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Channel Capacity & Noise – Advantages of Shielded Cable Systems

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The goal of this paper is to demonstrate through empirical data that a fully shielded communication infrastructure offers a higher level of performance than similar non-shielded infrastructures. A quality shield design prevents external noise from entering the cable, whether from other cables or from other external noise sources. Outside noise, a growing problem in many infrastructure environments, corrupts data packet transmission and, therefore, can dramatically restrict the network performance.

Channel capacity

Channel capacity is the maximum throughput that a telecommunications channel can accommodate. A complete channel consists of cable and connective hardware. The channel is designed so the capacity exceeds the requirements of the intended applications. This margin of additional performance ensures that system or environmental shortcomings do not affect transmissions. The information capacity in bits per second (b/s) gives the maximum value for transmitting data through the channel.

Cabling channel signal-to-noise-ratio (SNR)

Channel capacity is determined according to the Shannon-Hartley capacity theorem, which essentially states that capacity is proportional to the “area under the curve” of the SNR over the particular bandwidth, (i.e. integrated SNR power over bandwidth (BW)).

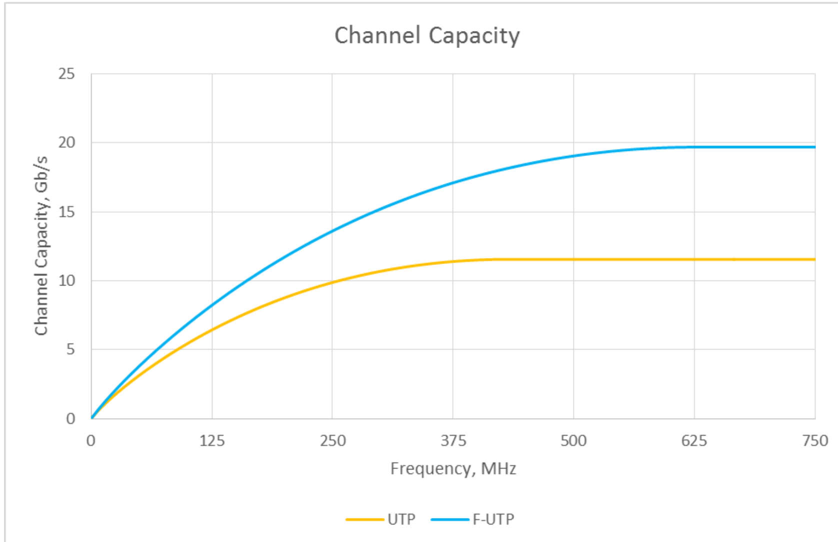
Shannon capacity

Shannon Capacity is an expression of SNR and bandwidth. Capacity is proportional to the integrated SNR (dB) over the bandwidth utilized. The Shannon capacity is the maximum information capacity available within a particular channel. The typical expression for Shannon capacity is given in the following equation.

$$\boldsymbol{C_{SH} = \int_0^{BW} log_2\left(\left(\frac{S(f)}{N(f)}\right) + 1\right) df}$$

Where,
C_{SH} = channel Shannon capacity
From Band-Limited Shannon Capacity evaluation
S(f) is simply the IL scaled by the TX launch power, and
N(f) is simply the band-limited white self-noise
BW is the signal bandwidth in Hz.
For simplicity use flat (white) TX power spectrum

The Shannon capacity is a calculation based on perfect coding and important assumptions about the noise structure. Because of practical limitations and variations in actual electronic systems, the calculated channel capacity must be greater than the minimum capacity required to reliably support a particular application. For example, the standards that support 10GBASE-T (10Gb/s) are based on values that result in 12-18Gb/s channel capacity. As a result, channels with lower noise will perform better. Shielded channels (F-UTP) have proven to be more immune to noise than unshielded channels (UTP) and they are naturally better at delivering maximum throughput. The advantage of a shielded solution can be seen in Graph 1. As frequency increases, the channel capacity of a shielded solution delivers more Gb/s than an unshielded one.



Graph 1.

