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ESD-TR-75-67

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Copy No. 1 of 2 <sup>SYS</sup> **COMPUTER SIMULATION OF MUX BUS VOLTAGE  
WAVEFORMS UNDER STEADY STATE CONDITIONS**

JUNE 1975

Prepared for

DEPUTY FOR DEVELOPMENT PLANS  
ELECTRONIC SYSTEMS DIVISION  
AIR FORCE SYSTEMS COMMAND  
UNITED STATES AIR FORCE  
Hanscom Air Force Base, Bedford, Massachusetts



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Project No. 6370  
Prepared by  
THE MITRE CORPORATION  
Bedford, Massachusetts  
Contract No. F19628-75-C-0001

ADA 013107

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESD-TR-75-67	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) COMPUTER SIMULATION OF MUX BUS VOLTAGE WAVEFORMS UNDER STEADY STATE CONDITIONS		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER MTR-2948
7. AUTHOR(s) R. A. Costa		8. CONTRACT OR GRANT NUMBER(s) F19628-75-C-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS The MITRE Corporation Box 208 Bedford, MA 01730		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. 6370
11. CONTROLLING OFFICE NAME AND ADDRESS Deputy for Development Plans Electronic Systems Division, AFSC Hanscom Air Force Base, Bedford, MA 01731		12. REPORT DATE JUNE 1975
		13. NUMBER OF PAGES 69
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) COMPUTER SIMULATION MUX BUSES MUX BUS VOLTAGE WAVEFORMS STEADY STATE COMPUTER SIMULATIONS		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Digital techniques involving multiplex busing are being advocated in many quarters as a means of satisfying the need for greater reliability, decreased modification cost, and simplified maintenance of airborne avionics systems. This paper documents efforts to develop a computer simulation of a shielded, twisted pair cable multiplex bus with multiple subscribers using steady state equations. The simulation predicts		

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voltage waveforms, driving point impedances, and power distributions for systems compatible with MIL-STD-1553 (USAF). Excellent agreement has been found between laboratory observations and the computer simulation, validating this approach.

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## SECTION I

### INTRODUCTION

The bulk of information available regarding the characteristics and performance of multiplex (MUX) bus systems is empirical in nature. Consequently, designers and system planners have had to hedge when asked to estimate voltage waveforms, driving point impedances and power distribution for a proposed multiplex bus system. Either educated guesses based on past experience are made or a laboratory duplicate of the candidate system is built on which the required parameter measurements can be made. When relying on educated guesses the possibility of error has to be tolerated, especially when the system under consideration is radically different from the majority of existing designs. While measurements on a laboratory system generally give more trustworthy results, they may require considerable time and expense. This paper describes a third alternative, computer simulation, which offers a reasonable compromise between the two extremes.

The use of computer simulation rather than physical realization offers several significant advantages. First, it greatly simplifies system analysis when the bus topology must be changed to investigate various cable routing schemes. In the initial design phase when the optimum bus arrangement and routing is usually uncertain, the use of simulation could eliminate the need for costly laboratory mock-ups. Also, a knowledge of the system's sensitivity to variations in cable or component parameters is of considerable importance but difficult to obtain in the laboratory. Finally, a need for worst-case information in many cases leads to the application of physical "cut and try" analysis. If applied to a complex MUX Bus, this method would likely be excessively expensive and time consuming.

The computer simulation described in this paper may be applied to any MUX Bus which meets the architectural constraints of MIL-STD-1553 (1) (see Section III). Also, because of the computer program's reliance on steady-state analysis, systems which exhibit significant transient response cannot be completely simulated. However, laboratory investigation has shown that the transient response is not significant when the bus architecture of MIL-STD-1553 is used.

## SECTION II

### CONCLUSIONS

As a result of this investigation, several observations of potential importance to MUX Bus system planners have been made.

- 1) A digital computer steady-state simulation of MIL-STD-1553 compatible multiplex buses has been developed and tested against laboratory measurements, yielding acceptable levels of agreement. This simulation provides driving point impedances, power distributions and voltage waveforms at various locations throughout the bus. The ability to change both system architecture and component parameters in software makes this simulation a valuable tool for analysis of proposed MUX Bus configurations.
- 2) Laboratory observations and simulation results suggest that an engineering trade-off must be made between power transferred from transmitter to receiver along the bus and the level of signal distortion in the received waveform. Power transfer is greatest when the stub driving point impedances are low. However, low stub impedances increase the loading on the bus thereby causing an increase in waveform distortion. Computer simulation may help to make this trade-off a more rational one.
- 3) It has been found that under certain situations normal manufacturing variation of component parameters may drastically alter bus performance. The only tractable method available for determining these sensitivities appears to be computer simulation.

### SECTION III

#### MIL-STD-1553 (USAF)

In an effort to define operational characteristics and avionics interfaces for multiplex buses used in intra-aircraft signaling the Air Force Aeronautical Systems Division (AFASD) has published a document entitled "Military Standard for Aircraft Multiplex Data Bus," (MIL-STD-1553 (USAF)). The following is a listing of characteristics defined in the standard which are relevant to this discussion.

Transmission Medium:	Twisted, shielded pair, $Z_0 = 71$ ohms
Bus Discipline:	Command/Response, half duplex; bus control exercised by a Bus Control Unit
Transmission Bit Rate:	1 Megabit per second
Modulation:	PCM, using Manchester II code
Timing:	Asynchronous, carried by Manchester Code
Number of Terminals:	33 maximum including Bus Control Unit
MAX Bus Length:	300 ft. max.
Length of Terminal Stubs:	20 ft. max.
Short Circuit Protection:	54 ohms resistor in each conductor of the stub pair.
Stub Driving Point Impedance (Receive Mode):	$\geq 6800$ ohms dc to 100 kHz $\geq 2000$ ohms 100 kHz to 1 MHz

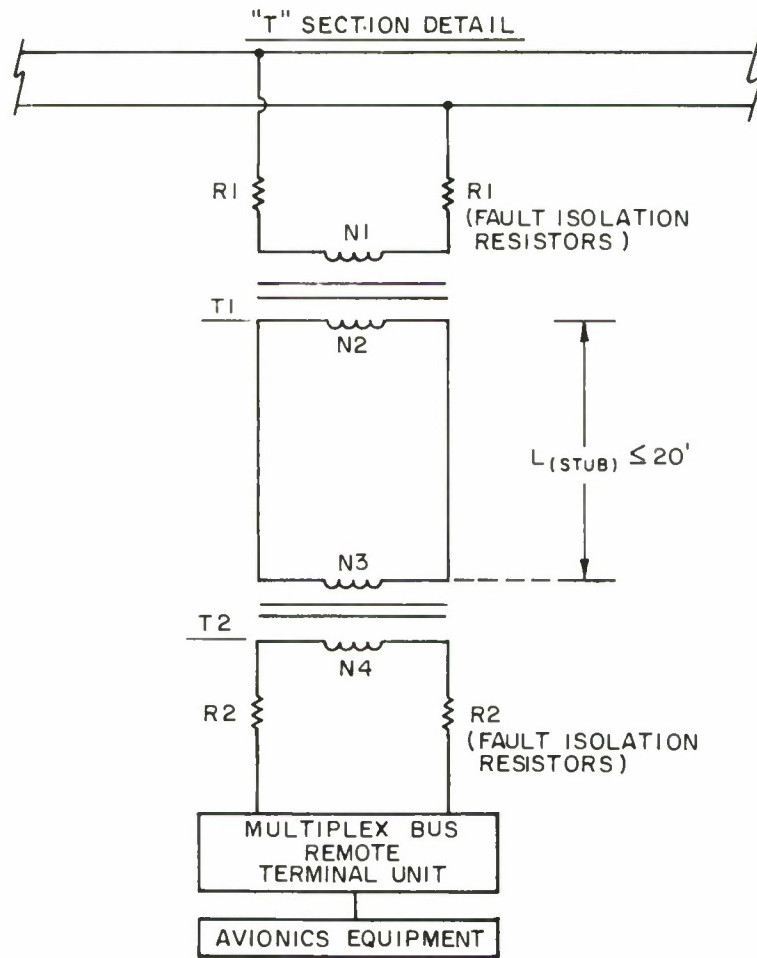
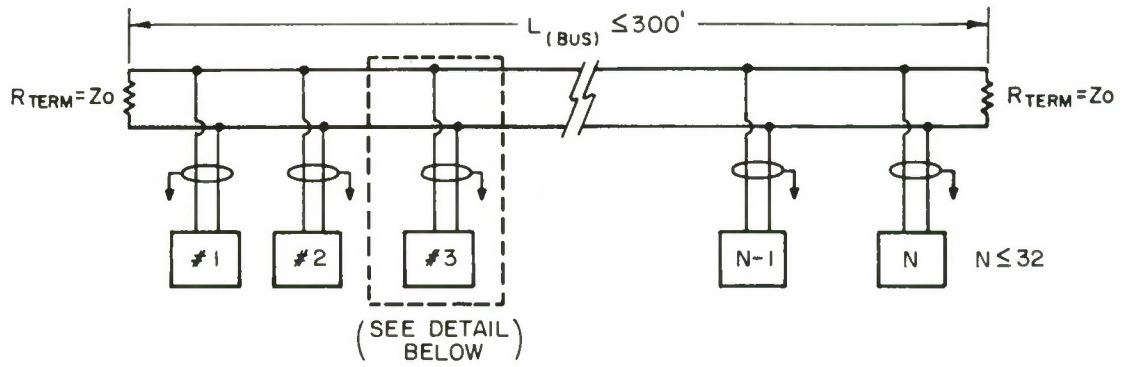
Figure 1 depicts the bus architecture, defined by MIL-STD-1553, which was used as a basis for the simulation. For the cases examined in this paper, the following values were chosen for the variables of Figure 1:

Bus Length:	$L(\text{bus}) = 250'$
Number of Stubs:	$N = 20$

Length of each Stub:	$L(\text{stub}) = 20'$	
Transformer Turns Ratios:	$N1:N2 = 1:1$	Pulse Engineering, Inc.
	$N3:N4 = 1:1$	Type 5163
Isolation Resistances:	$R1 = 54 \text{ ohms}$	
	$R2 = 0 \text{ ohms}$	
Receiver Input Impedance:	$6800 \text{ ohms}$	

To assure that reasonable values were chosen for the cable characteristics employed in the simulation, Haveg Industries type LE-572-0003/0002 cable was used as a guide. This cable, a lightweight version of RG-108A, has been recommended for use in multiplex bus applications on the B-1 aircraft by North American Rockwell. Laboratory measurements on samples of this cable produced the following parameter values:

$C = 21.8 \text{ pf per foot,}$   
 $L = .109 \mu\text{h per foot,}$   
 $R = .0288 \text{ ohms per foot,}$   
 $Z_0 = 71 \text{ ohms}$



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Figure 1 MUX-BUS ARCHITECTURE

## SECTION IV

### CELL APPROACH

#### Definition

In the MUX Bus system of MIL-STD-1553, each Multiplex Bus Remote Terminal Unit (RTU, see Figure 1) is capable of transmitting information onto the bus. Of course, only one may transmit at a time. If the computer simulation is to be sufficiently flexible to allow this type of operation, some form of modularization is required. The "T" section of Figure 1 will be defined as a basic module, or "cell", of the MUX Bus. Each cell may contain one RTU, two transformers, four fault isolation resistors and three sections of shielded, twisted pair cable. In addition, the first (leftmost) and last (rightmost) cells each contain a bus termination resistor whose value is equal to the cable's characteristic impedance,  $Z_0$ . The division point between adjacent cells is chosen such that only  $N$  cells, where  $N$  is the number of stubs, are required to represent a given MUX Bus.

#### Circuit Analysis of a Cell

##### Transmitting Cell

Consider the cell shown in Figure 2 whose RTU is transmitting onto the bus. Complex impedances  $Z(1)$  and  $Z(2)$ , the driving point impedances seen looking into the adjacent cells, will be assumed known for the moment. The first step taken by the simulation is to determine values for  $Z(4)$  and  $Z(5)$  by use of the following relationships:(3)

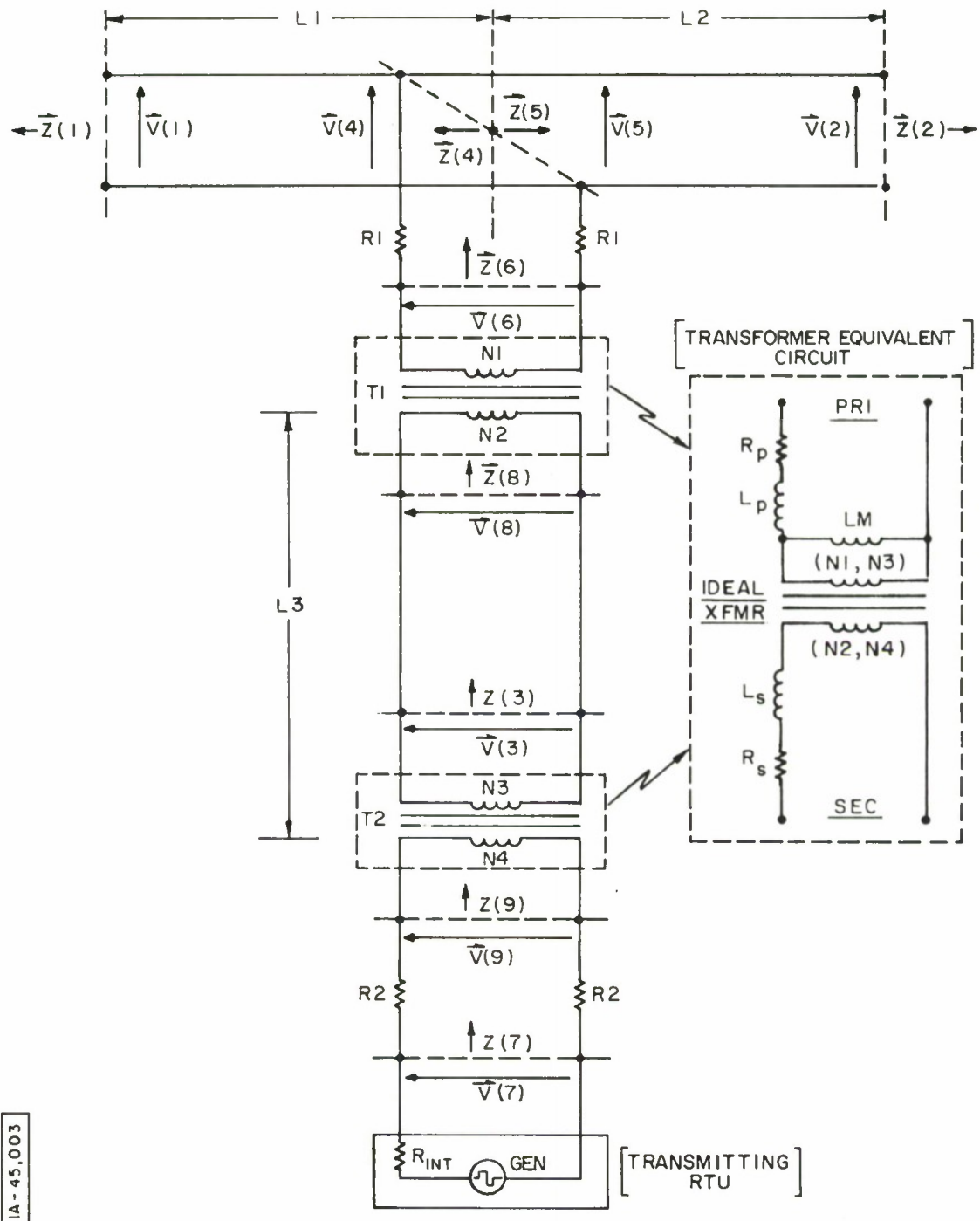
$$\frac{Z(5)}{Z_0} = \frac{Z(2) \cosh(\vec{\gamma} \cdot L_2) + Z_0 \sinh(\vec{\gamma} \cdot L_2)}{Z_0 \cosh(\vec{\gamma} \cdot L_2) + Z(1) \sinh(\vec{\gamma} \cdot L_2)} \quad (1)$$

$$\frac{Z(4)}{Z_0} = \frac{Z(1) \cosh(\vec{\gamma} \cdot L_1) + Z_0 \sinh(\vec{\gamma} \cdot L_1)}{Z_0 \cosh(\vec{\gamma} \cdot L_1) + Z(1) \sinh(\vec{\gamma} \cdot L_1)} \quad (2)$$

where:  $\vec{\gamma}$  = propagation constant of the cable

$Z_0$  = characteristic impedance of the cable

Impedances  $Z(6)$ ,  $Z(8)$ ,  $Z(3)$ ,  $Z(9)$ , and  $Z(7)$  are obtained in a similar manner using the above relationship combined with steady state circuit analysis and the transformer lumped component



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Figure 2 TRANSMITTING CELL SCHEMATIC DIAGRAM

equivalent circuit. This procedure must be repeated at each frequency which corresponds to an harmonic component of the RTU output, voltage  $\vec{V}(7)$  of Figure 2. The waveform in Figure 3 is a normalized representation of this unit's output voltage. The Fourier series for this voltage is:

$$\vec{V}(7) = \sum_{n=1}^{\infty} C_n \cos(n\omega t) \quad (3)$$

where:

$$C_n = \left[ \frac{\sin \pi \frac{n t_1}{T}}{\pi \frac{n t_1}{T}} \right] \left[ \frac{\sin \pi \frac{n(t_0 + t_1)}{T}}{\pi \frac{n(t_0 + t_1)}{T}} \right]$$

$n$  = harmonic number = 1, 3, 5, . . .

Therefore, as many odd harmonics of the fundamental frequency as accuracy requirements dictate will have to be considered in the impedance calculations. [NOTE: For rise/fall times consistent with MIL-STD-1553 and a 1 MHz fundamental frequency, approximately six or more odd harmonics should be considered.]

