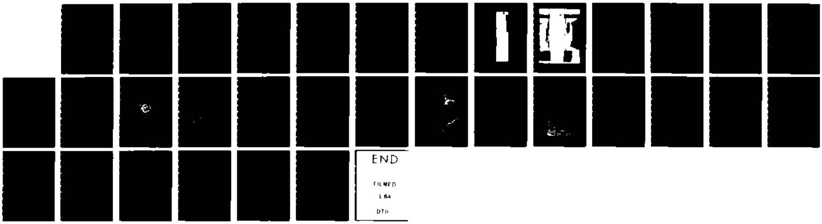
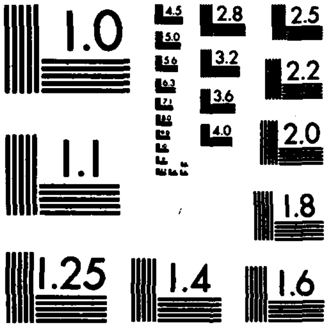
AD-A135 144 CYLINDRICAL MICROSTRIP ARRAY - C-BAND BEACON ANTENNA ARRAY WITH 48 RECTAN..(U) NEW MEXICO STATE UNIV LAS CRUCES PHYSICAL SCIENCE LAB H D WEINSCHEL ET AL. 1/1

UNCLASSIFIED JUL 83 PC-01036 AFGL-TR-83-0218 F/G 9/5 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

AFGL-TR-83-0218

CYLINDRICAL MICROSTRIP ARRAY

C-Band Beacon Antenna Array with 48 Rectangular Radiating Elements Fed In-phase

H. Dieter Weinschel
Al Waterman

Physical Science Laboratory
New Mexico State University
Box 3548
Las Cruces, New Mexico 88003-3548

July 1983

Scientific Report No. 1

Approved for Public Release; distribution unlimited.

Prepared for

Air Force Geophysics Laboratory
Air Force Systems Command
United States Air Force
Hanscom AFB, Massachusetts 01731

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service(NTIS).

This technical report has been reviewed and is approved for publication

Raymond E Wilton

RAYMOND E. WILTON
Contract Manager

Edward F. McKenna

EDWARD F. McKENNA
Branch Chief

FOR THE COMMANDER

C Nealon Stark

C. N. STARK
Division Director

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFGL-TR-83-0218	2. GOVT ACCESSION NO. AD-A135144	3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

CYLINDRICAL MICROSTRIP ARRAY

C-Band Beacon Antenna Array with 48 Rectangular Radiating Elements Fed In-Phase

5. TYPE OF REPORT & PERIOD COVERED

Scientific Report No. 1

6. PERFORMING ORG. REPORT NUMBER

PC01036

7. AUTHOR(s)

H. Dieter Weinschel
Al Waterman

8. CONTRACT OR GRANT NUMBER(s)

F19628-81-C-0004

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Physical Science Laboratory
Box 3548, NMSU
Las Cruces, New Mexico 88003

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

62101F
675904BA

11. CONTROLLING OFFICE NAME AND ADDRESS

Air Force Geophysics Laboratory
Hanscom AFB, Massachusetts 01731
Contract Monitor: Raymond E Wilton: LCR

12. REPORT DATE

July 1983

13. NUMBER OF PAGES

33

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

A - Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Microstrip antenna
Conformal Antenna
Antenna
Array
C-Band

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

The Pysical Science Laboratory/NMSU has designed a C-Band microstrip array for a nominal 17 inch diameter vehicle. Impedance and radiation pattern measurements were made on a prototype antenna.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The Physical Science Laboratory at New Mexico State University developed a conformal, C-Band microstrip antenna for a 17.2 inch diameter cylindrical vehicle. A computer program was written from a theoretical study by Carver and Coffey [1] to calculate the patch dimensions and its driving point impedance. Another program was written based on an article published in Microwaves [2] to calculate the characteristic impedances and effective dielectric constants of the lines used in the harness. A third program was developed to design the harness and to document the antenna. An antenna was fabricated to obtain impedance and radiation measurements.

A physical description of the antenna and the measurements illustrating its electrical performance are presented in the report.

2.0 PHYSICAL DESCRIPTION OF THE ANTENNA

The Model 94.001 antenna is a microstrip array fabricated from 0.062" printed circuit board (CuClad 250 by 3M). The substrate is the GX type teflon impregnated woven fiber glass.

The array was designed for a 17 inch diameter cylinder and consists of three subarrays. Each subarray has sixteen elements which are fed in-phase with a corporate harness which is photoetched on the same board as the elements. When the elements are mounted on a cylinder they are connected in-phase with coaxial cable through a three-way power divider. The subarray feeds for attaching the coaxial cable are SMA connectors. The antenna is shown in Figures 1 and 2.

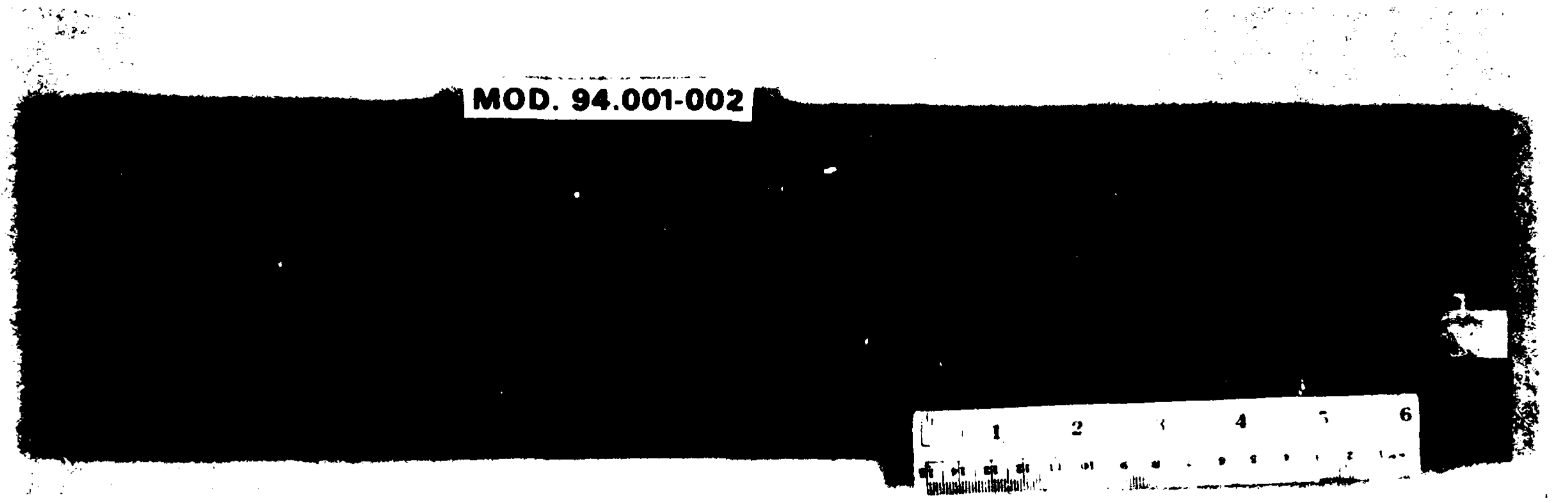


Figure 1. Model 94.001 C-Band Subarray

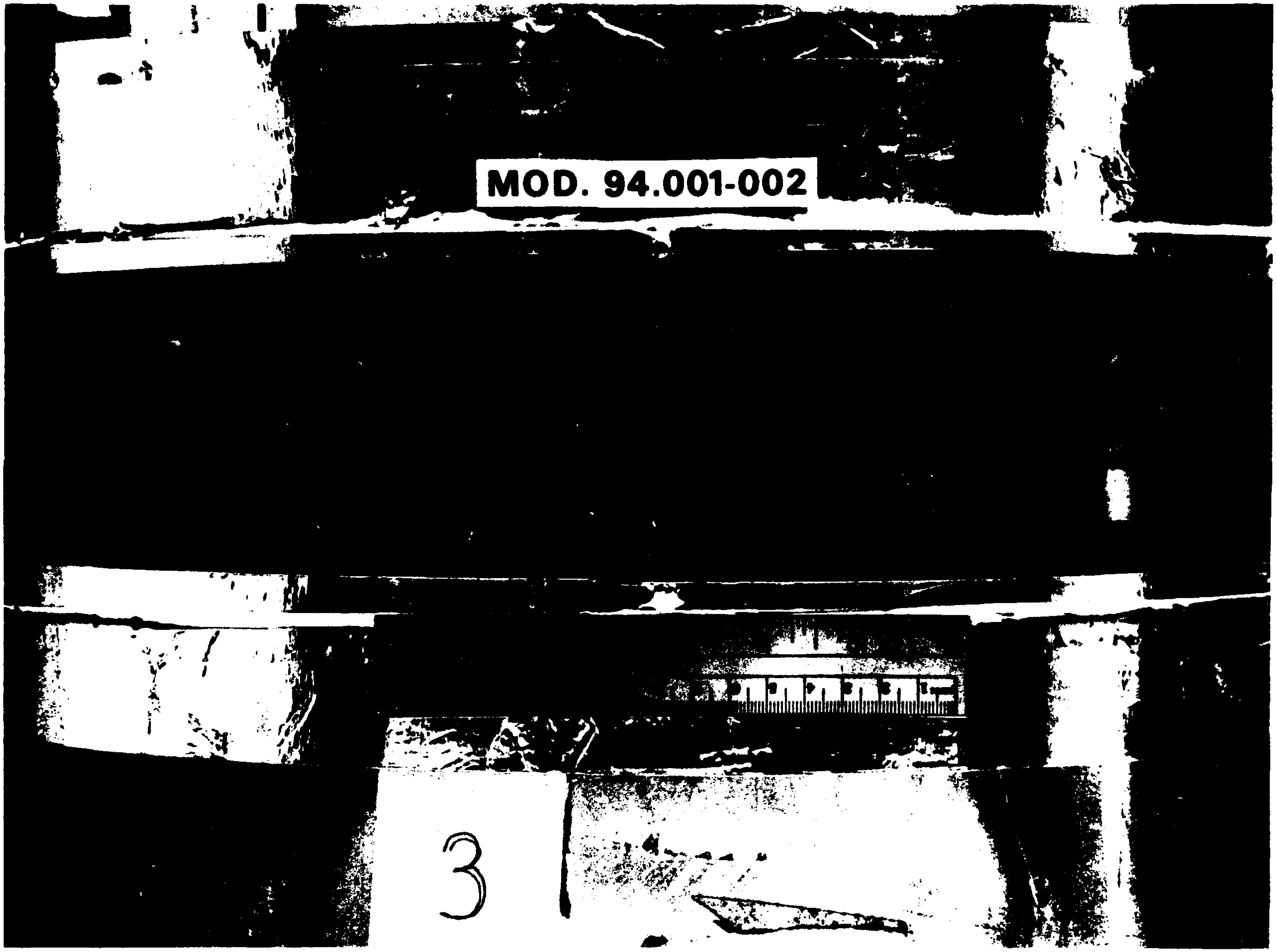


Figure 2. Model 94.001 C-Band Array mounted on a 17 inch diameter cylinder.

