8.10 Shielded isolation transformer
A shielded transformer is a two-winding transformer, usually delta"star connected and serves the following purposes:

- Voltage transformation from the distribution voltage to the equipment's utilization voltage.
- Converting a 3-wire input power to a 4-wire output thereby deriving a separate stable neutral for the power supply wiring going to sensitive equipment.
- Keeping third and its multiple harmonics away from sensitive equipment by allowing their free circulation in the delta winding.
- Softening of high-frequency noise from the input side by the natural inductance of the transformer,
particularly true for higher frequency of noise for which the reactance becomes more as the frequency increases.

- Providing an electrostatic shield between the primary and the secondary windings thus avoiding transfer of surge/impulse voltages passing through inter-winding capacitance.

Figure 8.27 shows the principle involved in a shielded transformer. The construction of the transformer is such that the magnetic core forms the innermost layer, followed by the secondary winding, the electrostatic shield made of a conducting material (usually copper) and finally the primary winding.

![Figure 8.27 Principle of a shielded two winding transformer](image)

Figure 8.28 shows this detail.

![Figure 8.28 Construction of a shielded two-winding transformer](image)

It can be seen that the high-frequency surge is conducted to ground through the capacitance between the primary winding (on the left) and the shield, which is connected to ground. Besides the shield, the magnetic core, the neutral of the secondary winding and the grounding wire from the electronic equipment are all terminated to a ground bar, which in turn, is connected to the power supply ground/building ground. It is also important that the primary wiring to and secondary wiring
from the isolation transformer are routed through separate trays/conduits. If this is not done, the inter-cable capacitances may come into play negating the very purpose of the transformer.

Figure 8.29 shows the proper way for an isolation transformer to be wired. Note that the AC power supply wiring and the secondary wiring from the transformer are taken through separate conduits. Also, the common ground connection of the isolation transformer serves as the reference ground for the sensitive loads. The AC system ground electrode connection is taken through a separate metal conduit. If these methods are not followed and wiring/earth connections are done incorrectly, noise problems may persist in spite of the isolation transformer.

![Figure 8.29 Wiring/earthing of a shielded two-winding transformer](image)

**Figure 8.29 Wiring/earthing of a shielded two-winding transformer**

**Avoidance of earth loop**

8.11 Avoidance of earth loop

We discussed earlier in this chapter about the earth loop being a primary mechanism of noise injection into sensitive signal circuits. One of the important noise mitigation measures is therefore the avoidance of ground loops altogether. We have also seen in the previous chapters that while keeping a separate ground for the sensitive equipment may resolve noise issues, it is an unsatisfactory solution from the safety point of view.

The correct approach is therefore to keep a common electronic ground but bond it firmly with the power system ground at the source point. Figure 8.30 shows an installation with a ground loop problem.
Here, the main computer system (bottom) and its user terminal are shown connected to the power circuit (including ground wiring) at two different points. A communication cable runs between the computer and its terminal. A ground loop is thus formed with the length of communication cable and the ground wire acting together in series.

Figure 8.31 shows one way in which this loop can be tackled, by bringing the two power and ground connections together to outlets at a single point.

This arrangement may not be feasible or practical to adopt. What is really possible is to introduce additional impedance in the ground loop so that the high-frequency noise prefers to take another low-impedance path and diverts itself away from the communication path. This is the principle
behind the use of a longitudinal (or 'balun') transformer. Figure 8.32 demonstrates the action of this method.

![Diagram of a balun transformer](image)

**Figure 8.32 Use of a 'balun' transformer for noise mitigation**

### 8.12 Use of insulated ground (IG) receptacle

The IG receptacles are used in situations where we wish to avoid the mixing of sensitive equipment ground and the building power system ground at all points except the power source (say, the secondary of the shielded isolation transformer) thus avoiding ground loops from forming. Figure 8.33 shows such a receptacle.

![Diagram of an IG receptacle](image)

**Figure 8.33 An exploded view of IG receptacle**
The receptacle frame has a separate ground connection, which is bonded to the general ground system through the metallic conduit to ensure safe conditions. But the grounding wire from the sensitive equipment is an insulating wire, which runs through the conduit directly to the ground point of the source. Figure 8.34 illustrates such a connection.

