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SURVEY OF RAPID-SCANNER PRINCIPLES

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NRL REPORT NO. R 34

SURVEY OF RAPID-SCANNER PRINCIPLES

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Problem No. 34R09-23

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The material of this survey first appeared in a report to the Subpanel on Rapid Scanning of the Panel on Radiating Systems of the Joint Research and Development Board. The present report is a revision and expansion of that material. Acknowledgment for constructive criticisms is made to Dr. L. C. Van Atta, Dr. S. Silver, and to the members of the Subpanel on Rapid Scanning.

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PART II: DETAILED DESCRIPTION OF SPECIFIC RAPID-SCANNING ANTENNAS

PART III: RAPID-SCANNING TECHNIQUES - FUTURE

ABSTRACT

This report is a survey of rapid-scanning antennas, their system requirements, and principles of design. Requirements of future systems which find need for rapid-scanning techniques are described. Principles of rapid-scanner design are discussed. Present antenna types are described in detail and analyzed in the light of possible future systems. Proposed scanning methods are discussed and recommendations made as to those lines of research which pertain most directly to improved rapid-scanner designs.

PROBLEM STATUS

This report concludes the work on this phase of the problem. Work will continue on the basic problem 34R09-23.

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SURVEY OF RAPID-SCANNER PRINCIPLES

INTRODUCTION

The rapid-scanning antennas developed during World War II were designed with the immediate purpose of getting something into the field for emergency use. They capitalized on the more obvious means of achieving rapid scans of the radar beam. The resulting antennas were very successful in their limited applications, but many are too difficult of construction and too heavy for permanent use, and most of them fail to meet the present-day needs.

With the advent of jet and rocket propulsion, the development of radar systems for aircraft-early-warning, fighter-control-interception, gunfire and missile control, and high-altitude blind bombing becomes increasingly difficult. The future success of radar for many applications depends upon its ability to scan the radar beam very rapidly throughout the region in which a prospective target may lie.

It is the purpose of this survey to discuss generally the problems of rapid-scanner design, to describe in some detail the methods of rapid-scanner design which are presently known, and to indicate those lines of investigation which appear to bear the most promise for future systems.

PART I

THE RAPID-SCANNER PROBLEM

THE TACTICAL PROBLEM

A large proportion of the radar systems which are dictated by present and future tactical requirements find need for rapid-scanning antennas. The following is a survey of the needs for the various fields of application.

1. Ground-Based or Shipborne Search Radar

Long-Range Search and Airport-Traffic Control - Complete azimuth coverage out to ranges as great as 300 miles is required. The scan in elevation need not be greater than 45 degrees and in many cases only as great as 25 degrees to 30 degrees. The rate of scan should be in the order of one look every five or six seconds. This rate is severely limited by range and pulse-rate considerations. The most desirable method of scanning is to use a two-dimensional scanner to cover a solid angle of space, and a number of identical systems to cover the total 360 degrees in azimuth.

A proposed system for long-range search which possibly represents a solution to the problem of avoiding the fundamental limitation of more than one pulse per target associated with pulsed radar is to use extremely rapid scanning with a very-high-power c-w transmitter (1).* The rate of scan should be upwards of 5000 looks per minute with a beam width of 1/2 degree or less in order to achieve sufficient discrimination.

Hemispheric Search - A rapid scan of a pencil beam through an angle of 90 degrees in elevation at a rate of about 1800 scans per minute is required. The entire assembly is rotated about its vertical axis, thus providing a complete hemispherical coverage. Maximum range on a single aircraft, while fixed in large measure by the rate of scan, should be in excess of 15 miles, perhaps as great as 50 miles.

Surface Search, Height Finding, Mortar or Missile Detection - A rapid linear scan of a pencil beam through an angle of 10 degrees to 40 degrees is required, depending upon the application. The rate of scan should be 600 to 1200 looks per minute.

2. Target-Acquisition and Fire-Control Radar

Philosophy of Acquisition Radar - Target acquisition may be achieved in general by two methods, (a) an intermediate radar system to receive information from the long-range search radar, to scan the area near the target with great accuracy, and to designate this target to the fire-control radar; (b) an acquisition scan as part of the fire-control tracking system (accomplished in the past by use of a conical-spiral scan).

Target Acquisition - The need in target-acquisition radar antennas is for a variable-area scan to provide for scanning a solid angle from 5° x 5° to 20° x 20°. The rate of scan should be in the order of 300 looks per minute.

Fire or Missile Control - This system is required to track high-speed aircraft and direct anti-aircraft gunfire or to direct defensive missiles. The range on individual aircraft should be greater than 15 miles. The antenna should probably be a simultaneous or a sequential lobing device. The former is a monopulse comparison system. The latter is a pulse-to-pulse comparison system.

3. Airborne Radar

Aircraft Interception - This is an equipment for the purpose of directing fire against enemy aircraft. The system should provide both a search function and a fire-control function. The region to be searched is a hemisphere symmetric about the line of flight of the airplane, with ranges on individual aircraft up to 10 miles. The scan for the search function should be in the order of 1000 scans per minute. The fire-control function should direct fire by automatic tracking, with a scan of about 2000 looks per minute. On aircraft larger than fighters, the separate functions might be obtained by individual systems corresponding to hemispheric-search and fire-control radars, but in fighter aircraft both functions must be incorporated in a single antenna with means of rapidly converting from one function to the other.

Navigation and Bombing - This system must provide a rapid scan in azimuth of a $\csc^2\theta$ beam of narrow azimuthal width through as much as ±90 degrees, thus sweeping

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* Numbers in parenthesis refer to references listed at end of report.

out a map of the ground beneath the aircraft to provide information for navigation or bombing. The maximum range for uniform ground return should be in excess of 50 miles. The rate of scan should be about 1000 looks per minute.

THE DESIGN PROBLEM

Any rapid-scanning antenna design must provide some means of causing an angular shift in the direction of the radar beam. All of the potential methods of producing a scan appear to fall into one of three categories: (a) mechanical motion of the antenna as a whole, (b) mechanical motion of some part of the antenna, thereby causing a linear change in phase across the aperture of the antenna, (c) electrical changes involving no mechanical motion of radiating antenna parts, which affect the wave propagation, thus producing a linear phase change across the aperture of the antenna. For high-speed scanners, the first method is difficult and impractical. Antennas employing method (b) must, to be successful high-speed scanners, provide a scan of the radar beam by a simple motion of only a small part of the antenna, which is light and has a very small moment of inertia. Such antennas, together with those whose scan is achieved by method (c), embrace a class of antennas that we choose to call "electrical scanners".

The designer of a rapid scanner is limited in the selection of possible methods of scan by considerations of the antenna pattern and the preservation of this pattern throughout the entire scan, the resolution of the antenna, the angle of scan, and the rate of scan. In addition, it is desirable that the antenna should be readily manufacturable and should not offer difficult installation or maintenance problems. It is obvious that no limitation imposed by one of these considerations is entirely independent of the others.

The requirements of rapid-scanning antennas outlined above indicate that the scanning problems are of two general kinds. In one kind of scanning, the radar beam is required to scan rapidly in only one plane, either because the beam is flared in the other plane or because the scan in the other plane can be accomplished by rotating the entire antenna. The angles of scan involved in these linear scanners varies from 10 degrees to 180 degrees. The other kind of scanning requires a device which can scan the beam rapidly in both planes. The solid angles involved vary from about a 4-degree square to a 60-degree square. The task before the designers of rapid-scanning antennas is to improve on the methods of scanner design which are known at present and to develop new methods to meet the needs of both present and future radar systems.

