The Lenkurt® Demodulator

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SHIELDING and GROUNDING

A trend in modern communications toward greater circuit density and higher operating frequencies has increased the possibility of interference or crosstalk between adjacent wires or cables — even when they are shielded. Many long-established shielding and grounding practices may not be fully adequate with sensitive, modern equipment. Strong sources of interference such as nearby radio transmitters, can severely test shielding effectiveness. This article reviews basic shielding and grounding methods for reducing interference.

In electrical communication, virtually any type of disturbance which impairs communication by obscuring the signal has come to be termed "noise," a very broad term which now includes hum, crosstalk, spurious signals, and of course, thermal noise. Any of these tend to limit the quality and permissible length of a communications circuit.

One of the important ways of reducing some of this noise is to intercept the interference energy with shielding, and carry it away by grounding the shield. When properly done, this technique is very effective. However, many standard practices established long ago to cope with the interference problems of that time have not changed significantly with time. As a result, some shielding may be inadequate, others may be greatly "over-engineered" — using extremely costly materials, when a simpler approach might do better.

In a conventional telephone system, speech or carrier signals are carried on a "balanced" transmission line consisting of two conductors. Signals are transmitted as a current which travels down one conductor, returning on the other, thus forming a *transverse* or "metallic" circuit. Both conductors are at the same electrical potential above ground (hence the term "balanced"). A second type, the "unbalanced" transmission line, normally uses a single conductor to carry the signal, with ground providing the return path. "Ground" may take the form of another conductor which is grounded, or common to several circuits. All early telegraph and telephone lines were of the unbalanced type, since only half as much wire was required. Because the unbalanced line is very vulnerable to interference, however, its use has been generally limited to coaxial circuits.

A balanced line is basically free of external interference. Signal currents travel in opposite directions on the two conductors as they complete the loop. Ideally, interference acts equally on the two conductors, inducing equal voltages which travel in the *same* direction on the two wires and thus oppose and cancel each other.

Although externally induced voltages tend to cancel their flow around the transverse circuit, they do seek a return path through ground, thus forming a so-called *longitudinal* circuit, as shown in Figure 1. If the interfering voltages induced in the two parallel conductors are unequal, perhaps because of circuit imbalance, or because the source of the disturbance is closer to one conductor than the other, a net transverse current may result, thus introducing interference into the circuit. Most interference enters a circuit in this way.

Sources of Interference

When a current flows through a conductor, it sets up two distinct fields around the conductor, the electrostatic or "electric" field, and the magnetic field. Both are capable of inducing longitudinal voltages in adjacent conductors, and both increase in proportion to the power and frequency of the current from which they result. They differ greatly, however, in how they affect nearby circuits.

The voltage resulting from magnetic induction varies inversely with the impedance of the line. That is, the higher the line impedance, the less voltage that can be induced by a magnetic field. Line impedance is usually determined by the reactance of the line itself and the nature of the terminating equipment. The voltage induced by the electric field, however, increases in direct proportion to line impedance. Thus, the higher the impedance, the greater the electric or capacitive pickup, and the lower the magnetic or inductive coupling. Figure 2 shows equivalent circuits for both types of coupling. Note that magnetic coupling is equivalent to being in series with the line, thus requiring a low impedance to be effective. Electric coupling is capacitive and requires a very high impedance in order to develop maximum potential.

Another source of interference is radio transmission which occurs in the same frequency ranges used for carrier transmission. Certain naval transmitters operate at very low frequencies which happen to coincide with some open-wire carrier channels. LORAN navigational transmissions may cause similar problems. This type of interference is

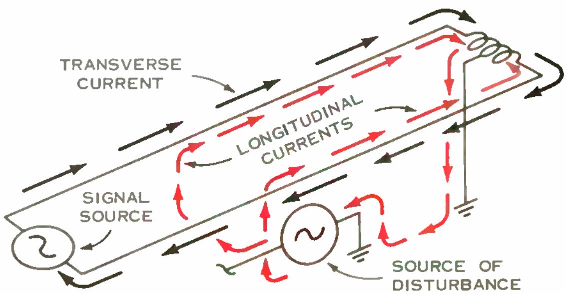

Figure 1. In a perfectly balanced line, longitudinal currents (red) cancel out in transverse circuit, but seek a ground return. Any imbalance converts some longitudinal current to transverse, producing interference.

