

NOISE REDUCTION TECHNIQUES IN ELECTRONIC SYSTEMS

SECOND EDITION

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WILEY

A WILEY-INTERSCIENCE PUBLICATION

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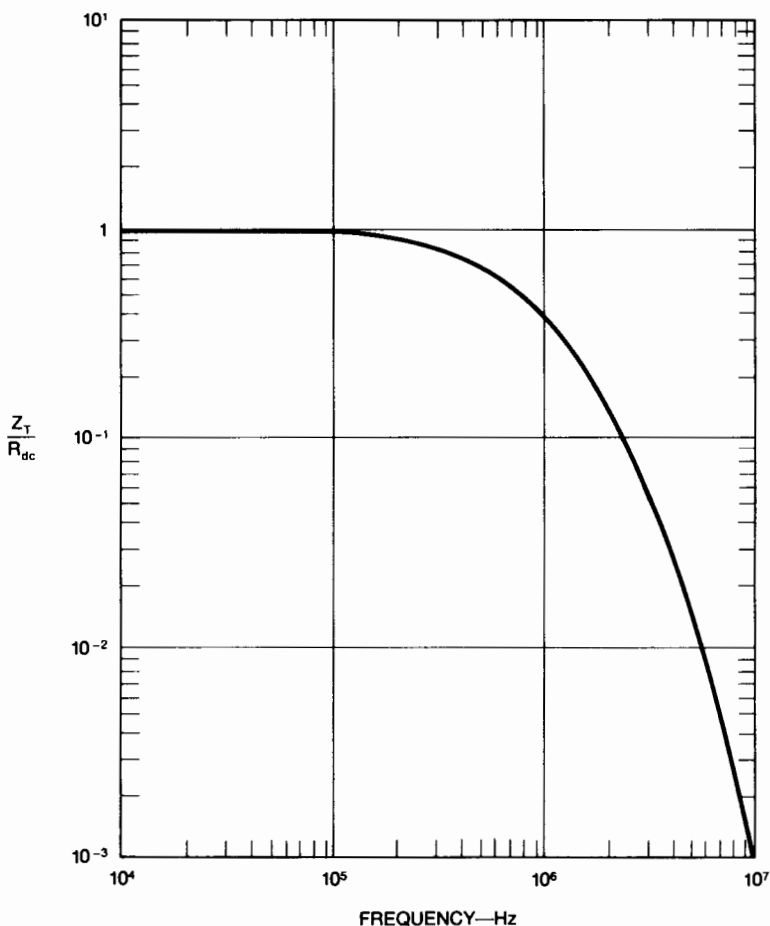


Figure 2-26. Magnitude of normalized transfer impedance for a solid shield.

EXPERIMENTAL DATA

The magnetic field shielding properties of various cable configurations were measured and compared. The test setup is shown in Fig. 2-27, and the test results are tabulated in Figs. 2-28 and 2-29. The frequency (50 kHz) is greater than five times the shield cutoff frequency for all the cables tested. The cables shown in Figs. 2-28 and 2-29 represent tests cables shown as *L2* in Fig. 2-27.

In circuits *A* through *F* (Fig. 2-28), both ends of the circuit are grounded. They provide much less magnetic field attenuation than do circuits *G* through *K* (Fig. 2-29), where only one end is grounded.

