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LOW NOISE EBS JAMMER.(U)

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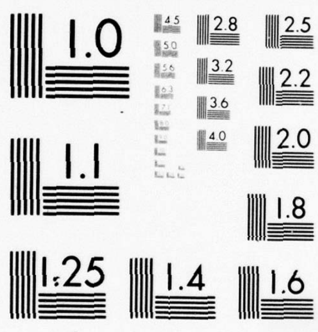

MICROCOPY RESOLUTION TEST CHART

LEVEL II

Research and Development Technical Report

DELET-TR-78-2958-2

LOW NOISE EBS JAMMER

Douglas B. Clark
John B. Rettig
WATKINS-JOHNSON COMPANY
3333 Hillview Avenue
Palo Alto, CA 94304

June 1979

Second Triannual Report for Period 1 Dec 1978 - 31 Mar 1979

Prepared for:
ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

ERADCOM

US ARMY ELECTRONICS RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

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LOW NOISE EBS JAMMER

SECOND TRIANNUAL REPORT

1 DECEMBER 1978 THROUGH 31 MARCH 1979

Contract No. DAAB 07-78-C-2958

File No. WJ-78-4172TR2

Prepared by:

Douglas B. Clark
John B. Rettig

For

U.S. Army Electronics Technology & Devices Laboratory
Electronics Research and Development Command
Fort Monmouth, New Jersey 07703

Watkins-Johnson Company
3333 Hillview Avenue
Palo Alto, California 94304

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this program is to reduce the output power level of spurious noise signals, intermodulation (IM) products and harmonic distortion generated by deflection modulated electron beam semiconductor (EBS) amplifiers. Work performed during this period included characterization of existing EBS amplifiers, computer aided electron gun analysis, beam shape analysis of operating electron guns, and design modifications to the existing electron guns.

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FOREWORD

Identification of Engineering Personnel

Douglas B. Clark, Project Engineer

John B. Rettig, Member of Technical Staff

Descriptive Background of Key Personnel

Biographical sketches for each of the key personnel are included in the Appendix.

Publication, Lectures, Reports and Conferences

1.	Publications	None
2.	Lectures	None
3.	Reports	Monthly Status Reports December 1978 through March 1979
4.	Conferences	Progress on subject contract. Watkins-Johnson Company personnel and Mr. Robert M. True of ERADCOM, Fort Monmouth, N.J. Held at Watkins-Johnson Company on 20-22 March 1979.

Program for the Next Internal

The Program Plan shown in Figure 2-2 and described in Section 6.0 represents our best estimate of work to be carried out during the next reporting period.

TABLE OF CONTENTS

ILLUSTRATIONS

1.0 INTRODUCTION

1.1 Objective

The program objective is to reduce the output power level of spurious noise signals, intermodulation (IM) products and harmonic distortion generated by deflection modulated electron beam semiconductor (EBS) amplifiers.

1.2 Technical Approach

Figure 1-1 illustrates the configuration of a deflected beam EBS amplifier. This type of amplifier has been developed by Watkins-Johnson Company over a period of several years. Measurements of existing EBS amplifiers will be made to determine the typical values of IM products, spurious noise and harmonic distortion. The existing electron beam profile will be characterized using a slit beam analyzer. The EBS performance will be correlated to the measured beam profile using a mathematical analysis implemented by a computer program. A second computer program will perform an analysis of the expected beam profile generated by the existing gun geometry and these results will be correlated with the measured beam profile. Modifications will then be performed on the electron gun to improve the linearity, IM products and harmonic distortion; and the re-designed gun will be fabricated and tested on the beam analyzer. Two devices using the re-designed gun will be fabricated, tested and delivered as part of this contract.

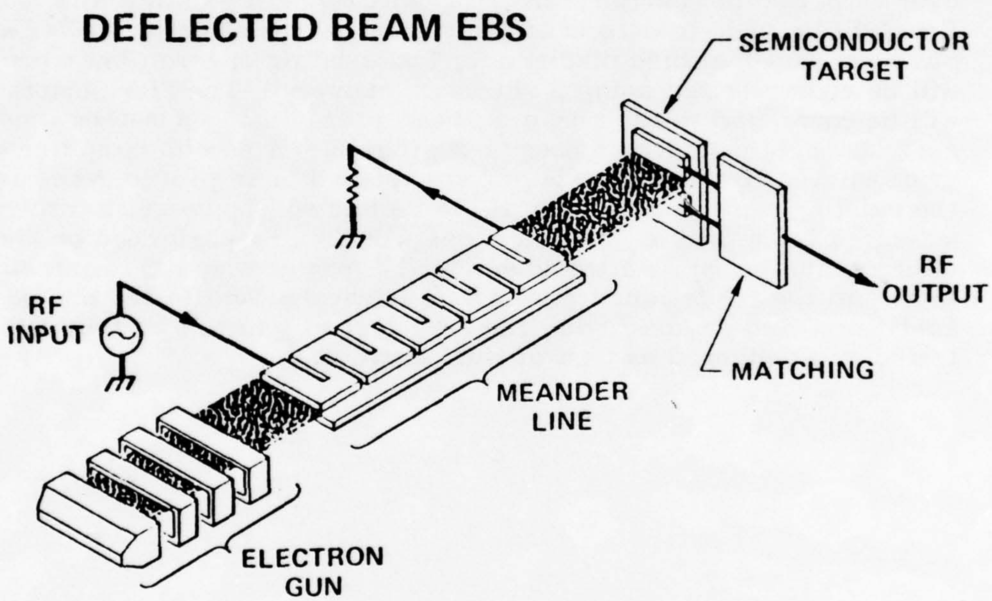

Figure 1-1. Deflected Beam EBS Configuration

2.0 PROGRAM SUMMARY

2.1 Summary of Work

During the four month period covered by this report, the following was accomplished:

1. The existing EBS amplifiers having 2 × 6 diode arrays were completely characterized in terms of linearity and intermodulation products as a function of device efficiency.

2. The computer aided analysis of the present gun performance was completed. Several conclusions were drawn from the results, and areas of potential improvements were identified.

3. Work continued on methods of analyzing actual shape of electron beams. Calibration of an existing slit diode array was not satisfactory, so a fabrication of a new slit diode array was begun. Phosphor screens were used as a secondary method of beamshape observation.

4. Several guns were checked using the phosphor screen method. Poor beam shape was observed, and the guns were checked for dimensional conformation to the present design. Some problems were identified in this regard, and redesigned tooling and parts were ordered to correct these problems.

2.2 Program Schedule

Figure 2-1 shows the Program Schedule, updated as of April 1979. The primary cause of slippage has been lack of a suitable method of measuring beam shape. This problem has been solved by the use of phosphor screens and the fabrication of a new slit diode array.

All other tasks are proceeding on schedule with one exception: because of results obtained by beam shape analysis performed as part of this program, emphasis has been shifted away from the development of the metal-ceramic version of the sheet beam gun and increased emphasis has been put on fabrication techniques using the present glass envelope configuration. For this reason, the two tasks having to do with development of the metal ceramic gun have been deleted from the program.

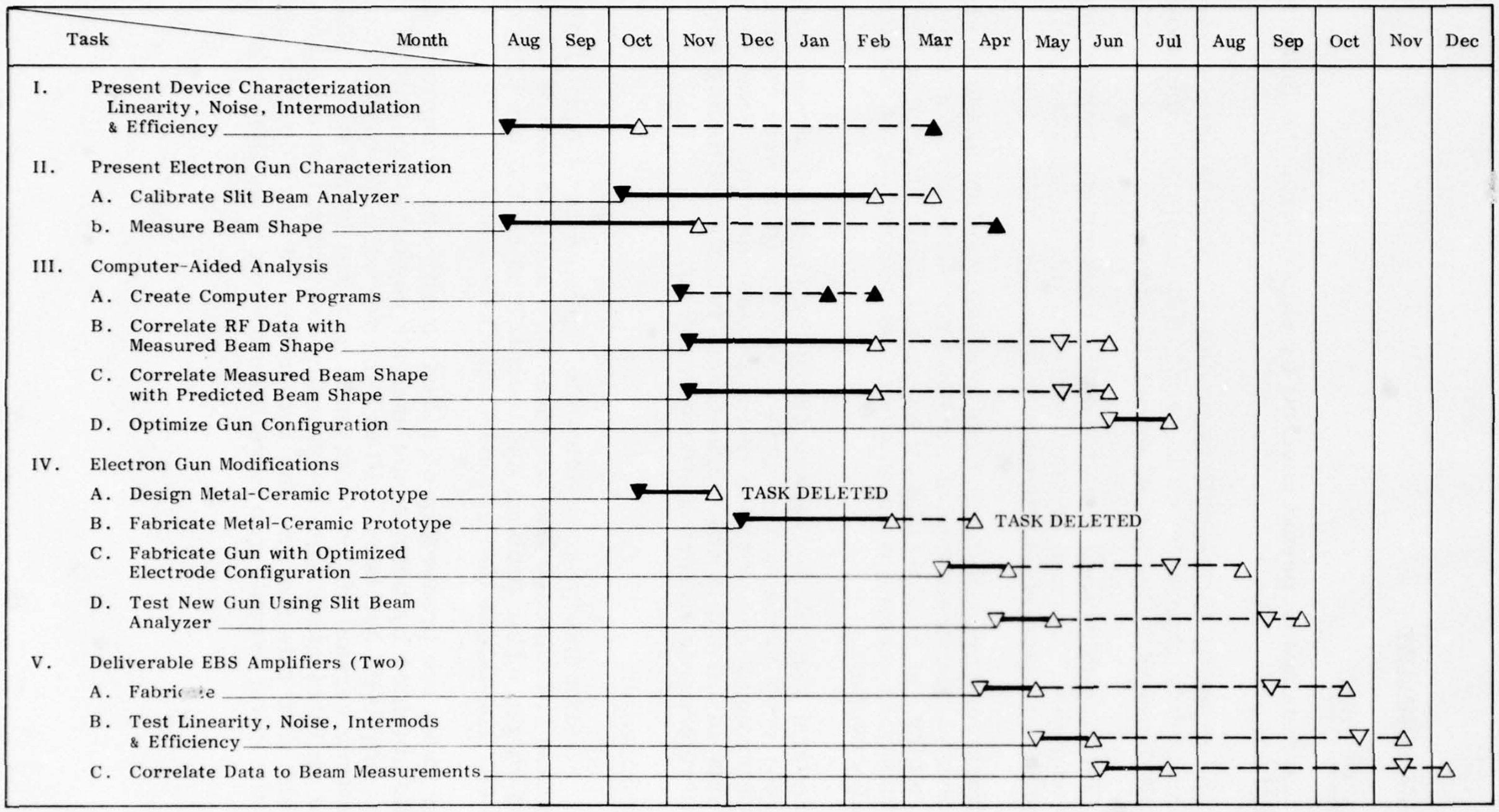

Figure 2-1. Program Milestone Schedule

3.0 CHARACTERIZATION OF EXISTING DEVICES

Extensive linearity and intermodulation measurements were performed on a deflected beam amplifier, WJ-3662-1 S/N 9. The device was set up for saturated output power of 46.0 dBm at maximum efficiency. The balanced two tone method of measurement was used, and in most cases, the fundamental tones and their 3rd, 5th, and 7th intermodulation products were measured over a 20-33 dB dynamic range. The parameter varied during these tests was the voltage on anode 3, the next to last anode in the gun stack. (Anode 4 is held at ground potential.) Figures 3-1 through 3-5 summarize these results, and Figure 3-6 expresses the tradeoff between linearity and efficiency. The criterion for linearity is the maximum 3rd order intermodulation product referenced to fundamental saturation level; note that the case for "best" linearity by this criterion ($A_3 = 3400$) is not coincident with the case where the fundamental deviates the least from constant gain ($A_3 = 3500$), nor with the case where single tone saturated efficiency is maximum ($A_3 = 3300$). The reason for this is attributed to the sidelobes present in the beam density profile, which has been observed on phosphor screens. At maximum efficiency, the amplifier is running in class C, i.e., with a tightly focused beam smaller than the diode spacing. At other points, class AB predominates, with current spillover severely reducing efficiency. Since the beam profile as predicted by computer for class C is not perfectly rectangular, the intermodulation products are more severe than for class AB, which in spite of spillover has a better beamshape within the width of the diode spacing.

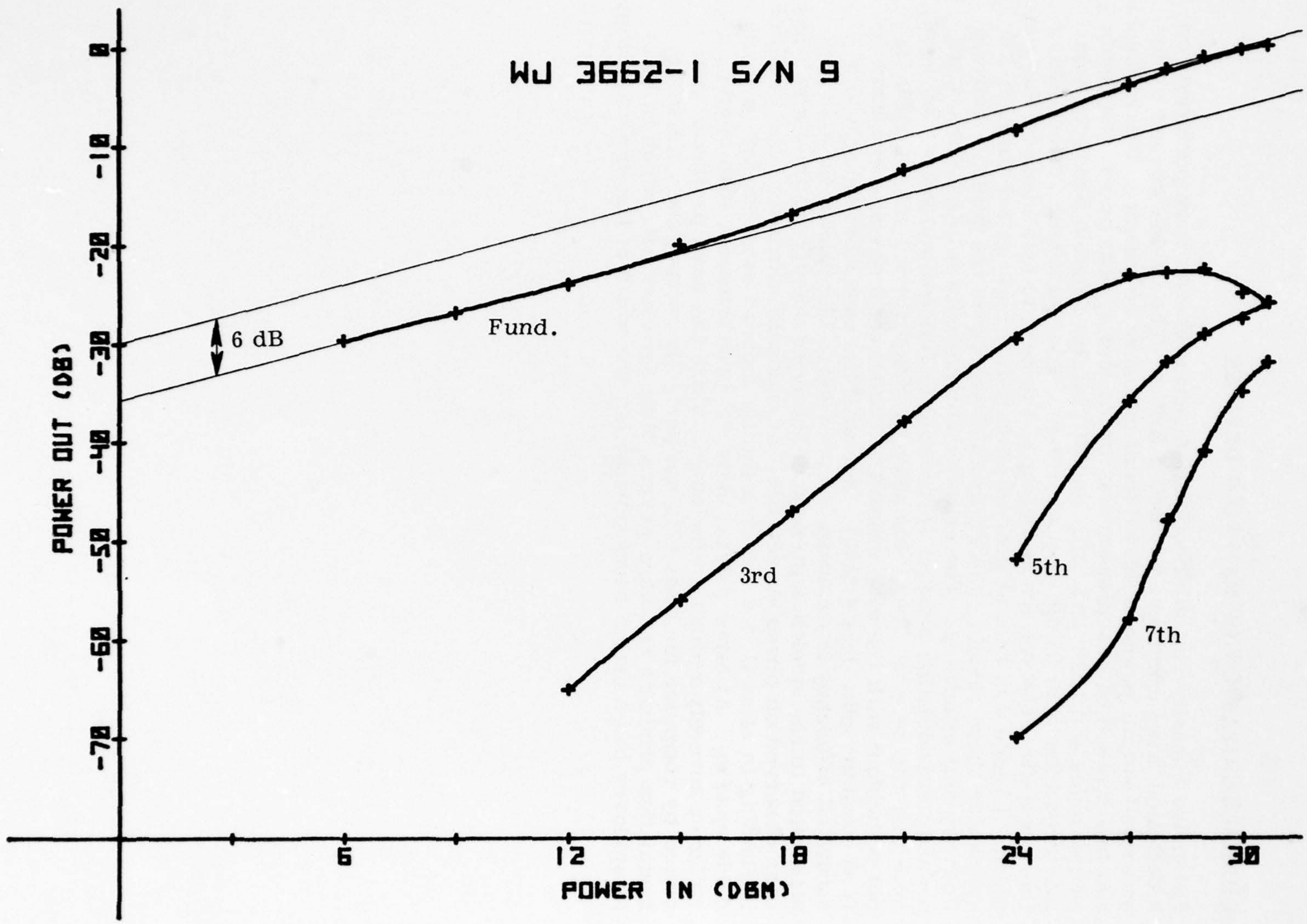

Figure 3-1. IMD Performance (A_3 = 3100 V).

