EtherNet/IP
Benefits of Industrial Connectivity in Industrial Applications

Camilo Aladro
Tanvi Desai
Bob Lounsbury

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1. Introduction to Ethernet

EtherNet/IP is the most mature and reliable Ethernet network available for industrial automation applications. The high speed of network protocol allows it to be used in applications where other networks fall short. EtherNet/IP utilizes both standard Ethernet and TCP/IP technologies and an open application layer protocol called the Control and Information Protocol (CIP). This is the application layer used in DeviceNet and ControlNet networks. All of these networks follow the Open Systems Interconnection (OSI) model which is shown below in Figure 1. This model defines the network application, from the physical connectivity to the user interface layer. The combination of all these technologies allows an enterprise to integrate industrial automation control devices with local area networks (LAN) or wide area networks (WAN) for consolidated data management.
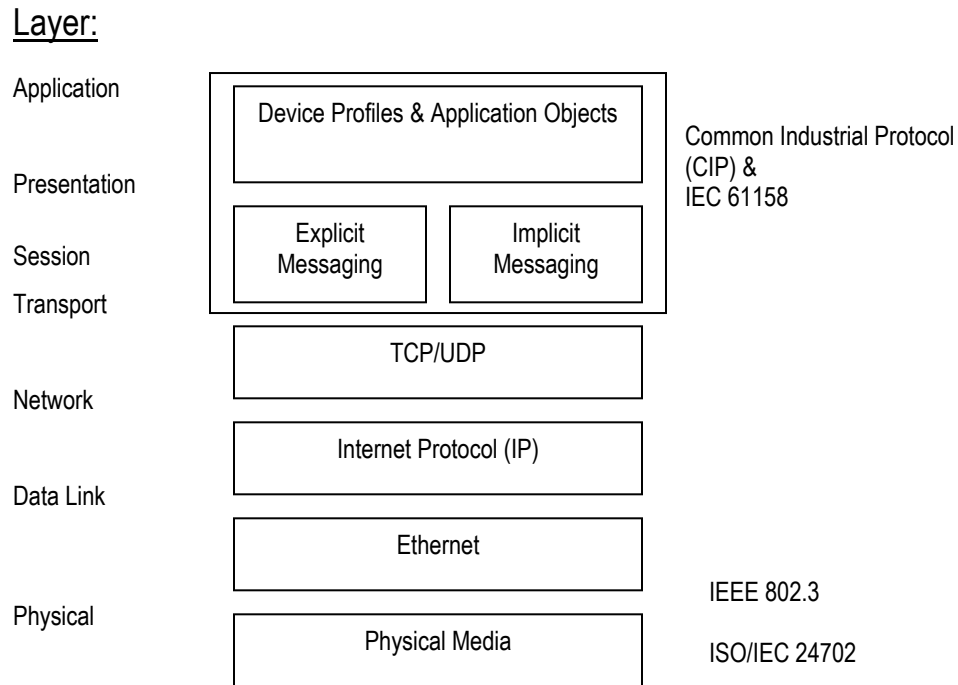
Layer:

Layer		
Application	Device Profiles & Application Objects	Common Industrial Protocol (CIP) &
Presentation		IEC 61158
Session	Explicit Messaging / Implicit Messaging	
Transport		
Network	TCP/UDP	
Data Link	Internet Protocol (IP)	
	Ethernet	IEEE 802.3
Physical	Physical Media	ISO/IEC 24702

Figure 1:EtherNet/IP Configuration of CIP

This paper covers the Physical Media requirements that are specifically designed to integrate seamlessly between the front office network and factory floor while providing superior performance in the harsh environments.

2. What is Industrial Ethernet

Over the past several years, Ethernet has evolved from a coaxial cable running at 10 megabits per second (Mbps) to twisted pair running data rates up to 1 gigabit per second (Gbps). For each phase of the evolution, the demands on the media and connector have substantially increased. Cable design has been optimized to have greater data throughput and to minimize both internal and external interference.

The migration from 10 Mbps to 100 Mbps was driven by the need to transfer more data within a shorter time. As video and audio find their way into the information stream, the demand for more data in a shorter time has propelled Ethernet into the next evolution of 10 and 40 Gbps data rates. Once again we find, through growth, that Ethernet is becoming useful in factory automation applications.

Unlike information networks, industrial control networks place a greater burden on the designers of system components. An industrial control network requires fast and guaranteed (deterministic) throughput to effectively control machines and manufacturing processes. Additionally, some industrial environments require a greater level of performance due to the elevated levels of noise and contaminants common to those installations.

Many industrial networks are required to be deterministic and have relatively low-message turnaround times. Recent optimizations to the protocol and higher data rates have solved this problem in Ethernet based systems. As the popularity of 100 Mb (Fast) Ethernet increases and component costs decrease, the use of Ethernet for control applications becomes increasingly attractive.

However, there are significant hurdles to overcome when using Ethernet in industrial environments. These can be grouped in two categories: Performance and Materials.

From a performance perspective, cables designed for higher-speed communications do not always translate to higher data rates in industrial environments. Due to operating conditions, it is more important to optimize the entire communications channel to yield the maximum possible throughput.

When choosing Materials, office-quality Ethernet products may not be suitable for use in some of the harsher industrial environments. In fact they may become a failure point if not properly designed and protected. In most instances, cable connector and component construction may need to be modified or optimized for use in some of the more extreme applications.

The first part of this paper will discuss the levels and types of noise common in industrial and manufacturing facilities.

In general, the higher the date rate the more sensitive the communication system will be to noise. In addition, from an Ethernet signaling perspective, the amplitude on the wire is less for 100mb/s systems versus 10mb/s systems. The amplitude for MLT-3 100Mb/s signaling (fast Ethernet) is about 1/2 that of manchestered 10Mb/s Ethernet. The overall symbol amplitude is greater for 100mb/s however the difference between a bit transition for 100mb/s is only 525mVolts Figure 2 as compared to 2.2 Volts in Figure 3 for 10mb/s Ethernet. This effectively reduces the s/n ratio for fast Ethernet. Fast Ethernet uses a sophisticated signal processing to help increase the S/N ratio in the PHY.
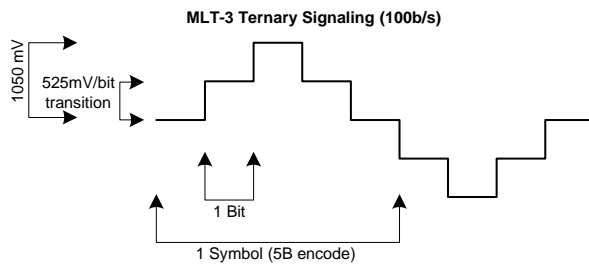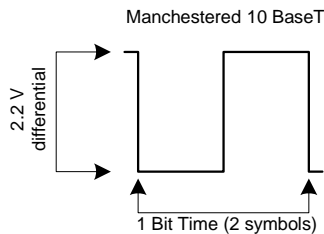

Figure 2 MLT-3 Data (100Mb/s Ethernet)

Figure 3 Manchestered Data (100Mb/s Ethernet)

Connectors play a vital role in the overall performance of the Ethernet channel. However, tests have shown that not all commercial, off-the-shelf RJ45 connectors designed for Ethernet networks are suitable for industrial environments. For

example vibration causes contact movement whereby eroding contact plating leading to contact failure. Performance may vary from manufacture to manufacture.

