MHARNESS User Manual

(Version 4.0)

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DRAFT

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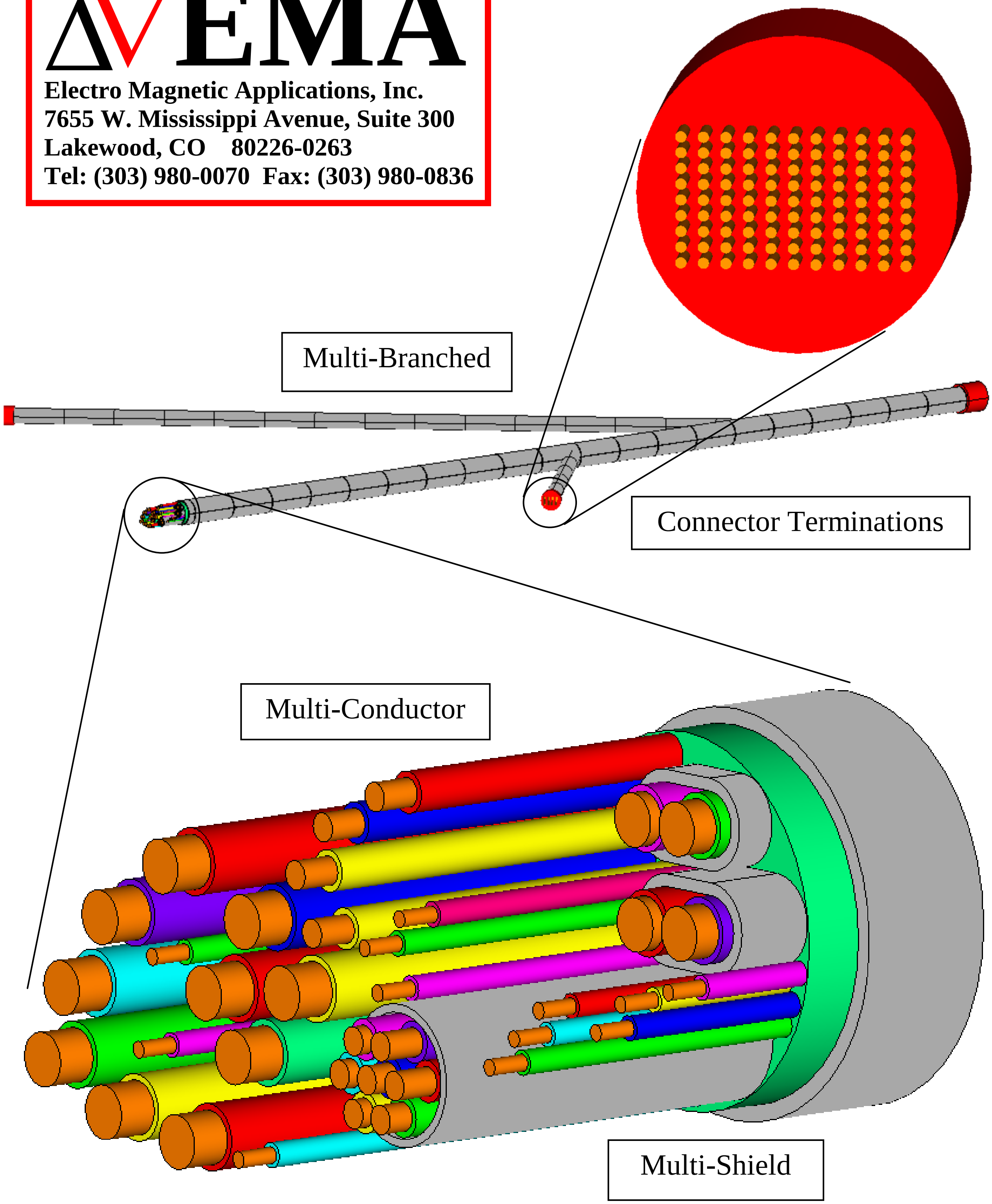

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CHAPTER 1 Introduction

This document is a user manual for the commercially available software product MHARNESS. The program MHARNESS is a multi-conductor, multi-shield, multi-branched cable harness transmission line solver based upon the finite difference time domain technique. The implementation of a time domain technique provides broad-band results often required to accurately characterize complex cable harness system behavior. MHARNESS can be used to analyze complex systems as well as simple configurations such a wire over a ground plane. Where appropriate, MHARNESS can be used as a transmission line approximation of more complex three-dimensional systems.

The MHARNESS program is fully integrated with the software program EMA3D. EMA3D is a commercially available software product available from Electro Magnetic Applications, Inc. EMA3D is a three-dimensional full-wave electromagnetic solver based upon the finite difference time domain (FDTD) technique. Calling MHARNESS from EMA3D enables the computation of complex cable responses, in a fully self-consistent, strongly coupled fashion, with the three-dimensional solution of a full wave solver. The implementation of MHARNESS within EMA3D is discussed in the EMA3D user manuals.

Each cable harness branch can contain layers of shields, wires, and conductors - all immersed in a variety of respective media. Within MHARNESS are algorithms to analyze electromagnetic coupling through various cable shields to the conductors and wires within. Cable connectors, often possessing different impedance characteristics then the cable itself, are easily defined and employed. A variety of methods are available to terminate each conductor, wire, and shield within a cable harness including circuit terminations. Many types of sources are available to drive the cable system including pin voltages, electric fields, current sources, and plane wave sources.

The algorithms within MHARNESS are designed to read an input text file. This file contains all of the necessary descriptions and definitions necessary to completely define the problem. This manual is designed to present the capabilities of MHARNESS, explain the terminology used, and to provide complete easy-to-understand instructions on how to properly construct the MHARNESS input file.

This manual begins with a brief description of the transmission line formalism. This description is the subject of Chapter 2. A complete presentation of the features and capabilities of MHARNESS is provided in Chapter 3. MHARNESS cable terminology is presented in Chapter 4. Conventions used in the MHARNESS input file are described in Chapter 5. A complete listing of the input file, conveying the format, is provided in Chapter 6. Explanations of the input file listing that was provided in Chapter 6 are given in Chapter 7. MHARNESS considerations regarding the integration with EMA3D are provided in Chapter 8. Instructions on executing the MHARNESS program are provided in Chapter 9. Finally, some helpful examples are presented in Chapter 10.

CHAPTER 2 Transmission Line Formalism

2.0 Introduction

A brief description of the transmission line formalism, along with the finite difference technique, is presented in this chapter. This is not a complete, detailed discussion but introduces certain concepts that those unfamiliar with the technique need to know. For a more detailed discussion the many references available may be consulted. The analytical transmission line equations are provided in Section 2.1. The finite difference technique, applied to the transmission line equations, is the subject of Section 2.2.

2.1 Transmission Line Formalism and Equations

The single conductor transmission line equations are:

$$L\frac{\partial I}{\partial t} + RI = -\frac{\partial V}{\partial x} + E_x^{inc} \tag{2.1}$$

and

$$C\frac{\partial V}{\partial t} + GV = -\frac{\partial I}{\partial x} \tag{2.2}$$

where: I is the current on the conductor line,
V is the voltage on the line,
C is the capacitance coefficient,
L is the inductance coefficient,
R is the resistance coefficient,
G the conductance coefficient, and
E the external incident electric field along the line.

The external incident electric field (E) is one of many sources of energy that can couple and drive the line.

The speed of electromagnetic propagation, v, along the conductor line is defined by:

$$LC = v^{-2} \tag{2.3}$$

For a multi-conductor line, the line coefficients, C, L, R, and G, become matrices while I, V, and E become column vectors. The above equations, in matrix form, are:

$$[L]\frac{\partial [I]}{\partial t} + [R][I] = -\frac{\partial [V]}{\partial x} + [\ E_x^{inc}\ ] \tag{2.4}$$

and

$$[C]\frac{\partial[V]}{\partial t}+[G][V]=-\frac{\partial[I]}{\partial x} \tag{2.5}$$

Similarly the speed of propagation is now defined by

$$[L][C]=\frac{1}{v^2}[ID] \tag{2.6}$$

where: [*ID*] is the identity matrix.

The coefficient matrices, or impedance matrices, [*C*], [*L*], and [*G*] are symmetric with off diagonal terms characterizing the coupling between conductors making up the line. The resistance matrix [*R*] is diagonal.

2.2 Transmission Line Finite Difference Formalism

Equations (1) and (2) can be put in finite difference form. Doing so renders the corresponding equations below:

$$\frac{L}{\Delta t}\left(I^{n+1}(i)-I^{n}(i)\right)+RI^{n+1}(i)=-\frac{1}{\Delta x}\left(V^{n}(i+1)-V^{n}(i)\right)+E^{n+1}(i) \tag{2.7}$$

and

$$\frac{C}{\Delta t}\left(V^{n+1}(i)-V^{n}(i)\right)+GV^{n+1}(i)=-\frac{1}{\Delta x}\left[I^{n+1}(i)-I^{n+1}(i-1)\right] \tag{2.8}$$

where:

$$I^{n}(i)=I\left(x_1(i),t_0(n)\right) \tag{2.9}$$

$$V^{n}(i)=V\left(x_0(i),t_1(n)\right) \tag{2.10}$$

$$x_0(i)=(i-1)\Delta x \tag{2.11}$$

$$x_1(i)=(i-0.5)\Delta x \tag{2.12}$$

$$t_0(n)=(n-1)\Delta t \tag{2.13}$$

$$t_1(n)=(n-0.5)\Delta t \tag{2.14}$$

Equation (2.7) and Equation (2.8) can be rewritten as:

$$I^{n+1}(i) = \left(\frac{L}{\Delta t} I^n(i) - \frac{1}{\Delta x}\left(V^n(i+1) - V^n(i)\right) + E^{n+1}(i) \right) \Big/ \left(\frac{L}{\Delta t} + R \right) \tag{2.15}$$

and

$$V^{n+1}(i) = \left(\frac{C}{\Delta t} V^n(i) - \frac{1}{\Delta x}(I^{n+1}(i) - I^n(i-1)) \right) \Big/ \left(\frac{C}{\Delta t} + G \right) \tag{2.16}$$

Equation (2.15) and Equation (2.16) are known as the current and voltage time advance equations, respectively, or just the advance equations. A forward differencing scheme is applied to the *R* and *G* terms to handle all values of the coefficients.

Examination of these equations reveals the staggered nature, in both space and time, of the current and the voltage advance equations. The staggered spatial nature of both the voltage and the current is portrayed in Figure 2.2.1. The spatial increment or cell size is also shown. Examination of the figure reveals the voltages to lie at whole integral index points, or nodes, and the currents at half-integral index points.

A special case exists at the end of the line. The line is usually terminated on a voltage node. Examination of Figure 2.1 reveals the absence of a necessary current value at either end of the line. For example, if the line began at the index of 1, then the voltage advance equation would be:

$$V^{n+1}(1) = \left(\frac{C}{\Delta t} V^n(1) - \frac{1}{\Delta x}(I^{n+1}(1) - I^n(0)) \right) \Big/ \left(\frac{C}{\Delta t} + G \right) \tag{2.17}$$

However, there is no $I(0)$ finite difference current available. For this value, the current to ground is used, as shown in Figure 2.2.2. Generally, this current is a function of $V(1)$ and the manner in which the conductors in the line are terminated (that is, the impedance to ground).

To insure numerical stability, the cell size must satisfy the Courant condition:

$$\Delta t < \frac{\Delta x}{v} \tag{2.18}$$

The generalization of Equations (2.15) and (2.16) to the matrix Equations (2.4) and (2.5) is realized by replacing the scalar variables by the corresponding matrices and column vectors.

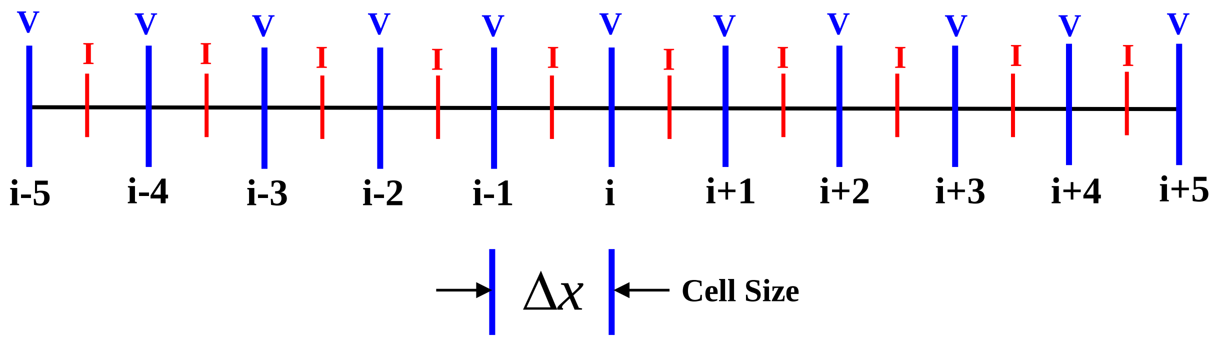


Figure 2.2.1 Staggered Spatial Nature of the Current (I) and the Voltage (V)

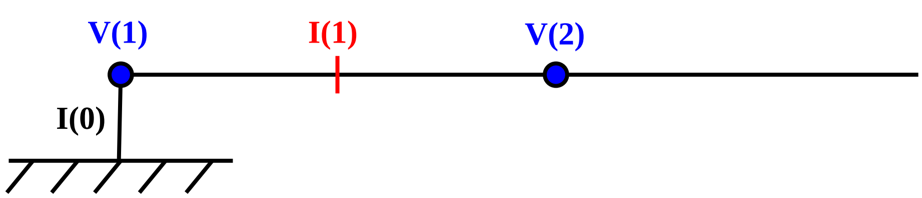


Figure 2.2.2 Terminal Voltage Node

CHAPTER 3 MHARNESS Capabilities and Features

3.0 Introduction

The capabilities and features of MHARNESS are presented and described here to provide an overall view of the functionality of the software. Presenting the capabilities up front allows immediate focus upon relevant aspect of particular interest.

MHARNESS is a multi-conductor, multi-shield, multi-branched cable harness transmission line solver. Each cable harness branch can contain layers of shields, wires, and conductors - all immersed in a variety of respective media. Within MHARNESS are algorithms to analyze electromagnetic coupling through various cable shields to the conductors and wires within. Cable connectors, often possessing different impedance characteristics then the cable itself, are easily defined and employed. A variety of methods are available to terminate each conductor, wire, and shield within a cable harness including circuit terminations. Many types of sources are available to drive the cable system including pin voltages, electric fields, current sources, and plane wave sources.

An outline of the MHARNESS capabilities is provided below for easy inspection. The new enhanced capabilities associated with MHARNESS Version 4 are provided in red font. A brief description of the contents within the outline are provided in the sections that follow .

1. **Cable Geometry / Topology (Section 3.1)**
    - Multi-branched
    - Multi-shield – three levels
    - Multi-conductor
2. **Cable Impedance Matrices/Parameters (Section 3.2)**
    - Capacitance
        - Manually defined
        - Automatically computed
    - Inductance
        - Manually defined
        - Automatically computed
    - Resistance
    - Conductance – lossy media
    - Skin depth
    - Magnetostatic
3. **Cable Connectors (Section 3.3)**
    - Capacitance
    - Inductance
        - Manually defined
        - Automatically computed
    - Resistance

- Conductance – lossy media

4. **Coupling through Shields (Section 3.4)**
   - Shield transfer direction
     - Unidirectional
       - In
       - Out
     - Bidirectional
   - Shield transfer impedance
     - Manually defined
     - Automatically computed
     - Frequency dependent
   - Low Frequency Approximation

5. **Cable Harness Reference Conductor (Section 3.5)**
   - Ground
     - PEC
     - Lossy
   - Branch conductor – individual wire

6. **Individual Conductor Terminations (Section 3.6)**
   - Resistive
     - Shorted
     - Floating
   - Capacitive
   - Inductive
   - Circuits

7. **Sources (Section 3.7)**
   - Plane wave illumination
   - Pin voltage
   - Electric field
     - Localized
     - Entire cable branch
     - Entire cable system
   - Current
     - Localized
     - Entire cable branch
     - Entire cable system
   - Waveforms
     - Read in from data file
       - Text
       - Binary
     - Automatically computed
       - Gaussian
       - Derivative of Gaussian
       - Double exponential
       - Derivative of double exponential
       - Double exponential with sine squared front
       - Sine wave

        - Sine squared
        - Linear ramp
        - Damped sinusoid
    - EMA3D self-consistent sources

8. **MHARNESS Output (Section 3.8)**
    - Universal file header
    - Customized header information
    - Structure Probe
    - Skin depth probe
    - Types
        - Sources
        - Pin voltages
        - Conductor currents
        - Conductor voltages
        - Radiated fields
    - Format
        - Text
        - Binary

Each of the above outline topics is briefly discussed in the sections to follow.

3.1 Cable Geometry / Topology

There is no limit to the number of cable branches, cable shields, individual wires, and individual conductors defined. However, there is a limit to the number of layered shields employed. Presently only two embedded layers of shielding is permitted in MHARNESS, as illustrated below and on the cover of this manual.

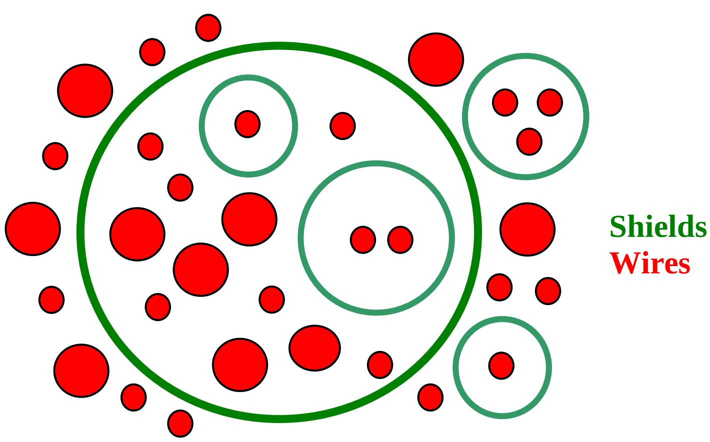


Figure 3.1.1 Cable Cross-Section with Two Layers of Shields

3.2 Cable Impedance Matrices / Parameters

The impedance matrices, identified by the symbols **C**, **L**, **R**, and **G** in Chapter 2 define the relationship between the various wires and shields within a branch of an MHARNESS cable, incorporating the effects of the surrounding media. The symbol **C** stands for the capacitance matrix, **L** for the inductance matrix, **R** for the resistance matrix and **G** for the conductance matrix. The presence of a conductance matrix allows the cable conductors to be immersed in a variety of lossy media. In MHARNESS the impedance matrices are all time independent.

For a single conductor branch **C**, **L**, **R**, and **G** are real numbers. For a line with n conductors, these entities are $n \times n$ matrices. The matrices can be sparse or densely populated depending on how the conductors interact with each other. The capacitance, inductance, and conductance matrices are all full, whereas the resistance matrix is diagonal. The matrices define the interaction between the wires and shields within a single cable harness branch. In MHARNESS there is no interaction between branches except for the conservation of charge at the connection between adjoining branches.

Within MHARNESS is the capability to automatically compute the capacitance and inductance matrices, for all cable branches, given the cross-sectional geometry and material information. Cross-sectional geometry includes conductor diameters and jacket (insulation) thickness. Material information includes jacket electromagnetic parameter values, background media parameter values, and ground parameter values.

Shields and wires can be defined utilizing skin depth effects. When the skin depth facility is implemented the resistance of the shield/wire increases with frequency.

A magnetostatic capability is also available. This facility can be utilized when a quasi-magnetostatic configuration is expected. Implementation of the magnetostatic specification results in a user-defined increase in the various permittivity values of the cable and cable environment thereby enabling an associated increase in the MHARNESS time step. When utilized, this can greatly accelerate the speed of computation.

3.3 Cable Connectors

Many cable harnesses employ cable connectors to terminal boxes. The presence of cable connectors usually require different impedance matrices to characterize the ends of cable branches where the connectors are employed. The capacitance matrix pertaining to connectors must be manually defined. However, given the capacitance values, the associated inductance parameters are automatically computed. Inner shields and outer shields are often joined at the connector allowing current from the outer shield to couple directly to the wires inside of the inner shield. Within MHARNESS is the ability to easily models these connectors and incorporate the associated effects.

3.4 Coupling through Shields

Cable shields are characterized by specifying a shield transfer impedance. The transfer impedance relates the driving voltage on one side of the shield (the interior for example), to the current on the other side of the shield (the exterior for example). In MHARNESS all shields can be specified as unidirectional or bidirectional. A unidirectional shield allows electromagnetic coupling in one direction only - that is, from the exterior to the interior or from the interior to the exterior. A bidirectional specification enables electromagnetic coupling through the shield in both directions simultaneously. In many cases, a unidirectional coupling specification provides an excellent approximation.

The shield transfer impedance can be manually assigned or automatically computed. Automatic computation is performed using various shield parameters inputs. The algorithms assume the shield to be a weave-type structure. The transfer impedance is computed from the strand diameter, the strand conductivity, the weave angle, the number of carriers (bundles of strands), and the number of strands per carrier.

The shield transfer impedances can also be designated as frequency dependent. The frequency dependence is realized by using a sum of first order rational functions.

When MHARNESS is used within the software program, EMA3D, a low frequency approximation is available that correctly couples the electromagnetic energy through the shields to the conductors within. This facility is especially useful for low frequency phenomena such as lightning.

3.5 Cable Harness Reference Conductor

MHARNESS is a transmission line code and therefore requires a reference for implementation. If the impedance matrices are manually defined, then the reference is implicit in the entries of the matrices. However, for automatic computation the reference must be identified. In MHARNESS the reference is always assumed to be a ground plane unless otherwise specified. The ground plane can be perfectly conducting (PEC) or lossy. If a conductor reference, such as a wire, is desired instead, then this can also be specified.

3.6 Individual Conductor Terminations

Wires and shields within an MHARNESS cable system must be properly terminated – even those cable branches employing connectors. Terminations are realized by specifying a terminating circuit. Eight lumped parameter circuits are presently available. These available circuit terminations are shown in Figure 3.6.1. To terminate a wire or shield in a short, or to leave either end floating, a resistive termination is required. For a short, let R = 0.0 Ohms. To specify a floating configuration, let R be a large value such as 1.0e8 ohms.

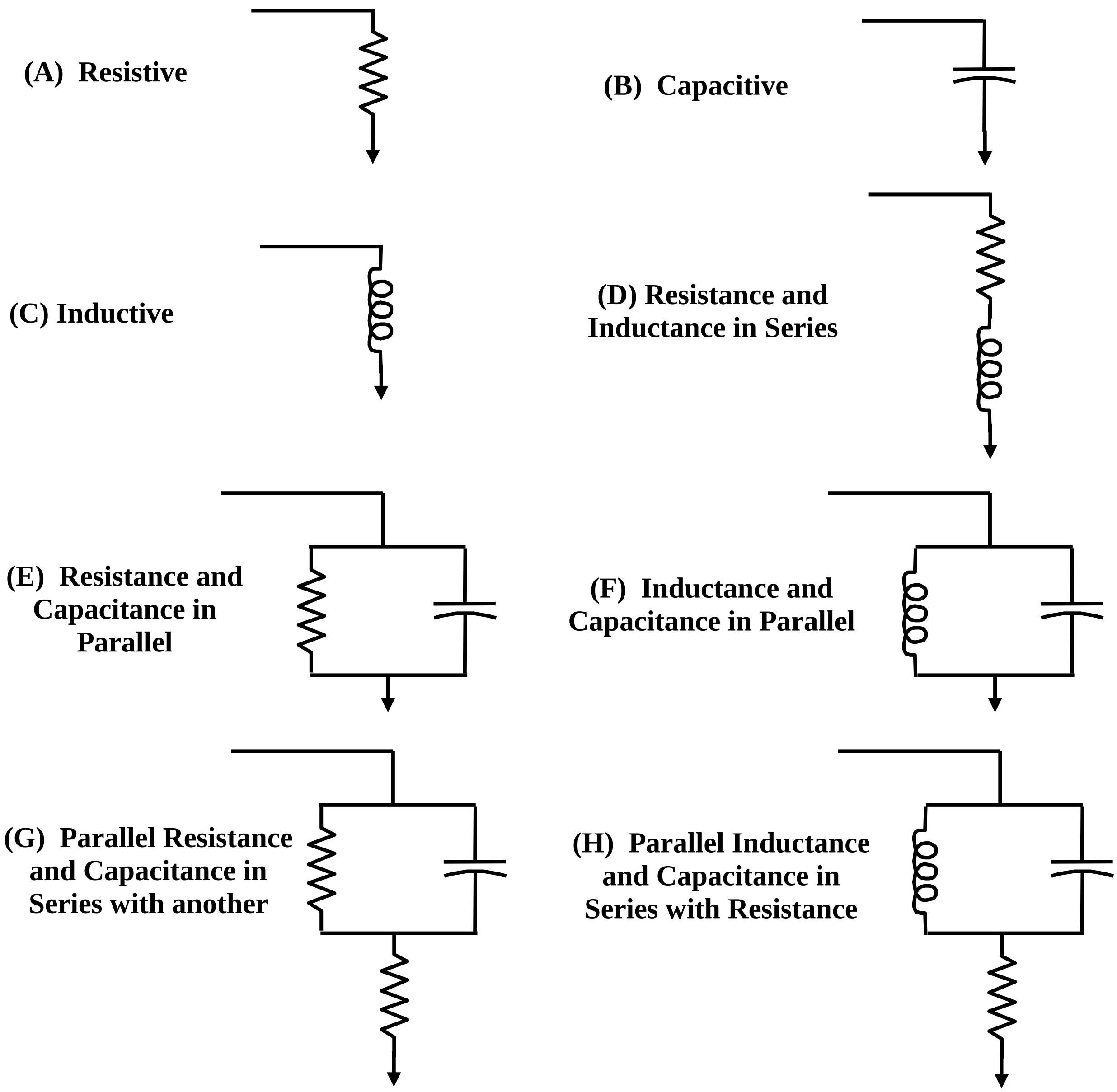


Figure 3.6.1 MHARNESS Circuit Termination Types

3.7 Sources

A variety of sources are available in MHARNESS. These sources include:

Plane wave illumination
Pin voltage sources
Electric field sources
Current sources
EMA3D self-consistent sources

The electric fields and current sources can be locally defined to drive a single conductor at one point or an entire conductor (wires or shields) within a particular cable branch. Current sources and electric field sources can also be defined globally to drive an entire cable branch or the entire cable harness system.

Within a data file, multiple local current source waveforms or electric field source waveforms can be easily defined to provide numerous unique local excitation drivers. This feature is often employed to simulate cable harness behavior in a complex three-dimensional external environment where fields and currents vary considerably over the physical extent of the harness. These sources are usually computed utilizing anther software program such as EMA3D.

Source waveforms can be read in from a data file or automatically computed by selecting a pre-determined waveform type and supplying the defining parameters. For example, a Gaussian waveform is mathematically defined below.

$$f(t) = A * e^{-((t-t_p)/w)^2}$$

By selecting a Gaussian waveform and supplying **A**, $\mathbf{t_p}$, and **w**, a Gaussian waveform will be automatically produced in MHARNESS and can then be used as a plane wave source, a pin voltage source, an electric field source, or a current source. The pre-determined waveform types are listed below.

Gaussian
Derivative of a Gaussian
Double exponential
Derivative of a double exponential
Double exponential with leading sine squared front
Sine wave (CW)
Sine squared (1/2 period of sine wave)
Linear ramp
Damped sinusoid

MHARNESS is also fully integrated with the software program EMA3D in a self-consistent strongly coupled fashion enabling the electromagnetic environment computed with EMA3D to provide the sources required to drive MHARNESS. The currents generated on the conductors within MHARNESS in turn, affect the EMA3D electromagnetic environment.

3.8 MHARNESS Output

There is a variety of MHARNESS probe outputs. A structure probe is present that creates a POSTSCRIPT file containing a drawing of the cross-section of any specified MHARNESS cable segment. A skin depth probe is provided that will output skin depth parameter information. Other MHARNESS output includes voltages and currents at any location, on any conductor, within any branch, of the cable harness system. This includes pin voltages and termination voltages. Outputs can also include electric fields radiated from the cable system along with the automatically computed source waveforms discussed in the previous section. Customized header information can be devised and written, as desired, to individual output files or generally to all output files. The format of the output files can be specified to be either text or binary.

CHAPTER 4 MHARNESS Cable Terminology

4.0 Introduction

The terminology employed within MHARNESS is discussed in this chapter. This information is necessary to understand the terminology employed within the MHARNESS input file and therefore is required in the proper construction of the input file. The topics addressed are provided below in outline form.

1. **Finite Difference Considerations - Cable Indexing**
2. **MHARNESS Coordinate system**
3. **Cable System Level Description**
   - System Level 0
   - System Level 1
   - System Level 2
4. **Cable Harness Topological Terms**
   - Segments/branches
   - Junctions/nodes
   - Terminations
5. **Cable Connectors**
6. **Cable Harness Reference**

Each of these topics is discussed in a separate sections to follow.

4.1 Finite Difference Considerations - Cable Indexing

The MHARNESS program is a transmission line solver based upon the finite difference time domain technique (see Chapter 2). There is thus an associated finite difference space step and a finite difference time step. Each cable segment is therefore assigned a finite difference space step (or cell size) as seen in Figure 4.1.1. The cable in the figure is 10 finite difference cells long. The cable finite difference cells are indexed 1 through 11. Cable voltages lie at whole integral index locations and the currents lie at half-integral index locations. For a cable consisting of 10 finite difference cells, there are 10 current locations and 11 voltage locations. When designating voltage output at the cable endpoints, the 1 and 11 voltage index should be specified.

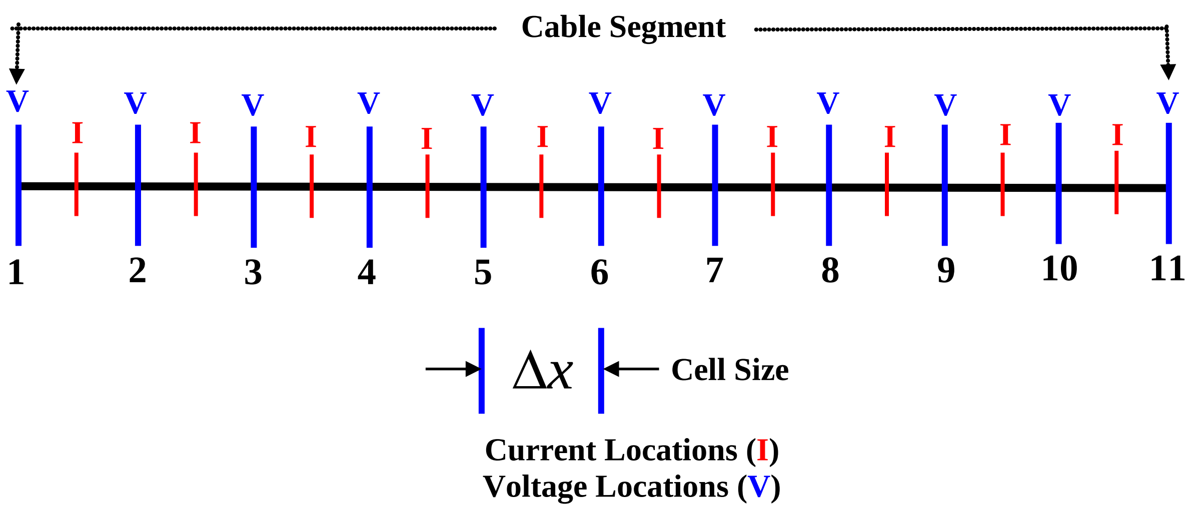


Figure 4.1.1 Finite Difference Spatial Grid of an MHARNESS Cable Segment

4.2 MHARNESS Coordinate System

A three-dimensional coordinate system is inherent within the algorithms of MHARNESS. However, this coordinate system is relevant only under three situations. These situations are, if plane wave excitation is employed, if automatic computation of the impedance matrices is specified, or if radiated fields are desired for output.

If a plane wave is specified, then the geometric relationship between the aspects of the plane wave (incident direction and electric field polarization) and the orientation of the cable conductors is important. If automatic computation of the impedance matrices is specified, then a detailed description of the cable cross-sectional geometry along with the geometric relation to the reference conductor (e.g. height above ground plane) is required. Important segment cross-sectional information includes the relative positions of the conductors, conductor radii, and jacket (insulation) radii. If radiated fields are desired for output, then the coordinate location of radiated field needs to be defined. All of these situations require a coordinate system for proper definition.

The coordinate system of MHARNESS assumes that the cable harness system exists on an xy plane, as depicted in Figure 4.2.1, although various portions of the cable system may exists at different heights. If a ground plane reference exists, then it is located on the xy coordinate plane at the z-coordinate of, z = 0.0. The cable harness system must be above the ground plane (z > 0.0).

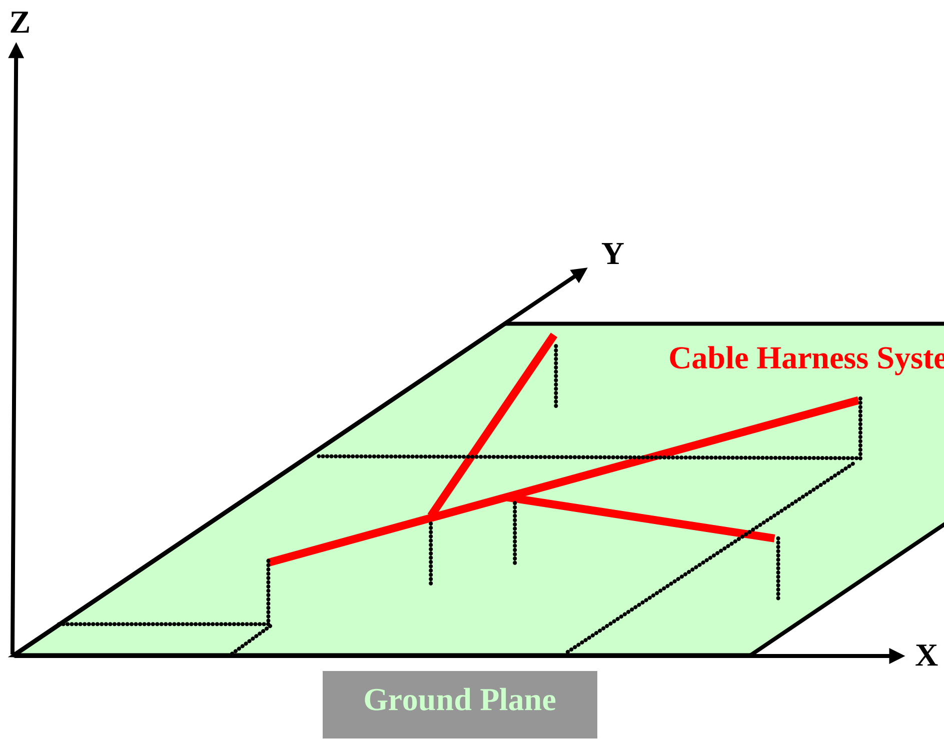


Figure 4.2.1 MHARNESS Coordinate System

4.3 Cable System Level Description

There is no limit to the number of shields, wires, and conductors defined within a single cable harness branch. However, there is a limit to the number of layered shields employed. A multi-conductor, multi-shield cable branch is shown in Figure 4.3.1. This particular cable branch contains 19 individual conductors, 17 wires and 2 inner shields, all within an outer conductive overbraid. Within one of the inner shields are five wires and within the other are three.

A system level is defined by a group of conductors (wires or shields) within another shield or between geometrically layered shields. For the cable of Figure 4.3.1, the first system level, or System Level 0, consists of all of the wires within the two inner shields. This is depicted by the colored elements seen in Figure 4.3.2A. For perfectly conducting shields there is no interaction between conductors within different inner shields. In this case, the capacitance matrix for this level would appear as shown in the figure.

The second system level, or System Level 1, consists of all conductors between both the inner shields and the overbraid shield. This includes the outer surfaces of the two inner shields, as depicted by the colored elements in Figure 4.3.2B. There are thus 11 conductors associated with System Level 1.

The third system level, or System Level 2, consists of the outer surface of the overbraid shield only, as portrayed by the colored shield in Figure 4.3.2C. There is only one conductor associated with System Level 2 in this branch of the cable harness.

The algorithms within MHARNESS are designed to simulate three system levels only. Another shield containing conductors placed within one of the two inner shields would result in four system levels and would not be allowable. Some examples of cable cross-sections possessing one, two, and three system levels are provided in Figure 4.3.3.

If an actual cable does contain four system levels, then this can be modeled by saving all currents on the inner most shields and using these as sources to drive another MHARNESS model. This would be a two-step process. A single two-step process could be used to model a four or five system level cable harness. By using consecutive two-step processes, a cable with any number of system levels could be modeled.

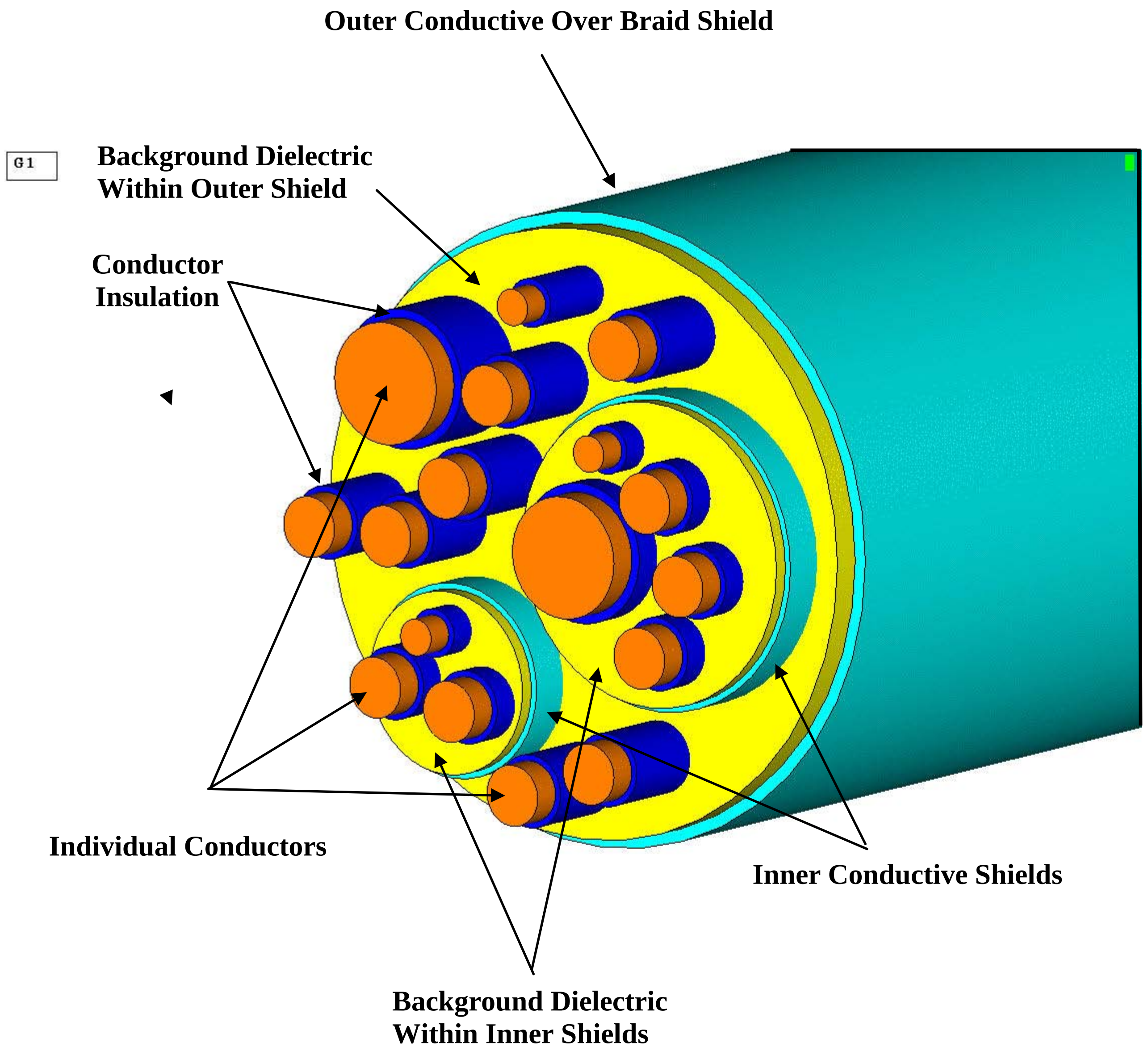
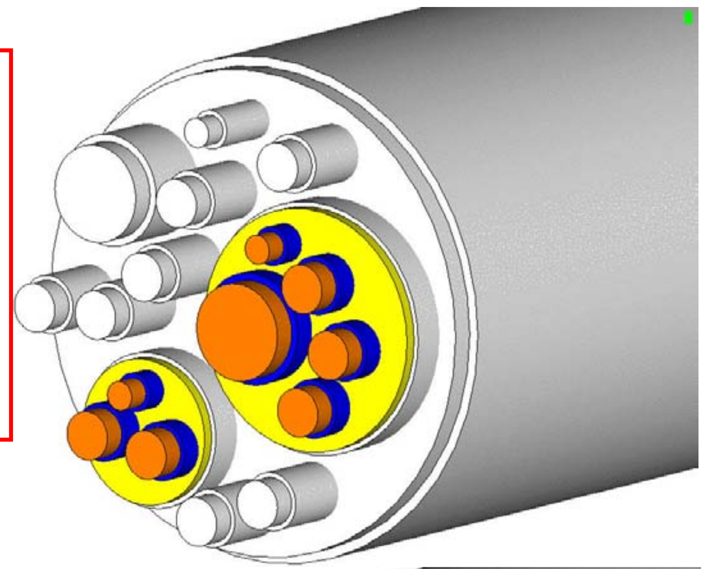


Figure 4.3.1 Multi-Conductor, Multi-Shield Cable Harness Branch

G1

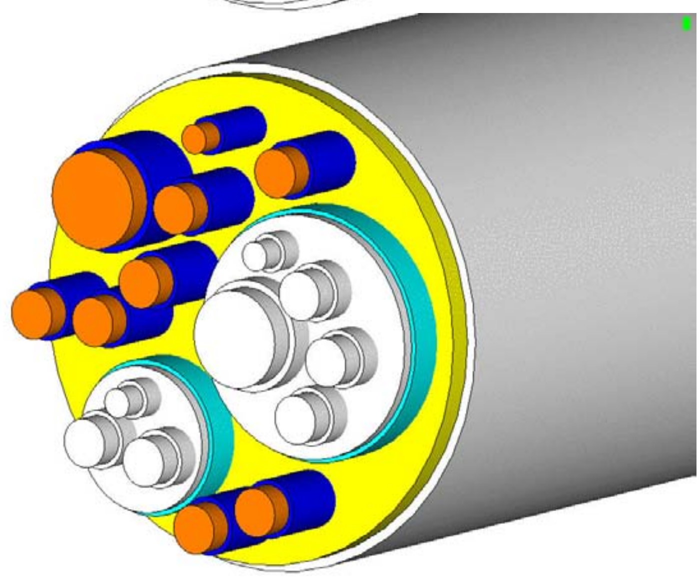
$$\begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & 0.0 & 0.0 & 0.0 \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & 0.0 & 0.0 & 0.0 \\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & 0.0 & 0.0 & 0.0 \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & 0.0 & 0.0 & 0.0 \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & c_{66} & c_{67} & c_{68} \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & c_{76} & c_{77} & c_{78} \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & c_{86} & c_{78} & c_{88} \end{bmatrix}$$



(A) System Level 0

G1

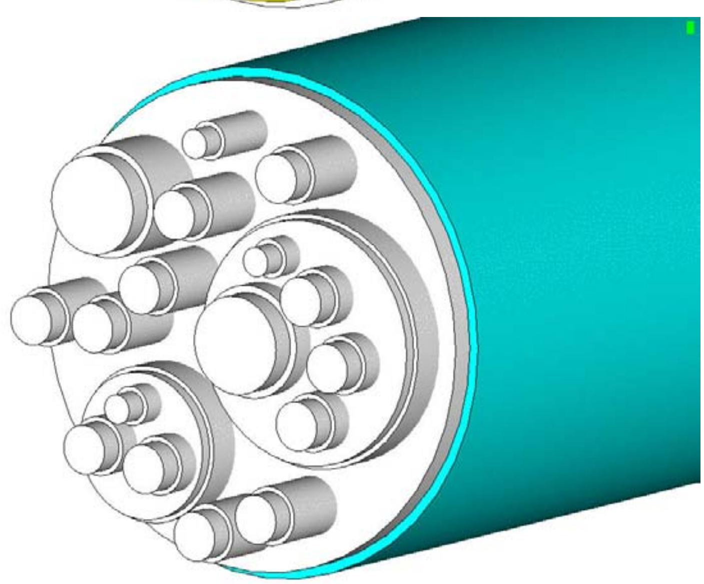
Dense 11 x 11 Impedance Matrices



(B) System Level 1

G1

Single Impedance Coefficients



(C) System Level 2

Figure 4.3.2 System Level Description of Cable Seen in Figure 4.3.1

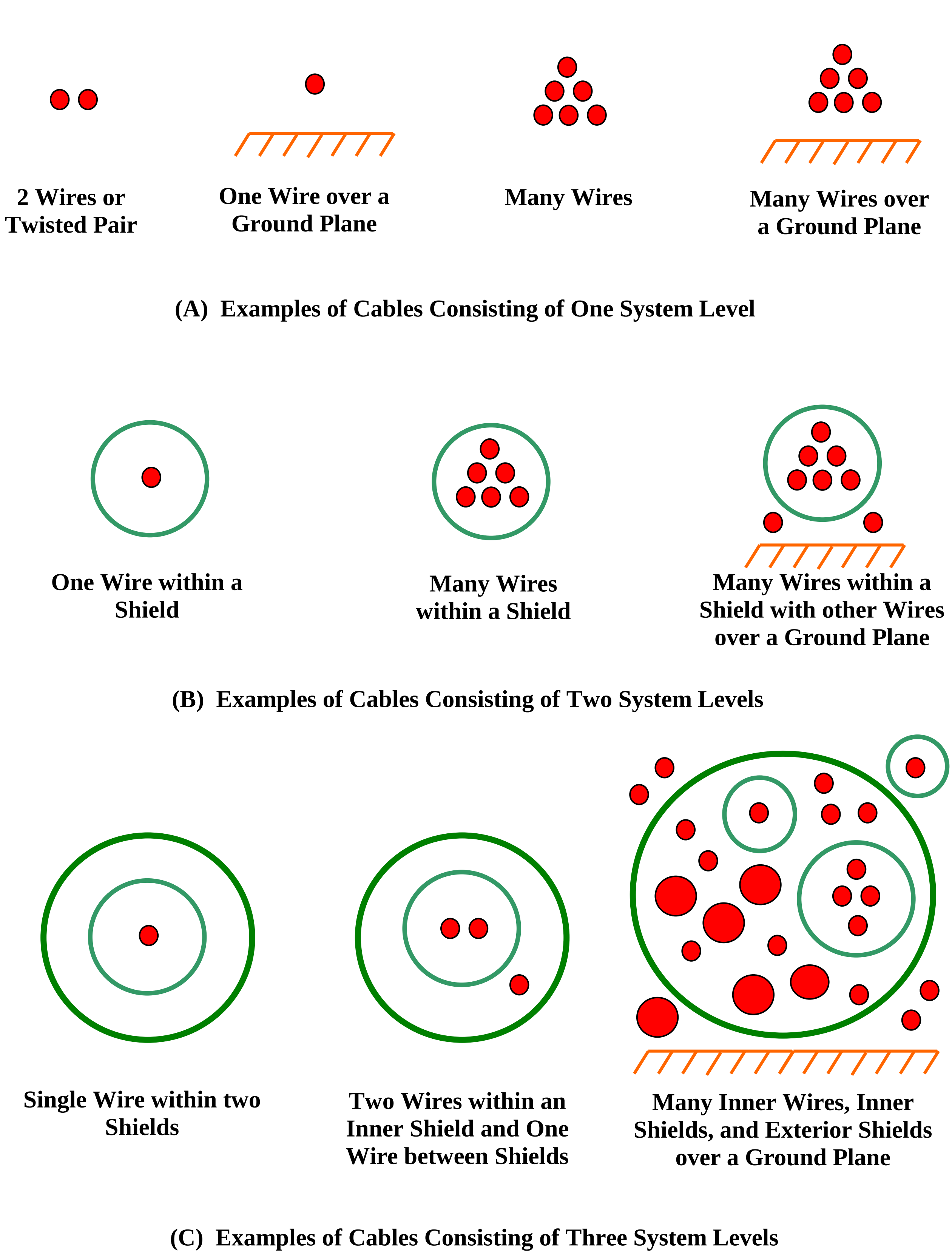


Figure 4.3.3 Examples of Allowable Cable Configurations – Cross-Sections

4.4 Cable Harness Topological Terms

An MHARNESS cable system is made up of segments, junctions, and terminals. A segment (or cable branch) is a straight uniform cable section between two junctions, between a junction and a terminal, or between two terminals. At most, three system levels can exist within any segment.

