Design of FAW antenna
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RADIO BRANCH

DESIGN OF FAW ANTENNA

OTTAWA

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NATIONAL RESEARCH COUNCIL OF CANADA
RADIO BRANCH

SECRET PRA-65

DESIGN OF FAW ANTENNA

CONTENTS

Page No.

1. General Description 1
2. Design of a Single Yagi 2
3. Horizontal Radiation Patterns of the Array 2
4. Vertical Radiation Patterns 3
5. Calculation of Range-Height Diagram 3
6. Comparison with Experiment 4
7. Conclusion 5

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NATIONAL RESEARCH COUNCIL
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S E C R E T | PRA-65

DESIGN OF THE FAW ANTENNA

1. General Description

The FAW is a mobile Forward Area Warning set for Army use. Specifications call for complete coverage on all aircraft in the range 20 to 50 miles up to an altitude of 30,000 feet, and azimuth accuracy of ± 5°. These requirements are partially met by the present ZPI, so that the substitution of an antenna with greater gain than the ZPI antenna, and having vertical gap filling, would allow the present ZPI transmitter and receiver to fulfil the requirements. This procedure minimizes the need of new production for the FAW set.

The type of antenna decided upon is very similar to that used with the British LW set, which was designed to serve the same general purposes as FAW. It consists of four horizontally polarized Yagi antennas mounted at the four corners of a vertical rectangle. The Yagis are supported on detachable wooden trusses which mount on the standard ZPI A-frame. The array may be thought of as a vertical stack of two antennas, the upper and lower antennas each consisting of a horizontal row of two Yagis. The two Yagis in each horizontal row are fed in phase at all times, producing a sharp horizontal radiation pattern. Gap filling is provided by feeding the upper and lower antennas either in phase or in antiphase, at the will of the operator. As will be shown later, the two vertical patterns thus produced fill each other's gaps. The phase-to-antiphase switching is accomplished by a solenoidal relay mounted in the rotating antenna framework, and may be understood by referring to Dwg. No. 342. This diagram shows the two cables leading from the upper and lower pairs of Yagis, and the matching transformers on these cables at the point where the leads from a pair of Yagis are paralleled. Since the cable is matched and has an impedance of 136 ohms, the impedance at the junction point is 68 ohms. Thus a quarter wave transformer of 96 ohms impedance is required to return to the 136 ohm impedance of the cable, and fortunately this is easily obtained by slipping a closely fitting brass tube over the unscreened cable for a quarter wavelength at the junction.

Power to operate the solenoidal switch is carried into the antenna framework by means of slip rings mounted inside the RF coupling ring assembly. Dwg. No. NRC-RI/C-53-D shows the assembly of the four Yagis on the rotating frame, and indicates the positions of the solenoidal switch and phasing lines. This drawing does not show the telcothene cable feeders extending from the phasing network to the four Yagis. The whole array mounted in position on the trailer is shown in photograph, see Figure 1.

2. Design of a Single Yagi

The assembly of a single Yagi is shown in Dwg. No. NRC-RI/C-44-B. The design of this Yagi may be summarized as follows:

(1) All elements are 3/8" diameter rod or tubing, mounted in a 1 1/2" x 2 1/4" wood member.

(2) The radiator is a folded dipole, length 86.7 cm, spacing between fed and folded parts 5.1 cm, centre to centre.

(3) Reflector is mounted 24 cm behind the radiator, length 104 cm.

(4) Directors are five in number. The first four are 85.5 cm long, and the end director is 72 cm long. All directors are spaced 67 cm.

(5) Input impedance to folded dipole at 150 mc/s is 136 ohms resistance.

(6) Measured horizontal radiation pattern at 150 mc/s is shown in Dwg. No. NRC-RI/C-103-A.

(7) Measured free space vertical radiation pattern at 150 mc/s is shown in Dwg. No. NRC-RI/C-104-A.

3. Horizontal Radiation Patterns of the Array

The horizontal radiation pattern of the whole four Yagi array is the resultant of mounting two Yagis at a horizontal separation of 8 ft. 6 in. = 259 cm. This pattern, as measured at 150 mc/s with the upper and lower antennas connected in phase, is shown in Dwg. No. NRC-RI/C-95-A.

The beam width at half field strength is 26°, which is sufficiently sharp to give considerably greater azimuthal accuracy than called for. It will be seen that spurious lobes are nowhere greater than 20% of the main beam, so that when the antenna is used for common transmitting and receiving, spurious echoes are not observed. Since variations of frequency are bound to occur in practice, the horizontal patterns at 145 mc/s and 153.5 mc/s were measured and are shown in Dwg. No. NRC-RI/C-102-A and 105-A respectively.

The horizontal pattern of the array at 150 mc/s with the upper and lower antennas in antiphase was difficult to measure, due to the small amount of horizontal radiation produced when the antennas are connected in this way. The difficulty was obviated by measuring the pattern at an angle of elevation of about 18°, and the result is shown in Dwg. No. NRC-RI/C-96-A.

The free space power gain of the whole array in phase over a simple dipole has been calculated from the radiation patterns, and found to be 39.

4. Vertical Radiation Patterns

Calculation of the vertical radiation patterns over a flat earth for phase and antiphase connections is carried out in the following steps:

(1) The earth is assumed to be perfectly conducting, an assumption which is justifiable for horizontal polarization. The earth is assumed to be flat everywhere within a radius of about 1000 feet of the antenna.

(2) Since a horizontal row of two Yagis has the same free space vertical pattern as a single Yagi, the single Yagi pattern is used as a basis for calculation. (Dwg. No. NRC-RI/C-104-A).

(3) The "ground reflection factor", $2 \sin \left(\frac{2\pi H}{\lambda} \sin \theta\right)$ is calculated for the upper ($H/\lambda = 4.10$) and lower ($H/\lambda = 2.60$) antennas, taking intervals of the angle of elevation, θ, of one or two degrees.

(4) Each ground reflection factor is then multiplied by the single Yagi free space vertical pattern, and the result is the vertical pattern of each of the upper and lower antennas in the presence of ground. (Plotted in Dwg. No. 340)

(5) To obtain the "in-phase" vertical pattern the two vertical patterns of Dwg. No. 340 are added; to obtain the "anti-phase" pattern they are subtracted. The results are plotted in Dwg. No. 341, which clearly shows the gap filling action of the antenna.

5. Calculation of Range-Height Diagram

Calculation of the theoretical range-height visibility diagram for the F.M. may be carried out fairly simply from the vertical patterns of Dwg. No. 341. The range of an RDF set along any radius vector drawn from its site varies as the fourth root of the transmitted power, and hence varies as the square root of the transmitted field strength. In our case the antenna is used for both transmitting and receiving, so that its field strength pattern is effectively squared. Thus the maximum range in any direction is proportional to the field strength in that direction, as plotted in Dwg No. 341, and it is only necessary to fix the absolute scale of range. This is done by estimating the maximum range to be expected of the F.M. from the known maximum ranges of other RDF sets with known types of antennas. Such estimates gave answers for the maximum range of the FAW on small aircraft ranging from 65 to 75 miles. The value of 68 miles has been chosen for calculation.

The following steps are now taken in the calculation:

(1) All the field strengths of Dwg. No. 341 are multiplied by a factor which makes the maximum field strength of the "in-phase" pattern equal to 68 miles slant range.

(2) These slant ranges and the angles at which they occur are converted to ground ranges in thousands of yards and heights in thousands of feet.

(3) The foregoing values are corrected for the geometrical effect of the earth's curvature, by subtracting from the various heights the amount by which the earth's surface has dropped beneath the tangent plane at the FAW site. No attempt has been made to take account of diffraction or refraction effects. The resulting values are plotted as curves of maximum visibility in the range-height diagram NRC-RI/C-55-D.

