TABLE OF CONTENTS

I.	INTRODUCTION	1
A.	Computer Environment	2
B.	Availability of Programs	3
II.	Electric and Magnetic Field Programs	
1.	TRIM	4
2.	LINDA	5
3.	THOR	5
4.	MAFCO	6
5.	COILS	7
6.	FORCE	8
7.	MAREC	8
8.	JASON	9
III.	Computer Programs for Orbit Calculations	
A.	Using Matrix Formalism	
1.	TRANSPORT	10
2.	OPTIK	11
3.	TRAMP	12
B.	Using Integration Techniques	
1.	CYDE	14
2.	GOC3D	16
3.	TRAJECTORY	17
4.	SOTRM	18
5.	PINWHEEL	18
6.	SYNCH	19
7.	MAGOP	20
IV.	Computer Programs for Circuit Design	
1.	CIRANB	22
2.	CIRCUS	23
3.	TERMI	24
4.	BIAS	26
5.	CORNAP	26
6.	PUZZLE	28
7.	PICASSO	29

APPENDICES

Appendix	I.	Bibliography	30
Appendix	II.	Program Summary Form	35

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COMPUTER PROGRAMS FOR
ACCELERATORS AND ELECTRONIC CIRCUIT DESIGNS

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ABSTRACT

This is the first of a series of publications intended to assemble under one cover the most important computer programs relative to various major activities in this Laboratory, and thus establish a permanent library of such programs. This publication will deal specifically with computer programs relating to accelerator design and electronic circuit design. Each program is described in terms of an abstract, and a table of vital statistics summarizes the most important information relative to that program.

INTRODUCTION

The purpose of this publication is twofold: first to assemble under one cover descriptions of the most important and commonly used computer programs for accelerator design and circuit design, and secondly to establish a permanent library of such programs.

The necessity of such a library of programs stems from the magnitude and complexity of the problems involved, as well as from the large capital investment required to develop and maintain such computer programs. In the past, duplication of effort and the consequent unnecessary expense, has created a large number of computer programs whose function in most respects is similar--not to say identical.

Most of the programs herein described have been utilized effectively by other laboratories. They are general in concept, easy to implement in computer environments other than the ones cited, they are fully documented and operational.

The subject matter of this document will be published by Academic Press in more extensive form in a forthcoming book entitled "Computer Programs for Accelerator Design".

In this report an abstract of each program is given along with a table of vital statistics, so that the potential user may determine immediately whether the program meets his requirements.

It is anticipated that this report will be updated periodically, to reflect additional programs developed, or contributed from elsewhere and revisions to existing codes.

Perhaps, the most important information contained in this report, relates to the fact that some of the programs listed herein have been modified, to run "on-line" from remote installations, through a communications terminal.

Eventually all programs listed will become available in this mode of operation so that users from other installations may avail themselves of this service.

Computer Environment

To familiarize the potential user with the computing facility at LRL, Berkeley, the following birds-eye-view is given.

Presently, there are two CDC 6600 and one CDC 7600 computer systems at Lawrence Radiation Laboratory in Berkeley, running respectively BKY and SCOPE operating systems.

For remote and interactive processing the Laboratory has implemented a system which allows a large number of users to utilize the computer facilities from remote locations. Approximately 120 teletypes channels are available for this purpose.

For semi-permanent data storage, there is an IBM data cell and an IBM 1360 photodigital storage system (the chipstore). Both systems are on line to all Laboratory computer. The IBM 1360 is capable of storing a third of a trillion bits of data which is equivalent to almost 3000 full magnetic tape.

To perform interactive and remote functions software packages have been developed which allow the user to perform the tasks which are listed below:

1. EDIT This facility provides for entering text on-line into a buffer, and for subsequently examining and modifying part or all of that text.

2. COMUT This subsystem evaluates a one line arithmetic replacement statement. This subsystem allows the terminal to be used as a sophisticated desk calculator.
3. LOAD This subsystem permits the loading of a program stored in semi-permanent storage.
4. STORE Permits the storing of a generated program (file).
5. XEQ This subsystem consists of an interpreter for a subset of FORTRAN IV. Its function is to execute programs entered via the text editor (EDIT) subsystem.
6. SUBMIT This subsystem permits submission of a program into the normal batch system.

Remote batch service will be available on about August 1, 1971, to users of the Laboratory's computing facility.

Availability of Programs

The programs listed in this publication are available from the LRL Computer Library, if interested write to:

Miss Judy Lawrence
Computer Library
Building 50B, Room 1232B
Lawrence Radiation Laboratory
Berkeley, California 94720

Questions relating to problem definition or to program operation should be addressed to:

John S. Colonias
Mathematics and Computing
Building 50B, Room 3209
Lawrence Radiation Laboratory
Berkeley, California 94720

For further information contact:

Mr. Eric Beals
Head, Users Services Group
Mathematics and Computing
Lawrence Berkeley Laboratory
Berkeley, CA 94720

Availability of Programs

The programs listed in this publication are available from the
LBL Computer Library; if interested write to:

Miss Judy Lawrence
Computer Center Library
Building 50B, Room 1232-B
Lawrence Berkeley Laboratory
Berkeley, CA 94720

Questions relating to problem definition or to program operation
should be addressed to:

John S. Colonias
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ELECTRIC and MAGNETIC FIELD PROGRAMS

1. TRIM^{1,2}

This program has been extensively used for the design of accelerator magnets. It is a general purpose, two-dimensional magnetostatic code capable of solving mathematical models of two dimensional magnets. It includes the effects of finite non-uniform permeability of the iron. The universe of the problem is composed of irregular interfaces and boundaries.

Additional features include:

- a. Variable triangular mesh of about 4000 points
- b. No geometrical restrictions are imposed. Any shape of magnet may be considered
- c. Symmetry about the median plane is not required, therefore, both symmetric and asymmetric magnets may be considered
- d. Any current distribution or conductor orientation may be considered
- e. Axially symmetric magnets may also be considered
- f. Energy stored in air and iron regions is calculated
- g. Boundary value problems may be considered
- h. Constant ($\nabla = \frac{1}{\mu}$) may also be solved.