A system with five segments, labeled **S1** through **S5**; two junctions, **J1** and **J2**, and four terminals, **T1** through **T4** is shown in Figure 4.4.1. Two or more segments meet at a junction. A junction exists at a terminal voltage node (see Figure 4.1.1). The average capacitance and conductance parameters for the adjoining segments are used to characterize the cable impedance parameters at the junction point. A terminal is where a segment terminates with a boundary condition. This boundary condition consists of one of the circuit terminations shown in Figure 3.6.1. There is no interaction between segments except for the conservation of charge at the junction.

For a multi-branched system, the conductors from connecting branches are properly joined by utilizing nodes at the junction. The individual conductors of the cable system in Figure 4.4.1 are depicted in Figure 4.4.2. There are four conductors within segment **S1**, two conductors in segment **S2**, three conductors in **S3**, one conductor in **S4**, and four conductors in **S5**.

There are four nodes in junction **J1**. These nodes are specified as **n1** through **n4**. A conductor in segment **S1** is connected to a conductor in **S2** at node **n1**. Another conductor in **S1**, a conductor in **S2**, and a conductor in **S3** are all connected together at node **n2**. Two conductors in **S1** are connected to two other conductors in **S3** at nodes **n3** and **n4**. There are also four nodes in junction **J2**. These nodes are specified as **n5** through **n8**. Three conductors in **S3** are connected to three other conductors in **S5** at nodes **n5**, **n6**, and **n7**. A conductor in **S4** is connected to a conductor in **S5** at node **n8**. Any conductor from a particular segment entering a junction is connected to one and only one node. No two conductors of the same segment are connected to the same node. This is not allowed in MHARNESS. Furthermore, a circuit boundary condition (see Section 3.6.1) is not allowed at a node, only at a terminal point.

Another example of an MHARNESS cable system is shown in Figure 4.4.3. A top view of the whole system is shown in Figure 4.4.3A. This system consists of three segments, **S1**, **S2**, and **S3** and one junction **J1**. A cross-section of each segment is shown in Figure 4.4.3B. This system thus consists of three twisted shielded wires pairs along with another wire in an overbraid shield. Segment **S1** contains three shielded twisted pairs and one other wire. Segment **S2** contains 1 shielded twisted pair while segment **S3** contains two shielded twisted pairs and one other wire.

The overbraid conductor of each segment constitutes System Level 2. System Level 2 consists of three segments, each containing 1 conductor, as shown in Figure 4.4.4A. These conductors are joined at node **n21**. There is one node at junction **J1** in System Level 2. Since there is one conductor in each segment the line impedance parameters consist of single coefficients, as shown in Figure 4.4.4A.

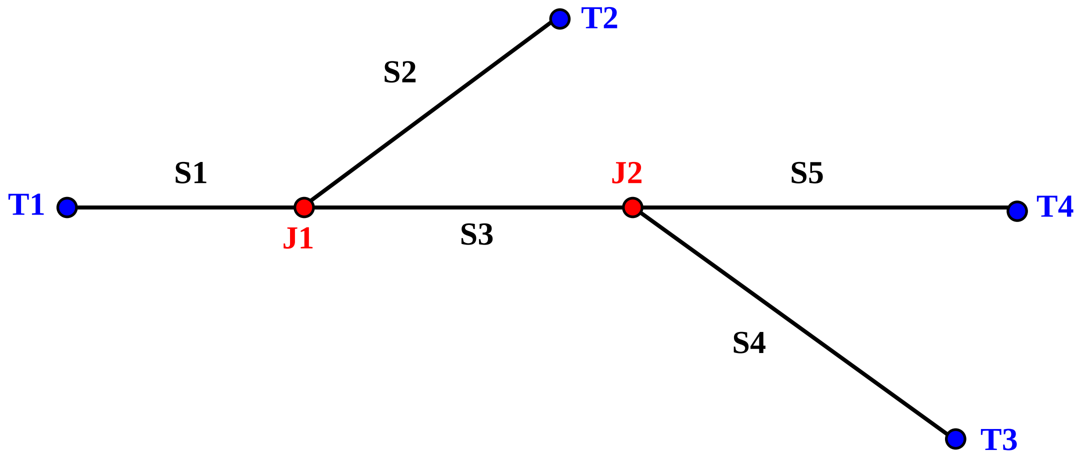


Figure 4.4.1 MHARNESS Cable System

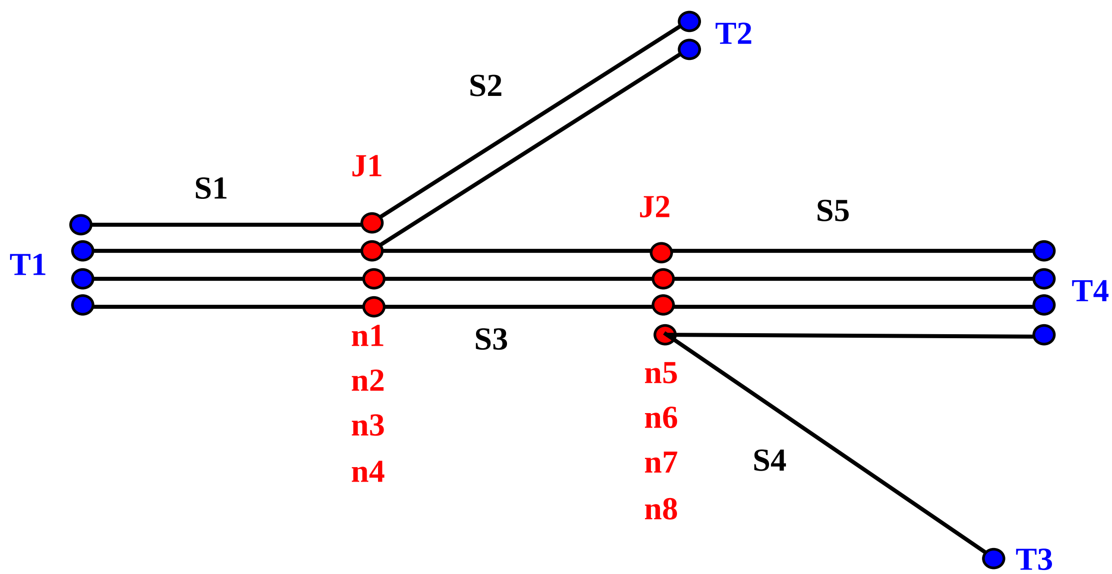


Figure 4.4.2 Conductors within the MHARNESS Cable System of Figure 4.2.1

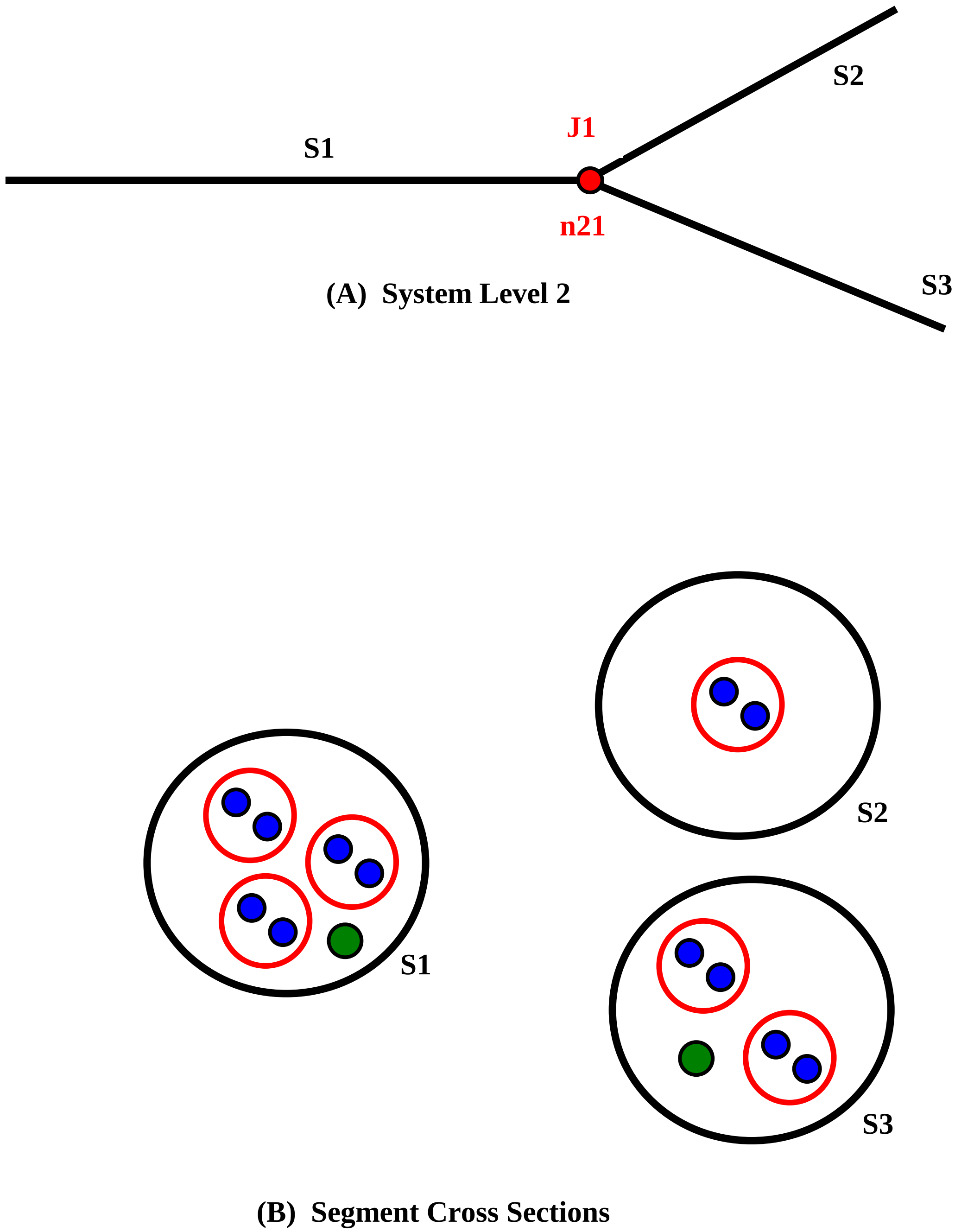


Figure 4.4.3 MHARNESS Cable System with Over Braid

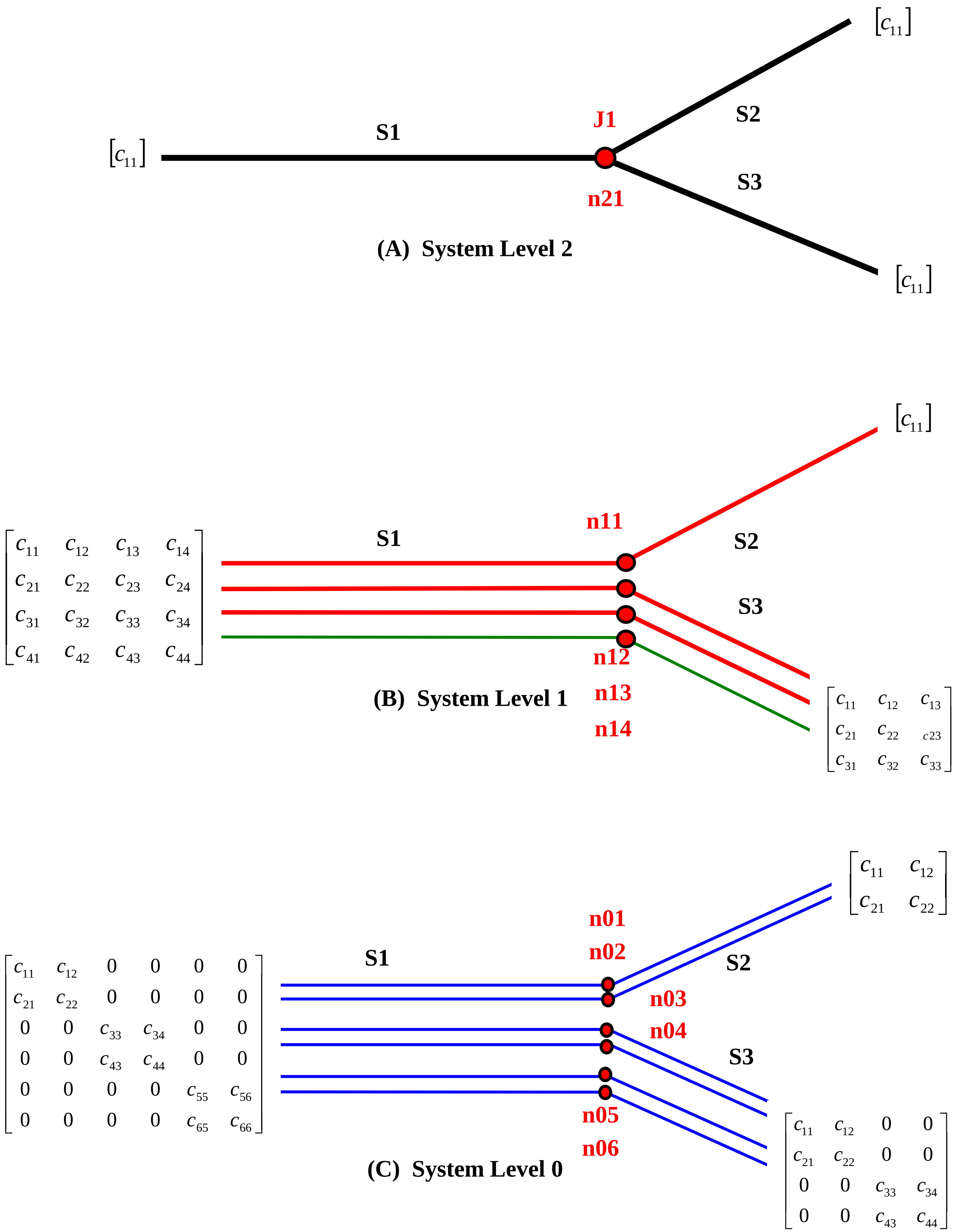


Figure 4.4.4 System Levels and Impedance Matrices for the MHARNESS Cable System of Figure 4.4.3

The shields of the twisted pairs and the one other wire constitute System Level 1, as shown in Figure 4.4.4B. System Level 1 consists of the same three segments. Segment **S1** contains four conductors, segment **S2** contains 1 conductor, and segment **S3** contains 3 conductors. There is one junction containing 4 nodes. These nodes are labeled, **n11**, **n12**, **n13**, **n14**. The line impedance parameters consists of full 4x4 matrices for segment **S1**, single coefficients for segment **S2**, and full 3x3 matrices for segment **S3**, as shown in Figure 4.4.4B.

System Level 0 consists of the same three segments. Segment **S1** contains six conductors, segment **S2** contains 2 conductors, and segment **S3** contains 4 conductors. There is one junction containing 6 nodes. These nodes are labeled, **n01**, **n02**, **n03**, **n04**, **n05**, and **n06**. Since each twisted pair of conductors exist within a separate shield, the line impedance parameters consists of block diagonal matrices composed of 2x2 blocks. For segment **S1**, the impedance matrices consist of 6x6 block diagonal matrices, for **S2** the impedance matrices are 2x2, and for **S3** the impedance matrices consist of 4x4 block diagonal matrices, as shown in Figure 4.4.4C.

4.5 Cable Connectors

Many cable harnesses employ cable connectors to terminal boxes. The presence of cable connectors usually require different impedance matrices to characterize the ends of cable branches where the connectors are employed. Different capacitance, inductance, resistance, and conductance matrices can be specified for connectors. The specification of connectors does not increase the length of the cable. Connectors are always associated with the last finite difference cell on the end of each meshed cable. If cable connectors are not specified, then the ends of each meshed cable assume the properties of the main portion of the cable.

4.6 Cable Harness Reference Conductor

MHARNESS is a transmission line code and, therefore, requires a reference for implementation. If the impedance matrices are manually defined, then the reference is implicit in the entries of the matrices. However, for automatic computation, the reference must be identified. In MHARNESS the reference is always assumed to be a ground plane (default condition) unless otherwise specified. If the default condition ground plane is assumed, then it exists at the z-coordinate of, z = 0.0, as discussed in Section 4.2. A wire reference may also be specified. In this case the cable harness may be at any z-coordinate location.

CHAPTER 5 MHARNESS Input File Conventions

5.0 Introduction

The MHARNESS input file is an ASCII file which contains all of the necessary information to completely describe the problem for MHARNESS. The input file consists of keywords, keyword descriptors, and comments. Comments are preceded by an asterisk "*". Comments and blank lines are ignored. All parameter data within the input file is expected in MKSA units.

Keywords are discussed in Section 5.1. The format of an input file entry is described in Section 5.2. Keyword descriptors are discussed in Section 5.3. Naming conventions are presented in Section 5.4. Finally, the polarity of the current within a particular cable segment is defined in Section 5.5.

5.1 Keywords

The ASCII text lines within an MHARNESS input file are referred to as file entries. File entries are assembled together into group entries, which define a particular cable topology, source type, or output probe. Each group entry is specified by a particular keyword. Keywords are categorized as level 1, level 2, or level 3. All level 1, level 2, and level 3 keywords are preceded by a "!", "!!" and "!!!", respectively. Level 1 keywords are used to identify group entries. Level 2 and 3 keywords provide additional definitions and refinements. Therefore, level 2 and 3 keywords are always associated with a level 1 keyword and cannot exist independently. All keywords are case insensitive.

5.2 Entry Format

Level 1 keywords and associated group entries can exist in any order within the MHARNESS input file. All lines following a level 1 keyword must adhere to the format associated with the keyword group entry. If a level 2 keyword is required, it must immediately follow the level 1 keyword. Likewise, a level 3 keyword must immediately follow the associated level 2 keyword. For example, if "Alpha" was a level 1 keyword and "Beta" and "Gamma" were associated level 2 and level 3 keywords, respectively, then the group entry in an input file containing these keywords would appear as:

```
!Alpha
!!Beta
!!!Gamma
```

Following the keywords are keyword descriptors used for further refinements and definitions. If "delta" and "epsilon" were keyword descriptors then the group entry in the input file would appear as:

```
!Alpha
!!Beta
!!!Gamma
```

```
delta  epsilon
```

For some group entries there may be many keyword descriptors. If “zeta”, “eta”, and “iota” were additional required keyword descriptors, then the entry may appear as:

```
!Alpha
!!Beta
!!!Gamma
delta  epsilon
zeta  eta  iota
```

or possibly as:

```
!Alpha
!!Beta
!!!Gamma
delta  epsilon
zeta  eta
iota
```

depending upon the required format.

Following the keyword descriptors for a level 3 keyword, the input file may contain a new level 3 keyword, assuming the same level 2 and level 1 keywords. For instance, the following two group entries are equivalent.

```
!Alpha
!!Beta
!!!Gamma1
delta1  epsilon1
!Alpha
!!Beta
!!!Gamma2
delta1  epsilon1
```

and

```
!Alpha
!!Beta
!!!Gamma1
delta1  epsilon1
!!!Gamma2
delta2  epsilon2
```

Analogously, following a level 1 keyword, many level 2 keywords may exist assuming the same level 1 keyword. For example, the following two group entries are equivalent.

```
!Alpha
!!Beta1
!!!Gamma1
delta1  epsilon1
!Alpha
!!Beta1
!!!Gamma2
delta2  epsilon2
!Alpha
!!Beta2
!!!Gamma3
delta3  epsilon3
```

and

```
!Alpha
!!Beta1
!!!Gamma1
delta1  epsilon1
!!!Gamma2
delta2  epsilon2
!!Beta2
!!!Gamma3
delta3  epsilon3
```

There are many defined keywords allowable in the MHARNESS input file. It is not necessary to have all the keywords present. A minimal set sufficient to define the problem of interest is all that is required. If a keyword does not appear in the input file, it is either irrelevant or a default condition can be assume. For example, if there are only two system levels, System Level 0 and System Level 1, then the keywords for System Level 2 are not required.

5.3 Keyword Descriptors

Keyword descriptors, introduced in the previous section, add the final refinement to the level 1 keyword. These descriptors can be characters (*c*), integer numbers (*i*), or real numbers (*r*), depending on the entry format. A real number possesses a decimal point, such as "3.0". An integer does not have a decimal point, such as "3".

All numerical data is assumed to utilize MKSA units. Data are entered with a maximum length of 128 characters per record. For records containing numerical descriptors only (no character descriptors), blank spaces, commas, or tabs can be used as delimiters. The asterisk character, "*", can be used for multiplicative entries. For example, 5*2.3 can be used in place of entering 2.3 five times. Two consecutive commas without any intervening number is not acceptable.

It is important to realize that a descriptor entry takes on a different meaning depending upon the alphanumeric type (*c*, *i*, *r*) used. For instance, the following data entries are perfectly legal.

```
!SPACE STEP
segment1    25.0
```

and

```
!SPACE STEP
segment1    25
```

The first line of either entry group is the keyword, "`SPACE STEP`". The second line consists of keyword descriptors. In the first entry there are two keyword descriptors. These are:

```
segment1    25.0
```

In the second entry, there are also two keyword descriptors. These are:

```
segment1    25
```

Upon first inspection, these keyword descriptor lines may appear identical, or at least equivalent. However, the second descriptor of the first entry is a real number, "25.0", and the associated descriptor of the second entry is an integer, "25". The different datum types imply two totally different meanings. In the first entry the real number defines the finite difference space step of `segment1` to be `25.0` meters. In the second entry, the integer defines the number of finite difference increments assigned to `segment1`. If `segment1` is 25.0 meters long, then the finite difference space step would be 1.0 meters in length. It is thus of paramount importance that a real number be entered with a decimal point, or in scientific notation, and there be no decimal point associated with an integer.

5.4 Cable System Naming Convention and Namespaces

An MHARNESS cable is made up of segments, conductors (shields and wires), junctions, and nodes. Each of these entities is identified by alphanumeric names – up to a maximum length of 64 characters. Acceptable alphanumeric characters are letters, numerals, and some common symbols such as underscores. Symbols such as, "*" "!","-", blank spaces, tabs, commas, and periods, that might cause confusion are not acceptable. Names are case sensitive. Names consisting of numerals only are acceptable. Numerals, like letters, are stored as character strings.

Namespaces associated with System Level 2, System Level 1, and System Level 0 are distinct. Names can be duplicated between different system levels. For instance, the same conductor name can be used to identify a wire in System Level 0 or a shield in System Level 1. Furthermore, conductor names are local to a segment. Therefore, the same name can be used to identify a wire running from one segment to the next. These properties simplify the logistical problem of naming and identifying parts and making required segment connections.

For the input file format description of Chapter 6, a segment name is represented by the characters, "`seg_id`". This character string represents any segment name desired by the user. Within a segment are various conductors. Each of the individual conductors is assigned an alphanumeric name represented by the character, "`cond_id`". This character string represents any conductor name desired by the user. Therefore, a particular conductor in a cable system is uniquely identified by the two character string pair of, “seg_id” and "cond_id". For simplicity, this set is referred to as the conductor identifier.

Two or more segments meet at a junction. Each junction is assigned an alphanumeric name represented by the characters, “junc_id”, in Chapter 6. This character string represents any junction name desired by the user. The end of any segment that terminates with a boundary condition must be designated with a junc_id of “0”.

Within a junction are nodes. Each node in Chapter 6 is assigned an alphanumeric name, represented by the characters, “node_id”. This character string represents any node name desired by the user. Two or more conductors from different segments meet at a node. The nodes within a junction are explicitly associated with that particular junction. Therefore, different junctions can share the same node names. Nodes are thus uniquely defined by the two character string pair of, “junc_id” and “node_id”.

5.5 Segment Current Polarity and Conventions

In the input file format description of Chapter 6, an MHARNESS cable segment is defined as beginning at one end, represented by the characters, “end_1”, and ending at the other end, represented by the characters, “end_2”. The character strings, "end_1" and "end_2", can be either a circuit termination, represented by a "0", or a junction/node, represented by user defied names. Each of the ends is assigned an integer identifier, “1” for "end_1" and “2” for "end_2". Positive current flows from end_1 to end_2. All conductors within a particular segment have the same current polarity. The first coordinates and/or the first junction number specified for the segment in the input file is end_1 of the segment.

CHAPTER 6 Listing of the MHARNESS Input File

6.0 Introduction

The MHARNESS input file consists of a collection of simple text lines which define cable topology, cable geometry, impedance matrices, sources, and output probe information. The algorithms of MHARNESS are designed to process these text lines. If a particular line does not have the right format, then an error message will result and the program will terminate. Error messages will be printed to the screen and appear in a diagnostic file (see Chapter 8). The text lines are referred to as file entries. File entries are assembled together into group entries. Each group entry is headed by a particular level 1 keyword.

The group entries in the input file can be arranged and grouped in any order. However, an adhered to prescribed order and grouping can eliminate confusion, errors, and repetitions. A recommended grouping and ordering scheme is presented in Section 6.1. Nomenclature used to clarify the MHARNESS input file listing is presented in Section 6.2. The complete MHARNESS input file listing, showing the format of all possible entries and group entries, is provided in Section 6.3. The definitions, relationships, and ramifications of the various entries and group entries are fully discussed in parallel sections of Chapter 7.

6.1 The MHARNESS Input file Ordering Format

It is recommended that the MHARNESS input file be constructed with eleven sections. Some of these sections are required while others are necessary only for particular configurations. When MHARNESS is used in conjunction with EMA3D, some sections are no longer necessary (see Chapter 8). The eleven input file sections are listed below.

1. Input File Section 1: GENERAL
2. Input File Section 2: TIME STEP
3. Input File Section 3: SPACE STEP
4. Input File Section 4: EXCITATION/SOURCES
5. Input File Section 5: Cable Conductor Topology
   - 5.1. Section 5A: System Level 2 - SHIELD TWO Topology
   - 5.2. Section 5B: System Level 1 - SHIELD ONE Topology
   - 5.3. Section 5C: System Level 0 - Wire Topology
6. Input File Section 6: Cable Conductor Impedance Parameters
   - 6.1. Section 6A: System Level 2 - SHIELD TWO Impedance Parameters
   - 6.2. Section 6B: System Level 1 - SHIELD ONE Impedance Parameters
   - 6.3. Section 6C: System Level 0 - Wire Impedance Parameters
7. Input File Section 7: Cable Connector Impedance Parameters
   - 7.1. Section 7A: System Level 2 - SHIELD TWO Connector Impedance Parameters
   - 7.2. Section 7B: System Level 1 - SHIELD ONE Connector Impedance Parameters
   - 7.3. Section 7C: System Level 0 - Wire Connector Impedance Parameters
8. Input File Section 8: Cable Shield Transfer Impedance Parameters
   - 8.1. Section 8A: System Level 2 - SHIELD TWO Transfer Impedance Parameters
   - 8.2. Section 8B: System Level 1 - SHIELD ONE Transfer Impedance Parameters
9. Input File Section 9: Cable Boundary Conditions
   - 9.1. Section 9A: System Level 2 - SHIELD TWO BOUNDARY CONDICTIONS
   - 9.2. Section 9B: System Level 1 - SHIELD ONE BOUNDARY CONDICTIONS
   - 9.3. Section 9C: System Level 0 - Wire BOUNDARY CONDICTIONS
10. Input File Section 10: Cable Reference / Ground Parameters
11. Input File Section 11: Output / PROBES

It is advisable to divide the input file into the various sections listed above and to construct each section in the order listed. Example input files (see Chapter 11) are provided with each distribution of MHARNESS. These example files may be used as a starting point for input file construction.

6.2 MHARNESS Input File Nomenclature

The complete MHARNESS input file listing is provided in the next section. This section contains nomenclature used to provide clarity to the complete listing of the MHARNESS input file. Incorporated within the input file listing are various entities surrounded by square brackets, [], parentheses, ( ), curly brackets, { }, or angle brackets < >. These are not present in the actual MHARNESS input file but are provided below for informational purposes only. The square brackets state the nature of the datum entry type. The datum entry type designators are, "*c*" for a character field, "*r*" for a real number, and, "*i*", for an integer. The parentheses contain the possible candidates for each entry. The curly brackets indicate certain restrictions, while the angle brackets provide additional clarifications. Remember, a first level keyword is preceded by a, "!", a second level keyword by a, "!!", and a third level keyword by a, "!!!". All of these input file entities and associated meanings are provided below for easy inspection.

[ ]	Contains the datum type
( )	Candidate entries
{ }	Restrictions on entry
< >	Additional clarification
c	Character
r	Real
i	Integer
*	Comment line
!	First level keyword
!!	Second level keyword
!!!	Third level keyword

6.3 Complete Listing of the MHARNESS Input File

```
*Header Information
*Header Line 1
*Header Line 2
*   .    .   .
*   .    .   .
```

****************************** Section 1: GENERAL *******************************

```
!LOW FREQUENCY APPROXIMATION
```

***************************** Section 2: TIME STEP ******************************

!TIME STEP		
!!type	[*c*]	(NOTCOMPUTE, COMPUTE)
dt itmax	[*r i*]	{NOTCOMPUTE}
time frequency ncells	[*r r i*]	{COMPUTE}

*--------------------

!MAGNETOSTATIC
t_1 $factor_1$
t_2 $factor_2$
.   .
.   .
.   .
t_n $factor_n$

****************************** Section 3: SPACE STEP ****************************

(Note: seg_id must pertain to the external system level)

!SPACE STEP	
dx	[*r*]

or

seg_id_1 dx_1	[*c r*]
seg_id_2 dx_2	[*c r*]
. .	.
. .	.
. .	.
seg_id_n dx_n	[*c r*]

or

seg_id_1 $ncells_1$	[*c i*]
seg_id_2 $ncells_2$	[*c i*]
. .	.
. .	.
. .	.
seg_id_n $ncells_n$	[*c i*]

********************** **Section 4: EXCITATION/SOURCES** ********************

```
!INPUT FORMAT                                                    <optional – default: TEXT>
type                                  [c]                        (BINARY, TEXT)


*--------------------


!EXCITATION TYPE
!!where                               [c]                        (CABLE,
                                                                  SHIELD ONE,
                                                                  SHIELD TWO)

!!!type                               [c]                        (PIN VOLTAGE DRIVE,
                                                                  PLANE WAVE DRIVE,
                                                                  LOCALIZED EFIELD DRIVE,
                                                                  LOCALIZED CURRENT DRIVE,
                                                                  SEGMENT EFIELD DRIVE
                                                                  SEGMENT CURRENT DRIVE
                                                                  GENERAL EFIELD DRIVE,
                                                                  GENERAL CURRENT DRIVE)

height theta phi alpha beta           [5*r]                      {PLANE WAVE DRIVE – when
                                                                 !segment !!type = simple}

theta phi alpha beta                  [4*r]                      {PLANE WAVE DRIVE – when
                                                                 segment type = complex, or
                                                                 segment type = complex2}


*--------------------
```

Note: there are items defined under the following SOURCE WAVEFORM *keyword that depend upon* EXCITATION TYPE *third level keywords, as indicated by some of the entries in the curly brackets.*

```
!SOURCE WAVEFORM
!!type                                [c]                        (DATAFILE,
                                                                  GAUSSIAN,
                                                                  DERIVATIVE OF GAUSSIAN,
                                                                  DOUBLE EXPONENTIAL,
                                                                  DERIVATIVE OF DBL EXP,
                                                                  SINE SQU LEADING DBL EXP,
                                                                  SINE,
                                                                  SINE SQUARED,
                                                                  LINEAR RAMP,
                                                                  DAMPED SINUSOID)

source_file_name                      [c]                        {DATAFILE}

amp time_to_peak width                [3*r]                      {GAUSSIAN OR
                                                                  DERIVATIVE OF GAUSSIAN}

amp salpha sbeta                      [3*r]                      {DOUBLE EXPONENTIAL
                                                                  DERIVATIVE OF DBL EXP OR
                                                                  SINE SQU LEADING DBL EXP}

amp frequency                         [2*r]                      {SINE OR
                                                                  SINE SQUARED}

amp time_to_peak                      [2*r]                      {LINEAR RAMP}
```

```
amp salpha frequency              [3*r]               {DAMPED SINUSOID}
```

Note: the following items depend upon the `EXCITATION TYPE` third level keyword, as indicated by the entry in the curly brackets..

```
seg_id cond_id end#               [c c i]             {PIN VOLTAGE DRIVE}

seg_id cond_id locl               [2*c r]             {LOCALIZED EFIELD OR
                                                       LOCALIZED CURRENT DRIVE}
```

or

```
seg_id cond_id loc1 loc2          [2*c 2*r]           {LOCALIZED EFIELD OR
                                                       LOCALIZED CURRENT DRIVE}
```

or

```
seg_id cond_id loc1               [2*c i]             {LOCALIZED EFIELD OR
                                                       LOCALIZED CURRENT DRIVE}
```

or

```
seg_id cond_id loc1 loc2          [2*c 2*i]           {LOCALIZED EFIELD OR
                                                       LOCALIZED CURRENT DRIVE}


seg_id                            [c]                 {SEGMENT EFIELD OR
                                                       SEGMENT CURRENT DRIVE}
```

or

```
seg_id cond_id                    [2*c]               {SEGMENT EFIELD OR
                                                       SEGMENT CURRENT DRIVE}
```

*********************** Section 5: Cable Conductor Topology ********************

***------------- Section 5A: System Level 2 – SHIELD TWO Topology ------------**

(Shield two definitions required only if there are shields)
(see format under System Level 0 – Section 4C)

```
!SHIELD TWO SEGMENT

!SHIELD TWO JUNCTION AND NODE
```

***------------- Section 5B: System Level 1 – SHIELD ONE Topology ------------**

(Shield one definitions required only if there are shields)
(see format under System Level 0 – Section 4C)

```
!SHIELD ONE SEGMENT

!SHIELD ONE JUNCTION AND NODE
```

***---------------- Section 5C: System Level 0 – Wire Topology ---------------**

```
!SEGMENT
!!type                          [c]        (SIMPLE, COMPLEX, COMPLEX2)
```

(for length specified)

```
seg_id bjunc_id ejunc_id length     [3*c r]                  {SIMPLE}
cond_id1
cond_id2
   .
   .
   .
cond_idn
```

or (for coordinate of ends specified, necessary for Plane Wave Illumination drive)

```
seg_id bjunc_id ejunc_id x1 y1  x2 y2     [3*c 4*r]          {SIMPLE}
cond_id1
cond_id2
   .
   .
   .
cond_idn
```

or (for shielded system, where the shielded segment will have the shielding segment dimension)

```
seg_id bjunc_id ejunc_id                  [3*c]              {SIMPLE}
cond_id1
cond_id2
   .
   .
   .
cond_idn
```

or (when conductor end coordinates are specified – required for automatic capacitance computation)

```
seg_id bjunc_id ejunc_id                          [3*c]              {COMPLEX}
cond_id1, x11, y11, z11, x12, y12                 [c, 5*r]
cond_id2, x21, y21, z21, x22, y22                 [c, 5*r]
   .       .    .    .    .    .                    .   .
   .       .    .    .    .    .                    .   .
   .       .    .    .    .    .                    .   .
cond_idn, xn1, yn1, zn1, xn2, yn2                 [c, 5*r]
```

or (when only beginning coordinates are specified <u>before rotation</u> [all others are parallel] - required for automatic capacitance computation)

```
seg_id bjunc_id ejunc_id Ref_Def                  [4*c]              {COMPLEX2}
xR1, yR1, zR1, xR2, yR2                           [5*r]        {Ref_Def: Cartesian}
xR1, yR1, zR1, L, Ang                             [5*r]        {Ref_Def: Polar}
cond_id1, x1, y1, z1                              [c, 3*r]
cond_id2, x2, y2, z2                              [c, 3*r]
   .       .    .    .                              .   .
   .       .    .    .                              .   .
   .       .    .    .                              .   .
cond_idn, xn, yn, zn                              [c, 3*r]
```

* *next segment*

```
       .
       .
       .

*--------------------
```

```
!JUNCTION AND NODE
junc_id                             [c]
node_id1                            [c]
seg_id11 cond_id11                  [2*c]
seg_id12 cond_id12                  [2*c]
   .        .                         .
   .        .                         .
   .        .                         .
seg_id1n cond_id1n                  [2*c]

   .
   .
   .

node_id2                            c
seg_id21 cond_id21                  [2*c]
seg_id22 cond_id22                  [2*c]
   .        .                       .
   .        .                       .
   .        .                       .
seg_id2n cond_id2n                  [2*c]

   .
   .
   .

node_idm                            c
seg_idm1 cond_idm1                  [2*c]
seg_idm2 cond_idm2                  [2*c]
   .        .                       .
   .        .                       .
   .        .                       .
seg_idmn cond_idmn                  [2*c]
```

********************* Section 6: Cable Impedance Parameters *********************

***------- Section 6A: System Level 2 – SHIELD TWO Impedance Parameters -------**

(shield two definition required only if there are shields)
(see format under System Level 1 – Section 5B & System Level 0 – Section 5C)

!SHIELD TWO CAPACITANCE

!SHIELD TWO CAPACITANCE COMPUTE

!SHIELD TWO INDUCTANCE

!SHIELD TWO INDUCTANCE COMPUTE

!SHIELD TWO RESISTANCE

!SHIELD TWO CONDUCTANCE

!SHIELD TWO SKIN DEPTH

***------- Section 6B: System Level 1 – SHIELD ONE Impedance Parameters -------**

(shield one definition required only if there are shields)
(see format under System Level 0 – Section 5C)

```
!SHIELD ONE CAPACITANCE

!SHIELD ONE CAPACITANCE COMPUTE

!SHIELD ONE INDUCTANCE

!SHIELD ONE INDUCTANCE COMPUTE

!SHIELD ONE RESISTANCE

!SHIELD ONE CONDUCTANCE

!SHIELD ONE SKIN DEPTH
```

***---------- Section 6C: System Level 0 – Wire Impedance Parameters ----------**

```
!CAPACITANCE
seg_id                               [c]
c11  c12  ...  c1n                   [r ... r]
c21  c22  ...  c2n                   [r ... r]
.    .         .                         .
.    .         .                         .
.    .         .                         .
cn1  cn2  ...  cnn                   [r ... r]
```

or

```
!CAPACITANCE
seg_id c11 ... c1n c21 ... c2n ... cn1 ... cnn      [c r ... r]

!CAPACITANCE COMPUTE
!!type                               [c]                     (DIELECTRIC,
                                                              RADII,
                                                              FILAMENT NUMBER)

seg_id epsb epsd                     [c 2*r]                 {DIELECTRIC}

seg_id cond_id cradius dradius       [2*c 2*r]               {RADII}

seg_id cond_id nfc nfd               [2*c 2*r]               {FILAMENT NUMBER}

*--------------------

!INDUCTANCE
```

same format as in capacitance

```
*--------------------

!INDUCTANCE COMPUTE
seg_id speed                         [c r]

*--------------------

!RESISTANCE
```

seg_id cond_id resistance [*2*c r*]

*--------------------

!CONDUCTANCE

same format as in capacitance

*--------------------

!SKIN DEPTH
seg_id cond_id sig thk

**************** Section 7: Cable Connector Impedance Parameters ****************

***-- Section 7A: System Level 2 – SHIELD TWO Connector Impedance Parameters --**
(see format under System Level 0 – Section 6C)

!SHIELD TWO CONNECTOR CAPACITANCE

!SHIELD TWO CONNECTOR INDUCTANCE

!SHIELD TWO CONNECTOR INDUCTANCE COMPUTE

!SHIELD TWO CONNECTOR RESISTANCE

!SHIELD TWO CONNECTOR CONDUCTANCE

***- Section 7B: System Level 1 – SHIELD ONE Connector Impedance Parameters --**
(see format under System Level 0 – Section 6C)

!SHIELD ONE CONNECTOR CAPACITANCE

!SHIELD ONE CONNECTOR INDUCTANCE

!SHIELD ONE CONNECTOR INDUCTANCE COMPUTE

!SHIELD ONE CONNECTOR RESISTANCE

!SHIELD ONE CONNECTOR CONDUCTANCE

***----- Section 7C: System Level 0 – Wire Connector Impedance Parameters ----**

!CONNECTOR CAPACITANCE

seg_id end#	[*c i*]
C_{11} C_{12} ... C_{1n}	[*r ... r*]
C_{21} C_{22} ... C_{2n}	[*r ... r*]
. . .	. .
. . .	. .
. . .	. .
C_{n1} C_{n2} ... C_{nn}	[*r ... r*]

or

```
!CONNECTOR CAPACITANCE
seg_id end# c11 ... c1n c21 ... c2n ... cn1 ... cnn [c i r ... r]

*--------------------

!CONNECTOR INDUCTANCE
```
same format as in !connector capacitance

```
*--------------------

!CONNECTOR INDUCTANCE COMPUTE
seg_id end# speed                  [c i r]

*--------------------

!CONNECTOR RESISTANCE
seg_id cond_id end# resistance     [2*c i r]

*--------------------

!CONNECTOR CONDUCTANCE
```
same format as in !connector capacitance

