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THE UNIVERSITY OF TENNESSEE
DEPARTMENT OF ELECTRICAL ENGINEERING

DEVELOPMENT OF A HIGH FREQUENCY STEERABLE ANTENNA

Navy Department
Bureau of Ships
Electronics Divisions

Interim Development
Report No. 12

Contract No. NObsr-57448
Index No. NE-091035 ST7
10 September 1953

Encl. (3) to BUSHIPS ltr Ser 362-806

A PROJECT OF THE ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE COLLEGE OF ENGINEERING

[redacted]

Knoxville 16, Tennessee

Encl 14

[redacted]

INTERIM DEVELOPMENT REPORT

FOR

DEVELOPMENT OF A HIGH FREQUENCY STEERABLE ANTENNA

This report covers the period
1 August 1953 to 31 August 1953

ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE
KNOXVILLE, TENNESSEE

Navy Department — Bureau of Ships
Electronics Divisions

Contract No. NObsr-57448 — Index No. NE-091035 ST7

10 September 1953

Copy No. 11

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ABSTRACT

This report covers work done on Contract No. NObsr-57448, Index No. NE-091035 ST7, at The University of Tennessee during the month of August 1953.

The following was accomplished:

1. The characteristics of an antenna consisting of several concentric rings of vertical monopoles were investigated.

2. More vertical patterns of the tilted-V, or Maypole, antenna were calculated in order to obtain more information on the effect on the pattern of the various antenna parameters.

3. Another source of information concerning angles-of-arrival was located.

PART I

Purpose

This project involves the development of a high frequency steerable antenna having the following characteristics:

1. It shall be operable throughout the frequency range of 4 to 32 megacycles per second.

2. It shall be capable of four, or more, simultaneous transmissions on different frequencies, and at different azimuth and elevation angles.

3. For each transmission, it shall be capable of being directed to any azimuth angle and to any elevation angle between the horizon and 30^{o} above the horizon.

The communication system shall provide reliable 24-hour day-to-day communication with a 20 decibel signal-to-noise ratio. The ranges to be covered are from approximately 500 nautical miles to 4000 nautical miles.

The development consists of two phases:

Phase I. Theoretical and experimental studies.

Phase II. Development of design criteria.

General Factual Data

F. V. Schultz	Project Director	31 1/2	Man-hours
J. D. Tillman	Assistant Engineer	9	Man-hours
W. J. Bergman	Junior Engineer	168	Man-hours
H. P. Neff	Junior Engineer	168	Man-hours
L. W. Ricketts*	Junior Engineer	162	Man-hours
G. R. Turner	Secy-Draftsman	16	Man-hours
L. Phillips	Technician	12	Man-hours
H. W. Knox	Student Computer	106	Man-hours
N. Boyd	Typist	10	Man-hours

* Preparation of antenna test facility.

References

Bruce, E. and Beck, A. C., "Experiments with Directivity Steering for Fading Reduction," Bell System Technical Journal, Vol. 14, p. 195, April 1935.

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Harrison, C. W., "The Inclined Rhombic Antenna," Proceedings of the Institute of Radio Engineers, Vol. 30, p. 241, May 1942.

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Jahnke, Eugene, and Emde, Fritz, Tables of Functions, Dover Publications, Inc., New York, 1945.

Jordan, E. C., Electromagnetic Waves and Radiating Systems, Prentice Hall, Inc., New York, 1950.

Knudsen, H. L., "The Field Radiated by a Ring Quasi-Array of an Infinite Number of Tangential or Radial Dipoles," Proceedings of the Institute of Radio Engineers, Vol. 41, p. 781, June 1953.

Knudsen, H. L., "The Necessary Number of Elements in a Directional Ring Array," Journal of Applied Physics, Volume 22, p. 1299, November 1951.

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"Research and Experimental Investigations Pertaining to Antenna AS-480( )/FRC, Final Report on Phase I," RCA Laboratories Division, Radio Corporation of America, July 15, 1952 to April 15, 1953.

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Williams, H. P., Antenna Theory and Design, Pitman and Sons, Ltd., London, 1950.

Detail Factual Data

1. Aside from the installation of the pattern recorder, the construction of the antenna test facility is essentially completed. It will be necessary, of course, to make additions and improvements from time to time, as the need arises.