One of the primary concerns is the effect of vibration and repetitive shock. The connector design must be such that vibration does not degrade the contact surface area over time (specifically 30 micro inches gold over 50 micro inches nickel). Additionally, the RJ45 connector contacts must meet some minimum level of performance specifications such as balance which is common to industrial-rated connectors. Contact surface areas must be optimized for vibration and the lever arm (see Figure 4) must have enough normal force to minimize movement during vibration.
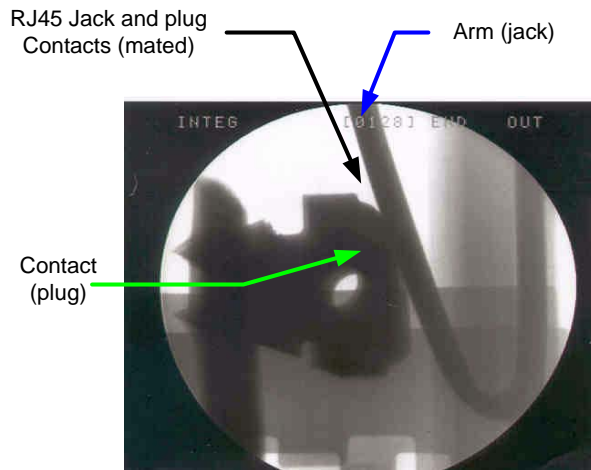
X-RAY of an RJ 45 Plug/Jack

Figure 4 X-Ray of an RJ45 Plug/Jack

Several off-the-shelf RJ45 connectors were evaluated in long-term vibration test simulation and exhibited no electrical discontinuity and minimal contact wear. Conversely, other off-the-shelf RJ45 connectors did not fare as well in identical testing, and quickly fell out of minimum performance specification. It is important to note that fretting due to micro contact movement and oxidation will eventually cause contact failure, and connector designs which minimize contact movement are preferable in areas in which vibration and shock are present.

Sealing an RJ45 for use in industrial areas represents a completely different challenge and can be achieved by providing a face seal around the connector-mating edge and cable entry point.

Deploying Ethernet into the plant floor requires the next level of communications and cable system performance.

For an office system, latency caused by link errors may go unnoticed. However, in a control system, link errors may lead to control jitter which may be unacceptable in some machine or process control applications.

To provide near deterministic performance, which may be mandatory in some control networks, network traffic must be minimized. Minimizing traffic requires optimization of the entire communications network and is in part accomplished by following proper installation guidelines, selecting the proper materials, reducing the influence of external interference and enhancing the electrical properties of the cabling infrastructure.

While network topology variations, increased wire speeds and the proper selection of active components can minimize collisions and errors and their effects, it is also important to minimize the number of errors caused by either deficiencies in the communications infrastructure or the operating environment itself. Equally important is the isolation of control networks from non-control networks through the use of firewalls and security measures.

Tests show that some industrial operating conditions (noise, temperature, etc.) can negatively affect the performance of a cabling system and, consequently, increase error rates. In addition, deficiencies in a cabling system's electrical properties, like impedance and cabling balance called Transverse Conversion Loss (TCL) have a negative impact on

data throughput performance.. The system common mode noise rejection (CMR) of a network is a function of the cabling TCL which can further add to error rates. As an example, the effects of worst-case impedance and capacitance unbalanced, coupled with the effects of temperature, can degrade system performance by anywhere from 7-14%.

This relationship of increased error rates and decreased performance (throughput) causes an increase in control jitter, which detracts from the network determinism.

In initial testing all off-the-shelf shielded and (unmodified) unshielded Ethernet cables examined, failed to meet one or more of the targeted industrial performance requirements.

Because of the presence common mode noise in many industrial environments, the CMR of the system should be as high as is technically and economically feasible. The tests indicate that the TCL for industrial communications cabling should be minimum of 56dB. To achieve high CMRR and minimize residual error rates the capacitance UN- balance of the cable must be kept below 0.5pf / meter, and the cabling system impedance should be controlled to less than +/- 5% from 1 – 32 MHz.
Minimizing impedance tolerance helps decrease residual errors caused by signal reflections.

The off-the-shelf cabling components can meet the capacitance UN-balance of 0.5pf/m but failed to meet the impedance tolerances and balance TCL

Tests have shown that unshielded Ethernet cables can be modified and optimized to provide an acceptable, in-spec performance. The advent of industrially-optimized unshielded cables should serve to offer the industrial user community a lower cost and less complex Ethernet cabling infrastructure versus shielded cabling solutions.

Testing has also shown that a cable's ability to meet the industrial operating standards targeted by this study is typically not in direct correlation with it's established ANSI/TIA/EIA Category rating.

From a connector perspective some off-the-shelf RJ45 connectors performed adequately when tested against the recognized shock and vibration specifications, yet others did not. The level of performance vs. specification varied among designs. Network and product designers targeting industrial environments should carefully select RJ45 connectors based on their performance versus shock and vibration specification.
Additionally, there are ongoing product enhancements and releases, which directly address shock and vibration and the IP65 and IP67 environmental sealing required in many industrial applications.

As mentioned earlier, to further ensure the highest level of determinism and system performance, switches should be employed in lieu of hubs, and careful consideration should be given to the operational/environmental limitations of the electronics selected.

Some electronics are designed for higher operating temperatures and humidity ranges. Conversely, some commercial-grade electronics have operational temperature, humidity, and noise immunity ratings that may not be acceptable in some industrial or manufacturing facilities. The selection of electronics is application-dependent, and the applications will vary from facility to facility.