************* Section 8: Cable Shield Transfer Impedance Parameters *************

--- Section 8A: System Level 2 – SHIELD TWO Transfer Impedance Parameters ---

(shield two definition required only if there are three system levels)

(see format under System Level 1 – Section 8B)

```
!SHIELD TWO GLOBAL TRANSFER DIRECTION              <optional - default: In>

!SHIELD TWO TRANSFER DIRECTION                     <optional - default: In>

!SHIELD TWO TO SHIELD ONE

!SHIELD TWO TO SHIELD ONE COMPUTE

!SHIELD TWO TRANSFER RESISTANCE

!SHIELD TWO TO SHIELD ONE FREQUENCY DEPENDENT
```

--- Section 8B: System Level 1 – SHIELD ONE Transfer Impedance Parameters ---

(shield one definition required only if there are two system levels)

(see format under System Level 0 – Section 8C)

```
!SHIELD ONE GLOBAL TRANSFER DIRECTION              <optional - default: In>
direction                             [c]           (In  Out  Both)

*--------------------

!SHIELD ONE TRANSFER DIRECTION                     <optional - default: In>
```

```
seg_id   cond_id   direction         [c]               (In  Out  Both)

*--------------------

!SHIELD ONE TO CABLE
shieldedseg# seg_id cond_id parallel sfact tzl1 tzl2 tzl3   [3*c 2*i 3*r]
```

or

```
shieldedseg# seg_id cond_id parallel sfact  tzl       [3*c 2*i 1*r]

*--------------------

!SHIELD ONE TO CABLE COMPUTE
shieldedseg_id seg_id cond_id parallel sfact          [3*c 2*i]
strand_dia,sigma,weaveangle,#carrier,#ends            [3*r 2*i]

*--------------------

!SHIELD ONE TRANSFER RESISTANCE
seg_id cond_id tr1 tr2 tr3          [2*c 3*r]
```

or

```
seg_id cond_id  tr                  [2*c 1*r]

*--------------------

!SHIELD ONE TO CABLE FREQUENCY DEPENDENT
shieldedseg# seg_id cond_id parallel sfact  nfd1   nfd2   nfd3    [3*c 5*i]
rdc1
afd11      bfd11                         [r r]
afd12      bfd12                         [r r]
 .          .                              .
 .          .                              .
 .          .                              .
afd1,nfd1   bfd1,nfd1                    [r r]
rdc2
afd21      bfd21                         [r r]
afd22      bfd22                         [r r]
 .          .                              .
 .          .                              .
 .          .                              .
afd2,nfd1   bfd2,nfd1                    [r r]
rdc3
afd31      bfd31                         [r r]
afd32      bfd32                         [r r]
 .          .                              .
 .          .                              .
 .          .                              .
afd3,nfd1   bfd3,nfd1                    [r r]
```

or

```
shieldedseg# seg_id cond_id parallel sfact  nfd2                  [3*c 3*i]
rdc2
```

```
afd21       bfd21                      [r r]
afd22       bfd22                      [r r]
 .           .                            .
 .           .                            .
 .           .                            .
afd2,nfd1   bfd2,nfd1                  [r r]
```

********************** Section 9: Cable BOUNDARY CONDITIONS **********************

***------- Section 9A: System Level 2 – SHIELD TWO BOUNDARY CONDITIONS --------**

(see format under System Level 0 – Section 7C)

```
!SHIELD TWO BOUNDARY CONDITION
```

***------- Section 9B: System Level 1 – SHIELD ONE BOUNDARY CONDITIONS --------**

(see format under System Level 0 – Section 7C)

```
!SHIELD ONE BOUNDARY CONDITION

*--------------------


!SHIELD ONE BOUNDARY VOLTAGE ZTR

*--------------------


!SHIELDS JOINED AT CONNECTOR
seg_id end#                         [c i]
```

***----------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------**

```
!BOUNDARY CONDITION
!!type                              [c]                     (RESISTIVE,
                                                             CAPACITIVE,
                                                             INDUCTIVE,
                                                             RCP, RLS, LCP
                                                             LCPRS, RCPRS)

seg_id cond_id end# res             [2*c i r]               {RESISTIVE}

seg_id cond_id end# cap             [2*c i r]               {CAPACITIVE}

seg_id cond_id end# ind             [2*c i r]               {INDUCTIVE}

seg_id cond_id end# res cap         [2*c i 2*r]             {RCP}

seg_id cond_id end# res ind         [2*c i 2*r]             {RLS}

seg_id cond_id end# ind cap         [2*c i 2*r]             {LCP}

seg_id cond_id end# ind cap res     [2*c i 3*r]             (LCPRS)

seg_id cond_id end# res cap res     [2*c i 3*r]             (RCPRS}

*--------------------
```

```
!BOUNDARY VOLTAGE ZTR
seg_id end#                        [c c i]


*************** Section 10: Cable Reference / Ground Parameters *************

!WIRE GROUND
!!type                             [c]                 (WIRE IN FREE SPACE,
                                                        DIELECTRIC
                                                        FILAMENT NUMBER)

seg_id  cradius  dradius           [c r i]             {WIRE IN FREE SPACE}
x1  y1  z1  x2  y2                 [3*r or 5*r]

seg_id  epsd                       [c r]               {DIELECTRIC}

seg_id   7    7                    [c]                 {FILAMENT NUMBER}


*--------------------


!GROUND RESISTANCE
seg_id  resistance                 [c r]


************************ Section 11: Output / PROBES ************************

!OUTPUT UNIVERSAL HEADER                               <optional – default: N>
value                              [c]                 (Y  N)


!OUTPUT FORMAT                                         <optional – default: TEXT>
type                               [c]                 (BINARY, TEXT)


*--------------------


!OUTPUT SOURCE
file_name                          [c]
end_time  del_time                 [(r,i)  (r,i)]


*--------------------


!STRUCTURE PROBE
filename                           [c]
pgor                               [c]               (H V)
legend                             [c]               (Y N)
reference  thick                   [c r]             (reference: Y N)
level  seg_id  cc    jc            [i 3*c]           (cc & sc: B C G Y O R L K)
level  seg_id  cond_id  cc  jc     [i 4*c]           (cc & sc: B C G Y O R L K)
 .      .       .     .   .           .                       .
 .      .       .     .   .           .                       .
 .      .       .     .   .           .                       .


*--------------------
```

```
!SKIN DEPTH PROBE
!!type                                          (SHIELD TWO
                                                 SHIELD ONE
                                                 CABLE)
filename1                            [c]
seg_id1  cond_id1                     [c c]
filename1                            [c]
seg_id1  cond_id1                     [c c]
 .      .       .     .   .             .                      .
 .      .       .     .   .             .                      .
 .      .       .     .   .             .                      .
filenamen                            [c]
seg_idn  cond_idn                     [c c]

*--------------------

!PROBE
!!type                               [c]              (GENERAL INFO,
                                                       SHIELD TWO CURRENT,
                                                       SHIELD TWO VOLTAGE,
                                                       SHIELD ONE CURRENT,
                                                       SHIELD ONE VOLTAGE,
                                                       CABLE CURRENT,
                                                       CABLE VOLTAGE,
                                                       RADIATED FIELD)

gen_info_text_line1                  [c]              {GENERAL INFO}
gen_info_text_line2                  [c]              {GENERAL INFO}
         .                            .                      .
         .                            .                      .
         .                            .                      .
gen_info_text_linen                       [c]         {GENERAL INFO}

file_name                            [c]
group_info_text                      [c]
        .                            [c]
        .                            [c]
group_info_text                      [c]

tstart tstop tstep                   [(3*r), (3*i)]

seg_id1 cond_id1 loc1                [2*c (r,i)]     {All currents and voltages}
seg_id2 cond_id2 loc2                [2*c (r,i)]     {All currents and voltages}
   .      .      .                    .    .                         .
   .      .      .                    .    .                         .
seg_idn cond_idn locn                [2*c (r,i) ]    {All currents and voltages}

x1   y1   z1                         [3*r]           {RADIATEDFIELD}
x2   y2   z2                         [3*r]           {RADIATEDFIELD}
.   .    .                             .                     .
.   .    .                             .                     .
xn   yn   zn                         [3*r]           {RADIATEDFIELD}
```

CHAPTER 7 MHARNESS Input File Explanation

7.0 Introduction

This chapter contains explanations of the MHARNESS input file listing of Chapter 6. The sections below are presented in the same order and possess a one-to-one correspondence with each section of the input file listing, as presented in the previous chapter. The section number and title are provided below.

12. Input File Section 1: GENERAL
13. Input File Section 2: TIME STEP
14. Input File Section 3: SPACE STEP
15. Input File Section 4: EXCITATION/SOURCES
16. Input File Section 5: Cable Conductor Topology
    16.1. Section 5C: System Level 0 - Wire Topology
    16.2. Section 5B: System Level 1 - SHIELD ONE Topology
    16.3. Section 5A: System Level 2 - SHIELD TWO Topology
17. Input File Section 6: Cable Conductor Impedance Parameters
    17.1. Section 6C: System Level 0 - Wire Impedance Parameters
    17.2. Section 6B: System Level 1 - SHIELD ONE Impedance Parameters
    17.3. Section 6A: System Level 2 - SHIELD TWO Impedance Parameters
18. Input File Section 7: Cable Connector Impedance Parameters
    18.1. Section 7C: System Level 0 - Wire Connector Impedance Parameters
    18.2. Section 7B: System Level 1 - SHIELD ONE Connector Impedance Parameters
    18.3. Section 7A: System Level 2 - SHIELD TWO Connector Impedance Parameters
19. Input File Section 8: Cable Shield Transfer Impedance Parameters
    19.1. Section 8B: System Level 1 - SHIELD ONE Transfer Impedance Parameters
    19.2. Section 8A: System Level 2 - SHIELD TWO Transfer Impedance Parameters
20. Input File Section 9: Cable Boundary Conditions
    20.1. Section 9C: System Level 0 - Wire BOUNDARY CONDICTIONS
    20.2. Section 9B: System Level 1 - SHIELD ONE BOUNDARY CONDICTIONS
    20.3. Section 9A: System Level 2 - SHIELD TWO BOUNDARY CONDICTIONS
21. Input File Section 10: Cable Reference / Ground Parameters
22. Input File Section 11: Output / PROBES

7.1 Input File Section 1: GENERAL

The general section contains only one possible first level keyword. This keyword is:

```
LOW FREQUENCY APPROXIMATION
```

This keyword is applicable only when MHARNESS is called from the software program EMA3D. When MHARNESS is used as a standalone program, this keyword is ignored. The `LOW FREQUENCY APPROXIMATION` is particularly applicable when modeling MHARNESS cables within a three-dimensional geometry that is being subjected to low frequency excitation, such as lightning.

When implementing the `LOW FREQUENCY APPROXIMATION` some keywords, if present within the MHARNESS input file are ignored. These keywords are listed below.

```
SHIELD TWO GLOBAL TRANSFER DIRECTION
SHIELD TWO TRANSFER DIRECTION
SHIELD ONE GLOBAL TRANSFER DIRECTION
SHIELD ONE TRANSFER DIRECTION
```

In addition, all shield transfer inductance values are set to zero and only resistive circuit terminations can be specified. This is acceptable in a low frequency limit.

The required input file text line format is:

```
!LOW FREQUENCY APPROXIMATION
```

7.2 Input File Section 2: TIME STEP

The time step can be manually assigned, or automatically computed by providing the highest frequency of interest. The time step is a global quantity that applies to the entire cable system. To insure numerical stability, the time step, Δt, and the smallest space step, Δx, for any segment, must satisfy the Courant condition:

$$\Delta t < \frac{\Delta x}{v}$$

where: Δx is the cell size (see Section 7.3), and
υ is the highest speed of signal propagation on the lines of the system.

Generally this is found to be satisfactory. However, there are times when the time step, so computed, does not satisfy the stability criterion, usually because of the time scale associated with the termination circuits. In such cases, a smaller time step is required.

There are two first level keywords associated with the time step input file section. These keywords are:

1) TIME STEP
2) MAGNETOSTATIC

7.2.1 The TIME STEP keyword

Following the time step keyword is a second level keyword. There are two possible second level keywords associated with this first level keyword. These second level keywords are:

- NOTCOMPUTE
- COMPUTE

NOTCOMPUTE

The NOTCOMPUTE keyword is used to specify the finite difference time step along with the total number of time steps desired for the simulation. The required input file text line format is:

```
!TIME STEP
!!NOTCOMPUTE
dt  itmax
```

where

dt:	is the finite difference time step
itmax:	is the total number of time iteration desired

COMPUTE

The `COMPUTE` keyword is used to compute the time step information and the total number of time step desired for the simulation. This is accomplished by supplying the final simulation time, the highest frequency of interest, and the desired number of finite difference cells required to resolve the highest frequency of interest. The required input file text line format is:

```
!TIME STEP
!!COMPUTE
time  frequency  ncells
```

where

`time`:	is the final simulation time
`frequency`:	is the highest frequency of interest
`ncells`:	is the desired number of finite difference cells required to resolve the highest frequency (shortest wavelength) of interest - (optional input, defaults to 10 cells)

Using the above variables, the values of `dt` and `itmax` are computed using the following equations:

$$dt = 0.95 / frequency / ncells$$
$$itmax = time / dt$$

7.2.2 The MAGNETOSTATIC keyword

For magnetostatic or quasi-magnetostatic configurations, the displacement current becomes small or negligible allowing the permittivity values of associated materials to be increased without significantly impacting cable electromagnetic behavior. Increasing the permittivity values enables an increase in the value of the time step. An increased time increment value can significantly reduce the number of time steps required to complete a temporal description.

Specification of magnetostatic time steps also requires the specification of constant time steps as discussed in Section 7.2.1. The constant time step specification defines the initial time step value and the computational time window. The magnetostatic time steps are specified in addition to the constant time step information. The magnetostatic time steps information specifies the manner in which the permittivity is to increase.

Magnetostatic time steps are realized by specifying a series of time and associated permittivity increase factors. The factors are all referenced with respect to the initial permittivity values assigned to each individual material (cable background and dielectric jackets). The time step increase factor is equal to the square root of the associated permittivity increase factor. For example, if the following magnetostatic information was provided:

$$t_0 \quad f_0$$
$$t_1 \quad f_1$$

$t_2 \quad f_2$

where t_n is the time for the permittivity to be increased by a factor of f_n over its initial value ε, then at time t_1 the permittivity would be specified to be increased to ($f_{1\times}\varepsilon$). Therefore, the associated time step value will have increased to ($dt\sqrt{f_1}$). At time t_2 the permittivity is specified to be increased by a factor of f_2, to the value of ($\varepsilon \times f_2$), thereby resulting in a time step increase of ($dt\sqrt{f_2}$). The method of increase is exponential, minimal at first and then exponentially increasing to achieve the specified value.

The first increase value, f_0 at time t_0, should always be assigned the value of 1.0. Therefore, the value t_0 specifies the time to begin the increase from 1.0 to the value f_1 at time t_1. If the first increase factor is not "1.0" an error message will be issued and the MHARNESS program terminated.

The required input file text line format is:

```
!MAGNETOSTATIC
t1 factor1
t2 factor2
.      .
.      .
.      .
tn factorn
```

where

`ti`	is the time to enact the permittivity increase given by `factori`
`factori`	is the permittivity increase factor

7.3 Input File Section 3: SPACE STEP

Each cable segment is assigned a finite difference space step (cell size). Ten cells per wavelength for the highest frequency (smallest wavelength) of interest is generally used as a guide for setting the spatial cell size. The space step can also be manually defined, or automatically computed from the time step value. The space steps can be different for different cable segments but are always constant within each particular segment. There are three possible formats for specifying the space step. The type of format depends on the number and type of variables following the first level `SPACE STEP` keyword.

If the second level `COMPUTE` keyword was specified under the first level `TIMESTEP` keyword (see Section 7.2.1), then a space step will be automatically computed and overwrite all specified space step information provided under the `SPACE STEP` keyword.

The three input file text line formats for specifying space steps are provided and described below.

Format 1

```
!SPACE STEP
dx
```

where

`dx`: is a real number containing the spatial cell size to be used for all segments

Format 2

```
!SPACE STEP
seg_id1  dx1
seg_id2  dx2
   .       .
   .       .
   .       .
seg_idn  dxn
```

where

seg_id_i: is an exposed segment name (exterior system level)
dx_i: is a real number containing the spatial cell size to be used for the segment seg_id_i

The cell size specified here is applied to the exterior system level. For three system levels this would be System Level 2. Therefore, if there are shields, the outer shield segment name is expected here. The same cell size is then assigned to all associated inferior system levels.

Format 3

```
!SPACE STEP
seg_id1  ncells1
seg_id2  ncells2
   .        .
   .        .
   .        .
seg_idn  ncellsn
```

where

`seg_id`$_i$: is an exposed segment name (exterior system level)
`ncells`$_i$: is an integer containing the number of cells for the segment identified

The number of cells specified here is applied to the exposed system level. For three system levels this would be System Level 2. Therefore, if there are shields, the outer shield segment name is expected here. The same cell size is then assigned to all associated inferior system levels.

7.4 Input File Section 4: EXCITATION/SOURCES

There are three first level keywords associated with cable excitation and sources. These keywords are listed below

1) `INPUT FORMAT`
2) `EXCITATION TYPE`
3) `SOURCE WAVEFORM`

7.4.1 The INPUT FORMAT keyword

The descriptor used along with this keyword determines whether the format of the source data file is text or binary. Text format is the default. Therefore, this keyword is necessary only if a binary format is present. The required input file text line format is:

```
!INPUT FORMAT
type
```

where

type: is the input format type, either "`TEXT`" or "`BINARY`"

7.4.2 The EXCITATION TYPE keyword

There are three second level keywords associated with the `EXCITATION TYPE` keyword. These are listed below.

`CABLE`:	Signifies excitation applied to System Level 0
`SHIELD ONE`	Signifies excitation applied to System Level 1
`SHIELD TWO`	Signifies excitation applied to System Level 2

These keywords specify at what cable system level the excitation is to be applied (System Level 2, System Level 1, or System Level 0).

There are eight third level keywords associated with the `EXCITATION TYPE` keyword. These are listed below.

- `PIN VOLTAGE DRIVE`
- `PLANE WAVE DRIVE`
- `LOCALIZED EFIELD DRIVE`
- `LOCALIZED CURRENT DRIVE`
- `SEGMENT EFIELD DRIVE`
- `SEGMENT CURRENT DRIVE`
- `GENERAL EFIELD DRIVE`

- GENERAL CURRENT DRIVE

The excitation of an MHARNESS cable system can be broadly classified as either local or global. The current sources and electric field sources can be locally defined to drive a single conductor at one point, a portion of a single conductor (wire or shield) within a particular cable segment, an entire conductor (wire or shield) within a particular cable segment, or all conductors within a cable segment. Current and electric field sources can also be defined globally to drive the entire cable harness system. Within a data file, multiple local current source waveforms or electric field source waveforms (often computed from another software program) can be easily defined to provide numerous unique local excitation drivers. This feature is often employed to simulate cable harness behavior in a complex three-dimensional external environment where fields and currents vary considerably over the physical extent of the harness.

Pin voltage drive, localized current drive, localized electric field drive, segment electric field drive, and segment current drive, are considered local excitation. Plane wave drive, generalized current drive, and generalized electric field drive, are considered global excitation.

For local excitation, pin voltage sources can be applied equally and simultaneously to any number of terminals. Other pin voltage sources can be applied to other sets of terminals. The ability to apply different sources to various locations is useful in the analysis of the differential modes in a system. Similarly, current sources or electric field sources, which are equivalent to voltage drivers using injection transformers, can be applied at any number of locations on any number of conductors.

All of these third level keywords, except for `PLANE WAVE DRIVE`, are discussed under the `SOURCE WAVEFORM` keyword that is discussed in Section 7.4.3. The exception is discussed here.

PLANE WAVE DRIVE

When using a plane wave source, the incident direction must be defined along with the electric field polarization direction. Two angles are used to specify the incident direction. These angles (θ,ϕ) are defined in Figure 7.4.2.1A. The variable, θ, is the incident direction polar angle and ϕ is the incident direction azimuthal angle. Like the incident vector, two angles are also used to specify the electric field polarization direction. These angles (α,β) are defined in Figure 7.4.2.1B. The variable, α, is the polarization direction polar angle and β is the polarization direction azimuthal angle. When using plane wave illumination, the source is properly time retarded at various locations on the system to produce realistic results.

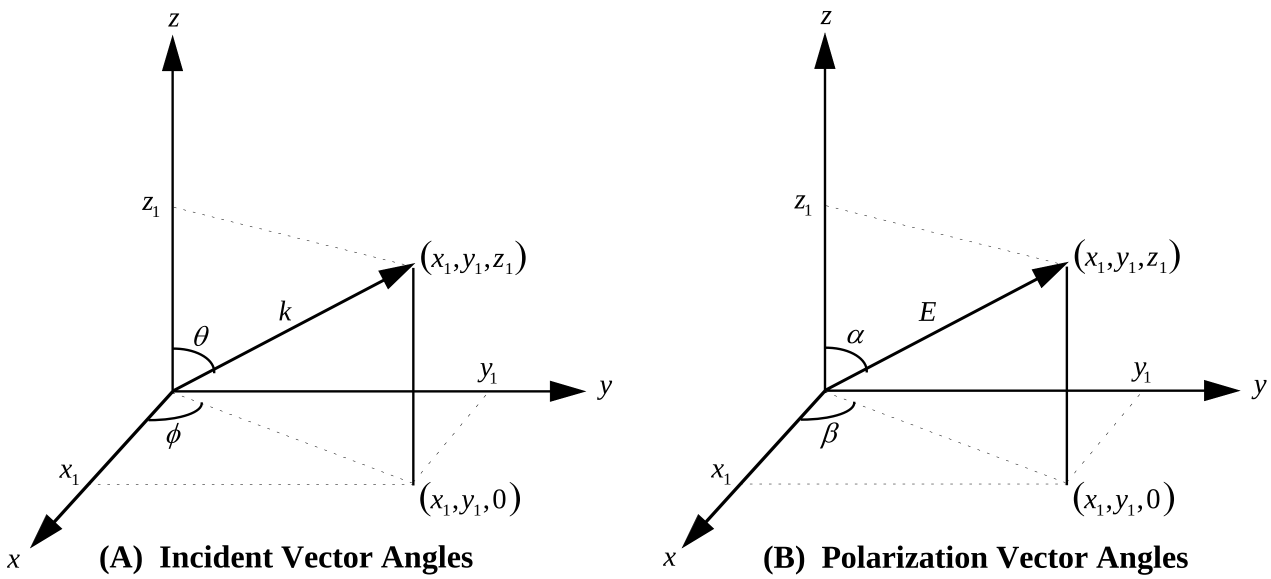


Figure 7.4.2.1 Plane Wave Descriptor Angles

There are two input file text line formats used to specify plane wave excitation. These formats depend upon the manner in which the MHARNESS cable segments and conductors were defined (see Section 7.5.1). When `PLANE WAVE DRIVE` is specified, <u>all</u> segments in the exposed system level must be specified with the `SEGMENT/SIMPLE` (with coordinate ends specified) combination pair or <u>all</u> segments in the exposed system level must be specified with the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` combination pair.

If a wire reference or ground is desired, then the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` combination pair must be used. Therefore, when the `SEGMENT/SIMPLE` combination pair is specified, the reference or ground is assumed to be a ground plane at the z-coordinate of, z=0.0.

<u>First Format</u>

The first input file format is necessary if the `SEGMENT/SIMPLE` (with coordinate ends specified), combination pair was used to define <u>all</u> cable segments in the exposed system level. In this case the transmission line impedance matrices for the exposed cables were manually defined and the associated reference (ground plane) information contained within the supplied matrix values. The height of the reference must therefore be provided. If System Level 2 were the exposed system level then the required input file text line format is shown below.

```
!EXCITATION TYPE
!!SHIELD TWO
!!!PLANE WAVE DRIVE
height  theta  phi  alpha  beta
```

where

`height`: is the height of the system above the ground plane
`theta`: is the incident (propagation) vector polar angle
`phi`: is the incident (propagation) vector azimuthal angle
`alpha`: is the electric field polarization vector polar angle
`beta`: is the electric field polarization vector azimuthal angle

Note: The height of the system above the ground plane is used in the computation of the reflected wave. If the `SEGMENT/SIMPLE` combination pair is specified, then for any cable containing multiple conductors, all conductors are assigned the same specified height above the ground plane. If the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` combination pair were used to define all cable segments in the exposed system level, in conjunction with the above `EXCITATION TYPE` format, then the z-coordinates of the conductors in the various segments (see Section 7.5.1) take precedence over the height specified here. The height parameter above is thus ignored.

Second Format

The second format is used if the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` combination pair was used to define all of the cable segments. For this case, all cable conductors and reference geometric information is defined and the height parameter is not necessary. The required input file text line format is shown below.

```
!EXCITATION TYPE
!!PLANE WAVE DRIVE
theta  phi  alpha  beta
```

where

`theta`: is the incident (propagation) vector polar angle
`phi`: is the incident (propagation) vector azimuthal angle
`alpha`: is the electric field polarization vector polar angle
`beta`: is the electric field polarization vector azimuthal angle

The file name containing the plane wave source is located under the `SOURCE WAVEFORM` keyword.

7.4.3 The SOURCE WAVEFORM keyword

There are two groupings of input file text lines under the first level `SOURCE WAVEFORM` keyword. The first group of lines is associated with the second level keyword under the `SOURCE WAVEFORM` keyword. This group of lines is used to specify source parameters. The second group of lines is dependent upon the third level keyword associated with the first level `EXCITATION TYPE` keyword. This group of lines is used to specify the location where the source is to be applied. The first group of lines is discussed in Section 7.4.3.1 and the second group of lines in Section 7.4.3.2.

7.4.3.1 SOURCE WAVEFORM Parameters

Source waveforms can be read in from a data file (text or binary) or automatically computed by selecting a pre-determined waveform type and supplying the defining parameters. There are ten second level keywords associated with the first level `SOURCE WAVEFORM` keyword. These are listed below:

- `DATAFILE`
- `GAUSSIAN`
- `DERIVATIVE OF GAUSSIAN`
- `DOUBLE EXPONENTIAL`
- `DERIVATIVE OF DOUBLE EXPONENTIAL`
- `SINE SQUARED LEADING DOUBLE EXP`
- `SINE`
- `SINE SQUARED`
- `LINEAR RAMP`
- `DAMPED SINUSOID`

These keywords are described in separate sections below in the order of appearance in the list above.

<u>DATAFILE</u>

This keyword it used if the source is to be read from a data file. The format of the data file, except for segment drive (EFIELD and CURRENT) and general drive (EFIELD and CURRENT) is

$$\begin{array}{cc} time_1 & amplitude_1 \\ time_2 & amplitude_2 \\ . & . \\ . & . \\ . & . \\ time_n & amplitude_n \end{array}$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!DATAFILE
source_file_name
```

where

`source_file_name:` is time domain waveform data file name

GAUSSIAN

This keyword is used if the source is to be a Gaussian waveform that is mathematically defined by the equation below.

$$f(t) = A * e^{-((t-t_p)/w)^2}$$

where A: is the amplitude
t_p: is the time to peak
w: is the width at half peak

The required input file text line format is:

```
!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
```

where

`amp`: is the amplitude, A
`time_to_peak`: is the time to peak, t_p
`width`: is the width at half peak, w

DERIVATIVE OF GAUSSIAN

This keyword is used if the source is to be the derivative of a Gaussian waveform that is mathematically defined by the equation below.

$$f(t) = \frac{d(A * e^{-((t-t_p)/w)^2})}{dt}$$

where A: is the amplitude
t_p: is the time to peak
w: is the width at half peak

The required input file text line format is:

```
!SOURCE WAVEFORM
!!DERIVATIVE OF GAUSSIAN
amp  time_to_peak  width
```

where

`amp`: is the amplitude, A
`time_to_peak`: is the time to peak, t_p
`width`: is the width at half peak, w

DOUBLE EXPONENTIAL

This keyword is used if the source is to be a double exponential waveform that is mathematically defined below.

$$f(t) = amp^{*}\left(\exp\left(-salpha^{*}t\right) - \exp\left(-sbeta^{*}t\right)\right)$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!DOUBLE EXPONENTIAL
amp  salpha  sbeta
```

where

`amp`:	is the amplitude
`salpha:`	is the first exponential factor
`sbeta:`	is the second exponential factor

Note: `amp` is not really an amplitude in the traditional sense. Assigning the `amp` variable a value of "1.0" will not yield a double exponential waveform with an amplitude of 1.0 but a waveform with an amplitude somewhat less than 1.0.

DERIVATIVE OF DOUBLE EXPONENTIAL

This keyword is used if the source is to be the derivative of a double exponential that is mathematically defined below.

$$f(t) = (d/dt)\left[amp^{*}\left(\exp\left(-salpha^{*}t\right) - \exp\left(-sbeta^{*}t\right)\right)\right]$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!DERIVATIVE OF DBL EXP
amp  salpha  sbeta
```

where

`amp`:	is the amplitude
`salpha:`	is the first exponential factor
`sbeta:`	is the second exponential factor

Note: See the note above for the double exponential waveform

SINE SQUARED LEADING DOUBLE EXPONENTIAL

This keyword is used if the source is to be a double exponential waveform with a sine squared leading front edge. The associated mathematical expression is defined below.

$$f(t) = amp^{*}\left[\sin\left((t/t_{p}) * (\pi/2.0)\right)\right]^{2} \qquad 0.0 \le t \le t_{p}$$
$$f(t) = amp^{*}\left(\exp(-salpha * t) - \exp(-sbeta * t)\right) \qquad t_{p} \le t$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!SIN SQU LEADING DBL EXP
amp  salpha  sbeta
```

where

`amp`: is the amplitude
`salpha:` is the first exponential factor
`sbeta:` is the second exponential factor

Note: See the note above for the double exponential waveform

SINE

This keyword is used if the source is to be a sine wave that is mathematically defined below.

$$f(t) = amp * \sin(2.0 * \pi * frequency * t)$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!SINE
amp  salpha  sbeta
```

where

`amp`: is the amplitude
`frequency`: is the frequency of the sine wave

SINE SQUARED

The sine squared waveform is defined to be nonzero only over the first half period of the CW sine wave. Use this keyword if the source is to be a sine squared waveform that is mathematically defined below.

$$f(t) = amp\left[\sin(\pi * frequency * t)\right]^{2} \qquad 0..0 \le (2.0 * frequency)^{-1}$$

$$= 0.0 \qquad \text{otherwise}$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!SINE SQUARED
amp  salpha  sbeta
```

where

`amp`: is the amplitude
`frequency`: is the frequency of the sine wave

LINEAR RAMP

This keyword is used if the source is to be a linear ramp that is mathematically defined below.

$$f(t) = amp * t / time\_to\_peak \qquad 0.0 < t \le time\_to\_peak$$

$$= amp \qquad t > time\_to\_peak$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!LINEAR RAMP
amp  time_to_peak
```

where

`amp`: is the amplitude
`time_to_peak`: is the time to peak

DAMPED SINUSOID

This keyword is used if the source is to be a damped sinusoid that is mathematically defined below.

$$f(t) = amp^{*} \exp(-salpha^{*} t)^{*} \sin(2^{*} \pi^{*} frequency^{*} t)$$

The required input file text line format is:

```
!SOURCE WAVEFORM
!!DAMPED SINUSOID
amp  salpha frequency
```

where

amp:	is the amplitude
salpha:	is the exponential factor
frequency:	is the frequency of the sine wave

7.4.3.1 SOURCE WAVEFORM Application Location

The second group of input file text lines is used to specify the SOURCE WAVEFORM application location. The format of the input file text lines is dependent upon the third level keyword under the EXCITATION TYPE keyword. The third level EXCITATION TYPE keywords are provided below.

- PIN VOLTAGE DRIVE
- PLANE WAVE DRIVE
- LOCALIZED EFIELD DRIVE
- LOCALIZED CURRENT DRIVE
- SEGMENT EFIELD DRIVE
- SEGMENT CURRENT DRIVE
- GENERAL EFIELD DRIVE
- GENERAL CURRENT DRIVE

PIN VOLTAGE DRIVE

If this third level keyword was used under the first level EXCITATION TYPE keyword, with a second level keyword of SHIELD TWO, and if a GAUSSIAN SOURCE was specified, then the required input file text line format, including that of the EXCITATION TYPE keyword group, is:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!PIN VOLTAGE DRIVE

!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
seg_id  cond_id  end#
```

where

seg_id	is the segment name
cond_id	is the conductor name within the segment
end#	is the segment end number (1 or 2)

PLANE WAVE DRIVE

The format of the `PLANE WAVE DRIVE` keyword group was discussed previously in Section 7.4.2. To reiterate, if this third level keyword was used under the first level `EXCITATION TYPE` keyword, with a second level keyword of `SHIELD TWO`, and if a `GAUSSIAN SOURCE` was specified, then the required input file text line format, including that of the `EXCITATION TYPE` keyword group, is:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!PLANE WAVE DRIVE
height  theta  phi  alpha  beta

!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
```

LOCALIZED EFIELD DRIVE

If this third level keyword was used under the first level `EXCITATION TYPE` keyword, with a second level keyword of `SHIELD TWO`, and if a `GAUSSIAN SOURCE` was specified, then the required input file text line format, including that of the `EXCITATION TYPE` keyword group, is:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!LOCALIZED EFIELD DRIVE

!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
seg_id  cond_id  loc1
```

or

```
!EXCITATION TYPE
!!SHIELD TWO
!!!LOCALIZED EFIELD DRIVE

!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
seg_id  cond_id  loc1  loc2
```

where

`seg_id`		is the segment name
`cond_id`		is the conductor name within the segment
`loc1`:	*int*	is the source start point, in number of cells from the start end of the segment
	real	is the distance of source start point from the start end of the segment

`loc2`: *int* is the source end point, in number of cells from the start end of the segment
real is the distance of source end point from the start end of the segment

<u>Note 1</u>: the interpretation of the "`loc1`" and "`loc2`" keyword descriptors depends upon whether these are integers or real numbers as indicated above. Real numbers are identified by the presence of a decimal point.

<u>Note 2</u>: The localized electric field source drives all cells between `loc1` and `loc2` on the particular conductor specified. If `loc2` is not specified, the source is applied to one cell only, with index specified by the *integer*, "`loc1`", or the cell containing the *real* point, "`loc1`".

LOCALIZED CURRENT DRIVE

If this third level keyword was used under the first level `EXCITATION TYPE` keyword, with a second level keyword of `SHIELD TWO`, and if a `GAUSSIAN SOURCE` was specified, then the required input file text line format, including that of the `EXCITATION TYPE` keyword group, is:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!LOCALIZED CURRENT DRIVE

!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
seg_id  cond_id  loc1
```

or

```
!EXCITATION TYPE
!!SHIELD TWO
!!!LOCALIZED CURRENT DRIVE

!SOURCE WAVEFORM
!!GAUSSIAN
amp  time_to_peak  width
seg_id  cond_id  loc1  loc2
```

where

`seg_id` is the segment name
`cond_id` is the conductor name within the segment
`loc1`: *int* is the source start point, in number of cells from the start end of the segment
real is the distance of source start point from the start end of the segment
`loc2`: *int* is the source end point, in number of cells from the start end of the segment
real is the distance of source end point from the start end of the segment

Note 1: the interpretation of the "loc1" and "loc2" keyword descriptors depends upon whether these are integers or real numbers as indicated above. Real numbers are identified by the presence of a decimal point.

Note 2: The localized current source drives all cells between loc1 and loc2 on the particular conductor specified. If loc2 is not specified, the source is applied to one cell only with index specified by the *integer*, "loc1", or the cell containing the *real* point, "loc1".

SEGMENT EFIELD DRIVE

This third level keyword is used to define electric field sources applied to an entire MHARNESS segment. If this keyword was used under the first level EXCITATION TYPE keyword, with a second level keyword of SHIELD TWO, and if the sources were read in from a data file, then there are two possible input file text line formats. Including the EXCITATION TYPE keyword group, these two formats are:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!SEGMENT EFIELD DRIVE

!SOURCE WAVEFORM
!!DATAFILE
source_file_name
seg_id
```

or

```
!EXCITATION TYPE
!!SHIELD TWO
!!!SEGMENT EFIELD DRIVE

!SOURCE WAVEFORM
!!DATAFILE
source_file_name
seg_id  cond_id
```

where

seg_id	is the segment name
cond_id	is the conductor name within the segment

The format of the associated data source file depends on the particular input format used. In the first case only the seg_id was specified and the format of the data source file is:

N_d
time S_{11} S_{12} S_{13} … S_{1n} S_{21} S_{22} S_{23} … S_{2n} S_{31} S_{32} S_{33} … S_{3n} … S_{n1} S_{n2} S_{n3} … S_{nn}

where: N_d: is the number of data entries in the data records that follow ($N_d = n^2+1$)

time: is the time associated with the data entries
S_{ij}: is the driving source data entries for the *jth* cell of conductor *i* of `seg_id`

In the second case both the `seg_id` and the `cond_id` are specified and the format of the data source file is:

N_d
$time_1$ S_{11} S_{12} S_{13} … S_{1n}
$time_2$ S_{21} S_{22} S_{23} … S_{2n}
$time_3$ S_{31} S_{32} S_{33} … S_{3n}
. . . . .
. . . . .
. . . . .
$time_n$ S_{n1} S_{n2} S_{n3} … S_{nn}

where: N_d: is the number of data entries in the data records that follow (N_d = n+1),
$time_i$: is the time associated with the data entries for conductor *i*, and
S_{ij}: is the driving source data entries for the *jth* cell of conductor *i* of `seg_id`

SEGMENT CURRENT DRIVE

This third level keyword is used to define current sources applied to an entire MHARNESS segment. If this keyword was used under the first level `EXCITATION TYPE` keyword, with a second level keyword of `SHIELD TWO`, and if the sources were read in from a data file, then there are two possible input file text line formats. Including the `EXCITATION TYPE` keyword group, these two formats are:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!SEGMENT CURRENT DRIVE

!SOURCE WAVEFORM
!!DATAFILE
source_file_name
seg_id
```

or

```
!EXCITATION TYPE
!!SHIELD TWO
!!!SEGMENT CURRENT DRIVE

!SOURCE WAVEFORM
!!DATAFILE
source_file_name
seg_id  cond_id
```

where

`seg_id` is the segment name
`cond_id` is the conductor name within the segment

The format of the associated data source file depends the particular input format used. In the first case only the `seg_id` was specified and the format of the data source file is:

N_d
time S_{11} S_{12} S_{13} … S_{1n} S_{21} S_{22} S_{23} … S_{2n} S_{31} S_{32} S_{33} … S_{3n} … S_{n1} S_{n2} S_{n3} … S_{nn}

where: N_d: is the number of data entries in the data records that follow ($N_d = n^2+1$)
time: is the time associated with the data entries
S_{ij}: is the driving source data entries for the *jth* cell of conductor *i* of `seg_id`

In the second case both the `seg_id` and the `cond_id` are specified and the format of the data source file is:

N_d
$time_1$ S_{11} S_{12} S_{13} … S_{1n}
$time_2$ S_{21} S_{22} S_{23} … S_{2n}
$time_3$ S_{31} S_{32} S_{33} … S_{3n}
. . . . .
. . . . .
. . . . .
$time_n$ S_{n1} S_{n2} S_{n3} … S_{nn}

where: N_d: is the number of data entries in the data records that follow ($N_d = n+1$),
$time_i$: is the time associated with the data entries for conductor *i*, and
S_{ij}: is the driving source data entries for the *jth* cell of conductor *i* of `seg_id`

GENERAL EFIELD DRIVE

This third level keyword is used to define electric field sources applied to the entire cable harness system. This particular source was implemented to provide an interface or method of communication with other software programs. If all of the electric fields along the cable harness, computed from some other simulation software, were recorded, then these could be used to provide detailed sources to drive the cable harness.

If this third level keyword was used under the first level `EXCITATION TYPE` keyword, with a second level keyword of `SHIELD TWO`, then including the `EXCITATION TYPE` keyword group, the required input file text line format is:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!GENERAL EFIELD DRIVE

!SOURCE WAVEFORM
!!DATAFILE
```

```
source_file_name
```

A source data file must be provided with `GENERAL EFIELD DRIVE`. The entries within the data file must be in matrix form as describe below.

N_d
time $(((S_E(i,j,k), i=1,ncell(k)), j=1,ncond(k)), k=1,nseg)$

where: N_d is the number of data entries or fields in the data records that follow
time is the time associated with the data entries
S_E is the driving source data entries
ncell(k) is the number of cells associated with segment k
ncond(k) is the number of conductors in segment k

Note: the order of the entries within the data file should correspond to the order of appearance of the segments and conductors as listed in the MHARNESS input file.

GENERAL CURRENT DRIVE

This third level keyword is used to define current sources applied to the entire cable harness system. This particular source was implemented to provide an interface or method of communication with other software programs. If all of the currents along a conductor representing the cable harness were recorded, computed from some other simulation software, then these could be used to provide detailed sources to drive the cable harness.

If this third level keyword was used under the first level `EXCITATION TYPE` keyword, with a second level keyword of `SHIELD TWO`, then including the `EXCITATION TYPE` keyword group, the required input file text line format is:

```
!EXCITATION TYPE
!!SHIELD TWO
!!!GENERAL CURRENT DRIVE

!SOURCE WAVEFORM
!!DATAFILE
source_file_name
```

A source data file must be provided with `GENERAL CURRENT DRIVE`. The entries within the data file must be in matrix form as describe below.

N_d
time $(((S_E(i,j,k),i=1,ncell(k)), j=1,ncond(k)), k=1,nseg)$

where: N_d is the number of data entries or fields in the data records that follow
time is the time associated with the data entries
S_E is the driving source data entries
ncell(k) is the number of cells associated with segment k

ncond(k) is the number of conductors in segment k

Note: the order of the entries within the data file should correspond to the order of appearance of the segments and conductors as listed in the MHARNESS input file.

7.5 Input File Section 5: Cable Conductor Topology

The terminology used for MHARNESS cable topology was discussed thoroughly in Chapter 4. This section contains input file descriptions on how to define the MHARNESS cable system.

The MHARNESS input file specifications for the cable topology parameters associated with the three system levels (see Section 4.1) are discussed in separate sections below. The input file descriptions for System Level 0 (input file Section 5C) are presented first followed by those for System Level 1 (input file Section 5B), and then System Level 2 (input file Section 5A).

7.5.1 Section 5C: System Level 0 – Wire Topology

There are two first level keywords associated with System Level 0 wire topology. These keywords are:

- `SEGMENT`
- `JUNCTION AND NODE`

The first keyword is used to define MHARNESS cable segments (see Section 4.1). The second keyword is used to define the cable junction and nodes (see Section 4.2). These topics are discuused in the sections to follow.

7.5.1.1 The `SEGMENT` Keyword

There are three second level keywords associated with the `SEGMENT` keyword. These are listed below:

```
SIMPLE
COMPLEX
COMPLEX2
```

The `SIMPLE` keyword is used if the impedance parameters/matrices are to be provided manually. In this case, the cross-sectional geometry need not be supplied since it is inherent within the impedance information. The `COMPLEX` or `COMPLEX2` keywords are required if the impedance parameters/matrices are to be automatically computed, if radiated fields are to be recorded, or in some cases, if plane wave excitation is specified. The use of these keywords are discussed below.

SIMPLE

There are three possible formats for defining a simple segment. These formats are listed below.

1) Length specified
2) Coordinate ends specified
3) Descriptors exist in higher system level

1) Length specified

The length specified format can be used if the three-dimensional cross-sectional geometry does not need to be provided. This is the case if there is no plane wave excitation, if radiated fields are not to be computed, or if the impedance parameters/matrices are to be manually defined (see Section 7.6). The cross-sectional geometry is then implicit within the impedance information. The required input file text line format is:

```
!SEGMENT
!!SIMPLE
seg_id  bjunc_id  ejunc_id  length
cond_id1
cond_id2
    .
    .
    .
cond_idn
```

where

`seg_id`:	is the segment name
`bjunc_id`:	is the junction name of end_1 of the segment, set this value to zero if there is a circuit termination
`ejunc_id`:	is the junction name of end_2 of the segment, set this value to zero if there is a circuit termination
`length`:	is the length of the segment
$cond\_id_1$	is the first conductor name within the segment
$cond\_id_2$	is the second conductor name within the segment
$cond\_id_n$	is the *nth* conductor name within the segment

Note 1: The keyword descriptors in the above input file text lines under the "`SIMPLE`" second level keyword may be repeated in the same format with the second segment and associated conductors.

Note 2: The ordering of the conductors has a one-to-one relationship with the impedance matrices (see Section 7.6). The first conductor listed is assumed to be associated with the (1,1) element of the matrices, the second with the (2,2) element, and so on.

Note 3: The length may be slightly altered to equal an integral number of specified mesh cells (see Section 7.3).

