

Electrical noise and transients

Application Note

Electrical noise is the result of more or less random electrical signals getting coupled into circuits where they are unwanted, i.e., where they disrupt information-carrying signals. Noise occurs on both power and signal circuits, but generally speaking, it becomes a problem when it gets on signal circuits. Signal and data circuits are particularly vulnerable to noise because they operate at fast speeds and with low voltage levels. The lower the signal voltage, the less the amplitude of the noise voltage that can be tolerated. The signal-to-noise ratio describes how much noise a circuit can tolerate before the valid information, the signal, becomes corrupted.

Noise is one of the more mysterious subjects in power quality, especially since it must be considered with its equally mysterious twin, grounding. To lessen the mystery, there are two key concepts to understand:

- The first is that electrical effects do not require direct connection (such as through copper conductors) to occur. For an electrician who's been trained to size, install and test wiring, this may not be intuitive. Yet think of lightning, or of the primary and secondary of an isolation transformer, or of the antenna to your radio: there's no direct, hard-wired connection, but somehow complete electrical circuits are still happening. The same electrical rules-of-behavior are in operation for noise coupling, as will be explained below.
- The second concept is that we can no longer stay in the realm of 60 Hz. One of the benefits of 60 Hz is that it's a low enough frequency that power circuits can be treated (almost) like dc circuits; in other words, basic Ohm's Law will get you most places you need to go. But when it comes

to noise, we need to keep in mind that signal circuits occur at high frequencies, that noise is typically a broad spectrum of frequencies, and that we need to consider the frequency-dependent behavior of potential sources of noise.

Coupling mechanisms

There are four basic mechanisms of noise coupling. It pays to understand them and how they differ one from the other because a lot of the troubleshooter's job will be to identify which coupling effect is dominant in a particular situation.

1. Capacitive coupling

This is often referred to as electrostatic noise and is a voltage-based effect. Lightning discharge is just an extreme example. Any conductors separated by an insulating material (including air) constitute a capacitor—in other words, capacitance is an inseparable part of any circuit. The potential for capacitive coupling increases as frequency increases (capacitive reactance, which can be thought of as the resistance to capacitive coupling, decreases with frequency, as can be seen in the formula: $X_C = 1/2\pi fC$).

2. Inductive coupling

This is magnetic-coupled noise and is a current-based effect. Every conductor with current flowing through it has an associated magnetic field. A changing current can induce current in another circuit, even if that circuit is a single loop; in other words,

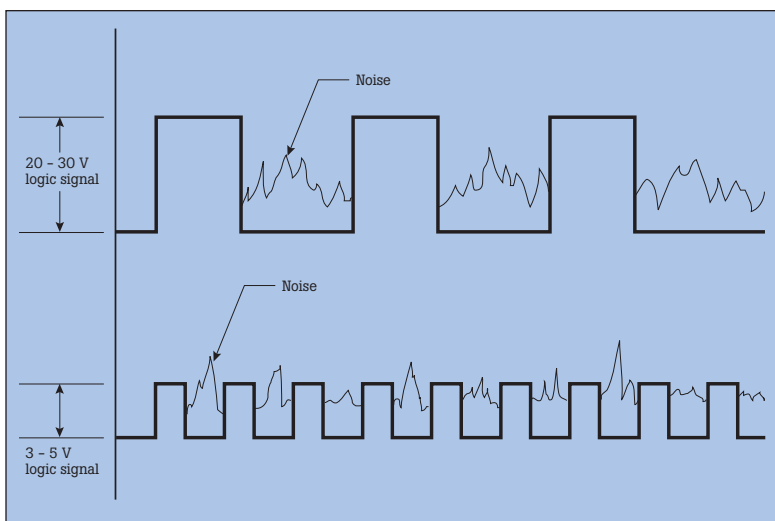


Figure 1. Lower voltage, faster signals increase sensitivity to noise.