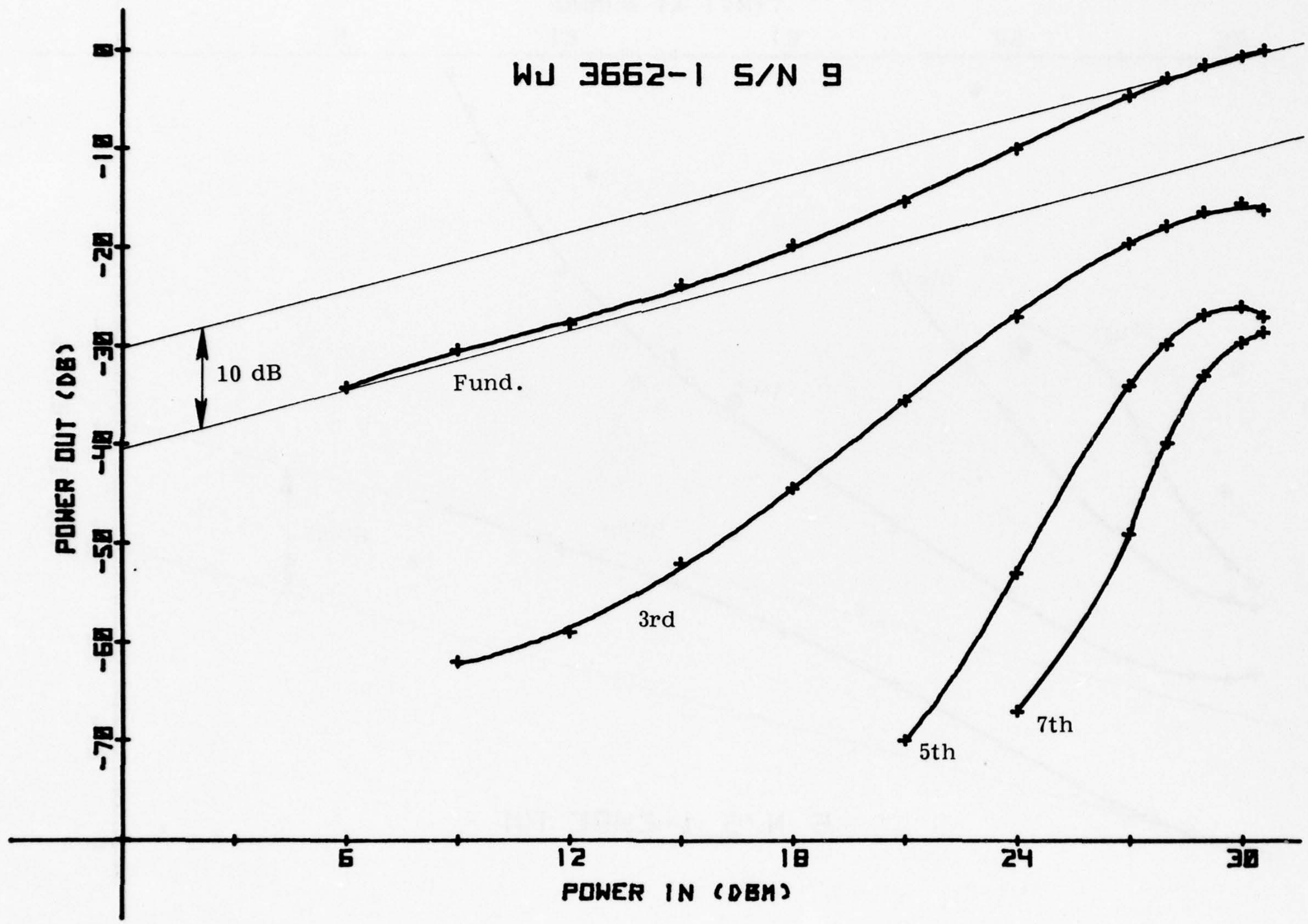

Figure 3-2. IMD Performance (A_3 = 3200 V).

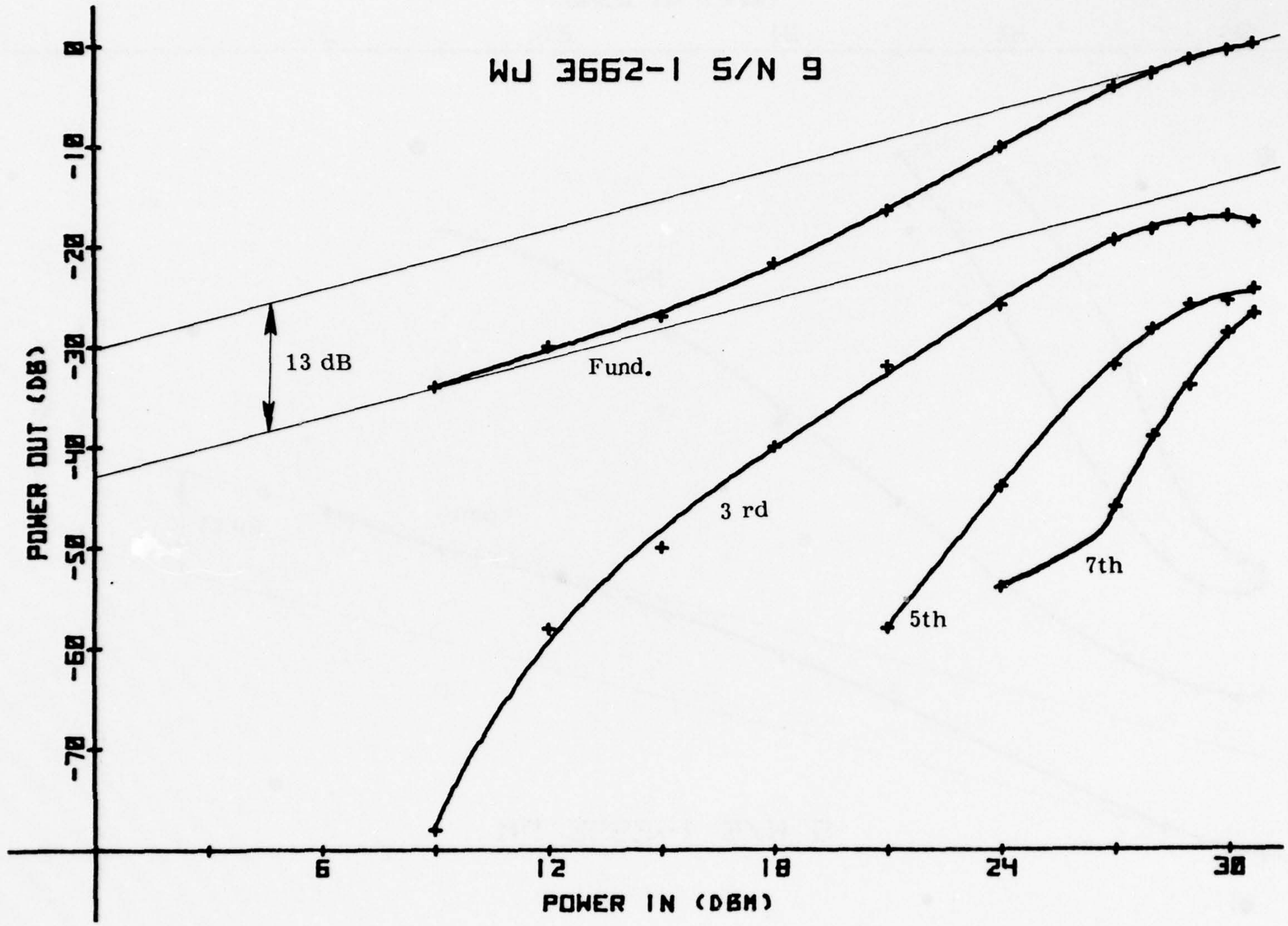

Figure 3-3. IMD Performance for the Case Where Maximum Target Efficiency Is Attained at Single Tone Saturation (A_3 = 3300 V).

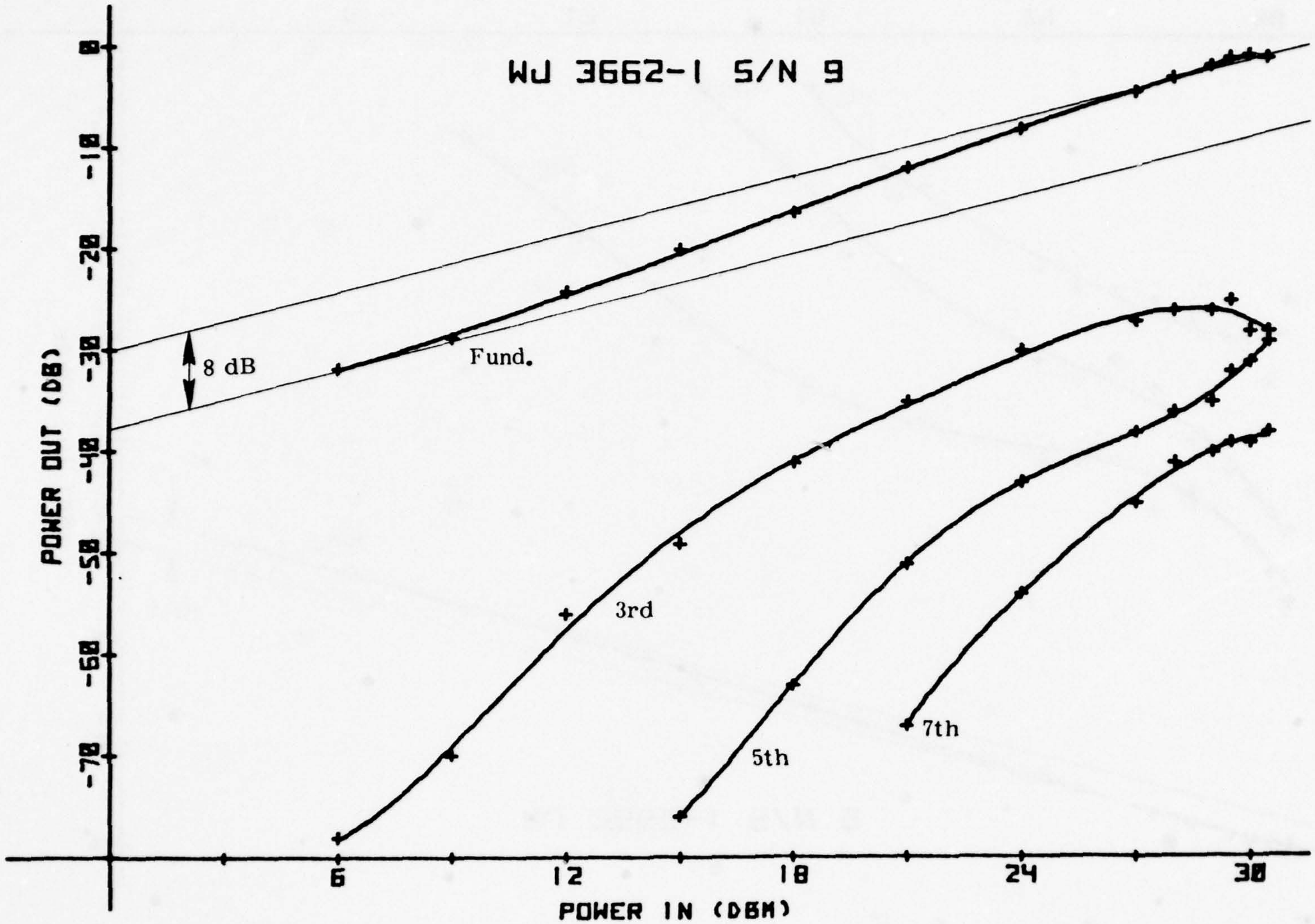

Figure 3-4. IMD Performance for the Case where Maximum 3rd Order IMD Is Minimized (A_3 = 3400 V).

