Electromagnetic Compatibility (EMC) Assurance of Automotive Signal/Data Transmission for Vehicle Transportation Systems

PROJECT PROGRESS REPORT - PHASE 2

Communication Structures, EMC Test Methodology and Frequency Domain Analysis

Submitted by

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1. Background

This report is prepared as a progress report for Phase 2 of the CTEM research project funded by the grant ***(Grant Number: G00000245)***. The report is submitted to Director of CTME for consideration for continuing funding for Phase 3 (last phase) of the project. Progress report for Phase 1 of this project has been submitted to Director of CTME in June, 2009.

The project focuses on various aspects of Electromagnetic Compatibility (EMC) and its significance to today's automotive signal/data communication systems that include navigation, communication, safety, information and entertainment. The requirements of high speed data transmission network (interconnecting wiring and connection system) to connect various systems are discussed. The importance of EMC assurance to minimize the system's emissions and susceptibility to electromagnetic Interference (EMI) was presented.

The research focuses on the identification of critical parameters that affect the performance of the data transmission network and the development of test methodology and analytical techniques to properly define its performance characteristics.

The project develops an unique test instrument to perform measurement of RF shielding effectiveness and RF (Radio Frequency) attenuation against Electromagnetic Interference (EMI) for the data communication transmission structures. The instrument will be a low cost alternative to the existing commercially available unit with greater flexibility, measurement efficiency and more user-friendly. The instrument will be used in designing the test configuration to perform measurement of transmission line parameters. Via industrial collaborations, test results will be compared to those measured at an automotive EMC laboratory.

The project will also provide EMC training for the students due to the increased demands for EMC engineers in design and testing of electrical/electronic systems. 4 students from YSU's Electrical & Computer Engineering department have been recruited to work on this project with technical training provided by the project investigators. This project will allow the investigators to develop EMC training sessions (to be embedded in existing Electrical Engineering Technology Courses) for YSU students in the Electrical Engineering Technology program.

Phase 3 of this project can be initiated with the approval of the YSU CTME administrator.

Project Outline and Deliverables:

A. Phase 1: Identification of transmission parameters (Functional EMC) and test methodology development in the laboratory

1. Assessment on Automotive Data Communication Systems
2. Development of concept for EMC Environmental Tests
3. Identifications of EMC Environmental Parameters
4. Identifications of EMC Functional Parameters
5. Identifications of Transmission Line Parameters

B. Phase 2: Focus on the development of the test procedures and measurements for the emissions characteristic (environmental EMC) of various transmission lines and connection systems.

1. Identifications of automotive communication architectures
2. Measurement Configurations (Functional) Development
3. Measurement Configurations (Environmental) Development
4. Design and development of RF Shielding effectiveness/RF Attenuation tests equipment
5. Work force Development and student training

C. Phase 3: Focus on the technology implementations, institutionalization of the student training and potential collaboration with the industry.

1. Construction of test instrument for frequency domain measurement
2. Implementation of test instrument in test configurations
3. Comparison measurement with standard industrial instrumentation
4. Measurement of data communication transmission lines: Functional and Environmental
5. Initiation of collaboration with industry: Comparison of with measurement data from automotive laboratory
6. Implementation of Data analysis/summary
7. Initiation of Work Force Development – Integrate EMC concept into Electrical Engineering Technology classes

This Phase 2 progress report summarizes the deliverables of phase 2 of the project (progress report for phase 1 was submitted to the director of CTME in June, 2009).

Several important issues for phase 2 are listed as follows:

1. Phase 2 competed the "Assessment of automotive data communication systems" as listed in Phase 1

2. YSU received RF equipment donation from Delphi Corporation enabling the project team to perform some of the test methodology development and transmission line measurement as specified in phase 3 of the project

3. Phase 2 was able to initiate the Work Force Development and Student Training activities by involving 4 students from YSU's Electrical and Computer Engineering department to assist in the design and implementation of the shielding effectiveness/RF attenuation test system. The results of the development were reported in YSU's Quest (undergraduate research presentation) and the Capstone Senior Design Project.

2. Introduction

EMC (ElectroMagnetic Compatibility) is defined as the ability of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. EMC technology is not new and has been around since the 1960's. However, it has been mainly utilized in the military where the electronic devices were incorporated into the communication and weapon systems. The communication industry was next to place emphasis on EMC when wireless communication became the main stream of the consumer market in the 1980s. The next large scale application of EMC came in around early 1990s when the automotive industry began to incorporate electronic devices into operational control of the automobile. Coupling of the first automotive EMC directive from EU (European Union) in 1992, most global automotive OEM (Original Equipment Manufacturer) began to develop and distribute product EMC specifications to the suppliers in the late 1990s. In order to provide a standardized test methodology for product evaluation, International Organization for Standardization (ISO) began to develop EMC test standards for the automotive industry to ensure immunity of the system to external electromagnetic disturbances .[4] These test standards later formed the basis for the EU EMC directives as well as most, if not all, automotive OEM's product specifications.

In order to meet these new product requirements and government regulations, OEM, Suppliers and independent laboratories began to establish EMC laboratories to test the automotive components, systems and vehicles. In additional to product testing and evaluations, many companies have also increased their EMC activities by incorporating EMC into research, design and development of their products.

In other to demonstrate the complexity of today's automotive electrical architecture, let us compare the electrical architectures of 1946 and 2000 vehicles. A typical electrical architecture of a vehicle built in 1946 had less than 100 terminals that were mostly ring terminals see Figure 1. Today's vehicles electrical architecture has in excess of 10,000 terminals as many as 500 connectors see Figure 2. Within today's electrical architecture exists multiple in-vehicle data communications networks. These networks are classified in three categories.

One category is infotainment and the other is that of vehicle operation. Each category can and typically does consist of multiple interconnected networks. Unfortunately, the EMC requirements (both functional and environmental) are not well defined and their performances were not well understood or determined. Therefore, the data communication transmission line structure of these two categories is the main focus of this research project.

The third category is safety architecture which has well defined requirements and will not be considered in this project.

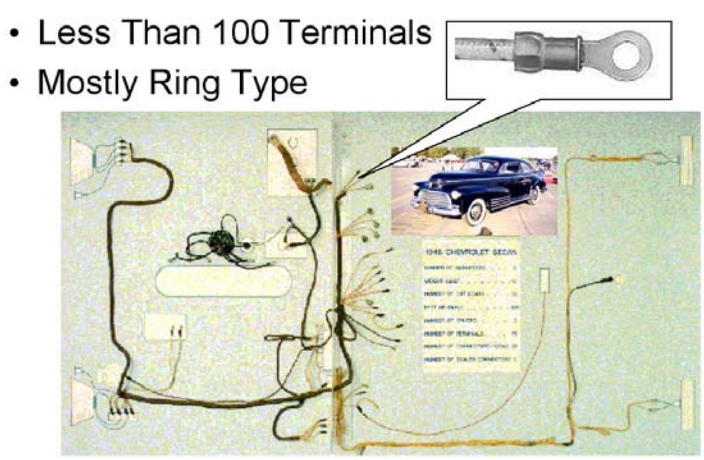


Figure 1 – Typical 1946 Vehicle Architecture

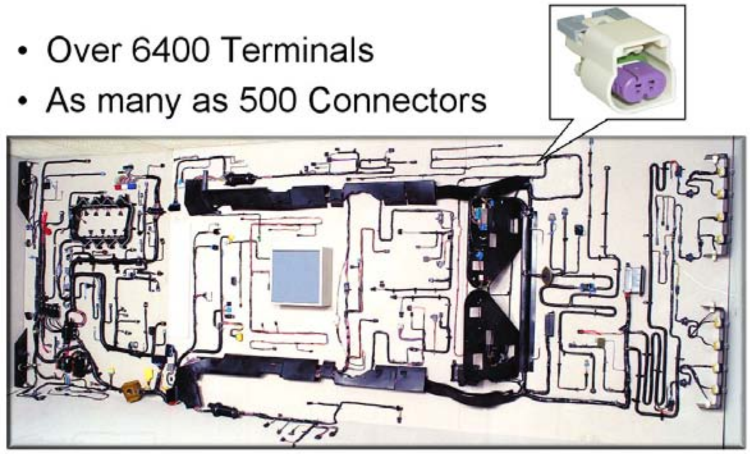


Figure 2 – Today's Typical Vehicle Architecture

A. Infotainment System

The infotainment category is concerned with the entertainment of passengers in the vehicle. Some familiar technologies utilized are playing CDs and DVDs, connecting USB devices, iPods, Xboxes, and PlayStations, surfing the internet, just to name a few. This category is for entertainment and information only and is not critical or needed for the operation of vehicle. Not to imply that this category is not important but rather to indicate that it is separate from the critical/essential operation of the vehicle.

This category also includes the analog and recently added digital audio in the familiar AM and FM radio bands, along with the digital audio broadcast from satellites. Today's automobiles presently have wireless connectivity to Internet through the use of cellular phone.

B. Vehicle Operational Control

This category includes engine management, safety critical systems, handling, and body functions (windows, door locks, latches, sliding doors, HVAC, lighting, etc…). This category also has links to the cellular phone and receives location information from GPS satellites.

This category is also very active and critical to the operation of the vehicle and safety of the driver and passenger. To give an idea of the use of information exchange in this category, as an example, the typical vehicle generates approximately 900 messages per second under normal operation. That equals over 3,240,000 messages every hour.

C. Safety System

The system includes the functions that control the safety related functions such as Airbags, engine management system. Brake and steering etc. The safety systems can communicate with each other via a safety network. The data communication transmission lines structures are well defined and therefore, will not be a subject of discussion in this research project.

3. Survey of Automotive Data Communication Protocols/Architectures

Since the infotainment system has the highest data rate, there are more EMC related issues and performance parameters that needs to be considered. Due to its complex measurement techniques, this research project will only list the parameters related to performance (functional and environmental EMC) of the transmission line structures and will not develop measurement techniques.

Therefore, the development of test methodology to analyze the performance parameters will be focused on the transmission line structures of the **vehicle operational control system.**

Various cabling can be used for data communications. One of the most important selection criteria for the cabling is the data rate. Table 1 lists some of the most popular protocols, data rates, and their cabling for vehicle operation.

As stated earlier, since this report will not cover the cabling for infotainment and therefore, this table excludes cabling for the infotainment protocols.

Table 1also excludes unique proprietary networks used by the makers of vehicles for special inter module communications. Figure 3 shows a rough graphical presentation of the cost versus performance of the various protocols listed in table 1.

Protocol	Max. Data Rate (bps)	Cabling	Notes
LIN	20 k	Single cable	Typically used in low cost application such as from modules to smart loads.
Single Wire CAN	50 k	Single cable	Typically in use for body functions.
Fault Tolerant CAN (FTCAN)	125 k	Cable pair	Special case of CAN that offers more robust comm. in the event of faults.
Medium Speed CAN (MSCAN)	125 k	Cable pair	Typically in use for body functions.
High Speed CAN (HSCAN)	1 M	Cable pair	Used at a maximum of 500 kbps. Most popular for vehicle networks.
FlexRay	10 M	Cable pair	Most probable next generation of automotive communication.
Ethernet	10 G	Cable pair	Possible next generation of automotive communication at 10 Mbps.

