A SURVEY OF TRANSIENT CIRCUIT ANALYSIS PROGRAMS

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SUMMARY

The basic features of ten automated nonlinear transient circuit analysis programs are listed and the values of each of the features discussed from a potential user's viewpoint. The features compared for each program include the types of analysis performed, the types of elements handled, built-in models, the computers on which the programs are operational, documentation, program availability, user convenience, special features, and mathematical solution formulation.

INTRODUCTION

This paper compares the major features of several digital computer programs for nonlinear transient circuit analysis. The features of the programs are presented from the user's viewpoint and include discussions of the capabilities, limitations, and availability of each program.

There are in existence a number of transient circuit analysis computer programs. Most of these programs can be applied to Transient Radiation Effects on Electronics (TREE) problems. Since there is no current, comparative documentation on the capability, limitations, and availability of these programs, the Defense Atomic Support Agency (DASA) requested the Air Force Weapons Laboratory (AFWL) review the programs in existence.

APPROACH

This survey complements earlier surveys by Wirth[1] in 1964 which briefly compared PREDICT, NET-1, CIRCUS, MISSAP, and ECAP; by Dickhaut[2] in 1965 which compared PREDICT, NET-1, and CIRCUS; and by Pritchard[3] in 1965 which compared TRAC with PREDICT, NET-1, and CIRCUS. Programs reviewed previously have been modified, new programs have been developed, and several other industry- and university-developed programs have become of general interest through recent listings in technical journals.[4,5]

Information for this survey was primarily gathered from a questionnaire which was sent to sixteen different government laboratories, corporations, and universities which were known to have developed sophisticated circuit analysis programs.

The questionnaire was formulated to gather information in a concise form about all aspects of the program of interest to a potential user of the program. The questionnaire consisted of seven sections:

I. Capability of the Program: This section was concerned with the types of analysis performed (ac, dc, transient), kinds and number of elements handled, and built-in model capability.

II. Computer Compatibility: This section asked on which computers the program was operational, in what language the program was written, the size memory required, and questions concerning the status and documentation of the program.

III. Radiation Effects: This section was concerned with special features of a program for handling radiation effects problems.

IV. Use, Convenience, and Flexibility Factors: This section was concerned with input and output formats, restrictions on circuit topology specification, and general features such as rerun options.

V. Mathematical Details: This section was concerned with the types of solution formulation and integration routines used in the program.

VI. Availability: This section was concerned with the availability of the program and the procedure for obtaining the program.

VII. Additional Information: This section asked for a user's manual and a sample problem run for each program.

RESULTS

From the information obtained from the questionnaires,* ten programs are categorized as automated nonlinear transient circuit analysis programs. These programs are automated in that they formulate the circuit equations from topological and component data and perform the solution calculations to provide a transient or time history analysis of the circuit. The programs are also powerful enough to include nonlinear elements (capacitors, resistors, inductors, or voltage or current sources) used to model active electronic devices.

The names of the ten programs included in this survey are given in Table I along with the names of the originating organization and

*See Acknowledgments section of this paper and references 6 through 13.

government sponsor. A comparison of the major features and capabilities of the programs is shown in Tables II through IV.

DISCUSSION

The program features are compared in Tables II through IV. The following is a user-oriented discussion of these features. As seen in Table II all programs except PREDICT provide a steady-state dc solution. Each program uses an iterative technique, usually a modified Newton-Raphson to obtain the dc solution. This provides an efficient means of obtaining the initial conditions required for a subsequent transient analysis. Two of the programs, the General Network Analysis program and the MISSAP I also provide nominal ac solutions and frequency or Fourier analysis.

One of the first concerns of a transient analysis is the initial conditions of the circuit. For all programs, except PREDICT, the initial conditions for the transient analysis can be automatically calculated by the dc solution portion of the program. For PREDICT the dc solution can be obtained by a separate "power supply turn-on" transient run. All of the programs except CIRCUS and the General Network Analysis program provide for entering user-supplied initial conditions. This feature is particularly useful for circuits which the dc iterative solution fails to converge and the circuit initial condition must be approximated from measurements or separate transient runs.