GENERAL PRINCIPLES OF SCANNER DESIGN

The art of rapid-scanning antenna design involves understanding the microwave optics of the various means of control of the microwave energy, such as reflectors, lenses, parallel plates, and linear arrays. In the use of reflectors and lenses there is an exact analogy between microwaves and light; consequently, it is highly advantageous to approach the problem of rapid scanning from the point of view of optics.

When the feed of a focusing objective (i.e., a paraboloidal reflector or converging lens) is moved off the axis a distance d, the beam tilts on the opposite side of the axis through an angle given approximately by d/f, where f is the focal length. The extreme tilt is limited by the presence in the optical system of defects known as aberrations. In general, as the ratio of the diameter to the focal length of the system is increased, the aberrations become worse. Thus the usable aperture of the realizable field of view (or angle of scan) is usually determined by the amount of aberration that can be tolerated.

For the common directive systems the aberrations may be classified as follows: spherical aberration, coma, curvature of field, astigmatism, and chromatic aberration (or frequency sensitivity). These aberrations make themselves felt in the gradual deterioration of the antenna pattern (i.e., broadening of the beam width and increase in side lobes) as the directive beam is made to tilt off axis by proper motion of the feed away from the focal point. As the number of elements in an optical system is increased, however, more degrees of freedom are made available for the correction of aberrations; hence well-corrected, wide-angle objectives must use several degrees of freedom.

Parallel metal plates have the advantage of confining microwave radiation to a two-dimensional medium which will propagate the radiation through bends and rolls with little or no effect. Parallel plates are conducting surfaces which are everywhere parallel to each other and are separated by a distance a. The mean surface is parallel to them and midway between them. Since optical paths are minimum length paths, rays are geodesics in the mean surface. A geodesic may be defined as the shortest arc joining two points on the surface. Two important properties of geodesics are (1) through every point on a surface and in every direction there is a unique geodesic, and (2) if a constant length is measured off on geodesic rays through a point, the resulting curve drawn through the points so obtained is perpendicular to the geodesics. That is, radiation from a point source between conducting surfaces propagates along a family of geodesics and the wave fronts are curves that cut each geodesic normally. If two mean surfaces intersect in a common curve, any geodesic crossing that intersection curve makes equal angles with the curve on both sides: this is equivalent to the optical relation that the angle of incidence is equal to the angle of reflection (2).

Parallel-plate optical devices are subject to the same aberrations as are three-dimensional optical devices. Dielectric lenses may be used between parallel plates exactly as in free space, with the exception, of course, that the lens is only two-dimensional. The particular advantage of parallel-plate optical systems is that developable surfaces conduct the energy independent of bends and rolls exactly as though the surfaces were perfectly flat, thus permitting the rolling of the surfaces so as to make the locus of the feed motion a portion of a circle.

A linear array is a succession of elementary antennas along a transmission line. The optical analogue is a diffraction grating. If a number of equally spaced radiating elements are arranged in a straight line, and if all are made to oscillate in phase, a beam of radiation will be formed normal to the array with a number of smaller secondary maxima. If the elements are spaced closer than about 0.7λ, the normal beam will be the only one of appreciable intensity. If the elements are not all fed in phase, but with a constant additive phase difference between adjacent elements, the beam will shift to an angle from the normal given by

$$\theta = \sin^{-1} (n - 1)\, \alpha\lambda/2\pi l$$

where α is the phase angle between elements, n is the number of elements in the array, and l is the distance between the first and last elements of the array (3). Thus in order to vary the angle of the beam relative to the normal it is necessary to change the electrical spacing of the elementary radiators, thereby accomplishing a variation of the phase of the successive elements. The most direct method of changing the electrical length between elements is to vary the frequency of the transmitted wave. This has not proved practical because frequency modulation in the microwave region has not yet been successful. Other more practical methods are to vary the distributed load along the transmission line or to vary the phase velocity of the traveling wave in the line by control of one or more of the transmission line parameters.

PART II - DETAILED DESCRIPTION OF SPECIFIC RAPID-SCANNING ANTENNAS

Any rapid-scanning antenna design must employ some of the foregoing principles, and the relative merit of the design is determined, not chiefly by the field of view of the system, but by the degree of correction which the system enjoys and the simplicity of mechanical design. The listing of the antennas whose descriptions follow is not in order of optical principle, however, but under the heads, "Moving-Feed Scanners" and "Variable-Phase Scanners," which appear to be more logical in cataloging them.

MOVING-FEED SCANNERS

The general class of moving-feed scanners embraces a great number of antennas. These include antennas with linear scans, which may be oscillatory or one-way linear, conical, arcuate, or spiral scans. The various types of moving-feed scanners are listed on the following pages, with a brief description of the design features, electrical characteristics, and systems performance.

1. Zoned Pillbox with Oscillating Feed (4)

Optical Principle - The feed is moved off the focus of a coma-corrected zoned parabolic reflector.

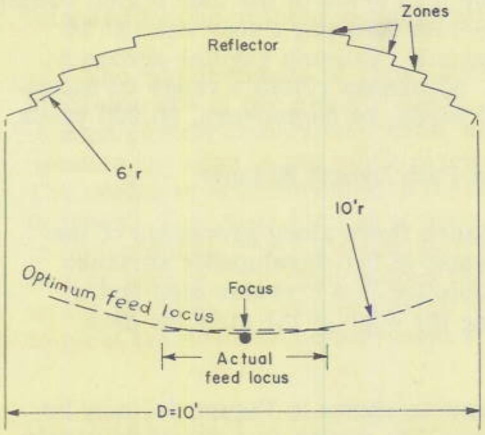


Fig. 1 - Zoned-Pillbox Antenna

Design Features - The pillbox reflector consists of a number of pieces of parabolas whose focal lengths differ by a half wavelength. The reason for zoning is to correct for coma, which is done by making all the parabolic pieces lie near a circle with center at the focus. The optimum curve for feed motion is a cirle of radius about 1 2/3 that of the coma circle, but for mechanical reasons the feed is made to oscillate on a line approximating the circle. The feed-driving mechanism is a trammel. See Figure 1.

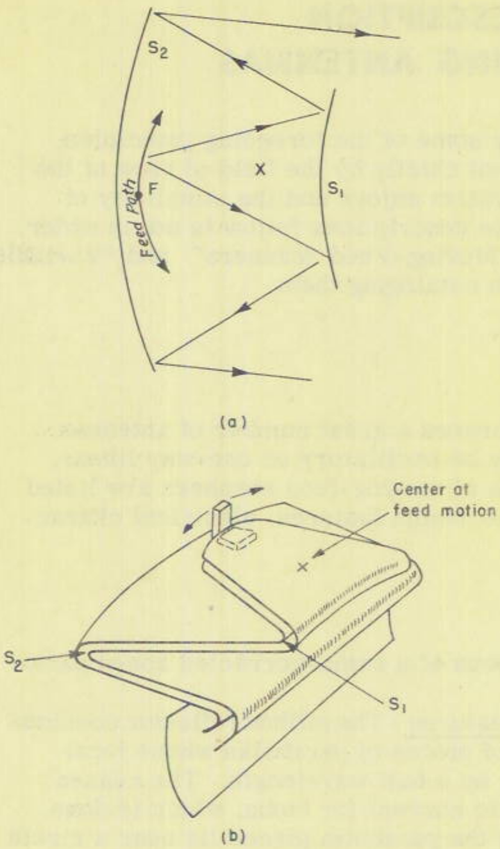
Electrical Characteristics - For a pillbox of 10-ft aperture at a wavelength of 3 cm, the beamwidth is 0.70 degree on axis and 0.75 degree at an angle 14 degrees off the axis. Side lobes are about 17 db down from the peak, with lobes of about -20 db persisting out to 20 degrees or 30 degrees from the main beam. The gain is about 5 db down from that of a uniformly illuminated aperture. This antenna will scan a sector of 28 degrees.