3. Cost of Troubleshooting

There are several maintenance systems in use today, ie; Preventative maintenance, Condition Based maintenance and Maintenance upon Fail (Run to Failure). Some are more costly than others to support and present their costs at different times during the maintenance cycle. Preventative and Conditioned based maintenance plans present their costs up front and can be amortized across a period in time. Run to Failure maintenance programs are unplanned and present their cost at the back end. In general the troubleshooting and repair costs are lower for Preventative and Conditioned based programs. Conditioned based maintenance relies on continuous monitoring of vital network statistics and setting trigger thresholds. When a threshold is exceeded, the maintenance planning and execution begins. The effectiveness of a Condition based program relies on accurately defined thresholds which may only come

with experience. These types of maintenance programs almost always involve some level of troubleshooting due to the fact they do not begin until a problem is either immanent or has occurred. The difference between the two is one can be scheduled during down time and the other may not be feasible to schedule. Unscheduled maintenance is generally more costly to maintain in the long run. In fact too many unscheduled maintenance incidents can cause companies to become unprofitable due to materials waste, unproductive workers and loss of production output. The cost of troubleshooting a failed system is far more costly than troubleshooting a condition based system failure. In fact some production facilities have reported the costs of down time to be in the $100K to $1M per hour. In general once a machine goes down due to communications faults, it takes on an average of 3 hours to return production back to a normal state. This time is highly dependant on the application. Some applications may take a minimum of 8 hours to return the system to a normal running state.   In a Preventative and Condition Based maintenance programs, the maintenance and troubleshooting can be planned during off production times in most cases.

Maintenance Program	Relative Costs Associated with each Maintenance Program				
	Component	Materials Loss	Troubleshooting labor	Lost Production	Program Cost
Preventative based	Low	Low	Moderate (spread over time)	Low	Moderate to high
Condition based	Moderate	Low	Moderate (spread over time)	Low	Low
Run to failure	Potentially high	Potentially High	High due to potential overtime	High	Potentially high

4. Ethernet Topology

At the physical layer Industrial Ethernet (EtherNet/IP) supports two topologies. The most common topology is a star as shown in Figure 5 . Industrial Ethernet also supports active linear bus topologies as shown in Figure 6. Each will be discussed in detail in the following paragraphs.
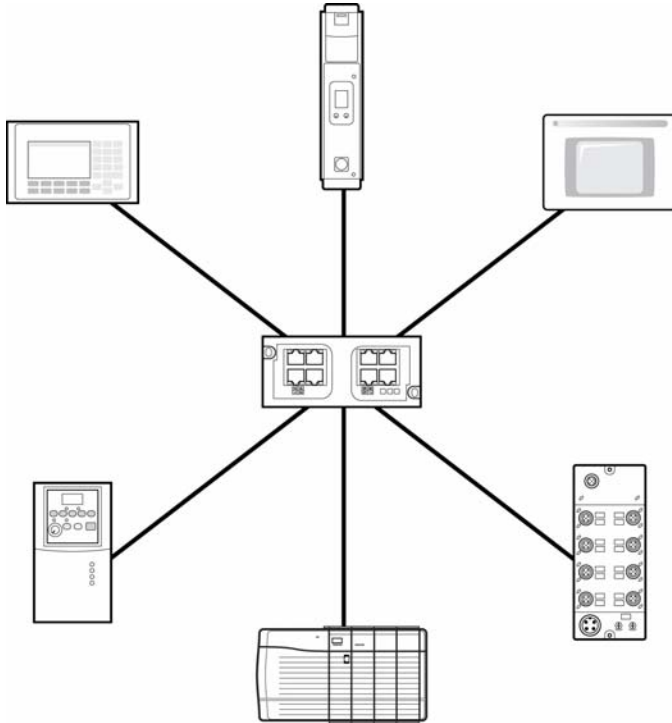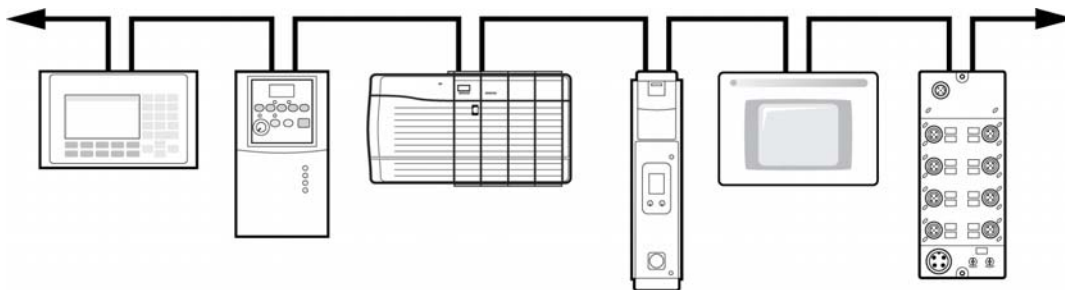
Figure 5 Star Topology

Figure 6 Active Linear Bus

Star topologies are built on generic cabling systems defined for commercial office buildings. This topology is ideal for supporting the many applications necessary for office applications such as telecommunications, data and video over the same cabling infrastructure. When constructed to the Generic Telecommunications standards the topology is often designed as a hierarchal star as shown in Figure 7. The hierarchal star topologies allow the expansion of the cabling system into coverage areas greater than 16000[1] square feet by cascading cross connect panels.

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[1] Assumes the star is centrally located within the coverage area. In cases where it is not, the coverage area is less.
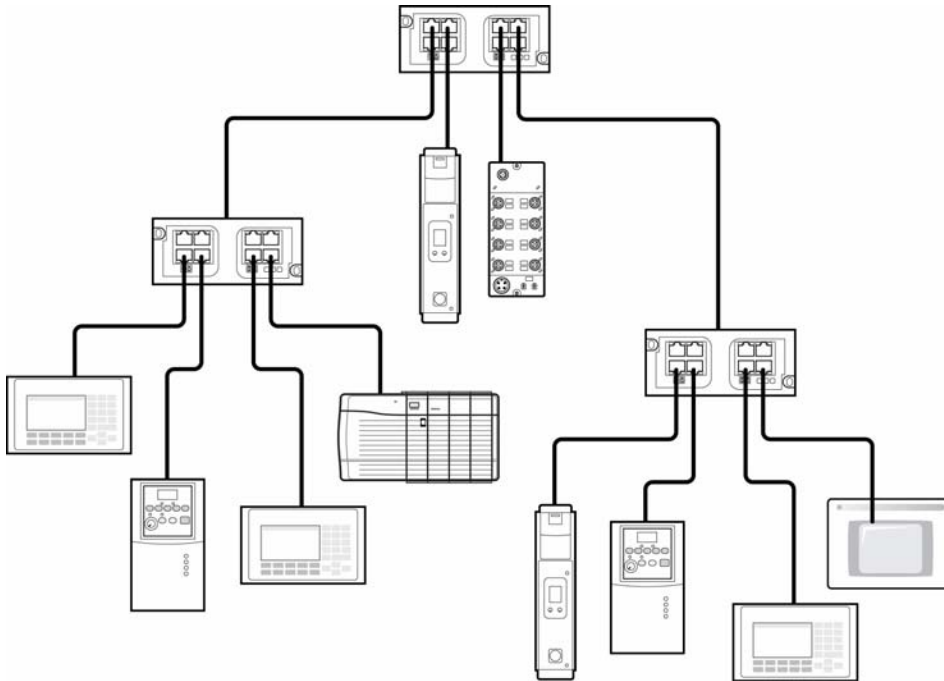
Figure 7 Hierarchal Star

In commercial office systems the location of the cross connects is based on coverage area. In an industrial controls application the cross connects located to serve the coverage area and the control of data. In addition the cross connects may be replaced with Ethernet switches. If only Ethernet switches are present, then the infrastructure can only support data.