6. Comparison with Experiment

In addition to the calculated range-height curves, Dwg. No. NRC-RI/C-55-D shows the results of flight tests with a controlled aircraft. Two types of aircraft, Bolingbroke and Hudson, were used, and comparison tests showed that maximum ranges obtained with the two types are identical within experimental error. The flight test technique consists of sending the aircraft out at a specified height on a straight line radial course from the FAW site. Some time after the aircraft's echo has disappeared on the outward flight, instructions are given for the aircraft to turn and fly straight back towards the test site, maintaining a constant altitude. All recorded observations are made while the aircraft is on the return flight, so that the effects of aspect are eliminated. The appearance and disappearance of the echo on the PPI tube are noted, together with a rough estimate of its intensity.

A number of test runs were made at altitudes ranging from 2,500 to 23,500 feet (the ceiling of the Hudson aircraft). Regions in which the target was visible are plotted as horizontal lines in Dwg. No. NRC-RI/C-55-D, and it will be seen that the agreement with theory is good. The flight test results have been smoothed into the experimental vertical radiation pattern of Dwg. No. NRC-RI/C-82-D, which is plotted so as to show true angles of elevation.

7. <u>Conclusion</u>

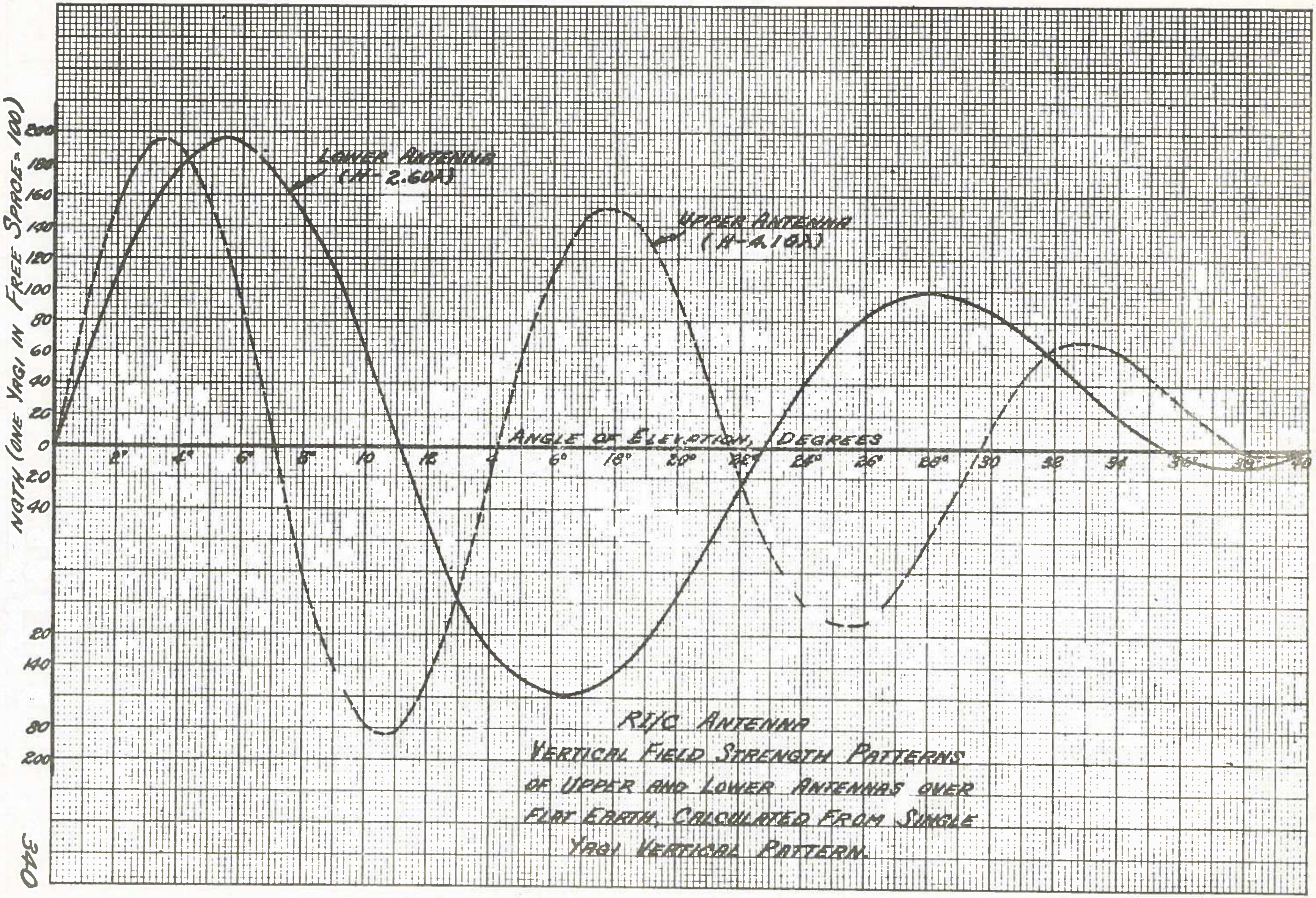
The FAW antenna was designed to give maximum range at low angles, and to do this the high angle cover is of course reduced. It will be noted from the flight test results that observations at ranges less than about 20,000 yards are not as good as with the ZPI, especially at high altitudes. This is partly the result of increased ground clutter due to the increased antenna gain, and partly due to a gap in the pattern at an elevation of 22°. The short range performance is of no importance in a warning device, but it does mean that this set would be less suitable than the ZPI for transferring target to the AFF.

The flight test results indicate that, for searching, the antennas will normally be operated in phase. However, an aircraft flying at 33,000 feet could approach to within 56,000 yards before being seen with the antennas in phase. Thus the antiphase connection should be used periodically to check for the presence of distant high flying aircraft.