2) `SIMPLE` - Coordinate ends specified

This format should be used if plane wave excitation is specified, the impedance parameters/matrices are to be provided manually, and the cable system exists over a ground plane. The z-coordinate of the conductors is then provided by the `height` parameter within the plane wave excitation specification (see Section 7.4). The x and y-coordinate information is required to define the cable conductor orientation with respect to the incident and polarization parameters of the plane wave. The required input file text line format is:

```
!SEGMENT
!!SIMPLE
seg_id  bjunc_id  ejunc_id  X1  y1  x2  y2
cond_id1
cond_id2
    .
    .
    .
cond_idn
```

where

seg_id:	is the segment name
bjunc_id:	is the junction name of end_1 of the segment, set this value to zero if there is a circuit termination
ejunc_id:	is the junction name of end_2 of the segment, set this value to zero if there is a circuit termination
X1:	is the x-coordinate of end_1
y1:	is the y-coordinate of end_1
X2:	is the x-coordinate of end_2
y2:	is the y-coordinate of end_2
$cond\_id_1$	is the first conductor name within the segment
$cond\_id_2$	is the second conductor name within the segment
$cond\_id_n$	is the *nth* conductor name within the segment

Note1: The keyword descriptors in the above input file text lines under the "SIMPLE" second level keyword may be repeated in the same format with the second segment and associated conductors.

Note2: The ordering of the conductors has a one-to-one relationship with the impedance matrices (see Section 7.6). The first conductor listed is assumed to be associated with the (1,1) element of the matrices, the second with the (2,2) element, and so on.

Note 3: The length and coordinates may be slightly altered to equal an integral number of specified mesh cells (see Section 7.3). However, the angle of the segment will remain unaltered.

3) SIMPLE - Descriptors exist in higher system level

This format can be used when the geometric descriptors exist in an associated higher system level and the impedance parameters/matrices for System Level 0 are to be provided manually. The required input file text line format is:

```
!SEGMENT
!!SIMPLE
seg_id  bjunc_id  ejunc_id
cond_id1
```

```
cond_id2
     .
     .
     .
cond_idn
```

where

seg_id:	is the segment name
bjunc_id:	is the junction name of end_1 of the segment, set this value to zero if there is a circuit termination
ejunc_id:	is the junction name of end_2 of the segment, set this value to zero if there is a circuit termination
$cond\_id_1$	is the first conductor name within the segment
$cond\_id_2$	is the second conductor name within the segment
$cond\_id_n$	is the *nth* conductor name within the segment

Note 1: The keyword descriptors in the above input file text lines under the "SIMPLE" second level keyword may be repeated in the same format with the second segment and associated conductors.

Note 2 The ordering of the conductors has a one-to-one relationship with the impedance matrices (see Section 7.6). The first conductor listed is assumed to be associated with the (1,1) element of the matrices, the second with the (2,2) element, and so on.

COMPLEX

When the COMPLEX keyword is specified, the Cartesian coordinate ends of each conductor must be specified. Since the conductor is always considered parallel to the xy-plane, only one z-coordinate is to be provided. The required input file text line format is:

```
!SEGMENT
!!COMPLEX
seg_id bjunc_id ejunc_id
cond_id1, x11, y11, z11, x12, y12
cond_id2, x21, y21, z21, x22, y22
   .       .     .    .    .    .
   .       .     .    .    .    .
   .       .     .    .    .    .
cond_idn, xn1, yn1, zn1, xn2, yn2
```

where

seg_id:	is the segment name
bjunc_id:	is the junction name of end_1 of the segment, set this value to zero if there is a circuit termination
ejunc_id:	is the junction name of end_2 of the segment, set this value to zero if there is a circuit termination
$cond\_id_1$	is the first conductor name within the segment

X_{11}:	is the x-coordinate of end_1 of conductor 1
Y_{11}:	is the y-coordinate of end_1 of conductor 1
Z_{11}:	is the z-coordinate of end_1 of conductor 1
X_{12}:	is the x-coordinate of end_2 of conductor 1
Y_{12}:	is the y-coordinate of end_2 of conductor 1
$cond\_id_2$	is the second conductor name within the segment
X_{21}:	is the x-coordinate of end_1 of conductor 2
Y_{21}:	is the y-coordinate of end_1 of conductor 2
Z_{21}:	is the z-coordinate of end_1 of conductor 2
X_{22}:	is the x-coordinate of end_2 of conductor 2
Y_{22}:	is the y-coordinate of end_2 of conductor 2
$cond\_id_n$	is the *nth* conductor name within the segment
X_{n1}:	is the x-coordinate of end_1 of conductor n
Y_{n1}:	is the y-coordinate of end_1 of conductor n
Z_{n1}:	is the z-coordinate of end_1 of conductor n
X_{n2}:	is the x-coordinate of end_2 of conductor n
Y_{n2}:	is the y-coordinate of end_2 of conductor n

Note 1: The keyword descriptors in the above input file text lines under the "COMPLEX" second level keyword may be repeated in the same format with the second segment and associated conductors.

Note 2 The ordering of the conductors has a one-to-one relationship with the impedance matrices (see Section 7.6). The first conductor listed is assumed to be associated with the (1,1) element of the matrices, the second with the (2,2) element, and so on.

Note 3: The length and coordinates may be slightly altered to equal an integral number of specified mesh cells (see Section 7.3). However, the angle of the segment will remain unaltered.

COMPLEX2

The COMPLEX2 keyword is used when a reference line description of a cable segment is to be specified. This reference line provides the orientation of the cable segment. All conductors are then considered parallel to this line. To specify the reference line, the Cartesian coordinates of the beginning (end_1) must be provided. The far end of the line (end_2) may be defined using Cartesian or polar coordinates. If Cartesian coordinates are specified, then the x and y coordinates of the far end of the line are to be provided. If polar coordinates are specified, then the length of the line and the angle the line makes with the x-axis are to be provided. Since the conductor is always considered parallel to the xy-plane, only one z-coordinate is to be provided.

When using the COMPLEX2 keyword all conductors are considered initially parallel to the x-axis. The beginning (end_1) coordinates points can then be defined accordingly. These conductors will then be rotated to be oriented parallel to the reference line. If a Cartesian coordinate system is used to define the reference line then the required input file test line format is:

```
!SEGMENT
!!COMPLEX2
seg_id bjunc_id ejunc_id Ref_Def
```

```
xR1, yR1, zR1, xR2, yR2
cond_id1, x1, y1, z1
cond_id2, x2, y2, z2
   .        .    .   .
   .        .    .   .
   .        .    .   .
cond_idn, xn, yn, zn
```

where

seg_id:	is the segment name
bjunc_id:	is the junction name of end_1 of the segment, set this value to zero if there is a circuit termination
ejunc_id:	is the junction name of end_2 of the segment, set this value to zero if there is a circuit termination
Ref_Def	is the coordinate definition of the reference line = CARTESIAN
X_{R1}:	is the x-coordinate of end_1 of the reference line
Y_{R1}:	is the y-coordinate of end_1 of the reference line
Z_{R1}:	is the z-coordinate of end_1 of the reference line
X_{R2}:	is the x-coordinate of end_2 of the reference line
Y_{R2}:	is the y-coordinate of end_2 of the reference line
$cond\_id_1$	is the first conductor name within the segment
X_1:	is the x-coordinate of end_1 of conductor 1
Y_1:	is the y-coordinate of end_1 of conductor 1
Z_1:	is the z-coordinate of end_1 of conductor 1
$cond\_id_2$	is the second conductor name within the segment
X_2:	is the x-coordinate of end_1 of conductor 2
Y_2:	is the y-coordinate of end_1 of conductor 2
Z_2:	is the z-coordinate of end_1 of conductor 2
$cond\_id_n$	is the *nth* conductor name within the segment
X_n:	is the x-coordinate of end_1 of conductor n
Y_n:	is the y-coordinate of end_1 of conductor n
Z_n:	is the z-coordinate of end_1 of conductor n

If a polar coordinate system is used to define the reference line then the required input file text line format is:

```
!SEGMENT
!!COMPLEX2
seg_id bjunc_id ejunc_id Ref_Def
xR1, yR1, zR1, L, Ang
cond_id1, x1, y1, z1
cond_id2, x2, y2, z2
   .        .    .   .
   .        .    .   .
   .        .    .   .
cond_idn, xn, yn, zn
```

where

`seg_id`: is the segment name
`bjunc_id`: is the junction name of end_1 of the segment, set this value to zero if there is a circuit termination
`ejunc_id`: is the junction name of end_2 of the segment, set this value to zero if there is a circuit termination
`Ref_Def` is the coordinate definition of the reference line = `POLAR`
X_{R1}: is the x-coordinate of end_1 of the reference line
Y_{R1}: is the y-coordinate of end_1 of the reference line
Z_{R1}: is the z-coordinate of end_1 of the reference line
`L`: is the length of the reference line
`Ang`: is the angle of the reference line to the x-axis
$cond\_id_1$ is the first conductor name within the segment
X_1: is the x-coordinate of end_1 of conductor 1
Y_1: is the y-coordinate of end_1 of conductor 1
Z_1: is the z-coordinate of end_1 of conductor 1
$cond\_id_2$ is the second conductor name within the segment
X_2: is the x-coordinate of end_1 of conductor 2
Y_2: is the y-coordinate of end_1 of conductor 2
Z_2: is the z-coordinate of end_1 of conductor 2
$cond\_id_n$ is the *nth* conductor name within the segment
X_n: is the x-coordinate of end_1 of conductor n
Y_n: is the y-coordinate of end_1 of conductor n
Z_n: is the z-coordinate of end_1 of conductor n

Note 1: The keyword descriptors in the above input file text lines under the "`COMPLEX2`" second level keyword may be repeated in the same format with the second segment and associated conductors.

Note 2: The ordering of the conductors has a one-to-one relationship with the impedance matrices (see Section 7.6). The first conductor listed is assumed to be associated with the (1,1) element of the matrices, the second with the (2,2) element, and so on.

Note 3: The length and coordinates may be slightly altered to equal an integral number of specified mesh cells (see Section 7.3). However, the angle of the segment will remain unaltered.

7.5.1.2 JUNCTION AND NODE

This keyword is the least flexible of all the keywords used. Each occurrence of this keyword is assumed to specify one and only one junction. Therefore, the number of occurrences of this keyword should be exactly equal to the number of junctions in the system. The required input file text line format is:

!JUNCTION AND NODE
junc_id
node_id
seg_id_1 $cond\_id_1$
seg_id_2 $cond\_id_2$

```
    .        .
    .        .
    .        .
seg_idn   cond_idn
```

where

junc_id:	is the junction name
$node\_id_i$:	is the name of the *ith* node in junction junc_id
seg_id_{ij}:	is the name of the *jth* segment containing cond_id
$cond\_id_{ij}$:	is the name of the *jth* conductor attached to the *ith* node of junc_id

Note 1: Since a node defines the joining of at least two conductors, there should be at least two sets of the (seg_id cond_id) descriptor pair following each node_id designation.

Note 2: The keyword descriptors in the above input file text lines under the "junc_id" keyword descriptor may be repeated in the same format with the second node and associated segments and conductors.

7.5.2 Section 5B: System Level 1 – SHIELD ONE Topology

The format of the input file text line used to specify System Level 1 (Shield One) topology is identical to that used for System Level 0. The only difference is in first level keywords which are preceded by the "SHIELD ONE" characters as illustrated below.

SEGMENT	replaced by	SHIELD ONE SEGMENT
JUNCTION AND NODE	replaced by	SHIELD ONE JUNCTION AND NODE

7.5.3 Section 5C: System Level 2 – SHIELD TWO Topology

The format of the input file text lines used to specify System Level 2 (Shield Two) topology is identical to that used for System Level 0. The only difference is in first level keywords which are preceded by the "SHIELD TWO" characters as illustrated below.

SEGMENT	replaced by	SHIELD TWO SEGMENT
JUNCTION AND NODE	replaced by	SHIELD TWO JUNCTION AND NODE

7.6 Input File Section 6: Cable Impedance Parameters

In the transmission line formalism, the interaction between various conductors in a segment, or cable branch, is characterized by cable impedance matrices. The impedance matrices, identified by the symbols **C**, **L**, **R**, and **G** in Chapter 2 define the relationship between the various conductors and shields within a cable segment of an MHARNESS cable system, incorporating the effects of the surrounding media. The symbol **C** stands for the capacitance matrix, **L** for the inductance matrix, **R** for the resistance matrix, and **G** for the conductance matrix. The presence of a conductance matrix allows the cable conductors to be immersed in a variety of lossy media. In MHARNESS the impedance matrices are all time independent.

For a single conductor each impedance matrix consists of a single real number. For a line with n conductors, the impedances are n x n matrices. The matrices can be sparse or densely populated depending on how the conductors interact. The capacitance, inductance, and conductance matrices can all be full, whereas the resistance matrix is diagonal. The matrices define the interaction between wires and shields within a single cable harness branch only. In MHARNESS, there is no interaction between branches except for the conservation of charge at the junction between adjoining branches.

The impedance matrices can be manually defined or automatically computed by MHARNESS. When manually defining impedance parameters, all values are understood to be per unit length. For automatic computation, the cross-sectional geometry must be accurately supplied. This requires the use of the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` input file keyword combination pair (see Section 7.5).

The capacitance matrix that is automatically computed by MHARNESS assumes coupling between <u>all</u> conductors in a segment. Therefore, the block diagonal capacitance matrix, such as that shown for the inner most conductors in Figure 4.3.2A, has to be assembled manually. However, the 5 x 5 and 3 x 3 matrix blocks within this 8 x 8 matrix can be computed automatically and then used in the manual assembly of the 8 x 8 matrix.

Since the segments are uniform, the cross-sectional geometry is constant throughout the entire length of a segment. This however, may not accurately reflect reality. Measured values, manually supplied, might be the most accurate. This could be accomplished by measuring the capacitance values and the speed of propagation.

The resistance matrix is independent of the capacitance, the inductance, and the conductance matrix values. However, the values within these latter three matrices are interdependent. The values within these three matrices must meet certain criteria to maintain the assumptions required for transmission line formalism. A flow chart is provided in Figure 7.6.1 that portrays the interdependency and relationship between these three matrices. This involves matrix specifications and the omission of such. The definition of impedance matrices within MHARNESS begin with the capacitance matrix. A capacitance matrix must be provided, or be specified for automatic computation, for each cable segment or an error will result and MHARNESS will terminate as indicated in the figure.

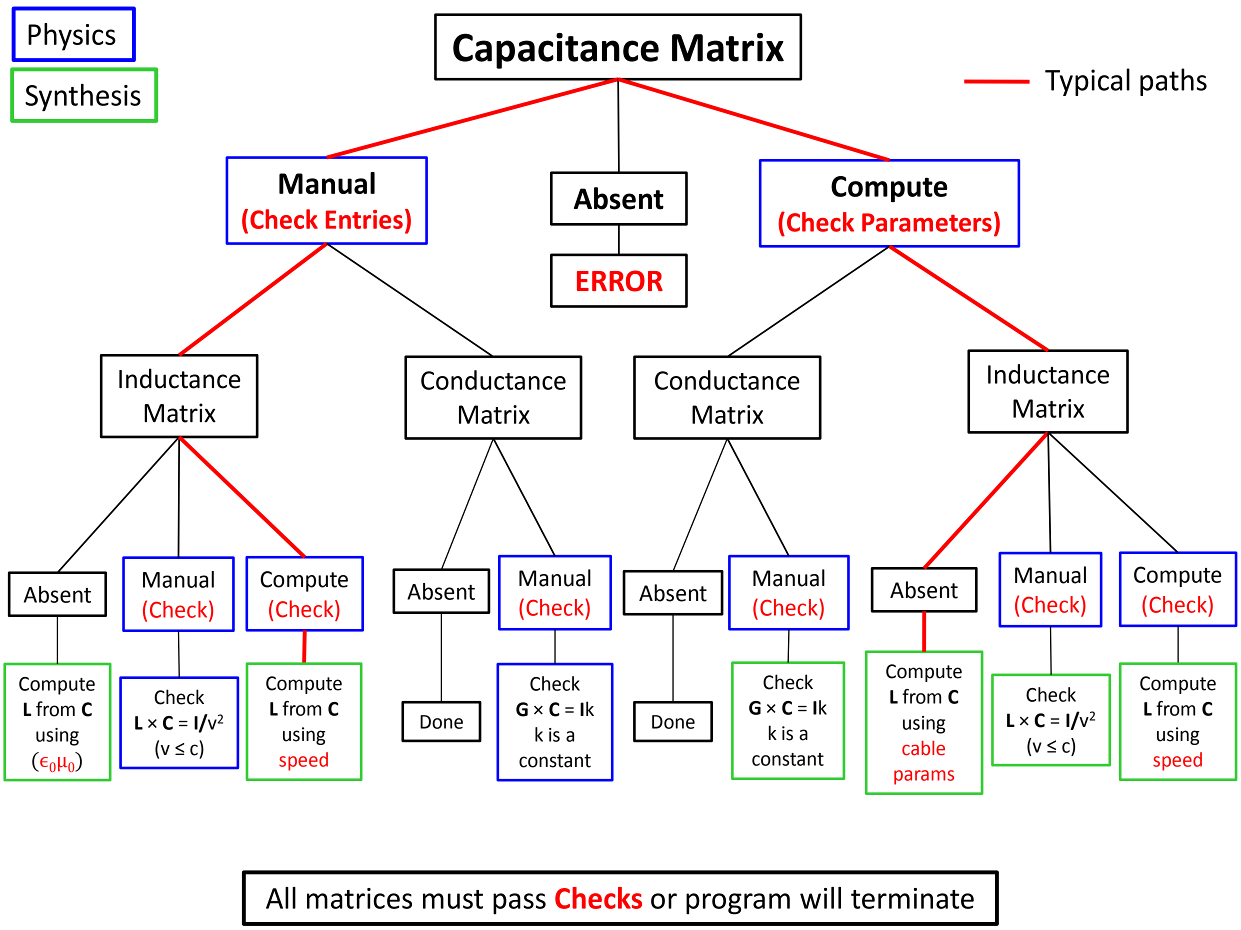


Figure 7.6.1 Impedance Matrix Interdependency and Physics Checks

The capacitance matrix can be manually defined or automatically computed. If the capacitance matrix is manually defined, then the matrix entries are checked for physical acceptability. If the matrix passes this test, then the associated inductance matrix and conductance matrix are examined. If the inductance matrix is absent, then it is automatically computed using vacuum electromagnetic parameter values. If the inductance matrix is manually defined, then the matrix is checked for physical acceptability including multiplication with the capacitance matrix. If the inductance matrix is specified to be automatically computed, then it will be done using the required provided speed of propagation. The flow chart within the figure can be used to assess the outcome of impedance matrix specifications, interdependencies, and omissions.

Each cable segment is assigned a finite difference space step (cell size) as seen in Figure 4.1.1. Cable voltages lie at whole integral index points, or nodes, and the currents lie at half-integral index points. Cable junctions and terminations occur at voltage nodes. Therefore, the average capacitance and conductance parameters for the adjoining segments are used to characterize the cable impedance parameters at the junction point.

The MHARNESS input file specifications for the cable impedance parameters associated with the three system levels (see Section 4.1) are discussed in separate sections below. The input file descriptions for System Level 0 (input file Section 6C) are presented first followed by those for System Level 1 (input file Section 6B), and then System Level 2 (input file Section 6A).

7.6.1 Section 6C: System Level 0 – Wire Impedance Parameters

There are six first level keywords associated with the cable impedance specification. These keywords are:

1) `CAPACITANCE`
2) `CAPACITANCE COMPUTE`
3) `INDUCTANCE`
4) `INDUCTANCE COMPUTE`
5) `RESISTANCE`
6) `CONDUCTANCE`
7) `SKIN DEPTH`

7.6.1.1 CAPACITANCE

The purpose of this keyword is to manually provide the cable capacitance parameters/matrix information. In general, for a segment with n conductors, a square matrix of dimension $n \times n$ is expected. There are two possible formats for specifying the capacitance. The first format is:

```
!CAPACITANCE
seg_id
c11  c12  ...  c1n
c21  c22  ...  c2n
.    .         .
.    .         .
.    .         .
cn1  cn2  ...  cnn
```

The second format is:

```
!CAPACITANCE
seg_id c11 ... c1n c21 ... c2n ... cn1 ... cnn
```

where

`seg_id`: is the segment name
c_{ij}: is the capacitance of the *ith* conductor with respect to the *jth* conductor of `seg_id`

Note 1: The first field in the record following the `CAPACITANCE` keyword should be the segment name. All subsequent fields should be real numbers. For a segment containing n conductors there should be n^2 real number fields. These fields can exist within the same record or be located on any subsequent records.

Note 2 The ordering of the matrix entry values has a one-to-one relationship with the specified conductors for each segment (see Section 7.5). The entry value c_{11} is assumed to be associated with the first conductor specified for the corresponding segment. The entry c_{22} is assumed associated with the second conductor, and so on.

Note 3: The keyword descriptors in the above input file text lines may be repeated under the "CAPACITANCE" keyword using the same format for the second segment and the associated capacitance matrix entry values.

7.6.1.2 CAPACITANCE COMPUTE

The purpose of this keyword is to specify the automatic computation of both the cable capacitance parameters and the associated cable inductance parameters. These parameters can be computed from the geometric location of the conductors in the segment. The conductor layout was defined by the SEGMENT/COMPLEX or the SEGMENT/COMPLEX2 keyword combination pairs discussed in Section 7.5. The CAPACITANCE COMPUTE keyword described here provides additional geometric and material parameter information necessary to compute the capacitance parameters/matrices. For the outermost system level the ground plane, at $z = 0.0$, is taken to be the default reference conductor. For the shielded conductors, System Level 1 or System Level 0, the shielding conductor, of System Level 2 or System Level 1, respectively, is taken to be the default reference conductor. If the default references are not the desired selections, then another reference can be specified (see Section 7.10).

There are three associated second level keyword. These are listed below.

1) DIELECTRIC
2) RADII
3) FILAMENT NUMBER

All three of these keywords should be present if the CAPACITANCE COMPUTE keyword is used. Each of these keywords provides necessary information required for the automatic computation of the capacitance matrix.

The required input file text line format is shown below.

```
!CAPACITANCE COMPUTE

!!DIELECTRIC
seg_id1  epsb1  epsd1
seg_id2  epsb2  epsd2
   .       .      .
   .       .      .
   .       .      .
seg_idn  epsbn  epsdn
```

```
!!RADII
seg_id1  cond_id1  cradius1  dradius1
seg_id2  cond_id2  cradius2  dradius2
   .        .         .         .
   .        .         .         .
   .        .         .         .
seg_idn  cond_idn  cradiusn  dradiusn

!!FILAMENT NUMBER
seg_id1  cond_id1  nfc1  nfc1
seg_id2  cond_id2  nfc2  nfc2
   .        .        .     .
   .        .        .     .
   .        .        .     .
seg_idn  cond_idn  nfcn  nfcn
```

Each of the second level keywords are discussed in separate sections below.

DIELECTRIC

This keyword is used to define the relative dielectric constant of the segment background material and the dielectric jacket (insulation) material. The format is:

```
!!DIELECTRIC
seg_idi  epsbi  epsdi
```

where

seg_id$_i$: is the segment name
epsb$_i$: is the segment background relative dielectric constant
epsd$_i$: is the segment jacket (insulation) relative dielectric constant

Note: If epsd$_i$ is not specified, bare wires are assumed. For air, epsb$_i$ = 1.0.

RADII

This keyword is used to specify the radius of conductor, cond_id, within segment, seg_id, and the associated conductor dielectric jacket. The coordinates of the center of the conductor were specified in the SEGMENT/COMPLEX or SEGMENT/COMPLEX2 keyword combination pair. The required format is:

```
!!RADII
seg_idi  cond_idi  cradiusi  dradiusi
```

where

seg_id$_i$: is the name of the segment containing cond_id$_i$

`cond_id`$_i$: is the name of a conductor associated with `seg_id`$_i$
`cradius`$_i$: is the radius of conductor `cond_id`$_i$
`dradius`$_i$: is radius of dielectric jacket (insulation) of conductor `cond_id`$_i$

Note: If the radius of the dielectric jacket, `dradius`, is not specified, a bare conductor is assumed. Conductors or dielectric jackets must not be in contact with each other, otherwise the MHARNESS program will terminate with an error message.

FILAMENT NUMBER

This keyword is used to specify the number of charge filaments designated to characterize the charge distribution on the various conductors within a cable segment to facilitate capacitance matrix computations. A diagram of the cross-section of two conductors is shown in Figure 7.6.1.2.1. One conductor has fifteen designated charge filaments, the other conductor five. The charge filaments are at equal angular increments around the circumference of each conductor. These charge filaments represent lines of constant charge along the length of each conductor. The actual charge distribution on each wire is therefore characterized by a discrete number of filaments. The more filaments that are used on each wire, the better the charge characterization. However, as the number of filaments increases, the greater amount of time required to compute the capacitance matrix.

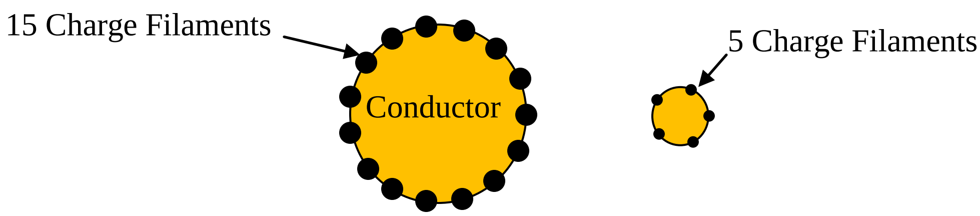


Figure 7.6.1.2.1 Charge Filaments used to characterize the conductor charge distribution

The ramification of filament number selection should be understood. As the distance between conductors increases, the number of filaments required to accurately represent the charge distribution generally decreases. As the distance between conductors decreases, the number of filaments require for accurate characterization generally increases. This is especially true when a small diameter conductor is near a large diameter conductor. If the small diameter conductor in Figure 7.6.1.2.1 is move closer to the large diameter conductor the charge distribution on the latter would vary greatly on the surface close to the small conductor. To accurately characterize this type of distribution, more filaments may be required.

The format for specifying the filament number is:

```
!!FILAMENT NUMBER
seg_idi  cond_idi  nfci  nfci
```

where

`seg_id`$_i$: the name of the segment containing `cond_id`$_i$

`cond_id`$_i$: the name of a conductor associated with `seg_id`$_i$
`nfc`$_i$: the number of filaments used to represent the charges on conductor, `cond_id`$_i$
`nfd`$_i$: the number of filaments used to represent the charges on the conductor jacket

Note: The default values are

$$nfc_i = 15$$
$$nfd_i = 15$$

7.6.1.3 INDUCTANCE

This keyword is used to manually provide the inductance information for the segment specified. The information provided under this keyword possesses the same format as that of the `CAPACITANCE` keyword. The required input file text format is:

```
!INDUCTANCE
seg_id
l11   l12   ...   l1n
l21   l22   ...   l2n
.     .           .
.     .           .
.     .           .
ln1   ln2   ...   lnn
```

or

```
!INDUCTANCE
seg_id l11 ... l1n l21 ... l2n ... ln1 ... lnn
```

where

`seg_id`: is the segment name
l_{ij}: is the inductance of the *ith* conductor with respect to the *jth* conductor of `seg_id`

Note 1: The first field in the record following the `INDUCTANCE` keyword should be the segment name. All subsequent fields should be real numbers. For a segment containing *n* conductors there should be n^2 real number fields. These fields can exist within the same record or be located on any subsequent records.

Note 2 The ordering of the matrix entry values has a one-to-one relationship with the specified conductors for each segment (see Section 7.5). The entry value l_{11} is assumed to be associated with the first conductor specified for the corresponding segment. The entry l_{22} is assumed associated with the second conductor, and so on.

Note 3: The keyword descriptors in the above input file text lines may be repeated under the "`INDUCTANCE`" keyword using the same format for the second segment and the associated inductance matrix entry values.

7.6.1.4 INDUCTANCE COMPUTE

This keyword is used to compute the inductance parameters from the associated capacitance parameters and the speed of propagation, v. The equation use to accomplish this is given below.

$$[L]=[C]^{-1}/v^2.$$

This keyword is only required if the capacitance parameters were manually defined. When using the `CAPACITANCE COMPUTE` keyword, the inductance values are computed automatically. The required format is:

```
!INDUCTANCE COMPUTE
seg_id  speed
```

where

`seg_id:` is the segment name
`speed:` is the speed of propagation associated with `seg_id`.

Note 1: This keyword is useful for bare wires or when the speed of propagation is known.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`INDUCTANCE COMPUTE`" keyword using the same format for the second segment and the associated speed of propagation.

7.6.1.5 RESISTANCE

This keyword is used to define the line resistance of the conductors – with one record for each conductor. The required format is:

```
!RESISTANCE
seg_id  cond_id  resistance
```

where

`seg_id:` is the name of the segment containing `cond_id`
`cond_id:` is the name of a conductor associated with `seg_id`
`resistance:` is the resistance of `cond_id`

Note 1: The resistance of a shield one conductor will be set equal to the maximum of the shield one resistance (see Section 7.8.1.6) and the shield one transfer resistance.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`RESISTANCE`" keyword using the same format for the next `seg_id` / `cond_id` pair and the associated resistance value.

7.6.3.6 CONDUCTANCE

This keyword is used to provide the conductance information for the segment specified. The information provided under this keyword possesses the same format as that of the CAPACITANCE keyword. The required format is:

```
!CONDUCTANCE
seg_id
g11   g12   ...   g1n
g21   g22   ...   g2n
.     .           .
.     .           .
.     .           .
gn1   gn2   ...   gnn
```

or

```
!CONDUCTANCE
seg_id g11 ... g1n g21 ... g2n ... gn1 ... gnn
```

where

seg_id: is the segment name
g_{ij}: is the conductance of the *ith* conductor with respect to the *jth* conductor of seg_id

Note 1: The first field in the record following the CONDUCTANCE keyword should be the segment name. All subsequent fields should be real numbers. For a segment containing *n* conductors there should be n^2 real number fields. These fields can exist within the same record or be located on any subsequent records.

Note 2 The ordering of the matrix entry values has a one-to-one relationship with the specified conductors for each segment (see Section 7.5). The entry value g_{11} is assumed to be associated with the first conductor specified for the corresponding segment. The entry g_{22} is assumed associated with the second conductor, and so on.

Note 3: The keyword descriptors in the above input file text lines may be repeated under the "CONDUCTANCE" keyword using the same format for the next segment and the associated conductance matrix entry values.

7.6.3.7 SKIN DEPTH

This keyword is used to provide the required information for the inclusion of skin depth effects. The required format is:

```
!SKIN DEPTH
```

seg_id   cond_id   sig   thk

where

seg_id:	is the name of the segment containing cond_id
cond_id:	is the name of a conductor associated with seg_id
sig:	is the conductivity of cond_id
thk:	is the thickness of cond_id

The thk parameter defines the thickness of the associated conductor. The thickness must always be less than or equal to the associated conductor radius. For shields (System Level 2 or System Level 1) the thickness constitutes the shield thickness. A thickness can also be applied to conductors at System Level 0. In most cases the thickness for System Level 0 conductors should be equal to the associated radius. If the thickness is less than the radius, then the System level 0 conductor would be consider a hollow cylindrical shell.

The skin depth effects implemented as a consequence of specifying this keyword are limited to an increased in associated conductor resistance with frequency.

Note: The keyword descriptors in the above input file text lines may be repeated under the "SKIN DEPTH" keyword using the same format for the next seg_id / cond_id pair and the associated conductivity and thickness values.

7.6.4 Section 6B: System Level 1 – SHIELD ONE Impedance Parameters

The format of the input file terms used to specify System Level 1 (SHIELD ONE) impedance parameters is identical to that used for analogous terms of System Level 0. The only difference is in first level keywords which are preceded by the "SHIELD ONE" characters, as illustrated below.

CAPACITANCE	replaced by	SHIELD ONE CAPACITANCE
CAPACITANCE COMPUTE	replaced by	SHIELD ONE CAPACITANCE COMPUTE
INDUCTANCE	replaced by	SHIELD ONE INDUCTANCE
INDUCTANCE COMPUTE	replaced by	SHIELD ONE INDUCTANCE COMPUTE
RESISTANCE	replaced by	SHIELD ONE RESISTANCE
CONDUCTANCE	replaced by	SHIELD ONE CONDUCTANCE
SKIN DEPTH	replaced by	SHIELD ONE SKIN DEPTH

7.6.5 Section 6A: System Level 2 – SHIELD TWO Impedance Parameters

The format of the input file terms used to specify System Level 2 (SHIELD TWO) impedance parameters is identical to that used for analogous terms of System Level 1. The only difference involves replacing the "SHIELD ONE" characters with "SHIELD TWO" characters, as illustrated below.

SHIELD ONE CAPACITANCE	replaced by	SHIELD TWO CAPACITANCE
SHIELD ONE CAPACITANCE COMPUTE	replaced by	SHIELD TWO CAPACITANCE COMPUTE

`SHIELD ONE INDUCTANCE`	replaced by	`SHIELD TWO INDUCTANCE`
`SHIELD ONE INDUCTANCE COMPUTE`	replaced by	`SHIELD TWO INDUCTANCE COMPUTE`
`SHIELD ONE RESISTANCE`	replaced by	`SHIELD TWO RESISTANCE`
`SHIELD ONE CONDUCTANCE`	replaced by	`SHIELD TWO CONDUCTANCE`
`SHIELD ONE SKIN DEPTH`	replaced by	`SHIELD TWO SKIN DEPTH`

7.7 Section 7: Connector Impedance Parameters

Many cable harnesses employ cable connectors to terminal boxes. The presence of cable connectors usually require different impedance matrices to characterize the ends of cable branches where the connectors are employed. Different capacitance, inductance, resistance, and conductance matrices can be specified for connectors. In MHARNESS the cable connector impedance parameters must be manually defined.

The specification of connectors does not increase the length of the cable. Connectors are always associated with the last finite difference cell on the ends of each meshed cable. If cable connectors are not specified, then the ends of each meshed cable assume the properties of the main portion of the cable.

In some situations an inner shield and an outer shield are electrically joined at the connector. In other situations, the effects of connectors can be accurately modeled using a terminal circuit This is especially desirable when the connector properties cannot be incorporated into the coefficient matrices. These two situations are associated with boundary conditions and are discussed in Section 7.9

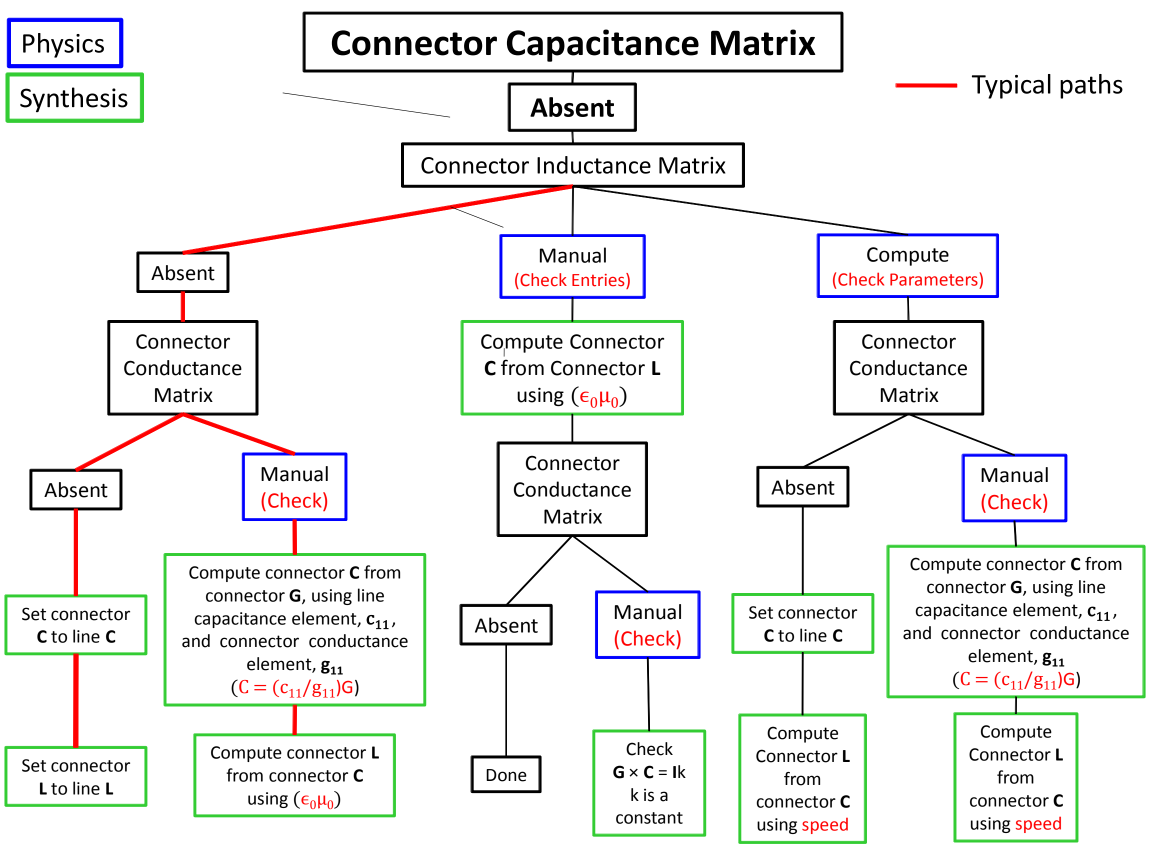
The cable segment line impedance parameter values are supplied in units per length. The connector impedance parameters, however, should consist of the <u>total</u> value. The associated per unit length value is computed internally.

The connector resistance matrix is independent of the connector capacitance, the connector inductance, and the connector conductance matrix values. However, the values within these latter three matrices are interdependent. The values within these three matrices must meet certain criteria to maintain the assumptions required for transmission line formalism. Flow charts are provided in Figure 7.7.1 that portray the interdependency and relationship between these three matrices. This involves matrix specifications and the omission of such.

The connector capacitance matrix can be manually defined or it will be automatically computed if another connector impedance matrix is provided. If the capacitance matrix is manually defined, then the matrix entries are checked for physical acceptability. If the matrix passes this test, then the associated connector inductance matrix and connector conductance matrix are examined. If the inductance matrix is absent, then it is automatically computed using vacuum electromagnetic parameter values. If the inductance matrix is manually defined, then the matrix is checked for physical acceptability including multiplication with the capacitance matrix. If the inductance matrix is specified to be automatically computed, then it will be done using the specified speed of propagation. The flow chart within the figure can be used to assess the outcome of impedance matrix specifications, interdependencies, and omissions.

This section contains input file descriptions for the connector cable impedance parameters associated with the three system levels in separate sections below. The input file descriptions for System Level 0 (input file Section 7C) are presented first followed by those for System Level 1 (input file Section 7B), and then System Level 2 (input file Section 7A).

(A) Process if Connector Capacitance Matrix is Manually Defined



(B) Process if Connector Capacitance Matrix is Absent

Figure 7.7.1 Connector Impedance Matrix Interdependency and Physics Checks

7.7.1 Section 7C: System Level 0 – Wire Connector Impedance Parameters

There are five first level keywords associated with the cable connector impedance specification. These keywords are:

1) `CONNECTOR CAPACITANCE`
2) `CONNECTOR INDUCTANCE`
3) `CONNECTOR INDUCTANCE COMPUTE`
4) `CONNECTOR RESISTANCE`
5) `CONNECTOR CONDUCTANCE`

7.7.1.1 CONNECTOR CAPACITANCE

The purpose of this keyword is to manually provide the connector capacitance matrix information for the first segment cell (`end#` = 1) or the last segment cell (`end#` = 2). In general, for a segment with *n* conductors, a square matrix of dimension *n x n* is expected. There are two possible input file text line formats for specifying the connector capacitance. The first format is:

```
!CONNECTOR CAPACITANCE
seg_id
c11  c12  ...  c1n
c21  c22  ...  c2n
.    .         .
.    .         .
.    .         .
cn1  cn2  ...  cnn
```

The second format is:

```
!CONNECTOR CAPACITANCE
seg_id  end#  c11  ...  c1n  c21  ...  c2n  ...  cn1  ...  cnn
```

where

`seg_id`: is the segment name
`end#`: is the end number (1 or 2) associated with `seg_id`
c_{ij}: is the capacitance of the *ith* connector element, with respect to the *jth* connector element of `seg_id`

Note 1: The first field in the record following the `CONNECTOR CAPACITANCE` keyword should be the segment name, `seg_id`. The next field should be the end number, `end#`. All subsequent fields should be real numbers. For a segment containing *n* conductors there should be n^2 real number fields. These fields can exist within the same record or be located on any subsequent records.

Note 2 The ordering of the matrix entry values has a one-to-one relationship with the specified conductors for each segment (see Section 7.5). The entry value c_{11} is assumed to be associated with the first conductor specified for the corresponding segment. The entry c_{22} is assumed associated with the second conductor, and so on.

Note 3: The keyword descriptors in the above input file text lines may be repeated under the "CONNECTOR CAPACITANCE" keyword using the same format for the next segment and end number pair along with the associated capacitance matrix entry values.

7.7.1.2 CONNECTOR INDUCTANCE

This keyword is used to provide the connector inductance matrix for the first segment cell (end# = 1) or the last segment cell (end# = 2). The format is similar to that of CONNECTOR CAPACITANCE keyword. There are two possible input file text line formats for specifying the CONNECTOR INDUCTANCE. The first format is:

```
!CONNECTOR INDUCTANCE
seg_id   end#
l11   l12   ...   l1n
l21   l22   ...   l2n
.     .           .
.     .           .
.     .           .
ln1   ln2   ...   lnn
```

The second format is:

```
!CONNECTOR INDUCTANCE
seg_id   end#   l11   ...   l1n   l21   ...   l2n   ...   ln1   ...   lnn
```

where

seg_id:	is the segment name
end#:	is the end number (1 or 2) associated with seg_id
l_{ij}:	is the inductance of the *ith* connector element, with respect to the *jth* connector element of seg_id

Note 1: The first field in the record following the CONNECTOR INDUCTANCE keyword should be the segment name, seg_id. The next field should be the end number, end#. All subsequent fields should be real numbers. For a segment containing n conductors there should be n^2 real number fields. These fields can exist within the same record or be located on any subsequent records.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "CONNECTOR INDUCTANCE" keyword using the same format for the next segment and end number pair along with the associated inductance matrix entry values.

7.7.1.3 CONNECTOR INDUCTANCE COMPUTE

This keyword is used to compute the connector inductance parameters, of the first segment cell (`end#` = 1) or the last segment cell (`end#` = 2), from the associated connector capacitance matrix and the speed of propagation, v. The equation used is given below:

$$[L] = [C]^{-1} / v^2 .$$

The required format is:

```
!CONNECTOR INDUCTANCE COMPUTE
seg_id  end#  speed
```

where

`seg_id:` is the segment name
`end#:` is the end number (1 or 2) associated with `seg_id`
`speed:` is the speed of propagation associated with `seg_id`.

Note 1: This keyword is useful for bare wires or when the speed of propagation is known.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`CONNECTOR INDUCTANCE COMPUTE`" keyword using the same format for the next segment and end number pair along with the associated speed of propagation.

7.7.1.4 CONNECTOR RESISTANCE

This keyword is used to define the resistance of the first cell (`end# = 1`) or the last cell (`end# = 2`) of the conductor specified. The required format is:

```
!CONNECTOR RESISTANCE
seg_id  cond_id  end#  resistance
```

where

`seg_id:` is the name of the segment containing `cond_id`
`cond_id:` is the name of a conductor associated with `seg_id`
`end#:` is the end number (1 or 2) associated with `cond_id`
`resistance:` is the resistance of the end cell (connector element) of `cond_id`

Note 1: The values entered here are total values, not values per unit length

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`CONNECTOR RESISTANCE`" keyword using the same format for the next segment and end number pair along with the associated resistance value.

7.7.1.5 CONNECTOR CONDUCTANCE

This keyword is used to provide the conductance information of the first cell (`end# = 1`) or the last cell (`end# = 2`) of the conductor specified. The information provided under this keyword possesses the same format as that of the `CONNECTOR CAPACITANCE` keyword. The required format is:

```
!CONNECTOR CONDUCTANCE
seg_id  end#
g11   g12   ...   g1n
g21   g22   ...   g2n
.     .           .
.     .           .
.     .           .
gn1   gn2   ...   gnn
```

or

```
!CONNECTOR CONDUCTANCE
seg_id  end#  g11  ...  g1n  g21  ...  g2n  ...  gn1  ...  gnn
```

where

`seg_id:` is the name of the segment containing `cond_id`
`cond_id:` is the name of a conductor associated with `seg_id`
`end#:` is the end number (1 or 2) associated with `cond_id`
g_{ij}: is the conductance of the *ith* connector element, with respect to the *jth* connector element of `seg_id`

Note 1: The values entered here are total values, not values per unit length

Note 2 The ordering of the matrix entry values has a one-to-one relationship with the specified conductors for each segment (see Section 7.5). The entry value g_{11} is assumed to be associated with the first conductor specified for the corresponding segment. The entry g_{22} is assumed associated with the second conductor, and so on.

