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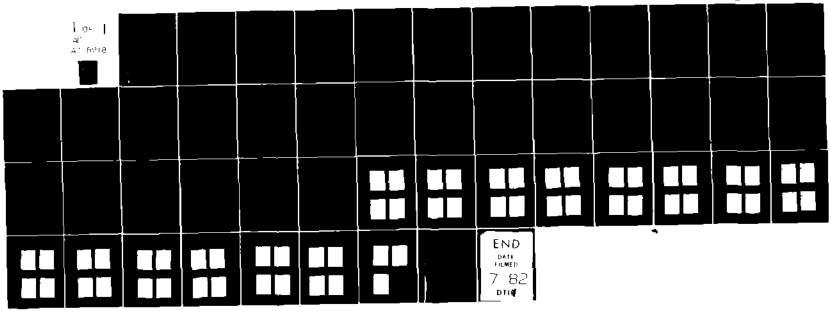

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COMPUTER PROGRAM FOR SMITH CHART DESIGN OF MICROWAVE MATCHING NETWORKS USING INTERACTIVE GRAPHICS

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SUMMARY

An experimental programme in the field of microwave transistor power amplifiers required study of the design of microstrip matching networks. The normal design process involving manual use of the Smith chart was potentially tedious and an alternative approach using interactive graphics was conceived.

A computer program was developed which plots impedance data and transformations on a Smith chart display, performing calculations analytically at several frequencies simultaneously. The program was brought to the stage where it can be used as a tool for design of microwave matching networks from specification of terminating impedances to determination of microstrip mechanical dimensions.

This Report describes the capabilities, facilities and operation of the program and gives examples of its use.

Departmental Reference: Space 588

LIST OF CONTENTS

1 INTRODUCTION

In the design of microwave matching networks the Smith chart[1] (see Appendix A) can be used to assist in the decisions on the type of matching network to be employed, on the types and values of components to be used and on their interconnections. When a basic design has been derived, its performance can be analysed in detail using a small-signal microwave analysis program such as the Redacal REDAP38 program available for use on the ICL 1906S computer at RAE. The design can subsequently be refined by repeated use of either or both of these procedures until a satisfactory design has been produced. However, achieving a satisfactory design in this way can be tedious because use of the Smith chart frequently requires a large number of numerical calculations to be performed manually. Also use of the general purpose small signal analysis programs can be a rather slow process due to the time taken to prepare input and obtain and interpret output and to the relatively long running times required.

The availability of interactive graphics computers offered the opportunity to remove much of the tedium of using the Smith chart for matching network design. The Smith chart could be displayed on a visual display unit and the computer could be used to plot initial and transformed impedances on the screen. Calculations would be performed analytically at several frequencies at once. Small signal analysis routines would reduce the need to use a separate general purpose network analysis program. Input and output could be in engineering units and in a convenient form for microwave circuit design.

In view of the needs of the research programme into the characteristics of microwave transistor power amplifiers which was being initiated in Space Department, RAE, the interest in computer graphics within the research group, and the availability of a suitable interactive graphics computer, it was decided to undertake a short programme of work to develop a computer program to implement the above ideas. In the event it was found possible to develop the program to a state where it could be used as a stand-alone program for Smith chart design of matching networks from specification of terminating impedances to determination of microstrip mechanical dimensions. At the time of writing, numerous matching networks designed using the program have been constructed and used with satisfactory results. It is the purpose of this Report to describe the facilities and capabilities offered by the program which has been developed, the "Electronic Smith chart" program, and to act as a user's guide to the program.

2 PROGRAM CAPABILITIES AND FACILITIES

2.1 General

This program requires the use of a computer with interactive graphics capability. This facility is briefly described in Appendix B.

The principal feature of the program is its capability for use in Smith chart design of microstrip matching circuits.

Paralleling the use of the manual Smith chart, impedance data can be entered and plotted on the Smith chart display. A stage-by-stage design of a matching network can be achieved by using the display to specify a sequence of transformations of the initial impedance data through connection of elementary components. The impedance resulting from each transformation is plotted on the Smith chart at each stage.

The computer program offers a number of additional features. It maintains a record of the specifications of the impedance transformations which may be printed out at any time relieving the user of the need to keep a separate record. Impedance transformations may be specified quickly and easily using interactive graphics and any details of these specifications may be displayed and modified at any time so that the user can quickly determine the effects of changes. The components that can be specified in impedance transformations are resistors, capacitors, inductors and lossless transmission lines. Component values and line parameters may be entered in convenient practical units, which include mechanical dimensions in the case of microstrip transmission lines, thus largely avoiding the need for separate conversion of units.

Impedance values for each impedance transformation are calculated and plotted by the computer, thus relieving the user of the need to compute reactance values, renormalise impedance values or plot impedance values, plot transformations or read impedance values from the Smith chart. Calculation may be made at several frequencies simultaneously and accuracy is substantially better than obtained by graphical methods. Impedance value calculations are made automatically whenever impedance transformations are specified or altered so that the effects of changes can be observed almost instantaneously. Impedance values tabulated vs frequency may be input, output or displayed on the screen in any common format, all necessary format conversions being done by the program. This further reduces the need for calculations to be done externally to the program.

A plot of transducer gain vs frequency may be substituted for the Smith chart display, when necessary, thus enabling the user to quickly assess the quality of the impedance match and relieving him of the need to perform this calculation.

In general the program enables the microwave engineer to carry out Smith chart design of matching networks while avoiding almost all the tedious numerical calculations associated with use of the manual Smith chart, thus allowing him to concentrate on the essentials of the task in hand. In practice this means that not only can designs be developed much more quickly than by using a manual Smith chart but also more complicated designs may be attempted.

Some minor facilities additional to those mentioned above are available and these are included in the list of facilities in section 2.3. The definition of impedance used by the program and the automatic calculation of impedance values which are central features of the program are described in section 2.2.

2.2 Impedance definition and calculation

For the purposes of this program, an impedance is defined as the impedance looking in a particular direction (implicitly defined) between a node of the network being specified and ground. This definition restricts the type of network which can be specified, but in practice this is of little consequence as microstrip construction imposes an almost identical restriction. On the other hand use of such a definition of impedance simplifies both the process of specifying impedances and the calculation of impedance values.

Though in practice most impedances are defined to be transformations, for flexibility four 'classes' of impedance definitions have been made available in the program namely 'terminations', 'transformations', 'combinations' and 'fixed data' (Fig 1).

An impedance of class 'Termination' is defined as the impedance of a single lumped component connected on one side to ground. The lumped component may be a resistor, capacitor or inductor.

An impedance of class 'Transformation' is defined as the impedance resulting from transforming another impedance by connecting to it a lumped component in series or parallel or a lossless transmission line with one side grounded.

An impedance of class 'Combination' is the impedance resulting from connection of two other impedances in parallel.

Finally an impedance of class 'Fixed Data' is an impedance having a value tabulated vs frequency at fixed spot frequencies.

Using these definitions multibranch ladder networks sharing a common ground may be specified in terms of impedances at the nodes.

Impedances are numbered and the definition of each one includes the details of the component used (if any), how it is connected (if necessary), and the numbers (if any) of the impedances transformed or combined. Impedances with numbers in the permitted range may be defined in any order and may refer to any other impedances in their definitions. Appropriate parameters of any impedance definitions may be specified or modified in any order.

Calculation and plotting, if required, of the values of each impedance is automatic. Each time any parameter of any impedance specification is altered, the program scans through the table it maintains of the state of definition of all the impedances to determine if any impedance has now become completely defined, redefined or undefined. If so, it calculates, recalculates or 'uncalculates' the corresponding impedance value. If any such calculation is made it repeats the scanning and calculation process and continues to so do until no further calculations can be made. Thus the impedances at all points in the ladder network subsequent to the point at which the change was made are correctly calculated. The state of calculation of impedances is consequently always consistent with the impedance specifications.

2.3 Full list of program facilities

The program provides for:-

(i) Specification of impedance, defined as the impedance looking into the network in a particular direction between a node and ground, in four ways:-

(a) Termination. The impedance of a lumped component (resistor, capacitor or inductor) connected to ground.

(b) Transformation. The impedance produced by transforming another impedance by connecting a lumped component (resistor, capacitor or inductor) in series or parallel or a lossless transmission line with one side grounded.

(c) Combination. The impedance resulting from connecting two other impedances in parallel.

(d) Fixed data. Impedance data tabulated vs frequency at fixed spot frequencies.

(ii) Specification of arbitrary sequences , in the form of branched ladder networks with one side grounded, of transformations and combinations terminated by terminations or fixed data.

(iii) Recording of impedance definitions.

(iv) Specification and display of any impedance definition and modification of any detail of any impedance definition using interactive graphics.

(v) Specification of impedance definitions, other than of fixed data, by identity of impedance or impedances transformed (if any), type of component (if any), connection of component (if appropriate) and numerical value or values of the component's value or parameters (if appropriate).

(vi) Specification of component's values or parameters in practical units as follows:-

Resistors	Ω
Capacitors	pF
Inductors	nH

Lines

	Impedance	Ω
and	Electrical length	cm
or	Mechanical width	cm
and	Mechanical length	cm

with velocity ratio displayed but not independently specifiable.

Lines are specified by electrical parameters or mechanical dimensions using modified versions of Wheeler's formulae for interconversion[2].

(vii) Specification and alteration of microstrip substrate parameters using practical units, viz relative dielectric constant and dielectric thickness in centimetres or thou.

(viii) Specification of frequency range for calculation of impedance values, input of fixed data, output of impedance values and display of impedance data in various forms using practical units as follows:-

Minimum frequency	GHz
Maximum frequency	GHz
Number of frequencies	
Frequency increment calculated by program and displayed	GHz.

(ix) Automatic calculation of the values of all impedances which are completely defined including updating of calculations after any alteration in any impedance definition or any change in frequencies or microstrip substrate parameters.

(x) Simultaneous display of any or all of the currently calculated impedance values plotted against frequency on a polar display using impedance, admittance or reflection coefficient co-ordinates.

(xi) Input, output or screen display (as an alternative to the polar display) of impedance data tabulated vs frequency where impedance is specified in any of the following formats:-

Absolute impedance	Ω	(Real and imaginary parts)
Normalised impedance	$(Z_0 = 50\Omega)$	(Real and imaginary parts)
Absolute admittance	$\mho$	(Real and imaginary parts)
Normalised admittance	$(Y_0 = 0.02\mho)$	(Real and imaginary parts)
Cartesian reflection coefficient	X and Y components	
Polar reflection coefficient	Amplitude and degrees	
Log polar reflection coefficient	dB and degrees	

(xii) Display (as an alternative to the polar display) of 'transducer gain' between any two calculated impedances, Z_A and Z_B, where transducer gain is defined by the formula

$$\text{transducer gain} = 1 - \left|\frac{Z_A - Z_B^*}{Z_A + Z_B}\right|^2$$

where Z_A and Z_B are expressed in the form of absolute complex impedance in Ω and Z_B^* is the complex conjugate of Z_B.

(xiii) Output at any time of a report specifying the substrate parameters and tabulating the parameters of all impedances which have been partly or fully defined indicating which parameters of any impedance have not yet been defined. Fully defined impedances are labelled as CALCULATED unless *either*, in the case of transformations or combinations one or both of the impedances transformed or defined has not been calculated, *or* in the case of fixed data, frequencies have been altered since the data was input. In such cases impedances are labelled as DEFINED.

(xiv) Selection of either console or paper tape reader for input of tabulated impedance data and either teletype, lineprinter or paper tape punch for output of tabulated impedance data or reports.

3 PROGRAM USAGE

3.1 Running the program

The program is run on a Digital Equipment Corporation PDP11/34 computer with interactive graphics operating under the RT11 single job operating system. After loading the disc containing the program files RT11 system commands are issued from the console to initialise the program run.

Immediately after initialisation the display on the screen of the visual display unit is as shown in Plates 1 (left side of screen) and 2 (right side of screen). To use the program the user selects items from the screen using the light pen, types in data at the console when necessary and receives output on the VDU screen, teletype console or line printer. Further details of the computer configuration and method of initiating and terminating a program run are given in Appendix C.

3.2 Contents of visual display

The contents of the visual display presented to the user when the program is running consists of five groups or 'fields' of information located on the screen of the VDU in the positions illustrated in Fig 2. Plates 1 and 2 show the initial contents of each field but the information in all fields changes as the program is used.

The information presented in the *display field* may consist of:

(i) a polar plot of reflection coefficient using impedance, admittance or reflection coefficient co-ordinates *or*

(ii) a rectangular plot of transducer gain vs frequency where transducer gain is as defined in section 2 *or*

(iii) a table of impedance values in any one of the available formats vs frequency.

The information presented in the *data field* consists of specification of current values or specifications of

(i) substrate dielectric thickness and dielectric constant;

(ii) minimum, maximum, increment and number of frequencies for input, output, calculation and display of impedance values;

(iii) impedance format for input, output or tabular display;

(iv) peripheral devices selected for input and output.

The information presented in the *instruction field* informs the user of his choice of actions or informs him what actions are being carried out.

The information presented in the *menu field* consists of one of the various menus which are offered to the user during use of the program and from which the user selects the items needed to define his problem. The main function, display, impedance definition, class, type, connection, screen, impedance format, I/O devices, substrate and end run menus may be displayed here. The contents and use of all these menus are described later.

The information presented in the *impedance selection field* consists of a list of the impedance numbers permitted for selection, with those impedance numbers selected for display on any polar display chart marked by an asterisk. The numbers of the impedances for definition, reference in definitions and display are selected from this field when required (following use of a menu in the menu field) and this relieves the user of having to type in impedance numbers.

3.3 Application of main function menu items

Two of the fields displayed on the VDU are sensitive to light pen hits and these are the menu field and the impedance selection field. At the start of a program run the menu field contains the main function menu and a message 'SELECT FUNCTION' appears in the instruction field. To use the program the user selects items in turn from the main function menu. Following each selection the function menu disappears to return again when the function selected has been used or abandoned. During use of any function alternative menus are displayed in the menu field and the user selects items from these menus. When an appropriate message is displayed in the instruction field, the user may be required to select items from the impedance selection field or type in data at the console.

In general all output is displayed on the VDU except when the user explicitly requests a report or tabulation of impedance data to be directed to the teletype or lineprinter.