After the impedances  $\vec{Z}(1)$  through  $\vec{Z}(9)$  are known at each applicable frequency, the next step is to apply each harmonic component of the RTU output voltage waveform  $\vec{V}(7)$  to the cell. Calculation of  $\vec{V}(9)$  and  $\vec{V}(3)$  from  $\vec{V}(7)$  is fairly straightforward and will not be explained in detail. Voltage  $\vec{V}(8)$  is found by using voltage  $\vec{V}(3)$  and the following equation (3):

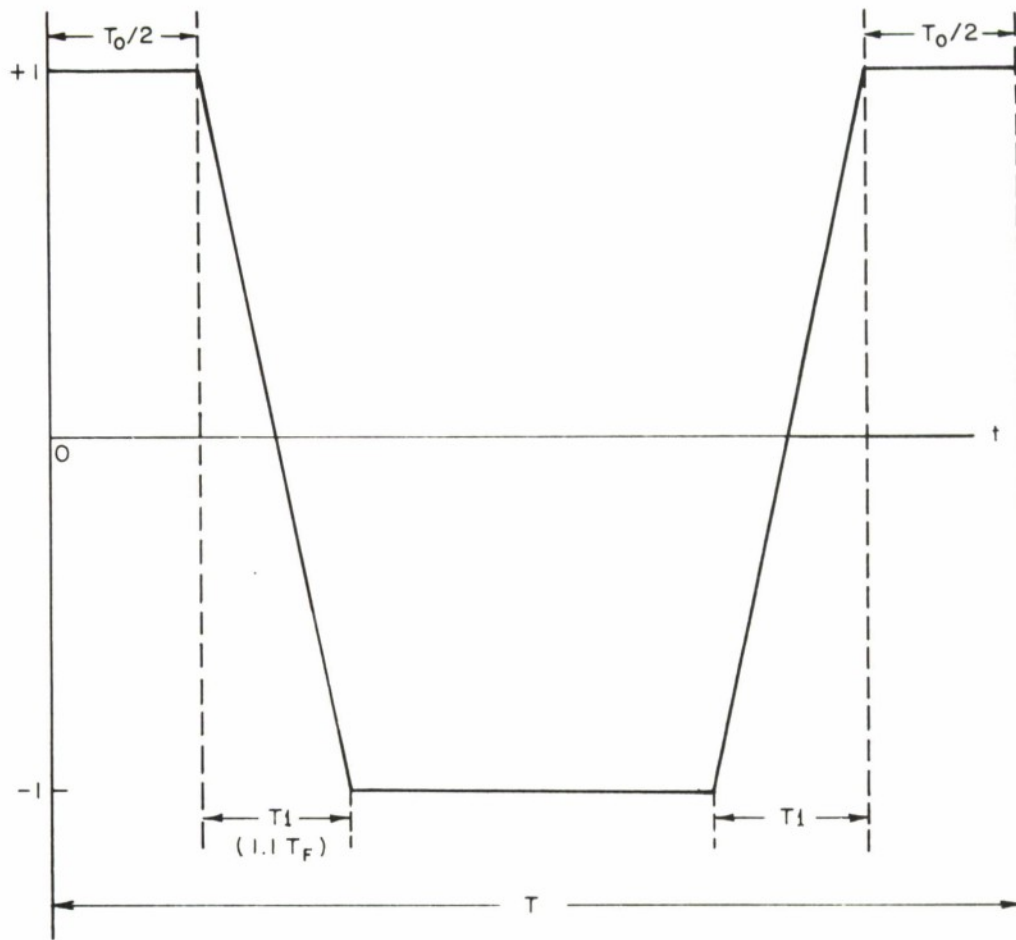
$$\vec{V}(8) = \vec{V}(3) [\cosh(\vec{\gamma} \cdot L_3) - (Z_0/Z(3)) \sinh(\vec{\gamma} \cdot L_3)] \quad (4)$$

Using this relationship, the transformer model, and AC circuit analysis, voltages  $\vec{V}(6)$ ,  $\vec{V}(4)$ ,  $\vec{V}(5)$ ,  $\vec{V}(1)$  and  $\vec{V}(2)$  may be obtained. As with the impedance calculations, this procedure must be repeated for each of the relevant harmonic frequencies.

The final step in the analysis of the transmitting cell is to determine the composite voltage waveforms, harmonic power distributions, and composite power distributions at each of the nine points shown in Figure 2. The composite voltage waveform at point Q is found by:

$$v(t) = \sum_{\substack{Q \\ (n=1,3,5\dots)}}^{NN} \vec{V}_n(Q) \cos(n\omega t) \quad (5)$$

[composite voltage]



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Figure 3 INPUT PULSE WAVEFORM (NORMALIZED)

where:  $n$  = harmonic number

$NN$  = highest odd harmonic considered

$Q$  = position number (1,2,...,9)

$\vec{V}_n(Q)$  = voltage phasor at point  $Q$  for frequency  $n$

In the computer program this summation is done at discrete time increments from  $t=0$  to  $t=T$ , where  $T$  is the period of the fundamental frequency.

The impedances previously calculated are actually driving point impedances at each of the measurement points indicated in Figure 2. Using this fact, along with the corresponding harmonic voltages, leads to the following expression for average harmonic power at point  $Q$ :

$$P_n(Q) = \frac{|\vec{V}_n(Q)|^2}{2|\vec{Z}_n(Q)|} \cos(\theta) \left[ \begin{array}{l} \text{average} \\ \text{harmonic} \\ \text{power} \end{array} \right] \quad (6)$$

where:  $\theta$  = angle of impedance  $\vec{Z}_n(Q)$

To find the composite average power at point  $Q$  requires a summation of the average harmonic powers, i.e.:

$$P_Q = \sum_{n=1,3,5}^{NN} P_n(Q) \left[ \begin{array}{l} \text{composite} \\ \text{average} \\ \text{power} \end{array} \right] \quad (7)$$

The only matter not covered at this point is where values for the previously assumed impedances  $Z(1)$  and  $Z(2)$  come from. This question, addressed in the next two sections, is the basis for the flexibility inherent in the cell approach.

#### Receiving Cell

Within the framework of MIL-STD-1553, only one RTU can transmit information onto the bus at any given time. Consequently,  $(N-1)$  cells (where  $N$  is the number of RTU's) are considered to be receiving cells. For the purpose of this discussion these  $(N-1)$  cells will be defined as either Left Cells (LCELL) or Right Cells (RCELL), depending on their location relative to the transmitting cell.

Right Cells. Figure 4 depicts impedance and voltage conventions within an RCELL. These conventions are applied to all RCELL's except the last, or rightmost cell. The difference in RCELL(LAST) is that  $Z(\vec{2})$  is actually equal to RTERM, a known constant, as can be seen from Figure 1. The significance of this point will be discussed in the section on chaining of cells.

As in the transmitting cell case, the first step in the simulation of an RCELL is to determine the driving point impedances throughout the cell. Assuming that the value of  $Z(\vec{2})$  is known:

$$\frac{Z(\vec{5})}{Z_0} = \frac{Z(\vec{2}) \text{Cosh}(\vec{\gamma} \cdot L_2) + Z_0 \text{Sinh}(\vec{\gamma} \cdot L_2)}{Z_0 \text{Cosh}(\vec{\gamma} \cdot L_2) + Z(\vec{1}) \text{Sinh}(\vec{\gamma} \cdot L_2)} \quad (8)$$

Note that this equation has the same form as Equation 1.

The receiving input impedance of the RTU,  $Z(\vec{7})$ , is known. Therefore, impedances  $Z(\vec{9})$  and  $Z(\vec{3})$  can be readily calculated. To find  $Z(\vec{8})$ ,  $Z(\vec{3})$  is used in the following equation:

$$\frac{Z(\vec{8})}{Z_0} = \frac{Z(\vec{3}) \text{Cosh}(\vec{\gamma} \cdot L_3) + Z_0 \text{Sinh}(\vec{\gamma} \cdot L_3)}{Z_0 \text{Cosh}(\vec{\gamma} \cdot L_3) + Z(\vec{3}) \text{Sinh}(\vec{\gamma} \cdot L_3)} \quad (9)$$

Solving for  $Z(\vec{6})$  using the transformer model and  $Z(\vec{8})$  allows the following relation for  $Z(\vec{4})$ :

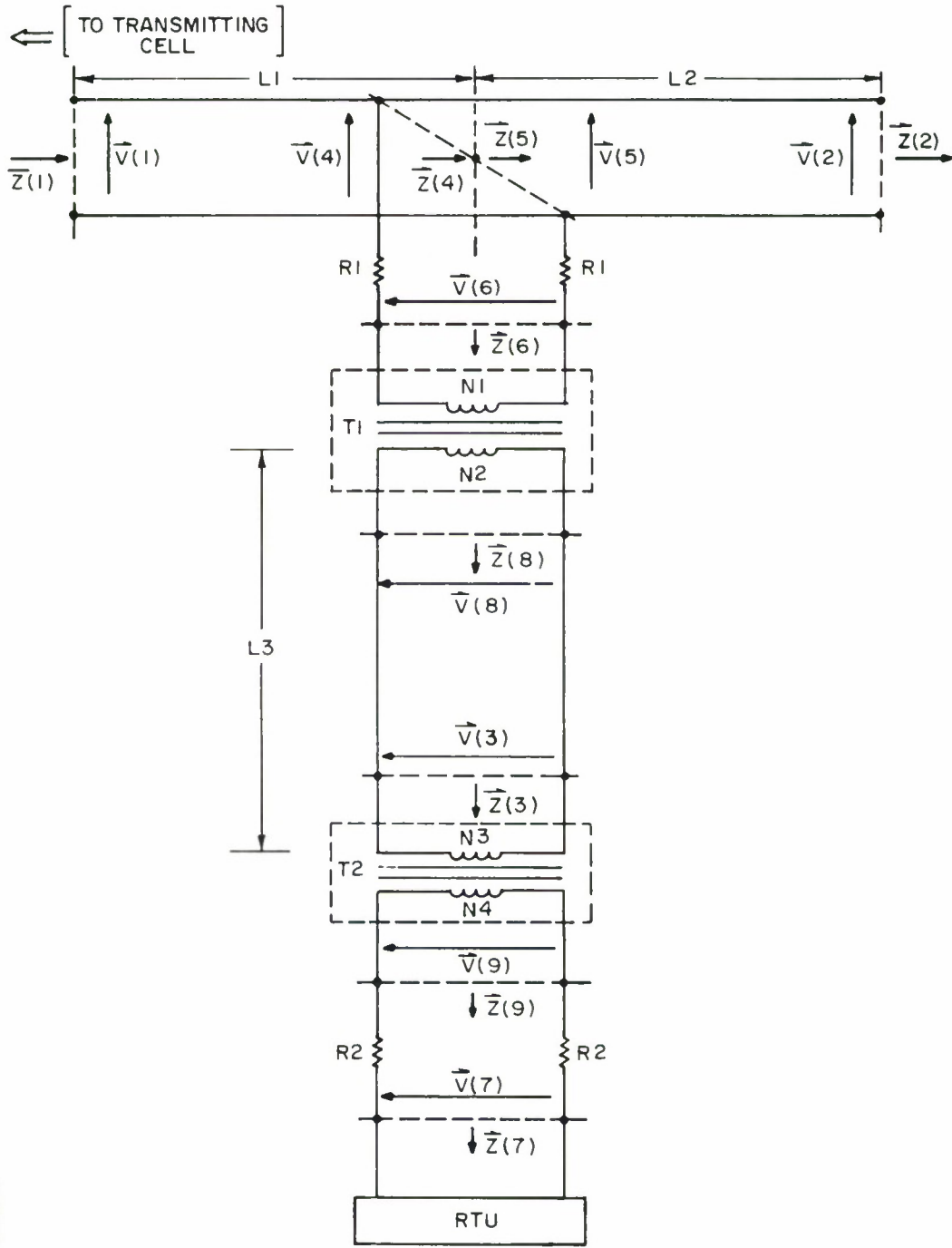
$$Z(\vec{4}) = [Z(\vec{6}) + 2 \cdot R_1] || Z(\vec{5}) \quad (10)$$

With the value of  $Z(\vec{4})$  determined,  $Z(\vec{1})$  can be found by:

$$\frac{Z(\vec{1})}{Z_0} = \frac{Z(\vec{4}) \text{Cosh}(\vec{\gamma} \cdot L_1) + Z_0 \text{Sinh}(\vec{\gamma} \cdot L_1)}{Z_0 \text{Cosh}(\vec{\gamma} \cdot L_1) + Z(\vec{4}) \text{Sinh}(\vec{\gamma} \cdot L_1)} \quad (11)$$

An important point to be made here is that  $Z(\vec{1})$  of this cell is identically equal to  $Z(\vec{2})$  of the preceding cell on the left. Conversely,  $Z(\vec{2})$  is equal to  $Z(\vec{1})$  of the following cell on the right. This transference of impedance values across cell boundaries provides a "daisy-chaining" effect, supplying values for  $Z(\vec{2})$  of the transmitter cell, which was assumed known in the previous discussion.

The next step in the analysis is to determine the voltages within the cell. Here the input voltage is considered to be  $V(\vec{1})$ , as opposed to  $V(\vec{7})$  in the transmitting cell case. Values for this



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Figure 4 RIGHT CELL SCHEMATIC DIAGRAM

voltage at the various harmonics are supplied by  $\vec{V}(2)$  of the cell on the immediate left. To find  $\vec{V}(4)$  apply  $\vec{V}(1)$  to:

$$\vec{V}(4) = \vec{V}(1) [\text{Cosh}(\vec{\gamma} \cdot L1) - (Z_0/\vec{Z}(1)) \text{Sinh}(\vec{\gamma} \cdot L1)] \quad (12)$$

which has the same form as Equation (2). Using the voltage divider relationship:

$$\vec{V}(6) = \vec{V}(4) \left[ \frac{\vec{Z}(6)}{\vec{Z}(6) + 2 \cdot R1} \right] \quad (13)$$

Solving for  $\vec{V}(8)$  using the transformer model leads to:

$$\vec{V}(3) = \vec{V}(8) [\text{Cosh}(\vec{\gamma} \cdot L3) - (Z_0/\vec{Z}(8)) \text{Sinh}(\vec{\gamma} \cdot L3)] \quad (14)$$

Calculating  $\vec{V}(9)$  from the transformer model, determine the received harmonic voltage at the RTU by:

$$\vec{V}(7) = \vec{V}(9) \left[ \frac{\vec{Z}(7)}{\vec{Z}(7) + 2 \cdot R2} \right] \quad (15)$$

where:  $\vec{Z}(7)$  represents the RTU receiver input impedance.

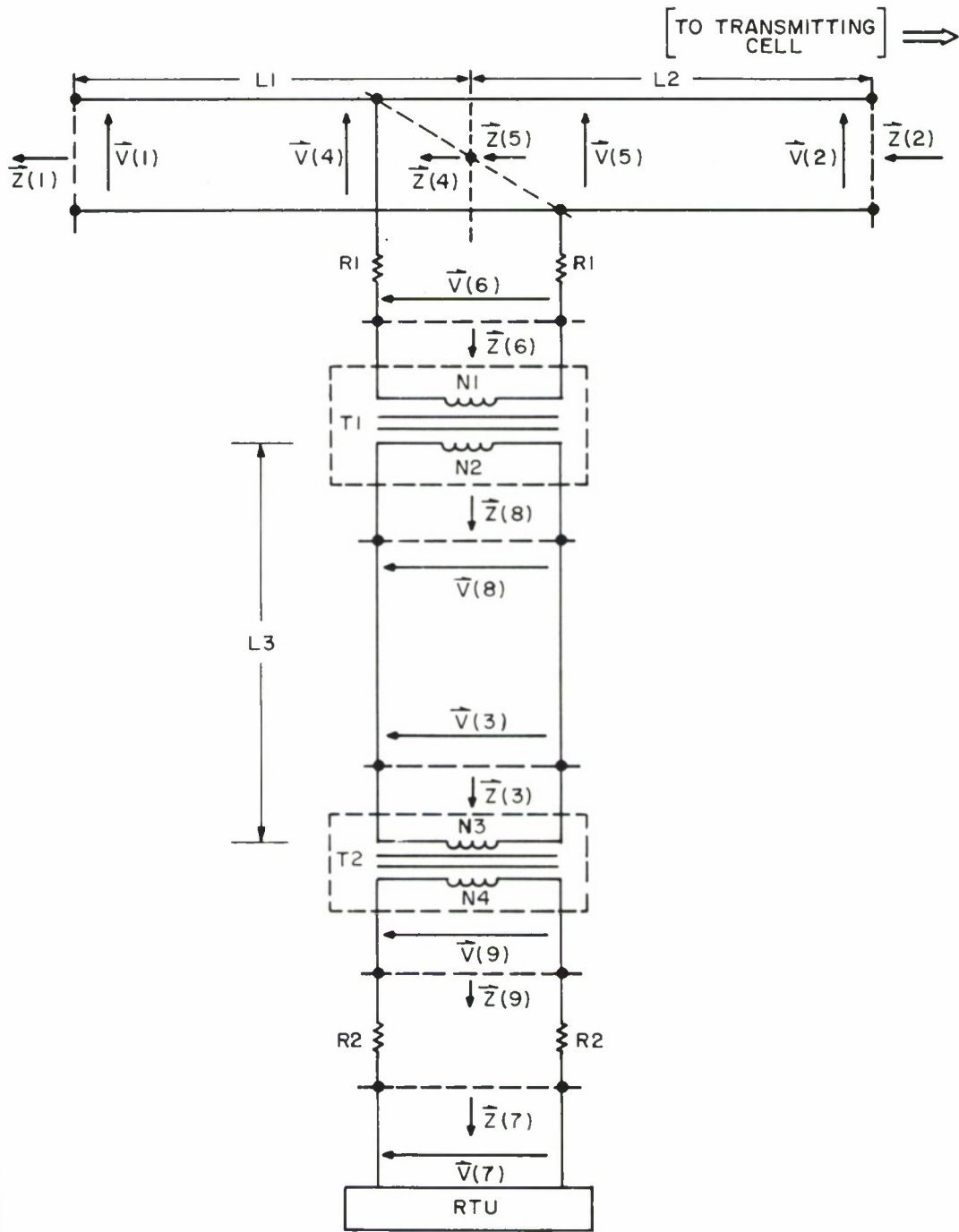
Returning to the bus/stub junction, apply the already determined value for  $\vec{V}(4)$  to:

$$\vec{V}(2) = \vec{V}(4) \text{Cosh}(\vec{\gamma} \cdot L2) - (Z_0/\vec{Z}(5)) \text{Sinh}(\vec{\gamma} \cdot L2)$$

As mentioned earlier, voltage  $\vec{V}(2)$  is the input voltage  $\vec{V}(1)$  for the next RCELL to the right.

After the above procedures have been used to obtain the impedances and voltages for each harmonic, Equations 5, 6, and 7 are used to determine the composite voltage waveforms, average harmonic powers and average composite powers in each of the RCELLS.

Left Cells. The analysis of LCELLS, cells which are to the left of the transmitting cell, is analogous to RCELLS. The voltage and impedance conventions for this case are shown in Figure 5. Again, the difference in the first or leftmost cell is that  $\vec{Z}(1)$  is equal to RTERM, a point that will be discussed further in the next section.



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Figure 5 LEFT CELL SCHEMATIC DIAGRAM

In an LCELL the entry point for impedance calculations is  $\vec{Z}(1)$ . Values for this impedance at each harmonic frequency are obtained from  $\vec{Z}(2)$  in the previous cell to the left. The order of calculation and methods used for an LCELL are the same as for an RCELL, i.e.,  $\vec{Z}(4)$  is found from  $\vec{Z}(1)$  and the impedance translation equation; impedances  $\vec{Z}(9)$ ,  $\vec{Z}(3)$ ,  $\vec{Z}(8)$ , and  $\vec{Z}(6)$  are obtained by using the transformer model, translation equation, and AC circuit analysis;  $\vec{Z}(2)$  is determined by using the parallel combination of  $\vec{Z}(4)$  and  $\vec{Z}(5)$  in the translation equation. Calculation of voltages within an LCELL is also analogous to RCELL's. Instead of using  $\vec{V}(1)$  as the input  $\vec{V}(2)$  is used, but the procedure to be followed is equivalent. The main difference between the analysis of an LCELL and an RCELL is the direction of the driving point impedances, and the variables which are used as inputs to the cell. This similarity greatly decreases the complexity of the computer simulation program. Also, it allows complete flexibility of transmitter location--a fact that will be illustrated in the following section.

#### Chaining of Cells

Having considered each of the different cell types separately, the next step is to show how they may be connected to form a complete multiplex bus. Consider the system of Figure 6 in which a transmitting cell, LCELL, and RCELL have combined to form a three subscriber MUX Bus.