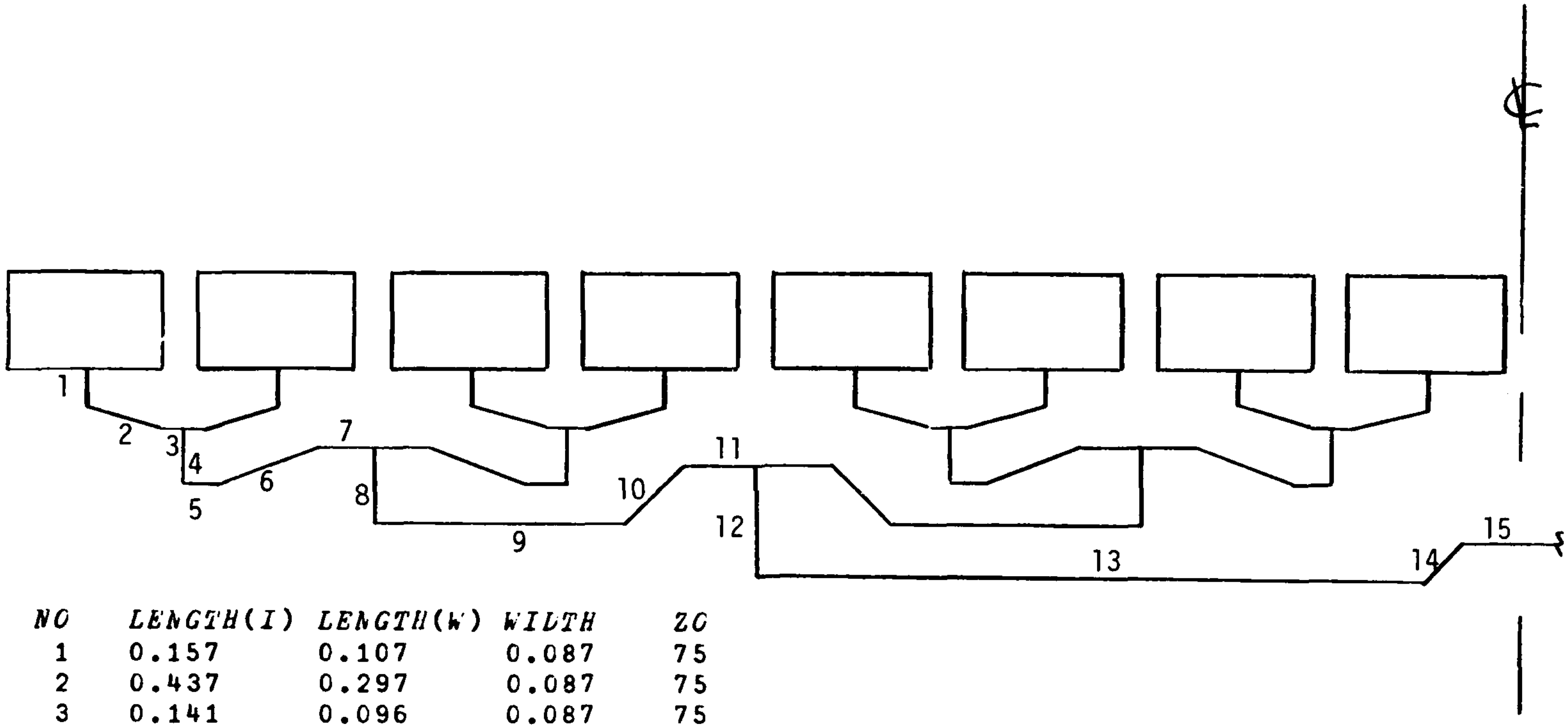
3.0 THE ANTENNA ARRAY DEVELOPMENT

Three small APL programs (PATCH, EPSL and H94001) were written to aid in the design of the radiating element and the harness. The programs PATCH and EPSL were based on the publications [1] and [2] respectively. PATCH calculates the resonant frequency and impedance of a rectangular element fed coaxially. EPSL calculates the effective dielectric constant and the characteristic impedance of a microstrip line. H94001 calculates the harness configuration of a corporate harness for a 16 element array as a function of the vehicle diameter.

The calculated dimensions for the radiating rectangular element were 2.68 by 1.488 cm at 5.71 GHz and a substrate thickness of 0.152 cm. The dielectric constant used for the calculations was 2.45 so that the dimensions in terms of wavelengths in the dielectric are 0.799 x 0.444 x 0.0453.

A schematic of the harness and the computer printout of the harness section lengths, widths and characteristic impedances is shown in Figure 3. Since the subarray is symmetric about the feed, only eight of the sixteen elements are shown in the sketch.

The time allotted for the development was severely limited. No attempt was therefore made to write the programs in the most efficient form. The CPU time for the calculations was short and using more time to write the program would not have been practical. The most questionable parameter in the calculations was the input impedance to each element in the array. The calculated impedance for a coaxial feed recessed 0.058 inches from the edge of the antenna was 75 ohms. To save time, harnesses were also calculated for 100 and 120 ohm input impedances. The three subarrays were fabricated and the impedance curves were measured. The best results were obtained from the harness for which the



NO	LENGTH(I)	LENGTH(W)	WIDTH	Z0
1	0.157	0.107	0.087	75
2	0.437	0.297	0.087	75
3	0.141	0.096	0.087	75
4	0.565	0.398	0.264	38
5	0.524	0.369	0.264	38
6	0.331	0.233	0.264	38
7	0.368	0.250	0.087	75
8	0.800	0.544	0.087	75
9	1.242	0.845	0.087	75
10	0.898	0.611	0.087	75
11	0.374	0.250	0.041	106
12	0.922	0.627	0.087	75
13	3.914	2.662	0.087	75
14	0.310	0.211	0.087	75
15	0.370	0.250	0.065	87

Figure 3. Schematic of the harness design.
Only one-half of the subarray is shown.

calculated 75 ohm element impedance was used. The radiation patterns for the planar subarray were measured and the results showed that the phasing and power division obtained with this harness were satisfactory. Two additional subarrays were fabricated and the three subarrays were mounted on a 17 inch diameter cylinder and fed in-phase from a three-way power divider.

4.0 THE ARRAY CHARACTERISTICS

The characteristics of the antenna are best described by impedance and radiation distribution measurements. The impedance data for the subarrays measured before they were mounted [illegible] the cylinder is shown in Figures 4 through 6. They show that [illegible] the design frequency the array impedance is close to the 50 ohm calculated impedance. The bandwidth is approximately 600 MHz over a 2:1 VSWR. In Figure 7 the impedance versus frequency curve is shown with the three subarrays mounted on the cylinder. The impedance is measured at the end of a 24 inch long feed cable. This configuration simulates the flight configuration and the impedances measured are those seen by the beacon. The data shows that the antenna is well matched over the entire band.

The radiation patterns are shown in Figures 9 through 14. The pattern coverage is quite good except for narrow nulls looking directly into the nose or the tail of the vehicle and about 30° off axis. The $\theta = 90°$ cut shows more irregular lobing then one would expect from the array. This is most likely the result of mounting the antenna on a sheetmetal cylinder rather then on a machined surface. Also, the prototype antenna was not truly cylindrical and some gaps between the cylinder and the antenna may have become excited.

