Electrical noise and mitigation - Part 1: Noise definition, categories and measurement

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8.1 Introduction
In this chapter, we will learn about noise in electrical circuits, the reasons for their generation, types of noise and mitigation. We will cover shielding as a means of noise control and the role played by grounding and how properly designed grounding can reduce noise. We will learn about zero signal reference grids for noise-prone installations. We will briefly deal with the subject of harmonics and how they affect power and electronic equipment and about ways of controlling them.

8.2 Definition of electrical noise and measures for noise reduction
Noise, or interference, can be defined as undesirable electrical signals, which distort or interfere with an original (or desired) signal. Noise could be transient (temporary) or constant. Unpredictable transient noise is caused, for example, by lightning. Constant noise can be due to the predictable 50 or 60 Hz AC 'hum' from power circuits or harmonic multiples of power frequency close to the data communications cable. This unpredictability makes the design of a data communications system quite challenging.

Noise can be generated from within the system itself (internal noise) or from an outside source
Examples of these types of noise are:

**Internal noise**
- Thermal noise (due to electron movement within the electrical circuits)
- Imperfections (in the electrical design).

**External noise**
- Natural origins (electrostatic interference and electrical storms)
- Electromagnetic interference (EMI) - from currents in cables
- Radio frequency interference (RFI) - from radio systems radiating signals
- Cross talk (from other cables separated by a small distance).

From a general point of view, there must be three contributing factors before an electrical noise problem can exist. These are:

1. A source of electrical noise
2. A mechanism coupling the source to the affected circuit
3. A circuit conveying the sensitive communication signals.

Typical sources of noise are devices, which produce quick changes (spikes) in voltage or current or harmonics, such as:

- Large electrical motors being switched on
- Fluorescent lighting tubes
- Solid-state converters or drive systems
- Lightning strikes
- High-voltage surges due to electrical faults
- Welding equipment.

Figure 8.1 shows a typical noise waveform and how it looks when superimposed on the power source voltage waveform.
Electrical systems are prone to such noise due to various reasons. As discussed in the previous chapter, lightning and switching surges are two of these. These surges produce high but very short duration of distortions of the voltage wave. Another common example is ‘notching’, which appears in circuits using silicon-controlled rectifiers (power thyristors). The switching of these devices causes sharp inverted spikes during commutation (transfer of conduction from one phase arm to the next). Figure 8.2 shows the typical waveform with this type of disturbance.

Harmonics in supply system is yet another form of disturbance. This subject will be reviewed in detail later in the chapter. A typical waveform with harmonic components is shown in Figure 8.3.
Switching of large loads in power circuits to which automatic data processing (ADP) loads are connected can also cause disturbances. Similarly, faults in power systems can cause voltage disturbances. All these distortions and disturbances can find their way to sensitive electronic equipment through the power supply mains connection and cause problems.

Apart from these directly communicated disturbances, sparks and arcing generated in power-switching devices and high-frequency harmonic current components can produce electromagnetic interference (EMI) in signal circuits, which will require to be properly shielded or screened to avoid interference. Figure 8.4 shows diagrammatically the reasons for noise from the equipment within a facility.

The following general principles are applicable for reducing the effects of electrical noise:

- Physical segregation of noise sources from noise-sensitive equipment
- Electrical segregation
- Harmonic current control

Figure 8.3 Waveform distorted by harmonics

Figure 8.4 Noise emanating from electrical systems within a facility
Avoiding ground loops which are a major cause of noise propagation (including measures such as zero signal reference grid, explained later in this chapter)

- Shielding/screening of noise sources and noise-susceptible equipment including use of shielded/twisted pair conductors.

**How are sensitive circuits affected by noise?**

8.3 How are sensitive circuits affected by noise?

Noise is only important if it is measured in relation to the communication signal, which carries the data or information. Electronic receiving circuits for digital communications have a broad voltage range, which determines whether a signal is binary bit '1' or '0'. The noise voltage has to be high enough to take the signal voltage outside these limits for errors to occur.