Circuit *A* in Fig. 2-28 provides essentially no magnetic field shielding. The

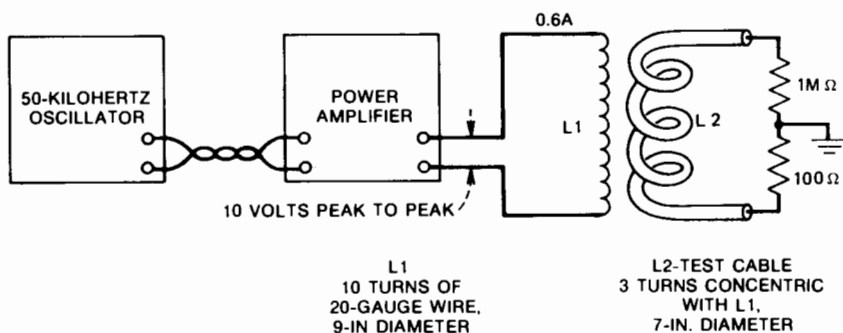


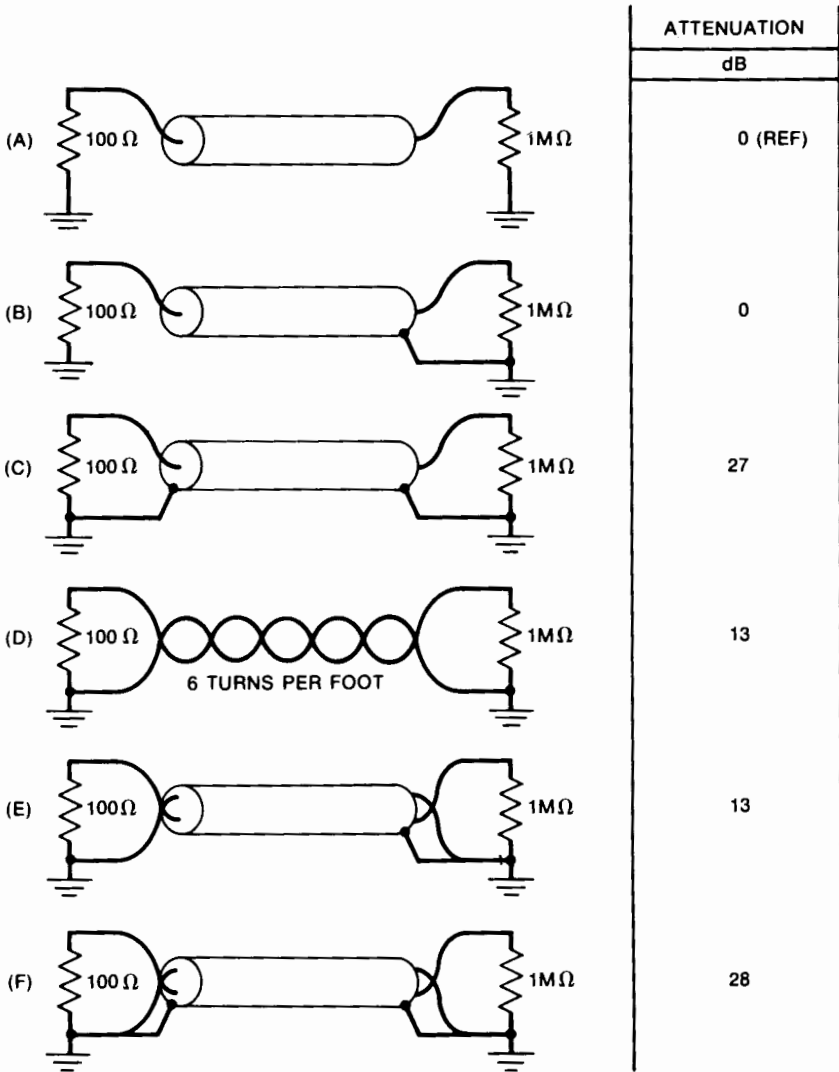
Figure 2-27. Test setup of inductive coupling experiment.

actual noise voltage measured across the one megohm resistor in this case was 0.8 V. The pickup in configuration *A* is used as a reference and is called 0 dB, to compare the performance of all the other circuits. In circuit *B*, the shield is grounded at one end; this has no effect on the magnetic shielding. Grounding the shield at both ends as in configuration *C* provides some magnetic field protection because the frequency is above the shield cutoff frequency. The protection would be even greater if it were not for the ground loop formed by grounding both ends of the circuit. The magnetic field induces a large noise current into the low-impedance ground loop consisting of the cable shield and the two ground points. The shield noise current then produces a noise voltage in the shield, as was shown in the preceding section.

