Transformers and Their Application to Control Noise
Chapter 11

Abstract

Isolation transformers have often been considered a "cure-all" for a plethora of grounding and power line noise problems. Contrary to popular opinion, isolation transformers cannot effectively isolate a circuit from noise caused by grounds without the intelligent use of proper shielding and ground design. This paper describes the theory behind the isolation transformer, its physical and electrical characteristics, and its proper application.

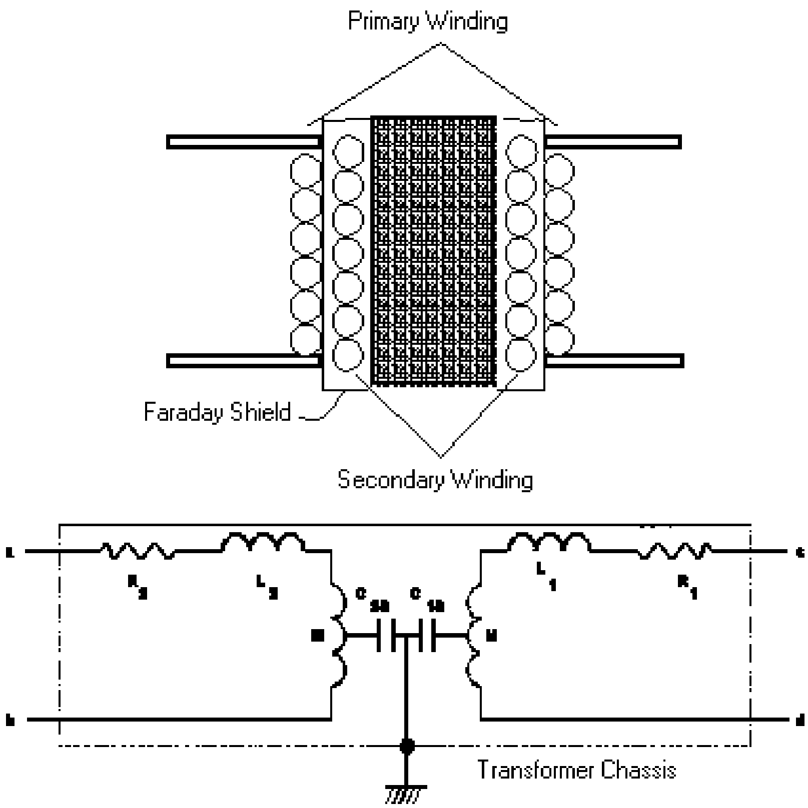

Figure 11-1 Regular Transformer

General Transformer Theory

All transformers provide isolation. They are generally constructed with a primary and secondary winding closely wrapped about the same ferrous core. Typical commercial transformers also incorporate a single Faraday shield between the primary and secondary windings to divert noise that would normally be electrically coupled between the primary and secondary windings to ground as shown in Figure 11-1.

The mechanism through which this electrical coupling of noise occurs is the capacitance between the coils of the primary and secondary windings of the transformer that does not include a Faraday shield. This same capacitance limits the upper frequency bandpass of the transformer in much the same manner as its low frequency cutoff is determined by the mutual and self inductances of the device. As the frequency of the exciting currents increases, the reactance caused by the capacitance between the windings, $1/j\omega C$, tends to shunt these currents, thereby limiting high frequency performance.

The single Faraday shield controls all manner of evils that could be attributed to the electric coupling of noise through a transformer. However, the problem with a single shield arises when it is bonded to the ground of either the primary or secondary side of the transformer. The inclusion of a Faraday shield between the primary and secondary windings eliminates inter-capacitance, but it also establishes two new capacitances between the shield and both windings. These two capacitances allow high frequency currents to flow in the grounding systems of both the primary and secondary. Bonding the transformer shield to either the primary or secondary ground establishes current paths for high frequency noise in the reference conductor of the circuit to be isolated. The particular choice of ground for connection of the shield only provides selection of the quieter of the primary and secondary circuits. In many applications, this current path defeats any isolating effects that a transformer might provide.

