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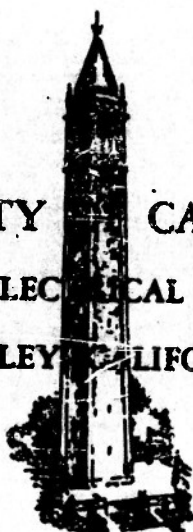
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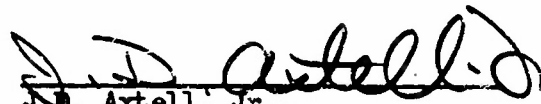
ELECTRONICS RESEARCH LABORATORY

Division of Electrical Engineering  
University of California  
Berkeley, California

Quarterly Progress Report  
Series 60, Progress Report No. 4  
January 1 - March 31, 1954

April 15, 1954

Prepared by:

  
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## FOREWORD

This Progress Report covers the research being done under Contract N7onr-29529, in effect with the Electronics Research Laboratory. The report also includes descriptions of some of the University-sponsored research which is actively being pursued at the present time. Following the wishes of Wright Air Development Center, the work on traveling-wave tubes being conducted under Contract AF33(616)-495 is not now included, but will be covered in interim technical reports from time to time.

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## 1. SCATTERING FROM A PROLATE SPHEROID

(Contract N7-onr-29529)

Prof. L.J. Black

Prof. S. Silver\*

Mr. J.S. Honda

### Summary of Previous Work

This problem is primarily a study of the scattered field from a prolate spheroid illuminated by an incident plane wave. The scattered field is very small compared with the incident signal; therefore a null method has been used to measure the scattered field. This technique requires a very precise balancing bridge mechanism, a frequency-stable signal generator, and a high power source. A stabilized klystron oscillator has been used to drive a two-cavity klystron power amplifier, which makes several watts available at 9375 megacycles.

A magic tee, and a directional coupler with large coupling and high directivity, have both been used as the balanced microwave bridge. However, in both methods, the received back-scattered signal has variations as a function of distance which have been ascribed to multiple scattering.

### Current Work

During the period of this report, a mechanically precise magic tee was constructed. This magic tee was milled out of solid brass to a dimensional accuracy of  $\pm 0.001$  inch. An additional feature of this tee is that a movable post with micrometer-controlled variable penetration is situated in the junction of the tee, so that the signal input arm and the detector output arm are decoupled by 75 db. An analysis indicated that the scattered signal must be 20 db above the null load and that a separation of approximately 80 db must exist between the input and detector arm in order to measure the scattered field to an accuracy  $\pm 1$  db.

When a sphere, the calibrating object, is pulled directly away from the transmitting and receiving horn, the received back-scattered signal varies from a maximum value to a minimum value in approximately quarter-wavelength intervals. To investigate the effects of multiple scattering that exist between the horn and the scatterer, a horn with an aperture area approximately the size of the sphere was used as the scatterer. Again, the received back-scattered signal varied similarly to that of the detected signal for the sphere. However, the signal received by the

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\* Prof. S. Silver is on sabbatical leave, but is in contact with all the work under his direction.



scattering horn varies according to theory; the power detected decays exponentially as the distance to the scattering horn is increased. This indicates that the large variation of the detected signal is not due to the multiple scattering which exists between the horn and the scatterer.

An attempt is being made to reduce any standing wave on the ground plane.

J.S. Honda

## 2. BEAM SHAPING ANTENNAS

(Contract N7-onr-29529)

Prof. S. Silver\*

Prof. J.R. Whinnery

Mr. R. Plonsey

### Summary of Previous Work

This study is an investigation of the diffraction phenomena of cylindrical reflectors. The object is to develop an analysis which will improve upon the geometrical optics solution, and be suitable for design problems.