Use of a twisted pair as in circuit *D* should provide much greater magnetic field noise reduction, but its effect is defeated by the ground loop formed by circuit grounds at both ends. This can clearly be seen by comparing the attenuation of circuit *H* to that of circuit *D*. Adding a shield with one end grounded, to the twisted pair as in *E* has no effect. Grounding the shield at both ends as in *F* provides additional protection, since the low-impedance shield shunts some of the magnetically induced ground-loop current away from the signal conductors. In general, however, none of the circuit configurations in Fig. 2-28 provide good magnetic field protection because of the ground loops. If the circuit must be grounded at both ends, configurations *C* or *F* should be used.

Circuit *G* shows a significant improvement in magnetic field shielding. This is due to the very small loop area formed by the coaxial cable and the fact that there is no ground loop to defeat the shielding. The coax provides a very small loop area since the shield can be represented by an equivalent conductor located on its center axis. This effectively locates the shield at or very near the axis of the center conductor.

It was expected that the twisted pair of circuit *H* would provide considerably more shielding than the 55 dB shown. The reduced shielding is due to



FREQUENCY = 50 KILOHERTZ FOR ALL TESTS

Figure 2-28. Results of inductive coupling experiment; all circuits grounded at both ends.

the fact that some electric field coupling is now beginning to show up. This can be seen in circuit I, where attenuation increases to 70 dB by placing a shield around the twisted pair. The fact that attenuation in circuit G is better than in I indicates that in this case the particular coaxial cable presents a smaller loop area to the magnetic field than does the twisted pair. This, however, is not necessarily true in general. Increasing the number of turns

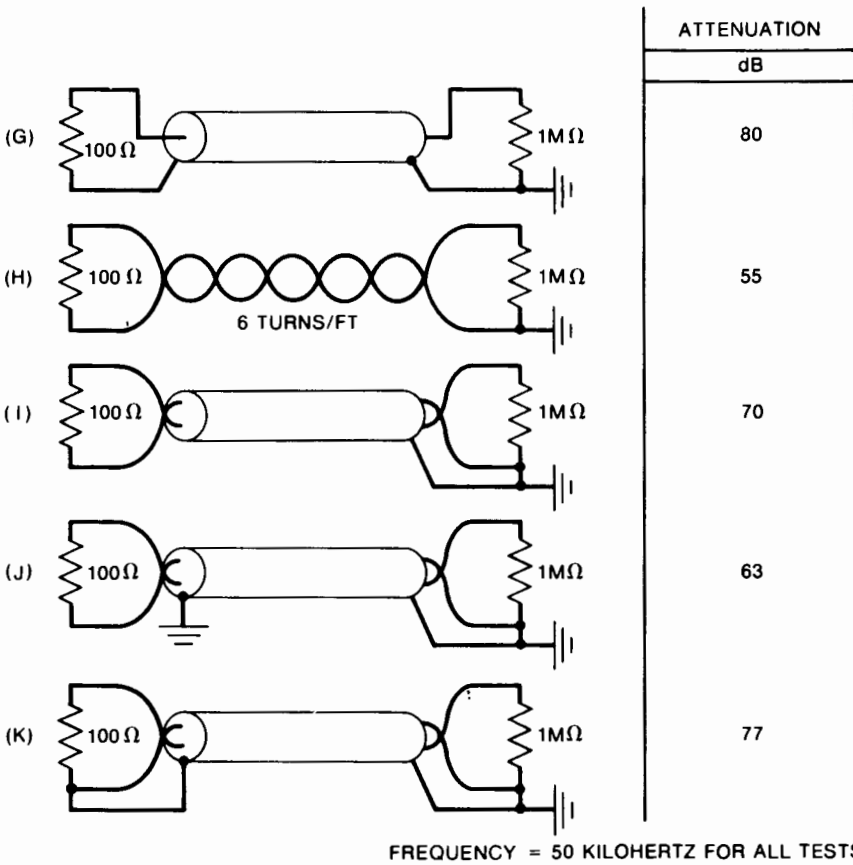


Figure 2-29. Results of inductive coupling experiment; all circuits grounded at one end only.

per foot for either of the twisted pairs (*H* or *I*) would reduce the pickup. In general, circuit *I* is preferred to circuit *G* for low-frequency magnetic shielding since in *I* the shield is not also one of the signal conductors.