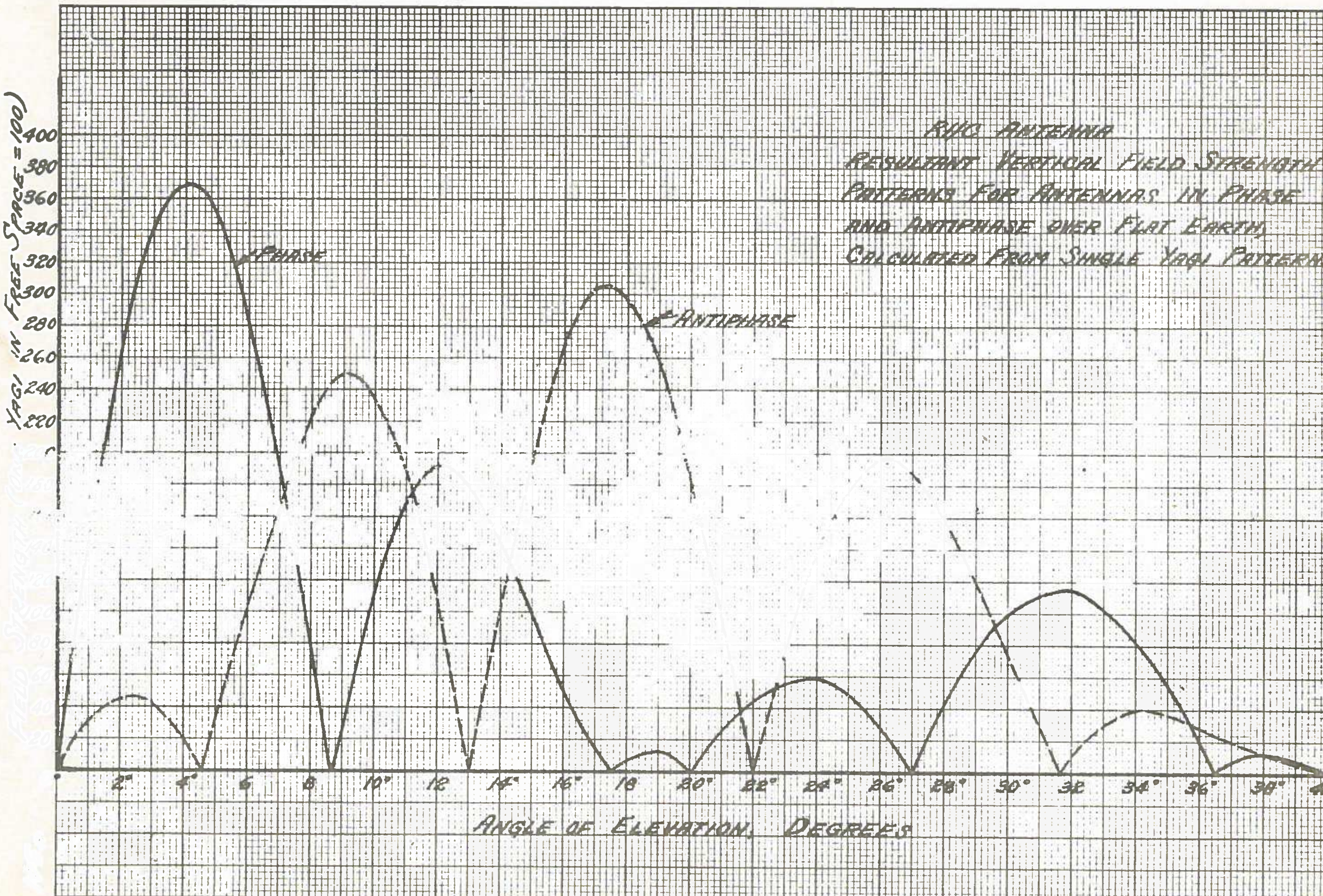
R. E. Bell

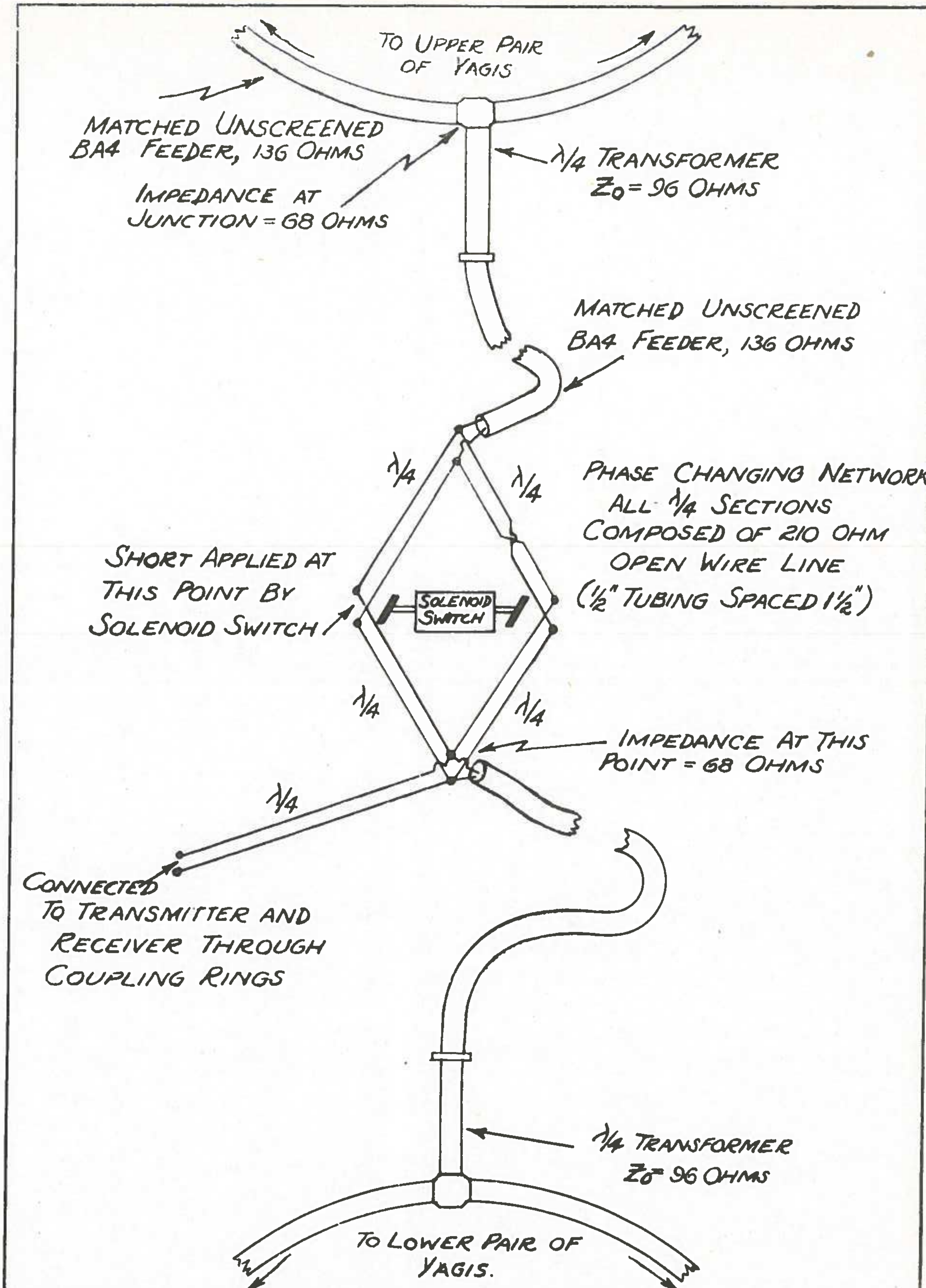
NRC
Photo

NRC
Photo

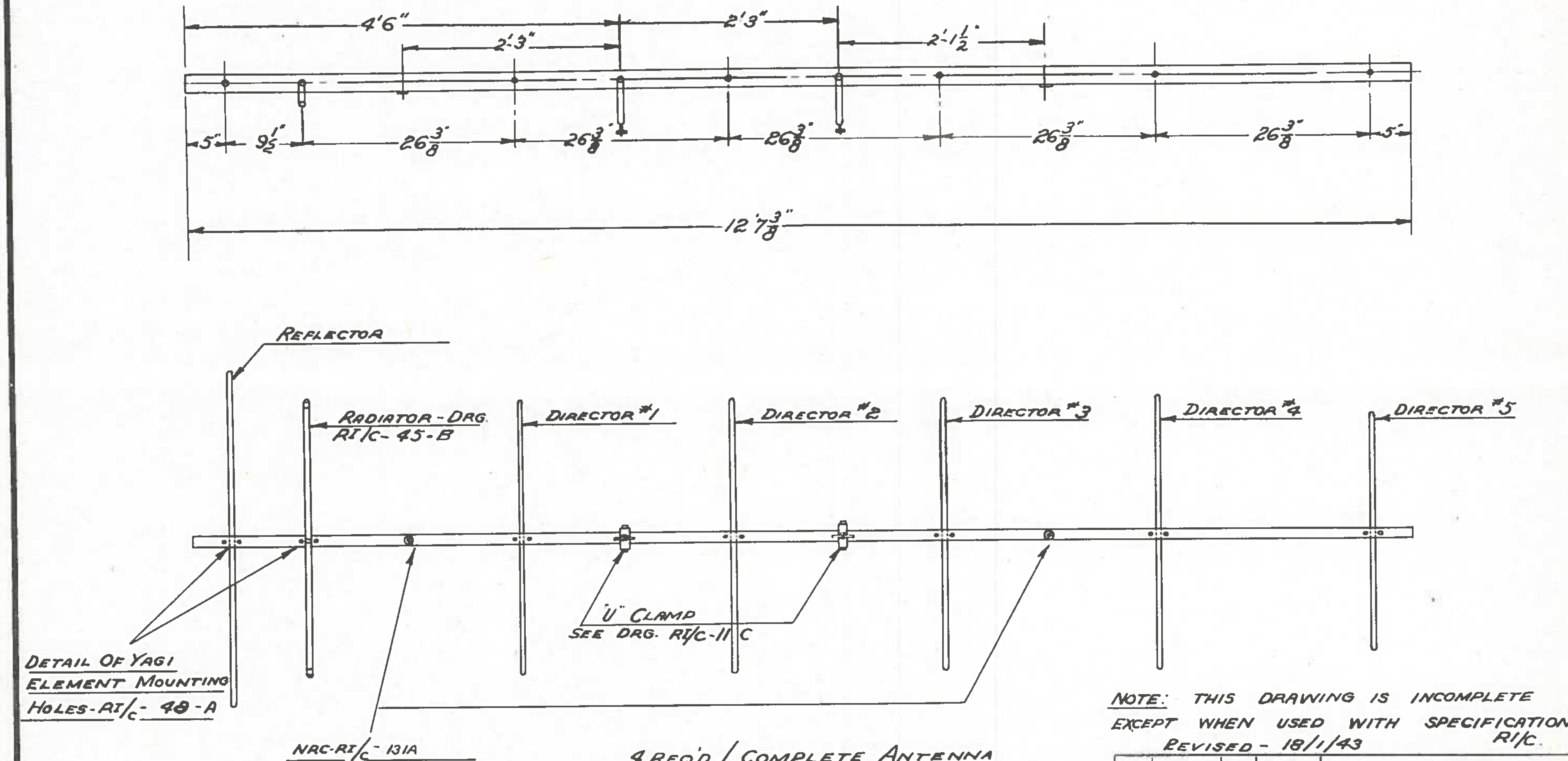


RI/C ANTENNA
VERTICAL FIELD STRENGTH PATTERNS
OF UPPER AND LOWER ANTENNAS OVER
FLAT EARTH, CALCULATED FROM SINGLE
YAGI VERTICAL PATTERN.


RHC ANTENNA
RESULTANT VERTICAL FIELD STRENGTH
PATTERNS FOR ANTENNAS IN PHASE
AND ANTIPHASE OVER FLAT EARTH,
CALCULATED FROM SINGLE YAGI PATTERN.
PHASE
ANTIPHASE
YAGI IN FREE SPACE = 100)
400
380
360
340
320
300
280
260
240
220
2°
4°
6
8
10°
12
14°
16°
18
20°
22°
24°
26°
28°
30°
32
34°
36°
38°
40°
ANGLE OF ELEVATION, DEGREES



NATIONAL RESEARCH COUNCIL -		OTTAWA CANADA	
APPROVED R.E.B.	- RADIO BRANCH. -	DATE JAN. 11, 1943.	PR 342
	RI/c ANTENNA FEED SYSTEM.		



NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/C.

REVISED - 18/1/43

