# SELECTIVE ISOLATION OF SIGNALS WHICH GENERATE ELECTROMAGNETIC FIELDS

## INTRODUCTION

TEMPEST is the area of engineering intended to limit the proliferation of compromising emanations. Unlike EMI, which limits the amplitude of all conducted and radiated emissions generated by electrical/electronic equipment, or EMP, which studies the impact (on the same hardware) when subjected to a high-level electromagnetic field ($\geqslant$ 50kV/m), TEMPEST is limited to only controlling the conducted and radiated emission of signals which contain information. For example, the raster picture displayed on home TVs is made up of a horizontal sync signal, vertical sync signal and the video signal. Although all three signals are necessary to produce a "picture" on the TV, the two sync signals do not contain information.

Typically, the techniques used to design TEMPEST compliant hardware are similar to those used for designing hardware to comply with EMI or EMP requirements. They are shielding, filtering, bonding, grounding, and signal isolation. The signal isolation involves isolating selected digital, analog, and RF signals from all "other" signals within the same piece of equipment, subsystem, or system. Within limitations, signal isolation is also of interest in the area of EMI but only to the extent of achieving circuit or equipment electromagnetic compatibility.

RF isolation may take the form of:

- Cables—cross talk or radiation;
- Fourier transform on broadband signals;
- Circuitry isolation;
- Power supply regulation as a low frequency RF isolator;
- Application of passive filters.

## CABLES—CROSS TALK AND RADIATION

Cable cross talk, radiation, and susceptibility to RF depend upon the type of cable used (coax, twisted-pair, single-conductor), type of intended signal connection (common mode or differential mode), and type of shield used (foil, braid). If a braid is used, then the amount of optical coverage provided by the braid weave directly relates to the shielding effectiveness. Also, how the shield is terminated (one-end, both ends, pigtail or circumferential termination) directly relates to the shielding effectiveness provided by the cable assembly.

Four examples of cable coupling are:

- Open-wire to open-wire;
- Shielded-wire to open-wire;
- Open-wire to shielded-wire and;
- Shielded-wire to shielded-wire.

An article on these types of cable coupling has been published by R.J. Mohr. Solutions to Mr. Mohr's coupling equations are provided for the open-wire to open-wire and shielded-wire to open-wire configurations in Table 1. The two configurations are representative of the conditions most often experienced in equipment cable harnesses.

$\ell$ = 3 ft. = length of parallel wire run
h = 1 in. = height over ground plane
D = 6 in. = conductor separation
$d_1 = d_2 = 0.020$ in. = 25 ga = conductor diameter
$R_a = R_b = R_c = R_d = 50\Omega$ = terminating and source resistance
f = 10 kHz to 1 GHz = frequency

| FREQUENCY | $A_{dB}$ |
|---|---|
| 10 kHz | -104dB |
| 100 kHz | -84dB |
| 1 MHz | -64dB |
| 10 MHz | -44dB |
| 100 MHz | -24dB |
| 1 GHz | -4dB |

**Table 1. Open-Wire to Open-Wire Coupling.**

One may then consider the potential coupling generated by a $T^2L$ signal with an amplitude of 5 V, a rise time of 10 ns, a frequency of 2.4 kHz, period = 417 $\mu$s and a pulse width of 208 $\mu$s. The pulse then will produce a spectrum which mathematically may be expressed as:

$$X(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left[ a_n \cos\left(\frac{2\pi nt}{T}\right) b_n \sin\left(\frac{2\pi nt}{T}\right) \right]$$

where T is the period of the periodic time function:

$$X(t), \text{ i.e., } X(t) = X(t+T).$$

Then, by solving the Fourier series, the amplitude at the frequency of the nth harmonic, $A_n$ of the pulse is given.

$$A_n = \left( \frac{2A(t+t')}{T} \times \frac{\sin[\pi F(t+t')]}{\pi F(t+t')} \times \frac{\sin[\pi ft']}{\pi ft'} \right)$$

Figure 1 shows a graph of the broadband spectrum produced by the $T^2L$ pulse. If the given digital signal was present on a conductor located in a cable bundle with conditions similar to those stated in Table 2, then the voltage transfer ratio could be added to the broadband spectrum amplitude to determine the coupled voltage, such as the broadband spectral amplitude given at 1 MHz = 128 dB$\mu$V/MHz and the voltage transfer ratio given at 1 MHz = 64 dB. Therefore the coupled energy at 1 MHz = 64 dB$\mu$V/MHz. The resultant amplitude could then be compared to the appropriate TEMPEST limits to determine if the selected design approach is adequate to fulfill the TEMPEST requirements. Then a more conservative design approach could be selected, such as using twisted-pair cable which requires using differential drivers and two conductors where otherwise one (plus ground) is adequate for current flow. However, the benefit is improved noise immunity.