Auxiliary programs allow the CalComp or CRT plotting of the resulting flux distribution and of the printing tables of the components of the magnetic field throughout the universe of the program.

A special interactive teletype version of this program exists allowing the user to submit and execute from a remote station.

2. LINDA³

Program LINDA uses a combination of scalar and vector potential to model two-dimensional magnetostatic problems with a single general interface, and iron of finite non-uniform permeability. The computer model consists of a rectangular problem space or universe with a single region of iron and one region (sometimes two) of air. There may be many current conductors inside or outside the problem space but currents in iron are not allowed. The problem space is divided into a mesh of uniform rectangles in which the magnet geometry is outlined. The program does not allow separate pieces of iron, however, it provides for a very flexible array of topologically defined types of magnets which provide the necessary information about the location of the interface on mesh borders.

LINDA is a very fast program, and it provides accurate results. Auxiliary programs allow for CalComp plotting of the resulting flux distribution and the printing of special tables of field components, permeabilities etc. at the discretion of the user.

3. THOR⁴

This is a general purpose three-dimensional magnetostatic program based on the one potential (vector) throughout. The algorithm utilizes a variational principle for the nonlinear magnetostatic field problem. A finite-element approximation for an arbitrary mesh is constructed from this principle, and the resulting equations are solved by nonlinear successive over-relaxation.

The program follows the same pattern as TRIM, that is it consists of a problem GENERATOR which uses a variable triangular prism mesh on which the magnet geometry is outlined. The GENERATOR calculates various quantities dependent on the magnet configuration and prepares a magnetic tape which is read by the second part of the program responsible for the calculation of the resulting magnetic fields.

The input definition is relatively simple and follows the same procedure as TRIM.

Presently, THOR, has produced acceptable solutions, with no convergence problems, however, the rate of convergence has been slow and means to increase its speed are being investigated.

The accuracy of the program is also being tested by comparing the calculated field components with those of measured fields.

4. MAFCO⁵

This computer program is capable of calculating the magnetic fields resulting from a given set of current-carrying conductors of arbitrary two or three dimensional geometry. The code is particularly well adopted to complicated geometries arising in plasma physics, however, it may be used in other instances where a generalized two or three dimensional solution is desired for a coil geometry in which no permeable material is present.

The elements which compose the generalized coil geometry are approximated by:

- a. Circular loops with designated position and orientation in space.

- b. Circular arcs with designated position and orientation space.
- c. Helices along the z-axis (in the cylindrical coordinate system) with any designated pitch, starting point and ending point.
- d. Straight lines with arbitrary orientation.
- e. General elements specified by a list of points which the program connects with straight lines.

The program provides for flexible output of the components of the fields at specified grid points, or CALCOMP plots of field lines and isobars of constant $|B|$.

5. COILS⁶

COILS is a general purpose computer program to calculate vector potentials, axial and radial components of magnetic fields, forces and mutual inductances between coaxial conductors or to plot lines of force, lines of constant B , B_z etc., of any system composed of current carrying elements.

These elements may be any combination of circular filaments, thin solenoids, cylindrical or plane current sheets, or thick cylindrical coils with rectangular cross sections. The computed fields are accurate even within the windings of the coils, and in most cases the accuracy is to a minimum of seven significant digits.

This program has been adapted to run interactively through a teletype terminal, allowing the user to exercise control over the operation of the program. The user may alter, delete, or

add conductors, print selective output and return to the computational loop for more calculations based on modified data.

6. FORCE⁷

This program is an extension of the previously described program MAFCO, and it is used to calculate the magnitude and direction of the local magnetic force.

Once the magnetic field resulting from the coil configuration specified has been calculated, FORCE, using Fouraboy's law calculates the magnetic force at the center of each straight line section according to the order in which these appear in the input data.

Since FORCE calculates forces for only straight line section, it is imperative to approximate curvilinear conductors by a series of straight line segments. Obviously the length of each line segment will determine the degree of refinement of the resulting force distribution, thus providing a handle for coarse or fine calculations at the expense or saving of computer time.

7. MAREC⁸

This program computes two-dimensional static magnetic fields and includes the effects of finite permeability of the iron. MAREC makes use of the modified scalar potential (same principal as program LINDA). The problem universe is divided in two parts: the air-coil region and the iron region. These parts are computed separately, thus realizing a considerable saving of computer time and memory space. MAREC was developed at CERN and has been used extensively in the magnet design studies of the intersecting storage ring project and in the present studies for the new 300-500 GEV facility.

The program is general enough to accept any reasonable pole configuration, including concavities, several minima, and a large number of coils of any shape.

The computer model consists of a rectangular mesh of 3250 points for the air region and 2900 points for the iron region.

8. JASON⁸

This is a two-dimensional electrostatic program capable of solving a variety of problems encountered in the design of electrostatic lenses, deflecting system, and in general, problems relating to the static evaluation of electric fields. Some of the outstanding characteristics of the program include: 1) use of both cylindrically symmetric systems and two-dimensional cartesian systems, 2) completely general boundary conditions (Neumann, Dirichlet), 3) generalized quadrilateral mesh, 4) use of block interactive methods for the solution of the equations, 5) ease and simplicity of input, 6) consideration of non-homogenous anisotropic media, 7) flexible output and CalComp plots of fields and equipotential lines.

COMPUTER PROGRAMS FOR ORBIT CALCULATIONS

A. Using Matrix Formalism

1. TRANSPORT^{10,11}

Perhaps the most versatile and widely applicable program for the design of beam transport systems is the program TRANSPORT. This program was originally written in the BALGOL language, and has subsequently been translated to FORTRAN. The version at LRL has the features listed below:

- a. Flexible array of beam elements
- b. First-and second-order optics
- c. Tracking up to 50 vectors $(x, x', y, y', \delta s, \frac{dp}{p}, p)$
- d. Transformation of apertures forward and backward in phase space to create acceptance polygons. The calculations may be cycled over energy so as to obtain energy spectra.
- e. Plotting on output paper the beam ellipsoid projections and the locations of up to 50 vectors in any phase plane desired.
- f. Plotting on output paper (at the end of each run) the beam line showing ellipse projections, vector projections and apertures.
- g. Space-charge calculation
- h. Calculations of Betatron functions
- i. Separators may be included in the beam line.

