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Final Report

ECM ANTENNAS AND COMPONENTS FOR MISSILES AND SPACE VEHICLES

Prepared for:

ELECTRONICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

CONTRACT AF 19(604)-3502

By: *W. J. Getsinger*

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

*SRI

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By: W. J. Getsinger

SRI Project No. 2605

Approved:

R. L. Tanner
R. L. TANNER, MANAGER ELECTROMAGNETICS LABORATORY

D. R. Scheuch
D. R. SCHEUCH, DIRECTOR ELECTRONICS AND RADIO SCIENCES DIVISION

Copy No. 45

ABSTRACT

This is the final report on Contract AF 19(604)-3502, under which various investigations were made from 16 July 1958 to 15 June 1961. These investigations included theoretical studies on surface wave antennas and on power pattern synthesis, studies of various realizations of leaky-wave antennas, studies of some frequency-independent structures and a twisted Yagi antenna, studies of a highly efficient surface-wave launcher, and of ridge waveguide directional couplers. The results of these studies contribute to the body of knowledge ultimately applicable to the Air Force electronic countermeasures problem.

CONTENTS

ABSTRACT ii

I INTRODUCTION 1

II RESEARCH PROGRESS 2

A. Theoretical Work 2

1. Synthesis of Modulated Corrugated Surface-Wave Structures 2
2. Radiation from Variable Reactance Surface-Wave Antennas 3
3. A Variational Method of Synthesizing Antenna Power Patterns 3

B. Leaky-Wave Antennas 4

1. A Leaky-Wave Antenna with a Curved Aperture 4
2. A Dielectric-Loaded Wire-Grid Antenna 6
3. An Antenna Array of Longitudinally-Slotted Dielectric-Loaded Waveguides 7
4. Leaky-Wave Antennas Using Periodically Spaced Small Apertures 8
5. A Wide-Band, Transverse-Slot, Flush-Mounted Array . . 9

C. Other Antennas 10

1. A Sinuous Flush-Mounted Frequency-Independent Antenna 10
2. Other Frequency-Independent Antennas 11
3. Twisted Yagi Antennas 11

D. Components 13

1. Flush-Mounted Surface-Wave Launcher 13
2. Ridge Waveguide Directional Couplers 14

III LIST OF SCIENTIFIC REPORTS PUBLISHED UNDER THIS CONTRACT . . 16

LIST OF KEY TECHNICAL PERSONNEL 17

ECM ANTENNAS AND COMPONENTS FOR MISSILES AND SPACE VEHICLES

I INTRODUCTION

The purpose of the investigations made under this contract was to develop new information on antenna systems that eventually might be useful for Air Force ECM systems. In this report the theoretical investigations of surface-wave antennas and leaky-wave antennas will be considered first, followed by discussion of a technique for determining the smoothest aperture distribution that will give a specified radiation pattern for any large aperture antenna. Next, a number of different antennas designed on a leaky-wave basis will be considered, followed by a discussion of other types of antennas, including frequency-independent-types. Finally, ridge-waveguide directional couplers--which can be very useful in ECM antenna systems--will be considered.

II RESEARCH PROGRESS

A. THEORETICAL WORK

1. Synthesis of Modulated Corrugated Surface-Wave Structures

The surface-wave antenna has shown promise as a flush-mounted end-fire antenna, but its development has been limited by the lack of basic theoretical knowledge of its mechanisms of radiation. Theoretical work under this contract has developed some of the needed information.

In Scientific Report 4, an exact procedure is described for designing a surface that will support a prescribed group of surface waves simultaneously. The surfaces developed by this procedure are modulated (i.e., contain periodic waves in the direction of propagation), and have surface impedance values that vary periodically in the direction of propagation. Finite-length surfaces of this type are reminiscent of Simon's "cigar antenna." The report presents several surface designs, and a discussion of some general properties of the surfaces and the composite waves they support. Certain limitations of the design procedure are described.

It is shown that an exact procedure exists for the design of a modulated corrugated surface to support a specified group of surface waves. In the illustrative examples the surface impedance level on such a surface attains values well in excess of the corresponding values for single-mode surfaces designed for the fastest wave in the group. This upholds the view that a modulated surface can support a wave of velocity slightly less than that of light, as a part of a relatively tightly bound wave system.

