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

Final Report

Submitted by

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Grant Number: *G00000245*

MARCH 31, 2012

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1. Background

This report is the final report of the Center for Transportation & Materials Engineering (CTME) research project funded by the grant ***(Grant Number: G00000245)***. The report is submitted to Director of CTME for partial fulfillment for the deliverables of the project. Progress reports for Phase 1, Phase 2 and Phase 3 of this project have previously been submitted to Director of CTME of YSU.

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 various data transmission networks (interconnecting wiring and connection system) to provide interface to various systems will be discussed. The importance of EMC assurance to minimize the system's emissions and susceptibility to electromagnetic Interference (EMI) will be examined.

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

The project will develop test methodology for measurement of both functional and environment Electromagnetic Compatibility (EMC) of the data bus/transmission line structures.

The major project will focus on the development of an unique test apparatus to perform measurement of Shielding Effectiveness and RF (Radio Frequency) attenuation against Electromagnetic Interference (EMI) for the data communication transmission structures. Shielding Effectiveness has been identified to be the key parameter in determine the system's ability to meet environmental EMC requirements.

The test methods for functional characteristics of the transmission lines (based on twisted pair) will be developed. Test procedures and test results for various samples will be summarized.

The test apparatus, known as YSU Triaxial Device (YSUTD), will be developed as a low cost alternative to the existing commercially available unit (known as Tube in Tube device as described in IEC 62153-4-7 (2004) "EMC – test method for measuring the transfer impedance and screening or the coupling attenuation – Tube in Tube". YSUTD will also have greater flexibility, higher measurement efficiency and more user-friendly. YSUTD will be designed by a team of YSU engineering students (as their Senior Capstone Project) under the supervision of the YSU faculty members and the project investigators. The design project will also be supported by the EMC laboratory of Delphi Corporation in Warren, Ohio.

The YSUTD will be constructed by the students and will be used in the implementation of the test procedures to perform measurement of transmission line parameters. Via industrial collaborations, test results measured will be compared to those measured with a commercial unit at Delphi EMC laboratory.

Based on the data comparisons, if necessary, the YSU Triaxial Device will be improved to better match the performance of the Tube in Tube device available commercially. The detailed of the improvement and the final test results will be presented.

As part of the Work Force Development initiatives, 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 (Edward Burden, Stephen Moy, Kristopher Rose and Michael Zahran) 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. Utilizing the test equipment donated by Delphi Corporation and acquired by the projecting funding, 2 students (Shawn Penwell and James Clover) in the electrical engineering Technology program will work on a research project to investigate the frequency domain analysis of the digital signal. The results will be compared to mathematical analysis, computer based simulations and Fast Fourier Transform from time domain data.

The original project outline and deliverables as defined in Phase 1 of this research project are shown in Appendix 1 of this report.

2. Introduction

EMC (ElectroMagnetic Compatibility) is defined as the ability of equipment or system to function satisfactorily in its electromagnetic environment without susceptible to and introducing intolerable electromagnetic disturbances in that environment.

EMC technology is not new and has been around since the 1960's. Initially, it has been a major concern for the military where the electronic devices were incorporated into the communication and weapon systems which could potentially be subjected to intentional or unintentional Electromagnetic Interference (EMI). 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 the 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 .CISPR who is responsible for developing international Electromagnetic Interference (RF Emissions) has expanded its applications to include protection of EMI emitted by automobiles, systems and components. These test standards later formed the basis for the EU EMC directives as well as most, if not all, automotive OEM's product specifications.

However, these EMC standards are mainly applicable to whole vehicle and electronic modules, and they are not applicable to the vehicle's data communication networks (wiring or transmission lines structure).

In order to meet these new product requirements and government regulations, OEM, Suppliers and independent laboratories began to establish EMC laboratories to test 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. Today, with large scale integration of electronic devices into the automobiles, the system becomes increasingly complex.

In other to demonstrate the complexity of today's automotive electrical architecture, let us compare the electrical architectures of 1946 model year and 2010 model year 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.

Typically, the vehicle manufacturers' EMC requirements are well defined for electronic modules and on board computers. However, EMC requirements do not include the interconnecting wiring structure (transmission line structure). The vehicle systems can usually be divided into 3 categories.

The first category is infotainment (**Info**rmation and enter**tainment**) system and the second category the system that controls the vehicle operation. Each category can and typically does consist of multiple interconnected networks. The infotainment system, due to its high data requirements, has a better defined EMC requirement. Unfortunately, the EMC requirements (both functional and environmental) of the vehicle control network (intermediate data rate) are not well defined and their performances were not well understood or determined. Therefore, the data communication transmission line structure of the control network is the main focus of this research project.

The third category is safety architecture which also has well defined requirements and will not be a main focused of in this project.

Although the measurements will be performed mainly on wiring design for vehicle operations and data communication structures (Unshielded Twisted Pairs and Shielded Twisted Pairs, the developed test methods as well as the design of the test apparatus (YSU Triaxial Device) will also be applicable for the high speed/frequency applications (Coaxial Cables & shielded Twisted Pairs) specified for Infotainment and system systems.

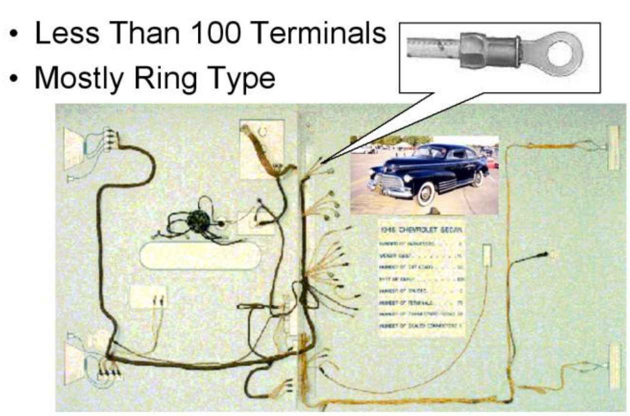

Figure 1 – Typical 1946 Vehicle Architecture

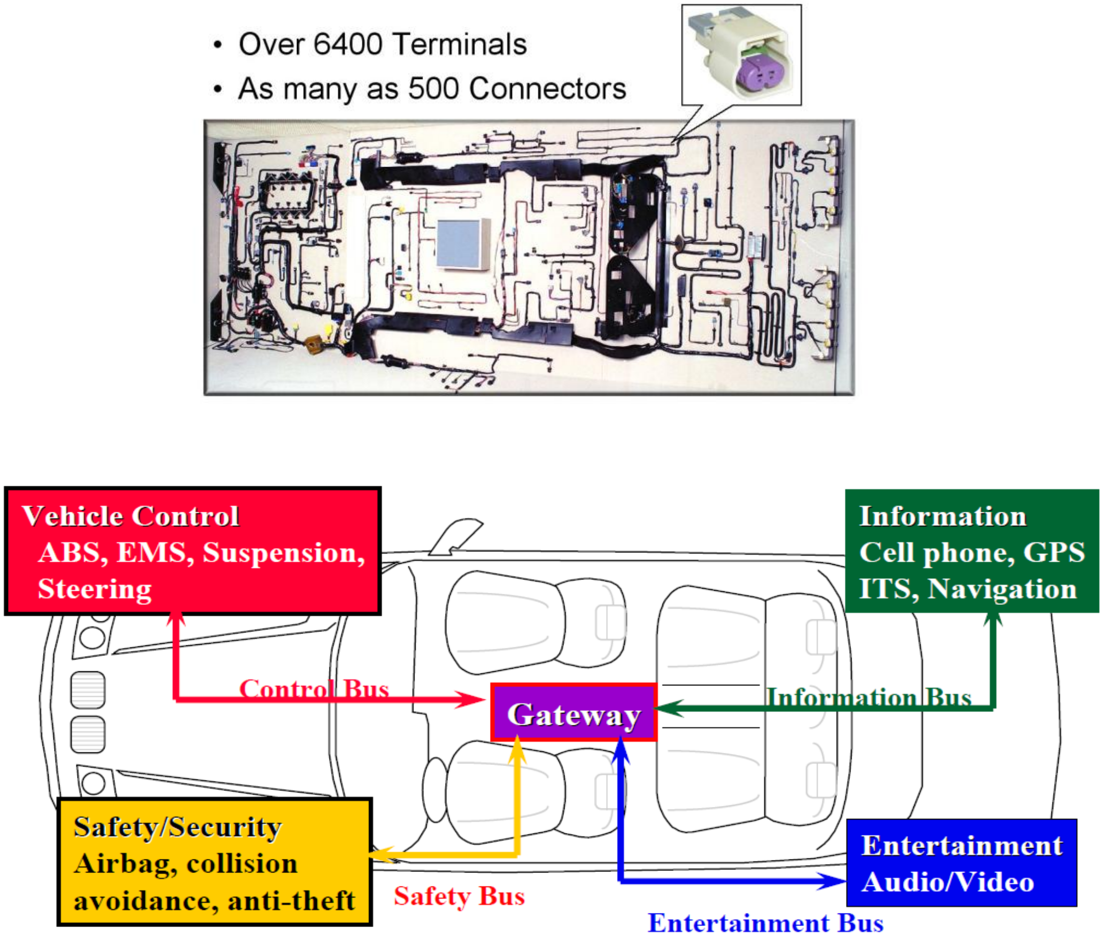

Figure 2 – Today's Typical Vehicle Architecture

A. Infotainment System

The infotainment (**Info**rmation + entert**ainment**) category is designed to focus on providing entertainment and information to the occupants in the vehicle. Some familiar technologies utilized are playing CDs and DVDs, Cell phones, GPS navigation system, radio & TV receptions, vehicle status, connecting USB devices, iPods, Xboxes, and PlayStations, surfing the internet, just to name a few. Recently, today's automobiles also have wireless connectivity to Internet through the use of cellular phone.

This category is for entertainment and information only and is neither critical nor required for the operation and control of vehicle. However, the system does require a high speed communication network and is potentially more susceptible to electromagnetic interference (EMI). Therefore, in most applications, the transmission line structure, due to its high data rate, has well- defined functional EMC requirements. However, the environmental EMC requirements are not as well defined. As indicated earlier, the test methodology developed in this project can be used to analyze the EMC environmental performance of the transmission line network.

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B. Vehicle Operational Control

This category includes engine management, critical systems, handling, and body functions (windows, door locks, latches, sliding doors, HVAC, lighting, etc…). This system also has links to the cellular phone and receives location information from GPS satellites to acquire information required for the proper operation and control of the vehicle.

This category is also very active to ensure 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.

Since vehicle control is relatively slow in comparison to the other system, it only requires a moderate transmission data rate. Subsequently, the transmission line specifications are often limited to physical properties and geometry of the system. Functional and environmental requirements are often not well defined.

In order to ensure compatibility to the electromagnetic environment (functional and environment), project investigators believes test methodology should be developed to properly design and evaluate the transmission structures. Hence, the main investigation of this project will be focused on the transmission line structure of this system.

C. Safety System

This system includes the functions that control the safety related functions of the vehicle such as Airbags, Engine Management System, Brake, Steering, and Collision Avoidance System, etc. The safety systems are able to communicate with each other via a safety network. It can connect to other vehicle system via a Gateway. In most cases, the system's architecture and protocol are proprietary and are well defined. Therefore, will not be a subject of discussion in this research project.

3. Assessment of Automotive Data Communication Systems

A. 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 and project time line , this research project will only discuss the parameters related to performance (functional and environmental EMC) of the transmission line structures and will not develop measurement techniques to analyze all of these parameters.

As discussed earlier, 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 to construct the data communication networks. One of the most important selection criteria for the cabling is the transmission data rate. Table 1 lists some of the most popular protocols, data rates, and their cabling for vehicle operation. The transmission lines (or cabling) can be defined as their physical structures where the geometry between the signal line and the signal return line is defined.

Table 1 includes only protocols for the open architecture. It excludes unique proprietary networks used by the makers of vehicles for special inter-module communications.

Table 1 – Sample of Present Vehicle Protocols (Open Architecture) and Cabling

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.

Acronyms used in table: LIN – Local Interconnect Network, CAN – Controller Area Network and OEM – Original Equipment Manufacturer.

B. 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. The attributes of the transmission line structures are listed below:

- **Infotainment system:**
    - Transmission lines have been extensively examined for the use in consumer electronics.
    - Transmission Lines have dedicated performance specifications for its construction and connection systems that automotive vehicle OEM cannot change.
    - The system is not critical to the vehicle operation and/ or safety systems. Adverse effect of the system will not have major impact to the safety of the vehicle and its occupants.
    - Infotainment systems are kept separate from vehicle operation and safety systems.

- **Safety System**
    - The transmission lines requirements for the safety system are typically defined by the vehicle manufacturers. Since the safety system is proprietary in nature, the cabling is designed and specified by as part of the system.
- **Vehicle Control System**
    - The proper selection of cabling for the vehicle operation network is not presently fully understood or explained.
    - Transmission lines for this system are usually specified for their physical dimension and parameters. EMC requirements (both functional and environmental) are not well defined.
    - The functional and environmental EMC performance are not known
    - Since the infotainment cabling is carrying the highest data rates and is sometimes included in the same vehicle harness bundles as the vehicle operation system's cabling, coupling (capacitive and inductive) between the wiring of the two systems could occur.

The 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.

As mentioned earlier, data rate of the communication system is critical in determining the design and proper selection of transmission lines. Therefore, it is important to know the data rates of various protocols that are in use today and in the near 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.

After performing literature search, some of the automotive data communication protocols are discussed below:

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.

It is important to point out, 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

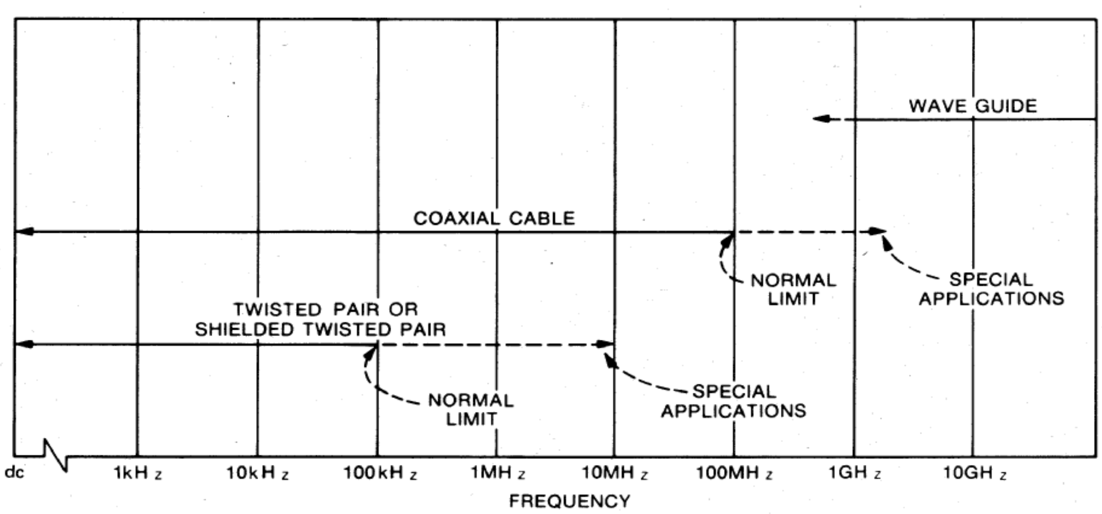


Figure 4 – Useful frequency range for various transmission lines

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:

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

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

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.

