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# When Ethernet Rotates: Ethernet and Slip Rings

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## Introduction:

There are cases when a slip ring must be utilized to carry the conductors of copper transmission line (cable) from a rotating platform to a stationary structure. The sharp growth in the use of Gigabit Ethernet has sparked a renewed interest in the ability of slip rings to function within a CAT 5 or CAT 6 network environment. Slip ring designers are able to meet the challenge of more exacting performance parameters with innovative methods of matching impedance, controlling crosstalk, and managing losses.

## Definitions:

- **Attenuation** (dB): The reduction in signal power through a cable or interconnect; also known as insertion loss.
- **NEXT** (dB): Near End Crosstalk (NEXT) is the coupling noise induced on other pairs of a cable by a single energized pair of the cable and measured on the transmitter end.
- **FEXT** (dB): Far End Crosstalk (FEXT) is the coupling noise induced on other pairs of a cable by a single energized pair of the cable and measured on the receiver end.
- **AXT** (dB): Alien Crosstalk (AXT) is the coupling noise induced on a cable by other cables in proximity. There are a variety of ways to break AXT out and evaluate.
- **Return Loss** (dB): The loss in signal power that results in reflections from discontinuities in the transmission line.
- **Delay Skew**: The difference in propagation delay between any two pairs within a cable.
- **SNR** (dB): The ratio of the signal power to noise power level.

There are a wide variety of network applications where rotary platforms are required. These applications vary from industrial robots to wind turbines to radar antennae. It is typical that these requirements include power, sensor, and control circuits to be run to and / or from these platforms, and slip rings are used to carry these channels across the rotary interface. Is it practical to include copper channels in the slip ring to carry LAN? Ethernet has become the primary LAN technology, and many new LAN installations / applications are using IEEE 802.3 1000BaseT Ethernet at the network of choice. This white paper addresses the issues presented when a rotary connection must be inserted into the 1000BaseT transmission line. Figure 1 shows a typical slip ring with power, signal and control, as well as LAN circuits.

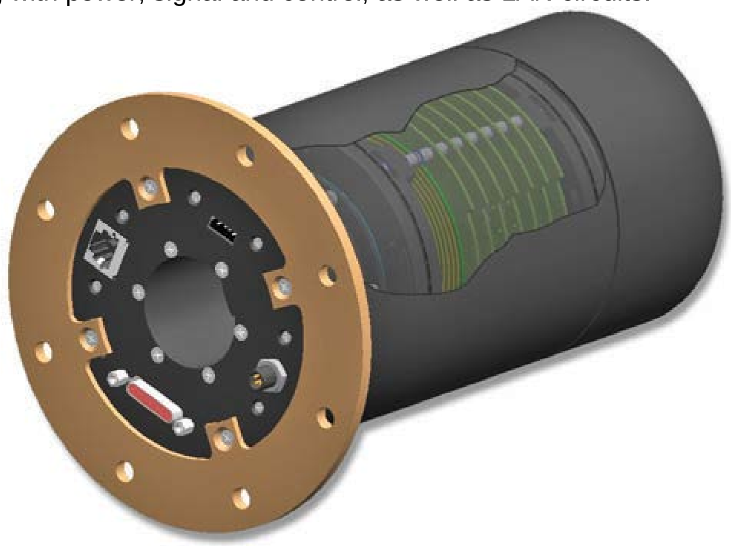

**Figure 1 – Slip Ring with Ethernet Connectors**

IEEE 802.3 along with the associated cabling specifications is tailored for permanent LAN installations in buildings and similar infrastructures. For this reason, the specifications build the requirements around a description of:

1. a permanent cabling length, with connectors at each end, of no more than 90 m;
2. patch cords on either end of no more than a total of 10 m in length for both which in turn are terminated (by connectors) to the Ethernet cards.

However, the advantages of Ethernet as a robust, inexpensive, widely supported format have led to its implementation in a wide variety of custom data communication networks that do not look anything like those described above. In these cases, it is important to have a very clear understanding of the critical features of 1000BaseT to be able to define cabling and component parameters that are both realistic and effective.

