot servo motors, or pedal adjust actuators. The next line of defense is to contain the source. If we enclose a device in a sealed metal box no EMI can escape. Such a box is called a Faraday cage. Most of the time we can't completely enclose an offending device. Wiring, actuator arms, or other parts of the device must have access to the airframe in order to do whatever it is intended to do. But often the metal cases of these devices provide a partial Faraday cage which is useful. Bonding the metal case - NOT the power lead - of the device increases the effectiveness of the case as a shield. Any device which has a metal case can benefit from this method.

  Noisy switching power supplies, DC-DC converters, light dimmers, etc., can often be suppressed by placing them inside a bonded metal box. If the device dissipates power (puts off heat) it is necessary to do a thermal analysis. The results may indicate that an internal cooling fan is required. Installing a fan means cutting holes in the box for airflow. Holes in the box will reduce the effectiveness of the Faraday cage. But this technique often provides *enough* suppression to obtain satisfactory results.

- **Use proper wiring techniques:** It is not possible to mitigate EMI in a complex system without observing certain rules regarding wiring. This is a topic unto itself and too lengthy to include in detail. Here are some essential wiring techniques helpful for suppressing EMI.

  1. **Bonding** and **grounding** are not the same things. They often *appear to be* but specific rules govern each technique. In all-metal aircraft the fuselage structural components and other parts provide the means for both bonding and grounding. The metal fuselage is a Faraday cage and it also provides multiple pathways for return power currents. In fabric-covered aircraft, and in our sims, different methods must be used because we do not have an all-metal fuselage. Bonding and grounding are still essential and both will work on a non-metal structure, but both must be done correctly.

  2. **Bonding** electrically connects all metallic components of the airframe together. In real airplanes bonding ensures that the fuselage is protected against lightning strikes and other forms of EMI. Bonding provides somewhere for "EMI to go." If you don't have bonded ground plane somewhere in your sim, you need it. Here are examples of bonding:

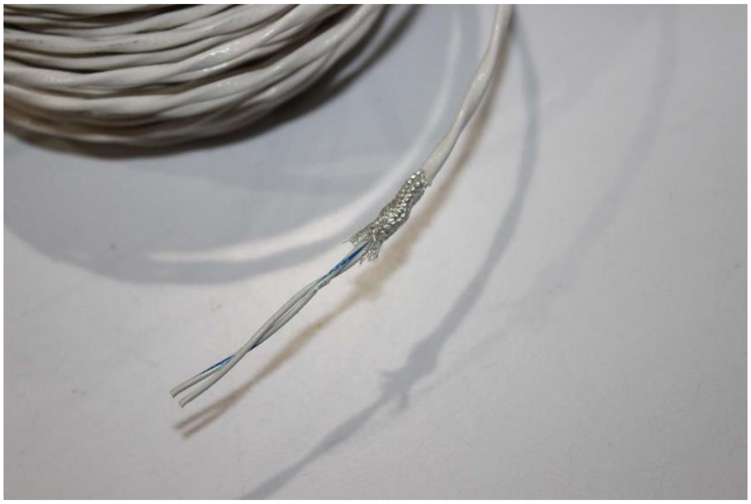


These metal parts are **bonded** together, but they are not necessarily grounded.

Here, the left side of the main instrument panel is **bonded** to the switch panel structure.

3. **Grounding** provides a common reference point for all electronic circuits in the airframe. But all “grounds” aren’t the same. It is necessary to provide **separate** return current pathways (“grounds”) for digital and analog signals and high-current devices such as batteries or power supplies.
4. **Flat pieces of metal,** even thin aluminum, can serve as alternatives to a metal fuselage for the purposes of EMI mitigation. These form ground planes and function as partial shielding when installed in the correct configuration. They must be **bonded** together.

5. **Shielded cable** is your friend, but only if connected properly. The shield in the cable "extends" the Faraday cage between connected devices and reduces both radiated and capacitively-coupled interference.
6. **Don't ground BOTH ENDS of shielded cable.** Doing so usually makes a nifty ground loop and will cause Trouble-with-a-capital-T. Some devices, such as communication antennas, require the shield be grounded at both ends. Special arrangements are required for these devices.
7. **Keep the positive and negative power conductors close together.** For example, a stick shaker requires two wires, one positive and one negative. These should be run in shielded cable end-to-end to the extent practical. Shielded, **twisted-pair**, cable is the preferred solution for aircraft power wiring and for various purposes around devices that generate EMI. Type M27500-22SE2S23 is a good example. You can substitute less expensive shielded, twisted-pair cable made for electronics systems. Note that **foil** shielded cable is less effective than **braided** shielded cable when used for EMI mitigation.



8. **Don't run power and signal circuits inside the same shield.** Usually this means you will need to run two or more cables to the same location, one dedicated to power and ground and the other(s) for digital, analog, switch, or pot signals.
9. **Do not stack interface cards tightly together.** All interface cards generate some EMI internally. If cards are too close to one another the processor on one card can cause interference to a neighbor. When cards are located close together the manner in which the interface ports are wired can be a problem. "Flat cable" is often used because it fits in the available space. But flat cable has parallel conductors that are difficult to shield. It is known to be susceptible to EMI because of the manner in which it is often utilized.

- **Make use of EMI resistant circuits and devices:** It's easy to forget that interface cards are just that – an interface. Every interface has specifications that describe parameters such as required voltage or current levels, timing, input impedance, etc. Interface cards that operate on low logic voltages, 3 volts or less for example, have poor EMI immunity and should be avoided. Many interface cards require 5 vdc for *power to run the card* but the onboard logic runs at 3.3 volts.