Isolation Transformers

An isolation transformer is designed to specifically address the problems associated with referencing its internal shields to ground. It is constructed with two isolated Faraday shields between the primary and secondary windings.

When properly installed, the shield that is closest to the primary winding is connected to the common power supply ground and the shield closest to the secondary winding is connected to the shield of the circuit to be isolated. The use of two shields in the construction of the isolation transformer diverts high frequency noise which would normally be coupled across the transformer to the grounds of the circuit in which they occur. The two shields provide more effective isolation of the primary and secondary circuits by also isolating their grounds. The isolation transformer adds a third capacitance between the two Faraday shields which may allow coupling of high frequency noise between the system grounds. However, this third capacitance is normally minimized by increasing the separation between the two Faraday shields. Additionally, the dielectric effect of the shields plus the increased

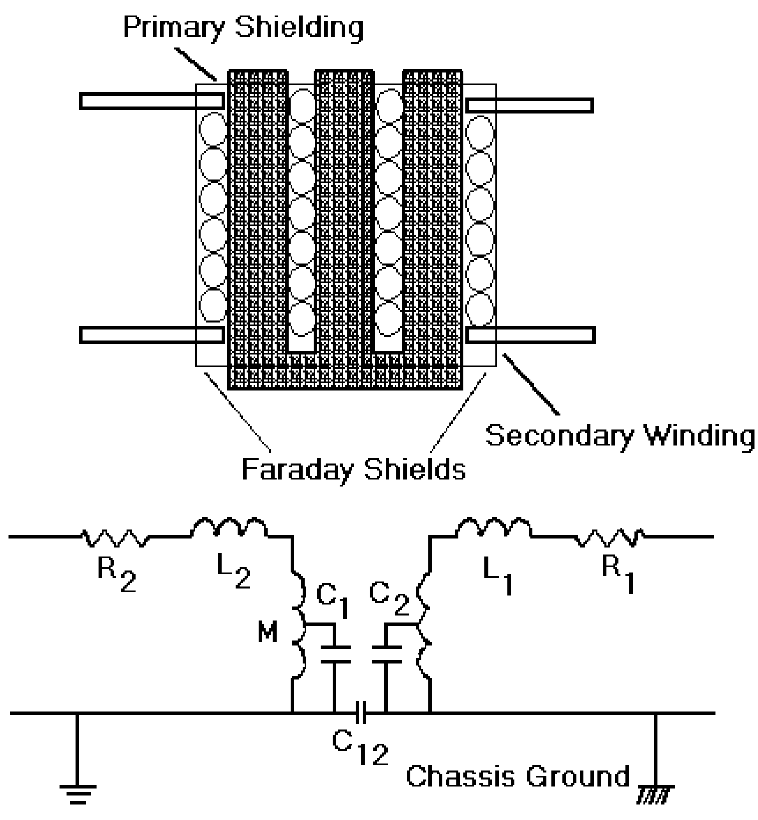

Figure 11-2 Isolation Transformer

separation of the two windings significantly reduce the inter-capacitance between the windings. An equivalent circuit for an isolation transformer is presented in Figure 11-2.

where:

R1 = Resistance in Primary Windings

R2 = Resistance in Secondary Windings

L1 = Primary Inductance Which Causes Leakage Flux

L2 = Secondary Inductance Which Causes Leakage Flux

M = Mutual Transformer Inductance

C1 = Capacitance Between Primary Windings and Primary Shield

C2 = Capacitance Between Secondary Windings and Secondary Shield

C12 = Capacitance Between Primary and Secondary Shields

Generally, a conductive foil completely enclosing the windings will provide a ground path for primary circuit noise, and has the advantage that a very much smaller capacitance exists between primary and secondary coils than in the case of a simple Faraday shield. The Faraday shield is simply a grounded single turn of conductive non-ferrous foil placed between coils to divert primary noise to ground. The enclosing shield, if grounded properly, will not re-radiate the noise signal, and will provide effective electromagnetic noise reduction. Typically, according to Topaz (1), at a distance of 18 inches from a transformer's geometric center, the field strength will be less than 0.1 gauss, and will roughly follow inverse cube laws.