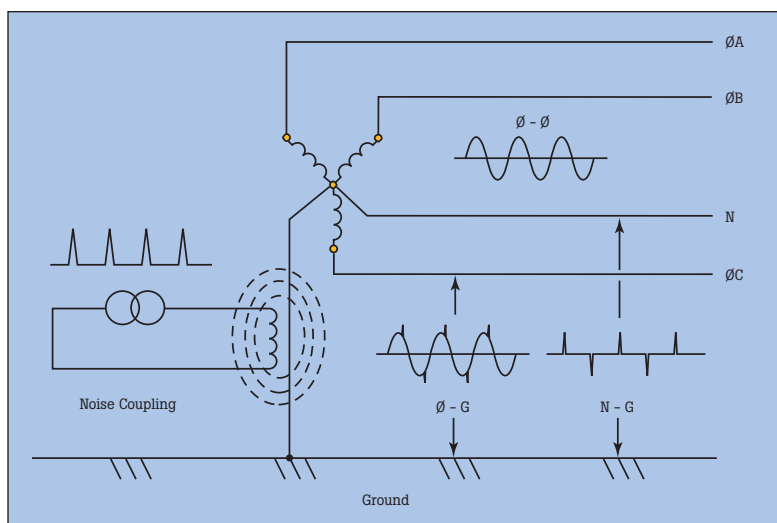


Figure 2. Noise coupling. Ground noise measured as ϕ -G or N-G noise.

the source circuit acts as a transformer primary with the victim circuit being the secondary. The inductive coupling effect increases with the following factors: (1) larger current flow, (2) faster rate of change of current, (3) proximity of the two conductors (primary and secondary) and (4) the more the adjacent conductor resembles a coil (round diameter as opposed to flat, or coiled as opposed to straight).

Here are some examples of how inductive coupling can cause noise in power circuits:

- A transient surge, especially if it occurs on a high-energy circuit, causes a very fast change in current which can couple into an adjacent conductor. Lightning surges are a worst case, but common switching transients or arcing can do the same thing.
- If feeder cables are positioned such that there is a net magnetic field, then currents can be induced into ground cables that share the raceway.
- It is well known that signal wires and power conductors should not be laid parallel to each other in the same raceway, which would maximize their inductive coupling, but instead be separated and crossed at right angles when

necessary. Input and output cables should also be isolated from each other in the same manner.

Magnetic fields are isolated by effective shielding. The material used must be capable of conducting magnetic fields (ferrous material as opposed to copper). The reason that a dedicated circuit (hot, neutral, ground) should be run in its own metal conduit when possible is that is in effect magnetically shielded to minimize inductive coupling effects.

Both inductive and capacitive coupling are referred to as near field effects, since they dominate at short distances and distance decreases their coupling effects. This helps explain one of the mysteries of noise—how slight physical repositioning of wiring can have such major effects on coupled noise.

3. Conducted noise

While all coupled noise ends up as conducted noise, this term is generally used to refer to noise coupled by a direct, galvanic (metallic) connection. Included in this category are circuits that have shared conductors (such as shared neutrals or grounds). Conducted noise could be high frequency, but may also be 60 Hz.

Common examples of connections that put objectionable noise currents directly onto the ground:

- Sub-panels with extra N-G bonds
 - Receptacles miswired with N and G switched
 - Equipment with internal solid state protective devices that have shorted from line or neutral to ground, or that have not failed but have normal leakage current. This leakage current is limited by UL to 3.5 mA for plug-connected equipment, but there is no limit for permanently wired equipment with potentially much higher leakage currents. (Leakage currents are easy to identify because they will disappear when the device is turned off).
 - Another common example is the so-called isolated ground rod. When it is at a different earth potential than the source grounding electrode, a ground loop current occurs. This is still conducted noise, even though the direct connection is through the earth.
 - Datacom connections that provide a metallic path from one terminal to another can also conduct noise. In the case of single-ended, unbalanced connections (RS-232), the connection to terminal ground is made at each end of the cable. This offers a path for ground currents if the equipment at each end is referenced to a different power source with a different ground.
- ### 4. RFI (Radio Frequency Interference)
- RFI ranges from 10 kHz to the 10 s of MHz (and higher). At these frequencies, lengths of wire start acting like transmitting and receiving antennas. The culprit circuit acts as a transmitter and the victim circuit is acting as a receiving antenna. RFI, like the other coupling mechanisms, is a fact of life, but it can be controlled (not without some thought and effort, however).