The power and logic voltages of present day devices have been drastically reduced and at the same time, the speed of these devices has increased with propagation times now being measured in picoseconds. While the speed of the equipment has gone up and the voltage sensitivity has gone down, the noise conditions coming from the power supply side have not reduced at all.

The best illustration that can be given of this condition is to consider where the signal voltage has been and what is happening to it compared to the noise voltage (see Figure 8.5). In years gone by, signal voltages may have been 30 V or more but since then have steadily been decreasing. As long as the signal voltage was high and the noise voltage was only 1 V, then we had what most instrument engineers would call a very high signal to noise ratio, 30:1.

![Figure 8.5 Relative magnitudes of signal and noise (then and now)](image)

Most engineers would say you have no problem distinguishing the signal as long as you have such a high signal to noise ratio. As the electronic equipment industry advanced, the signal strength went down further, below 10 and then below 5. Today we are fighting 1-, 2- and 3 V signals and still finding ourselves with 1, 2 and 3 V of electrical noise. When this takes place for brief periods of time, the noise signal may be larger than the actual signal. The sensors within the sensitive equipment turn and try to run on the noise signal itself as the predominant voltage.

When this takes place, a parity check or a security check signal is sent out from the sensitive equipment asking if this particular voltage is one of the voltages the sensor should recognize. Usually, this check fails when it is a noise voltage rather than the proper signal that it should be looking at and the equipment shuts down because it has no signal. In other words, the equipment
self-protects when there is no signal to keep it operating. When the signal to noise ratio has fallen from a positive direction to a negative direction, the equipment interprets that as the need to turn off so this it will not be running on sporadic signals.

In the top portion of Figure 8.5, a 20-30-V logic signal is well in excess of the noise that is occurring between the on and off digital signal flow. In the bottom picture, however, the noise has raised its head above the area of the logic signal which has now dropped significantly into the 3-5 V range and perhaps even lower. You will also notice that the difference between the upper and lower pictures in the graph shows the speed with which the signal was transmitted. In the upper graph, the ons and offs are relatively slow, evidenced by the large spaces between the traces. In the lower graph, the trace is now much faster. There are many more ons and offs jammed into the same space and as such, the erratic noise behavior may now interfere with the actual transmission.

The ratio of the signal voltage to the noise voltage determines the strength of the signal in relation to the noise. This 'signal to noise ratio' (SNR) is important in assessing how well the communication system will operate. In data communications, the signal voltage is relatively stable and is determined by the voltage at the source (transmitter) and the volt drop along the line due to the cable resistance (size and length). The SNR is therefore a measure of the interference on the communication link.

The SNR is usually expressed in decibels (dB), which is the logarithmic ratio of the signal voltage (S) to noise voltage (N).

\[
\text{SNR} = 10\log(S/N)\text{dB}
\]

An SNR of 20 dB is considered low (bad), while an SNR of 60 dB is considered high (good). The higher the SNR, the easier it is to provide acceptable performance with simpler circuitry and cheaper cabling.

In data communications, a more relevant performance measurement of the link is the bit error rate (BER). This is a measure of the number of successful bits received compared to bits that are in error. A BER of $10^{-6}$ means that one bit in a million will be in error and is considered poor performance on a bulk data communications system with high data rates.

A BER of $10^{-12}$ (one error bit in a million million) is considered to be very good. Over industrial systems, with low data requirements, a BER of $10^{-4}$ could be quite acceptable. There is a relationship between SNR and BER. As the SNR increases, the error rate drops off rapidly as is shown in Figure 8.6. Most of the communications systems start to provide reasonably good BERs when the SNR is above 20 dB.
Another useful way of evaluating the effects of noise is to examine its frequency spectrum. Noise can be seen to fall into three groups:

1. Wideband noise
2. Impulse noise
3. Frequency-specific noise.

The three groups are shown in the simplified frequency domain as well as the conventional time domain. In this way, we can appreciate the signal's changing properties as well as viewing the amplitude in the customary time domain.