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

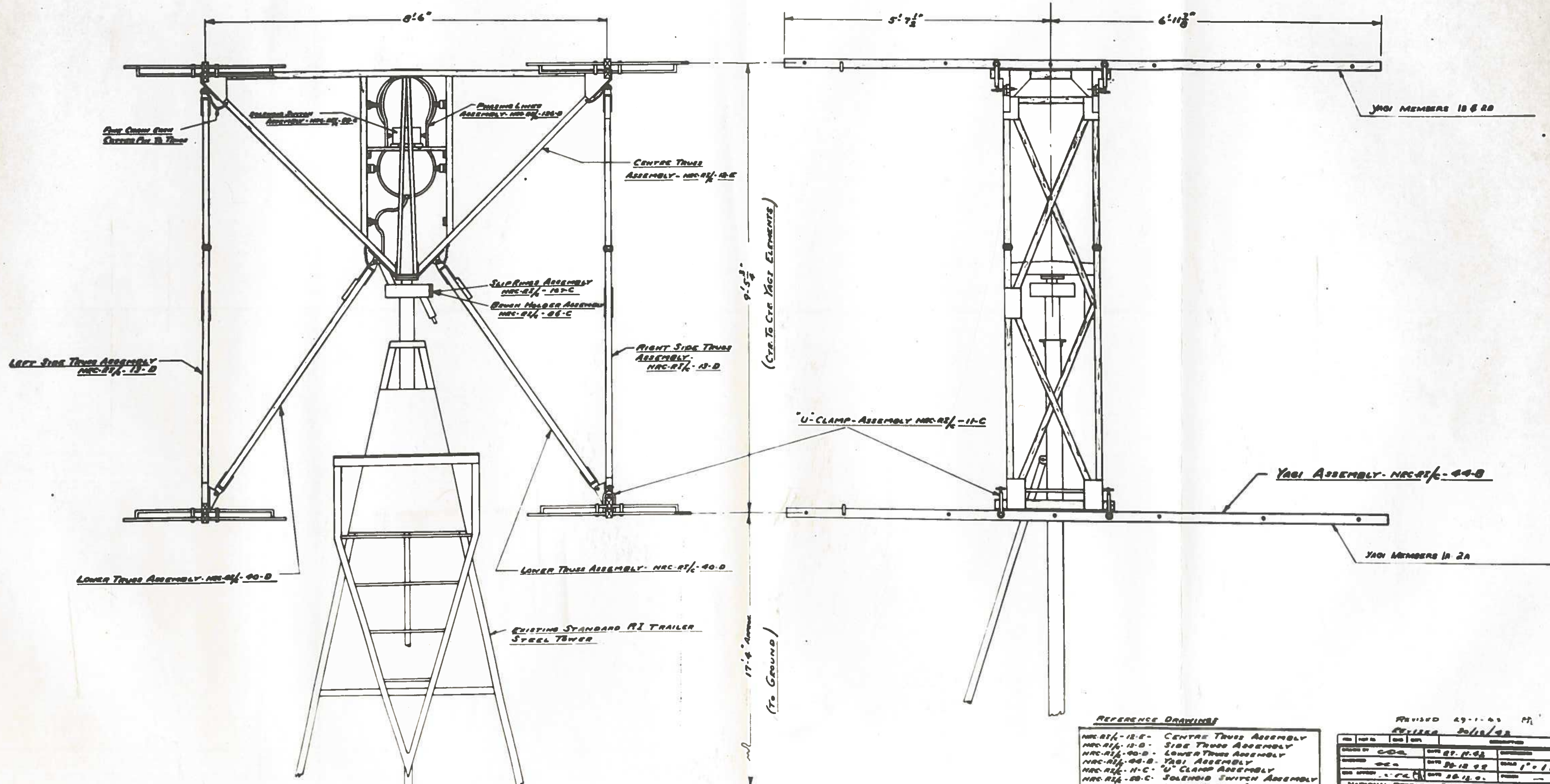
DRAWN BY E.H.B.	DATE Nov 20, 1942	SUPERSEDES
CHECKED CEA	DATE 21-11-42	SCALE 1" - 1 FT.
ENG. APPROV. REB	DATE Nov 20, 1942	FINISH —

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME RI/C - ANTENNA YAGI ASSEMBLY	DWG. NO. NRC-RI/C-44B

REVISED BY-J.R.D 26/1/43

NOTE. THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RS/C



REFERENCE DRAWINGS

NRC-RS/C-12-E-	CENTRE TRUSS ASSEMBLY
NRC-RS/C-13-D-	SIDE TRUSS ASSEMBLY
NRC-RS/C-40-D-	LOWER TRUSS ASSEMBLY
NRC-RS/C-44-B-	YAGI ASSEMBLY
NRC-RS/C-11-C-	"U" CLAMP ASSEMBLY
NRC-RS/C-89-C-	SOLENOID SWITCH ASSEMBLY
NRC-RS/C-86-C	BRUSH HOLDER ASSEMBLY
NRC-RS/C-107-C-	SLIP RINGS ASSEMBLY
NRC-RS/C-126-D-	PHASING LINES ASSEMBLY

REVISED 29-1-43

REVISED 30/12/42

DATE 27-11-42

DATE 30-12-42

SCALE 1" = 1 FT.