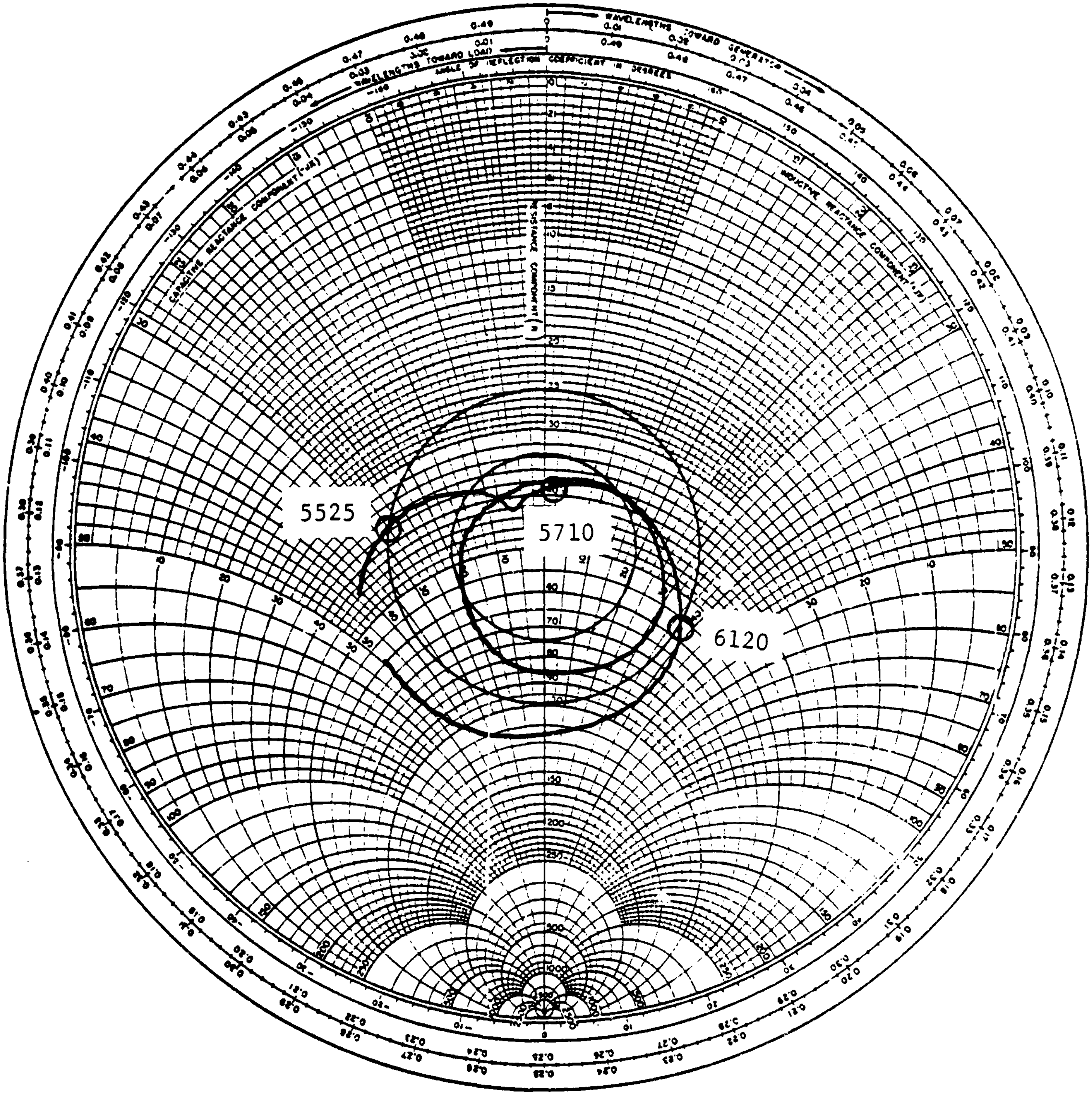


Figure 4. Model 94.001 (002A) Planar Subarray Driving Point Impedence

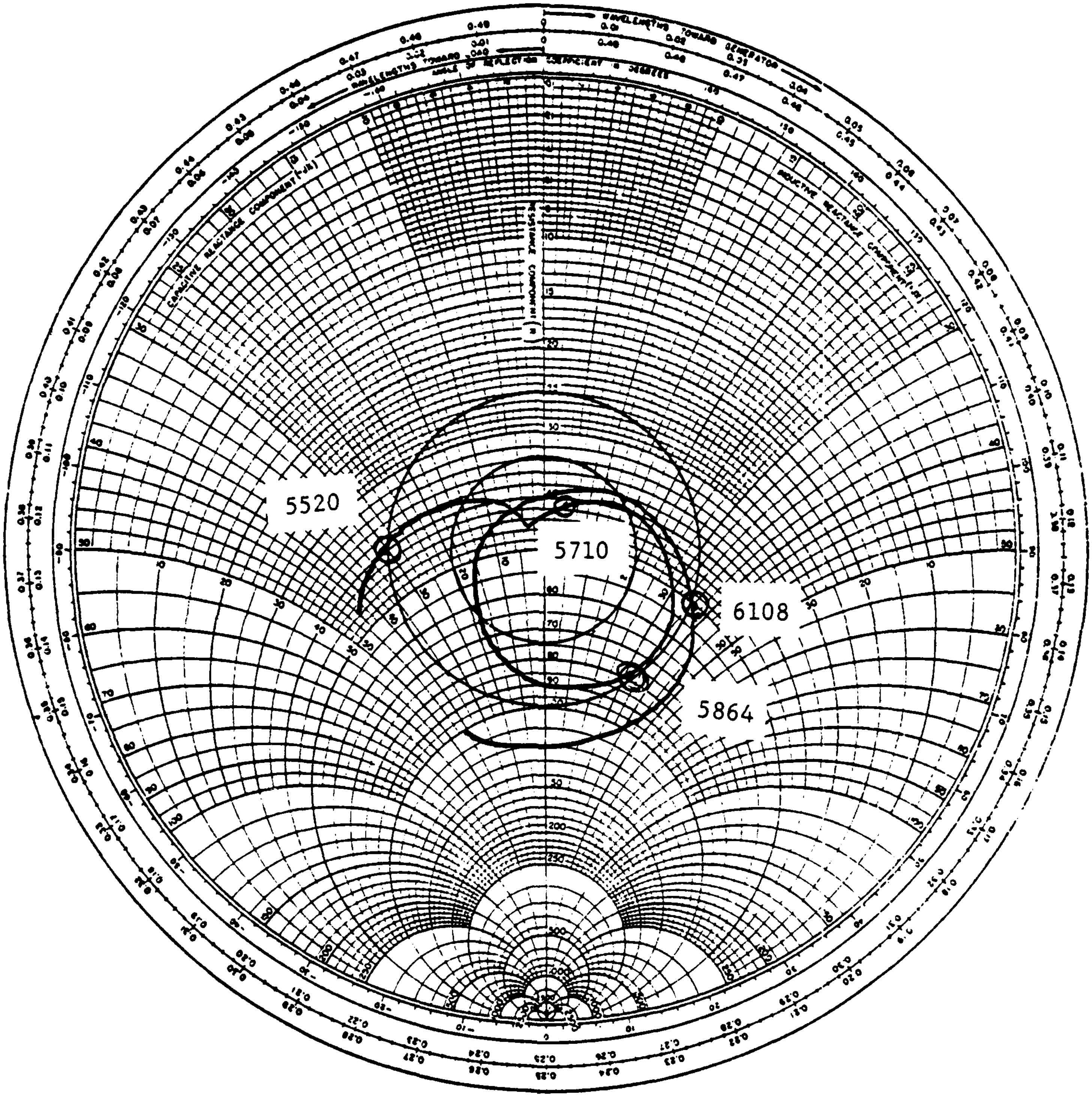


Figure 5. Model 94.001 (002B) Planar Subarray Driving Point Impedence

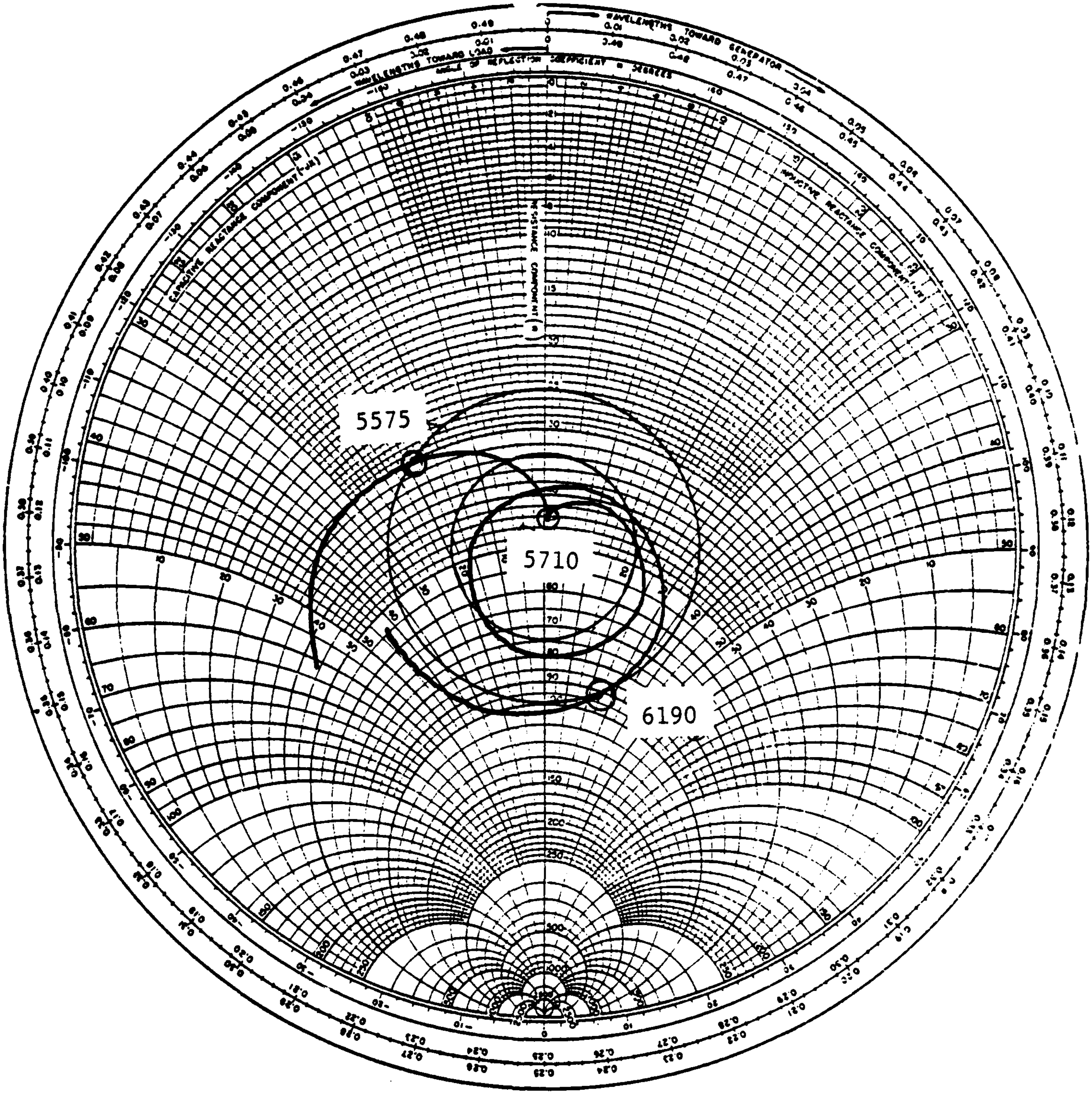


Figure 6. Model 94.001 (002C) Planar Subarray Driving Point Impedence

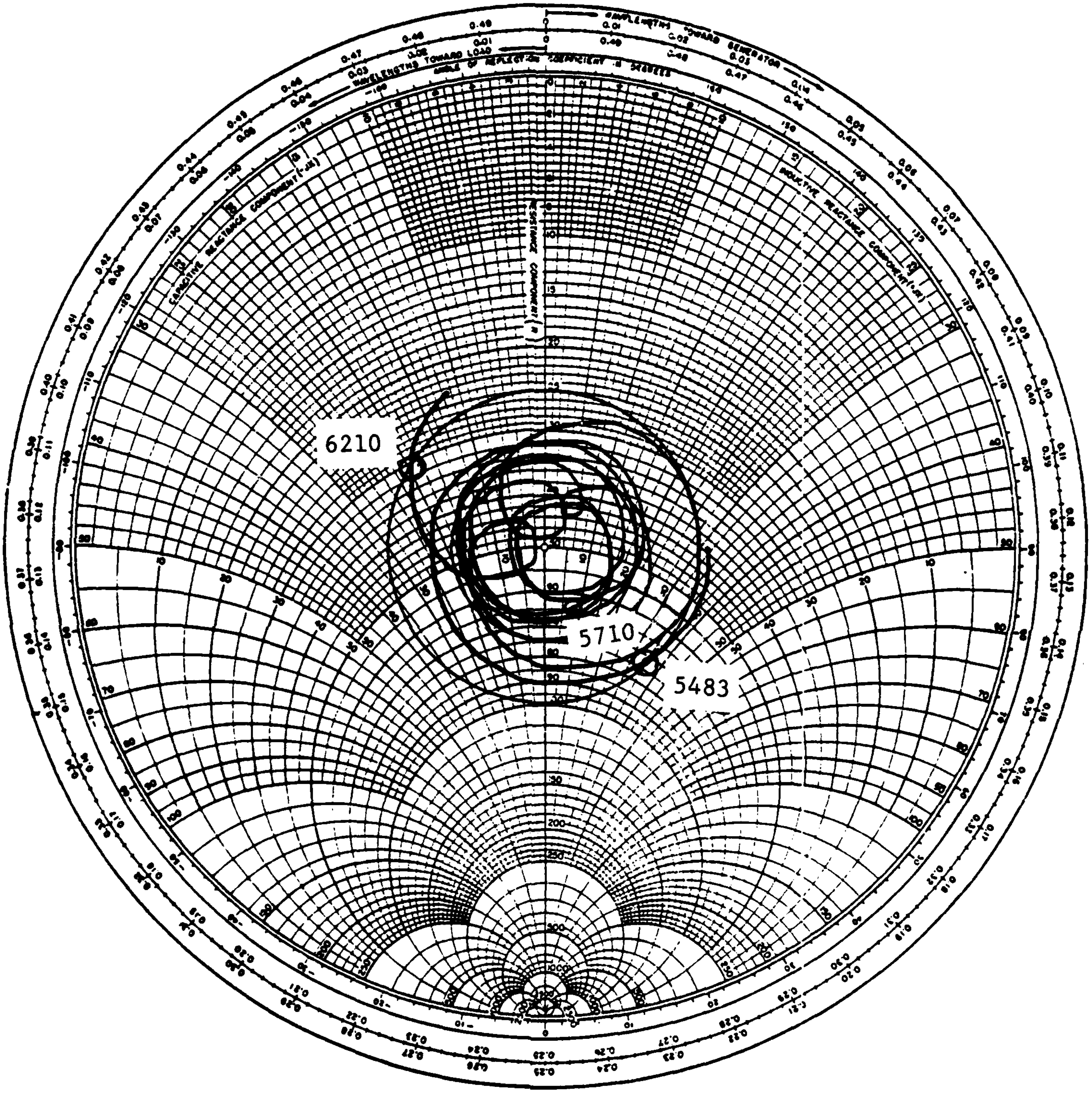


Figure 7. Model 94.001 (002A,B,C) mounted on a 17 inch diameter cylinder and measured at the end of the 24 inch long feed cable.