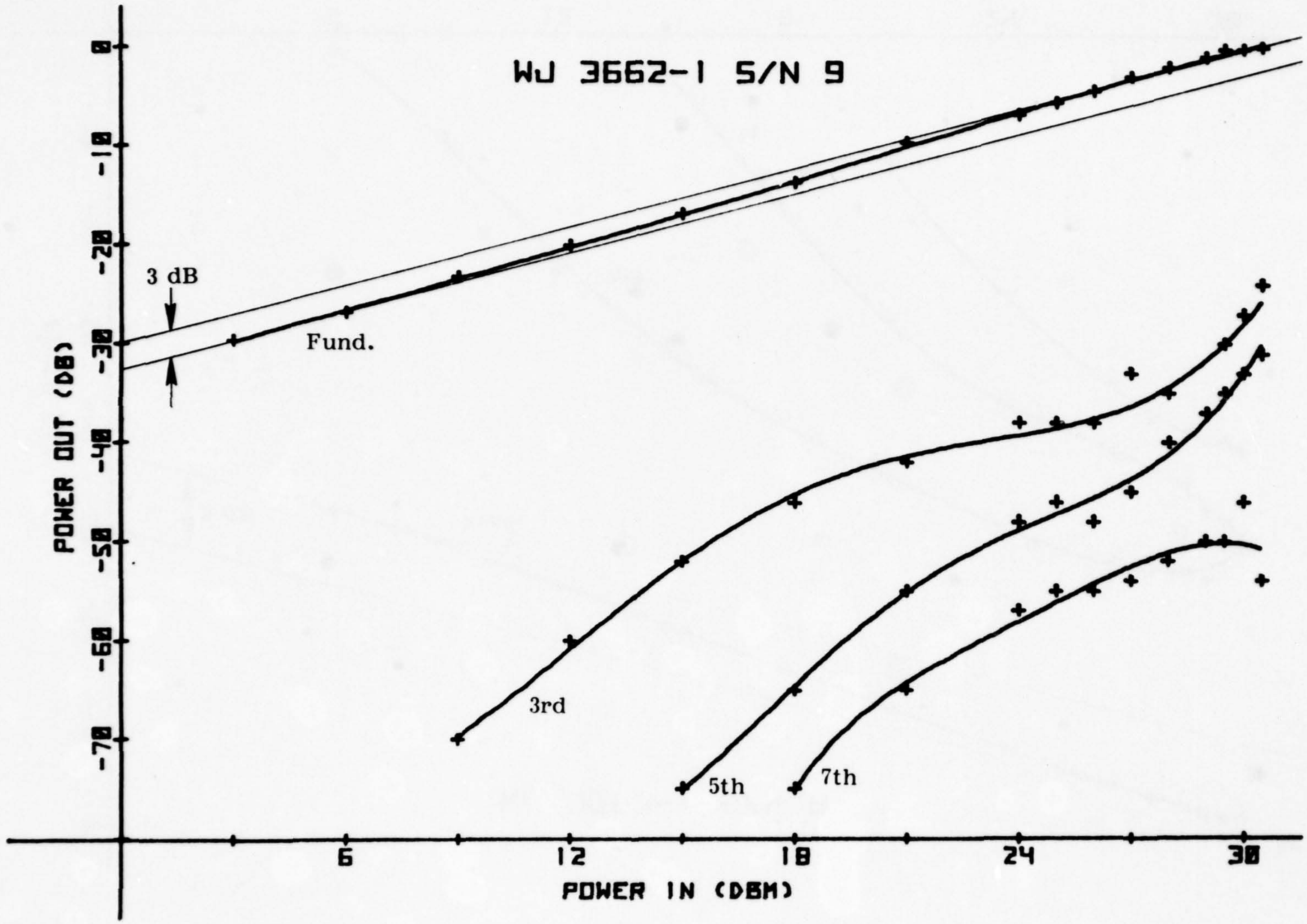

Figure 3-5. IMD Performance (A_3 = 3500 V).

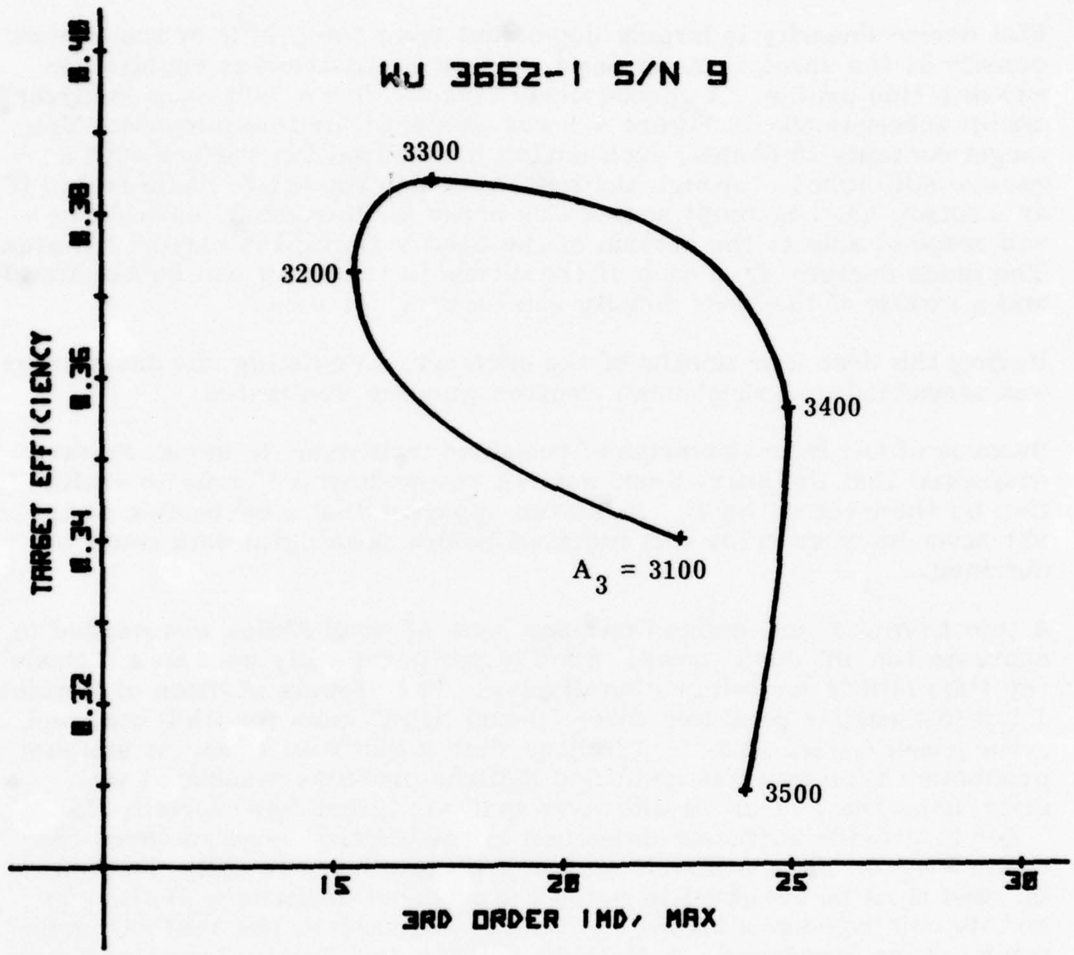

Figure 3-6. Linearity/Efficiency Tradeoff, expressed parametrically as a function of Anode 3 voltage.

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4.0 MEASUREMENT OF ELECTRON BEAM SHAPE

4.1 Slit Diode Array

EBS device linearity is largely dependent upon the profile of the current density of the sheet electron beam. An accurate means is required to measure this profile. A special diode target called a "slit beam analyzer" shown schematically in Figure 4-1 was prepared for this purpose. The target contains 10 diodes, each having a metalized top surface with a narrow slit etched through the metalization to the active diode layer. If an electron beam is swept across this array as illustrated, each diode will respond only to the portion of the beam striking the narrow slit area. The diode current from each of the diodes in the array can be monitored and a profile of the beam density can be thus obtained.

During the first four months of the contract, an existing slit diode array was assembled to a sheet beam electron gun and was tested.

Because of the inconsistencies of response from diode to diode, it was suspected that the array itself was not responding uniformly to excitation by the electron beam. It became apparent that a calibration of the slit beam analyzer array was required before meaningful data could be obtained.

A gun having a well-defined circular beam of small radius was needed to calibrate the slit diode array. Such a gun is typically used in a cathode ray tube (CRT) for information display. The Stewart Division of Watkins-Johnson Company produces these "pencil beam" guns for CRT use, and arrangements were made to purchase such a gun from them. A suitable production type gun was identified and the problems associated with interfacing the gun to the slit beam analyzer target were solved. In order to provide sufficient deflection of the electron beam to cover the entire target, using available sawtooth generators, the deflection coil to be used must be designed to match the physical dimensions of the gun and its coil impedance should be roughly the same as the sawtooth generator output impedance. A suitable coil was designed and procured from an outside vendor.

When the pencil beam gun was operated with the slit diode array, the diode current obtained was insufficient to provide a high enough signal-to-noise ratio. In addition, problems were experienced in obtaining a reasonable amount of cathode current from the gun.

The gun was removed from the slit diode array and sent back to the Stewart Division for installation of a new cathode. In conjunction with

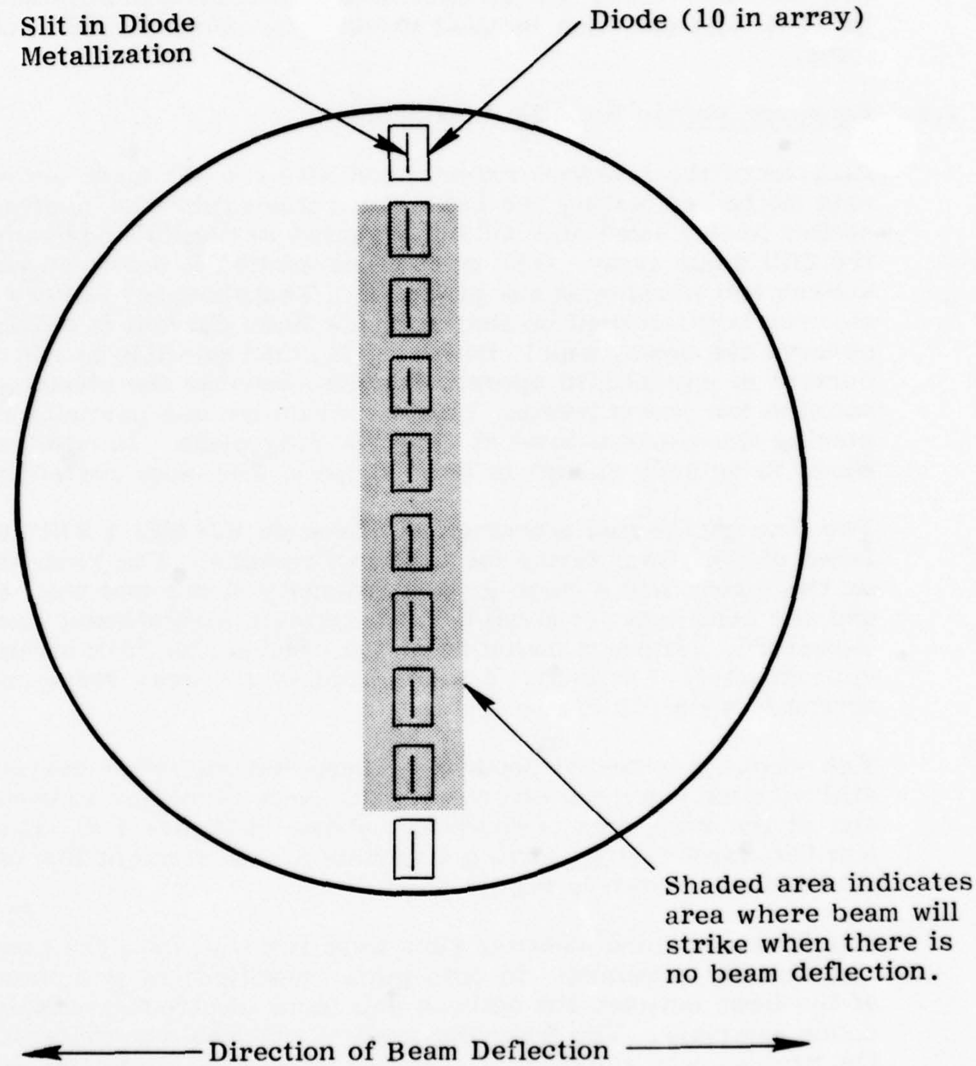

Figure 4-1. Slit Beam Analyzer Array

this, fabrication of a new slit diode array was begun, since several of the diodes in the slit diode array were not functioning.

The new slit diode array will have wider (0.002 inches) slits to provide greater response amplitude. Since the optimum beam width is 0.040 inches, resolution will still be far in excess of what is required. The new slit diode array will be first tested with the pencil beam gun to calibrate it, and can then be used to test beam shape on EBS sheet beam guns.

4.2 Phosphor Screen Beam Measurements

Because of the problems experienced with the slit diode array, an alternate method of testing the beam shape was explored. A phosphor screen similar to that used on a CRT is mounted to the EBS device in place of the EBS diode array. The beam cross-section is observed when the beam strikes and illuminates the phosphor. The phosphor is very sensitive to electron bombardment so that very low beam current is sufficient to observe the beam shape. However, it is not possible to run high beam current at normal EBS operating levels, because the phosphor is evaporated at low power levels. This disadvantage was partially alleviated by pulsing the electron beam at very low duty cycle. In addition, there seems to be little change in beam shape as the beam current is increased.

The first gun tested was originally used on WJ-3662-1 S/N 16, which failed at low power levels for unknown reasons. The beam shape shown on the screen had a much greater intensity at one end than at the other, and the beam was not straight but exhibited a significant amount of curvature. Maximum deviation of the beam center from straight line was approximately 0.04 inch. A photograph of the beam image on the phosphor screen is shown in Figure 4-2.

The second gun tested produced a beam having better overall shape, but still with too much curvature and with some increase in intensity and beam size at the very ends of the beam, shown in Figure 4-3. The third gun was the worst tested, having a deviation from straight line of approximately 0.05 inches, shown in Figure 4-4.

The first and third electron guns were removed from the phosphor screens and visually examined. In both guns, misalignment was noted in the plane of the beam between the cathode and focus electrode assembly and the anode assembly. The fixturing used to assemble the guns was checked and the problem was apparent - when the lengthwise dimension of the focus electrode assembly was increased in early 1978, the fixture had not been modified to take up the slack. New fixturing to correct the problem was ordered.