The first step in the analysis of this system is calculation of the driving point impedances. Referring to Cell 3 of Figure 6, an RCELL, several points about the cell boundaries become apparent. In the discussion of impedance calculations in an RCELL, mention was made that the value of  $\vec{Z}(2)$  would be supplied by  $\vec{Z}(1)$  of the next RCELL to the right. However, in this case  $\vec{Z}(2)$  is actually equal to ZTERM, a known constant. Therefore, impedances  $\vec{Z}(1)$  through  $\vec{Z}(9)$  can be calculated for this cell without regard to any other cell. If there were more than one RCELL, the value just calculated for  $\vec{Z}(1)$  in the rightmost cell would become the  $\vec{Z}(2)$  of the next RCELL to the left, with the process continuing until all of the RCELLS had been considered. The same procedure is applied to the LCELLS except that calculation begins at the leftmost cell in which  $\vec{Z}(1) = \text{ZTERM}$  and then progresses to the right until all LCELLS have been addressed. At that point the only driving point impedances not yet calculated would be those in the transmitting cell itself. Since there is no requirement that the number of LCELLS be equal to that of RCELLS the location of this remaining transmitting cell is completely arbitrary, a major advantage of the cell approach.

Returning to the transmitting cell of Figure 6, having found values for  $\vec{Z}(2)$  of the LCELL on the immediate left and  $\vec{Z}(1)$  of the RCELL on the immediate right, calculation of the driving point

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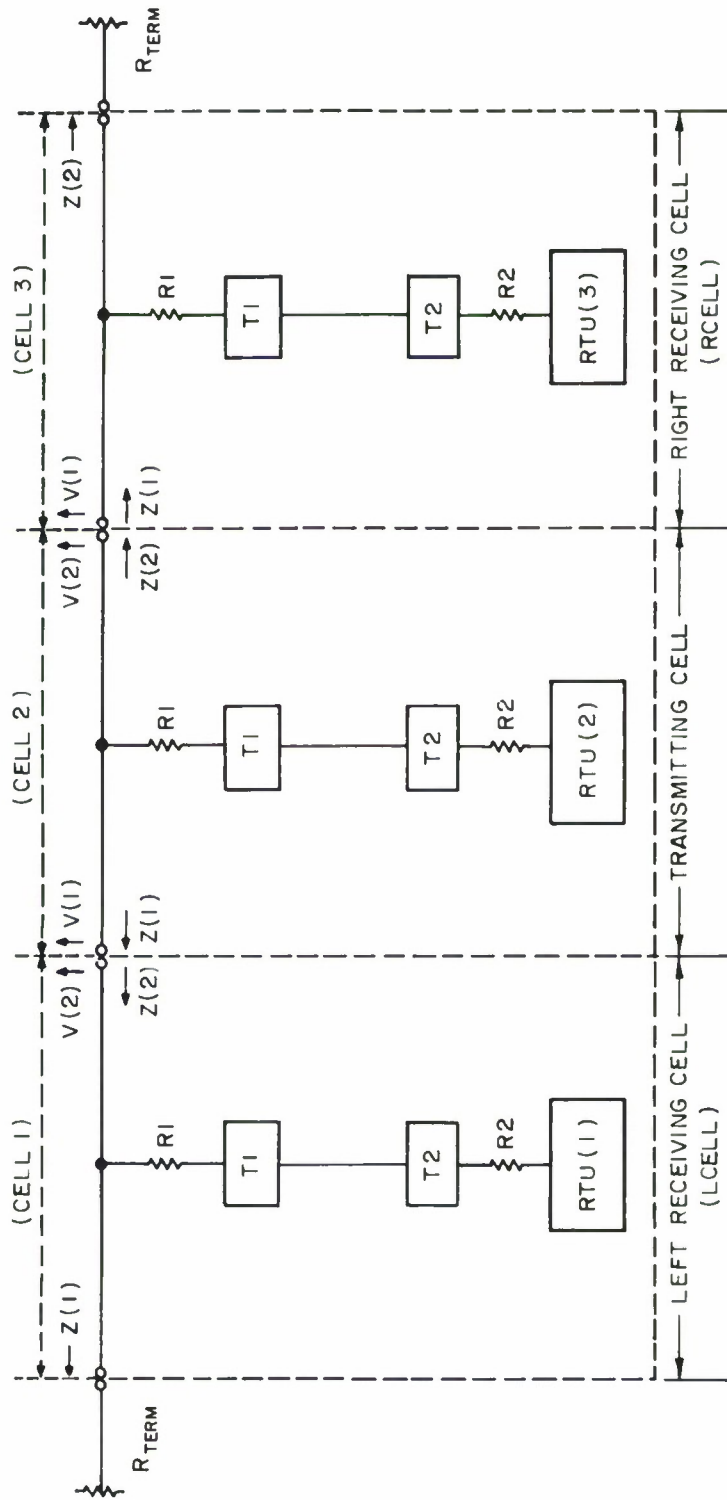


Figure 6 THREE CELL MULTIPLEX BUS

impedances within the transmitting cell follows the discussion in the Transmitting Cell Section.

Calculation of voltages throughout the bus proceeds in an analogous fashion but with an opposite direction of flow. Here the known values are the harmonic voltage amplitudes of the transmitting RTU's output waveform. Since all impedances have been determined, it is a simple matter to find the voltages within the transmitting cell using these amplitudes and the methods described previously. The values produced for voltages  $\vec{V}(1)$  and  $\vec{V}(2)$  become the inputs for the cells on the immediate left and right. The chaining process continues until all cell voltages on each side of the transmitting cell have been calculated. This sequence of operations may be summarized as follows: impedance calculations flow from the extremities of the mux-bus inward toward the transmitting RTU, while voltage calculations flow from the transmitting RTU outward toward the extremities of the bus.

With all voltages and impedances determined throughout the bus, calculation of the composite voltage waveforms, average harmonic powers, and average composite powers for each cell proceed as previously described in the Transmitting Cell Section.

## SECTION V

### MODEL VALIDATION

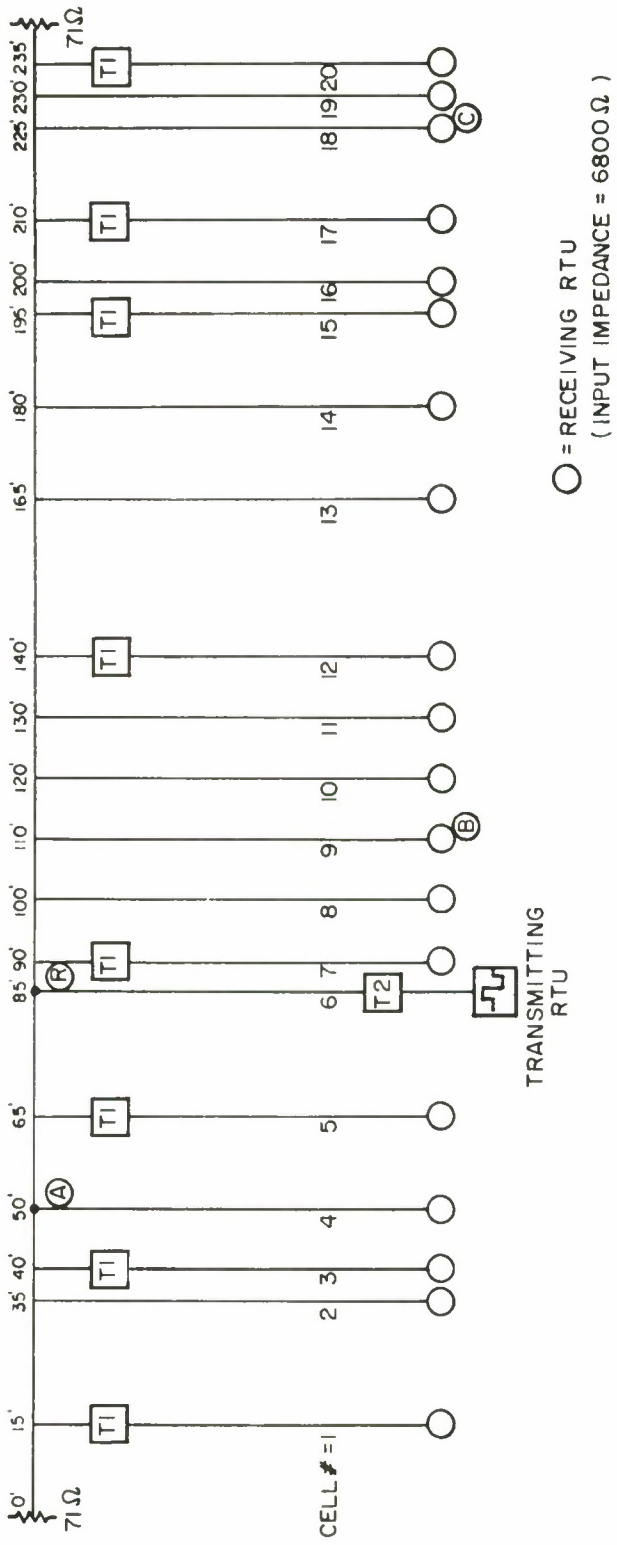
Validation of the MUX Bus simulation was accomplished in two stages. First, hand calculation and Smith chart analysis were used to check the driving point impedance and power distribution algorithms. Next, the voltage waveforms produced by the simulation were compared with oscillographs taken on a laboratory mock-up of a representative MUX Bus (2). The bus architecture used for this comparison, shown in Figure 7, had the characteristics discussed in Section III with one exception. Since it was possible to obtain only a limited supply of pulse transformers, the staggered transformer placement arrangement shown was adopted.

CASE I. The first comparison between laboratory waveforms and computer simulated plots is shown in Figure 8. The transmitter, a square wave pulse generator with output impedance equal to  $Z_0$ , was connected to the end of Stub 6. The point at which voltage waveforms were to be compared was the junction between Stub 4 and the bus (labeled point "A" on Figure 7). The laboratory oscillograph of this waveform when isolation resistors R1 (Figure 1) were included in all cells is shown on the left of Figure 8. The dashed line on the plot directly above this picture is the computer simulation of the same voltage measured over one time period and normalized to a  $\pm 1$  volt transmitter signal excursion. The solid line in this plot is the simulation plotted waveform for the reference point defined by MIL-STD-1553 (see point "R", Figure 7). For the sake of clarity, the oscillograph of this reference waveform is not shown.

The right half of Figure 8 shows the comparison between laboratory and simulated waveforms for the same measurement point (point "A", Figure 7) when the isolation resistors R1 are shorted out. Again, the dashed line on the computer generated plot represents the simulation's approximation of the waveform at this point.

When each set of comparisons is studied, two facts become apparent. First, the computer simulation plotted waveforms agree very closely with their associated laboratory oscillographs. This implies that the simulation is indeed valid. The second observation involves the utility of the isolation resistors (R1). As shown on the left of Figure 8, the observed and simulated waveforms are relatively free from distortion when R1 is included in each stub. However, as shown on the right, when this resistance is removed, there is a significant degree of "ringing" apparent. This distortion is a measure of the mutual interaction between stubs.

1A - 45,000

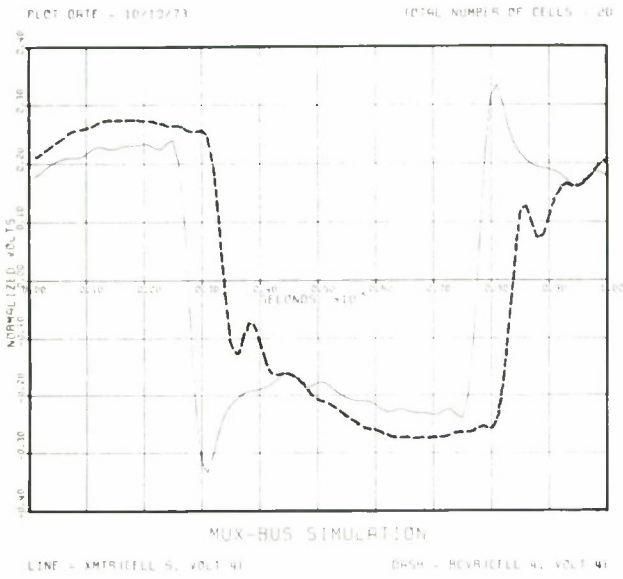


VOLTAGE MEASUREMENT POINTS:

- (A) = CELL 4, VOLTAGE V(4)
- (B) = CELL 9, VOLTAGE V(7)
- (C) = CELL 18, VOLTAGE V(7)

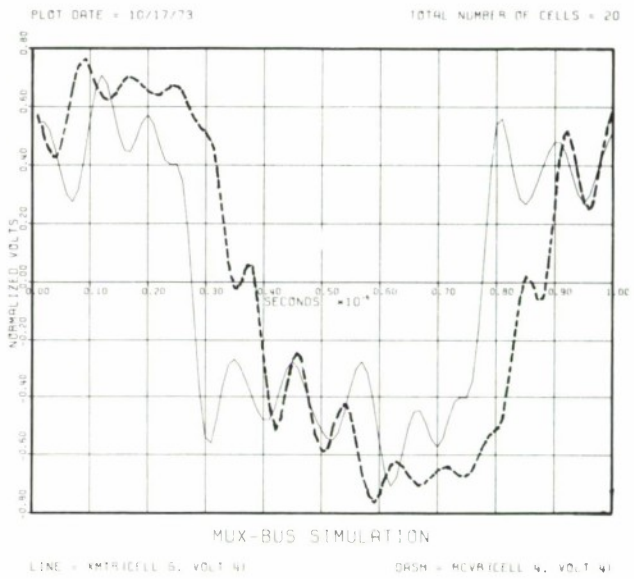
Figure 7 TWENTY CELL MULTIPLEX BUS

SERIAL NO. 14.54.13



$R1 = 56\Omega$   
 $R2 = 0\Omega$

SERIAL NO. 11.18.47



$R1 = 0\Omega$   
 $R2 = 0\Omega$



[ WAVEFORMS MEASURED AT POINT "A" OF FIGURE 7 ]

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Figure 8 COMPARISON OF LABORATORY OSCILLOGRAPHS AND COMPUTER PLOTTED WAVEFORMS

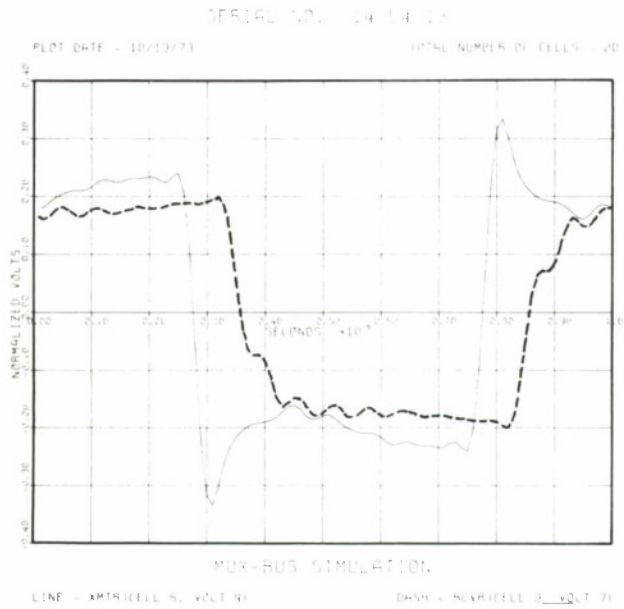
Since the degree of interaction is an inverse function of the driving point impedance of the stubs, the "smoothing" caused by the inclusion of resistances R1 is understandable.

CASE II. The second comparison to be discussed refers to the same bus architecture as CASE I, but considers the waveform at point "B" of Figure 7. The laboratory oscillographs and computer simulated waveforms with and without isolation resistances (R1) are shown in Figure 9. As in the previous case, good agreement between the oscillographs and the corresponding dashed waveforms on the computer plots empirically justifies the simulation algorithm. In addition, the set of waveforms for the  $R1 = 0$  situation graphically displays the type of problem that can occur if a high degree of interaction is allowed between stubs. If a zero-crossing detector were used on this waveform, an erroneous output would probably occur if low pass filtering were not used. However, since the simulation can predict this potential problem the designer could employ filtering, isolation resistors, or a different type of detector to avoid this situation in an operational system.

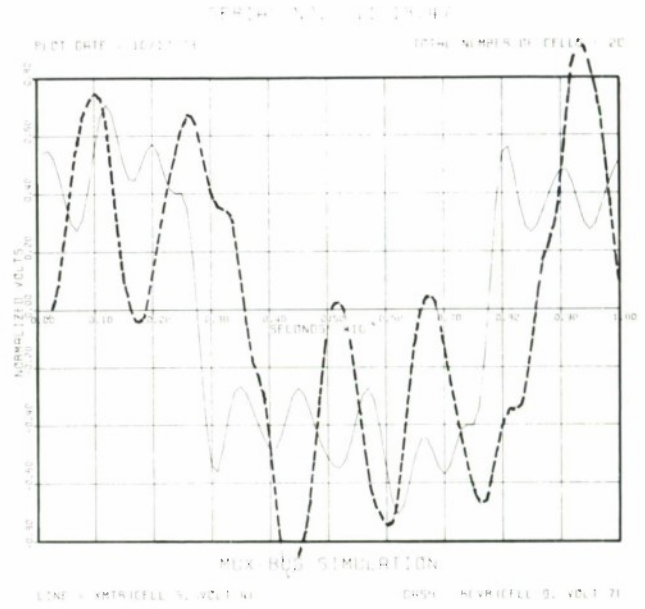
CASE III. The final comparison to be made is shown in Figure 10. As in the previous cases, the bus architecture and transmitter location are unchanged. Here the point of observation has been moved to "C" in Figure 7. Good agreement is again shown but, more importantly, the simulation exhibits the same bandwidth limitation on a long bus that was found during the laboratory investigation.

By considering the cases discussed above, along with many others not shown, a reasonable degree of confidence in the accuracy of the simulation was obtained. Hence, the next step in the investigation was to exercise the simulation beyond the scope of the laboratory effort in an attempt to expose possible problems or improvements in MIL-STD-1553. One of the early results of this study is shown in Figure 11.