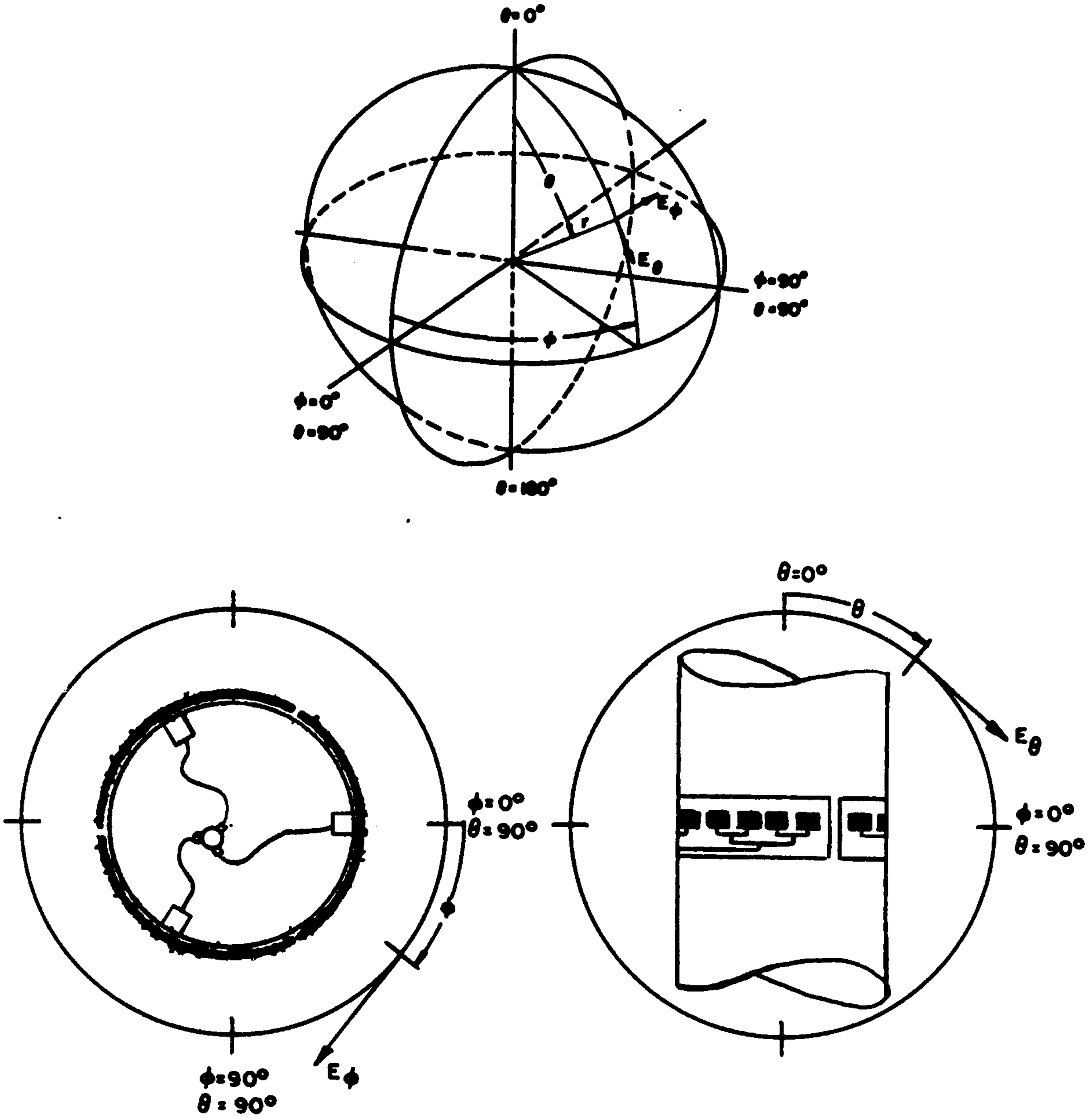


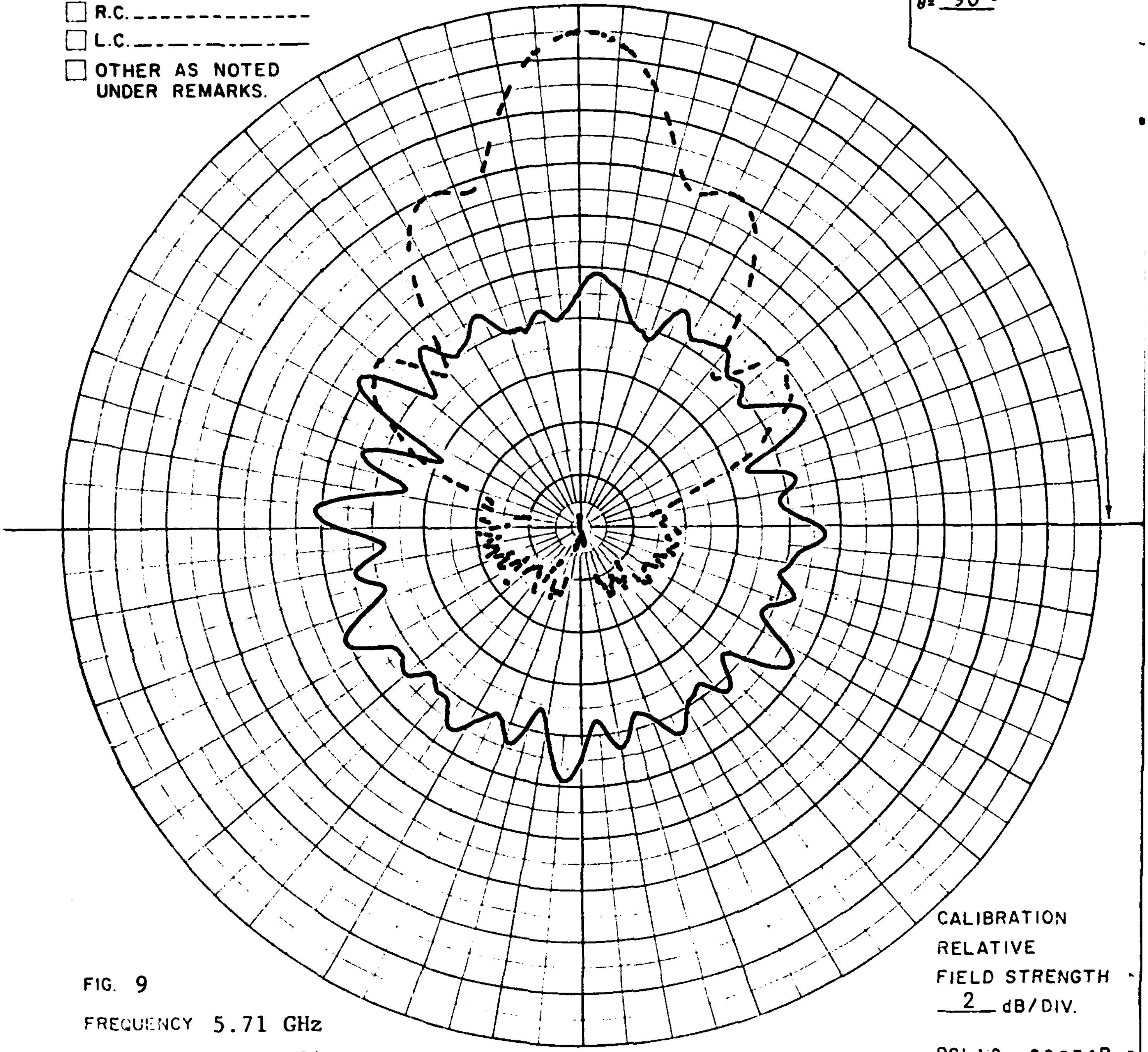
Figure 8. Coordinates for the radiation pattern measurements (RR 2792)

POLARIZATION

☒ GAIN REF.-- -- -- -- ---
☒ Eθ ______________
☐ Eϕ_ _ _ _ _ _ _ _ _
☐ R.C.- - - - - - - - - - - - -
☐ L.C.— - — - — - —
☐ OTHER AS NOTED UNDER REMARKS.

ϕ = 0° θ = 90° COORDINATE REFERENCE

ϕ = 90°
θ = 90°



CALIBRATION
RELATIVE
FIELD STRENGTH
2 dB/DIV.

FIG. 9

FREQUENCY 5.71 GHz

ANTENNA Model 94.001

REMARKS The gain of the reference antenna is 19 dBi.

PSL № 30251B

RR 2792

POLARIZATION

☐ GAIN REF.
☒ Eθ
☒ Eϕ
☐ R.C.
☐ L.C.
☐ OTHER AS NOTED UNDER REMARKS.

