Opto 22 Technical Note

TN9603B Operational Interference and Noise

Electrical noise presents one of the largest obstacles to achieving optimal performance from any electrical or electronic system. Normally, internal noise (that which is generated within the individual system components) is accounted for by the designers of the system. External noise, while also designed for, cannot in all cases be anticipated, and thus may still present severe problems to system operation. This is especially true of external noise at the interfaces into the system, including point-to-point signal wiring, power supply wiring, exposed components and transducers, and equipment ground. Fortunately, external noise can be greatly reduced by applying proper wiring, shielding, and grounding practices. This document will not address the effects of environmental noise on wireless communication links. It also does not address noise generation or compliance by electronic control systems, for more information on this topic, see Opto 22 Application Note 9603C.

It is physically impossible to remove all noise from any given system, as there are three fundamental noise components inherent in any electronic system operating at a temperature above absolute zero. What matters for electronic control and telemetry systems is that the noise level is reduced to the point where it no longer affects system operation. Unfortunately, this reduction is not easily quantifiable, as different system components will show different sensitivity to different forms of noise or interference. The millivolt signal from a thermocouple, for example, will more likely suffer from small amplitude induced voltage noise than the signals from a 5V logic high-speed quadrature counter. The quadrature counter signal, on the other hand, will be more sensitive to mid-to-high frequency large-amplitude noise (generating spurious "signal" pulses) than the thermocouple. The latter is buffered by input filters and its own thermal mass, making it sensitive only to low-frequency voltage noise of relatively small amplitude, while the former has a high "valid signal" threshold but is sensitive to any input above this point, even at high frequencies. Knowing the character of a system component's sensitivity can be extremely useful when determining how to deal with a noise problem. In general, small analog signals are significantly more prone to noise contamination than discrete signals.

I consider there to be three major types of noise sources in the industrial world, grouped more based on methods by which the problems are addressed rather than strictly by physical nature. Noise from each of these source types must be addressed differently, in terms of how to protect a signal. Below are the three major source types and summaries of their characteristics, followed by methods of signal protection.

I. Line to Line Interference

The primary source of line-to-line interference is capacitive and inductive coupling of signals between conductors located close to each other. Typically, this will be seen when a conductor carrying a small, sensitive signal runs parallel to a conductor carrying AC, or switched DC power—they might run in the same conduit. Less commonly, one finds leakage of signal from a small-signal line to another small signal line. The fields created by a signal change (60 Hz for U.S. AC, power on / off for DC) cause sympathetic charge movement or potentials in the small-signal line. If this line drives a high-impedance load, the potential change cause by the electromagnetic coupling (known as "cross talk") can result in a voltage error at the load end ("load end" being where the signal is read). More rarely, such induced currents or potentials can cause instability at the source end, leading to oscillations in the output driver stage of whatever device is generating the signal, leading to severe measurement inaccuracies. The simple solution here is to locate power cables as far from signal cables as possible, and also to locate discrete signal and analog signal conductors apart from each other. This separation of discrete and analog signals is especially important if 120VAC logic is in use. Typically, a few inches of separation between conductor types will suffice, though a greater separation might be required if voltages or currents are high. When sensitive signals must cross power conductors, they should cross at a right angle, but should never in any case form a loop around the current carrying cable by crossing it twice in opposite directions. It also helps if signal carrying conductors, especially ones carrying analog signals, are properly shielded (more later).

II. Power Supply Interference

Power supplies can represent a major source of interference in electronic control systems, causing noise on the power supply rails. This interference may be generated by the power supply itself, of simply passed through the supply from the AC (or DC) mains. Typically, this noise is caused by load switching, which generates voltage spikes, and by waveform distortion, caused by large numbers of linear or switching power supplies on the same main line. Waveform distortion is usually adequately addressed by the voltage regulator in whatever power supply is being used. The other main problems on power rails are voltage spikes and transients; they are quick enough phenomena that most power regulators cannot track them. This spurious signal can find its way into the logic supply, and cause problems from random hardware resets to physical damage of the controllers. The best way to address these transient problems is first to use separate power supplies for logic and electromechanical devices. Second, electromagnetic devices like motors and solenoids should have appropriate surge reduction devices attached; R-C snubbers and / or varistors for AC loads and commutating diodes for DC loads. As a last resort, zener diodes or metal oxide varistors can be added across the line on the DC side of the power supply, though they must be sized as not to interfere with the normal regulation of the line (having breakdown / conduction voltages higher than the normal operating range of the supply).

Sometimes, the power supply itself can be a source of noise. A poorly filtered switching supply, for example, might leak artifacts from its high-speed switch into its output, resulting in a noise signal at the switching frequency and its even harmonics, normally in the tens of kilohertz and higher. The switching circuits in these supplies sometimes also cause random RFI and EMI problems with low-level signals routed nearby. Switching supplies can cause quite severe problems on data bus lines (Pamux)-- especially if the bus clock frequency is a harmonic of the switch frequency. Linear power supplies can cause noise problems associated with their power transformers; mainly large alternating magnetic fields at line frequency. A linear supply, especially one of the "brute force" variety will also typically exhibit a very large current inrush when it is switched on. This inrush can affect other equipment on the same supply circuit.