RFI noise reduction employs a number of strategies:

- Fiber optic cable, of course, is immune to electrical noise.
- Shielded cabling (such as coax cables) attempts to break the coupling between the noise and signal.
- Balanced circuits (such as twisted pair) don't break the coupling, but instead take advantage of the fact that the RFI will be coupled into both conductors (signal and return). This noise (called Common Mode noise) is then subtracted, while the signal is retained. In effect, the balanced circuit creates a high impedance for the coupled noise.
- Another example of the high-impedance-to-noise approach is the use of RF chokes. Whether used with data or power cables, RF chokes can offer effective high-frequency impedance (X_L increases with frequency).
- A low-impedance path can be used to shunt away the noise. This is the principle behind filtering and the use of decoupling caps (low impedance to high frequency, but open at power line frequencies). But a sometimes-overlooked, yet critical, aspect is that the ground path and plane must be capable of handling high-frequency currents. High-frequency grounding techniques are used to accomplish this. The SRG (Signal Reference Grid), first developed for raised floor computer room installations, is an effective solution. It is essentially an equipotential ground plane at high-frequency. (For further information on high-frequency grounding, see the references listed on the back page.)

Signal grounding

To understand the importance of "clean" signal grounds, let's discuss the distinction between Differential Mode (DM) vs. Common Mode (CM) signals. Imagine a basic two-wire circuit: supply and return. Any current that circulates or any voltage read across a load between the two wires is called DM (the terms normal mode, transverse mode and signal mode are also used). The DM signal is typically the desired signal (just like 120V at a receptacle). Imagine a third conductor, typically a grounding conductor. Any current that flows now through the two original conductors and returns on this third conductor is *common* to both of the original conductors. The CM current is the noise that the genuine signal has to overcome. CM is all that extra traffic on the highway. It could have gotten there through any of the coupling mechanisms, such as magnetic field coupling at power line frequency or RFI at higher frequencies. The point is to control or minimize these ground or CM currents, to make life easier for the DM currents.

A Matter of Life and Death

Sometimes PQ troubleshooting is a matter of life and death.

Dave was the on-site field engineer at the hospital. One day he got a call from a very concerned nurse in the ER. One of their patients had died. But as upsetting as that was, it wasn't the main source of concern. What was really unusual was that this particular corpse had a heartbeat.

Dave soon arrived at the scene. A quick glance told him that the dead had not come back to life. The problem lay elsewhere. The nurses pointed out what they had seen, a signal on the EKG indicating a heartbeat. But there was something unusual about this signal (above and beyond the fact that it seemed to be coming from a dead body). He noticed that the signal was a 60 Hz sine wave

(slightly flat-topped). A further look at the signal wires told him that they had been laid parallel to the power cord. The coupling between signal and power wires caused the 60 Hz "Heartbeat" on the EKG machine. The moral of the story is to always isolate the signal and power conductors—before it becomes a matter of life and death.



Measurement

CM currents can be measured with current clamps using the zero-sequence technique. The clamp circles the signal pair (or, in a three-phase circuit, all three-phase conductors and the neutral, if any). If signal and return current are equal, their equal and opposite magnetic fields cancel. Any current read must be common mode; in other words, any current read is current that is not returning on the signal wires, but via a ground path. This technique applies to signal as well as power conductors. For fundamental currents, a ClampMeter or DMM + clamp would suffice, but for higher frequencies, a high bandwidth instrument like the Fluke 43 Power Quality Analyzer or ScopeMeter should be used with a clamp accessory.