ϕ= ____° θ= 0°

COORDINATE REFERENCE

ϕ= 0°
θ= 90°

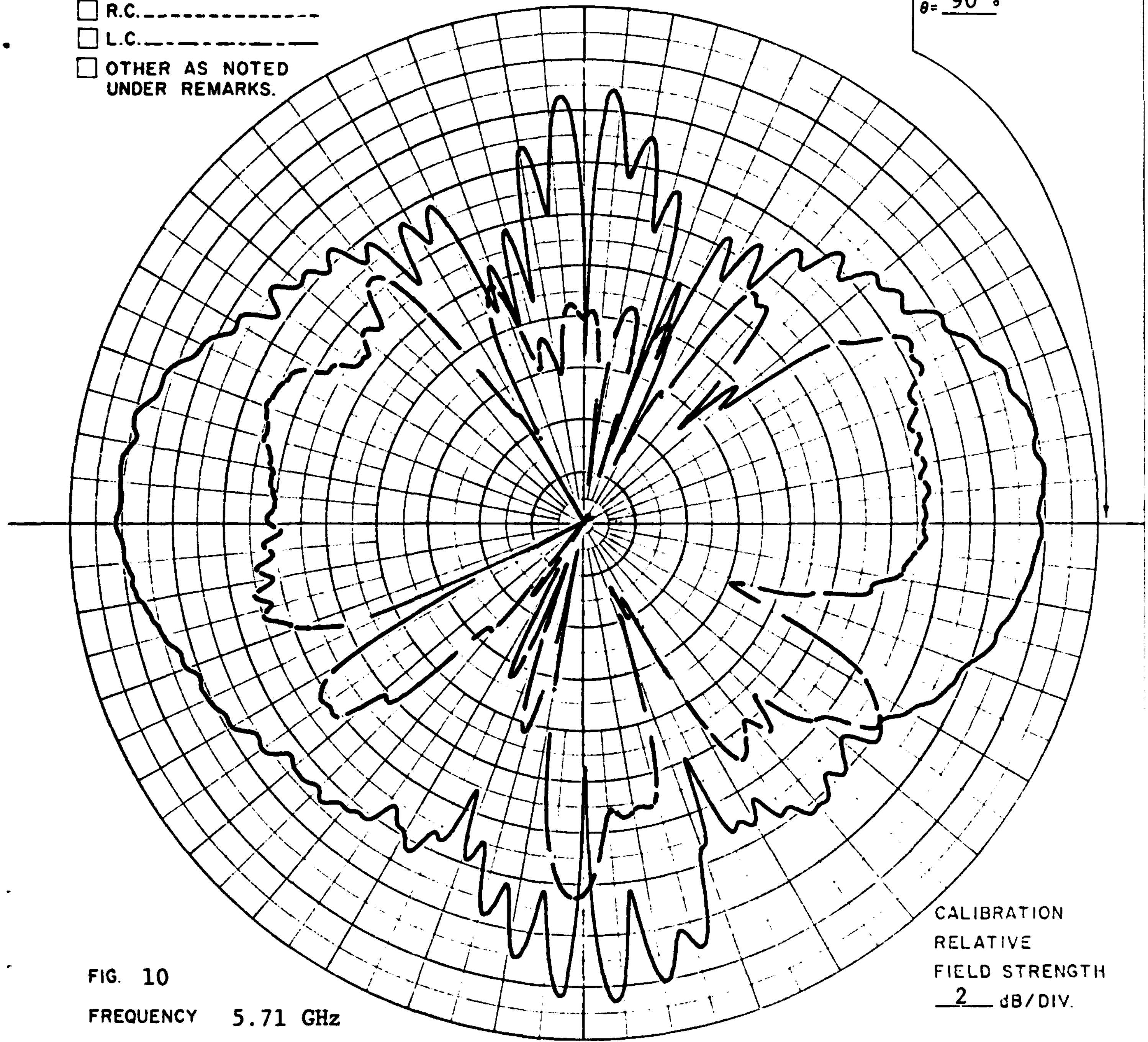


FIG. 10

FREQUENCY 5.71 GHz

ANTENNA Model 94.001

REMARKS Microstrip antenna, 48 element array mounted on a 17 inch diameter cylinder.

CALIBRATION
RELATIVE
FIELD STRENGTH
2 dB/DIV.

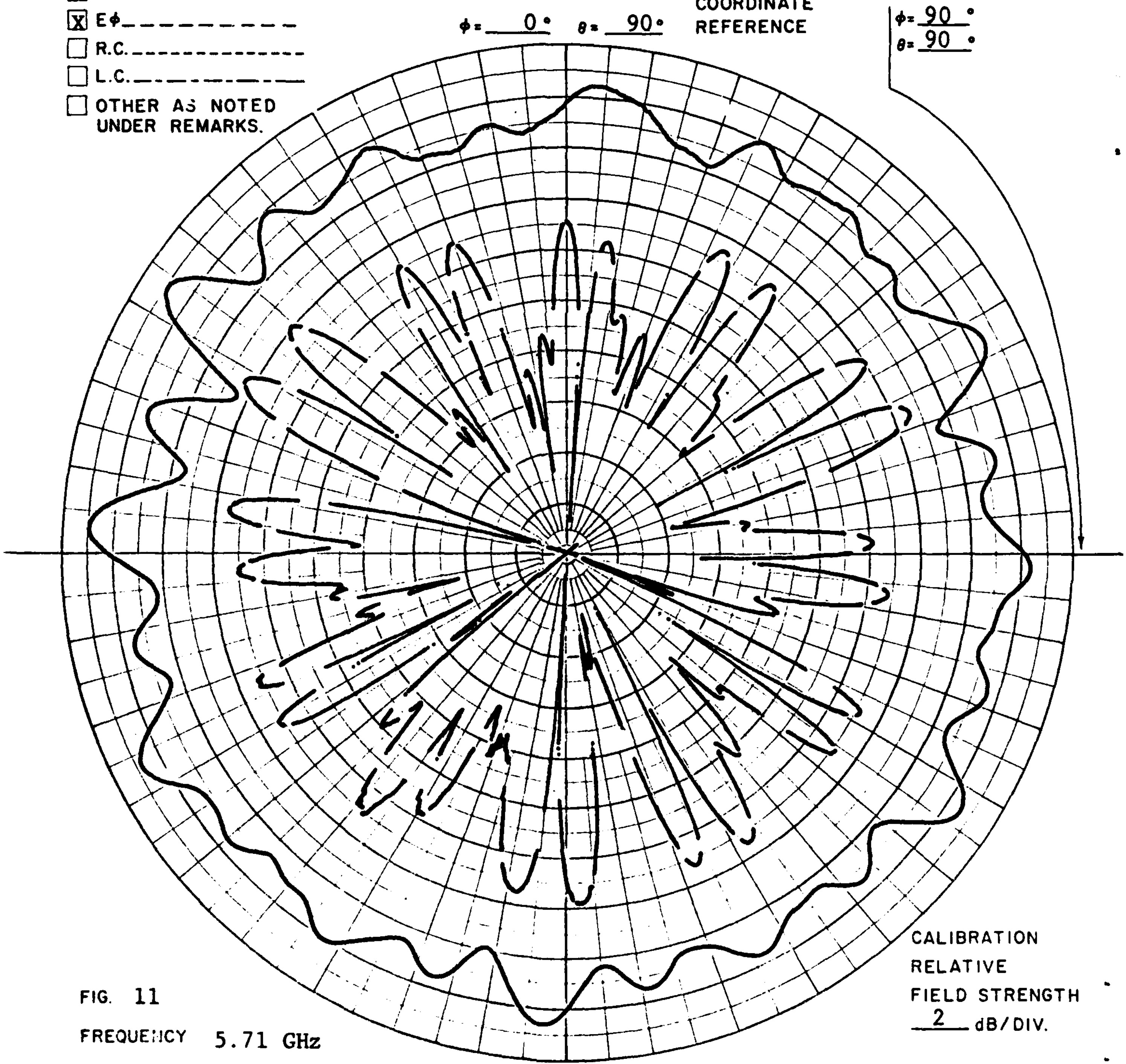
PSL № 30253B

RR 2792

POLARIZATION

☐ GAIN REF.
☒ Eθ
☒ Eφ
☐ R.C.
☐ L.C.
☐ OTHER AS NOTED UNDER REMARKS.

φ = 0° θ = 90° COORDINATE REFERENCE



CALIBRATION
RELATIVE
FIELD STRENGTH
2 dB/DIV.

FIG. 11

FREQUENCY 5.71 GHz

ANTENNA Model 94.001

REMARKS

PSL № 302598

RR 2792

POLARIZATION

☐ GAIN REF.
☒ Eθ
☐ Eφ
☐ R.C.
☐ L.C.
☐ OTHER AS NOTED UNDER REMARKS.