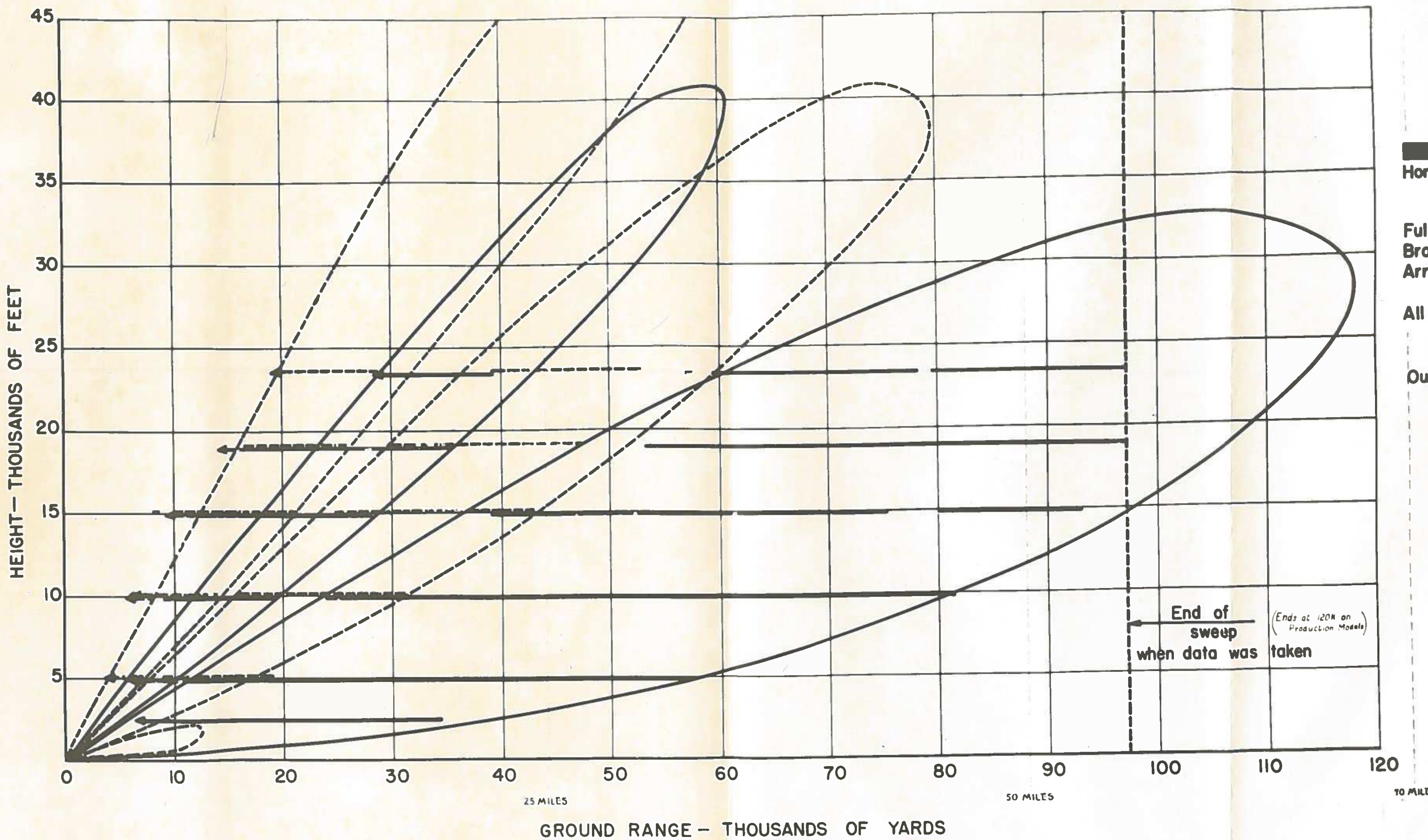
NATIONAL RESEARCH COUNCIL-RADIO SECTION-

ROTATING STRUCTURE ASSEMBLY

NRC-RS/C-53-D

R1/C ANTENNA; RANGE-HEIGHT DIAGRAM
FOR FLAT SITE

COMPARISON BETWEEN PLOT OF OBSERVED DATA AND THEORETICAL PATTERNS



NOTE:

[redacted]

Horizontal lines indicate observations on Bolingbroke Aircraft, Ottawa—Brockville Course.

Full lines—Antennas in Phase.

Broken lines—Antennas in Antiphase.

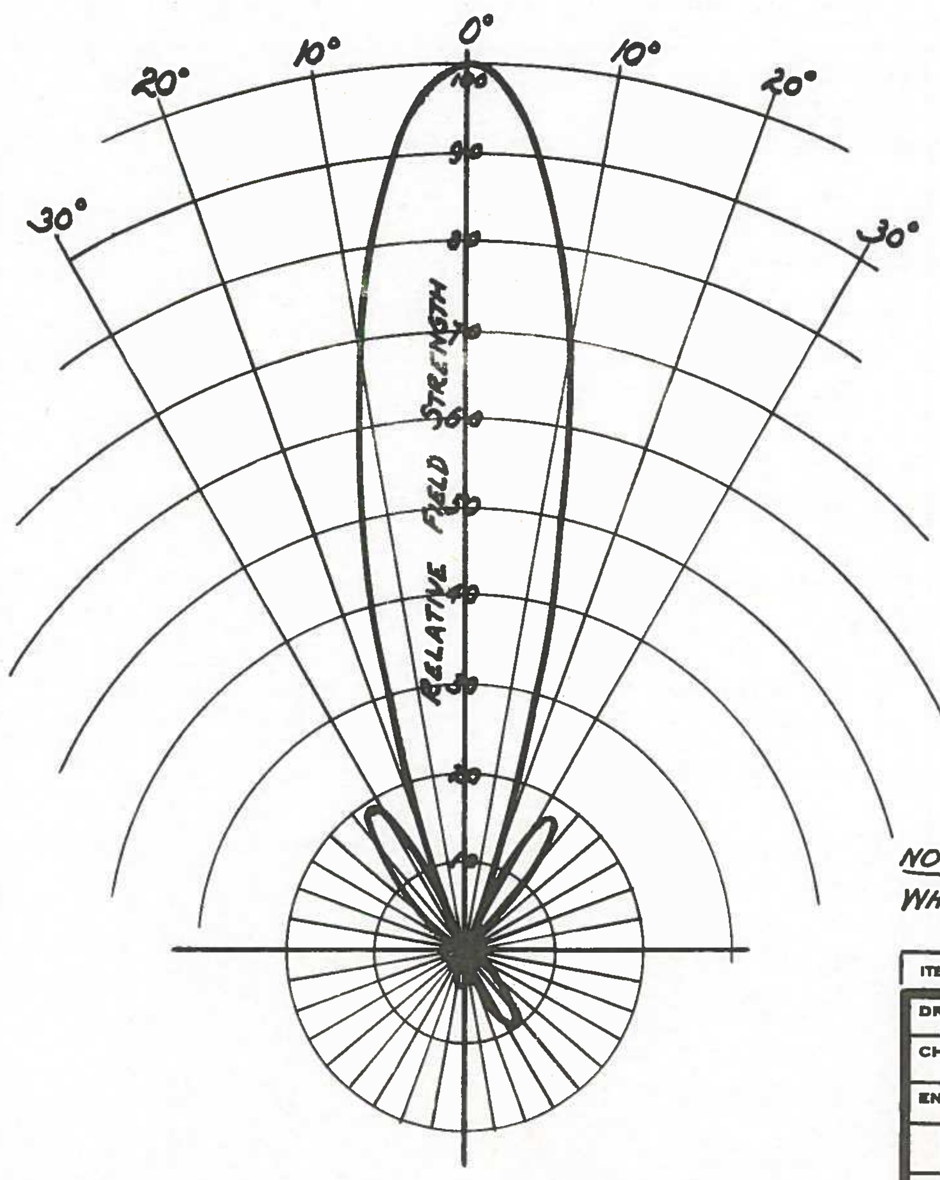
Arrow heads indicate echo lost in clutter at this point.