An important feature of each program is the type of elements or components which may be entered. All of the programs readily accept constant valued resistors, capacitors, inductors, and constant and time-varying voltage sources. All except NET-1 also include constant and time-varying current sources. All except TAG and TRAC provide for entering inductive coupling through mutual inductance. These elements along with built-in models for active devices provide an adequate tool for describing most standard discret component transistorized circuits. For applications such as modeling new semiconductor devices, more flexibility is required. For these applications it is important to be able to define functionally-variable elements and enter these into the program. Several of the programs provide for this by allowing variable elements defined by a table (F_2), equation (F_3), or subroutine (F_4), as shown in Table II.

An indication of the maximum size of the circuit which may be entered is shown in the next two colums of Table II. This varies from 30 nodes for the General Network Analysis program and 60 elements for the Oklahoma State Analysis program, to 300 nodes for the SCEPTRE program and 600 elements for the NET-1R program. For some of the programs, additional limits are placed on the number of each type of element, while others limit only the total number of elements or nodes.

The CIRCUS, General Network Analysis, NET-1R, and TRAC programs include fixed built-in models for active devices. These models are considered fixed models in that they cannot readily be changed by a user. The built-in transistor and diode models of these programs are nonlinear transient Ebers-Moll models and are essentially the same for each of these programs.

MISSAP III built-in models are defined in subroutines which can be changed by a user. Other programs, PREDICT, SCEPTRE, STRAP, and TAG do not include built-in models. For these programs active devices are entered by user-defined equivalent circuit models either as part of an overall circuit, or in the case of SCEPTRE, from a user-defined model library tape.

The last column on Table II indicates whether models or model parameter data may be stored and called from a model library tape. The SCEPTRE-stored model feature is unique in that the stored model is user defined and may have up to 25 external terminals.

Table III indicates the computers on which each of the programs are operational, the language it is written in, the extent of the documentation, and the availability of each program.

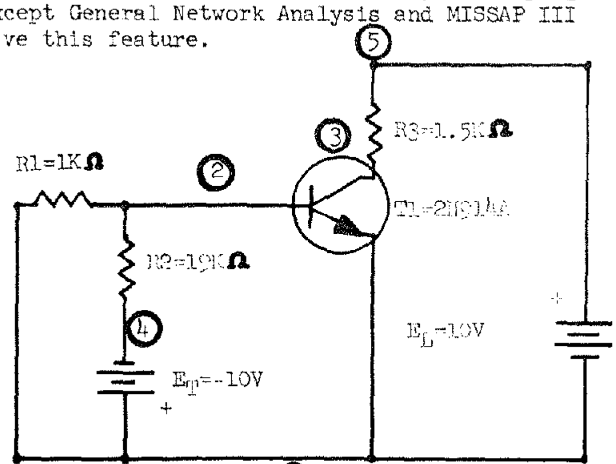
If a program is capable of solving a particular problem and is operational on an available computer, whether or not the program is used may be determined by how difficult the program is to use. All of the programs have been designed to be used by engineers without requiring the services of a programmer. All of the programs use an engineer-oriented input language. In general, the less restrictive, easier to use programs provide for a free-field input as indicated in Table IV.

An example free-field SCEPTRE input is shown in Figure 1. The input for this circuit would look similar for CIRCUS, with commas replacing the dash and equal signs, and for NET-1 with blanks replacing the commas, dashes, and equal signs. The input for PREDICT would be similar except the transistor would have to be specified as equivalent circuit elements and defining equations. STRAP would also appear similar except variable element values would be entered in a subroutine.

An example of the free-field subroutine format of MISSAP III is shown in Figure 2.

TAG also uses a free-field subroutine format which is flexible, but less convenient to use. TRAC uses a fixed field format for element specification plus the use of auxiliary FORTRAN equations for defining nonstandard elements or outputs.