The analysis is limited in application to two-dimensional corrugated surface radiators. It is further limited in that it provides no information on the bandwidth characteristics of the structures designed.

2. Radiation from Variable Reactance Surface-Wave Antennas

Scientific Report 12 presents a comprehensive investigation of radiation from surface-wave structures. This report is a theoretical study of the properties of flush-mounted or two-sided variable-reactance surface-wave antennas. The paradox of radiation from a constant-reactance surface wave antenna is examined to derive an understanding of the principle of radiation from a surface-wave antenna with periodically varying parameters. The report discusses the principle of radiation from Simon's "cigar" antenna, which has caused some controversy. Finally, a theory, which in principle is exact, is developed for variable reactance surface-wave antennas. By this theory, the surface field can be determined using a field representation in terms of coupled cylindrical modes. Approximate expressions for the surface field are derived, for use in practical designs. It is expected that this theory will be useful in cases requiring high accuracy in predicting the radiation pattern of a tapered surface-wave antenna.

In the design of distributed-aperture antennas, such as the leaky-wave antenna, it is often assumed that no sudden changes occur in the aperture distribution. However, a prescribed power pattern may be realized with any one of an infinite number of aperture distributions, and it is useful to know which aperture distribution is the smoothest for a given power pattern.

3. A Variational Method of Synthesizing Antenna Power Patterns

In Scientific Report 9, a variational approach is developed for determining both the phase and the amplitude of an antenna excitation function that approximates a prescribed far-field power pattern. No information on the phase of the prescribed pattern need be supplied. The resultant pattern will be an optimum approximation in a mean-square sense and the excitation function will be the smoothest one possible under the prescribed circumstances. The relative importance of the pattern fit and the smoothness of the excitation function can be adjusted by means of weighting factors. The width of the radiating aperture appears as an explicit parameter of the synthesis procedure, so trade-offs between aperture size, pattern error, and smoothness of excitation function may easily be examined. In particular, this latter feature makes possible an explicit determination of the relationship between a given amount of super gain and the resulting fluctuation of the excitation function in the radiating aperture. The smoothness requirement also has the effect of achieving the highest possible aperture efficiency consistent with the allowable pattern error.

A feature of the procedure is that both the aperture width and the extent of the angular region over which the pattern fit is to be achieved appear as explicit parameters of the problem. Also, either the phase or the amplitude of the aperture function can be prescribed. The synthesis procedure will then determine the other function. The function so determined will be conditionally optimum.

In the light of a limited amount of analysis, it appears that the necessary computations are well within the capabilities of moderately fast digital computers. Thus, the computing costs should not be a serious limitation in the practical application of the method.

B. LEAKY-WAVE ANTENNAS

1. A Leaky-Wave Antenna with a Curved Aperture

In the analysis of wide-aperture antennas excited by a traveling wave, the leaky-wave concept has proven to be very useful because the accuracy of such an analysis is less a limiting factor than is the precision with which an antenna can be built to the design. Leaky-wave antennas are of interest in airborne ECM work because they can be flush-mounted, they have relatively small volume, and can be scanned electrically. Different antennas based on the leaky-wave principle, each having unique construction or performance capabilities, have been developed under this contract. Scientific Report 5 presents the design and the measured performance of a leaky-wave antenna whose radiating aperture is curved to fit flush with a 30-degree sector of a cylindrical surface. The radius of curvature of the surface is about 46 inches, or 44 wavelengths at the design frequency. The aperture of this antenna is 18 inches in the E-plane with an arc length of 24 inches in the H-plane. It comprises an inductive sheet spaced over a conducting surface.

The radiation patterns of this antenna were measured over the frequency range 8 to 13 kMc. At the design frequency, 11.42 kMc, the experimental results check extremely well with the theoretical predictions for a pencil beam 3.8 degrees wide in the H-plane by 3 degrees in the E-plane, tilted 55 degrees in the H-plane from the normal to the surface at the feed end of the antenna.