Switch based architecture has a central point of failure where as a active linear bus topology does not. However communications downstream from a break are interrupted. Depending on the protocol, it is possible for an active linear bus network to form two smaller networks when the network is severed.

Redundant networks provide redundancy either by duplicating the network or by providing multiple paths for data in the event a path has failed. There are three types of redundant networks. The first is a complete duplicate of the other including active devices. The second is by providing paths in the hierarchal star between central points in each star as shown in
Figure 8. The last is a derivative of the active linear bus simply formed by connecting the two ends together[2] and is called a Ring Topology as shown in Figure 9. A single break in the ring does not cause the loss of nodes.
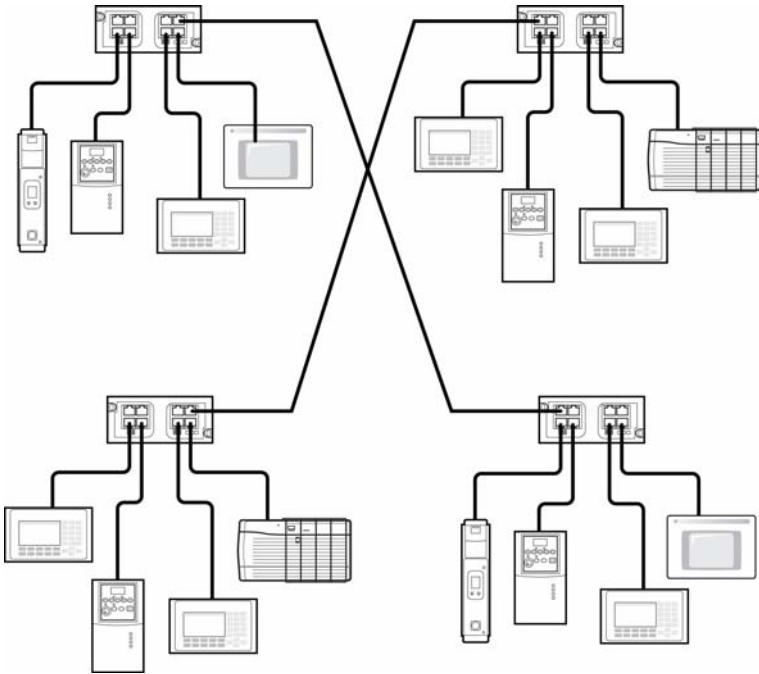
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[2] The protocol must support this feature.
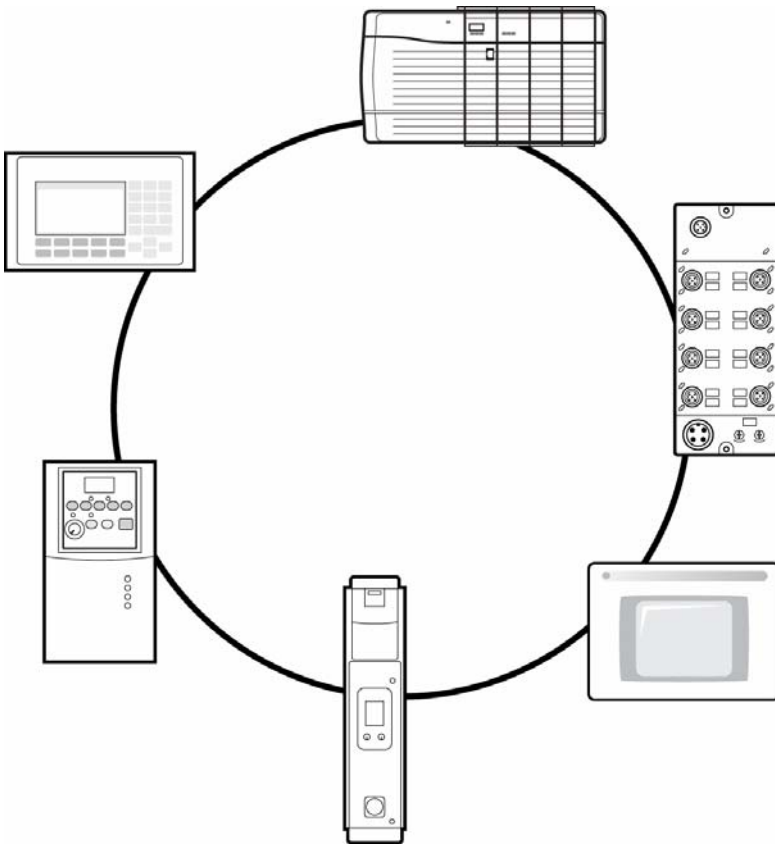
Figure 8 Spanning Tree

Figure 9 Ring Topology

5. Rockwell Automation Ethernet Connectivity Portfolio

Rockwell has selected Category 5e cabling as the mainstay performance. Category 5e cabling supports data rates to 1 GB/s. The main driving factor for selecting Category 5e cabling is its compatibility with 4 circuit connectivity. While Category 5e cabling supports 1 gb/s EtherNet/IP throughput needs are supported by 10/100Mb/s data rates.

Rockwell Automation's Cat5e cable was designed to provide a reliable network connection in harsh surroundings. By optimizing balance of twisted pair conductors inside a robust Thermoplastic Elastomer (TPE) Jacket, data is protected from noise, chemicals, and mechanical issues to $M_3I_3C_3E_3$ environmental protection levels. The cable is available in RJ45 patchcords for IP20 applications or in 4-pin D-coded M12 patchcords for IP67 applications where high vibration, fluids and other contaminants can threaten the reliability of a network. Two pair and four pair TPE cable is available, as well as a riser cable and a Plenum rated cable used for air duct applications.