Table 1 states briefly the use of each function in the function menu. When using the program use of the function menu items is largely self-explanatory because messages appearing in the instruction field inform the user of his options. However, full details of the method of use of each menu item are given in the next section.

Referring to Table 1, functions FREQ, IMP.FORMATS, I/O DEVICES and SUBSTRATE permit setting or alteration of basic parameters and the values of these parameters are displayed in the data field.

Functions DEFINE and INPUT are used to specify or modify impedance definitions.

Functions SCREEN and DISPLAY control the type of display to be shown in the display field and which impedances are to be plotted if a polar display is selected.

Functions OUTPUT and REPORT are used to obtain hard copy output of tabulated impedance data or a table specifying the state of definition of each impedance.

No function is provided for the calculation of values of impedances because such calculation is automatic whenever any change is made which could affect the 'state' of their calculation. Automatic calculation is carried out whenever necessary following the use of the functions INPUT, DEFINE, FREQ or SUBSTRATE.

A detailed description of how each function is used is given in the next section.

4 DETAILED DESCRIPTION OF USE OF MAIN FUNCTION MENU ITEMS

4.1 FUNCTION 1 : FREQ

This function is used to specify the range of frequencies over which the defined impedances are to be calculated and over which any tabulated impedance data to be input to the program is to be specified. On selection of the function the message TYPE MIN. FREQ. (GHz) appears in the instruction field (Plate 3). The user responds by typing the minimum frequency for analysis in GHz on the console. The message TYPE MAX. FREQ. (GHz) next appears and the user types the maximum frequency in GHz. Finally the message TYPE NO. OF FREQS. FROM 1 TO 21 appears and the user types the number of frequencies for analysis. The main function menu returns to the screen and the computer calculates the frequency increment FINC and displays its value in the data field together with values of FMIN, FMAX, and FNO. supplied by the user (Plate 4). The function may also be used to alter the frequencies in which case all impedances already calculated are recalculated at the new frequencies.

143

4.2 FUNCTION 2 : DEFINE

4.2.1 Use of function

This function enables the user to specify or modify any parameter of any impedance definition whilst displaying the current state of definition of that impedance. On selection of this function, the impedance definition menu is displayed with only one parameter, 0 IMP. NO ?, present (Plate 5) with a ? in the specification space to indicate that the value of this parameter is unspecified. The user builds up the definitions of the impedances by selecting the parameters with a ? in the specification space and providing values for these parameters. The computer then records the specifications of the parameters, displays their values in place of the ? in the specification spaces and displays any further parameters needing to be specified. The user may similarly select any parameters already specified and change their values. An impedance becomes fully defined when there are no remaining parameters with a ? in the specification space. Parameters present in the impedance definition menu may be specified or modified in any order. Details of the parameters offered for selection and the ways in which the parameters may be specified now follow.

4.2.2 Parameters to be defined

(i) Parameter 0 IMP. NO ?

This parameter is used purely to specify the number of the impedance whose definition is to be displayed. In this respect it differs from the rest of the parameters because in itself it is not used to alter the state of definition of an impedance. On selection of the parameter the message SELECT IMPEDANCE appears in the instruction field (Plate 6). The user then selects the required impedance number from the impedance selection field and the impedance definition menu now specifies the current state of definition of the impedance selected. The number of the impedance selected is also shown in the instruction field for reference during later stages in the specification of the impedance definition when the impedance definition menu is not present. Examples of possible impedance definitions which may be displayed at this point are shown in Plates 7 to 9.

If the impedance is undefined only parameter 1 CLASS ? will be present with a ? in its specification space to indicate that the parameter is undefined (Plate 7). If the impedance is partly defined the class will be specified and other parameters will also be present, at least some of which will have a ? in the specification space (Plate 8). If the impedance is fully defined an appropriate set of fully specified parameters will be present completely specifying the impedance definition (Plate 9).

(ii) Parameter 1 CLASS ?

This parameter permits the class, as defined in sections 2.2 and 2.3 of the impedance definition to be specified. When selected the class menu is initially displayed (Plate 10). An item from this menu is selected, the impedance definition menu returns to the screen and any change in the class is recorded and displayed. Subsequent action depends on the class menu item selected as follows:-

UNDEFINED. The class becomes or remains undefined. Any subsequent parameters previously present are removed (as Plate 7).

FIXED DATA . An impedance of this class may in the present version of the program only be produced using FUNCTION 3 : INPUT. On selection of this item the class remains unchanged.

TERMINATION. The class is recorded as a termination and parameter 4 TYPE ? appears in the impedance definition menu (Plate 11).

TRANSFORMATION. The class is recorded as a transformation and both parameters 2 OF IMP. NO.? and 4 TYPE ? appear in the impedance definition menu (Plate 12).

COMBINATION. The class is recorded as a combination and parameters 2 OF IMP. NO ? and 3 AND IMP NO. ? appear in the impedance definition menu (Plate 13).

UNCHANGED. The class remains unchanged.

(iii) Parameter 2 OF IMP. NO. ?

This parameter is present if the class is transformation or combination. It indicates the impedance number of the impedance to be transformed by connection of the component to be defined or of one of the impedances to be combined, parallel combination being always assumed. When this parameter is selected the message SELECT IMPEDANCE appears in the instruction field (Plate 14). An impedance is selected from the impedance selection field, the impedance definition menu returns to the screen and the impedance selected is recorded and displayed (Plate 15).

(iv) Parameter 3 AND. IMP. NO. ?

This parameter is present if the class is combination. It indicates the impedance number of the second impedance to be combined. If selected the impedance number is requested then recorded and displayed in the same way as for Parameter 2 OF IMP. NO. ? (Plate 16).

(v) Parameter 4 TYPE ?

This parameter is present if the class is termination or transformation. On selection of this parameter the type menu is displayed. An item from the type menu is selected, the impedance definition menu returns to the screen and any change in the type is recorded and displayed.

The type menu offered and subsequent actions depend on the class as follows:-

If the class is termination the type menu contains four options (Plate 17). When the impedance definition returns parameter 6 VALUE (units) ? is present where 'units' is OHM. (Plate 18), PF, or NH, for a resistor, capacitor or inductor respectively.

If the class is transformation the type menu contains five options (Plate 19). Parameters present when the impedance definition menu returns depend on the type selected. If the type is resistor, capacitor or inductor the additional parameters are 5 CONNECTED ? as well as 6 VALUE (units) ? (Plate 20). If the type is line the additional parameters are 6 LINE IMP. (OHMS) ? , 7 VEL. RATIO, 8 ELEC. LENGTH : (CM) ? , 9 MECH. LENGTH: (CM) ? and 10 MECH. WIDTH : (CM) ? (Plate 21).

(vi) Parameter 5 CONNECTED ?

This parameter is present if the class is transformation and the type is resistor, capacitor or inductor. It permits the method of connection of a lumped component to produce an impedance transformation to be defined. On selection of this parameter the connection menu appears (Plate 22).

An item is chosen from this menu, the impedance definition menu returns and the connection is recorded and displayed as either series or parallel (Plate 23).

(vii) Parameter 6 VALUE (units) ?

This parameter is present in this form if the type is resistor, capacitor or inductor. On selection the message 'TYPE VALUE (units)' appears in the instruction field where units is OHM., PF or NH according to the component type (Plate 24). The value in Ω , pF or nH is typed on the console, the impedance definition menu returns and the value is recorded and displayed (Plate 25).

(viii) Parameters 6 LINE IMP. (OHMS)?, 7 VEL. RATIO, 8 ELEC. LENGTH: (CM)?, 9 MECH. LENGTH: (CM)? and 10 MECH. WIDTH: (CM)?

These parameters are present, with parameter 6 taking the above form, if the type of the transformation is line. A line may be specified by its electrical parameters viz characteristic impedance and electrical length (parameters 6 and 8) or by its mechanical parameters, mechanical length and mechanical width (parameters 9 and 10). If the latter method of specification is used, substrate parameters must first be defined using FUNCTION 10: SUBSTRATE. If the mechanical parameters, 9 and 10 are defined or either is changed the electrical parameters (6 and 8) and the velocity ratio (parameter 7) will be calculated by the program. Conversely if electrical parameters, 6 and 8 are defined then provided that substrate parameters have been specified, the mechanical parameters (9 and 10) and the velocity ratio (parameter 7) will be calculated by the program. On selection of one of the parameters other than parameter 7 VEL RATIO which is always calculated by the program, the corresponding TYPE... instruction, *eg* TYPE LINE IMP. (OHMS) (Plate 26) appears in the instruction field. The user types in the value in appropriate units, viz Ω or cm, the impedance definition menu returns and the computer records and displays this value (Plate 27) and computes and displays the values of such other line parameters as appropriate. For example after selecting 8 ELEC. LENGTH in this instance the message TYPE ELEC. LENGTH (CM) would be displayed (Plate 28) and on return of the impedance definition menu 7 VEL. RATIO, 9 MECH. LENGTH and 10 MECH. WIDTH would be calculated and displayed in addition (Plate 29).

4.2.3 Examples of fully defined impedances

Plates 30 to 34 give examples of the specifications of fully defined impedance definitions indicating all the possible forms (combinations of parameters) for such definitions. Plates 30 to 33 show impedance definitions specified using FUNCTION 2 : DEFINE . PLATE 34 shows an impedance definition of class fixed data resulting from use of FUNCTION 3 : INPUT .

4.3 FUNCTION 3 : INPUT

This function is used for input, in tabular form, of impedance data which has fixed values over a specified range of frequencies. This class of data is referred to by the program as fixed data. If the function is selected a check is made to ensure that frequencies have been defined, using FUNCTION 1 : FREQ , and if not the message UNDFINED FREQS. appears in the instruction field and the function menu remains displayed. If frequencies have been defined the instruction SELECT IMPEDANCE appears in the instruction field (Plate 35). The user selects an impedance number from the impedance selection field and the instruction TYPE IMPEDANCE appears in the instruction field (Plate 36). If the input device (I/P DEVICE in Plate 1) specified in the data field is KEYBOARD , input frequencies are listed one by one on the console and the user types in the corresponding values of impedance at each frequency in the format (IMP. FORMAT in Plate 1) specified in the data field. Input data may alternatively be taken from the paper tape reader if this input device has previously been selected using FUNCTION 9 : I/O DEVICES. Similarly input data may be entered in a different format if the impedance format setting has previously been altered using FUNCTION 8 : IMP. FORMATS. When all the data has been entered the impedance becomes recorded as fully defined and calculated, consequent impedance calculations or recalculations or changes in displayed data are made and the SELECT IMPEDANCE message returns to the screen. If one of the polar displays is present in the display field the impedance will be displayed thereon in addition to any other impedances already present until the user selects a different impedance to enter further impedance data or EXIT to return to the main function menu.

4.4 FUNCTION 4 : OUTPUT

This function is used to obtain hard copy output of calculated impedance values tabulated vs frequency. On selection of the function a check is made to ensure that frequencies have been defined and if not the message UNDEFINED FREQS. appears in the instruction field and the main function menu remains displayed. If frequencies have been defined the message SELECT IMPEDANCE appears in the instruction field (Plate 37). An impedance is selected from the impedance selection field and the computer checks whether the impedance has been calculated and if not the message UNCALCULATED is displayed in the instruction field. If the impedance has been calculated a heading is printed followed by a tabulation of the impedance values as a function of frequency on the console or other output device as specified by O/P DEVICE in the data field, the impedance format being as specified by IMP. FORMAT in the data field. The number of the impedance being output is indicated in the instruction field (Plate 38). The output device or impedance format may be altered by prior use of FUNCTION 9 : I/O DEVICES or FUNCTION 8 : IMP. FORMATS . Any number of different impedances may similarly be selected for output before finally selecting EXIT to return to the main function menu. Fig 3 gives a typical example of output produced using this function.

143

4.5 FUNCTION 5 : REPORT

This function is used to produce a hard copy tabulated listing of the states of definition of all impedance which have been partly or fully defined. On selection of the function the message OUTPUT OF REPORT (Plate 39) appears in the instruction field and a report is printed on the output device specified by O/P DEVICE : in the data field. The report consists of a heading which includes a specification of the microstrip substrate parameter values followed by a table specifying the state of definition of each impedance which has been partly or fully defined. Individual impedances are specified in the same form as used in the impedance definition menu except that asterisks, eg ***.** are used instead of ? to signify undefined parameters. An additional column specifies whether each impedance is partly defined (   ), fully defined (DEFINED) or fully defined and calculated (CALCULATED). An example of a report is shown in Fig 4. When the report has been fully listed the main function menu returns to the screen.

4.6 FUNCTION 6 : DISPLAY

This function is used to select which impedances are to be displayed, if calculated, when one of the polar displays (impedance, admittance or reflection coefficient) is present in the display field. When the function is selected the display menu appears (Plate 40). The user selects either IMP. ON or IMP. OFF depending on whether impedances are to be added to or removed from the list of impedances to be displayed and a box appears around the item selected (Plate 41). The user may then select from the impedance selection field the numbers of the impedances which are to be displayed or not on the polar display. The numbers of the impedances which have been selected for display are indicated by a * to the left of the impedance number in the impedance selection field (Plate 42). The current values of such impedances will be displayed on any polar display present in the display field (Plate 43) immediately in the case of those impedances already calculated or subsequently whenever any of the impedances become calculated. If all the impedances are to be displayed or not displayed the user may select ALL after selecting IMP. ON. or IMP. OFF . The user may select EXIT at any time to return to the main function menu.

4.7 FUNCTION 7 : SCREEN

This function is used to select the form of output display to be shown on the screen in the display field. If the function is selected the screen menu appears and on first use of the function, the screen menu takes its basic form (Plate 44), the impedance chart remaining displayed in the display field. The user may now select items from the screen menu to change the form of the display in the display field.

If screen menu items 1 IMPEDANCE , 2 ADMITTANCE or 3 REF. COEFF are selected then charts of impedance (Plate 45), admittance (Plate 46) or reflection coefficient (Plate 47) will be displayed in the display field and the screen menu will have its basic form (Plate 44). Impedances to be displayed, if calculated, on any of these charts when present are selected using FUNCTION 6 : DISPLAY .