Grounding both ends of the shield as in circuit *J* decreases the shielding slightly. This is due to the high shield current in the ground loop formed by the shield inducing unequal voltages in the two center conductors. Circuit *K* provides more shielding than *I* since it combines the features of the coax *G* with those of the twisted pair *I*. Circuit *K* is not normally desirable since any noise voltages or currents that do get on the shield can flow down the signal conductor. It is almost always better to connect the shield and signal conductors together at just one point. That point should be such that noise current from the shield does not have to flow down the signal conductor to get to ground.

flow through the lower-impedance shield, rather than the center conductor. In the case of circuit *E* the shielded twisted pair is also grounded at both ends to shunt some of the ground-loop current from the signal conductors. If additional noise immunity is required, the ground loop must be broken. This can be done by using transformers, optical couplers, or a differential amplifier.

An indication of the type of performance to be expected from the configurations shown in Fig. 3-21 can be obtained by referring to the results of the magnetic coupling experiment presented in Figs. 2-28 and 2-29.

GROUND LOOPS

Ground loops at times can be a source of noise. This is especially true when the multiple ground points are separated by a large distance and are connected to the ac power ground, or when low-level analog circuits are used. In these cases it is necessary to provide some form of discrimination or isolation against the ground-path noise.

Figure 3-22 shows a system grounded at two different points with a potential difference between the grounds. As shown in the figure, this can cause an unwanted noise voltage in the circuit. The magnitude of the noise voltage compared to the signal level in the circuit is important: if the signal-to-noise ratio is such that circuit operation is affected, steps must be taken to remedy the situation. Two things can be done, as shown in Fig. 3-22. First, the ground loop can be avoided by removing one of the grounds, thus converting the system to a single-point ground. Second, the effect of the multiple ground can be eliminated or at least minimized by isolating the two circuits. Isolation can be achieved by (1) transformers, (2) common-mode chokes, (3) optical couplers, (4) balanced circuitry, or (5) frequency selective grounding (hybrid grounds).

Figure 3-23 shows two circuits isolated with a transformer. The ground noise voltage now appears between the transformer windings and not at the input to the circuit. The noise coupling is primarily a function of the parasitic capacitance between the transformer windings, as discussed in the

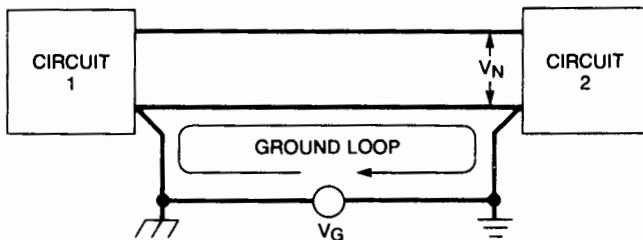


Figure 3-22. A ground loop between two circuits.

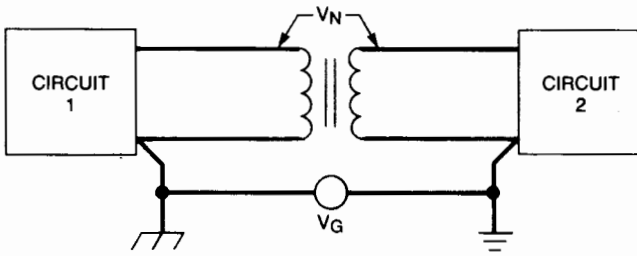


Figure 3-23. A ground loop between two circuits can be broken by inserting a transformer.

section on transformers in Chapter 5, and can be reduced by placing a shield between the windings. Although transformers can give excellent results, they do have disadvantages. They are large, have limited frequency response, provide no dc continuity, and are costly. In addition, if multiple signals are connected between the circuits, multiple transformers are required.