Systems for Which Used - Experimental only.

2. Schwarzchild Antenna (5)

Optical Principle - Two reflector coma-corrected optical system with moving source.

Design Features - Given two mirrors in a symmetrical optical system, it is possible to shape these mirrors in such a way as to correct for first order aberration. To avoid



the blocking of one mirror by the other, the function of the reflectors is performed in parallel plates by toroidal bends. Actually these bends are not exactly equivalent to reflectors, but by making the middle line of the torus the shape of the calculated reflector there is sufficiently good optical equivalence. See Figure 2. The two mirrors are separated by 1/3 focal length, and the the aperture ratio is unity.

Electrical Characteristics - For a model of 52λ aperture, the patterns were measured with the beam on axis and off axis up to 8 degrees. Patterns indicate a 3-db reduction in gain at 8 degrees off axis. Side lobes are about -17 db. Up to 6 degrees off axis the gain decreases only slightly.

Systems for Which Used - SCR-598, a 3 cm harbor-surveillance and fire-control radar, packaged in a waterproof van.

Systems Performance (9) - Half-power width, 0.66 degree in azimuth. Tracking is accomplished by rotating the feed arms of the four horns, causing a 10 degree sector one-way linear scan at 16 cycles per second. Azimuth angular accuracy, 0.03 degree. Maximum reliable range on battleships, 50,000 yards; on destroyers, 35,000 yards.

Fig. 2 - Schwarzchild Antenna

3. Controlled Path Length Scanner

Optical Principle - Radiation between parallel planes flows along geodesics of the mean surface. If the mean surface is assumed to consist of two developable surfaces connected along a part of their boundaries, a unique solution is a circular disc and a section of a 60-degree cone. The source moves along the edge of the ciruclar disc. See Figure 3.

Design Features - The parallel plates, whose shape is shown in Figure 3a, may be rolled into the shape shown in Figure 3b. The feed arm then moves in a complete circle.

Electrical Characteristics - This design has the disadvantage that the center of the field, towards which the horn points if it is following the path of best focus, is not the center of the aperture. A feed displacement e around the edge of the disc causes the center of illumination at the aperture to shift more than e.

Systems for Which Used - Experimental only.

4. Turntable Scanner (6)

Optical Principal - Circular reflector with aberration-corrected lens at the source.

Design Features - The circular aberration introduced by the surface-of-revolution reflector is corrected by lenses which travel with the moving waveguide sources. The circular reflector is a toroidal bend in parallel plates. The lenses serve to correct the point-source radiation so that the toroidal bend may completely collimate the radiation. The ler has a similar function to the correcting plate in a Schmidt-type telescope with the difference that it corrects between the focus and the reflector. See Figure 4.

Electrical Characteristics - An experimental model at 1.25 cm has a beam width of 1.1 degrees to 1.3 degrees in azimuth. The beam scans linearly one way 80 degrees in azimuth, 1200 scans per minute. On axis, the beam width is 1.1 degrees, the side lobes are 17 db down. The pattern, lobes, and gain change very little over a ±30 degrees sector, but between 30 degrees and 40 degrees tilt, the beam widens to 1.3 degrees, the gain drops 1.4 db, and the side lobes rise to -13 db.

Systems for Which Used - Experimental only.

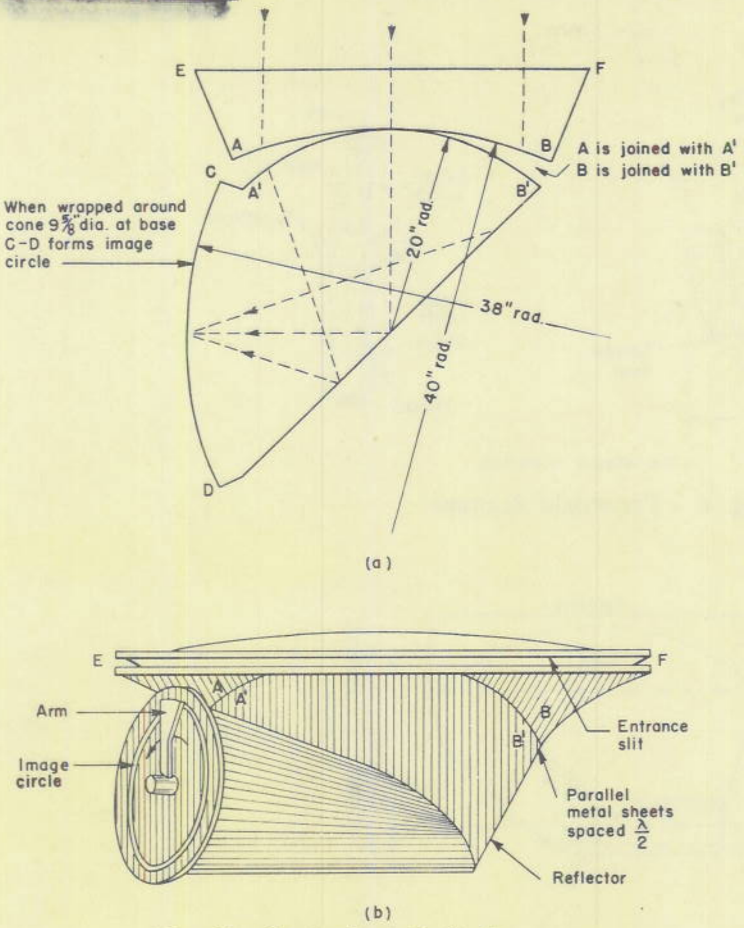


Fig. 3 - Controlled-Path Scanner

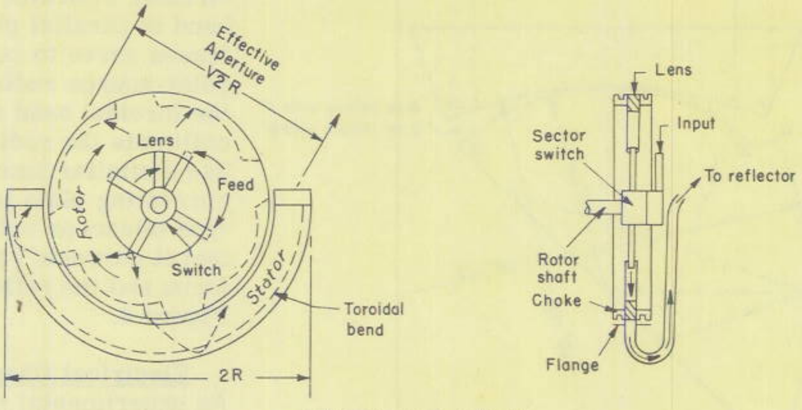
Remarks - The advantage of aberration-free optics in this antenna is opposed by the mechanical difficulties involved in the construction, the driving, and the aligning of the rotating parts.