If screen menu item 4 TD. GAIN is selected a plot or skeleton plot of transducer gain in dB vs frequency will be displayed in the display field and two extra items will be added to the screen menu, viz 6 FIRST T.G. IMP. NO. and 7 SECOND T.G. IMP. NO. (Plate 48). These additional items are used to specify the impedances between which the transducer gain is to be calculated. On selection of either item the screen menu is removed and the message SELECT IMPEDANCE (Plate 49) appears in the instruction field. The user selects the required impedance number from the impedance selection field, the screen menu returns and the impedance number is recorded and displayed on the transducer gain display. When both impedance numbers have been defined in this way the transducer gain will be calculated immediately if both impedances have been calculated (Plate 50) or subsequently whenever both impedances become calculated. The transducer gain plot is automatically scaled according to the magnitude of the highest numerical value of transducer gain (0.25, 1.0, 2.5 or 10.0 dB/div).

If screen menu item 5 DIGITAL is selected, a table or skeleton table of impedance data vs frequency will be displayed in the display field and one extra item will be added to the basic screen menu, viz 6 DIGITAL IMP. NO. (Plate 51). On selection of this item SELECT IMPEDANCE appears in the instruction field, the screen menu disappears, and the user selects an impedance number from the impedance selection field. The screen menu then returns and the number of the impedance whose value is to be tabulated vs frequency is recorded and displayed at the top of the impedance data table in the display field. If the impedance specified is calculated or subsequently becomes calculated its current value will be tabulated (Plate 52) as a function of frequency in the format specified by IMP. FORMAT in the data field. After changing the form of display as required the user selects EXIT to return to the main function menu.

4.8 FUNCTION 8 : IMP. FORMATS

This function is used to change the impedance format for input, output or tabulated display. On selection of the function the impedance format menu appears (Plate 53). The user selects the required impedance format and the selection is recorded and displayed by IMP. FORMAT in the data field. Impedance formats available are absolute impedance (ZABS), normalised impedance $Z_0 = 50\Omega$ (ZNORM), absolute admittance (YABS), normalised admittance $Y_0 = 0.02$ ℧ (YNORM), reflection coefficient in absolute magnitude and phase (R.C.(POL.-LIN)), reflection coefficient in cartesian coordinates (R.C.(CART.)) and reflection coefficient in logarithmic magnitude (dB) and phase (R.C.(POL.-LOG)). If a digital display is present in the display field and already calculated it will immediately be recalculated in the new format. The user selects EXIT to return to the main function menu.

4.9 FUNCTION 9 : I/O DEVICES

This function is used to alter the peripheral devices for input and output of tabulated impedance data and reports. If it is selected the I/O devices menu is displayed (Plate 54). The user selects one of the numbered I/O device menu items for input and/or output and the program records the selection under I/P DEVICE:- or O/P DEVICE:- in the data field. If the function is not used input will be taken from the console (KEYBOARD) and output directed to the console teletype (TELETYPE). The paper tape reader may alternatively be used for input and paper tape punch or lineprinter for output. The user selects EXIT to return to the main function menu.

4.10 FUNCTION 10 : SUBSTRATE

This function permits the user to specify or alter the microstrip substrate parameters. If the function is selected the substrate menu appears (Plate 55). Item 1 DIELECTRIC CONSTANT permits the dielectric constant of the microstrip dielectric to be specified and the items 2 DIELECTRIC THICKNESS H (CM) and 3 DIELECTRIC THICKNESS H (THOU.) permit the thickness of the microstrip dielectric to be specified in either unit. On selection of one of these items the substrate menu disappears, a TYPE ... instruction such as TYPE H (THOU.) (Plate 56) appears in the instruction field, the user types the appropriate value, the substrate menu returns and the computer records the value and displays it in the data field (Plate 57). If the thickness is specified in thou then its corresponding value in centimetres will also be calculated and displayed and vice versa.

Item 4 FIXED LINE PARAMETERS : ..... is used to specify which parameters are to be held constant when substrate parameters are changed. Selection of this item causes 4 FIXED LINE PARAMETERS : ELECTRICAL to change to 4 FIXED LINE PARAMETERS : MECHANICAL or vice versa. If fixed line parameters are electrical then parameters 9 MECH. LENGTH, 10. MECH. WIDTH and 7 VEL. RATIO of any transformations of type line will be recalculated whenever any substrate parameter is changed. Conversely if fixed line parameters are mechanical, parameters 6 LINE IMP., 8 ELEC. LENGTH and 7 VEL. RATIO of any transformation of type line will be recalculated when any substrate parameter is changed and recalculation of all impedance values affected will be performed. The user selects EXIT to return to the main function menu.

4.11 FUNCTION 11 : GRID

This function is used for program development only.

4.12 FUNCTION 17 : ENDRUN

This function is used to terminate a run of the program and empty the lineprinter and paper tape punch buffers. On selection the endrun menu appears (Plate 58) and the user selects YES to terminate the run or NO to return to the main function menu.

5 EXAMPLE OF PROGRAM USAGE

5.1 Introduction

The example is to design a broadband matching network to match the output of an MRA1417-11 power transistor to 50Ω. This problem was considered in four stages as follows:-

Stage 1. Derive simple equivalent circuit to fit manufacturer's transistor output impedance data.

Stage 2. Derive component values for lumped component matching network.

Stage 3. Derive line dimensions for distributed version of matching network.

Stage 4. Derive final network design adding bias network and incorporating final adjustments.

The general procedure at each stage was

(i) Define frequencies using FREQ function.

143

(ii) Define network being designed with impedances in appropriate order and display impedance at appropriate node using DEFINE, DISPLAY and if needed SUBSTRATE functions.

(iii) Define and display target value of impedance at this node using DEFINE or INPUT and DISPLAY functions.

(iv) Adjust specifications of impedance definitions defining network for best agreement between displayed network impedance and target value.

5.2 <u>Stage 1</u> Derive simple equivalent circuit to fit manufacturer's output impedance data.

In this stage frequencies were defined as 1.4 to 1.7 GHz in three steps. Manufacturer's data was entered into impedance 14 as fixed data. The network of Fig 5 was defined with impedances ordered 11-10-9. Impedances 14 and 9 were displayed on the impedance display. Starting values of the components for impedances 11, 10 and 9 were obtained from a simple physical model. Their values were then finely adjusted for best agreement between impedances 9 and 14 over all three frequencies. This resulted in the component values tabulated in the report illustrated in Fig 4.

5.3 <u>Stage 2</u> Derive component values for lumped component matching network.

A Chebychev design including the transistor reactances could not be employed because of the restriction imposed by the values of the transistor reactances. Consequently it was decided to use a five element network as shown in Fig 6 where part of the network consisted of components internal to the transistor.

Frequencies were initially defined as 1 GHz to 2 GHz in 11 steps. The network of Fig 6 was defined with impedances ordered 11-10-9-18-17-16-15. Impedances 11, 10 and 9 were as derived in Stage 1. Impedances 15 and 1 were displayed the object being to match impedance 15 to 50 Ω as closely as possible over the frequency range 1.4 to 1.7 GHz. Impedances 18, 17, 16 and 15 were adjusted for best agreement of impedance 15 with impedance 1 using a systematic trial-and-error approach based on the following processes.

(i) Using relatively large value for capacitor of impedance 17, set values of components of impedances 18, 16 and 15 to give LC product appropriate to operating frequency on each side of impedance 17, while setting ratio between values of components in LC pairs appropriate to impedance transformation ratio between impedances 11 and 1.

(ii) Adjust value of 'coupling' capacitor of impedance 17 for suitable degree of overcoupled response as indicated by loop in display of impedance 15.

(iii) Scale component values to correct the centre frequency.

(iv) Make fine adjustment of values of components of impedances 18, 16 and 15 for best match and fine adjustment of impedance 17 for optimum bandwidth (degree of overcoupling).

(v) Narrow frequency range as design objective approaches.

(vi) Change to display of transducer gain between impedances 15 and 1 when loop in impedance 15 encircles impedance 1 and finally adjust component values for best but uniform transducer gain over the desired frequency range.

The whole procedure took only a few minutes and resulted in the component values shown in the report of Fig 4.

5.4 Stage 3 Derive line dimensions for distributed version of matching network.

The object here was to convert the components, external to the transistor, of the lumped component matching networks to lines of convenient practical dimensions.

Frequencies were defined as 1.4 GHz to 1.7 GHz in 13 steps and substrate parameters were also specified. The network of Fig 7 was defined with impedances ordered 11-10-9-8-7-5-2. The definitions of the impedances of the lumped component network of Fig 6 were also retained thus impedances, 8, 7, 5 and 2 in the distributed version corresponded to impedances 18, 17, 16 and 15 respectively in the lumped version. Impedances 8 and 18 were initially displayed and impedance 8 adjusted for best coincidence with impedance 18. Impedance 7 was then similarly adjusted for best coincidence with impedance 7 followed by impedance 5 for best coincidence with impedance 16 and impedance 2 for best coincidence with impedance 15. All four impedances of the distributed network were then finely adjusted to correct the centre frequency and bandwidth. In adjusting the impedance definitions, line length was usually altered while the line width was only coarsely adjusted to keep the line lengths reasonable, normally less than a quarter wavelength. Line widths were chosen to avoid, as far as possible, producing large impedance steps between adjoining lines.

5.5 Stage 4 Derive final network design adding bias network and incorporating final adjustments.

The network of Fig 7 was finally modified to give the network of Fig 8. Impedance 5 was combined with impedance 2 to produce a single line of intermediate width and specified in two sections as impedances 5 and 3 to accommodate attachment of the quarter wave bias line using impedance 4, a combination. Impedance 7 was inserted between impedances 6 and 8 to give scope for tunability and reduce the step in line width.

It was found that a useful range of tunability could be obtained by adjusting the width of the line of impedance 8 in combination with adjustment of the relative lengths of impedances 7 and 6. The report of Fig 4 lists the parameters of the final network design. Transducer gain at the nominal tuning position was better than -0.2 dB over the frequency range, as illustrated in Plate 50. The final value of impedance 3 which also shows the quality of the match is shown in Plate 59.

6 DISCUSSION

The interactive graphics program described in this Report has at the time of writing been used extensively for a wide variety of applications in support of the experimental program on microwave transistor power amplifiers being carried out in Space Department. Such applications have included:-

(i) design of matching networks for Class C transistor power amplifiers to be tuned for good linearity where the load impedance presented to the transistor is critical;

(ii) design of matching networks for driver amplifiers designed using S-parameter techniques where the capability to immediately display the impedance presented to the transistor over a wide range of frequencies has permitted design for stable operation using stability circles, to be carried out quickly and conveniently;

(iii) design and investigation of tuning area of matching networks designed for useful range of tunability including designs with variable capacitors;

(iv) analysis of manufacturer's test-circuit designs;

(v) such simple applications such as converting data formats and displaying numerically measured data on a Smith chart display.

The program has been found to be useful, and relatively much easier to use, on many occasions when it would otherwise have been necessary to use a conventional microwave small-signal analysis program.

During the development of the program and during its subsequent use numerous ideas for enhancements to the program arose. These included capability to display impedance data with variable normalisation, capability to store and retrieve partly developed network designs, increase in the number of impedances specifiable, extensions of range and type of interconnection of components and many others. Such additions may be made if and when the need arises.

The original objective was, however, to design an interactive graphics program to facilitate the design of microwave matching networks and this objective has been achieved.

7 CONCLUSIONS

The computer program described in this paper facilitates the Smith chart design of microstrip microwave matching networks. The capabilities, facilities and operation of the program have been described. It has been found possible to use the program as a stand alone tool for the design of microstrip matching networks from specification of terminating impedances to determination of microstrip mechanical dimensions. Possible enhancements to the program have been identified. Extensive use has been made of the program, for design of microstrip networks in the experimental program on microwave transistor power amplifiers in progress in Space Department, RAE.

143

Appendix A

THE SMITH CHART AND AN EXAMPLE OF ITS USE

A Smith chart[1] (see Fig A1) consists of a set of normalised complex impedance co-ordinates on which any impedance can be plotted. The chart was devised to facilitate calculations of impedance in transmission lines. The magnitude and phase of the reflection coefficient at a point on the line may be plotted on the chart using polar co-ordinates, the peripheral circle corresponding to unity reflection coefficient. The chart shows the impedance at this point, normalised to the characteristic impedance of the line. The chart is also useful to the microwave engineer for plotting and manipulating impedance data even where no transmission line components are involved.

As an example we consider the problem of determining the impedance looking into a single microstrip transmission line terminated in a 50Ω load at a frequency of 1.55 GHz. Line parameters are:- length = 0.8 cm, width = 0.7 cm. Substrate parameters are:- thickness = 17 thou, relative permittivity = 2.55.

The electrical parameters of the line may be deduced using Wheeler's formulae[2]. Computed values are:- electrical lengths = 1.23 cm, characteristic impedance = 12.6 Ω.

The load impedance (Z_L) is normalised to the characteristic impedance of the line ($Z_L = 50/12.6 \triangleq 4.0$) and plotted on the Smith chart (point A).

The length (L) of the transmission line in wavelengths is computed.

$$\left(L = \frac{\text{electrical length} \times \text{frequency}}{\text{velocity of light}} = \frac{1.23\text{ cm} \times 1.55\text{ GHz}}{30\text{ cm/ns}} = 0.064\right) .$$

An arc AB is constructed centred at the origin of the peripheral circle and of length corresponding to the line length in "wavelengths towards generator" as indicated on the peripheral scale. The transformed normalised impedance is read from the impedance co-ordinates at point B namely 1.2 - j1.6. This value is denormalised by multiplying by the line impedance to give the required result of 15 - j20 Ω.