TRANSPORT helps the beam designer by providing him with a flexible array of beam elements of which to develop his beam line. Many of the parameters may be varied subject to specified

constraints on the beam ellipsoid (or transformation matrix). Problems involving unknown quadrupole excitations, spacings etc. may be solved.

Three main versions of TRANSPORT exist at LRL

1. Off-line version (standard version)
2. On-line version. This version of TRANSPORT uses the CDC 252 display console. Existing software provide for the utilization of the light pen, for programmable interrupts, use of teletype to enter or extract data and for performing various on-line plotting functions. This interactive mode of operation has increased the the usefulness of TRANSPORT, by allowing the user to become a dynamic part of the computational loop.
3. Teletype version. The same interactive features or (2) above, but without the display console. This version may run remotely through the BRF system, providing the user the same interactive features and flexibility.

Selective teletype printout options are available and free format input routines add to the flexibility of the program.

2. OPTIK^{12,13}

This program as well as TRANSPORT, provide the experimenter with the facility to handle problems encountered in the optical design of high energy particle beams. It was originally written by Devlin for the IBM 709 Computer System, and it has been modified considerably by Chaffee and others to increase its usefulness and flexibility.

The present version of OPTIK, allows the experimenter to track particles through a beam transport system consisting of

- a. Field free regions
- b. Bending magnets (either wedge-shaped or rectangular regions of homogeneous magnetic field)
- c. Quadrupole lenses with one or two degrees of freedom
- d. Velocity separators.

The program produces solutions only to first order calculation for displacement and divergence, and first and second order for momentum dispersion. Various forms of output are available as well as CalComp plots of phase space area and ray tracing plots. One severe limitation of the program is that in satisfying a given condition OPTIK will vary only the strength of the quadrupole lenses. Another restriction is that no more than two variable symmetric triplet can be treated in any one beam section.

3. TRAMP^{14,15}

Program TRAMP was developed at Rutherford High Energy Laboratory by Gardner and Whiteside to provide solutions to problems encountered in beam transport design. It has been extensively modified by various experimenters in the field to fit the needs and the computer environments of their respective Laboratories.

The version mentioned here is capable of tracking and matching trajectories, beam profiles, or phase space ellipses through a given beam transport system. The beam elements that may be used in TRAMP are represented by 2x2 matrices for each

plane, transforming the displacement-divergence vectors from beginning to end.

Matching beam conditions are achieved by breaking up the beam into sections, and by making systematic changes in specified variable elements, setting up matrices for each section, until, through an iterative procedure, the product matrix is determined conform with the specified matching conditions. The program is capable of matching for: a) focal and phase-space conditions, b) waist and/or magnification matching and c) matching of dispersion and separation conditions.

A special version of TRAMP allows the combination of OPTIK and TRAMP plus graphic display interaction routines, thus providing on-line capabilities.

B. With Integration Techniques

1. CYDE¹⁶

This is a collection of cyclotron development programs used to calculate:

- a. Isochronous equilibrium orbit properties
- b. Predict trim coil currents which give a least squares fit to a desired magnetic field shape
- c. Magnetic fields produced by sets of trim coil currents. These are currents used in previous cyclotron runs, and also currents predicted by the least squares fit program.
- d. Phase history, SINO, for both previously run beams and least squares predicted
- e. Fourier coefficients for a harmonic analysis of measured field data.

Specifically, the programs responsible for these functions are:

- a. LESCO. Obtains a base magnetic field $B(I, R, \theta)$ for use in the rest of the codes. Thus, given a current I and an input tape containing interpolating polynomial coefficient LESCO constructs an output tape containing $R(I, R, \theta)$.
- b. DORO. This program is mainly concerned with the calculation of an isochronous field $B_s(R, \theta)$, and as a byproduct it furnishes orbit properties corresponding

to the specified field (e.g., ν_z , ν_r). If desired DORO will Fourier analyze the fields.

- c. CYDEB. It furnishes field effects dB/dI for the main field and trim coils, and calculates various field derivatives. These quantities will be used either in DOR88 (a subroutine of CYDEA) or in TRIMCO.

When called DOR88 takes specified coil currents as input and using these values obtains a constructed field $B=B(I,R,\theta) + \sum_J \left(\frac{dB}{dI} \right)_J \Delta I_J$, the sine of the phase, $SINO(R)-SINO_0$ and various associated field derivatives.

- d. TRIMCO. This is the least square fitting routine. The procedure used is based on specifying a desired average magnetic field vs radius. This is obtained on a "model beam" by running various field shapes and selecting the "model beam" it is used to predict all the other particles and energies in the same scaling mode, i.e., with the same number of particle revolutions during acceleration. For example, the model beam of 50 MeV -particle with 50 KV on the dee, has the same number of revolutions on 60 MeV or at 60 KV on the dee, or 30 MeV protons with 60KV on the dee etc. The field profile for TRIMCO is given relative to the isochronous field, or as the required field divided by the isochronous field.

2. GOC3D^{17,11}

This is general orbit code incorporating a flexible selection of magnetic field input geometries² encountered in accelerator design. The code uses a three dimensional field array or a two dimensional field map, if median plane symmetry is assumed. It will track up to 60 specified particles, track a grid of phase space, or calculate equilibrium orbit properties using the methods of Gordon and Walton. The code also provides for the calculation of the first order transfer matrix for small deviations about any trajectory.

Theta (θ), is taken as the independent variable and the equations for r, p_r, z, p_z , and T (time) are simultaneously integrated. The energy may be changed during the integration process, by action of R. F. acceleration or a scaling of E and B to simulate Betatron acceleration.

Orbit output is available at every integration step, every revolution, or every n^{th} revolution. Additional orbit output may be requested at up to four special azimuths which lie on integration steps. The code has been used for the study of isochronous cyclotrons, the 184 inch synchro-cyclotron, the electron ring accelerator project and the 5 MeV Livermore storage ring.

Two versions of this code are now available,

- 1) AGOC3D with 3000 points in the main and perturbation field array
- 2) BGOC3D with 3000 points in the main and 33000 points in the perturbation field map.