Data encoding

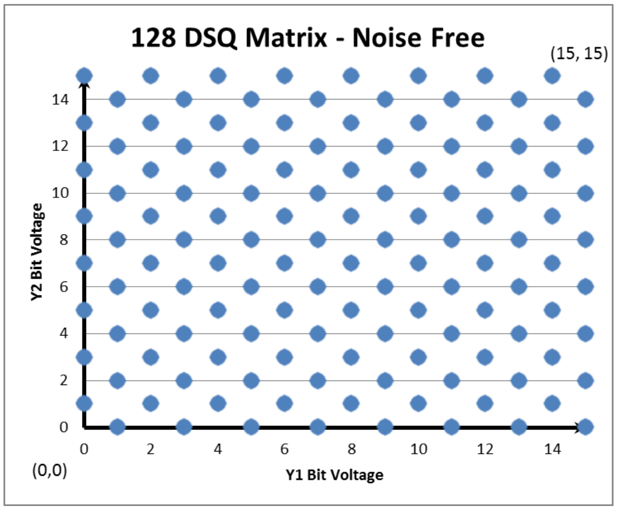
In order to transmit higher data rates, more complex signal encoding schemes have been developed to more fully utilize the noise and bandwidth properties of Category cables. As the data rates have increased, continued optimization of clock rates and the number of voltage levels has evolved.

For 100Mb Ethernet, a 3 level encoding system is used, requiring the receiver to discern which of the 3 levels of voltage were transmitted for each and every bit.

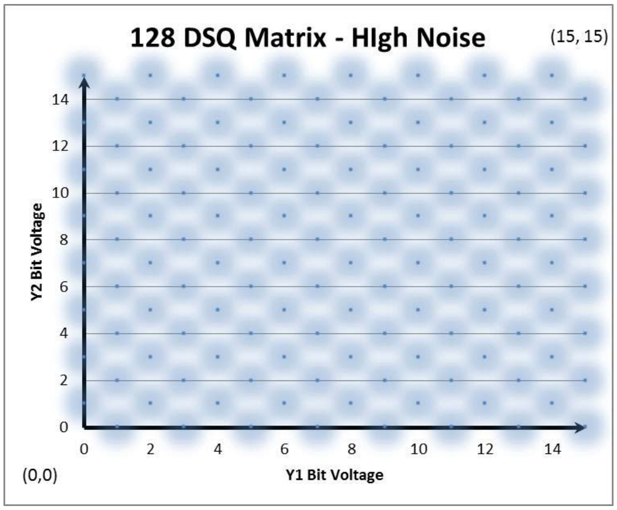
Gigabit Ethernet increased the encoding levels to 5, making the distinction between the different voltage levels more challenging.

10Gbit Ethernet encoding required expanding the frequency range as well as adding more smaller voltage changes in order to provide the bandwidth required. Each of the four pairs transmits 2.5Gb with an encoding scheme using 16 voltage steps (see Graph 2). Due to the much smaller voltage steps, the sensitivity to noise with the encoding system resulted in the addition of Alien Crosstalk requirements for Category 6A cables.

The encoding sequence of bits for 10Gb Ethernet builds a 128DSQ (Double square coset-partition constellation) that enables each bit to send greater amounts of information (Graph 2). However, this complex encoding relies on a low noise environment. With excessive noise (Graph 3), the points in the constellation become "blurred" together, resulting in high bit error rates or loss of the communication link. Note that zero voltage is a voltage step, therefore the graph includes all voltage steps, 0 through 15.