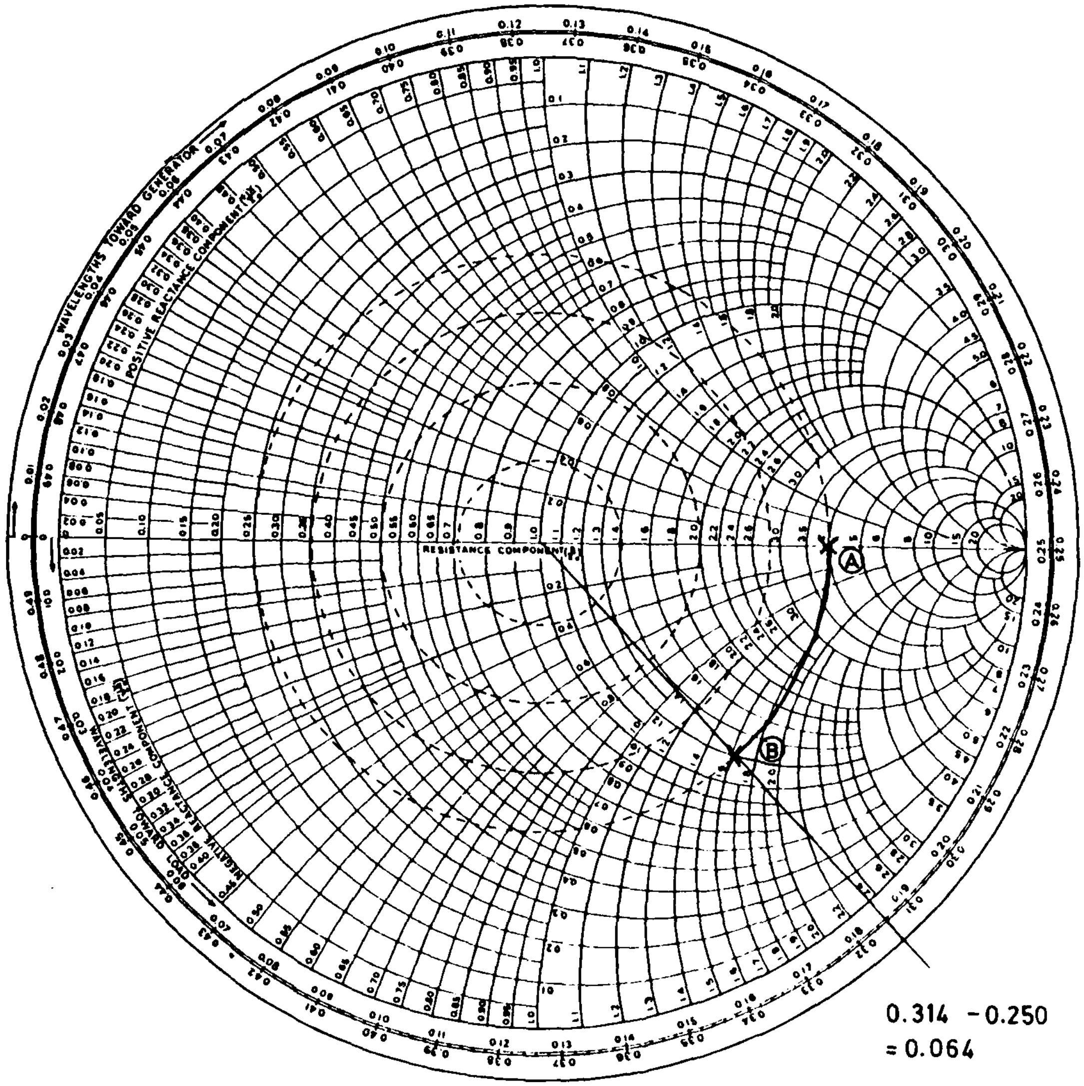

Fig A1   The Smith Chart and an example of its use

Appendix B

APPLICATION OF INTERACTIVE GRAPHICS

Use of an interactive graphics computer is central to the operation of the program. The computer is programmed to display alphanumeric and graphical data on a visual display unit. Separate elements of the display are designated as sensitive and the computer repeatedly scans the whole area of the display until it detects a light pen 'hit' which occurs when the user points the computer's light pen at a sensitive element. On receipt of a light pen hit the computer notes which sensitive element was selected and executes a sequence of instructions appropriate to the item defined in the element. In many cases the computer is programmed to offer its user a 'menu' of items from which the user may select an appropriate item. For example in defining a component type the user might be offered a menu consisting of a table of four words each separately sensitive, viz INDUCTOR, RESISTOR, CAPACITOR, LINE. On selection of one of these words using the light pen the computer then records the type of the component in question and performs any consequent actions.

Appendix C

COMPUTER CONFIGURATION REQUIRED AND PROCEDURES TO INITIATE AND TERMINATE A PROGRAM RUN

Computer configuration

Digital equipment corporation

PDP11/34	with 32K parity core memory, extended instruction set and hardware bootstrap.
RK05	Dual disc pack.
VT11-AB	Display processor with 17 inch CRT and light pen (Visual Display Unit - VDU).
LA36	Decwriter II teletype/console.
LP11	Line printer.
PT11	Paper tape reader and punch.
RT11	Operating system configured for single-job operation.

Initiating program run

(i) Switch on computer at main switch.

(ii) Load disc containing program files into upper disc unit and set RUN/LOAD switch to RUN.

(iii) Plug light pen directly into socket on VDU.

(iv) Type the following commands in reply to the underlined responses from the computer (<CR> ≡ carriage return)

RT11SJ V02C-02

. SET USR NOSWAP <CR>

. R SMITH <CR>

(v) Wait about 30 seconds for display to appear.

Terminating program run

(i) After selecting ENDRUN type <CR> on console.

(ii) Set RUN/LOAD switch on disc unit to LOAD, wait about 30 seconds then remove disc.

(iii) Switch off computer at mai switch.

Table 1

USE OF FUNCTION MENU ITEMS

	Function	Use
1	FREQ	Specification of frequencies for input, output, calculation and display of impedance values.
2	DEFINE	Specification, display and modification of impedance definitions of classes termination, transformation and combination.
3	INPUT	Input of impedance data tabulated vs frequency specifying impedances of class fixed data.
4	OUTPUT	Output of impedance data tabulated vs frequency.
5	REPORT	Output of table of current specifications of impedance definitions
6	DISPLAY	Selection of impedances to be plotted, whenever calculated, on polar display.
7	SCREEN	Selection of type of display, *ie* either a polar plot with impedance, admittance or reflection co-ordinates or a plot of transducer gain vs frequency or a digital display of impedance data vs frequency. Initially a polar plot with impedance co-ordinates.
8	IMP. FORMATS	Specify format for input, output and display of impedance data tabulated vs frequency. Initially specified as absolute impedance.
9	I/O DEVICES	Specify devices for input and output of impedance data and reports. Initially operator's console/teletype.
10	SUBSTRATE	Specification of microstrip substrate parameters, dielectric constant and dielectric thickness.
11	GRID	Used in program development only.
17	ENDRUN	Terminate run of program.

REFERENCES

No.	Author	Title, etc
1	P.H. Smith	Electronic applications of the Smith chart. McGraw Hill (1969)
2	R.P. Owens	Accurate analytical determination of quasi-static microstrip line parameters. Radio and Electronic Engineer, Vol 46, No.7, pp 360-364, July 1976

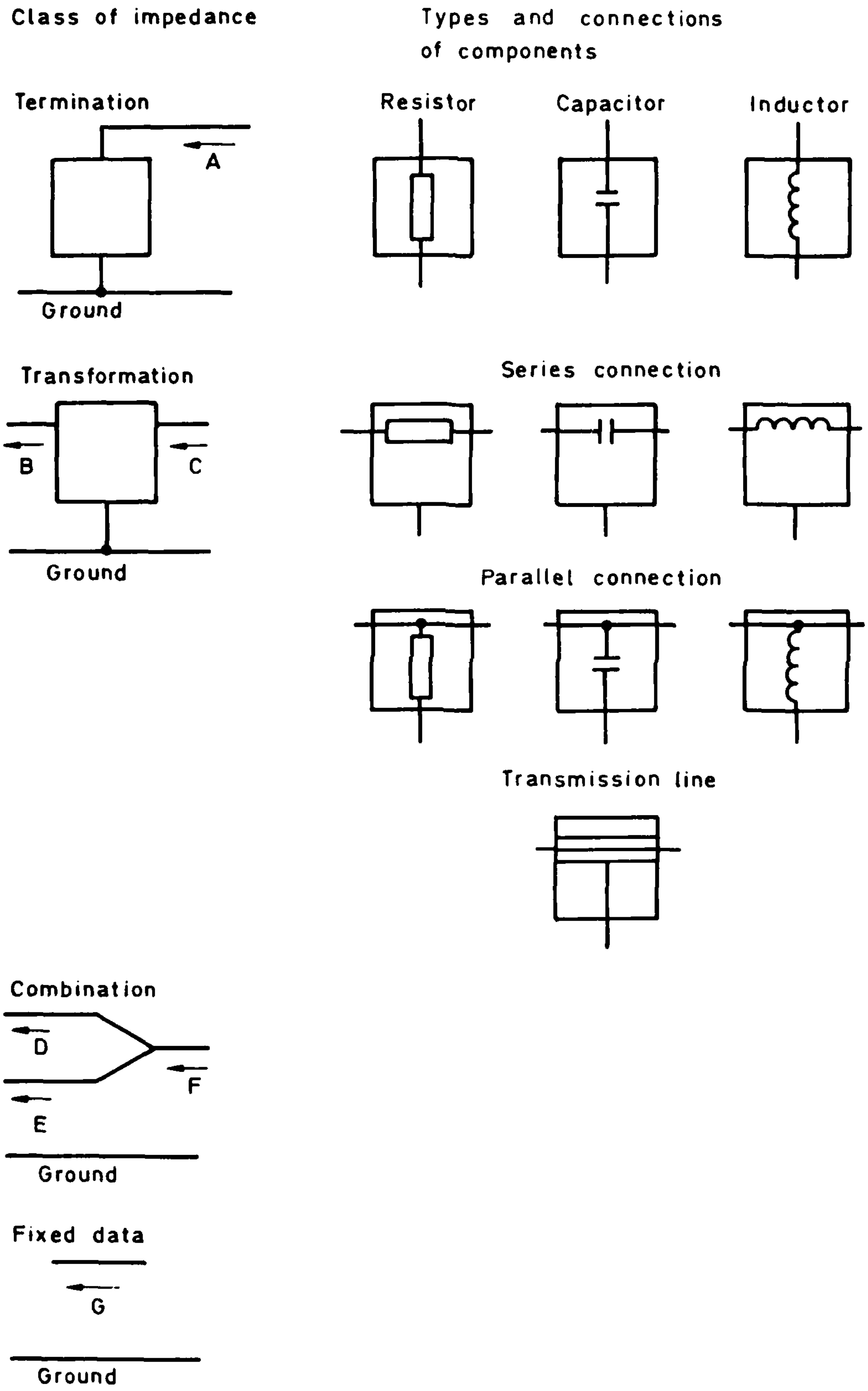

Fig 1 Classes of impedance definitions

TR 80143

Fig 2

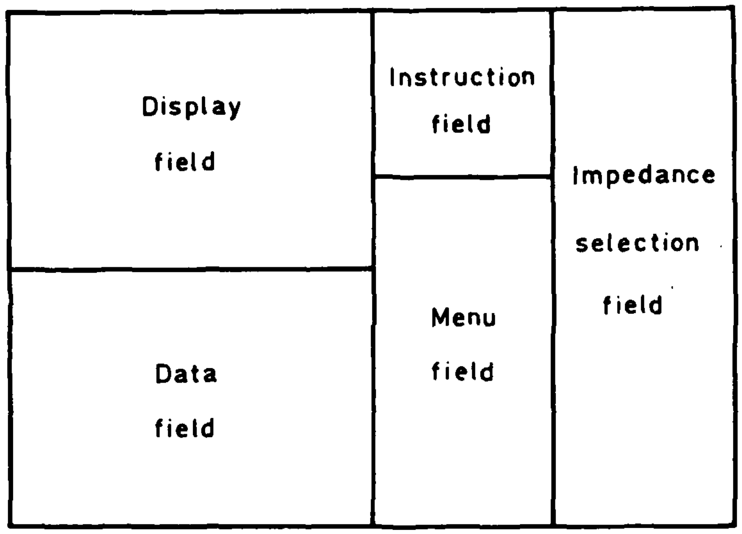

Fig 2 Fields of information on visual display unit with approximate relative locations

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IMP No.8

Impedance format: ZABS - ohms

Frequency GHz	Real	Imaginary
1.00	1.7574	-0.6129
1.05	1.8441	-0.0853
1.10	1.9663	0.4080
1.15	2.1276	0.8641
1.20	2.3310	1.2759
1.25	2.5774	1.6300
1.30	2.8615	1.9070
1.35	3.1661	2.0831
1.40	3.4557	2.1376
1.45	3.6760	2.0679
1.50	3.7670	1.9056
1.55	3.6917	1.7191
1.60	3.4595	1.5894
1.65	3.1225	1.5737
1.70	2.7457	1.6881
1.75	2.3801	1.9161
1.80	2.0542	2.2286
1.85	1.7781	2.5973
1.90	1.5509	3.0008
1.95	1.3672	3.4245
2.00	1.2201	3.8597

TR 80143

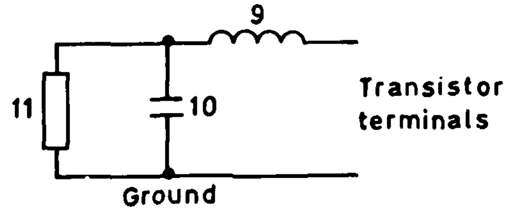
Fig 3 Typical example of print-out of tabulated impedance data

ELECTRONIC SMITH CHART NETWORK DESIGN REPORT

Microstrip dielectric constant: 2.55 Microstrip dielectric thickness: 0.0432 cm - 17.00 thou

Imp	Class	Of imp	And imp	Type	Connection	Value	Vel ratio	Elec length cm	Mech length cm	Mech width cm	Definition status
1	Termination			Resistor		50.00 ohm					Calculated
3	Transformation	4		Line		19.54 ohm	0.660	3.790	2.500	0.420	Calculated
4	Combination	5	12								Calculated
5	Transformation	6		Line		19.54 ohm	0.660	1.364	0.900	0.420	Calculated
6	Transformation	7		Line		9.13 ohm	0.644	0.466	0.300	1.000	Calculated
7	Transformation	8		Line		4.37 ohm	0.635	2.675	1.700	2.200	Calculated
8	Transformation	9		Line		12.58 ohm	0.650	1.231	0.800	0.700	Calculated
9	Transformation	10		Inductor	Series	0.60 nh					Calculated
10	Transformation	11		Capacitor	Parallel	11.50 pf					Calculated
11	Termination			Resistor		20.00 ohm					Calculated
12	Transformation	13		Line		70.00 ohm	0.701	4.830	3.387	0.070	Calculated
13	Termination			Capacitor		100.00 pf					Calculated
14	Fixed data										Defined
15	Transformation	1		Capacitor	Parallel	5.20 pf					Calculated
16	Transformation	15		Inductor	Series	2.30 nh					Calculated
17	Transformation	16		Capacitor	Parallel	20.00 pf					Calculated
18	Transformation	17		Inductor	Series	0.70 nh					Calculated