4. Electromagnetic Compatibility (EMC) – Functional EMC and Environmental EMC

EMC can be considered in two areas. The first one is “Functional” and the second one is “Environmental” as shown below.

Functional EMC implies that the system will function as design without being exposed to the electromagnetic environment (to be discussed in the next section) that it will encounter. The functional characteristics are important since the data/signal must be transmitted from the generator to the receivers via the transmission medium. The transmission medium can be free space, copper based transmission lines and plastic and glass optical fibers. For this research project, only copper based transmission lines are considered.

EMC - Environmental and Functional

- Functional EMC Compatibility

  The ability of the system to meet system functional performance objectives (to perform as design)

- Environmental EMC Compatibility

  (Electromagnetic Environmental Effects - E^3)

  The system must be compatible with (not affected by and not cause interference to) the electromagnetic (EM) environment

A. Functional EMC

In order for the system to meet functional EMC requirements, the transmission lines must be carefully designed to ensure proper transmission of the signal/data between the transmitter and the receiver. Some of the critical parameters are shown below:

Functional EM Compatibility

The ability of the system to meet system functional performance objectives (information/data must be transmitted from transmitter to receiver)

- Some critical parameters are:
  - Electrical (voltage, current, resistance …..)
  - Electromagnetic/RF:
    - Operating Frequency
    - Impedance
    - Insertion Loss
    - Capacitance
    - VSWR
    - Power budget
    - Others

B. Environmental EMC

Although the system has to meet the functional EMC requirements, it must also be able to maintain its performance when subjected to electromagnetic interference (EMI) in the electromagnetic environment in which the system must function.

The environmental EMC is also known as E^3 (Electromagnetic Environmental Effect) in the military applications.

There are two aspects for environmental EMC. The first one is **EM Immunity**. It implies that the system must be immune to the electromagnetic disturbances. One of the methods to protect the system from EMI is through the proper utilization of RF cables in the system's transmission line structure. The transmission lines are designed to minimize the EM disturbances from entering the system via coupling or radiation. In this situation, RF cables (shielded, twisted or shielded/twisted cables) are used. The critical parameter that determines the ability of protect against EMI is

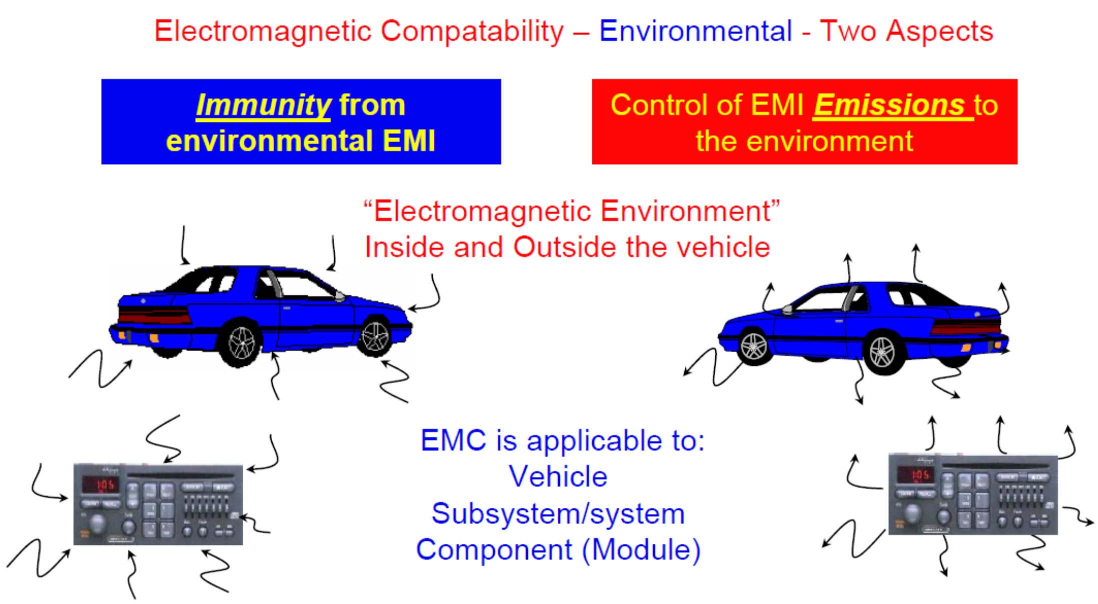
“Shielding Effectiveness” of the cable. This parameter will be examined in details in the later part of this report.

The second aspect is the **EM Emissions**. It is the levels and frequencies of the EM Emissions (radiated and conducted) from the system into the EM environment adversely affecting the proper performance of other systems. In order to avoid inter-system interference, the EM Emissions from electronic system must be limited. Due to principle of reciprocity, the RF cables which are utilized to ensure the system’s immunity from EMI can also be used to limit the EM Emissions of that system.

The critical parameter, “Shielding Effectiveness”, of the RF cables will help to determine the system’s immunity to and emissions of EMI.

The immunity to and emissions of conducted EMI (propagating within the transmission line structure via conduction) will require different test methods and it is not within the scope of this project.

A brief description is shown below:



Environmental (Electromagnetic Environmental Effects - E^3)

The system must be compatible with (**not affected by** and **cause interference to**) the electromagnetic (EM) environment

- Radiated Interference - EM Interference Through Radiation (to and from E/E systems)

- Conducted Interference - EM Interference Through Conduction (with the E/E systems)

Source of EMI

- Radiated electromagnetic field
  - Radiated electric field
    - CW
    - Modulated CW
    - Pulsed
    - Digital (square wave)
    - EMP (Electromagnetic Pulse)
  - Radiated magnetic field
- Conducted high voltage transients
- Conducted RF
- ElectroStatic Discharge (ESD)

5. Application of Transmission Lines (TL) for EMC

In applying transmission line to meet system's EMC requirements, in additional to performance characteristics, the cost must be minimized for automotive applications.

Figure 3 is a brief illustration of performance vs. cost of the various protocols:

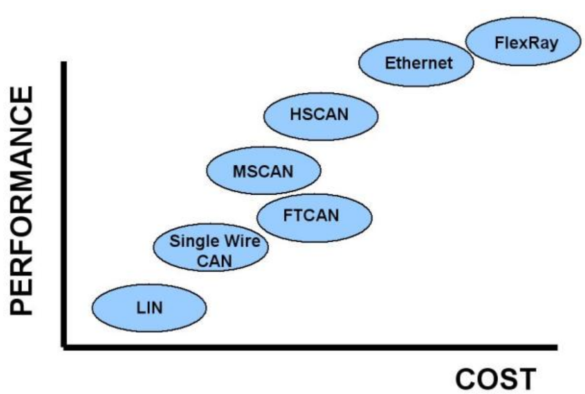


Figure 3 – Performance vs. Cost of Various Automotive Protocols

6. Descriptions of Various RF Cables

RF (Radio Frequency) cables are typically used as transmission lines for various architectures. The transmission lines serve 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)

Assessment of various types of transmission lines on their effectiveness in attenuating various EM disturbances is shown 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

* Note: Good if balanced circuit is used

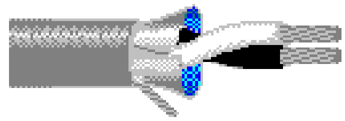
B. Physical Descriptions of various transmission lines

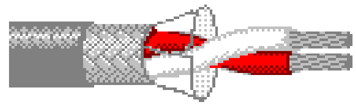
Two types of transmission lines are typically utilized for vehicle operational control architecture. They are shielded cable and coaxial cable. The characteristics and constructions of these cables are discussed below:

a. Shielded Cables with Various Shield Constructions

<u>Common Types of Shielded Cable</u>

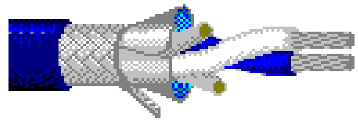
- Braid Shields





- Foil Shields

- Combination Foil/Braid Shields



- **<u>Braid Shields</u>**
  - 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

- **<u>Foil Shields</u>**

  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 addressed when the drain wire is applied:

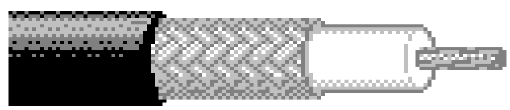
Foil Shield/Drain Wire Issues

- 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

Although coaxial cable has a metal shield over the center conductor, is not considered to be a shielded cable because the signal returns in the shielded instead of a separate signal return line for the shielded cable. Due to its symmetry, it has a very good shielding effectiveness characteristic.

It 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

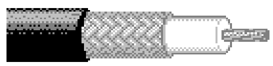
- Coaxial cable is not a "shielded" cable if the braid shield carries signal current
- Coaxial cable works well as RF cable because of :
  - Its fixed symmetrical geometric structure to maintain characteristic impedance
  - Lower insertion loss and Low capacitance
  - At high frequency, due to skin effect, 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 be 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 Shielded Twisted Pair both provide shielding against electric and magnetic fields. The performance comparisons for these two cable constructions are shown below:

Shielded Cable

Coaxial Cable



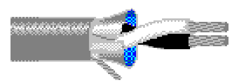
Signal Transmission

- **DC to 1 GHz**
- **Low Capacitance**
- **Low loss below a few hundred MHz**
- **Uniform Zo**

Shielding Performance

- **OK for 1 MHz < f < 100 MHz**
  - **f < 1 MHz, common resistance coupling**
  - **f > 100 MHz, braid "leaks" RF**

Shielded Twisted Pair (STP)



Signal Transmission

- **Dc to 1 MHz**
- **High Capacitance**
- **High loss above 1 MHz**

Shielding Performance

- **Excellent, depends somewhat on construction (spiral, cigarette, etc.)**
- **Characteristics similar to tri-axial cable**

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

- **Coaxial 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

- **STP 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. Transmission Lines EMC Parameters – Functional and Environmental

Since the type of cabling has been identified as Unshielded Twisted Pair **(UTP)** and Shielded Twisted pair **(STP)**, the next step is to determine the critical parameters that must be measured and analyzed to ensure that the cabling will be applicable for the intended data rates and EM 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 parameters to be measured and the frequency range for each parameter, the selection of test equipment can best be optimized for cost and capability. The two critical parameters are Characteristic Impedance and Shielding Effectiveness. For the measurement of characteristic impedance and shielding effectiveness (attenuation), the frequency range will be 100 kHz to 50 MHz and 1 MHz to 1 GHz respectively.

In additional to the EMC parameters, there are other issues associated with the construction of the twisted pairs that will influence the EMC performance of the cable. These issues are twist rate, cable gauge, cable insulation material, shield material, shield application, and drain wire implementation, etc. These issues must be considered and documented for all measurements. The effect of these issues on the shielding effectiveness of the cable can be determined utilizing the test methodology developed in this project.

A. Functional EMC - Transmission line parameters

Although all the parameters listed below would impact the functional characteristics of the transmission lines, the first three parameters (shown in bold) are the most significant for the transmission line itself. The others are influenced by the characteristics of the system (input and output impedance of the generator and loads). In this project, development of test methodology and analysis will focus only on the first three parameters as identified by the Bold Letters below:

- **Characteristic Impedance**
- **Line Delay**
- **DC Line resistance**
- input Impedance
- Load Impedance
- Transmission Coefficient
- Reflection Coefficient
- S parameters

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

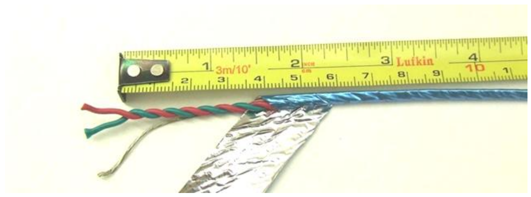


Figure 6 – 100 twist/m STP with drain

b. Test Configurations and Test Results

1. Characteristic Impedance Z_0 (Ω) Measurements

Characteristic Impedance is a critical parameter for the cable. In order for proper function of the system, it must match the output impedance of the transmitter and the input impedance of the load. With the matched system, the data/signal can be transmitted from the transmitter to the load without reflection. This would reduce the signal loss and potential of undesirable electromagnetic emissions.

a. **Test Configurations**

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). Two types of cable are analyzed: 1. Unshielded Twisted Pair (UTP) and 2 Shielded Twisted Pair (STP).

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

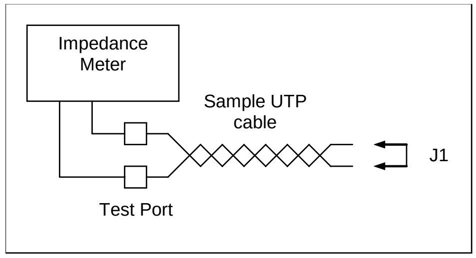


Figure 7 – UTP Characteristic Impedance Measurement Setup

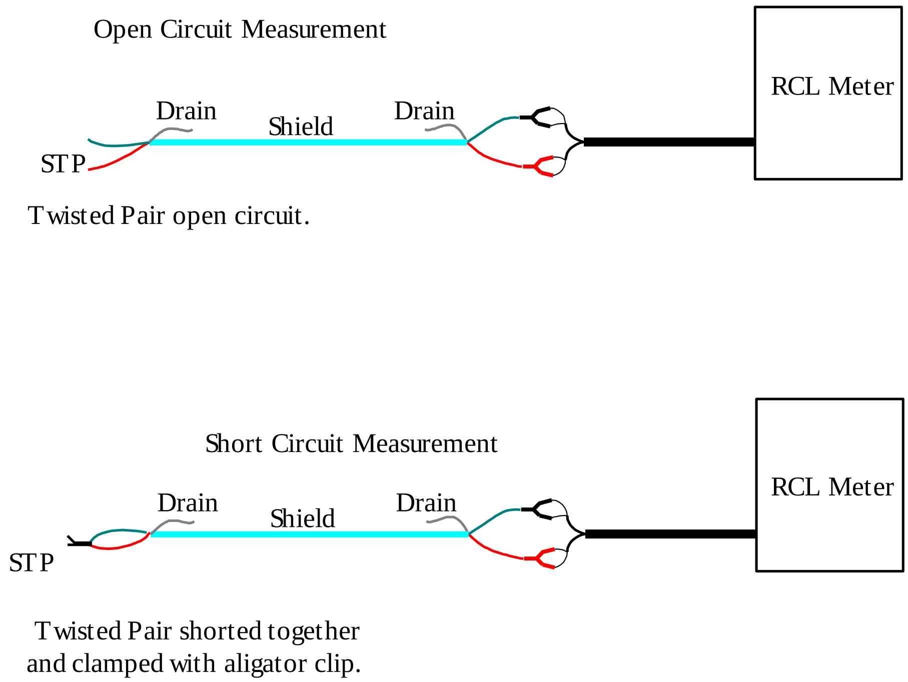


Figure 8 – STP Characteristic Impedance Measurement Setup 10 kHz to 100 kHz

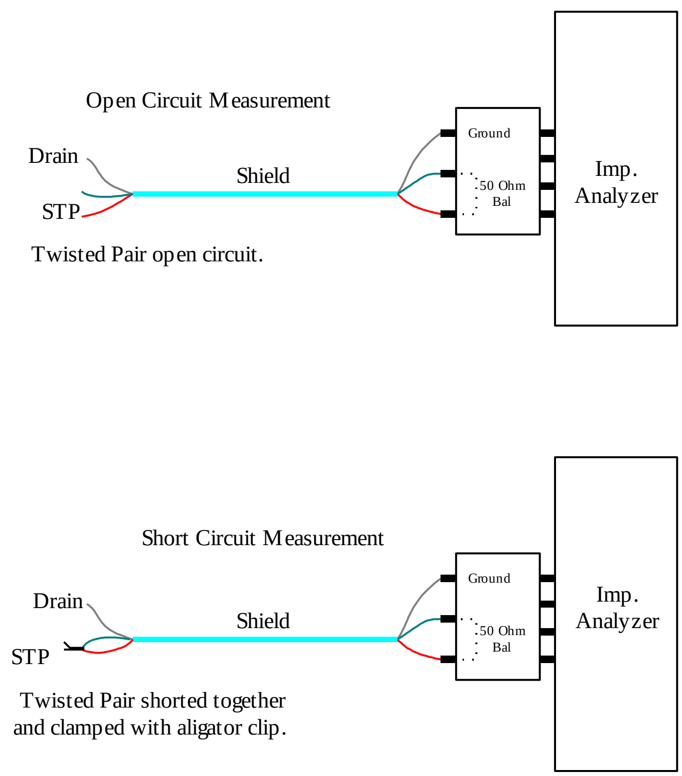


Figure 9 – STP Characteristic Measurement Setup for 1 MHz to 10 MHz

b. **Characteristic Impedance Measurement Results**
The characteristic impedance of UTP and STP 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