3. TRAJECTORY¹⁸

This program integrates simultaneously the equations of motion of a charged particle in a magnetic field and the differential equations for the ion optic matrix representing small motion about the paraxial trajectory. The orbit calculation is carried out in the median plane with the vertical transformation matrix calculated from a Taylor series expansion of the magnetic field off the median plane. The matrix so calculated is readily used with the iron-optic transport codes TRANSPORT or OPTIK. The trajectory data can be used to obtain internal target positioning for a given beam line.

The charged particles (protons, positive or negative pions, etc.) can be started individually from a specified R , θ and ϕ and tracked forward to find the trajectory traced by a particle leaving a target, or can be run backward so that the beam line can be extended back into the cyclotron to find the required target location. The particles can, also, be started from a rectangular array of R , ϕ , (Pr) values at a fixed azimuth θ so that a slit or aperture acceptance can be determined by reverse tracking.

The orbit calculation can be stopped at any desired radius, azimuth, or value of trajectory length, so that the accuracy of the matrix can be checked by comparison with the matrix determined by actual ray tracing.

Detailed output is provided with the trajectory printed in polar and rectangular coordinates.

4. SOTRM^{19,20}

This program generates first and second order transformation elements by integrating numerically through a specified magnetic field a specific set of rays. SOTRM can also ray trace up to 30 nearby rays while integrating for the central orbit. For the purpose of evaluating the significance on the generated elements, it has the ability to apply a previously generated set of elements to the initial conditions of the nearby rays currently being obtained by integration and thus compare the integrated values of the solution with those obtained by applying the transformation.

This program consists of a number of subroutines and it is easily adaptable to various physical problem.

5. PINWHEEL^{21,22}

This program traces trajectories of charged particles moving in a combined electric and magnetic field. The problem considered is

$$\frac{d^2 \mathbf{r}}{dt^2} = \left(\frac{q}{m} \right) \left(\mathbf{E} + \frac{\partial \mathbf{r}}{\partial t} \times \mathbf{B} \right) \quad \text{Eq. 1}$$

where $\mathbf{r} = (x, y)$ is the radius vector, $\mathbf{E} = -\text{grad } V$ is the electric field and $\mathbf{B}$ is the magnetic flux density. The initial conditions are:

$$\frac{\partial \mathbf{r}}{\partial t} (0) = \mathbf{r}_0$$

$$\mathbf{r}(0) = \mathbf{r}_0$$

This program is a modification of the Michigan State University version of PINWHEEL and as it is presently written it is restricted to two-dimensional cases with $E = (E_x, E_y)$ and $B = B_z$. It integrates Eq. (1) and tabulates the position (x, y) , the momentum (p_x, p_y) and the kinetic energy versus the integration variable time. If desired, orbit center points may be output and orbits may be plotted using a CalComp plotter.

This program is useful for orbit tracking, and was developed for cyclotron center region studies.

6. SYNCH²³

This program obtains certain information relative to transverse or bit motion in a synchrotron, such as calculation of the betatron function, the momentum-compaction, and the closed orbit in the presence of misalignments. At present, the code solves problems for which the accelerator may be thought of as made up of the following linear elements:

1. Drift spaces
2. Bending magnets with uniform gradient
3. Quadrupole magnets
4. Misalignments
5. Arbitrary elements specifiable by input matrices
6. Other transformations not expressible as matrices

For each element the code constructs two 3×3 matrices respectively describing the transverse motion in the radial and vertical planes. These matrices are to be thought of as operating respectively either on the column vectors $(x, x', \Delta p/p)$ and $(y, y', \frac{\Delta p}{p})$, or, when solving misalignment problems on the column vectors $(x, x', 1)$ and $(y, y', 1)$. The code will construct

other matrices representing assemblages of elements by means of the usual matrix operations. These matrices may be expressed in terms of the betatron function, which describe the betatron oscillation, and in terms of the eigenvector with unit eigenvalue which is the closed orbit if the matrix describes the whole accelerator, or a repeat period of the accelerator.

The code may be used to obtain the matrix product of all elements comprising the accelerator (or a repeat length thereof), to cycle that product with similarity transformation to obtain the one-turn transfer matrices starting from each of the constituent elements, and then to calculate the betatron function of these matrices. As a result, one may obtain linear orbit information at every point around the ring. Certain design problems for alternating gradient synchrotrons may be solved, such as the adjustment of an FDDF repeat length (or cell) to produce a specified phase advance, or the design of long straight sections.

Particle orbits may be traced through the synchrotron or through any part of it. For this purpose, the synchrotron may include non-linear elements.

7. MAGOP²²

This program calculates the orbit of a charged particle in median plane of a symmetric magnetic field, and it determines first-order horizontal and vertical transfer matrices associated with the orbit.

MAGOP solves the vector equation of a charged particle moving in a static magnetic field defined by Eq. (1)

$$\frac{d^2 \vec{r}}{ds^2} - \frac{q}{p} \frac{d\vec{r}}{ds} \times \vec{B}$$

where $\vec{r}$ is the position vector of the particle, s is the arc length, q is the particle charge, p the momentum and $\vec{B}$ is the magnetic field.

The equations of motion of particles near the central orbit in the horizontal and vertical sections are taken to be

$$\frac{d^2 n}{ds^2} = - \left[\frac{q}{p} \frac{dB_y}{dn} + \left(\frac{q}{p} B_z \right) \right] n + \frac{q}{p} B_z \frac{\delta p}{p}$$

and

$$\frac{d^2 \sigma}{ds^2} - \frac{q}{p} \frac{dB_z}{dn} \sigma$$

where n is the displacement of the deviating orbit in the median plane measured positively in the direction of the vector $\hat{k} \times \frac{d\vec{r}}{ds}$, p and δp are the momentum of the deviating orbit in the median plane, and σ is the displacement of the deviating orbit in the vertical direction measured from the median plane.

One of two sets of transfer matrices is calculated depending on the sign chosen for the arc lengths. For a positive, s , the forward transfer matrices, corresponding to transformation from the initial to the final point, are calculated. For a negative s , the reverse transfer matrix is calculated.