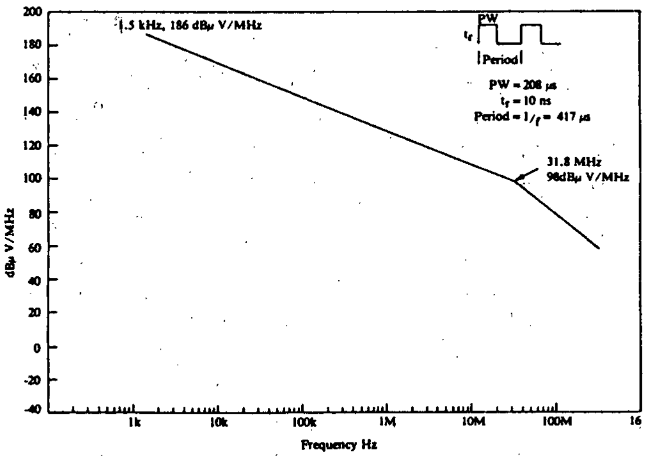


**Figure 1. Broadband Spectrum of a 2.4 kHz T²L Signal.**

Twisted-pair conductors form a double helix. The resultant magnetic field is reduced considerably as compared with two parallel conductors. The maximum flux density generated by a twisted-pair line may be approximated by:

$$B = \frac{\mu o I}{\sqrt{pr}} \quad q I_o \, q^{\exp(-2\pi r/p)}, \; .05 < q < .67, T$$

or

$$B = \frac{\mu o I d}{2\pi r\,(r + d)} \quad \text{CLOSE TO CABLE, } r < \frac{p}{3}, T$$

where, d = helix diameter, m
p = helix pitch, m
r = distance from axis of helix, m
q = $\pi d/p$, helix parameter, dimensionless
$I_o$ (x) = 0th order modified Bessel function of the first kind.

Field-to-wire coupling measurements have been performed on a twisted-pair cable with and without a braided shield. The measurements performed on the twisted-pair cable with no shield showed that the antenna polarization of the source antenna had little

h = 1 in. = height over ground plan
D = 6 in. = wire separation
$d_s$ = 0.116 in. = inner diameter of shield
$\ell$ = 3 ft = length of parallel wire run
$R_s$ = .00255Ω resistance of shield (RG-223)
$R_a = R_b = R_c = R_d$ = 50Ω = terminating and source resistance
f = 10 kHz to 1 GHz = frequency

| FREQUENCY | AdB |
|---|---|
| 10 kHz | -120dB |
| 100 kHz | -118dB |
| 1 MHz | -116dB |
| 10 MHz | -114dB |
| 100 MHz | -111dB |
| 1 GHz | -109dB |

**Table 2. Shielded-Wire to Open-Wire Coupling.**

effect on the voltage transfer ratio (VTR). Effectively, the voltage transfer ratio becomes a function of the cable electrical length. Figures 2 through 6 show the results of field-to-wire coupling measurements performed using various shield grounding techniques.

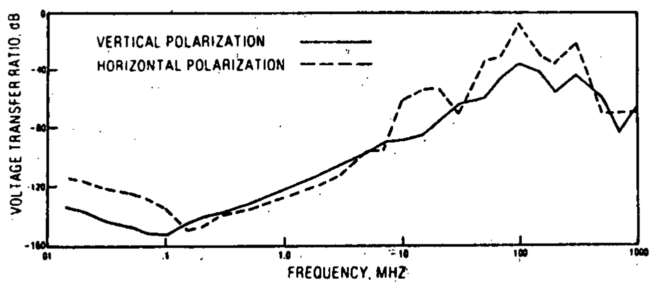


**Figure 2. Twisted-Pair Cable, No Shield.**

Twisted-pair cable used to conduct differentially coupled signals offers the greatest reduction in field-to-wire or wire-to-wire coupling. After the decision is made to utilize a twisted-pair cable, the next issue of importance is the selection of a shield and the shield termination techniques. Figures 3 through 6 show that the use of a pigtail shield grounding technique actually increases the field-to-wire coupling degrading any potential benefit the braided shield may provide. However, grounding the shield circumferentially at both ends decreases the field-to-wire coupling at all frequencies (see Figure 3).

