WIRING AND CABLING OF ELECTRONIC SYSTEMS

Many systems engineers have difficulty in determining the best methods of cabling, interconnection, and signal routing with the minimum of loss, degradation, and noise pickup. Often, simple solutions such as selecting the correct cable, eliminating common mode grounds or space separating long runs of parallel cables will make the difference between a good or bad system.

As an introduction, the systems engineer should study the system parameters and noise environment before selecting his interface components. Consideration must be given to signal frequencies, voltage and power levels, tolerable losses or degradation, and pickup of noise from direct contact common mode and ground loop returns, or radiated stray magnetic and capacitive fields.

Due to the susceptibility of circuit wiring and cabling to the pickup of noise, all low voltage level wiring should be shielded regardless of frequency to be transmitted. Coax cable, although primarily designed to carry RF, is excellent to use as low frequency shielded wire since it is relatively inexpensive and readily available.

For higher frequencies, coax cable must be used for point-to-point wiring, since it has the transmission characteristics, flexibility and economy necessary for most systems.

More sophisticated cables and connectors of twinax, triax and quadrax are also available to improve external noise rejection, or to contain classified signals and keep them from becoming a security compromise.

To successfully complete any signal transmission system, the engineer must move the various signals from place to place with (1) minimum signal degradation and loss, (2) reduce unwanted external noise to an acceptable level, or a mix of 1 and 2.

SIGNAL DEGRADATION

Signal degradation in any transmission medium usually consists of voltage amplitude reductions, wave shape changes, phase or delay changes, or power losses where power is transmitted. Since the interconnecting cable is the longest transmission path in most systems, its selection, manufacture, testing and installation should be carefully considered. When selecting cable from specifications, the length of the cable run, and heat exposure should be considered, as well as the frequency and power to be transmitted vs. the acceptable losses inherent in the cable, the external noise fields and the frequencies to be anticipated or encountered. Too small a cable will always be cause for excessive losses. Fast rise time digital pulses will have the leading edge distorted due to the high resistance "skin" effect of small coax cables. When selecting a cable for a long run, the insertion loss should be observed to assure that the signal gets to its destination without too much loss. Incomplete copper coverage in the outer braid over the dielectric will also cause transmission line losses as well as cable susceptibility to signal leakage or noise pickup. Unseen manufacturing faults produce signal path impedance changes or discontinuities which can only be detected by "frequency sweeping" the cable. In system design, cables should not physically support equipment, be subject to prolonged heat exposure, or be tightly bundled.

Coax Cable Connectors. Any connector must be able to interconnect with very low dc series resistance, something less than 10 milliohms. The impedence of a connector is usually of no consequence below approximately 30 MHz since the connector does not contribute to circuit performance until its length approaches 1/20th of a wave-length. For this reason, 50 Ω connectors can be attached to 75 Ω video cables with no detrimental effect. Above 300 MHz, coax connectors should be impedance matched to the system impedance.

There are many types and series of coax connectors presently available. Much can be written to discuss the advantages of one series of connectors over another and usually the choice is either economic or performance depending upon the required system parameters. This discussion is outside the intended purpose of this article; however, a mention should be made of the cable to connector attachment philosophy concerning crimping or soldering.

Crimping is normally used where speed of attachment is important or where it is virtually impossible to solder due to lack of available soldering iron power, as on the top of a telephone pole or in a cable vault. Crimping requires an expensive crimp tool that can be improperly used or out of adjustment to give a poor connection. Additionally, crimped contacts over a period of time usually corrode, making for a bad contact, particularly in chemical or salt atmosphere. Soldering, on the other hand, does not require any expensive tools. The soldered connection will not corrode, provided adequate heat is correctly applied to avoid a "cold solder joint." One of the advantages of the solder approach is that many coax connectors are now made to be used over and over again with no special tools and no replacement parts required.

NOISE

Most electronic equipment systems do not produce random noise unto themselves and usually perform the singular task they were designed to do. When assembled and connected to other equipments to form a system, unwanted noise is picked up by the interconnecting wiring through the direct contact action of ground loops and common mode returns, or by inductive and capacitive pickup of nearby radiated fields. A desired signal in one circuit can be noise to another, and could be produced by local circuits within the system or from equipment completely removed and external to the system. Conversely, these same cables will *radiate* or *cross talk* the signal they are carrying into adjacent circuits becoming themselves a generator of interference to other data systems, or the cause of security compromises in classified military communications. This action is further compounded by poor cable to equipment impedance matching, which produces signal reflections and high standing wave ratios. In other words, poorly selected and installed cabling can act as both noise transmitting and receiving antennas or as undesired primary and secondary windings of coupling transformers, placing interference where it should not be.

Systems are often designed, fabricated, and installed using the simplest multiwire cable or grounded coax between equipment, racks, and buildings. Nearby electrical equipment such as high power radar, broadcast stations, power distribution mains, fluorescent lighting, arcing motors, teletype, and communications circuits are but a few of the noisemakers which can interfere with these systems. The lower the system signal voltage level, the greater is the susceptibility to this outside interference.