An economically important feature is a save and continue feature that permits the user to save the results of a transient run in a form that permits the run to be continued from that point. This is particularly valuable for analyzing large circuits which may require several minutes of computer time for a few microseconds of problem time and where the circuit recovery time cannot be estimated accurately. All programs except General Network Analysis and MISSAP III have this feature.



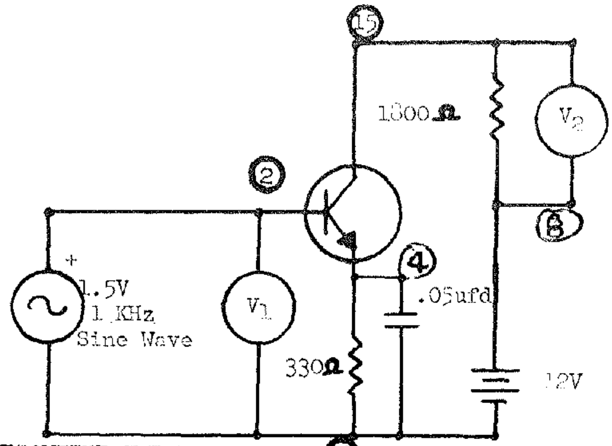
CIRCUIT DESCRIPTION
ELEMENTS
R1, 1 - 2 = 1
R2, 2 - 4 = 19
R3, 5 - 3 = 1.5
E1, 1 - 5 = 10
ET, 4 - 1 = 10
T1, 2 - 1 - 3 = MODEL 2N914A (PERM)
OUTPUTS
VR3, VR1, VCXT1, PLOT
RUN CONTROLS
STOPTIME = 500
RUN INITIAL CONDITIONS
END

Figure 1, Example of SCEPTRE Input Format

Another convenient feature of most of the programs is one that permits the circuit analysis to be rerun automatically, with circuit parameter changes (element value, transient forcing function, etc.) by requiring only specification of the changes.

For all the programs, transient output is a time history of the circuit response. Some of the programs such as CIRCUS, General Network Analysis, and NET-1R essentially provide only node voltages and semiconductor junction currents and voltages as output. PREDICT provides only element currents and voltages as output. Other programs such as SCEPTRE, TAG, and TRAC also provide for additional user-defined outputs which are combinations of circuit variables. Using this feature, quantities such as element power dissipation and voltage between arbitrary points in a circuit are readily available for output. MISSAP III provides a unique method for specifying output by inserting voltmeters and ammeters in the circuit and then printing these "meter readings" as output.

Most of the programs provide for plotted results as well as printed listings as shown in the "plots" column of Table IV. Some of the programs such as CIRCUS and SCEPTRE provide plot information which can be processed by user installation supplied plot routines to obtain additional plotted results.




```
SUBROUTINE CKT 1
DIMENSION MEM (1000)
COMMON MEM
CALL MISSAP (61, 40, 1000)
CALL E (2, 6, 3, 1.5, 0, 1.0E-3, 1000., 0)
CALL V (2, 6, 1, 1, 1.0E-3)
CALL T (2, 4, 2, 15, 1.0E-6, 0.98, 1.0E-7, 39.5)
CALL R (4, 6, 330.0)
CALL C (4, 6, 0.05E-6, 0.7, 0)
CALL R (15, 8, 1800.0)
CALL DC (8, 6, 12.0)
CALL V (15, 8, 2, 1, 1.0E-3)
CALL QRUN (0, 5.0E-3, 5.0E-4)
RETURN
END
```

Figure 2, Example of MISSAP III Input Format

The next four columns of Table IV indicate the solution termination options available for each program. Most of the programs provide for solution termination when the problem response time limit specification is reached, when a specified computer machine time limit is reached, and when the solution time step increments decrease below a minimum limit. MISSAP III, SCEPTRE, and TAG also provide for termination when circuit variables exceed user-specified limits.

One of the major uses of these programs is providing circuit nuclear radiation response calculations. All but three of the programs, MISSAP III, Oklahoma State Systems Analysis, and TAG were either designed or have been adapted specifically for radiation effects applications.