Note 3: The keyword descriptors in the above input file text lines may be repeated under the "`CONNECTOR CONDUCTANCE`" keyword using the same format for the next segment and end number pair along with the associated conductance matrix entry values.

7.7.2 Section 7B: System Level 1 – SHIELD ONE Connector Impedance Parameters

The format of the input file terms used to specify System Level 1 (SHIELD ONE) connector impedance parameters is identical to that used for analogous terms of System Level 0. The only difference is in first level keywords which are preceded by the "`SHIELD ONE`" characters, as illustrated below.

`CONNECTOR CAPACITANCE`	replaced by	`SHIELD ONE CONNECTOR CAPACITANCE`
`CONNECTOR INDUCTANCE`	replaced by	`SHIELD ONE CONNECTOR INDUCTANCE`
`CONNECTOR INDUCTANCE COMPUTE`	replaced by	`SHIELD ONE CONNECTOR INDUCTANCE COMPUTE`
`CONNECTOR RESISTANCE`	replaced by	`SHIELD ONE CONNECTOR RESISTANCE`
`CONNECTOR CONDUCTANCE`	replaced by	`SHIELD ONE CONNECTOR CONDUCTANCE`

7.7.3 Section 7A: System Level 2 – SHIELD TWO Connector Impedance Parameters

The format of the input file terms used to specify System Level 2 (`SHIELD TWO`) connector impedance parameters is identical to that used for analogous terms of System Level 1. The only difference involves replacing the "`SHIELD ONE`" characters with "`SHIELD TWO`" characters, as illustrated below.

`SHIELD ONE CONNECTOR CAPACITANCE`	replaced by	`SHIELD TWO CONNECTOR CAPACITANCE`
`SHIELD ONE CONNECTOR INDUCTANCE`	replaced by	`SHIELD TWO CONNECTOR INDUCTANCE`
`SHIELD ONE CONNECTOR INDUCTANCE COMPUTE`	replaced by	`SHIELD TWO CONNECTOR INDUCTANCE COMPUTE`
`SHIELD ONE CONNECTOR RESISTANCE`	replaced by	`SHIELD TWO CONNECTOR RESISTANCE`
`SHIELD ONE CONNECTOR CONDUCTANCE`	replaced by	`SHIELD TWO CONNECTOR CONDUCTANCE`

7.8 Input File Section 8: Cable Shield Transfer Impedance Parameters

In MHARNESS, cable shields contain wires and perhaps other cable shields. The coupling of electromagnetic energy through cable shields is characterized by specifying a shield transfer impedance. The cable shield transfer impedance relates the driving voltage on one side of the shield (the interior for example), to the current on the other side of the shield (the exterior for example). In MHARNESS all shields can be specified as unidirectional or bidirectional. A unidirectional shield allows electromagnetic coupling in one direction only - that is, from the exterior to the interior or from the interior to the exterior. A bidirectional specification enables electromagnetic coupling through the shield in both direction simultaneously. In many cases, a unidirectional coupling specification provides an excellent approximation.

The shield transfer impedance can be manually assigned or automatically computed. Automatic computation is performed using various shield parameter inputs. The algorithms assume the shield to be a weave-type structure. The transfer impedance is computed from the strand diameter, the strand conductivity, the weave angle, the number of carriers (bundles of strands), and the number of strands per carrier.

The shield transfer impedance is given by

$$\mathrm{Z}_t = \mathrm{Z}_d + j\omega \mathrm{M}_{12} \tag{7.1}$$

where: $\mathrm{Z_d}$ is the resistive (diffusive) part, and
M_{12} the inductive part.

Typically $\mathrm{Z_d}$ is the supplied resistance of the shield unless specified otherwise. MHARNESS allows the direct input of $\mathrm{Z_d}$ and M or automatically computes these values using the following formula from “Coupling to Shielded Cables,” by E. F. Vance, John Wiley & Sons, Inc., 1978:

$$\mathrm{Z}_d \approx \frac{4}{\pi \mathrm{N} d^2 C \sigma \cos\alpha} \tag{7.2}$$

$$\mathrm{M}_{12} \approx \frac{\pi\mu}{6C}(1-k)^{3/2} \frac{e^2}{\mathrm{E}(e) - (1-e^2)\mathrm{K}(e)} \qquad \alpha > 45^\circ \tag{7.3}$$

$$\approx \frac{\pi\mu}{6C}(1-k)^{3/2} \frac{e^2}{\sqrt{1-e^2}} \left[\frac{1}{\mathrm{K}(e) - \mathrm{E}(e)}\right] \qquad \alpha < 45^\circ \tag{7.4}$$

$$\begin{aligned} e &= \sqrt{1-\tan^2\alpha} \qquad \alpha > 45^\circ \\ &= \sqrt{1-\cot^2\alpha} \qquad \alpha < 45^\circ \end{aligned} \tag{7.5}$$

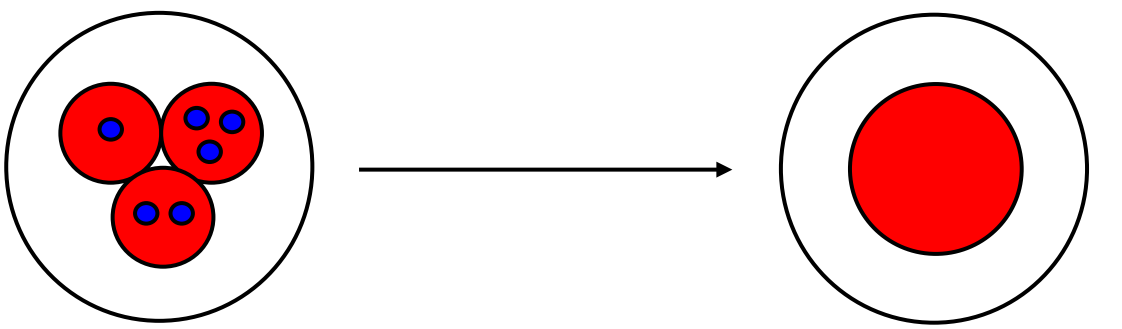
$$Fill: \quad F = \frac{\mathrm{N} d C}{4\pi a \cos\alpha} \tag{7.6}$$

$$Optical \quad \mathrm{cov}erage: \quad k = 2F - F^2 \tag{7.7}$$

where: a: is the radius of the shield
C: is the number of carriers
N: is the number of strands per carrier, also called the ends
d: is the strand diameter
α: is the weave angle
K(e): is the complete elliptic integral of the first kind
E(e): is the complete elliptic integral of the second kind

These variables are functions of the shield and are typically provided by the manufacturer. In the above equations, the imaginary part of Z_d has been neglected. This is valid in the limit of small strand diameter compared to the skin depth. This dc approximation is justified by the fact that at high frequency, the inductive part, M, is dominant.

In some cases, conductive cable shields possess internal conductors that may be in direct electrical contact. Current thereby flows freely from one inner cable shield to another. A cross-sectional drawing depicting this situation is shown in Figure 7.8.1A. Since these conductors are in contact, a transmission line approximation, keeping each shield distinct, is not applicable. To model such a configuration, the shields should be merged into a single conductor of appropriate size, as shown in Figure 7.8.2B. The computed current for this single conductor can then be divided equally among the shields and the individual shield transfer impedances used to drive the associated interior conductors.



(A) Shields in Contact **(B) Single Shield Conductor**

Figure 7.8.1 Procedure for Cable Shields in Direct Electrical Contact

The cable configuration of Figure 7.8.1 consists of three system levels. To model this situation System Level 1 should consists of the single shield conductor of Figure 7.8.1B. With the proper specifications, the current computed on this single conductor is automatically divided by 3 and through the transfer impedance of each of the individual three shields, the interior conductors are driven. This procedure has the inherent approximation that the current is equally divided among the shields in contact. This however, may not be the case in all situations.

7.8.1 Section 8B: System Level 1 – SHIELD ONE Transfer Impedance Parameters

There are six first level keywords associated with System Level 1 transfer impedance definitions. These keywords are listed below.

1) `SHIELD ONE GLOBAL TRANSFER DIRECTION`
2) `SHIELD ONE TRANSFER DIRECTION`
3) `SHIELD ONE TO CABLE`
4) `SHIELD ONE TO CABLE COMPUTE`
5) `SHIELD ONE TO CABLE FREQUENCY DEPENDENT`
6) `SHIELD ONE TRANSFER RESISTANCE`

7.8.1.1 SHIELD ONE GLOBAL TRANSFER DIRECTION

This keyword is used to set the global transfer direction for <u>all</u> System Level 1 shields. The required input file text line format is:

```
!SHIELD ONE GLOBAL TRANSFER DIRECTION
direction
```

where

`direction:` is the transfer direction to be used for <u>all</u> System Level 1 shields.

There are three possible values for the "`direction`" parameter. These values are:

`IN`	<default>
`OUT`	
`BOTH`	

If the "`IN`" parameter was specified, then electromagnetic energy is coupled only from the exterior of System Level 1 shields to the interior. No energy is coupled outward through the shield. The "`IN`" direction is the default direction for all System Level 1 shields. In an analogous manner, if the "`OUT`" direction was selected, then electromagnetic energy is coupled only from the interior of System Level 1 shields to the exterior. The "`BOTH`" selection allows energy coupling in both directions.

7.8.1.2 SHIELD ONE TRANSFER DIRECTION

This keyword is used to specify the transfer direction for individual System Level 1 shields. Specifications provided here overwrite those provided by the "`SHIELD ONE GLOBAL TRANSFER DIRECTION`" keyword. The required input file text line format is:

```
!SHIELD ONE TRANSFER DIRECTION
```

seg_id cond_id direction

where

seg_id:	is the System Level 1 segment name
cond_id:	is the System Level 1 conductor name
direction:	is the transfer direction to be used for the above associated System Level 1 shield

There are three possible values for the "direction" parameter. These values are:

```
IN          <default>
OUT
BOTH
```

Specification of this parameter will overwrite the global specification. If the "IN" parameter was specified, then electromagnetic energy is coupled only from the exterior of the associated System Level 1 shield to the interior. No energy is coupled outward through the shield. In an analogous manner, if the "OUT" direction was selected, then electromagnetic energy is coupled only from the interior of the associated System Level 1 shield to the exterior. The "BOTH" selection allows energy coupling in both directions.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "SHIELD ONE TRANSFER DIRECTION" keyword using the same format for the next segment and conductor pair along with the associated direction.

7.8.1.3 SHIELD ONE TO CABLE

This keyword is used to manually assign System Level 1 shield transfer inductances. These transfer inductances are used to compute the coupling through the System Level 1 shield. The degree of coupling is applied equally to all associated System Level 0 conductors. This keyword defines transfer inductances only, transfer resistances are assigned using a different keyword (see Section 7.8.1.6).

There are two input file line text formats used for this keyword. The first format is used if the ends of the segment (ie connectors) have a different transfer inductance than the main line of the cable. The second format is used if this is not the case.

The first format is:

```
!SHIELD ONE TO CABLE
shieldedseg_id  seg_id  cond_id  parallel  sfact  tzl1  tzl2  tzl3
```

the second format is:

```
!SHIELD ONE TO CABLE
shieldedseg_id  seg_id  cond_id  parallel  sfact  tzl2
```

where

`shieldedseg_id`:	is the System Level 0 shielded segment
`seg_id`:	is the System Level 1 segment name containing the System Level 1 conductor, `cond_id`.
`cond_id`:	is the System Level 1 shield conductor name containing the System Level 0 shielded segment, `shieldedseg_id`
`parallel`:	=1 if the System Level 1 shield and the System Level 0 segment are parallel. = -1 otherwise
`sfact`:	is an integer divisor of the shield current (see Figure 7.8.1)
`tzl1`:	is the transfer inductance per unit length of end_1 of `cond_id`
`tzl2`:	is the transfer inductance per unit length of the main body of `cond_id`
`tzl3`:	is the transfer inductance per unit length of end_2 of `cond_id`

Note 1: In the actual cable harness system there may be distinct System Level 1 conductor shields each containing System Level 0 conductors. If these System Level 1 conductor shields are in electrical contact with each other then these must be combined and specified as a single System Level 1 shield conductor. This is a good approximation as far as the response of System Level 1 is concerned. However, to the accurately simulate the System Level 0 behavior requires dividing the System Level 1 combined single conductor current by the number of System Level 1 conductor shields in contact. This is the purpose of the `sfact` descriptor (see discussion surrounding Figure 7.8.1). The `sfact` descriptor is used to reduce the current responsible for driving the associated System Level 0 conductors.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`SHIELD ONE TO CABLE`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

7.8.1.4 SHIELD ONE TO CABLE COMPUTE

This keyword is used to automatically compute the System Level 1 conductor shield transfer inductances from the nature of the conductive stands composing the conductor shields (see discussion at the beginning of Section 7.8). These transfer impedances are used to compute the coupling through the System Level 1 shield. The degree of coupling is applied equally to all associated System Level 0 conductors.

To automatically compute System Level 1 conductor shield transfer impedances requires the radii of the conductor shields. This information should be provided under the `SHIELD ONE CAPACITANCE COMPUTE` keyword. The required input file text line format is:

```
!SHIELD ONE TO CABLE COMPUTE
shieldedseg_id  seg_id  cond_id  parallel  sfact
strand_dia  sigma  weaveangle  #carriers  #ends
```

where

`shieldedseg_id`: is the System Level 0 shielded segment

seg_id: is the System Level 1 segment name containing the System Level 1 conductor, cond_id.
cond_id: is the System Level 1 shield conductor name containing the System Level 0 shielded segment, shieldedseg_id
parallel: =1 if the System Level 1 shield and the System Level 0 segment are parallel. = -1 otherwise
sfact: is an integer divisor of the shield current (see note below)
strand_dia: is the diameter of the wire strands composing the conductor shield
sigma: is the conductivity of the wire strands
weaveangle: is the wire strand weave angle
#carriers: is the number of carriers in a braid
#ends: is the number of strands per carrier

Note 1: In the actual cable harness system there may be distinct System Level 1 conductor shields each containing System Level 0 conductors. If these System Level 1 conductor shields are in electrical contact with each other then these must be combined and specified as a single System Level 1 shield conductor. This is a good approximation as far as the response of System Level 1 is concerned. However, to accurately simulate the System Level 0 behavior requires dividing the System Level 1 combined single conductor current by the number of System Level 1 conductor shields in contact. This is the purpose of the sfact descriptor (see discussion surrounding Figure 7.8.1). The sfact descriptor is used to reduce the current responsible for driving the associated System Level 0 conductors.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "SHIELD ONE TO CABLE COMPUTE" keyword using the same format for the next segment and conductor pair along with the associated parameters.

7.8.1.5 SHIELD ONE TO CABLE FREQUENCY DEPENDENT

This keyword is used to manually assign System Level 1 frequency dependent shield transfer inductances. These transfer inductances are used to compute the coupling through the System Level 1 shield. The degree of coupling is applied equally to all associated System Level 0 conductors. This keyword defines frequency dependent transfer inductances only, transfer resistances are assigned using a different keyword (see Section 7.8.1.6).

Frequency dependent shields can be characterized by:

$$Z_t(\omega) = R_{DC} + \sum_{k=1}^{nfd} \frac{afd_k}{bfd_k + j\omega} \qquad (a_k \geq 0.0, \quad b_k > 0.0)$$

where:

R_{DC} is the DC conductivity ($R_{DC} \geq 0.0$)
afd_k: is the first, first order electric material expansion coefficient ($afd_k \geq 0.0$)
bfd_k: is the second, first order electric material expansion coefficient ($bfd_k > 0.0$)

ω: is the angular frequency

It is the responsibility of the user to determine the coefficients and the number of terms in the representation above. The acceptable parameter ranges are provided above in the description list. Assigning values outside of the range given will result in an error message in MHARNESS and program termination. The required input file text line format is:

There are two input file line text formats used for this keyword. The first format is used if the ends of the segment (ie connectors) have a different transfer inductance characterization than the main line of the cable. The second format is used if this is not the case.

The first format is:

```
!SHIELD ONE TO CABLE FREQUENCY DEPENDENT
shieldedseg# seg_id cond_id parallel sfact  nfd1   nfd2   nfd3
rdc1
afd11       bfd11
afd12       bfd12
 .           .
 .           .
 .           .
afd1,nfd1   bfd1,nfd1
rdc2
afd21       bfd21
afd22       bfd22
 .           .
 .           .
 .           .
afd2,nfd1   bfd2,nfd1
rdc3
afd31       bfd31
afd32       bfd32
 .           .
 .           .
 .           .
afd3,nfd1   bfd3,nfd1
```

The second format is:

```
shieldedseg# seg_id cond_id parallel sfact  nfd2
rdc2
afd21       bfd21
afd22       bfd22
 .           .
 .           .
 .           .
afd2,nfd1   bfd2,nfd1
```

where

shieldedseg_id:	is the System Level 0 shielded segment
seg_id:	is the System Level 1 segment name containing the System Level 1 conductor, cond_id
cond_id:	is the System Level 1 shield conductor name containing the System Level 0 shielded segment, shieldedseg_id
parallel:	=1 if the System Level 1 shield and the System Level 0 segment are parallel. = -1 otherwise
sfact:	is an integer divisor of the shield current (see note below)
nfd1:	is the number of first order poles for end_1 of cond_id
nfd2:	is the number of first order poles for the main body of cond_id
nfd3:	is the number of first order poles for end_2 of cond_id
rdc_1:	is the DC resistance of end_1 of cond_id
afd_{1i}:	is the first, first order pole coefficient of the ith ($1 \le i \le$ nfd1) expansion term of end_1 of cond_id
bfd_{1i}:	is the second, first order pole coefficient of the ith ($1 \le i \le$ nfd1) expansion term of end_1 of cond_id
rdc_2:	is the DC resistance of the main body of cond_id
afd_{2i}:	is the first, first order pole coefficient of the ith ($1 \le i \le$ nfd1) expansion term of the main body of cond_id
bfd_{2i}:	is the second, first order pole coefficient of the ith ($1 \le i \le$ nfd1) expansion term of the main body of cond_id
rdc_3:	is the DC resistance of end_2 of cond_id
afd_{3i}:	is the first, first order pole coefficient of the ith ($1 \le i \le$ nfd1) expansion term of end_2 of cond_id
bfd_{3i}:	is the second, first order pole coefficient of the ith ($1 \le i \le$ nfd1) expansion term of end_2 of cond_id

Note 1: The keyword descriptors in the above input file text lines may be repeated under the "SHIELD ONE TO CABLE FREQUENCY DEPENDENT" keyword using the same format for the next segment and conductor pair along with the associated parameters.

7.8.1.6 SHIELD ONE TRANSFER RESISTANCE

This keyword is used to defined System Level 1 transfer resistances. The transfer resistance is the real part of the transfer impedance.

There are two input file line text formats used for this keyword. The first format is used if the ends of the segment (ie connectors) have a different transfer resistance than the main line of the cable. The second format is used if this is not the case.

The first format is:

```
!SHIELD ONE TRANSFER RESISTANCE
seg_id  cond_id  tr1  tr2  tr3
```

The second format is:

```
!SHIELD ONE TRANSFER RESISTANCE
seg_id  cond_id  tr2
```

where

`seg_id`:	is the System Level 1 segment name containing the System Level 1 shield conductor, `cond_id`.
`cond_id`:	is the System Level 1 shield conductor name containing the System Level 0 wires
`tr1`:	is the transfer resistance per unit length of end_1 of `cond_id`
`tr2`:	is the transfer resistance per unit length of the main body of `cond_id`
`tr3`:	is the transfer resistance per unit length of end_2 of `cond_id`

Note 1: The resistance of the shield one conductor will be set equal to the maximum of the shield one resistance (see Section 7.6.1.5) and the shield one transfer resistance.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`SHIELD ONE TRANSFER RESISTANCE`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

7.8.2 Section 8A: System Level 2 – SHIELD TWO Impedance Parameters

The format of the input file terms used to specify System Level 2 (`SHIELD TWO`) transfer impedance parameters is identical to that used for analogous terms of System Level 1. The only difference involves replacing the "`SHIELD ONE`" characters with "`SHIELD TWO`" characters, as illustrated below.

`SHIELD ONE GLOBAL TRANSFER DIRECTION`	replaced by	`SHIELD TWO GLOBAL TRANSFER DIRECTION`
`SHIELD ONE TRANSFER DIRECTION`	replaced by	`SHIELD TWO TRANSFER DIRECTION`
`SHIELD ONE TO CABLE`	replaced by	`SHIELD TWO TO SHIELD ONE`
`SHIELD ONE TO CABLE COMPUTE`	replaced by	`SHIELD TWO TO SHIELD ONE COMPUTE`
`SHIELD ONE TO CABLE FREQUENCY DEPENDENT`	replaced by	`SHIELD TWO TO SHIELD ONE FREQUENCY DEPENDENT`
`SHIELD ONE TRANSFER RESISTANCE`	replaced by	`SHIELD TWO TRANSFER RESISTANCE`

Note1: For the `SHIELD TWO TO SHIELD ONE` keyword the `sfact` descriptor should always be equal to 1

Note2: Under the keyword, `SHIELD TWO TO SHIELD ONE COMPUTE`, the required System Level 2 shield radius should be provided under the `SHIELD TWO CAPACITANCE COMPUTE` keyword.

7.9 Section 9: Boundary Conditions Terminations

Conductors within an MHARNESS cable system are terminated in a junction or in a boundary condition. Junction terminations were discussed in Section 7.5. Boundary condition terminations are the topic of this section. There are two classifications of boundary condition terminations in MHARNESS. The first classification involves predefined circuit terminations. The second classification involves manners in which shields may be terminated.

There are eight predefined lumped parameter circuit terminations that are presently available in MHARNESS. These available circuit terminations were shown previously in Figure 3.6.1. This figure is duplicated in Figure 7.9.1 with the MHARNESS terminology identifying the particular circuit type included in red font.

To terminate a conductor or shield in a short, or to leave either end floating, a resistive termination is required. For a short, let R = 0.0 ohms. To specify a floating or open circuit configuration, let R be a large number such as 1.0e8 ohms. The default termination is an open circuit.

The second classification of boundary condition terminations involves the manner in which shields may be terminated. These situations are discussed in the Section 7.9.2 under the keywords, "`SHIELD ONE BOUNDARY VOLTAGE ZTR`" and "`SHIELDS JOINED AT THE CONNECTOR`"

This section contains input file descriptions for the boundary condition parameters associated with the three system levels in separate sections below. The input file descriptions for System Level 0 (input file Section 9C) are presented first followed by those for System Level 1 (input file Section 9B), and then System Level 2 (input file Section 9A).

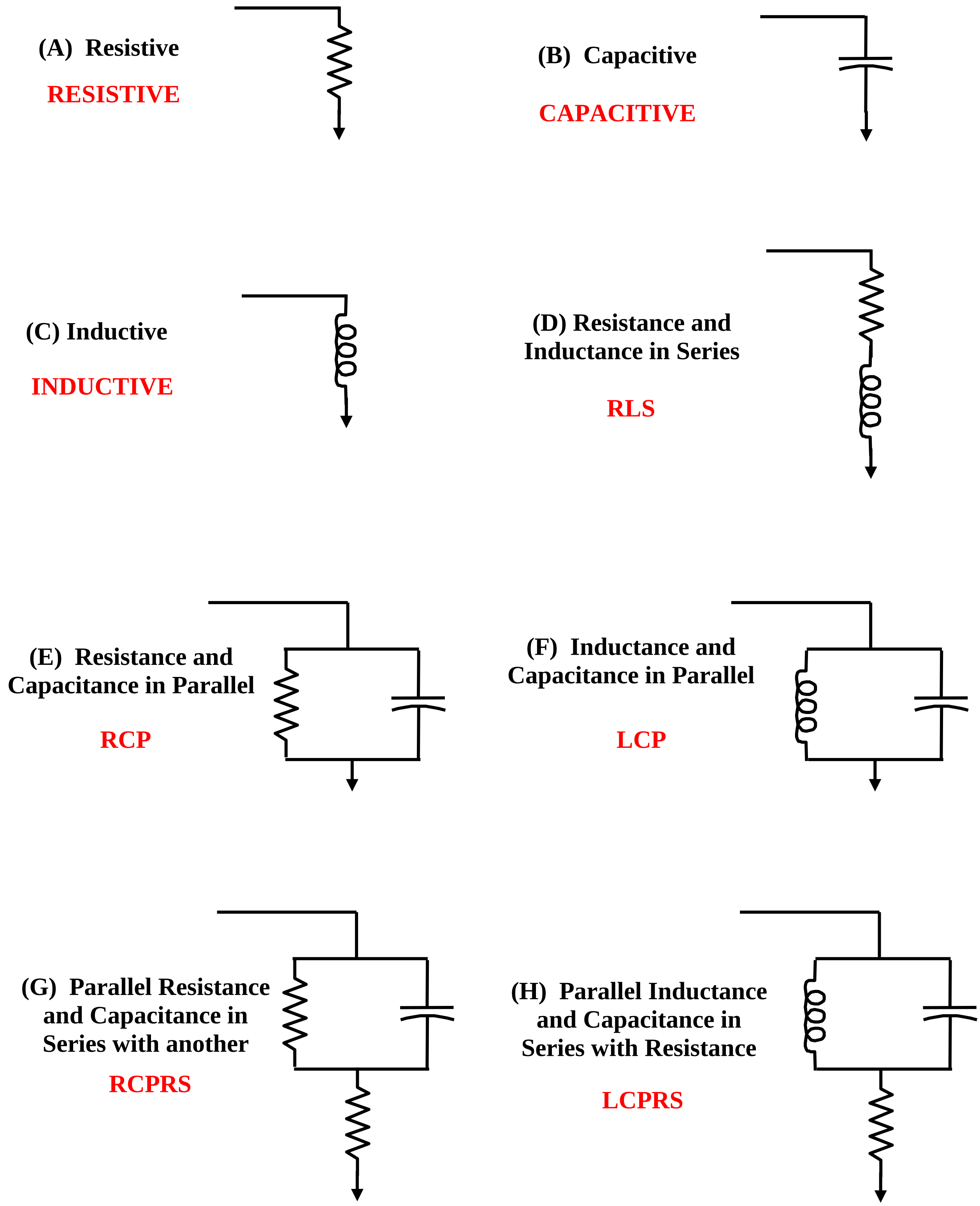


Figure 7.9.1 MHARNESS Circuit Termination Types with Input File Identifying Terminology in Red Font

7.9.1 Section 9C: System Level 0 – Wire Boundary Conditions

There are eight second level keywords associated with the first level `BOUNDARY CONDITION` keyword. These keywords are:

- `RESISTIVE`
- `CAPACITIVE`
- `INDUCTIVE`
- `RLS`
- `RCP`
- `LCP`
- `RCPRS`
- `LCPRS`

The keyword terminology associated with the circuit terminations is provided in Figure 7.9.1.

RESISTIVE

This keyword is used to define the resistive value associated with the boundary condition termination circuit of Figure 7.9.1A. The required input file text line format is:

```
!BOUNDARY CONDITION
!!RESISTIVE
seg_id   cond_id   end#   res
```

where

`seg_id:`	is the name of the segment containing `cond_id`
`cond_id:`	is the name of a conductor associated with `seg_id`
`end#:`	is the end number (1 or 2) associated with `cond_id`
`res:`	is the resistance value of the termination circuit of the end cell of `cond_id`

Note 1: To terminate a conductor or shield in a short let R = 0.0 ohms. To specify a floating or open circuit configuration, let R be a large number such as 1.0e8 ohms.

Note 2: The keyword descriptors in the above input file text lines may be repeated under the "`BOUNDARY CONDITION`" keyword and the "`RESISTIVE`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

CAPACITIVE

This keyword is used to define the capacitive value associated with the boundary condition termination circuit of Figure 7.9.1B. The required input file text line format is:

```
!BOUNDARY CONDITION
!!CAPACITIVE
```

```
seg_id   cond_id   end#   cap
```

where

`seg_id:`	is the name of the segment containing `cond_id`
`cond_id:`	is the name of a conductor associated with `seg_id`
`end#:`	is the end number (1 or 2) associated with `cond_id`
`cap:`	is the capacitance value of the termination circuit of the end cell of `cond_id`

Note: The keyword descriptors in the above input file text lines may be repeated under the "`BOUNDARY CONDITION`" keyword and the "`CAPACITIVE`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

INDUCTIVE

This keyword is used to define the inductive value associated with the boundary condition termination circuit of Figure 7.9.1C. The required input file text line format is:

```
!BOUNDARY CONDITION
!!INDUCTIVE
seg_id   cond_id   end#   ind
```

where

`seg_id:`	is the name of the segment containing `cond_id`
`cond_id:`	is the name of a conductor associated with `seg_id`
`end#:`	is the end number (1 or 2) associated with `cond_id`
`ind:`	is the inductance value of the termination circuit of the end cell of `cond_id`

Note: The keyword descriptors in the above input file text lines may be repeated under the "`BOUNDARY CONDITION`" keyword and the "`INDUCTIVE`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

RLS

This keyword is used to define the resistive and inductive values associated with the termination circuit of Figure 7.9.1D. The required input file text line format is:

```
!BOUNDARY CONDITION
!!RLS
seg_id   cond_id   end#   res   ind
```

where

`seg_id:`	is the name of the segment containing `cond_id`
`cond_id:`	is the name of a conductor associated with `seg_id`
`end#:`	is the end number (1 or 2) associated with `cond_id`

`res`: is the resistance value of the termination circuit of the end cell of `cond_id`
`ind`: is the inductance value of the termination circuit of the end cell of `cond_id`

<u>Note</u>: The keyword descriptors in the above input file text lines may be repeated under the "`BOUNDARY CONDITION`" keyword and the "`RLS`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

<u>RCP</u>

This keyword is used to define the resistive and capacitive values associated with the termination circuit of Figure 4.9.1E. The required input file text line format is:

```
!BOUNDARY CONDITION
!!RCP
seg_id  cond_id  end#  res  cap
```

where

`seg_id`: is the name of the segment containing `cond_id`
`cond_id`: is the name of a conductor associated with `seg_id`
`end#`: is the end number (1 or 2) associated with `cond_id`
`res`: is the resistance value of the termination circuit of the end cell of `cond_id`
`cap`: is the capacitance value of the termination circuit of the end cell of `cond_id`

<u>Note</u>: The keyword descriptors in the above input file text lines may be repeated under the "`BOUNDARY CONDITION`" keyword and the "`RCP`" keyword using the same format for the next segment and conductor pair along with the associated parameters.

<u>LCP</u>

This keyword is used to define the inductive and capacitive values associated with the termination circuit of Figure4.9.1F. The required input file text line format is :

```
!BOUNDARY CONDITION
!!LCP
seg_id  cond_id  end#  ind  cap
```

where

`seg_id`: is the name of the segment containing `cond_id`
`cond_id`: is the name of a conductor associated with `seg_id`
`end#`: is the end number (1 or 2) associated with `cond_id`
`ind`: is the inductance value of the termination circuit of the end cell of `cond_id`
`cap`: is the capacitance value of the termination circuit of the end cell of `cond_id`

Note: The keyword descriptors in the above input file text lines may be repeated under the "BOUNDARY CONDITION" keyword and the "LCP" keyword using the same format for the next segment and conductor pair along with the associated parameters.

RCPRS

This keyword is used to define the two resistive values and capacitive value associated with the termination circuit of Figure 4.9.1G. The required input file text line format is :

```
!BOUNDARY CONDITION
!!RCPRS
seg_id  cond_id  end#  ress  cap  resp
```

where

seg_id: is the name of the segment containing cond_id
cond_id: is the name of a conductor associated with seg_id
end#: is the end number (1 or 2) associated with cond_id
ress: is the series resistance value of the termination circuit of the end cell of cond_id
cap: is the capacitance value of the termination circuit of the end cell of cond_id
resp: is the parallel resistance value of the termination circuit of the end cell of cond_id

Note: The keyword descriptors in the above input file text lines may be repeated under the "BOUNDARY CONDITION" keyword and the "RCPRS" keyword using the same format for the next segment and conductor pair along with the associated parameters.

LCPRS

This keyword is used to define the inductive, capacitive, and resistive values associated with the termination circuit of Figure 4.9.1H. The required input file text line format is:

```
!BOUNDARY CONDITION
!!LCPRS
seg_id  cond_id  end#  ind  cap  res
```

where

seg_id: is the name of the segment containing cond_id
cond_id: is the name of a conductor associated with seg_id
end#: is the end number (1 or 2) associated with cond_id
ind: is the inductance value of the termination circuit of the end cell of cond_id
cap: is the capacitance value of the termination circuit of the end cell of cond_id
res: is the resistance value of the termination circuit of the end cell of cond_id

Note: The keyword descriptors in the above input file text lines may be repeated under the "BOUNDARY CONDITION" keyword and the "LCPRS" keyword using the same format for the next segment and conductor pair along with the associated parameters.

7.9.2 Input File Section 9B: System Level 1 – Shield One Boundary Conditions

The format of the input file terms used to specify System Level 1 (`SHIELD ONE`) boundary conditions is identical to that used for analogous terms of System Level 0. The only difference is in first level keywords which are preceded by the "`SHIELD ONE`" characters, as illustrated below.

`BOUNDARY CONDITION` replaced by `SHIELD ONE BOUNDARY CONDITION`

However, there are two additional keyword associated with System Level 1 terminations. These keywords are provided below:

- `SHIELD ONE BOUNDARY VOLTAGE ZTR`
- `SHIELDS JOINED AT CONNECTOR`

SHIELD ONE BOUNDARY VOLTAGE ZTR

In some situation, the effects of connectors can be accurately modeled using a terminal circuit. This is especially desirable when the actual connector properties cannot be incorporated into the corresponding connector coefficient matrices. There is never a problem incorporating the resistance into the resistance coefficient matrix. However, if the connector is capacitive with respect to the terminal box, there is no way to include this capacitance into the C matrix of the line. The only way to simulate this particular configuration is to include this capacitance in a parallel RC terminating circuit. The question then arises as to how to couple the connector current into the inside conductors when the shields are joined at the connector. This is handled in MHARNESS by injecting the relevant terminal voltage into the internal wires if requested. The use of the terminal voltage assumes that the connector circuit, incorporating the connector capacitance to the terminal box, is the entire terminating circuit.

This keyword allows the voltage at the ends of a System Level 1 conductor shield to drive the associated System Level 0 conductors. The required input file text line format is:

```
!SHIELD ONE BOUNDARY VOLTAGE ZTR
seg_id  end#
```

where

`seg_id:` is the System Level 1 segment name
`end#:` is the end number (1 or 2) associated with `seg_id`

The default condition is not to use this voltage for System Level 0 driving.

SHIELDS JOINED AT CONNECTOR

Typically connectors to terminal boxes are considered to be part of the outermost shield (System Level 2) in a numerical model. If this is the case, then the current on the outermost shield would drive the inner conductors (System Level 1) via the shield transfer impedance. However, in some situations, the outermost shield (System Level 2) and an inner shield (System Level 1) are electrically joined at the connector, via pigtails or some other configuration, thereby allowing current from the outer shield to flow directly onto the inner shield. The ability to model this situation is inherent within MHARNESS. This keyword allows the voltage at the ends of a System Level 2 conductor shield to drive the associated System Level 0 conductors. The input file text line format is:

```
!SHIELDS JOINED AT CONNECTOR
seg_id  end#
```

where

`seg_id:` is the System Level 1 segment name
`end#:` is the end number (1 or 2) associated with `seg_id`

7.9.3 Section 9A: System Level 2 – SHIELD TWO Boundary Conditions

The format of the input file terms used to specify System Level 2 (`SHIELD TWO`) boundary conditions is identical to that used for analogous terms of System Level 1. The only difference involves replacing the "`SHIELD ONE`" characters with "`SHIELD TWO`" characters, as illustrated below.

`SHIELD ONE BOUNDARY CONDITION` replaced by `SHIELD TWO BOUNDARY CONDITION`

7.10 Section 10: Ground/Reference Parameters

MHARNESS is a transmission line code and therefore, requires a reference for implementation. The reference is always associated with the exposed system level. If the impedance matrices are manually defined, then the reference is implicit within the entries of the matrices. However, for automatic computation, the reference must be identified. In MHARNESS the reference is always assumed to be a ground plane (default condition) unless otherwise specified. The ground plane can be perfectly conducting (PEC) or lossy. A PEC ground is the default condition. If a wire reference is desired instead, then this can also be specified.

There are two first level keywords associated with ground parameter information. These keywords are:

1) `WIRE GROUND`
2) `GROUND RESISTANCE`

7.10.1 WIRE GROUND

This keyword is used in conjunction with the `CAPACITANCE COMPUTE` keyword. In the absence of the `WIRE GROUND` keyword, the usual return ground for the exposed system level is assumed. The usual return ground is a ground plane, at z = 0.0. With the `WIRE GROUND` keyword, a segment conductor can be designated as the ground return. The exposed segment plus the wire ground are then assumed to be in free space as indicated by the choice of the second level keyword "`WIRE IN FREE SPACE`" which is required in the input file.

There are three second level keywords associated with the `WIRE GROUND` keyword. These are:

- `WIRE IN FREE SPACE`
- `DIELECTRIC`
- `FILAMENT NUMBER`

WIRE IN FREE SPACE

This keyword allows the specification of a wire ground. The wire must be associated with a cable segment but is not associated with any previously defined conductors. The information provided under the `WIRE IN FREE SPACE` keyword defines the location of the wire ground conductor. The required input file text line format is:

```
!WIRE GROUND
!! WIRE IN FREE SPACE
seg_id  cradius  dradius
X1  Y1  Z1  X2  Y2
```

where

`seg_id`: is the name of the segment containing the wire ground
`cradius`: is the radius of the wire ground
`dradius`: is the radius of dielectric jacket (insulation) of the wire ground
X_1: is the x-coordinate of end_1 of the wire ground
Y_1: is the y-coordinate of end_1 of the wire ground
Z_1: is the z-coordinate of end_1 of the wire ground
X_2: is the x-coordinate of end_2 of the wire ground
Y_2: is the y-coordinate of end_2 of the wire ground

DIELECTRIC

This keyword is used to specify the relative dielectric constant associated with the wire ground dielectric jacket insulation. The background dielectric constant is specified when the associated segment is defined. For this reason a wire ground can only be defined when the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` keyword combination pairs are used to define the corresponding segment to which the wire ground is associated. The required input file text line format is:

```
!WIRE GROUND
!!DIELECTRIC
seg_id  epsd
```

where

`seg_id`: is the segment name
`epsd`: is the segment jacket (insulation) relative dielectric constant

FILAMENT NUMBER

This keyword is used to specify the number of charge filaments designated to characterize the charge distribution on the wire ground required for the computation of the segment capacitance matrix. A description of the charge filaments was provided in Section 7.6.1.2. The required input file text line format is:

```
!WIRE GROUND
!!FILAMENT NUMBER
seg_id  nfc  nfd
```

where

`seg_id`: is the segment name
`nfc`: is the number of filaments used to represent the charges on wire ground conductor
`nfd`: is the number of filaments used to represent the charges on wire ground jacket

Note: the default value for "nfc" and "nfd" is 15

7.10.2 GROUND RESISTANCE

This keyword is used to specify the resistance of the ground/reference conductor associated with any particular segment. This could be the default ground plane or a wire ground. The required input file text line format is:

```
!GROUND RESISTANCE
seg_id  resistance
```

where

`seg_id`: is the segment name
`resistance`: is the ground/reference resistance value

7.11 Section 11: Output / Probes

The output of MHARNESS can be the currents and voltages at any location, on any conductor, within any branch, of the cable harness system. This includes pin voltages and termination voltages. Outputs can also include electric fields radiated from the cable system along with the automatically computed predetermined source waveforms of the previous section. The format of the output files can be either text or binary. A probe is available that specifies the creation of a POSTSCRIPT file that contains a drawing of the cross-sectional structure of any cable segment. There is also a skin depth probe that creates a file containing skin depth resistance information as a function of frequency. In addition, customized header information can be devised and written, as desired, to the output files.

The probe section of the input file is used to specify the MHARNESS output. There are six first level keywords associated with the `PROBE` section. These keywords are listed below:

1) `OUTPUT UNIVERSAL HEADER`
2) `OUTPUT FORMAT`
3) `OUTPUT SOURCE`
4) `STRUCTURE PROBE`
5) `SKIN DEPTH PROBE`
6) `PROBE`

The format of these keywords is discussed in the sections to follow in the order of appearance in the list above.

7.11.1 OUTPUT UNIVERSAL HEADER

This keyword is used to specify a universal header to be inserted in all output files created when the `PROBE` keyword is used. If a universal header is specified then three header lines, in all `PROBE` output files, are created containing the following information:

The MHARNESS version
The MHARNESS input file name
The date of execution

The three lines of header information are each preceded by a "#" character. The required input file text line format is:

```
!OUTPUT UNIVERSAL HEADER
value
```

where

`value` specifies if a universal header is to be provided ("Y" for yes and "N" for no)

If the "Y" is specified then a universal header will be created in all `PROBE` files. If a "N" is specified, then there will be no universal header. The default value is "N". Therefore, this keyword is necessary only if universal header information is desired.

7.11.2 OUTPUT FORMAT

This keyword is used to specify the format of the output file. This keyword will set the format for <u>all</u> `PROBE` files. The required input file text line format is:

```
!OUTPUT FORMAT
type
```

where

`type`: has the value of "TEXT" or "BINARY".

The "TEXT" format is the default value. Therefore, this keyword is necessary only if a binary output format is desired.

7.11.3 OUTPUT SOURCE

This keyword is used to write the source waveform to an output file. This is especially useful when the source waveform designated is one of the nine predetermined, automatically computed, waveform types (see Section 7.4). The data records are of the form

```
t, val1, val2, val3, val4, ...
t, val1, val2, val3, val4, ...
```

where:

`t`: is the simulation time
`val1:` is the respective values of the waveforms associated with the first source
`val2:` is the respective values of the waveforms associated with the second source
`val3:` is the respective values of the waveforms associated with the third source
`etc.:`

The ordering of the waveforms corresponds to the order of appearance within the input file. The first source specification to appear in the input file is the first waveform (`val1`), the second specification to appear is the second waveform (`val2`), and so on.

The required input file text line format is:

```
!OUTPUT SOURCE
file_name
end_time  del_time
```

where

`file_name:`	is the name of the source output file containing the source waveforms
`end_time:`	is the final time value to stop producing the source output
`del_time:`	is the time increment within the source output file

There are two possible formats for specifying the output times. The format depends upon the type of variables used following the `file_name` descriptor. The two formats are provided and described below.

(1) Two real numbers: `end_time del_time`

`end_time:` the final time value to stop producing the source output
`del_time:` the time increment within the source output file

(2) Two integer numbers: `end_time del_time`

`end_time:` the final time step to stop producing the source output
`del_time:` the number of time steps between the output records within the source output file

Note: The default condition is no output of source data written. The defaults for the `end_time` and `del_time` descriptors are those specified for the first probe designation.

7.11.4 STRUCTURE PROBE

The Structure Probe is used to create POSTSCRIPT files of the cross section of a particular MHARNESS cable segment. The required input file text format is:

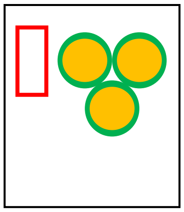
```
!STRUCTURE PROBE
!!type
file_name
pgor
legend
reference  thick
level  seg_id  cc  jc
level  seg_id  cond_id  cc  jc
```

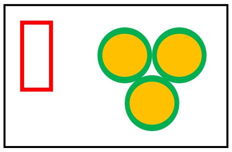
where

`file_name:`	is the output POSTSCRIPT file name
`pgor:`	is the page orientation ("H" of "V")
`legend:`	specifies the creation of a legend
`reference:`	specifies the inclusion of the segment reference ("Y" or "N")
`thick:`	is the thickness of the reference to be drawn
`level:`	is the system level
`seg_id:`	is the name of the segment containing `cond_id`

`cond_id`: is the conductor name within the segment, `seg_id`
`cc:` is the conductor color
`jc:` is the associated dielectric jacket color

The page orientation parameter (`pgor`) specifies the orientation of the drawn cable cross section on the page. There are two possible orientations – vertical and horizontal. The result of drawing a three conductor cable with dielectric jackets, for a vertical specification and a horizontal specification, is shown below.


Vertical


Horizontal

The `legend` parameter provides a colored list of all conductors within the drawing. The legend is outlined in red in the above picture.

The `reference` parameter specifies that the associated reference conductor is to be drawn. This could be a ground plane, a shield reference, or another wire. The `thick` parameter determines how thick to draw the lines depicting the reference.

There are two different types of input text lines used to specify which conductors and jackets, along with associated colors, are to be incorporated within the POSTSCRIPT file. These lines are:

```
level  seg_id  cc  jc

level  seg_id  cond_id  cc  jc
```

The `level` parameter specifies what system level, along with all associated inferior system levels, are to be drawn. If only the first line above is used, then all conductors associate with the provided segment, and all associated inferior segments, are drawn with the conductor color of `cc` and the jacket color of `jc.` If the second line is used in conjunction with the first, then individual conductors and jackets within the same system level, or any associated inferior system level, can be assigned individual colors.