C. Computer Programs for
Circuit Design

1. CIRANB²⁴

This is a computer program used to perform AC steady-state and transient analysis of linear networks. The circuit schematic and analysis options are described to the program by means of the CIRANB problem-description language, which is a format-free routine allowing the user to describe his circuit analysis problem in terms familiar to circuit designers.

It is a modified version of a linear circuit-analysis program written at the University of Illinois under the direction of D. A. Calahan. Some of the features of the program are:

1. Relatively free-format input description
2. Library of input waveforms for use in transient analysis
3. Capability of changing the analysis options and of altering the values of any arbitrary number of components for variational analysis without redefining the complete problem.
4. Capability of adding or deleting components from the circuit for variational analysis without redefining the complete problem.
5. Writing of a plot tape for use by an additional plotting program, which can superimpose related curves from variational analysis on the same graph frame.

2. CIRCUS^{25,26}

This is a time response analysis program for electronic circuits. It is most suitable for analysing circuits where nonlinearities are essential for proper operation. All the present day junction devices are suitably represented by standard, accurate models.

It is the fourth generation of Branim's TAP¹ and the direct descendent of Malmberg et al's NET-1². Some of the main characteristics of this program are:

1. Flexible input format with minimal restrictions
2. Any current, voltage and power dissipation can be printed and plotted as output.
3. Junction device parameters can be stored in a library tape and be used when called. At present there are about 200 transistors and 20 diodes available.
4. Except for ohmic resistances of the junction devices, all parameters can be varied one at a time or all at once.

CIRCUS adopts the "state space" approach rather than the traditional nodal or loop formulation. The program first converts the junction devices into their equivalent circuit models with conventional R,L,C and voltage or current generation. Then the topology of the circuit is translated into the incidence matrix of zeros and ones, with a "1" representing a branch connecting two nodes and a "0" if there is no branch connecting the two nodes. After this a "normal free" is picked to insure that the equations obtained later are all linearly independent. From the

"normal free" and the incidence matrix, η first-order differential equation can be written of the form

$$[\dot{X}] = [Z] [X] + [U] + [\hat{S}] [\dot{U}] - [I] \quad \text{Eq. 1}$$

where $[X]$ = Independent branch currents and node voltage vector
(these are state variables)

$[Z]$ = R,L,C matrix

$[U]$ = Independent current and voltage sources vector

$[S]$ = Matrix for independent voltages and current sources

$[S]$ = Derivative matrix for independent voltage and current sources.

Dot implies first derivative.

Eq. 1 involves only first derivatives, and it is therefore relatively easy to solve. CIRCUS makes use of Pope's exponential numerical integration scheme which lessens the severity of the incompatibility problem between the circuit time constant and integration step size in cases where the latter becomes too large.

3. TERMI²⁷

This is a wirelist program, written to provide a convenient way of recording all pin-to-pin connections and to generate printouts of the connections arranged in various ways.

TERMI can be thought of as an interface between the designer of the circuits in a bin and the people who wire and debug it. Input essentially consists of cards containing a function name, followed by a number of pins which are to be connected together to perform the function.

Output consists of three lists. The first two are pin lists one arranged alphabetically in order of function, the other by order of pin-number. These two provide cross reference during debugging for tracing the wiring of a particular function or pin. The third list consists of pin-pairs, arranged by color. This list is intended for use during the wiring of the bin.

Colors may be assigned to particular function names so the color will appear next to all pins of this function in the lists. Also, the pin-connection cards can specify connections to be made from a function to an external appliance (external in the sense that it is not located on a card connector) such as cable-plug, light, or switch. These external contacts may also be connected to each other.

Because other versions of the program are used for taper-pin connectors, a basic assumption is that no more than two wires will be connected to any one pin. This might appear to impose excessive restrictions in the connection routing for wire-wrap, where 3 or 4 connections can be made to a pin, but in practice it is seldom much more complex. Also, the wiring density is kept lower, permitting easier use of scope probes. Each set of pins and external connections to be connected together must be given a unique function name. This permits pins on several different IBM cards to be interconnected without the necessity of placing the cards together in the input deck. If no function name is given, the program will make up one.

4. BIAS²⁸

This program solves for the DC node-to-datum voltages and transistor operating points of circuits containing resistors, bipolar (NPN or PNP) transistors, current sources and grounded voltage sources. The nonlinear model used for bipolar transistors is equivalent to that of Ebers and Moll. Additionally, if requested, BIAS will calculate the small signal incremental input resistance and voltage gain for a specified part description. Analysis may be repeated for several values of an DC source and/or for several different temperatures.

The program is limited by the following topological restrictions

- a) 40 dependent nodes + datum node
- b) 40 resistors
- c) 30 bipolar transistors (NPN or PNP)
- d) 20 current sources
- e) 20 grounded voltage sources

5. CORNAP²⁹

The purpose of this program is to obtain the state equations and desired transfer functions, together with frequency and time responses of an N-part linear active network. The program provides plots of frequency and time response as directed, by an easy to use format free language.

The linear analysis performed by CORNAP is restricted to networks whose dimensions do not exceed 24 independent nodes and 64 branches. The time invariant lumped linear elements of the network may be of the following types:

1. Ordinary two-terminal passive circuit elements (R,L,C)
2. Mutual inductance and capacitance
3. The four two-terminal controlled sources (voltage/current-controlled voltage/current sources)

Two-port active and nonreciprocal elements such as negative-impedance converters, ideal transformers and gyrators can be made up of the one-part elements described above. Inputs are defined by attaching independent voltage and current sources to the network. The topological description of the network is given in terms of cards accompanied by a few control cards dictating the quantities to be calculated and/or plotted. The output consists of a listing of the input data and a listing of the poles and zeros and the given constants of the transfer function desired. The state and output-state matrices may be listed. Time and frequency response may be computed and the tabulated results plotted.

6. PUZZLE³⁰

This program is designed to provide solutions to the printed circuit card design problem. It is capable of designing two-sided boards with a variety of components, and a multiplicity of interconnections (from 1 to 550). PUZZLE allows the user to code his board dimensions (with variable spacing on the connector tabs), thus yielding complete representation of the finished board.