COAX CABLE

In all cases of potential interference, low or high frequency, shielded cable should be used to protect against magnetic and capacitive stray fields. Grounded coax cable installations are excellent, and can be used from 20 kHz to 5 GHz for most systems. But even coax, if subjected to very strong interference, will not completely protect the desired signal. Then, more sophisticated cable and equipment isolation techniques must be used, dependent upon the frequency of the interfering noise and how it enters the cable system. What additional measures are taken to reduce noise will conversely reduce outgoing radiation and cross talk.

GROUND LOOPS AND COMMON MODE RETURNS

Coax cable consists of an inner and an outer conductor insulated from each other, with both conductors carrying the desired signal currents (source to load and return). In-as-much as the outer conductor is usually grounded at the source, load, bulkheads and other intermediate points, "ground loop" or "common mode" currents caused by potential differences of external noise sources are also carried on the outer conductor. (See Figure 1.)

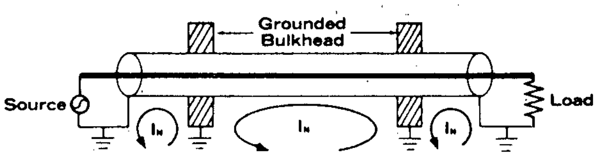


Figure 1. Non-Insulated Feed Thru. Multiple Noise Currents (In).

Since the desired signal and the undesired noise are both carried on the same outer conductor simultaneously, noise will be introduced into the system, greatly reducing the "signal-to-noise ratio." Low frequency signals (20 kHz to 6 MHz) are particularly susceptible to both ground loop and common mode interference. In this case, coax cable is recommended with the complete coax chain having a minimum number of outer conductor ground contacts. Reducing the number of ground connections reduces the number of possible ground loops. This demands that major equipment, relays, switches, connectors, patch panels, etc., be isolated from ground with the ultimate being one system ground connection at the source. (See Figure 2.)

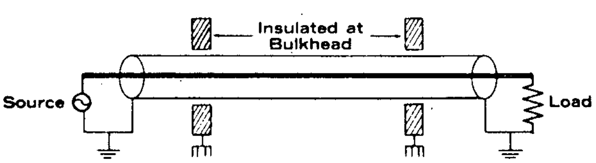


Figure 2. Insulated Feed Thru. No Noise Currents (In) in Signal Return.

RADIATED FIELDS

Where strong radiated noise fields exist, such as high-powered radar, broadcast stations, power lines, fluorescent lighting, office and industrial machinery, multiple cable runs, etc., the cable conductors act as receiving antennas or secondary windings of transformers, and pickup the external noise sources.

A particularly bad source of noise pickup is the "cross talk" or induced currents encountered in large multiple cable installations.

To protect against these radiated noise sources, two types of improved cable are used:

TRIAX CABLE. Triax is coax cable with an additional outer copper braid, insulated from the signal carrying conductors that acts as a true shield and protects the enclosed coax conductors. This braid or shield is grounded and by-passes both ground loop and capacitive field noise currents away from the signal carrying coax, thereby greatly improving the "signal to noise" ratio over the standard coax cable usage. (See Figure 3.)

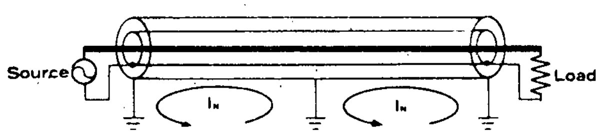


Figure 3. Triax Cable Provides Additional Shield, Insulated from Signal Carrying Coax.

Triax cable is also used in "driven shield" applications where the inner conductor and first braid are driven in parallel at the transmitting end, and work against the outer braid which is insulated above ground. (See Figure 4.) At the receiving end, the inner braid is left floating, providing a "Faraday" shield between the inner conductor and outer braid. In this way the cable's distributed capacitance is greatly reduced, thereby reducing cable losses and loading. This application is most effective in hi frequency transducer data systems where the distributed capacity in coax cable limits the data accuracy. Still another use for triax is to use only the two outer braids as a low impedance transmission line (approximately 12 ohms) which can be used to carry high-current pulses to low impedance laser lamps or exploding bridge wire (EBW) ordnance systems. Triax cable and connectors completely insulated from the ground are available for these applications.

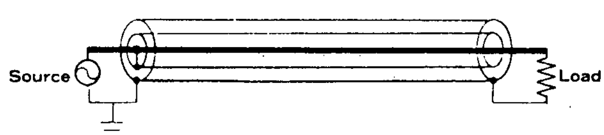


Figure 4. Triax Driven Shield.