Fig 4 Typical example of print-out of a report



N B Numbers refer to impedances specifying components indicated

Fig 5 Simple equivalent circuit to fit manufacturer's output impedance data

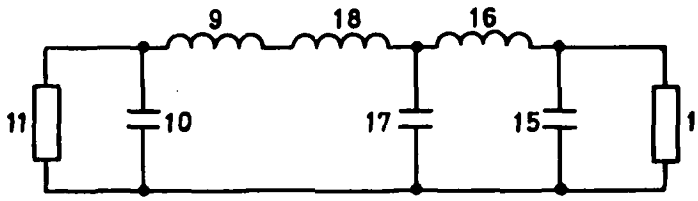


Fig 6 Lumped component matching network

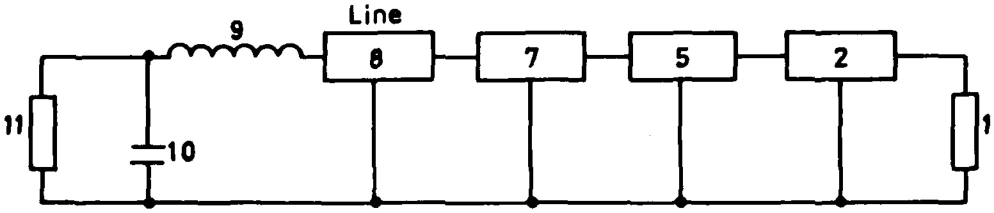


Fig 7 Initial distributed component matching network

Fig 8

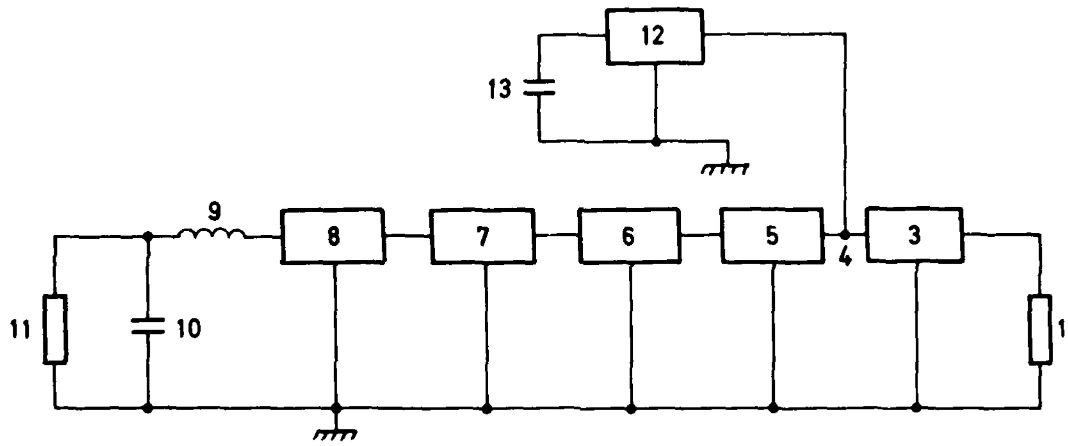


Fig 8 Final distributed component matching network

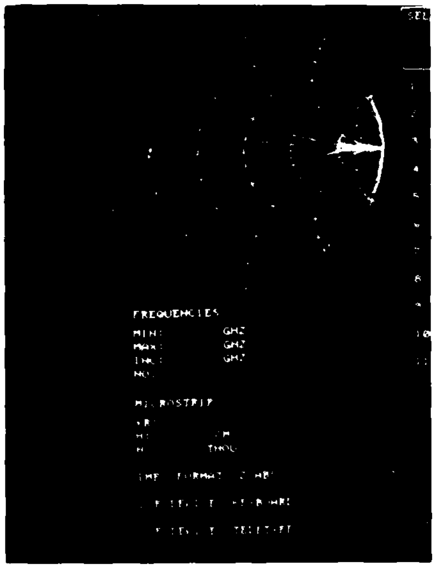


Plate 1 Contents of left of screen of VDU immediately after initiating a program run

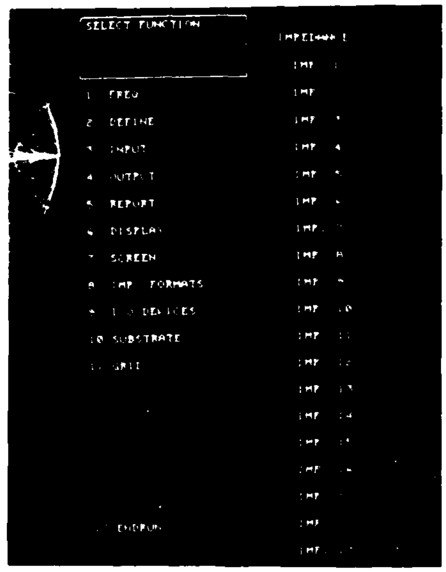


Plate 2 Contents of right of screen of VDU immediately after initiating a program run

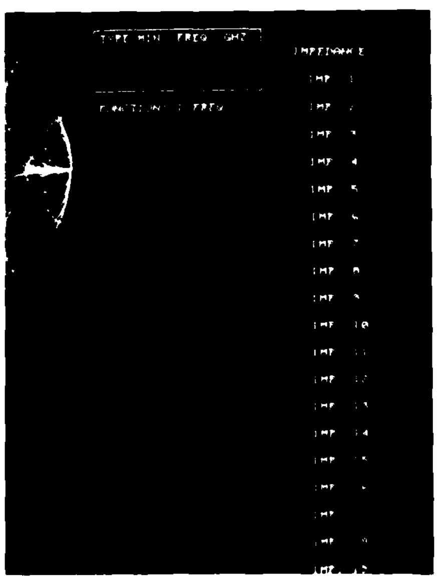


Plate 3 Function 1 FREQ. Message to type minimum frequency on console

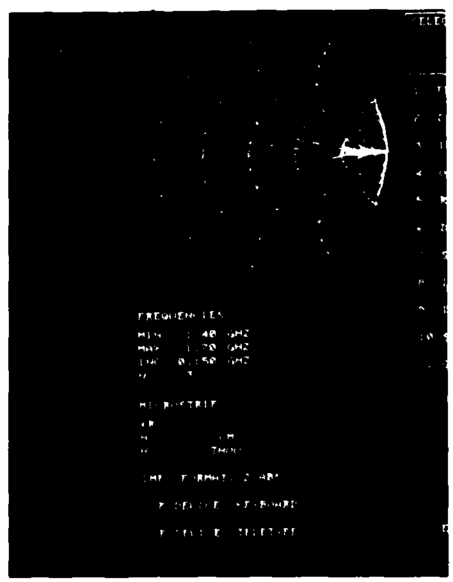


Plate 4 Display of frequencies in data field

Plates 5-8

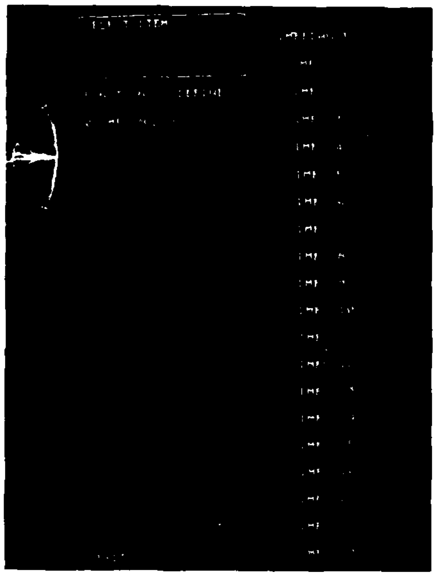


Plate 5 Function 2 DEFINE. Impedance definition menu immediately after selection of function

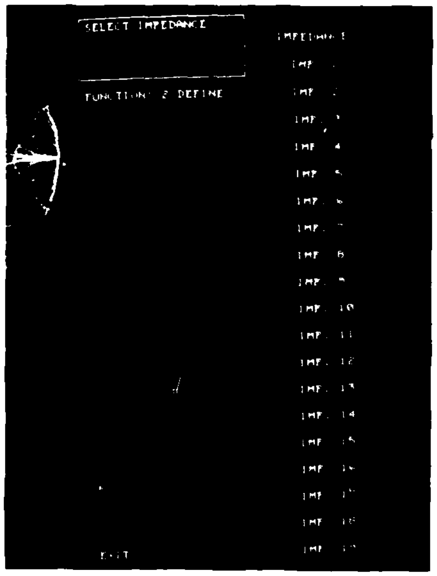


Plate 6 Function 2 DEFINE. Message to select impedance number

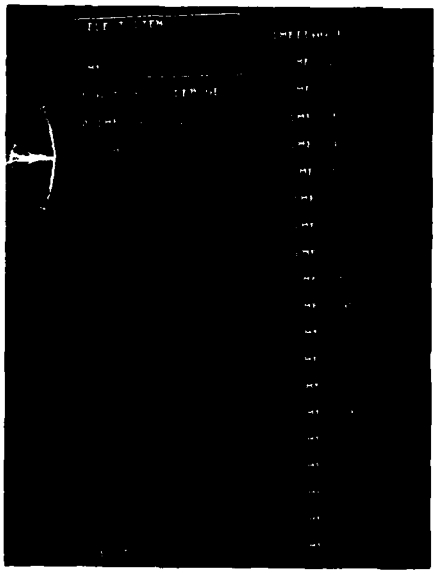


Plate 7 Function 2 DEFINE. Impedance definition menu after selection of impedance number

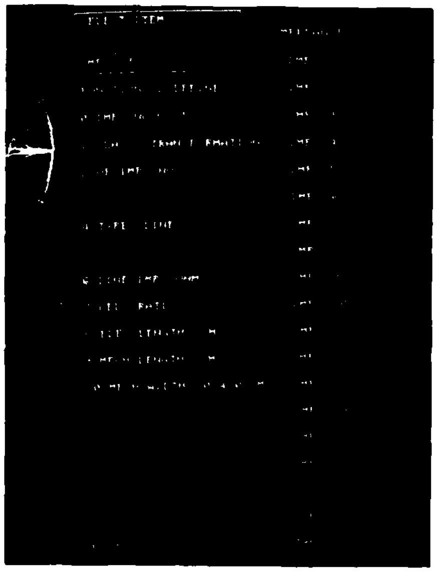


Plate 8 Function 2 DEFINE. Impedance definition menu displaying parameters of partly defined impedance

TR 80143

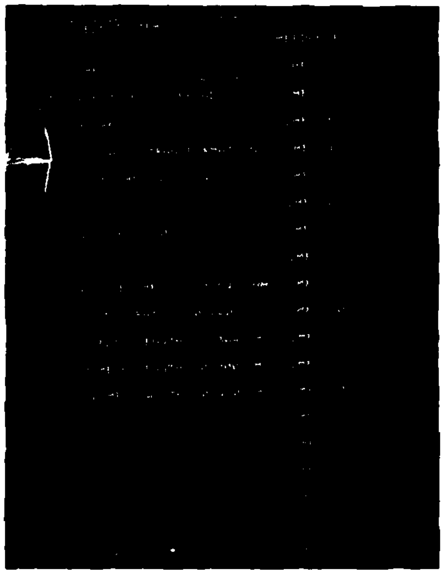


Plate 9 *Function 2* DEFINE. Impedance definition menu displaying parameters of fully defined impedance

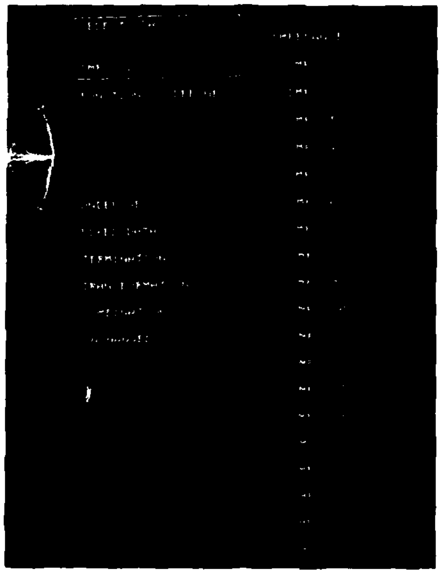


Plate 10 Function 2 DEFINE. The class menu

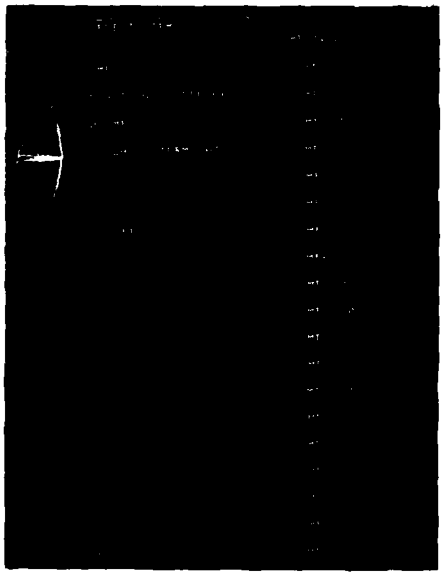


Plate 11 Function 2 DEFINE. Impedance definition menu after selection of class termination

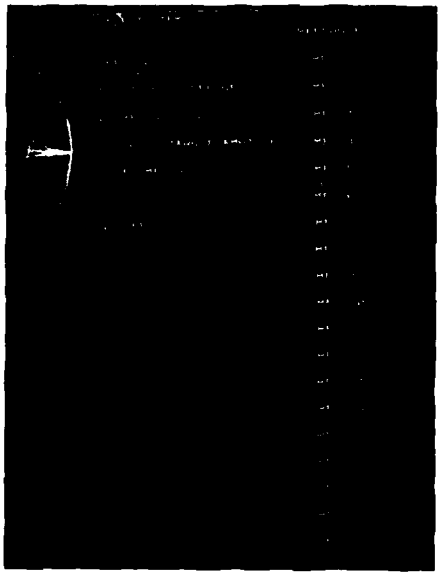


Plate 12 Function 2 DEFINE. Impedance definition menu after selection of class transformation