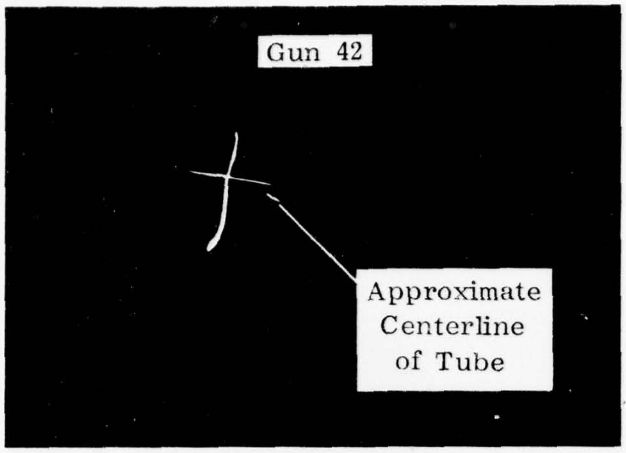

Figure 4.2 - Beam shape of gun #42 measured on a phosphor screen

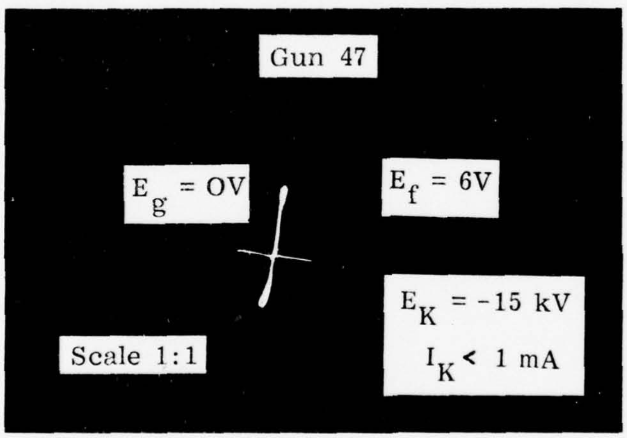

Figure 4.3 - Beam shape of gun #47 measured on phosphor screen.

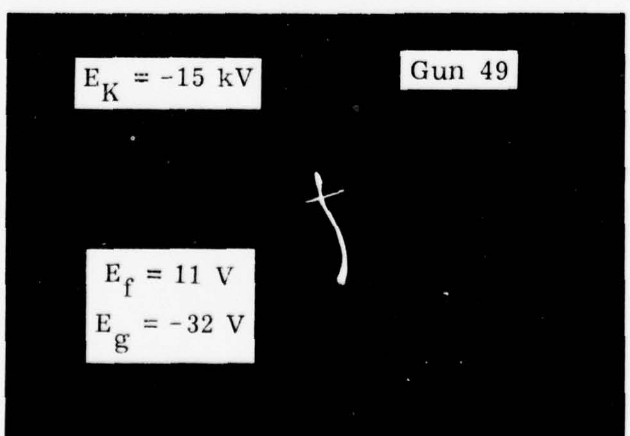

Figure 4.4 - Beam shape of gun #49 measured on a phosphor screen.

The last gun, which had the most pronounced beam curvature, also had a noticeable warpage in the first anode.

To reduce the "dogbone" effect of higher beam size and intensity near the ends of the beams, modifications were begun on the gun electrode designs. The modifications will increase the length of the slot in all the gun electrodes.

To increase the precision of the anodes themselves, a new method of fabricating the anodes was developed. Presently, each anode is machined to the desired dimensions. The new method involves machining each anode in two parts, placing the parts on a mandrel, and laser welding the two pieces together. Since the mandrel can be made with very good accuracy, the internal dimensions of the finished anode should be better using the new method.

5.0 COMPUTER AIDED ANALYSIS OF ELECTRON GUN

During the present reporting period, the final computer program was written to complete the correlation between the rectangular gun geometry and the Fourier components of the output signal. All of the programs currently used for gun analysis are listed in Table I. The first three perform the function of determining beam profile through the acceleration region, i.e., up to the meanderline. The fourth accounts for beamspread through the drift region, from the meanderline to the target. Finally, the last performs a convolution of the beam density profile with diode shape to determine the output waveform, then does a Fourier transform on this waveform to determine the spectral components and calculates the target efficiency for the fundamental.

The design of a new gun structure has typically involved the use of only the first two programs. Generally, the quality of the beamshape is quite obvious after the second program is run, and if there are severe problems with a design, there is no point in carrying out further calculations. For this reason, Parts (1) and (2) of Table I have been streamlined to run with one job submission. The remainder of the programs, however, take a great deal of effort to run, and are used only to check out a design that has been finalized from (2). A complete listing of all above programs is given in Appendices I through IV.

Table I

COMPUTER ELECTRON OPTICS PROGRAMS
AVAILABLE FOR GUN ANALYSIS

	Name	System	Language	Purpose	Author	Listing
1.	RCTGUN I	IBM VM370	FORTRAN	Equipotential locator to set up RCTGUN II	John Rettig	Appendix I
2.	RCTGUN II (XMGUN)	IBM VM370	FORTRAN	Slow region beam analysis	George Wada	(Proprietary)
3.	RCTGUN III	IBM VM370	FORTRAN	Fast region, large area beam analysis	John Rettig	Appendix II
4.	Beamspread	HP 9825A	HPL	Beamspread through drift space	John Rettig	Appendix III
5.	Convolve	HP 9825A	HPL	Beam density convolution, and FFT analysis of output waveform and efficiency calculation	Steve Brierley	Appendix IV

6.0 MODIFICATION TO ELECTRON GUN

Figure 6-1 and 6-2 illustrate the 2-dimensional beam profile resulting from the present electrode geometry and ideal Pierce geometry, respectively. Figure 6-2 has served as a model for the development of a new anode geometry, based on the following areas of improvement that have been identified from Figure 6-1:

1. The effective cathode location is not necessarily at the zero potential line.

2. The grid is biased negative relative to the cathode, in order to reduce emission. As mentioned previously, this crowds the emission density into the center of the cathode.

3. Potentials farther from the cathode are such that emission at the cathode can not be reduced without causing the beam area to be smaller, thereby increasing current density.

Problems (2) and (3) are being addressed by construction of a gridded anode in front of the cathode, which will take over the function of beam control and allow the focus anode to be run at or near cathode potential. Problem (1) is not being pursued at this time because the flexibility of the new geometry should allow small adjustments to be made on the focus anode potential, in order to satisfy the Pierce field characteristics. Note that the intent of the gridded anode is to shield the Pierce field region from the acceleration region of the gun, to prevent the lensing effects seen in Figure 6-1. The beam control function is a necessary side effect of the primary shielding function, and is predicted to require potentials of 100-200 volts relative to cathode.

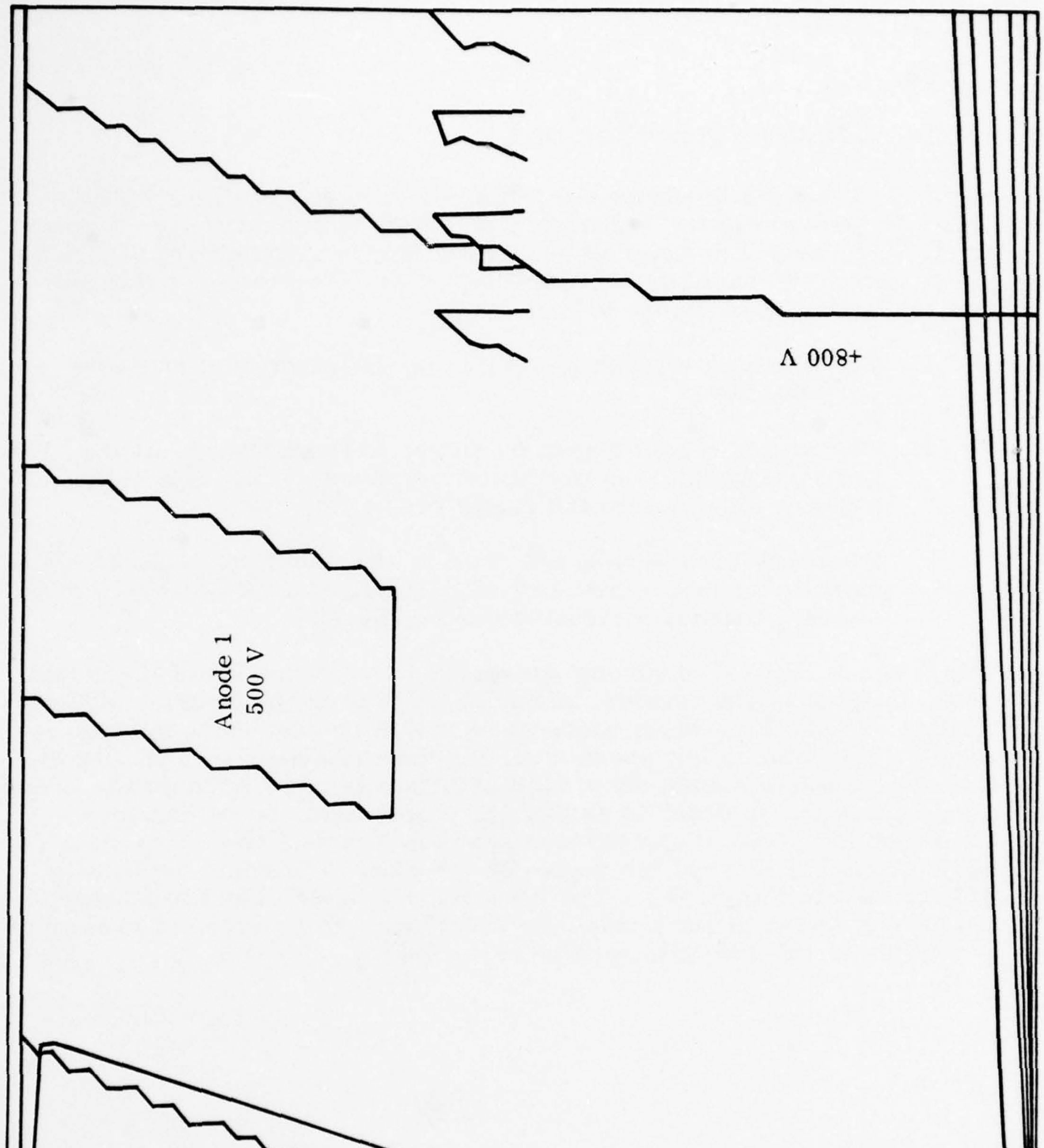

Figure 6-1. Part of the trajectory solution for the rectangular beam gun used in the 3662 Amplifier.

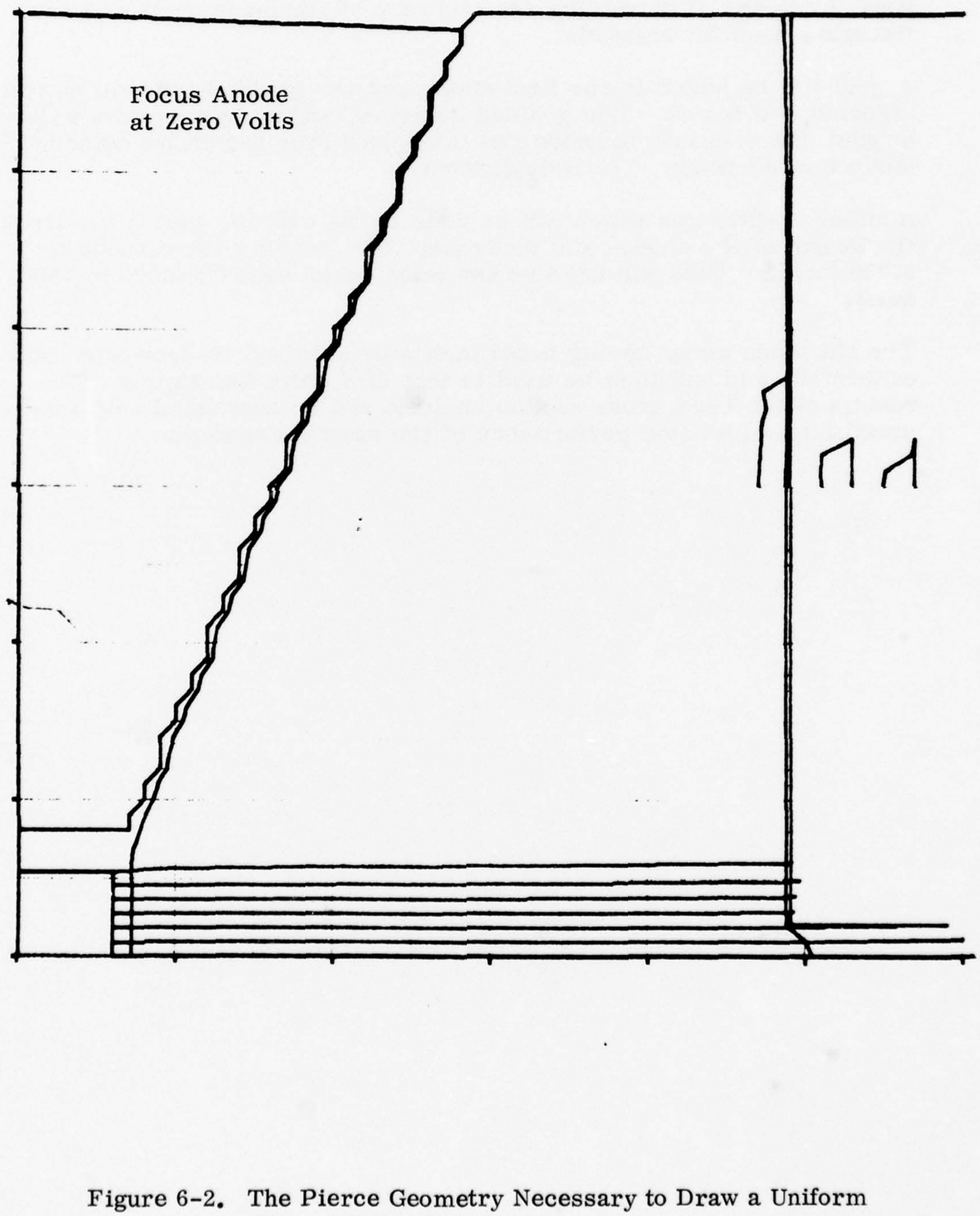

Figure 6-2. The Pierce Geometry Necessary to Draw a Uniform Beam Off the Cathode

7.0 PROGRAM FOR THE NEXT PERIOD

During the next four month period, effort will be directed at developing a method of producing election guns with improved cross-sectional profiles, by means of increasing the accuracy of the piece parts and the fixturing used for assembly.