The problem has been separated essentially into two parts; the first part has been the determination of the currents induced on a reflector by a primary source which would be an improvement over that calculated by means of geometrical optics. The second is the determination of the far fields from the aforementioned reflector currents in a fairly direct manner but one which, perhaps, will be an improvement over the stationary phase method. To date, the first part has been emphasized.

In this connection, asymptotic expansions of the Kline-Luneberg type were examined to see if they would provide a correction to the geometrical optics currents. Success with this technique seemed unlikely. Additional probing of the literature<sup>(1)</sup> into the use of integral equations, the variational principle, and Riblet's<sup>(2)</sup> use of asymptotic series, has failed to reveal, so far, any way of obtaining these corrections.

In the early stages of this study, experimental work was made on an open waveguide between parallel plates and subsequently on the field of a pillbox fed by an open guide at the center of the aperture plane. The most significant

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\* See page 1

result was that the near zone field of the pillbox was determined primarily by the diffraction effects of the feed blocking, and by the aperture edge.

#### Current Work

Another look was given the asymptotic expansions. There was no doubt that the Kline-Luneberg expansion would not handle diffraction problems near (or in) the shadow regions, since no information is contained in the geometrical optics formulation of the shadow region. However, if we restrict attention to infinite bodies with illumination such as to produce no shadows then the question arises whether, under such favorable conditions, the series may give valid results. The affirmative position is taken in a report by Dr. C. Schensted.<sup>(3)</sup> However, in the illustrative example (a paraboloid of revolution illuminated by a plane wave propagating parallel to the axis of the paraboloid) geometrical optics gives an exact solution, so that the question as to whether a diffraction problem can be handled is not resolved. (Reference is made to the report of G. Jeromson, in this Progress Report, for additional comments).

The fact that the paraboloid of revolution possesses an exact solution which is that of geometrical optics, raised the question as to whether other shapes may also possess this property. A consideration of the necessary and sufficient conditions for geometrical optics to be an exact solution of Maxwell's equations while satisfying the boundary conditions at a semi-infinite body was carried out jointly with G. Jeromson, and reference is made to his report.

The work of Moullin<sup>(4)</sup> shows that for strips of width greater than  $1/2\lambda$ , the geometrical optics value for the currents can be used satisfactorily everywhere except very near the edges. (The geometrical optics value is exceeded only in the last  $1/25\lambda$ ). At the edges it turns out that the current distribution is practically identical with that of an infinite half-plane. Thus he was able to set up the problem by taking geometrical optics currents everywhere, but adding Sommerfeld currents at the edges. (And since they are localized in such very narrow strips they can be taken to be equivalent line currents). This suggests that the first part our problem might be met in practice, for a general cylindric shape, by using geometrical optics currents plus the Sommerfeld current at the edges. (In our case, of course, we must take account of the angle of incidence to the edges). Such a suggestion was made to this writer in correspondence from Prof. M. Kline of New York University.

Effort has been directed toward placing this suggestion on a semi-quantitative basis. Fock's integral equation is being examined to see if it verifies the use

of geometrical optics currents for radii of curvature large compared with wavelength, and for distances from edges of a wavelength or so. Moullin's results would seem adequate to justify use of Sommerfeld currents at the edge of a general cylinder.

If the previous analysis is correct, then it must be that the really significant features of diffraction must come out of the calculation of the field from those currents, i.e., part two. To date, far fields are obtained in a simple way by means of stationary phase evaluations of the integral over all the sources.<sup>(5)</sup> However this ignores the effect of the edges, and the overall result is equivalent to that obtained by means of geometrical optics.<sup>(6)</sup> It is hoped that a technique involving neutralizer functions (developed by Prof. J.G. Van Der Corput, now at the University of California at Berkeley) may be used, which will provide a connection to the geometrical optics by including consideration of the edges. That is the definite integral for the far field can be set asymptotically equal to the asymptotic residues of the critical points which include the stationary phase point plus the points at the ends (edges). This matter will be carefully studied in the coming quarter.