2. An investigation has been undertaken to determine the feasibility of employing several concentric circular ring antenna arrays of vertical elements with a single element in the center to provide the characteristics necessary for the present project. Such an array can be made to provide a directional, steerable pattern that is independent of frequency by proper choice of the total current in each of the concentric rings with respect to the current in the center element. It has been found that the field of an omnidirectional single circular ring array is given by

$$E = j^n I \epsilon^{j(\omega t + n\phi)} J_n \left(\frac{2\pi\rho}{\lambda} \cos \triangle \right)$$

when n is the number of complete cycles of phase shift around the ring, and is an integer. I is the total current in the ring, ρ is the radius of the ring, $\triangle$ the angle of elevation, and ϕ is the angle of azimuth. This equation is correct only if a sufficient number of elements are used in the ring.

If several concentric rings are used the field from the kth ring is

$$E = j^n I_k \epsilon^{jn\phi} J_n \left(\frac{2\pi\rho_k}{\lambda} \cos \triangle \right)$$

with $\epsilon^{j\omega t}$ understood.

Let a single element be added at the center of P-1 concentric rings and let the current in the center element be I_o/P. Let the number of cycles of phase shift n be equal to the number k of the ring with the larger ring having the greater number of cycles of phase shift. Let the total current in each ring be I_k/P, and choose the phasing such that $\epsilon^{jn\phi}$ becomes $\epsilon^{jn(\phi - \pi/2)}$. Then since j^n is equal to $\epsilon^{jn\pi/2}$ the field from each ring is

$$E = \frac{I_k}{P} \epsilon^{jk\phi} J_k \left(\frac{2\pi\rho_k}{\lambda} \cos \triangle \right)$$

and the total field from all rings plus the center element is

$$E_T = \frac{I_o}{P} + \sum_{k=1}^{P-1} \frac{I_k}{P} J_k\left(\frac{2\pi\rho_k}{\lambda} \cos\Delta \right) \epsilon^{jk\phi} .$$

At $\Delta = 0$, $\cos \Delta = 1$ and

$$E_T = \frac{I_o}{P} + \sum_{k=1}^{P-1} \frac{I_k}{P} J_k\left(\frac{2\pi\rho_k}{\lambda} \right) \epsilon^{jk\phi} .$$

Now let $I_k = \dfrac{I_o}{J_k\left(\frac{2\pi\rho_k}{\lambda}\right)}$.

Then at $\Delta = 0^o$

$$E_T = \frac{I_o}{P} + \sum_{k=1}^{P-1} \frac{1}{P} \frac{I_o}{J_k\left(\frac{2\pi\rho_k}{\lambda}\right)} J_k\left(\frac{2\pi\rho_k}{\lambda} \right) \epsilon^{jk\phi} ,$$

and

$$E_T = \frac{I_o}{P} + \sum_{k=1}^{P-1} \frac{I_o}{P} \epsilon^{jk\phi} ,$$

or

$$E_T = \frac{I_o}{P} \sum_{k=0}^{P-1} \epsilon^{jk\phi} .$$

This reduces to

$$E_T = \frac{I_o}{P} \frac{\sin \frac{P\phi}{2}}{\sin \frac{\phi}{2}} \epsilon^{j\frac{\phi}{2}(P-1)}$$

which is independent of frequency.

The term $\dfrac{\sin \frac{P\phi}{2}}{P \sin \frac{\phi}{2}}$ produces an azimuthally directional pattern that is dependent on P, with the beamwidth decreasing as P increases. This function has been plotted for several values of P and is shown in Figure 1.

It is apparent that the relation

$$I_k = \frac{I_o}{J_k\left(\frac{2\pi\rho_k}{\lambda}\right)}$$

must hold for all values of frequency if the pattern is to remain unchanged, and that the pattern will remain constant only at $\triangle = 0^o$, or in the ground plane. However, a pattern constant over a range of frequencies may be obtained at any particular elevation angle $\triangle'$ by making

$$I_k = \frac{I_o}{J_k\left(\frac{2\pi\rho_k}{\lambda}\cos\triangle'\right)} \quad .$$

The frequency range considered for this project is from 4 to 32 megacycles, and the wavelength λ varies from 246 feet at 4 mc to 30.7 feet at 32 mc, or, over a range of eight to one. Thus, with fixed radii, the argument of the Bessel functions $(2\pi\rho_k/\lambda)$ will also vary over an 8 to 1 range. Investigation of tables and curves of $J_p(x)$, with constant p and varying x, shows that for $p \geq 3$ the value of $J_p(x)$ will either become prohibitively small, or pass through zero as x is varied over a range of eight to one. Since from the standpoint of beamwidth more than three rings are necessary, the total currents in the rings other than the first three will become exceedingly large if the pattern is to remain unchanged over the entire frequency range.

