RUGGEDIZED ETHERNET CABLES FOR AUTOMOBILES

Introduction

High Speed Ethernet for automotive applications has been in place for several years. The common thought among most automotive and related industry people is that Automotive Ethernet is used to surf the internet or provide movies and games to entertain the children during long trips in the car. The future of the Automobile and how we drive, is changing and is changing very rapidly.

The following is an article in published in the Bloomberg news August 18, 2016.

"Starting later this month, Uber will allow customers in downtown Pittsburgh to summon self-driving cars from their phones, crossing an important milestone that no automotive or technology company has yet achieved. Google, widely regarded as the leader in the field, has been testing its fleet for several years, and Tesla Motors offers Autopilot, essentially a souped-up cruise control that drives the car on the highway. Earlier this week, Ford announced plans for an autonomous ride-sharing service. But none of these companies has yet brought a self-driving car-sharing service to market.

Uber's Pittsburgh fleet, which will be supervised by humans in the driver's seat for the time being, consists of specially modified Volvo XC90 sport-utility vehicles outfitted with dozens of sensors that use cameras, lasers, radar, and GPS receivers. Volvo Cars has so far delivered a handful of vehicles out of a total of 100 due by the end of the year. The two companies signed a pact earlier this year to spend $300 million to develop a fully autonomous car that will be ready for the road by 2021." [1]

Safety and fuel economy are another major concern for Automobile manufactures.   Most new vehicles are now equipped with cameras that detect cars located in the "blind spots" and provide automatic braking if a vehicle or other object is rapidly approaching. These devices are stepping stones towards autonomous driving vehicles.   Others are envisioning automobiles electronically linked, like cars in train, traveling along interstate highways to increase fuel economy and reducing drag.

Ethernet cables will play small yet significant and important role in the development of autonomous vehicles.   The OPEN Alliance has developed many standards, including the electrical performance parameters for the network physical layer, including the cable and connectors for a single twisted pair cable capable of 100 mbit/second and 1000 mbit/second data transmission.

A single twisted pair Ethernet Cable offers advantages over Ethernet cables such as LVDS, Star-quads and Coaxial cables and even fiber optic. These advantages include lower cost, reduced weight, reduced space and lower connectivity cost.
This is the first in a series of white papers that will address Automotive Ethernet twisted pairs:

- Concept and function
- Cable design
- Cable manufacturing
- Quality assurance and testing
- Cable harnessing
- What the future may bring

Concept and Function of Ethernet Cables

The first twisted pair design was conceived and used by Alexander Graham Bell in 1881 to send analogue voice signals from one place to another for very long distances. The twisted pair concept is very simple, consisting of copper wire insulated with a dielectric insulator and twisting the two wires together. An electrical signal is sent through the twisted pair.

Today's digital technology utilizes a "differential signal". A differential signal is a method to electrically transmit data using two complementary signals. The same electrical signal, *opposite in polarity*, is sent through each conductor of the pair which determines the value of the digital signal (digital signals are binary, either "on" or "off", i.e "0" or "1").

In order to transmit a stream of binary values at a high rate or high frequency, it is critical that the quality of an electrical signal and its signal integrity is maintained in the transmission line, in order to assure data can be sent and read without errors. The following criteria are used to assure the cable / transmission line is acceptable.

- **Characteristic Impedance**
- **Insertion Loss**
- **Return Loss**
- **Conversion mode**

Characteristic Impedance

The Impedance requirement for the OPEN Alliance = 100 +/- 10 ohms. It is important to meet the impedance requirement, because it is a major factor, contributing to other electrical parameters such as insertion loss and return loss.

There are two major parameters that determine the Characteristic Impedance of a twisted pair:

- Distance between the conductors
- Dielectric constant of the insulation materials

Any material surrounding (shields or cable jackets) or near other objects (cables in a harness) the twisted pair, will also have an effect on Characteristic Impedance.

Insertion Loss

Insertion loss is the loss of signal power from the device through the twisted pair. Insertion loss is affected by the following parameters:

- Characteristic Impedance
- DC Resistance
- Dielectric Constant
- Dissipation Factor

Return Loss

Return loss is the loss of power in the signal which is reflected (think of an echo) by a discontinuity in the transmission line. This reflection is typically an impedance mismatch, in the line or termination point.

Conversion mode

This parameter is used to measure the uniformity of each lead wire in the twisted pair. Uniformity is defined as dimensional uniformity and electrical uniformity (matched DC resistance, capacitance dielectric constant). A perfectly matched pair is more immune to outside interference and radiates less electrical energy, thus reducing the need for shielding. The external electrical signals impact both twisted wires identically, thus minimizing the impact to the differential signal. It is critical that the twisted pair is symmetrical and balanced in order to maximize the conversion mode performance.

Cross-Talk

Cross talk occurs when the signal from one pair is radiated to another twisted pair. A common analogy sometimes occurs on a telephone line when you hear a second conversation over the phone. Obviously, this is an unwanted characteristic that can contaminate a data signal and make it unreadable. Crosstalk is measured in DB. A low crosstalk DB value is desired. Since the OPEN Alliance automotive Ethernet cable consists of a single twisted pair, this is not an issue. However, if there are multiple pairs in wiring harness, "alien" cross talk can become an issue. Alien crosstalk can only be measured in the cable harness and not in the Ethernet cable alone.