Wideband noise contains numerous frequency components and amplitude values. These are depicted in the time domain graph shown in Figure 8.7 and in the frequency domain graph shown in Figure 8.8.

In the frequency domain, the energy components of wideband noise extend over a wide range of frequencies (frequency spectrum).
Wideband noise will often result in the occasional loss or corruption of a data bit. This occurs at times when the noise signal amplitude is large enough to confuse the system into making a wrong decision on what digital information or character was received. Encoding techniques such as parity checking and block character checking (BCC) are important for wideband error detection so that the receiver can determine when an error has occurred.

Impulse noise is best described as a burst of noise, which may last for a duration of say up to 20 ms. It appears in the time domain as indicated in Figure 8.9.

Figure 8.10 illustrates the frequency domain of this type of noise. It affects a wide bandwidth with decreasing amplitude vs frequency.
Impulse noise is brought about by the transient disturbances in electrical activity such as when an electric motor starts up, or from switching elements within telephone exchanges. Impulse noise swamps the desired signal, thus corrupting a string of data bits. As a result of this effect, synchronization may be lost or the character framing may be disrupted. Noise of this nature usually results in garbled data making messages difficult to decipher. Cyclic redundancy checking (CRC) error detection techniques may be required to detect such corruption.

Although more damaging than wideband noise, impulse noise is generally less frequent. The time and frequency domain plots for impulse noise will vary depending on the actual shape of the pulse. Pulse shapes may be square, trapezoid, triangular or sine for example.

In general, the narrower and steeper a pulse, the more energy is placed in the higher-frequency regions.

Frequency-specific noise is characterized by a constant frequency, but its amplitude may vary depending on how far the communication system is from the noise source, the amplitude of the noise signal and the shielding techniques used.

This noise group is typical of AC power systems (Figures 8.11 and 8.12) and can be reduced by separating the data communication system from the power source. As this form of noise has a predictable frequency spectrum, noise resistance is easier to implement within the system design.

Filters are typically used to reduce this to an acceptable level.
8.5 Categories of noise

An electrical noise falls under one of the following categories: transverse mode or common mode. Transverse-mode noise is a disturbance, which appears between two active conductors (phase or neutral) in an electrical system. Such a noise is therefore measurable between two line conductors or between a line conductor and neutral. This is usually having its genesis from within the power system (Figure 8.13).

Common-mode noise, on the other hand, appears simultaneously in each active conductor and therefore cannot be measured like a transverse-mode noise. It usually involves the ground conductor.
and originates from some external disturbance (Figure 8.14).

![Common-mode noise](image)

**Figure 8.14** Common-mode noise

### 8.6 Disturbances from other equipment in the same distribution system

An important factor to be taken note of in dealing with electrical system generated noise is electrical segregation of noise-producing equipment and noise-sensitive equipment. Figure 8.15 illustrates this principle. In case A, the ‘noisy’ AC units and noise-sensitive ADP loads share a common power supply system. Frequent starts of AC compressors could cause voltage fluctuations, which will be communicated to ADP power units and can translate as noise in ADP units’ electronic circuits. In case B, a separation of circuits has been achieved by employing different sub-circuits for AC loads and ADP loads but this may not have much impact as far as noise is concerned since the sources are shared.

![Segregation of noisy loads](image)

**Figure 8.15** Segregation of noisy loads

In case C, a two-winding transformer has been introduced in the ADP circuit feeder. This will act as a cushion for the noise due to the inherent inductance of the transformer, which will not allow steep noise fronts to pass through. In case D, two separate transformers feed the AC loads and ADP loads with transfer-switching provision. The two-winding transformer has been retained. Obviously, D is the best case solution but expensive. In some situations, it may not be feasible to implement too. C will, however, provide an acceptable solution without being quite as expensive as D and can be retrofitted easily where required.
Coming up in Part 2: Earth loop as a cause of noise, the ways in which noise can enter a signal cable and its control, and shielding.

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