As an alternate approach, the variational method may be used to get the far fields, with the Sommerfeld edge effect added to the geometrical optics current as a trial function.

Finally, it is intended to compare these results with those obtained by numerical integration and with experimental measurements. Construction of experimental equipment will be delayed until further developments show exactly what features are most desirable for experimental study.

1. Electronics Research Laboratory, University of California, Progress Report No. 3, Jan. 15, 1954.
2. Riblet, H.J., The Asymptotic Solution of a Diffraction Problem, (Unpublished Paper).
3. Schensted, C., Electromagnetic Transport Equation and the Luneberg-Kline Method of Solution, Memo 15 - 25 - (504) - 3, University of Michigan.
4. Moullin and Phillips, "On the Current Induced in a Conducting Ribbon by the Incidence of a Plane Electromagnetic Wave", Proc. Inst. of Electrical Engineering, Part IV, Vol. 99, pp. 137-150, (July 1952).

5. They have also been calculated by numerical integration involving geometrical optics currents, a method which has given good results thereby emphasizing the importance of part II. (Note Sect. 13.7: Microwave Antenna Theory and Design, S. Silver, McGraw-Hill, 1949).
6. The connection between stationary phase and geometrical optics is shown in general in Section 4.7: Microwave Antenna Theory and Design, S. Silver, (McGraw-Hill, 1949).
- . For cylindrical reflectors the relationship is specifically shown in the report of A.S. Dunbar, Stanford Research Institute, Report No. 21, (May 1951).

R. Plonsey

### 3. DIFFRACTION THEORY

(Contract N7-onr-29529)

Prof. S. Silver\*

Prof. J.R. Whinnery

Mr. G. Jeromson

#### Summary of Previous Work

This study is concerned with a theoretical investigation of electromagnetic diffraction problems. The initial phase of the project consisted primarily of a study of asymptotic solutions, principally that of M. Kline.<sup>(1)</sup> It was concluded earlier that while the series of Kline can be successfully applied to several electromagnetic problems, it is as yet unadaptable to situations involving diffraction, such as might occur through an aperture in a conducting plane, or even by a bounded conducting obstacle. Another method that was appraised<sup>(2)</sup> consisted of assuming an "asymptotic-like" series for the electric and magnetic field expressions, and attempting to make these expressions into solutions by properly choosing coefficients. The expansion was in inverse powers of frequency, so that the leading coefficient represented a geometrical optics solution. The other coefficients were determined from derived recursion relations, based on the first term. Thus, in the case of an obstacle of finite extent, where there is a shadow zone, the geometrical optics solution vanishes identically, and the method will generate no "correction" terms.

#### Current Work

Recent work by Schensted<sup>(3)</sup> indicates that, at least in some electromagnetic problems, the assumed-series method gives results. As was pointed out in this

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\* See page 1

work, valid results can only be expected when there exists no shadow zone (i.e., obstacles must be infinite in extent, in addition to satisfying certain obvious surface regularity conditions). The cited paper shows that for axial incidence of a plane wave on the exterior of a paraboloid of revolution, all "correction" terms vanish, and the ray optics solution is, indeed, an exact solution to the problem. Uniqueness, however, has not been demonstrated, for the usual tests involve sources contained in bounded regions.

This result raises the question: In what other problems can geometrical optics be an exact solution to Maxwell's equations, and also satisfy the necessary boundary conditions? This was investigated, and the following result obtained:

Theorem.

$$\text{Let } \vec{E} = \vec{a}(x, y, z) e^{ikL(x, y, z)}, \vec{H} = \vec{\beta}(x, y, z) e^{ikL(x, y, z)}$$

be geometrical optics fields. (By this is meant,  $|\nabla L| = 1$ ,

$$\vec{a} \cdot \nabla L = 0, \text{ and } \nabla L \times \vec{a} = \frac{1}{\epsilon} \vec{\beta})$$

Then  $\vec{E}$  and  $\vec{H}$  constitute an exact solution if and only if

$$\nabla \cdot \vec{a} = 0 \text{ and } \nabla \cdot \vec{\beta} = 0.$$

This theorem can also be reformulated slightly differently, involving only statements about either  $\vec{a}$  or  $\vec{\beta}$ , with a conservation of energy condition substituted for the omitted one.