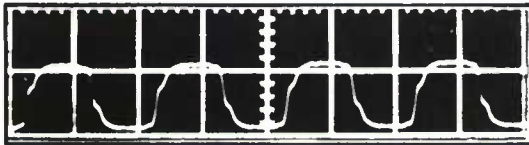
The question addressed here was the effect, if any, on voltage waveforms caused by variation in the inductance of the cable used for the bus. A laboratory analysis of this question would be impractical, to say the least. However, as shown by the plotted waveforms in Figure 11, a possible problem area would be missed if this study were not done. In all four plots the dashed waveform is the simulated voltage at point "B" of Figure 7. Case II previously discussed this voltage waveform for a nominal cable inductance of  $0.109 \mu\text{h}$  per foot. Plots "A" and "B" on the left of Figure 11 show the waveforms produced by varying the cable inductance  $\pm 10\%$  about its nominal value when isolation resistances R1 were installed in the bus of Figure 7. Comparing these two plots it is apparent that little sensitivity to an inductance variation of this magnitude



$R1 = 56 \Omega$   
 $R2 = 0 \Omega$



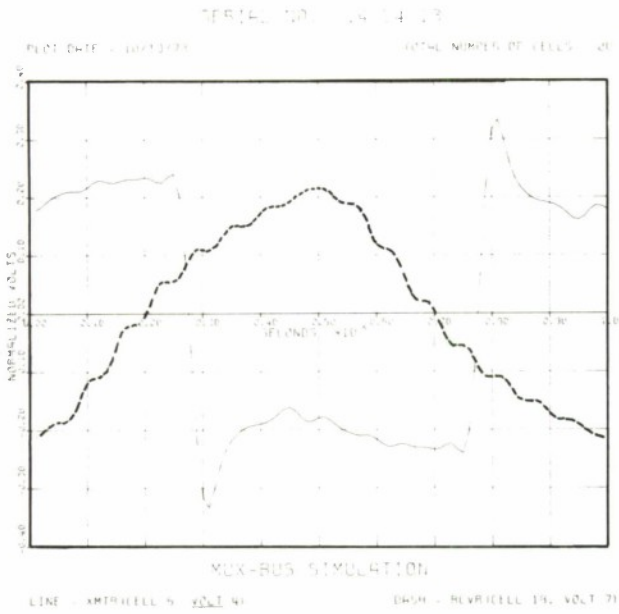
$R1 = 0 \Omega$   
 $R2 = 0 \Omega$



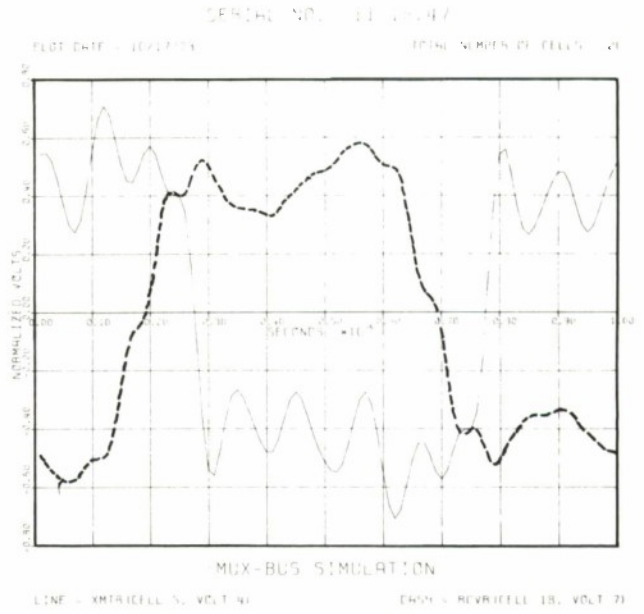
[ WAVEFORMS MEASURED AT POINT "B" OF FIGURE 7 ]

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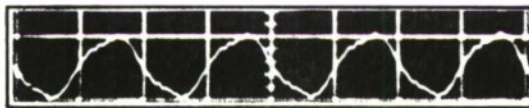
Figure 9    COMPARISON OF LABORATORY OSCILLOGRAPHS  
AND COMPUTER PLOTTED WAVEFORMS



$R1 = 56 \Omega$   
 $R2 = 0 \Omega$



$R1 = 0 \Omega$   
 $R2 = 0 \Omega$

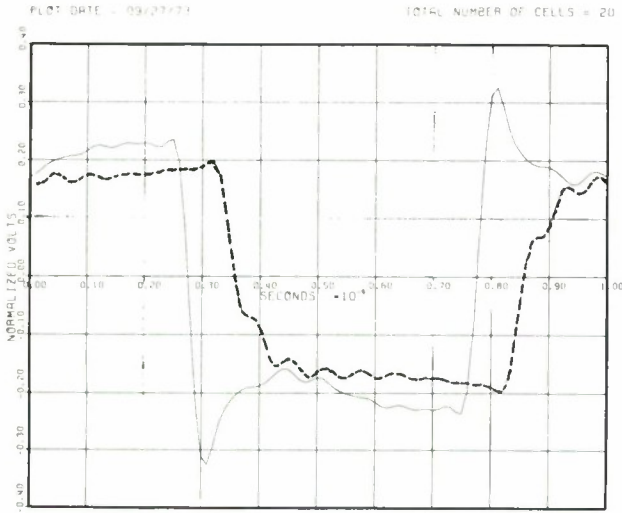


[ WAVEFORMS MEASURED AT POINT "C" OF FIGURE 7 ]

1A-45,190

Figure 10 COMPARISON OF LABORATORY OSCILLOGRAPHS AND COMPUTER PLOTTED WAVEFORMS

SERIAL NO. 15.59.26

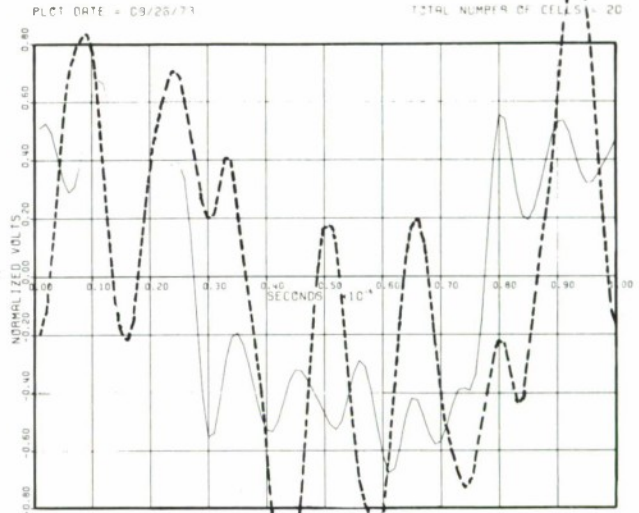


RI = 56Ω

(A)

L = NOM. + 10%

SERIAL NO. 09.16.50



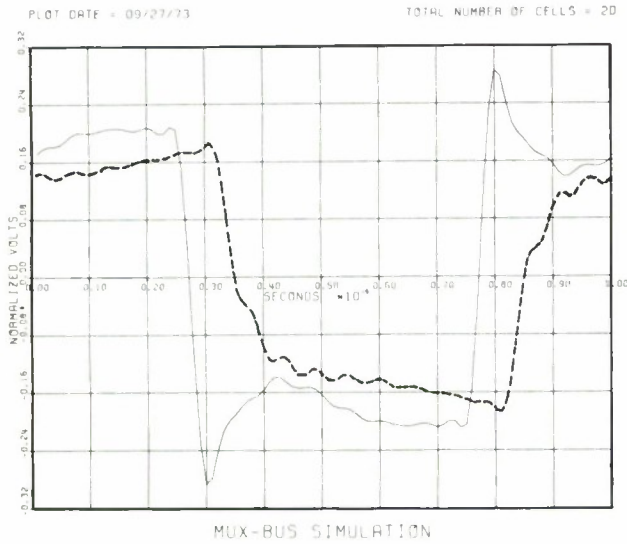
RI = 0Ω

(C)

L = NOM. + 10%

[ WAVEFORMS MEASURED AT POINT "B" OF FIGURE 7 ]

SERIAL NO. 08.39.03

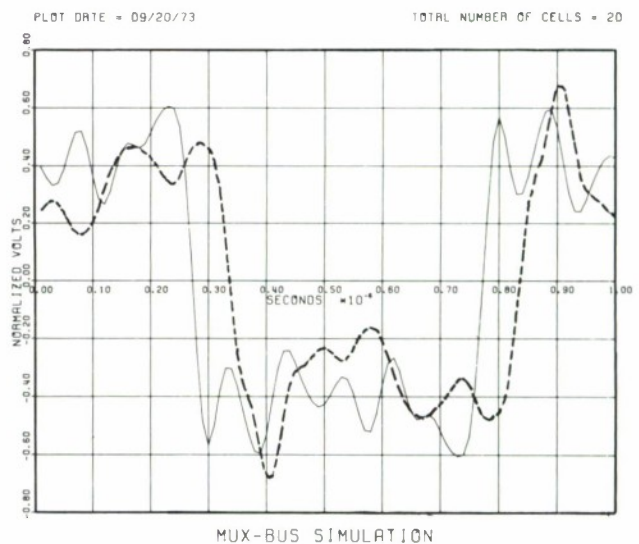


RI = 56Ω

(B)

L = NOM. - 10%

SERIAL NO. 11.14.13



RI = 0Ω

(D)

L = NOM. - 10%

IA-45,191

Figure II CABLE INDUCTANCE VARIATION ANALYSIS

would be expected. However, consider plots "C" and "D" on the right of Figure 11. Here a considerable change in waveform is displayed when resistors R1 are removed from the stubs and L is varied over the same  $\pm 10\%$  range. Since cable manufacturing tolerances are within the range considered, it is entirely possible that a designer expecting waveform "D" might instead find waveform "C" when the bus was actually constructed, perhaps causing incompatibility with his detection circuitry. This inherent ability of computer simulation to permit variation of any system parameter by a simple change in software provides a powerful tool for analysis of multiplex bus systems.

## APPENDIX I

### SIMULATION SOFTWARE

In order to provide a better understanding of the simulation and to facilitate its use by interested parties, the following four topics will be addressed:

- Part 1 - The computer system on which the simulation was exercised, including required capacities and peripheral equipment.
- Part 2 - The basic simulation routine, called TPMOD2, with a discussion of required inputs and available outputs.
- Part 3 - The plotting routine, PLMOD2, which produced the voltage waveform plots shown in Section IV.
- Part 4 - The operational steps required to exercise the simulation on a computer installation similar to the author's.

Part 1: Computer System Requirements - The simulation actually consists of two separate programs, TPMOD2 and PLMOD2. Both of these programs were written in FORTRAN IV and run on an IBM 370/155 computer. To exercise the programs without modification, the requirements of Table A1, Figure I.1 should be met. Table A2 lists the core and CPU demands found during a representative run made for a 32 stub MUX Bus.

Part 2: Description of TPMOD2 - In order to reduce computer core requirements and to increase flexibility, the simulation was broken into two parts. The first part, called "TPMOD2", uses the architectural and component parameter inputs to produce a magnetic tape on which the complex voltage "phasors" for each harmonic at each node of Figure 1 are written. The operation of this program can best be explained by reference to the flow chart of Figure I.2 and the listing of the program immediately following.

TPMOD2 has essentially a three tiered structure. The first level, or main program, handles input and output, generation of the input voltage harmonic components, power calculations, and the sequencing of subroutine calls. Since this analysis is multi-variate, involving both positions along the bus and frequency (harmonic), there are several nested loops in the sequencing portion of the routine. The harmonic number, or frequency, forms the outer loop inside of which the cell number, or position along the bus, is varied. As these parameters take on their allowed doublets, calls

COMPUTER SYSTEM REQUIREMENTS	
TO EXERCISE TPMOD2 WITHOUT MODIFICATION	TO EXERCISE PLMOD2 WITHOUT MODIFICATION
1) FORTRAN $\text{IV}$ COMPILER 2) COMPLEX NOTATION & ARITHMETIC 3) 9-TRACK TAPE DRIVE	1) FORTRAN $\text{IV}$ COMPILER 2) COMPLEX NOTATION & ARITHMETIC 3) 9-TRACK TAPE DRIVE 4) 7-TRACK TAPE DRIVE 5) CALCOMP PLOTTER AND SOFTWARE PACKAGE

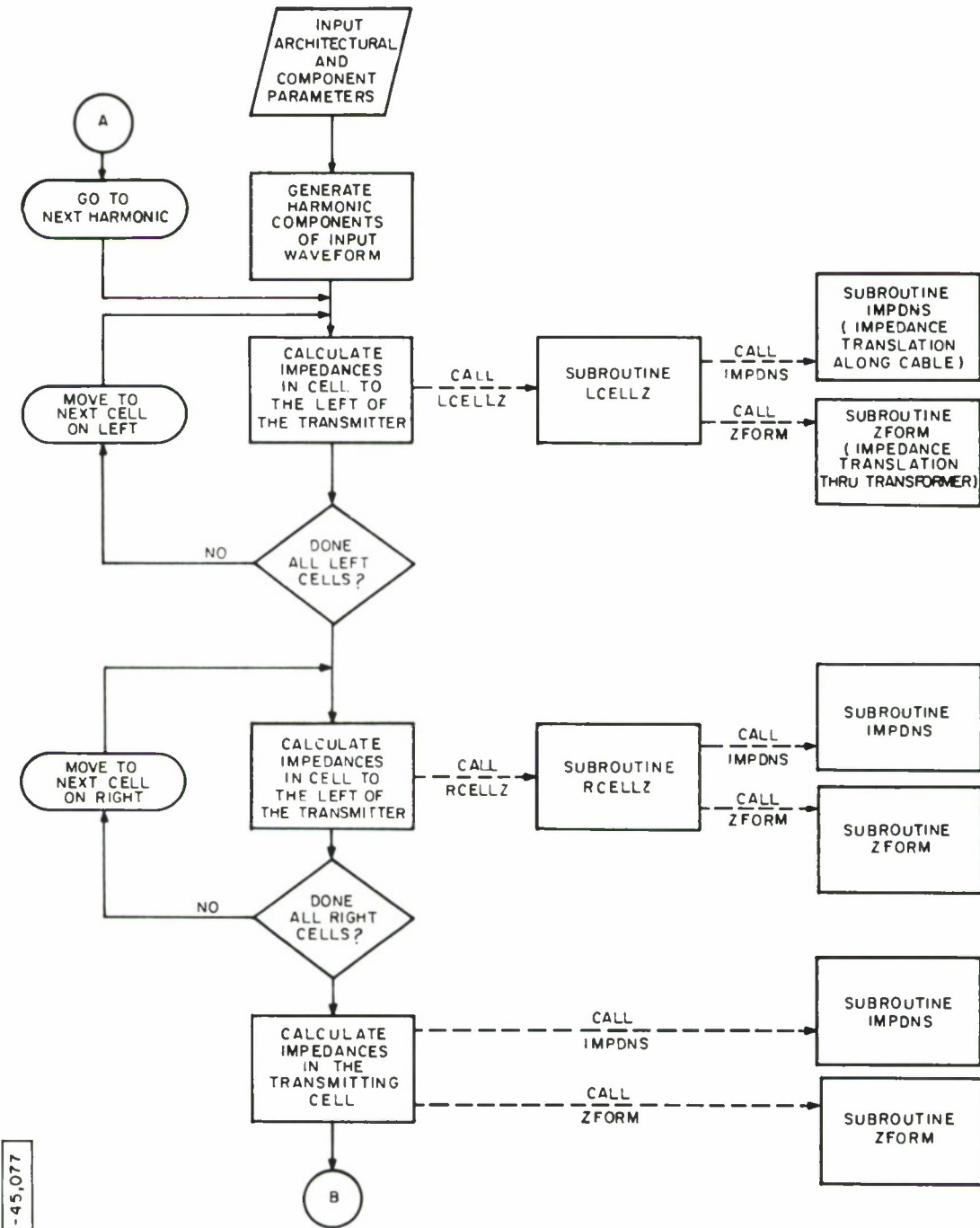
TABLE A1

REPRESENTATIVE CORE REQUIREMENTS AND CPU TIMES FOR A 32 STUB MUX-BUS SIMULATION				
STEP	TPMOD2		PLMOD2 ( 13 PLOTS PRODUCED )	
	<u>CPU</u>	<u>CORE</u>	<u>CPU</u>	<u>CORE</u>
COMPILE	15S	120K	6S	104K
LINK/EDIT	2S	122K	2S	122K
RUN	7S	246K	11S	242K