7.11.5 SKIN DEPTH PROBE

The Skin Depth Probe creates a file that contains conductor resistance information, in the frequency domain, as a result of skin depth effects. The file contains three fields. The first field contains the frequency, the second field contains the actual skin depth resistance, the third field contains a fit curve. The fit curve is used by the algorithms of MHARNESS. A separate file is created for each conductor for which skin depth information is specified.

There is one second level keyword associate with the skin depth probe. This second level keyword can have three possible values. These values are:

- SHIELD TWO
- SHIELD ONE
- CABLE

The assigned second level keyword value specifies the system level for which skin depth information is be provided. The required input file text line format is:

```
!SKIN DEPTH PROBE
!!type
filename₁
seg_id₁  cond_id₁
filename₂
seg_id₂  cond_id₂
   .        .
   .        .
   .        .
filenameₙ
seg_idₙ  cond_idₙ
```

where

`filename`$_i$:	is the output file name
`seg_id`$_i$:	is the name of the segment containing `cond_id`$_i$
`cond_id`$_i$:	is the conductor name within the segment, `seg_id`$_i$

The `seg_id`$_i$ and `cond_id`$_i$ determine the segment and conductor for which skin depth information is to be provided.

7.11.6 PROBE

This keyword is used to specify the MHARNESS simulation output. There are eight associated second level keywords. These keywords are listed below:

- GENERAL INFO
- SHIELD TWO CURRENT
- SHIELD TWO VOLTAGE
- SHIELD ONE CURRENT
- SHIELD ONE VOLTAGE
- CABLE CURRENT
- CABLE VOLTAGE
- RADIATED FIELD

GENERAL INFO

The use of this keyword enables the specification of additional header information to be written to all output data files. This information follows the three universal header lines, if specified, that were discussed above. This keyword should only appear once in the input file, otherwise the last to appear will supersede the others. The required input file text line format is:

```
!PROBE
!!GENERAL INFO
gen_info_text_line1
gen_info_text_line2
        .
        .
        .
gen_info_text_linen
```

where

gen_info_text_line$_i$: is an 80 character line of text

Note: Within the output files, the provided gen_info_text_line$_i$ will be preceded by the '#' character.

SHIELD TWO CABLE CURRENT

This keyword is used to specify a conductor current output at System Level 2. If desired, additional lines of text (group_info_text_line$_i$) can be specified. These lines will follow any lines of text specified with the GENERAL INFO keyword or from any lines resulting from the specification of an OUTPUT UNIVERSAL HEADER.

If no additional lines of text are desired, then the required input file text line format is:

```
!PROBE
!!CABLE CURRENT
file_name
tstart  tstop  tstep
seg_id11  cond_id21  loc1
seg_id12  cond_id22  loc2
   .         .         .
   .         .         .
   .         .         .
seg_id1n  codn_id2n  locn
```

If additional lines of text are desired, then the required input file text line format is:

```
!PROBE
!!CABLE CURRENT
file_name
group_info_text_line1
group_info_text_line2
```

```
        .
        .
        .
group_info_text_line_n
tstart  tstop  tstep
seg_id_11  cond_id_21  loc_1
seg_id_12  cond_id_22  loc_2
   .          .          .
   .          .          .
   .          .          .
seg_id_1n  cond_id_2n  loc_n
```

where

`file_name:`	is an 80 character output file name
$group\_info\_text\_line_i$	is an 80 character line of text
`tstart:`	is the simulation time to commence writing the output
`tstop:`	is the simulation time to end writing the output
`tstep:`	is the time increment between output records
seg_id_i:	is the *ith* segment name containing `cond_id`
$cond\_id_i$:	is the *ith* conductor where current output data is desired
loc_i:	is a location on `cond_id` where current output data is desired

The `tstart`, `tstop`, and `tstep` descriptors can be specified using a real or integer format. If a real format is used, then the descriptors refer to the actual computation time. The real value of `tstep` must be greater than or equal to the simulation time increment `dt` (see Section 7.2). If an integer format is used, then the descriptors refer to the time iteration index, in steps of `dt`. If the integer `tstep` is not specified, then a value of 1 is used. If both integer values of `tstop` and `tstep` are not specified, then the last time iteration, `itmax` (see Section 7.2) is used with a `tstep` value of 1.

The loc_i descriptor can be specified using a real or integer format. If a real format is used, then the descriptor refers to the distance from end_1 of the conductor. If an integer format is used, then the descriptor refers to the number of cells from end_1.

Note: the output file name should be 80 characters or less with no spaces or other characters that might interfere with computer file naming conventions.

SHIELD TWO VOLTAGE

This keyword is used to specify a conductor voltage output at System Level 2. The variable descriptors are similar to those defined above for the `SHIELD TWO CURRENT` output with the second level keyword, "`SHIELD TWO CURRENT`", replaced by, "`SHIELD TWO VOLTAGE`".

SHIELD ONE CURRENT

This keyword is used to specify a conductor current output at System Level 1. The variable descriptors are similar to those defined above for the SHIELD TWO CURRENT output with the second level keyword, "SHIELD TWO CURRENT", replaced by, "SHIELD ONE CURRENT".

SHIELD ONE VOLTAGE

This keyword is used to specify a conductor voltage output at System Level 1. The variable descriptors are similar to those defined above for the SHIELD TWO CURRENT output with the second level keyword, "SHIELD TWO CURRENT", replaced by, "SHIELD ONE VOLTAGE".

CABLE CURRENT

This keyword is used to specify a conductor current output at System Level 0. The variable descriptors are similar to those defined above for the SHIELD TWO CURRENT output with the second level keyword, "SHIELD TWO CURRENT", replaced by, "CABLE CURRENT".

CABLE VOLTAGE

This keyword is used to specify a conductor voltage output at System Level 0. The variable descriptors are similar to those defined above for the SHIELD TWO CURRENT output with the second level keyword, "SHIELD TWO CURRENT", replaced by, "CABLE VOLTAGE".

RADIATED FIELD

This keyword specifies the computation of radiated electromagnetic fields from the outermost shields or conductors of the cable system. To specify the location where radiated fields are desired requires coordinate information. The use of coordinate information requires precise cable conductor geometric information. Therefore, the use of this keyword requires all conductors to be defined using the SEGMENT/COMPLEX or the SEGMENT/COMPLEX2 keyword combination pair. For radiated electromagnetic field computations the z-coordinate must be greater than zero.

If desired, additional lines of text (group_info_text_line$_i$) within the radiated field output file can be specified. These lines will follow any lines of text specified with the GENERAL INFO keyword or any lines resulting from the specification of an OUTPUT UNIVERSAL HEADER.

If no additional lines of text are desired, then the required input file text line format is:

```
!PROBE
!!RADIATED FIELD
file_name
tstart  tstop  tstep
x1  y1  z1
x2  y2  z2
.   .   .
.   .   .
```

```
.    .    .
xn   yn   zn
```

If additional lines of text are desired, then the required input file text line format is:

```
!PROBE
!!RADIATED FIELD
file_name
group_info_text_line1
group_info_text_line2
         .
         .
         .
group_info_text_linen
tstart  tstop  tstep
x1   y1   z1
x2   y2   z2
.    .    .
.    .    .
.    .    .
xn   yn   zn
```

where

file_name:	is an 80 character output file name
$group\_info\_text\_line_i$	is an 80 character line of text
tstart:	is the simulation time to commence writing the output
tstop:	is the simulation time to end writing the output
tstep:	is the time increment between output records
x_i:	is the x-coordinate of the ith location where radiated field information is desired
y_i:	is the y-coordinate of the ith location where radiated field information is desired
z_i:	is the z-coordinate of the ith location where radiated field information is desired

The `tstart`, `tstop`, and `tstep` descriptors can be specified using a real or integer format. If a real format is used, then the descriptors refer to the actual simulation time. The real value of `tstep` must be greater than or equal to the simulation time increment `dt` (see Section 7.2). If an integer format is used, then the descriptors refer to the time iteration index, in steps of `dt`. If the integer `tstep` is not specified, then a value of 1 is used. If both integer values of `tstop` and `tstep` are not specified, then the last time iteration, `itmax` (see Section 7.2) is used with a `tstep` value of 1.

Note: The output file name should be 80 characters or less with no spaces or other characters that might interfere with computer file naming conventions. The additional file header information provided by the optional descriptor, `group_info_text`, should be 80 characters or less. The z-coordinate must be greater than zero.

CHAPTER 8 EMA3D Considerations

There are some aspects that must be considered when calling MHARNESS from EMA3D. These aspects are listed below.

- The MHARNESS time step will be ignored
- The MHARNESS space step will be ignored
- MHARNESS plane wave excitation is forbidden
- Cables in MHARNESS must possess the same length as those specified in EMA3D
- All capacitance matrices associated with conductors in the exterior system level must be automatically computed.

The time step specification defined in EMA3D takes precedence over any specifications in MHARNESS. There is thus no need for time step information in MHARNESS. All such information will be ignored.

The space step information defined in EMA3D takes precedence over any specifications in MHARNESS. Furthermore, when MHARNESS cables are specified in EMA3D a cubic mesh is required. All cables within MHARNESS will be assigned a space step equal to that of the EMA3D cubic mesh dimension. There is thus no need for space step information in MHARNESS. All such information will be ignored.

Plane wave excitation is not allowed in MHARNESS. Plane wave excitation must originate within the three-dimensional space of EMA3D. Plane wave specification in MHARNESS will be ignored.

MHARNESS cables within EMA3D are defined by meshed lines. The cable lengths specified in MHARNESS must be the same lengths as the meshed counterpart in EMA3D.

The exposed MHARNESS conductors are those in the outer system level. These conductors require a reference in order to facilitate impedance matrix computations. The reference is supplied by EMA3D and is unavailable. Manually computing the impedance matrices is therefore not possible. The impedance matrices must be computed automatically by the algorithms of MHARNESS using the proper reference supplied by EMA3D. This requires that the `SEGMENT/COMPLEX` or the `SEGMENT/COMPLEX2` keyword combination pair be used to define all conductors in the exposed MHARNESS system level.

CHAPTER 9 Executing MHARNESS

The program MHARNESS can be invoked with one or two command line arguments. The follow two forms are acceptable.

```
$mharness   infile
```

```
$mharness   infile   diagfile
```

The first argument, "infile", specifies the input file name; the second argument, "diagfile" if present, specifies the name of the diagnostic file. The input file must have the extension, "inp". The diagnostic file must have the extension, "diag". If no diagnostic file is provided (only one command line argument), then a diagnostic file with the same base name as that of the input file, with an extension of, "diag", is automatically created.

The diagnostic file contains all error and warning messages that result from execution of the MHARNESS program. If fatal errors are detected, then the process will be aborted with error messages written to the diagnostic file. In addition, information on the geometrical layout of the system and the line parameters are also provided in the diagnostic file.

For the Windows platform, the invocation of MHARNESS in a command prompt window is similar. However if the input file and diagnostic file are not specified, an open file dialog box appears for the selection of the input file. MHARNESS can also be invoked by double-clicking on the MHARNESS icon. The input file name is again entered via the dialog box. The dialog box has the built-in filter to show files with the ‘.inp’ extension only. The diagnostic file in this case defaults to the input file base name with a ‘.diag’ extension.

CHAPTER 10 MHARNESS Examples

10.0 Introduction

This chapter contains examples of the MHARNESS input file applied to eight configurations. The examples illustrate some of the capabilities and options available. For each of the examples, MHARNESS was invoked with the command:

$mharness   ex*n*.inp

where: *n* is the numeral of the example of interest, from 1 to 8.

For WINDOWS, MHARNESS can be invoked in a Command Prompt window or by double clicking the associated icon. When performing the double-click operation, a window will appear for input file selection in which the diagnostic file shall default to ex*n*.diag.

A drawing depicting the geometry and topology of each example is presented first, followed by a brief explanation, the actual MHARNESS input file listing, and finally the computed results. The diagnostic files and data files from the runs are included in the software distribution.

10.1 Example 1

Problem

Example 1 consists of one of the simplest configurations possible – a wire over a ground plane driven by a normally incident plane wave pulse with the electric field polarized along the length of the wire. The wire is 3.0 meters long and 2 inches (0.0508 meters) above the ground with one end shorted to the ground and the other end left floating. The wire has a line resistance of 5.0e-3 ohms/meter. The background media is air.

The excitation source is a plane wave with the double exponential electric field waveform provided by the equation below:

$$E(t) = C(e^{-\alpha t} - e^{-\beta t})$$

where: C = `5.25e4`
α = `4.0e6`
β = `4.76e8`

The computed responses desired are the short circuit current at the shorted wire end and the open circuit voltage at the floating end.

The layout of Example 1 is shown in Figure 10.1.1

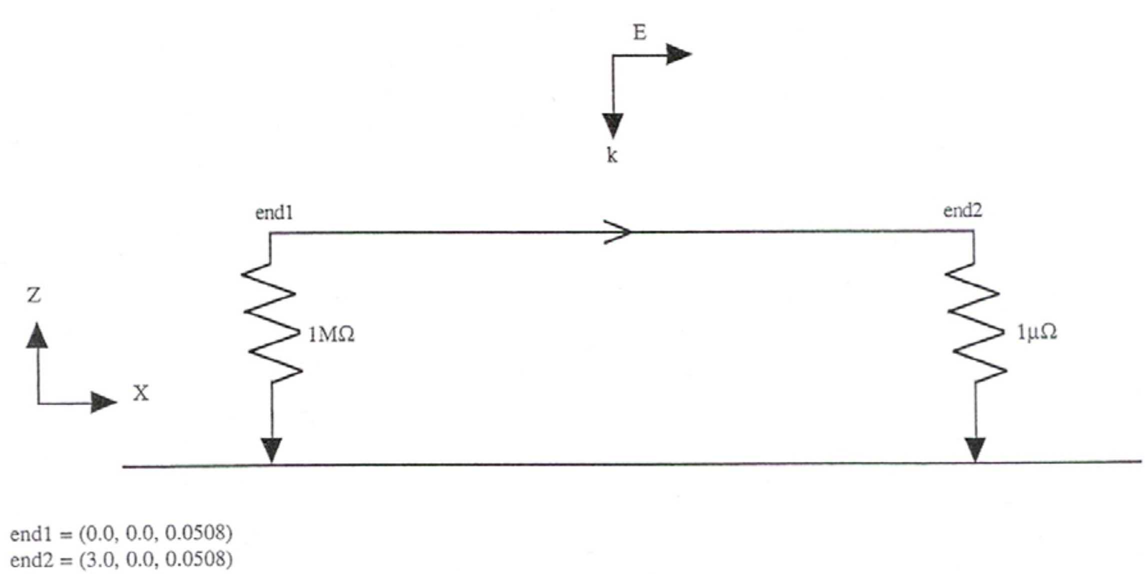


Figure 10.1.1 Example 1 Layout

Considerations

The electric field source waveform is plotted in Figure 10.1.2. The time domain waveform is plotted in Figure 10.1.1A and the frequency domain waveform in Figure 10.1.1B. Inspection of Figure 10.1.1B reveals the upper frequency limit of 500MHz to provide an excellent bandwidth to characterize the waveform. The wavelength of 500 MHz is 0.6 meters. Using ten cells per highest frequency of interest (500 MHz), results in a space step of 0.06 meters. Using the Courant condition:

$$dt < dx / v$$

mandates that

$$dt < 2.0e - 10$$

Use:

$$dt = 1.9e - 10$$

To obtain the peak response associated with the source waveform, the simulation will be executed to a time of 80 nanoseconds or for 420 time steps.

Since plane wave excitation is required, then the `EXCITATION TYPE / EMP DRIVE` keyword pair should be used. Plane wave excitation requires specification of the coordinates of the wire ends. This can be done using the `SEGMENT/SIMPLE` keyword pair with the height specified under the `EXCITATION TYPE keyword`. Without loss of generality, let the wire lie along the x-axis. Let the start point (end_1) exist at the Cartesian coordinates (x, y) of (0.0, 0.0), and the end point (end_2) at the coordinates of (3.0, 0.0).

For a height of 0.0508 meters above a ground plane the capacitance is easily calculated to be:

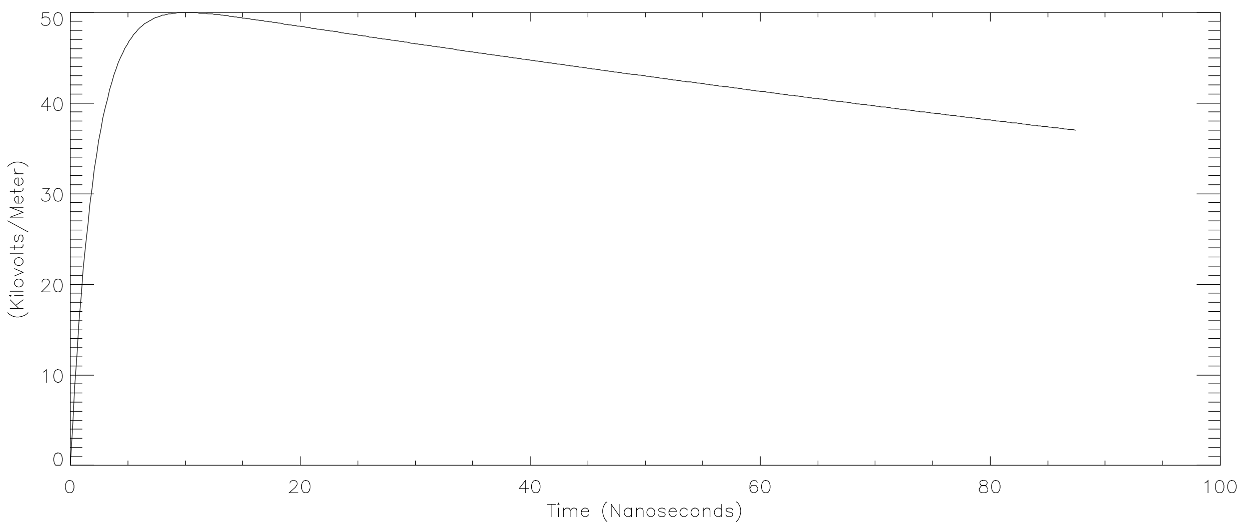
$$C = 6.667e - 12$$

The line inductance is computed using the propagation speed of light, 3.0e8m/s. Since there is no conductance, there is no `CONDUCTANCE` keyword in the input file and the wire conductance defaults to 0.0.

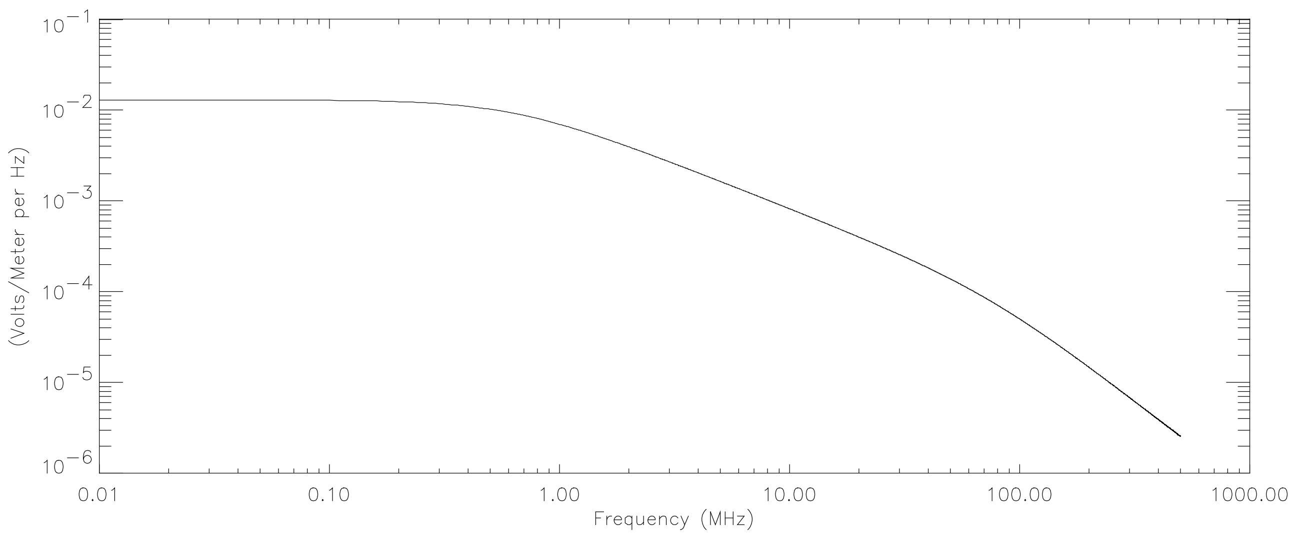
The wire is open at end_1, as indicated by the high resistance, 1.0e6 ohms in Figure 10.1.1, and shorted at end_2, as indicated by the small resistance of 1.e-6 ohms. Both ends are thus resistively terminated.

Two probes are required, one monitoring the open circuit voltage at end_1, and the other, the short circuit current at end_2. The responses should be recorded at every time step. Therefore, the output files will contain 420 records. Let the output files names be, “ex1voltout” and “ex1curout”, respectively.

The source is also written out every time step until the end of the simulation. Let the file name containing the source waveform be, “ex1srcout”.



(A) Time Domain



(B) Frequency Domain

Figure 10.1.2 Electric File Waveform

Input file listing

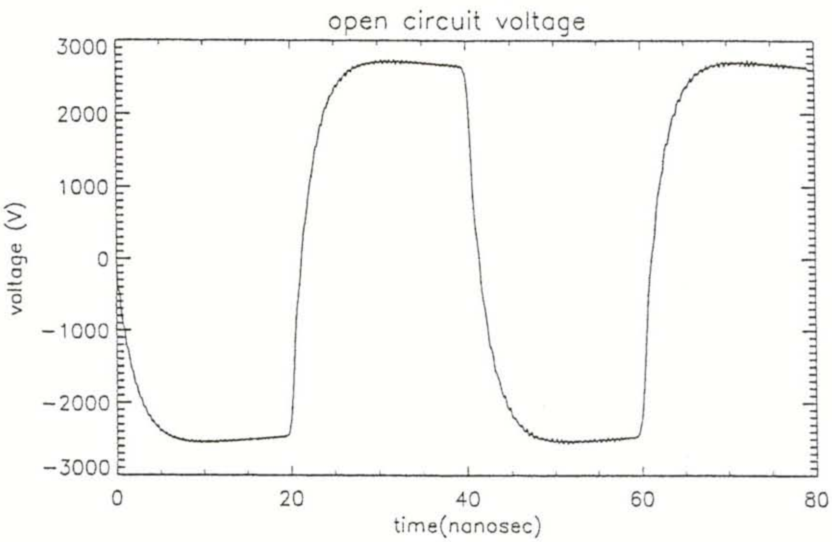
The MHARNESS input file for Example 1 is listed below.

```
* file name: ex1_alpha.inp
* input file for MHARNESS
* example 1, emp on single bare cable
* the numeral, 1, is used to name both segment and wire

*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!NOTCOMPUTE
1.9e-10  420

*************************** Section 3: SPACE STEP **************************

!SPACE STEP
0.06

*********************** Section 4: EXCITATION/SOURCE ***********************

!SOURCE WAVEFORM
!!DOUBLE EXPONENTIAL
5.25e4 4.0e6 4.76e8

*--------------------

!EXCITATION TYPE
!!CABLE
!!!PLANE WAVE DRIVE
5.08e-2  180.0  90.0  90.0  0.0

******************** Section 5: Cable Conductor Topology *******************

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!SIMPLE
1  0  0  0.0  0.0  3.0  0.0
1

************** Section 6: Cable Conductor Impedance Parameters *************

*---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------

!CAPACITANCE
1
6.667e-12

*--------------------

!INDUCTANCE COMPUTE
1 ,  3.0e8

*--------------------

!RESISTANCE
```

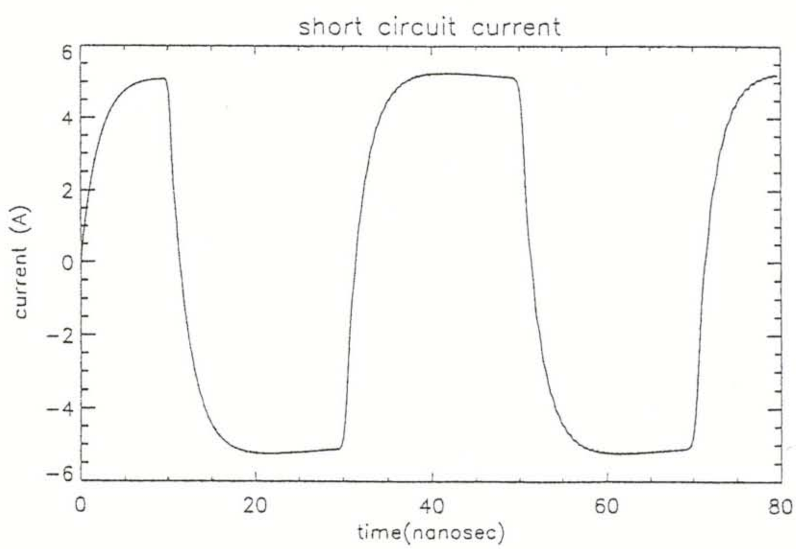
```
1 1  5.0e-3

****************** Section 9: Cable BOUNDARY CONDITIONS ******************

*---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------

!BOUNDARY CONDITION
!!RESISTIVE
1  1  1 , 1.e6
1  1  2 , 1.e-6

************************ Section 10: Output / PROBE **********************

!OUTPUT SOURCE
ex1srcout
420

*--------------------

!PROBE
!!CABLE VOLTAGE
ex1voltout
0.0, 80e-9, 1
1,1,0.0

!PROBE
!!CABLE CURRENT
ex1curout
0.0, 80e-9, 1
1,1,3.0
```

Results

The open circuit voltage is plotted in Figure 10.1.3A, and the short circuit current in Figure 10.1.3B



(A) Open Circuit Voltage



(B) Short Circuit Current

Figure 10.1.3 The Computed Responses of Example 1

10.2 Example 2

Problem

Example 2 consists of four wires joined at a junction to form a cross. All wires are left floating at the other opposite ends. The wire segments exist at a constant height of 5.08e-2 meters (2 inches) above a ground plane. The wires all possess a resistance of 5.0 milliohms. The layout is shown in Figure 10.2.1.

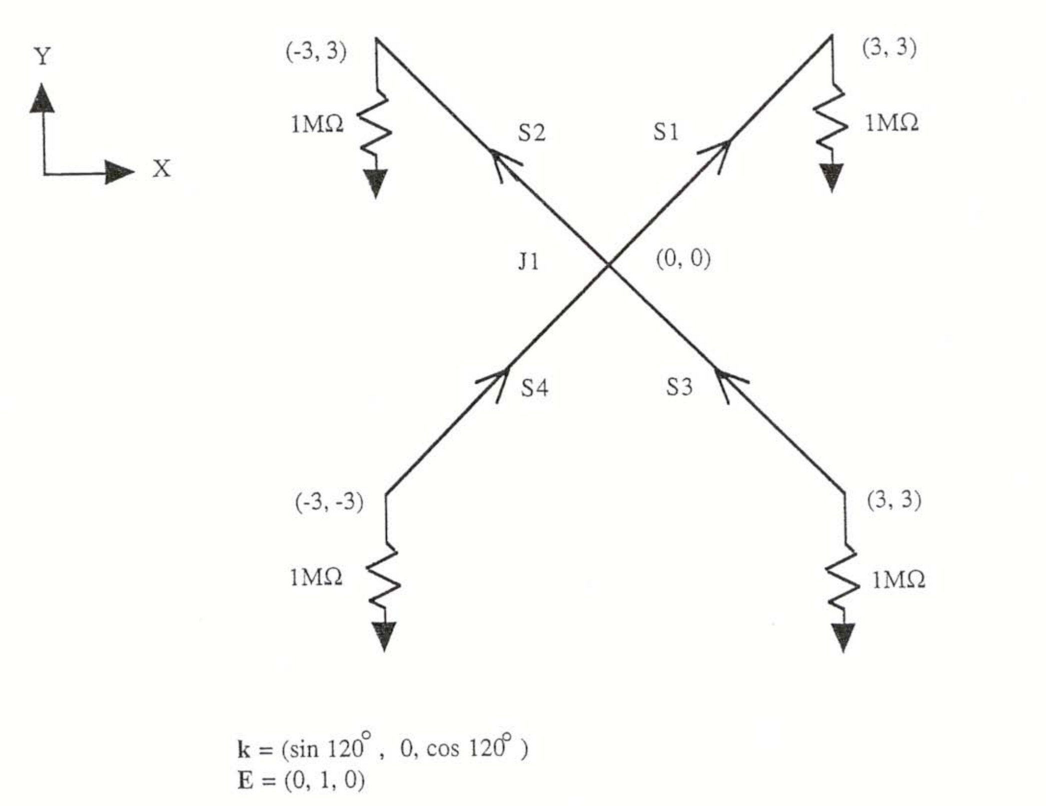


Figure 10.2.1 Example 2 Layout

The segment arms are oriented at 45° to the x and y axes with (x, y) coordinates and directions as indicated in the figure. The segments are driven by an incident plane wave pulse possessing a polar angle of 60° with the electric field polarized in the y-direction. The background media is air. The excitation source is a plane wave with the double exponential electric field waveform provided by the equation below:

$$E(t) = C(e^{-\alpha t} - e^{-\beta t})$$

where: C = `5.25e4`
α = `4.0e6`
β = `4.76e8`

The computed responses desired are the short circuit current of segment S1 at the junction and the open circuit voltage at the floating end of S1.

Considerations

The electric field source waveform is plotted in Figure 10.2.2. The time domain waveform is plotted in Figure 10.2.2A and the frequency domain waveform in Figure 10.2.2B. Inspection of Figure 10.2.2B reveals the upper frequency limit of 350MHz to provide an adequate bandwidth to characterize the waveform. The wavelength of 350 MHz is approximately 0.86 meters. Using ten cells to resolve the wavelength of the highest frequency of interest (350 MHz), results in a space step of 0.086 meters. Using the Courant condition:

$$dt < dx / v$$

mandates that:

$$dt < 2.87e - 10$$

Let's use:

$$dt = 1.414e - 10$$

To obtain the peak response associated with the source waveform, the simulation will be executed to a time of 80 nanoseconds or for 565 time steps.

The wire segments are approximately 4.24 meters long. To produce a space step of approximately 0.086, the length can be divided by 50.

Since plane wave excitation is required, then the `EXCITATION TYPE / EMP DRIVE` keyword pair should be used. Plane wave excitation requires the specification of the coordinates of all wire ends. This can be done as in Example 1 or by using the `SEGMENT/COMPLEX` keyword pair with the height not included in the specification under the `EXCITATION TYPE keyword`.

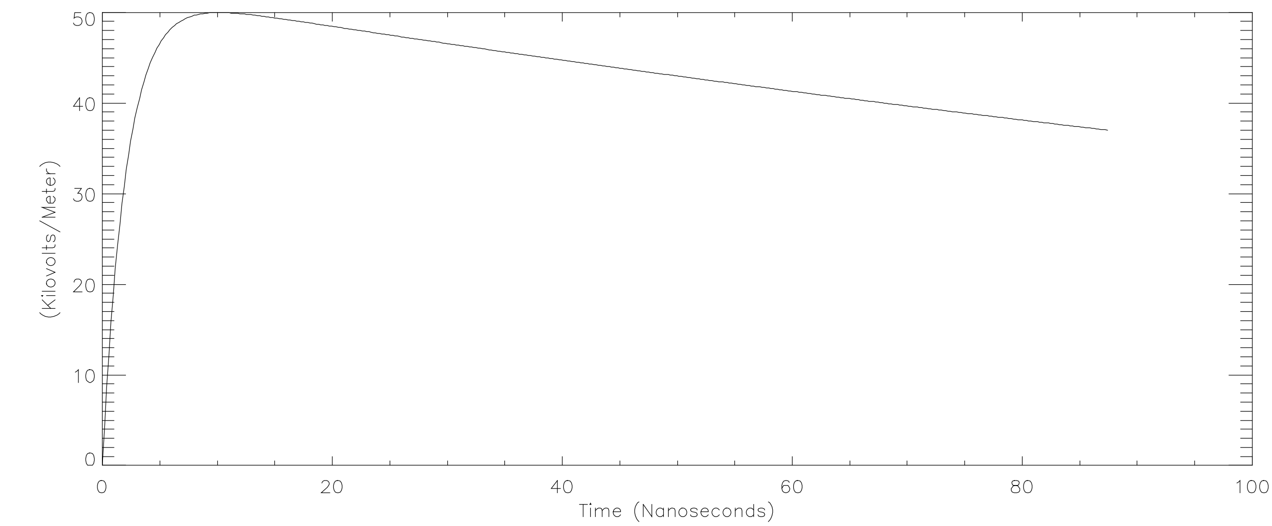
Examination of Figure 10.2.1 reveals two of the wire segments to begin at the junction while the other two segments end at the same junction. Note the different ways of specifying the segments, the capacitances and the resistances.

For a height of 0.0508 meters above a ground plane, the capacitance is easily calculated to be:

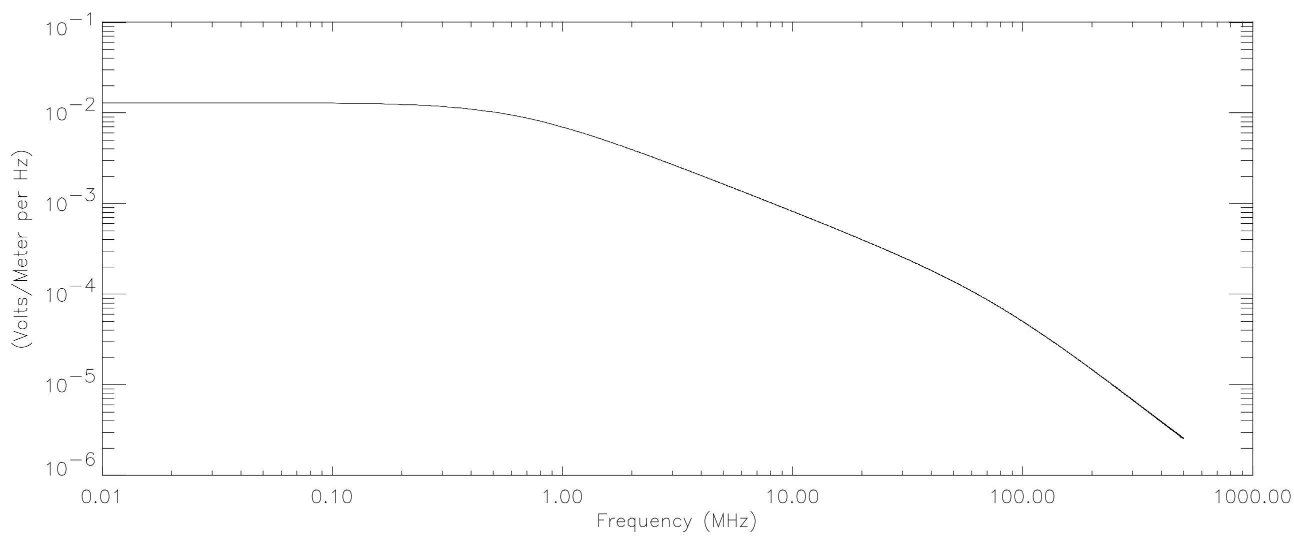
$$C = 6.667e - 12$$

The line inductance is computed using the propagation speed of light, 3.0e8m/s.

Two probes are required, one monitoring the current on S1 at the junction end (end_1) and the other, the open circuit voltage at the floating end (end_2). The responses should be recorded every time step. Therefore, the output files will contain 565 records. Let the output files names be, "ex2curout" and "ex2voltout", respectively.



(A) Time Domain



(B) Frequency Domain

Figure 10.2.2 Electric File Waveform

Input file listing

The MHARNESS input file for Example 2 is listed below.

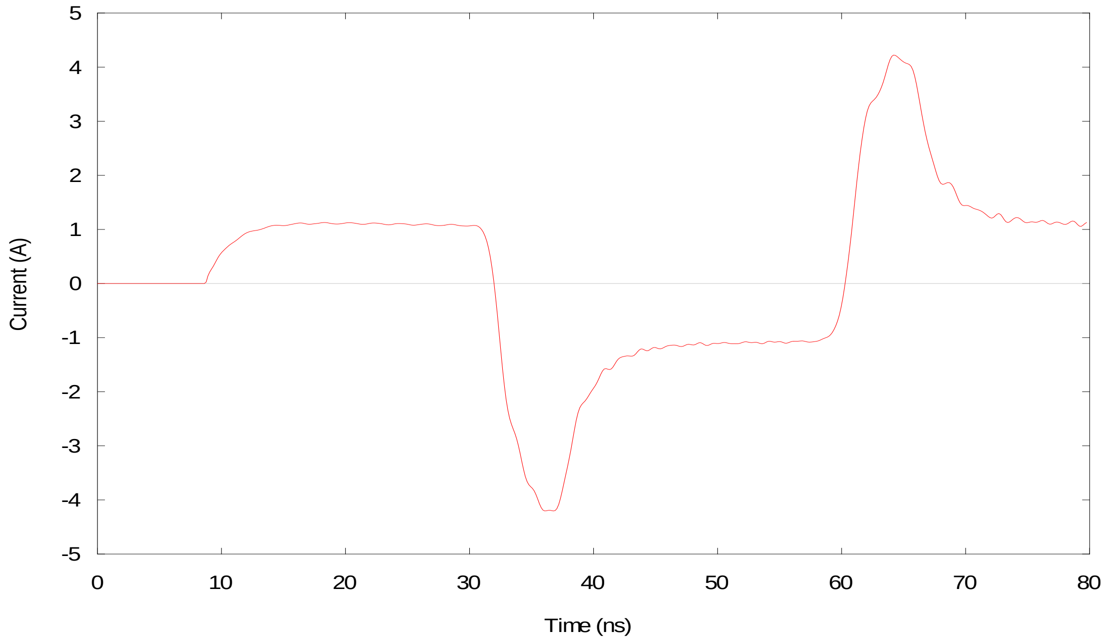
```
* filename: ex2_alpha.inp
* input file for mharness
* example 2, emp on a cross make up of bare cables

*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!NOTCOMPUTE
1.414e-10 565

*************************** Section 3: SPACE STEP **************************

!SPACE STEP
 s1  50
 s2  50
 s3  50
 s4  50

*********************** Section 4: EXCITATION/SOURCE ***********************

!EXCITATION TYPE
!!CABLE
!!!PLANE WAVE DRIVE
120.0  0.0  90.0  90.0

*--------------------

!SOURCE WAVEFORM
!!DOUBLE EXPONENTIAL
5.25e4  4.0e6  4.76e8

******************** Section 5: Cable Conductor Topology *******************

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!COMPLEX
s1  1  0
1,  0.0  0.0  5.08e-2, 3.0  3.0
s3, 0, 1,
1, 3.0  -3.0  5.08e-2, 0.0  0.0
s4, 0, 1,
1, -3.0 -3.0  5.08e-2, 0.0, 0.0
s2    1    0
1    0.0    0.0  5.08e-2   -3.0   3.0

*--------------------

!JUNCTION AND NODE
1

1
s1  1
```

```
s2  1
s3  1
s4  1


************** Section 6: Cable Conductor Impedance Parameters *************

*---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------

!CAPACITANCE
s1    6.667e-12

!CAPACITANCE
s2
6.667e-12

!CAPACITANCE
s3
6.667e-12

!CAPACITANCE
s4
6.667e-12

*--------------------

!INDUCTANCE COMPUTE

s1 3.0e8
s2 3.0e8
s3 3.0e8
s4 3.0e8

*--------------------

!RESISTANCE
s1 1  5.0e-3
s4 1  5.0e-3
s2 1  5.0e-3
s3 1  5.0e-3


******************* Section 9: Cable BOUNDARY CONDITIONS *******************

*---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------

!BOUNDARY CONDITION
!!RESISTIVE
s1,  1,  2,  1.e6
s2,  1,  2,  1.e6
s3,  1,  1,  1.e6
s4,  1,  1,  1.e6


************************* Section 10: Output / PROBE **********************

!PROBE
!!CABLE VOLTAGE
ex2voltout
0.0, 80e-9, 1
s1,1,1
s1,1,51
s2,1,51
s3,1,1
```

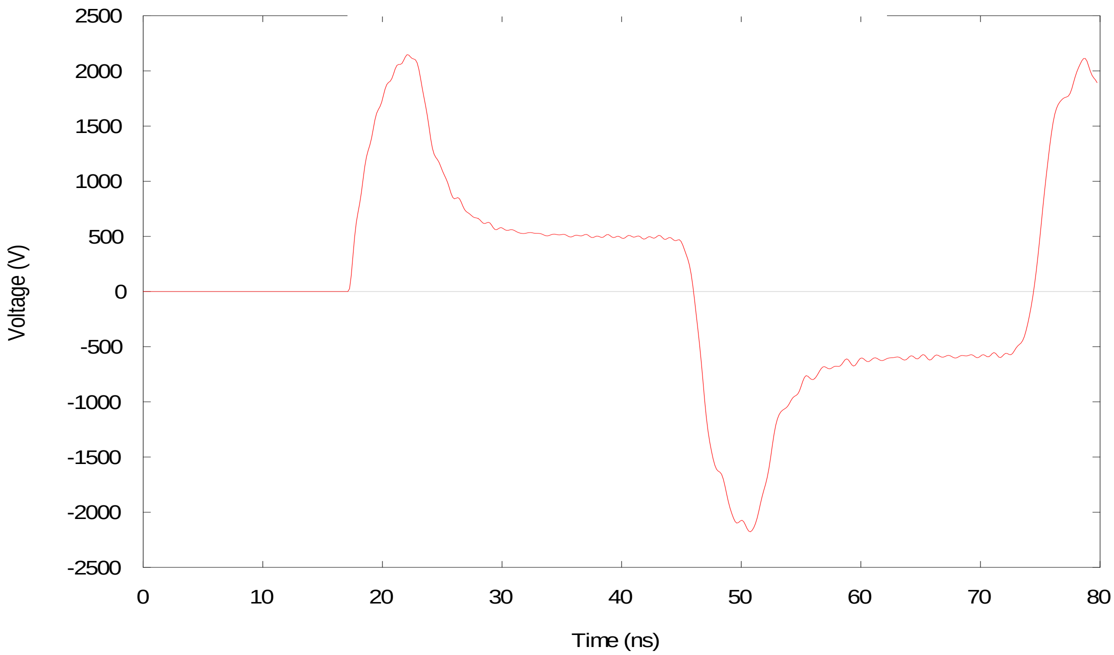
```
s4,1,1

!PROBE
!!CABLE CURRENT
ex2curout
0.0, 80e-9, 1
s1,1,1
s1,1,50
s2,1,50
s3,1,1
s4,1,1
```

Results

The short circuit current on S1 at the junction is plotted in Figure 10.2.3A, and the open circuit voltage at the floating end in Figure 10.2.3B



(A) Current on S1 at the Junction



(B) Voltage at Floating End of S1

Figure 10.2.3 The Computed Responses of Example 2

10.3 Example 3

Problem

Example 3 consists of two equal length parallel PEC wires, 0.3048 meters (12 inches) long. The highest frequency of interest is 5 GHz. The capacitance and inductance matrices are defined below.

$$C = \begin{bmatrix} 62.8e-12 & -4.94e-12 \\ -4.94e-12 & 62.8e-12 \end{bmatrix}$$

and the inductance matrix is defined to be:

$$L = \begin{bmatrix} 494.6e-9 & 63.3e-9 \\ 63.3e-9 & 494.6e-9 \end{bmatrix}$$

The cable layout is shown in Figure 10.3.1.

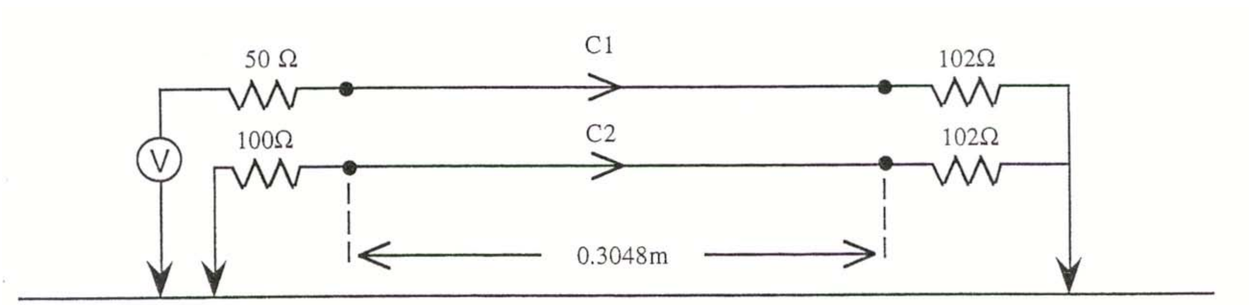


Figure 10.3.1 Example 3 Layout

One of the conductors, denoted as C1 in the figure, is terminated in 50 ohms at the start end and 102 ohms at the other end. The other conductor, denoted as C2, is terminated in 100 ohms at the start end and 102 ohms at the other end. The cable system is driven by a pin voltage on the 50 ohm terminated end. The pin voltage waveform consists of a linear ramp function given by the following equation.

$$V(t) = amp * t / t_p \qquad 0 \le t \le t_p$$

$$V(t) = amp \qquad t > t_p$$

where: amp = `4.0`

t_p = `1.5e-9`

The computed responses desired are the voltages at the 102 ohm terminated end of C1, and at both terminated ends of C2.