Table 1 – Sample of Present Vehicle Protocols and Cabling

Acronyms used in table: LIN – Local Interconnect Network, CAN – Controller Area Network and

OEM – Original Equipment Manufacturer.

4. Communication systems' requirements for copper based data transmission medium (transmission lines/wiring structures)

As mentioned in the last section of this report, this research project mainly focuses on the performance parameters of the transmission line structures of the vehicle operational control system. Some of the reasons are discussed below:

- Infotainment system cabling has been extensively examined for the use in consumer electronics.
- Infotainment system cabling has dedicated performance specifications for its construction and connection systems that automotive vehicle OEM cannot change.
- This cabling is not critical to the operation and or safety systems within the vehicle and they are utilized for information and entertainment only.
- The main focus is on the proper selection of cabling for the vehicle operation network which is not presently fully understood.
- Infotainment systems are kept separate from vehicle operation and safety systems.
- Since the infotainment cabling is carrying the highest data rates and is included in the same vehicle harness bundles as the vehicle operation cabling, this project will investigate that the possible adverse effect of cross coupling to the vehicle operation cabling.

This project focuses on the category for vehicle operation and specifically on the in vehicle cabling used for the data communications between electronic modules within the vehicle.

These data communications between electronic modules are critical and necessary for proper vehicle operation. In most applications, serial communication is utilized for module-to-module exchange of data/information.

Serial communications consists of transferring binary code (only the values 0 and 1 are defined) data one bit at a time. This is the same type of communications used by computers to connect to the Internet.

This project will focus on the investigation of the electromagnetic compatibility (EMC) of the cabling used to provide communication between the electronic modules.

In the process of investigating the various cabling used for serial transmission of data, it is important to know the data rates that are in use today and in the future.

Data rate is defined as the number of bits being transferred per second (also known as baud rate) and is measured as bits per second (bps). By knowing the data rate, the proper aspects relevant to functional performance and parametric requirements for the transmission lines of the cabling can be measured and analyzed.

5. Functional performance parametric requirements for the transmission lines

Figure 3 is a brief illustration of performance vs. cost of the protocols listed in Table 1. Various protocols are discussed below:

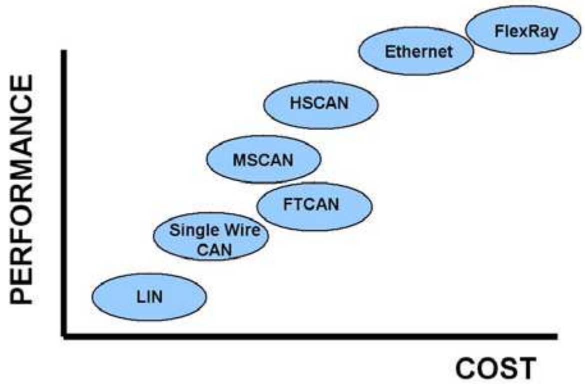


Figure 3 – Performance vs. Cost of Various Automotive Protocols

A. LIN (Local Interconnect Network)

LIN is a low-speed (1- 20 kbps) serial multiplexing protocol primarily intended for body electronics systems in vehicles (e.g., seat controls, blower motors, window controls). Applications target the interconnection of switches, actuators and sensors into a localized sub-bus which connects to the main bus, which is usually a CAN bus. Vehicle subsystems that could use a LIN sub-bus are the door, roof, steering column, climate control, switch panel and intelligent wipers. LIN can also be used for engine diagnostics. LIN, however, is not designed exclusively for auto applications, and so can be applied to industrial electronics as well.

The LIN Consortium (the LIN standard organization) started as a work group in late 1998. The objective of this work group is to specify an open standard for low-cost Local Interconnect Networks (LIN) in vehicles where the bandwidth and versatility of CAN are not required.

The governing LIN Protocol Specification establishes the key LIN Data Link Layer requirements. Basic LIN data link transfers are based on the UART (Universal Asynchronous Receiver Transmitter), a common serial communication method available on many microcontrollers. The LIN standard includes the specification of the transmission protocol, the transmission medium, the interface between development tools, and the interfaces for software programming. More information about LIN can be found at www.lin-subbus.org.

B. Controller Area Network (CAN)

CAN is a serial communications protocol that supports real time control while maintaining a high level of data integrity. Originally developed for automotive subsystem applications, CAN has gained wide acceptance in a number of application areas. CAN is an open international standard which is defined in the CAN 2.0B specification maintain by the industry organization known as "CAN In Automation", or CIA.

CAN is a message oriented transmission protocol. Messages are identified by a message identifier. Each identifier must be unique within the network, as it defines the identity and the priority of the message. This is important when several nodes are competing for access to the bus.

Transmission requests are handled in the order of importance of the messages for the system as a whole, which is helpful in overload situations. Since bus access is prioritized on the basis of the messages, low individual latency times in real-time systems can be guaranteed.

CAN is an open architecture and its information is available to users. Its technical specifications can be found at www.can-cia.de.

There are three major variants of CAN being implemented today: Single-Wire, Fault Tolerant, and High- Medium- Speed.

C. **Single Wire CAN** (SAE J2411)

SAE J2411 establishes requirements for a low speed, single wire, and physical layer with sleep/wakeup capability. SAE J2411 is compatible with CAN and all other protocols that are based on dominant/recessive logic. SWCAN is typically used in body electronics applications such as climate control, door locks, instruments clusters, seat positioning and other body and convenience systems. The SWCAN Physical Layer contains three operational modes: 1) normal communication mode, 2) high-voltage wake up mode, and 3) high-speed mode. SAE J2411 establishes two data rates: a normal rate of 33.3 kbps and a maximum of 32 nodes and a high-speed rate of 83.3 kbps.

D. **Fault Tolerant CAN** (FTCAN)

FTCAN is a physical layer that transmits at medium speed (single transfer rate limited to a maximum of 125 kbps) for body bus applications. Fault tolerance is the ability of a system or component to continue normal operation despite the presence of hardware or software faults. A fault tolerant CAN transceiver can continue communication after one single network wiring problem. Communication will be possible for any of the following single wiring faults on the CAN bus: either of the CAN wires open, a short circuit between either of the CAN lines and ground, a short circuit between either of the CAN lines and battery (+12V), or a short circuit between CAN lines. The most recent standard for FTCAN is ISO 11898-3 for fault-tolerant transceivers, which is to replace ISO 11519-2. The ISO 11898-3 specifies low-power consumption and switch-off modes as well as the wake-up procedure.

E. **Medium Speed CAN (MSCAN)**

MSCAN is a lower data rate dual wire CAN which is defined by SAE J2284-1. The lower bit rate of MSCAN enables use of reducing the costs compared to HSCAN by employing less complex control electronics because the CAN slot utilization requirements. The MS-CAN messaging strategy is optimized for open-loop event based applications commonly found in body, audio, and climate subsystems. This does not prohibit the use of periodic frames, but it ensures that when an event frame must arbitrate for the bus it will unlikely experience any delay.

F. **High-Speed CAN** (HSCAN) - (ISO 11898-2 and SAE J2284)

HS CAN defines requirements for a high-speed, dual-wire bus line with common return terminated at both ends by resistors to suppress reflections representing the characteristic impedance of the line. This physical layer is also compatible with other protocols that are based on dominant/recessive logic. It is intended for applications where a high data communication rate is the main requirement.

Nearly all carmakers in Europe, America, and the Far East use CAN high-speed networks (e.g. 500 kbps) in their power engine systems, which are compliant with the ISO 11898-2 physical layer standard. In addition, most European passenger cars have CAN-based multiplex systems to link door and roof control units as well as lighting and seat control units.

G. FlexRay

Flex Ray is a bus system intended for high-speed applications in automotive engineering. The protocol targets x-by-wire systems applications that demand high-speed bus systems that are deterministic, fault-tolerant, and capable of supporting distributed control systems. FlexRay was developed by several automotive OEMs and suppliers in cooperation with semiconductor manufacturers. Its features include:

- Static and dynamic data transmission (scalable)
- Gross data rate of up to 20 Mbit/sec (2 channels with 10 Mbit/sec each)
- Time-triggered services implemented in hardware

FlexRay uses a specifically designed high-speed transceiver, and it embraces the definition of hardware and software interfaces between various components of a FlexRay node. The FlexRay protocol defines the format and function of the communication process within a networked automotive system. FlexRay is initially targeted for a data rate of approximately 2.5, 5 and 10 Mbps per channel, but the design of the protocol allows much higher data rates. More information about FlexRay can be found at www.flexray.com.

H. Ethernet

Ethernet is an extremely popular consumer protocol as evidenced by the fact that all computers sold today have this as a connection method. Ethernet is a serial data communication that the IEEE released as a standard in 1983. It started as a 10 Mbit/sec data rate and has evolved to data rates as high as 10 Gbit/sec. The Ethernet is being placed into some of today's automobiles but only as an extension of the automotive infotainment category. Because of its popularity, the automotive industry is investigating Ethernet for possible use as an in vehicle network for the vehicle operation and safety systems. This would be a separate Ethernet network from that of the infotainment Ethernet as is done with the other networks used for this intended purpose. The presently the data rate of 10 Mbit/sec is being investigated for possible use. Some of the concerns of using for this automotive application are the robustness of this protocol and its timing of communications. More information about Ethernet can be found at www.ethernetalliance.org.

As mentioned before, since infotainment system protocols such as D2B, IEEE 1394, USB and MOST are mostly utilized for non-automotive applications, it is not the focus of this research project. However, it might be considered in the future projects when these protocols are applied to automotive data communication systems.