The isolation provided by the wiring may be inadvertently offset by coupling which occurs within the circuitry that either drives the cables or terminates the cables. For instance, T²L gates (hex buffer) have been evaluated in a laboratory environment to determine the input to output RF isolation with the $T^2L$ input set to a Logic 1 and a Logic 0, and the RF input varied from 14 kHz to 1 GHz. Results of the tests show at best one hex buffer will provide 60 dB of isolation. However, a similar test program performed on an opto-isolator showed that an additional 40 dB of isolation could be achieved, as shown in Figure 7. Therefore, use of the opto-isolators as line drivers will further reduce the amplitude of out-of-band signals coupled into circuit wiring.

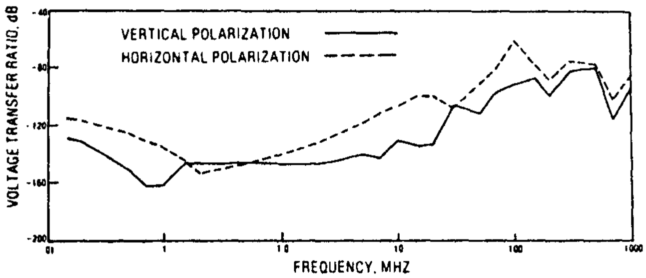


**Figure 3. Twisted-Pair Cable, with Shield Circumferentially Grounded at Both Ends.**

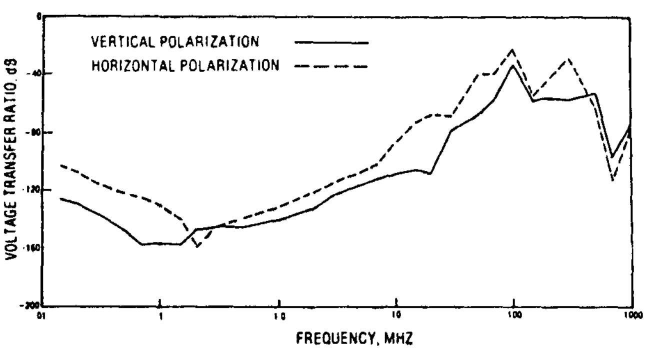


**Figure 4. Twisted-Pair Cable, with Shield Circumferentially Grounded at One End.**

Considerable information has been published concerning the topic of shielding. All TEMPEST engineers realize that shielding effectiveness is defined by:

$$SE = R + A + K$$

where: R = Reflection loss in dB
A = Absorption loss in dB
K = Correction factor for waves reflecting inside the walls

and: $A = 3.3 \times 10^{-3}\, T\sqrt{f\sigma\mu}$, dB

T = wall thickness in mils
f = frequency in Hertz
$\sigma$ = material conductivity relative to copper
$\mu$ = material magnetic permeability

for a plane wave:

$$R_p = 168 + 10 \text{ Log } \frac{\sigma}{\mu f}, \text{ dB}$$

for an E-field wave:

$$R_e = 354 + 10 \frac{\sigma}{f^3 \mu D^2}, \text{ dB}$$

D = distance from the radiating element to the shield in inches

for an H-field wave:

$$R_h = 20 \text{ Log } \left[ \frac{0.46}{D} \sqrt{\frac{\mu}{f\sigma}} + 0.14D \sqrt{\frac{\mu}{f\sigma}} + 0.35 \right], \text{ dB.}$$

The foregoing equations are particularly useful to calculate shielding effectiveness below about 100 MHz, and to thereby decide if the shield must have a high permeability (such as steel) or a low conductivity (such as copper or aluminum). Above approximately 100 MHz, the calculations provide physically unachievable quantities. At the higher frequencies, bonding between mating joints becomes the critical factor because, for each box to be useful, holes must be made to mount I/O connectors, primary power, or ventilation. The manner in which the connectors or filters or covers are

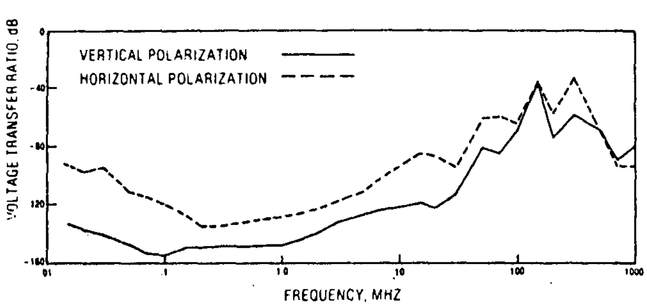


**Figure 5. Twisted-Pair Cable, with Shield Grounded in a One-inch Pigtail at Both Ends.**

bonded to the mating surface will probably limit the final shielding effectiveness. Usually about 100 dB is achievable in the frequency range of 14 kHz to 1 GHz whereas about 60 dB is maintained throughout the life of the delivered product. Degradation usually results from corrosion between the bonded surfaces, dirty joints due to access panels being opened and closed without cleaning the surfaces, and EMI gaskets which take a set and no longer provide an effective RF seal.