A grid will be added to the first anode and the gridded gun will be constructed and tested. The gridded design should provide a more well-shaped beam because emission can take place over the entire cathode surface at all levels of cathode current.

Another modification which will be done to the existing gun is to increase the length of the anodes and focus electrode, leaving the cathode at 0.700 inches. This will improve the beam shape near the ends of the beam.

The slit diode array having 0.002 inch wide slits will be fabricated and calibrated, and will then be used to test EBS sheet beam guns. The results of the beam cross-section analysis will be correlated with measured intermodulation performance of the same electron gun.

Appendix I

RCTGUN I

```
C
C ..............................................................
C
C
C      RECTANGULAR GUN ANALYSIS PACKAGE
C
C      JOHN B RETTIG       1/31/79
C
C
C      MAIN DRIVER ROUTINE, PART I - EQUIPOTENTIAL SOLUTIONS
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 COND(9)
      REAL*8 X(200),Y(200),UX(200),UY(200)
      REAL*8 TITLE(4)
      INTEGER ICOND(9)
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DX0,
     *           YMIN,YMAX,DY0,
     *           M,N,NXY
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
      COMMON /D/ X,Y,UX,UY
      COMMON /E/ TITLE
      DATA BW /.2/
      DATA NEQP /31/
      DATA YEQP /4.5D-3/
      DATA RELERR /1.D-4/
      DATA ITER /20/
      DATA X1,X2,Y1,Y2 /0.,4.D-3,0.,6.D-3/
      DATA ENGMET /39.37/
C
C      READ IN INITIAL INFORMATION
C
      CALL INIT
C
C      READ IN VOLTAGES FROM PREVIOUS RUN
C
      READ(8) V
C
C      READ IN CONDUCTOR CONFIGURATION
C
      CALL MESH
C
C      RELAX VOLTAGE MATRIX
C
      ERRMAX=RELERR*(CMAX-CMIN)
      CALL RELAX (1,1,ERROR,ERRMAX)
      IF (ERROR.LT.ERRMAX)  GO TO 4
      KSTEP=1
    1 KSTEP=2*KSTEP
      IF (MOD(M-1,KSTEP).NE.0)  GO TO 2
      IF (MOD(N-1,KSTEP).NE.0)  GO TO 2
      GO TO 1
    2 KSTEP=KSTEP/2
```

```
      CALL RELAX (ITER,KSTEP,ERROR,ERRMAX)
      IF (ERROR.LT.ERRMAX)  GO TO 3
      CALL RELAX (ITER,1,ERROR,ERRMAX)
C
C        RECORD V MATRIX FOR NEXT USAGE
C
    3 REWIND 8
      WRITE(8) V
    4 WRITE(1,100)  ERROR
C
C        PLOT CONTOURS
C
      CALL CONPLT (BW,NEQP)
C
C        DETERMINE EQUIPOTENTIAL SURFACE IN VICINITY OF Y=YEQP
C
      VO=PINT(X1,Y1+.75*(Y2-Y1))-COFF
      CALL EQPTL (VO,X1,X2,Y1,Y2)
C
C        WRITE OUT THEN CONVERT TO INCHES
C
      WRITE(1,101)  VO
      DO 10  I=1,NXY
      WRITE(1,102)  X(I),Y(I)
      X(I)=X(I)*ENGMET
      Y(I)=Y(I)*ENGMET
   10 CONTINUE
C
C        GENERATE INPUT FILE FOR XMGUN
C
      WRITE(2,103)  TITLE(3),VO,VO
      X(1)=X(2)
      Y(1)=.2125
      NCARDS=1+(NXY-1)/7
      WRITE(2,104)  NCARDS,COND(2),COND(3)
      DO 20  I=1,NXY,7
      JF=MINO(8,NXY+1-I)
      WRITE(2,105)  (Y(NXY+2-I-J),X(NXY+2-I-J),J=1,JF)
   20 CONTINUE
      WRITE(2,106)
      STOP
  100 FORMAT (///' MAXIMUM CHANGE IN MESH ON LAST ITERATION = ',D12.4)
  101 FORMAT (///' COORDINATES IN METERS OF EQUIPOTENTIAL LINE ',
     *           ' VO = ',D12.4//6X,'X',11X,'Y'/)
  102 FORMAT (2D12.4)
  103 FORMAT (A8,2X,2F10.0,'     .10    6  2  2  100  60 10001001100',6X,
     *        '6.'/'.21251000..0115.015 .0115.050 .0115.100 .0115')
  104 FORMAT ('3',9X,I2,' 2',6X,2('1'F9.0))
  105 FORMAT (8(2F5.4))
  106 FORMAT ('.0    .200 .0    .017 .0149.017 .42911.017'
     *       /'.41421.081.1041.1254.1041.0807.119 .0807.44391.081'
     *       /3('.0',8X),'1.        .0         -.009875')
      END
C
C ..............................................................
```

```
C
      SUBROUTINE INIT
C
C         RECTANGULAR GUN ANALYSIS PACKAGE
C
C         JOHN B RETTIG        1/31/79
C
C
C         DATA INITIALIZATION ROUTINE
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 COND(9)
      REAL*8 TITLE(4)
      INTEGER ICOND(9)
      INTEGER NCHAR(9),LINE(120),SPACE
      DATA NCHAR /1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      DATA SPACE /1H /
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
      COMMON /E/ TITLE
      DATA CMINO /1.D4/
C
C         DATA DECK SETUP ON LOGICAL RECORD 3  (ALL UNITS MKS)
C
C         CARD     VARIABLE         FORMAT       DESCRIPTION
C
C          1         TITLE(1-2)      2A8     IDENTIFICATION
C
C          2         TITLE(3-4)      2A8     TITLE
C
C          3           M,N           2I5     V MESH SIZE
C
C          4         DXO,DYO         2D12.2  V MESH INCREMENTS (M)
C
C         5-13       ICOND,COND    I1,3X,   CONDUCTOR CODES - ICOND IS
C                                  F6.0     THE CHARACTER USED IN THE MESH
C                                           TO REPRESENT POTENTIAL COND
C                                           (9 OR LESS MAY BE SPECIFIED)
C
C         LAST                                 (END OF RECORD CARD)
C
C
      READ(3,100) (TITLE(I),I=1,4),M,N
      READ(3,101) DXO,DYO
C
C         ESTABLISH BOUNDARIES
C
      XMIN=0.
      XMAX=XMIN+DXO*DFLOAT(M-1)
      YMIN=0.
      YMAX=YMIN+DYO*DFLOAT(N-1)
```

```
C
C      WRITE OUT GEOMETRICAL AND INITIAL CONDITION INFORMATION
C
      WRITE(1,102)  (TITLE(I),I=1,4),M,N,
     *              XMIN,XMAX,DXO,
     *              YMIN,YMAX,DYO
C
C      READ CONDUCTOR CODING AND POTENTIALS
C
      DO 10  I=1,9
      NCOND=I
      READ(3,103,END=11) ICOND(I),COND(I)
 10   CONTINUE
C
 11   NCOND=NCOND-1
C
C      CALCULATE MAX, MIN, AND OFFSET
C
      CMIN=COND(1)
      CMAX=COND(1)
C
      DO 20  I=1,NCOND
      IF (CMIN.GT.COND(I))  CMIN=COND(I)
      IF (CMAX.LT.COND(I))  CMAX=COND(I)
 20   CONTINUE
      COFF=CMINO-CMIN
      RETURN
C
100   FORMAT (2A8/2A8/2I5)
101   FORMAT (3D12.4)
102   FORMAT (/////10X,'IDENT        ',2A8//10X,'TITLE        ',2A8///
     *   ' MESH SIZE IS ',I3,' * ',I3,' POINTS'//
     *   ' XMIN = ',D10.4,10X,'XMAX = ',D10.4,10X,'XINC = ',D10.4,
     *   ' METERS'//
     *   ' YMIN = ',D10.4,10X,'YMAX = ',D10.4,10X,'YINC = ',D10.4,
     *   ' METERS'//)
103   FORMAT (I1,3X,F6.0)
      END
C
C ...............................................................
C
      SUBROUTINE MESH
C
C      RECTANGULAR GUN ANALYSIS PACKAGE
C
C      JOHN B RETTIG       1/31/79
C
C      THIS ROUTINE SETS UP A BRAND NEW MESH OF CONDUCTORS IN THE
C      POTENTIAL MATRIX V.  ADVANTAGE IS TAKEN OF ANY PREVIOUS
C      SOLUTION OF A SIMILAR TYPE BY CHANGING ONLY THOSE MESH
C      VALUES WHERE A NEW CONDUCTOR IS LOCATED.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 COND(9)
```

```
      INTEGER ICOND(9)
      INTEGER NCHAR(9),LINE(120),SPACE
      DATA NCHAR /1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      DATA SPACE /1H /
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
C
C         DATA DECK SETUP ON LOGICAL RECORD 4 (CONDUCTOR GEOMETRY)
C
C         CARD     VARIABLE     FORMAT       DESCRIPTION
C
C          1-N                   M*A1     CONDUCTOR MESH CODES
C
C         LAST                            (END OF RECORD CARD)
C
C
C         READ IN CONDUCTOR INFORMATION
C
      DO 20  J=1,N
      READ(4,100) (LINE(I),I=1,M)
      DO 10  I=1,M
      V(I,J) = DMAX1(DABS(V(I,J)),CMINO)
      IF (LINE(I).EQ.SPACE)  GO TO 10
      DO 11  K=1,9
      KO=K
      IF (LINE(I).EQ.NCHAR(KO))  GO TO 12
 11   CONTINUE
      GO TO 30
 12   DO 13  K=1,NCOND
      K1=K
      IF(KO.EQ.ICOND(K1))  GO TO 14
 13   CONTINUE
      GO TO 30
 14   V(I,J)= -(COND(K1)+COFF)
 10   CONTINUE
 20   CONTINUE
      RETURN
 30   WRITE(1,101)  J,I,(LINE(I),I=1,M)
      STOP
C
100   FORMAT (120A1)
101   FORMAT (/////' INPUT MESH ERROR',10X,' LINE ',I5,
     *             10X,' CHARACTER ',I5//1X,120A1)
      END
C
C .....................................................................
C
      SUBROUTINE RELAX (ITER,KSTEPO,ERROR,ERRMAX)
C
C         RECTANGULAR GUN ANALYSIS PACKAGE
C
C         JOHN B RETTIG       1/31/79
```

```
C
C
C        THIS ROUTINE IMPLEMENTS THE 4-NODE DISCRETIZED LAPLACIAN
C        OPERATOR TO SOLVE LAPLACE'S EQUATION WITHIN A SPECIFIED
C        M*N MESH.  A SUCCESSIVE OVERRELAXATION TECHNIQUE IS
C        EMPLOYED TO PROVIDE FAST CONVERGENCE, ALONG WITH A SCHEME
C        THAT STARTS WITH A COARSE MESH AND SUCCESSIVELY WORKS TO
C        THE FINE MESH (I.E. EVERY SINGLE MESH POINT).  THE LARGEST
C        OF MESH GRADES EMPLOYED IS SPECIFIED BY KSTEP, WITH THE
C        RESTRICTION THAT KSTEP BE AN INTEGRAL DIVISOR OF BOTH (M-1)
C        AND (N-1).  AFTER EACH COARSE RELAXATION IS COMPLETE, THE
C        NEXT FINER MESH IS INTERPOLATED LINEARLY.  THIS INTERPOLATION
C        IS PERFORMED USING A FOUR NEAREST NEIGHBOR CALCULATION FIRST
C        FOR THOSE POINTS FALLING AT DISTANCE SQRT(2) FROM THE COARSE
C        MESH, AND THEN FOR THOSE POINTS FALLING AT DISTANCE (.5)
C        FROM THE COARSE MESH.
C        THE LAST FEW STEPS FOR THE FINEST GRADE MESH (KSTEP=1)
C        RELAXATION ARE GAUSS-SEIDEL (W=.25) IN ORDER TO SMOOTH OUT
C        THE ROUGH EDGES LEFT OVER FROM THE OVERRELAXATION.
C
C        IF KSTEPO=1, ONLY KSTEP=1 IS USED, AND THE PROGRAM WILL
C        REPEAT UNTIL ERROR<ERRMAX.  OTHERWISE, MORE COARSE MESHES ARE
C        USED TO START, WORKING TO THE FINER MESH AND REPEATING THIS
C        FINE MESH UNTIL ERROR<ERRMAX.  USE CAUTION WHEN CHOOSING ERRMAX
C        AS A 41*401 MESH TAKES ABOUT 4-5 MINUTES ON AN IBM 370/148
C        WITH ERRMAX SET TO .01 PERCENT OF THE MAXIMUM LESS MINIMUM
C        MESH POTENTIALS.
C
C        SEE CARNAHAN, LUTHER, AND WILKES, APPLIED NUMERICAL
C        METHODS, WILEY,1969, OR FORSYTHE AND WASOW, FINITE DIFFER-
C        ENCE METHODS FOR PDE, WILEY, 1960.
C
C        IF THE MESH IS NOT ENCLOSED BY CONDUCTORS, PERIODICITY OF
C        THE SOLUTION IS ASSUMED AND THE BOUNDARIES ARE FOLDED OVER
C        (I.E. MIRROR IMAGE SYMMETRY IS ASSUMED).  IF THIS CANNOT
C        BE TOLERATED, BE SURE TO SPECIFY CONDUCTORS ALL THE WAY
C        AROUND THE MESH.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
C
C        MESH COARSENESS LOOP
C
      KSTEP=2*KSTEPO
    1 KSTEP=MAXO(1,KSTEP/2)
      KOFF=KSTEP
      T=3.14159/DFLOAT(MINO(M/KSTEP,N/KSTEP))
      W=0.5/(1.+DSIN(T))
      IF (KSTEPO.EQ.1)  W=.25
      LMAX=ITER/KSTEP
      IO=1
```

```
      IF=M
      JO=1
      JF=N
C
C        RELAXATION LOOP
C
      DO 30  L=1,LMAX
      ERROR=0.
      DO 20  I=IO,IF,KSTEP
      IUP=I+KOFF
      IDN=I-KOFF
      IF (I.EQ.M)  IUP=IDN
      IF (I.EQ.1)  IDN=IUP
      DO 10  J=JO,JF,KSTEP
      VO=V(I,J)
      IF(VO.LT.0.) GO TO 10
      JUP=J+KOFF
      JDN=J-KOFF
      IF (J.EQ.N)  JUP=JDN
      IF (J.EQ.1)  JDN=JUP
      VOFF=W*(DABS(V(IDN,J))-VO+DABS(V(IUP,J))-VO
     *        +DABS(V(I,JDN))-VO+DABS(V(I,JUP))-VO)
      V(I,J)=VO+VOFF
      ERROR=DMAX1(ERROR,DABS(VOFF))
 10   CONTINUE
 20   CONTINUE
      WRITE(6,200)  L,KSTEP,W,ERROR
C
C        RETURN IF ERROR SATISFIED WITH FINEST MESH AND GAUSS-SEIDEL
C        HAS BEEN PERFORMED
C
      IF (KSTEP.EQ.1.AND.ERROR.LT.ERRMAX.AND.W.EQ..25)  RETURN
C