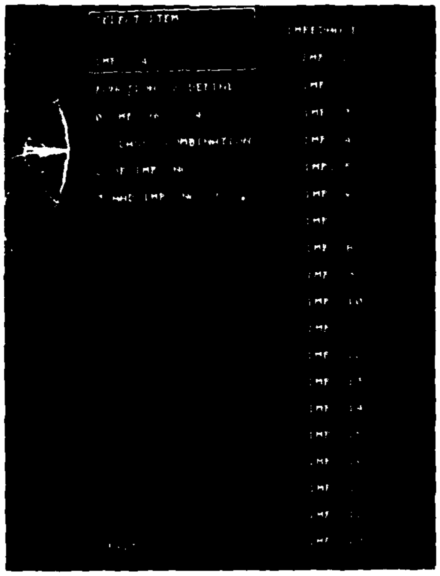


Plate 13 Function 2 DEFINE. Impedance definition menu after selection of class combination

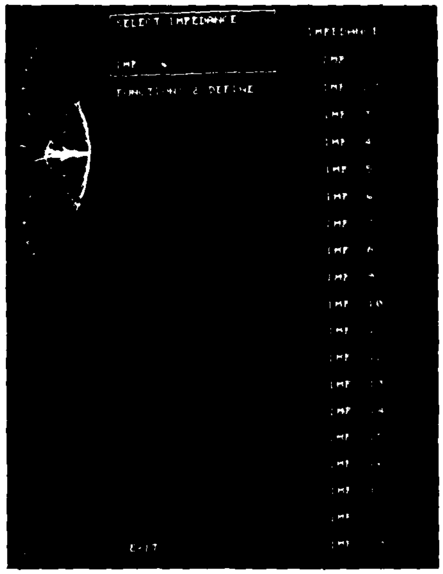


Plate 14 Function 2 DEFINE. Message to select impedance

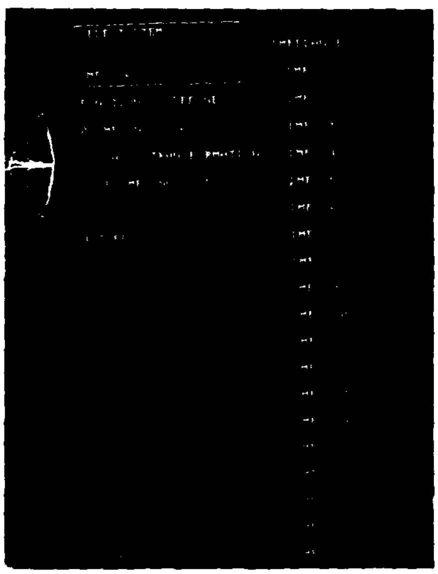


Plate 15 Function 2 DEFINE. Impedance definition menu after selection of impedance transformed

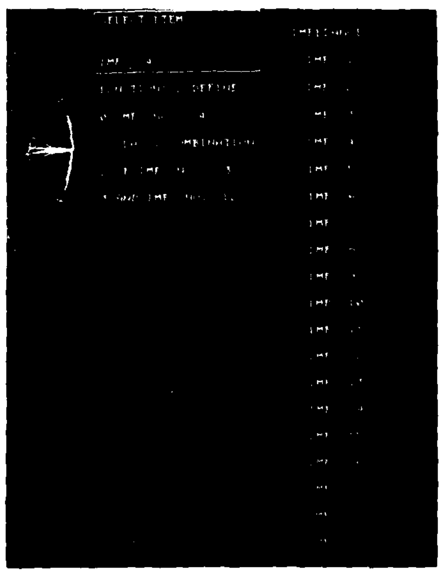


Plate 16 Function 2 DEFINE. Impedance definition menu after selection of impedances combined

TR 80143

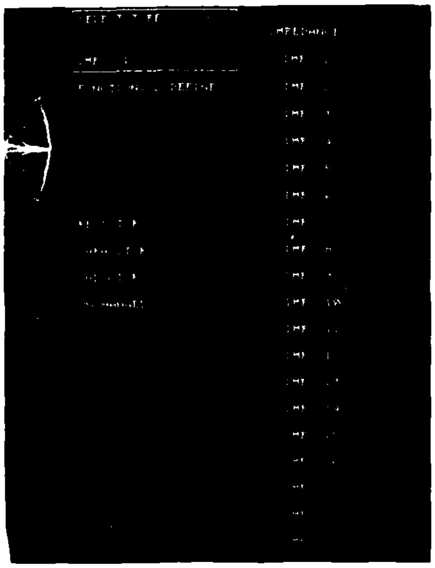


Plate 17 Function 2 DEFINE. Type menu for class termination

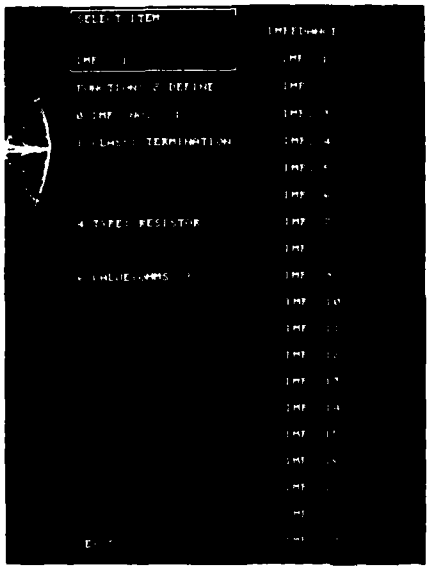


Plate 18 Function 2 DEFINE. Impedance definition for termination after selection of type resistor

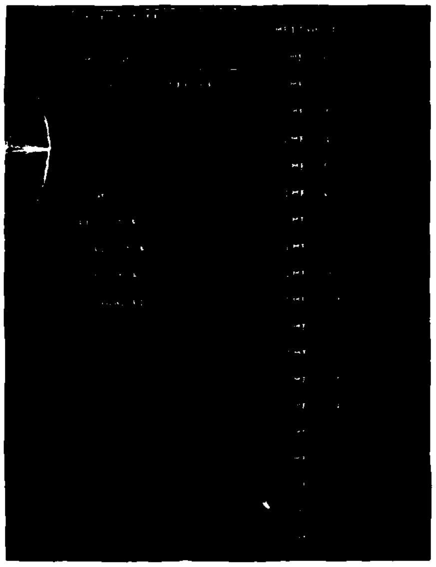


Plate 19 Function 2 DEFINE. Type menu for class transformation

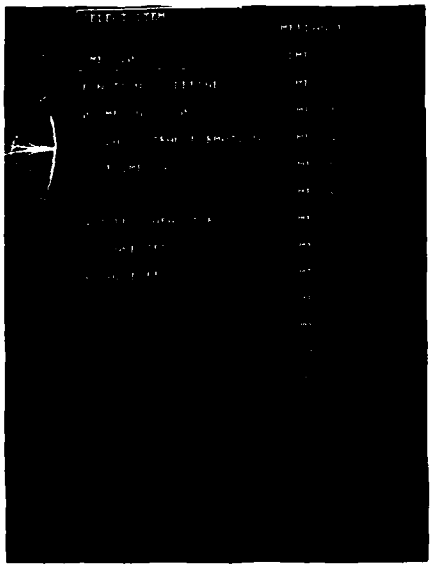


Plate 20 Function 2 DEFINE. Impedance definition menu for transformation after selection of type capacitor

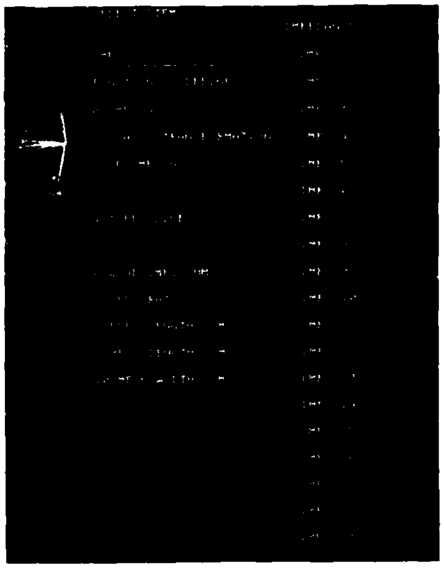


Plate 21 *Function 2 DEFINE. Impedance* definition menu for transformation after selection of type line

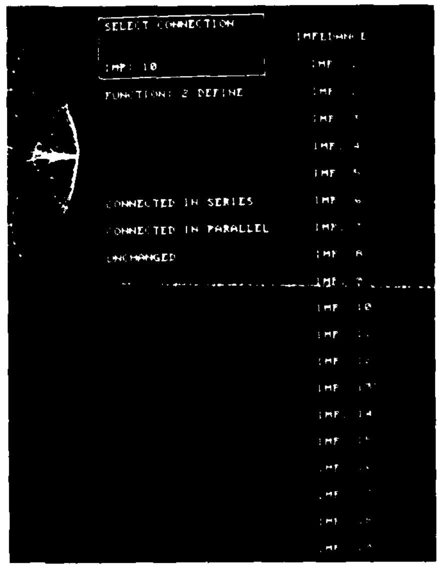


Plate 22 Function 2 DEFINE. The connection menu

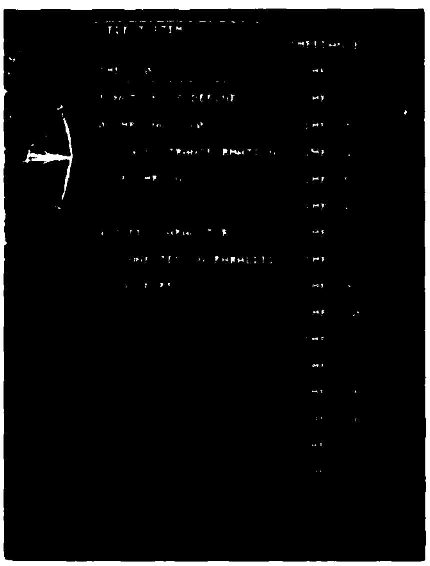


Plate 23 Function 2 DEFINE. Impedance definition menu after selection of connection

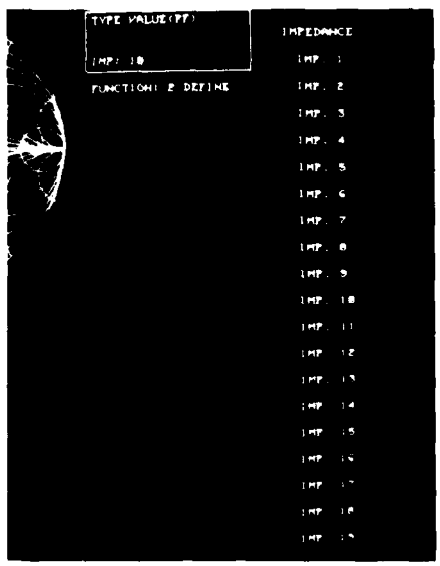


Plate 24 Function 2 DEFINE. Message to type capacitor value

TR 80143

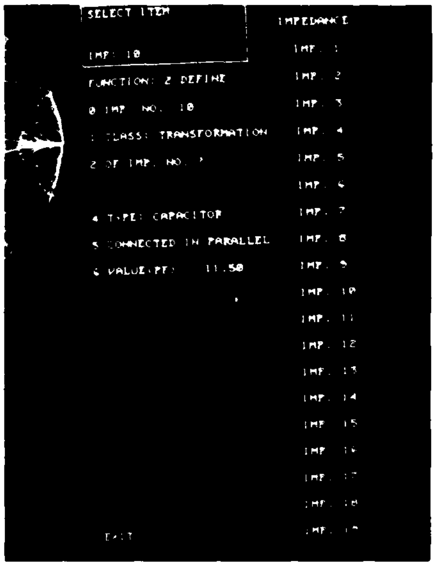


Plate 25 Function 2 DEFINE. Impedance definition menu after entering capacitor value

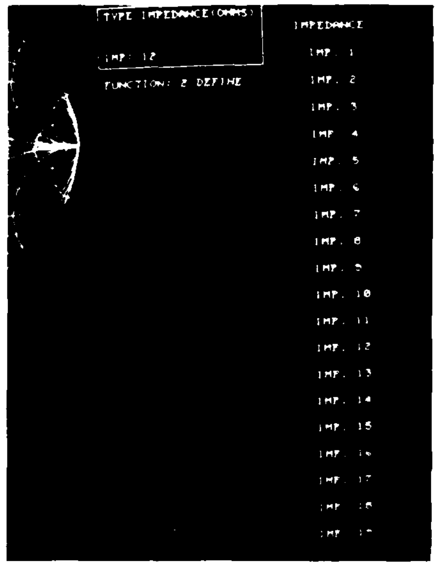


Plate 26 Function 2 DEFINE. Message to type line impedance

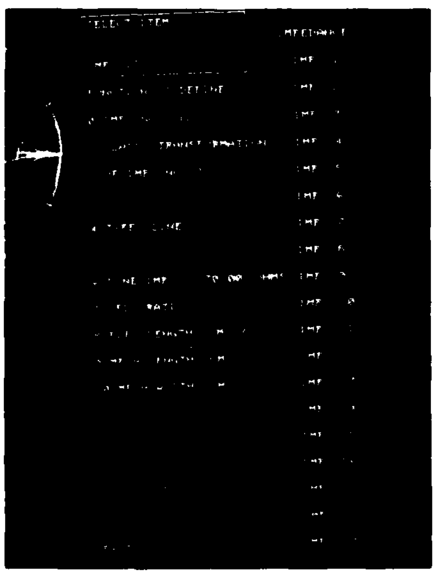


Plate 27 Function 2 DEFINE. Impedance definition menu after entering line impedance

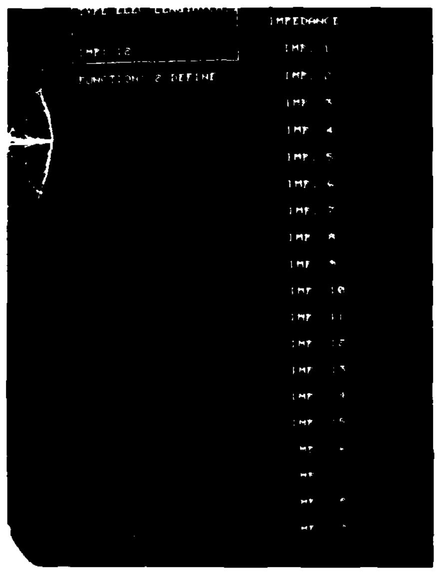


Plate 28 Function 2 DEFINE. Message to type line electrical length

TR 80143

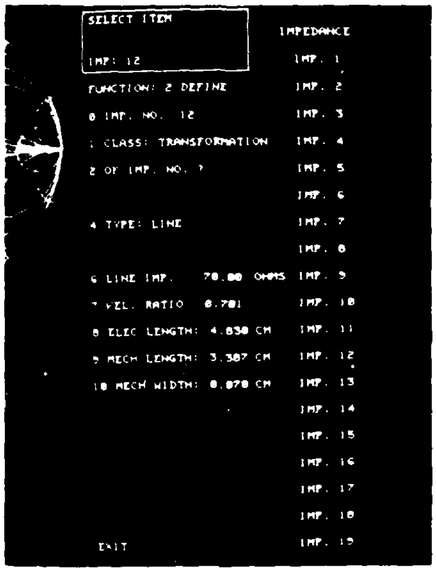


Plate 29 Function 2 DEFINE. Impedance definition menu after entering line electrical length