Digital Twisted Pair

Technology for telephone transmission changed from using analogue to digital signals beginning in the 1960's. Computer Ethernet networks systems changed from coaxial network cables to twisted pairs in the mid to late 1980's. In general, for non- broadband and short distances, twisted pairs are preferred over coaxial cables. Twisted pairs have faster data rates, are less expensive to purchase and install and use less space and are lighter weight.

EIA/TIA created committees and standards groups that created requirements for Ethernet Cables. As the technology for the PHY software and twisted pair cables increased, 100 megabits /second speeds were achieved in the 1990's for 4 pair category 5 and 5E cables, which are the standard today for most home and office network applications. Higher speed Category 6A, and 7A are also available with data rates up to 10 gigabits/second. These standards are based on 100 meter cable lengths.

Cable length plays an important role in data transmission rate. Data signal strength is reduced over the length of a cable. Therefore, the shorter the cable length, potentially, more data can be transmitted. When the EIA/TIA committee set standards for cable length, 100 meters was chosen as the cable length, to use in the home and office environment.

The OPEN alliance recognizes that a car does not need 100 meters of cable for data transmission and instead chose 15 meters for its standard Ethernet cable length. That is one of the reasons why up to 1000 mbits/second can be transmitted over a single twisted pair. The 15 meter length also allows for the opportunity to use dielectric materials more suited for automotive applications.

Materials, The Ethernet Cable foundation

As we mentioned in the paragraphs above, a twisted pair is a fairly simple design. It comprised of two conductors each with a dielectric insulator that are twisted together.

Conductors

The typical Ethernet cable uses a solid copper conductor for stationary Ethernet cable and a stranded copper conductor for patch cables. Copper an excellent choice for a conductor, its conductivity $58.5 \text{ X } 10^6$ is second only to silver $62.1 \text{ X } 10^6$. Copper is typically the conductor of choice due to lower cost and ease of termination with most connectors. Although aluminum is lighter weight its conductivity is $36.9 \text{ X } 10^6$, much worse than copper, and has many issues with standard crimp terminations.

Solid copper conductors are best suited for Ethernet cables and work well in static applications where there is little movement or vibration. Stranded copper conductors are used for patch cables, because the cables are bent and twisted many times when the cable is reconnected from one network port to another.

The automotive environment has similar needs as patch cable systems. Due to the constant vibration and jarring movements of a vehicle ("strumming"), automotive wiring uses stranded copper conductors consisting of seven strands or higher. Solid conductors will typically break early in the life cycle in an automotive environment.

The geometry of the multi stranded conductor, creates more issues to send a differential signal than the uniform circular solid strand conductor. This is one of the challenges of automotive Ethernet.

Dielectric Material

Standard Ethernet cables use one of three insulations. Polyethylene, Polypropylene and Teflon (typically FEP). These insulations are chosen due to their excellent dielectric properties, including dielectric constant and dissipation factor. Other insulations such as PVC have much higher dielectric constants and change with temperature.

Dielectric Constant/Relative Permittivity

Permittivity is the material property that affects the Coulomb force between two point charges in the material. Relative permittivity is the factor by which the electric field between the charges is decreased relative to a vacuum. In layman's term a high dielectric constant material acts more like a capacitor and captures and stores the electrical signal. Therefore, a low dielectric constant insulation material is preferable to assure the signal reaches its destination without detrimental loss.

A dielectric constant of 2.5 or less is a preferable choice for insulation materials. It is also very important to mention, the dielectric constant can change with temperature and frequency.

Dissipation Factor/Loss Tangent

Dissipation factor is defined as the reciprocal of the ratio between the insulating materials capacitive reactance to its resistance at a specified frequency. It measures the inefficiency of an insulating material. The higher the dissipation factor, the more signal is lost through the transmission line. Again, like the dielectric constant, the dissipation factor changes with frequency. It is very important to know the dissipation factor of a dielectric material over the desired frequency range.

Ethernet cables for the Auto Environment

The automotive environment is much different than the home or office. The automobile can be exposed to temperatures ranging from -40 to 150°C and even as high as 200°C. There is potential exposure to many chemicals, oils and moisture.

We mentioned the need for stranded copper due to vibration and jarring movements in an automobile. The cable insulations in an automotive environment need to be able to have good abrasion, cut through and fluid resistance as well as resistance to extreme temperatures.

Numerous automotive wiring standards have been written for wire and cable used in an Automobiles. Some common standards are:

- SAE J1127, 1128

- JASO
- ISO 6722-1

Each of these standards has a long list of requirements for wire and cable used in automotive applications. We often tell our new associates, “every requirement written in these standards has a story of some wiring disaster that occurred at one time or another”. Usually, these “wiring disasters” happened when an engineer selected a wire that had an “Achilles Heel” that no one suspected would cause a problem. When designing Automotive Ethernet cables, we do not want to repeat those disasters.

Selecting a conductor is a relatively easy choice. A stranded copper conductor works well for both Automotive and Ethernet applications. The choice of dielectric materials become much more complicated due to the bumpy marriage of Automotive and Ethernet requirements.

[1] “Uber’s First Self Driving Fleet Arrives in Pittsburgh This Month” Bloomberg Businessweek, August 18, 2016

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