C        IF ALMOST COMPLETE, SWITCH TO GAUSS-SEIDEL
C
      IF (ERROR.LT.10.*ERRMAX.AND.KSTEP.EQ.1)  W=.25
C
 30   CONTINUE
C
C        CHECK IF INTERPOLATION NECESSARY FOR NEXT FINER MESH
C        OR IF COMPLETED
C
      IF (KSTEPO.EQ.1)  RETURN
      IF (KSTEP.EQ.1)  GO TO 1
C
C        INTERPOLATE INBETWEEN POINTS
C
      KOFF=KSTEP/2
      IO=1+KOFF
      IF=M-KOFF
      JO=1+KOFF
      JF=N-KOFF
C
C
C
```

```
      DC 50  J=J0,JF,KSTEP
      JUP=J+KOFF
      JDN=J-KOFF
      DC 40  I=I0,IF,KSTEP
      IF (V(I,J).LT.0.)  GO TO 40
      IUP=I+KOFF
      IDN=I-KOFF
      V(I,J)=.25*(DABS(V(IDN,JDN))+DABS(V(IUP,JDN))
     *             +DABS(V(IDN,JUP))+DABS(V(IUP,JUP)))
   40 CONTINUE
   50 CONTINUE
      I0=1+KOFF
      IF=M-KOFF
      J0=1
      JF=N
C
C
C
      DC 70  J=J0,JF,KSTEP
      JUP=J+KOFF
      JDN=J-KOFF
      IF (J.EQ.1)  JDN=JUP
      IF (J.EQ.N)  JUP=JDN
      DC 60  I=I0,IF,KSTEP
      IF(V(I,J).LT.0.) GO TO 60
      IUP=I+KOFF
      IDN=I-KOFF
      V(I,J)=.25*(DABS(V(IDN,J))+DABS(V(IUP,J))
     *             +DABS(V(I,JDN))+DABS(V(I,JUP)))
   60 CONTINUE
   70 CONTINUE
      I0=1
      IF=M
      J0=1+KOFF
      JF=N-KOFF
      DC 90  J=J0,JF,KSTEP
      JUP=J+KOFF
      JDN=J-KOFF
      DC 80  I=I0,IF,KSTEP
      IF(V(I,J).LT.0.) GO TO 80
      IUP=I+KOFF
      IDN=I-KOFF
      IF (I.EQ.M)  IUP=IDN
      IF (I.EQ.1)  IDN=IUP
      V(I,J)=.25*(DABS(V(IDN,J))+DABS(V(IUP,J))
     *             +DABS(V(I,JDN))+DABS(V(I,JUP)))
   80 CONTINUE
   90 CONTINUE
      GC TO 1
  200 FORMAT ('***',2I10,F10.4,F10.2)
      END
C
C ...............................................................
C
      SUBROUTINE CONPLT (BW,NEQP)
```

```
C
C     RECTANGULAR GUN ANALYSIS PACKAGE
C
C     JOHN B RETTIG       1/31/79
C
C
C     THIS ROUTINE GENERATES A CONTOUR EQUIPOTENTIAL PLOT ON THE
C     LINE PRINTER.  CONDUCTORS, CODED AS NEGATIVE NUMBERS IN THE
C     MESH, ARE SYMBOLIZED BY DIGITS FROM 1-9, ACCORDING TO THE
C     SCHEME SET UP IN THE ARRAYS ICOND AND COND.  OPEN SPACES
C     ARE REPRESENTED BY LETTERS ACCORDING TO THE VALUES OF BW AND
C     NEQP.  THE PARAMETER NEQP IS THE NUMBER OF DESIRED EQUI-
C     POTENTIALS (MAXIMUM 48), WHILE BW IS A BANDWIDTH SPECIFIER.
C     THE WAY THE PARAMETER BW WORKS IS BEST ILLUSTRATED BY AN
C     EXAMPLE.
C
C            ASSUME NEQP=4, BW=.10, AND 10 < V < 40
C
C                 A        9 < V < 11
C                 B       19 < V < 21
C                 C       29 < V < 31
C                 D       39 < V < 41
C
C            HOWEVER, IF BW=.50 WITH ALL ELSE THE SAME
C
C                 A      7.5 < V < 12.5
C                 B     17.5 < V < 22.5
C                 C     27.5 < V < 32.5
C                 D     37.5 < V < 42.5
C
C     THUS, BW=0 WILL PRINT A BLANK PAGE, AND BW=1 WILL PRINT A
C     SOLID PAGE OF CHARACTERS.
C
C     THE PARAMETER NEQP MIGHT BE ADJUSTED BY THE PROGRAM TO
C     OBTAIN AESTHETIC EQUIPOTENTIAL SPACINGS.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 COND(9)
      INTEGER ICOND(9)
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
      DATA MAX /120/
      INTEGER NCHAR(9),ACHAR(48),SPACE,UNIDNT,PRT(120)
      DATA NCHAR /1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      DATA ACHAR /1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,
     *            1HJ,1HK,1HL,1HM,1HN,1HP,1HQ,1HR,
     *            1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ,
     *            1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,
     *            1HJ,1HK,1HL,1HM,1HN,1HP,1HQ,1HR,
     *            1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ/
      DATA SPACE /1H /, UNIDNT /1H*/
```

```
      VINC=(CMAX-CMIN)/DFLOAT(NEQP-1)
      VLINC=DLOG10(VINC)
      IEXP=IDINT(1.01*VLINC)
      IFRCT=IDINT(1.01*10.**(VLINC-DFLOAT(IEXP)))
      IF (IFRCT.EQ.7.OR.IFRCT.EQ.9)  IFRCT=IFRCT+1
      VINC=DFLOAT(IFRCT)*10.**IEXP
      IMIN=IDINT(1.001*CMIN/VINC)
      IMAX=1+IDINT(.999*CMAX/VINC)
      NEQP=IMAX-IMIN+1
      WRITE(1,100)
      DO 10  I=1,NCOND
      WRITE(1,101)  ICOND(I),COND(I)
 10   CONTINUE
      WRITE(1,102) BW
      DO 20  I=1,NEQP
      VCENT=DFLOAT(IMIN+I-1)*VINC
      VLO=VCENT-VINC*BW/2.
      VHI=VCENT+VINC*BW/2.
      WRITE(1,103)  ACHAR(I),VLO,VCENT,VHI
 20   CONTINUE
      WRITE(1,104)
      MO=MIN0(MAX,M)
      IOFF=0
 40   DO 60  J=1,N
      DO 50  IO=1,MO
      I=IO+IOFF
      PRT(IO)=SPACE
      VO=V(I,J)
      IF (VO.LT.0.)  GO TO 51
      V1=(VO-COFF)/VINC+BW/2.
      IV1=IDINT(V1)
      IF(DABS(V1-DFLOAT(IV1)).GT.BW)  GO TO 50
      PRT(IO)=ACHAR(IV1-IMIN+1)
      GO TO 50
 51   DO 52  K=1,NCOND
      KO=K
      IF (-VO.EQ.COND(KO)+COFF)  GO TO 53
 52   CONTINUE
      PRT(IO)=JNIDNT
      GO TO 50
 53   IV1=ICOND(KO)
      PRT(IO)=NCHAR(IV1)
 50   CONTINUE
      WRITE(1,105)  (PRT(I),I=1,MO)
 60   CONTINUE
      IF (MO+IOFF.GE.M)  RETURN
      IOFF=IOFF+MO
      MO=MIN0(M-IOFF,MO)
      WRITE(1,104)
      GO TO 40
100   FORMAT (/////' ***** CONDUCTOR CODES *****'//
     *        10X,' CODE     VOLTS'/)
101   FORMAT (12X,I1,F12.2)
102   FORMAT (/////' ***** POTENTIAL CODES *****'//
     *        10X,' WINDOW = ',F6.4//
```

```
     *              ' CODE          LOW           MEAN           HIGH'/)
103   FORMAT(2X,A1,4X,3F12.2)
104   FORMAT (1H1/1H0)
105   FORMAT (1X,120A1)
      END
C
C ...................................................................
C
      SUBROUTINE EQPTL (V0,X1,X2,Y1,Y2)
C
C         RECTANGULAR GUN ANALYSIS PACKAGE
C
C         JOHN B RETTIG        1/31/79
C
C
C         THIS PROGRAM LOCATES AND PROVIDES COORDINATES FOR THE
C         EQUIPOTENTIAL LINE OF VALUE V0, IN THE V MESH.  A LINEAR
C         INTERPOLATION IS PERFORMED BETWEEN MESH POINTS.  IT IS
C         ASSUMED THAT THE VOLTAGE MATRIX V IS STRICTLY MONOTONIC
C         IN THE Y DIRECTION, WITHIN A REGION ABOUT THE EQUIPOTENTIAL
C         LINE.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 X(200),Y(200),UX(200),UY(200)
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DX0,
     *             YMIN,YMAX,DY0,
     *             M,N,NXY
      REAL*8 COND(9)
      INTEGER ICOND(9)
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
      COMMON /D/ X,Y,UX,UY
      V1=V0+COFF
      I1=MAX0(1,1+IDINT((X1-XMIN)/DX0))
      I2=MIN0(M,1+IDINT((X2-XMIN)/DX0))
      J1=MAX0(1,1+IDINT((Y1-YMIN)/DY0))
      J2=MIN0(N,1+IDINT((Y2-YMIN)/DY0))
      NXY=0
      DO 10  I=I1,I2
      JDN=J1
      JUP=J2
      VDN=DABS(V(I,JDN))-V1
      VUP=DABS(V(I,JUP))-V1
      IF (VDN*VUP)  1,10,10
    1 JMD=(JDN+JUP)/2
      VMD=DABS(V(I,JMD))-V1
      IF (JDN.EQ.JMD)  GO TO 4
      IF (VDN*VMD)  2,10,3
    2 JUP=JMD
      VUP=VMD
      GO TO 1
    3 JDN=JMD
      VDN=VMD
      GO TO 1
```

```
 4    NXY=NXY+1                                                         EQP00510
      DJ=0.                                                             EQP00520
      IF (VDN.EQ.VUP)  GO TO 5                                          EQP00530
      DJ=VDN/(VUP-VDN)                                                  EQP00540
 5    X(NXY)=XMIN+DFLOAT(I-1)*DX0                                       EQP00550
      Y(NXY)=YMIN+DY0*(DFLOAT(JMD-1)-DJ)                                EQP00560
10    CONTINUE                                                          EQP00570
      RETURN                                                            EQP00580
      END                                                               EQP00590
C                                                                       PIN00010
C ....................................................................  PIN00020
C                                                                       PIN00030
      FUNCTION PINT (X,Y)                                               PIN00040
C                                                                       PIN00050
C        RECTANGULAR GUN ANALYSIS PACKAGE                               PIN00060
C                                                                       PIN00070
C        JOHN B RETTIG        1/31/79                                   PIN00080
C                                                                       PIN00090
C                                                                       PIN00100
C        PINT INTERPOLATES THE V MATRIX IN BETWEEN THE MESH POINTS      PIN00110
C        USING A 4 POINT LINEAR INTERPOLATION.  IF ANY BOUNDARY IS      PIN00120
C        EXCEEDED, MIRROR IMAGE SYMMETRY IS ASSUMED ABOUT THAT          PIN00130
C        BOUNDARY AND THE INTERPOLATION PERFORMED AS IF THE POINT       PIN00140
C        FELL IN THE MESH.                                              PIN00150
C                                                                       PIN00160
      IMPLICIT REAL*8 (A-H,O-Z)                                         PIN00170
      REAL*8 V(41,401)                                                  PIN00180
      COMMON /A/ V                                                      PIN00190
      COMMON /B/ XMIN,XMAX,DX0,                                         PIN00200
     *           YMIN,YMAX,DY0,                                         PIN00210
     *           M,N,NXY                                                PIN00220
      XINT=X                                                            PIN00230
      YINT=Y                                                            PIN00240
      IF (X.LT.XMIN)  XINT=2.*XMIN-X                                    PIN00250
      IF (Y.LT.YMIN)  YINT=2.*YMIN-Y                                    PIN00260
      IF (X.GT.XMAX)  XINT=2.*XMAX-X                                    PIN00270
      IF (Y.GT.YMAX)  YINT=2.*YMAX-Y                                    PIN00280
      X0=DFLOAT(M-1)*(XINT-XMIN)/(XMAX-XMIN)                            PIN00290
      Y0=DFLOAT(N-1)*(YINT-YMIN)/(YMAX-YMIN)                            PIN00300
      IX=1+IDINT(X0)                                                    PIN00310
      IY=1+IDINT(Y0)                                                    PIN00320
      FX=X0-DFLOAT(IX-1)                                                PIN00330
      FY=Y0-DFLOAT(IY-1)                                                PIN00340
      V0=DABS(V(IX,IY))                                                 PIN00350
      V1=DABS(V(IX+1,IY))                                               PIN00360
      V2=DABS(V(IX,IY+1))                                               PIN00370
      V3=DABS(V(IX+1,IY+1))                                             PIN00380
      DV1=V0+(V1-V0)*FX                                                 PIN00390
      DV2=V2+(V3-V2)*FX                                                 PIN00400
      PINT=DV1+(DV2-DV1)*FY                                             PIN00410
      RETURN                                                            PIN00420
      END                                                               PIN00430
```