## *The Specifications*

Our specific interest in IEEE 802.3 1000BaseT is the physical layer or PHY which is the media that connects network devices. The primary function of the PHY is to support the data transmission requirements imposed by the upper layer protocols. The IEEE 802.3-2008 specification, Section 3, Clause 40.1.3 provides a good overview of the 1000BaseT architecture:

> *The 1000BaseT PHY employs full duplex baseband transmission over four pairs of Category 5 balanced cabling. The aggregate data rate of 1000 Mb/s is achieved by transmission at a data rate of 250 Mb/s over each wire pair. The use of hybrids and cancellers enables full duplex transmission by allowing symbols to be transmitted and received on the same wire pairs at the same time. Baseband signaling with a modulation rate of 125 MBd is used on each of the wire pairs. The transmitted symbols are selected from a four dimensional 5-level symbol constellation. Each four-dimensional symbol can be viewed as a 4-tuple (An, Bn, Cn, Dn) of one-dimensional quinary symbols taken from the set {2, 1, 0, –1, –2}. . .Five-level Pulse Amplitude Modulation (PAM5) is employed for transmission over each wire pair. The modulation rate of 125 MBaud matches the GMII (Gigabit Media Independent Interface) clock rate of 125 MHz and results in a symbol period of 8 ns.*

In Clause 40.7.1 the specification goes on to specify "4-pair Class D cabling with a nominal impedance of 100 Ω as specified in ISO / IEC 11801:1995. The cabling system components (cables, cords, and connectors) used to provide the link segment shall consist of Category 5 components as specified in ANSI / TIA / EIA-568-A:1995 and ISO / IEC 11801:1995." This cable is commonly known as CAT 5e or "enhanced" which represents improved performance parameters over the older CAT 5 cable. The 1000BaseT architecture is designed to allow Gigabit Ethernet to run on existing CAT 5 infrastructure, but the Gigabit Ethernet Alliance recommends that all new cable installations designed for 1000BaseT deployment should be specified as Category 5e.

CAT 6 and CAT 6a cables (250 and 500 MHz cables respectively) are defined in ANSI / TIA / EIA-568-B (as well as in ISO / IEC 11801) and represent improved performance over CAT 5e primarily achieved by improved pair-to-pair shielding. Although designed for 10 Gbase-T, CAT 6 and CAT 6a cables are sometimes used to improve performance "headroom" in 1000BASE-T applications. The latest amendments of ISO / IEC 11801 even define a CAT 7 cable (1000 MHz) for possible use with 40 Gbase Ethernet. The ANSI / TIA / EIA-568-A:1995 referred to in IEEE 802.3 has been replaced with four different specifications: ANSI / TIA / EIA-568-C.0, -C.1, -C.2, and -C.3. The 568-C.2 is specifically for the Balanced Twisted Pair Cabling and Components. However, the specific requirements for CAT 5e remain the same from the -A:1995 to the -C.2 revisions.

## *Critical Parameters*

Figure 2, similar to Figure 40-2 in IEEE 802.3-2008, shows the PHY configuration of 1000BaseT with a bit rate of 125 Mbps.