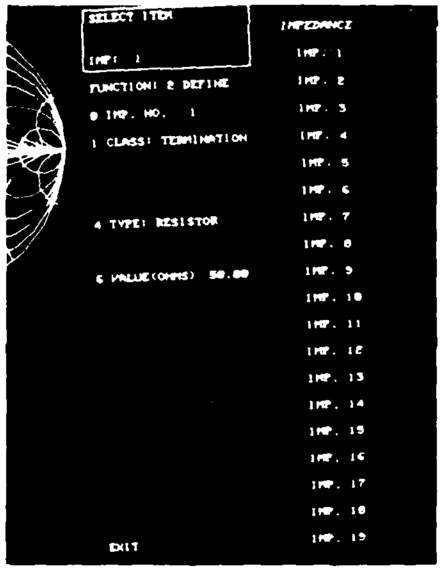


Plate 30 Function 2 DEFINE. Impedance definition menu for fully defined impedance of class termination

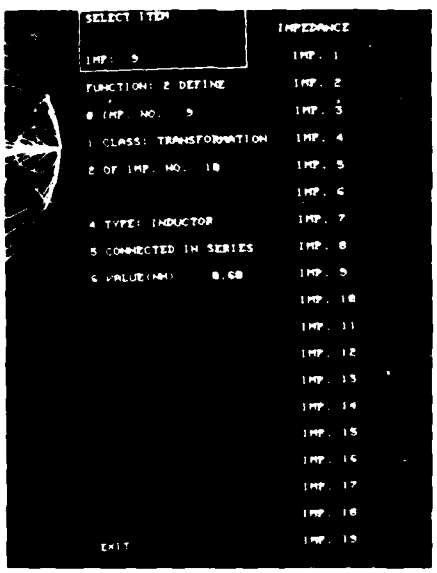


Plate 31 Function 2 DEFINE. Impedance definition menu for fully defined impedance of class transformation, type inductor

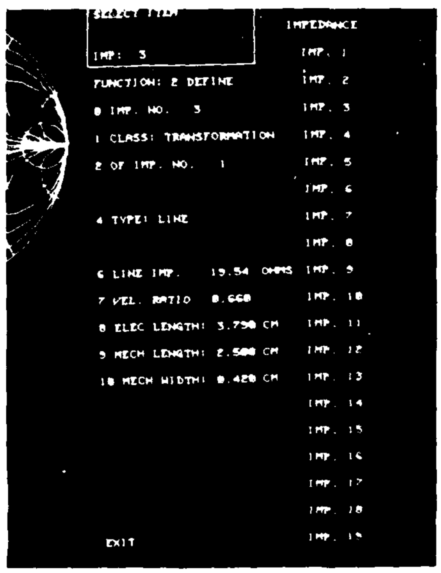


Plate 32 Function 2 DEFINE. Impedance definition menu for fully defined impedance of class transformation, type line

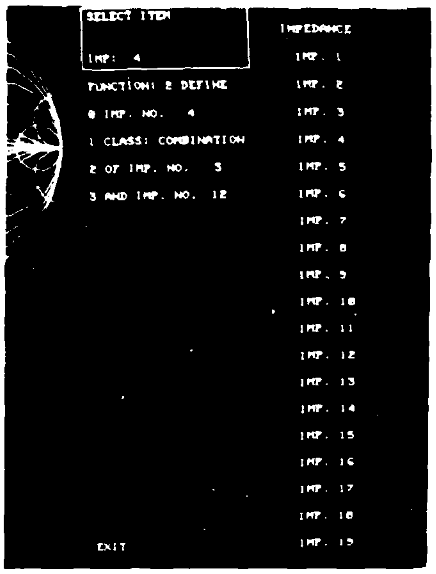


Plate 33 Function 2 DEFINE. Impedance definition menu for fully defined impedance of class combination

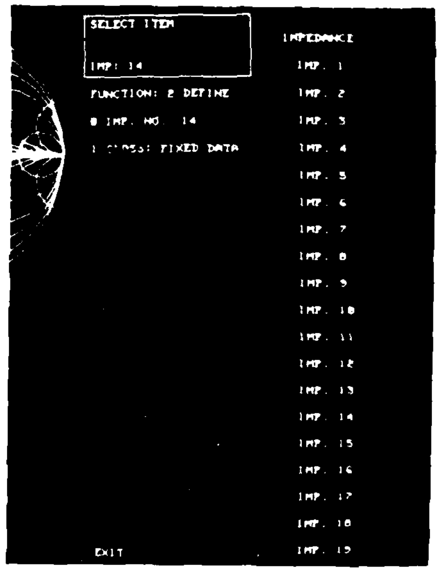


Plate 34 Function 2 DEFINE. Impedance definition menu for fully defined impedance of class fixed data

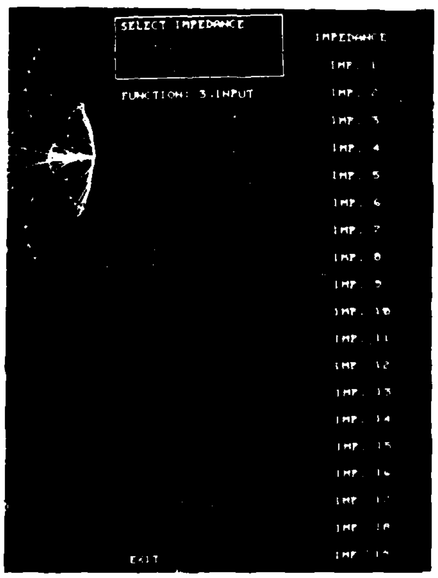


Plate 35 Function 3 INPUT. Message to select impedance number

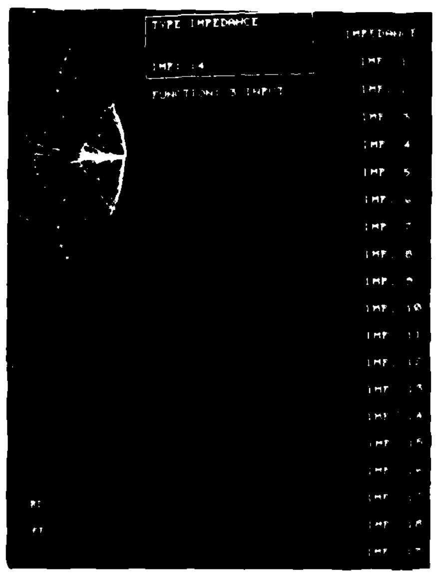


Plate 36 Function 3 INPUT. Message to type impedance values

TR 80143

Plates 37-40

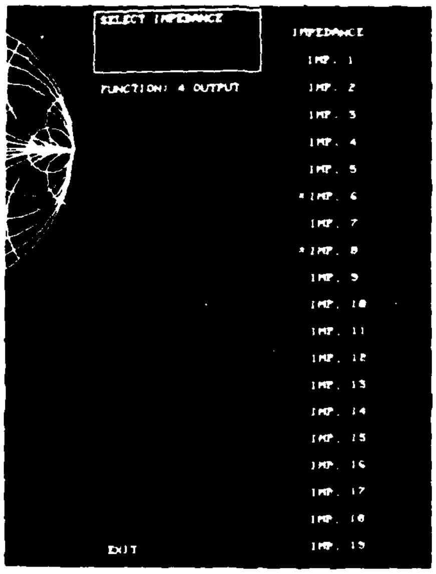


Plate 37 Function 4 OUTPUT. Message to select impedance

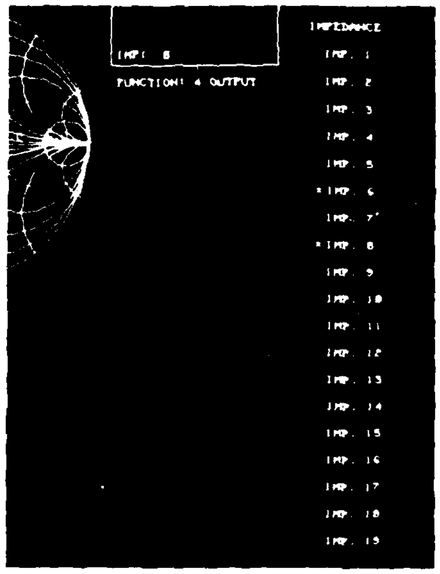


Plate 38 Function 4 OUTPUT. Message specifying number of impedance being output

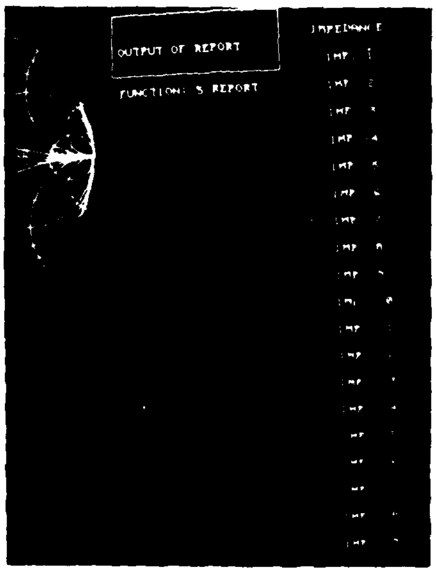


Plate 39 Function 5 REPORT. Message *indicating output of report*

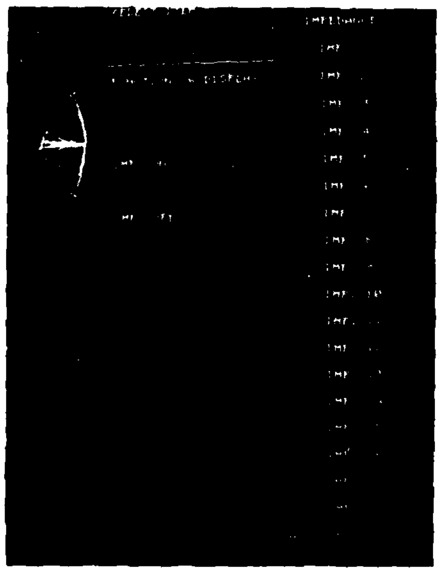


Plate 40 Function 6 DISPLAY. Display menu on selection of function

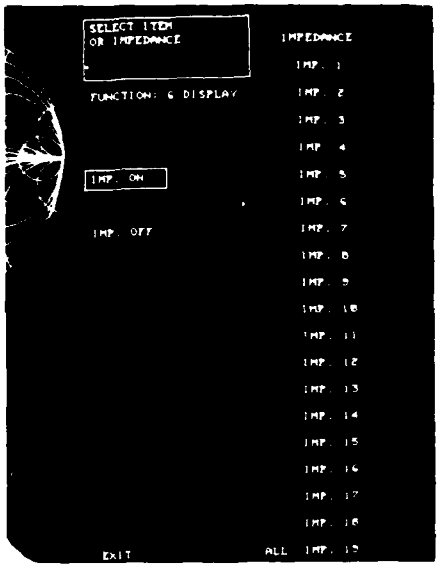


Plate 41 Function 6 DISPLAY. Display menu after selection of option to specify impedances to be displayed