Some of the programs provide directly for radiation effects analysis as shown in Table IV by including photocurrent generators in the built-in semiconductor device models. These programs also usually provide a simple format for entering radiation effects data. These programs also provide for entering or calculating radiation induced device model parameter changes.

The remaining columns of Table IV indicate the basic approach used for the equation formulation and solution by each of the programs. For the transient solution either a state variable (capacitor voltage and inductor current) or nodal (admittance matrix) formulation is used. Generally, an explicit numerical integration routine is used with the state variable formulation. Generally, for the nodal formulation, implicit integration by including recursive difference approximations in the admittance matrix is used for solution with an accompanying iteration solution technique for nonlinearities and dependent sources at each solution time increment.

There are other important aspects of these programs that have not been included in this paper. One is the relative solution efficiency of the various programs. Previous comparisons have shown differences of up to a factor of ten in the computer time required for different programs to calculate the same circuit response on a similar computer. Although efficiency is important, its accurate evaluation requires that all programs be run on the same computer for a family of circuit problems.

CONCLUSIONS

The programs reviewed were quite similar in capability of analyzing most transistorized circuits. The entering of most circuit data is convenient and quite similar for CIRCUS, NET-1R, and SCEPTRE, with TAG and TRAC probably the least convenient.

Considerable differences in the flexibility of the programs were noted. CIRCUS, General Network Analysis, and NET-1R programs are fairly inflexible in that only fixed value elements are permitted outside of the built-in models. The other programs are capable of processing functionally variable elements and so are useful for performing modeling work. However, the ease of entering variable elements varies considerably between programs. Only PREDICT, SCEPTRE, and STRAP make provisions for describing variable elements in simple engineer-oriented language.

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REFERENCES

1. Wirth, J. L., "The Design and Analysis of Electronic Circuits by Digital Computers," SCR-64-1355, Sandia Corporation, October 1964.

2. Analytical Methods and Fundamental Parameters for Predicting Responses of Electronic Circuits to Transient Nuclear Radiation, with Application to Hardened Circuit Design, AFWL TR 65-105, Air Force Weapons Laboratory, July 1965.

3. Memorandum, Pritchard, G. K., Air Force Weapons Laboratory, to Ballistic Systems Division, Evaluation of TRAC Computer Code (unpublished).

4. Falk, Howard (Editor), "Computer Programs for Circuit Design," Electro-Technology, Vol. 77, No. 6, Jun 1966, pp. 54-57.

5. Dunanian, John, "Check Design Program Availability," Electronic Design, Vol. 14, No. 23, 11 October 1966, pp. 76-80.

6. Milliman, L. D., Massena, W. A., Dickhaut, R. H., User's Guide to CIRCUS, to be published, 1967.

7. Perlich, D. R., and Kimball, E. M., Utilization Manual Computer Program 2M23, General Network Analysis Nonlinear Steady-State and Nonlinear Transient Programs, Lockheed Missile and Space Company.

8. The Michigan State System Analysis Program, MISSAP I, Michigan State University, East Lansing, Michigan, 15 May 1966.

9. MISSAP III, General Information Manual, Electronic Circuit Analyses, Michigan State University, East Lansing, Michigan, 25 July 1966.

10. Malmberg, A. F., Cornwell, F. N., NET-1 Network Analysis Program, 7090/7094 Version, LA-3119, Los Alamos Scientific Laboratory, Sept 1964.

11. Automated Digital Computer Program for Determining Responses of Electronic Systems to Transient Nuclear Radiation, PREDICT Circuit Analysis Program, WL TDR 64-62, Vol II, Air Force Weapons Laboratory, August 1964.

12. Automated Digital Computer Program for Determining Responses of Electronic Circuits to Transient Nuclear Radiation (SCEPTRE), Vol. I, SCEPTRE User's Manual, Vol. II, SCEPTRE Formulation, PREDICT Support, AFWL TR 66-126, Air Force Weapons Laboratory, February 1967.