Transients

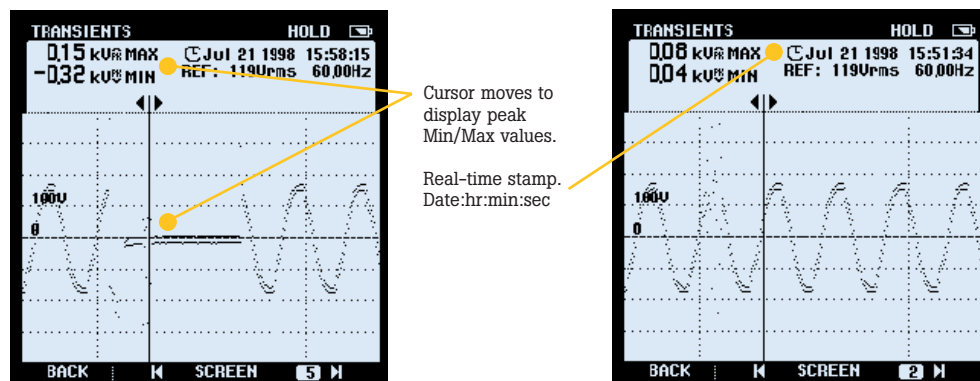


Figure 3. Fluke 43B can capture and save up to 40 transients.

Transients should be distinguished from surges. Surges are a special case of high-energy transient which result from lightning strikes. Voltage transients are lower energy events, typically caused by equipment switching.

They are harmful in a number of ways:

- They deteriorate solid state components. Sometimes a single high energy transient will puncture a solid state junction, sometimes repetitive low energy transients will accomplish the same thing. For example, transients which exceed the PIV (peak inverse voltage) rating of diodes are a common cause of diode failure.
- Their high-frequency component (fast rise times) cause them to be capacitively coupled into adjoining conductors. If those conductors are carrying digital logic, that logic will get trashed. Transients also couple across transformer windings unless special shielding is provided. Fortunately this same high frequency component causes transients to be relatively localized, since they are damped (attenuated) by the impedance of the conductors (inductive reactance increases with frequency).

- Utility capacitor switching transients are an example of a commonly-occurring high-energy transient (still by no means in the class of lightning) that can affect loads at all levels of the distribution system. They are a well known cause of nuisance tripping of ASDs: they have enough energy to drive a transient current into the dc link of the drive and cause an overvoltage trip.

Transients can be categorized by waveform. The first category is "impulsive" transients, commonly called "spikes," because a high-frequency spike protrudes from the waveform. The capacitor switching transient, on the other hand, is an "oscillatory" transient because a ringing waveform rides on and distorts the normal waveform. It is lower frequency, but higher energy.

Causes

Transients are unavoidable. They are created by the fast switching of relatively high currents. For example, an inductive load like a motor will create a kickback spike when it is turned off. In fact, removing a Wiggy (a solenoid voltage tester) from a high-energy circuit can create a spike of thousands of volts! A

capacitor, on the other hand, creates a momentary short circuit when it's turned on. After this sudden *collapse* of the applied voltage, the voltage rebounds and an oscillating wave occurs. Not all transients are the same, but as a general statement, load switching causes transients.

In offices, the laser copier/printer is a well-recognized "bad guy" on the office branch circuit. It requires an internal heater to kick in whenever it is used and every 30 seconds or so when it is not used. This constant switching has two effects: the current surge or inrush can cause repetitive voltage sags; the rapid changes in current also generate transients that can affect other loads on the same branch.

Measurement and recording

Transients can be captured by DSOs (Digital Storage Oscilloscopes). The Fluke 43 PQ Analyzer, which includes DSO functions, has the ability to capture, store and subsequently display up to 40 transient waveforms. Events are tagged with time and date stamps (real time stamps). The VR101S Voltage Event Recorder will also capture transients at the receptacle. Peak voltage and real time stamps are provided.

Transient voltage surge suppressors (TVSS)

Fortunately, transient protection is not expensive. Virtually all electronic equipment has (or should have) some level of protection built in. One commonly-used protective component is the MOV (metal oxide varistor) which clips the excess voltage.