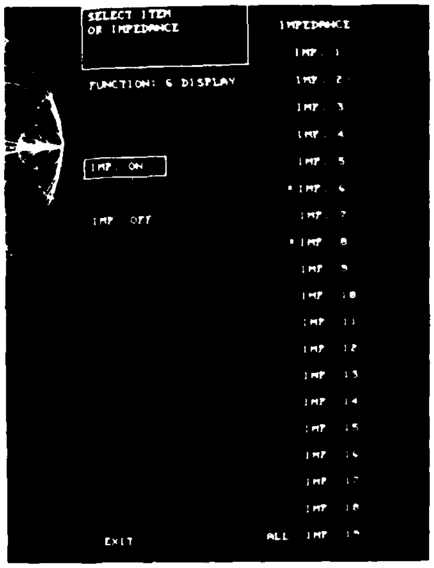


Plate 42 Function 6 DISPLAY. Impedances selected for display marked by asterisks

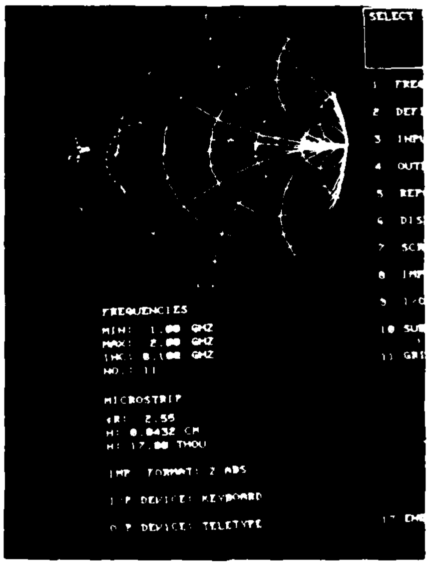


Plate 43 Impedances displayed on impedance chart in display field

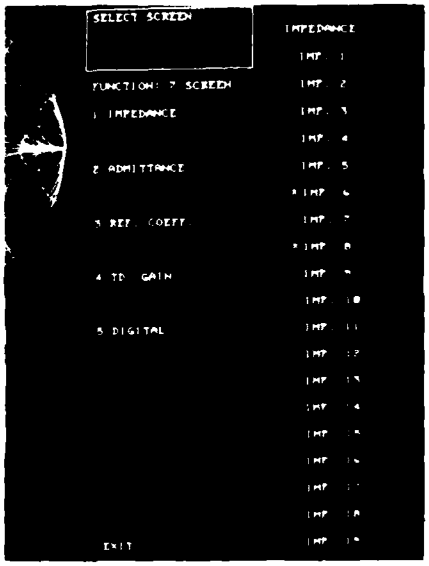


Plate 44 Function 7 SCREEN. The basic screen menu

Plates 45-48

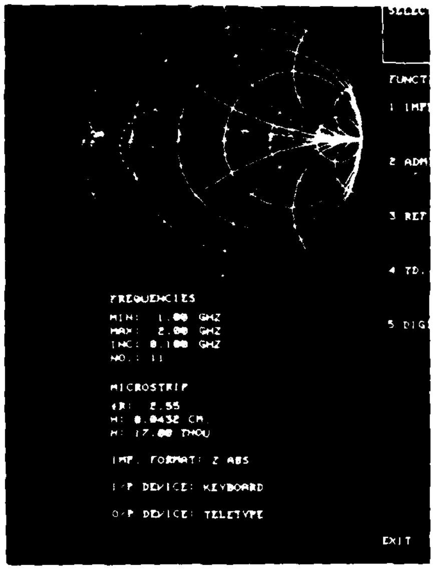


Plate 45 Impedance chart in display field

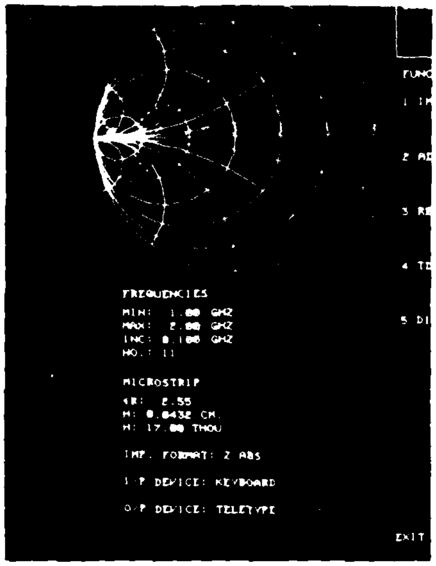


Plate 46 Admittance chart in display field

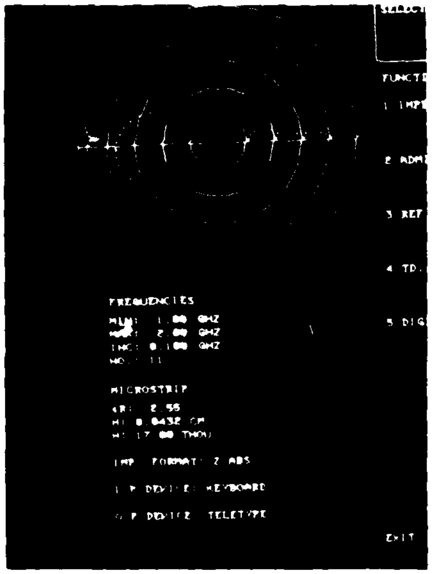


Plate 47 Reflection coefficient chart in display field

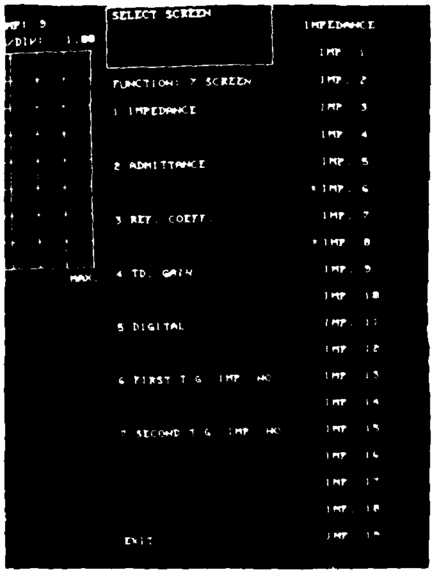


Plate 48 Function 7 SCREEN. Screen menu after selection of transducer gain display

TR 80143

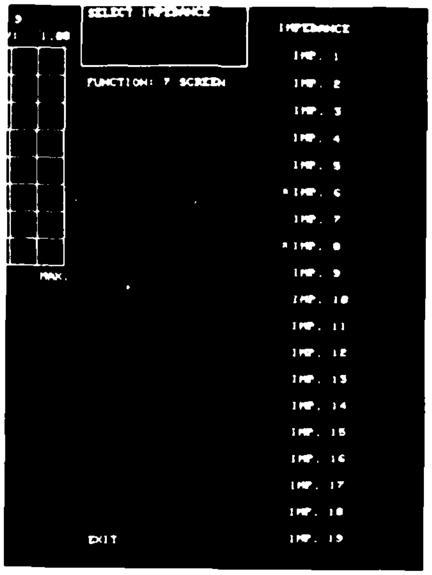


Plate 49 Function 7 SCREEN. Message to select impedance

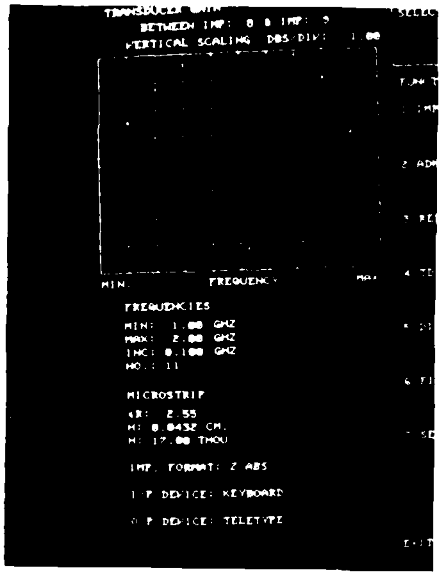


Plate 50 Transducer gain plot in display field

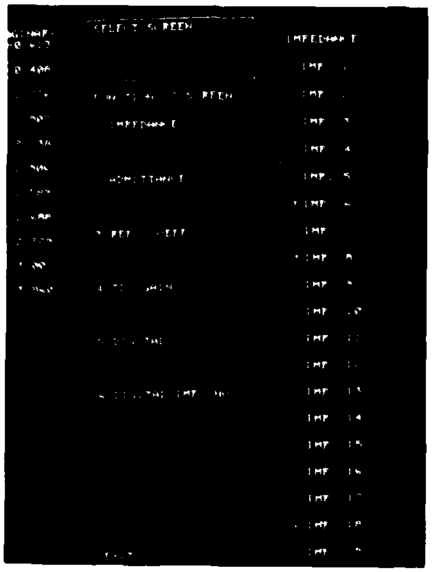


Plate 51 Function 7 SCREEN. Screen menu after selection of digital display of tabulated impedance data

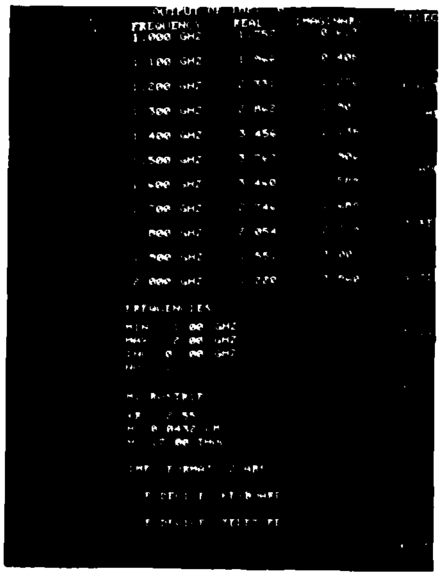


Plate 52 Digital display of tabulated impedance data in data field

TR 80143

Plates 53-56

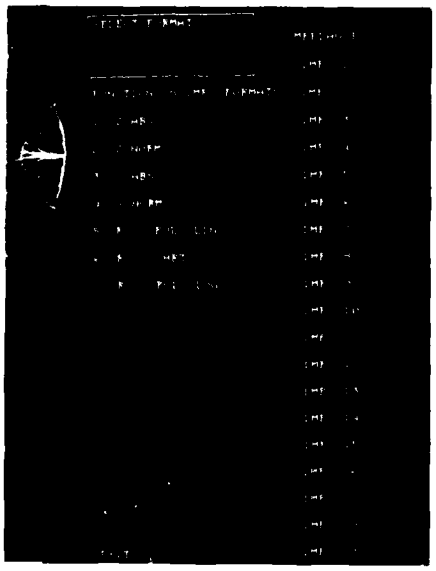


Plate 53 Function 8 IMP FORMATS. Impedance formats menu

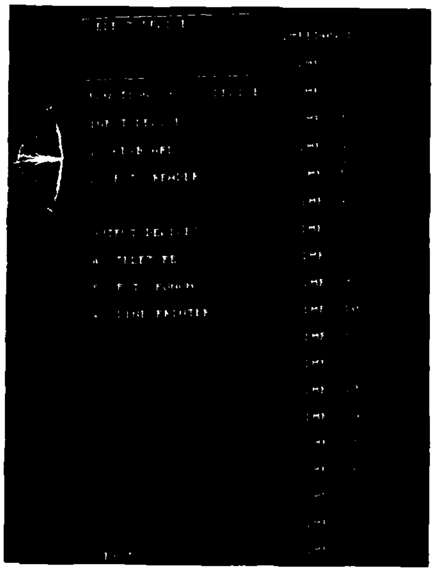


Plate 54 Function 9 I/0 DEVICES. I/0 devices menu

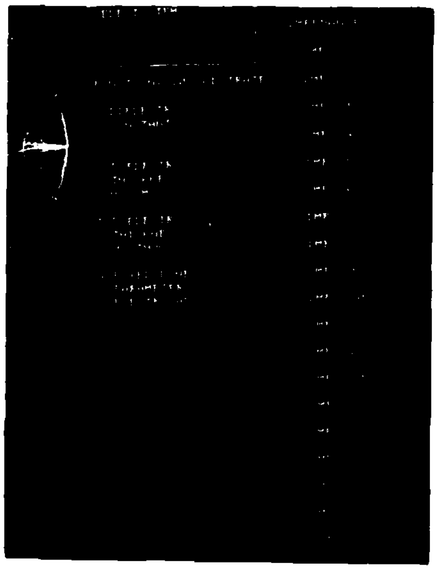


Plate 55 Function 10 SUBSTRATE. Substrate menu

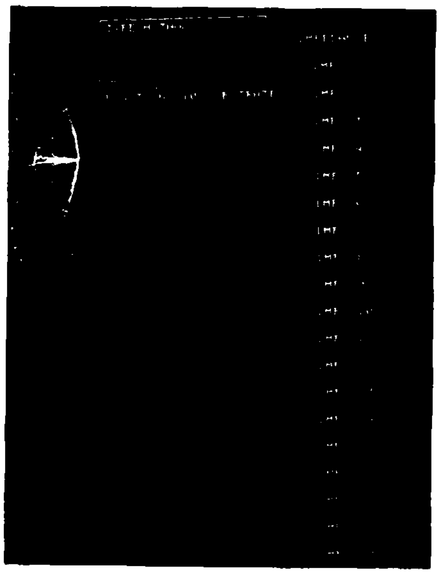


Plate 56 Function 10 SUBSTRATE. Message to type dielectric thickness

TR 80143

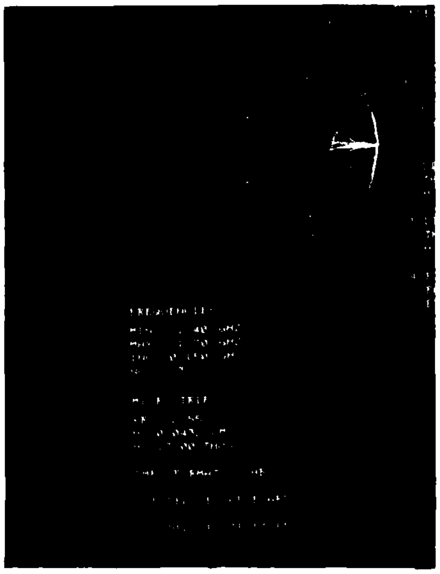


Plate 57 Substrate parameters displayed in data field

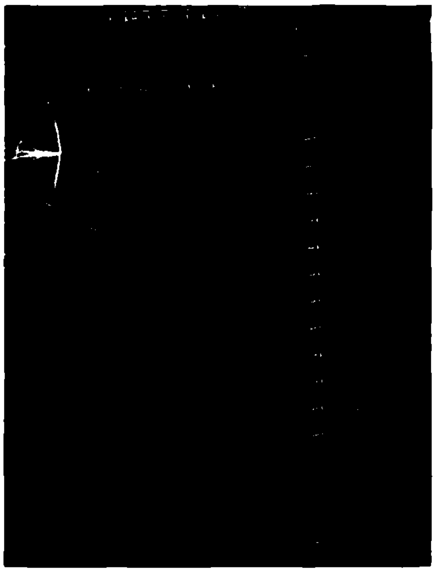


Plate 58 Endrun menu

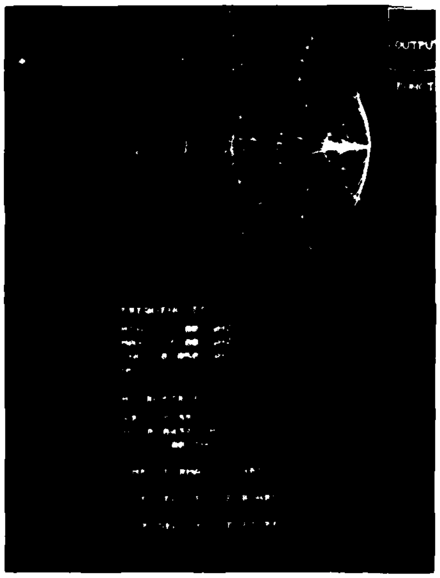


Plate 59 Example of program usage. Plot of final value of impedance 3

TR 80143

REPORT DOCUMENTATION PAGE

Overall security classification of this page

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Microwave matching networks. Computer aided design. Smith chart.

17. Abstract

An experimental programme in the field of microwave transistor power amplifiers required study of the design of microstrip matching networks. The normal design process involving manual use of the Smith chart was potentially tedious and an alternative approach using interactive graphics was conceived.

A computer program was developed which plots impedance data and transformations on a Smith chart display, performing calculations analytically at several frequencies simultaneously. The program was brought to the stage where it can be used as a tool for design of microwave matching networks from specification of terminating impedances to determination of microstrip mechanical dimensions.

This Report describes the capabilities, facilities and operation of the program and gives examples of its use.

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