In Fig. 3-24 the two circuits are isolated with a transformer connected as a common-mode choke that will transmit dc and differential-mode signals while rejecting common-mode ac signals. The common-mode noise voltage now appears across the windings of the choke and not at the input to the circuit. Since the common-mode choke has no effect on the differential signals being transmitted, multiple signal leads can be wound on the same core without crosstalk. The operation of the common-mode choke is described in the next section.

Optical coupling (optical isolators or fiber optics), as shown in Fig. 3-25, is a very effective method of eliminating common-mode noise since it completely breaks the metallic path between the two grounds. It is most useful when there are very large differences in voltage between the two grounds, even thousands of volts. The undesired common-mode noise voltage appears across the optical coupler and not across the input to the circuit.

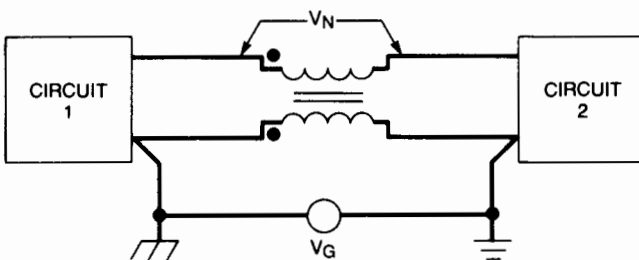


Figure 3-24. A ground loop between two circuits can be broken by inserting a common-mode choke.

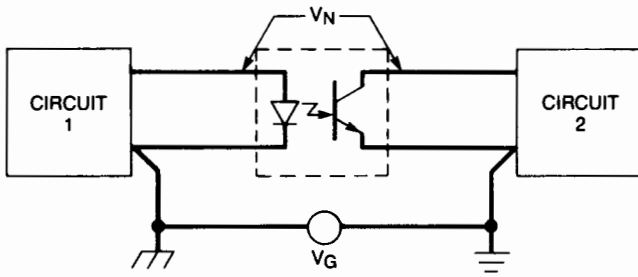


Figure 3-25. An optical coupler can be used to break the ground loop between two circuits.

Optical couplers are especially useful in digital circuits. They are less suitable for analog circuits because linearity through the coupler is not always satisfactory. Analog circuits have been designed, however, using optical feedback techniques to compensate for the inherent nonlinearity of the coupler (Waaben, 1975).

Balanced circuits, as shown in Fig. 3-26, provide another way to discriminate against common-mode ground noise voltages. In this case the common-mode voltages induce equal currents in both halves of the balanced circuit, and the balanced receiver responds only to the difference between the two inputs. The better the balance, the larger is the amount of common-mode rejection. As frequency increases, it becomes more and more difficult to achieve a high degree of balance. Balancing is discussed further in Chapter 4.

When the common-mode noise voltages are at a frequency different from the desired signal, frequency-selective (hybrid) grounding can be used.

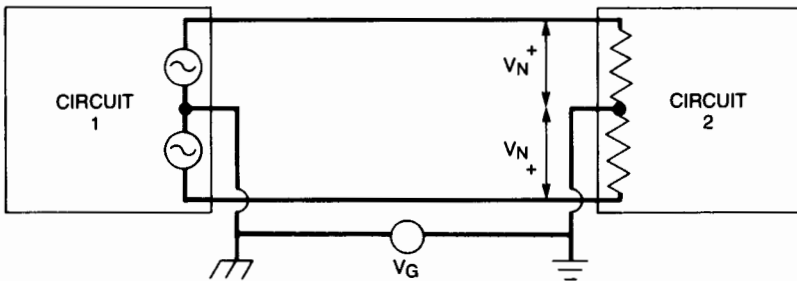


Figure 3-26. A balanced circuit can be used to cancel out the effect of a ground loop between two circuits.