TABLE A2

IA-45,078

Figure I.1 COMPUTER SYSTEM REQUIREMENTS



IA-45,077

Figure 1.2 FLOW CHART OF TPMOD2

IA-45,076

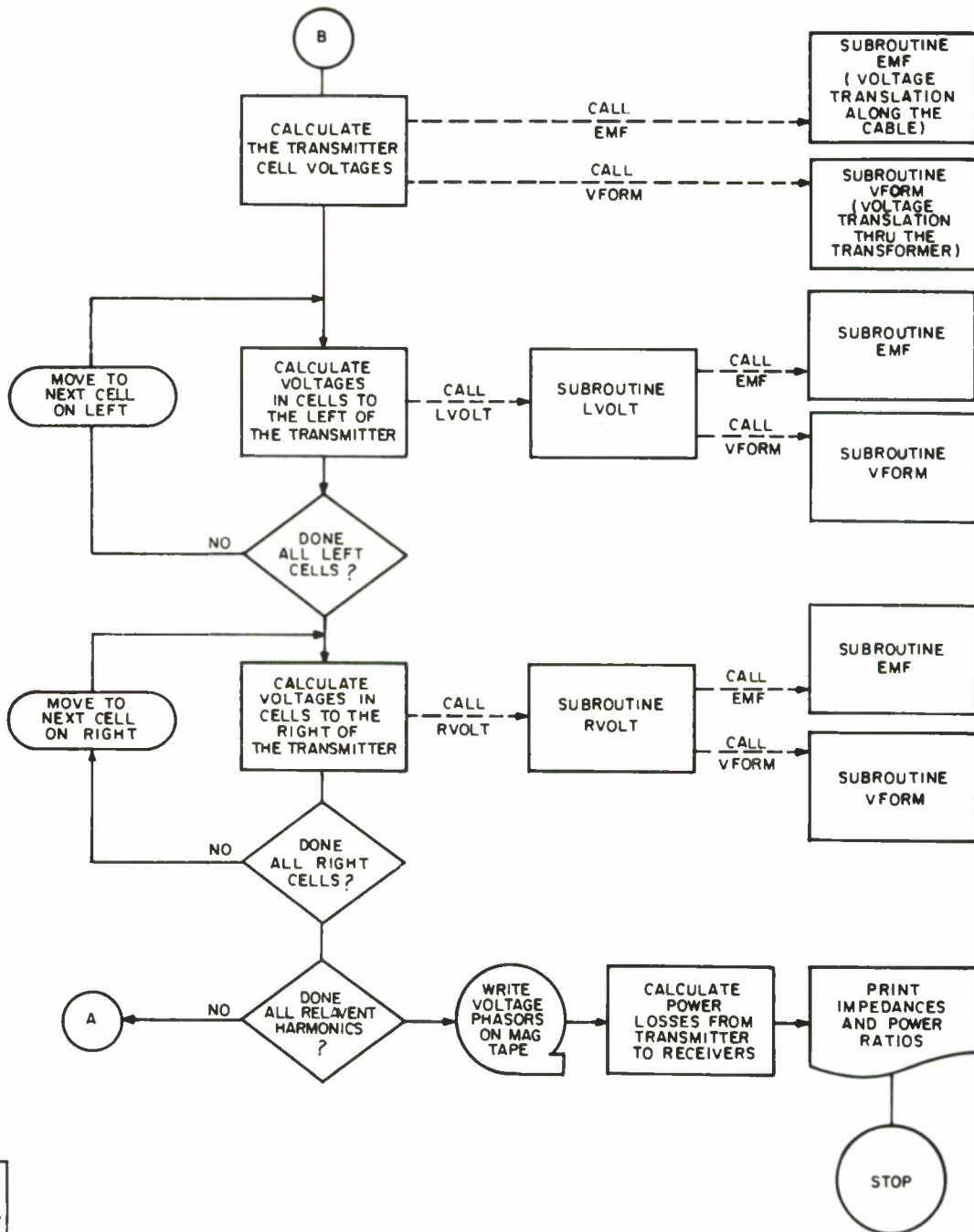


Figure 1.2 FLOW CHART OF TPMOD2 (CONT.)

```

C THIS PROGRAM DETERMINES VOLTAGE WAVEFORMS,
C DRIVING POINT IMPEDANCES AND POWER DISTRIBUTION
C FOR A MULTIPLEX BUS SYSTEM CONTAINING UP TO 32 STJRS
C WITH FLEXIBILITY OF TRANSMITTER LOCATION
C AND TRANSFORMER PARAMETERS
C
C R=LINE SERIES RESISTANCE IN OHMS/UNIT LENGTH
C IN=LINE SERIES INDUCTANCE IN HENRIES/UNIT LENGTH
C G=LINE SHUNT CONDUCTANCE IN MHOS/UNIT LENGTH
C C=LINE SHUNT CAPACITANCE IN FARADS/UNIT LENGTH
C T=TRAPEZOIDAL WAVE PERIOD IN SECONDS
C
C TRANSFORMER PARAMETERS ARE REFERENCED TO SIDE OF TRANSFORMER
C CLOSEST TO BUS/STUJH JUNCTION
C
C INPUT TRAPEZOIDAL WAVE HAS AMPLITUDE OF ONE
C WHEN FED INTO 75 OHM RESISTIVE LOAD.
C
C IN E(K,M,N) *** N=HARMONIC ** L=VOLTAGE ** N=CELL ***
C
C REAL LSTUJH,MAX,IND,N1,LLAST,N1,N2
C INTEGER XMTR,SERIAL,IXEMR,IXFMR
C COMPLEX E,Z,FIN(30),ZSTUB,ZGEN,XMTRZ,PARLL,ZO,GAMMA,AMPEID,Y,
C IREFZ(30,6,32),ALPHASO
C DIMENSION RSTUB(32),LSTUH(32),SERIAL(2),
C IXMTRPR(15),LRCELL(15),RCVRRP(15,32),RCVRTP(32)
C COMMON Z(30,9,32),ZSTUB(30,32),E(30,9,32),L(3,32),R1(32),R2(32),
C IXFMR(32),IXEMR(32),PI
C COMMON/IMPMEF/ZO,ALPHA,BETA
C COMMON/TRANS/N1(5),N2(5),TR1(5),TR2(5),TL1(5),TL2(5),TLM(5),XMTR,T
C
C INITIALIZATION:
C
C CALL CLOCK (SERIAL)
C PI=3.14159265
C READ(5,50)(N1(K),N2(K),TR1(K),TR2(K),TL1(K),TL2(K),TLM(K),K=1,2)
C 50 FORMAT(4F5.2,3E10.4)
C 100 READ(5,100)R,IND,S,C,T,MAXHAR
C 100 FORMAT(5E12.6,I3)
C 101 READ(5,101)RISE,TFALL,PERCNT,ZGEN
C 101 FORMAT(5E12.6)
C 110 READ(5,110)LAST,XMTR,RES1,L1,RLAST,LLAST
C 110 FORMAT(2I2,4E10.4)
C T1=RISE
C T2=(T-2.*T1)/2.
C XOMEGA=2.*PI/T
C XL=XOMEGA*IND
C XC=XOMEGA*C
C AMPEID=CMPLX(R,XL)
C Y=CMPLX(G,XC)
C ZO=CSQRT(AMPEID/Y)
C RO=REAL(ZO)
C XC=AIMAG(ZO)
C GAMMA=CSQRT(AMPEID*Y)

```

LISTING OF TPMD02

```

0029 ALPHA=REAL(GAMMA)
0030 BETA=AIMAG(GAMMA)
0031 DO 112 N=1, LAST
0032   RSTUB(5,115)(R1(N),R2(N),RSTUB(N),LSTUB(N),L(1,N),L(2,N),L(3,N),
      1 TXFMR(N),RXFMR(N))
0033   I15 FORMAT(3F10.0,E10.4,5I5)
0034     TXFMR(N)=I
0035     RSTUB(N)=3730
0036   112 CONTINUE
C
C WRITE THE INITIAL CONDITIONS:
C
0037   WRITE(6,123) SERIAL
0038   FORMAT(40X,' ***** SERIAL NO. ',Z4,' *****',///)
0039   WRITE(6,130)
0040   FORMAT('INPUT QUANTITIES:')
0041   WRITE(6,135)R,IND,G,C,T
0042   FORMAT('0 CABLE CHARACTERISTICS R=',E12.6,' L=',E12.6,' G=',
      1,E12.6,' C=',E12.6,' PULSE WIDTH=',E12.6)
0043   WRITE(6,137)RISE,TFALL,PERCENT,ZGEN
0044   FORMAT('C RISE=',E12.6,' TFALL=',E12.6,' PERCENT CUTOFF=',
      1,F5.2,' GEN. IMPEDANCE=',E12.6,'+1(',E12.6,')')
0045   WRITE(6,140)RO,XO
0046   FORMAT('0 CHARACTERISTIC IMPEDANCE = ',E14.3,' +1(',E14.3,')')
0047   WRITE(6,145)LAST,XMTR
0048   FORMAT('0 NUMBER OF CELLS=',I3,' XMTR IN CELL',I3)
0049   WRITE(6,147)RESI,L1
0050   FORMAT('C LEFT TERMINATION RES.=',E10.4,
      1, LEFT TERMINATION IND.=',E10.4)
0051   WRITE(6,148)RLAST,LLAST
0052   FORMAT('C RIGHT TERMINATION RES.=',E10.4,
      1, RIGHT TERMINATION IND.=',E10.4)
0053   WRITE(6,153)(K,NI(K),N2(K),TRI(K),TR2(K),TL1(K),TL2(K),
      1,LM(K),K=1,2)
0054   FORMAT('0 IN TRANSFORMER ',I2,' NI=',F5.2,' N2=',F5.2,
      1, R1=',F5.2,' R2=',F5.2,' L1=',E10.4,' L2=',E10.4,
      3, LM=',E10.4)
0055   DO 165 N=1, LAST
0056   WRITE(6,155)N
0057   FORMAT(' - IN CELL',I3)
0058   WRITE(6,160)(I,N),L(2,N),L(3,N),LSTUB(N),R1(N),R2(N),RSTUB(N)
0059   I, TXFMR(N),RXFMR(N)
0060   L(1,N)=,I3,2X,'L(2,N)=',I3,2X,'L(3,N)=',I3,2X,
      1,LSTUB(N)=',E10.4,2X,'R1(N)=',F6.0,2X,'R2(N)=',F6.0,2X,'RSTUB(N)=',
      2,F6.0,2X,'TXFMR=',I3,2X,'RXFMR=',I2)
0060   CONTINUE
C
C CALCULATE VALUES FOR EIN:
C
0061   CJTOFF=0.0
0062   DO 1 J=1,MAXHAR,1
0063   AJ=J+(J-1)
0064   EXN=2.*SIN(PI*AJ*TI/T)*SIN(PI*AJ*(TO+TI)/T)
0065   EXD=PI*AJ*TI/T*PI*AJ*(TO+TI)/T
0066   EX=2.*EXN/EXD
0067   HEX=EX**2
0068   NN=J
0069   EIN(J)=CMPLX(EX,0.0)

```

```

0070 IF(MEX.LE.CUTOFF)GO TO 195
0071 IF(J.GT.1)GO TO 1
0072 CUTOFF=(EX**2)*PERCENT/100.
0073 1 CONTINUE
0074 195 CONTINUE
0075 N=2*NN-1
0076 WRITE(6,185)NN
0077 185 FORMAT('0 NUMBER OF HARMONICS CONSIDERED=',I4)
0078 WRITE(6,187)N
0079 187 FORMAT('0 HIGHEST HARMONIC=',I4)
0080 WRITE(6,128)SERIAL
0081 WRITE(6,900)XMTR
0082 900 FORMAT(1H1,/,/,10X,'DRIVING POINT IMPEDANCE AT XMTR/STUB JUNCTION',
1'.VS. FREQUENCY,/,2X,' XMTR IS IN CELL ',I3,/,/,17X,'HERTZ',
2,15X,' OHMS',30X,'MAGNITUDE',14X,'ANGLE')
C
C COMPUTE IMPEDANCES AND VOLTAGES AT EACH HARMONIC
C
0083 DO 2 K=1,NN
0084 O=2.*K-1.
0085 XLI=XL*O
0086 XCI=XC*O
0087 AMPED=CMPLX(R,XLI)
0088 Y=CMPLX(G,XCI)
0089 ZG=CSQRT(AMPED/Y)
0090 GAMMA=CSQRT(AMPED*Y)
0091 ALPHA=REAL(GAMMA)
0092 BETA=AIMAG(GAMMA)
C
C COMPUTE STUB IMPEDANCES
C
0093 DO 4 N=1,LAST
0094 XLSTUB=XOMEGA*O*LSSTUB(N)
0095 ZSTUB(K,N)=CMPLX(RSTUB(N),XLSTUB)
0096 4 Z(K,N)=ZSTUB(K,N)
C
C COMPUTE TERMINATION IMPEDANCES
C
0097 XLI=XOMEGA*O*LI
0098 Z(K,1)=CMPLX(RF51,XLI)
0099 XLLAST=XOMEGA*O*LLAST
0100 Z(K,2,LAST)=CMPLX(RLAST,XLLAST)
C
C GENERATE LEFT CELL IMPEDANCES
C
0101 N=1
0102 IF(N.EQ.XMTR)GO TO 12
0103 10 CONTINUE
0104 CALL LCELLZ(K,N)
0105 N=N+1
0106 IF(N.LT.XMTR)GO TO 10
C
C GENERATE RIGHT CELL IMPEDANCES
C
0107 12 CONTINUE
0108 N=LAST
0109 IF(N.EQ.XMTR)GO TO 17
0110 15 CONTINUE

```

```

0111 CALL RCELLZ(K,N,LAST)
0112 N=N-1
0113 IF(N.GT.XMTR)GO TO 15
0114 17 CONTINUE
C
C GENERATE XMTR CELL IMPEDANCES
C
0115 N=XMTR
0116 IF(N.EQ.1)GO TO 20
0117 Z(K,1,N)=Z(K,2,N-1)
0118 20 CONTINUE
0119 IF(N.EQ.LAST)GO TO 25
0120 Z(K,2,N)=Z(K,1,N+1)
0121 25 CONTINUE
0122 CALL IMPDONS(Z(K,1,N),L(1,N),Z(K,4,N))
0123 CALL IMPDONS(Z(K,2,N),L(2,N),Z(K,5,N))
0124 Z(K,6,N)=Z(K,4,N)*Z(K,5,N)/Z(K,4,N)+Z(K,5,N)+2.*Z(1,N)
0125 Z(K,8,N)=Z(K,6,N)
C
C REFZ IS THE IMPEDANCE AT THE HUS/STUB JUNCTION
C
0126 REFZ(K,6,N)=Z(K,6,N)-2.*Z(1,N)
0127 IF(IXFMR(N).LT.1)GO TO 26
C
C CALL THE IMPEDANCE XFMR SUBROUTINE
C
0128 M=3
0129 LSET=1
0130 CALL ZFORM(K,M,N,LSET)
0131 26 CONTINUE
0132 CALL IMPDONS(Z(K,2,N),L(3,N),Z(K,3,N))
0133 Z(K,9,N)=Z(K,3,N)
0134 IF(IXFMR(N).LT.1)GO TO 27
C
C CALL THE IMPEDANCE XFMR SUBROUTINE
C
0135 M=9
0136 LSET=2
0137 CALL ZFORM(K,M,N,LSET)
0138 27 CONTINUE
0139 XMTRZ=Z(K,9,N)+2.*Z(2,N)
0140 Z(K,7,XMTR)=XMTRZ
0141 RCTRZ=REAL(XMTRZ)
0142 CXTRZ=AIMAG(XMTRZ)
0143 SIZE=SQRT(RETRZ**2+CXTRZ**2)
0144 XMTNG=(ATAN2(CXTRZ,RETRZ))/PI*180.
0145 FRQ=(2*K-1)*1./T
0146 WRITE(6,901)FRQ,RETRZ,CXTRZ,SIZE,XMTNG
0147 901 FORMAT(/,16X,F8.3,6X,F8.2,1X,'+J',F8.2,1X,
120X,F8.2,15X,F7.2)
C
C GENERATE XMTR CELL VOLTAGES
C
0148 N=XMTR
0149 E(K,7,N)=EIN(K)*XMTRZ/(XMTRZ+ZGEN)

```

```

0150 E(K,9,N)=E(K,7,N)*Z(K,9,N)/(Z(K,9,N)+2.*RZ(N))
0151 E(K,3,N)=E(K,9,N)
0152 IF(BXFM(N).LT.1)GO TO 28
C CALL THE VOLTAGE XFMR SUBROUTINE
C
0153 M=3
0154 LSET=2
0155 CALL VFORM(K,M,N,LSET)
C
0156 28 CONTINUE
0157 CALL EMF(E(K,3,N),Z(K,3,N),L(3,N),E(K,8,N))
0158 E(K,6,N)=E(K,8,N)
0159 IF(TXFM(N).LT.1)GO TO 29
C CALL THE VOLTAGE XFMR SUBROUTINE
C
0160 M=6
0161 LSET=1
0162 CALL VFORM(K,M,N,LSET)
C
0163 29 CONTINUE
0164 PARLL=Z(K,4,N)*Z(K,5,N)/(Z(K,4,N)+Z(K,5,N))
0165 E(K,4,N)=E(K,5,N)*PARLL/(PARLL+2.*R1(N))
0166 E(K,5,N)=E(K,4,N)
0167 CALL EMF(E(K,4,N),Z(K,4,N),L(4,N),E(K,1,N))
0168 CALL EMF(E(K,5,N),Z(K,5,N),L(5,N),E(K,2,N))
C GENERATE LEFT CELL VOLTAGES
C
0169 IF(XMTR.EQ.1)GO TO 35
0170 N=XMTR-1
0171 30 CONTINUE
0172 CALL LVOLT(K,N)
0173 V=N-1
0174 IF(N.EQ.1)GO TO 30
0175 35 CONTINUE
C GENERATE RIGHT CELL VOLTAGES
C
0176 IF(XMTR.EQ.LAST)GO TO 45
0177 N=XMTR+1
0178 40 CONTINUE
0179 CALL RVOLT(K,N)
0180 N=N+1
0181 IF(N.LE.LAST)GO TO 40
0182 45 CONTINUE
0183 2 CONTINUE
C WRITE COMPLEX PHASOR VALUES ON MAG TAPE
C
0184 WRITE(11)SERIAL,LAST,XMTR,T,NN
0185 WRITE(11)((E(K,M,N),K=1,NN),M=1,9),N=1,LAST,1)
C DETACHED STUB IMPEDANCE
C
0186 N=1
0187 IF(N.EQ.XMTR) N=2

```

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947 CONTINUE
WRITE(6,128)SERIAL
WRITE(6,905)N
905 FORMAT(1H1,/,10X,'DRIVING POINT IMPEDANCE OF STUB ',12,
1,' .VS. FREQUENCY',/,17X,'HERTZ',15X,' OHMS',
230X,'MAGNITUDE',14X,'ANGLE')
M=6
00 950 K=1,NN,1
FRO=(2*K-1)*1./T
REZ=REAL(Z(K,M,N))+2.*31(N)
CXZ=AIMAG(Z(K,M,N))
SIZE=SQRT(REZ**2+CXZ**2)
STUBNG=(ATAN2(CXZ,REZ))/PI*180.
WRITE(6,906)FRO,REZ,CXZ,SIZE,STUBNG
906 FORMAT(1,15X,F8.3,6X,F8.2,1X,'*J(',F8.2,')',
120X,F8.2,15X,F7.2)
950 CONTINUE
C
C GENERATE THE AVERAGE XPTR POWER .VS. FREQUENCY
C
TXMTRP=0.0
00 955 K=1,NN
XMTRZ=Z(K,7,XMTR)
CONST=(CABS(E(K,7,XMTR)**2))/(2.*CABS(XMTRZ))
REZ=REAL(XMTRZ)
CXZ=AIMAG(XMTRZ)
ANG=ATAN2(CXZ,REZ)
XMTRPR(K)=CONST*CSUS(ANG)
TXMTRP=TXMTRP+XMTRPR(K)
955 CONTINUE
C
C NODE DRIVING POINT IMPEDANCE
C
N=0
960 CONTINUE
TOTPWR=0.0
N=N+1
WRITE(6,128)SERIAL
WRITE(6,907)N
907 FORMAT(1H1,/,10X,'NODE DRIVING POINT IMPEDANCE .VS. FREQUENCY',
1,' FOR CELL ',12,/,17X,'HERTZ',15X,' OHMS',
220X,'MAGNITUDE',10X,'ANGLE',13X,'POWER RATIO(DB)')
M=6
IF(N.LT.XMTR) M=5
IF(N.GT.XMTR) M=4
K=0
980 CONTINUE
HARPWR=0.0
K=K+1
F=(2*K-1)*1./T
IF(N.EQ.XMTR)Z(K,M,N)=REFZ(K,M,N)
REZ=REAL(Z(K,M,N))
CXZ=AIMAG(Z(K,M,N))
SIZE=SQRT(REZ**2+CXZ**2)
ANONG=(ATAN2(CXZ,REZ))/PI*180.
C
C GENERATE POWER RATIOS(DB) AT NODES
C
C

```

```

0232 IF(N.EQ.XMTR) E(K,M,N)=E(K,4,N)
0233 CONST=(CABS(E(K,M,N))**2)/(2.*CABS(Z(K,M,N)))
0234 ANG=ATAN2(CXZ,REZ)
0235 HARPWR=CONST*COS(ANG)
0236 PWRRAT=10.*ALOG10(RAT)
0237 TOTPR=TOTPWR+HARPWR
0238 WRITE(6,910) F,REZ,CXZ,SIZE,ANDNG,PWRRAT
0239 FORMAT(/,16X,F8.3,6X,F8.2,1X,'+',J('F8.2,')',
0240 110X,F8.2,10X,F7.2,15X,F7.2)
0241 IF(K.LT.NN) GO TO 980
0242 RAT=TOTPWR/TXMTRP
0243 TOTRAT=10.*ALOG10(RAT)
0244 WRITE(6,915) TOTRAT
0245
915 FORMAT(////,10X,'POWER RATIO=(POWER AT THIS NODE)/(REFERENCE POWER
1) IN DB',/,15X,'THE REFERENCE POWER IS THE XMTR OUTPUT POWER.',
2//,10X,'TOTAL POWER RATIO(DB)='F8.2)
IF(N.LT.LAST) GO TO 960
WRITE(6,128) SERIAL

```

C C GENERATE POWER RATIOS AT THE RECEIVERS

```

0248 DO 961 K=1,NN
0249 LCELL(K)=2*K-1
0250 961 CONTINUE
0251 M=7
0252 DO 965 N=1, LAST
0253 IF(N.EQ.XMTR) GO TO 965
0254 RCVTRP(N)=0.0
0255 DO 970 K=1,NN
0256 CONST=(CABS(E(K,M,N))**2)/(2.*CABS(ZSTUB(K,N)))
0257 REZ=REAL(ZSTUB(K,N))
0258 CXZ=AIMAG(ZSTUB(K,N))
0259 ANG=ATAN2(CXZ,REZ)
0260 HARPWR=CONST*COS(ANG)
0261 RAT=HARPWR/XMTRP(K)
0262 RCVTRP(N)=RCVTRP(N)+HARPWR
0263 970 CONTINUE
0264 RAT=RCVTRP(N)/TXMTRP
0265 RCVTRP(N)=10.*ALOG10(RAT)
0266 965 CONTINUE
0267 WRITE(6,975) (LCELL(K),K=1,NN)
0268 FORMAT(1H,////,40X,'POWER RATIO AT RECEIVERS (DB)',/,/,49X,
0269 1** HARMONIC **/,/24X,'COMBINED',6X,10(I2,7X))
0270 WRITE(6,977)
0271 FURMAT(/,10X,'**RECEIVER**')
0272 DO 981 N=1, LAST
0273 IF(N.EQ.XMTR) GO TO 981
0274 WRITE(6,990) (N,RCVTRP(N),(RCVTRP(K,N),K=1,NN))
0275 FORMAT(15X,I2,6X,F7.2,5X,10(F7.2,2X))
0276 981 CONTINUE
0277 WRITE(6,995)
0278 FORMAT(////,10X,'POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN
1 DB',/,/)
0279 STOP
0280 WRITE(6,128) SERIAL
0281 END

```