2. Line Delay (ns/m) Measurements

a. Test Configurations
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

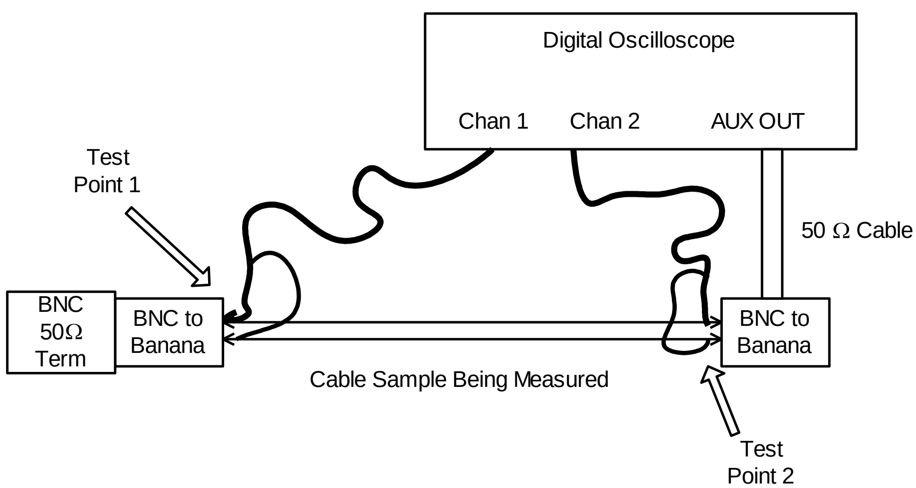


Figure 10 – Time Delay Measurement Test Configuration

b. **Time Delay Measurement Results**

The measurement results are summarized 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

3. 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.

a. **Test configurations**

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

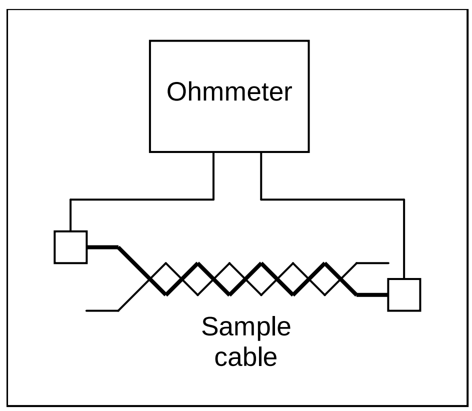


Figure 11 – DC Line Resistance Measurement Setup

b. **DC Line Resistance Measurement Results**

The measurement 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

B. Environmental EMC – RF Cable Parameters – Shielded Effectiveness (SE)

The key parameter that determines the overall EMC performance of the transmission lines (shielded cables) is the **Shielding Effectiveness (SE)**. SE determines the ability of the shielded cable to attenuate electromagnetic wave (into or out of the transmission lines).

Beside the shielding effectiveness, other parameters listed SE will also directly or indirectly affect the shielding effectiveness performance. Therefore, if changes are made to these parameters, it will have an effect on the shielding effectiveness of the cable. By using the test methodology developed for shielding effectiveness measurement, the impact on shielding effectiveness due to the variation of these parameters could be determined.

Therefore, the main focus is to develop a cost effective and reliable test method which can accurately measure the shielding effectiveness of the shielded and twisted cables.

- **Shielding Effectiveness (Attenuation Characteristics)**
  - 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

1. Shielding effectiveness (attenuation) Measurements (IEC 62163 - 4- 5)

Experiments were performed to determine shielding effectiveness (attenuation characteristics) of RF cable.

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. It can be noted that the graph indicates the shielding is more effective at the lower frequency.

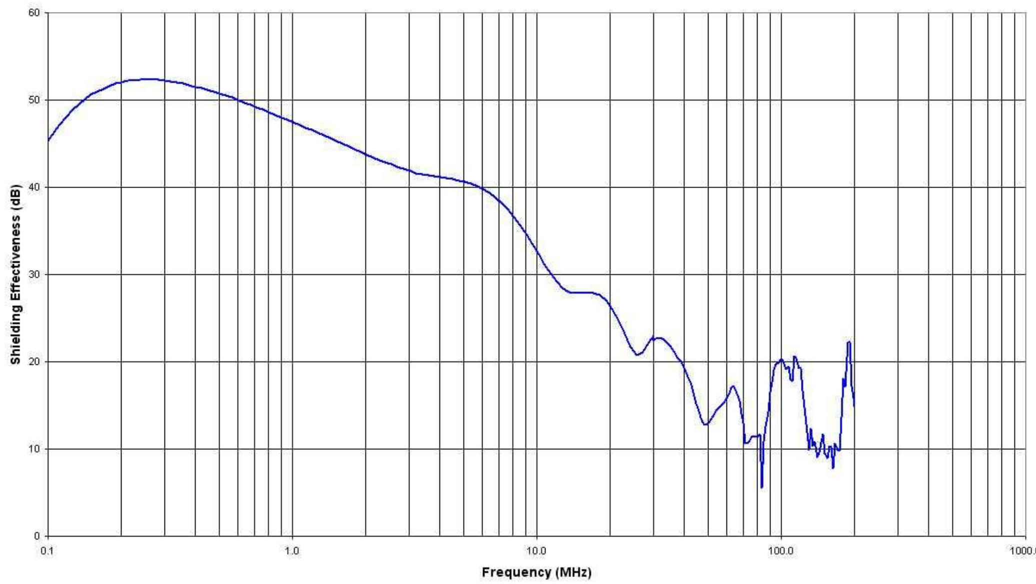


Figure 12 – Shielding Effectiveness of 0.35mm² STP

2. Shielding Effectiveness/Attenuation Test Method – Tube in Tube Triaxial Device

Shielding Effectiveness (SE) is the parameter determining the effective of the shield to attenuate the electromagnetic interference. This parameter is obtained by comparing the induced voltage from the test sample to the outer shield which is connected to the measuring instrument. The induced voltage from test sample without shield is first measured and recorded by the test instrument as V_1. This is the baseline measurement. The experiment will be repeated by replacing the baseline sample (no shield) by the sample under test. After the induced voltage (V_2) is obtained, it will be compared by the instrument internally and the result is displayed as the shielding effectiveness (in dB) as a function of frequency. Mathematically, the ratio of the two voltages is expressed in dB using the following relationship.

$$SE = 20 \log \frac{V_2}{V_1} \quad \text{dB}$$

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.

As indicated above, one of the test methods which can accurately determine the shielding effectiveness of cables is the Tube in Tube Device (Triaxial device) developed several years ago. This device is currently available commercially and is specified in an international test standard. However, our analysis has shown that this device is prohibitively expensive (in excess of $ 25,000) and is lacking flexibility to meet high volume testing, reduced test time and low test cost (typically required in the automotive industry testing laboratories).

In order to overcome these cost and performance issues, the YSU project team decided to design, develop and construct a new Triaxial Device that is comparable in performance to the commercial device with a cost target of less than $5,000 while incorporating the desirable new features as described in section 8 of this report. This Triaxial device is named “YSU Triaxial Device” or “YSUTD”

In order to meet the project time line and reduce cost of the test system, the design team implemented the following strategy:

YSUTD Design Strategy:

- **Solicit equipment donation from Delphi Corporation (including Network Analyzer and Spectrum Analyzer) for the development phase of the project**
- **Design the YSU Triaxial Device to be compatible with existing test standard.**
- **Perform Shielding Effectiveness measurements in YSU’s Electromagnetic Fields Research and Instrumentation Center (EFRIC)**
- **Perform some experiments in Delphi’s EMC laboratory to compare experimental results between Tube in Tube device and the YSU Triaxial Device to ensure performance**
- **Purchase equipment for YSU utilizing the project equipment budget to enable additional testing to improve on performance of the YSU Triaxial Device**
- **Improve YSUTD performance (if necessary)**

Design & Development for YSUTD

It is the vision of the YSU 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 (See Appendix 2). With the assistance provided by the consulting instrumentation specialist, and the project investigators, 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.

A. Tube in Tube Triaxial Device- Principle of Operation

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 attenuation characteristics will directly provide the shielding effectiveness performance of the test sample.

The Tube in Tube test apparatus acts as a coaxial cable, allowing the measurement of voltage drop at the outside of the Tube.

YSUTD 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 Tube in Tube design will allow engineers to manipulate the twisted pairs without having to disassemble the apparatus.

Since the YSUTD design allows our ability to construct the triaxial device at a fraction of the cost of today's commercially available Tube in Tube units, it can be mass produced for laboratory applications with greatly reduced test time.

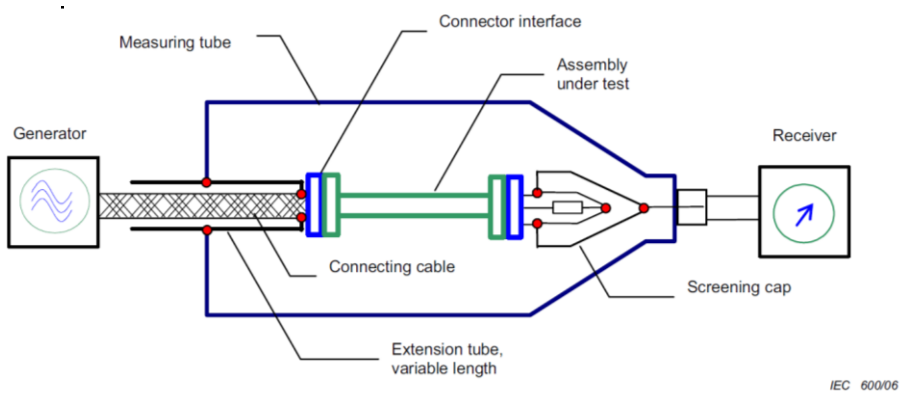
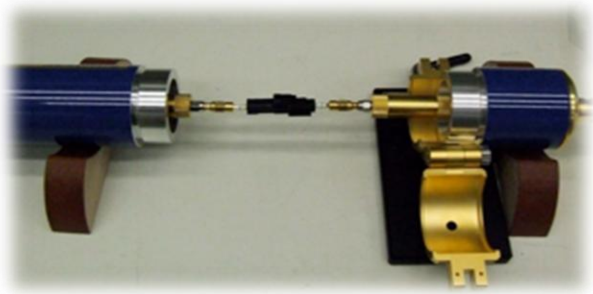


Figure 13 Test setup to measure transfer impedances and screening of connectors

B. Tube in Tube Design and Construction

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 where quick change of test samples or internal connectors is necessary. This makes the device cumbersome and unwieldy. Furthermore, the Tube in Tube device does not accommodate high volume testing of specimen where quick changes are needed.

YSUTD will be designed to overcome these issues and is described in section 8 of this report.

8. YSU Triaxial Device (YSUTD) - Design and Development

The YSU project team decided to design, develop and construct a YSUTD as part of the test methodology development effort. Due to project time line, the YSU development team must have access to the test equipment and have support from EMC laboratory which had extensive technical experience and capability in the Tube in Tube test methodology. In order to meet the project time line and reduce cost of the test system, the design team implemented the following strategy:

<u>YSUTD Design and Implementation Strategy</u>:

- Solicit equipment donation from Delphi Corporation (including Network Analyzer and Spectrum Analyzer) for the development phase of the project
- Design the YSU Triaxial Device to be compatible with existing test standard.
- Perform Shielding Effectiveness measurements in YSU's Electromagnetic Fields Research and Instrumentation Center (EFRIC)
- Perform some experiments in Delphi's EMC laboratory to compare experimental results between Tube in Tube device and the YSU Triaxial Device to ensure performance
- Purchase equipment for YSU utilizing the project equipment budget to enable additional testing to improve on performance of the YSU Triaxial Device
- Improve YSUTD performance (if necessary)

It is the vision of the YSU 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, Principal Investigator, Senior 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 Network Analyzer.

The development project would also serve 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 (See Appendix 2). With the assistance provided by the consulting instrumentation specialist, and the project investigators, the students design, developed and construct the Tube in Tube test apparatus with improved flexibility 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.

A. Design Features of YSUTD

After numerous discussions and analysis of the Tube in Tube device, the YSU research team decided the YSUTD will meet the design target as shown below:

a. Construction and Material cost will be less than $5,000

b. Performance comparable to commercial Tube in Tube device

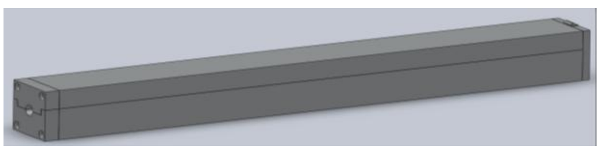
c. Easy to operate – allowing quick change of test samples

d. Utilization of commercially available materials

e. Ability to test both connectors and cables
f. No specially designed and built parts
g. Easy to set up without requiring special test stand as in Tube in Tube device
h. Incorporating standard RF connectors such as N, SMA, and BNC
i. Ability to directly interface with test instruments
j. Suitable for use as test apparatus in international test standard – IEC 62153-4-7

B. Design, Development and Construction of YSUTD

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.



	Commercial Fixture (mm)	YSU Fixture (mm)
Inside diameter of outer tube	39.9	39.9
Outside diameter of inner tube	17.4	15.8

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.