![Figure 8.34 Grounding while using an IG receptacle](image)

**Zero signal reference grid and signal transport ground plane**

8.13 Zero signal reference grid and signal transport ground plane

From the foregoing, it will be clear that correct ground connection is a key factor for error-free operation of sensitive equipment and elimination of ground loops to the best possible extent is of extreme importance.

A practical way in which the above can be achieved is by using the support structures of the raised floor (which are common in computer installations and control rooms) as a ground grid called the zero signal reference grid (ZSRG). The grid is formed by the support structures of the raised floor usually arranged as 2 ft square tiles. Copper conductor of #4 AWG size is clamped to the structures forming a grid. All signal grounds of the sensitive equipment and enclosures of the equipment are connected to this grid by short grounding leads.

The grid itself is connected to the power ground through more than one conductor. It is ideal to place the isolation transformer also on this grid and connect the secondary neutral point to the reference grid. Figure 8.35 shows the construction of a ZSRG installation.
When communication cables are used to interconnect two sensitive equipment, use of a signal transport ground plane (STGP) is recommended. This is a copper foil or a GI sheet on which the communication cable is placed so that it is shielded from electrostatic transfer of noise.

Metallic cable trays on which a cable is placed and clamped close to it can also serve as an STGP. Within the same room the STGP can be bonded to the ZSRG at one or more points. When a cable runs between installations in different parts of a building, it will be necessary to have individual ZSRGs in each area and also ensure that the STGP is bonded at either end to these grids. In case balun transformers are also used on the signal cable, noise will be further reduced. Figure 8.36 shows such an installation.

Use of ZSRG has an added bonus too. It provides numerous parallel grounding paths and thus avoids resonance situation. Resonance happens when the length of a ground lead coincides with quarter wavelength of the noise frequency (or 3/4, 1 1/4, etc.) causing the earth lead to act as an open
circuit to these frequencies. With multiple ground paths, this is unlikely to happen.

A judicious mix of ZSRG, shielded transformer and STGP used appropriately will go a long way in avoiding grounding related noise problems.

Raised floor-supporting structure as a signal reference grid:

- Bolted down stringers (struts between supporting posts) assure low electrical resistance joints.
- Isolation from building steel except via computer system earthing conductors, conductor to computer systems central earthing point and to power source earth.
- Ideal floor height for crawling access is 30 in. less than 18 in. restricts airflow. For larger computer rooms, install firewall separation barriers to confine fire and Halon extinguishing gas.

### 8.13.1 Self-resonance effect in grounding/bonding conductors

When dealing with grounding of power system conductors, we are concerned with the ground circuit resistance. But when dealing with circuits with high-frequency signals, it becomes necessary to consider the impedance of the grounding conductor. The grounding electrode conductors (the conductors that connect a system to the ground electrode) exhibit distributed capacitance and inductance in the length of the conductor. A particular conductor may resonate at a certain frequency (or it multiples) and may thus behave like an open-circuited conductor (refer Figure 8.37).

![Figure 8.37 Impedance variation of a typical grounding electrode conductor](image)

It is therefore advisable that grounding circuits of such systems be connected using multiple conductors with different lengths so that the combined grounding system does not resonate as a whole for any frequency. The ZSRG thus fulfills this need by providing multiple ground paths of differing lengths so that the ground path always has low impedance for any signal frequency (refer Figure 8.38).
Harmonics in electrical systems
8.14 Harmonics in electrical systems
The subject of harmonics is not directly related to this course, except that it is also a contributory factor in electrical noise. It also causes several other problems in power circuit components such as motors, transformers and capacitor banks.

A load that is purely resistive has the same wave shapes for voltage and current. Both are normally pure sinusoids. Most induction motors fed directly from AC mains also behave in a similar manner except that they draw some reactive load as well. The current waveform is still sinusoidal (see Figure 8.39).

However, the current waveform gets distorted when power electronic devices are introduced in the system to control the speed of motors. These devices chop off part of the AC waveform using thyristors or power transistors, which are used as static switches.