The method a power supply is attached to the system it powers plays a major part in the amount of interference that will pass through it, and in the potential sources of interference. As stated earlier, it is important that independent supplies be used to power the logic and electromechanical elements of the system. Also, it is important to remember that the common terminal on the power supply is not the same as earth ground; treating it or connecting it as such might open up a system to common-mode problems, ground loops, or other problems associated with non-ideal earth grounds. Please see Opto 22 data sheet form #1271 for more information regarding power supplies.

III. Radio Frequency and Electromagnetic Interference

RFI and EMI normally present much less of a noise threat to an electronic control system than conducted or close-coupled interference as described in the previous sections. When a system has been properly designed with respect to line filtration and layout, RFI and EMI will become the major sources of external interference to a control system. Unfortunately, these two types of interference (actually, RFI is a subset of EMI) can be the most difficult to protect a system against. Fortunately, there are few locations and environments where electronic industrial control systems are used that have sufficiently powerful RF and EM noise energy sources to cause problems. Exceptions to this include environments where high electrical currents are present and switched (arc welding), environments with large rotating or changing magnetic fields (large AC or DC motors, close proximity to large solenoids), or environments close to RF emitters (broadcasting towers, radar systems).

RFI and EMI typically enter electronic systems through various interconnecting conductors, which act as antennae. These unintentional antennae take the form of power supply and signal leads, circuit board traces, and data lines. The noise currents generated in the lines by the interference are typically very small, as the radiated power absorbed by a line is minimal. Unfortunately, a interconnect of the proper dimensions can be made to resonate, effectively increasing the power received by large amounts. This noise, even amplified, is still normally not a problem for most electronic control systems because there is insufficient current available to drive the recipient device. Devices with extremely high input impedances like MOSFETs, though, will allow sufficient voltage buildup from a small current signal to cause problems. This is why a data line or circuit board trace driving a transistor gate might present more of an RFI or EMI receptor problem than a control line driving a device that needs a larger amount of current to operate, like the LED in an Optocoupler.

Radio-Frequency Interference, spanning the EM spectrum from about 100 kHz to 100 GHz, is the most common form of electromagnetic interference found on Earth, especially in industrialized nations. Noise sources include everything from broadcast radio stations to satellite uplinks to military and civilian radar. The majority of RFI noise problems can be eliminated by ensuring that the susceptible devices are well shielded. Grounded (conductive) metal cases and braid or foil shielded interconnection cables are normally sufficient. Please see Opto 22 Application Note 9603A for information on shielding practice. Sometimes shielding a data line is not enough; some RFI is powerful enough given a large enough antenna to break through a shield by either capacitive coupling to the lines from the shield or by shield saturation. If this is the case, a fiber-optic data link may be required. Typically, the logic boards and associated circuitry for an electronic control system is compact enough to place in an enclosure with enough shielding to deal with any RFI problem.

EMI, as stated before, actually contains RFI as a component. For the purposes of this document, EMI will refer to electromagnetic interference at relatively low frequencies, those below about 100 kHz. Extremely high frequency electromagnetic radiation can also damage electronic equipment; anything above about 10^{16} Hz certainly has the potential not only to penetrate a conventional shield, but to erase EPROMS, damage microcircuitry, and the like. As this sort of EMI is found in large quantities only in space and in specialized facilities, this document will not address it. Low frequency EMI, especially EMI at line frequencies (to 400 Hz) associated with AC power transformers, as well as that generated by switching power supplies and boost converters ("flyback" converters in CRTs), is of greater concern in industrial environments. The magnetic fields generated by these devices can induce an EMF in nearby conductors that can get large enough to cause problems with electronic equipment.

Unfortunately, it is extremely difficult to shield equipment from low-frequency magnetic fields, as these fields will permeate non-magnetic conductors like copper and aluminum, as well as thin layers (thin being several inches, in some cases) of nominally magnetic materials like steel. Shielding materials (mu-metal, ferrite, amorphous alloys, permalloy) are available, but the design of magnetically shielded enclosures is complex, and is probably best addressed as a last resort. Often, it is easier to simply move the source of the EMI away from the electronic controls, or vice-versa. Use of low-leakage (toroidial) or shielded transformers is also an option. Completion of an open magnetic circuit (some autotransformers, some electromechanical actuators, non-toroidial inductors) by providing a high-mu path for the field flux will also significantly reduce EMI in nearby devices. Keeping conductors orthogonal to existing magnetic fields (in the plane perpendicular to the winding axis) will also help to minimize pickup of EMI. In no case should a sensitive signal line be allowed to run parallel with the winding axis of a magnetic device.

Overall, electronic noise of various sorts can be a major cause of undesirable behavior in electronic control systems. Fortunately, this noise is easily addressed by common and proper practices in system design and implementation. For the most part, electronic industrial control hardware is designed with typical environmental electronic noise in mind. Implementation of the hardware can also play a major role in the noise susceptibility of the overall system, but by following good design and installation practice, this susceptibility can be greatly reduced. If noise is still an issue, more extreme measures can be taken to protect the system, the methodology depending on what the source of the interference is.