Investigation of Figure 1 shows that at least eleven rings will be necessary to produce a beamwidth sufficiently narrow for the present project. It is impossible to maintain practical values of ring currents throughout the entire frequency range because of the variations in $J_k\left(\frac{2\pi\rho_k}{\lambda}\right)$. Usable current values can be maintained if narrow frequency bands, at which the various Bessel functions pass through zero, are omitted. The radii and the number of elements necessary for such an array are dependent on the range of values over which the Bessel functions are allowed to vary, and for one practical case the radii were of the order of 40 feet for the inner ring and 300 feet for the outer ring, with a total of 733 elements necessary. The complexities of feeding, phasing, and maintaining such an array for the purposes of the present project appear to make it beyond the realm of practicality.

3. The investigation of tilted-V, or Maypole, antennas continued. More calculations were made of vertical patterns through the plane of symmetry of the antenna, and these calculations are now being checked. These patterns are to show the variation in the vertical plane caused when one of the following three antenna parameters is varied and the other two are held constant: leg length, height and included angle.

4. It has been learned that in June 1953 the Signal Corps Radio Propagation Unit issued a report which includes considerable data on angles-of-arrival. A copy of this report has been requested. It is considered unwise to attempt to complete the propagation calculations until this additional information is obtained.

5. An investigation was started to determine the possibility of accomplishing vertical steering of the antenna beam of using two rhombics stacked vertically.

DEPARTMENT OF ELECTRICAL ENGINEERING
ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE

PROJECT PERFORMANCE AND SCHEDULE

Index No. NE-091035 ST7

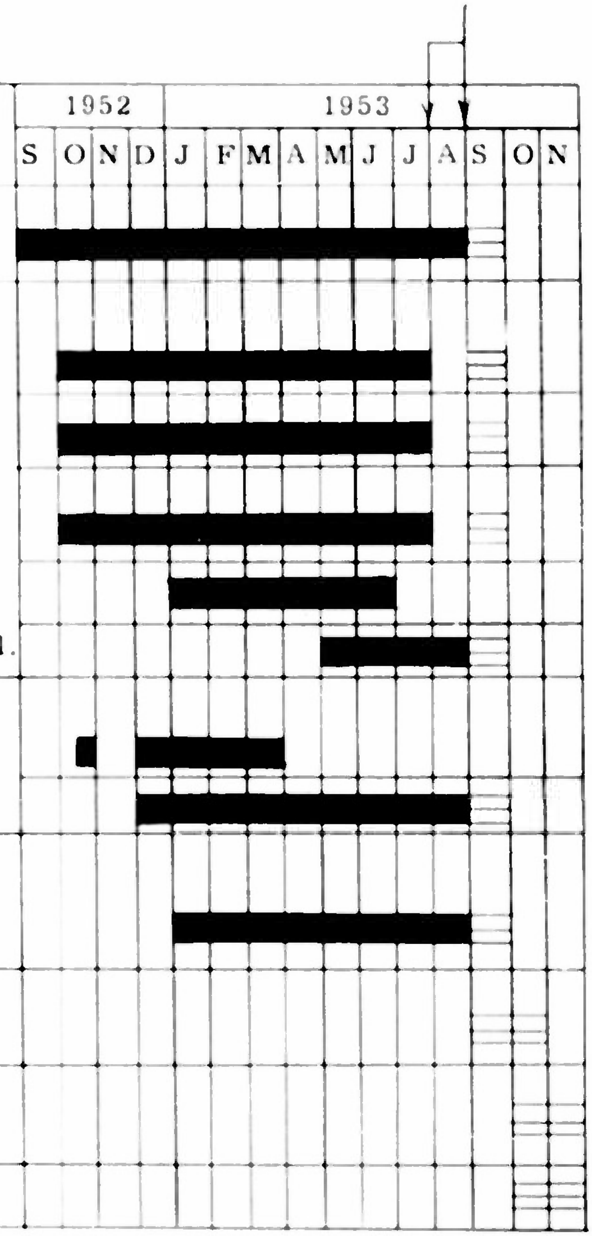
Contract No. NObsr-57448 Date: 10 September 1953

Legend: ■ Work Performed Period Covered: 1/8/53 to 31/8/53

▭ Schedule of Projected Operation

Subject

1. Development of Field Test Facilities.
2. Study of Propagation Problem.
   a. Investigation of paths lying entirely in night region.
   b. Investigation of paths lying entirely in day region.
   c. Investigation of paths lying partly in day and partly in night region.
   d. Investigation of auroral refraction.
   e. Investigation of angles-of-arrival.
3. Determination of Suitable Antenna Type or Types.
   a. Search of literature.
   b. Theoretical study.
4. Detailed Theoretical and Experimental Investigation of Most Promising Antenna Types.
5. Development of Network System Suitable for Driving Array.
6. Experimental Study of Final Array.
7. Preparation of Phase Report.