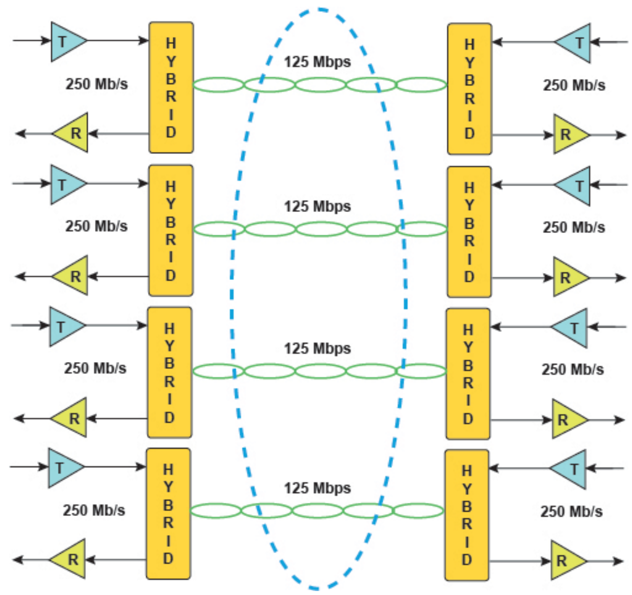


**Figure 2 – 1000BaseT Topology**

The PAM 5 encoding used to allow the transmission of 1000MBAUD of full duplex data using an aggregate data rate of 500 Mbps leads to a unique eye pattern on each of the four cable pairs as a result of its five voltage levels. (Figure 3). This eye pattern highlights the important features required for data quality. First, the vertical height of each eye is limited to 0.5 V. Although the full pulse height is +/- 1.0 volts, information is carried in 0.5 volt increments. Since the receiver has to distinguish a 0.5 V differential in digital pulses, the signal to noise ratio (SNR), compared to 100BaseT which has the same clock rate but a pulse voltage differential of 1.0 V

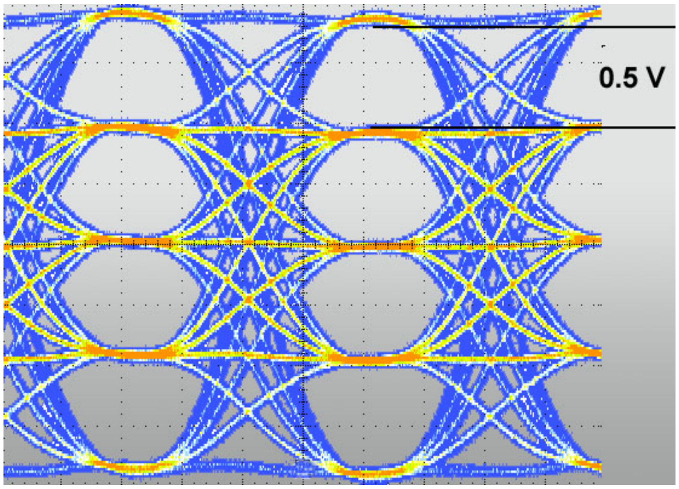


**Figure 3 – Eye Pattern of PAM 5 Data Stream**

becomes very important. The PAM 5 encoding scheme allows efficient use of bandwidth, but the sacrifice is in

SNR sensitivity. So the specifications for 1000BaseT are much more concerned with noise generation than those for 100BaseTx (Fast Ethernet).

1000BaseT carries data on all four of the twisted pairs in the cable compared to only two of the four in 10Base or 100Base. Differential noise generated by cross-coupling of the conductors (crosstalk) within the cable therefore becomes more critical. IEEE 802.3 differentiates between crosstalk on a cable pair that appears at the transmitter end (NEXT) and receiver end (FEXT) because different cancellation strategies are used to reduce the resultant noise. NEXT canceling is more effective since the symbols transmitted by the three noise producers are available to the cancellation processor. These noise cancelers can reduce NEXT interference by at least 20 dB. Since symbols from the transmitter are not immediately available at the receiver end, the FEXT cancelling process is not as effective as the NEXT cancellation, but FEXT noise is not as dominant as NEXT. (Figure 4 illustrates NEXT and FEXT).

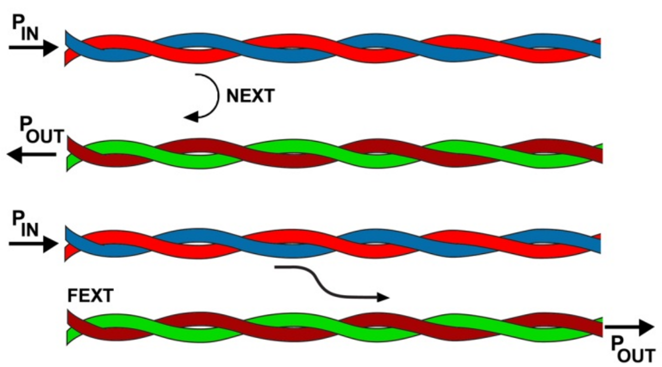


**Figure 4 – NEXT and FEXT**

Noise produced by other adjacent "alien" cables is also important. Information about this noise is not available to the noise canceler so it is important to reduce the alien noise to the specification level as defined in Clause 40.7.6: "Measured at the output of a filter connected to the output of the near end of a disturbed duplex channel the noise should not exceed 40 mV peak-to-peak. The filter for this measurement is a fifth order Butterworth filter with a 3 dB cutoff at 100 MHz."