Since inter-winding capacitances are the primary path by which significant powerline and transient related noise couples to the system, more information is needed to describe what occurs. During the time power is being transferred between transformer windings, noise potentials between the primary circuits and ground is similarly coupled to the secondary through both capacitive and resistive paths. This noise appears in three forms in a transformer circuit: common-mode, differential (transverse)-mode, and electromagnetic.

Common-Mode Noise

This noise appears between both sides of a power line and ground as shown in Figure 11-3. Since this noise is referenced to the power system ground, the most obvious method of eliminating this noise is by grounding the transformer center tap to the system ground via the lowest impedance path possible.

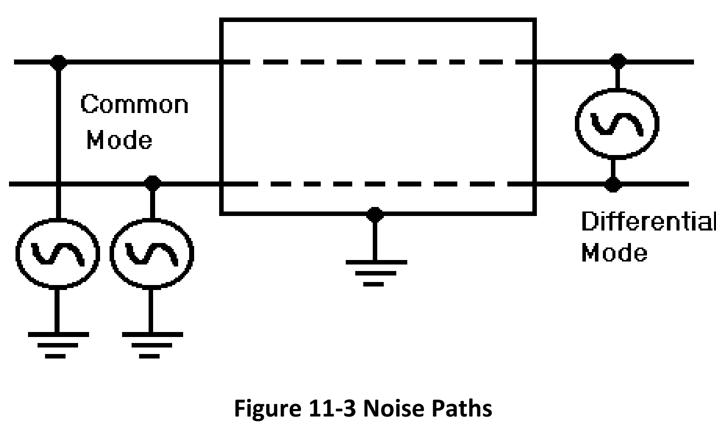

Figure 11-3 Noise Paths

Internal transformer designs that separate the coils to reduce capacitive coupling have some advantage, but they also increase leakage inductance and reduce the power transfer.

Differential (Transverse) Mode Noise

Differential-mode noise is much more difficult to eliminate than common-mode noise. The key to maximum noise reduction here, according to various sources[1,2,3], is to differentiate between power and noise, and then reduce only the noise.

Noise and power are separated by the difference in their frequencies. The most effective transformer for the purpose is designed to be exactly opposite to an audio transformer. The objective is to transfer the power required by the load at the fundamental power frequency, and to eliminate all higher and lower frequencies. Sub-harmonic frequencies are attenuated by operating the transformer at a relatively high flux density, which is effective in greatly reducing or eliminating these frequencies. Above the fundamental frequency, noise is reduced by introducing as much leakage inductance as possible, consistent with good power transfer to the secondary.

Differential-mode noise appears as a voltage across both the primary and secondary windings of an isolation transformer. It occurs when a common-mode signal causes current to flow in the primary winding (or secondary winding), and from there to ground via capacitance to a grounded shield. Common-mode noise can also be transformed into transverse-mode noise, and thereby, through magnetic coupling, contaminate the secondary of an isolation transformer. Normally, by proper selection of core loss verses primary winding inductance, well designed isolation transformers will eliminate the majority of this type of noise. Here again, grounding the transformer shield to the lowest impedance path available will result in noise currents using this return path rather than some other higher impedance path to the noise source ground.

Electromagnetic Generated Noise

Compared to common-mode and transverse-mode noise, electromagnetic noise does not constitute a major problem in most applications. Where it is sometimes critical is in recording or digital data systems, and in making electromagnetic interference measurements during equipment verification testing.

Box Level Applications

Because of the greater isolation achieved, isolation transformers are often used to protect high gain circuits, or prevent noise ground paths in instrumentation. Shielding at the instrument level is difficult and often ineffective. Since most commercial instrumentation has single shielding in its power transformer, designers sometimes hope that by adding a second or primary shield (an isolation transformer), system ground problems can be eliminated. This approach often results in

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[1] *Mathews, P., Protective Current Transformers and Circuits, The Macmillan Company, New York, 1955.*

[2] *Morrison, R., Grounding and Shielding Techniques in Instrumentation, John Wiley and Sons, New York, 1967.*

[3] *Gabrielson, B.C., Noise Suppression Using Isolation Transformers, Published and Presented at USAF TEMPEST Course, Aerospace Corporation, Los Angeles, 1984.*

no benefits to the system unless all other ground paths in the instrument can be totally isolated. An isolation transformer is not a substitute for the proper shielding or grounding of individual instruments. A typical transformer application at the box level is shown in Figure 11-4.