It had been shown previously that the behavior of a wire-grid leaky-wave structure on a flat surface could be very precisely predicted, permitting independent and precise control of the phase and amplitude distributions across a flat antenna aperture. These new measurements showed that nearly as precise control can be obtained when the antenna is curved gradually in the H-plane to fit flush with a curved surface. An appreciably smaller radius of curvature could be used before the errors would become significant for most applications. It follows, then, that leaky-wave antennas of this type can be designed to fit any singly curved surface whose radius of curvature along the aperture lies between some lower limit (less than 44 wavelengths) and infinity. They can be designed to radiate pencil-beam or shaped-beam patterns.

It could not be definitely determined whether the very slight discrepancies that occurred (3 db differences at 40 db down from the main lobe on one side of the beam) were due to approximations made in predicting the radiation from a curved surface, to approximations made in the design of the leaky-wave structure, to finite tolerances in the construction of the experimental antenna, or to combinations of these factors.

Although the antenna described was constructed by stretching large numbers of parallel wires across the aperture, the wire grid could be replaced by a grid of flat strips photo-etched on a Teflon-glass fiber laminate. The width of the flat strips would be twice the diameter of the round wires.

2. A Dielectric-Loaded Wire-Grid Antenna

Scientific Report 8 describes the design and the measured performance of a flat, leaky-wave antenna in which the inductive, leaky surface is backed with a slab of dielectric. The analysis is based on a transverse resonance analysis which determines the physical dimensions of the antenna for a specified aperture distribution.

The antenna consists of a 28- by 18-inch trough filled with a dielectric material over which parallel wires are strung. At the design frequency, 4.75 Gc, the antenna radiates a pencil beam 9.4 by 8.3 degrees wide at an angle of 54 degrees measured from the normal to the inductive surface.

The beam can be scanned from approximately 75 degrees down to 12 degrees, measured from the normal to the aperture, by changing the frequency from 5.25 Gc to 4.20 Gc. Beyond both limits the radiation pattern deteriorates rather sharply.

It is shown that by using a transverse-resonance analysis, the behavior of the flat dielectric-loaded leaky-wave antenna can be predicted with very good accuracy. The refraction at the interface causes the antenna to scan over a wide angle for only a small change of frequency. In the first model built, the dielectric was molded. The antenna behaved substantially as predicted, but losses in the dielectric and poor mechanical stability led to the construction of a second model in which the dielectric was machined to fit the antenna. This gave a poorer fit and consequently the radiation pattern did not agree with the predicted patterns as well as in the first model. However, the gain of the second model was close to the estimated value.

The availability of a new low-loss dielectric resin led to the design of a conical leaky-wave antenna. The design is described in detail in the report. Construction of the antenna was not completed within the contract period due to difficulties with the casting process.

The report describes a method of designing a leaky-wave antenna on a digital computer. Dimensions for the flat antenna were calculated from the curves and compared with those from the machine program. The maximum difference was 0.002 inch.

The dielectric-loaded leaky-wave antenna has several advantages over the non-loaded type. Some of these are:

1. The inductive surface is better supported.
2. Beam scanning can be accomplished within a narrower frequency range.
3. The loaded antenna is thinner than the air-filled antenna working at the same frequency.
4. The dielectric raises the breakdown point inside the antenna.

Whether these features outweigh such disadvantages as higher cost, less accurate aperture control, and greater weight, will depend on the requirements in each case.

3. An Antenna Array of Longitudinally-Slotted Dielectric-Loaded Waveguides

Scientific Report 6 describes the design and measured performance of an antenna made up of an array of dielectric-loaded rectangular waveguides with common narrow walls. There is a longitudinal slot in the center of each broad wall. The preferred form of this antenna has a slab of dielectric over all the slots, although it can also operate with dielectric within each guide. The report discusses an approximate theory, and presents empirical design data from which an experimental model of this antenna is designed. Empirical data are also given for cases with dielectric inside the waveguides. The radiated H-field from this antenna is parallel to the antenna aperture, and the main beam is directed up from the aperture at an angle equal to the arc cosine of the velocity of light divided by the slotted-waveguide phase velocity.