Current Rockwell Products include:

Raw Cable Spools: All Ethernet cable is rated to Cat 5e, braided, unshielded, and 24 AWG. Cable has been designed with twisted pairs to preserve signal balance through the cable to provide noise immunity and return loss, which requires no termination of the shield.
Internal Link: http://ramilwapps02.ra.rockwell.com/Applications/Channel/abusa_chmk.nsf/Doc/EE98E378715167E85862573DF00685FFF?OpenDocument
External Link: https://channel.automation.rockwell.com/Applications/Channel/abusa_chmk.nsf/Doc/EE98E378715167E85862573DF00685FFF?OpenDocument

Jacket Material	Number of Conductors	Jacket Color	Applications
Robotic TPE	4	Teal	Flex
Robotic TPE	8	Teal or Red	Flex
Plenum PVC	8	Red	Use in air ducts
Riser PVC	8	Teal	Standard

M12 D-code field attachable (in Figure 1) insulation displacement connectors (IDC) are available in both shielded and unshielded housings. Male and female shielded connectors are available.
Catalog numbers: Male unshielded: 1585D-M4DC-H, Female Shielded: 1585D-F4DC-SH, Male Shielded: 1585D-M4DC-SH.

Figure 1 – M12 IDC Connector

M12 D-code overmolded pre-assembled patchcords (in Figure 2) are available with 2 pair TPE cable. The cable has been designed in a twisted pair which is durable for flex applications and provides better performance in applications with noise and vibration. The overmolded housing protects the integrity of the signal providing a reliable connection.
Catalog number: 1585D-M4TBDM-* (Replace * with cable length 2, 5, 10meters)

Figure 2 – M12 D-Code Overmolded Patchcord

Male 8-pin RJ45 connectors are available in both a crimp termination and a tool-less IDC (in Figure 3) connector for custom cabling. The RJ45 IDC connector is rated to CAT 6 and provides a simple, easy, reliable termination. The termination of the conductors maintains equal balance, unlike crimp connectors which may be difficult to terminate. The IDC connector requires no special tools because by stripping the cable jacket and placing the conductors in the proper location, a rugged connection is made.
Catalog number: 1585J-M8CC-H

Figure 3 – RJ45 IDC Connector

Male 8-pin RJ45 pre-assembled patchcords (in Figure 4) are available with two pair TPE cable; four pair TPE cable; four pair Riser cable; and four pair Plenum cable. The ruggedized RJ45 plug is designed with a robust metal retaining assembly that helps to firmly hold the cable strain relief in place. The strain relief provides protection for the cable while allowing for the proper bend radius and maximizing flexibility.

Catalog numbers: Riser PVC Jacket: 1585J-M8PBJM-*, TPE Robotic Jacket: 1585J-M8TBJM-*, Plenum Jacket: 1585J-M8MBJM-*
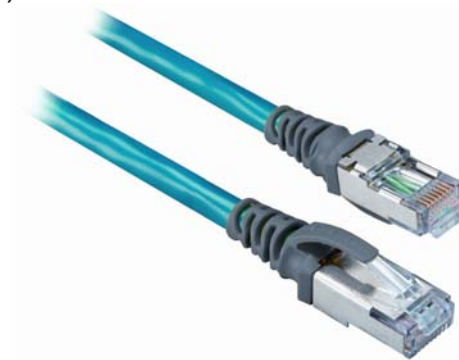(Replace * with cable length 2, 5, 10meters)

Figure 4 – RJ45 Patchcords

Rockwell Automation's M12 to RJ45 bulkhead connector (in Figure 5) provides an elegant transition for network architecture from an IP20 setting to an IP67 environment, in cabinet to an on-machine solution. The adaptor also provides the proper termination for 4 pair cables as defined by the standards. Furthermore, the adapter can be used to connect remote junction boxes or implement an On-Machine solution with Armor I/O products.
Catalog number: 1585A-DD4JD

Figure 5 – M12 to RJ45 Bulkhead Adapter

Rockwell Automation's Ethernet media portfolio provides reliable connectivity to maintain network integrity and prevent costly downtime from troubleshooting.

6. Technical Data

Abate noise

Industrial Ethernet began with studies to quantify the performance from both an electrical and mechanical perspective. The studies showed that electrical noise abatement is required. Since the emission of noise levels cannot be reduced, noise enhanced cabling designs and mitigation is required. Studies showed that the level of cabling enhancements required exceeded technical and cost feasible levels for cabling. Therefore a balance of component enhancements and installation constraints is required. The greater the component enhancements the greater the component costs. The greater the cabling protection the greater the installation complexity and material costs will be. Bit Error Rate (BER) can be broken into two types in a communications system. The first being, burst errors and the second being residual errors. Each has its own dependencies. Burst errors are caused by the emission, conduction of noise those ingresses into the cabling system. The magnitude of the coupled noise is dependant on many things including the imbalances in the cabling system. If we consider a cable with LCTL (Longitudinal Conversion Transfer Loss) as shown in Figure 10 below, one can see the direct relationship between BER and LCTL.
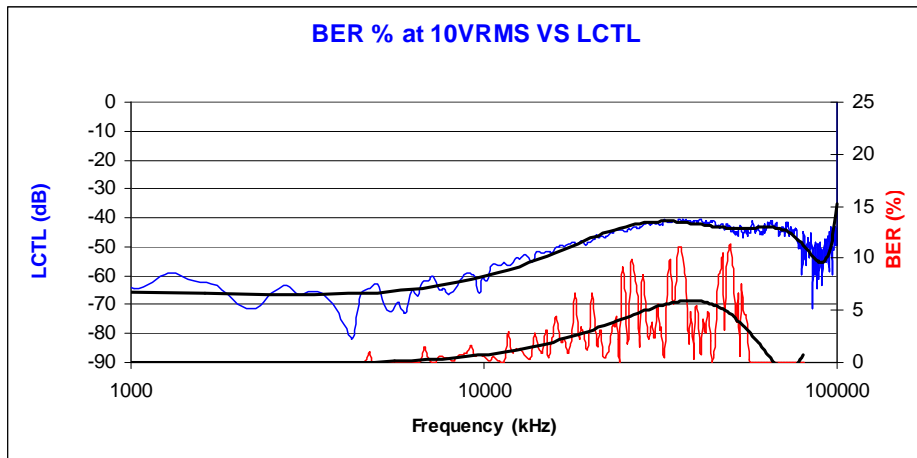