5. Reflector Roll and Lens Antenna (7)

Optical Principle - This antenna is optically equivalent to a lens with a source oscillating about the focal point.

Design Features - The antenna consists of a pair of trapezoidal plates between which is a dielectric or metal plate lens to collimate the radiation from a flared horn feed. The feeding of the system is rendered rotary by first placing a shorting strip between the plates at 45 degrees to the axis, and then rolling the parallel plates so that the feed path becomes a circle. The horn feed simply rotates about the axis of the rolled portion of the parallel plates. See Figure 5.

Electrical Characteristics - For an antenna with a 34-inch aperture and 40-inch focal length at $\lambda = 1.25$ cm, the azimuth pattern has a beam width of 0.97 degree on axis, with side lobes at -24 db. At 10 degrees tilt the beam width is 1.1 degrees, the side lobes -19 db, and the gain reduced by 1 db. The calculated loss of the dielectric lens is



(The reflector is omitted)

Fig. 4 - Turntable Scanner

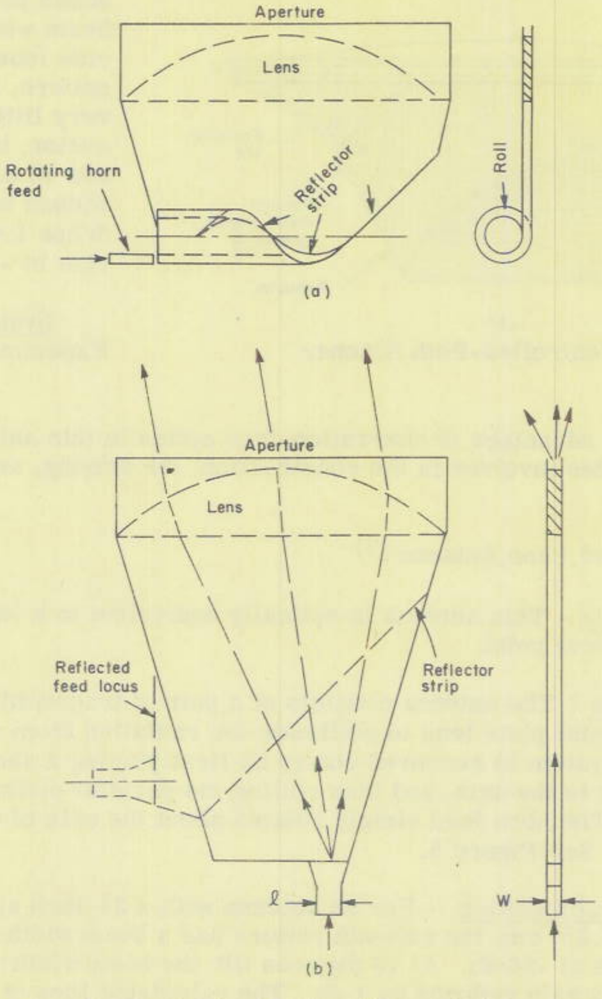


Fig. 5 - Reflector Roll and Lens Antenna

0.5 db. This antenna can scan a total of 20 beam widths with maintenance of good pattern and reasonable gain.

Systems for Which Used - Experimental only.

6. Reverse-Roll Antenna (8)

Optical Principle - This antenna is optically equivalent to a parabolic reflector with a point source moving about the focus.

Design Features - In order to convert the oscillatory motion of the source into a rotary motion, a pair of trapezoidal parallel plates are folded and rolled so that the short side of the trapezoid on which the feed moves is a complete circle. The long side of the trapezoid is the aperture. The resulting horn is bifocal and a bifocal reflector is used in conjunction with it. See Figure 6.

Electrical Characteristics - An antenna of this type with a reflector 5 ft x 15 ft and with an aperture in the parallel plates of 8 ft, at $\lambda = 8.5$ cm, has an azimuth half-power width of 3.5 degrees and an elevation half-power width of 1.1 degrees on axis. The antenna scans in elevation through a total angle of 10.5 degrees at 10 cycles per second. On axis the side lobes are -20 db; at 3.8 degrees tilt, -17 db; and at 6.9 degrees tilt, -10 db. Likewise the gain is reduced 1.5 db at 6.9 degrees tilt and the half-power width is 1.2 degrees.

Systems for Which Used - SCI height finder.

Systems Performance (9) - Azimuth angular accuracy ±1/2 degree; range on bombers 75 nautical miles; altitude accuracy ± 500 ft at 50 miles.

7. Conical Scanner (6,10)

Optical Principle - Rotation of an off-center source in a parabolic reflector about the axis, with result that beam describes a cone.

Design Features and Electrical Characteristics - Several different types of off-center feeds have been developed. Some of these are shown in Figure 7. The feed shown in Figure 7c, the "squint feed," has an effective center of phase displaced from the axis. If the feed is rotated about its axis the center of phase describes a circle about the focal point of the parabolic reflector. The feed squints by virtue of the fact that there is, in addition to the transverse current on the dipole, a longitudinal current on the feed line. By proper adjustment of the disc-to-choke distance there is a