Some of the limitations of the program are:

1. The path lengths are not minimized. The routing logic tends to produce short paths but no effort is made to assume that they are the shortest paths available.
2. Through holes are not minimized the smoothing routine tends to reduce the number of holes carrying lines back and forth through the surface of the boards but the algorithm does not minimize them.
3. No 45-degree diagonal paths are allowed (future modifications will incorporate this feature).

PUZZLE produces CALCOMP output for the representation of the circuit board, three graphs are produced for each successful routine. The first graph pictures the board from the parts side but shows both sides. The second graph shows all lines that are to appear on the "parts side" of the board. The third graph shows the "wiring side" of the board, essentially horizontal lines.

7. PICASSO

This is a general interactive graphics program for constructing a complicated data structure by the time-proven method of drawing pictures. The program can serve as a "front-end" module for any model-building program which interprets and analyses a user-defined data structure.

In many applications the picture itself is the desired output, as in printed circuit design layout or flow charting of procedures and programs, and for these, PICASSO is self-contained.

The philosophy of the program is to allow the user to create and edit diagrams, which are treated as entities. The diagrams may consist of basic elements (lines and/or text) or they may be built from other (previously defined) diagrams as well. The recursive nature of the data structure provides for the construction of models based on user-defined components, such as logic diagrams (which can serve as input to a wirewrap or circuit design and analysis program), mechanical engineering drawing, physical plant layout, optical systems design, or almost any problem where the model is easier to draw than to encode in digital form by hand.

APPENDIX I
Bibliography

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- 31.

APPENDIX II

PROGRAM SUMMARY FORM

Date MAY 10, 1971Title of Program TRIM I.D. Number EIM-1Write-up or User Guide Available UCRL-18439BERKELEY, CALIF.Source Code Available YES Number of Cards 22500Host Computer CDC 6600 Operating System BKYCDC 7600SCOPEProgramming Language (s) Used FORTRAN + COMPASSMemory Requirements 156K^{*} Program Overlaid NoAverage Running Time 15-20 MIN. Number of Magnetic Tapes Required 1What Other Peripherals are Used A SPECIAL VERSION OF TRIM
EXISTS WHICH USES CRT DISPLAY
CONSOLE.Terminal Supported YES, AVAILABLE FOR ON-LINE TELETYPE
USE FOR REMOTE TERMINAL FACILITIES.

Restrictions _____

* Memory requirements depend on the mesh size used.
The above at 156K is maximum size of 4000 points.

36
PROGRAM SUMMARY FORM

Date MAY 10, 1971

Title of Program LINDA I.D. Number EM-2

Write-up or User Guide Available Yes, REQUEST INTERNAL REPORT
(UNPUBLISHED)

Source Code Available YES Number of Cards ≈ 11,000

Host Computer CDC 6600 Operating System BIK
CDC 7600 SCOPE

Programming Language (s) Used FORTRAN ONLY

Memory Requirements 220K 8* Program Overlaid No

Average Running Time 10-15 MIN. Number of Magnetic Tapes Required 2

What Other Peripherals are Used CAL-COMP PLOTTER

Terminal Supported AVAILABLE FOR ON-LINE TELETYPE USE FOR
REMOTE TERMINAL FACILITIES.

Restrictions _____

QUANTITY FOR 160x60 MESH SIZE. MEMORY REQUIREMENTS
DEPEND ON MESH SIZE SELECTED.

PROGRAM SUMMARY FORM

Date MAY 12, 1971Title of Program THOR I.D. Number EM-3Write-up or User Guide Available NoSource Code Available No Number of Cards ~ 1000Host Computer CDC 7600 Operating System BK4SCOPEProgramming Language (s) Used FORTRAN + COMPASSMemory Requirements 130K₈* Program Overlaid NoAverage Running Time 1.2 HRS Number of Magnetic Tapes Required 1What Other Peripherals are Used NONETerminal Supported NoRestrictions NOT OPERATIONAL AT THIS TIME, PRESENTLY BEING TESTED.

* REQUIRED FOR A 31X31X21 MESH.

MEMORY REQUIREMENTS VARY, DEPENDING ON MESH SELECTED.

PROGRAM SUMMARY FORM

Date MAY 10, 1971Title of Program MAFCO I.D. Number EM-4Write-up or User Guide Available LCRL-7744 URL, BERKELEYSource Code Available YES Number of Cards ≤ 1200Host Computer CDC 6600 Operating System PK4
CDC 7600 SCOPEProgramming Language (s) Used FORTRANMemory Requirements 67K Program Overlaid NOAverage Running Time 1-3 MIN. Number of Magnetic Tapes Required NONEWhat Other Peripherals are Used NONETerminal Supported AVAILABLE FOR ON-LINE TELETYPE USE FOR
REMOTE TERMINAL FACILITIES.

Restrictions

PROGRAM SUMMARY FORM

Date MAY 15, 1971Title of Program COILS I.D. Number EM-5Write-up or User Guide Available ORNL-3575 OAK RIDGE NATIONAL
LABORATORY REPORTSource Code Available YES Number of Cards ~ 2000Host Computer CDC 6600 Operating System TRW
CDC 7600 SCOPEProgramming Language (s) Used FORTRANMemory Requirements 50K Program Overlaid NOAverage Running Time < 60 SEC. Number of Magnetic Tapes Required NONEWhat Other Peripherals are Used NONETerminal Supported AVAILABLE FOR ON-LINE TELETYPE USE FOR
REMOTE TERMINAL FACILITIES.

Restrictions

PROGRAM SUMMARY FORM

Date JUNE 2, 1971Title of Program FORCE I.D. Number EM-7Write up or User Guide Available UCRL - 14917 COL, BERKELEYSource Code Available YES Number of Cards ~ 2000Host Computer CDC 6600 Operating System PKY
CDC 7600 SCOREProgramming Language (s) Used FORTRANMemory Requirements 50K₀ Program Overlaid NOAverage Running Time 460 SEC. Number of Magnetic Tapes Required NONEWhat Other Peripherals are Used NONE.Terminal Supported AVAILABLE FOR AN-LINE TELETYPE USE FOR
REMOTE TERMINAL FACILITIES.