TVSS are applied to provide additional transient protection. TVSS are low voltage (600 V)

devices and are tested and certified to UL 1449. UL 1449 rates TVSS devices by Grade, Class and Mode. As an example, the highest rating for a TVSS would be Grade A (6000 V, 3000 A), Class 1 (let-through voltage of 330 V max) and Mode 1 (L-N suppression). The proper rating should be chosen based on the load's protection needs:

- A lower Grade might result in a TVSS that lasts one year

instead of ten years. The solid state components in a TVSS will themselves deteriorate as they keep on taking hits from transients.

- A lower Class might permit too much let-through voltage that could damage the load. Class 1 is recommended for switch mode power supplies.
- A Mode 2 device would pass transients to ground, where they could disrupt electronic circuit operation.

Voltage susceptibility profile

The new ITIC profile (Information Technology Industry Council) is based on extensive research and updates the CBEMA curve. The CBEMA curve (Computer Business Equipment Manufacturers Association, now ITIC) was the original voltage susceptibility profile for manufacturers of computers and other sensitive equipment. Similar curves are

being developed for 230 V/50 Hz equipment and for adjustable speed drives. Sensitive equipment should be able to survive events inside the curve. Events outside of the curve could require additional power conditioning equipment or other remedial action. A major change in ITIC is that the ride-through times for outages as well as the tolerance for sags have both been

increased. The field troubleshooter must keep in mind that the profiles are recommendations and that a particular piece of equipment may or may not match the profile. Having said that, the profiles are still useful because, when recorded events are plotted against them, they give a general idea of the voltage quality at a particular site.

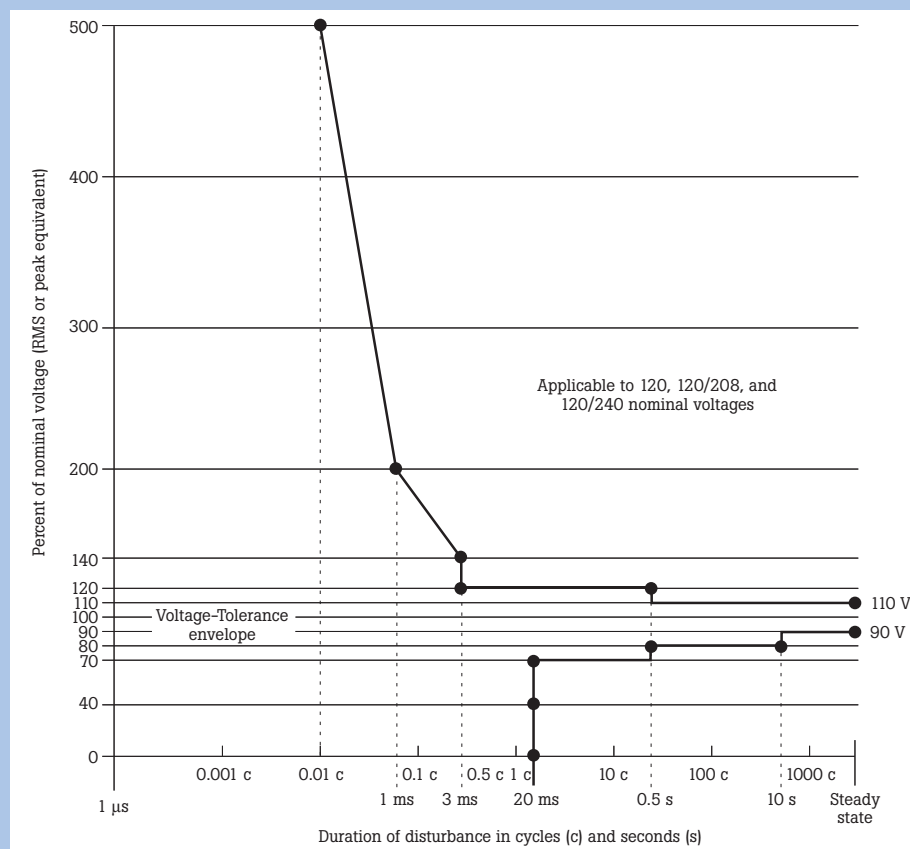


Figure 4. ITIC Curve.

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