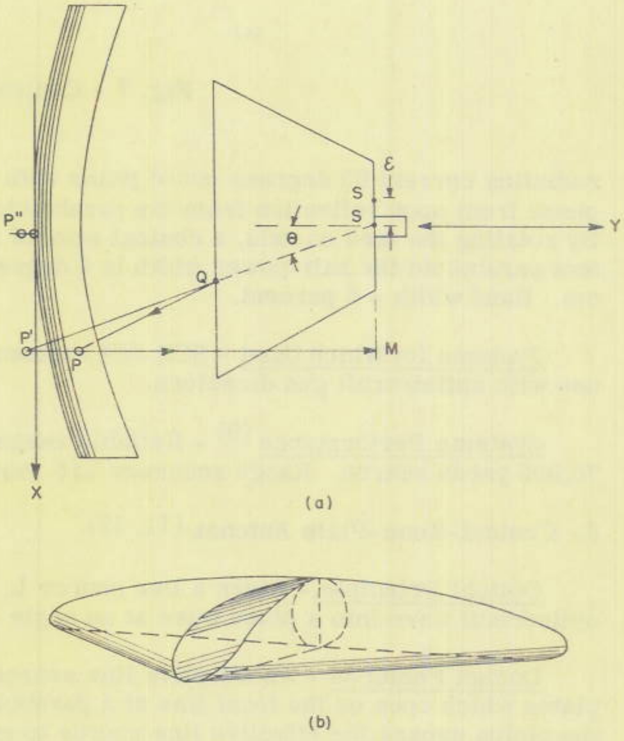


Fig. 6 - Reverse-Roll Antenna

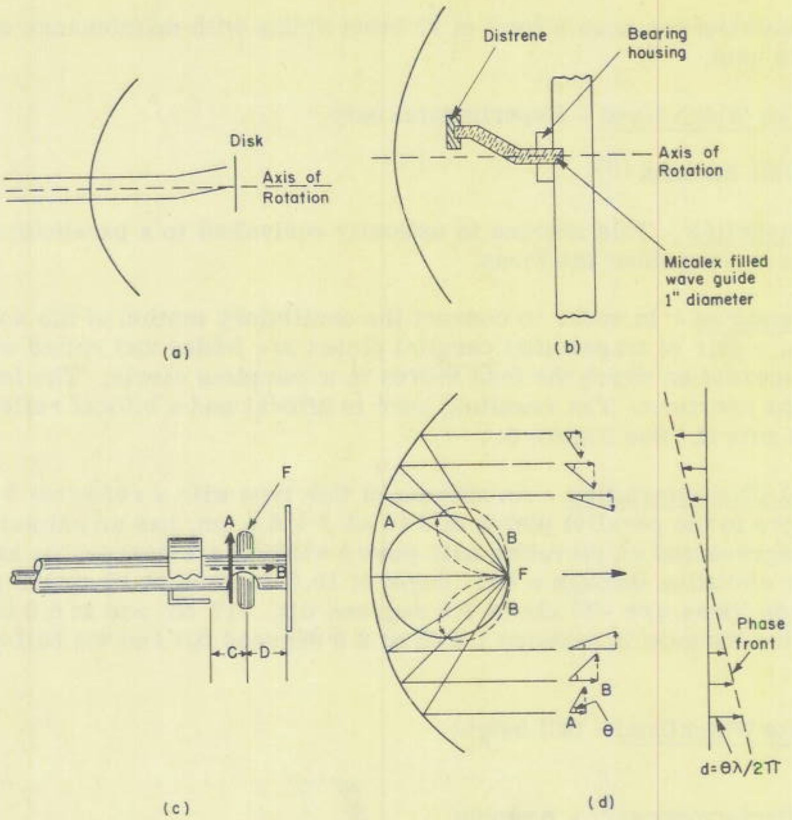


Fig. 7 - Conical Scanner

radiating current 90 degrees out of phase with the dipole current, resulting in a tipped phase front upon reflection from the paraboloid. This is shown graphically in Figure 7d. By rotating the feed on axis, a conical scan of fixed crossover is obtained. In a six-foot paraboloid the half-power width is 4 degrees, the crossover 80 percent at λ = 10.7 cm. Band width = 6 percent.

<u>Systems for Which Used</u> - SCR-584, automatic-tracking and fire-control radar for use with antiaircraft gun directors.

Systems Performance (9) - Reliable range on bombers; 32,000 yards tracking, 70,000 yards search. Range accuracy ±15 yards. Angular accuracy ±0.6 mils.

8. Conical-Zone-Plate Antenna (11, 12)

Optical Principle - Given a line source L, the surface required to reflect the radiated cylindrical wave into a plane wave at an angle α with the normal is an elliptical cone.

Design Features - An effective line source is obtained by a source between parallel plates which open on the focal line of a parabolic cylinder. Moving the source between the plates causes the effective line source to move. If the moving line source feeds a properly chosen elliptical cone, a tilting plane wave is obtained. The elliptical cone may be zoned for reduction of aberration. A model of this antenna is shown in Figure 8.

Electrical Characteristics - The 12-ft experimental model shown in Figure 8, for $\lambda = 3.2$ cm, gave a beam width of 0.6 degree with -13-db side lobes. A 35-λ model (4 ft at 3.2 cm) gave ±6 half-power-widths tilt with 1-db loss in gain, with -15-db side lobes on axis.

Systems for Which Used - Experimental only.

9. Spherical-Reflector Antenna (13)

Optical Principle - Source is moved on the focal circle of a spherical reflector. (This is similar to the Turntable Antenna.)

Design Features - A zone of a spherical reflector is fed with a directive source. For a model built at ADRDE, England, the source is an array of four polyrods at λ spacing. Details of mechanical motion of the array on the focal circle are not available.

Electrical Characteristics - A reflector of aperture 10 ft, radius 15 ft, i.e., focal length $7\frac{1}{2}$ ft, for $\lambda = 3$ cm gave a pattern with half-power width of 0.66 degree and side lobes of -17 db. With a 3 degree tilt of the beam, the side lobes increased to -14 db on one side.

Systems for Which Used - For application connected with coastal defense. No details available.

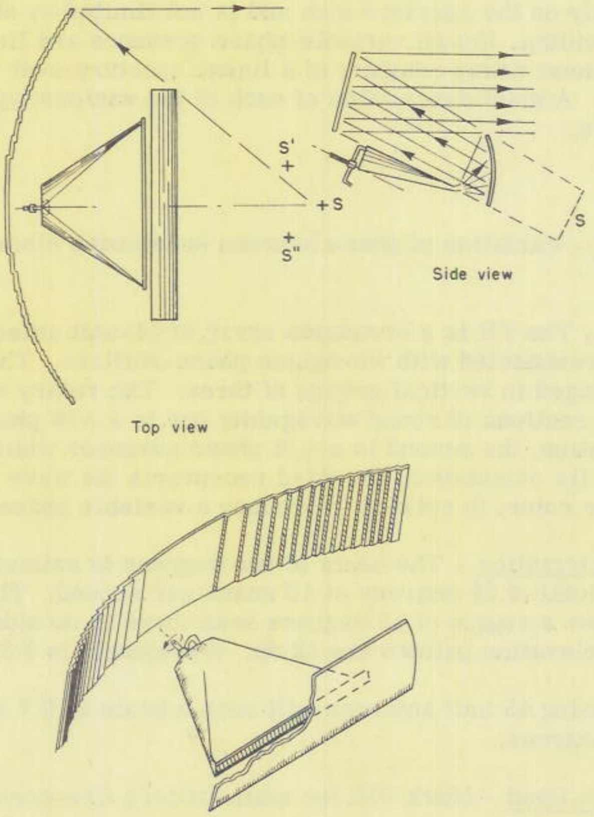


Fig. 8 - Conical-Zone-Plate Antenna

10. Schmidt-System Scanner (14)

Optical Principle - Coma and spherical aberration may be corrected in a circular reflector by a correcting lens in the aperture of the reflector.

Design Features - A metal-plate correcting lens was placed in a pillbox with a circular reflector. The waveguide horn feeding the pillbox was rotated by a mechanically resonant system about the center of the circular reflector.

Electrical Characteristics - No data.

Systems for Which Used - APS-32 modification by Philco.

Systems Performance - No data.

VARIABLE-PHASE SCANNERS

Several scanning antennas have been developed which consist of an array of equally spaced radiators. The beam is scanned by changing the phase increment of successive radiators. The beam shape for any of these arrays is affected by changes in illumination, and even more seriously by non-linearity of the phase of the radiating elements. One of the problems of design is therefore to preserve good illumination and phase throughout the scan. Since frequency variation tilts the beam, an angle calibration problem is presented. The array scanners are not subject to optical aberrations; therefore their scan does not depend strictly on the aperture size and is not limited by aberrations to a certain number of beam widths. Not all variable-phase scanners are linear arrays. One of those which is not a linear array consists of a linear aperture over which the phase is continuously variable. A brief description of each of the various types of variable-phase scanners follows.

1. FH Musa (6,15,16)

Optical Principle - Variation of phase between successive elements of an array of radiators.

Design Features - The FH is a broadside array of 14-unit antennas spaced two wavelengths apart and interconnected with waveguide phase-shifters. The unit antennas are 28-inch polyrods arranged in vertical groups of three. The rotary waveguide phase-shifters involve three sections of round waveguide; one is a $\lambda/4$ phase advancer to produce circular polarization, the second is a $\lambda/2$ phase advancer which advances or retards the wave according to its orientation, the third reconverts the wave to linear polarization. The second section, or rotor, is rotated to produce a variable phase.