| Parameter | 802.3 SPEC | 568-C.2 CAT 5e | 568-C.2 CAT 6 |
|---|---|---|---|
| Insertion Loss (dB) | 24.0 | 24 | 21.3 |
| Return Loss (dB) | 8.01 | 10 | 12 |
| NEXT (dB) | 27.10 | 30.1 | 39.9 |
| External Coupled Noise (dB) | 30.97 | N/A | N/A |

**Table 1: 1000BaseT Performance Requirements Evaluated at 100 MHz**

The overall SNR and timing jitter requirements presented in clauses 4.6 and 4.7 of the 802.3 specification are built around noise requirements with an understanding of the cancellation and compensation capabilities of standard Ethernet electronics (see Table 1 for a summary of the requirements). The cabling requirements defined in the ANSI / TIA / EIA 568 and ISO / IEC 11801 were developed to provide these performance requirements over a copper cable up to 100 m long. Figure 5 illustrates the SNR parameters.

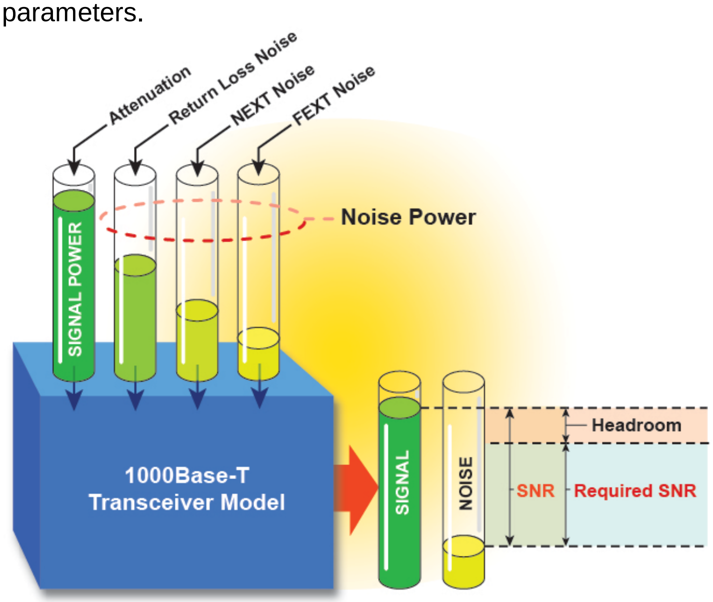


**Figure 5 – SNR Illustration**

## *Slip Ring Effect*

What is the effect of placing a slip ring into a 1000BaseT cable? Physically, this means dedicating one ring and brush set to each of the 8 conductors of a CAT 5e cable. Figure 6 shows ring brush configuration for one pair of conductors in a platter configuration. It should be clear from this simple illustration that this wire-ring-brush-wire transition does not exactly duplicate the cable or connectors addressed in the ANSI / TIA / EIA specification. However, the slip ring designer can come "close enough" to the cable requirements to satisfy the Ethernet performance requirements. There are two specific areas that we should address and clarify.