Restrictions

PROGRAM SUMMARY FORM

Date MAY 29, 1971Title of Program MAREC I.D. Number EM-8Write-up or User Guide Available C.E.R.N. 67-7Source Code Available YES Number of Cards ~ 3000Host Computer CDC 6600 Operating System RSX
QDC 7600 SCURFProgramming Language (s) Used FORTRANMemory Requirements 122K_B Program Overlaid NOAverage Running Time 5-10 MIN.* Number of Magnetic Tapes Required 1What Other Peripherals are Used NONETerminal Supported NoRestrictions USER REQUIRED TO WRITE HIS OWN OUTPUT ROUTINE(S)
TO PRINT BX, BY COMPONENTS OF THE MAGNETIC FIELD.

* TIME FOR ~ 3000 POINTS IN 1000.

42
PROGRAM SUMMARY FORM

Date JUNE 20, 1971

Title of Program JASON I.D. Number EM-9

Writs-up or User Guide Available UCRL-18721 LRL, BERKELEY

Source Code Available YES Number of Cards ~ 700

Host Computer CDC 6600 Operating System BKY
CDC 7600 SCOPE

Programming Language (s) Used FORTRAN

Memory Requirements 165K * Program Overlaid No

Average Running Time 3-5 MIN. Number of Magnetic Tapes Required 1

What Other Peripherals are Used CAL-COMP PLOTTER

Terminal Supported No

Restrictions _____

* FOR A 2000 POINT MESH.

43
PROGRAM SUMMARY FORM

Date MAY 20, 1971

Title of Program TRANSPORT I.D. Number PST 1

Write-up or User Guide Available UCRL-19414, UCRL-18816

URL, BERKELEY

Source Code Available YES Number of Cards 46000

Host Computer CDC 6600 Operating System BK

EDC 7600

SCOPE

Programming Language (s) Used FORTRAN

Memory Requirements 60-100 K^{*} Program Overlaid NO

erage Running Time ** Number of Magnetic Tapes Required NONE

What Other Peripherals are Used CRT DISPLAY CONSOLE
TELETYPE } INTERACTING-VERSION
ONLY

Terminal Supported A SPECIAL VERSION OF THE CODE EXISTS FOR THE
ON-LINE TELETYPE USE FOR REMOTE FACILITIES.
ANOTHER VERSION ALLOWS GRAPHIC-DISPLAY
INTERACTION.

Restrictions

* REQUIREMENTS VARY TO WHETHER 1ST OR 2ND ORDER OPTICS ARE DESIRED.
TIME ALSO VARIES FOR DIFFERENT VERSIONS, 1-10 min.

44
PROGRAM SUMMARY FORM

Date JUNE 10-1971

Title of Program OPTK I.D. Number B2

Write-up or User Guide Available UCLRL-9727 LRL, BERKELEY

Source Code Available YES Number of Cards ~ 4000

Host Computer CDC 6600 Operating System BUG
CDC 7600 SCOPE

Programming Language (s) Used FORTRAN

Memory Requirements 50K Program Overlaid No

Average Running Time 1-2 min. Number of Magnetic Tapes Required NONE

What Other Peripherals are Used CRT DISPLAY CONSOLE
TELETYPE

Terminal Supported THERE IS A SPECIAL GRAPHIC-INTERACTION VERSION.

Restrictions _____

45
PROGRAM SUMMARY FORM

Date JUNE 3, 1971

Title of Program TRAMP I.D. Number B53

Write-up or User Guide Available NIRL/M/41 JAN. 1963 -
RANTHERFORD HIGH ENERGY LAB, ENGLAND.

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System BUG
CDC 7600 SCOPE

Programming Language (s) Used FORTRAN

Memory Requirements 66 K₈ Program Overlaid No

Average Running Time 1-2 min. Number of Magnetic Tapes Required NONE

What Other Peripherals are Used NONE

Terminal Supported No.

Restrictions _____

46
PROGRAM SUMMARY FORM

Date JUNE 20, 1971

Title of Program CYDE I.D. Number 0-1

Write-up or User Guide Available UCID-2869 LRL, BERKELEY

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System PKY
CDC 7600 SCOPE

Programming Language (s) Used FORTRAN

Memory Requirements 66 Kb Program Overlaid No

Average Running Time 1 MIN. Number of Magnetic Tapes Required 1

What Other Peripherals are Used NONE

Terminal Supported *

Restrictions _____

* UNDER DEVELOPMENT FOR ON-LINE TELETYPE USE
FOR REMOTE FACILITIES.

17
PROGRAM SUMMARY FORM

Date JUNE 13, 1971

Title of Program GEC3D I.D. Number 0-2

Write-up or User Guide Available ORNL-2765 OAK RIDGE NAT. LAB.
(RECENT UGRL REPORT. SOON TO BE PUBLISHED)

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System BKH

CDC 7600

SEMP

Programming Language (s) Used FORTRAN

Memory Requirements 60K Program Overlaid NO

Average Running Time 1 MIN. Number of Magnetic Tapes Required 1

What Other Peripherals are Used NONE

Terminal Supported NO

Restrictions _____

48
PROGRAM SUMMARY FORM

Date MAY 20, 1971

Title of Program TRAJECTORY I.D. Number 0-3

Write-up or User Guide Available UCRL-19407 URL, BERKELEY

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System BIK
CDC 7600 SCAPE

Programming Language (s) Used FORTRAN

Memory Requirements 50K Program Overlaid No

Average Running Time 1-2 min. Number of Magnetic Tapes Required NONE*

What Other Peripherals are Used NONE

Terminal Supported No

Restrictions _____

MAGNETIC FIELD INPUT MAY BE READ IN BY TAPE OR CARDS.

PROGRAM SUMMARY FORM

Date MAY 10, 1971Title of Program SOTRM I.D. Number 0-4Write-up or User Guide Available UCRL-198UCRL-19812 } LRU, BERKELEYSource Code Available YES Number of Cards _____Host Computer CDC 6600 Operating System PXYCDC 7600SCODEProgramming Language (s) Used FORTRANMemory Requirements 113K₈ Program Overlaid NoAverage Running Time 3-4 min Number of Magnetic Tapes Required 1What Other Peripherals are Used NONETerminal Supported No

Restrictions _____

50
PROGRAM SUMMARY FORM

Date JULY 7, 1971

Title of Program PINWHEEL I.D. Number 0-5

Write-up or User Guide Available REQUEST COPY FROM LRL COMPUTER CENTER, BERKELEY.