TWINAX CABLE. Twinax cable is a two-conductor twisted balanced wire line having a specific impedance with a shielding braid around both wires. Twisting the two balanced signal-carrying wires provides cancellation of any random induced noise voltage pickup, thereby giving protection against magnetic noise field of the low-frequency variety that passes through the copper braid. This cable also provides protection against ground loops and capacitive fields, as did triax cable. Twinax cable usefulness, however, is limited to approximately 15 MHz, since it has rather high transmission losses above this frequency. Twinax cable and concentric connectors are available for low frequency, digital and video distribution systems. (See Figure 5.)

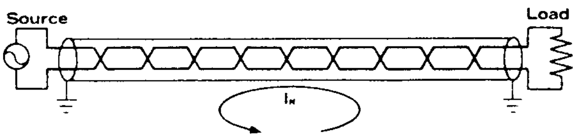


Figure 5. Twinax Cable Provides A Shield, Insulated from The Twisted Pair Signal Carrying Conductors.

GUARDED TWINAX CABLE HOOKUP

Additional common mode rejection of noise can be obtained in instrumentation systems, where thermocouple and other transducer information must be remotely recorded, by using twinax with only one ground contact located at the transducer. Insulated concentric twinax connectors are available. (See Figure 6.)

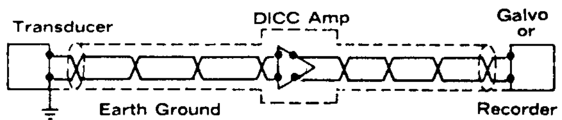


Figure 6. Guarded Twinax Cable System (one ground).

QUADRAX GUARDED CIRCUIT

For the ultimate in flexible cable providing protected and guarded circuits, twinax cable with two separate and insulated braids (quadrax) can be used, wherein the two braids are connected to "system" ground and "earth" ground, respectively. (See Figures 7 A & 7 B.)

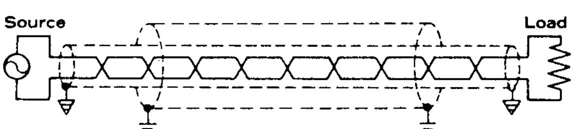


Figure 7A. Quadrax Guarded Circuit.

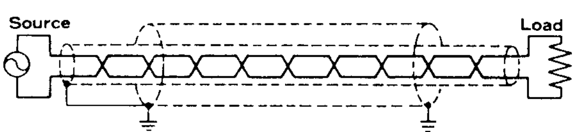


Figure 7B. Quadrax Guarded Circuit.

Quadrax cable can also be used to provide additional noise and EMI suppression by connecting both shielding braids earth ground at one place if a separate equipment ground is not available. The inner braid is left floating above ground at all other locations to act as a Faraday shield and provide additional circuit isolation. Coax cable with two extra and insulated braids can be used in similar engineering concepts for unbalanced systems. (See Figures 8 A, 8 B & 8 C.)

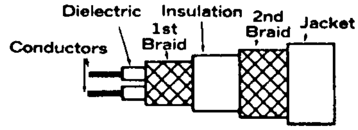
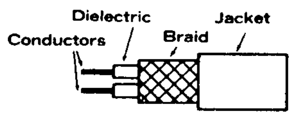


Figure 8A. Quadrax Cable.



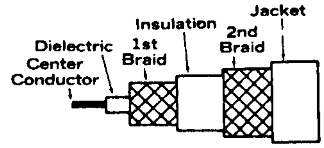


Figure 8B. Twinax Cable. **Figure 8C. Triax Cable.**

BONDING AND GROUNDING

Good bonding and grounding are also absolutely essential if noise pickup reduction is to be accomplished.

Following are common conditions that require detailed consideration:

- "Earth" grounds require extensive grids, ground rods, and chemical preparation to obtain an extremely low resistance and impedance system ground return.
- Where equipment systems comprising a low frequency data system are widely separated, equipment ground "planes" in many instances should be isolated from earth grounds to avoid "noisy" ground loops caused by power and other equipment in the immediate area.
- If parallel cabling is necessary, cabling of similar functions should be space isolated, i.e., RF from RF, video from video, and cables carrying vastly different voltage levels so that they do not have mutual capacitive or inductive coupling.
- All pulse and high frequency cables should be properly terminated in their characteristic impedance so that the cable reactive components are cancelled out and the voltage standing waves are reduced to a minimum.
- It is necessary to select the proper cable for the job. The higher the frequency, the faster the pulse rise time, or the longer the cable run, the bigger the cable must be to reduce dielectric losses and lessen the distortion of pulse shapes.
- If "system" ground and "earth" ground must be connected, it should be done at minimal locations (preferably one) using extremely low-impedance bonding paths and materials. On the other hand, RF and high frequency bonding should be made quite frequently to provide the shortest RF path to ground and prevent the ground return from acting as an additional length of antenna.

This article was written for ITEM 85 *by Ed Trompeter, President, Trompeter Electronics, Chatsworth, CA.*