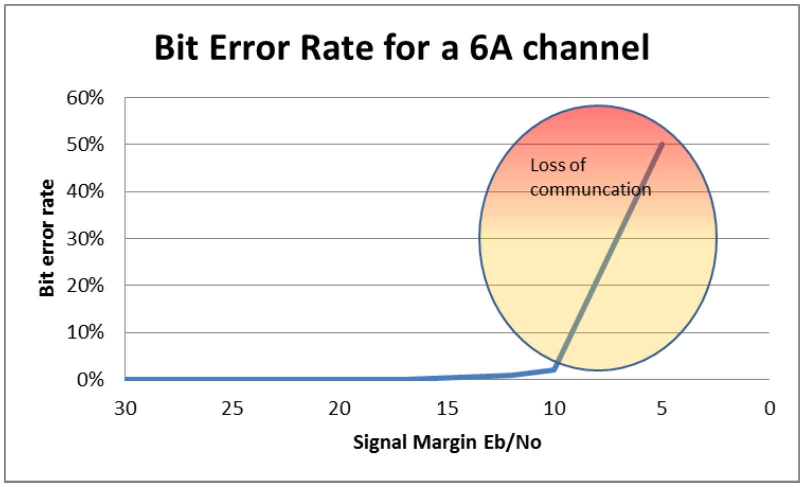
Graph 2.



Graph 3.

Bit Error Cliff

Another property of digital communication is that the bit error rises dramatically as the noise level increases. Just a few decibels of change in the noise level compared to the signal can have a dramatic effect on transmission errors. In practical terms, once the noise level approaches a critical value, the communication link effectively "shuts down". Thus maintaining a reliably quiet environment is important to avoid systematic or short term link outages caused by noise in the environment.



Graph 4.

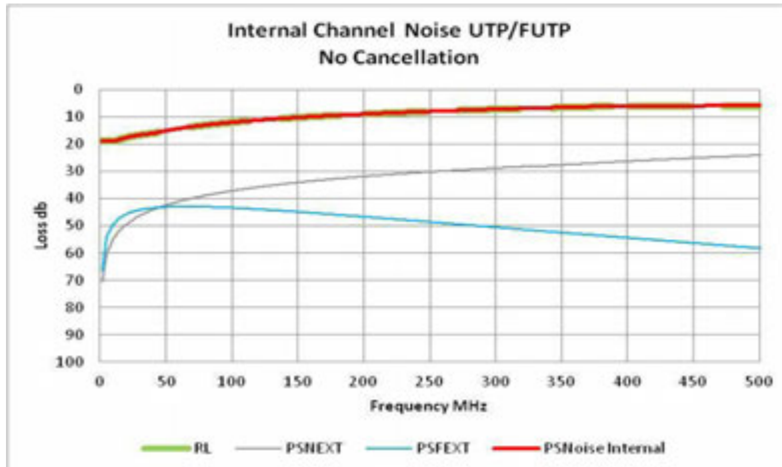
In Graph 4 we identify how the increase in bit error rate is tied to the decline of signal margin. Through electronics, the link is able to overcome limited noise. As the noise increases it erodes signal performance until the complete signal failure occurs.

Internal Noise sources

Internal cable noise comes from several sources:

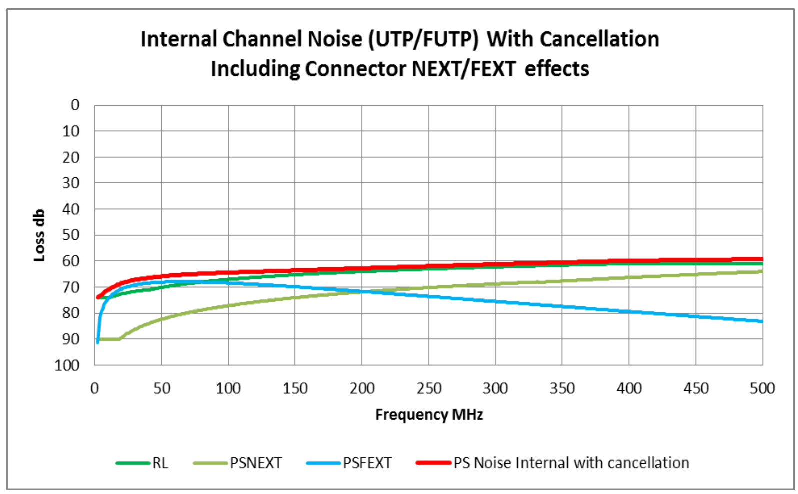
- Crosstalk among pairs within the cable – near and far end effects
- Return Loss – Reflections within the cable and at the terminations
- Electronic component noise in the transmitter/receiver circuit

A key characteristic of internal noise sources is that there is a high level of predictability. This predictability enables the ability to cancel out internal noise sources through electronics. For any pair in the cable, the timing and magnitude of the signals on the other 3 pairs is known and can be reliably and significantly cancelled. The levels of the internal noise sources are the same whether the cable is of a shielded or non-shielded design, since they are driven by the standards for cable crosstalk and return loss.