Interface cards that operate at higher logic levels can provide superior EMI immunity. Some cards accept logic inputs up to 30 volts and have optically isolated inputs. Many cards run on standard 5 volt logic levels and a few will run on 12 volts. The EMI performance of cards that run standard 5 volt logic is often superior to cards that run 3 volt logic.

"Active low" logic has been the basis of many industry standards since the 1970s. Active low means that a logic card input is considered to be "logic true" when the input is at zero volts (grounded). Switch and relay contacts, or other logic card outputs, provide a ground for the logic input for the desired condition. Many interface cards can be configured for either active low or active high logic. Active low interfaces provide superior EMI performance than active high (for the same input conditions).

VERIFY that any switching devices such as power supplies, DC-DC converters, PWM devices, have internal EMI filtering on *both* the input and output. A noisy input side of such devices can contaminate an entire DC bus on the airplane with EMI.

- **Harden essential devices against EMI:** Sometimes the device we need to use in our sim exhibits poor EMI/EMC behavior and no alternative device exists. It is possible to improve the EMI/EMC characteristics of some devices by adding filters, shielding, relocating the device, or changing the configuration. This is known as "hardening" the device.

  Many different types of EMI filters are readily available from electronics distributors. Select a filter that provides suppression at the frequencies of the EMI *present in your sim*. The simple ones, ferrite beads that snap around a conductor, are the least effective, but they're also the least expensive and the easiest to try. Do not overlook these because sometimes they are exactly what is needed. Another simple type of "filter" is a capacitor connected directly across the power wiring at the offending device. *Observe correct polarity* when using polarized capacitors or you will soon let the smoke out of the capacitor. (Do not ask me how I know this.) If the device is reversible, for example a DC servo motor, only non-polarized capacitors can be used. Common-mode filters are usually needed for things that contain DC motors (stick shakers, pedal adjust actuators, etc.). Common-mode filters are also readily available for purchase at a nominal cost. Filters work best when they are physically located as close to the EMI source as is practical and wired with short, shielded, leads.

  When filters and shielding are insufficient it is necessary to resort to more extreme measures. Relocate the source of the EMI – the badly behaving device – as far away from sensitive devices as is possible. Change the wiring pathways to keep EMI sources and susceptible devices separated. A few feet of physical separation can make a big difference.

  Interface card input impedance is sometimes responsible for poor EMC performance. Many interface cards provide on-board pull-up resistors. The internal resistors are high value to reduce power consumption in the chipset. (The internal pull-up resistors on the ATMega family chipsets are 20K-50K ohms.) This results in a high input impedance at the interface card input port where switches and other hardware are connected. High input impedance can produce poor EMC performance. This can be improved by adding external pull-up resistors to the interface **card** inputs (not the IC inputs). The specific value to use depends on the chipset in the interface card and the length of the input wiring, but 2700-5000 ohms is a common range for pull-up resistors in 5 volt systems.

It is common practice to tie unused processor I/O pins to ground or V+ to avoid false operation from noise on floating pins. Chipsets that have programmable I/O pins (configurable as an input OR an output) do not support connecting un-used inputs to ground or V+. This technique cannot be used with the ATMega family.

- **Sometimes the dragon wins:** It is not uncommon to find that two devices with acceptable EMI levels *individually* fail to play nicely when operated together. For example, running the stick shaker and lighting dimmers at the same time may cause false operations somewhere. These situations can often be corrected with sufficient effort, but sometimes the only *practical* choice is to use different parts. Get a different model stick shaker, to use our example, or replace a PWM dimmer with an analog dimmer.

- **Sometimes EMI isn't the problem.** Faulty software can be mistaken for EMI problems. No operating system is without flaws and no software suite is error free. It is difficult to troubleshoot faulty software without special tools and skills. But if a builder can eliminate EMI as a potential source of problems what remains is generally software.

    - EMI problems tend to be sporadic in nature. It is often difficult to reproduce the problem on demand. If something works three days in a row and then doesn't for 5 minutes, and then goes back to working all by itself, it's likely EMI.
    - Software problems tend to fail in the same way for every occurrence. For example, the RMUs stop working **every** time a frequency of 122.60 is selected on COM1.
    - An ongoing problem for all computer users is operating system (OS) updates. It is unfortunately common for a Windows update to fix one thing and break six other things. Sometimes an update disables OS functionality on which a sim function depends. Correlate suspected sim issues with OS updates. Did the EICAS messages stop working correctly **just after** updates were installed?
    - ElectroStatic Discharge (ESD) can cause all manner of goofy problems. If you have carpet in your sim make sure it is **rated** "Static-Free" or "ESD Safe." Make sure the **seats** are bonded to the metal parts of the airframe. If you **feel** a spark when you walk across the floor and touch a metal part in your sim, you have ESD problems. **Bonding** is your best friend when dealing with ESD problems.

EMI, like nearly any other problem faced by a sim builder, can be fixed or mitigated. **Careful observation** of the system behavior will often turn up clues to the source of the problem. Ask yourself these three questions, **in the order given**. The answers will be helpful in tracking down problems.

1. **Did it *ever* work right?**

2. **What, *EXACTLY what,* causes you to think it's *not* working correctly?**

3. ***What happened*, either just before or at the same time the problem appeared?**