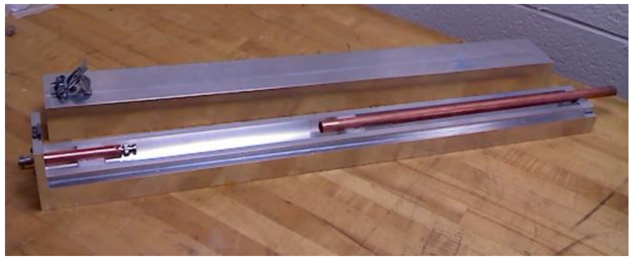


Figure 14: Copper Structures Inside Aluminum Housing

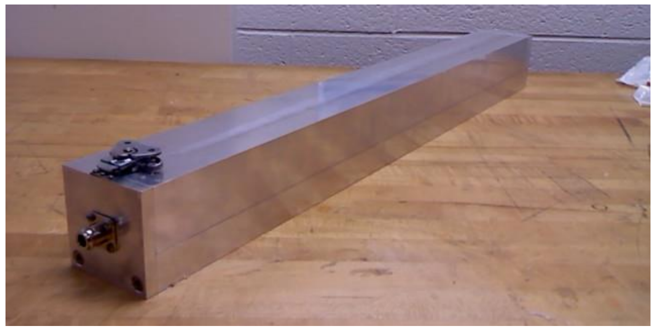


Figure 15: Fully Assembled Device

Figure 16: Signal Input End of Assembled Device

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

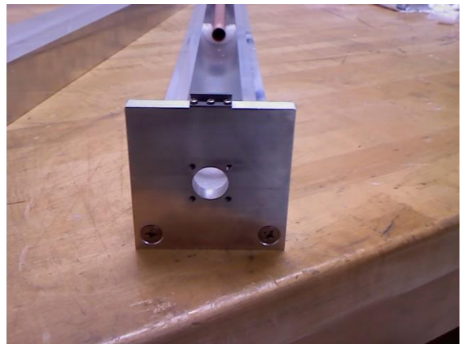


Figure 18: Unloaded Receiver End with Latch Keeper Plate

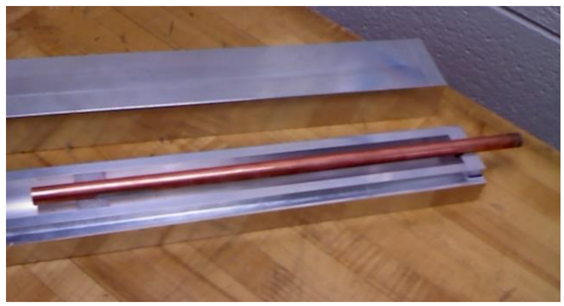


Fig 19: Input Tube in Device

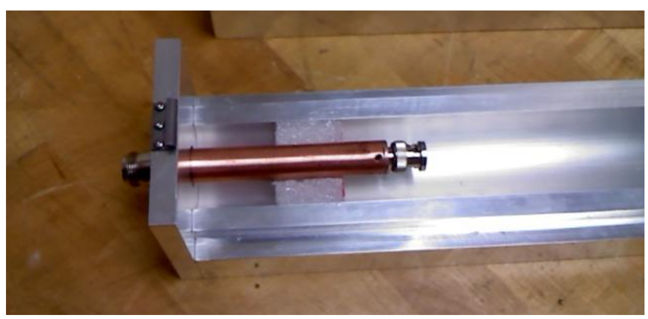


Figure 20: Receiver Structure in Device with Foam Concentric Spacer

C. Advantages of YSU Triaxial Device Design vs. Tube in Tube

After completing the construction of YSUTD, the design team analyzed the features of the device to ensure the design target had been met. They are shown below:

a. Significant Cost Reduction over the Tube in Tube device

YSUTD's material and construction cost is approximately $ 2,500 in comparison to the Commercial Tube in Tube cost of $25,000. It is actually 50% less than the targeted cost of $5,000. It could be mass- produced to enable high volume of testing. If required, it can also be rescale to various dimensions and send to machine shop for construction to meet different cable design and test requirements.

b. Reduced Test Time (over 70%)

The cover of the YSU Triaxial Device can be lifted off and on quickly (Tube in Tube requires clamping and screwing down to tighten the cover).

It allows easy access to samples allowing for more experiential investigation. The Tube in Tube device was constructed with all test samples enclosed reducing the accessibility. This also allows for easily seeing effects of different dielectrics surrounding samples.

This design results in a test time saving of almost 70% (in comparison to the test time required for the Tube in Tube device) based on assessment by the YSU students' Capstone project timing chart. The comparisons are shown in the pictures below:

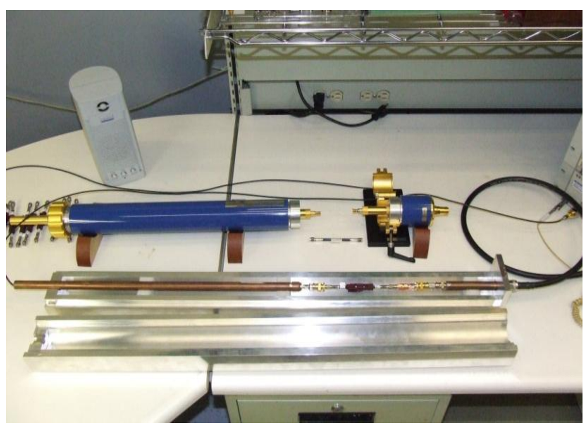


Figure 21: Both End Open

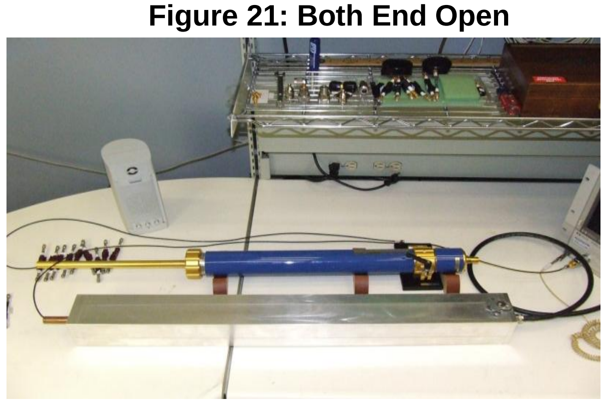


Figure 22: Both Fixtures Closed

Figure 23: Comparison Between YSUTD and Tube in Tube

c. RF Seal Maintained without clamp

YSU TD relies on weight to maintain RF seal vs. commercial fixture requiring a specialty Clamp

Figure 24: Tube in Tube - Specialty Screw - Down Clamp Required

d. Open Dielectric Support - Reducing Test Setup Time

The commercial fixture utilizes blind dielectric supports inside outer tube. This is difficult for technician to keep in place. YSU Triaxial Device utilizes using open dielectric supports which allow for easy modifications to construct different sample terminations

Figure 25: YSUTD - Dielectric Support Design

e. Customized Special Materials Not Required

Utilizing common material for the construction, special customized construction materials are not required. the YSU fixture modifications are quicker, easier, and less expensive. The YSU fixture uses common plumbing copper piping and fixtures found in any hardware store. Commercial unit uses custom brass tubing. YSU fixture uses easily modified aluminum and standard N connector to inner tube. Commercial fixture uses expensive custom machined n connector to inner tube.

YSU Device - Standard N Connector and Aluminum Plate with 2 Screws

Tube in Tube Fixture Machined Brass N Connector to Inner

Figure 26: Tube in Tube Expensive Customized Tubes and Brass Connections

f. Special Test Stand Not Required

YSU Triaxial Device is flat and therefore requires no supports commercial fixture is round and requires supports.

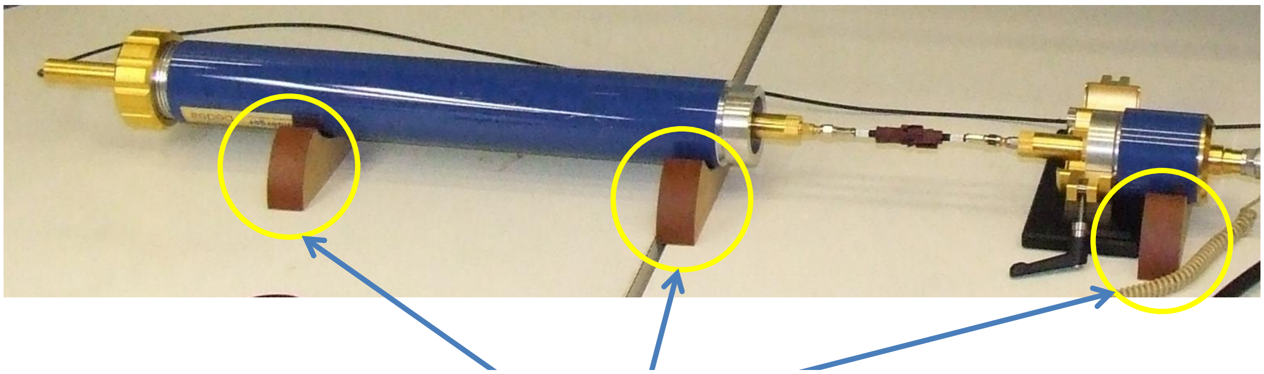


Figure 27: Tube in Tube Custom Stand Required

g. Flexibility in Allowing Changing length in Test Samples

If long sections of cables were to be tested, the YSUTD (with open air dielectric support) can be modified quickly since the length is not controlled by the fixed dimension of the dielectric support utilized by the Tube in Tube design.

The YSUTD allows for easier use of suspending the long sample in the center which is required to maintain coaxial geometry of test specifications.

D. Development of Test Methodology for Shielding Effectiveness (SE) Measurement for YSUTD

A. Descriptions

Initially, the test configuration was developed to allow for the measurement of one type of transmission line. After careful considerations, the design was modified to accommodate multiple types of transmission lines.

In order to demonstrate its flexibility, shielding effectiveness of different coaxial cables was measured. Coaxial cable is used since it is widely available and its good EMC performance characteristic is well specified.

One important aspect of the YSUTD is to determine its ability to determine the change in shielding effectiveness of coaxial cables with potential manufacturing defects. To achieve this, various physical flaws were intentionally introduced into the cable structure in order to determine the corresponding degradations to shielding effectiveness (RF attenuation characteristics) of the coaxial cables.

The attenuation of the cable at desired frequencies was first determined. A network analyzer was utilized and a S_{21} transmission calculation was done. The attenuation is a measure of how much ambient signal could couple into the cable, as well as amount of signal flowing inside the cable would escape.

The test set-up is shown below. The network analyzer sends a signal into the device. Once the top is on and closed, the entire device acts as a coaxial line, 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 signals are sent through the receiver end of the device into the network analyzer.

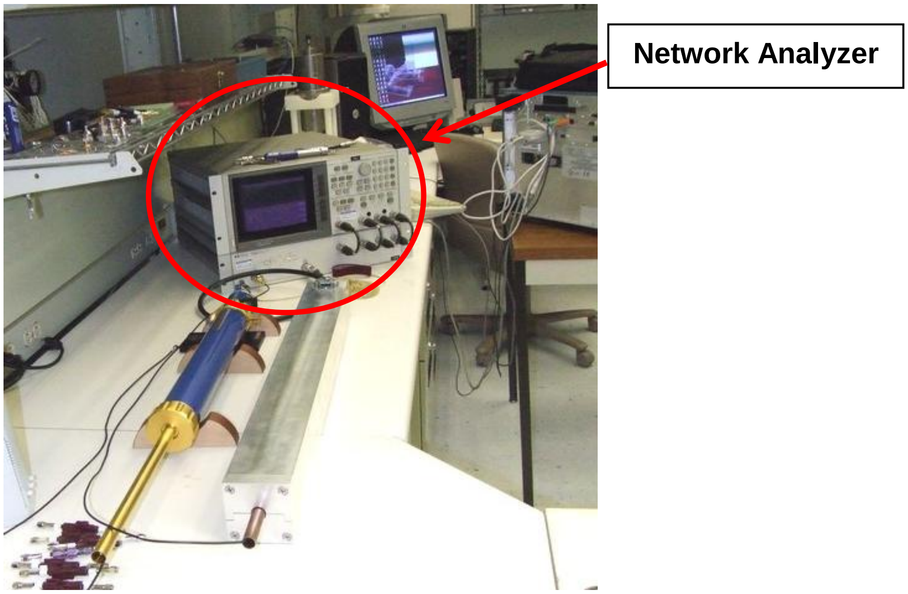


Figure 28: Shielding Effectiveness Test Configuration

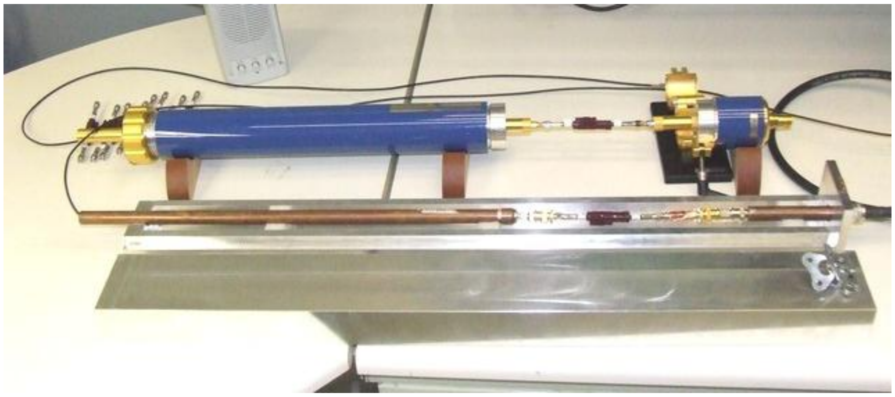


Figure 29: Shielding Effectiveness Test Configuration – Sample Connections

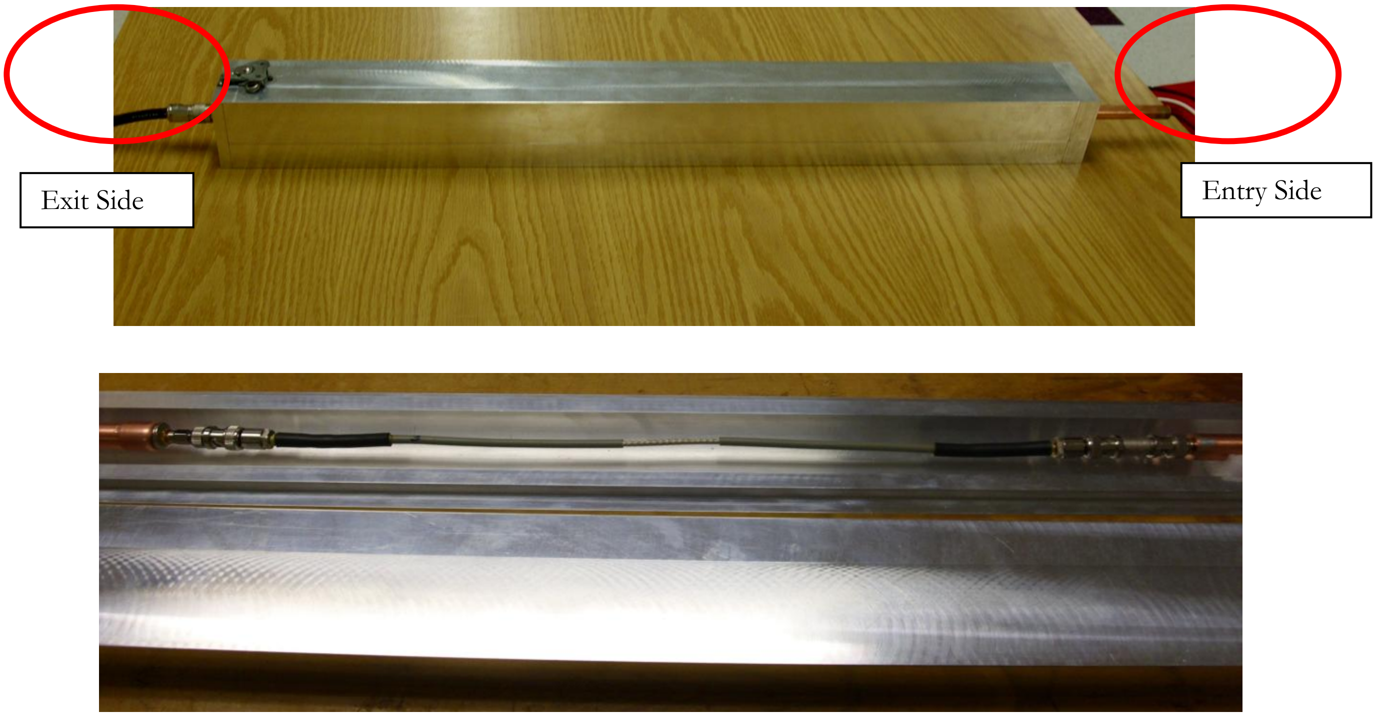


Figure 30: YSU Triaxial Device – Test Sample configurations

B. Test Procedures Development

The Tube in Tube in the standard shielding effectiveness measurement test method developed and implemented by Delphi’s EMC laboratory was replaced by the YSU Triaxial Device. The experiments were repeated in order to provide comparisons between the two devices

For these particular experiments in the project, the shielding effectiveness of RG-58 coaxial cables (95% shield coverage) were tested with the YSUTD and the results were compared to those obtained with the Tube in Tube device.