Considerations

The highest frequency of interest is 5 GHz. The space step can be computed automatically from this frequency value. Let’s use the default condition of ten cells to resolve the wavelength of the highest frequency of interest and let’s compute the time domain result out to a time of 5.0 nanoseconds.

One probe is required to record the three voltage responses. The responses should be recorded at every time step. Let the output file name be, “ex3voltout”.

Input file listing

The MHARNESS input file for Example 3 is listed below.

```
*
* input file for MHARNESS
* example 3, two-wire segment, voltage drive
*

*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!COMPUTE
5.0e-9  5.0e9

*********************** Section 4: EXCITATION/SOURCE ***********************

!EXCITATION TYPE
!!CABLE
!!!PIN VOLTAGE DRIVE

*--------------------

!SOURCE WAVEFORM
!!LINEAR RAMP
4.0  1.5e-9
1  1  1

******************** Section 5: Cable Conductor Topology *******************

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!simple
1  0  0  2  0.3048

************** Section 6: Cable Conductor Impedance Parameters *************

*---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------

!CAPACITANCE
1
62.8e-12  -4.94e-12
-4.94e-12  62.8e-12

*--------------------

!INDUCTANCE
1
494.6e-9    63.3e-9
63.3e-9     494.6e-9

*--------------------

!!RESISTIVE
1  1  2  102.0
1  2  2  102.0

*--------------------
```

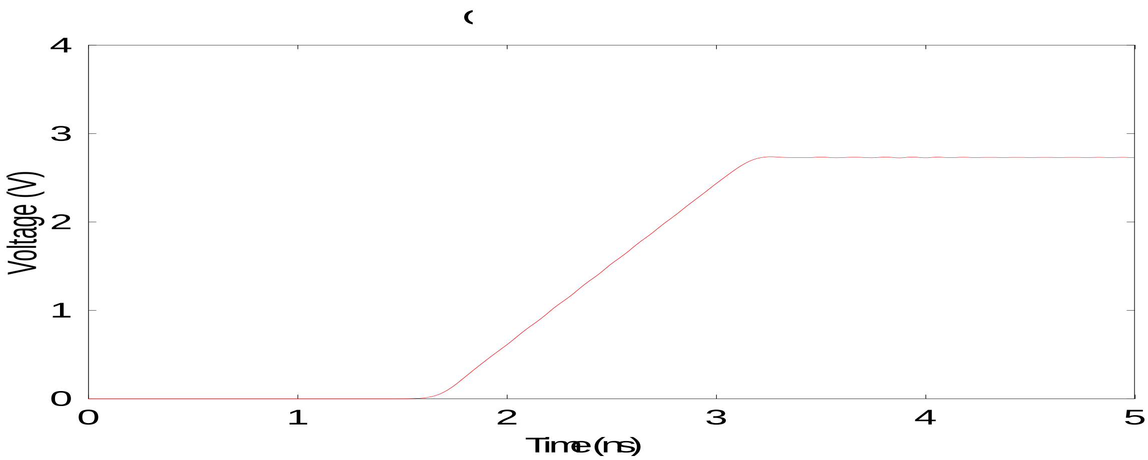
```
!CAPACITANCE
1
62.8e-12  -4.94e-12
-4.94e-12  62.8e-12

****************** Section 9: Cable BOUNDARY CONDITIONS ******************

*---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------

!BOUNDARY CONDITION
!!RESISTIVE
1  1  1  50.0
1  2  1  100.0

************************ Section 10: Output / PROBE **********************

!OUTPUT SOURCE
ex3srcout
2.5e-9

*--------------------

!PROBE
!!CABLE VOLTAGE
ex3voltout
0.0, 5.0e-9, 1
1,1,0.3048
1,2,0.0
1,2,0.3048
```

Results

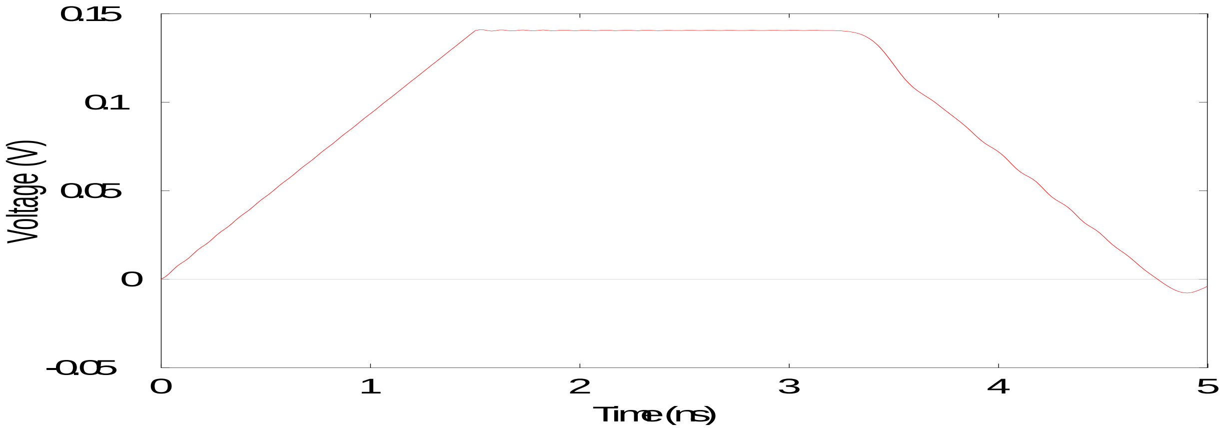
The voltage on the 102 ohm end of conductor C1 is plotted in Figure 10.3.2A, the voltage on the 100 ohm end of C2 is plotted in Figure 10.3.2B, and the voltage on the 102 ohm end of C2 is plotted in Figure 10.3.2C.

The coupling of C1 to C2 in the segment is illustrated in the voltage plots. Comparable results for a similar setup are presented by:

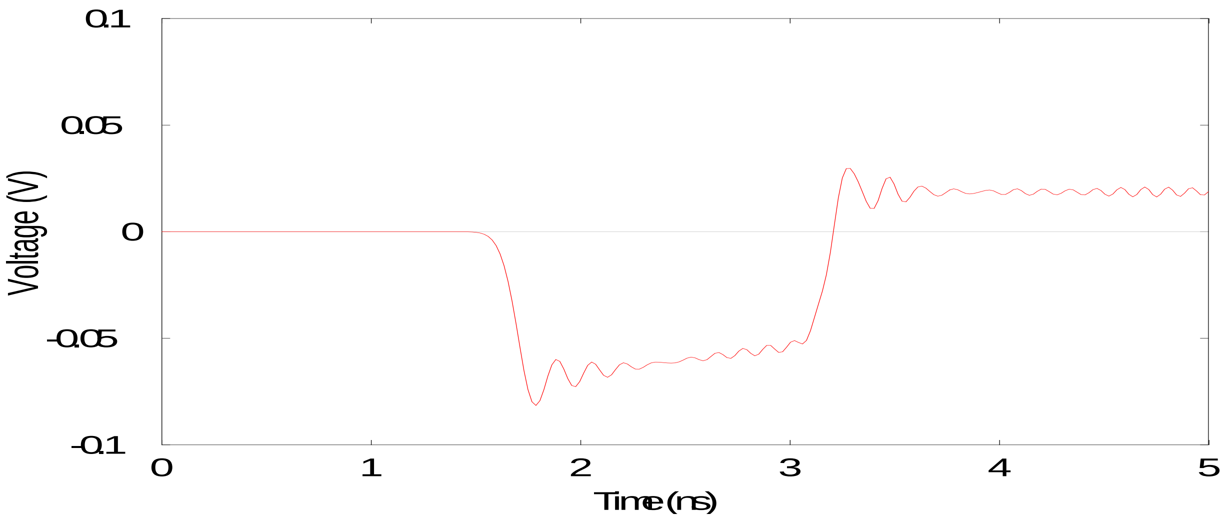
A. R. Djordjevic, T. K. Sarkar and R. F. Harrington, "Time Domain Response of Multiconductor Transmission Lines," Proceedings of the IEEE, Vol. 75, No. 6, pp. 111-132, June 1987.



(A) The Voltage at End_2 of C1



(B) The Voltage at End_1 of C2



(C) The Voltage at End_2 of C2

Figure 10.3.2 Computed Responses of Example 3

10.4 Example 4

Problem

Example 4 consists of 5 cable segments. The layout is shown in Figure 9.4.1.

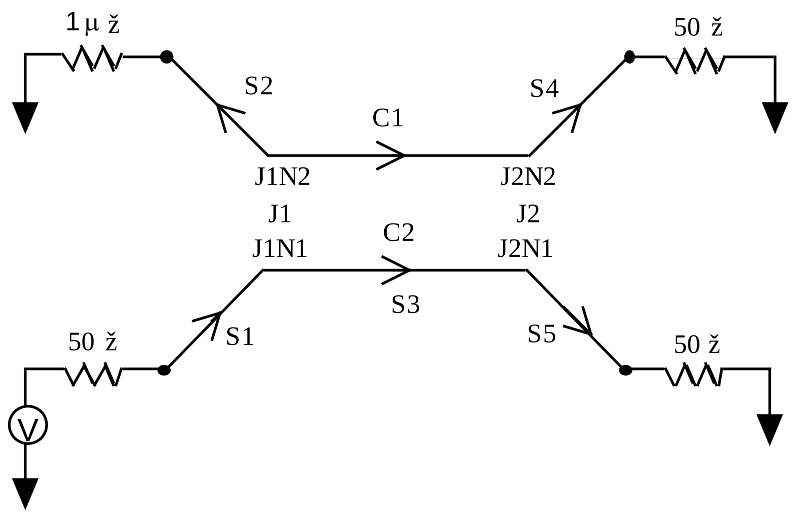


Figure 10.4.1 Example 4 Layout

All segments consist of one conductor except segment S3. Segment S3 consist of two conductors labeled, “C1” and “C2”. Segments S1, S2, S4, and S5 have lengths of 0.120 meters. Segment S3 has a length of 0.0245 meters.

There are two junctions labeled, “J1” and “J2” in the Figure 10.4.1. Within each junction are two nodes. In junction J1 the nodes are labeled “J1N1” and “J1N2”. In junction J2 the nodes are labeled “J2N1” and “J2N2”. Each of the four nodes has two connected conductors. The single conductor of segment S1 connects to conductor C2 of segment S3 at node J1N1 within Junction J1. Likewise, the single conductor of segment S4 connects to conductor C1 of segment S3 at node J2N2 within Junction J2. Three of the five segments have one end terminated in 50 ohms. Segment S2 is shorted at end_2.

The capacitance matrix for segment S3 is defined to be:

$$C = \begin{bmatrix} 2.242e-10 & -7.453e-11 \\ -7.453e-11 & 2.242e-10 \end{bmatrix}$$

The capacitance for the other segments is defined to be 1.915e-10.

The speed of propagation for segments S1, S2, S4, and S5 is defined to be 1.041e8 m/s. The speed of propagation for segment S3 is defined to be 1.059e8 m/s.

The system is driven by a Gaussian voltage source (pin voltage drive) at end_1 of segment S1. The Gaussian waveform is given below.

$$f(t) = A * e^{-((t-t_p)/w)^2}$$

where: A = 1.0
t_p = `400.0e-12`
w = `100.0e-12`

The time step is defined to be 3.23e-12. The space step for all segments, except S3, is defined to be 1.5e-3. The space step for segment S3 is defined to be 1.02e-3. This is smaller than that of the other segments. The simulation is to be executed for 2000 time steps.

The computed responses desired are the voltage at end_1 of the single conductor of segment S1 (at the 50 ohm termination), the voltage at end_2 of the single conductor of segment S4 (at the 50 ohm termination), and the voltage at end_2 of the single conductor of segment S5 (at the 50 ohm termination). Record these voltage responses at every computation time step in a file named, “ex4voltout”.

An output file containing the source waveform should also be created. Record the source waveform at <u>every</u> <u>other</u> computational time step in a file named, “ex4srcout”.

<u>Considerations</u>

Note: there needs to be as many appearances of the keyword, “`JUNCTION AND NODE`” as there are junctions in the problem. For Example 2 there are two junctions. Therefore, the `JUNCTION AND NODE` keyword should appear twice in the input file.

Input file listing

The MHARNESS input file for Example 4 is listed below.

```
* input file for mharness
* example 4, directional coupler


*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!NOTCOMPUTE
3.23e-12  2000


*************************** Section 3: SPACE STEP **************************

!SPACE STEP
S1  1.5e-3
S2  1.5e-3
S3  1.02e-3
S4  1.5e-3
S5  1.5e-3


*********************** Section 4: EXCITATION/SOURCE ***********************

!EXCITATION TYPE
!!CABLE
!!!PIN VOLTAGE DRIVE

*--------------------

!SOURCE WAVEFORM
!!GAUSSIAN
1.0,  400.0e-12,  100.0e-12
S1  1  1


******************** Section 5: Cable Conductor Topology *******************

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!SIMPLE
S1  0  J1  0.120
1
S2  J1  0  0.120
1
S3  J1  J2  0.0245
C1
C2
S4  J2  0  0.120
1
S5  J2  0  0.120
1

*--------------------

!JUNCTION AND NODE
J1
```

```
J1N1
S1 1
S3 C2

J1N2
S2 1
S3 C1


!JUNCTION AND NODE
J2

J2N1
S3 C2
S5 1

J2N2
S4 1
S3 C1
```

************** Section 6: Cable Conductor Impedance Parameters *************

*---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------

```
!CAPACITANCE
S5  1.915e-10
S4  1.915e-10
S2  1.915e-10
S1  1.915e-10
S3
 2.242e-10,  -7.453e-11
-7.453e-11,   2.242e-10

*--------------------

!INDUCTANCE COMPUTE
S1 1.041e8
S2 1.041e8
S3 1.059e8
S4 1.041e8
S5 1.041e8
```

******************* Section 9: Cable BOUNDARY CONDITIONS *******************

*---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------

```
!BOUNDARY CONDITION
!!RESISTIVE
S1  1  1  50.0
S2  1  2  1.0e-6
S4  1  2  50.0
S5  1  2  50.0
```

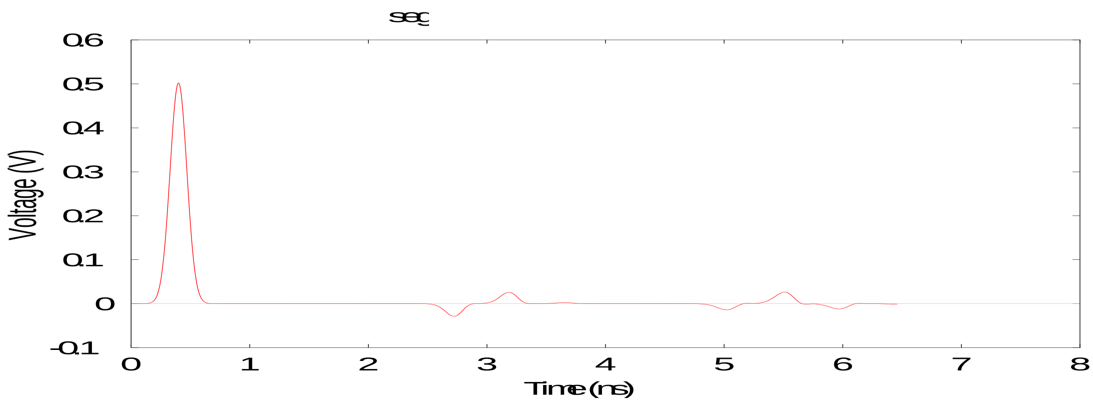
************************* Section 10: Output / PROBE **********************

```
!OUTPUT SOURCE
ex4srcout
2000,  2

*--------------------
```

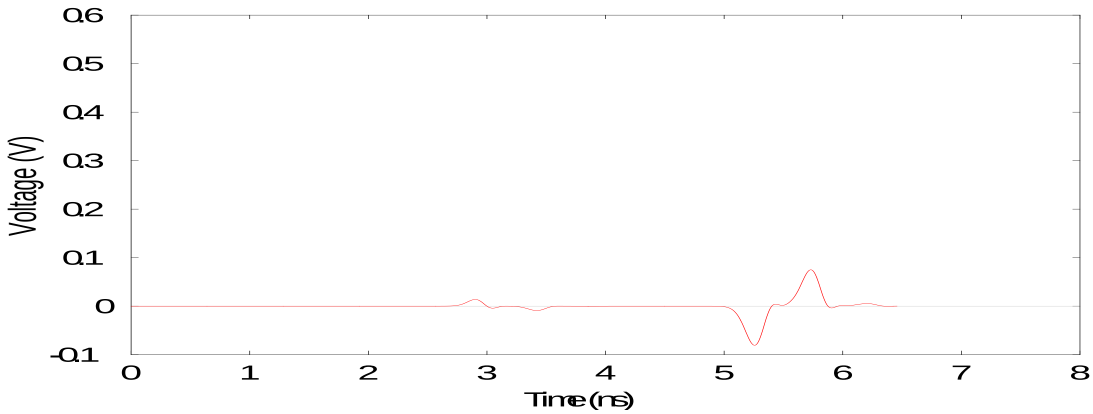
```
!PROBE
!!CABLE VOLTAGE
ex4voltout
1, 2000, 1
S1,1,0.0
S4,1,0.120
S5,1,0.120
```

Results

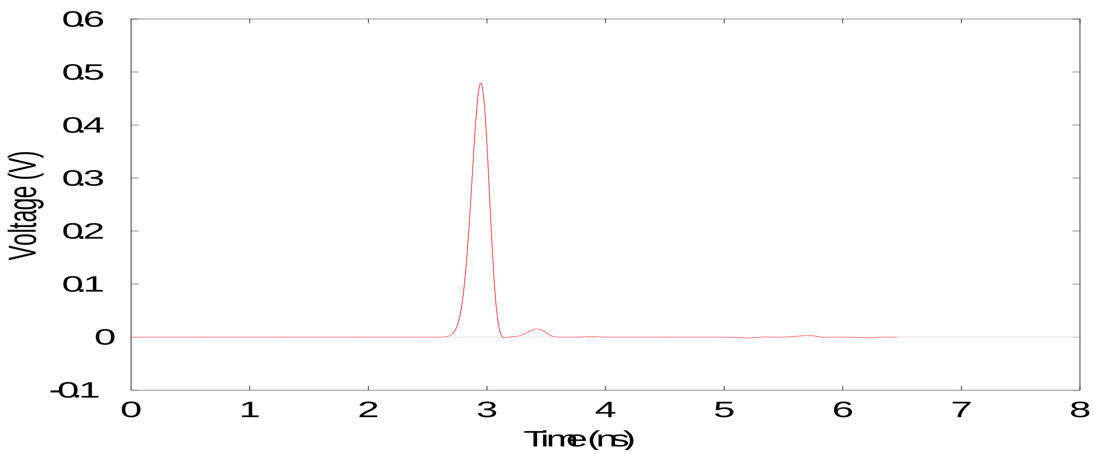
The voltage at end_1 of the single conductor of segment S1 is plotted in Figure 10.4.2A, the voltage at end_2 of the single conductor of segment S4 is plotted in Figure 10.4.2B, and the voltage at end_2 of the single conductor of segment S5 is plotted in Figure 10.4.2C. The scattering matrix, S, can be computed from the output of this example.



(A) Voltage at End_1 of Segment S1



(B) Voltage at End_2 of Segment S4



(C) Voltage at End_2 of Segment S5

Figure 10.4.2 Computes Responses of Example 4

10.5 Example 5

Problem

Example 5 consists of a shielded pair of wires, positioned over a PEC ground plane, illuminated by a plane wave pulse. The plane wave is normally incident upon the ground with the electric field polarized along the length of the cable segment. The cable segment is 0.540 meters long and positioned at a height of 0.508 meters (2 inches) above the ground. The layout is shown in Figure 10.5.1.

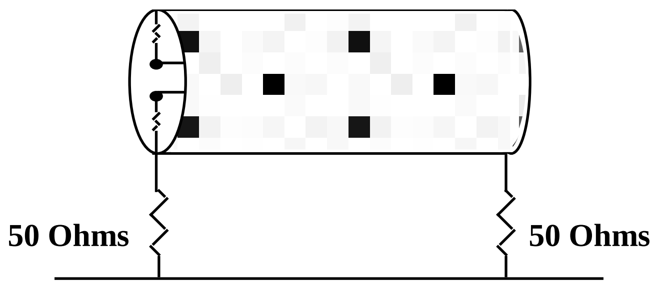


Figure 10.5.1 Example 5 Layout

Both of the wires and the shield are terminated in 50 ohms. The shield has a resistance of 22.9e-3 ohms/meter and a transfer inductance of 4.0e-9 V/(A-s).

The capacitance matrix for the two wires is defined to be:

$$C = \begin{bmatrix} 85.0e-12 & -20.5e-12 \\ -20.5e-12 & 85.0e-12 \end{bmatrix} \quad \text{farads/meter}$$

The capacitance of the shield is defined to be 20.27e-12 farads/meter.

The speed of propagation for the two wires is defined to be 2.01e8 m/s. The speed of propagation for the shield conductor is defined to be 3.0e8 m/s.

The excitation source is a plane wave with the double exponential electric field waveform provided by the equation below:

$$E(t) = C(e^{-\alpha t} - e^{-\beta t})$$

where: C = 5.25e4
α = 4.0e6
β = 4.76e8

The time step is defined to be 0.5e-10. Use 18 finite difference special increments to model the cable segment. The simulation is to be executed for 600 time steps.

The computed responses desired are the current on end_2 of the shield and the induced voltage on end_2 of one of the conductors.

Considerations

Note: it is not necessary to input the coordinates or the length of the two shielded wires. These values default to those associated with the shield. In addition, responses are desired at end2 for both the shield and one of the shielded wires. However the cable system is symmetric at either end and therefore the particular end selected is irrelevant, especially since the polarity of the plane wave electric field vector was never defined.

Input file listing

The MHARNESS input file for Example 5 is listed below.

```
* input file for mharness
* example 5, two-wire segment with shield, emp drive

*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!NOTCOMPUTE
 0.5e-10 600

*************************** Section 3: SPACE STEP *************************

!SPACE STEP
sh1  18

*********************** Section 4: EXCITATION/SOURCE **********************

!EXCITATION TYPE
!!SHIELD ONE
!!!PLANE WAVE DRIVE
5.08e-2,  180.0, 90.0,  90.0, 0.0

*--------------------

!SOURCE WAVEFORM
!!DOUBLE EXPONENTIAL
5.25e4  4.0e6   4.76e8

******************** Section 5: Cable Conductor Topology *******************

*------------ Section 5B: System Level 1 – SHIELD ONE Topology -------------

!SHIELD ONE SEGMENT
!!SIMPLE
sh1,  0,  0,  0.0, 0.0, 540.0e-3, 0.0
1

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!SIMPLE
1  0  0
1
2

************** Section 6: Cable Conductor Impedance Parameters *************

*------ Section 6B: System Level 1 – SHIELD ONE Impedance Parameters -------

!SHIELD ONE CAPACITANCE
sh1
20.27e-12
```

```
*--------------------

!SHIELD ONE INDUCTANCE COMPUTE
sh1  3.0e8

*--------------------

!SHIELD ONE RESISTANCE
sh1, 1, 22.9e-3

*--------------------

!SHIELD ONE TO CABLE
1,sh1,1,1,1,4.0e-9
```

***---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------**

```
!CAPACITANCE
1
85.0e-12  -20.5e-12
-20.5e-12  85.0e-12

*--------------------

!INDUCTANCE COMPUTE
1  2.01e8
```

********************* Section 9: Cable BOUNDARY CONDITIONS *********************

***------- Section 9B: System Level 1 – SHIELD ONE BOUNDARY CONDITIONS -------**

```
!SHIELD ONE BOUNDARY CONDITION
!!RESISTIVE
sh1  1  1  50.0
sh1  1  2  50.0
```

***---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------**

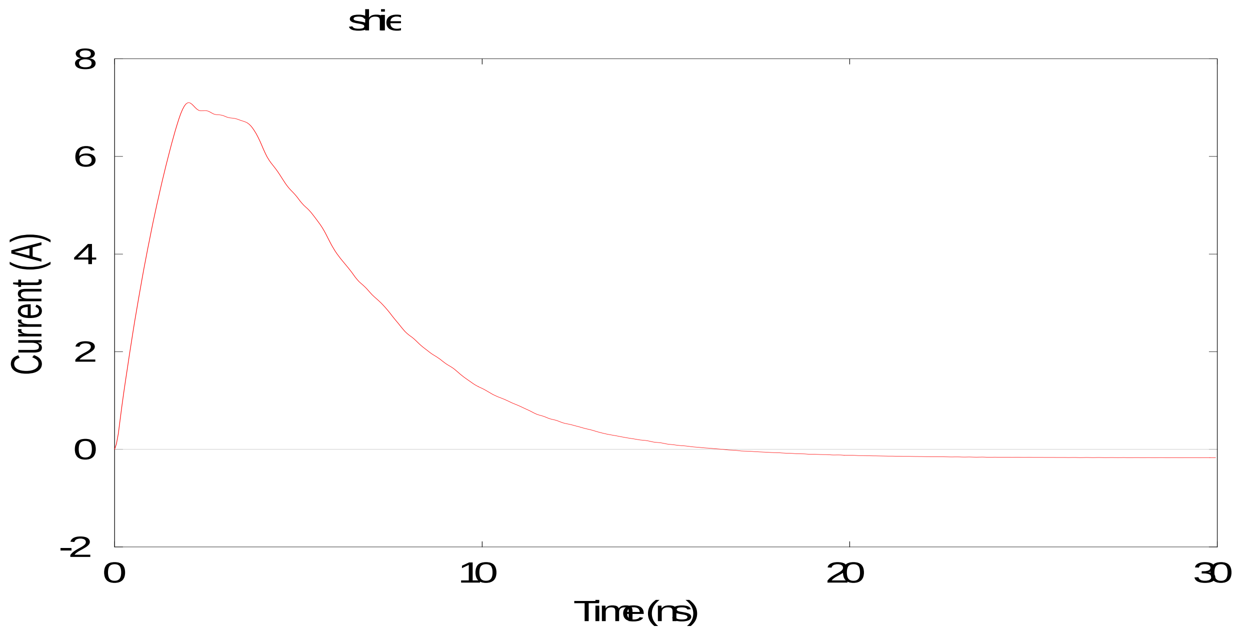
```
!BOUNDARY CONDITION
!!RESISTIVE

1  1  1  50.0
1  1  2  50.0
1  2  1  50.0
1  2  2  50.0
```

*************************** Section 10: Output / PROBE *************************

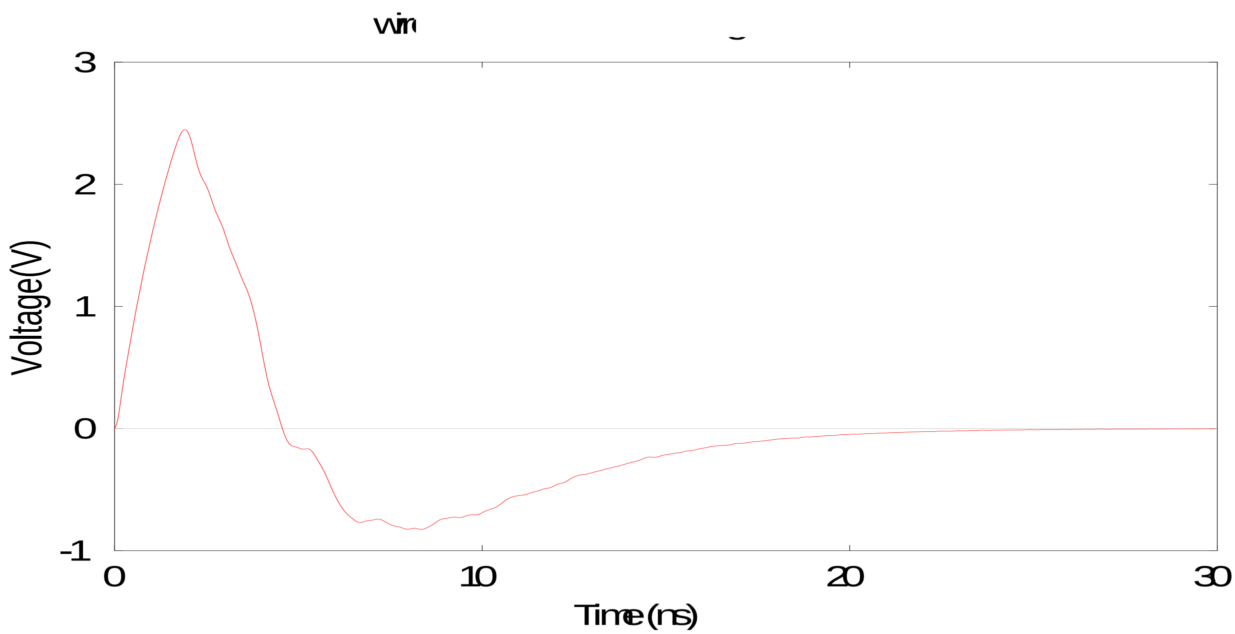
```
!PROBE
!!SHIELD ONE CURRENT
ex5s1cout
0 600 1
sh1 1 1
sh1 1 18
!!CABLE VOLTAGE
ex5vout
0, 600,  1
1,1,1
1 1 19
```

Results

The current at end_2 of the shield is plotted in Figure 10.5.2A, and the induced voltage at end_2 of one of the shielded conductors is plotted in Figure 10.5.2B



(A) Current at End_2 of the Shield



(B) Induced Voltage at End_2 of a Shielded Wire

Figure 10.4.2 Computed Responses of Example 5

10.6 Example 6

Problem

Example 6 consists of three insulated wires located over a PEC ground plane. The layout is shown in Figure 10.6.1 with segment and wire labels provided.

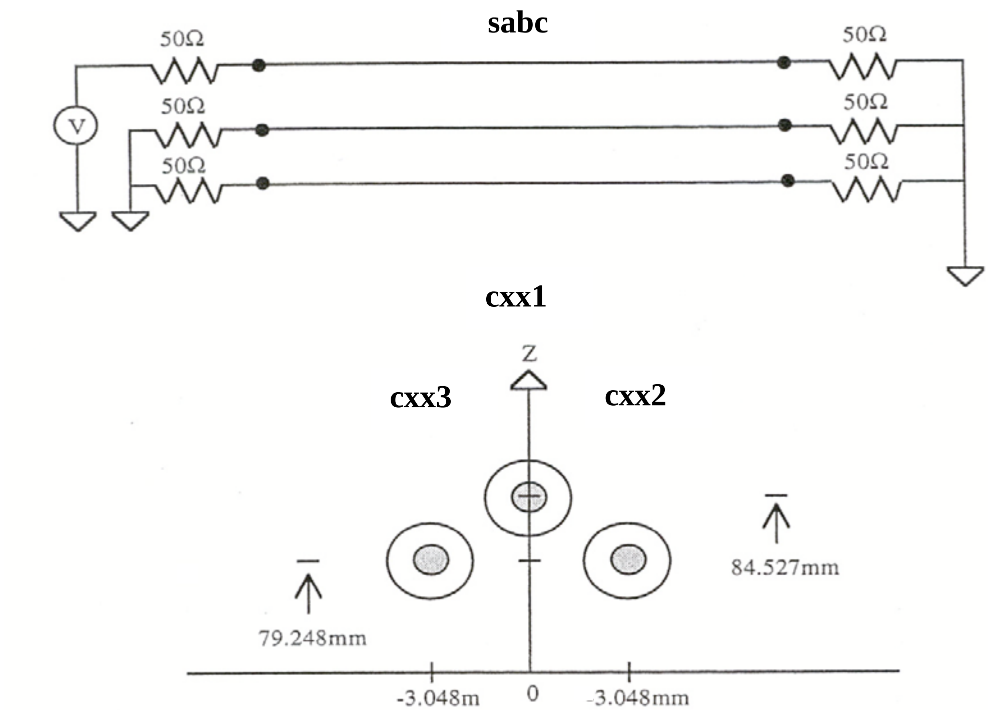


Figure 10.6.1 Example 6 Layout

The wires are 10 meters long and located at the heights given in the figure. All wires are terminated in 50 ohms at both ends. The wires all have a radius of 2.146e-3 meters with an insulation radius of 3.047e-3meters (thickness = 9.01e-4 meters). The wire insulation has a relative dielectric constant of 2.26. The background medium is air (relative dielectric constant of 1.0).

The system is driven by a sine squared voltage source (pin voltage drive) at end_1 of one of the wires. The sine squared waveform is given below.

$$V(t) = A * \sin^2(\omega t) \qquad 0 \le t \le T/2$$
$$V(t) = 0.0 \qquad t > T/2$$

where: A = 1.0

ω = 1.0472e9 (frequency = 1.6667e8 Hz)

The time step is defined to be 0.5e-10. Use 300 finite difference space steps to model the three wire segment. The simulation is to be executed for 1400 time steps.

The computed responses desired are the voltages on all three wires at the opposite end from the pin voltage source. Let the output file be named, “ex6voltout”, and record the responses every time step. In addition, record the source waveform at every computational time step in a file named, “ex6srcout”.

Considerations

Without loss of generality, let the x-coordinate axis lie along the length of the three wire segment. In addition, let all wire ends at the driving voltage location be designated as end_1. The voltage responses are thus desired at end_2.

Input file listing

The MHARNESS input file for Example 6 is listed below.

```
* input file for mharness
* example 6, three-wire segment, voltage drive, compute L and C


*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!NOTCOMPUTE
0.5e-10, 1400


*************************** Section 3: SPACE STEP **************************

!SPACE STEP
sabc 300


*********************** Section 4: EXCITATION/SOURCE ***********************

!EXCITATION TYPE
!!cable
!!!pin voltage drive

*--------------------

!SOURCE WAVEFORM
!!SINE SQUARED
1.0, 1.6667e8
sabc, cxx1, 1


******************** Section 5: Cable Conductor Topology *******************

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!COMPLEX
sabc  0  0
cxx1   0.0,       0.0,  84.527e-3,    10.0,     0.0
cxx2   0.0,  3.048e-3, 79.248e-3,    10.0,  3.048e-3
cxx3   0.0, -3.048e-3, 79.248e-3,    10.0, -3.048e-3


************** Section 6: Cable Conductor Impedance Parameters *************

*---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------

!CAPACITANCE COMPUTE
!!DIELECTRIC
sabc, 1.0,  2.26

!!RADII
sabc, cxx1, 2.146e-3, 3.047e-3
sabc, cxx2, 2.146e-3, 3.047e-3
sabc, cxx3, 2.146e-3, 3.047e-3

!!FILAMENT NUMBER
```

```
sabc, cxx1, 15, 15
sabc, cxx2, 15, 15
sabc, cxx3, 15, 15
```

********************* Section 9: Cable BOUNDARY CONDITIONS *********************

***---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------**

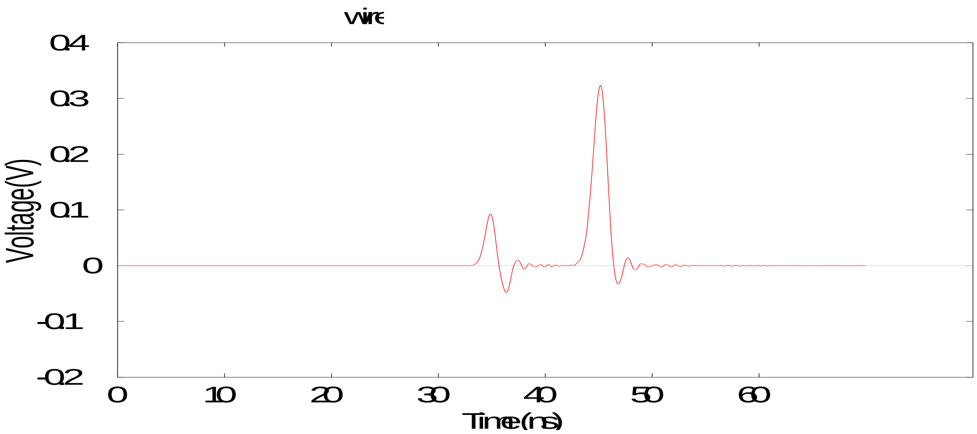
```
!BOUNDARY CONDITION
!!RESISTIVE
sabc  cxx1  1   50.0
sabc  cxx1  2   50.0
sabc  cxx2  1   50.0
sabc  cxx2  2   50.0
sabc  cxx3  1   50.0
sabc  cxx3  2   50.0
```

*************************** Section 10: Output / PROBE *************************

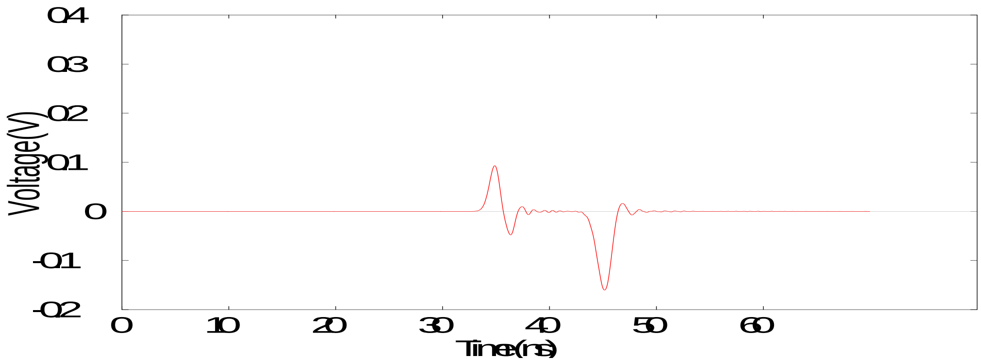
```
!OUT PUT SOURCE
ex6src_alphaout
1400

*---------------------

!PROBE
!!CABLE VOLTAGE
ex6voltout
1, 1400, 1
sabc,cxx1,300
sabc,cxx2,300
sabc,cxx3,300
```

Results

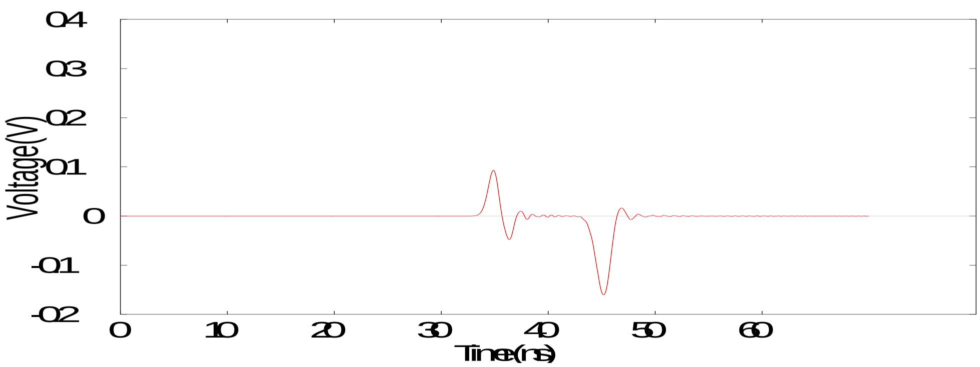
The voltage results are plotted in Figure 10.6.2. The voltage waveforms can be compared to experimental results of A. K. Agrawal and H. J. Price,"Experimental Characterization of Partially Degenerate Three Conductor Transmission Lines in the Time Domain," IEEE Trans. Electromagnetic Compatibility, Vol. EMC-23, No. 3, pp. 133-138, Aug. 1981.



(A) Voltage at End$_2$ of Wire cxx1



(B) Voltage at End$_2$ of Wire cxx2



(C) Voltage at End$_2$ of Wire cxx3

Figure 10.6.2   Computed Responses of Example 6

10.7 Example 7

Problem

Example 7 consists of a cable system composed five MHARNESS segments located in an air background medium. The cable segment layout is shown in Figure 10.7.1.

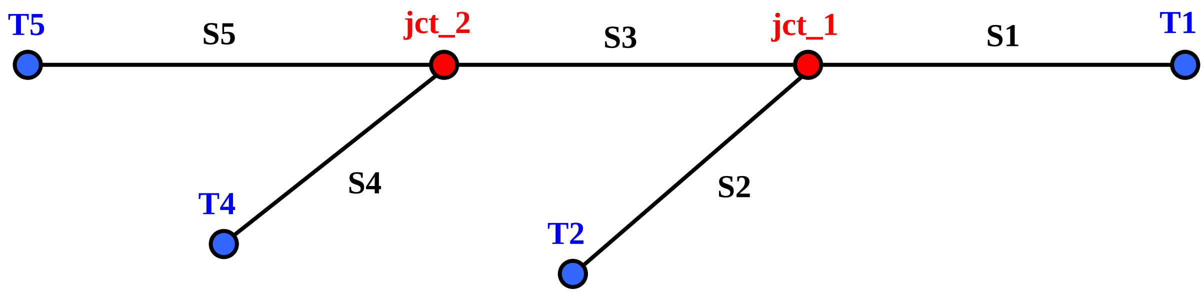


Figure 10.7.1 Example 7 Layout

Along with the five segments there are two junctions labeled, "**jct1_1**" and "**jct_2**", and four terminations labeled, "**T1**", "**T2**", "**T4**", and **T5**". The cross-section of each cable segment is shown in Figure 10.7.2.

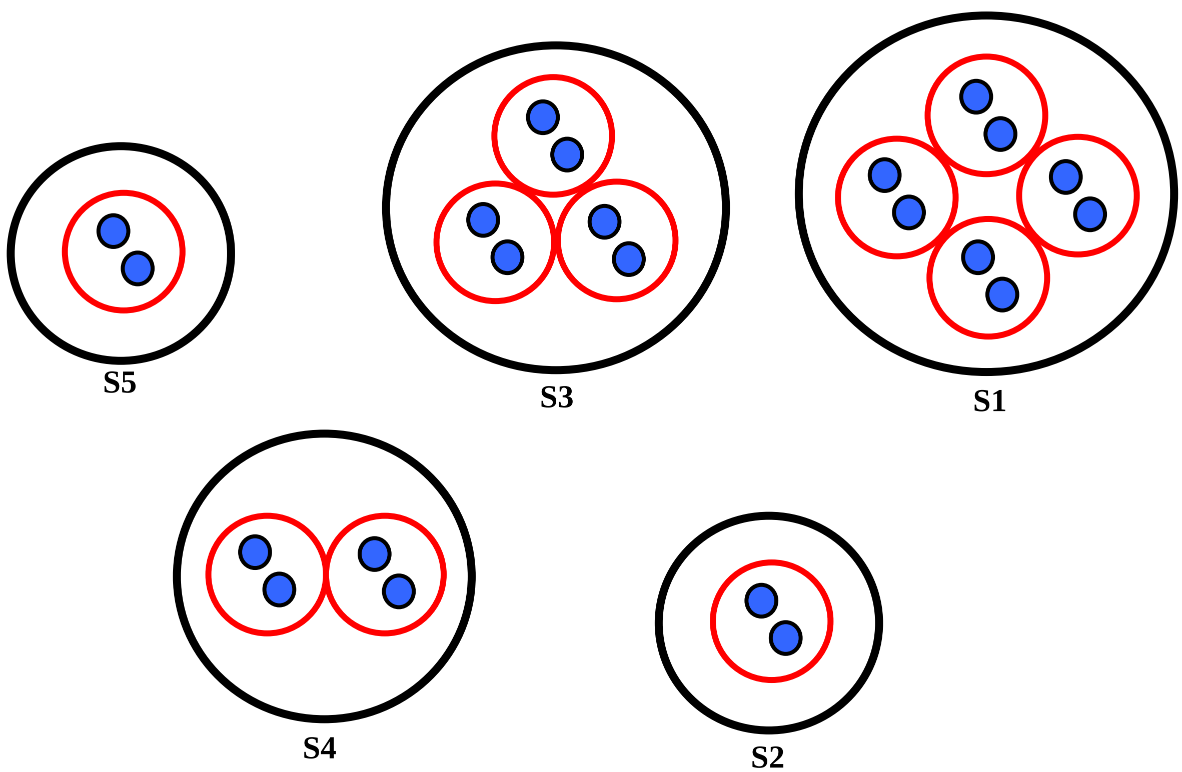


Figure 10.7.2 Example 7 Segment Cross-Sections

Each segment consists of an over braid shield containing one or more shielded twisted wire pairs. There are thus three system levels associated with this cable harness.