Electrical Characteristics - The beam is two degrees in azimuth and 6.5 degrees in elevation. It scans a total of 29 degrees at 10 scans per second. The gain is 29 db with -14 db side lobes. Over a region of 18 degrees scan there is no side lobe less than -12 db. Side lobes in the elevation pattern are 12 db. Wavelength is 9.8 cm.

A 3-cm version using 45 unit antennas will scan a beam of 0.7 degree half-width through a total of 30 degrees.

Systems for Which Used - Mark VIII for main-battery fire-control.

2. Variable-Width Waveguide Array $^{(6,17)}$

Optical Principle - Variation of phase between successive elements of a linear array.

Design Features - The variable-width waveguide consists of two pieces which form the broad side of the guide. The pieces do not make contact, but an effective electrical contact is made by means of chokes which run the length of the waveguide. One piece carries (Figure 9) the dipoles at about 0.7-λ spacing, and is kept fixed. A mechanism is provided for moving the other piece while keeping it parallel to the first, thus varying the width of the guide and consequently varying the phase velocity of the transmitted wave in the guide. The beam is normal to the array when the guide is at maximum width, and tilts toward the input end as the guide narrows. A back-and-forth coverage on both sides of normal is accomplished by an oscillatory motion of the guide width together with a quick switching of the input to the opposite end at the time when the beam is passing the normal.

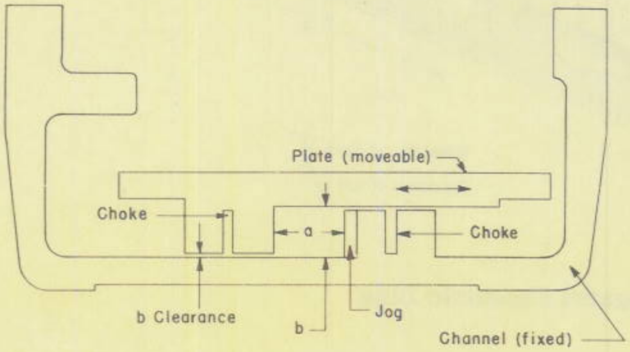


Fig. 9 - Variable Width Waveguide

Electrical Characteristics - For a 15.6-ft array of 250 dipoles at $\lambda = 3.2$ cm the beam width is .42 degree when normal to the array. Side lobes are -17 db. As the beam scans 30 degrees off the normal, the side lobes increase to -13 db, the gain drops 2 db, and the beam width increases to .50 degree. The scan is ± 30 degrees at $1\frac{1}{2}$ scans per second.

Systems for Which Used - AN/APQ-7 and AN/MPN-1. APQ-7 (Eagle) is a radar bombsight system.

Systems Performance $^{(9)}$ - Range up to 160 miles on cities with APQ-7; bombing accuracy, 30 mils.

3. Corrugated Eccentric Line Array $^{(11,18)}$

Optical Principle - Variation of phase between successive elements of a linear array.

Design Features - The radiating elements of the array are transverse slots, the relative strength of each of which can be adjusted by varying the length or width of the slots. Variation in phase velocity in the coaxial line, whose inner conductor is mounted eccentrically and corrugated eccentrically (Figure 10), is brought about by rotating the inner conductor about its eccentric axis. This rotation produces a smooth variation in the wavelength in the line and thus varies the phase difference between successive elements. A greater scan angle may be obtained by rotation of the inner rod about the axis of the discs on the rod (the corrugations).

Electrical Characteristics - For an array 17 ft long, in 7/8-in. line at $\lambda = 9.1$ cm, the half-power width of the beam is 1 degree. The first side lobe is about -14 db.

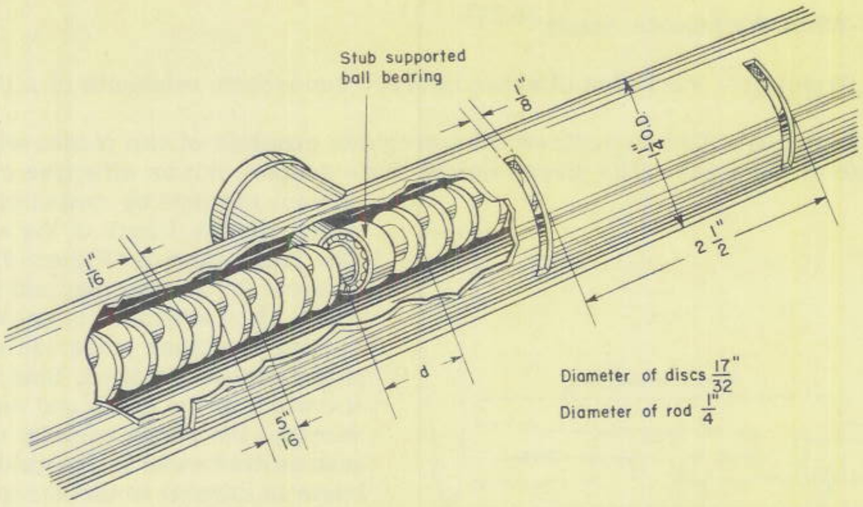


Fig. 10 - Corrugated Eccentric Line

Rotation of the inner corrugated conductor about its axis produces a scan of about 4 degrees; rotation about the eccentric discs produces a scan of 9 degrees. The angle of scan could be increased by increasing the diameter of the discs which would reduce the clearance between the inner and outer conductors, but this would reduce the power capacity of the line.

Systems for Which Used - LRASV (AN/APA-2)

4. Leaky-Waveguide Scanner (19)

Optical Principle - Continuous variation of phase across a linear aperture.

Design Features - This scanner is a waveguide radiating through two slots running the whole length of the narrow side of the guide. The side of the guide between these slots is a bar which moves to vary the broad dimension of the guide (Figure 11). To compensate for power decay, which is a function of the waveguide width, the channel is shaped so that larger clearances are presented at larger guide widths.

Electrical Characteristics - The whole scanning lies on one side of the normal. For an 18-in. waveguide at $\lambda = 3.2$ cm, the half-power width is about 5 degrees at the center

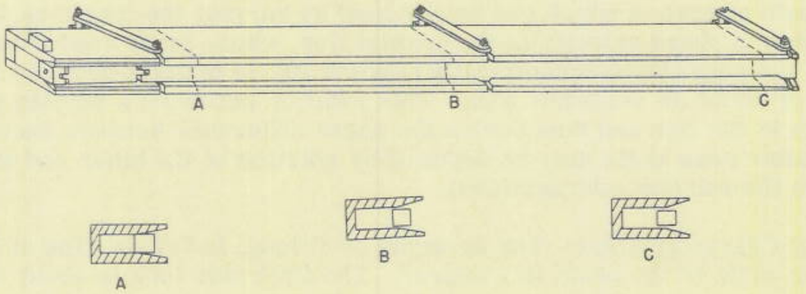


Fig. 11 - Leaky Waveguide Scanner

of the scan, and increases to about $6\frac{1}{2}$ degrees at $\pm 22\frac{1}{2}$ degrees from the center of the scan. The gain decreases 3 db at this widest tilt angle. The center of the scan occurs at approximately $29\frac{1}{2}$ degrees from the normal, the scan being from 7 degrees to 53 degrees. The side lobes average about -17 db.

Systems for Which Used - Experimental only.

5. Rotating-Cone Scanner (6,20)

Optical Principle - Continuous variation of phase across a linear aperture.