Source Code Available YES Number of Cards 42000

Host Computer CDC6600 Operating System BK4
CDC7600 SCOPE

Programming Language (s) Used FORTRAN

Memory Requirements 55K8 Program Overlaid NO

Average Running Time 1 MIN. Number of Magnetic Tapes Required NONE

What Other Peripherals are Used CAL-COMP PLOTTER

Terminal Supported NO

Restrictions

PROGRAM SUMMARY FORM

Date MAY 10, 1971Title of Program SYNCH I.D. Number 0-6Write-up or User Guide Available UCID-10153, LRL BERKELEYSource Code Available YES Number of Cards ~ 8500Host Computer CDC 6600 Operating System BK4CDC 7600 SCOPEProgramming Language (s) Used FORTRANMemory Requirements 100K₈ Program Overlaid NOAverage Running Time 1-3 min. Number of Magnetic Tapes Required NONEWhat Other Peripherals are Used CRT DISPLAY CONSOLETELETYPE } INTERACTING VERSION
ONLYTerminal Supported THERE IS AN INTERACTING GRAPHIC-DISPLAY VERSION.

Restrictions _____

PROGRAM SUMMARY FORM

Date MAY 14, 1971Title of Program MAGOP I.D. Number 0-7Write-up or User Guide Available REQUEST COPY FROM UCL, BERKELEYCOMPUTER CENTER.Source Code Available YES Number of Cards ~300Host Computer CDC 6600 Operating System BLKCDC 7600SCOREProgramming Language (s) Used FORTRANMemory Requirements 50K₈ Program Overlaid NOAverage Running Time 1 MIN Number of Magnetic Tapes Required 1*What Other Peripherals are Used NONETerminal Supported NO

Restrictions

* MAGNETIC FIELD INPUT CAN BE READ IN BY TAPE OR CARDS.

53
PROGRAM SUMMARY FORM

Date July 20, 1971

Title of Program CIRANB I.D. Number CAD-1

Write-up or User Guide Available UCRL-18185, UCL BERKELEY

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System IBKX

Programming Language (s) Used FORTRAN

Memory Requirements 50K₈ Program Overlaid NO

Average Running Time 2-3 min. Number of Magnetic Tapes Required NONE

What Other Peripherals are Used CAL-COMP PLOTTER

Terminal Supported NO.

Restrictions _____

Title of Program **CIRCUS** I.D. Number **CAD-2**

Write-up or User Guide Available UCLR-19329, URL BERKELEY
EE-1319, URL BERKELEY ENGIN-
ERING DEPT.

Source Code Available	YES	Number of Cards	2000000000
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Host Computer **EDC 6600** Operating System **BEY**

Programming Language (s) Used **FORTRAN**

Memory Requirements 127 Kb Program Overlaid No

Average Running Time 1 min. Number of Magnetic Tapes Required NONE*

What Other Peripherals are Used *cal-comp? plotter*

Terminal Supported **NO**

Restrictions

* AN INPUT TAPE MAY BE USED TO PROVIDE ^{THE} CODE WITH A TRANSISTED MODEL LIBRARY.

55
PROGRAM SUMMARY FORM

Date JULY 20, 1971

Title of Program TERMI * I.D. Number CAD-3

Write-up or User Guide Available UCID-3287 LRL, BERKELEY

EE-1278 ** LRL, BERKELEY

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System BK4

Programming Language (s) Used FORTRAN

Memory Requirements 125K 8 Program Overlaid NO

Average Running Time 203 min. Number of Magnetic Tapes Required NONE

What Other Peripherals are Used NONE

Terminal Supported NO

Restrictions _____

* THIS CODE WILL BE SOON BE REPLACED BY PROGRAM WIRELIST.

** ENGINEERING DEPT.

56
PROGRAM SUMMARY FORM

Date July 21, 1971

Title of Program BIAS I.D. Number CAD-4

Write-up or User Guide Available EE-1345 EECS-141 UCL, BERKELY
ENGINEERING DEPT.

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System BKY

Programming Language (s) Used FORTRAN

Memory Requirements 100K Program Overlaid NO

Average Running Time 1-3 MIN. Number of Magnetic Tapes Required NONE

What Other Peripherals are Used NONE

Terminal Supported NO

Restrictions _____

57
PROGRAM SUMMARY FORM

Date JULY 25, 1971

Title of Program CORNAP I.D. Number CAD-5

Write-up or User Guide Available UCID-9411
EE-1337 LRL, BERKELEY
ENGINEERING DEPT.

Source Code Available YES Number of Cards _____

Host Computer CDC6600 Operating System DKY

Programming Language (s) Used FORTRAN

Memory Requirements 101 K_B Program Overlaid NO

Average Running Time 1-3 MIN. Number of Magnetic Tapes Required _____

What Other Peripherals are Used CAL-COMP PLOTTER

Terminal Supported NO

Restrictions _____

58
PROGRAM SUMMARY FORM

Date JULY 25, 1971

Title of Program PUZZLE I.D. Number CAD-6

Write-up or User Guide Available UCRL-18172 URL, BERKELEY

Source Code Available YES Number of Cards _____

Host Computer CDC 6600 Operating System DKT

Programming Language (s) Used FORTRAN

Memory Requirements 125K₈ Program Overlaid No

Average Running Time 10-15 SEC. Number of Magnetic Tapes Required 2

What Other Peripherals are Used CAL-COMP PLOTTER

Terminal Supported No

Restrictions _____

PROGRAM SUMMARY FORM

Date JULY 27, 1971Title of Program PICASSO I.D. Number CAD-7Write-up or User Guide Available (UCCRL PAPER PENDING)Source Code Available YES Number of Cards _____Host Computer CDC 6600 Operating System BK4SCOPEProgramming Language (s) Used FORTRANBLIMPMemory Requirements 50K₈ Program Overlaid NOAverage Running Time VARIABLE Number of Magnetic Tapes Required 1What Other Peripherals are Used MODEL 52 DISPLAY CONSOLETELETYPETerminal Supported NO

Restrictions _____