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IN THIS ISSUE

EMC- What's all the Noise about

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The widespread use of electronic circuits for communication, computation, automation, and other purposes makes it necessary for diverse circuits to operate in close proximity. All too often these circuits affect each other adversely. Nowadays more then ever circuit designers need to do more than just make their systems operate under ideal conditions in a laboratory. Besides this obvious task they need to ensure that their equipment works with other equipment nearby without being affected by external noise sources and should not itself be a source of noise to the environment. Electromagnetic Compatibility (EMC) should be a major design objective.

Definition of EMC:

The ability of an electronic system to:

1 function properly in its intended electromagnetic environment and

2 not to be a source of pollution to that environment.

Interference is the undesirable effect of noise. If a noise voltage causes improper operation of a circuit, it is interference. Noise cannot be eliminated but reduced in magnitude until it no longer causes interference.

Noise sources can be grouped into three categories:

- intrinsic noise,
- noise due to natural disturbances such as lightning and
- man-made noise, such as motors, switches, digital electronics and radio transmitters.

Coupling Modes

Three types of coupling are considered in this article.

- resistive (or conductive) coupling,
- capacitive (or electric) coupling and
- inductive (or magnetic) coupling.

2

...Coupling Modes (continued)

Resistive coupling is noise transmitted electrically through a common ground impedance path. A common example is seen at home where television reception is impaired while a hair dryer operating in another part of the house causes noise to be conducted through the house's power supply causing interference to the reception.

Capacitive coupling results from the interaction of electric fields between circuits. The magnitude of capacitively coupled current depends on the following:

■ the rate of change of the interference voltage (dv/dt) of the source (both magnitude and frequency) and

■ capacitance between the source and the signal lines.

This in turn depends on,

- the separation distance between the source to the signal lines and

- the distance over which the cables run in parallel.

Inductive coupling

Magnetic fields are present around every circuit element, including conductors that carry an electric current.

Inductive coupling results from the interaction of the magnetic fields of two circuits. If there is an adjacent element then a portion of this magnetic field will link with that element inducing a noise voltage.

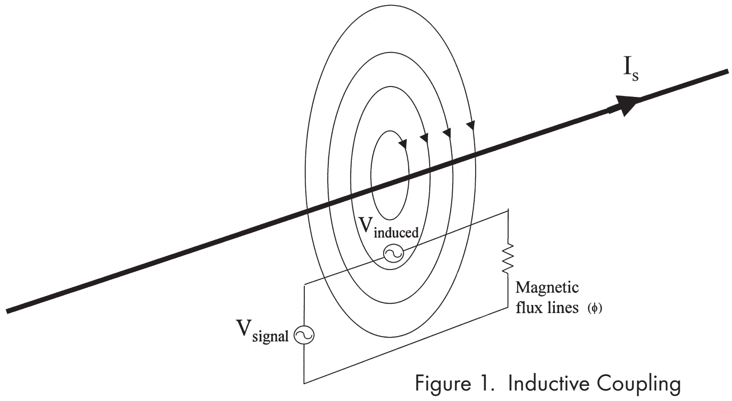

Figure 1. Inductive Coupling

Factors influencing inductive coupling:

■ the rate of change of current (di/dt) in the source conductor,

■ the signal loop area through which lines of flux pass and

■ the separation of the conductors from the disturbing signal.

Cabling

Cabling is important due to the fact that they are the longest parts of a system and therefore act as efficient antennas that pickup and or radiate noise.

Where there is a combination of power, lighting, control, instrumentation and communication cables, the cable layouts should be designed as far away from each other as possible to avoid or reduce the effects of (resistive) galvanic, capacitive and inductive coupling. This is of particular importance in modern automated plants, substations and buildings where measurement and control systems depend on reliable data communications between several electronic devices. Large power electronic devices on the power system such as rectifiers, AC and DC drives, soft starters, UPS systems, etc are increasingly common in industrial plants and modern buildings. They are major sources of harmonic voltages (high dv/dt) and high current (di/dt) in the power system.

To combat the interference problem one must first try and determine:

■ what the noise source is,

■ what the receptor is and

■ how the source and the receptor are coupled together.

Once this is determined, the next step is to decide how to break the noise path. There are three ways in which to accomplish this:

■ to suppress the noise at the source,

■ to make the receptor insensitive to the noise and/or

■ minimise the transmission through the coupling channel.

It is often the third option that is the easiest to tackle.

Resistive Coupling

To minimise resistive coupling, use filters either on the source output or the victim's input or both in some cases.

Isolation transformers will also reduce the effects of resistive/galvanic coupling especially transformers with an earthed shield separating the primary winding from the secondary winding.

Isolation by the use of optical couplers are ideal providing current/voltage is small.

Capacitive Coupling

As the name suggests, ***capacitive coupling*** is the coupling of noise currents via stray capacitance. From basic circuit theory we know that capacitance (C) is related to area (A) and distance (d) in the following manner:

$$C = \frac{\varepsilon A}{d} \quad \text{(eqn.A)}$$

That is to say, capacitance increases as area is increased, and decreases as distance is increased. The easiest thing to do then is to keep the cables separated from one another. Generally only small attenuation is gained by spacing the conductors at a distance greater than 40 times their diameter.