Dependence upon shielding should be minimized or at least localized to the circuitry producing the troublesome electromagnetic fields. Overall shielded boxes are appropriate when producing a design to comply with the requirements of NACSEM-5204, MIL-STD-461 or EMP. Shielded boxes are frequently unnecessary when producing a design to comply with NACSIM-5100A. More often than not, a commercial product may be redesigned to comply with NACSIM-5100A without altering the exterior appearance. This can usually be accomplished by attention to circuit layout, use of CMOS integrated circuits to minimize RF energy, use of fiber optics to avoid long internal wiring, and localized shields around particularly troublesome areas.

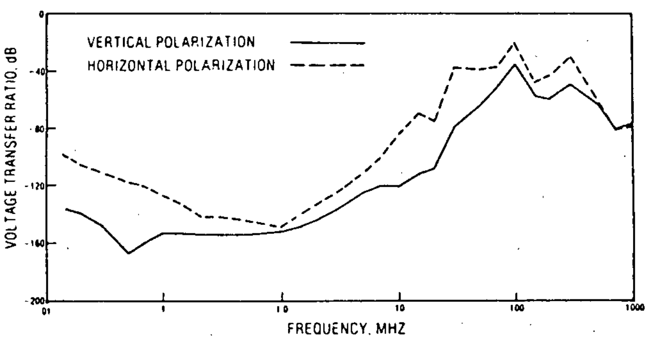


**Figure 6. Twisted-Pair Cable, with Shield Grounded in a One-inch Pigtail at One End.**

Then, of course, comes the application of signal and power line filters. Filtering also should be minimized since EMI filters require space and add weight. Filtering signal lines may be simplified by simply using capacitors, lossy line or fiber optics. However, filtering power lines is a requirement which usually cannot be avoided. Utilizing a filter which provides 100 dB of attenuation from 14 kHz to 1 GHz on a 60 Hz power line requires physically large components resulting in a heavy, bulky filter. Besides, the power supply can be designed to provide effective low frequency filtering. An insertion loss of 40 dB to 60 dB from the power supply dc output to the ac input is reasonably achievable, so filtering the dc lines may be more effective. Usually more filters will be required to filter dc lines than the two that would be required to filter single phase ac lines. However, each filter would be considerably smaller and some filters may be simple LC components mounted on a circuit board.

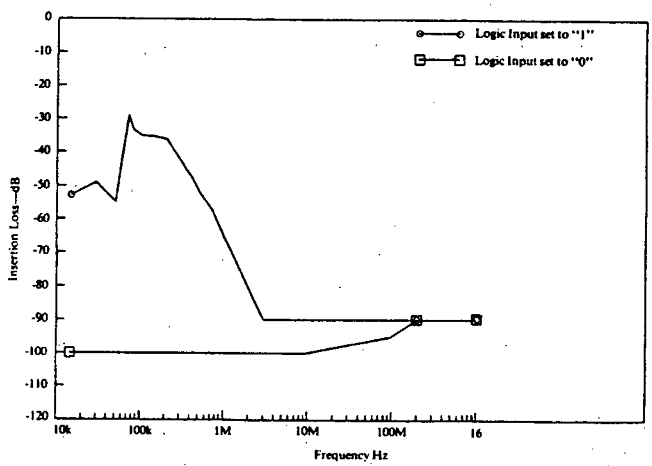


**Figure 7. Opto-Isolator RF Isolation.**

Each TEMPEST program is unique. The most cost effective approach to achieve a TEMPEST compliant design requires a balance of analytical skills, test skills and electrical/mechanical design skills, all of which must be weighed with the program's non-recurring and recurring costs. Much too frequently, the small production quantities will not justify the cost of an eloquent design, so the approach taken is the one which offers the lowest risk technique. That is, the approach will comply with the TEMPEST requirements in the first test with minimal redesign.

The ultimate goal is to provide a TEMPEST compliant product which is a) useful, b) aesthetically acceptable, and c) competitively priced, all healthy traits of the business area.

## REFERENCES


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3. John W. Hafer, Jr., "The Effects of Shield Grounding Techniques for Isolation to Electromagnetic Waves." Presented at the 1981 IEEE International Symposium on Electromagnetic Compatibility.



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