13. King, K. O., Gillet, K., Libaw, W., TAG User's Manual, R-847, Planning Research Corporation, June 1966.

TABLE I--AUTOMATED NONLINEAR TRANSIENT CIRCUIT ANALYSIS PROGRAMS, ORIGINATORS, AND SPONSORS

Program	Originator	Sponsor
CIRCUS (Circuit Simulator)	Boeing Company	
General Network Analysis Program	Lockheed Sunnyvale, Calif	US Navy
MISSAP III (Michigan State Systems Analysis Program)	Michigan State University East Lansing, Michigan	
NET-1R (Network Analysis Program, Radiation Version)	Los Alamos Scientific Laboratory and Braddock, Dunn, & McDonald, Inc	LASL (AEC) HDL, US Army
Oklahoma State Systems Analysis Program	Oklahoma State University Stillwater, Oklahoma	
PREDICT (Prediction of Radiation Effects by Digital Computer	IBM Corporation Owego, New York	AFWL, USAF
SCEPTRE (System for Circuit Evaluation and Prediction of Transient Radiation Effects)	IBM Corporation Owego, New York	AFWL, USAF
STRAP (Simplified Transient Radiation Analysis Program)	Douglas Aircraft Co. Santa Monica, Calif	
TAG (Transient Analysis Generator)	Jet Propulsion Laboratory Pasadena, Calif	NASA
TRAC (Transient Radiation Analysis by Computer)	Autonetics Anaheim, Calif	

TABLE II: MAJOR FEATURES AND CAPABILITIES

Program	D.C. Analysis					Transient Initial Conditions		Types of Elements								Built-in Models								
	Initial Conditions	Sensitive Coefficient	Component Variation	A.C. Analysis	Transient Analysis	Automatically Calculated	Entered by User	Resistors	Capacitors	Inductors	Mutual Inductance or Coefficient of Coupling	Voltage Source	Current Source	Maximum No. Elements	Maximum No. Nodes	Transistor	Diode	Tunnel Diode	Zener	SCR	FET	Magnetic Core	Fixed Model	Stored Model
CIRCUS	X		X		X	X		C	C	C	C	C,F_{1}	C,F_{1}	400	200	X	X	X		X			X	X
GEN NET-WORK ANAL PROGRAM	X	X	X	X	X	X		C	C	C	C	C,F_{1}	C,F_{1}		30	X	X	X	X		X		X	X
MISSAP III	X		X	X*	X	X	X	C,F_{4}	C,F_{4}	C,F_{4}	C	C,F_{14}	C,F_{14}	** 100		X	X							X
NET-1R	X				X	X	X	C	C	C	C	C,F_{1}		600	100	X	X						X	X
OKLAHOMA STATE ANAL PRO	X				X	X	X	C,F_{3}	C,F_{3}	C,F_{3}	C	C,F_{13}	C,F_{13}	60		X	X							
PREDICT					X		X	C,F_{123}	C,F_{123}	C,F_{123}	C	C,F_{123}	C,F_{123}	300	100									
SCEPTRE	X		X		X	X	X	C,F_{1234}	C,F_{1234}	C,F_{1234}	C,F_{134}	C,F_{1234}	C,F_{1234}	300	300		X							X
STRAP	X				X	X	X	C,F_{123}	C,F_{123}	C,F_{123}	C,F_{123}	C,F_{123}	C,F_{123}	300	100		X							
TAG	X		X		X	X	X	C,F_{1234}	C,F_{1234}	C,F_{1234}	***	C,F_{1234}	C,F_{1234}		100									
TRAC	X		X		X	X	X	C,F_{134}	C,F_{134}	C,F_{134}		C,F_{134}	C,F_{134}	100	60	X	X					X	X	

* MISSAP I
** In state vector
*** Ideal transformer

Element Values

C = Constant value
F = User-defined variable value
F_1 = Function of time
F_2 = Function of circuit variables defined by a table
F_3 = Function of circuit variables defined by an equation
F_4 = Function of circuit variables defined by a subroutine