We also know that the current through a capacitor has the following relationship.

$$I_C = C\frac{dv}{dt} \quad \text{(eqn.B)}$$

In other words, the larger the stray capacitance, the larger the current that will flow. Also, the larger the rate of change of voltage (magnitude and/or frequency) with respect to time, the larger the current that will pass through the stray capacitance.

To tackle this type of coupling, you can begin by separating the victim from the source to reduce the capacitance. From equation (A), we can see that capacitance is also reduced if the surface area as 'seen' by the conductors is reduced. In other words try not to have the conductors running in parallel for long distances. (see Figure 2)

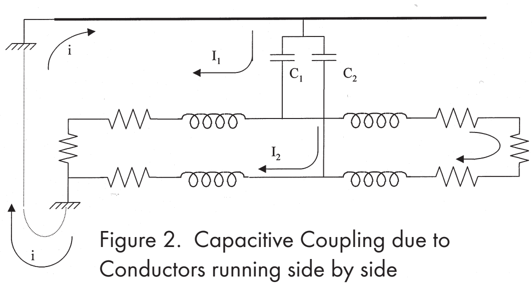

Figure 2. Capacitive Coupling due to Conductors running side by side

The use of an outer conductive screen (an envelope of conductive material around the signal conductors) will reduce the capacitively coupled noise - provided that the screen is connected to earth to provide a path for the capacitive current. The coupled currents then flow through the capacitance C to the screen and then to the earth, instead of flowing through the signal conductors.

Ideally with both the shield and the signal reference conductor connected to earth **at one end**, they would be at the same potential and a zero voltage difference would exist between them. In practice, the screen will not be at zero voltage along its length.

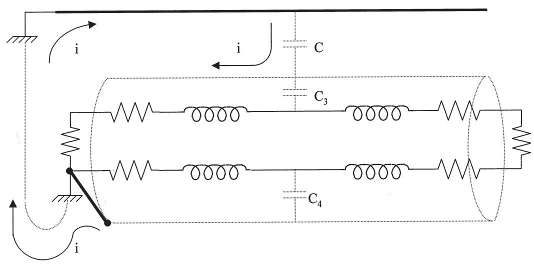

Figure 3. Screened Signal Conductors

From the Figure 3 it is clearly not necessary for both ends of the screen to be earthed to divert capacitively coupled noise currents to earth. In fact earthing at more than one point can introduce other problems, such as earth loops during earth faults, which could damage the screen material or the earth connection of the drain wires. Consequently,

...Capacitive Coupling (continued)

the electrostatic screen is usually earthed at one end only.

However, when the screen is earthed at one end only, the capacitively coupled currents flowing through the screen impedance will result in a volt drop along the length of the screen. The screen voltage can, in turn, be capacitively coupled into the signal conductors via capacitance C_3 and C_4.(refer to fig 3).

Consequently, to keep this volt drop to a minimum, the screen should be made of a high conductivity material, such as copper or aluminium.

Using a balanced connection between the two terminal devices and twisting the two signal conductors provides a balanced capacitive coupling which tends to make C_1=C_2 in the case of an unscreened situation, or C_3=C_4 in a balanced connection. (refer figure 4)

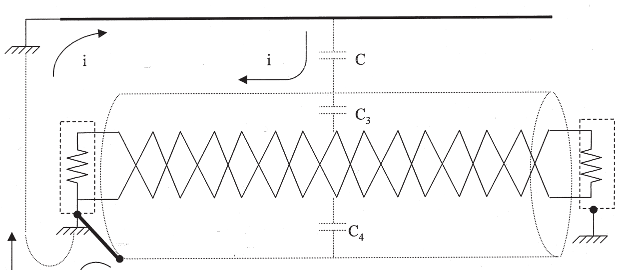

Figure 4. Capacitive Coupling reduced further using twisted pairs and shielding

Inductive coupling

Inductive coupling occurs because two or more circuits are magnetically coupled through a mutual inductance. After some complex derivations using Faraday's law the induced voltage is found to be:

$$V_N = j\omega BA\cos\varnothing = j\omega M_{12} I_1 = M\frac{di_1}{dt}$$

(eqn. C)

Please note: Most formulae must have some assumptions made. It is beyond the scope of this article to delve into these assumptions and derivations.

Where, B is the magnetic flux density given by:

$$B = \frac{\mu I}{2\pi r}$$ (eqn. D)

From equations (C and D), we can see that the induced voltage is dependent on the following:

1. frequency, (since $\omega = 2\pi f$)

2. current,

3. distance from the source (r)

4. area (A) and

5. orientation of the area ($\cos\varnothing$)

Knowing this, it's easy to conclude that cables carrying large currents are obvious noise sources and in particular, cables carrying fast changing currents (see equation 3).