An experimental antenna using standard 0.900- by 0.400-inch waveguide, had an aperture 9 inches wide by 20 inches long. The antenna was fed from a hog-horn that yielded an approximately sinusoidal H-plane illumination over the 9-inch aperture width. The slot width was varied over the 20-inch length to obtain a Taylor aperture distribution yielding a theoretical radiation pattern with -25.5-db E-plane sidelobes and with a 5.4-degree beamwidth. At the design frequency of 10 kMc the beamwidths were 5.4 degrees (E-plane) and 8.0 degrees (H-plane), and the first-sidelobe levels were -22.0 db (E-plane) and -23 db (H-plane). Good radiation patterns were obtained from 8 to 11 kMc. Using the experimental data, it should be possible to design this antenna to yield a variety of radiation patterns.

The antenna can be flush mounted in the skin of an aircraft or space vehicle. It requires only about one wavelength of depth, and the dielectric covering the aperture can act as a radome.

The array of slotted waveguides can excite a surface wave in the dielectric. However, by restricting the thickness of the dielectric slab, the amplitude of the surface wave can be kept very small, at least 30 db below the main-beam peak. The excitation of the surface wave should not hinder the practical application of this antenna.

4. Leaky-Wave Antennas Using Periodically Spaced Small Apertures

Scientific Report 10 describes the application of Bethe's small-aperture theory and leaky-wave-antenna theory to the design of narrow-beam antennas radiating through small apertures periodically spaced along one wall of a rectangular waveguide.

The first antenna described uses a dielectric-filled rectangular waveguide with rectangular apertures spaced along one narrow wall, radiating into a parallel-plate region, which flares into a horn. This antenna was 30 inches long and was designed for a center frequency of 11.0 Gc. It gave reasonably good patterns from about 10.4 to 11.8 Gc, scanning from about 55° to 25°, measured from the waveguide axis. The beamwidth was between 4.75° and 6.5° in this frequency range.

The other antenna described is a single rectangular waveguide designed to be part of an array of waveguides laid side-by-side, radiating through crossed slots in their broad walls. This antenna radiated an elliptically polarized wave, but the design analysis is applicable to linear polarization as well. The antenna was 20 inches long. It scanned a five-degree beam through about 22 degrees, with ellipticity less than six db, over a 25% frequency band centered at about 9.0 Gc.

Design analyses, formulas, and measured performance are presented for these antennas. Both worked sufficiently well to demonstrate the applicability of small-aperture leaky-wave concepts to the design of narrow-beam antennas.

5. A Wide-Band, Transverse-Slot, Flush-Mounted Array

Scientific Report 2 describes the design analysis and measured performance of an antenna composed of an H-plane array of parallel waveguides having quarter-wavelength-thick transverse slots extending completely across the array. Each relatively wide nonresonant slot in this array radiates only a small amount of power, and the dimensions of the slots are relatively uncritical. The radiated H field from this antenna lies parallel to the transverse slots. The cosine of the angle between the direction of maximum radiation and the plane of the antenna is equal to the velocity of light divided by the phase velocity of propagation along the array.

An experimental antenna was built with a radiating aperture 9 inches wide and 20 inches long. The antenna was fed from a hog horn which yielded approximately sinusoidal H-plane illumination over the 9-inch aperture width. The power coupled from the transverse slots was varied along the 20-inch length of the aperture to achieve a Taylor aperture distribution with -25-db E-plane side lobes. At the design frequency of 11 kMc the beamwidths were 5.4 degrees (E-plane) and 7.3 degrees (H-plane), while the first-side-lobe levels were -24.7 db (E-plane) and -24.2 db, (H-plane)--in close agreement with theoretical expectations. The direction of maximum radiation was within 0.35 degrees of the design value at 11 kMc. Good radiation patterns were obtained from 7.0 kMc--which is slightly above the cut-off frequency of the guides--to 11.5 kMc, which is slightly below the frequency at which spurious lobes are generated by the widely spaced slots.

The measured performance of the wide-band, transverse-slot, flush-mounted, antenna array agrees well in all essential points with the theoretical analysis. Therefore it is believed that the analysis presented in this report may be safely used to design this type of antenna to give a wide variety of pattern shapes for various applications.

This type of antenna can be flush mounted in the skin of an aircraft or space vehicle and requires only about one wavelength of depth. The angular position of the beam can be varied over an angular interval of about 35 degrees by varying the operating frequency from 7 to 11.5 kMc. If the antenna were mounted behind a radome so that it could be mechanically scanned, it would probably have less volume than a parabolic antenna having equivalent electrical performance.