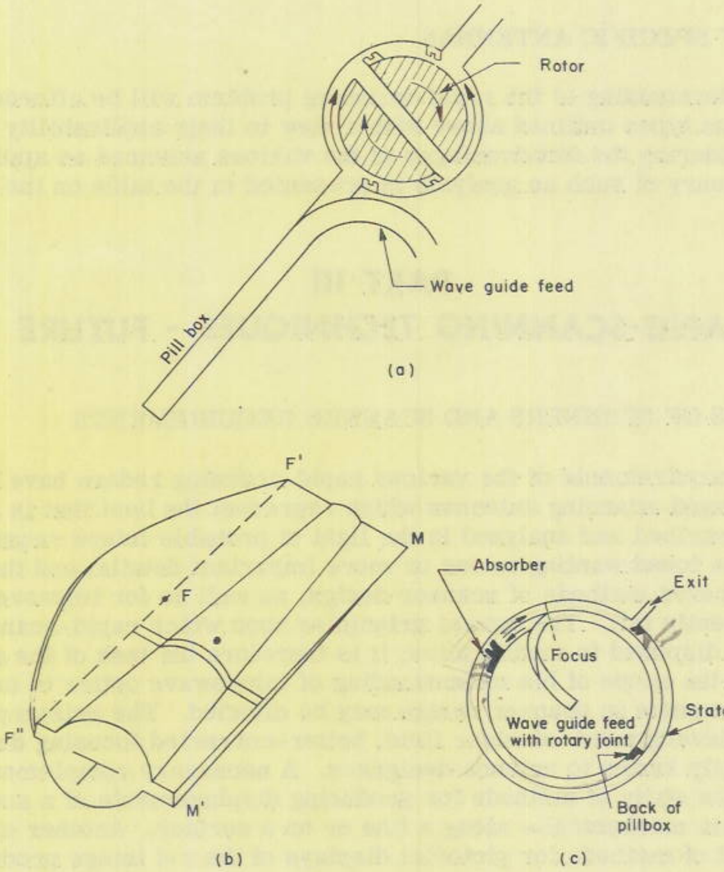


Fig. 12 - Rotating Cone Scanner

Design Features - One form of the rotating-cone antenna has an inner conical rotor and an outer conical stator with uniform spacing between them. The parallel-plate region thus formed is fed by a pillbox. The inner cone has a full-length slot through it, through which the collimated energy is directed by means of a larger number of barrier teeth. A second set of teeth directs the energy into the conical parallel-plate region again, and a third directs it into the linear aperture, as shown in Figure 12a. Figure 12b is an assembly. Figure 12c shows an improved version containing a rolled pillbox inside the inner conical rotor.

Electrical Characteristics - The result of turning the rotor at a uniform rate is to vary the phase at the aperture by virtue of a continuously changing path length. The total scan angle thus obtained is very nearly equal to the developed angle of the cone. Scans up to 65 degrees are realizable. A 52-in. rolled pillbox scanner at $\lambda = 1.25$ cm, gave a half-power width of .74 degree with -20 db side lobes at zero scan angle, and a .79 degree half-power width with -19 db lobes at 10.5 degrees tilt. About 1/2 db loss occurs in the barrier teeth. For other antennas, side lobes vary from -19 db to -13 db.

Systems for Which Used (21) - Experimental systems for hemispheric radar, mortar-fire detection, fire control, etc.

EVALUATION OF SPECIFIC ANTENNAS

A further understanding of the rapid-scanning problem will be afforded by considering the various antenna types outlined above with a view to their applicability to future systems and by considering the disadvantages of the various antennas as applied to the systems. A summary of such an analysis is presented in the table on the following page.

PART III

RAPID-SCANNING TECHNIQUES - FUTURE

CONSIDERATIONS OF SCANNERS AND SCANNER REQUIREMENTS

The tactical requirements of the various rapid-scanning radars have been discussed, and a number of rapid-scanning antennas which represent the best that is presently available have been described and analyzed in the light of probable future requirements. These antennas have been found wanting in one or more important details, and the need for new scanners and improved methods of scanner design, as well as for improvements in present techniques, is urgently felt. The optical principles upon which rapid-scanner designs are based are not disposed to modification; it is therefore the task of the antenna designer to broaden the scope of his understanding of microwave optics in order that the necessary improvements in scanner design may be effected. The primary objective in this study is the development of wider field, better-corrected focusing devices than have been previously known to antenna designers. A necessary complement to researches of such a kind is the study of methods for producing displacements of a source or sources— by means other than mechanical— along a line or on a surface. Another approach lies in the development of methods for pictorial displays of the r-f image produced by a focusing objective in its focal plane by conversion of the r-f image into a visible image on a sensitive screen in the focal plane (11). It is with these considerations in mind that a number of new rapid-scanner designs, components, or methods of scanning have been proposed, some of which are at present in the experimental stage. A brief description of each of these follows:

1. Fresnel Zone Plate - A new approach to the problem of focusing microwave radiation utilizes a zone plate in which alternate Fresnel zones have their phase advanced or retarded by use of metal-plate or dielectric refracting media. Preliminary investigations indicate a wide field of view and a low frequency sensitivity.

2. Constrained-Wave Lenses - Given a zone of a parabolic spheroid reflector, it has been demonstrated that a constraining medium consisting of metal plates radial about

SYSTEMS APPLICATIONS	ANTENNA TYPE	DISADVANTAGES	OUTSTANDING FEATURES
Long-Range Search	Schmidt System Scanner	Has possibility of wide-angle scan, but indications are that pattern would not be well preserved over scan. Mechanical difficulties in high-speed scanning.	
	FH Musa	Excessive weight. Intricate waveguide system. High side lobes Comparatively small scanning angle.	
	Variable-Width-Waveguide Array	Slow scanning rate. Mechanical tolerances in construction. High side lobes.	
	Corrugated Eccentric Line	Low power capacity. Relatively small scanning angle. High side lobes.	
	Leaky-Waveguide Scanner	Slow scan rate. Low power capacity. Poor preservation of pattern over scan.	
Hemispheric Search	Turntable Scanner	Mechanical difficulties and machining tolerances in alignment of large rotor. Mechanical difficulties in construction of toroidal bend. High side lobes (probably could be improved). Useful scanning angle limited to ±30 degrees.	Aberration-free optics: comparatively wide angle of scan.
	Spherical Reflector	Spherical aberration necessitates illumination of only small portion of total reflector area; hence large reflector required for narrow beam.	Inherently wide scan angle.
	Rotating-Cone Scanner	Mechanical difficulties in construction and in alignment of rotor. High side lobes. Size and weight.	Comparatively wide angle of scan with preservation of pattern. High scan rate possible.
Surface Search, Height	Zoned Pillbox	Comparatively high side lobes. Weight and mechanical	

Finding, Mortar or Missile Detection		complexity of feed motion.	
	Schwarzchild Antenna	Mechanical difficulties in construction. Size and weight.	
	Reflector Roll and Lens Antenna	Mechanical difficulties in present design. Size and weight.	
	Reverse-Roll Antenna	Constructional difficulties. High Side lobes.	
	FH Musa	Excessive weight. Intricacy of waveguide system. High side lobes.	
	Variable-Width-Waveguide Array	Slow scanning rate. High side lobes.	
	Rotating-Cone Scanner	Mechanical difficulties in construction. High side lobes. Weight.	
Target Acquisition	None applicable		
Fire or Missile Control	Conical Scanner	Errors arising from random signal fluctuations and changing target aspect, even at extremely high scan speeds.	
Aircraft Interception	None applicable		
Navigation and Bombing	Turntable Scanner	As above (see Hemispheric Search)	
	Rotating-Cone Scanner	As above (see Hemispheric Search)	
	Variable-Width-Waveguide Array	As above (see Long-Range Search)	

the center of the generating circle will, upon proper adjustment of the thickness and inner radius of the constraining medium, provide almost complete correction for spherical aberration. Constrained-wave lenses have a number of possible applications whose merit may be determined when the theory of constrained waves is better understood.