```

0001 SUBROUTINE LCELLZ (K,N)
0002 COMPLEX Z,ZSTU5,E,PARLL
0003 INTEGER BXFMR,TFMR
0004 COMMON Z(30,9,32),ZSTUR(30,32),E(30,9,32),L(3,32),R1(32),R2(32),
0005 ITXFMR(32),BXFMR(32),PI
0006 IF(N.EQ.1)GO TO 1000
0007 Z(K,1,N)=Z(K,2,N-1)
0008 CONTINUE
0009 CALL IMPDMS(Z(K,1,N),L(1,N),Z(K,4,N))
0010 Z(K,3,N)=ZSTUR(K,N)+2.*R2(N)
0011 Z(K,9,N)=Z(K,3,N)
0012 IF(BXFMR(N).LT.1)GO TO 100
0013
0014 CALL THE TRANSFORMER SUBROUTINE
0015 LSET=1 MEANS USE TOP XFMR PARAMETERS
0016 LSET=2 MEANS USE BOTTOM XFMR PARAMETERS
0017
0018 M=3
0019 LSET=2
0020 CALL ZFORM(K,M,N,LSET)
0021 CONTINUE
0022 CALL IMPDMS(Z(K,3,N),L(3,N),Z(K,6,N))
0023 Z(K,8,N)=Z(K,6,N)
0024 IF(TXFMR(N).LT.1)GO TO 200
0025
0026 CALL THE TRANSFORMER SUBROUTINE
0027 M=6
0028 LSET=1
0029 CALL ZFORM(K,M,N,LSET)
0030 CONTINUE
0031 PARLL=Z(K,6,N)+2.*R1(N)
0032 Z(K,5,N)=Z(K,4,N)*PARLL/(Z(K,4,N)+PARLL)
0033 CALL IMPDMS(Z(K,5,N),L(2,N),Z(K,2,N))
0034 RETURN
0035 END

```

```

0001 SUBROUTINE RCELLZ (K,N,LAST)
0002 COMPLEX Z,ZSTUR,E,PARLL
0003 INTEGER BXFMR,IXFMR
0004 COMMON Z(30,9,32),ZSTUB(50,32),E(30,9,32),L(3,32),R1(32),R2(32),
0005 IIXFMR(32),RXFMR(32),PI
0006 IF(N.EO.LAST)GO TO 2000
0007 Z(K,2,N)=Z(K,1,N+1)
0008 CALL IMPDMS(Z(K,2,N),L(2,N),Z(K,5,N))
0009 Z(K,3,N)=ZSTUB(K,N)+2.*R2(N)
0010 Z(K,9,N)=Z(K,3,N)
0011 IF(RXFMR(N).LT.1)GO TO 100

C
C CALL THE TRANSFORMER SUBROUTINE
C LSET=1 MEANS USE TOP XFMR PARAMETERS
C LSET=2 MEANS USE BOTTOM XFMR PARAMETERS
C
M=3
LSET=2
CALL ZFORM(K,M,N,LSET)
100 CONTINUE
CALL IMPDMS(Z(K,3,N),L(3,N),Z(K,5,N))
Z(K,8,N)=Z(K,5,N)
IF(IXFMR(N).LT.1)GO TO 200

C
C CALL THE TRANSFORMER SUBROUTINE
C
M=6
LSET=1
CALL ZFORM(K,M,N,LSET)
200 CONTINUE
PARLL=Z(K,5,N)+2.*R1(N)
Z(K,4,N)=Z(K,5,N)*PARLL/(Z(K,5,N)+PARLL)
CALL IMPDMS(Z(K,4,N),L(1,N),Z(K,1,N))
RETURN
END
0019
0020
0021
0022
0023
0024
0025
0026
0027

```

LISTING OF SUBROUTINE RCELL Z

```

0001 SUBROUTINE LVOLT (K,N)
0002 COMPLEX E,Z,ZSTUB,ALPHSQ
0003 INTEGER I,XFMR,IXFMR
0004 REAL NI,NZ
0005 COMMON Z(30,9,32),ZSTUB(30,32),E(30,9,32),L(3,32),R1(32),R2(32),
0006 I(XFMR(32),IXFMR(32)),PT
0007 COMMON/TRANS/NI(5),N2(5),TR1(5),TR2(5),TL1(5),TL2(5),TLM(5),XNTR,T
0008 E(K,2,N)=E(K,1,N+1)
0009 CALL EMF(E(K,2,N),Z(K,2,N),L(2,N),E(K,5,N))
0010 E(K,4,N)=E(K,5,N)
0011 CALL EMF(E(K,4,N),Z(K,4,N),L(1,N),E(K,1,N))
0012 E(K,6,N)=E(K,5,N)*Z(K,5,N)/(Z(K,5,N)+2.*R1(N))
0013 E(K,8,N)=E(K,6,N)
0014 IF(IXFMR(N).LT.1)GO TO 10
0015 C
0016 C CALL THE VOLTAGE XFMR SUBROUTINE
0017 C
0018 M=8
0019 LSET=1
0020 CALL VFORM(K,M,N,LSET)
0021 10 CONTINUE
0022 CALL EMF(E(K,2,N),Z(K,2,N),L(3,N),E(K,5,N))
0023 E(K,9,N)=E(K,3,N)
0024 IF(IXFMR(N).LT.1)GO TO 20
0025 C
0026 C CALL THE VOLTAGE XFMR SUBROUTINE
0027 C
0028 M=9
0029 LSET=2
0030 CALL VFORM(K,M,N,LSET)
0031 20 CONTINUE
0032 E(K,7,N)=E(K,9,N)*ZSTUB(K,N)/(ZSTUB(K,N)+2.*R2(N))
0033 RETURN
0034 END

```

LISTING OF SUBROUTINE LVOLT

```

0001 SUBROUTINE RVOLT (K,N)
0002 COMPLEX E,Z,ZSTUB,ALPHSQ
0003 INTEGER BXFMR,TFMR
0004 REAL N1,N2
0005 COMMON Z(30,9,32),ZSTUB(30,32),E(30,9,32),L(3,32),R1(32),R2(32),
0006 ITXFM(32),RXFMR(32),PI
0007 E(K,1,N)=E(K,2,N-1)
0008 CALL EMFIE(K,1,N),Z(K,1,N),L(1,N),E(K,4,N))
0009 E(K,5,N)=E(K,4,N)
0010 CALL EMFIE(K,5,N),Z(K,5,N),L(2,N),E(K,2,N))
0011 E(K,6,N)=E(K,4,N)*Z(K,6,N)/(Z(K,6,N)+2.*R1(N))
0012 E(K,8,N)=E(K,6,N)
0013 IF(TXFM(N).LT.1)GO TO 10
C
C CALL THE VOLTAGE XFMR SUBROUTINE
C
0014 M=8
0015 LSET=1
0016 CALL VFORM(K,M,N,LSET)
0017 10 CONTINUE
0018 CALL EMFIE(K,8,N),Z(K,3,N),L(3,N),E(K,3,N))
0019 E(K,9,N)=E(K,3,N)
0020 IF(BXFMR(N).LT.1)GO TO 20
C
C CALL THE VOLTAGE XFMR SUBROUTINE
C
0021 M=9
0022 LSET=2
0023 CALL VFORM(K,M,N,LSET)
0024 20 CONTINUE
0025 E(K,7,N)=E(K,9,N)*ZSTUB(K,N)/(ZSTUB(K,N)+2.*R2(N))
0026 RETURN
0027 END

```

LISTING OF SUBROUTINE RVOLT

```

0001 SUBROUTINE ZFORM(K,M,N,LSET)
0002 COMPLEX Z,ZSTUB,F,PARLL,ALPHSQ,REACL1,REACL2,REACLM
0003 INTEGER R,XNTR
0004 REAL N1,N2
0005 COMMON Z(30,9,37),ZSTUB(30,32),F(30,9,32),L(3,32),R1(32),R2(32),
0006 ITXPMR(32),BXPMR(32),PI
0007 COMMON/TRANS/N1(5),N2(5),TRI(5),TR2(5),TL1(5),TL2(5),TLM(5),XNTR,T
0008 R=LSET
0009 ATURNS=(N1(R)/N2(R))**2
0010 ALPHSQ=CMLPX(ATURNS,0.0)
0011 Q=2.**K-1.
0012 XOMEGA=2.*3.14159265/T
0013 CONST=Q*XOMEGA*TL1(R)
0014 REACL1=CMLPX(TRI(R),CONST)
0015 CONST=Q*XOMEGA*TL2(R)
0016 REACL2=CMLPX(TR2(R),CONST)
0017 CONST=Q*XOMEGA*TLM(R)
0018 REACLM=CMLPX(0.0,CONST)
0019 IF(N.EQ.XNTR)GO TO 200
0020 PARLL=ALPHSQ*(Z(K,M,N)+REACL2)
0021 Z(K,M,N)=(PARLL*REACL1)/(PARLL+REACLM)+REACL1
0022 GO TO 300
0023 200 CONTINUE
0024 ATURNS=(N2(R)/N1(R))**2
0025 ALPHSQ=CMLPX(ATURNS,0.0)
0026 PARLL=ALPHSQ*(Z(K,M,N)+REACL1)
0027 Z(K,M,N)=(PARLL*(ALPHSQ*REACL1))/(PARLL+ALPHSQ*REACL1)+REACL2
0028 300 CONTINUE
0029 RETURN
    END

```

LISTING OF SUBROUTINE ZFORM

```

0001 SUBROUTINE VFORM(K,M,N,LSET)
0002 COMPLEX Z,ZSTU,IE,ALPHA,ALPHSQ,REACL1,REACL2,REACLM,DUMMY
0003 INTEGER R,XMTR
0004 REAL NI,NZ
0005 COMMON Z(30,9,32),ZSTUB(30,32),E(30,9,32),L(3,32),R1(32),R2(32),
0006 ITXFMR(32),R1FMR(32),PI
0007 COMMON/TRANS/NI(5),N2(5),TR1(5),TR2(5),TL1(5),TL2(5),TLM(5),XMTR,T
0008 R=LSET
0009 TURNS=NI(R)/N2(R)
0010 ALPHA=CMPLX(TURNS,C.0)
0011 ALPHSQ=ALPHA*ALPHA
0012 Q=2.*K-1.
0013 XMEGA=2.*PI/T
0014 CONST=Q*XMEGA*TL1(R)
0015 REACL1=CMPLX(TR1(R),CONST)
0016 REACL2=CMPLX(TR2(R),CONST)
0017 CONST=Q*XMEGA*TLM(R)
0018 REACLM=CMPLX(C.0,CONST)
0019 IF(N.EQ.XMTR)GO TO 200
0020 DUMMY=(ALPHSQ)*Z(K,M,N)+REACL2)
0021 DIMMY=REACLM*DUMMY/(REACLM+DUMMY)
0022 E(K,M,N)=E(K,M,N)*DUMMY/(DUMMY+REACL1)
0023 E(K,M,N)=E(K,M,N)*Z(K,M,N)/(REACL2+Z(K,M,N))
0024 E(K,M,N)=E(K,M,N)/ALPHA
0025 GO TO 300
0026
0027 CONTINUE
0028 DUMMY=(Z(K,M,N)+REACL1)/ALPHSQ
0029 DIMMY=DUMMY*(REACLM/ALPHSQ)/(DUMMY+REACLM/ALPHSQ)
0030 E(K,M,N)=E(K,M,N)*(DUMMY/(DUMMY+REACL2))
0031 E(K,M,N)=E(K,M,N)*Z(K,M,N)/(Z(K,M,N)+REACL1)
0032 E(K,M,N)=E(K,M,N)*ALPHA
0033 RETURN
0034 END

```

LISTING OF SUBROUTINE VFORM

C  
C

```

0001 SUBROUTINE IMPDMS (ZL,L,ZS)
0002 COMPLEX ZZ,ZL,ZS,A,B,NUM,DENOM
0003 COMMON/IMPDMF/ZZ,ALPHA,BETA
0004 E=ALPHA*L
0005 F=BETA*L
0006 A=ZZ*L*COSH(E)*COS(F)+ZZ*ZZ*SINH(E)*COS(F)
0007 B=ZZ*L*SINH(E)*SIN(F)+ZZ*ZZ*COSH(E)*SIN(F)
0008 C=REAL(A)-AIMAG(B)
0009 D=AIMAG(A)+REAL(B)
0010 NUM=CMPLX(C,D)
0011 A=ZZ*COSH(E)*COS(F)+ZL*SINH(E)*COS(F)
0012 B=ZZ*SINH(E)*SIN(F)+ZL*COSH(E)*SIN(F)
0013 C=REAL(A)-AIMAG(B)
0014 D=AIMAG(A)+REAL(B)
0015 DENOM=CMPLX(C,D)
0016 ZS=NUM/DENOM
0017 RETURN
0018 END

```

LISTING OF SUBROUTINE IMPDMS

```
0001 SUBROUTINE EMF (ES,ZS,I,ER)  
0002 COMPLEX ES,ZS,ZO,ER,C,D,E  
0003 COMMON/IMP/EMF/ZO,ALPHA,BETA  
0004 A=ALPHA*L  
0005 B=BETA*L  
0006 C=ZS*COSH(A)*COS(B)-ZO*SINH(A)*COS(B)  
0007 D=ZS*SINH(A)*SIN(B)-ZO*COSH(A)*SIN(B)  
0008 F=REAL(C)-AIMAG(D)  
0009 G=AIMAG(C)+REAL(D)  
0010 ER=ES*F/ZS  
0011 ER=ES*F/ZS  
0012 RETURN  
0013 END
```

LISTING OF SUBROUTINE EMF

are made to the routines in the second tier: LCELLZ, RCELLZ, LVOLT, and RVOLT. Each of these subroutines controls the calculation sequence within a given cell, making calls to the four service routines, IMPDNS, EMF, ZFORM, and VFORM when appropriate. IMPDNS and EMF exercise the transmission line translational relationships for impedance and voltage, respectively. VFORM and ZFORM transform voltages and impedances through each of the two transformers that may be contained in a stub.

The complex voltages and impedances calculated by the above procedure for each relevant harmonic of the input waveform are stored in memory. When all values have been found, the voltage phasors are written onto a 9-track magnetic tape for later use by the plotting routine, PLMOD2. The power transfer ratios from the transmitter to the receivers are then calculated and printed along with the complex impedances previously determined.

Input Data Format - The input data required by the program, including format and card column designations, is shown in Figure I.3. The column marked "Data Card Number" refers to the order in which the data cards appear in the source deck.

Output Formats - In addition to the complex voltages written on magnetic tape, TPMOD2 produces hard copy listings of the following:

- a) The input data, including the calculated value of the cable characteristic impedance and the number of odd harmonics considered. (See Figure I.4.)
- b) The driving point impedance seen by the transmitter as a function of frequency (Figure I.5).
- c) The driving point impedance of a detached stub as seen by the main bus (Figure I.6).
- d) The driving point impedance looking into each junction of a stub and the main bus. For cells to the left of the transmitter, this corresponds to  $\bar{Z}(5)$  of Figure 5, while for cells on the right this is  $\bar{Z}(4)$  of Figure 4. In the transmitter cell this impedance corresponds to  $\bar{Z}(4)$  in parallel with  $\bar{Z}(5)$ . Also included is the power loss from the transmitter to the junction, both as a function of frequency and total (Figure I.7).
- e) The power loss from the transmitter to each receiving RTU, combined and as a function of frequency. This data, shown in Figure I.8, is an essential input to the determination of required transmitter power levels.

DATA CARD NUMBER	VARIABLE NAME	DESCRIPTION	CARD COLUMNS	FORMAT	COMMENTS
1	NI(1)	TRANSFORMER T1 PRIMARY TURNS	1-5	F5.2	$N_1$ OF FIG. 2
	N2(1)	T1 SECONDARY TURNS	6-10	F5.2	$N_2$ OF FIG. 2
	TR1(1)	T1 PRIMARY RESISTANCE ( $\Omega$ )	11-15	F5.2	$R_p$ OF FIG. 2
	TR2(1)	T1 SECONDARY RESISTANCE	16-20	F5.2	$R_s$ OF FIG. 2
	TL1(1)	T1 PRIMARY LEAKAGE INDUCTANCE	21-30	E10.4	$L_p$ OF FIG. 2
	TL2(1)	T1 SECONDARY LEAKAGE INDUCTANCE	31-40	E10.4	$L_s$ OF FIG. 2
	TLM(1)	T1 MAGNETIZING INDUCTANCE	41-50	E10.4	$L_M$ OF FIG. 2
2	NI(2)	T2 PRIMARY TURNS	1-5	F5.2	} SAME AS ABOVE
	N2(2)	T2 SECONDARY TURNS	6-10	F5.2	
	TR1(2)	T2 PRIMARY RESISTANCE	11-15	F5.2	
	TR2(2)	T2 SECONDARY RESISTANCE	16-20	F5.2	
	TL1(2)	T2 PRIMARY LEAKAGE INDUCTANCE	21-30	E10.4	
	TL2(2)	T2 SECONDARY LEAKAGE INDUCTANCE	31-40	E10.4	
	TLM(2)	T2 MAGNETIZING INDUCTANCE	41-50	E10.4	
3	R	CABLE SERIES RESISTANCE/FOOT	1-12	E12.6	} UNIT OF LENGTH IS ARBITRARY AS LONG AS ALL ARE EQUAL ; CHARACTERISTIC IMPEDANCE $Z_0$ IS CALCULATED INTERNALLY BY THE SIMULATION
	IND	CABLE SERIES INDUCTANCE/FOOT	13-24	E12.6	
	G	CABLE SHUNT CONDUCTANCE/ FOOT	25-36	E12.6	
	C	CABLE SHUNT CAPACITANCE/ FOOT	37-48	E12.6	
	T	INPUT PULSE WIDTH (SECONDS)	49-60	E12.6	
	MAXHAR	MAXIMUM NUMBER OF HARMONICS ALLOWABLE	61-63	I3	SEE NOTE AT " PERCNT " ON CARD # 4

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Figure I.3 TPMOD2 INPUT DATA CARD FORMAT

DATA CARD NUMBER	VARIABLE NAME	DESCRIPTION	CARD COLUMNS	FORMAT	COMMENTS
4	TRISE	INPUT PULSE RISE TIME	1-12	E12.6	FOR FOURIER SERIES PRESENTLY USED TRISE = TFALL ; MEASURED FROM 0-100%
	TFALL	INPUT PULSE FALL TIME	13-24	E12.6	
	PERCNT	PERCENT ENERGY CUTOFF FOR INPUT HARMONIC GENERATOR	25-36	E12.6	HARMONICS OF INPUT WAVEFORM ARE GENERATED UNTIL ENERGY FALLS BELOW THIS PERCENT OF THE FUNDAMENTAL'S ENERGY
	ZGEN	INPUT WAVEFORM GENERATORS	37-48	E12.6	
			INTERNAL IMPEDANCE	49-60	E12.6
5	LAST	NUMBER OF LAST CELL ON RIGHT	1-2	I2	EQUIVALENT TO THE TOTAL NUMBER OF STUBS
	XMTR	NUMBER OF CELL CONTAINING TRANSMITTER	3-4	I2	CELLS NUMBERED FROM LEFT TO RIGHT
	RESI	LEFT BUS TERMINATION'S RESISTANCE	5-14	E10.4	EQUIVALENT TO RTERM
	LI	LEFT BUS TERMINATION'S INDUCTANCE	15-24	E10.4	GENERALLY = 0
	RLAST	RIGHT BUS TERMINATION'S RESISTANCE	25-34	E10.4	SAME AS ABOVE
	LLAST	RIGHT BUS TERMINATION'S INDUCTANCE	35-44	E10.4	
6-37*	R1(N)	TOP ISOLATION RESISTANCES	1-10	F10.0	TOTAL TOP ISOLATION RESISTANCE = 2* R1(N)
	R2(N)	BOTTOM ISOLATION RESISTANCES	11-20	F10.0	
	RSTUB(N)	STUB TERMINATION'S RESISTIVE COMPONENT	21-30	F10.0	DETERMINED BY THE RECEIVING RTU'S INPUT IMPEDANCE
	LSTUB(N)	STUB TERMINATION'S INDUCTIVE COMPONENT	31-40	E10.4	
	L(1,N)	CELL CABLE LENGTH	41-45	I5	SEE FIG 2
	L(2,N)	"	46-50	I5	
	L(3,N)	"	51-55	I5	
	TxFMR(N)	INDICATES IF TOP TRANSFORMER IS PRESENT	56-60	I5	= 1, TRANSFORMER PRESENT
	BxFMR(N)	INDICATES IF BOTTOM TRANSFORMER IS PRESENT	61-65	I5	= 0, TRANSFORMER ABSENT

\* ONE CARD CONTAINING THESE PARAMETERS IS REQUIRED FOR EACH OF THE N CELLS IN THE SYSTEM BEING SIMULATED

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Figure I.3 TPMOD2 INPUT DATA CARD FORMAT (CONT.)

\*\*\*\*\* SERIAL NO. C9.53.51 \*\*\*\*\*

INPUT QUANTITIES:

CABLE CHARACTERISTICS R=0.288000E-01 L=0.108900E-05 G=0.100000E-09 C=0.216000E-10  
PULSE WIDTH=0.99999E-06  
TRISE=0.400000E-07 TFALE=0.400000E-07 PERCENT CUTOFF= 0.10 GEN. IMPEDANCE=C.750000E 02\*I(0.0 )  
CHARACTERISTIC IMPEDANCE = 0.71020386E 02 \*I(-.14939566E 01)  
NUMBER OF CELLS= 32 XMTR IN CELL 14  
LEFT TERMINATION RES.=0.7100E 02 LEFT TERMINATION IND.=0.0  
RIGHT TERMINATION RES.=0.7100E 02 RIGHT TERMINATION IND.=0.0  
IN TRANSFORMER 1,N1= 2.50 N2= 1.00 R1=14.00 R2= 5.60 L1=0.7000E-05 L2=0.1100E-05 LM=0.1000E-01  
IN TRANSFORMER 2,N1= 1.00 N2= 1.00 R1=14.00 R2= 7.60 L1=0.7000E-05 L2=0.2100E-05 LM=0.1000E-01  
IN CELL 1 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 11  
IN CELL 2 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 4  
IN CELL 3 L(2,N)= 5 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 7  
IN CELL 4 L(2,N)= 7 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 6  
IN CELL 5 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 9  
IN CELL 6 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 5  
IN CELL 7 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 5  
IN CELL 8 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 7  
IN CELL 9 L(2,N)= 5 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
L(1,N)= 3  
IN CELL 10

FIGURE I.4

L(1,N)= 5 L(2,N)= 5 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 11  
 L(1,N)= 6 L(2,N)= 7 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 12  
 L(1,N)= 7 L(2,N)= 2 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 13  
 L(1,N)= 3 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 14  
 L(1,N)= 7 L(2,N)= 5 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 15  
 L(1,N)= 5 L(2,N)= 2 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 16  
 L(1,N)= 1 L(2,N)= 3 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 17  
 L(1,N)= 4 L(2,N)= 3 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 18  
 L(1,N)= 3 L(2,N)= 7 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 19  
 L(1,N)= 7 L(2,N)= 2 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 20  
 L(1,N)= 3 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 21  
 L(1,N)= 5 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 22  
 L(1,N)= 5 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 23  
 L(1,N)= 5 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 24  
 L(1,N)= 5 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1  
 IN CELL 25  
 L(1,N)= 3 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

FIGURE I.4 (Cont'g)