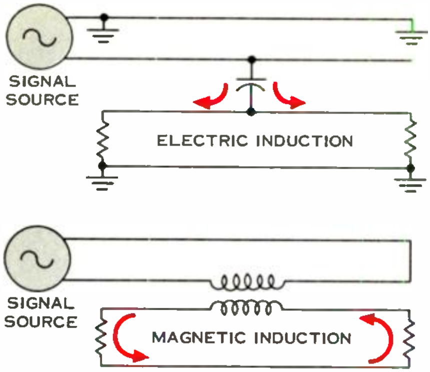

Figure 2. Comparison of electromagnetic ("magnetic") and electrostatic ("electric") coupling. Magnetic coupling is effectively "in series" with line, thus is suppressed by high impedance. Electric coupling is essentially capacitive, is reduced by low impedance line.

difficult to cope with, since measures designed to block reception of the radio transmission may interfere with the carrier signal. If this kind of interference is encountered in the central office, it may be possible to reduce it by shielding. If the interference is picked up on open wire lines, however, it may only be possible to reduce it, then only by careful balancing or special shielding techniques.

Shielding Techniques

If it were possible to keep all telephone circuits perfectly balanced with respect to ground, most interference would be eliminated. Unfortunately, a perfectly balanced circuit is all but impossible to obtain, except under laboratory conditions, and impracticable to maintain.

The most effective method of eliminating unwanted coupling is to isolate the disturbed circuit from the source of interference by some form of shielding. In principle, either the disturbing circuit, the disturbed circuit, or both, are surrounded by a metallic covering which intercepts the interfering fields and provides an alternate path for the longitudinal currents which are induced.

The nature of the shielding varies greatly, depending on the nature of the interference, its strength, and frequency. A good shield against electric fields may be ineffective against a magnetic field. Essentially, some sort of magnetic material such as iron or steel is required to block interference due to magnetic fields. Electric fields are best shielded by excellent conductors such as aluminum or copper.

At the lower (audio) frequencies, magnetic coupling can be minimized by enclosing the conductors in a braid or tape covering of steel, which tends to absorb magnetic fields. Electric coupling is usually negligible at these frequencies, so that magnetic shielding is usually all that is needed.

At higher (carrier) frequencies, braid, tape, or solid sheathing of copper, aluminum, or lead is somewhat effective against magnetic fields, due to induced eddy currents within the shield which oppose and partially neutralize the fields that produce them. The effectiveness of these materials against electric fields increases with frequency and with their conductivity and thickness. As frequency rises, the electric coupling remains much less than the magnetic coupling across the whole frequency range.

Another class of shielding uses a covering of steel wool, or a paper or fabric impregnated with carbon or some powdered metallic substance, which converts radio or other electromagnetic radiation into heat, and effectively dissipates these interfering fields. This form of shielding is particularly effective against high-powered, high-frequency radio interference, which may be capable of filtering through the gaps on braided or overlapped shielding materials. In this respect, a laminated shield of two different materials is a far more effective shield than a solid shield of the same thickness made of only one material, due to reflective losses introduced at each interface. At 1 mc, a double braid of copper provides about 25 db better shielding than single braid, and a triple braid is 30 db better than the double. Coaxial cable with conventional copper braiding encased in a steel braid, and in turn encased in an outer copper braid provides a very effective shield for coaxial circuits from 10 kc up to several megacycles.

Although these generalities concerning shielding materials can be helpful, it is necessary to identify the exact nature of the interference in order to achieve maximum shielding effectiveness. Since magnetic and electric coupling cause different effects, shielding will have to be tailored to the type of interference encountered in the specific application.