To reduce this type of coupling, you can start off by simply separating the cables. Reducing the area of a signal circuit can be achieved by using a twisted pair cable. This actually does a few things.

■ Reduces the area linked by the flux lines,

■ lowers the inductance per metre. This in turn allows higher frequencies to be transmitted over longer distances before signal distortion becomes significant and

■ the induced voltage is reversed with every twist - effectively cancelling each other out. Therefore the overall induced voltage will tend toward zero.

Where signal cables have to cross power cables, the best thing to do is to make them cross at right angles to each other. This will reduce voltages being induced where the cables

...Inductive Coupling (continued).

are at the closest (see equation.C: (cos ø = cos90=0).

Shielding for inductive coupling

Surrounding the victim conductor with a conductive shield that is earthed **at both ends** further reduces the induced noise voltage. This is because a voltage is induced in both the shield and the victim conductor from the source conductor, but then the shield in turn induces a voltage on the victim conductor but with a reversed polarity. The voltage on the victim conductor is then the voltage induced from the source minus the voltage induced from the shield.

$$V_{noise}=V_{source\ induced}-V_{shield\ induced}$$

Variable Speed Drives

VSDs employ high frequency switching of voltage and current commonly known as Pulse Width Modulation (PWM) to obtain high efficiency and low acoustic noise in the motor, such frequencies result in EMI and RFI at the switching frequency and harmonics of this frequency. As EMI and RFI can involve very complex coupling modes, not all solutions can be found and explained. However, most problems can be solved by observing the following guidelines.

The main problem of EMI is interference to sensitive equipment nearby. Noise is coupled into the earthing system and on the cable from the drive to the motor. Once in the earth system these interference currents circulate to other equipment, then the higher frequency components will radiate interference to other systems causing further problems. (see figure 5)

The higher EMI frequencies must be prevented from radiating by using screen cable, good earthing techniques and bonding. At this point one must realise that there is far more to the EMI mechanism than just the drive itself. A system approach is the best solution. That is, consider the way that the drive is installed.

To further reduce the effects of coupling, lets take a closer look at filtering, earthing and shielding.

Filtering

The use of filters in suppressing EMI from VSDs is aimed at preventing the interference passing down the lines and also aimed at changing impedance conditions so

that EMI on the ground system is re-directed back to its source. On the input side of the VSD, the use of capacitors is effective in suppressing the EMI.

Together with a choke significant benefits can be seen when using such a filter. Input filters are used to prevent harmonics from affecting upstream apparatus. On the drive output, however, the use of capacitors is severely restricted due to their effect on drive performance. Often the output side filter consists of a low value choke.

The positioning and installation of these devices are critical.

Earthing

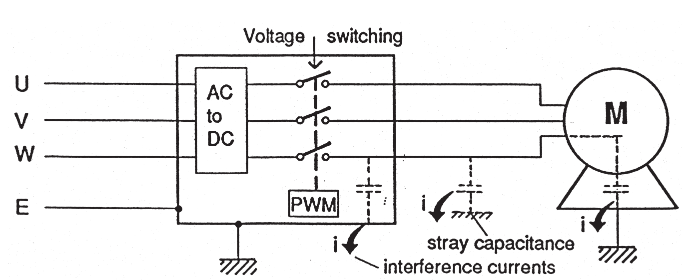

Figure 5. Noise Coupled Into the Earthing System

It is definitely with the earthing that most problems occur. There is a major difference between a safety earth and a EMI earth, especially at higher frequencies. What is needed for EMI is a low HF impedance earth system. The standard earthing presents a relatively high impedance at HF due to skin effect. This high impedance results in greater levels of radiation from the system (and increase sensitivity to external interference).

Shielding/ Screening

It is almost essential that the cables from the VSD to the motor be shielded. This screen should be connected to both the motor earth and the drive earth and be continuous from VSD to the motor.

Practical recommend-ations

A) The communications cables should be laid as far from the power cables as possible at the outer extremes of the cable ladder or duct. (The cable ladder or duct should be made from a conductive magnetic material, such as galvanised steel).

B) If possible, the power cables laid up in trefoil and preferably armoured to minimise the associated EM fields.

C) The cable trays, ducts, conduits and barriers should be electrically bonded together at every join. They should be earthed at least at both ends and at any other convenient locations.

D) The communications cable should be a shielded twisted pair, with electrostatic shield earthed at one end.

E) Where data cables cross power cables, the ideal angle is at 90^{o}.

F) Optic fibre cables are increasingly attractive alternatives to copper conductors for data communications circuits in high interference environments. Fibre cables do not suffer from coupled noise or longitudinal voltage stresses.

Referenced material:

Henry W. Ott, “Noise Reduction Techniques in Electronic Systems”, John Wiley.
Electromagnetic Compatibility Lecture Notes - (A/Prof S Shihab), “Earthing, Shielding, and Surge Protection of Electronic Equipment for Instrumentation and Control” - Automated Control Systems Training Division WA, “Taian T-Verters Detailed Training” by Lew Mallia NHP Electrical Engineering Products Pty Ltd.

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