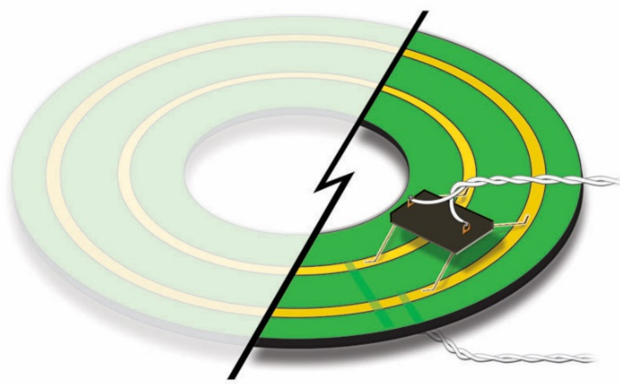

**Figure 6 – Ring Brush Configuration for a Single Twisted Pair**

The first area of concern that often arises is the sliding contacts themselves and their possible effect on random jitter.  Slip rings transfer signals across rotating interfaces by the use of sliding electrical contacts. These contacts are designed to minimize variation in contact resistance during sliding by the use of precious metal contacts, and typical values of 20 mohms results in noise less than 0.2 mV which is a full ***2 orders of magnitude less*** than the allowable coupled noise value of Clause 40.7.6.  This -74 dB noise contribution is insignificantly compared to other noise contributions outlines in Table 1. A recent paper presented at the IEEE Conference on Electrical Contacts discusses the negligible effect of electrical contact on data transfer[1].

The more significant effect of placing a slip ring in the transmission line is the effect that an impedance discontinuity has on the quality of the transmission line and the potential effect on deterministic jitter.  Special design provisions are made in slip rings for impedance matching, crosstalk protection, and low attenuation, but there is inevitably some effect on all the parameters listed in Table 1.  Since the TIA / EIA 568 cabling specification provides no assistance in evaluating non-cable, non-connector hardware, some judgment is required to develop appropriate specifications.  There are three possible techniques that can be used to specify a slip ring (or for that matter any other non-standard hardware) in a 1000BaseT transmission line.

1. The slip ring can be tested with 100 m of CAT 5e, CAT 6, or CAT 6e cable using a standard Gigabit Ethernet tester. These testers report on all the parameters specified in the appropriate TIA / EIA 568 specification and provide a pass / fail report. Since the cable specification allows for and specifies the parameters for a maximum of 100 m of cable, this method allows virtually no adverse contribution from the slip ring.  As Table 1 shows there is minimal margin between the IEEE 802.3 specification and the allowable values of a 100 m CAT 5e cable. There are some slip rings with very good performance parameters that can “squeeze in” under the margin, but using this specification strategy severely limits the size, complexity, and flexibility of the slip ring.
2. The slip ring can be tested with some amount of cable less than 100 m using a standard GigE tester. This method essentially allocates a certain equivalent length of cable to the slip ring.  For example, if the specific Ethernet installation requires only 20 m of installed cable, the slip ring specification can allow for testing of the slip ring with 20 m of cable.  The tester will then evaluate the slip ring and cable against the 100 m requirement, and the slip ring has the 80 m of cable performance as its allowable equivalent effect.   It is important to understand that both the ANSI / TIA / EIA 568 cable and 802.3 Ethernet specifications are very conservative, and there is no reason to add overhead to the test by adding unused cable.  In the case of the use of CAT 6 or 6a cable, using these performance parameters to evaluate slip rings serves to place additional performance constraints on slip rings that could reduce flexibility.  The CAT 5e requirement is closest to the actual IEEE 802.3 specification, so even if CAT 6 or 6a cable is used the evaluation requirement can be set to 5e on the cable tester. This provides additional margin for the slip ring.
3. A system loss and noise budget can be developed and compared directly with the Ethernet specification, or more specifically to the transmitter and receiver used in the system.  The ability to compare to the Ethernet requirement allows the designer to take advantage of margin achieved by better cabling (CAT 6 instead of CAT 5e for example).  The link budget can be defined using values from the cabling and connector standards, published slip ring specifications, and Ethernet transmitter and receiver specifications.  This approach provides the greatest flexibility to the slip ring performance.

## Summary

Cabling specifications such as ANSI / TIA / EIA 568 and ISO / IEC 11801 are frequently used to specify or evaluate non-standard components such as slip rings for use in IEEE 802.3 transmission lines, but these specifications are not designed for this purpose. They do however provide guidance, and test equipment designed around these specifications are handy evaluation tools. Proper evaluation of the test results require a clear understanding of the specific IEEE 802.3 performance parameters and a judicious use of the information provided by cable testers.

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[1]Dorsey, G, et al, High Speed Data Across Rotating Interfaces. IEEE Holm Conference, 2012, Portland, OR.