The cable test sample was placed into the YSUTD and the top was then closed. The network analyzer is set up for S_{21} transmission calculations and a frequency sweep was performed from 300 kHz to 3GHz. These frequencies were chosen to maximize the operation of the network analyzer.

Small cuts were made in the shield of various cable samples. Shielding effectiveness measurements were performed. The difference in shielding effectiveness (attenuation) for corresponding test samples were recorded and analyzed.

Images of the cable and the corresponding output are shown in Figure 31. It is noted that at higher frequencies the shielding effectiveness was worse (or attenuation was not as good). This is due to the fact that wavelengths are shorter at higher frequencies. Subsequently, it is easier for RF to penetrate the shield openings. Likewise, a big difference isn't noticeable at lower frequencies due to the longer wavelength. .

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

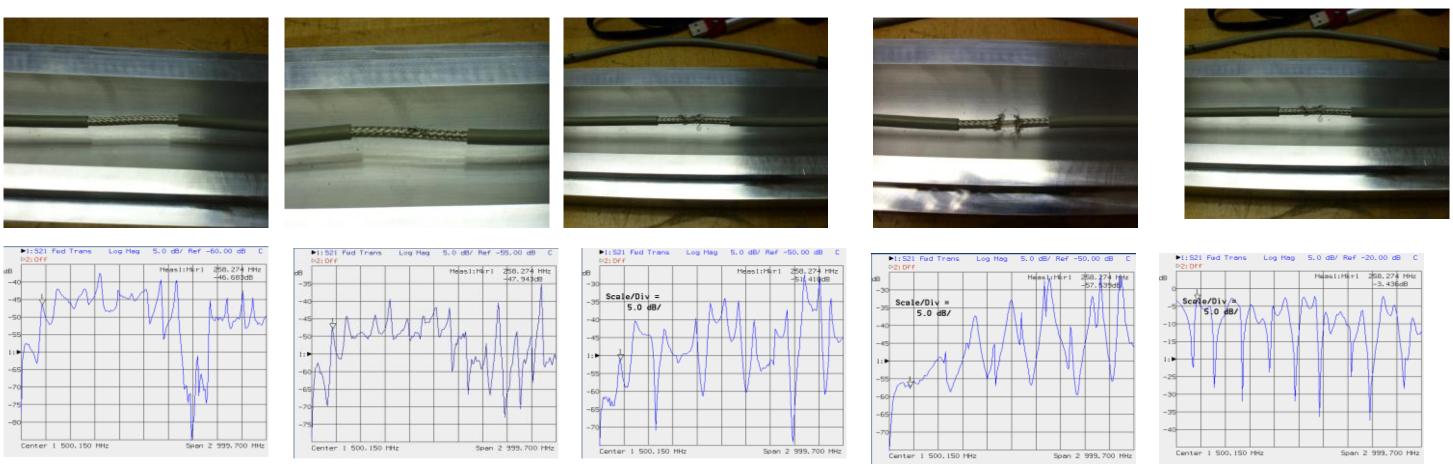


Figure 31: YSU Triaxial Device – initial Shielding Effectiveness Measurements

C. Analysis of Initial Test Results

The pictures, as shown above, illustrated various cuts to the cable shield of the cable samples. It was anticipated that these cut would affect the shielding integrity of the cables resulting in corresponding changes in shielding effectiveness. Below is a comparison chart for the results obtained. As a common practice in the industry, the data points were recorded the peaks (worst-case points).

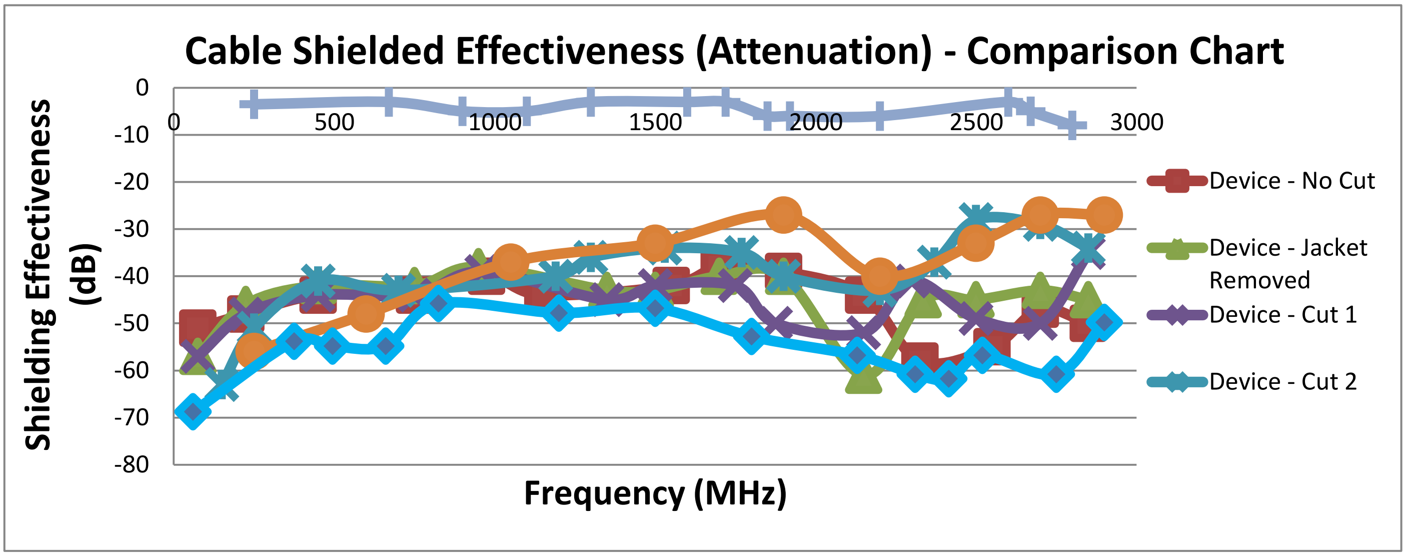


Figure 32: YSU Triaxial Device – SE of Various Cable Samples (to 3 GHz)

Below is a comparison chart between the uncut cables in the YSU Triaxial 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.

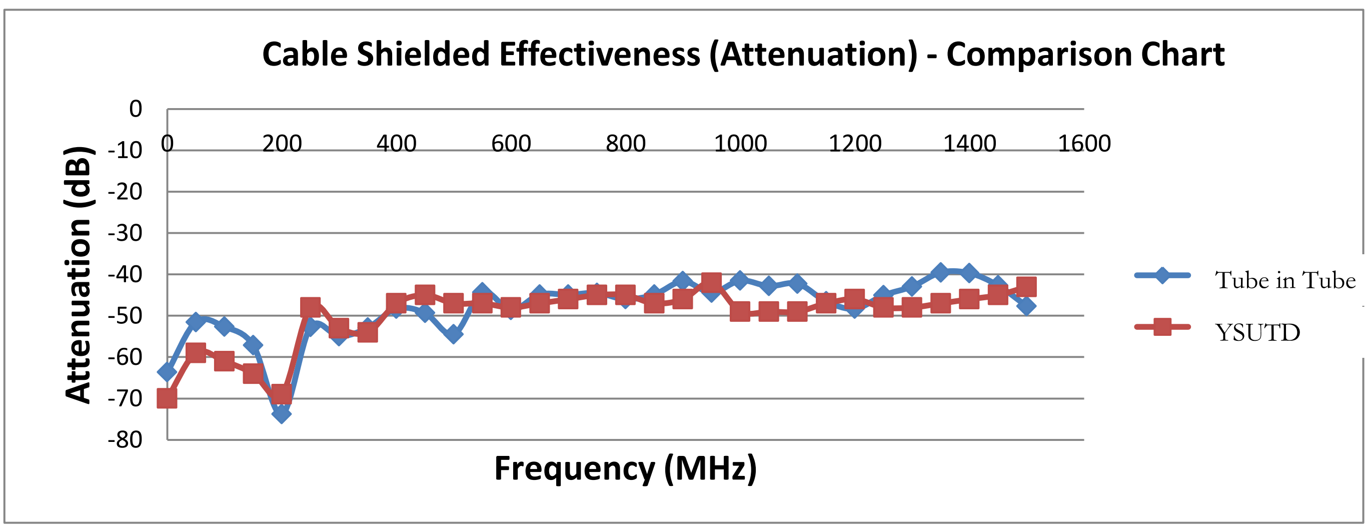


Figure 33: YSU Triaxial Device – SE of Various Cable Samples (300 kHz to 1.6 GHz)

These results indicated that the YSU Triaxial Device produces comparable general trend of results to that of the Tube in Tube device, especially at lower frequencies.

Since good correlations of test results have been found, the advantages of the YSU design are more valuable. Based on these experiments, it was noted that the testing time could be decreased by as much as 90%. The Styrofoam holders used in YSUTD had more desirable dielectric properties.

The square base of YSUTD made the device easier to operate and more user-friendly. While originally designed to test up to 300 MHz, the YSUTD was actually capable of operating into the GHz frequency range.

Although the trend of the test results was similar to the Tube in Tube device, further detailed analysis with more accurate instrumentation has indicated that various resonant frequencies did not match up between the two devices. Since the two devices have equivalent physical dimensions for the measurement area, the resonance frequencies for both devices should be similar.

Multiple test samples with two different cable constructions were used for the analysis to ensure the variance in shielding effectiveness were due to the YSU Triaxial Device itself and were not due to the test samples.

By analyzing the test results, it can be observed the variance between test samples for both the Tube in Tube and the YSU Triaxial Device was relatively small. This led to the conclusion that the test samples were not the cause of the measurement variations. Further investigation of the YSU Triaxial Device will need to be implemented to determine the root cause of the problems.

9. Improvement of Shielding Effectiveness (SE) Performance of YSU Triaxial Device

As indicated in the test result analysis section of this report, although the general trend for the Shielding Effectiveness test results obtained with the YSU Triaxial Device and the Tube in Tube device was similar, the resonant frequencies for the respective test results did not match up. In other words, since both devices have almost identical physical dimension, their resonance points (peak and valley of the graphs) should occur at the same frequencies. Clearly, this was not the case.

Since earlier analysis indicated that the test samples did not contribute to the problem, there were two probable conditions that might have caused these inconsistencies. The first one could be due to the difference at the interface between test samples and the YSU Triaxial Device and the second one could be due to the impedance mismatch at the connections between the inner tube and the coaxial connector interfaced with the test instrument.

In order to perform additional measurements to determine the root cause of the problem, new test samples were constructed with two types of cables.

A. Initial Comparisons

After the students had completed their project and graduated from YSU, the project investigator began to investigate the difference in resonant frequencies between the two devices. Since YSU had not received all the equipment purchased for the project, project investigators decided to perform the initial analysis at Delphi's EMC laboratory.

The YSU Triaxial Device was delivered to Delphi's EMC Laboratory by the Principal .Investigator (PI). Shielding Effectiveness measurements were performed on the YSU Triaxial Device and the Tube in Tube device to assess their performance.

In order to eliminate the effect of the cable samples, automotive grade shielded connectors (SMB RF in-line connectors) were used.

The YSUTD was compared to the Tube in Tube device by performing shielding effectiveness testing of automotive grade SMB RF in-line connectors according to *IEC 62153 Part 4-7: Electromagnetic compatibility (EMC) – Test method for measuring the transfer impedance and the screening – or the coupling attenuation – Tube in Tube method*

The test samples & accessories and pictures of the experiments are shown in Figure 34 and Figure 35.

Figure 34: Test Samples

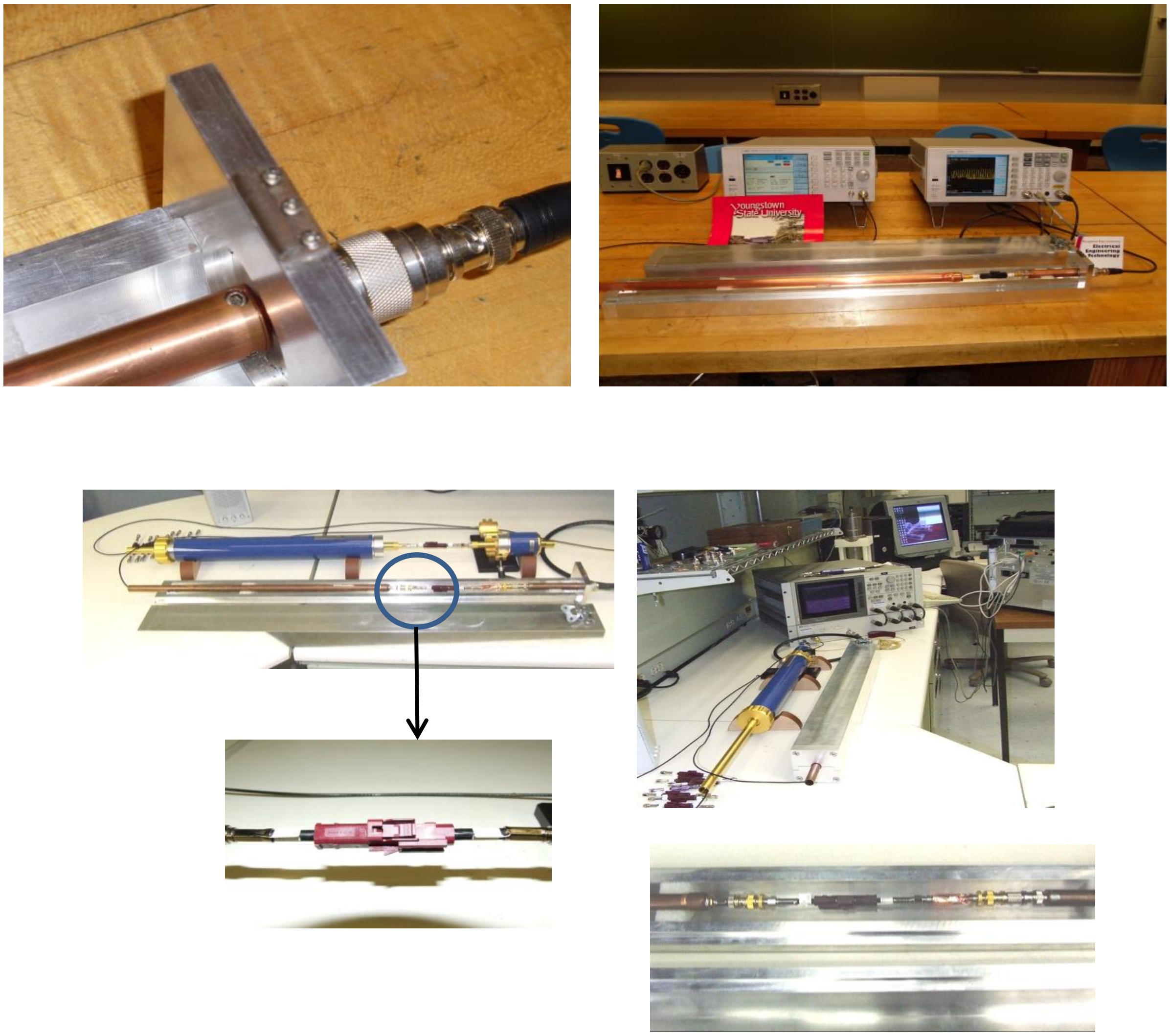


Figure 35: Test Instrumentation for Measurement of SMB In-line Connectors

Two samples were used for each Triaxial Device to assess the variance between samples.