By means of a simple test, it is possible to identify the nature of the coupling between two lines, as shown in Figure 3. A variable-frequency oscillator is connected to one circuit, and a sensitive voltmeter is connected to the other to measure the induced voltage. The oscillator is adjusted to a normal operating frequency and the far ends of both lines are short-circuited. Since voltages induced by magnetic coupling are *inversely* proportional to the line impedance, the low line impedance caused by the short circuit will result in a much reduced voltage if the principal coupling is electric. Conversely, if the principal fields are electromagnetic, the induced voltage will increase. The test should be repeated with the far ends of both lines open. The induced voltage will be the result of electric (or capacitive) coupling. Once the type of field has been identified, the most appropriate method shielding can be specified.

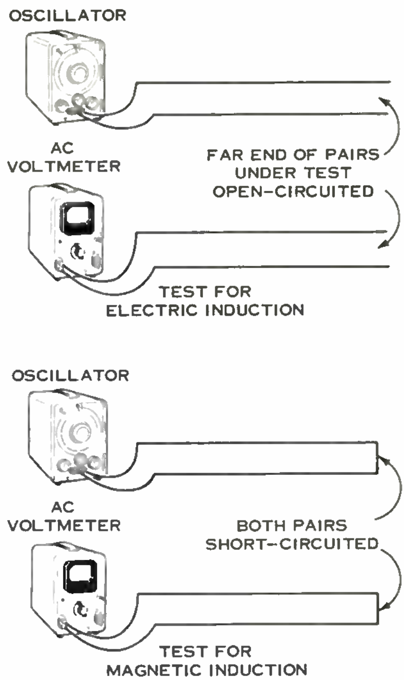

Figure 3. Type of coupling can be identified by simple tests. By opening or short-circuiting pairs at far end, relative degree of magnetic and electric coupling can be determined.

Very often, a change in line impedance can reduce interference (since coupling is frequency sensitive). Thus, if the impedance of a line is doubled, any voltage resulting from magnetic induction will be halved (at the same time, the voltage due to electrostatic coupling is doubled). If both fields are of equal strength, a change of impedance will have no effect, since the voltage increase from one source is cancelled by the decrease from the second source.

Unbalanced Circuits

Unbalanced circuits present special shielding problems, since the shielding serves as the return path for the signal, and thus helps carry the signal. Even though part of the signal return may travel through other ground paths, a portion of it will travel through the shield, where it may be subject to interference caused by induced longitudinal voltages.

When coaxial cables are grounded at both ends, a longitudinal path or "ground loop" may be established which makes the cable vulnerable to interference from external magnetic fields. Even though the inner conductor may be shielded from the external field, longitudinal currents induced into the shield are, in effect, "in series" with the signal current flow through the shield, thus directly affecting the signal. Note that the low impedance of the ground loop restricts its effect to magnetic pickup. Interference primarily consists of lower frequencies, such as a-c hum from power mains, transformers, and other low frequency inductive components.

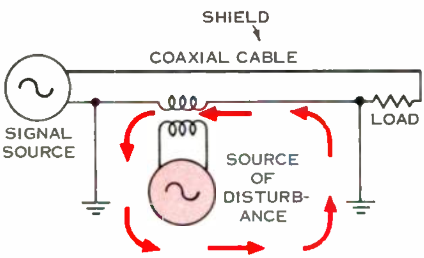

Figure 4. When coaxial cable used in unbalanced circuit is grounded at both ends, ground loop may introduce interference despite quality of shielding. Longitudinal currents induced magnetically share outer conductor with signal return.

In a run consisting of two or more coaxial cables, the possibilities of intercable coupling are great, simply because all shields are normally grounded at each end of the cable, and the shield of one cable could quite easily become the return path for the inner conductor of its neighbor, at least for some part of its full length. This can be reduced by enclosing the coaxial cable in heavy copper tubing or braiding, which serves as a ground return path for neighboring coaxial circuits.