Due to bandwidth requirements and operating frequencies for various protocols, different cables/transmission lines will need to be used. The types of transmission lines required for various frequencies are listed in the table below:

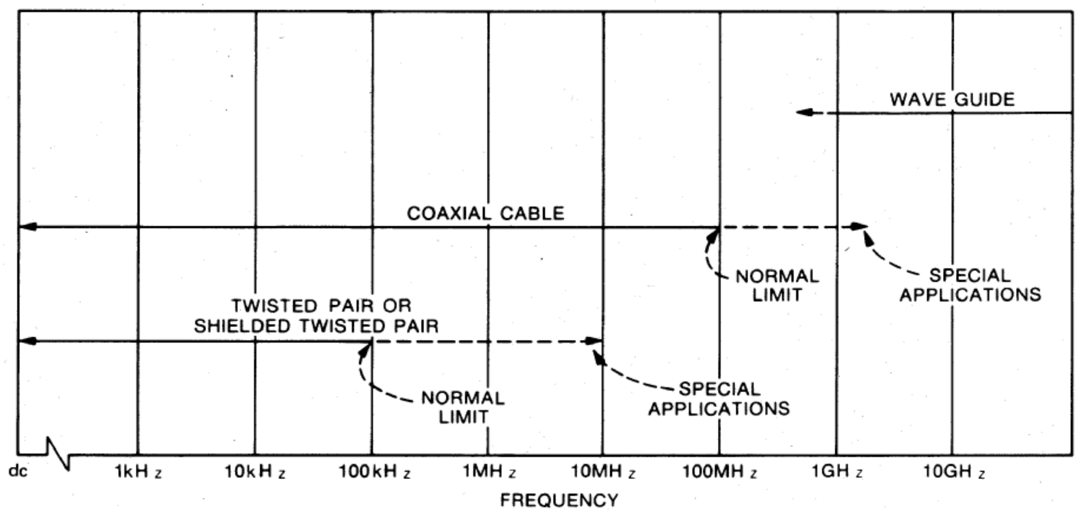


Figure 4 – Useful frequency range for various transmission lines

Although test method development will not be developed in this project for the high speed data link for various protocols, their characteristics were investigated. A summary to compare them is shown in Table 2 below:

High Speed Data Link Comparison						
	MML	**D2B Optical**	**MOST**	**IEEE 1394**	**IEEE 1394 Optical**	**USB**
Topology	Star	Ring	Ring	Hierarchical Pt-Pt	Pt-Pt	Tree
Optimization	Isochronous	Isochronous	Isochronous	Isochronous & Asynchronous	Isochronous & Asynchronous	Isochronous & Asynchronous
Max Baud Rate	110.592M	12.288M (Multiple of ISDN)	49.152M (Multiple of ISDN)	98/196/393M (Multiples of ISDN)	122.88 Proposed by NEC (Use 8 to 10 Encoding of 98M) * Higher Speeds Under Development	1.5M or 12 M
Max Data Rate	98.304 (Multiple of ISDN)	6.144M	24.576M	Dependent on Isochronous Channel BW and Number of Channels Dedicated	Dependent on Isochronous Channel BW and Number of Channels Dedicated	Dependent on Isochronous Channel BW and Number of Channels Dedicated
Typical Data Payload (Max Data Rate)	80-90%	75%	75%	30-90%	30-70%	70-80%
Encoding	8 to 9	Biphase	Biphase	NRZ + Strobe	8 to 10	NRZI with bit stuffing
Single Node Failure Effect on Network	One Node	Total Network Loss	Total Network Loss	Automatically forms separate clusters	Comm to Other Bridge	Lower Nodes in Hierarchy Lost
Media	POF	POF	POF	Dual STP+ Power + Shield	POF	TP+Shield
EMI/RFI	Low	Low	Low	Medium/High	Low	Medium to Low
Mass	Low	Low	Low	High	Low	Medium to Low
Open Standard	No	No	No	Yes	Yes	Yes
Architecture	Closed	Closed	Closed	Open	Open	Open
Application	Auto Entertainment	Auto Entertainment	Auto Entertainment	* Consumer/PC Entertainment Bus * Possible Auto Version (ERTICO, PAVO, others)	VESA Home Bus Backbone	PC Peripheral Bus
Developer	Delco/Delphi	Philips	Silicon Systems & Oasis	Consortium	Consortium	Consortium
Notes					* Special Version of 1394 to go 100 m	Must Have Embedded Controller

Table 2 – Comparisons of various high speed data links of different protocols

The method utilized for module-to-module exchange of information is serial communication. Serial communications consists of transferring binary (only the values 0 and 1 are defined) data one bit at a time. This is the same communications used by computers to connect to the Internet. This project will investigate the Electromagnetic Compatibility (EMC) of the cabling used to provide communication between the electronic modules.

6. Descriptions of Various RF cables

RF (Radio Frequency) cables are typically used as transmission lines for various architectures. The transmission line serves two purposes. The first purpose is functional - where the data must be transmitted from the transmitter (source) to the receiver (load) without unacceptable signal degradations. The second purpose is environmental (electromagnetic) - where the data/signal must be compatible with the electromagnetic environment (without being interfered by EM disturbances and without generating unacceptable levels of EM emissions). The EM disturbances could be either Electric field (E) dominated or Magnetic field (H) dominated or both depending on the characteristics of the interference source. Various transmission line structures have different degrees of effectiveness in attenuating different types of EM disturbances.

A. Effectiveness of transmission lines against Electromagnetic Interference (EMI)

A discussion on various types of transmission lines and their effectiveness in attenuating various EM disturbances is listed below:

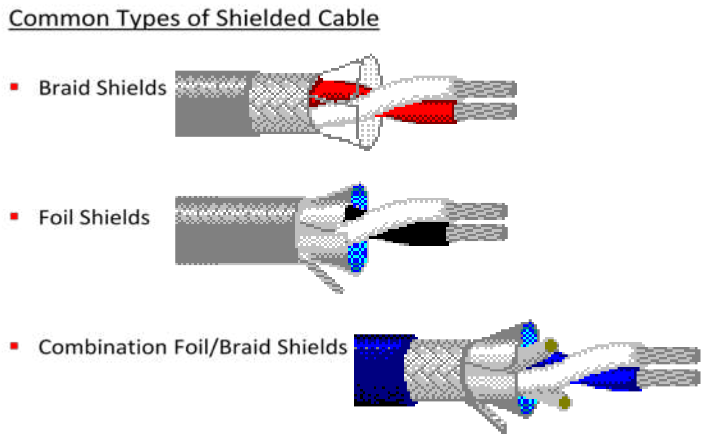
Constructions	Effectiveness against EMI	
Non-structured (random Lay)	None (Base line)	
Parallel Wire	Electric - None	Magnetic – Minimum
Unshielded Twisted Pair (UTP)	Electric - Minimum*	Magnetic – Good
Shielded Pair	Electric - Good	Magnetic – Minimum
Shielded Twisted Pair (STP)	Electric - Good	Magnetic – Good
Coaxial Cable	Electric - Best	Magnetic – Best

* Good if balanced circuit is used

B. Physical Descriptions of various transmission lines

Two types of transmission lines are typically utilized for vehicle operational control architecture. They are shielded cable and coaxial cable. The characteristics and constructions of these cables are discussed below:

a. **Shielded Cables with various shield constructions**



- **Braid Shields**
  - Bare or tinned copper shield
  - High mechanical strength
  - Good flexibility and flex life
  - Higher conductivity than foil
  - Less braid coverage than foil (60% to 90% typical)
  - More expensive than foil
  - Does not require drain wire

- **Foil Shields**

  Aluminum foil shield laminated to polyester or polypropylene film:
  - 100% shield coverage
  - Better high frequency (UHF & above) performance than braid
  - Mainly utilized for protection from Electric Field
  - Smaller, lighter, and less expensive than braid
  - More flexible than braid, but shorter flex life (in applications not requiring repetitive flexing)
  - Drain wire needed for shield termination and grounding

- **Combination Foil/Braid Shields**
  - Combines more than one layer of shielding to provide maximum shield efficiency across the frequency spectrum.

- 100% foil coverage, plus strength, flexibility, and high electrical conductivity of braid.
- Available combinations include:
  - foil/braid
  - braid/braid
  - foil braid/foil
  - foil/braid/foil/braid
- Drain wire may or may not be needed depending on cable constructions
- Bulky, heavy, expensive, and requires metal connectors

In order to achieve effective shielding against EMI, the shield must be electrically grounded. Grounding of the shield is achieved by using a drain wire (a copper wire without insulation). The drain wire is placed inside the foil (touching the conductive side). One end of the drain wire is connected to the electrical ground of the system. In this configuration, the EMI coupled to the shield will be drained the electrical ground via the drain wire. There are several important issues that must be considered when the drain wire is applied:

- **Foil Shield/Drain Wire Issues**
  - Maintain good and continuous contact between foil and drain wire
  - To avoid ground loop problem for coupling of magnetic field, ground drain only at one end
  - Shield may open when cable is flexed and leak RF – especially without extruded jacket, i.e., tape.
  - Avoid exposing drain wiring through the shield contacting other ground structure and/or power feed
  - Conventional construction: conductive foil face inward enclosing drain wire
  - Spirally wrapped foil forms a long solenoid (inductor) if turns are not shorted by drain wire. Resonance problems can arise in high frequency applications
  - Longitudinally wrapped foil (cigarette wrap) is better, but the seam must be electrically solid
  - If multiple twisted pairs are shielded, drain wire should be spirally wrapped around all pairs (not necessary for single twisted Pair)

b. Coaxial Cable

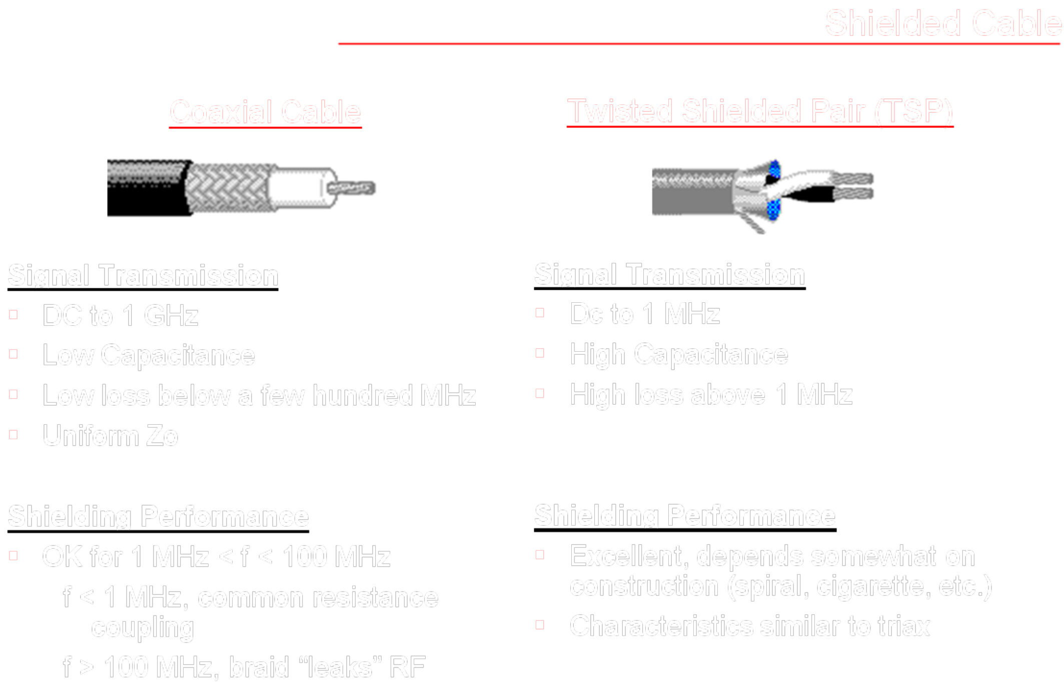
Coaxial cable is widely used in telecommunication industry due to its effectiveness in achieving EMC and its low signal loss characteristics. However, it is typically more expensive than shielded cable and is not easily adaptable to traditional automotive high speed manufacturing system. Some of its characteristics are discussed below:

Coaxial Cable

- Coaxial cable is not a “shielded” cable if the braid carries signal current
- Coaxial cable works well as RF cable because of :
  - Its fixed symmetrical geometric structure to maintain characteristic impedance
  - Lower insertion loss and Low capacitance
  - At high frequency, due to skin effect, signal flows on inner surface and noise flows on outer surface of the shield
- Critical parameters for coaxial assembly (@ Operating frequency)
  - Characteristic impedance
  - Frequency range
  - Cable Insertion Loss
  - Connector insertion loss
  - Assembly insertion loss
  - Shield type/coverage
- Cable assembly should based on cost & system power budget requirements
- Bulky, heavy, expensive, and requires metal connectors and 360º grounding

c. Performance comparison between coaxial cable and shielded cable

Coaxial cable and Twisted Shielded Pair both provide shielding against electric and magnetic fields. The performance comparisons for these two cable constructions are shown below:



The connection systems required for the coaxial and twisted shielded pair are shown below:

- **Connection System**
  - Metal connector
  - Connector connected to shield
  - Shield grounding via connector
  - Assembly completed shielded
  - Ground maintained through connectors
  - Special tool required
  - Connector RF performance specified

- **Connection System**
  - Plastic connector
  - Connector not connected to shield
  - Shield ground via drain wire
  - Gap between shield and connector
  - Ground not maintained through connector unless with special design
  - Special tool not required
  - No RF performance required

7. Cable Parameters to be Measured and Analyzed

Now that the type of cabling has been identified as UTP and STP, the next step is to determine which parameters must be measured and analyzed to ensure that the cabling will be applicable for the intended data rates and environment. The cable parameters identified for twisted pairs are; characteristic impedance, differential impedance, conductor-to-conductor capacitance, line delay, DC resistance, attenuation, and shielding effectiveness. Associated with some of these parameters is the frequency range. The frequency range is directly related to the maximum data rate of cabling to be used. As stated earlier in this report, the maximum data rate of concern is 10 Mbps.

By knowing the parameter to be measured and the frequency range for each parameter, the selection of test equipment can best be optimized for cost and capability. For the parameters of characteristic impedance, differential impedance, and attenuation, the frequency range will be to 100 kHz to 50 MHz. The shielding effectiveness measurements will be in the frequency range of 1 MHz to 1 GHz.

Along with the parameters to be measured there are some parameters that are defined by the construction of the twisted pairs. These parameters are twist rate, cable gauge, cable insulation material, shield material, shield application, and drain wire implementation. These parameters must be identified for all measurements made and in addition to be documented, these parameters can be varied to analyze impact of the variation.

These parameters are listed below:

A. Functional EMC - Transmission line parameters;

- Characteristic Impedance
- input Impedance
- Load Impedance
- Transmission Coefficient
- reflection Coefficient
- S parameters

B. Environmental EMC – RF Cable Parameters:

- Shields – Thickness, conductivity, permittivity and permeability
- Shield integrity (overlaps and seams)
- Braid shield and solid shield
- Shield termination techniques and pigtail effect on EM attenuation
- Twisting – tightness, uniformity, number of twists

- Effectiveness of various grounding schemes
- Number of layers of shields
- Spiral vs. overlay shield wrapping
- Shielded cable vs. twisted cable vs. shielded twisted pair in attenuation of electric field, magnetic and electromagnetic field
- Effect of gap in shield on attenuation characteristics
- Layout of drain wire and grounding of drain wire
- Effect of different dielectric materials

C. Shielding effectiveness and/or attenuation characteristics on cable samples

Experiments were performed to determine attenuation characteristics of RF cable (Twisting and/or shielding effectiveness) – Phase 2

a. Descriptions of Test Samples:

The following are the first sets of measurements of 2 types of data communication cables. The 2 types of data communication cables are;

- 0.35mm^2 Thin Wall PVC 100 twists per meter UTP (see Figure 5)
- 0.35mm^2 Thin Wall PVC 100 twists per meter STP with drain (see Figure 6)

Figure 5 – 100 twist/m UTP

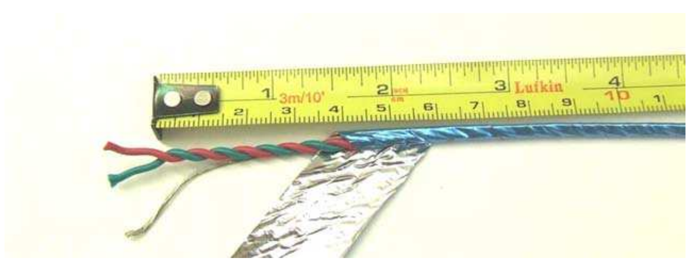


Figure 6 – 100 twist/m STP with drain

b. Test Configurations and Test Results

1. Characteristic Impedance Z_0 (Ω) Measurements

The first measurement made of 1-meter samples of the 2 data communication cables is characteristic impedance. The characteristic impedance measurements were made by measuring the impedance of the sample with ends short circuited (Z_{SC}) and open circuit (Z_{OC}). These impedances were then used as follows to calculate the characteristic impedance (Z_0);

$$Z_0 = \sqrt{Z_{OC} \times Z_{SC}}$$

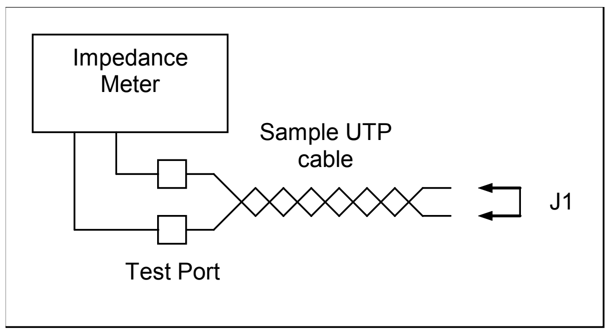
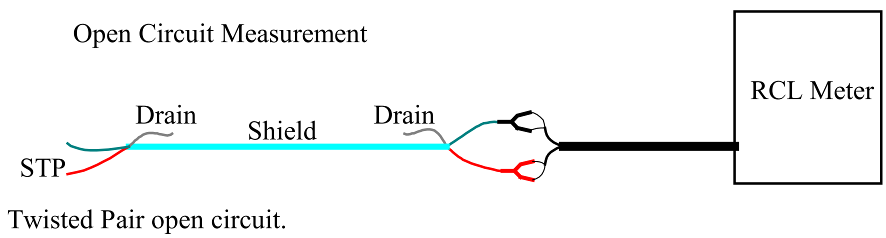


Figure 7 – UTP Characteristic Impedance Measurement Setup



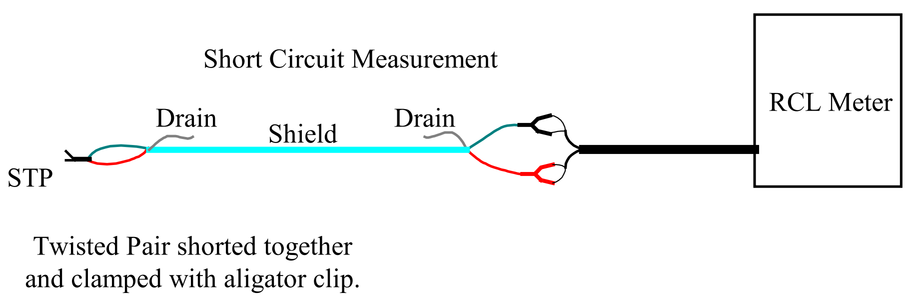


Figure 8 – STP Characteristic Impedance Measurement Setup 10 kHz to 100 kHz

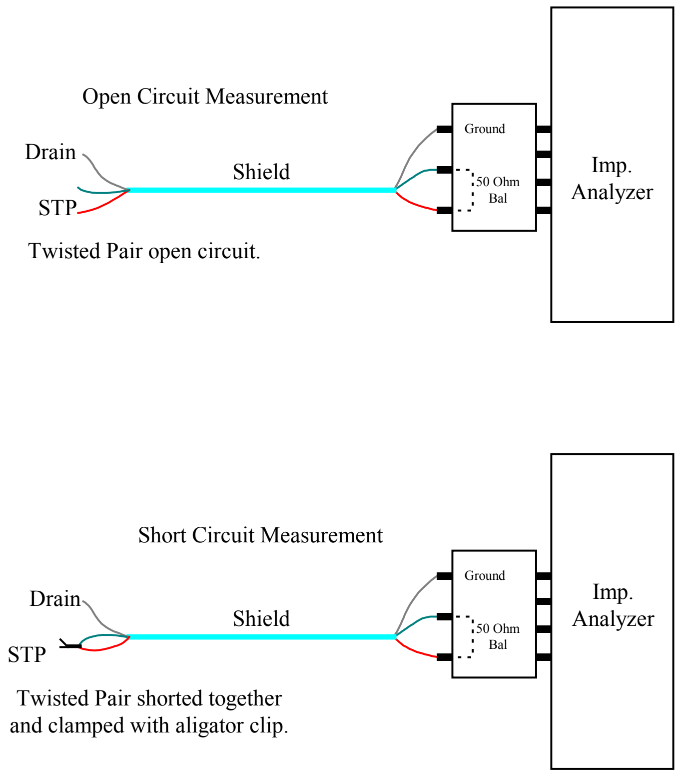


Figure 9 – STP Characteristic Measurement Setup for 1 MHz to 10 MHz

2. Characteristic Impedance measurement results

The characteristic impedance of UTP with thin wall PVC insulation is summarized in Table 3

Table 3 – Characteristic Impedance Measurement Results

UTP 0.35mm² Thin Wall PVC Characteristic Impedance (Ω)						
Twist/m	**10 kHz**	**100 kHz**	**1.0 MHz**	**3.0 MHz**	**5.0 MHz**	**10 MHz**
100	178.3	105.1	97.8	98.4	98.0	95.3
STP 0.35mm² Thin Wall PVC Characteristic Impedance (Ω)						
Twist/m	**10 kHz**	**100 kHz**	**1.0 MHz**	**3.0 MHz**	**5.0 MHz**	**10 MHz**
100	133.7	83.9	70.98	69.84	69.37	68.23

3. Line Delay (ns/m) Measurements

Line delay measures the time it takes for electrical signal to travel through the cable in comparison to the speed of light (no delay). Line delay measurement is performed on 1-meter samples of the 2 data communication cables. Excessive line delay will impact of the timing of the data stream. The test configuration is shown in Figure 10

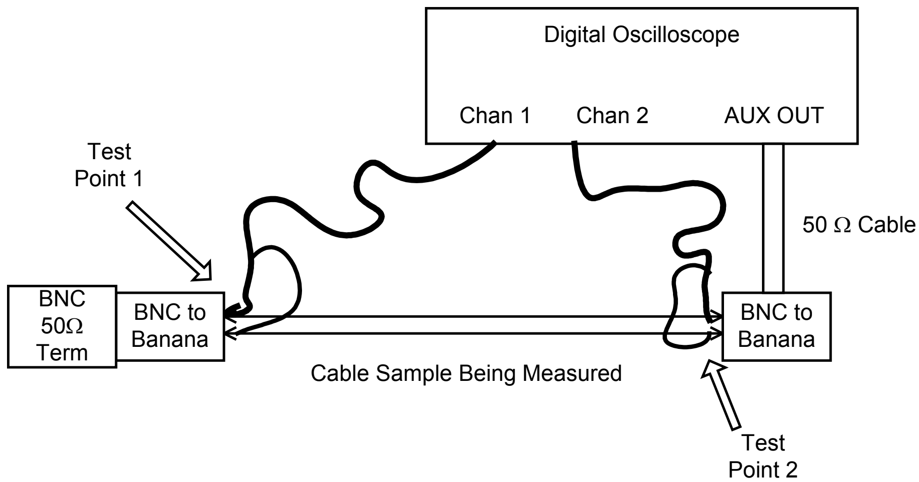


Figure 10 – Time Delay Measurement Test Configuration

The summary of the test results is shown in table 4

Table 4 – Time Delay Measurement Results

	UTP 0.35mm²	STP 0.35mm²
Twist/m	**Delay (ns/m)**	
100	5.6	6.1

4. DC Line Resistance (per unit length) (mΩ/meter)

The DC resistance per unit length determines the Ohmic loss of the signal due to the cable resistance.