The results indicated: 1. The variance of resonance frequencies between test samples were very small within each Triaxial Device and 2. The resonance frequencies between two devices were different. The results are shown in the graph below:

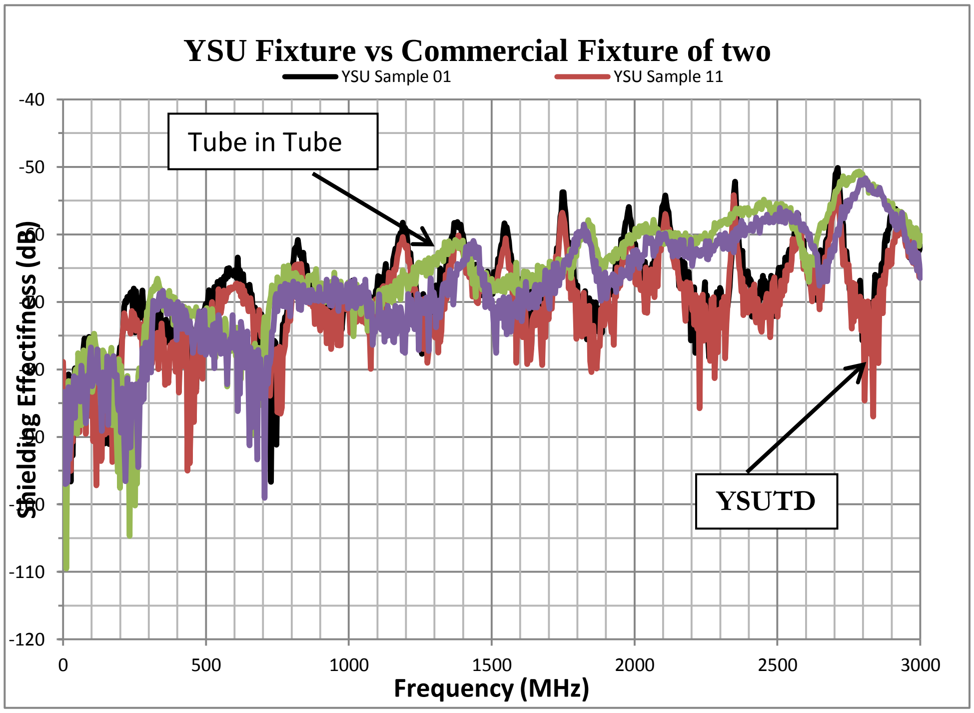


Figure 36: SE Measurements YSU and Tube in Tube Device (300 kHz to 3 GHz)

Because the tubes were similar in length and the dimensions of the internal tube and outer tube were also similar then the resonant peaks in data graph should be similar.

The YSU Triaxial Device showed resonant peaks separated by approximately 200 MHz However; the Tube in Tube device did not show these resonant peaks.

Based on this observation, it could be concluded that the resonance points of the YSUTD were caused by either the test sample or the impedance mismatch at the connection point between the device and the test instrument. It could also be concluded that the Tube in Tube device did not have these problems. The first step was to investigate if the test samples had caused the resonance points

B. Investigation into if Test Samples Caused Impedance Mismatch

To demonstrate that the resonant peaks were not related to the samples, a 150 mm length of ordinary single shielded RG58 cable was tested in both fixtures.

In order to ensure that the YSU Triaxial Device was repeatable, experiments for the sample of the 150 mm length of RG 58 were performed 3 times. This data is shown in the figure below.

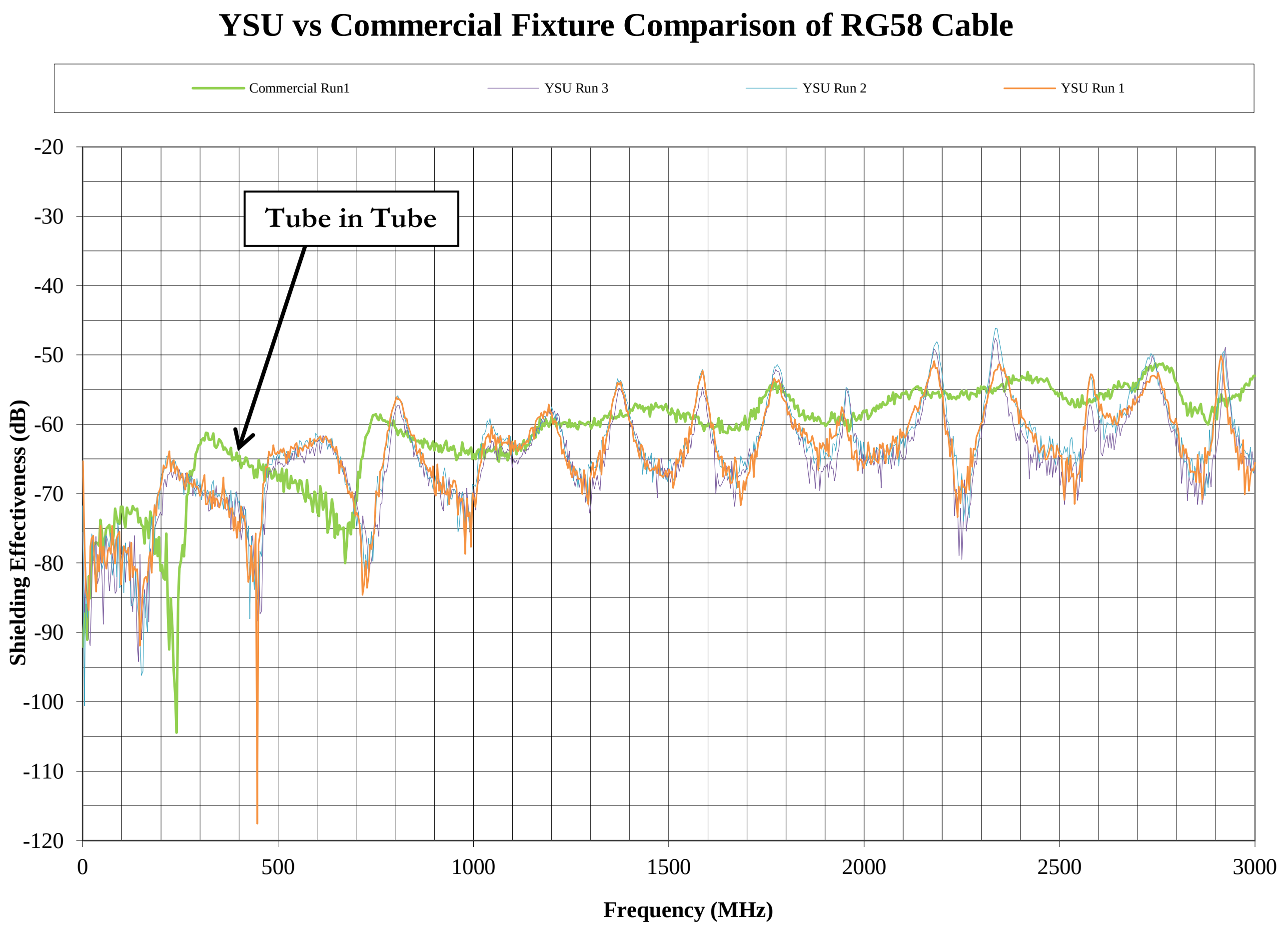


Figure 37: SE Measurements of RG 58 Cables - YSUTD and Tube in Tube Device

This data clearly shows that although the YSU Triaxial Device was repeatable among three experiments, it still exhibited the resonant frequency peaks in similar positions. Again, the peaks were not presence in the Tube in Tube device. This indicated that the test samples did not the cause of the resonant frequency peaks.

Investigation was to be focused on the YSU Triaxial Device. The most likely cause for the resonance was the impedance mismatch at the connection between the device and the test instrument. n the data indicates that there is something not constructed correctly on the YSU fixture.

C. Investigation of Impedance Mismatch at the Connection (between YSUTD & Network analyzer)

In order to determine the location of the impedance mismatch, Time Domain Reflectometer (TDR) was used. Since the YSU Triaxial Device and Tube in Tube were both designed to have a 50 Ω characteristic Impedance, TDR would be able to identify the location of the impedance mismatch (from 50 Ω). Both devices were examined using a TDR. The connection is shown below:

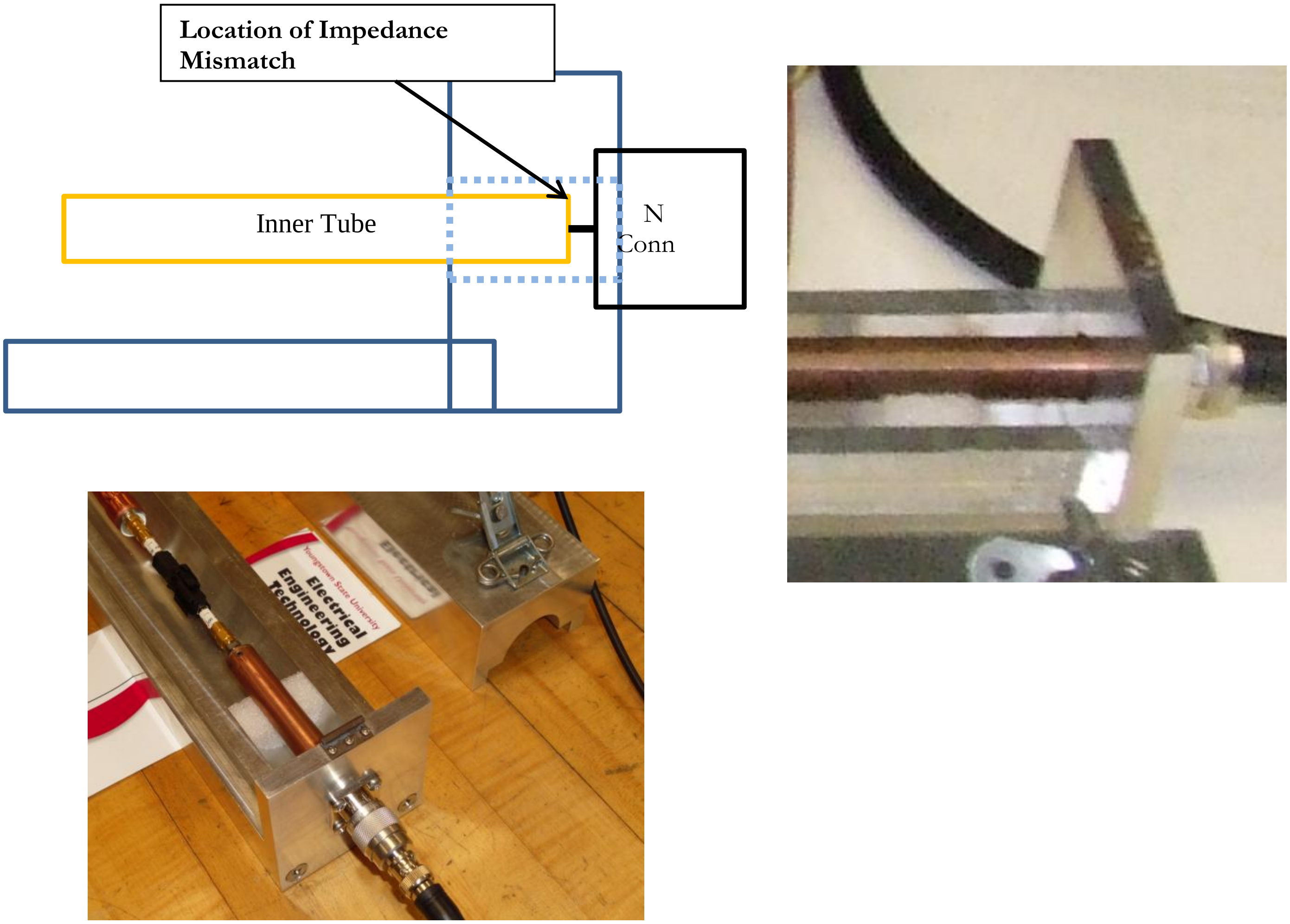


Figure 38: Transition Area at Connection between YSUTD and Test Instrument

Based on the results of the TDR analysis, the mismatch outside diameter of the YSUTD was located in the transition region of the inner tube to the N connector.

This transition point showed a large impedance discontinuity, the impedance dipped at this transition. By inference a large dip in the impedance was an indication that the coaxial dimensions transitioning from the N connector to inner tube was not correct to maintain the 50 Ω of the system. This resulted in the impedance mismatch causing the signal to be reflected back by the load (measuring instrument). Reflected wave (with high reflection coefficient) created a high Standing Wave Ratio (SWR) for the measurement system.

Because of this revelation, the end of YSUTD was delivered to a machine shop and the transition was made to be closer to 50 Ω by milling a diameter (based on theoretical calculation as shown in the next section) equal to the outer tube ID closer to the entrance of the N connector as indicated in Figure 29. This picture illustrates the small diameter hole with the inner tube leading into the N connector.