From this theorem, we can conclude that for such a situation to exist, there must exist a function  $\phi(x, y, z)$  such that

$$\vec{a}(x, y, z) = \nabla \phi(x, y, z)$$

where

$$\nabla^2 \phi(x, y, z) = 0$$

Hence, the problem is reduced to finding a harmonic function  $\phi(x, y, z)$  satisfying, on the boundary of the conducting obstacle, the condition

$$\vec{n} \cdot (\nabla \phi(x, y, z) + \vec{E}^{\text{inc.}}) = 0$$

and also permitting fulfillment of the energy condition referred to above.

We are attempting to determine which geometries can exhibit such a function  $\phi$ .

Further theoretical investigations of the above material will be carried out in the future. In particular, the integral equations of diffraction theory will be re-examined with a view towards using them to obtain asymptotic solu-



tions of aperture problems.

1. Kline, M., An Asymptotic Solution of Maxwell's Equations, N.Y.U. Mathematics Research Group, Report EM24.
2. Riblet, H.J., The Asymptotic Solution of a Diffraction Problem, (Unpublished Paper).
3. Schensted, C., Electromagnetic Transport Equation and The Luneberg-Kline Method of Solution, University of Michigan, Willow Run Research Center, Engineering Research Institute Memorandum, 15-25-(504)-3.

G. Jeromson

#### 4. NON-RESONANT CIRCULAR SLOTS IN VARIOUS GROUND PLANE SHAPES

(Contract N7-onr-29529)

Prof. L.J. Black

Mr. G.K. Tajima

##### Summary of Research

This study is concerned principally with the behavior of the admittance characteristics of large-surface antennas of circular symmetry having a circular slot. Several theoretical methods of approach have been utilized and illustrated by examples, and the results compared with experiment. The emphasis lies in the determination of the susceptible component of the admittance.

A spherical antenna fed by a narrow slot at the equator was first investigated. The quasi-theoretical admittance was obtained by utilizing a static capacity measurement in conjunction with a mode expansion solution.

The second configuration investigated was the biconical horn of large cone-apex angle. The Schwinger variational method was applied to obtain the theoretical result. The solution for the admittance appeared in two parts; one part corresponding to a spherical antenna, and a second part constituting a correction term for the removal of the spherical surface. Since the spherical antenna admittance had already been evaluated, the additional computation involved only the determination of the correction term.

Another antenna studied was the circular disk. The theoretical result was obtained by a perturbation of the results for the biconical horn. Experimental results have also been obtained. A secondary problem arising out of

this antenna is the analysis of the junction between a coaxial line and a radial line. An equivalent circuit representation was developed and the circuit parameters determined from measurements.

Experimental measurements have been made on these three forms of antennas, utilizing a Chipman line in several different ways. A frequency range of 300 to 1500 mc was covered, using antennas about 17 cm in diameter.

Most of the computations have been completed and the agreement between theory and experiment is good within the range of validity of the theory. The preparation of the report on this problem is under way and should be completed soon.

G.K. Tajima

## 5. INTERNAL COUPLING BETWEEN WIDE LONGITUDINAL SLOTS

(Contract N7-onr-29529)

Prof. J.R. Whinnery

Dr. G. Held

Mr. H. Unz

### Summary of Previous Work

This study is concerned with the inside interaction between two wide slots in the surface of a standard  $TE_{10}$  mode waveguide. It was decided to take the case of wide resonant slots (length  $\frac{\lambda}{2}$ ; width  $\frac{\lambda}{4}$ ) in one side of the broad face of the waveguide. Various methods of measuring the interaction between the slots as well as their equivalent circuit representation have been considered.