φ = ____° θ = 0° COORDINATE REFERENCE

φ = 359°
θ = 90°

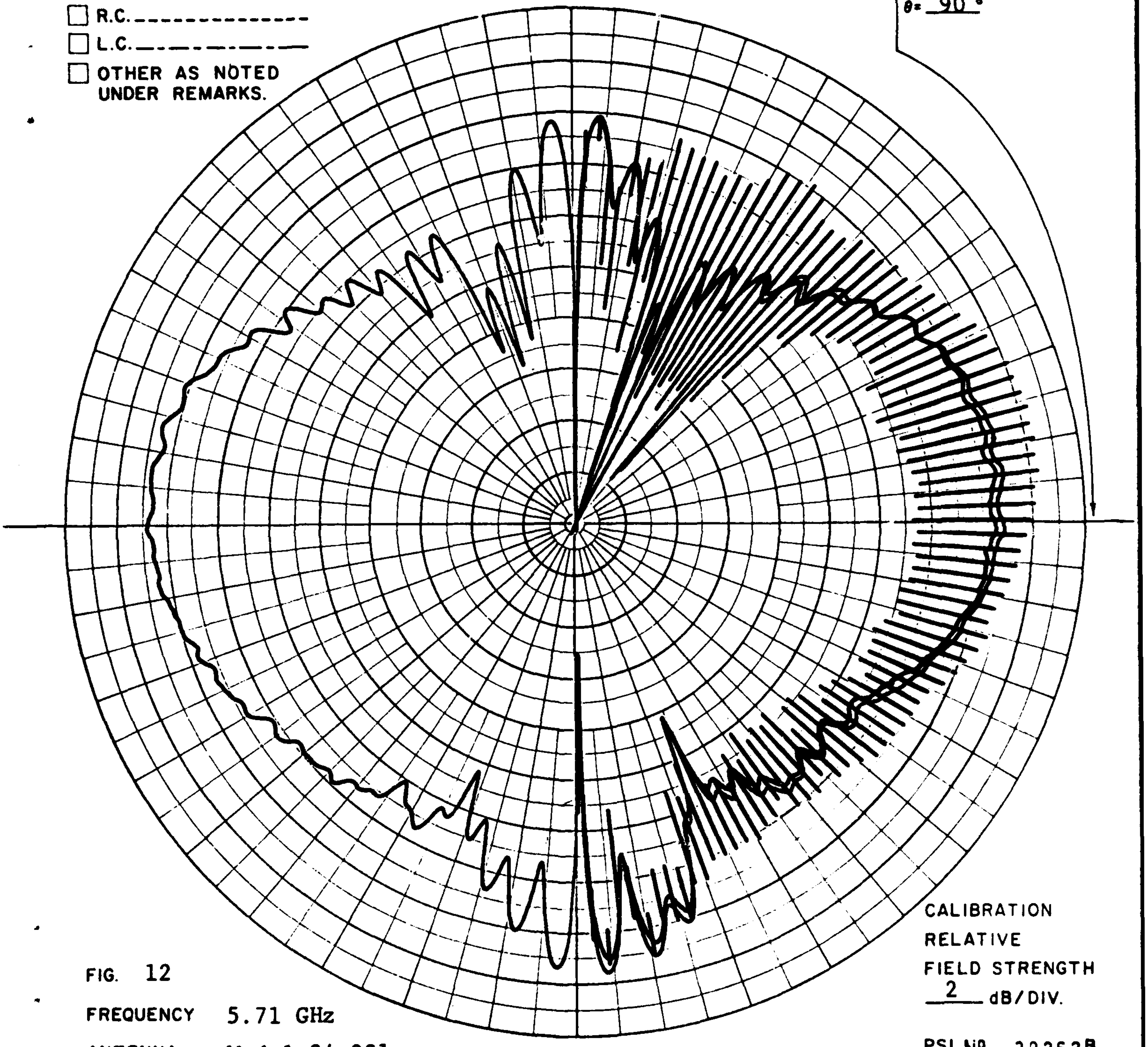


FIG. 12

FREQUENCY 5.71 GHz

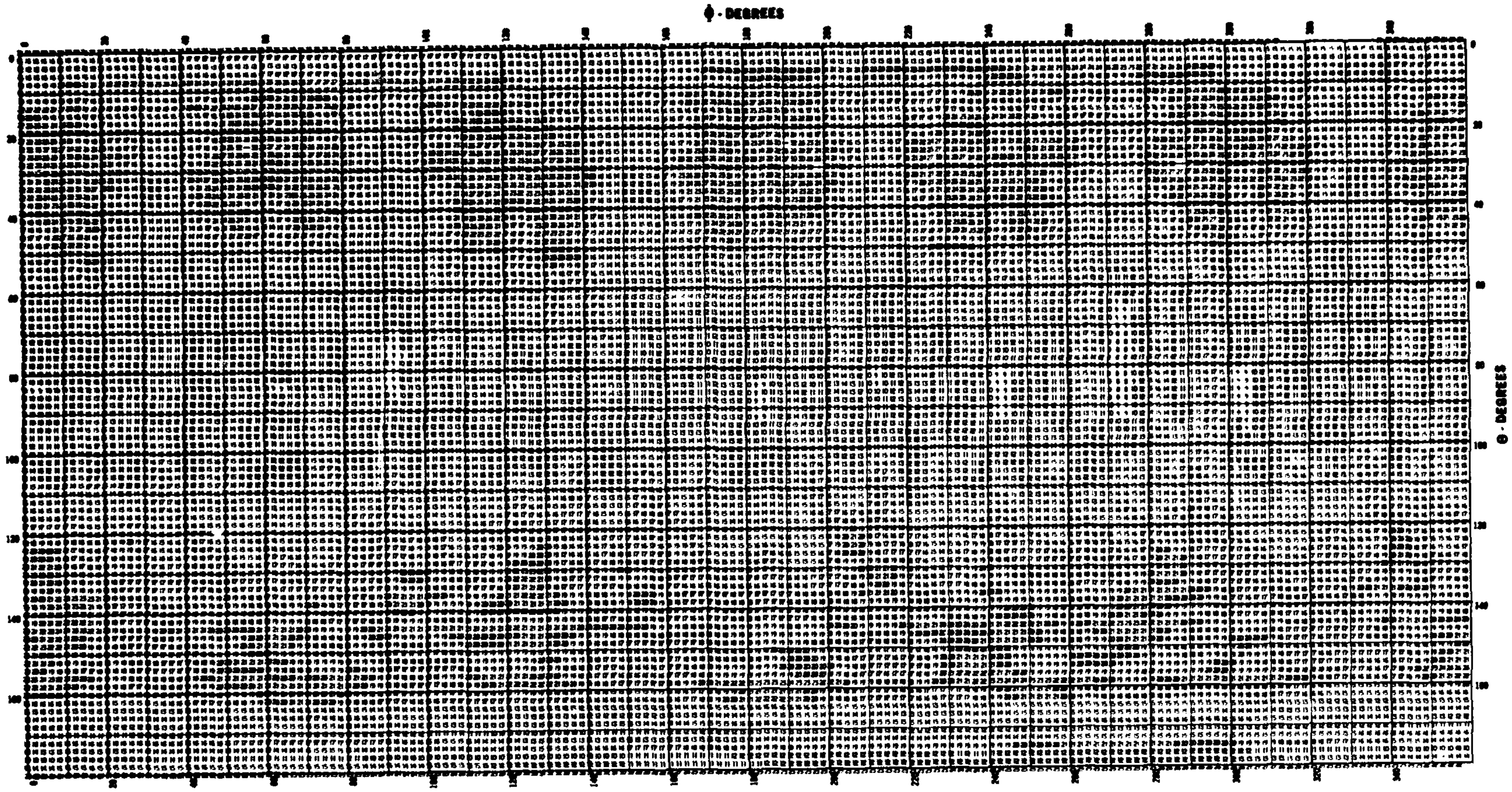
ANTENNA Model 94.001

REMARKS Amplitude variation as a function of φ in 2° increments of θ.

CALIBRATION
RELATIVE
FIELD STRENGTH
2 dB/DIV.

PSL № 30262B

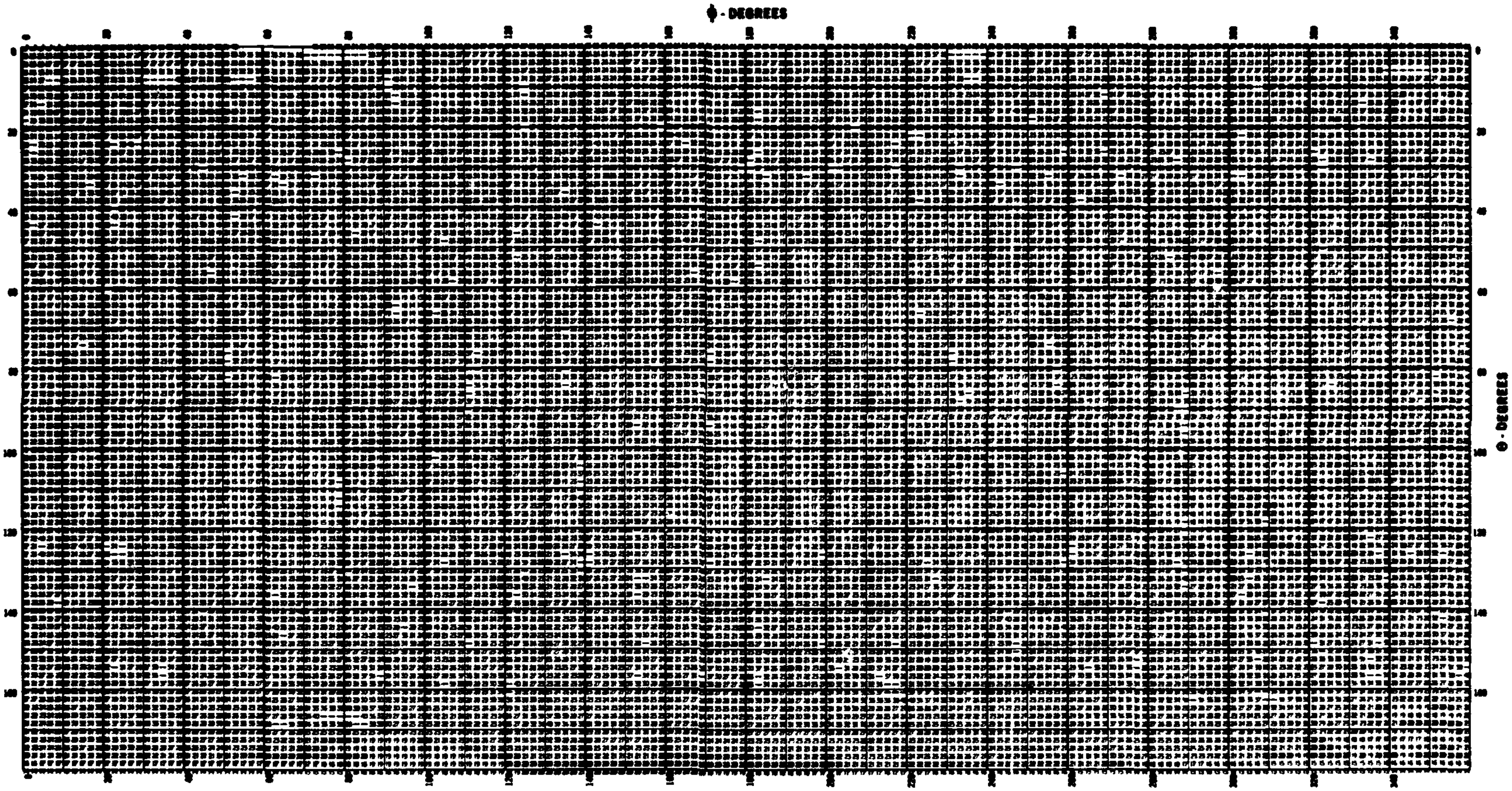
RR 2792



TEST PROGRAM OR VEHICLE: C-BAND DEVELOPMENT INSTRUMENTATION SYSTEM: MODEL K393 PROJECT: RR 2792
DATE: 17 JUN 83 PATTERN NO: RDP 457 ORGANIZATION: PSL/NMSU ENGRS: WEINSCHEL
ANTENNA TYPE: MOD, 94,001-002 SNA,B,C, FREQ. RANGE: C-BAND PATTERN MEASUREMENT FREQ: 5710
PREDOMINANT POLARIZATION: LINEAR E-θ MODEL SCALE: 1:1 LOCATION OF POINT P'y (φ=0, θ=90°): FP OF ANTENNA A

GAIN PLOT: ☒ POLARIZATION COMPONENT RECORDED: LINEAR ☐ E_ϕ, ☒ E_θ; CIRCULAR ☐ RH, ☐ LH
GAINS ARE IN DECIBELS BELOW A REFERENCE LEVEL OF ☒+ ☐− 10 DB RELATIVE TO AN ISOTROPIC ANTENNA OF LINEAR POLARIZATION
PHASE-ANGLE PLOT: ☐ PHASE ANGLE RECORDED: ☐δ, ☐δ'
PHASE ANGLES ARE RECORDED VALUES IN DEGREES MULTIPLIED BY 10.
REF PAT 30261B
CONT PAT 30262 B
TAPE PUNCH 457

Figure 13. Model 94.001 Radiation Distribution Pattern (E_θ)



TEST PROGRAM OR VEHICLE: C-BAND DEVELOPMENT INSTRUMENTATION SYSTEM: MODEL K393 PROJECT: RR2792
DATE: 17 JUNE 83 PATTERN NO. RDP 458 ORGANIZATION: PSL/NMSU ENGRS. WEINSCHEL
ANTENNA TYPE: MOD.94.001-002 SN A,B,C FREQ. RANGE: C-BAND PATTERN MEASUREMENT FREQ. 5710
PREDOMINANT POLARIZATION: LINEAR E θ MODEL SCALE: 1:1 LOCATION OF POINT P'y (θ=0, θ=90°): FP OF ANTENNA A

GAIN PLOT: ☒ POLARIZATION COMPONENT RECORDED: LINEAR ☒ Eφ, ☐ Eθ; CIRCULAR ☐ RH, ☐ LH
GAINS ARE IN DECIBELS BELOW A REFERENCE LEVEL OF +☒ −☐ 10 DB RELATIVE TO AN ISOTROPIC ANTENNA OF LINEAR POLARIZATION
PHASE-ANGLE PLOT: ☐ PHASE ANGLE RECORDED: ☐ δ, ☐ δ'
PHASE ANGLES ARE RECORDED VALUES IN DEGREES MULTIPLIED BY 10
REF PAT 30263 B
CONT PAT 30264 B TAPE PUNCH 458

Figure 14. Model 94.001 Radiation Distribution Pattern (E_ϕ)

5.0 CONCLUSIONS

A computer aided design was made for a 48 element conformal microstrip array. The harness lengths are defined in terms of element spacing which is determined by the number of elements used and the vehicle diameter, the same program can therefore be used for a range of vehicle diameters. An antenna array was fabricated and the antenna performance was documented by impedance and radiation distribution pattern measurements. It is believed that the results demonstrate that this is a usable design.