The amount of ground isolation provided by the transformer at the box level is limited by the use of a single chassis shield enclosing the box. High frequency noise currents generated by the box circuitry can be coupled onto the circuit reference conductors through the connection of both transformer's shields to the circuit reference. Additionally, any potential difference between the power system ground at the isolation transformer primary input and the power system ground at the isolation transformer primary input and the power system ground at the equipment and the power system ground at the equipment chassis will cause currents to flow in the reference conductor of the circuitry.

Rack Level Applications

The most effective application of isolation transformers is with racks of equipment. A rack acts as an outer shield for internal instruments. While serving as the zero-signal reference for system output signals. Isolation transformers are used to control shield currents, and to break up the mutual capacitances between rack instrumentation and an unknown power ground.

An isolation transformer application at the rack level is shown in Figure 11-5. The main benefit of using an isolation transformer with a rack of equipment is the enhanced control of currents in the equipment shields. Any potential differences between the utility power ground and the rack's ground will cause currents to flow in the loop 3-2-1-3 as indicated in the figure.

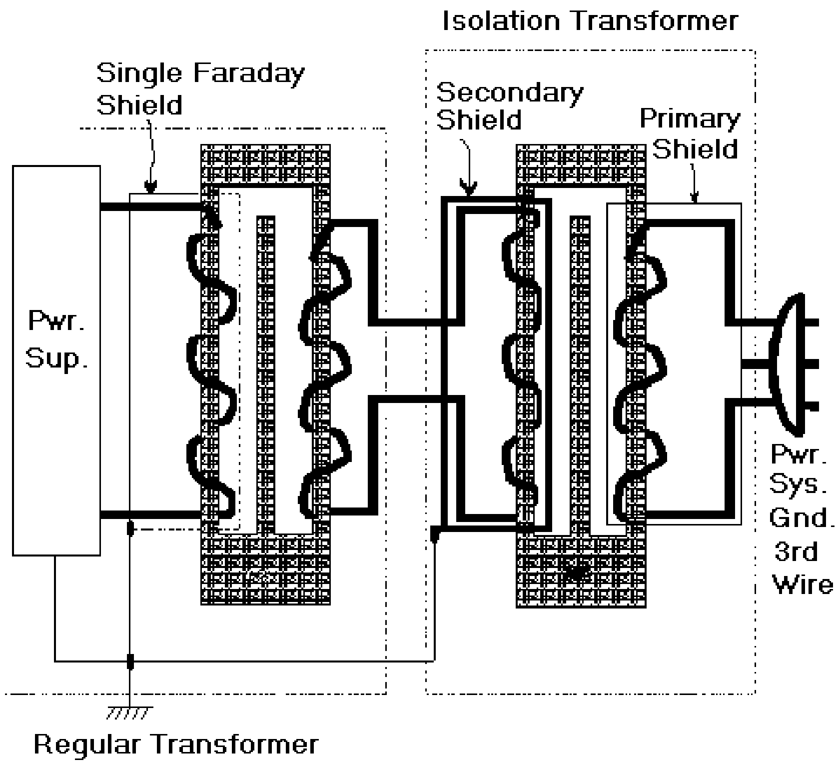

Figure 11-4 Box Level Application of Isolation Transformer

The isolation transformer allows these "ground" currents to be directed through a portion of the rack's shielding which will not effect the operation of sensitive circuits and completely isolates these currents from the internal equipment reference conductors.