C. OTHER ANTENNAS

1. A Sinuous Flush-Mounted Frequency-Independent Antenna

The leaky-wave antennas discussed in the preceding section are wide-aperture narrow-beam antennas operating over a moderate frequency range. Another type of antenna having application to ECM work is the frequency-independent antenna, which has a moderate beamwidth but an extremely wide frequency range. The frequency-independent antennas investigated under this contract were flush-mounted types.

In Scientific Report 3, the design and measured performance of a sinuous flush-mounted frequency-independent antenna are described. This class of antennas has constant input impedance and pattern shape over an essentially unlimited frequency band. The antenna described had linearly polarized radiation patterns with beamwidth and direction of maximum radiation essentially constant over a 5-to-1 frequency range, extending from 3.2 to 16 kMc. The bandwidth of this type of antenna is limited by the bandwidth of the ridge-loaded feeding waveguide. It is believed that the operating bandwidths could be increased by using a more heavily ridge-loaded feed or shielded coaxial feed structures having maximum dimensions much smaller than the smallest operating wavelength. The antenna can easily be scaled to operate over other frequency bands.

The experimental antenna was well matched and was efficiently excited from a heavily loaded ridge waveguide. The performance of four different antennas was measured, illustrating how the beamwidth and direction of maximum radiation is influenced by the antenna dimensions. Because the effective center of radiation moves along the antenna with frequency, it is believed that it could be used for frequency scanning, either by mounting the antenna at the focal surface of a reflector, or by distorting it to lie on a cylindrical surface.

2. Other Frequency-Independent Antennas

Two other frequency-independent antennas were worked on briefly under this contract. One consisted of 38 closely spaced dipole elements arranged so that element spacing and length changed by a constant multiplier in proceeding from one to the next. The elements and balanced feed line were made by printed circuit methods on either side of a thin Teflon-glass fiber sheet, which was mounted over a reflecting cavity in such manner that the distance from the plane of the elements to the reflecting wall changed linearly in the same proportion as the element length and spacing. This arrangement allowed the antenna to be flush-mounted.

The intended frequency range of this antenna was about six to one, but difficulties with the feed and input impedance reduced the range of satisfactory operation to something less than four to one. Insufficient time remained on the contract to pursue the development of this antenna further.

The other frequency-independent antenna consisted of a tapered single-ridge waveguide with a row of tilted slots cut along the center of the nonridged wall. In this antenna only a small portion of the energy was radiated, and in such manner that the pattern was not frequency-independent. To overcome this, it would be necessary to tilt the slots more or make the structure much longer. Tilting the slots more would have increased non-frequency-independent, cross-polarized radiation which was already as great as could be tolerated. The antenna was more than twice as long as a dipole frequency-independent antenna covering the same frequency range, so making it much larger was impractical. Therefore, no further development was done on the ridge-waveguide frequency-independent antenna.

3. Twisted Yagi Antennas

A different approach to modulated traveling-wave antennas was investigated in Scientific Report 1. This report discusses the limitations of conventional traveling-wave antennas, and the advantages of modulating either the phase or amplitude of the guided wave. Uniform traveling-wave antennas--such as the long Yagi, the polyrod, and the corrugated-surface antenna--have useful end-fire radiation characteristics when the axial dimension of the antenna is not too great (less than about 20 wavelengths). The end-fire characteristics may be preserved for even greater lengths if either the amplitude or the phase (or both) of the traveling-wave propagation along the antenna is appropriately modulated. The gradual twisting of the elements of a long Yagi antenna about its central axis were found to yield some of the advantages gained from other forms of modulation. In addition, circular polarization of the field in the axial direction may be attained. The expressions for the field patterns of the twisted Yagi were derived, and compared with measured patterns taken on a model ten-wavelengths long.

The agreement was considered close enough to allow the design of antennas on the basis of the theory, coupled with experimental results on the velocity of propagation of the surface wave as a function of the antenna parameters. This relationship should be measured more accurately than was done in this investigation, since the phase velocity is the most critical design parameter of the antenna.

The two most important results of applying the twist principle are

(1) The attainment of arbitrarily high gain at a fixed phase velocity that is sufficiently low to allow for easy excitation of the antenna

(2) The production of circular polarization.