Such altered waveforms may be mathematically analyzed using Fourier transforms as a combination of vectors of the power frequency (50/60 Hz) and others whose frequency is a multiple of the power frequency. The power frequency component is called the fundamental and higher multiples are called harmonics.
It should be remembered that all electrical generators produce only voltage at fundamental frequency. But there has to be a source if a harmonic current has to flow. It is therefore construed theoretically that all harmonic-producing loads are current sources of harmonics. These sources drive harmonic currents through the rest of the system consisting of the source as well as other loads connected to it. These currents flowing through the different impedances of the system appear as harmonic voltages.

It is usual for the voltage waveform of such a system to appear distorted. Also, the harmonic currents flowing through the other loads of the system give rise to several abnormalities (refer Figure 8.40 for the effects harmonics have on different system components).

<table>
<thead>
<tr>
<th>Effects of harmonics</th>
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<tbody>
<tr>
<td><strong>Capacitors</strong></td>
</tr>
<tr>
<td>Amplify harmonics on electrical distribution system</td>
</tr>
<tr>
<td><strong>Electrical wiring</strong></td>
</tr>
<tr>
<td>Phase and neutral conductors undersized</td>
</tr>
<tr>
<td><strong>Engine generators</strong></td>
</tr>
<tr>
<td>Transferring capability and operation disrupted</td>
</tr>
<tr>
<td><strong>Induction motors</strong></td>
</tr>
<tr>
<td>May fail prematurely due to fifth harmonic</td>
</tr>
<tr>
<td><strong>Metering</strong></td>
</tr>
<tr>
<td>Inaccurate measurement of power</td>
</tr>
<tr>
<td><strong>Over-current protection</strong></td>
</tr>
<tr>
<td>Breaker and fuse nuisance tripping</td>
</tr>
<tr>
<td><strong>Sensitive electronic loads</strong></td>
</tr>
<tr>
<td>Voltage drop between neutral and earth</td>
</tr>
<tr>
<td><strong>Transformers</strong></td>
</tr>
<tr>
<td>Decreased efficiency and overheating</td>
</tr>
<tr>
<td><strong>Uninterruptible power systems</strong></td>
</tr>
<tr>
<td>Line and load interaction</td>
</tr>
</tbody>
</table>

*Figure 8.40 Effects harmonics have on different system components*
Let us see how these shunt filters function. We can use a computer to show what happens as harmonics are filtered from a distorted wave. The example chosen is a 120° square wave current with a 10° commutation time; a typical line current waveform for a DC motor drive and for many AC drives.

Here is the square wave before any filtering. The distortion factor is 26% not too pretty a waveform (Figure 8.41a). Now let us take out the fifth harmonic.

This may not look a whole lot better, but the distortion factor is down from 26 to 18%, so things are improving (Figure 8.41b). Now let us take out the seventh as well.

Things are actually looking better now. We can see the sine wave starting to emerge. Distortion factor is down to 11% (Figure 8.41c). Next, we take out the eleventh.

Still no beauty queen, but the distortion factor is now only 8% (Figure 8.41d). Let us add in the final element and remove the thirteenth harmonic.
This is our final current waveform (Figure 8.41e). The distortion factor is 6%, so we are putting a reasonable current into the utility. Of course, the significance of this current waveform to the voltage distortion would depend on the source impedance and the current level.

**Figure 8.41 Reduction of harmonics by filters**

Higher-frequency harmonics can be propagated by the power conductors acting as antennae and appear as induced noise voltages in nearby signal circuits.

It is not possible to prevent harmonic currents altogether. But they can be prevented from flowing through the entire system by providing a separate low-impedance path for them. This is done by the use of adequately rated series tuned circuits consisting of a reactor and capacitor, which have equal impedance at a specific harmonic frequency.

Several such tuned banks (one for each harmonic frequency) will be needed to totally divert all harmonics away from the system. However, for practical reasons, only a few of the lower order harmonics with larger magnitudes are filtered out, which is adequate to provide substantial reduction of harmonic content.

Figure 8.41 shows how a filter might remove the high-frequency components and how the wave shape might appear as the removal takes place. A full treatment of this subject is beyond the scope of this book.

**8.15 Summary**

In this chapter, we have dealt with electrical noise in detail and the ways in which noise finds a path into sensitive signal circuits. We learnt the various methods by which noise can be reduced by avoiding shields, by separating the cabling, by using shielding transformers, by eliminating earth loops and by using zero signal reference grounds and signal transport ground planes. We also briefly dealt with the generation of harmonics and how they can be filtered.

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