Appendix II

RCTGUN III

```
C
C ....................................................................
C
C        RECTANGULAR GUN ANALYSIS PACKAGE
C
C        JOHN B RETTIG        1/31/79
C
C        MAIN DRIVER ROUTINE, PART III- TRAJECTORY CALCULATIONS
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 COND(9)
      REAL*8 X(200),Y(200),UX(200),UY(200)
      INTEGER ICOND(9)
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
      COMMON /D/ X,Y,UX,UY
      COMMON /E/ TITLE1,TITLE2,TITLE3,TITLE4
      CALL INIT
      READ(8) V
      CALL TRAJ
      STOP
      END
C
C ....................................................................
C
      SUBROUTINE INIT
C
C        RECTANGULAR GUN ANALYSIS PACKAGE
C
C        JOHN B RETTIG        1/31/79
C
C
C        DATA INITIALIZATION ROUTINE
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      REAL*8 COND(9)
      REAL*8 TITLE(4)
      INTEGER ICOND(9)
      INTEGER NCHAR(9),LINE(120),SPACE
      DATA NCHAR /1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      DATA SPACE /1H /
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /C/ COND,ICOND,NCOND,CMIN,CMAX,COFF
      COMMON /E/ TITLE
      DATA CMINO /1.D4/
C
C        DATA DECK SETUP ON LOGICAL RECORD 3  (ALL UNITS MKS)
```

```
C
C     CARD     VARIABLE         FORMAT         DESCRIPTION
C
C      1        TITLE(1-2)      2A8       IDENTIFICATION
C
C      2        TITLE(3-4)      2A8       TITLE
C
C      3           M,N          2I5       V MESH SIZE
C
C      4        DXO,DYO         2E12.2    V MESH INCREMENTS (M)
C
C     5-13      ICOND,COND      I1,3X,    CONDUCTOR CODES - ICOND IS
C                                F6.0     THE CHARACTER USED IN THE MESH
C                                         TO REPRESENT POTENTIAL COND
C                                         (9 OR LESS MAY BE SPECIFIED)
C
C     LAST                                      (END OF RECORD CARD)
C
C
      READ(3,100) (TITLE(I),I=1,4),M,N
      READ(3,101) DXO,DYO
C
C     ESTABLISH BOUNDARIES
C
      XMIN=0.
      XMAX=XMIN+DXO*CFLOAT(M-1)
      YMIN=0.
      YMAX=YMIN+DYO*CFLOAT(N-1)
C
C     WRITE OUT GEOMETRICAL AND INITIAL CONDITION INFORMATION
C
      WRITE(1,102)  (TITLE(I),I=1,4),M,N,
     *              XMIN,XMAX,DXO,
     *              YMIN,YMAX,DYO
C
C     READ CONDUCTOR CODING AND POTENTIALS
C
      DO 10  I=1,9
      NCOND=I
      READ(3,103,END=11) ICOND(I),COND(I)
   10 CONTINUE
C
   11 NCOND=NCOND-1
C
C     CALCULATE MAX, MIN, AND OFFSET
C
      CMIN=COND(1)
      CMAX=COND(1)
C
      DO 20  I=1,NCOND
      IF (CMIN.GT.COND(I))  CMIN=COND(I)
      IF (CMAX.LT.COND(I))  CMAX=COND(I)
   20 CONTINUE
      COFF=CMINO-CMIN
      RETURN
```

```
C
100   FORMAT (2A8/2A8/2I5)
101   FORMAT (3D12.4)
102   FORMAT (/////10X,'IDENT        ',2A8//10X,'TITLE        ',2A8///
     *   ' MESH SIZE IS ',I3,' * ',I3,' POINTS'//
     *   ' XMIN = ',D10.4,10X,'XMAX = ',D10.4,10X,'XINC = ',D10.4,
     *   ' METERS'//
     *   ' YMIN = ',D10.4,10X,'YMAX = ',D10.4,10X,'YINC = ',D10.4,
     *   ' METERS'//)
103   FORMAT (I1,3X,F6.0)
      END
C
C ..........................................................................
C
      SUBROUTINE TRAJ
C
C         RECTANGULAR GUN ANALYSIS PACKAGE
C
C         JOHN B RETTIG       1/31/79
C
C
C         THIS PROGRAM FINDS THE TRAJECTORY OF A CHARGED PARTICLE IN
C         THE PRESENCE OF AN ELECTRIC FIELD CREATED BY CONDUCTORS OF
C         VARIOUS POTENTIALS.  THERMAL EFFECTS, RELATIVITY, AND SPACE
C         CHARGE EFFECTS ARE NOT TAKEN INTO ACCOUNT.  FIELD GRADIENTS
C         ARE TAKEN FROM THE POTENTIAL MATRIX V (ASSUMED TO HAVE ALREADY
C         BEEN SOLVED BY SOME MEANS).  THEN, A DISCRETIZED FOURTH
C         ORDER DISCRETIZED RUNGE-KUTTA INTEGRATION SCHEME IS USED TO
C         PIECE OUT THE PATH OF THE PARTICLE THROUGH THE MATRIX.
C
C         IF DESIRED, PARTICLES MAY BE BOUNCED OFF OF BOUNDARIES ABOUT
C         WHICH THE FIELD IS ASSUMED TO BE MIRROR IMAGE SYMMETRICAL.
C
C
C
C         DATA DECK SETUP ON LOGICAL RECORD 5
C
C         CARD     VARIABLE      FORMAT       DESCRIPTION
C
C           1    X1,Y1,U1,P1    3D12.4,    INITIAL POSITION AND VELOCITY
C                               F12.2      FOR PARTICLE 1 - X1 AND Y1 IN
C                                          METERS, U1 IN METERS/S, P1 IN
C                                          DEGREES FROM +X AXIS
C
C           2+                             (SAME FOR PARTICLE 2, ETC)
C
C         LAST                             (END OF RECORD CARD)
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 X(200),Y(200),UX(200),UY(200)
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /C/ CONC,ICOND,NCOND,CMIN,CMAX,COFF
```

```
      COMMON /D/ X,Y,UX,UY
      REAL*8 F(4),Z(4)
      EQUIVALENCE (X1,Z(1)),(Y1,Z(2)),(UX1,Z(3)),(UY1,Z(4))
      INTEGER RUNGE
      DATA TMIN /0./
      DATA DT /2.D-11/
      DATA PI /3.141592653D+0/
C
C        ELECTRON CHARGE/MASS, MKS
C
      DATA ETA /1.758794SD11/
      TMAX=TMIN+2.*(YMAX-YMIN)/DSQRT(2.*ETA*(CMAX-CMIN))
C
      I=0
 10   I=I+1
      READ(5,100,END=30) X1,Y1,U1,P1
      R0=(PI/180.)*P1
      UX1=U1*DCOS(R0)
      UY1=U1*DSIN(R0)
      X(1)=X1
      Y(1)=Y1
      UX(1)=UX1
      UY(1)=UY1
      NXY=1
      T=TMIN
C
C        COMPUTE STEP
C
 11   K=RUNGE (4,Z,F,T,DT)
C
C        K=1 FLAGS THAT DERIVATIVES ARE NEEDED
C
      IF (K.NE.1)  GO TO 12
C
C        COMPUTE GRADIENTS IN POTENTIAL USING CENTRAL DIFFERENCES
C
      VXH=PINT(X1+.5*DX0,Y1)
      VXL=PINT(X1-.5*DX0,Y1)
      VYH=PINT(X1,Y1+.5*DY0)
      VYL=PINT(X1,Y1-.5*DY0)
C
      GRADVX=(VXH-VXL)/DX0
      GRADVY=(VYH-VYL)/DY0
C
C        COMPUTE DERIVATIVES AND CONTINUE RUNGE INTEGRATION
C
C           - F(1)=DX/DT=UX
C           - F(2)=DY/DT=UY
C           - F(3)=DUX/DT=ETA*GRADVX
C           - F(4)=DUY/DT=ETA*GRADVY
C
      F(1)=UX1
      F(2)=UY1
      F(3)=ETA*GRADVX
      F(4)=ETA*GRADVY
```

```
C
      GO TO 11
C
 12   NXY=NXY+1
C
C        BOUNCE OFF DESIRED BOUNDARIES
C
      IF (X1.GT.XMIN)  GO TO 13
      X1 =2.*XMIN-X1
      UX1 =-UX1
 13   CONTINUE
C     IF (Y1.GT.YMIN)  GO TO 14
C     Y1=2.*YMIN-Y1
C     UY1=-UY1
C14   CONTINUE
C     IF (X1 .LT.XMAX)  GO TO 15
C     X1 =2.*XMAX-X1
C     UX1 =-UX1
C15   CONTINUE
C     IF (Y1.LT.YMAX)  GO TO 16
C     Y1=2.*YMAX-Y1
C     UY1=-UY1
C16   CONTINUE
C
C        RECORD POSITIONS
C
      X(NXY)=X1
      Y(NXY)=Y1
      UX(NXY)=UX1
      UY(NXY)=UY1
C
C        CHECK LIMITS
C
      IF (X1.LT.XMIN.OR.X1.GT.XMAX.OR.Y1.LT.YMIN.OR.Y1.GT.YMAX
     *            .OR.T.GT.TMAX.OR.NXY.EQ.200)  GO TO 20
      GO TO 11
C
C        PRINT AND PLOT INFORMATION
C
 20   WRITE(1,101) I
      DO 21  K=1,NXY
      T=TMIN+DFLOAT(K-1)*DT
      U=DSQRT(UX(K)*UX(K)+UY(K)*UY(K))
      ANG=(180./PI)*DATAN2(UY(K),UX(K))
      WRITE(1,102)  T,X(K),Y(K),U,ANG
 21   CONTINUE
      CALL TJPLOT
      GO TO 10
 30   CALL POFF
      RETURN
C
100   FORMAT (3D12.4,F12.2)
101   FORMAT (/////10X,' ***** PARTICLE ',I2,' *****'//
     *    6X,'T(S)',8X,'X(M)',8X,'Y(M)',8X,'U(M/S)',6X,'ANGLE')
102   FORMAT (1X,4D12.3,F10.2)
```

```
      END
C
C ...............................................................
C
      FUNCTION RUNGE (N,Y,F,X,H)
C
C         RECTANGULAR GUN ANALYSIS PACKAGE
C
C         JOHN B RETTIG       1/31/79
C
C
C         FOURTH ORDER RUNGE-KUTTA INTEGRATION
C
C         COPIED FROM CARNAHAN, LUTHER, & WILKES, 'APPLIED NUMERICAL
C         METHODS', NEW YORK, WILEY, 1969, PP 374-5.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER RUNGE
      REAL*8 PHI(4),SAVEY(4),Y(N),F(N)
      DATA M/0/
C
      M=M+1
      GO TO (1,2,3,4,5),M
C
C     ....PASS 1....
  1   RUNGE=1
      RETURN
C
C     ....PASS 2....
  2   DO 22  J=1,N
      SAVEY(J)=Y(J)
      PHI(J)=F(J)
 22   Y(J)=SAVEY(J)+0.5*H*F(J)
      X=X+0.5*H
      RUNGE=1
      RETURN
C
C     ....PASS 3....
  3   DO 33  J=1,N
      PHI(J)=PHI(J)+2.0*F(J)
 33   Y(J)=SAVEY(J)+0.5*H*F(J)
      RUNGE=1
      RETURN
C
C     ....PASS 4....
  4   DO 44  J=1,N
      PHI(J)=PHI(J)+2.0*F(J)
 44   Y(J)=SAVEY(J)+H*F(J)
      X=X+0.5*H
      RUNGE=1
      RETURN
C
C     ....PASS 5....
  5   DO 55  J=1,N
 55   Y(J)=SAVEY(J)+(PHI(J)+F(J))*H/6.0
```

```
      M=0
      RUNGE=0
      RETURN
C
      END
C
C ..............................................................
C
      FUNCTION PINT (X,Y)
C
C        RECTANGULAR GUN ANALYSIS PACKAGE
C
C        JOHN B RETTIG         1/31/79
C
C
C        PINT INTERPOLATES THE V MATRIX IN BETWEEN THE MESH POINTS
C        USING A 4 POINT LINEAR INTERPOLATION.  IF ANY BOUNDARY IS
C        EXCEEDED, MIRROR IMAGE SYMMETRY IS ASSUMED ABOUT THAT
C        BOUNDARY AND THE INTERPOLATION PERFORMED AS IF THE POINT
C        FELL IN THE MESH.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 V(41,401)
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      XINT=X
      YINT=Y
      IF (X.LT.XMIN)  XINT=2.*XMIN-X
      IF (Y.LT.YMIN)  YINT=2.*YMIN-Y
      IF (X.GT.XMAX)  XINT=2.*XMAX-X
      IF (Y.GT.YMAX)  YINT=2.*YMAX-Y
      XO=DFLOAT(M-1)*(XINT-XMIN)/(XMAX-XMIN)
      YO=DFLOAT(N-1)*(YINT-YMIN)/(YMAX-YMIN)
      IX=1+IDINT(XO)
      IY=1+IDINT(YO)
      FX=XO-DFLOAT(IX-1)
      FY=YO-DFLOAT(IY-1)
      VO=DABS(V(IX,IY))
      V1=DABS(V(IX+1,IY))
      V2=DABS(V(IX,IY+1))
      V3=DABS(V(IX+1,IY+1))
      DV1=VO+(V1-VO)*FX
      DV2=V2+(V3-V2)*FX
      PINT=DV1+(DV2-DV1)*FY
      RETURN
      END
C
C ..............................................................
C
      SUBROUTINE TJPLOT
C
C        RECTANGULAR GUN ANALYSIS PACKAGE
C
```

```
C         JOHN B RETTIG       1/31/79
C
C
C         TRAJECTORY PLOT SETUP FOR THE ZETA PLOTTER
C
      REAL*8 V(41,401)
      REAL*8 X(200),Y(200),UX(200),UY(200)
      REAL*8 XMIN,XMAX,DXO,YMIN,YMAX,DYO,TMIN,TMAX,DT
      COMPLEX*16 IDENT,TITLE
      COMMON /A/ V
      COMMON /B/ XMIN,XMAX,DXO,
     *           YMIN,YMAX,DYO,
     *           M,N,NXY
      COMMON /D/ X,Y,UX,UY
      COMMON /E/ IDENT,TITLE
      DATA WIDTH /4./
      DATA IFLAG /0/
C
C         FIRST TIME THROUGH?
C
      IF (IFLAG.NE.0)  GO TO 50
      IFLAG=1
      CALL PLOTF (10,2)
      CALL FACTOR (2.)
C
C         DEFINE SCALES
C
      XL=WIDTH
      YL=WIDTH*SNGL((YMAX-YMIN)/(XMAX-XMIN))
      DX=SNGL(XMAX-XMIN)/XL
      DY=SNGL(YMAX-YMIN)/YL
      XO=SNGL(XMIN)
      YO=SNGL(YMIN)
C
C         TITLE
C
      CALL SYMBOL (YL/3.,XL+1.,.15,IDENT,0.,16)
      CALL SYMBOL (YL/3.,XL+.50,.15,TITLE,0.,16)
C
C         SCALE ALL FUTURE PLOTTING TO GUN DIMENSIONS
C
      CALL OFFSET (YO,DY,XO,DX)
C
C         DRAW CONDUCTORS
C
      DO 20  I=1,M
      XO=SNGL(DXO)*FLOAT(I-1)
      JTEST=0
      DO 10  J=1,N
      IF (V(I,J).LT.0..AND.JTEST.EQ.0)  GO TO 11
      IF (V(I,J).GT.0..AND.JTEST.EQ.1)  GO TO 12
      IF (J.EQ.N.AND.JTEST.EQ.1)  GO TO 12
      GO TO 10
   11 JTEST=1
      JSTART=J
```

```
      GO TO 10
 12   JTEST=0
      JSTOP=J-1
      IF (J.EQ.N)  JSTOP=J
      IF(JSTART.EQ.JSTOP)  GO TO 10
      YO=SNGL(DYO)*FLOAT(JSTART-1)
      CALL PLOTX (YO,XO,13)
      YO=SNGL(DYO)*FLOAT(JSTOP-1)
      CALL PLOTX (YO,XO,12)
 10   CONTINUE
 20   CONTINUE
C
      DO 40  J=1,N
      YO=SNGL(DYO)*FLOAT(J-1)
      ITEST=0
      DO 30  I=1,M
      IF (V(I,J).LT.O..AND.ITEST.EQ.0)  GO TO 31
      IF (V(I,J).GT.O..AND.ITEST.EQ.1)  GO TO 32
      IF (I.EQ.M.AND.ITEST.EQ.1)  GO TO 32
      GO TO 30
 31   ITEST=1
      ISTART=I
      GO TO 30
 32   ITEST=0
      ISTOP=I-1
      IF (I.EQ.M)  ISTOP=I
      IF(ISTART.EQ.ISTOP)  GO TO 30
      XO=SNGL(DXO)*FLOAT(ISTART-1)
      CALL PLOTX (YO,XO,13)
      XO=SNGL(DXO)*FLOAT(ISTOP-1)
      CALL PLOTX (YO,XO,12)
 30   CONTINUE
 40   CONTINUE
 50   CALL LINE (Y,X,NXY,2,0,12)
      RETURN
C
      END
```