The test configuration for DC line resistance is shown in Figure 11.

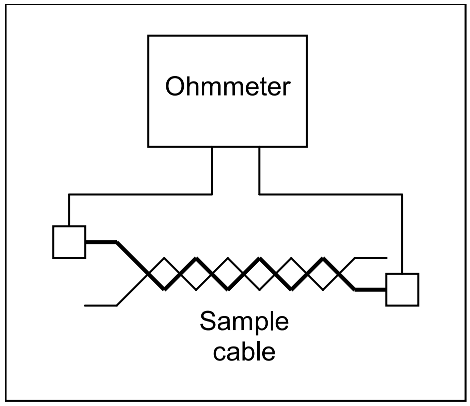


Figure 11 – DC Line Resistance Measurement Setup

The test results are summarized in table 5

Table 5 – DC Line Resistance Results

	UTP 0.35mm²	STP 0.35mm²
Twist/m	**DC Line Resistance (mΩ/m)**	
100	58.7	58.7

5. Shielding Effectiveness or Attenuation Measurements (IEC 62163 - 4- 5)

Shielding effectiveness or attenuation of the cable determines its ability to reduce or attenuate the electromagnetic interference emitted to or coupled from the environment.

For the STP (Shielded Twisted Pair), the shielding effectiveness is measured according to IEC 62153-4-5 Absorbing Clamp Method. The results are shown in Figure 12.

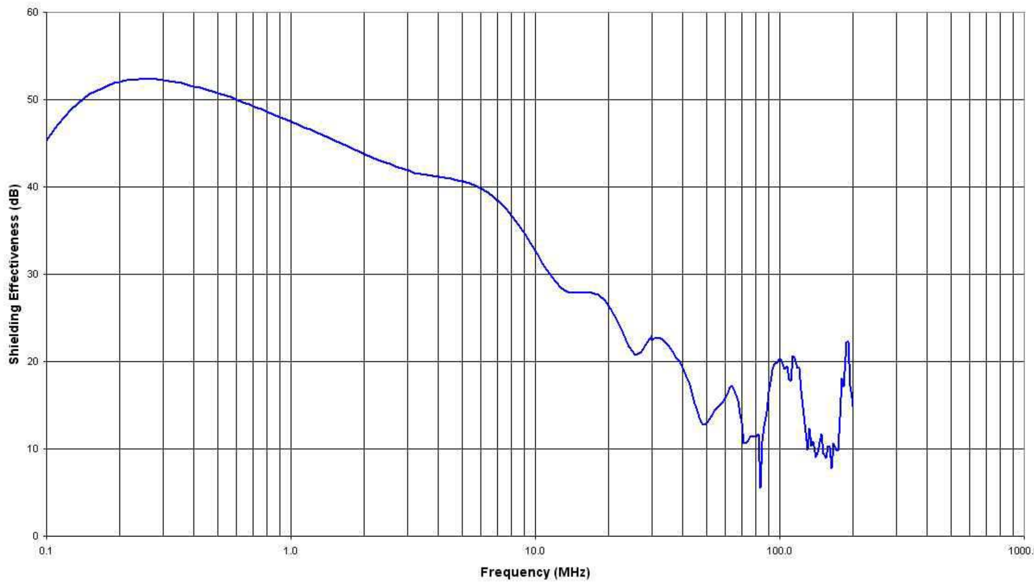


Figure 12 – Shielding effectiveness of 0.35mm^2 STP

6. Shielding Effectiveness/RF Attenuation Test Method – Tube in Tube

Although the Absorbing Clamp is effective in determining the shielding effectiveness/RF attenuation of the transmission lines, it is not particularly useful in determining the shielding effectiveness/RF attenuation of the transmission line assembly (cable and connectors) and/or connection system. A new test equipment, Tube in Tube, has been developed in the last 5 years to enable the measurement of connection system and transmission line assembly. The test is performed with the use of the network analyzer to determine the surface transfer impedance of the assembly and/or connection system. The surface transfer impedance is indicative of the effectiveness of the transmission line assembly against EMI.

However, the commercial version of the tube in tube is very expensive (over $20,000) and is not very efficient in perform high volume of experiments. The network analyzer can also cost over $50,000. Since the total cost of the test system exceeds the $ 20,000 budget of this project, an alternative must be found.

The project team has decided to design and build a YSU version of the tube in tube instrument with a budget target of $5,000 and also to solicit equipment donation (network and spectrum analyzer) from Delphi Corporation. Although the older equipment might not very accurate and efficient, it would allow the development and verification of the test system.

It is the vision of the research team that once the test methodology is verified, the project equipment budget would allow the purchase of the necessary instrument.

With technical assistance provided by Delphi Corporation, Senior Investigator and Principal Investigator and a team of 4 senior students from YSU's Electrical & Computer Engineering department were teamed together to design and build the test apparatus, to develop the test procedures and to perform the initial measurements. The results will then be compared with those obtained in the EMC laboratory in Delphi Corporation using the commercial version of the tube in tube apparatus and their latest version of the Network Analyzer.

The development project also serves as part of the work force development and student training initiative of this research project.

In the summer of 2009, Delphi Corporation donated the Spectrum analyzer and Network Analyzer to YSU in support of this project. With the assistance provided by the consulting instrumentation specialist, the students design, developed and built the tube in tube test apparatus with improved design and cost.

The test procedures were developed to perform measurement of RF attenuation of UTP transmission line assembly. The measurements were performed at YSU and the results were compared with those measured at Delphi's EMC laboratory.

The tube in tube development project by the students was presented in YSU's Quest, and was also summarized into a research report/presentation for the students' Capstone Senior Design Project.

The development effort and test results for the tube in tube test methodology are presented below.

A. Delphi Equipment Donation

"Delphi Corporation will donate the following test equipment to the Engineering Technology Department (Electrical) at Youngstown State University in June 2009. This donation is to support the research efforts of your research project funded by Center of Transportation & Materials Engineering through a grant by RITA of US Department of Transportation. The estimated fair market values of the equipment are listed below for your reference."

Serial #	Description	Approximate value
1A00249 & 806A00184	HP8568B Spectrum Analyzer 100Hz – 1.5GHz	$4,500
2511A00411	HP54100A DSO	$2,000
2947A01021	HP85685A RF Pre-selector 20Hz – 2.0GHz	$4,500
3031A00368	HP3577B Network Analyzer 5Hz – 200MHz	$4,500
2846A02008	HP35677A S-Parameter Test Set 5Hz – 200MHz	$3,000
2839A04067	HP8590A Spectrum Analyzer 10kHz – 1.5GHz	$4,500
3035A03129	HP54111D Digital Oscilloscope	$4,500
2810A02949	HP54201A Digital Oscilloscope	$700
B011027	Tektronix TDS340A Digital Real Time Oscilloscope	$800
B142067	Tektronix 576 Curve Tracer	$500
25-1822-02	Thermotron Temp. Chamber	$1,000
B137943	Tektronix 466 Storage Scope	$200
B274617	Tektronix 475 Oscilloscope	$500
None	HP 85032B Type N connector Calibration Kit	$800
B361585	Tektronix 576 Curve Tracer	$500
2231A05092	HP 3468B Bench top Digital Multimeter	$100
E863826	GW GPS-3303 DC Power Supply	$250
B274617	TEK 475 Oscilloscope	$500
B137943	TEK 466 Oscilloscope	$500
Various	20 Oscilloscope Probes	$500
	Total:	**$34,350**

B. Tube in Tube Principle of Operation

The descriptions of the project are as follows (Extracted from the student's research project report):

Design and Construction of a Low Cost Tube-in-Tube Triaxial Device

The tube-in-tube test method is utilized for measuring the transfer impedance and the shielding and screening attenuation of the coupling of electromagnetic interference. It is a triaxial method for testing Electromagnetic Compatibility (EMC) of data communication transmission line structures (cable assembly and connection system). It provides an efficient and accurate way to test electromagnetic leakage at low frequencies.

The network analyzer is used to measure the attenuation characteristics at the output of the tube-in-tube with test samples. Frequency sweep by the network analyzer will generate information on attenuation provided by the sample (cable assembly and/or connectors) at various test frequencies.

The tube-in-tub test apparatus acts as a coaxial cable, allowing the measurement of voltage drop at the outside of the tube. This device is designed to allow for a cost improvement over a commercially available apparatus with similar functions. The device is also constructed to allow for better test flexibility to decrease test time and test cost. This is accomplished by incorporating a custom built lid and base assembly create a sealed chamber that is easy to open and close, making it more user-friendly. An adjustable end connector allows one to test different lengths of wire samples. Test results comparable to the commercially available device are verified.

The Tube-in-Tube test method for determining the amount of signal leaked from electrically short connectors is performed according to IEC 62153-4-7 (triaxial method). Previously, low frequency attenuation tests required increasingly larger electrically shielded test rooms as well as measurement and calculations of signal reflection. However with the advent of the Tube-in-Tube design (see Fig. 13) this is no longer the case.

With the Tube-in-Tube design, it is possible to test low frequency leakage in a much smaller space. The proposed Tube-in-Tube design will allow engineers to manipulate the twisted pairs without having to disassemble the apparatus.

The design will also allow companies the ability to procure their own Tube-in-Tube at a fraction of the cost of today's commercially available units. This will allow them to conduct testing that otherwise would have been cost prohibitive and/or that would have had to been outsourced.