### Current Work

The method which was adopted in order to measure the interaction between the wide slots, was as follows:

A set of waveguide sections of the same "electrical length" ( $l=2n\lambda, n=2$  or  $3$ ) with two identical, wide slots in each waveguide section were used, the space  $x$  between the centers of the slots being the parameter. By comparing them through a "magic T" bridge, a certain attenuation and phase shift were found for each. Plotting this attention and phase shift as a function of the spacing  $x$ , between the slots, cyclic curves with the period of  $\lambda g$  were obtained. Each maximum attenuation is connected with a minimum of phase shift ( $x=n\lambda g$ ), and vice versa

$[x = (n + \frac{1}{2}) \lambda_g]$  . In the range  $x \leq \frac{\lambda_g}{2}$  (approximately), we can see a certain noncontinuity in the cyclic characteristics of the curve.

Theoretical considerations of the equivalent circuits of the above waveguides (T sections for the slots and transmission lines for the waveguide) have shown the cyclic period to be  $\lambda_g$ , but the amplitudes found by experiment were not verified theoretically.

By extrapolation of the cyclic curve to the range  $x \leq \frac{\lambda_g}{2}$  (approximately), we can see the amount and the range at which non-propagating higher modes cause interaction between the slots. This interaction curve has about the same shape and the same order of range as the one obtained by Frank<sup>1</sup> in considering higher mode interaction between slits in waveguides.

Measurements of the difference of power radiating from the slots in each waveguide have been started. Although no definite results have been obtained, it appears that there is a cyclic curve of the difference power radiated from two slots in each waveguide vs. the slot spacing  $x$ . We get a minimum difference in the radiating power when  $x = n \frac{\lambda_g}{2}$ , which may be expected due to equivalent circuit considerations.

It is intended, in the coming period, to modify the bridge network as well as the accuracy of the instrument measuring the power radiated from the slots. Also equivalent circuits will be considered and it is hoped to find a definite correlation between them and the measured results.

H. Unz

## 6. BROADBAND SLOT ARRAYS

(Contract N7-onr-29529)

Prof. D.J. Angelakos

Dr. G. Held

### Summary of Previous Work

Work has begun on the design and analysis of a broad band slot radiator array. As was pointed out in the former report, preliminary investigations have suggested two basic problems:

- a) The input impedance of slots of arbitrary length
- b) Interaction between adjacent slots

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1. Montgomery, Dicke, Purcell, J., Principles of Microwave Circuits, (radiation Laboratory, Series No. 8, p. 173).



### Current Work

Investigations of both of these problems have started. In investigating the input impedance of slots of arbitrary length, we have decided to treat the multimode guide from the very beginning. This would solve the problem for the single mode and multimode guide, and at the same time allow more freedom in the frequency band in the guide.

The method developed formerly for resonant slots has been extended. At the present time an expression for the input impedance of a slot of arbitrary length has been obtained, and a computer is working on the plotting of this function. Experimental investigations have been carried out to compare with the theoretical curve when it is plotted.

During this work it became evident that we could compute the scattering of a slot of arbitrary length in a multimode guide. Such a task has been undertaken. A paper submitted to the U.R.S.I. meeting in Washington, D.C., has been accepted for presentation.

In the coming period the investigation along these lines will be continued.

G. Held

## 7. BROADBAND TRANSMISSION IN WAVEGUIDES

(Contract N7-onr-29529)

Prof. D.J. Angelakos

Mr. K. Malinovsky

### Current Work

A study is being made of loading a rectangular waveguide with dielectric material in such a way as to lower the guide's cutoff frequency and/or obtain a more uniform field distribution in its cross section.