```

IN CELL 26
L(1,N)= 4 L(2,N)= 2 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

IN CELL 27
L(1,N)= 1 L(2,N)= 3 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

IN CELL 28
L(1,N)= 3 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

IN CELL 29
L(1,N)= 7 L(2,N)= 4 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

IN CELL 30
L(1,N)= 3 L(2,N)= 2 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

IN CELL 31
L(1,N)= 1 L(2,N)= 6 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

IN CELL 32
L(1,N)= 7 L(2,N)= 8 L(3,N)= 20 LSTUB(N)=0.0 R1(N)= 54. R2(N)= 0. RSTUB(N)= 3730. TXFMR= 1 BXFMR= 1

```

NUMBER OF HARMONICS CONSIDERED= 9

HIGHEST HARMONIC= 17

\*\*\*\*\* SERIAL NO. 09.53.51 \*\*\*\*\*

FIGURE I.4 (Con't)

DRIVING POINT IMPEDANCE AT XMTR/STUB JUNCTION .VS. FREQUENCY  
 XMTR IS IN CELL 14

HERTZ	OHMS	MAGNITUDE	ANGLE
.100E 07	170.09 +J( 254.41)	306.03	56.23
.300E 07	382.67 +J( 845.24)	927.83	65.64
.500E 07	581.66 +J( 267.51)	640.22	24.70
.700E 07	131.47 +J( 897.22)	906.80	81.66
.900E 07	84.64 +J( 1399.32)	1391.89	86.51
.110E 08	74.93 +J( 1830.43)	1831.96	87.66
.130E 08	76.21 +J( 2281.55)	2282.82	88.09
.150E 08	94.83 +J( 2328.01)	2829.60	88.08
.170E 08	444.55 +J( 4265.13)	4288.23	84.05

\*\*\*\*\* SERIAL NO. 09.53.51 \*\*\*\*\*

FIGURE I.5

DRIVING POINT IMPEDANCE OF STUB 1 .VS. FREQUENCY

HERTZ	OHMS	MAGNITUDE	ANGLE
.100E 07	934.45 +J(-2050.66)	2253.53	-65.50
.300E 07	254.28 +J(-423.72)	494.16	-59.03
.500E 07	199.38 +J( 120.31)	232.87	31.11
.700E 07	186.10 +J( 502.02)	535.40	69.66
.900E 07	184.06 +J( 847.32)	867.08	77.74
.110E 08	190.61 +J( 1213.58)	1228.46	81.07
.130E 08	218.98 +J( 1695.03)	1709.11	82.64
.150E 08	434.75 +J( 2798.05)	2831.62	81.17
.170E 08	1735.93 +J(-2085.90)	2713.75	-50.23

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FIGURE I.6

NODE	DRIVING POINT IMPEDANCE HERTZ	.VS. OHMS	FREQUENCY FOR CELL 1	MAGNITUDE	ANGLE	POWER RATIO(DB)
.100E 07	70.33 +J(	-2.03)	70.36	-1.65	-13.99	
.300E 07	65.48 +J(	-7.62)	65.92	-6.64	-15.96	
.500E 07	55.62 +J(	6.98)	56.04	7.05	-25.44	
.700E 07	57.16 +J(	7.33)	67.61	6.65	-14.99	
.900E 07	69.54 +J(	5.27)	69.74	4.34	-15.66	
.110E 08	70.27 +J(	3.76)	70.37	3.06	-16.68	
.130E 08	70.57 +J(	2.68)	70.63	2.17	-17.05	
.150E 09	70.70 +J(	1.55)	70.72	1.25	-15.36	
.170E 09	69.77 +J(	-1.54)	69.79	-1.27	-12.41	

POWER RATIO=(POWER AT THIS NODE)/(REFERENCE POWER) IN DB  
 THE REFERENCE POWER IS THE XMTX OUTPUT POWER.

TOTAL POWER RATIO(DB)= -14.16 \*\*\*\*\* SERIAL NO. 09.53.51 \*\*\*\*\*

FIGURE I.7

POWER RATIO AT RECEIVERS (DB)

**RECEIVER**	** HARMONIC **																
	COMBINF	1	3	5	7	9	11	13	15	17							
1	-33.78	-33.76	-31.87	-39.20	-36.90	-42.03	-45.17	-45.75	-41.93	-31.11							
2	-33.77	-33.75	-32.05	-38.40	-36.33	-41.64	-44.88	-45.55	-41.82	-31.00							
3	-33.76	-33.75	-32.34	-36.04	-35.53	-41.57	-45.12	-45.82	-41.95	-30.93							
4	-33.74	-33.78	-32.22	-34.28	-35.70	-41.92	-44.93	-45.45	-41.73	-30.70							
5	-33.70	-33.83	-31.39	-32.73	-35.11	-41.36	-44.90	-45.82	-41.82	-30.73							
6	-33.68	-33.86	-30.80	-32.13	-35.61	-41.22	-44.99	-45.30	-41.61	-30.59							
7	-33.64	-33.90	-30.36	-31.23	-34.71	-41.29	-44.51	-45.36	-41.83	-30.55							
8	-33.55	-33.95	-29.93	-29.52	-34.30	-41.34	-44.87	-45.54	-41.60	-30.40							
9	-33.49	-33.97	-29.85	-28.54	-34.55	-41.11	-44.87	-45.04	-41.69	-30.46							
10	-33.34	-33.99	-29.85	-26.96	-34.72	-40.72	-44.23	-45.49	-41.55	-30.14							
11	-33.10	-33.99	-29.80	-25.37	-34.51	-40.96	-44.64	-45.29	-41.63	-30.21							
12	-32.76	-33.94	-29.39	-23.90	-33.69	-41.06	-44.48	-45.43	-41.53	-30.14							
13	-32.63	-33.91	-29.21	-23.43	-33.55	-40.72	-44.08	-45.53	-41.48	-30.18							
15	-32.78	-33.95	-29.04	-24.06	-33.79	-40.29	-44.90	-44.63	-40.82	-30.06							
16	-32.93	-33.99	-29.08	-24.67	-33.89	-40.58	-45.20	-44.45	-40.80	-30.00							
17	-33.20	-34.07	-29.19	-25.84	-33.95	-41.38	-45.40	-44.53	-41.45	-30.26							
18	-33.37	-34.13	-29.24	-26.67	-34.02	-41.75	-45.01	-45.04	-41.50	-30.36							
19	-33.66	-34.22	-29.19	-28.73	-35.02	-41.09	-45.36	-44.70	-41.42	-30.34							
20	-33.72	-34.23	-29.17	-29.34	-35.40	-40.89	-45.64	-44.60	-41.64	-30.56							
21	-33.82	-34.24	-29.35	-30.51	-35.51	-41.41	-45.10	-45.30	-41.09	-30.35							
22	-33.88	-34.21	-29.69	-31.57	-35.19	-42.19	-45.15	-44.86	-41.70	-30.80							
23	-33.94	-34.15	-30.36	-33.12	-35.19	-41.67	-45.84	-45.03	-41.16	-30.49							
24	-33.97	-34.08	-31.02	-34.79	-35.77	-41.19	-45.35	-45.36	-41.67	-31.03							
25	-33.99	-34.03	-31.56	-35.21	-36.31	-41.46	-45.07	-44.78	-41.55	-30.77							
26	-33.97	-33.97	-32.12	-37.68	-36.68	-42.24	-45.58	-44.96	-41.26	-31.01							
27	-33.97	-33.95	-32.31	-38.43	-35.65	-42.42	-45.81	-45.24	-41.42	-31.23							
28	-33.95	-33.91	-32.68	-39.41	-36.36	-42.31	-45.89	-45.45	-41.77	-31.24							
29	-33.93	-33.85	-32.85	-42.26	-36.61	-41.99	-45.62	-45.11	-41.47	-31.29							
30	-33.91	-33.84	-32.60	-43.95	-37.30	-42.25	-45.81	-45.36	-41.70	-31.42							
31	-33.91	-33.84	-32.51	-44.48	-37.53	-42.32	-45.82	-45.37	-41.74	-31.31							
32	-33.92	-33.85	-32.27	-45.84	-38.29	-42.73	-46.01	-45.41	-41.73	-31.52							

POWER RATIO=(RECEIVER POWER/XMTR OUTPUT POWER) IN DB.

\*\*\*\*\* SERIAL NO. 09.53.51 \*\*\*\*\*

FIGURE I.8

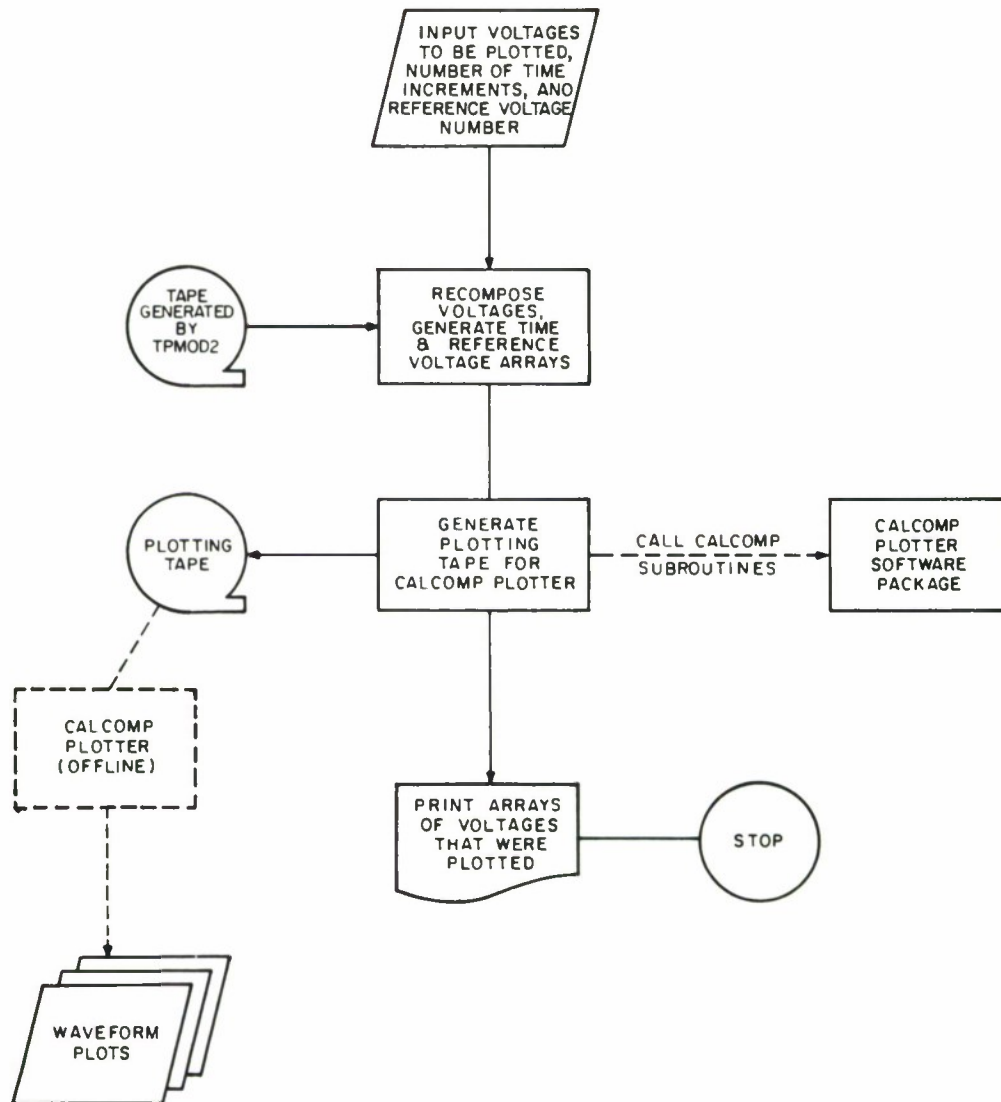
The information supplied by these tables, when combined with the waveform plots produced by PLMOD2, provided an essentially complete picture of the performance that can be expected from a proposed multiplexed bus.

Part 3: Description of PLMOD2 - The purpose of PLMOD2 is to reconstruct and plot the voltage waveforms at the points considered by TPMOD2. The operation of the program is shown in the flow chart of Figure I.9 and the listing which immediately follows.

Input Data - Input to the plotting routine comes from two sources. The 9-track magnetic tape produced by TPMOD2 provides the harmonic voltage amplitudes and phases required to reconstruct the waveforms. Selection of the waveforms to be plotted, the number of time increments per pulse period, and designation of the reference voltage in the transmitter cell are all entered as data cards in the source deck. A listing of the elements contained on these cards is shown in Figure I.10.

Output Format - PLMOD2 produces two types of output data. A 7-track magnetic tape containing machine instructions for the off-line plotter is generated during execution of the program. The plots ultimately produced from this tape have the format of those in Figure 8, of Section V. As an adjunct to these waveform plots PLMOD2 lists the voltage arrays that correspond to the N discrete points plotted, where N is the number of time increments. An example of this listing is shown in Figure I.11.

Part 4: Operational Steps - The chart shown in Figure I.12 briefly describes the sequence of steps required to exercise the program as written on a computer facility equivalent to the author's.



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Figure I.9 FLOW CHART OF PLMOD2