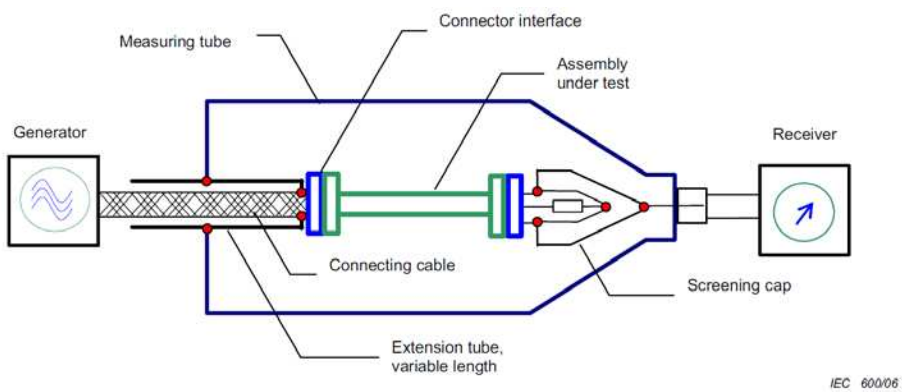
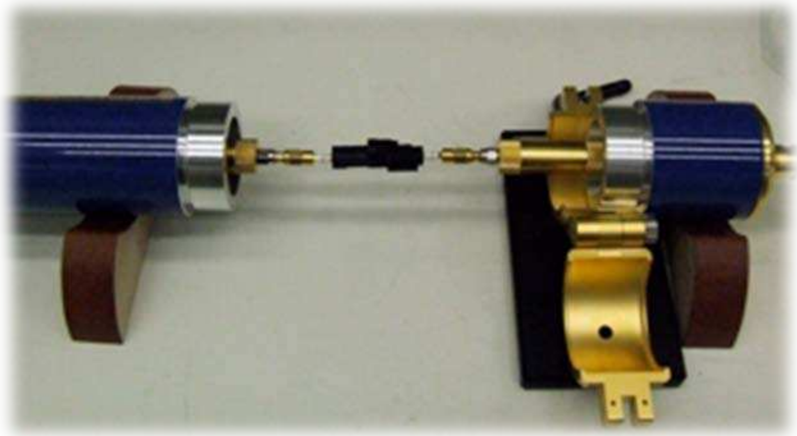


Figure 13 Test setup to measure transfer impedances and screening of connectors

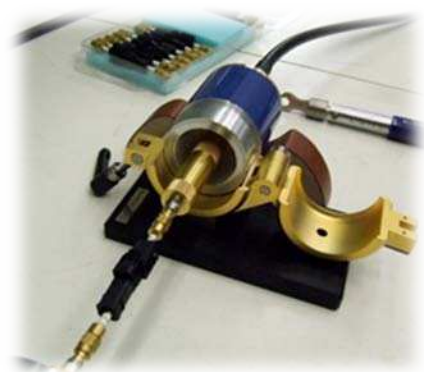
C. Tube in Tube Design and Construction

a) Commercial Design

The commercially available tube-in-tube test apparatus is available for the price of approximately $20,000. This device provides a wide variety of testing over a broad range of connector types and frequencies. It also includes an expansive array of parts to accompany the broad range connectors it supports. This, combined with the level of machining and design, makes the device expensive. The design is a solid aluminum cylinder bored out to create a chamber to house the assembly under testing.



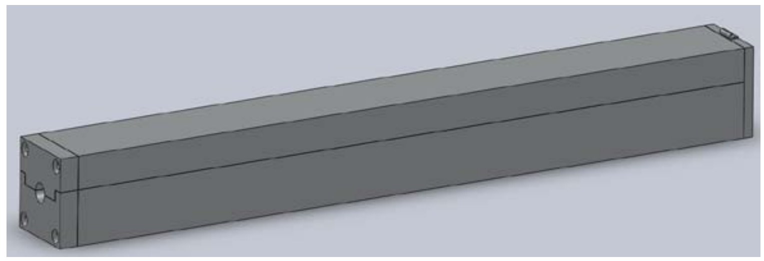
The receiver assembly is to be secured onto the main cylinder thus creating a sufficient electrical seal such that high frequency testing can be conducted without signal leakage. Inside the apparatus precision machined copper components conduct signal and hold specimens in place. These copper components are kept concentric to the aluminum via special low permittivity plastic devices. The entirety of the cylinder structure is then placed into a clamp-like device which secures the unit from rolling off of the testing surface.



The nature of the aforementioned design leads to problems when one wishes to quickly change out test samples or change out the internal connectors. This makes the device cumbersome and unwieldy. Furthermore the design does not assist those who have specific testing needs and would never utilize the higher abilities of the device. A new design is called for that would solve these problems as well as be affordable to small facilities.

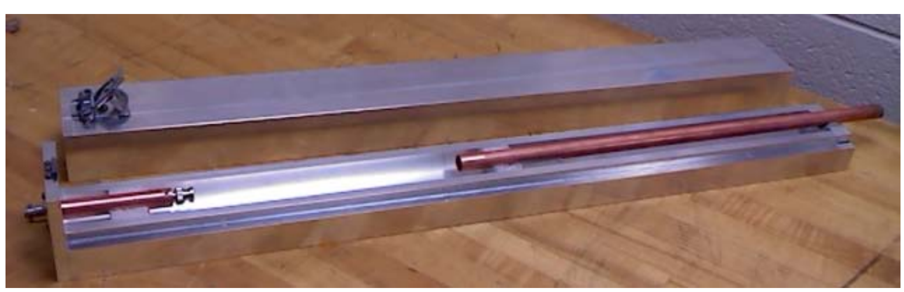
b) YSU's Tube in Tube Design

The Tube-in-Tube test apparatus is constructed from a solid rectangular aluminum block. A cylinder is bored lengthwise through the block. The bored block is then separated into top and bottom sections to facilitate quick and easy replacement of test samples. The adjacent surfaces between the upper and lower halves of the tube are machined to facilitate an electrically sealed enclosure. Furthermore, a latch is added at an end of the device to allow for easy access to the test specimen. See Appendix A for more design drawings.



The internal structure of the device is comprised of two pieces. The input portion is a standard ½" copper pipe, available from most home improvement stores. This section will house part of the test specimen. Its length is manipulated by the test engineer so that the amount of specimen undergoing testing can be altered with ease. This is similar to the commercial design. The receiving portion of the device is a shorter section of ½" copper pipe. It has two industry standard connectors pressed into the ends. On one end there exists a standard BNC connector. This connector houses a 50 Ohm resistor that allows for load matching with the network analyzer. The opposite end contains BNC panel connector. This connector attaches to the receiver plate of the apparatus. More design drawings are shown below.

The copper structures are held concentric to the aluminum tube by low-permittivity foam. This foam has a much lower permittivity than the plastic that is used in the commercial device. Additionally, special material called "Soft-Shield 5000" from Chomerics was installed to seal the input end of the device from signal leakage.



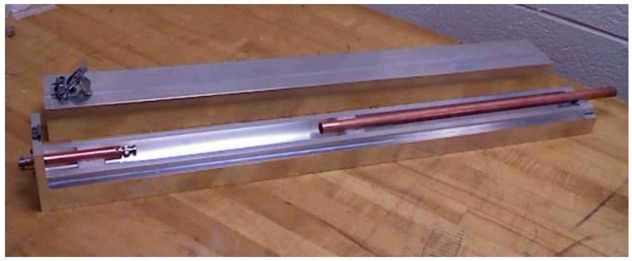


Figure 14: Copper Structures Inside Aluminum Housing

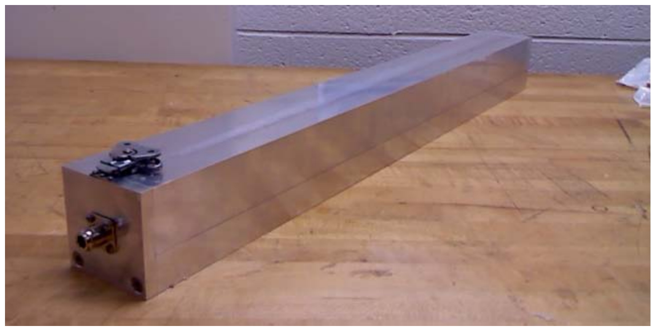


Figure 15: Fully Assembled Device

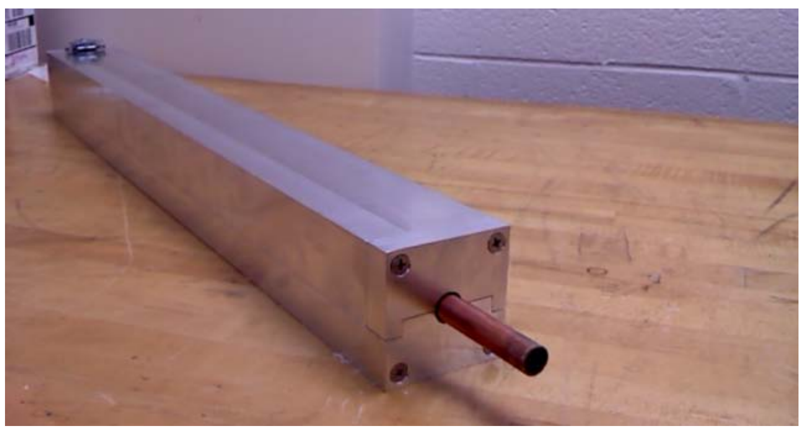


Figure 16: Signal Input End of Assembled Device

Figure 17: Receiver Structure. BNC Connector and 50 Ohm Load Matching BNC

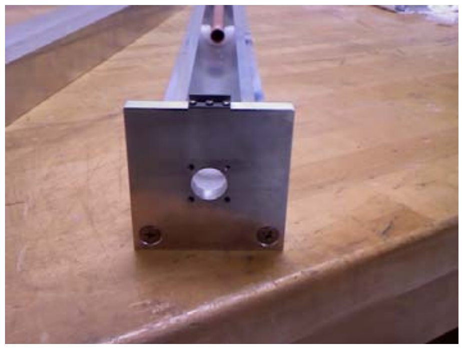


Figure 18: Unloaded Receiver End with Latch Keeper Plate

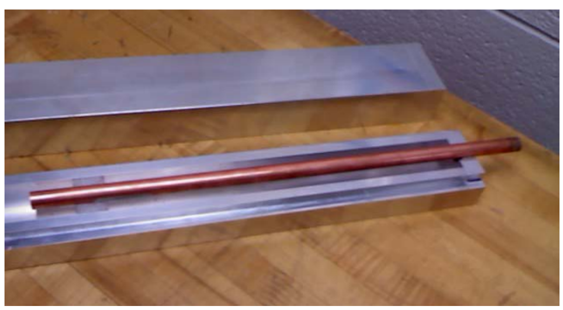


Fig 19: Input Tube in Device

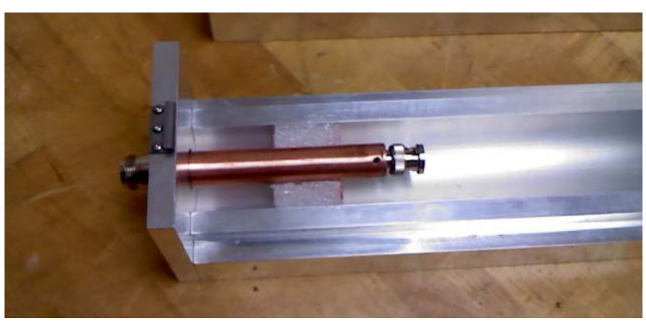


Figure 20: Receiver Structure in Device with Foam Concentric Spacer

c) Development of Test Configurations

The test configuration is developed first to allow for the measurement of one type of transmission line. The purpose of the tests is to determine the shielding effectiveness of different coaxial cables. Various flaws were physically introduced into the cable structure in order to determine the corresponding degradations to shielding effectiveness and/or RF attenuation characteristics of the coaxial cables. In order to accomplish this task, one must first determine the attenuation of the cable at desired frequencies. A network analyzer is utilized and a S_{21} transmission calculation is done. The attenuation is a measure of how much ambient signal can leak into the cable, as well as how much signal flowing through the cable will leak out. The FCC regulates the attenuation of cables at certain frequencies, which determines the parameters for the tests.