6.0 RECOMMENDATIONS

The short time allowed for the development did not permit the incorporation of a heat shield which should be the second phase of the investigation. It would be useful to investigate two forms of protection. A dielectric radome and a slotted metallic shield. The radome adaptation should be uncomplicated, but adding the metallic shield will probably require a major change in the harness configuration since the transmission lines should then be in the stripline mode.

The first suggested use for the antenna would be for the BERT Project.

REFERENCES

[1] "Theoretical Investigation of the Microstrip Antenna," Keith R. Carver and Edgar L. Coffey, Technical Report PT-00929, January 23, 1979.

[2] "A Designer's Guide to Microstrip Line," I.J. Bahl and D.K. Trivedi, Microwaves, May 1977.

APPENDIX A

APL PROGRAMS

```
     ∇ PATCH
[1]   ⍝ THE PROGRAM CALCULATES THE RESONANT FREQ.
[2]   ⍝ THE RESONANT IMPEDANCE, AND THE BANDWIDTH
[3]   ⍝ FOR A RECTANGULAR MICROSTRIP ANTENNA.
[4]   ⍝ PROBE FED ANTENNA ONLY
[5]   ⍝*********************************************************
[6]   ⍝ I N P U T
[7]    'WIDTH (CM)'
[8]    WP←⎕
[9]    'HEIGHT (CM)'
[10]   HP←⎕
[11]   'SUBSTR. THICK.'
[12]   T←⎕
[13]   'DIELC. CONST.'
[14]   ER←⎕
[15]   'FEED POSITION'
[16]   Y0←⎕
[17]  ⍝*********************************************************
[18]  ⍝ C O N S T A N T S
[19]   A←14.4
[20]   B←2.08
[21]   C←10
[22]   D←0.00836
[23]   E←0.01668
[24]   F←0.412
[25]   G←0.3
[26]   H←0.262
[27]   I←0.258
[28]   K←0.813
[29]   J←2362
[30]   L←0.7747
[31]   M←0.5977
[32]   N←0.1638
[33]   O←2998000000
[34]   P←8.85E¯12
[35]  ⍝⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃⊃
[36]  ⍝ APPROX. RESONANT FREQ (GHZ)
[37]   FRA←A÷HP×ER*0.5
[38]  ⍝ APPROX. RESONANT FREE-SPACE WAVELENGTH (CM)
[39]   FSWL←B×HP×ER*0.5
[40]  ⍝ EFFECT/ DIELC. CONST.'
[41]   EE←((ER+1)÷2)+(((ER−1)÷2)÷((1+C×T÷WP)*0.5))
[42]  ⍝ WALL CONDUCTANCE (MHOS)
[43]   GW←D×WP÷FSWL
[44]  ⍝WALL SUSCEPTANCE (MHOS)
[45]   WPT←WP÷T
[46]   DELT←F×((EE+G)÷(EE−I))×((WPT+H)÷(WPT+K))
[47]   BW←E×DELT×WP×EE÷FSWL
[48]  ⍝ IMPEDANCE PARAMETER (ALPHA)
[49]   AB←WP÷HP
[50]   FPA←L+(M×(AB−1))−(N×((AB−1)*2))
[51]   RALPH←¯1×J×T×BW×FPA÷FSWL×WP
[52]   IALPH←J×T×GW×FPA÷FSWL×WP
[53]   ALPH←RALPH PJ IALPH
[54]   KAP←HP×ALPH
[55]  ⍝↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓
[56]  ⍝ CALCULATE DELTA
[57]   U←1
[58]   DELTA←0 PJ 0
[59]  LBL1:U←U
[60]   DELTA←DELTA
[61]   NDEL←(2×KAP) CMUL((○1) CADD−DELTA) ⍝NUM. OF FIRST TERM
[62]   DDEL←(((KAP CPWR 2) CADD(○2×DELTA)) CADD−(DELTA CPWR 2)) CADD−(○1)*2
[63]   SDEL←(DELTA CPWR 3)÷3 ⍝ SECOND TERM
[64]   DELTA←(NDEL CDIV DDEL) CADD−SDEL
[65]   U←U+1
[66]   →LBL1×⍳U<6
[67]   →LBL2
[68]  LBL2:DELTA5←DELTA
```

```
[69] ⍝↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑
[70] ⍝COMPLEX EIGENVALUE (CM¯1)
[71]  KY←(Q1-HP) CADD-(DELTA5-HP)
[72] ⍝ COMPLEX RESONANT FREQ. (RAD S¯1)
[73]  OMG←(Q-EP*0.5)×KY
[74] ⍝REAL RES. FREQ. (HZ)
[75]  FRQ←(RS OMG)÷○2
[76] ⍝ CALCULATE Q
[77]  QU←(RS OMG)÷2×RS IM OMG
[78] ⍝PATCH CAPACITANCE (FARADS)
[79]  CAPA←(EE×F×WP×HP-2×T×100)÷((2○(○YQ-HP))*2)
[80] ⍝RESONANT RESISTANCE
[81]  RESRES←QU÷(RS OMG)×CAPA
[82] ⍝ BANDWIDTH
[83]  DFRQ←FRQ÷QU
[84] ⍝=====================================================
[85] ⍝ O U T P U T
[86]  3⍴⎕TCNL
[87]  OM2←⍉ 1 3 ⍴(FRQ×1E¯9),RESRES,(DFRQ×1E¯6)
[88]  A1←'REAL RES.FREQ (GHZ)    '
[89]  A2←'RES. RESISTANCE (OHMS)'
[90]  A3←'BANDWIDTH (MHZ)       '
[91]  A4← 3 22 ⍴A1,A2,A3
[92]  '22A1,F10.3' ⎕FMT(A4;OM2)
[93]  3⍴⎕TCNL
    ∇
```

```
    ∇ EPSL
  ⍝CALCULATES THE MICROSTRIP PARAMETERS
  ⍝FROM THE EQUATIONS GEVEN IN MICROWAVES, MAY,1977
  ⍝THE PARAMETERS ARE:
  ⍝EFFECTIVE DIELECTRIC CONSTANT
  ⍝EFFECTIVE LINE WIDTH
  ⍝CHARACTERISTIC IMPEDANCE
  ⍝LOSS DUE TO THE COPPER CONDUCTOR
  ⍝LOSS DUE TO THE DIELECTRIC SUBSTRATE
   ' '
  ⍝CHOOSE METRIC OR ENGLISCH UNITS
  ⍝ TYPE 1 FOR ENGLISH UNITS ANY OTHER NUMBER FOR METRIC
   '1 FOR ENGL.'
   U←⎕
   ' '
  ⍝THE CONSTANTS ARE:
   'ENTER EPSILAM'
   D←⎕
   T←0.003556 ⍝ CONDUCTOR THICKNESS (CM)
   'ENTER SUBSTR. THICKNES IN INCHES'
   HINCH←⎕
   H←HINCH×2.54
   F←5535000000 ⍝ FREQUENCY (HZ)
   MU←○4E¯9 ⍝PERMABILITY (HENRY/CM)
   SIG←580010 ⍝CONDUCTIVITY OF COPPER (MHO/CM)
   LTAN←0.002
   LAM←29980000000÷F ⍝WAVELENGTH (CM)
   ' '
  ⍝THE RANGE OF THE LINE WIDTH
   W←0.05×⍳25 ⍝ LINE WIDTH (CM)
   WI←W÷2.54 ⍝ LINE WIDTH (INCHES)
   ' '
  ⍝ THE EFFECTIVE LINE WIDTH
   R←W÷H
   IR←+/R≤○0.5
   RS1←IR↑R ⍝W/H≤1/2(PI)
   RL←IR↓R ⍝W/H>1/2(PI)
   ERS←RS1+(T÷○H)×(1+⍟○4×RS1×H÷T)
   ERL←RL+(T÷○H)×(1+⍟2×H÷T)
   ER←ERS,ERL ⍝WE/H THE RATIO OF THE EFF. L.W. TO SUBSTR. THICKN.
   ' '
  ⍝THE EFFECTIVE DIELECTRIC CONSTANT
   IE←+/ER≤1
   ESR←IE↑ER ⍝WE/H≤1
   ELR←IE↓ER ⍝WE/H>1
   EFS←((D+1)÷2)+((D-1)÷2)×(((1+12÷ESR)*¯0.5)+(0.04×(1-ESR)*2))
   EFL←((D+1)÷2)+((D-1)÷2)×(1+12÷ELR)*¯0.5
   EF←EFS,EFL
   ' '
  ⍝THE CHARACTERISTIC IMPEDANCE
   ZOS←(60÷EFS*0.5)×⍟((8÷ESR)+0.25×ESR) ⍝ FOR WE/H≤1
   ZOL←((○120)÷EFL*0.5)÷(ELR+1.393+0.667×⍟(ELR+1.444)) ⍝ FOR WE/H>1
   ZO←ZOS,ZOL
   ' '
```

```
[54] ⍝ CONDUCTOR LOSS
[55] ⍝ ER IS WE/H FOR ALL VALUES OF W
[56] ⍝ERS IS WE/H FOR  WE/H≤1/2(PI)
[57]  IC←+ ERL≤2
[58]  ERM←IC↑ERL ⍝ 1/2(PI)<WE/H≤2
[59]  ERG←IC↓ERL ⍝ WE/H>2
[60]  RES1←(○F×MU÷SIG)*0.5
[61]  P←1-(ER÷4)*2
[62]  QS←1+(-ERS)+(÷○ERS)×((⍟○4×ERS×H÷T)+T÷ERS×H)
[63]  QM←1+(-ERM)+(÷○ERM)×((⍟2×ERM×H÷T)+T÷ERM×H)
[64]  QG←1+(-ERG)+(÷○ERG)×((⍟2×ERG×H÷T)+T÷ERG×H)
[65] ⍝SEPARATE THE CHARACTERISTIC IMPEDANCE VALUES
[66] ⍝INTO THE APPROPRIATE RANGES
[67]  ZS←IR↑ZO ⍝ WE/H≤1/2(PI)
[68]  ZM←IC↑IR↓ZO ⍝ 1/2(PI) < WE/H ≤ 2
[69]  ZG←IC↓IR↓ZO ⍝ WE/H > 2
[70] ⍝ CONDUCTOR LOSS FOR WE/H≤ 1/2(PI)
[71]  ALFHS←8.68×RES1×(IR↑P)×QS÷○2×ZS×H
[72] ⍝CONDUCTOR LOSS FOR 1/2(PI)< WE/H ≤2
[73]  ALFHM←8.68×RES1×(IC↑IR↓P)×QM÷○2×ZM×H
[74] ⍝CONDUCTOR LOSS FOR WE/H>2
[75]  COEF←8.68×RES1×QG÷ZG×H
[76]  SCND←(ERG+(2÷○1)×⍟(○2×*1×((ERG÷2)+0.94)))*2
[77]  THRD←ERG+((ERG÷○1)÷((ERG÷2)+0.94))
[78]  ALFHG←COEF×THRD÷SCND