```

C      THIS PROGRAM RECOMPOSES THE OUTPUT OF TPM002
C      INTO THE TIME DOMAIN. THE VOLTAGE WAVEFORMS
C      ARE THEN PRESENTED IN BOTH TABULAR AND CALCOMP
C      PLOT FORMATS.
C
C
C
C
C
0001      COMPLEX E(30,9,32)
0002      INTEGER CELL,CELLKT,VLT,SERIAL,DDDD,XMTR,VOLT,REFVLT
0003      DIMENSION V(100,9,32),CELL(32),VLT(32,9),SERIAL(2),DDDD(2),T(102),
0004      1XMTRV(102),PLOTV(102),TBUF(2000)
0005      DATA V/28600*0.0/,VLT/28600/
0006      CALL DATE (DDDD)
0007      CELLKT=0
0008      READ(11)SERIAL,LAST,XMTR,TM,NN
0009      READ(11)((E(K,M,N),K=1,NN,1),M=1,9,1),N=1,LAST,1)
0010      READ(5,100)NTINCT
0011      100  FORMAT(I3)
0012      READ(5,105)REFVLT
0013      105  FORMAT(1E)
0014      N=1
0015      5  READ(5,110)(CELL(N),(VLT(N,M),M=1,9,1))
0016      110  FORMAT(1I2,9I1)
0017      IF(CELL(N).GT.50)GO TO 10
0018      CELLKT=CELLKT+1
0019      N=N+1
0020      GO TO 5
0021      10  CONTINUE
0022      XOMEGA=2.*3.14159265/TM
C
C      RECOMPOSE VOLTAGE PHASORS INTO THE TIME DOMAIN
C
0023      DO 50 N=1,CELLKT,1
0024      DO 40 M=1,9,1
0025      IF(VLT(N,M).EQ.0)GO TO 40
0026      DO 30 K=1,NN,1
0027      PHASE=ATAN2((AIMAG(E(K,VLT(N,M),CELL(N)))),REAL(E(K,VLT(N,M),CELL(
0028      1N))))
0029      DO 25 KT=1,NTINCT,1
0030      ANGLE=(2.*K-1.)*XOMEGA*KT*TM/NTINCT
0031      V(KT,VLT(N,M),CELL(N))=V(KT,VLT(N,M),CELL(N))*CABS(E(K,VLT(N,M),CE
0032      1LL(N)))*COS(ANGLE+PHASE)
0033      25  CONTINUE
0034      30  CONTINUE
0035      40  CONTINUE
0036      50  CONTINUE
C
C      GENERATE THE REFERENCE VOLT ARRAY
C
0037      N=CELLKT+1
0038      M=REFVLT
0039      VLT(N,M)=REFVLT
0040      CELL(N)=XMTR
0041      DO 57 K=1,NN,1
0042      PHASE=ATAN2((AIMAG(E(K,VLT(N,M),CELL(N)))),REAL(E(K,VLT(N,M),CELL(
0043      1N))))
0044      DO 55 KT=1,NTINCT,1

```

LISTING OF P1MOD2

```

0041      ANGLE=(2.*N-1.)*X)MEGA*KT*TM/NTINCT
0042      V(KT,VLT(N,M),CELL(N))=V(KT,VLT(N,M),CELL(N))+CABS(E(K,VLT(N,M),CE
      ILL(N)))*COS(ANGLE+PHASE)
0043      55 CONTINUE
0044      57 CONTINUE
      C
      C      LOAD THE TIME ARRAY
      C
0045      DELT=TM/NTINCT
0046      T(1)=DELT
0047      DO 60 I=2,NTINCT
0048      60 T(I)=T(I-1)+DELT
      C
      C      LOAD XMTR VOLTAGE ARRAY
      C
0049      DO 65 I=1,NTINCT,1
0050      XMTRV(I)=V(I,REFVLT,XMTR)
0051      65 CONTINUE
0052      CALL PLOTS(1300,2000)
0053      CALL SCALE(XMTRV,3.,NTINCT,1)
0054      FIR=XMTRV(NTINCT+1)
0055      DEL=XMTRV(NTINCT+2)
0056      IFRAME=0
      C
      C      GENERATE THE PLOTS
      C
0057      CALL PLOT(0.,-12.,-3)
0058      F=0.7
0059      CALL FACTOR(F)
0060      CALL SCALE(T,10.,NTINCT,1)
0061      CELLS=LAST
      C
      C      LOAD THE 'Y' ARRAY
      C
0062      DO 80 N=1,CELLKT,1
0063      DO 75 M=1,9,1
0064      IF (VLT(N,M).EQ.0) GO TO 75
0065      DO 70 I=1,NTINCT,1
0066      PLOTV(I)=V(I,VLT(N,M),CELL(N))
0067      70 CONTINUE
0068      CALL SCALE(PLOTV,8.,NTINCT,1)
      C
      C      ADJUST 'Y' SCALING IF NECESSARY
      C
0069      TEST=PLOTV(NTINCT+2)
0070      IF (TEST.LE.DEL) GO TO 82
0071      XMTRV(NTINCT+1)=PLOTV(NTINCT+1)
0072      XMTRV(NTINCT+2)=PLOTV(NTINCT+2)
0073      FIRST=PLOTV(NTINCT+1)
0074      DELTA=PLOTV(NTINCT+2)
0075      GO TO 84
0076      82 CONTINUE
0077      FIRST=FIR
0078      DELTA=DEL
0079      XMTRV(NTINCT+1)=FIR
0080      XMTRV(NTINCT+2)=DEL

```

LISTING OF PLMOD2 (Con't)

```

0081      PLOTV(NTINCT+1)=FIR
0082      PLOTV(NTINCT+2)=DEL
0083      94 CONTINUE
0084      IFRAME=IFRAME+1
0085      IF(IFRAME.GT.1)GO TO 71
0086      PX=0.0
0087      PY=1./F*5.5
0088      CALL PLOT(PX,PY,-3)
0089      GO TO 72
0090      71 CONTINUE
0091      PX=1./F*12.0
0092      PY=0.0
0093      CALL PLOT(PX,PY,-3)
0094      72 CONTINUE
0095      CALL AXIS(0.0,0.0,7HSECONDS,-7,10.0,0.0,(TINCT+1),T(TINCT+1))
0096      CALL AXIS(0.0,-4.0,16HNORMALIZED VOLTS,10,3.0,21.0,PICT,DELTA)
0097      CALL SYMBOL(0.0,4.5,0.14,12HPLOT DAT = ,0.0,12)
0098      CALL SYMBOL(999.0,999.0,0.14,000D,0.0,0)
0099      CALL SYMBOL(5.50,4.5,0.14,74HTOTAL NUMBER OF CELLS = ,0.0,0)
0100      CALL NUMBER(999.0,999.0,0.14,CELLS,0.0,-1)
0101      CALL SYMBOL(3.00,5.0,0.21,12HSERIAL NO. ,0.0,12)
0102      CALL SYMBOL(999.0,999.0,0.21,SERIAL,0.0,0)
0103      CALL SYMBOL(3.15,-4.5,0.21,16HMAX-RMS SIMULATION,0.0,12)
0104      XTCELL=XMTR
0105      XTVOLT=XREFVLT
0106      CALL SYMBOL(0.0,-5.0,0.14,17HINT = XMTR(CELL ,0.0,17)
0107      CALL NUMBER(999.0,999.0,0.14,XTCELL,0.0,-1)
0108      CALL SYMBOL(999.0,999.0,0.14,74, VOLT ,0.0,7)
0109      CALL NUMBER(999.0,999.0,0.14,XTVOLT,0.0,-1)
0110      CALL SYMBOL(999.0,999.0,0.14,1H),0.0,1)
0111      RCELL=CELL(N)
0112      RVOLT=VLT(N,M)
0113      CALL SYMBOL(6.3,-5.0,0.14,17HOSH = RCVR(CELL ,0.0,17)
0114      CALL NUMBER(999.0,999.0,0.14,RCELL,0.0,-1)
0115      CALL SYMBOL(999.0,999.0,0.14,7H, VOLT ,0.0,7)
0116      CALL NUMBER(999.0,999.0,0.14,RVOLT,0.0,-1)
0117      CALL SYMBOL(999.0,999.0,0.14,14),0.0,1)
0118      CALL PLOT(0.,-4.,-3)
0119      CALL LINE(T,XMTRV,NTINCT,1,0,0)
0120      CALL DASH(T,PLOTV,NTINCT,1,0,0)
0121      CALL PLOT(0.,4.,-3)
0122      IF(TEST.LE.DEL) GO TO 75
0123      CALL SYMBOL(3.4,2.7,0.21,16HALTERED Y-AXIS,0.0,14)
0124      CALL SYMBOL(3.6,2.2,0.21,12HSCALE FACTOR,0.0,12)
0125      75 CONTINUE
0126      80 CONTINUE
0127      CALL PLOT(14.0,0.0,999)
0128      PRINT THE VOLTAGE ARRAYS
0129      WRITE(6,1000)SERIAL,000D
0130      1000 FORMAT('1 SERIAL NO. ',2A4,' DATE IS ',2A4)
0131      WRITE(6,1002)ITH,NTINCT,NN
0132      1002 FORMAT('0 PERIOD=',E10.4,' # OF TIME INCREMENTS=',I0,
0133      1' # OF ODD HARMONICS CONSIDERED=',I3)
0134      WRITE(6,1003)XREFVLT
0135      1003 FORMAT('0 REFERENCE VOLTAGE IN XMTR CELL IS # ',I0)
0136      WRITE(6,10091)

```

LISTING OF PLMOD2 (Con't)

```
0135      1009 FORMAT(/,25X,' ARRAY ELEMENTS ARE ORDERED FROM LEFT TO RIGHT',
0136             1/,25X,' AND TOP TO BOTTOM OF THE TABLES')
0137      00 200 N=1,CELLKT,1
0138      WRITE(6,1010)CELL(N)
0139      1010 FORMAT('0 CELL ',I2)
0140      DO 190 M=1,9,1
0141      IF(VLT(N,M).EQ.0)GO TO 190
0142      VOLT=VLT(N,M)
0143      WRITE(6,1012)VOLT
0144      1012 FORMAT('0 VOLTAGE',I2)
0145      1020 FORMAT(' ',10F11.7)
0146      190 CONTINUE
0147      200 CONTINUE
C
C      PRINT THE REFERENCE VOLTAGE ARRAY
C
0148      WRITE(5,1010)XMTR
0149      M=REFVLT
0150      WRITE(5,1012)M
0151      WRITE(6,1020)(V(I,M,XMTR),I=1,NTINCT,1)
0152      STOP
0153      END
```

LISTING OF PLMOD2 (Con't)

DATA CARD NUMBER	VARIABLE NAME	DESCRIPTION	CARD COLUMNS	FORMAT	COMMENTS
1	NTINCT	NUMBER OF TIME INCREMENTS PER PULSE PERIOD	1 - 3	I3	DETERMINES GRANULARITY OF PLOTS PRODUCEO
↓					
2	REFVLT	NUMBER OF VOLTAGE IN TRANSMITTER CELL WHICH IS CONSIDERED THE REFERENCE. (e.g. 4 = V(4), 7 = V(7), ETC.)	1 - 2	I2	THE REFERENCE VOLTAGE IS PLOTTED ON EVERY PLOT TO GIVE A POINT OF COMPARISON FOR BOTH AMPLITUDE AND PHASE
↓					
3	CELL(N)	NUMBER OF CELL CONTAINING THE VOLTAGES TO BE PLOTTED	1 - 2	I2	CELL NUMBERS MUST BE RIGHT JUSTIFIED
↓					
	VLT(N,M)	THE NUMBER OF THE VOLTAGE IN CELL (N) TO BE PLOTTED	3	I1	THE NUMBERS OF THE VOLTAGES IN THIS CELL THAT ARE TO BE PLOTTED ARE ENTERED SEQUENTIALLY WITHOUT IMBEDDED BLANKS OR DELIMITERS  ( e.g. 12 372 = PLOT VOLTAGES V(3), V(7), & V(2) OF CELL # 12 )
			4	I1	
			↓	↓	
			11	I1	
4 → K					
(K ≤ 34)		EACH CARD HAS THE SAME FORMAT AS # 3 ABOVE. A FIXED NUMBER OF DATA CARDS IS NOT REQUIRED, BUT ONE CARD IS NEEDED FOR EACH CELL CONTAINING A VOLTAGE TO BE PLOTTED			
K + 1	—	A NUMBER > 50 IS PLACED HERE AS A TRAILER TO SIGNIFY THE END OF THE DESIRED PLOT LISTING	1 - 2	I2	CUSTOMARILY : 99

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Figure I.10 PLMOD2 INPUT DATA CARD FORMAT

SERIAL NO. 15.20.46 DATE 15 10/04/74

PERIOD=0.10000-05 # OF TIME INCREMENTS=100 # OF ODD HARMONICS CONSIDERED= 7

REFERENCE VOLTAGE IN XMTR CELL IS # 4

ARRAY ELEMENTS ARE ORDERED FROM LEFT TO RIGHT  
AND TOP TO BOTTOM OF THE TABLES

CELL 1

VOLTAGE 7	-0.1470073	-0.1392342	-0.1269646	-0.1114267	-0.0941740	-0.0759026	-0.0523586	-0.0346134	-0.0113952	0.0118752
0.0333140	0.0519485	0.0576954	0.0817351	0.0943323	0.1160749	0.1160749	0.1160749	0.1160749	0.1160749	0.1160749
0.1404219	0.1445231	0.1482445	0.1512551	0.1533317	0.1547924	0.1557934	0.1573017	0.1594377	0.1564303	0.1510479
0.1245313	0.1322038	0.1329175	0.1331132	0.1327941	0.1324117	0.1319844	0.1314859	0.1309293	0.1303119	0.1502119
0.1589534	0.1577352	0.1567949	0.1557737	0.1548377	0.1539844	0.1532356	0.1525921	0.1519566	0.1513288	0.1506995
0.1470074	0.1392344	0.1269656	0.1114279	0.0941743	0.0759033	0.0523583	0.0346131	0.0113967	0.0118747	0.0118747
-0.0333127	-0.0519473	-0.0576845	-0.0817352	-0.0943329	-0.0943329	-0.1062935	-0.1160740	-0.1160740	-0.1160740	-0.1160740
-0.1404220	-0.1444290	-0.1484450	-0.1512551	-0.1532326	-0.1547924	-0.1557934	-0.1573007	-0.1594373	-0.1564303	-0.1510475
-0.1245310	-0.1322040	-0.1329175	-0.1331132	-0.1327942	-0.1324117	-0.1319844	-0.1314853	-0.1309293	-0.1303117	-0.1502117
-0.1589533	-0.1577355	-0.1567942	-0.1557739	-0.1548374	-0.1539844	-0.1532356	-0.1525921	-0.1519567	-0.1513292	-0.1506995

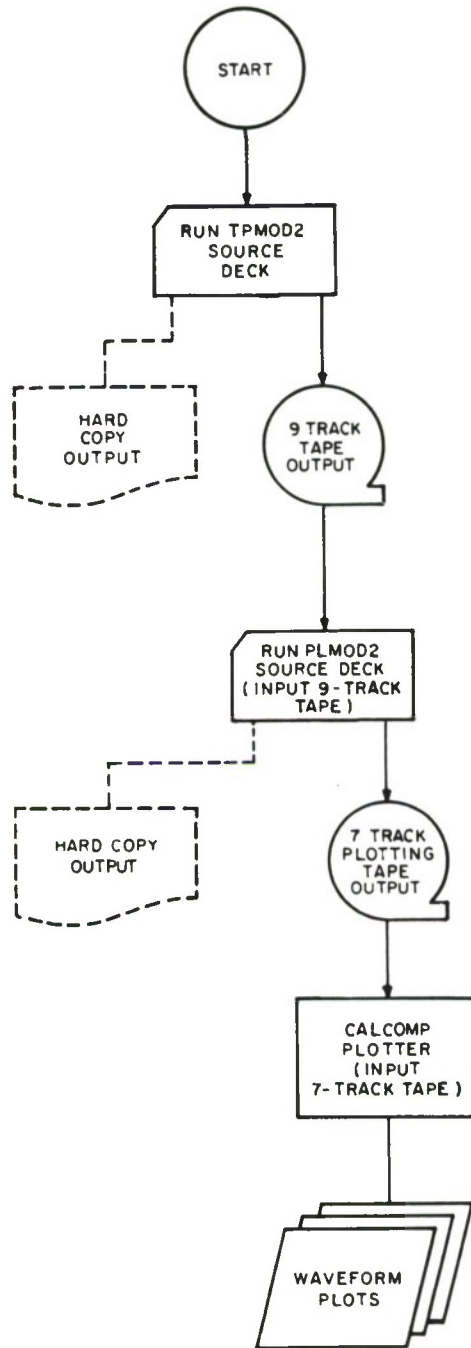
CELL 32

VOLTAGE 7	-0.1470073	-0.1392342	-0.1269646	-0.1114267	-0.0941740	-0.0759026	-0.0523586	-0.0346134	-0.0113952	0.0118752
0.0333140	0.0519485	0.0576954	0.0817351	0.0943323	0.1160749	0.1160749	0.1160749	0.1160749	0.1160749	0.1160749
0.1404219	0.1445231	0.1482445	0.1512551	0.1533317	0.1547924	0.1557934	0.1573017	0.1594377	0.1564303	0.1510479
0.1245313	0.1322038	0.1329175	0.1331132	0.1327941	0.1324117	0.1319844	0.1314859	0.1309293	0.1303119	0.1502119
0.1589534	0.1577352	0.1567949	0.1557737	0.1548377	0.1539844	0.1532356	0.1525921	0.1519566	0.1513288	0.1506995
0.1470074	0.1392344	0.1269656	0.1114279	0.0941743	0.0759033	0.0523583	0.0346131	0.0113967	0.0118747	0.0118747
-0.0333127	-0.0519473	-0.0576845	-0.0817352	-0.0943329	-0.0943329	-0.1062935	-0.1160740	-0.1160740	-0.1160740	-0.1160740
-0.1404220	-0.1444290	-0.1484450	-0.1512551	-0.1532326	-0.1547924	-0.1557934	-0.1573007	-0.1594373	-0.1564303	-0.1510475
-0.1245310	-0.1322040	-0.1329175	-0.1331132	-0.1327942	-0.1324117	-0.1319844	-0.1314853	-0.1309293	-0.1303117	-0.1502117
-0.1589533	-0.1577355	-0.1567942	-0.1557739	-0.1548374	-0.1539844	-0.1532356	-0.1525921	-0.1519567	-0.1513292	-0.1506995

CELL 14

VOLTAGE 4	0.2330322	0.2069555	0.1782544	0.1512625	0.1242706	0.0972787	0.0702868	0.0432949	0.0163030	-0.0106911
0.2104793	0.2069555	0.2062341	0.2021322	0.1994544	0.1941747	0.1864411	0.1749723	0.1590353	0.1390353	0.1148214
0.1822602	0.1782544	0.1751625	0.1745391	0.1745391	0.1770001	0.1844411	0.1997237	0.2085080	0.2179262	0.2246213
-0.1013463	-0.1437762	-0.1633008	-0.1685995	-0.1647293	-0.1562517	-0.1424722	-0.1230727	-0.0985080	-0.0719267	-0.0444217
-0.2330319	-0.2397915	-0.2412577	-0.2399795	-0.2380762	-0.2370155	-0.2367697	-0.2364376	-0.2360880	-0.2357404	-0.2353928
-0.2330319	-0.2332324	-0.2317494	-0.2305030	-0.2287338	-0.2275027	-0.2262716	-0.2250405	-0.2238094	-0.2225783	-0.2213472
-0.2106795	-0.2059861	-0.2042348	-0.2021325	-0.1994547	-0.1961744	-0.1922437	-0.1870106	-0.1807106	-0.1734217	-0.1651328
-0.1822604	-0.1782551	-0.1751625	-0.1745394	-0.1745394	-0.1770004	-0.1844414	-0.1997237	-0.2085080	-0.2179262	-0.2246213
-0.1013426	-0.1437746	-0.1633006	-0.1664994	-0.1647238	-0.1562511	-0.1424705	-0.1230723	-0.0985055	-0.0719223	-0.0444189
0.2330359	0.2397927	0.2412694	0.2399812	0.2380994	0.2370156	0.2367901	0.2365637	0.2363373	0.2361109	0.2358845

FIGURE I.11



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Figure I.12 OPERATIONAL FLOW CHART

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3. "Reference Data for Radio Engineers," Fifth Edition, Howard W. Sams & Company, New York, N.Y., 1974.