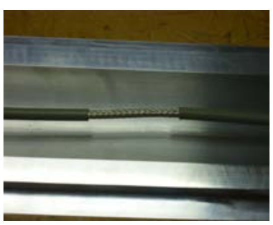
The test set-up is shown below. The network analyzer sends a signal into the device. Once the top is one and closed, the whole device acts as a coaxial cable, with the cable acting as the center conductor and the inside of the tube acting as the outer conductor. The receiver ends acts as an antenna, and the voltage drop is measured between the antenna and the inside of the tube. These results are sent through the receiver end of the device into the network analyzer.

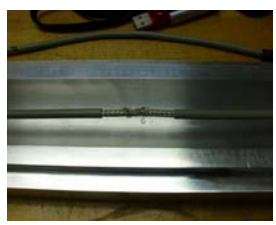
d) Test Procedures Development

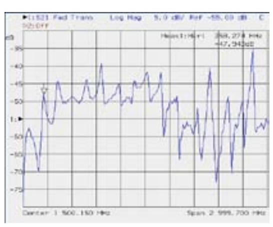
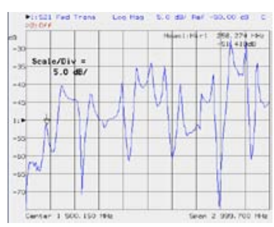
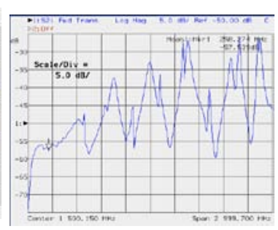
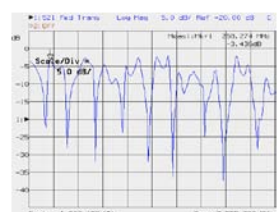
For the particular tests done for this project, RG-58 coaxial cables (95% shield coverage) were tested and compared to the commercial device. The cable for testing is placed into the device and the top is closed. The network analyzer is set up for S_{21} transmission calculations and a frequency sweep is run from 300 kHz to 3GHz. These frequencies are chosen to maximize the operation of the network analyzer. Small cuts are made in the shield of the cable and the difference in attenuation is noticed.

Images of the cable and the corresponding output are shown below. Notice that at higher frequencies the attenuation is worse. This is due to the decrease in wavelength. This is because it is easier for signal to leak through the smaller space. Likewise, a big difference isn't noticeable at lower frequencies due to the long wavelength. However, due to the regulations, any difference may be important.

The horizontal axis represents the frequency and the vertical axis represents the attenuation. The lower the output is on the vertical axis, the better the attenuation is.

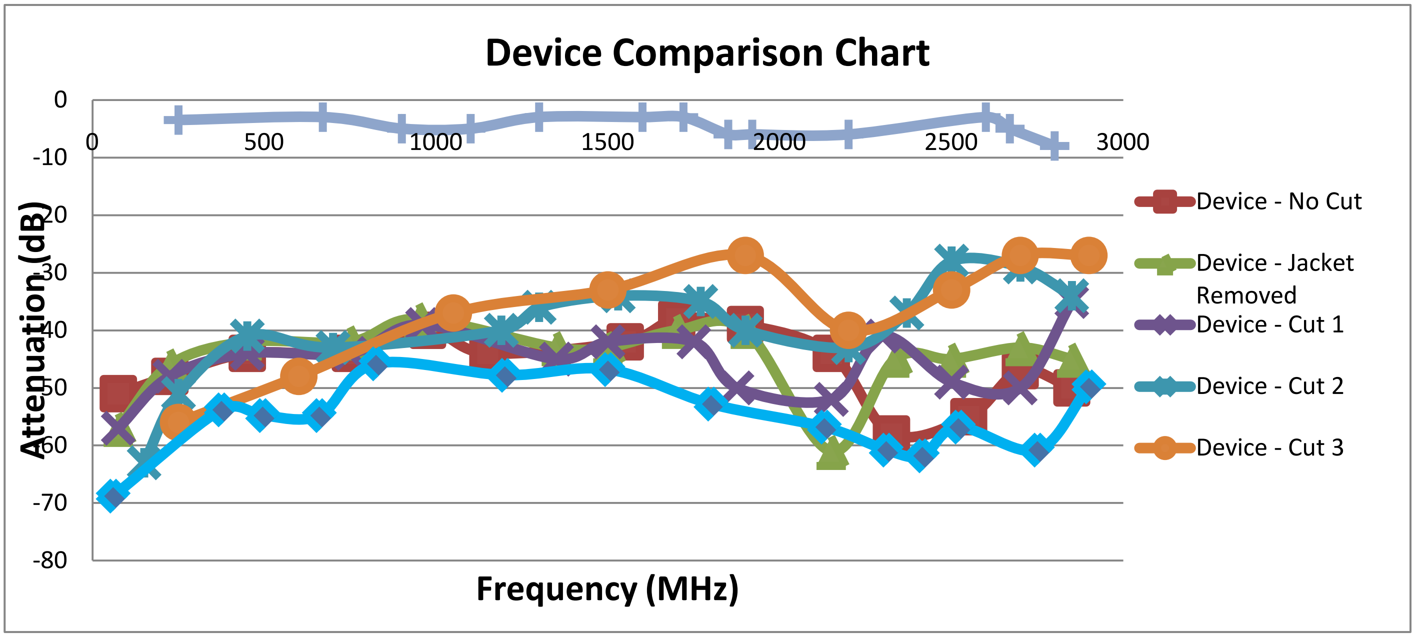




e) Test results

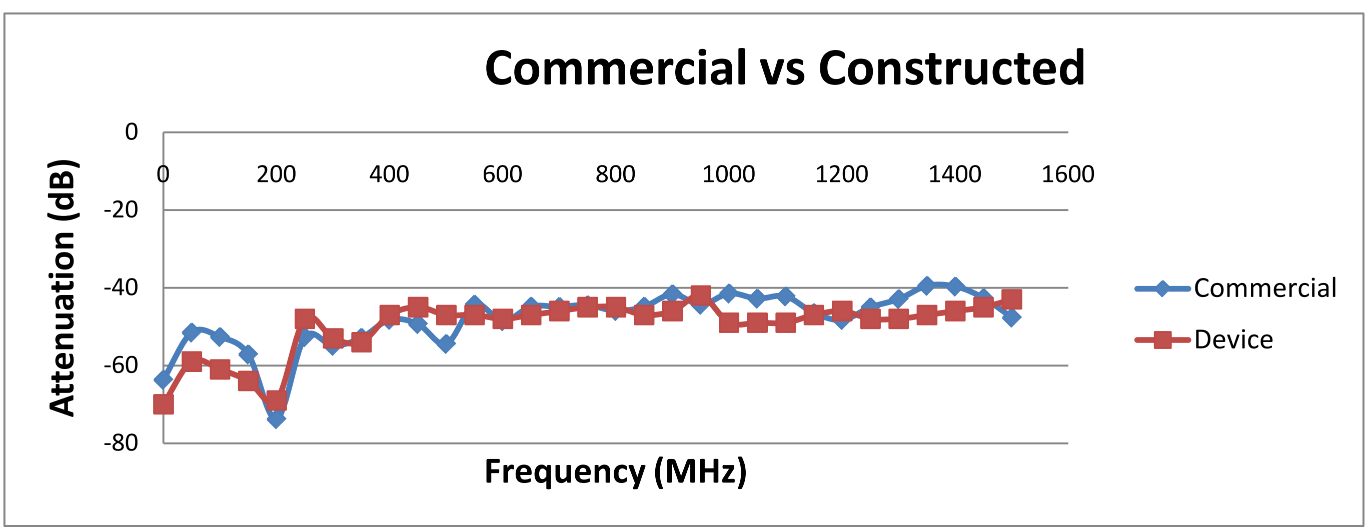
As shown above, various cuts to the cable shield were made to the cable samples. It is anticipated that these cut would affect the shielding integrity resulting in changes in shielding effectiveness of the cables. Below is a comparison chart for the results obtained. The points taken are at the peaks, which are the "worst-case" points. These are used since they are the data points desired for industry. Also below is a comparison chart between the uncut cables in the constructed device vs. the uncut cable in the commercial device. Since the device was originally designed for measuring at low frequencies, the chart only goes from 300 kHz to 1.5 GHz. As shown, very similar results were obtained.



f) Comparisons of Tube in Tube Performance – YSU vs. Commercial Unit

These results indicated that the device created produces comparable results to that of the commercial device, especially at lower frequencies.

Since similar results were found, the advantages of the YSU design are more valuable. Testing time is decreased by approximately 90%. The Styrofoam holders have more desirable dielectric properties. The square base makes the device easier to operate and more user-friendly. While designed to test up to 300 MHz, the device is operable into the GHz range.



8. Work Force Development and Student Training

One of the project initiatives is the work force development and student training. This initiative is planned to be implemented in phase 3 of the project. However, the project investigators believed that the training could be implemented at both phase 2 and phase 3 of the project.

4 YSU Electrical and Computer Engineering students received training during Phase 2 from the project investigators at YSU and at Delphi Corporation.

1. Training at Delphi Corporation

The students received extensive EMC training at Delphi's EMC Laboratory in Warren, Ohio by Professor Moy and Mr. Boyer (see picture below). The training included the EMC test methodology, Tube in tube design and development, test instrumentation, sample preparations and data analysis. The training enabled the students to properly design the tube in tube test apparatus and to effectively develop and perform testing for shielding effectiveness/RF attenuation of transmission line structures.