Grounding

The objective of any grounding technique is to provide a path to earth of as low a resistance or impedance as possible. This is because the flow of current causes a voltage drop that is directly proportional to the resistance of the path to ground. Any resistance results in an unwanted difference of potential, the source of coupling to other circuits.

In a telecommunications system, it is necessary to provide a good ground for a wide variety of currents that may range from dc to very high radio frequencies. This is not easy to accomplish, since a low-resistance path for direct current is not necessarily a low-resistance path at radio frequencies. For example, the d-c resistance of any conductor is inversely proportional to its cross-sectional area, and directly proportional to its length. However, because of the self-inductance of the conductor, alternating currents tend to concentrate near the surface of the wire, rather than flowing uniformly through the whole conductor as in dc. This effect, diagrammed in Figure 5, which is called the "skin effect," increases as frequency and wire size become greater.

As a result, a typical solid copper conductor of 24 gauge shows a resistance of approximately 26 ohms per 1000 feet to direct current, and 37 ohms per 1000 feet at 500 kc. At 10 mc, the same wire shows a resistance of 170 ohms per 1000 feet.

Since any resistance to a flow of current creates a difference of potential, and a standing difference of potential contributes noise to the communications circuit, it is advantageous to provide the greatest possible conducting surface for any ground path. Thus, for direct current, a solid copper ground conductor is chosen which has a total current-carrying capacity substantially higher than the sum of all internal currents that share this ground. For alternating current, stranded conductors are preferred, since the perimeter of each strand provides a separate path for high-frequency currents, resulting in a much greater surface, or "skin" area for the whole conductor, and hence less resistance.

Since we must accept the fact that every ground path has some resistance or impedance, no matter how small, it is apparent that as more paths are added, the total resistance to ground can be reduced by adding parallel paths. Two basic grounding techniques may be used in achieving a physical ground. One technique, known as the single-point or common ground, uses a single driven ground rod, or some similar buried electrode, to which each ground wire is connected. The second approach, known as a distributed ground, employs a very heavy grounded buss, to which individual ground circuits are connected.

The same techniques also apply to grounding within electronic equipment. Several conductors requiring a ground connection can be joined at a single grounded "tie point," or can be connected at intervals along the chassis or a ground buss. In any multiple grounding procedure, however, it is extremely important to maintain all ground paths as near to one resistance as possible in order to maintain a fairly constant difference of potential. Should one path have a substantially larger difference of potential, there is additional danger of creating a ground loop.

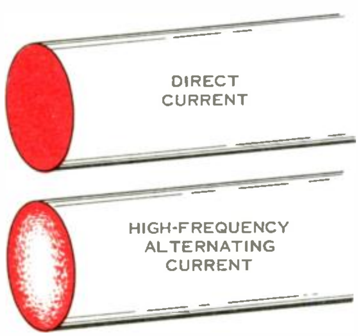

Figure 5. Increasing inductance of conductor at high frequencies forces electrons to flow near surface where flux density is less. This "skin effect" reduces available conduction path, increases a-c resistance.

Good Practice

The first requirement for a new installation (or for "quieting" an existing one) is to provide a well-bonded, low-impedance ground plane, which can normally be accomplished by electrically bonding all metal structures such as equipment racks, overhead rack supports, cable troughs, chassis, and equipment cabinets. The overall ground plane can usually be improved by spot-welding metallic structures at all joining surfaces. If at all possible, the ambient RF noise level within the building should be evaluated, and an attempt made to reduce it. In this respect, many items of test equipment often found in communications facilities are particu-