TABLE III--COMPUTER COMPATIBILITY, DOCUMENTATION, AND AVAILABILITY

Program	Operational on Following Computers	Language and Size of Source Deck	Minimum Memory Words (Decimal)	Documentation: User's Manual	Documentation: Math Description	Documentation: Program Org	Program Availability: Readily Available (no cost)	Program Availability: Special Restrictions	Request Through
CIRCUS	IBM 7094, SRU 1107/1108, GE 625/635, CDC 6600	98% FORTRAN IV 5500 cards	32K	X	X	X	X		R. Puttcamp, Harry Diamond Labs, Wash, DC
GEN NETWORK ANAL PRO	SRU 1107/1108	100% FORTRAN IV 3000 cards	65K	X				Available to Government	Director, Special Projects, Code SP 2702, Wash, DC
MISSAP III	CDC 3600	99.5% FORTRAN IV, 2000 cards	32K	X				Negotiated Contract	R. J. Reid, Michigan State Univ, East Lansing, Mich
NET-1R	IBM 7094, IBM 7040/7044, MANIAC II	100% FAP 30,000 cards	32K	X*			X		R. Puttcamp, Harry Diamond Labs, Wash, DC
OKLA ST. ANAL PRO	IBM 1410 (IBM 7040 version planned)	100% FORTRAN IV, 2000 cards	40K		X			Small cost IBM 7040 version to be available	J. Walden, Okla State University, Stillwater, Okla
PREDICT	IBM 7090/7094	50% FORTRAN II 50% FAP, 10,000 cards	32K	X	X	X	X		G. Pritchard, Air Force Weapons Lab, Kirtland AFB, New Mexico
SCEPTRE	IBM 7090/7094 (CDC 6600 & IBM 360 versions planned)	100% FORTRAN IV, 15,000 cards	32K	X	X	X	X		G. Pritchard, Air Force Weapons Lab, Kirtland AFB, New Mexico
STRAP	IBM 7090/7094	100% FORTRAN IV	32K	X **	X	X		Negotiated Contract (Undefined)	G.C. Litman, Douglas Acft, Santa Monica, Calif
TAG	IBM 7090/7094	98% FORTRAN II 12,000 cards	32K	X	X		X		W.J. Thomas, Jet Propulsion Lab, Pasadena, Calif
TRAC	IBM 7090/7094	95% FORTRAN II 1500 cards	32K	X	X	X		Availability Undefined	C. Kleiner, Autonetics, Anaheim, Calif

* NET-1 only
** Being published

TABLE IV: CONVENIENCE, SPECIAL FEATURES, AND MATHEMATICAL DETAILS

Program				Outputs				Termination				Radiation		D.C. Solution		Solution Formulation					
	Free Field Input	Save and Continue	Rerun with Changes	Node Voltage	Element Current Voltage	Junction Current Voltage	Plots	Problem Time	Computer Time	Minimum Step	Circuit Response	Photo Current	Parameter Permanent Changes	Iterative (Newton-Raphson)	Integration	Explicit Integration	Implicit Integration	Iterative	State Variable	Nodal	Automatically Variable Time Step
CIRCUS	X	X	X	X		X		X	X	X		X	X	X		X			X		X
GEN NETWORK ANAL PRO				X		X	*	X	X			X	X	X	X		X	X		X	
MISSAP III	X		X	X	X	X	***	X	X	X	X			X	X		X	X	X		X
NET-1R	X	X		X		X		X				X	X	X		X			X		X
OKLA STATE ANAL PRO	X+	X+	X		X	X		X	X					X		X		X	X		X+
PREDICT	X	X			X		**	X	X	X						X			X		X
SCEPTRE	X	X	X	#	X	X	***	X	X	X	X			X		X			X		X
STRAP	X	X	X	X	X	X	***	X				X	X	X			X			X	X
TAG	X	X	X	#	#	#	*	X	X	X	X			X		X		X	X		X
TRAC		X		X	X #	X	* ***	X	X	X		X	X	X			X	X		X	X

* SC 4020
** Cal Comp
*** Printer Plots

\+ IBM 7040 Version
\# User Defined Output Available