2. Quest (YSU)

The research project conducted by the 4 students were summarized into a poster and presented in Quest's poster session in April, 2010. Professor Moy and Dr. Jalali served as advisors for the students. The 4 students gained valuable experience in presenting the project to faculty members and other students. Their poster and presentation pictures are as shown below:

TRIAXIAL METHOD RESONANT CHAMBER FOR LOW FREQUENCY ELECTROMAGNETIC TESTING

Edward Burden, Stephen Moy, Kristopher Rose and Michael Zahran
Department of Electrical and Computer Engineering
Youngstown State University
Faculty Advisor: Dr. Jalal Jalali

Methods for Analysis of EM Signal Leakage:

- Reflection Calculations
- Anechoic Chamber
- Triaxial Test Method

TRIAXIAL TEST DEVICE COMPARISON

COMMERCIAL DEVICE vs. OUR DEVICE

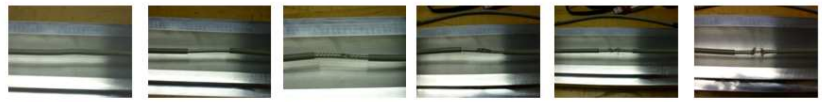
DEVICE MECHANICAL AND ELECTRICAL CHARACTERISTICS

- Overall Length : 750 mm
- Base : 80 mm X 80 mm
- Inside Cylindrical Diameter : 20 mm
- Weight : Approximately 40 lbs
- Material : 6061 Aluminum
- Material Creates Good Electrical Seal
- Cylindrical Inside Acts as a Resonant Chamber
- 50 Ω Impedance Matching Resistor in Terminal End
- Dielectric Rings Made of Styrofoam

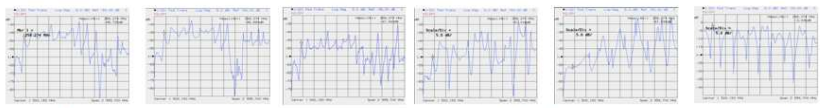
TEST PROCEDURE AND RESULTS

- Tested Cable : Coaxial cable with 95% shielding effectiveness
- V.N.A. calibrated at 50Ω load impedance
- Frequency Sweep : 300 kHz to 3 GHz
- Cuts made into the cable shielding
- dB levels measured to draw conclusions about shielding effectiveness at different frequencies
- dB level says how much outside signal will leak into cable as well as much inside signal will escape
- Attenuation correction performed on output to compensate for tube

Cable Shielding



Network Analyzer Output



Cable in tact. This is the gauge for all other tests.

Outer jacket removed. Not much difference in plots since shielding is provided by outer layer of cable and not the jacket.

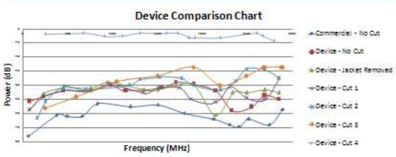
Small cut in shield. At high frequency, more signal leaks due to shorter wavelength. No noticeable difference at low frequencies due to longer wavelength. This decreases the odds of signal leaking through the gap.

Small circle cut into shield. The dB levels are lower at all frequencies now, and especially noticeable at large frequencies.

Large square removed from shield. At all frequencies the effectiveness of the shield is now approx. 35-45dB. Peaks now occur at very low dB levels.

Section of shield completely removed around conductor. Large amount of signal leak at all frequencies. Cable shielding is effectively gone.

COMPARISON PLOT



- At low frequencies, dB levels are similar due to the long wavelength in for the signal
- At high frequencies, considerable change is seen as shielding is removed

DESIGN ADVANTAGES OVER COMMERCIAL DEVICE

- Low cost – Approx 10x Cheaper
- Length of Tube – 750mm tube with adjustable copper pipe allows for testing of different length of cables, and allows for testing of long wires. Commercial device requires attachments to test longer wire samples. Also allows for performance of more low frequency testing.
- Ease of Use – Removable top provides immediate access to cable being tested which makes performing multiple tests much more convenient. Commercial device requires much more work to access the cable sample.
- Flat Bottom – Provides much more sturdy base when setting up test and changing samples. Round base of commercial device requires wooden supports during use.

CONCLUSIONS

DESIGN

- All features contribute to simpler operation
- Testing takes at least 10x less time
- Weight of aluminum creates a good electrical seal at a fraction of the cost

RESULTS

- As shielding is removed, a considerable drop in dB level is shown on plot
- Comparable plots obtained for frequency sweep
- Device was originally designed for frequency testing up to 200 MHz, but is functional all the way up to 3 GHz

3. Capstone – Senior Design Project

The students utilized the research project and followed the product/process development guidelines established within the Capstone Senior Design Project (ECEN 4899). Under the guidance of Dr. Jalali (Senior Investigator and Chair of Electrical & Computer Engineering), the students developed and submitted a research project book summarizing their research findings. The final cost for the device was $ 2,131 (less half of the allotted budget of $5,000) and significantly below the $20,000 price tag of the commercial device. The project was presented to the ECEN faculty members and Professor Moy (PI) in May, 2010. All 4 students completed the project and graduated from YSU with a Bachelor of Engineering Degree.

TRIAXIAL METHOD RESONANT CHAMBER FOR LOW

FREQUENCY ELECTROMAGNETIC TESTING

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CONTENTS

INTRODUCTION

The following project is to be conducted for the Capstone Senior Design class at Youngstown State University. The members of Group 5 include Edward Burden, Stephen Moy, Kristopher Rose and Michael Zahran. All four students are seniors in the electrical engineering program at YSU.

The Tube-in-Tube test method for determining the amount of signal leaked from electrically short connectors is performed according to IEC 62153-4-7 (triaxial method). Previously, low frequency attenuation tests required increasingly larger electrically shielded test rooms as well as measurement and calculations of signal reflection. However with the advent of the Tube-in-Tube design (see Fig. 1.) this is no longer the case.

With the Tube-in-Tube design, it is possible to test low frequency leakage in a much smaller space. The proposed Tube-in-Tube design will allow engineers to manipulate the twisted pairs without having to disassemble the apparatus.

The design will also allow companies the ability to procure their own Tube-in-Tube at a fraction of the cost of today's commercially available units. This will allow them to conduct testing that otherwise would have been cost prohibitive and/or that would have had to been outsourced.

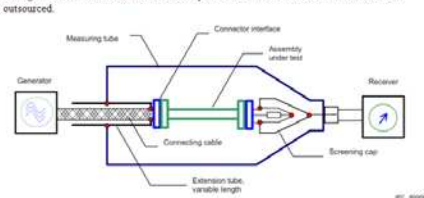

Fig. 1. Test setup to measure transfer impedances and screening of connectors

FUNDING / EXPENSES

The Tube-in-Tube apparatus is primarily funded through the Center for Transportation and Materials Engineering. The Center for Transportation and Materials Engineering at YSU was established in late 2006 as a result of funding received from the United States Department of Transportation. The funding, on the order of approximately $500,000 per year for four years was included in the 2005 Federal Transportation Efficiency Act of the 21st Century. The budget for this particular project is approximately $20,000, the cost of a commercially available tube-in-tube testing apparatus.

Due to several existing unknowns in the overall design of the device, specific numbers cannot yet be determined. Below is a list of all materials purchased thus far. Once the design is finalized with approval from Rich Boyer, the group's budget can be completed.

Table 2. Budget

Product	Supplier	Cost
Screws	Bolt Depot	$15.00
Latches	SouthCo	$38.14
Machining - Main Bottom	Kiraly Tool & Die	$640.00
Machining - Main Top	Kiraly Tool & Die	$620.00
Machining - Receiver Plate	Kiraly Tool & Die	$115.00
Machining - Input Plate Top	Kiraly Tool & Die	$100.00
Machining - Input Plate Bottom	Kiraly Tool & Die	$100.00
Machining - Custom Keeper Plate	Kiraly Tool & Die	$120.00
Styrofoam	Michaels	$4.78
Copper Tube and other misc. materials	Handyman Hardware	$17.37
Internal Components for Device	Kiraly Tool & Die	$585.00
Soft-Shield 5000 Series Conductive Jacket over Foam	Chomerics	donated

Total	$2,130.50

9. Summary

The status for each deliverables for Phase 2 is listed below:

A. Identifications of automotive communication architectures (100% completion)

- The automotive communication architectures were identified and summarized
- The transmission lines utilized for these architectures were discussed
- Assessment for these transmission lines effectiveness against electromagnetic Interference (EMI) were made

B. Measurement Configurations (Functional) Development (100% completion)

- The measurement techniques for functional EMC parameters were developed
- Measurements were performed on Unshielded Twisted Pair (UTP) and Shielded Twisted pair (STP) for the following parameters:
    - Characteristic Impedance Z_0
    - Line delay
    - DC Resistance

C. Measurement Configurations (Environmental) Development (100% completion)

- The test methodology to measure shielding effectiveness/RF attenuation characteristics were developed for the following instrumentation:
    - Absorbing Clamp
    - Tube in Tube – commercial unit
    - Tube in Tube – YSU Design

D. Design and development of RF Shielding effectiveness/RF Attenuation tests equipment (100% completion)

- Designed and developed a cost effectiveness design of Tube in Tube device
- Constructed the Tube in Tube device – meeting performance cost target
- Developed test methodology to perform shielding effectiveness measurements
- Performed shielding effectiveness measurements on various cable samples with artificially introduced cuts to the cable shields.
- Compared test results to the commercial design – comparable performance with improved operating efficiency

E. Work force Development and student training (50% completion)

Phase 2 of the project initiated the work force development and student training initiatives of the project. The following activities were completed:

- Recruited 4 YSU students from Electrical & Computer Engineering Department to work on the design, development, construction and application of the Tube in Tube project. Project investigated provided training to the students on product development process, technical knowledge, instrumentation and test methodology development at YSU and at EMC laboratory of Delphi Corporation
- Under the advisement of the principal and senior investigators, students participated in the poster session of the 2010 YSU Quest to present the research project. Students gained valuable experience from the event.
- The students, using the information of the research project, completed the Senior Design Project (Capstone) for the Department of Electrical & Computer Engineering. The project was documented and presented to students, faculty members and project investigators. All 4 students graduated from YSU in Spring/Summer 2010 with a Bachelor of Engineering degree.

F. Phase 3

Phase 3 of the project could be initiated with approval for continuation of funding by CTME. The deliverables of phase 3 are as follows:

1. Construction of test instrument for frequency domain measurement **(50% completed in Phase 2)**
2. Implementation of test instrument in test configurations
    - Improve the test configuration to allow for large volume of testing of various samples – acquire instruments from allocated equipment budget
3. Comparison measurement with standard industrial instrumentation
    - Obtain additional measurement data to compare various test methodology
4. Measurement of data communication transmission lines: Functional and Environmental
    - Perform measurements for additional data communication transmission lines
    - Established specifications for critical parameters for transmission lines
5. Initiation of collaboration with industry: Comparison of with measurement data from automotive laboratory
    - Perform measurements at YSU and Delphi Corporation to establish measurement collaborations
6. Implementation of Data analysis/summary
7. Initiation of Work Force Development – Integrate EMC concept into Electrical Engineering Technology classes (**40% completed in Phase 2)**