It was established that for no variation of dielectric in the y-direction,  $TE_{no}$  modes may exist separately in the structure. Thus, transcendental equations have been set up to give the cutoff and propagation characteristics for the  $TE_{10}$  and  $TE_{20}$  modes in the guide shown below (Fig. 1.). Solutions of the equations are now being worked out for all possible combinations of the dimensions  $l$ ,  $h$ , and  $d$ , and for the ratio of dielectric constants,  $\frac{\epsilon_1}{\epsilon_2}$ .

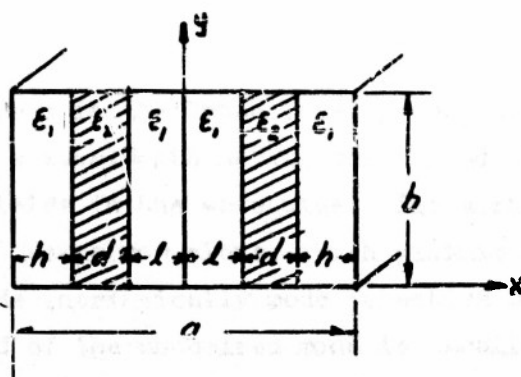


FIG. 1

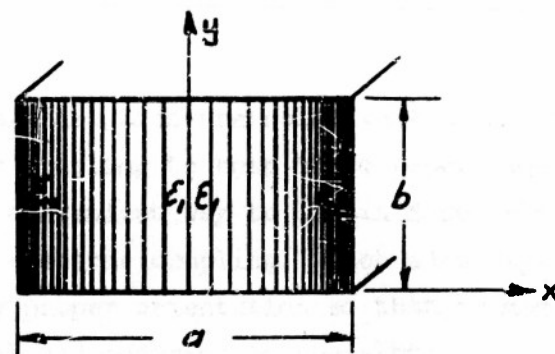


FIG. 2

If, instead of the slabs of Fig. 1., we have a continuously varying dielectric (Fig. 2.) in the cross section of the guide, the problem becomes a boundary value problem for the eigenvalues of frequencies and eigenfunctions of field distributions in the guide. There exist methods by which the lowest approximate eigenvalues are quite readily obtained, but for finer refinement the series solution method is employed. Calculations are now being carried out along this line for linear, quadratic and cubic variation of dielectric across the guide.

In the laboratory, apparatus is now being set up to measure the propagation constants and field distributions in these guides, in order to obtain experimental verification for the calculated results.

K. Malinovsky

### 8. MULTI-MODE DIRECTIONAL COUPLERS

(Contract N7-onr-29529)

Prof. D.J. Angelakos

Mr. H.A. Judy

#### Summary of Previous Work

This is a study of waveguide directional couplers using rectangular waveguide propagating  $TE_{10}$  and  $TE_{20}$  modes simultaneously. The primary objective is to develop and study directional coupling schemes which will be mode selective, in order that different modes in the same waveguide system may be handled and studied separately. The frequency band around 9375 mc is being used. The two modes are propagated in waveguide with 0.4" x 1.6" inside dimensions and coupled to the standard 0.4" x 0.9" waveguide where the  $TE_{10}$  mode is excited.

Apertures in the broad face of the waveguide which are relatively small with respect to a wavelength may be considered as coupling to both the electric and magnetic fields in the waveguide. The most convenient way to obtain mode selection is to use narrow slots, which minimize electric coupling. Each slot may then be made intrinsically mode selective by proper orientation so that no magnetic field of the undesired mode is parallel and adjacent to the slot.

#### Current Work

At present three designs are being studied experimentally and theoretically. For coupling to the  $TE_{20}$  mode, two longitudinal slots spaced a quarter of a guide wavelength longitudinally and centered on the wide main waveguide are used. These excite the  $TE_{10}$  mode at the edge of the auxiliary waveguide, which is standard X-band waveguide parallel to the main waveguide. The best design to couple to the  $TE_{10}$  mode, from the standpoint of mode selection, utilizes two transverse slots which are spaced a quarter of a wavelength and centered on the main waveguide. These excite the  $TE_{10}$  mode at the center of the auxiliary waveguide. The other design for coupling to the  $TE_{10}$  mode is similar to the "crossguide" type directional coupler, with longitudinal slots at positions where the  $TE_{20}$  longitudinal magnetic field is zero.