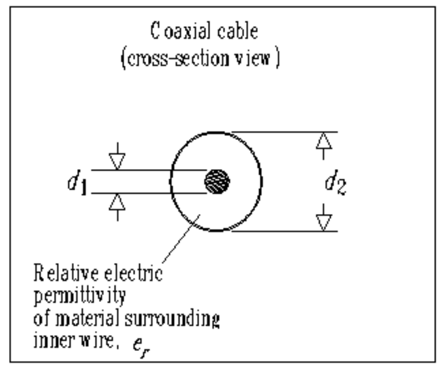
D. Modifications to YSU Triaxial Device & Performance Verifications

Using the geometric dimension of the YSU Triaxial Device, the impedance at the connection of the interface was calculated to be 11.28 Ω. This is a very large impedance mismatch resulting in Standing Wave Ratio (SWR) of 4.43. The mathematical calculations are shown below:

- **Characteristic Impedance Calculations**

The characteristic impedance of a coaxial transmission line is defined as;

$$Z_0 = \frac{60}{\overline{\epsilon_r}} ln \frac{d_2}{d_1}$$



Where;

Z_0 = Characteristic impedance
$\mathcal{E}_r$ = Relative Permittivity
d_2 = ID of the outer
d_1 = OD of the inner

Using the dimensions of 17.4 mm for d_1, the OD of the copper pipe and 21 mm for d_2, the ID of the hole leading to the N connector; and $\mathcal{E}_r = 1$, the characteristic impedance was calculated to be

Z_0 = 11.28 Ω

- **Reflection Coefficient (τ) and Standing Wave Ratio (SWR)**

Using normal input impedance of 50 Ω for the test instrument and characteristic impedance of 11.28 Ω of the Triaxial Device (as calculated above), reflection coefficient (τ) and SWR were calculated as shown below:

Calculation of d_2 to achieve Z_o = 50 Ω:

$$\tau = \frac{50-11.28}{50+11.28} = 0.632 \qquad 50 = 60\ \frac{d_2}{17.4\ mm}$$ yields **d_2 = 40.02 mm**

$$\text{SWR} = \frac{1+0.632}{1-0.632} = 4.43$$

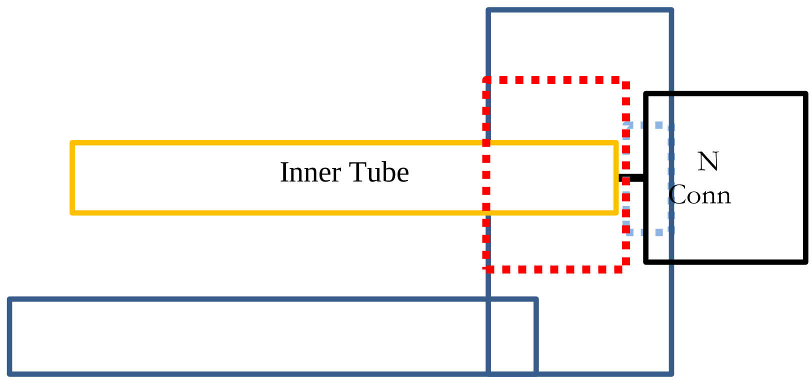
- **Characteristic Impedance of YSU Triaxial Device after modification**

In order to achieve 50 Ω characteristic impedance, the Outside Dimension (d_2) was calculated to be 40.02 mm using the equation above.

The copper pipe was modified by the machine shop to have a diameter of 40 mm.

After the modifications, the characteristic impedance was measured to be 49.79 Ω.

The modifications are shown in the figure below:



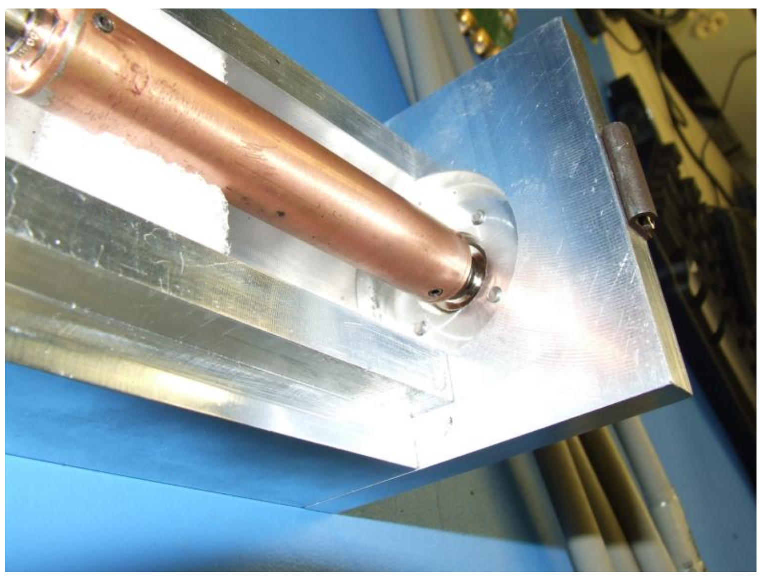


Figure 39: Modified Connection between YSU Triaxial Device to Achieve Zo = 50 Ω

After the modifications, Shielding Effectiveness (SE) measurements were performed on the modified YSU Triaxial Device and the Tube in Tube using a high quality RF SMA male to male in-line connector as test sample (Figure 39)

The data now shows a good correlation between the 2 devices on the shielding effectiveness measurements (Figure 40). This is a significant improvement over the original comparisons between the two devices (Figure 41). The results matched very well especially between the frequency ranges of 1- 2 GHz

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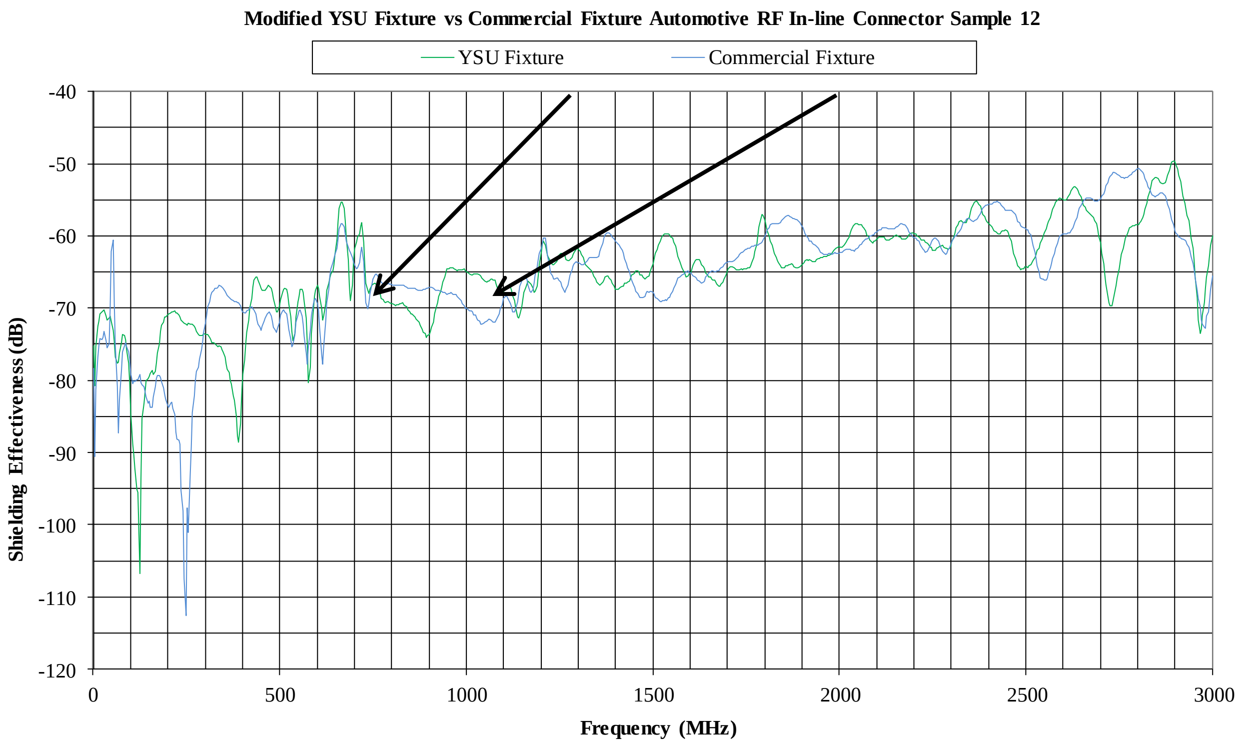


Figure 40: SE Measurement - Modified YSU Triaxial Device vs. Tube in Tube

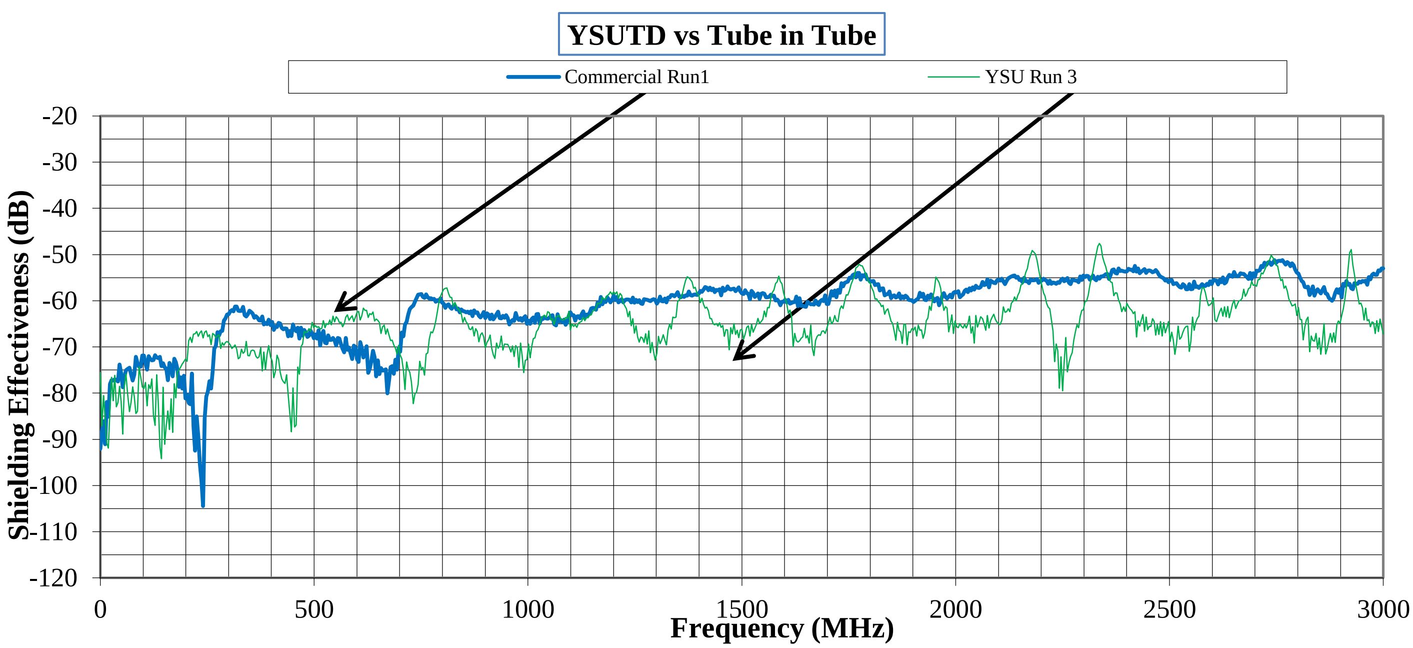


Figure 41: SE Measurement – Before Modification YSUTD vs. Tube in Tube

10. Work Force Development and Student Training

One of the project initiatives is the work force development and student training. This initiative was originally planned for implementation 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.

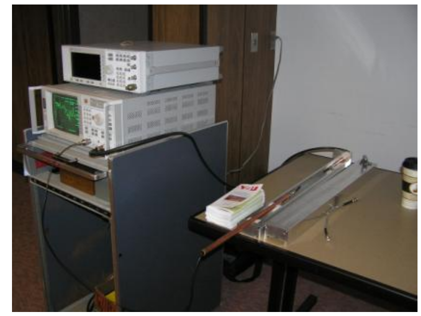
A. Training at Delphi Corporation

4 YSU Electrical and Computer Engineering students received training during Phase 2 from the project investigators at YSU and 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 apparatus and to effectively develop and perform testing for shielding effectiveness/RF attenuation of transmission line structures.

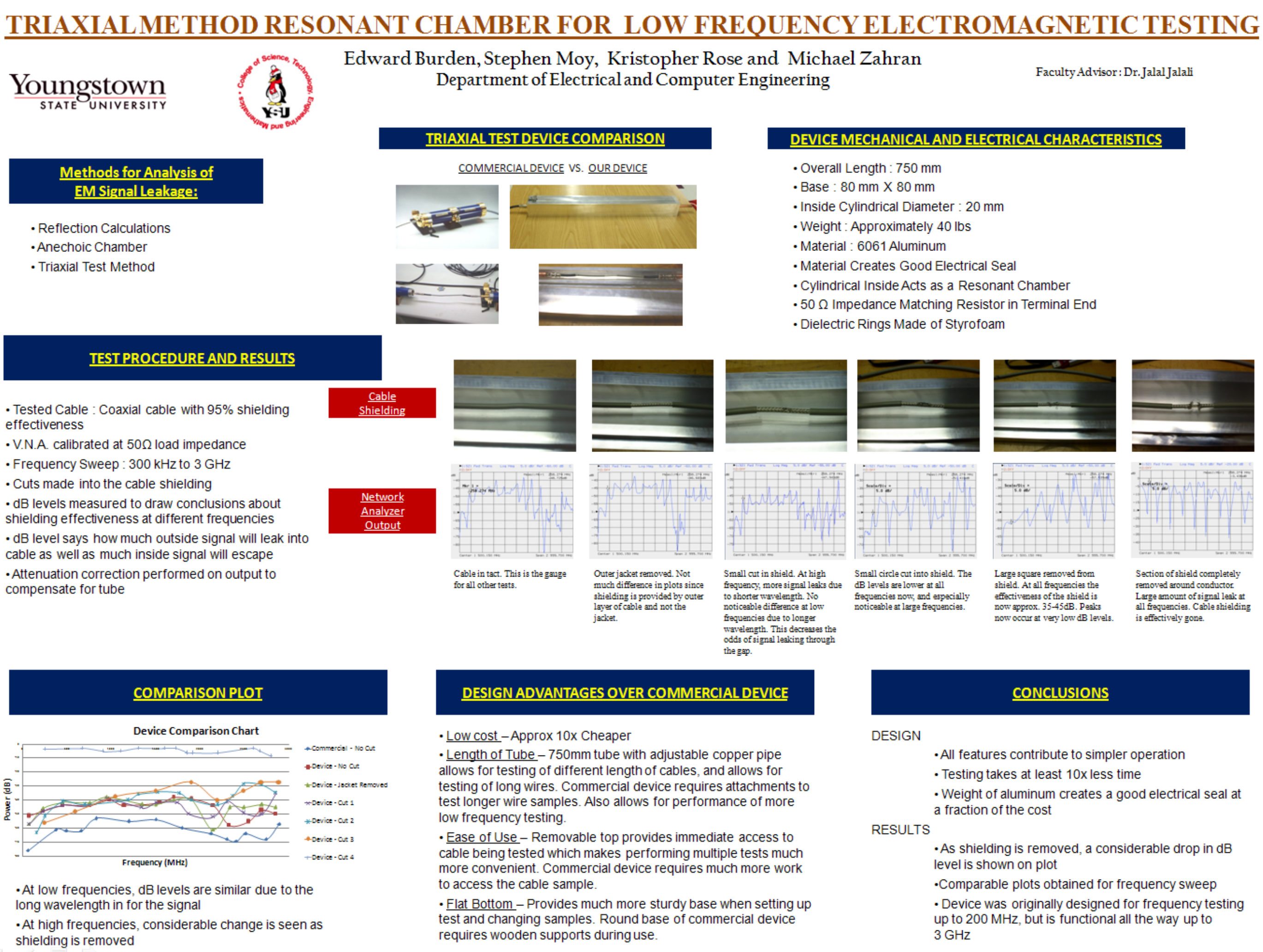
Throughout the design, development and construction of YSUTD, the 4 students spend numerous hours in Delphi. Many experiments were performed in Delphi's laboratory in order to compare with the measurements performed at YSU. This was to establish site to site correlation of the test systems.