3. Simultaneous-Lobing Antenna (22) - This is a combination of four horns, the necessary r-f plumbing and suitable directional couplers, such as magic T's, to produce four simultaneous lobes spaced at 90 degrees to the axis of the directive systems (metal-plate lens). The signals from the four horns are grouped in pairs and fed to the directional couplers in such a fashion that sum-and-difference information is obtained, giving position information corresponding to horizontal and vertical displacements of the target from the axis of the antenna. This information is obtained without reference to a rotating beam, since the four simultaneous lobes are fixed in space relative to the axis of the directive system. The primary objective in the development of this antenna is an improved automatic-tracking system for gunfire control and the location of missiles. Material progress has been made in the study of simultaneous-lobing antennas, and experimental analysis is proceeding.

4. Metal-Plate Lenses - The general field of microwave optics, including metal-plate refracting media, is being developed; and a study is being made of the methods of designing wide field of view metal-plate lenses (22). Attention has been given to the possibility of developing a "lens of revolution" in which the collimating lens is a figure of revolution about a revolving source (23). The optical theory has been thoroughly studied. It can be shown that such a lens is optically possible, but the design is physically impractical with conventional feed designs.

5. Microwave Iconoscope - In order to achieve a very rapid scan, the possibility of a microwave iconoscope in conjuntion with a lens system for image focusing is being investigated. The iconoscope is thought of as consisting of an electron beam scanning a mosiac composed of discrete nonlinear elements upon which the microwave image has been focused. The information thus obtained provides azimuth and elevation data only. It is possible, by pulse modulation, to obtain range information on any discrete target and at the same time to obliterate all other undesirable signals.

5. R-F Sensitive Screens - Certain physical characteristics of a given material are modified by r-f irradiation of that material. Any of these characteristic modifications offers a means of direct indication of an r-f image through the development of an r-f sensitive screen or mosiac. Examples of considerable interest in this connection are the temperature sensitivity of the light-emitting properties of certain phosphors which can be deposited on r-f absorbing screens, and the rotation by electric fields of the plane of polarization of light in certain materials which can be placed in the strong fields produced in r-f cavities.

7. Electrical Phasing Methods (14) - Some consideration has been given to entirely electrical means of producing phase changes for a variable-phase scanner. One possibility is to control the charge density within a medium through which microwaves are being conducted, since the phase velocity of the wave is dependent upon the charge density. A second method is to apply a controllable magnetic field perpendicular to the electric field in a dielectric medium through which microwave energy is being conducted, thus causing a phase change in the radiated energy due to elliptical rotation of the induced electric oscillations within the dielectric. These methods have been briefly investigated experimentally without noticeable success, but further consideration would undoubtedly be worth while.

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CONCLUSIONS

The foregoing considerations have indicated certain well-defined lines along which the research and development of rapid-scanning techniques should proceed. These are:

1. Wide-angle focusing devices, such as metal-plate lenses, low-aberration reflectors, and Fresnel zone plates.
2. Special combinations of lenses or reflectors or lenses and reflectors to obtain extremely wide field of view.
3. New feed motions for improved scanning, i.e., the motion of a source along a line or on a surface for feeding wide-angle focusing objectives.
4. Electronic scanning techniques, i.e., microwave iconoscope.
5. Thermionic image-conversion techniques, i.e., r-f sensitive screen research.
6. Electrical phasing methods for extremely high-speed scanning.

The rapid-scanning-antenna developments of the past have provided a considerable understanding of the rapid-scanner problem and the limitations of certain antenna components. A number of rapid-scanning methods have been proposed which bear much promise of future success.

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REFERENCES

1. Air Materiel Command, Cambridge Field Station, Report No. 5-1, L. M. Hollingsworth, Target-pulsed CW radar, 2 Dec. 1946, Secret

2. M.I.T. Rad. Lab. Report 646, S. B. Meyers, Parallel plate optics for electrical scanning, 15 Dec. 1944, Unclassified

3. M.I.T. Rad. Lab., Report 73-1, L. W. Alvarez, Microwave linear radiators, 31 July 1942, Unclassified

4. Bell Telephone Lab., Report No. MM-44-160-65, C. B. Feldman, H. A. Baxter, The translating feed zoned parabola Mark VIII antenna, March, 1944

5. L. N. Ridenour (ed), Radar systems engineering, vol. 1, McGraw-Hill (1947) pp. 295-98

6. C. V. Robinson, Electrical scanning antennas, (unpublished notes)

7. L. N. Ridenour, op. cit., p. 304

8. M.I.T., Rad. Lab. Report 688, C. V. Robinson, M. A. Taggart, M. D. Pearson, The SCI rapid scan height-finding antenna, 9 July 1945, Restricted

9. NDRC Div. 14 Progress Report, April 1944 to August 1945

10. M.I.T., Rad. Lab. Report 81-1, R. S. Phillips, Conical scanning, 4 August 1942, Unclassified

11. M.I.T., Rad. Lab. Report 54-27, G. G. Harvey, Report of conference on rapid scanning, 15 June 1943, Unclassified

12. M.I.T., Rad. Lab. Report 54-17, C. V. Robinson, Rapid scanning, high resolution antennas; preliminary report, 15 February 1943, Unclassified

13. Great Britain, Air Defense Research & Development Estab., Research Report No. 209, A. B. Pipparel, J. Ashmead, Narrow beam scanning aerials at 3 cm, July, 1943, Secret

14. Philco, Report CD827, Task #8--rapid scan, December, 1946, Confidential

15. Bell Telephone Lab. Report No. MM-42-160-106, C. B. Feldman, Rapid scanning radars, 4 Sept. 1942, Secret

16. Bell Telephone Lab. Report No. MM-42-180-59, C. B. Feldman, D. H. Ring, Some design features of the FH(10) antenna with discussion relating to the proposed FH(3) antenna, May, 1942

17. L. N. Ridenour, op. cit., pp. 291-95

18. M.I.T., Rad. Lab. Report 415, L. Buchwalter, G. G. Harvey, LRASV (AN/APA-2) antenna, 13 October 1943, Unclassified

19. M.I.T., Rad. Lab. Report 557, J. Steinberger, Leaky waveguide rapid scanner, 18 November 1944, Unclassified

20. M.I.T., Rad. Lab. Report 635, J. S. Foster, Linear electrical scanner, 6 January 1945, Restricted

21. M.I.T., Rad. Lab. Report 1064, H. R. Worthington, Jr., Mortar fire detection, April, 1945, Restricted

22. NRL Letter Report Serial 1380-58/47, L. C. VanAtta, Rapid scanning for fire control antennas, 13 February 1947, Unclassified

23. Watson Laboratories Manufacturers' Conference, Lens Antennas, 15-16 November, 1945, Secret