Figure 10 BER Versus Conducted RF

Residual errors are errors that occur as a function of imperfections in the cabling system and are not always noise related. Imperfections in the cabling system such as Return Loss, Pair cross talk will cause an abnormal level of errors to occur in the communications network. Poor quality cables or connectors, too many connectors in a channel can degrade the RL and cross talk performance. Figure 11 below shows how poor RL performance of a patch cord can negatively affect the packet error rate.
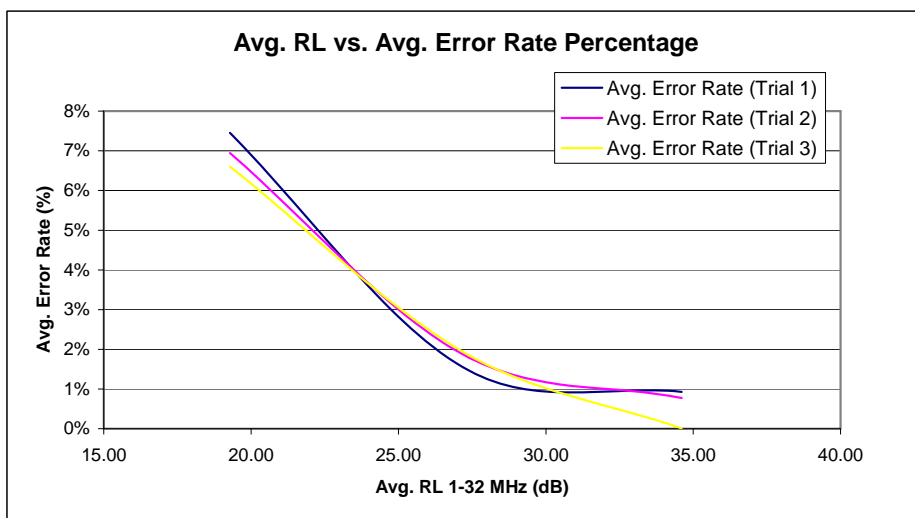

Figure 11 BER Versus Return Loss

In addition there are concerns that placing UTP cable constructions in small diameter metallic conduit can further degrade the return loss of a cable. Figure 12 below shows a slight shift upwards in the return loss for a cable installed in a conduit.
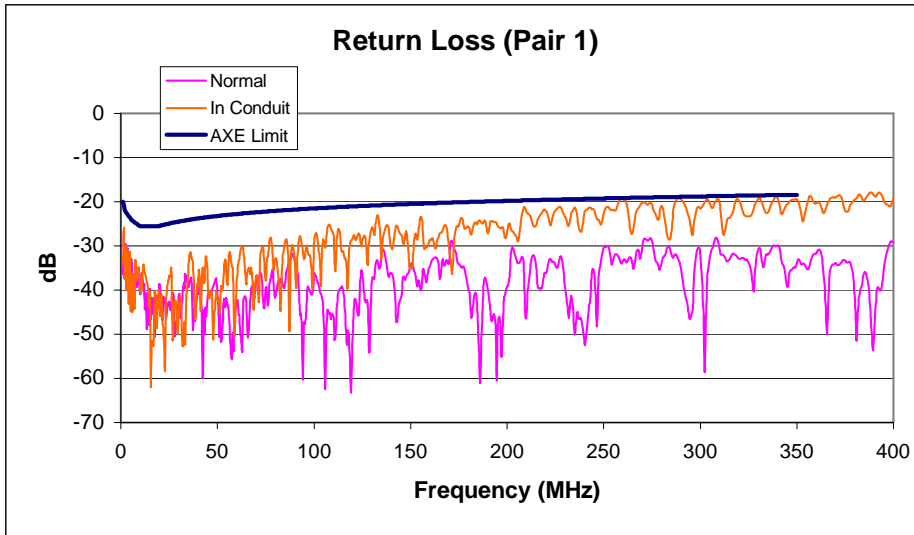
Figure 12 RL In and Out of Conduit

Based on the studies of several companies (including Rockwell Automation) it was found that there is a acute need for enhanced cabling balance and coupling attenuation (for UTP, ScTP respectively) to achieve better noise immunity. The Rockwell Automation study showed that the balance for UTP cabling needed to be roughly 56dB for zero mitigation. The balance of 56dB is not technically or economically feasible with today's technology. In the fall of 2006 the first international standard was published that set balance and coupling attenuation for industrial cabling. These values are technically feasible, however as with anything new on the market, there is a cost associated with these enhanced cables. As mentioned earlier, in November of 2006 ISO/IEC released the first international standard in support of Industrial Telecommunications networks. The published balance and coupling attenuation values can be found in Table 1, Table 2 and Table 3 below.

Table 1 TCL for Cabling

Class	Frequency MHz	Environmental classification		
		E1	E2	E3
		Minimum TCL (dB) UTP Cable Types		
D	$1 \leq f \leq 30$	53-15 x log (f). 40 max	63-15 x log (f). 40 max	73-15 x log (f). 40 max
	$30 \leq f \leq 100$	60.4 – 20 x log (f)	70.4 – 20 x log (f)	80.4 – 20 x log (f)
E	$1 \leq f \leq 30$	53 – 15 x log (f)	63 – 15 x log (f). 40 max	73 – 15 x log (f). 40 max
	$30 \leq f \leq 250$	60.4 – 20 x log (f)	70.4 – 20 x log (f)	80.4 – 20 x log (f)
F	$1 \leq f \leq 30$	53 – 15 x log (f)	63 – 15 x log (f). 40 max	73 – 15 x log (f). 40 max
	$30 \leq f \leq 600$	60.4 – 20 x log (f)	70.4 – 20 x log (f)	80.4 – 20 x log (f)
NOTE: Values above 100 MHz are for information only				

Table 2 ELTCTL for Cabling

Class	Frequency MHz	Environmental classification		
		E1	E2	E3
		Minimum ELTCTL (dB) UTP Cable Types		
D. E and F	$1 \leq f \leq 30$	30 – 20 x log (f)	40 – 20 x log (f)	50 – 20 x log (f). 40 max.

Table 3 Coupling Attenuation for Cabling

Class	Frequency MHz	Environmental classification		
		E1	E2	E3
		Minimum Coupling Attenuation (dB) Shielded Cable Types		
D	$30 \leq f \leq 100$	40	50	60
E	$30 \leq f \leq 250$	80 – 20 x log (f). 40 max	90 – 20 x log (f). 50 max.	100 – 20 x log (f). 60 max.
F	$30 \leq f \leq 600$	80 – 20 x log (f). 40 max	90 – 20 x log (f). 50 max.	100 – 20 x log (f). 60 max.

NOTE: Coupling attenuation applies to maximum frequency of class and beyond that to 1 GHz for general EMC information.

There are three levels called classifications for noise detailed in the table (E1, E2 and E3). The balance called TCL (transverse conversion loss) and ELTCTL (equal level transverse conversion transfer loss) is a function of the expected level of noise in the environment local to the cabling.