In addition to other applications, the twisted Yagi can be used as a research instrument for studying the general principle of modulated surface-wave structures, since it achieves the effect of an amplitude-modulated antenna at constant phase velocity. Invariably, other forms of modulation, such as those produced by varying the spacing or length of elements, result in a mixture of modulations of the amplitude and phase velocity of the traveling wave.

The report gives examples of arrays of twisted sections, describing them in simplified terms for purposes of discussion. Using well-known methods of pattern synthesis, it should be possible to obtain patterns with specified ratios of main-lobe to side-lobe level by employing twist sections of different lengths and phase velocities. One could also synthesize patterns having the main lobe at a specified angle with the axis, although this could probably be done more efficiently by other forms of modulation.

D. COMPONENTS

1. Flush-Mounted Surface-Wave Launcher

Some work was done on transmission-line components that might be useful in the study or the application of ECM antenna systems. Scientific Report 11 describes an investigation of a flush-mounted surface-wave launcher of very high efficiency. The launcher consists of an array of partially dielectric-filled waveguides coupled to a dielectric slab outside the waveguides by small slots cut in the broad faces of the waveguides. The launcher supports two normal modes with slightly different phase velocities. All power can theoretically be extracted from the waveguide system for a coupling length of half of the beat wavelength of the normal modes, provided that the dimensions of the launcher satisfy the following two conditions: (1) The normal modes of the uncoupled system must have the same phase velocity, and (2) Each normal mode of the coupled system must carry the same power inside as outside the waveguides.

Measurements were made on a surface-wave launcher consisting of an array of five waveguides coupled to a dielectric slab. It was shown that more than 99.9 percent of the waveguide power can be extracted from the waveguides for a coupling length of 7.5 wavelengths. There was close agreement between theory and experimental results. Because of the finite width of the launcher, some of the extracted power is radiated from the sides of the launcher. This side-radiation decreases when the width of the launcher is increased. The side-radiation can be eliminated by placing metal sheets at the sides of the launcher.

The theory was used to design a surface-wave launcher which couples one rectangular waveguide to a dielectric slab with metal sides. With this launcher, there is no side-radiation. The theory was further used to predict the coupling between two rectangular waveguides.

2. Ridge Waveguide Directional Couplers

Ridge waveguide has been extensively used in ECM work because of its relatively wide single-mode bandwidth. In a ridge waveguide ECM system, directional couplers can be very useful. For instance, they can be used as sampling devices for monitoring transmitted power, wave shape, or spectrum. They can be used as integral parts of recirculating storage loops for pulse generation or storage, or as directional filters. Directional couplers have also been discussed in connection with the "look-through" problem. In Scientific Report 7, both cross-guide and broad-wall couplers are described. The couplers were made in both single- and double-ridge waveguides using cross sections approximating those of some commercially available ridge-guide.

An approximate determination was made of the dominant-mode fields in ridge waveguides at all frequencies. Evaluations were made of the fields along the walls of a commercially standard single-ridge guide having a usable frequency range from 3.75 to 15.0 Gc, and of a commercially standard double-ridge guide having a usable frequency range from 4.7 to 11.0 Gc. Graphs were drawn so that the results could be applied in practical situations.

Using Bethe's small aperture theory, design formulas were developed for simple cross-guide directional couplers in both single- and double-ridge guide. These formulas and the field-graphs mentioned above were used to design and construct two cross-guide couplers. For the single-ridge cross-guide coupler the coupling varied from about 42.5 db at 3.75 Gc to about 38 db at 14 Gc, and was within about one db of the predicted coupling over most of the band. A sudden change in coupling, not predicted by the theory, began at about 14.5 Gc and reduced the value of coupling to about 27.5 db at 15.0 Gc. The smallest value of directivity was about 8.5 db and the largest about 12 db. The directivity was approximately as predicted. For the double-ridge cross-guide coupler the coupling varied between about 48 and 51 db over the band from 4.7 to 11.0 Gc--substantially as predicted. The directivity was about 30 db at 8.0 Gc, and over 20 db across the frequency band except at the low frequency end, where it measured 14 db. The theory indicated a directivity greater than 20 db over the band.