The limitation of mode selectivity is due to two separate factors. The first is the amount of desired magnetic coupling relative to the undesired electric coupling. The second is the amount of magnetic coupling to the desired mode relative to that of the undesired mode. It is a simple matter to decrease the electric coupling of the undesired mode. A centered series type slot is at a null of both the electric field and the transverse magnetic field of the  $TE_{20}$  mode and at the maximum of the transverse magnetic field of the  $TE_{10}$  mode. When a slot cannot be placed at a position of zero electric field of the undesired mode, the coupling of this field may be made negligible through the following. A slot couples more to a parallel magnetic field than an electric field and the attenuation through the slot due the finite thickness of the waveguide wall is much greater in the case of the electric coupling. A slot with a length .420", width .060", and thickness .030" couples about 40db more closely to the magnetic field and this can be easily increased by either making the slot narrower or thicker. The practical limitation of mode selectivity is the rejection of the magnetic coupling of the undesired mode. Since the transverse variations of the magnetic fields are sinusoidal, the slot need not be far from the null of the undesired field to couple appreciably. In the case of the centered longitudinal slot, which should not couple to the

TE<sub>10</sub> mode (like the slot for a sliding probe), if the slot is off center 0.002", the coupling is only 23 db below that which it would be if the slot were at the edge of the waveguide. The mode selection is greater than this by about 8 db because the longitudinal magnetic field is stronger in the TE<sub>20</sub> mode due to the proximity to cutoff. It can be seen from the foregoing discussion that mode selection can be as good as machining tolerances permit. The experimental model of this design has a mode selectivity of 35 db.

A relatively simple sliding load technique has been developed. It is expected that the experimental evaluation of the couplers under consideration and the correlation with theory will be completed during the next quarter.

H.A. Judy

9. PROPERTIES OF FERRITES IN  
BROADBAND MICROWAVE SYSTEMS  
(Contract N7-onr-29529)

Prof. D.J. Angelakos

Mr. D. Stinson

Summary of Previous Work

This study concerns the experimental evaluation of the components of the permeability tensor for various ferromagnetic materials with a view toward applying this knowledge to the development of broadband systems. The effect upon these materials of the variation of such parameters as the intensity of the magnetostatic field and the shape and the size of the ferromagnetic sample will be noted. An evaluation of techniques most probable of yielding significant results has been made. Three schemes were considered, and a technique for measuring the components of the permeability tensor utilizing a small coupling slot in two TE<sub>10</sub> guides is considered the most feasible.

Current Work

A microwave coupler consisting of two TE<sub>10</sub> guides and a narrow rectangular slot has been built. The narrow slot is located longitudinally in the main guide and transversely in the single ended auxiliary guide. In both cases the slots are centered in the broad faces of the guides. It is intended that small samples of various ferrites will be inserted in the aperture of the slot. Due to the location of the slot in the main guide, no energy should couple to the auxiliary guide unless a magnetostatic field is applied normal to the plane of the slot.

A magnet for obtaining this magnetostatic field is nearing completion. The magnet has been designed to obtain a magnetostatic field in the air gap of 10,000 oersteds for a 3 cm gap. This should be sufficient to cover all phenomena of interest in ferrites at X band and should also be sufficient to cover the most pertinent phenomena up to K band frequencies.

It is expected that experimental verification of this slot technique for measuring the tensor permeability of ferrites will occur shortly. If the method is found feasible, other schemes employing slot coupling will be investigated.