System Level 2 is depicted in Figure 10.7.3A. There are five segments, two junctions, and four terminations. The segments are labeled, "`shield2_1`", "`shield2_2`", "`shield2_3`", "`shield2_4`", and "`shield2_5`". Each segment consist of one and only one conductor (the over braid shield). The conductors are labeled, "`sh21c1`", "`sh22c1`", "`sh23c1`", "`sh24c1`", and "`sh25c1`". These conductors are uniquely identified by the (`seg_id cond_id`) combination pair. The conductor identifier pair and the associated lengths are listed below.

Identification Pair	Length
(`shield2_1, sh21c1`)	0.540 meters
(`shield2_2, sh22c1`)	0.343 meters
(`shield2_3, sh23c1`)	0.165 meters
(`shield2_4, sh24c1`)	0.356 meters
(`shield2_5, sh25c1`)	0.178 meters

The capacitance parameters and line resistance parameters, for System Level 2, are provided below.

Conductor Capacitances

(`shield2_1, sh21c1`)	20.27e-12 farads/meter
(`shield2_2, sh22c1`)	17.14e-12 farads/meter
(`shield2_3, sh23c1`)	19.15e-12 farads/meter
(`shield2_4, sh24c1`)	18.35e-12 farads/meter
(`shield2_5, sh25c1`)	17.14e-12 farads/meter

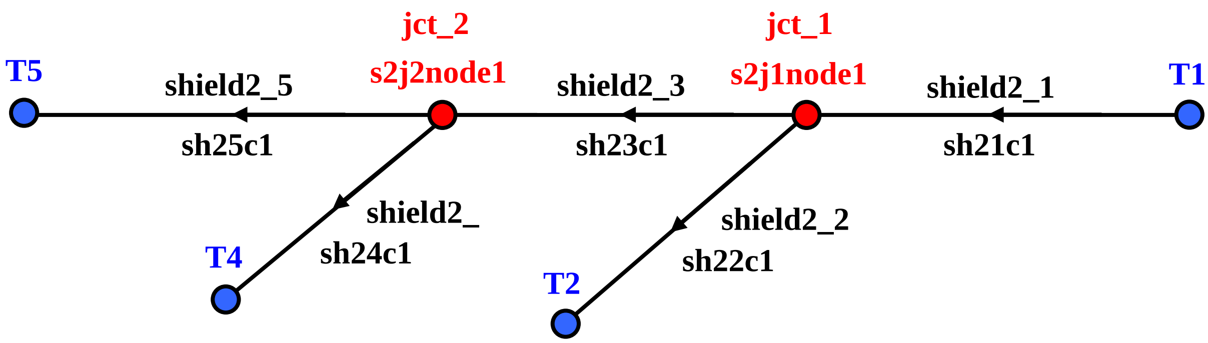
Conductor Line Resistances

(`shield2_1, sh21c1`)	22.9e-3 ohms/meter
(`shield2_2, sh22c1`)	11.8e-3 ohms/meter
(`shield2_3, sh23c1`)	17.3e-3 ohms/meter
(`shield2_4, sh24c1`)	14.8e-3 ohms/meter
(`shield2_5, sh25c1`)	11.8e-3 ohms/meter

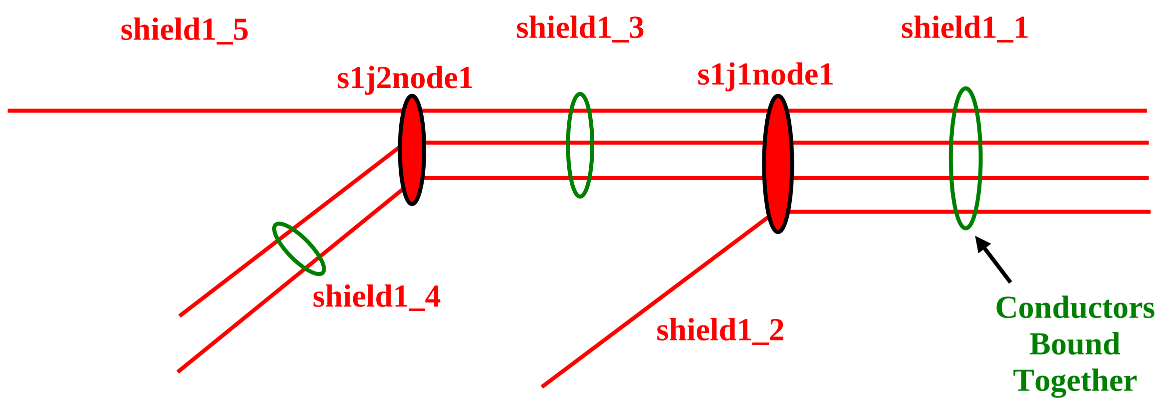
The over braid shield constituting System Level 2 has a transfer inductance. These values, for each shield conductor, are listed below.

Over Braid Transfer Inductances

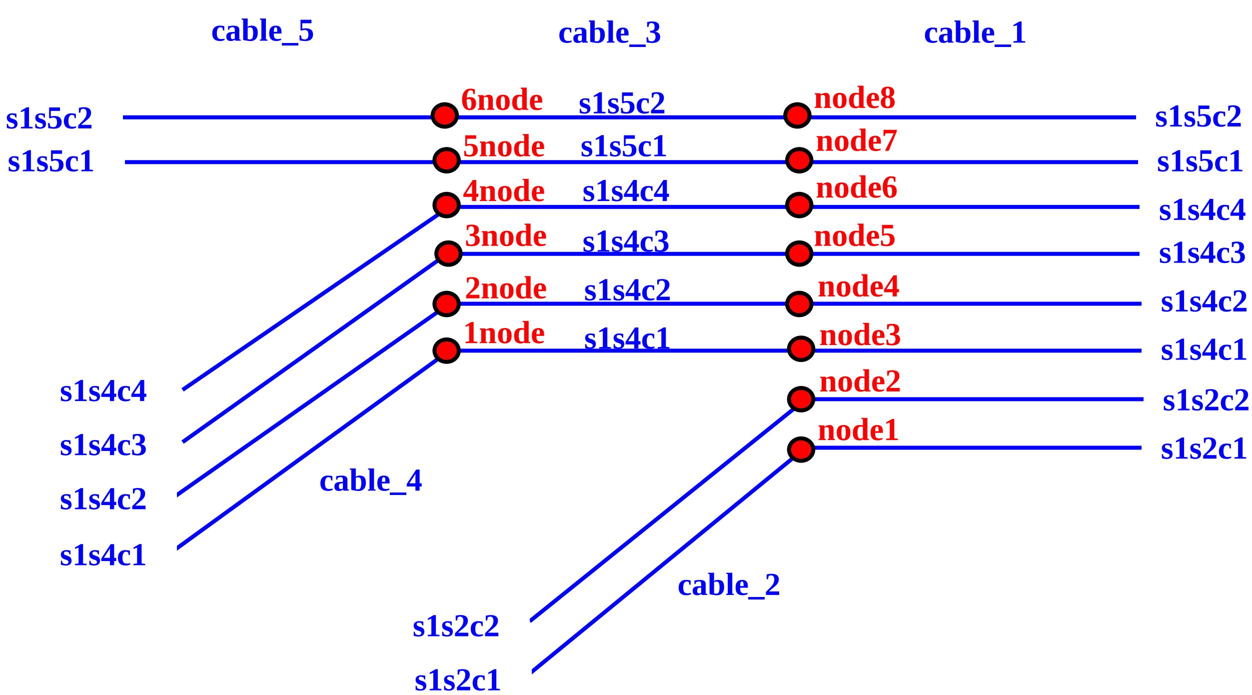
(`shield2_1, sh21c1`)	8.9e-9 V/(A-s)
(`shield2_2, sh22c1`)	7.4e-9 V/(A-s)
(`shield2_3, sh23c1`)	3.0e-9 V/(A-s)
(`shield2_4, sh24c1`)	4.5e-9 V/(A-s)
(`shield2_5, sh25c1`)	0.9e-9 V/(A-s)



(A) System Level 2



(B) System Level 1



(C) System Level 0

Figure 10.7.3 The Three System Levels of Example 7

The two junctions, **jct_1** and **jct_2**, each contain one node each. These nodes are labeled, "s2j1node1", and "s2j2node1", respectively. The nodes are uniquely identified by the (junc_id, node_id) combination pair. The node identifier pairs are listed below.

(jct_1, s2j1node1)
(jct_2, s2j2node1)

The terminations are labeled, "T1", "T2", "T4", and "T5". The direction, start to end, of each segment is also indicated by the segment arrows shown in Figure 10.7.3A. The resultant locations of these terminations are listed below.

T1	end_1 of (shield2_1, sh21c1)
T2	end_2 of (shield2_2, sh22c1)
T4	end_2 of (shield2_4, sh24c1)
T5	end_2 of (shield2_5, sh25c1)

At each termination there exists a connector and a terminating circuit. These connectors have line resistances and transfer inductances. These values are listed below.

Connector Line Resistances

Connector at T1	100.0e-3 ohms
Connector at T2	19.0 ohms
Connector at T4	504.0e-3 ohms
Connector at T5	22.3e-3 ohms

Connector Transfer Inductances

Connector at T1	2.6e-9 V/(A-s)
Connector at T2	2.6e-9 V/(A-s)
Connector at T4	2.6e-9 V/(A-s)
Connector at T5	2.6e-9 V/(A-s)

The terminating circuits are resistive with the values listed below.

Termination Resistances

Termination T1	R = 0.7e-3 ohms
Termination T2	R = 1.0 ohms
Termination T4	R = 200.0e-3 ohms
Termination T5	R = 165.0 ohms

System Level 1 consists of all of the shields of the twisted wire pairs, as shown in Figure 10.7.2. These shields are bare and in direct electrical contact. Therefore, these shields must be modeled as one conductor. A diagram of System Level 1 is shown in Figure 10.7.3B. In this figure each shield conductor is shown bounded to the other shield conductors in that segment. There are four bound shields in segment S1, one shield conductor is S2, three bound shields in segment S3, two bound shields in segment S4, and one shield conductor in segment S5. Each of these bound shield groups constitutes one conductor. There is thus one conductor in each of the five segments of System Level 1.

The segments of System Level 1 are labeled, "shield1_1", "shield1_2", "shield1_3", "shield1_4", and "shield1_5". Each segment consists of one and only one conductor. The conductors are all labeled, "1", in each segment. The conductor identifier pairs are listed below.

System Level 1 Identification Pair

(shield1_1, 1)
(shield1_2, 1)
(shield1_3, 1)
(shield1_4, 1)
(shield1_5, 1)

The segment lengths are defined as equal to the System Level 2 counterparts.

The capacitance parameters and line resistance parameters for System Level 1 are provided below.

Conductor Capacitance

(shield1_1, 1)	558.4e-12 farads/meter
(shield1_2, 1)	323.1e-12 farads/meter
(shield1_3, 1)	471.9e-12 farads/meter
(shield1_4, 1)	363.7e-12 farads/meter
(shield1_5, 1)	323.1e-12 farads/meter

Conductor Line Resistance

(shield1_1, 1)	3.9e-3 ohms/meter
(shield1_2, 1)	12.2e-3 ohms/meter
(shield1_3, 1)	6.5e-3 ohms/meter
(shield1_4, 1)	4.2e-3 ohms/meter
(shield1_5, 1)	5.7e-3 ohms/meter

The speed of propagation for System Level 1 is 1.544e8 meters/second.

The twisted pair shields of System Level 1 have transfer inductances. These values, identical for each shield, are listed below.

Shield Transfer Inductance

(shield1_1, 1)	4.2e-9 V/(A-s)
(shield1_2, 1)	4.2e-9 V/(A-s)
(shield1_3, 1)	4.2e-9 V/(A-s)
(shield1_4, 1)	4.2e-9 V/(A-s)
(shield1_5, 1)	4.2e-9 V/(A-s)

The current computed on the shield conductors of System Level 1 is the total current on the bound shield group. When coupling through the shields to the twisted wire pairs of System Level 0, the current values must reflect that on each of the individual shields. Therefore, if there are four shields in segment S1, then the current computed on the shield group must be divided by four. This is the `sfact` parameter in the `SHIELD ONE TO CABLE` keyword. The `sfact` parameters for each System Level 1 segments are listed below.

sfact Parameter Value

(shield1_1, 1)	4
(shield1_2, 1)	1
(shield1_3, 1)	3
(shield1_4, 1)	2
(shield1_5, 1)	1

The two junctions, **`jct_1`** and **`jct_2`**, each contain one node each. These nodes are labeled, "`s1j1node1`", and "`s1j2node1`", respectively. The node identifier pairs are listed below.

(jct_1, s1j1node1)
(jct_2, s1j2node1)

The terminations are labeled, "T1", "T2", "T4", and "T5". The resultant locations of these terminations are listed below.

T1	end_1 of (shield1_1, 1)
T2	end_2 of (shield1_2, 1)
T4	end_2 of (shield1_4, 1)
T5	end_2 of (shield1_5, 1)

At each termination the twisted wire pair shields are shorted (R = 1.0e-6 ohms).

System Level 0 consists of the twisted pair wires shown in Figure 10.7.2. A diagram of System Level 0 is shown in Figure 10.7.3C. There are five segments within System Level 0. The segments are labeled, "`cable_1`", "`cable_2`", "`cable_3`", "`cable_4`", and "`cable_5`". The number of wires within each segment is listed below.

Number of Wires in each Segment

cable_1	8
cable_2	2
cable_3	6
cable_4	4
cable_5	2

The conductors within each segment of System Level 0 are also labeled in the figure. The conductor identifier pairs are listed below.

Segment S1 Identification Pairs

(cable_1, s1s2c1)
(cable_1, s1s2c2)
(cable_1, s1s4c1)
(cable_1, s1s4c2)

```
(cable_1, s1s4c3)
(cable_1, s1s4c4)
(cable_1, s1s5c1)
(cable_1, s1s5c2)
```

<u>Segment S2 Identification Pairs</u>

```
(cable_2, s1s2c1)
(cable_2, s1s2c2)
```

<u>Segment S3 Identification Pairs</u>

```
(cable_3, s1s4c1)
(cable_3, s1s4c2)
(cable_3, s1s4c3)
(cable_3, s1s4c4)
(cable_3, s1s5c1)
(cable_3, s1s5c2)
```

<u>Segment S4 Identification Pairs</u>

```
(cable_4, s1s4c1)
(cable_4, s1s4c2)
(cable_4, s1s4c3)
(cable_4, s1s4c4)
```

<u>Segment S5 Identification Pairs</u>

```
(cable_5, s1s5c1)
(cable_5, s1s5c2)
```

The segment lengths are defined as equal to the System Level 2 and System Level 1 counterparts.

The capacitance matrices for System Level 0 consist of 2 x 2 block diagonal matrices as expected. These matrices are provided below.

<u>S1 Capacitance Matrix (farads/meter)</u>

$$C = \begin{bmatrix} 105.5e-12 & -20.5e-12 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ -20.5e-12 & 105.5e-12 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 105.5e-12 & -20.5e-12 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & -20.5e-12 & 105.5e-12 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 105.5e-12 & -20.5e-12 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & -20.5e-12 & 105.5e-12 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 105.5e-12 & -20.5e-12 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & -20.5e-12 & 105.5e-12 \end{bmatrix}$$

<u>S2 Capacitance Matrix (farads/meter)</u>

$$C = \begin{bmatrix} 105.5e-12 & -20.5e-12 \\ -20.5e-12 & 105.5e-12 \end{bmatrix}$$

<u>S3 Capacitance Matrix (farads/meter)</u>

$$C = \begin{bmatrix} 105.5e-12 & -20.5e-12 & 0.0 & 0.0 & 0.0 & 0.0 \\ -20.5e-1 & 105.5e-12 & 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 105.5e-12 & -20.5e-1 & 0.0 & 0.0 \\ 0.0 & 0.0 & -20.5e-1 & 105.5e-12 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 & 105.5e-12 & -20.5e-1 \\ 0.0 & 0.0 & 0.0 & 0.0 & -20.5e-1 & 105.5e-12 \end{bmatrix}$$

<u>S4 Capacitance Matrix (farads/meter)</u>

$$C = \begin{bmatrix} 105.5e-12 & -20.5e-12 & 0.0 & 0.0 \\ -20.5e-12 & 105.5e-12 & 0.0 & 0.0 \\ 0.0 & 0.0 & 105.5e-12 & -20.5e-12 \\ 0.0 & 0.0 & -20.5e-12 & 105.5e-12 \end{bmatrix}$$

<u>S5 Capacitance Matrix (farads/meter)</u>

$$C = \begin{bmatrix} 105.5e-12 & -20.5e-12 \\ -20.5e-12 & 105.5e-12 \end{bmatrix}$$

The speed of propagation for all segments of System Level 0 is 2.01e8 meters/second.

The two junctions, **`jct_1`** and **`jct_2`**, contain 8 nodes and 6 nodes, respectively. The node identifier pairs within each junction are listed below.

<u>Node Identification Pairs in `jct_1`</u>

```
(jct_1, node1)
(jct_1, node2)
(jct_1, node3)
(jct_1, node4)
(jct_1, node5)
(jct_1, node6)
(jct_1, node7)
(jct_1, node8)
```

<u>Node Identification Pairs in `jct_2`</u>

```
(jct_2, node1)
(jct_2, node2)
(jct_2, node3)
(jct_2, node4)
(jct_2, node5)
(jct_2, node6)
```

The terminations are labeled, "T1", "T2", "T4", and "T5". The resultant locations of these terminations are listed below.

T1	end_1 of (`cable_1`)
T2	end_2 of (`cable_2`)
T4	end_2 of (`cable_4`)
T5	end_2 of (`cable_5`)

At each termination there exists a terminating circuit. The terminating circuits (see Figure 4.8.1) are provided below.

T1 Terminations

(cable_1, s1s2c1)	RESISTIVE: R = 1.0e10 ohms
(cable_1, s1s2c2)	LCPRS: L= 30.0e-12 henries, C = 60.0e-9 farads, R = 50.0e-6 ohms
(cable_1, s1s4c1)	RESISTIVE: R = 1.0e10 ohms
(cable_1, s1s4c2)	LCPRS: L= 30.0e-12 henries, C = 60.0e-9 farads, R = 50.0e-6 ohms
(cable_1, s1s4c3)	RESISTIVE: R = 1.0e10 ohms
(cable_1, s1s4c4)	LCPRS: L= 30.0e-12 henries, C = 60.0e-9 farads, R = 50.0e-6 ohms
(cable_1, s1s5c1)	RESISTIVE: R = 1.0e10 ohms
(cable_1, s1s5c2)	LCPRS: L= 30.0e-12 henries, C = 60.0e-9 farads, R = 50.0e-6 ohms

T2 Terminations

(cable_2, s1s2c1)	RESISTIVE: R = 50.0 ohms
(cable_2, s1s2c2)	RESISTIVE: R = 50.0 ohms

T4 Terminations

(cable_4, s1s4c1)	CAPACITIVE: C = 3.00e-12 farads
(cable_4, s1s4c2)	CAPACITIVE: C = 2.70e-12 farads
(cable_4, s1s4c3)	CAPACITIVE: C = 34.0e-12 farads
(cable_4, s1s4c4)	CAPACITIVE: C = 35.0e-12 farads

T5 Terminations

(cable_5, s1s5c1)	RESISTIVE: R = 50.0 ohms
(cable_5, s1s5c2)	RESISTIVE: R = 50.0 ohms

The excitation source consists of an electric field driving the System Level 2 conductor, (`shield2_1 sh21c1`) at the points between 0.3 and 0.4 meters from the start end. The electric field source consists of a Gaussian waveform provided by the equation below.

$$E(t) = A * e^{-((t-t_p)/w)^2}$$

where: A = 1.0

t_p = `5.0e-9`

w = `1.25e-9`

The computed responses desired consist of the current on conductor (`shield2_1 sh21c1`) at the location 0.1 meters from the start end (end_1), the terminal voltage on end_1 of conductor (`cable_1 s1s2c2`), and the terminal voltage on end_1 of conductor (`cable_1 s1s4c2`). To compute these voltages the associated currents will be recorded and then multiplied by the associated 50 ohm termination.

Write out the computed responses at every simulation time step. Let the output file containing the computed current on conductor (`shield2_1 sh21c1`) be named, “ex7s2cout”, and the output file for the other two computed currents be named, “ex7curout”. Since the computed responses are to be written out every time step, then the keyword descriptors, `tstop` and `tstep` need not be specified under the `PROBE` keyword.

Considerations

No considerations

Input file listing

The MHARNESS input file for Example 7 is listed below.

```
*
* input file for mharness: ex7_alpha.inp
* example 7, cable with two shields, uninsulated twisted shielded pair
*       in an overbraid
* local e field drive

*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!NOTCOMPUTE
0.5e-10  1000

*************************** Section 3: SPACE STEP **************************

!SPACE STEP
3.0e-2

*********************** Section 4: EXCITATION/SOURCE ***********************

!EXCITATION TYPE
!!SHIELD TWO
!!!LOCALIZED EFIELD DRIVE

*--------------------

!SOURCE WAVEFORM
!!GAUSSIAN
1.0  5.0e-9   1.25e-9
shield2_1, sh21c1, 0.3, 0.4

********************* Section 5: Cable Conductor Topology *******************

*------------- Section 5A: System Level 2 – SHIELD TWO Topology -------------

!SHIELD TWO SEGMENT
!!SIMPLE
shield2_1, 0, jct_1,  0.540
sh21c1
shield2_2, jct_1, 0,  0.343
sh22c1
shield2_3, jct_1, jct_2,  0.165
sh23c1
shield2_4, jct_2, 0,  0.356
sh24c1
shield2_5, jct_2, 0,  0.178
sh25c1

*--------------------

!SHIELD TWO JUNCTION AND NODE
jct_1
s2j1node1
shield2_1, sh21c1
shield2_2, sh22c1
```

```
shield2_3, sh23c1

!SHIELD TWO JUNCTION AND NODE
jct_2
s2j2node1
shield2_3, sh23c1
shield2_4, sh24c1
shield2_5, sh25c1
```

***------------ Section 5B: System Level 1 – SHIELD ONE Topology -------------**

```
!SHIELD ONE SEGMENT
!!SIMPLE
shield1_1, 0, jct_1
1
shield1_2, jct_1, 0
1
shield1_3, jct_1, jct_2
1
shield1_4, jct_2, 0
1
shield1_5, jct_2, 0
1

*--------------------

!SHIELD ONE JUNCTION AND NODE
jct_1
s1j1node1
shield1_1, 1
shield1_2, 1
shield1_3, 1

!SHIELD ONE JUNCTION AND NODE
jct_2
s1j2node1
shield1_3, 1
shield1_4, 1
shield1_5, 1
```

***--------------- Section 5C: System Level 0 – Wire Topology ----------------**

```
!SEGMENT
!!SIMPLE
cable_1, 0, jct_1
s1s2c1
s1s2c2
s1s4c1
s1s4c2
s1s4c3
s1s4c4
s1s5c1
s1s5c2
cable_2, jct_1, 0
s1s2c1
s1s2c2
cable_3, jct_1, jct_2
s1s4c1
s1s4c2
s1s4c3
s1s4c4
s1s5c1
```

```
s1s5c2
cable_4, jct_2, 0
s1s4c1
s1s4c2
s1s4c3
s1s4c4
cable_5, jct_2, 0
s1s5c1
s1s5c2

*--------------------

!JUNCTION AND NODE
jct_1

node1
cable_1, s1s2c1
cable_2, s1s2c1

node2
cable_1, s1s2c2
cable_2, s1s2c2

node3
cable_1, s1s4c1
cable_3, s1s4c1

node4
cable_1, s1s4c2
cable_3, s1s4c2

node5
cable_1, s1s4c3
cable_3, s1s4c3

node6
cable_1, s1s4c4
cable_3, s1s4c4

node7
cable_1, s1s5c1
cable_3, s1s5c1

node8
cable_1, s1s5c2
cable_3, s1s5c2


!JUNCTION AND NODE
jct_2

1node
cable_3, s1s4c1
cable_4, s1s4c1

2node
cable_3, s1s4c2
cable_4, s1s4c2

3node
cable_3, s1s4c3
cable_4, s1s4c3

4node
```

```
cable_3, s1s4c4
cable_4, s1s4c4

5node
cable_3, s1s5c1
cable_5, s1s5c1

6node
cable_3, s1s5c2
cable_5, s1s5c2
```

**************** Section 6: Cable Conductor Impedance Parameters *************

***------ Section 6A: System Level 2 – SHIELD TWO Impedance Parameters -------**

```
!SHIELD TWO CAPACITANCE
shield2_1, 20.27e-12
shield2_2, 17.14e-12
shield2_3, 19.15e-12
shield2_4, 18.35e-12
shield2_5, 17.14e-12

*--------------------

!SHIELD TWO INDUCTANCE COMPUTE
shield2_1  3.0e8
shield2_2  3.0e8
shield2_3  3.0e8
shield2_4  3.0e8
shield2_5  3.0e8

*--------------------

!SHIELD TWO RESISTANCE
shield2_1, sh21c1, 22.9e-3
shield2_2, sh22c1, 11.8e-3
shield2_3, sh23c1, 17.3e-3
shield2_4, sh24c1, 14.8e-3
shield2_5, sh25c1, 11.8e-3

*--------------------

!SHIELD TWO TO SHIELD ONE
shield1_1, shield2_1, sh21c1, 1, 1, 2.6e-9, 8.9e-9, 8.9e-9
shield1_2, shield2_2, sh22c1, 1, 1, 7.4e-9, 7.4e-9, 2.6e-9
shield1_3, shield2_3, sh23c1, 1, 1, 3.0e-9, 3.0e-9, 3.0e-9
shield1_4, shield2_4, sh24c1, 1, 1, 4.5e-9, 4.5e-9, 2.6e-9
shield1_5, shield2_5, sh25c1, 1, 1, 0.9e-9, 0.9e-9, 2.6e-9
```

***------ Section 6B: System Level 1 – SHIELD ONE Impedance Parameters -------**

```
!SHIELD ONE CAPACITANCE
shield1_1, 558.4e-12
shield1_2, 323.1e-12
shield1_3, 471.9e-12
shield1_4, 363.7e-12
shield1_5, 323.1e-12

*--------------------

!SHIELD ONE INDUCTANCE COMPUTE
shield1_1  1.544e8
```

```
shield1_2  1.544e8
shield1_3  1.544e8
shield1_4  1.544e8
shield1_5  1.544e8

*--------------------

!SHIELD ONE RESISTANCE
shield1_1, 1, 3.9e-3
shield1_2, 1, 12.2e-3
shield1_3, 1, 6.5e-3
shield1_4, 1, 4.2e-3
shield1_5, 1, 5.7e-3

*--------------------

!SHIELD ONE TO CABLE
cable_1, shield1_1, 1, 1, 4, 3*4.2e-9
cable_2, shield1_2, 1, 1, 1, 3*4.2e-9
cable_3, shield1_3, 1, 1, 3, 3*4.2e-9
cable_4, shield1_4, 1, 1, 2, 3*4.2e-9
cable_5, shield1_5, 1, 1, 1, 3*4.2e-9
```

***---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------**

```
!CAPACITANCE
cable_1
105.5e-12, -20.5e-12, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
-20.5e-12, 105.5e-12, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0
0.0, 0.0, 105.5e-12, -20.5e-12, 0.0, 0.0, 0.0, 0.0
0.0, 0.0, -20.5e-12, 105.5e-12, 0.0, 0.0, 0.0, 0.0
0.0, 0.0, 0.0, 0.0, 105.5e-12, -20.5e-12, 0.0, 0.0
0.0, 0.0, 0.0, 0.0, -20.5e-12, 105.5e-12, 0.0, 0.0
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 105.5e-12, -20.5e-12
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, -20.5e-12, 105.5e-12

cable_2
105.5e-12, -20.5e-12
-20.5e-12, 105.5e-12

cable_3
105.5e-12, -20.5e-12, 0.0, 0.0, 0.0, 0.0
-20.5e-12, 105.5e-12, 0.0, 0.0, 0.0, 0.0
0.0, 0.0, 105.5e-12, -20.5e-12, 0.0, 0.0
0.0, 0.0, -20.5e-12, 105.5e-12, 0.0, 0.0
0.0, 0.0, 0.0, 0.0, 105.5e-12, -20.5e-12
0.0, 0.0, 0.0, 0.0, -20.5e-12, 105.5e-12

cable_4
105.5e-12, -20.5e-12, 0.0, 0.0
-20.5e-12, 105.5e-12, 0.0, 0.0
0.0, 0.0, 105.5e-12, -20.5e-12
0.0, 0.0, -20.5e-12, 105.5e-12

cable_5
105.5e-12, -20.5e-12
-20.5e-12, 105.5e-12

*--------------------

!INDUCTANCE COMPUTE
cable_1  2.01e8
cable_2  2.01e8
```

```
cable_3  2.01e8
cable_4  2.01e8
cable_5  2.01e8

*-------------------

!RESISTANCE
cable_1, s1s2c1, 62.0e-3
cable_1, s1s2c2, 62.0e-3
cable_1, s1s4c1, 62.0e-3
cable_1, s1s4c2, 62.0e-3
cable_1, s1s4c3, 62.0e-3
cable_1, s1s4c4, 62.0e-3
cable_1, s1s5c1, 62.0e-3
cable_1, s1s5c2, 62.0e-3
cable_2, s1s2c1, 62.0e-3
cable_2, s1s2c2, 62.0e-3
cable_3, s1s4c1, 62.0e-3
cable_3, s1s4c2, 62.0e-3
cable_3, s1s4c3, 62.0e-3
cable_3, s1s4c4, 62.0e-3
cable_3, s1s5c1, 62.0e-3
cable_3, s1s5c2, 62.0e-3
cable_4, s1s4c1, 62.0e-3
cable_4, s1s4c2, 62.0e-3
cable_4, s1s4c3, 62.0e-3
cable_4, s1s4c4, 62.0e-3
cable_5, s1s5c1, 62.0e-3
cable_5, s1s5c2, 62.0e-3
```

**************** Section 7: Cable Connector Impedance Parameters *************

***- Section 7A: System Level 2 – SHIELD TWO Connector Impedance Parameters --**

```
!SHIELD TWO CONNECTOR RESISTANCE
shield2_1, sh21c1, 1, 100.0e-3
shield2_2, sh22c1, 2, 19.0
shield2_4, sh24c1, 2, 504.0e-3
shield2_5, sh25c1, 2, 22.3e-3
```

********************* Section 9: Cable BOUNDARY CONDITIONS *********************

***------- Section 9A: System Level 2 – SHIELD TWO BOUNDARY CONDITIONS -------**

```
!SHIELD TWO BOUNDARY CONDITION
!!RESISTIVE
shield2_1, sh21c1, 1, 0.7e-3
shield2_2, sh22c1, 2, 1.0
shield2_4, sh24c1, 2, 200.0e-3
shield2_5, sh25c1, 2, 165.0
```

***------- Section 9B: System Level 1 – SHIELD ONE BOUNDARY CONDITIONS -------**

```
!SHIELD ONE BOUNDARY CONDITION
!!RESISTIVE
shield1_1, 1, 1, 1.0e-6
shield1_2, 1, 2, 1.0e-6
shield1_4, 1, 2, 1.0e-6
shield1_5, 1, 2, 1.0e-6
```

***---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------**

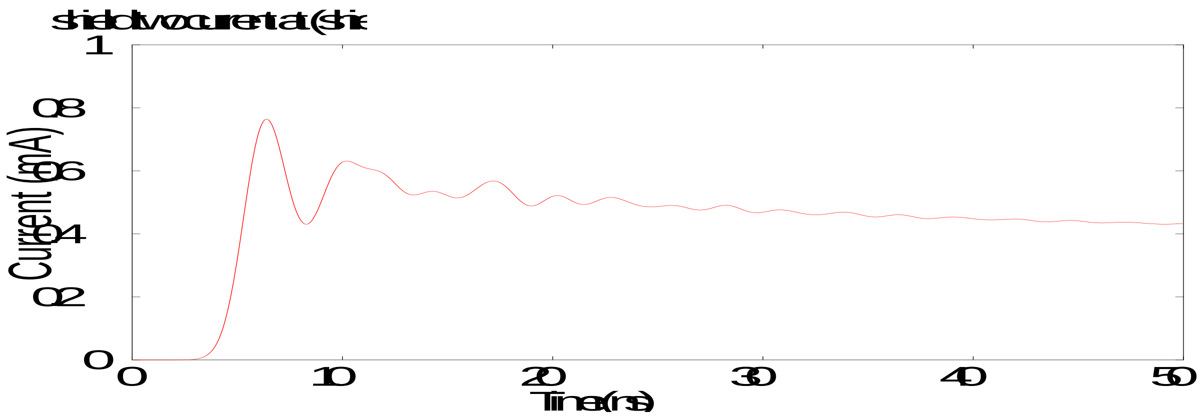
```
!BOUNDARY CONDITION
!!RESISTIVE
cable_1, s1s2c1, 1, 1.0e10
cable_1, s1s4c1, 1, 1.0e10
cable_1, s1s4c3, 1, 1.0e10
cable_1, s1s5c1, 1, 1.0e10
cable_2, s1s2c1, 2, 50.0
cable_2, s1s2c2, 2, 50.0
cable_5, s1s5c1, 2, 50.0
cable_5, s1s5c2, 2, 50.0

!!LCPRS
cable_1, s1s2c2, 1, 30.0e-12, 60.0e-9, 50.0
cable_1, s1s4c2, 1, 30.0e-12, 60.0e-9, 50.0
cable_1, s1s4c4, 1, 30.0e-12, 60.0e-9, 50.0
cable_1, s1s5c2, 1, 30.0e-12, 60.0e-9, 50.0

!!CAPACITIVE
cable_4, s1s4c1, 2, 3.0e-12
cable_4, s1s4c2, 2, 2.7e-12
cable_4, s1s4c3, 2, 34.0e-12
cable_4, s1s4c4, 2, 35.0e-12
```

*************************** Section 10: Output / PROBE *************************

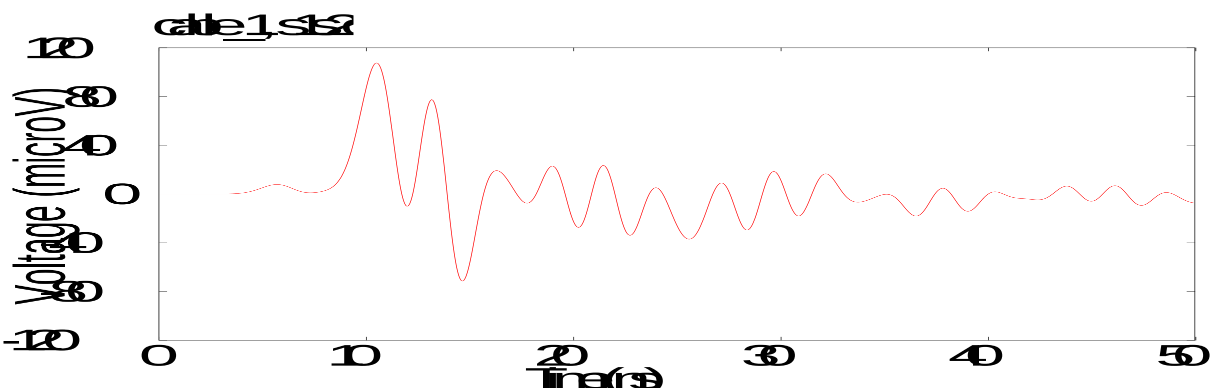
```
!PROBE
!!SHIELD TWO CURRENT
ex7s2cout
0.0
shield2_1, sh21c1,  0.1

!!CABLE CURRENT
ex7curout
0.0
cable_1, s1s2c2, 0.0
cable_1, s1s4c2, 0.0
```

Results

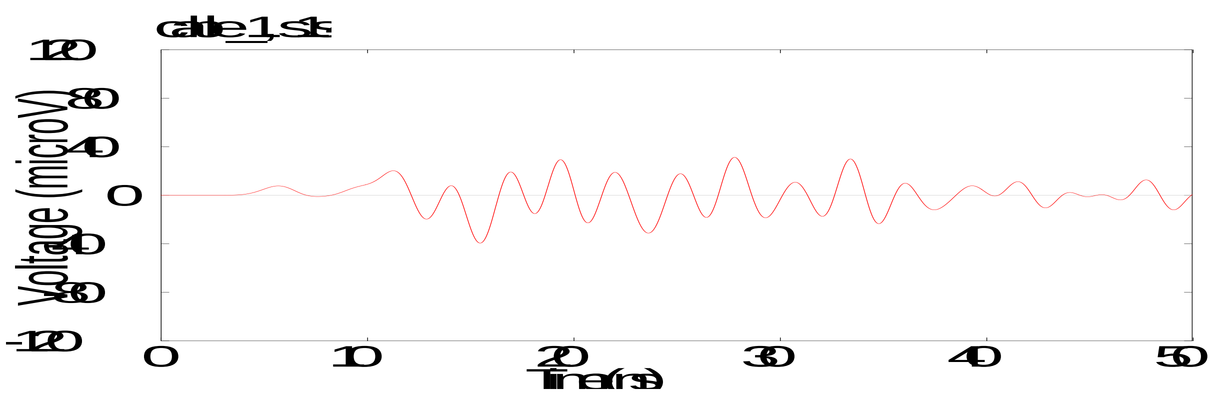
The current and voltage results are plotted in Figure 10.7.4.



(A) Current on (`shield2_1 sh21c1`)



(B) Terminal Voltage on (`cable_1 s1s2c2`)



(C) Terminal Voltage on (`cable_1 s1s4c2`)

Figure 10.7.4 Computed Responses of Example 7

10.8 Example 8

Problem

Example 8 is the same as Example 3 except end_1 of conductor C2 is also driven with a linear ramp pin voltage of opposite polarity to that driving conductor C1. There are thus two pin voltage driving sources. Let the output file name be, "ex8voltout". Let the source waveform output file name be, "ex8srcout".

Considerations

See Example 3 considerations

Input file listing

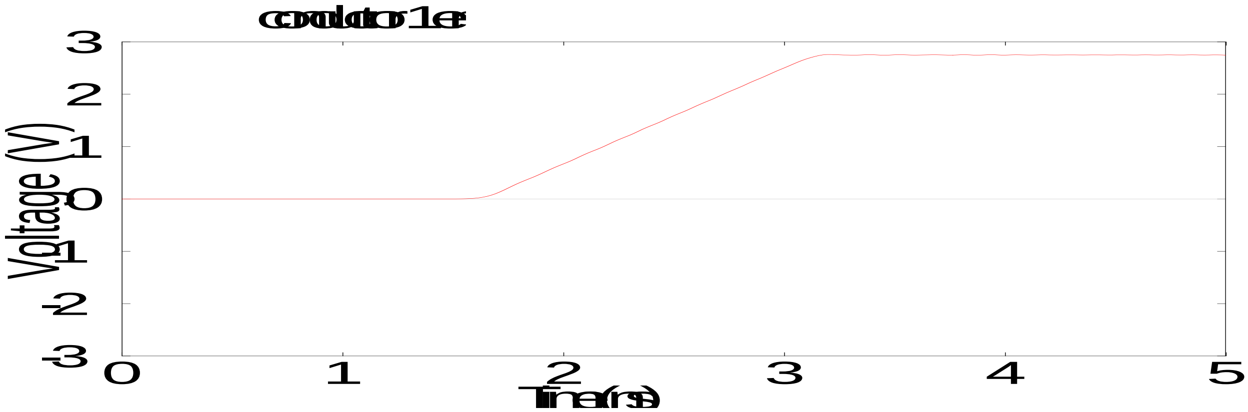
The MHARNESS input file for Example 8 is listed below.

```
* input file for mharness
* example 8, two-wire segment, voltage drive with two different sources

*************************** Section 2: TIME STEP ***************************

!TIME STEP
!!COMPUTE
 5.0e-9 5.0e9

*********************** Section 4: EXCITATION/SOURCE ***********************

!EXCITATION TYPE
!!cable
!!!PIN VOLTAGE DRIVE

*--------------------

!SOURCE WAVEFORM
!!LINEAR RAMP
4.0 1.5e-9
1 1 1

!!LINEAR RAMP
-4.0 1.5e-9
1 2 1

******************** Section 5: Cable Conductor Topology *******************

*--------------- Section 5C: System Level 0 – Wire Topology ----------------

!SEGMENT
!!SIMPLE
1  0  0  0.3048
1
```

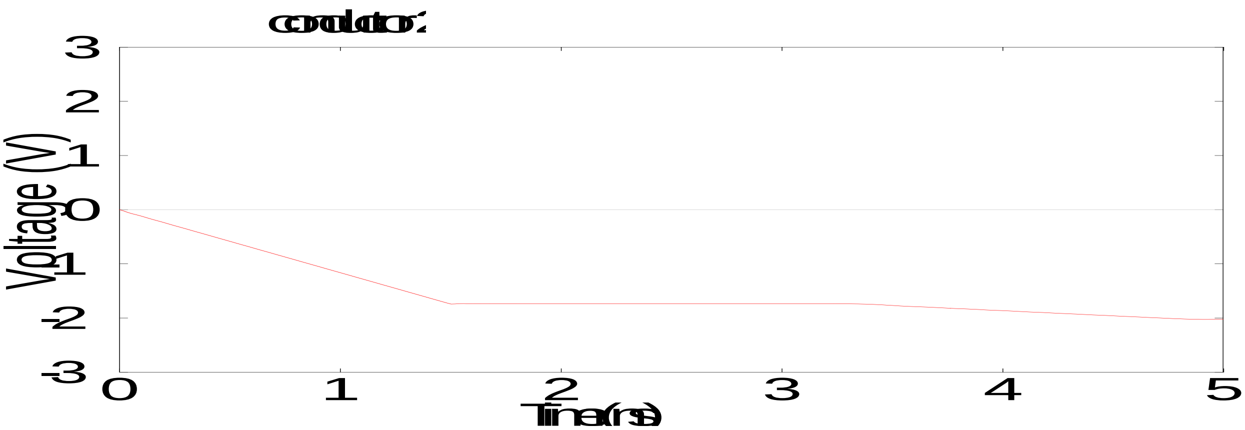
```
2

************** Section 6: Cable Conductor Impedance Parameters *************

*---------- Section 6C: System Level 0 – Wire Impedance Parameters ---------

!CAPACITANCE
1
62.8e-12  -4.94e-12
-4.94e-12  62.8e-12

*--------------------

!INDUCTANCE
1
494.6e-9    63.3e-9
63.3e-9     494.6e-9

*--------------------

!!RESISTIVE
1  1  2  102.0
1  2  2  102.0


****************** Section 9: Cable BOUNDARY CONDITIONS ******************

*---------- Section 9C: System Level 0 – Wire BOUNDARY CONDITIONS ----------

!BOUNDARY CONDITION
!!RESISTIVE
1  1  1  50.0
1  2  1  100.0


************************ Section 10: Output / PROBE **********************

!OUTPUT SOURCE
ex8srcout

*--------------------

!PROBE
!!CABLE VOLTAGE
ex8voltout
0.0, 5.0e-9, 1
1,1,0.3048
1,2,0.0
1,2,0.3048
```

Results

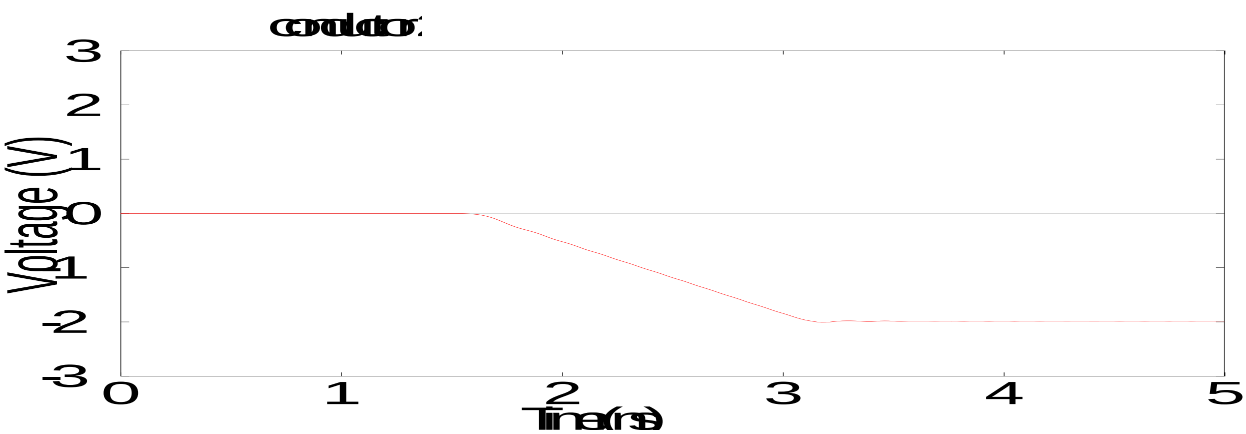
The voltage results are plotted in Figure 9.8.1.



(A) The Voltage at End$_2$ of C1



(B) The Voltage at End$_2$ of C2



(C) The Voltage at End$_2$ of C2

Figure 10.8.1 Computed Responses of Example 8