Design formulas were developed for multi-hole, broad-wall-coupled ridge waveguide directional couplers. The coupling for the single-ridge broad-wall coupler ranged between about 22 and 29 db over the 3.75 to 15.0 Gc band. The coupling of the low points near the ends of the frequency band were about equal, as predicted. The predicted directivity was greater than 40 db, but measured values were 16 db at the lower frequency end of the band and over 20 db elsewhere.

The coupling for the double-ridge broad-wall coupler was between 26 and 33 db over the 4.7 to 11.0 Gc range. Coupling at the ends of the band differed by about 1.5 db, but the coupler could have been modified to eliminate this difference. The predicted directivity of this coupler was greater than 40 db over the frequency range, and measured values were 15 db at the lower end of the band, rising to about 27 db at the center of the band.

It is believed that the directivity of the broad-wall couplers could be improved by great care in construction, or by using many more apertures for the same coupling. These couplers can be made to have reasonably flat coupling over the broad frequency ranges of the ridge-guides, although it is difficult to achieve close coupling or high directivity.

The field-graphs and formulas given in this report make possible the practical design of ridge waveguide directional couplers for such uses as signal sampling, power measurement, and storage loops in ECM systems.

LIST OF SCIENTIFIC REPORTS PUBLISHED UNDER THIS CONTRACT

Scientific Report 1 -	"Twisted Yagi Antennas," by D. K. Reynolds, November 1958.
Scientific Report 2 -	"A Wide-Band Transverse-Slot Flush-Mounted Array," by E. M. T. Jones and J. K. Shimizu, November 1959.
Scientific Report 3 -	"A Sinuous Flush-Mounted Frequency-Independent Antenna," by J. K. Shimizu, E. M. T. Jones, and R. C. Honey, December 1959.
Scientific Report 4 -	"Synthesis of Modulated Corrugated Surface-Wave Structures," by J. T. Bolljahn, November 1959.
Scientific Report 5 -	"A Leaky Wave Antenna with a Curved Aperture," by J. K. Shimizu and R. C. Honey, February 1960.
Scientific Report 6 -	"An Antenna Array of Longitudinally-Slotted Dielectric-Loaded Waveguides," by E. D. Sharp and E. M. T. Jones, March 1961.
Scientific Report 7 -	"Ridge Waveguide Directional Couplers," by W. J. Getsinger, June 1961.
Scientific Report 8 -	"A Dielectric-Loaded Leaky-Wave Antenna," by J. Aasted and R. C. Honey, June 1961.
Scientific Report 9 -	"A Variational Method of Synthesizing Antenna Power Patterns," by E. Proctor and C. Ablow, June 1961.
Scientific Report 10 -	"Leaky-Wave Antennas Using Periodically Spaced Small Apertures," by W. J. Getsinger, June 1961.
Scientific Report 11 -	"Flush-Mounted Surface-Wave Launcher," by M. G. Andreasen, June 1961.
Scientific Report 12 -	"Radiation from Variable-Reactance Surface-Wave Antennas," by M. G. Andreasen, March 1961.

LIST OF KEY TECHNICAL PERSONNEL

J. Aasted
C. M. Ablow
M. G. Andreasen
J. T. Bolljahn
W. J. Getsinger
R. C. Honey
E. M. T. Jones
E. K. Proctor, Jr.
D. K. Reynolds
E. D. Sharp
J. K. Shimizu

STANFORD
RESEARCH
INSTITUTE

MENLO PARK, CALIFORNIA

REGIONAL OFFICES AND LABORATORIES

SOUTHERN CALIFORNIA LABORATORIES
820 Mission Street
South Pasadena, California

NEW YORK OFFICE
270 Park Avenue
New York 17, N. Y.

WASHINGTON OFFICE
711 14th Street, N. W.
Washington 5, D. C.

EUROPEAN OFFICE
Pelikanstrasse 37
Zurich 1, Switzerland

RESEARCH REPRESENTATIVES

HONOLULU, HAWAII
Finance Factors Building
195 South King Street
Honolulu, Hawaii

PORTLAND, OREGON
Suite 914, Equitable Building
421 Southwest 6th Avenue
Portland, Oregon

PHOENIX, ARIZONA
Suite 216, Central Plaza
3424 North Central Avenue
Phoenix, Arizona