Graph 5.

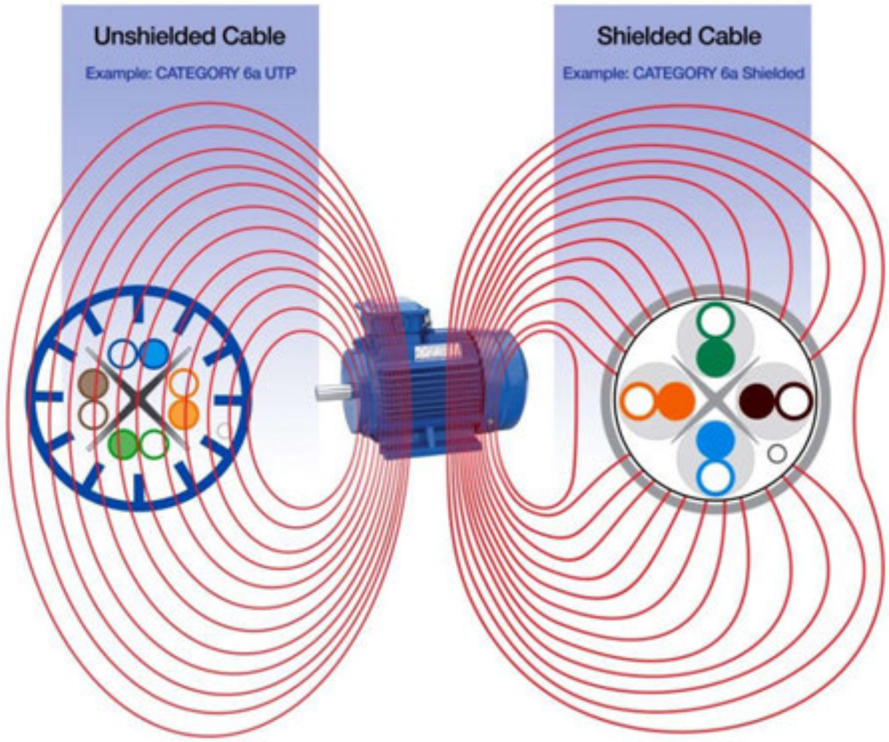
Graph 5 shows the level of internal noise within a Category 6A cable with no electronic noise cancellation. Graph 6 shows the noise level with active electronic noise cancellation. The network electronics are capable of reducing inside noise to a level that permits channel performance. It was also found that electronic noise cancellation worked equally well regardless of whether the cable was a shielded cable or an unshielded cable.



Graph 6.

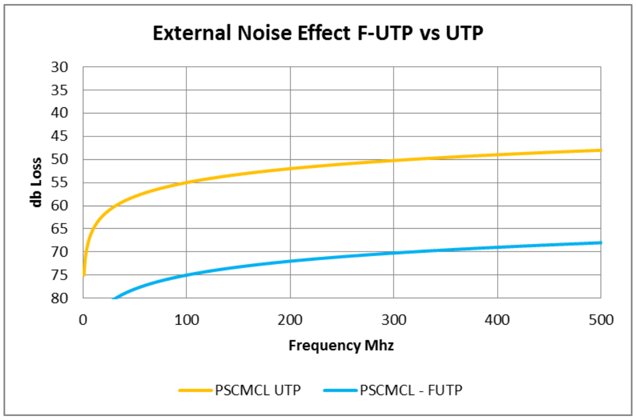
External noise sources influence performance

External noise sources that can negatively impact channel performance can be random and erratic. Sometimes their origin is known, and at other times they go unknown. This type of noise is difficult, if not impossible to cancel because of the signal unpredictability. Examples of external noise would be fan motors, elevator motors, light ballasts, medical equipment, manufacturing equipment, etc. External noise not only comes from the environment around the cable, but from adjacent cables as well. High voltage cables, especially those that draw power intermittently, can be significant sources of noise.