Appendix III

BEAMSPREAD

```
gular  *"
1: prt "*  Beams
 pread  *";spc 2
2: dim Q$[1],
 R[3],A$[3,20]
3: 1.758e11→N;
 8.856e-12→E;
 flt 3
4: cfg 13;enp
 "Number of disc
 rete intervals?
 ",M;if flg13;
 jmp 0
5: dim J[2,M],
 Y[0:M]
6: cfg 13;enp
 "Spacing of
 intervals (M)?"
 ,S;if flg13;
 jmp 0
7: dsp "Enter
 initial current
  densities";
 wait 2000
8: for I=1 to M
9: enp J[1,I];
 next I
10: ""→Q$;ent
 "Want profile
 plot(Y/N)?",Q$
11: cfg 0;if
 cap(Q$)="Y";
 sfg 0;0→R[1];
 9→R[2];12→R[3];
 trk 0;ldf 10
12: if not flg0;
 gto "Drift"
13: plt 0,0,1
14: for I=1 to M
15: plt S(I-1),
 J[1,I],2
```

```
19: flt 3
20: "Drift":
21: cfg 13;enp
 "Acceleration
 potential (kV)?
 ",V;if flg13;
 jmp 0
22: cfg 13;enp
 "Drift space
 (M)?",D;if flg1
 3;jmp 0
23: 0→K→Y[0];
 (1000V)↑(-3/
 2)DD/4E√(2N)→C
24: for I=1 to
 M;K+SJ[1,I]→K
25: IS+CK→Y[I];
 J[1,I](S/(Y[I]-
 Y[I-1]))→J[2,I]
26: spc ;prt "Y
 = ",Y[I],"J =
 ",J[2,I]
27: next I;spc
28: prt "K = ",
 K," A/M";spc 3
29: if not flg0;
 gto "Drift"
30: plt 0,0,1
31: for I=1 to M
32: plt Y[I-1],
 J[2,I],2
33: plt Y[I],
 J[2,I],2
34: next I
35: plt Y[M],0,
 2;pen
36: gto "Drift"
37: end
```

Appendix IV

CONVOLVE

```
Beam      * ,"
Convolution  *
";spc 2
1: dim M[2];dim
 G[-16:16];dim
 Y[65];dim N[3];
 rad
2: enp "Diode
 spacing?",S,
 "Diode width?",
 W
3: enp "No. beam
  points?",Q,
 "Increment betw
 een points?",D
4: enp "Start
 beam drive?",
 N[1],"End beam
 drive?",N[3],
 "Increment?",
 N[2]
5: enp "Pos.
 sens.?",M[1],
 "Neg. sens.?",
 M[2],"Data sour
 ce?",r2
6: if r2#0;enp
 "File?",r9;jmp
 3
7: enp "Beam
 type?",r16
8: if r16;enp
 "Truncation?",
 r17
9: enp "Highest
 harmonic?",C,
 "Plot?",r8,"Sat
 uration drop?",
 r12
10: if r8=1;sfg
 1
[illegible]
14: if r8=2;sfg
 3
15: dim F[-Q:Q]
16: if N[2]=0;
 jmp 3
17: (N[3]-N[1])/
 N[2]→r5
18: dim P[2,0:r5
 +1]
19: W+S→L
20: "Beam":cll
 'Generate'(Q)
21: cll 'Zero'
22: enp "DC Tran
 sfer?",r1
23: if r1;cll
 'DC'
24: fmt 2,f6.2,
 2x,e8.2
25: spc ;flt 4;
 prt "Beam profi
 le";spc
26: for I=-Q to
 Q;wrt 16.2,ID,
 F[I];next I
27: N[1]→r3;0→r1
28: "Response":s
 pc
29: cll 'Convolv
 e'
30: cll 'Fourier
 '(C)
31: cll 'Efficie
 ncy'
32: if N[2]=0;
 gto "Quit"
33: (r3-N[1])/
 N[2]→r4
34: r3↑2→P[1,r4]
35: [illegible]
```

```
"Response"
37: max(F[*])→r1
 3;0→I
38: if F[I]>=.5r
 13;jmp 2
39: I-1>0→I;jmp
 -1
40: min(S+ID,S-
 ID+W)→r3
41: cll 'Convolv
 e'
42: cll 'Fourier
 '
43: A[1]↑2→P[2,
 r5+1]
44: dsp "Transfe
 r plot"
45: stp
46: scl -20,10,-
 20,10
47: axe 0,0,2,2;
 sfg 14
48: for I=0 to
 r5;10log(P[1,
 I]/r3↑2)→X;10lo
 g(P[2,I]/P[2,
 r5+1])→Y
49: prt "Pin",X,
 "Pout",Y;spc
50: if X<-20;-
 20→X
51: if Y<-20;-
 20→Y
52: plt X,Y
53: next I
54: pen;plt -20,
 -20;pen
55: "Quit":prt
 "***************
 **";spc 3;end
56: "Generate":i

 ture
58: if r16;jmp 3
59: for I=-p1
 to p1;1→F[I]
60: next I;jmp 6
61: for I=-p1
 to p1;if (exp(-
 6.9I↑2/Q↑2)→F[I
 ])>r17;r17→F[I]
62: next I;jmp 4
63: "Data":for
 I=-p1 to p1;
 ent F[I]
64: next I
65: trk 1;rcf
 r9,F[*];trk 0
66: ret
67: "Tape":trk
 1;ldf r9,F[*];
 trk 0
68: ret
69: "Fourier":π/
 32→p2
70: gsb "Foure"
71: if p1=0;gto
 "Finish"
72: prt "Fourier
  Current Harmon
 ics (dB)";spc
73: fmt 0,f1.0,
 f8.2
74: if (abs(A[0]
 /A[1])→r7)>1e-
 10;wrt 16,"A[",
 0,"] = ",20log(
 r7)
75: for I=1 to N
76: if (abs(A[I]
 /A[1])→r7)>1e-
 10;wrt 16,"A[",
```

```
 10;wrt 16,"B[",
 I,"] = ",20log(
 r7)
78: spc ;next I
79: "Finish":ret

80: "Foure":rad;
 cfg 2;1→J;0→I;
 2π→p3
81: if (I+1→I)>6
 5;gto +8
82: -π+(I-1)p2→X
 ;Y[I]→Y;if I=1
 or I=65;1→M;
 gto +3
83: if M=4;2→M;
 gto +2
84: 4→M
85: cos(2πX/p3→E
 )→p4→F;sin(E)→p
 5→G
86: MYF+A[J]→A[J
 ];MYG+B[J]→B[J]
87: if (J+1→J)<=
 N;p4F-p5G→T;
 p5F+p4G→G;T→F;
 gto -1
88: 1→J;gto -7
89: Y[1]+4Y[2]+
 Y[65]→p4;3→I
90: p4+2Y[I]+
 4Y[I+1]→p4;jmp
 (I+2→I)>=65
91: p4p2/3p3→A[0
 ];1→J
92: 2A[J]p2/3p3→
 A[J];2B[J]p2/
 3p3→B[J];jmp
 (J+1→J)>N
93: ret
```

```
 )→r10
96: next I
97: if r10=0;
 0→r11;jmp 2
98: 32A[1]r12/
 r10→r11
99: fxd 2;prt
 "Displ = ",r3
100: fxd 4;prt
 "Effic = ",r11
101: spc ;ret
102: "Convolve":
 for I=-16 to 16
103: 0→G[I]
104: r3sin(Iπ/
 32)→P
105: for J=-Q
 to Q
106: if abs(P+
 JD)>L;0→H;gto
 "Sum"
107: if abs(P+
 JD)<S;0→H;gto
 "Sum"
108: if P+JD<=-
 S;-M[2]→H;gto
 "Sum"
109: if P+JD>=S;
 M[1]→H
110: "Sum":F[J]H
 D+G[I]→G[I]
111: next J
112: next I
113: max(G[*])→Z
114: for I=-16
 to 16;G[I]→Y[I+
 17]
115: next I
116: for I=15
 to -16 by -1;
```

```
 9π/4,-1.2,1.2
120: if flg1;
 jmp 3
121: axe 0,0,π/
 4,.2
122: sfg 1
123: for K=1 to
 65
124: plt (K-1)π/
 32,Y[K]/Z
125: next K
126: pen
127: "Done":ret
128: "DC":enp
 "No. of transfe
 r points",p1
129: 1.5(W+S)/
 p1→p2
130: for I=1 to
 p1;Ip2→P
131: 0→p3
132: for J=-Q
 to Q
133: if abs(P+
 JD)<S;0→H;gto
 "Add"
134: if abs(P+
 JD)>L;0→H;gto
 "Add"
135: if P+JD<=-
 S;-M[2]→H;gto
 "Add"
136: if P+JD>=S;
 M[1]→H
137: "Add":F[J]H
 D+p3→p3
138: next J
139: prt "Drive"
 ,Ip2,"Current",
```

```
144: if abs(JD)<
 S;0→H;gto "Tota
 l"
145: if abs(JD)>
 L;0→H;gto "Tota
 l"
146: if JD<=-S;
 M[2]→H;gto "Tot
 al"
147: if JD>=S;
 M[1]→H
148: "Total":F[J
 ]HD+r6→r6
```

Appendix IV

KEY PERSONNEL

DOUGLAS B. CLARK, Member of the Technical Staff, Tube Division, Devices Group. Born December 31, 1946, Oakland, California. Nine years experience. B.S., Electrical Engineering, University of California at Berkeley, 1969. Graduate studies in Electrical Engineering at Loyola University of Los Angeles.

Mr. Clark is currently a Project Engineer with the Electron Bombarded Semiconductors Group. He is responsible for design and development of state-of-the-art EBS devices.

From February 1974 to May 1977, Mr. Clark was with the Solid State West Division of Varian Associates in Palo Alto, California. He was Project Engineer on a variety of development and production projects involving Gun diode amplifiers, YIG-tuned Gunn Oscillators, and bipolar transistor amplifiers.

From June 1969 to February 1974, Mr. Clark was with the Hughes Aircraft Company, Electron Dynamics Division, where he was a Member of the Technical Staff. His responsibilities included that of Project Engineer on state-of-the-art, dual mode, multi-octave traveling-wave tubes. He also was responsible for production of high pulse power space tubes.

JOHN B. RETTIG, Member of the Technical Staff, Tube Division. Born January 8, 1954, Toledo, Ohio. B.S.E.E., 1977, M.S.E.E., 1978, Purdue University.

Mr. Rettig is presently working on the development of an EBS space amplifier for NASA Goddard Research Center that must meet stringent linearity and efficiency specifications.

Formerly he was a research assistant at Purdue University, engaged in High Gradient Magnetic Separation studies. This involved experimental quantization of 3-dimensional buildups of small paramagnetic particles on saturated ferromagnetic wires.

Mr. Rettig is a member of Tau Beta Pi and IEEE.