All observations made with aircraft pointing directly towards R1/C set.

Outline curves were calculated from theory.

Revised 29-1-43
Revised 8-12-42

Drawn by E.H.B.	Date Nov. 16, 1942		
Checked	Date 21-11-42	Scale	
Eng. Approv.	Date Jan. 29, 1943		
NATIONAL RESEARCH COUNCIL-RADIO SECTION			
Name R1/C Antenna - Range - Height Diagram		Dwg. No. DRL-R1/C 51 D	



RI/C ANTENNA- 150 MC/S
HORIZONTAL FIELD STRENGTH
PATTERN (IN PHASE)

NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/C.

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY D.C	DATE 4-12-42	SUPERSEDES	
CHECKED CCG	DATE 4-12-42	SCALE	
ENG. APPROV. R.E.B.	DATE DEC. 4, 1942.	FINISH.	

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME	DWG. NO.
RI/C ANTENNA PATTERN (IN PHASE)	NRC-RI/C-95-A

RI/C ANTENNA

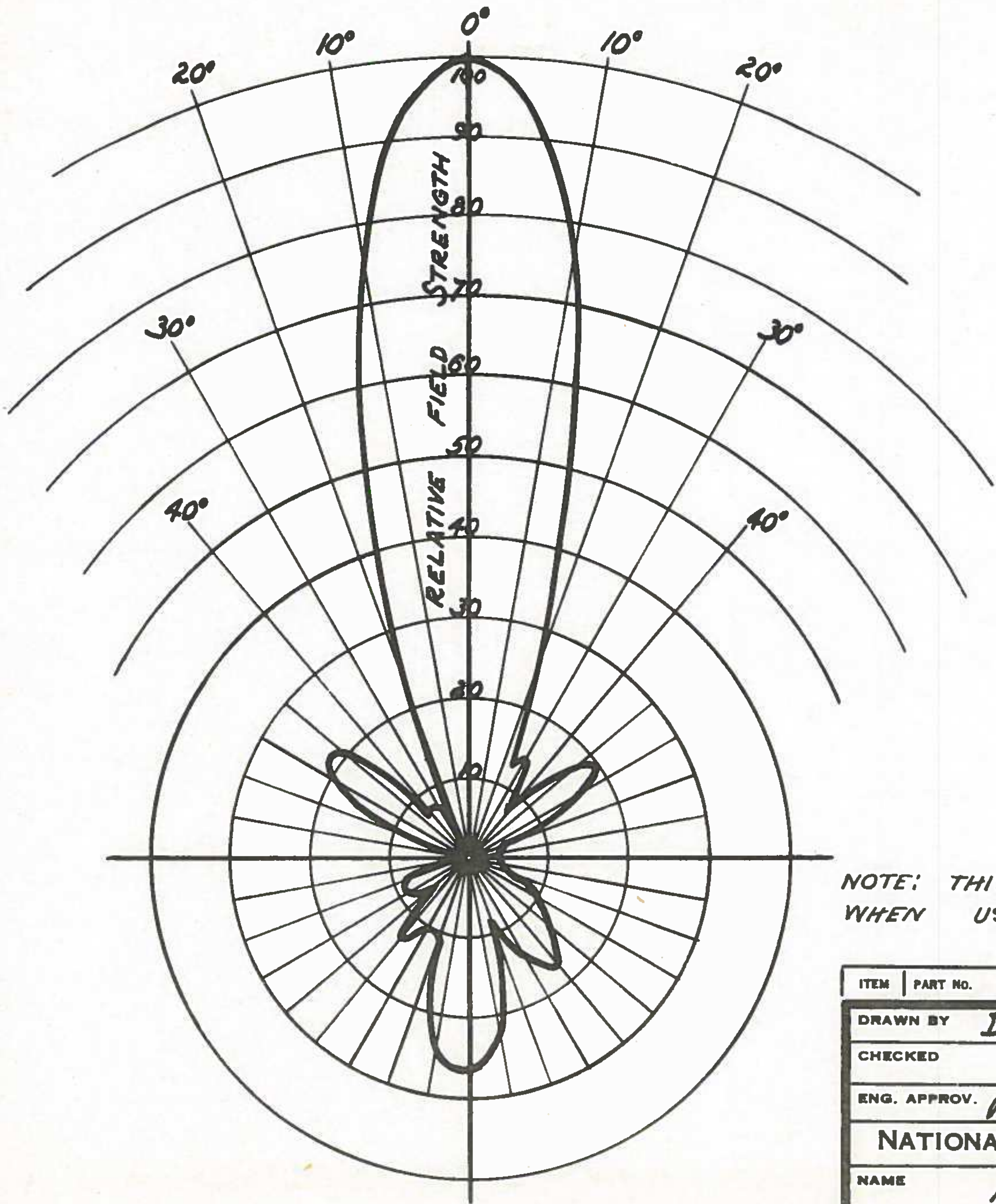
EXPERIMENTAL VERTICAL POLAR DIAGRAM

taken on flat site at Radio Field Station, using Bolingbroke Aircraft.

Full Lines — Antennas in phase.

Broken Lines — Antennas in antiphase.

NATIONAL RESEARCH COUNCIL—RADIO SECTION



RI/c ANTENNA - 150 Mc/s
HORIZONTAL FIELD STRENGH
PATTERN (IN ANTIPHASE)

NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/C

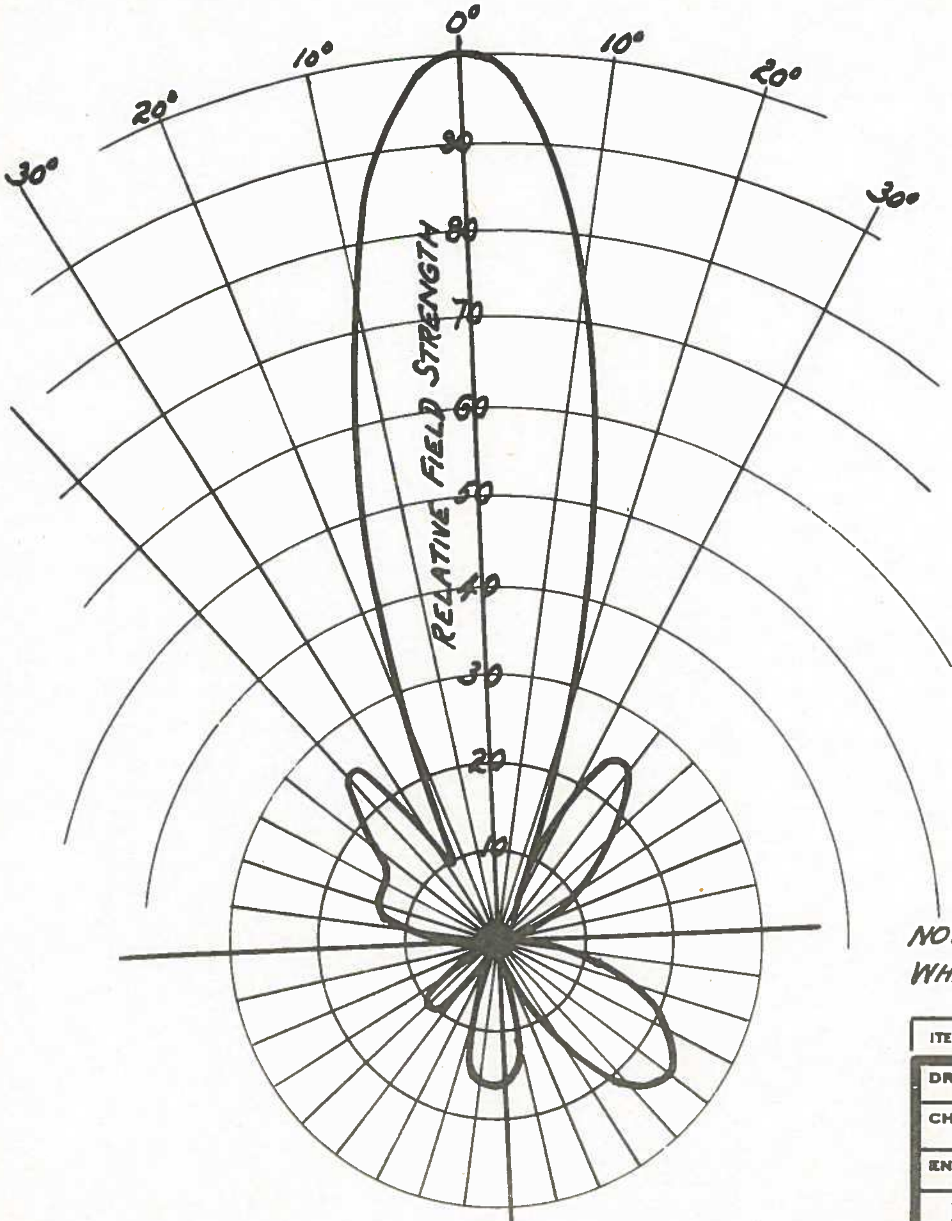
Exp. ARRAY No. 1

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY D.C	DATE 4-12-42.	SUPERSEDES
CHECKED	DATE	SCALE
ENG. APPROV. R.E.B.	DATE DEC. 4, 1942.	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME	DWG. NO.
RI/c ANTENNA PATTERN (IN ANTIPHASE)	NRC-RI/c-96-A



RI/C ANTENNA-HORIZONTAL
FIELD STRENGTH PATTERN
(IN PHASE) AT 195 MC/S.

NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/C

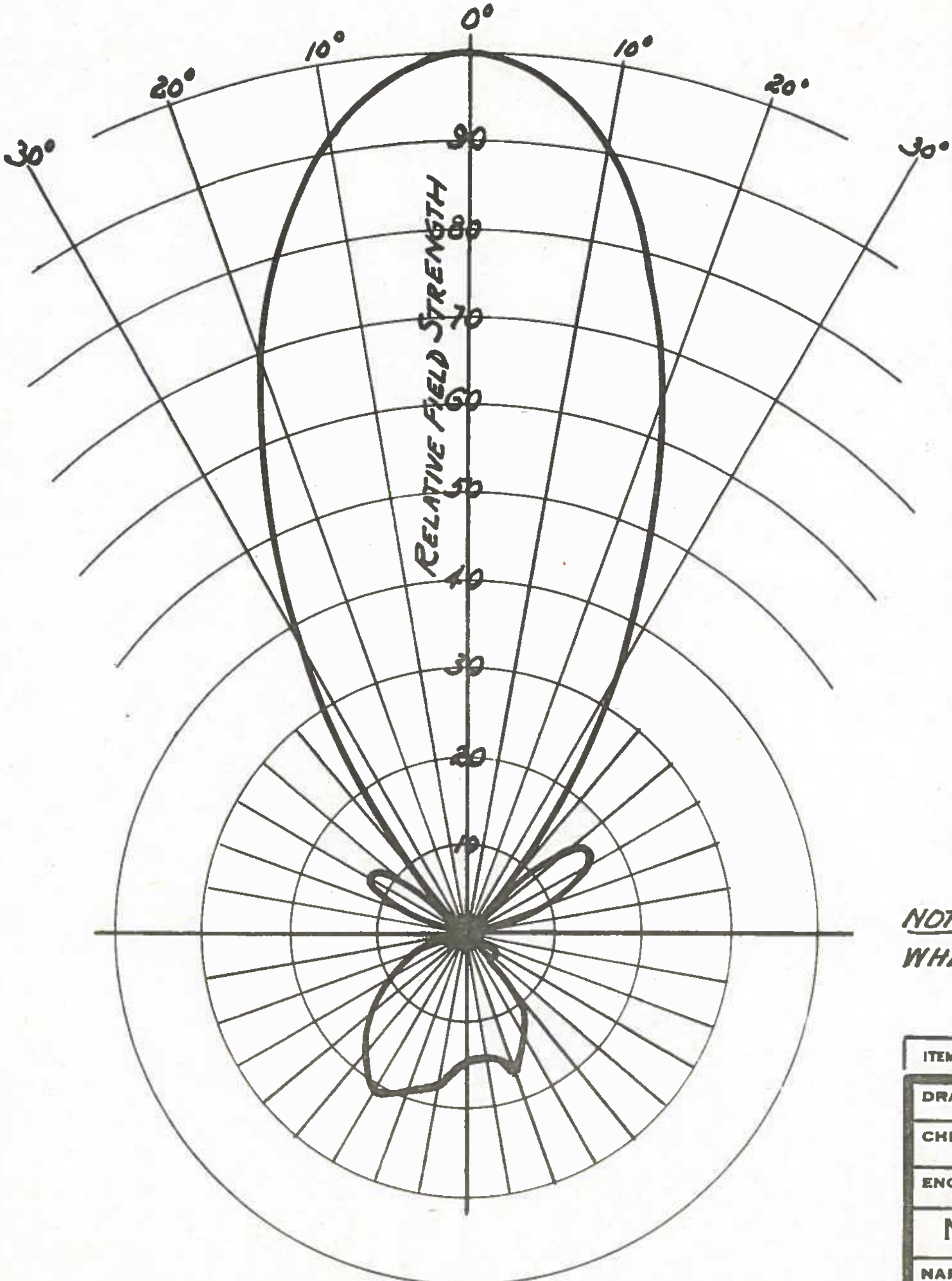
ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY	D.C	DATE	5-12-42	SUPERSEDES
CHECKED	cea	DATE	9-12-42	SCALE
ENG. APPROV.	R.E.B.	DATE	8-12-42.	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME	RI/C ANTENNA PATTERN	DWG. NO. NRC-RI/C-102-A