Rockwell Automation set out to find world class cable suppliers to work closely with in the development of the most cost effective and technical solution to minimize the installation constraints and requirements. These high tech cables provide low noise, high flex, chemically resistant cabling for the most harsh environments.

7. Cable Performance

In the previous chapter we covered the technical aspects of the cabling system. In this chapter will cover the cabling performance. There are several aspects that make up the cable performance. The ability to reject noise is only one attribute that must be considered when selecting cables for your system. The following is a simple list of attributes to consider;

Environmental aspects
Flexing
Weld Splatter
Connectors
Grounding and bonding.

All of these attributes contribute to the cabling performance. Some are in conflict with each other. For example, high flex cabling requires special stranded constructions that sometimes require exotic alloys. The insertion loss of stranded cables is considerably greater (x 1.4) when compared to solid copper constructions. Fortunately, there are no technical tradeoffs for balanced cabling that has been optimized for noise. In a given environment, electromagnetic noises are present in various levels and frequency spectrums.
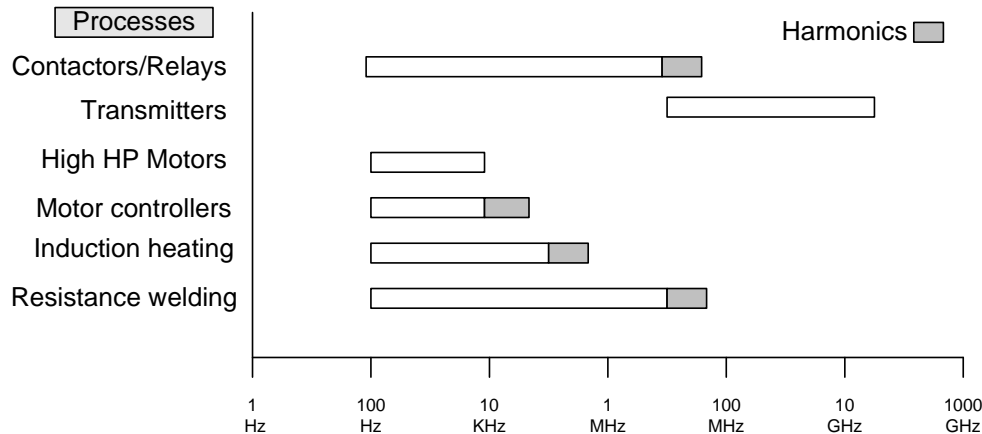

Figure 13 Frequency spectrum of Noise

The noise Ingress mechanisms are a function of the frequency and type of noise type. For example; the noise generated by nearby high power transmitters or machinery producing electrical fast transients may have two ingress mechanisms, conducted through cables and radiated directly into the equipment. In general conducted noise both RF and Electrical Fast transient are common mode to all the conductors within the cables. In the case of balanced twisted pair cables, the cables ability to reject these types of noises is based on how well the pairs are balanced (conductor #1 = conductor #2). The balance is quantifiable and is expressed in dB.
Recently standards organizations have assigned balance specifications for Industrial Ethernet UTP cabling, known as TCL and ELTCTL. The magnitude of the TCL and ELTCTL is based on where the cabling will be installed with regards to the noise generating equipment (see MICE concept). Rockwell Automation has played a large role in the setting of these values and the development of the MICE concept. The levels were based on early on performance testing of off-the-shelf cables in the presents of noise. In the end, Rockwell Automation

has worked with a multitude of cable vendors to create a new bread of cables that have optimized performance characteristics to minimize the effects of noise, making installation much less complex for the end user.

The Figure 14 and Figure 15 is a prediction of a cable noise rejection based on the TCL of two opposite end cables in the presents of 10V common mode noise. Figure 14 shows the predicted differential noise of a poorly balanced cable. The red line is a marker at 0.05 volts which represents a typical fast Ethernet lower end sensitivity. Noise above this line will have a direct impact on the S/N in the channel.
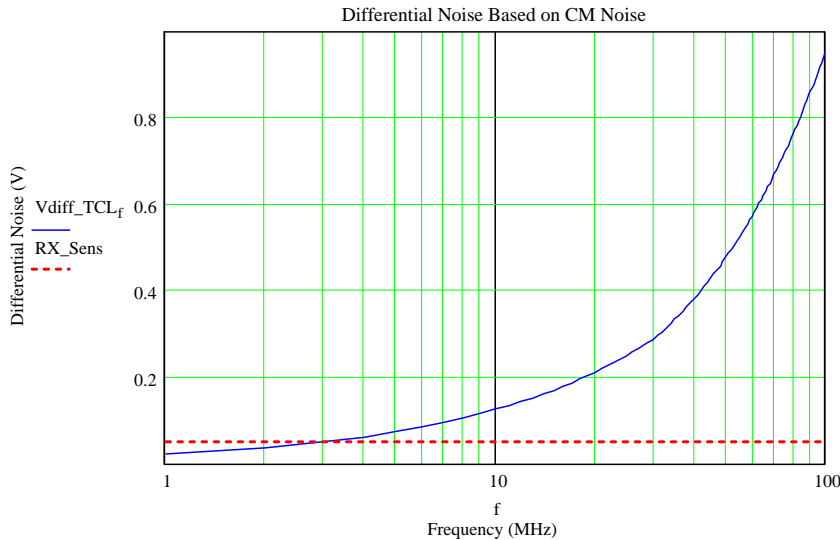

Figure 14 Predicted Differential Noise caused by 10V CM noise TCL = E1

When the cable's TCL is improved the predicted performance also improves. Note the differential noise voltage remains below the RX sensitivity until the frequency reaches 53 MHz, which is above most of the noise generated by common processes in the factory (see Figure 13).
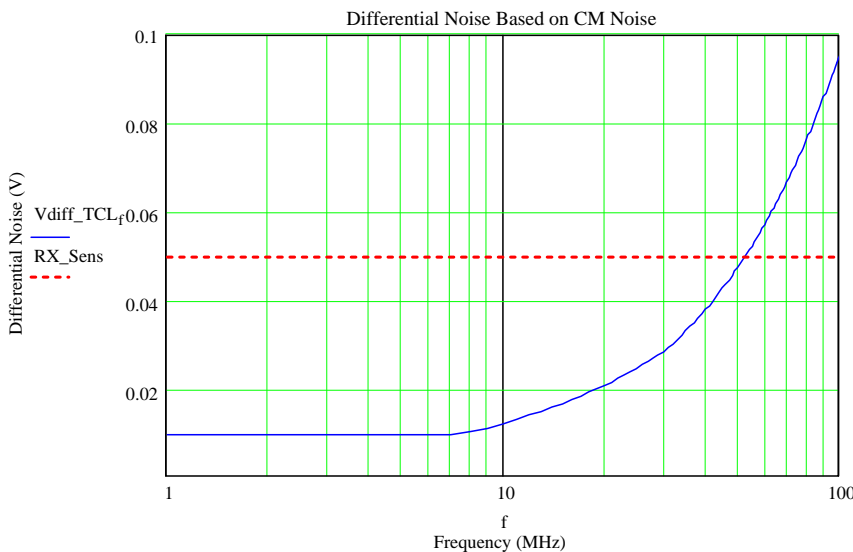

Figure 15 Predicted Differential Noise caused by 10V CM noise TCL = E3

There are three important transmission performance attributes necessary for reducing errors in the system, 1)Return Loss, 2) Balance and 3) Insertion loss. When all of these parameters are optimized the network yields the best performance possible in most environments. Insertion loss can be corrected by reducing the channel length.