Conclusions

1. The antenna consisting of several concentric rings of vertical monopoles does not appear to be a practical solution to the problem outlined for the project.

PART II

Program for Next Interval

1. Experimental work will be initiated on the circular traveling-wave antenna.

2. Very likely the limited investigation of the Maypole antenna will be completed.

3. It is believed that it will be possible to obtain more information on angles-of-arrival.

4. The investigation of the possibility of accomplishing vertical steering of the antenna beam by using two rhombics stacked vertically will be continued.

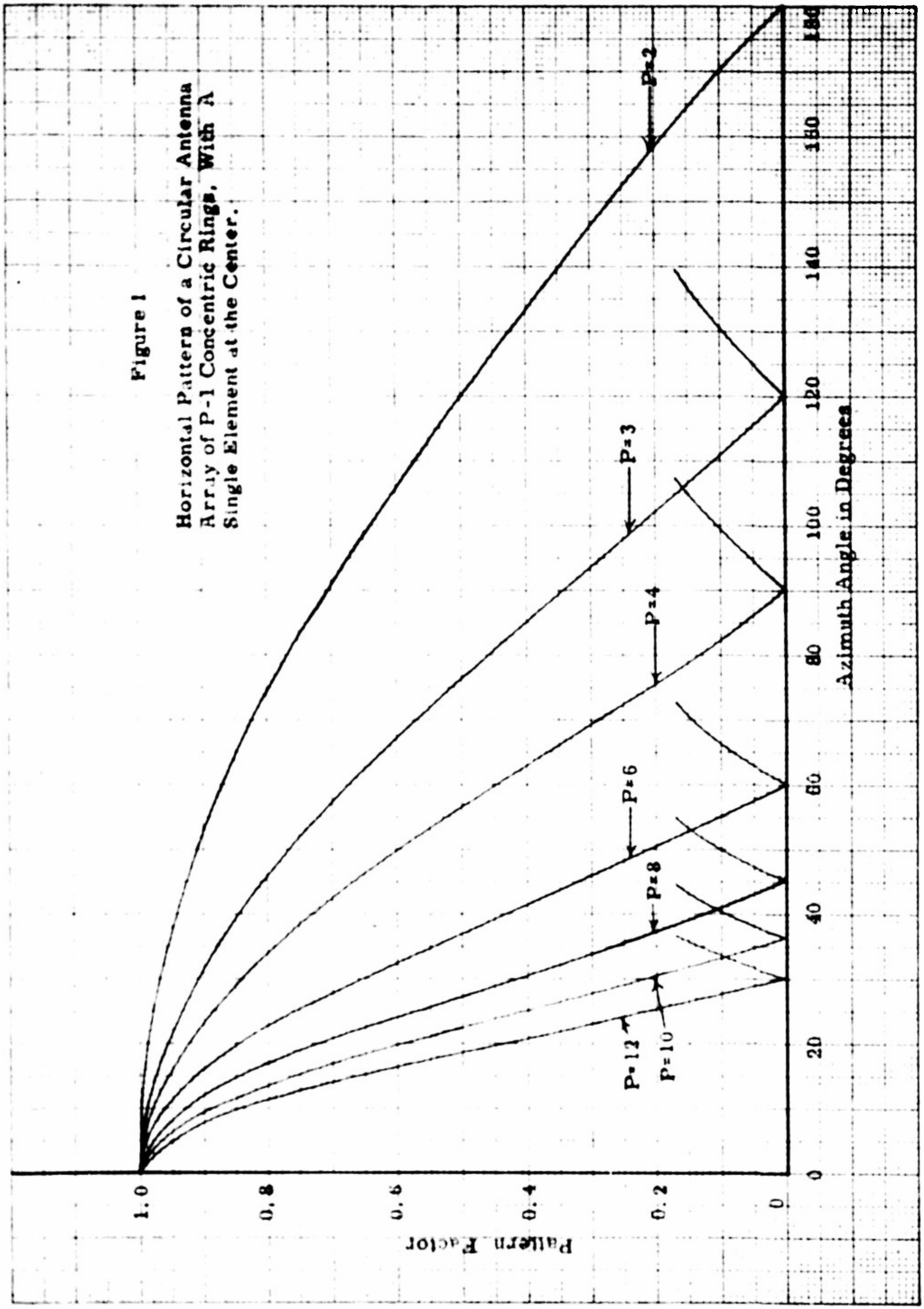


Figure 1

Horizontal Pattern of a Circular Antenna Array of P-1 Concentric Rings, With A Single Element at the Center.