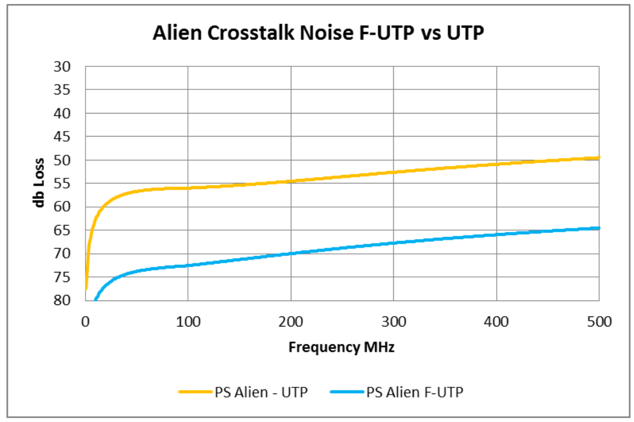


For communication cables to work properly in a high-noise environment, shielding from the noise is necessary. A cable shield provides a protective barrier from external electrical fields around the cable. The shield, a conductive metallic foil with a polyester backing, surrounds the cable pairs and helps prevent extraneous voltages from influencing the signal on the pairs beneath the shield layer. Image 1 illustrates how external electrical fields interact with an unshielded twisted pair cable (UTP), left, and a twisted pair cable with an overall shield (F-UTP), right. The shield on the F-UTP cable actually causes the electrical fields to bend around the cable such that the voltage at the surface of the shield is practically at ground potential. The amount of external field energy within the shield is essentially zero. By contrast, the electrical fields surrounding a UTP cable penetrate the jacket and directly interact with the pairs. Without a shield, only the pair twist and pair balance help offer immunity to the noise.

The following graphs (Graph 7 & 8) highlight the differences for UTP vs F-UTP in pair noise from external sources and for alien crosstalk. The charts reflect pair noise for coupling attenuation that is 20db improved, and alien crosstalk performance improvement of 15db. You can see that measured noise from external sources and alien crosstalk (adjacent cables) is much higher in unshielded cable than shielded cable.

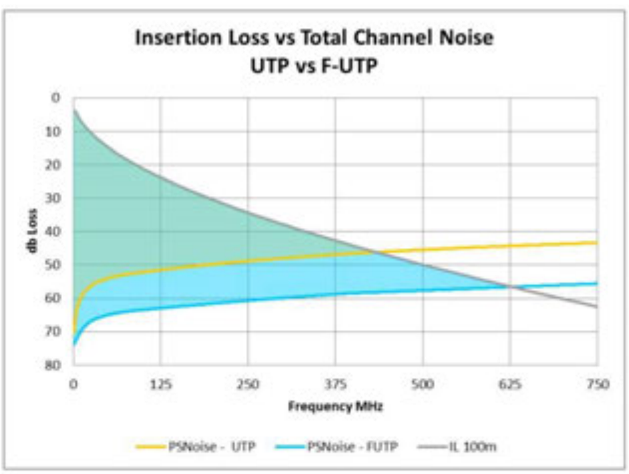


Graph 7.



Graph 8.

The noise level must be compared to the signal level to have a full view of the channel capacity. Graph 9 shows the signal level or Insertion Loss (IL) compared to the total noise for an unshielded cable and a shielded cable. The intersection of the signal strength curve and the noise curve occurs at a much higher frequency for shielded cables. The higher intersection point means that there is signal at higher frequencies available and also more noise margin at all frequencies. The extra noise margin (shaded in blue) adds reliability and robustness to the channel.