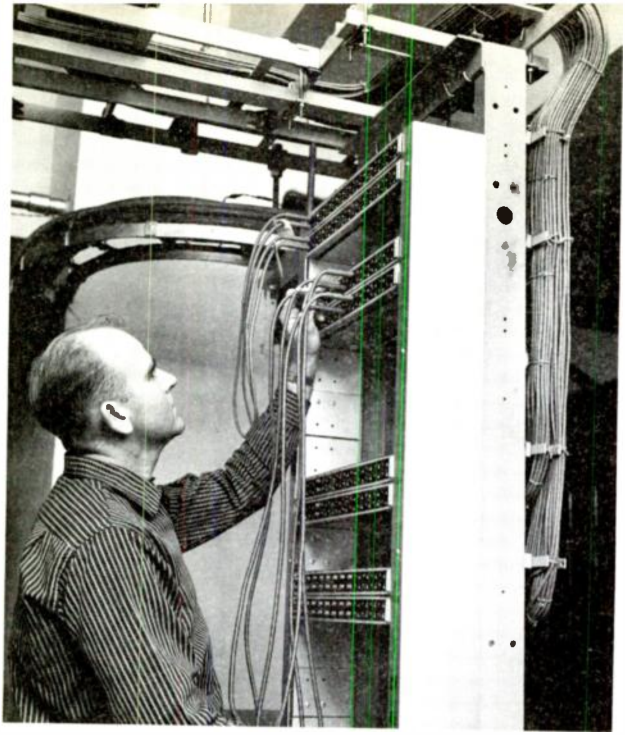

Figure 6. Typical HF or carrier frequency patch panel in telephone toll office. Shielded twisted pair is used to minimize coupling between adjacent circuits.

larly guilty of generating radio interference — among these are counters, oscillators, digital recorders, and similar instruments.

Finally, the appropriate coaxial cable or shielded wire should be selected for the prevailing signal frequencies and powers. The wide variety of shielded conductors available today makes it possible to achieve adequate isolation on either balanced or unbalanced transmission lines under most circumstances. However, at typical "HF" or carrier baseband frequencies, *shielded twisted pair* will usually prove superior to coaxial cable, particularly when the load must be isolated from ground. The improved balance obtained by the transposition or twisting of the conductors, plus the final protection of the outside shield, provides superior isolation. Thus, ground loops and RF pickup in areas of high signal level, can be controlled. In addition, there are certain applications where the frequency response limitations of transformers deny the use of a balanced line, and it is necessary to resort to unbalanced circuits. However, in many cases, the final selection may depend on the input or output configuration of the terminating equipment, and require some experimentation with the nature and location of the grounding. ●

Bibliography

1. F. H. Gooding & H. B. Slade, "Shielding of Communication Cables," *Communications and Electronics*; July, 1955.
2. O. K. Coleman, "Why Ground?," *Electrical Engineering*; May, 1956.
3. I. H. Pollack, "Skin Effect Resistance Data," *Electrical Design News*; December, 1956.
4. I. M. Newman and A. L. Albin, "An Integrated Approach to Bonding, Grounding, and Cable Selection," *Seventh Conference on Radio Interference Reduction and Compatibility*, IRE; November, 1961.

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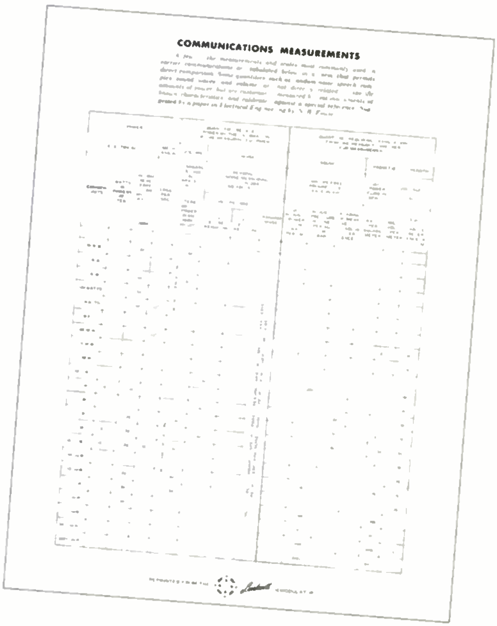
Free Reference Chart

A chart comparing many of the physical units used in communications engineering is now available. Some of the quantities that are compared include electrical power, radio field strength, sound, and telephone noise.

Originally published in the August, 1959 DEMODULATOR, the chart has been enlarged to notebook size for easy reference. Copies are available free on request to the Editor.



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