Improved Balance Means Less Noise Problems
A mix of cables including cables with improved TCL were placed on a special cable test fixture (Figure 16) and subjected to common mode noises while passing MLT3 data at 100 Mb/s (Fast Ethernet). The number of transmitted bits and number received bit errors were

collected during the test. A test frame as defined in standard ANSI X3.263 (TP-PMD Standard) was used to evaluate the cables and to provide consistent results.

Figure 16 Cable Test Fixture Conducted Immunity

It was confirmed that Rockwell Automation's optimized cables do perform better than others in the presents of noise with less mitigation. The following graph in Figure 17 demonstrates the improved TCL and BER performance in noise.
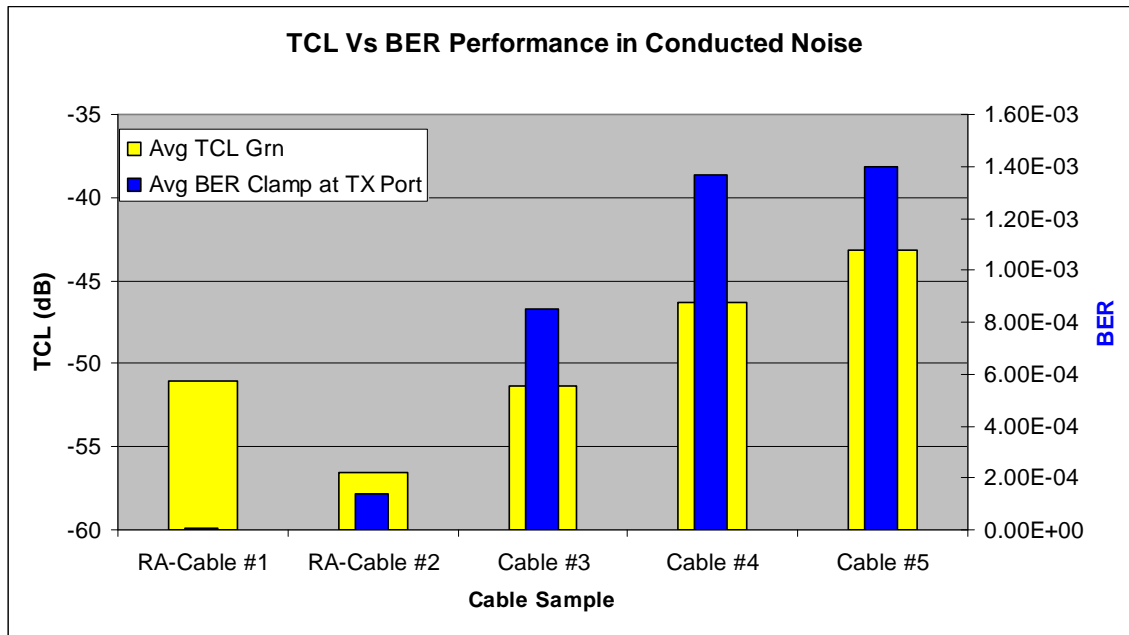

Figure 17 BER Performance VS TCL

The average BER (blue bars) improves as the TCL improves (yellow bars). When the TCL is improved as in the case of Cable #1 and CS2003, then there are other limiting factors that can impact the cable performance. The BER tests were performance using full 100M segments of cable. A low BER means an increase in Throughput. As the attenuation of the cable approaches the allowable channel limit line, the error rates will tend to increase.

8. Conclusion

Ethernet technology is becoming more popular in industrial applications. Higher speeds, more data transfer within a shorter amount of time, and a reliable, long lasting solution will be the focus for many industrial applications. This paper explains the important factors that should be taken into account when selecting an Ethernet solution. This includes the technical aspects that make one cable better than another considering noise, vibration, electrical, mechanical, and overall cable performances as well as various Ethernet topologies.

When considering the connector, minimizing contact movement will cause less vibration and shock problems which will give a better connection, unlike with contact movement and oxidation which will eventually cause contact failure. Minimizing traffic also provides better performance. This requires proper infrastructure analysis of electrical properties, external interference, and proper materials. Degradation of the cable is caused by error rates related to the impedance, balance (TCL), and common mode noise rejection (CMR). It is tested that maximum CMR and minimum TCL provide the most reliable cable.

Implementing Ethernet in an infrastructure requires the proper physical layer. There are many types of Ethernet topologies. The star topology supports the cabling of many applications. Hierarchal star topology supports more area coverage. Spanning tree topology which is a hierarchal topology with a path in between the central points supports redundant networks. Finally a ring topology connects the two ends together, keeping all connections regardless of a break in one of the nodes.

Electrical and mechanical performance is very important to consider when selecting an Ethernet cable. Error rates, imbalances in noise, return loss, cross talk, diameter size, and attenuation can all cause negative effects in a cabling system, therefore should be closely evaluated. Unshielded cables provide less installation mishaps, and tolerate noise environments. The design of Rockwell Automation cable provides enhanced performance with the conductors designed in a twisted pair to withstand harsh environments.

Rockwell Automation's portfolio provides a reliable solution addressing the EtherNet/IP standards and requirements. All Ethernet cable is unshielded, CAT5e, chemical resistant, low noise, and offered in a variety of cable jackets, Thermoplastic Elastomer (TPE), Riser PVC, and a Plenum. The TPE cable is a flex rated cable specified for 10 million cycles. For less harsh industrial environments, the Riser PVC cable is sufficient, and for air duct applications the Plenum cable is recommended. The tests and analysis performed demonstrates that Rockwell Automation Ethernet cables utilize a market leading design. Analyzing the cabling system, keeping proper maintenance and troubleshooting for failures will reduce downtime and in turn offer cost savings. Overall, Rockwell Automation cables have been specially designed for harsh and industrial environments which offer a dependable solution.