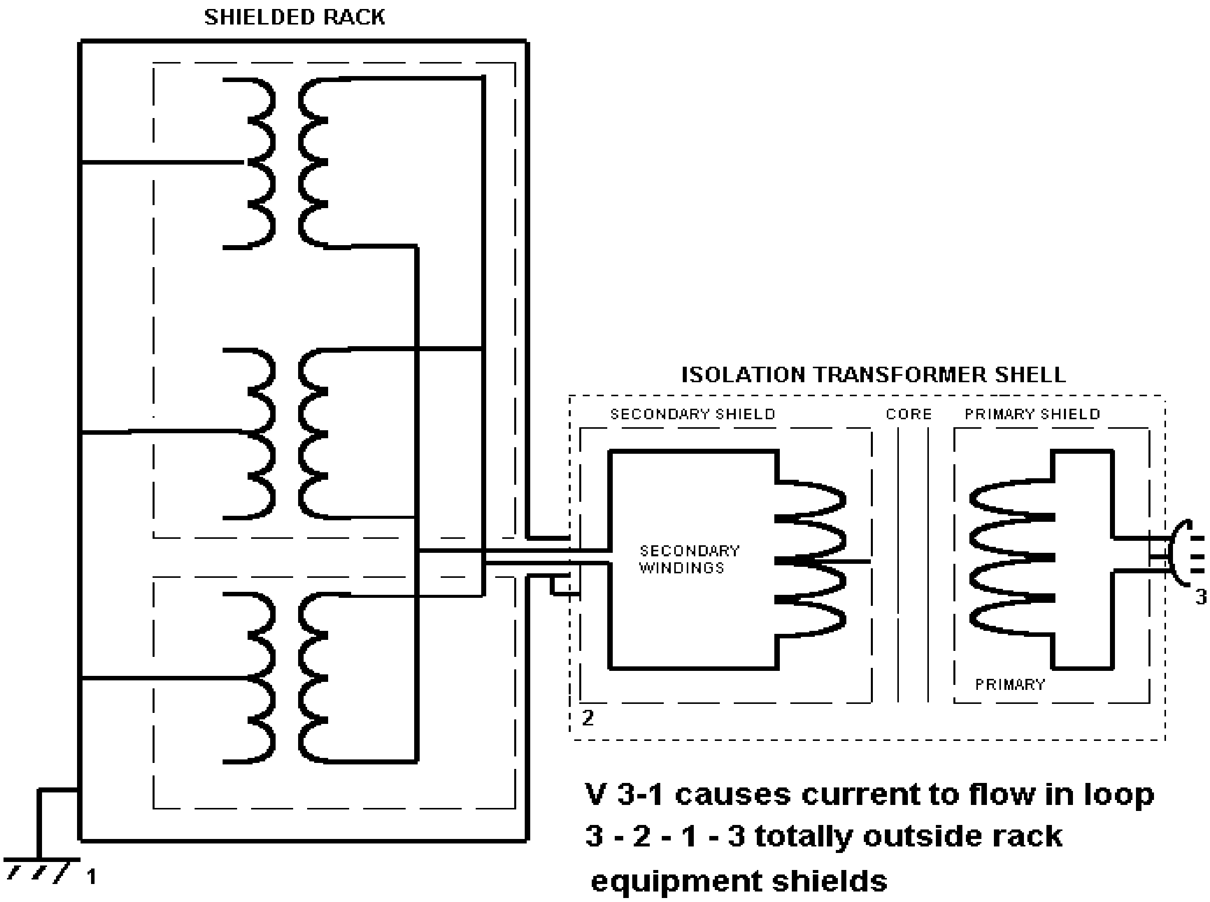

Figure 11-5 Rack Level Application of Isolation Transformer

Room Level Applications

It is often necessary to isolate test enclosures or secure facilities from noisy or potentially compromising building grounds. Not only can isolation transformers be used to effectively decouple building power, but since they also act as tuned circuits, they reduce the differential noise generated by externally or internally located equipment. While it is recognized a second isolation transformer located inside the test room will greatly reduce powerline ambient noise, this chapter will only consider using transformers on the power lines to a typical shielded test enclosure or shielded secure area.