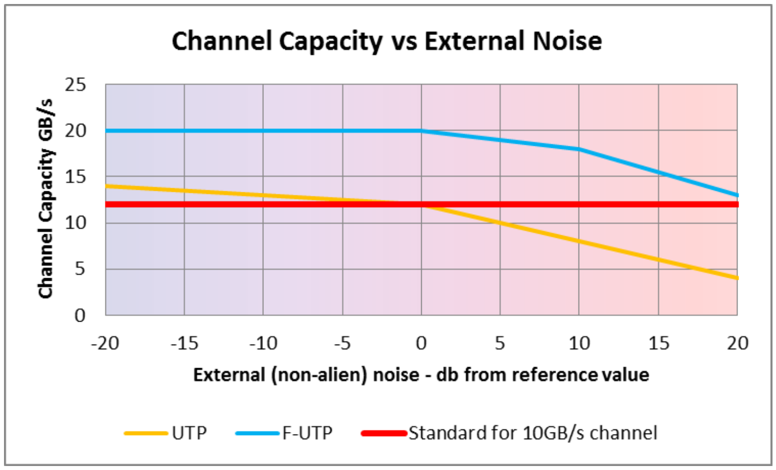


Graph 9.

Channel Capacity vs External Noise

Present and future applications benefits from the additional channel capacity shielded solutions provide (Graph 10). For existing applications, the quieter channel offers a more robust, error free communication link that is more resistant to short or long term changes in the electrical noise environment. (Think compressors turning on or off, or a new bank of fluorescent lighting installed near a raceway.)

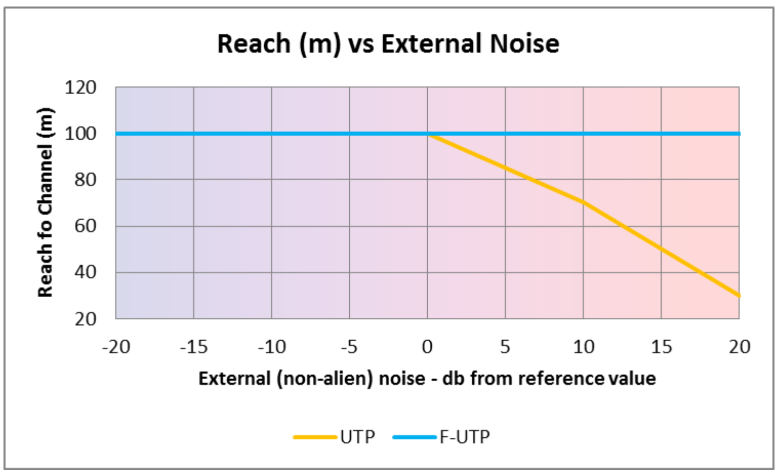
The standards for channel performance are built around assumptions of an external noise environment that consists of alien crosstalk from other cables, and noise from other external sources. For UTP cables, there is little additional margin built in to the system. However, standards for home environments or specific industrial environments rise to 10V/m (+10db) or more. In these cases the channel capacity is better maintained by shielded cables across a much wider range of external noise environments.



Graph 10.

Channel Reach vs External Noise

Expressing the effects of noise in another way, the noise level affects the "reach" of a channel. When the channel is longer than the reach, the channel capacity falls below that needed for successful communication. For UTP channels in higher noise environments, the reach does not meet the 100m requirements, but the shielded cables maintain the reach at 100m across a wide range of noise environments (Graph 11).



Graph 11.

Future Applications

Future applications will most likely further stress the channel capacity. One example is the current investigation that might allow 2.5Gbit over Category 5e or 5Gb over Category 6. Both of these examples use a 16 level encoding similar to the one used in the 10Gb systems and highly stress the limits of the noise environment. Also both of these potential applications will introduce alien crosstalk and noise immunity to the category 5e and 6 discussions. A shielded cable will have a much higher capability of supporting these new applications without the need to worry about the external noise environment.