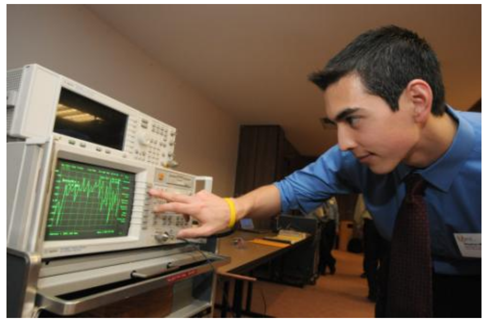
B. YSU Quest (Undergraduate Research Forum) – Electrical & Computer Engineering – Stephen Moy, Edward Burden, Kristopher Rose & Michael Zahran

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.



The students demonstrate the YSU Triaxial Device, the Shielding Effectiveness (SE) measurement system and preliminary test data to YSU faculty members and students. Their poster and presentation poster and pictures are as shown below:




The four students and faculty advisor as shown in the group picture (taken at YSU QUEST) above were:

Stephen Moy, Edward Burden, Professor Moy, **Kristopher Rose** and **Michael Zahran**

C. Senior Design Project (Capstone) – Electrical & Computer Engineering

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 design, development and construction of the YSU Triaxial Device have been shown in section 8 of this report. The students have successfully completed a working unit. Utilizing the test equipment at YSU and Delphi's EMC laboratory, the student also completed the development of test method and test procedures.

The final cost for the YSUTD 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 in 2010.

An excerpt of their Capstone presentation to the faculty panel and students of YSU's Department of Electrical & Computer Engineering is shown below:

TRIAXIAL METHOD RESONANT CHAMBER FOR LOW

FREQUENCY ELECTROMAGNETIC TESTING

Edward Burden
Stephen Moy
Kristopher Rose
Michael Zahran

Department of Electrical and Computer Engineering

Youngstown State University

5 May 2010

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.

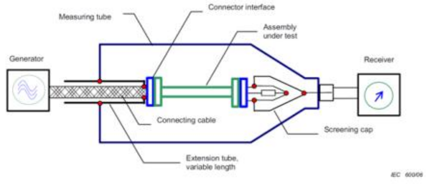


Fig. 1. Test setup to measure transfer impedances and screening of connectors

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

D. Electrical Engineering Technology Students

a. YSU Quest (Undergraduate Student Research Forum)

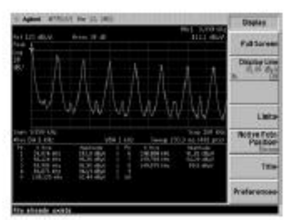
Research Project: **"**Digital Communication – Waveform Analysis – Fourier Series & Fourier Transform"

Utilizing the equipment obntained from the CTME research project, two students from YSU's Electrical Engineering Department conducted athe research project to analyze ditigal waveforms. The measurement results of frequency spectrum were compared with mathematical calculations, computer simulations.and time domain measurements ulitizing Fast Fourier Transform (FFT).

The poster was also submitted to and presented at Choose Ohio First Scholarship Program (COFSP) conference held at University of Akron in April, 2011.

The pictures of the experiment and the poster (available at COFSP Website) are shown below:

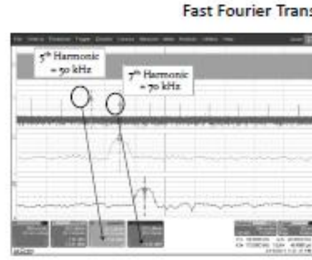
Voltage Spectrum – Spectrum Analyzer

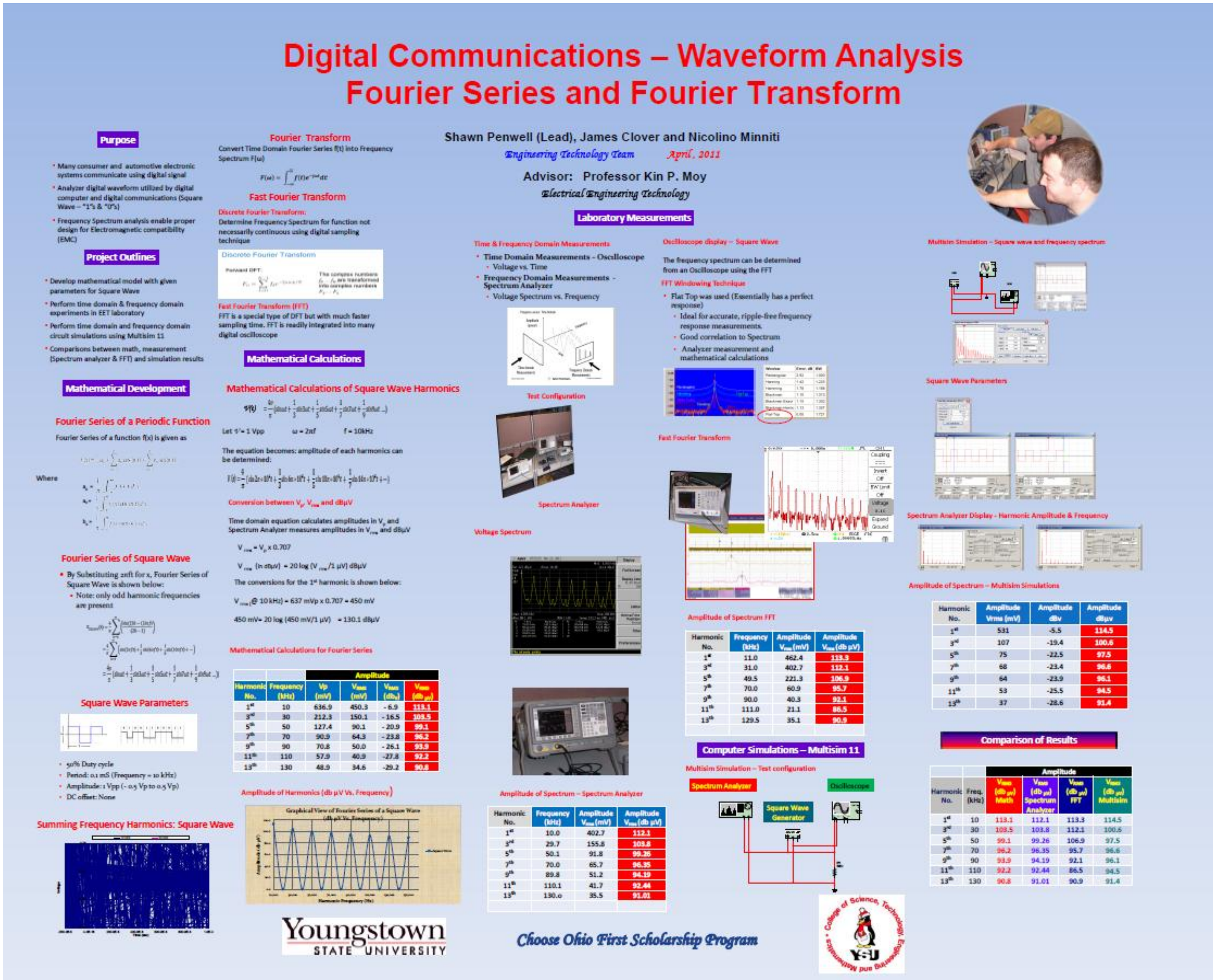


Amplitude of Spectrum – Spectrum Analyzer

Harmonic No.	Frequency (kHz)	Amplitude V_{rms} (mV)	Amplitude V_{rms} (db µV)
1st	10.0	402.7	112.1
3rd	29.7	155.8	103.8
5th	50.1	91.8	99.26
7th	70.0	65.7	96.35
9th	89.8	51.2	94.19
11th	110.1	41.7	92.44
13th	130.0	35.5	91.01

Fast Fourier Transform





The two students were: **Shawn Penwell** (Junior) and **James Clover** (Sophmore)

Note: after received training, James Clover currently works for Delphi’s EMC laboratory

b. Integration of EMC Technology into Electical Engineering Technology Program

a. **Electronic Communication Systems (EET 3780)**

A Power Point presentation was prepared based on the information obtained when perfroming this research project. The presentation was given to the students of this class in one of the lectures. Demonstration of RF Communication was also shown to the class utilizing the equipemnt purchased under this project.

Students gained insight into:

- Technical background of EMC
- Coupling of EMI into electronic systems
- EMI emissions radiated by digital communication systems
- EMC design for electronic systems
- Demonstration of frequency domain and domain analysis using Spectrum Analyzer and Digital Oscilloscope
- Applications of RF cables to meet EMC requirements
- RF cables/transmission lines functional and environmental characteristics
- Automotive data communication networks (structures and protocols)

b. **Electronics 1 & 2 (EET 2605 & 3706)**

Concept of EMC was introduced to the classes. The discussions focused on how EM noise is coupled into the electronic systems.through conduction and radiation. Students were also introduced to noise reduction techniques in electronic systems.In the future, experiments will be developed to utilize the new equipment purchased for this project.

During the lectures, the following topics were introduced to the students:

- Concept of EMC
- Concept of EM noise
- Couping of EM noise (Conduction and Radiation)
- Noise reduction techniques (Filtering, waveshaping, data line partitioning, transient suppressions and apllication of RF cables
- Transmission lines parameters and performance characteristics
- Concept of time doamin and frequency domian analysis
- Electrical Filters and Bode Plot – Gain and frequency

11. Summary:

All the deliverables for this research as identified in Phase 1 of the project (See Appendix 1) have been met. The deliverables are listed below:

A. Identifications of automotive communication architectures

- Identified and summarized the automotive communication architectures
- Discussed the applications of transmission lines for these architectures
- Assessed transmission lines effectiveness against electromagnetic Interference (EMI)

B. Test Methods Development (Functional EMC)

- Developed measurement techniques for functional EMC parameters
- Performed measurements on Unshielded Twisted Pair (UTP) and Shielded Twisted pair (STP) for the following parameters:
  - Characteristic Impedance Z_0
  - Line delay
  - DC Resistance

C. Test Methods Development (Environmental EMC)

- Developed test methodology to measure shielding effectiveness/RF attenuation characteristics for the following instrumentation:
  - Absorbing Clamp Method
  - Tube in Tube Method

D. Design and development of RF Shielding effectiveness/RF Attenuation tests equipment

- Developed design strategy, performance and cost target
- Designed and developed a cost effectiveness design of YSU Triaxial Device
- Constructed the YSU Triaxial Device – Meeting performance and cost target
- Work with Delphi corporation EMC Laboratory via industrial collaborations
- Developed test methodology to perform shielding effectiveness measurements

E. Shielding Effectiveness (SE) Measurement Utilizing YSUTD

- 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

- Assessed YSUTD against the design criteria to ensure compliance to all design requirements
- Analyzed test data and provided conclusions

F. Modification of YSUTD to Match Performance of Tube in Tube Device

- Analyzed data between YSUTD and Tube in tube Device
- Identified and Investigated performance deviations – due to non-repeatability of the resonant frequencies
- Identified the cause of inconsistent resonant frequencies between the two devices
- Performed mathematical calculations to establish proper geometry for modifications
- Modified the YSUTD – interface between connection point and measuring instrument (Network Analyzer)
- Performed Shielding Effectiveness measurements at Delphi and YSU to establish correlations for both devices
- Completed the design

G. Work force Development and Student Training

Phase 2 and 3 of the project initiated the work force development and student training initiatives of the project. The following activities were completed:

a. Senior Design Project (Capstone) – Electrical & Computer Engineering

YSUTD Design, Development & Constructions and Test System Development

- 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.
- For additional information, see section 10 of this report

b. Research Project – Electrical Engineering Technology Students

Digital Communication Waveform Analysis

- 2 Electrical Engineering Technology students investigated and analyzed the digital communication waveform both in time and frequency domain.
- The digital signal was analyzed utilizing technology and equipment acquired from this research project.
- The digital signal was analyzed using various techniques:
  - Frequency domain analysis – Spectrum Analyzer
  - Frequency Domain Analysis – Conversion from time domain measurement (Oscilloscope) using Fast Fourier Transform (FFT)
  - Mathematical calculation of frequency spectrum using Fourier Series and Fourier Transform
  - Analysis using computer based electrical simulation software – Multisim 11
- Results of the research were summarized into 2 posters for presentation by the 2 students at:
  - Quest 2011 – YSU undergraduate research forum
  - COFSP (Choose Ohio First Scholarship Program) poster session at The university consortium (University of Akron, Case Western Reserve University, Cleveland State University, Kent State University and Youngstown State University) at University of Akron.
  - For additional information, see section 10 of this report

c. Electrical Engineering Technology (EET) Classes – Integration of Technical Topics

- The technical inform obtained from this research project has been incorporated into the lectures for 3 EET classes – Electronics 1 (EET 2605/L); Electronics 2 (EET 3706/L) and Electronic communication Systems (EET 3780)
- Students were exposed to the topics of EMC technology, EM noise in electronic systems, noise reduction techniques in electronic systems, application of transmission lines/RF cables
- Equipment acquired for this research project was utilized for the laboratory sessions of these classes.
- For additional information, see section 10 of this report

H. Final Report

The final report is part of the deliverables of the project. The comprehensive report summarizing the activities for all 3 phases of this research project was written and submitted by the Principal Investigator (PI) to Director of Center for Transportation and Material Engineering at Youngstown State University by the deadline of March 31, 2012. The project was completed within the budget approved by the Director of CTME at YSU.

Appendix 1

Original Project Outline and Deliverables (as Identified in Phase 1of the project)

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

Appendix 2

Equipment Donation from Delphi Corporation

Delphi Corporation has donated 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**

Appendix 3
Equipment Acquired for the Project

The following equipment were purchased with the funds allocated by the project. These equipment were approved by Ms. Denise Dunn, Grant Manager of UIC program office on April 25, 2011.

The purchased equipment are listed below:

Equipment	Supplier	Estimated Cost	Applications
Vector Network Analyzer / Impedance Analyzer E5061B – 3L5	Agilent	$ 30,000	Measurement of transmission line impedance and transmission/reflection characteristics @ high frequency.
Spectrum Analyzer N9320B with tracking generator	Agilent	$ 9,100	Measurement of conducted and radiated electromagnetic emissions spectrum from signal/data transmission system @ high Frequency
Digital oscilloscope DSOX3054A	Agilent	$ 9,900	Measurement of time domain steady state and transients characteristics for signal/data transmission system
RF Signal Generator N9310A	Agilent	$ 6,200	Characterization of the transmission system using various modulated signals/data.
LCR Meter 7600 Plus	QuadTech	$ 12,000	Precision measurement of resistance, inductance and capacitance of transmission system parameters

The total cost of the equipment is $67,200

The equipment has been utilized to perform measurements for the modified YSU Triaxial Device. They were also used to train students in Electrical Engineering Technology Program in Electronics and Electronic Communication Sytems.