As with any transformer, isolation transformers radiate magnetic fields. Physically locating the transformer adjacent to, or connected to a shielded enclosure may increase rather than decrease ambient noise. Since the metal case of a transformer, as well as the primary winding shield, are normally connected to the third-wire power safety ground of the supplied power connector, the secondary winding shield must be isolated from the transformer case and connected only to the conduit shield going to the shielded room to achieve proper ground isolation. The conduit acts as an RF shield for the room's power, and completes the connection between the shielded room and the secondary winding shield in the transformer.

If the transformer is three phase and supplies more than one room, the best application for isolation between rooms is to use only one phase for each room, with a limit of three rooms per transformer. With this approach, power line filters will effectively isolate the room while providing practical noise attenuation. The application of an isolation transformer at the shielded room level is shown in Figure 11-6.

Conclusions

Proper transformer design, wiring, and above all, grounding, are the only effective means of reducing the three types of noise problems. Grounding is controlled using the lowest impedance path possible (i.e. bonding) to the central reference ground system to insure maximum attenuation of noise sources. To achieve the maximum protection from an isolation transformer, the main concerns are no extra grounds and physical isolation.

References

1. Topaz Electronics, Noise Suppression Reference Manual, San Diego, CA, 1980.

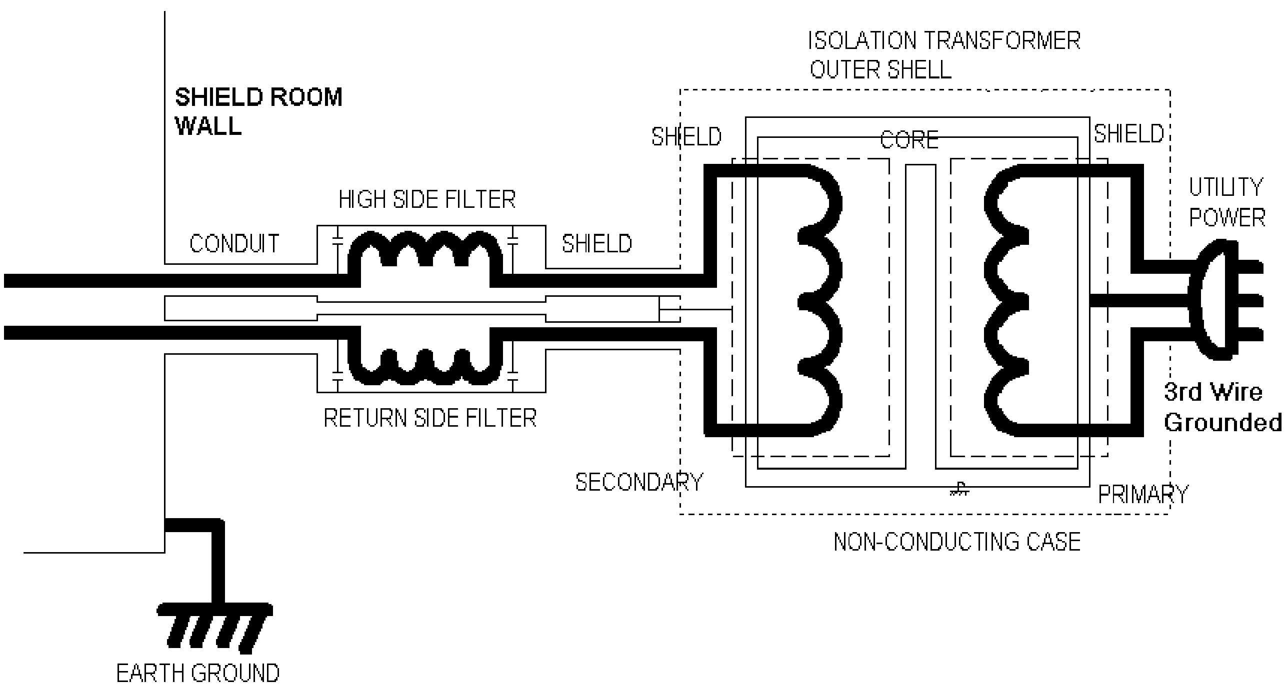

Figure 11-6 Shielded Room Application of an Isolation Transformer