[79]  ALFH←ALFHS,ALFHM,ALFHG
[80]  ' '
[81] ⍝DIELECTRIC LOSS ASSUMING ZERO CONDUCTIVITY
[82]  DLOSS←(27.3×D×(EF-1)×LTAN)÷(EF*0.5)×(D-1)×LAM
[83]  →ENG×⍳V=1
[84]  10⍴⎕TCNL
[85]  'EFFECTIVE LINE WIDTH VS LINE WIDTH'
[86]  100 100 PLOT(ER×H) VS W
[87]  '                               WIDTH (CM)'
[88]  10⍴⎕TCNL
[89]  'EFFECTIVE DIELECTRIC CONSTANT VS LINE WIDTH'
[90]  100 100 PLOT EF VS W
[91]  '                               WIDTH (CM)'
[92]  10⍴⎕TCNL
[93]  'CHARACTERISTIC IMPEDANCE VS LINE WIDTH'
[94]  100 100 PLOT ZO VS W
[95]  '                               WIDTH (CM)'
[96]  10⍴⎕TCNL
[97]  'CONDUCTOR LOSS VS LINE WIDTH'
[98]  100 100 PLOT ALPH VS W
[99]  '                               WIDTH (CM)'
[100]  10⍴⎕TCNL
[101]  'DIELECTRIC LOSS VS LINE WIDTH'
[102]  100 100 PLOT DLOSS VS W
[103]  '                               WIDTH (CM)'
[104]  10⍴⎕TCNL
[105]  'TOTAL LOSS VS LINE WIDTH'
[106]  100 100 PLOT(ALPH+DLOSS) VS W
[107]  '                               WIDTH (CM)'
[108]  10⍴⎕TCNL
[109]  'EFFECTIVE LINE WIDTH TO SUBSTRATE RATIO  VS LINE WIDTH'
[110]  100 100 PLOT ER VS W
```

```
[111]  '                             WIDTH (CM)'
[112]  ' '
[113]  →0
[114] ENG:10⍴⎕TCNL
[115]  'EFFECTIVE DIELECTRIC CONSTANT VS LINE WIDTH'
[116]  100 100 PLOT EF VS WI
[117]  '                                         LINE WIDTH (INCHES)'
[118]  10⍴⎕TCNL
[119]  'CHARACTERISTIC IMPEDANCE VS LINE WIDTH'
[120]  100 100 PLOT ZO VS WI
[121]  '                                         LINE WIDTH (INCHES)'
[122]  10⍴⎕TCNL
[123]  'EFFECTIVE LINE WIDTH TO SUBSTRATE RATIO VS LINE WIDTH'
[124]  100 100 PLOT ER VS WI
[125]  '                                             LINE WIDTH (INCHES)'
[126]  10⍴⎕TCNL
[127]  'WAVELENGTH VS LINE WIDTH'
[128]  100 100 PLOT(LAM÷2.54×EF*0.5) VS WI
[129]  '                                         LINE WIDTH (INCHES)'
     ∇
```

```
    ∇ H94001;L1;L2;L3;L4;L5;L6;L7;L8;L9;L10;L11;L12;L13;L14;L15
[1]  ⍝ CALCULATE THE HARNESS FOR A 16 ELEMENT SUBARRAY
[2]  ⍝ THREE AUBARRAYS ARE USED FOR 17.2 INCH DIAMETER VEHICLE
[3]  ⍝ CONSTANTS
[4]   SUTH←0.062
[5]   EPS←2.47
[6]   D←17.2 ⍝ VEHICLE DIA. (INCHES)
[7]   F←5.71 ⍝ FREQUENCY (GHZ)
[8]   Z← 75 37.5 75 75 106.75 87
[9]   E← 1.977 2.117 1.977 1.977 1.91 1.977 1.947
[10]  LW← 0.08699999999999999 0.264 0.08699999999999999 0.08699999999999999 0.04
1 0.08699999999999999 0.065
[11]  W←11.803÷F×E⋆0.5 ⍝ EFFECTIVE WAVELENGTH (INCHES)
[12]  WA←11.803÷F ⍝ WAVELENGTH IN AIR (INCHES)
[13]  C←○D
[14]  NH←2×⌊C÷WA ⍝ INTEGRAL NUMBER OF HALFWAVELENGTH IN THE CIRCUMFERENCE
[15]  SE←16 ⍝ NUMBER OF ELEMENTS PER SUBARRAY
[16]  SP←C÷3×SE ⍝ SPACING BETWEEN ELEMENTS CENTERS (INCHES)
[17]  EH←0.4454×11.803÷F×EPS⋆0.5
[18]  EW←0.8×11.803÷F×EPS⋆0.5 ⍝ ELEMENT WIDTH (INCHES)
[19]  GW←SP−EW ⍝ GAP BETWEEN ELEMENTS (INCHES)
[20]  SPW←SP÷W ⍝ SEVEN ELEMENT VECTOR
[21]  EWW←EW÷W ⍝ SEVEN ELEMENT VECTOR
[22]  GWW←EW÷W ⍝ SEVEN ELEMENT VECTOR
[23]  'ENTER 1 TO SUPPRESS PARAM. PRINT'
[24]  X←⎕
[25] LBL:'ENTER SPACING BETWEEN LINES (IN) '
[26]  U1←⎕
[27]  U←(((LW[1]+LW[2])÷2)+U1[1]),(((LW[2]+LW[4])÷2)+U1[2]),(((LW[4]+LW[6])÷2)+U
1[3])
[28] ⍝
[29]  'ENTER LEG L. IN WAVEL.'
[30]  K←⎕
[31]  K[2 3 4]←K[2 3 4]−0.25
[32] ⍝ TWO ELEMENTS
[33]  TH1←0.2618 ⍝ IN RADIANS
[34]  CM←K[1],(SPW[1]÷2),(SPW[1]÷8)
[35]  M← 3 3 ⍴ 1 1 1 0 ,(2○TH1), 1 0 0 1
[36]  SM←CM⌹M
[37]  L1←SM[1]
[38]  L2←SM[2]
[39]  L3←SM[3]
[40] ⍝
[41] ⍝ FOUR ELEMENTS
[42]  TH2←○0.25
[43]  L4←U[1]÷W[2]
[44]  L7←0.25 ⍝FOR W[3]
[45]  CM1←(K[2]−L4),(SPW[2]−0.25×W[3]÷W[2])
[46]  M1← 2 2 ⍴ 1 1 1 ,(2○TH2)
[47]  SM1←CM1⌹M1
[48]  L5←SM1[1]
[49]  L6←SM1[2]
[50] ⍝
[51] ⍝ EIGHT ELEMENTS
[52]  TH3←TH2
[53]  L8←((L6×W[2]×1○TH2)+U[2])÷W[4]
[54]  L11←0.25 ⍝ FOR W[5]
[55]  CM2←(K[3]−L8),((2×SPW[4])−L11×W[5]÷W[4])
[56]  M2←M1
[57]  SM2←CM2⌹M2
[58]  L9←SM2[1]
[59]  L10←SM2[2]
[60] ⍝
[61] ⍝ SIXTEEN ELEMENTS
[62]  TH4←TH2
```

```
[63]   L12←((L10×W[4]×1○TH2)+U[3])-W[6]
[64]   L15←0.25 ⍝ FOR W[7]
[65]   CM3←(W[4]-L12),((4×SPW[4])-L15×W[7]-W[6])
[66]   M3←M1
[67]   SM3←CM3⌹M3
[68]   L13←SM3[1]
[69]   L14←SM3[2]
[70]   LL←L1,L2,L3,L4,L5,L6,L7,L8,L9,L10,L11,L12,L13,L14,L15 ⍝LENGTH IN TERMS OF
WAVELENGHTS
[71]   →LBL1×⍳X=1
[72]   ⎕TCNL
[73]   'LEGS IN TERMS OF EFFECTIVE WAVELENGTH'
[74]   +/L1,L2,L3
[75]   +/L4,L5,L6,L7
[76]   +/L8,L9,L10,L11
[77]   +/L12,L13,L14,L15
[78] LBL1:LI1←LL[1 2 3]×W[1]
[79]   LI2←LL[4 5 6]×W[2]
[80]   LI3←LL[7]×W[3]
[81]   LI4←LL[8 9 10]×W[4]
[82]   LI5←LL[11]×W[5]
[83]   LI6←LL[12 13 14]×W[6]
[84]   LI7←LL[15]×W[7]
[85]   LI←LI1,LI2,LI3,LI4,LI5,LI6,LI7
[86]   ⎕TCNL
[87]   →LBL2×⍳X=1
[88]   '      PARAMETERS'
[89]   OM2← 6 16 ⍴'SUBSTR. THICK.  DIELEC. CONST.  ELEM. H.         ELEM. W.
  DIAMETER          FREQUENCY         '
[90]   OM3← 6 1 ⍴SUTH,EPS,EH,EW,D,F
[91]   '16A1,F6.3' ⎕FMT(OM2;OM3)
[92]   ⎕TCNL
[93]   OM4← 3 21 ⍴'ELE.SP. (INCHES)      GAP (INCHES)           ELE. SP. (WAVEL. AIR
)'
[94]   OM5← 3 1 ⍴SP,GW,(SP÷WA)
[95]   '21A1,F6.3' ⎕FMT(OM4;OM5)
[96]   ⎕TCNL
[97]   OM6← 3 11 ⍴'CHAR. IMP  EFF. DIEL. LINEWIDTH  '
[98] LBL2:OM7← 3 7 ⍴Z,E,LW
[99]   '11A1,F10.3,6(F8.3)' ⎕FMT(OM6;OM7)
[100]   OM8← 1 31 ⍴'NO LENGTH(I) LENGTH(W) WIDTH ZO'
[101]   M← 2 7 ⍴LW,Z
[102]   OM92← 15 2 ⍴(6⍴M[;1]),(6⍴M[;2]),M[;3],(6⍴M[;4]),M[;5],(6⍴M[;6]),(M[;7])
[103]   OM9←(⍉ 3 15 ⍴(⍳15),LI,LL),OM92
[104]   2⍴⎕TCNL
[105]   '2A1,X2,10A1,10A1,6A1,X3,3A1' ⎕FMT(OM8)
[106]   'I2,F8.3,F10.3,F10.3,X3,I3' ⎕FMT(OM9)
[107]   ⎕TCNL
[108]   'HARNESS WIDTH'
[109]   LI[1]+(LI[2]×1○TH1)+LI[4]+LI[8]+LI[12]-(LI[6]×1○TH2)+LI[10]×1○TH2
[110]   SS1←LI[1]+(LI[2]×1○TH1)+LI[4]-(LI[6]×1○TH2)+LW[3]÷2
[111]   SS2←SS1+(LW[3]÷2)+LI[8]-(LI[10]×1○TH2)+LW[5]÷2
[112]   SS3←SS2+(LW[5]÷2)+LI[12]-(LI[14]×1○TH2)+LW[7]÷2
[113]   ⎕TCNL
[114]   'SPACING BETWEEN LINE EDGE AND ELEMENT PATCH'
[115]   HH← 1 22 ⍴'LINE 7 LINE 11 LINE 15'
[116]   SS← 1 3 ⍴SS1,SS2,SS3
[117]   'X5,7A1,X3,8A1,X2,7A1' ⎕FMT(HH)
[118]   '3F10.3' ⎕FMT(SS)
[119]   2⍴⎕TCNL
[120]   →LBLX×⍳X=1
[121]   →0
     ∇
```