EXP. ARRAY NO. 1



RI/c ANTENNA-HORIZONTAL FIELD STRENGTH PATTERN OF A SINGLE YAGI AT 150 MC/s

NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/C

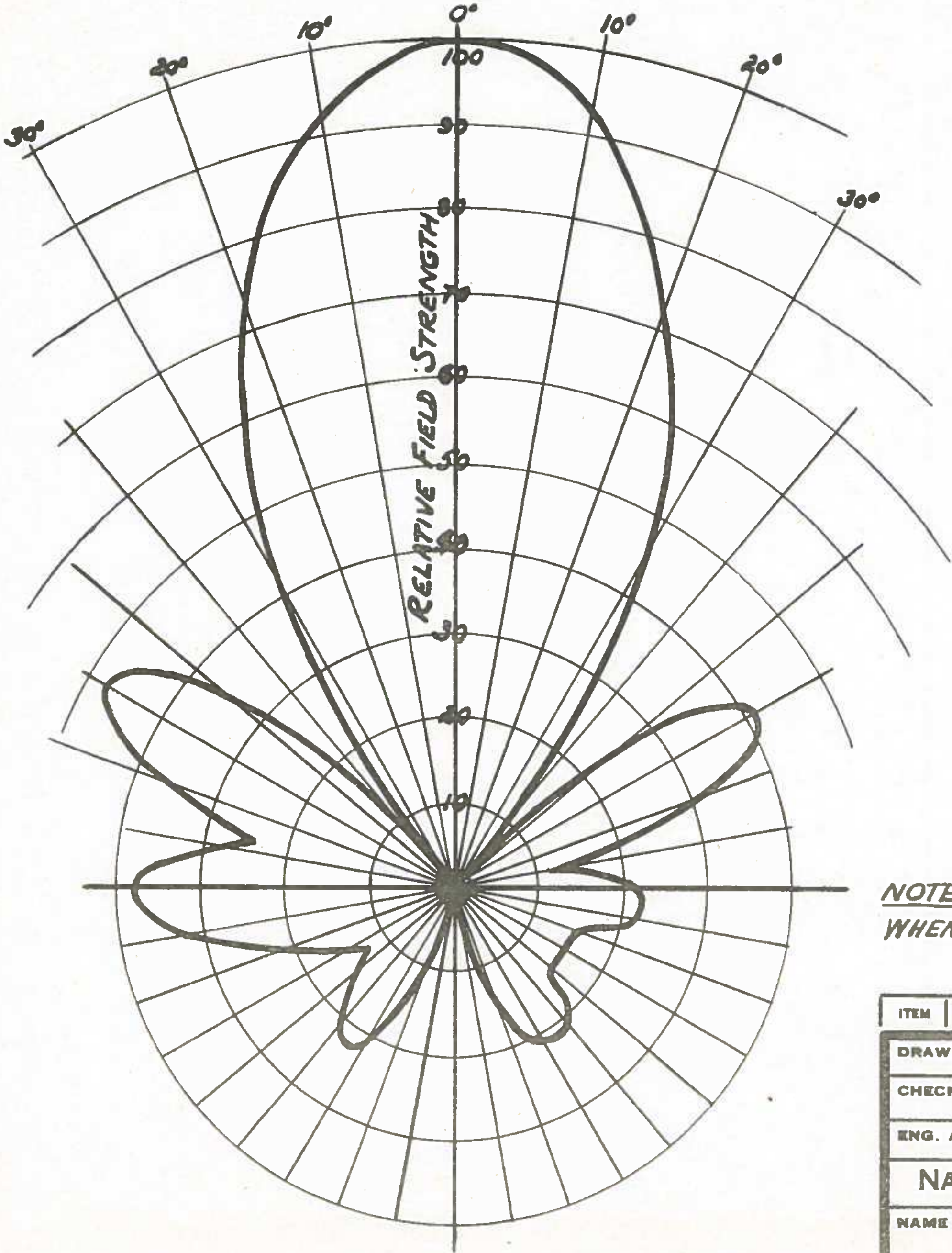
ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY	D.C.	DATE	8-12-42	SUPERSEDES
CHECKED	CCC	DATE	9-12-42	SCALE
ENG. APPROV.	R.E.B.R.	DATE	8-12-42.	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME	DWG. NO.
RI/c ANTENNA PATTERN	NRC-RI/c-103-A

EXP. ARRAY No. 1.



Exp. Array No. 1

RI/c ANTENNA–FREE SPACE
VERTICAL FIELD STRENGTH PATTERN
OF A SINGLE YAGI AT 150 MC/s

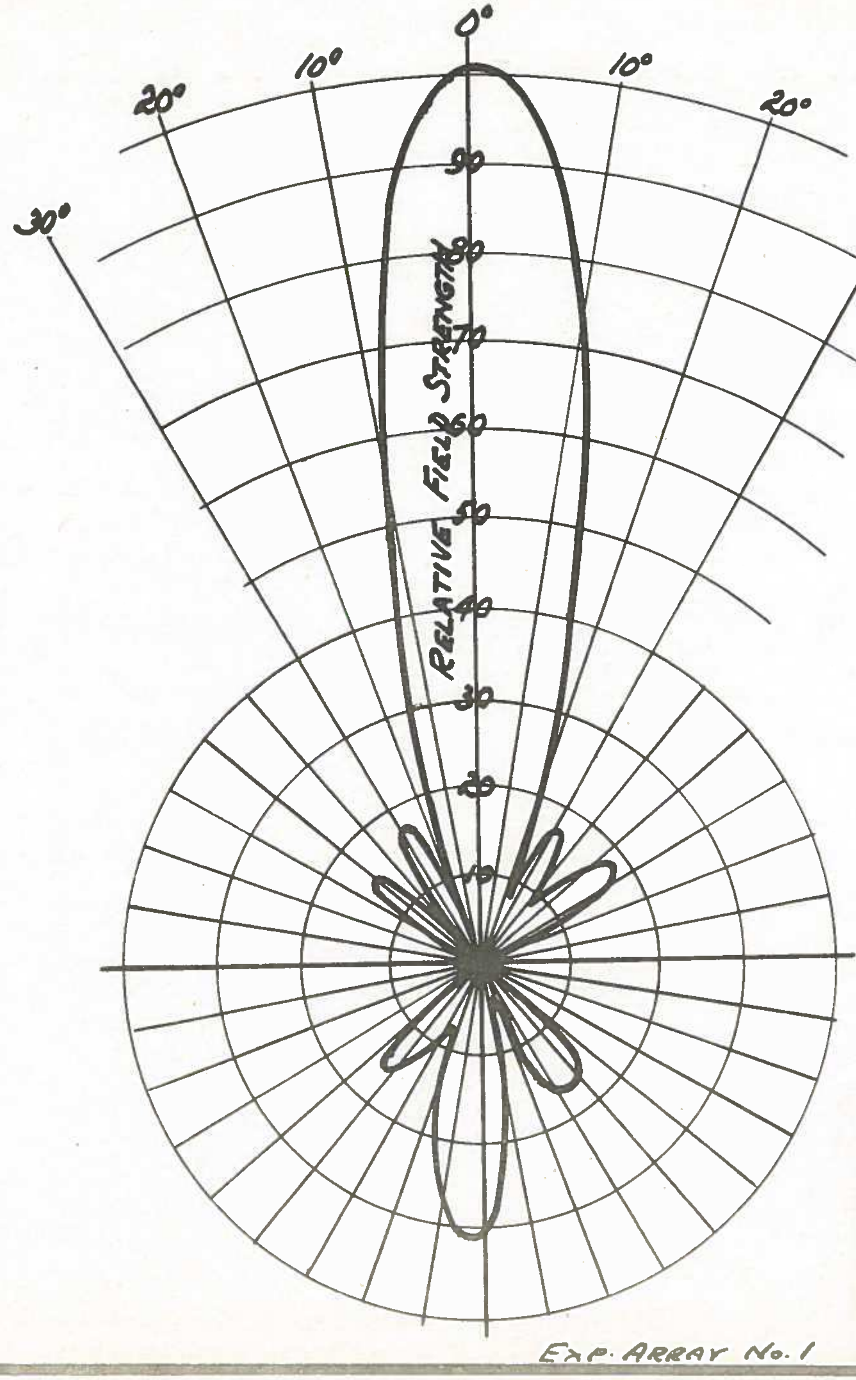
NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/c.

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY	D.C.	DATE	8-12-42	SUPERSEDES
CHECKED	cea	DATE	9-12-42	SCALE
ENG. APPROV.	R.E.B.	DATE	8-12-42	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME	RI/c ANTENNA PATTERN	DWG. NO. NRC-RI/c-104-A



RI/C ANTENNA–HORIZONTAL
FIELD STRENGTH PATTERN
(IN PHASE) AT 153.5 Mc/s

NOTE: THIS DRAWING IS INCOMPLETE EXCEPT WHEN USED WITH SPECIFICATION RI/C

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY D.C.	DATE 8-12-42	SUPERSEDES
CHECKED CCG	DATE 9-12-42	SCALE
ENG. APPROV. R.E.B.G.R.	DATE 8-12-42.	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME	DWG. NO.
RI/C ANTENNA PATTERN	NRC-RI/C-105-A