D. Stinson

## 10. SYNTHESIS OF BROADBAND MATCHING NETWORKS

(University Sponsored Research)

Prof. G.L. Matthaei

Work is continuing on extending Fano's method for synthesis of lossless broadband matching networks.<sup>1</sup> The objectives of the present phase of the work are:

1. To obtain a computationally easy method for determining the optimum design parameters for the cases where Fano's method requires the use of all-pass sections with coupled coils in the circuit in order to obtain the necessary degrees of freedom.
2. To search for a method for finding circuit element values, which will be general in its application, yet as computationally simple as possible.
3. To show how this method can be applied to more varied types of band-pass matching problems.

A computationally simple method has been found for carrying out the first objective for cases such as the low-pass matching problem presented in Appendix III of Fano's paper. The parameters chosen by Fano for this design were found to be not quite the optimum ones but close to optimum. By use of changes in variables which eliminate all hyperbolic functions, and also by use of some plotted curves, the optimum values of the design parameters for such cases can be computed without difficulty. Work will be done in the future to adapt this computational procedure for use in band-pass designs, also.

Progress has been made toward achieving the second objective. This work has been based on a generalized Cauer continued-fraction method of design such as was described in the report Some Techniques for Network Synthesis.<sup>2</sup> Techniques have been organized for making continued-fraction expansions for obtaining the element values for the simple ladder parts of the network as well as for the more complicated parts which arise when an extra all-pass structure is introduced. This continued-fraction method is based mainly on repetition of long division, and some degeneration of accuracy results as one gets towards the end of the

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1. Fano, R.M., "Theoretical Limitations on the Broadband Matching of Arbitrary Impedances", Journal of the Franklin Institute, Vol. 249, Jan. and Feb., 1950.
  2. Matthaei, G.L., Some Techniques for Network Synthesis, Electronics Research Laboratory; (Institute of Engineering Research, Series 60, Issue 103); University of California, 1953.



expansion. To reduce this to a minimum, first a detailed study was made of the general relations between the input impedances at opposite ends of the resistively terminated network. Then from this knowledge it was possible to improve the accuracy of the circuit element values obtained by making a continued fraction expansion of the impedance for one end and carrying this out until the elements from this end to the middle of the network are determined; and then starting from the impedance at the other end, the elements from that end to the middle were determined.

Work will soon begin on the third objective. In particular, methods will be studied for designing band-pass matching networks for load equivalent networks such as that treated by Fano (for the low-pass case only) in Appendix III of his paper, as well as other band-pass networks for the more commonly treated RLC series or shunt resonant-load equivalent circuits.

G.I. Matthaei

## II. CHARGE EXCHANGE ACCELERATOR

(University Sponsored Research)

Prof. J.R. Woodyard

Prof. D.H. Sloan

Mr. T.H. Koski

Mr. P.D. Compton\*

This is the second progress report on this project to appear here. The first report (Series 60, Issue No. 3, Jan. 15, 1954) gave a brief statement of previous work in which many things were included for completeness but were only briefly mentioned in order to avoid undue length. This report will give more details including progress of current work.

Since the last quarterly report period the principal effort has been put into preparing the one m.e.v. accelerator for testing with a beam. Because the arrangement of this accelerator is somewhat unusual, a diagram is shown in schematic form in Fig. 1. It will be noted that both ion source and target are at ground potential, as well as all auxiliary apparatus such as diffusion pump, hydrogen generator, and magnet power supply. Since the ion source differs from the usual type and has some advantages, its principle of operation will be described briefly. It may be characterized as a low-pressure cold-cathode discharge in parallel electric and magnetic fields. This type of gas conduction is also used in the cold-cathode high-voltage rectifier mentioned in the first report. As shown in Fig. 1., a hollow cylindrical anode is placed between two cathodes in an axial magnetic field. Any electron in the central region is trapped by the magnetic field in an electrostatic potential valley and oscillates back and forth many times until it makes a collision with a gas molecule, which results in a positive ion. The ion is immediately accelerated to one of the cathodes which it strikes, producing secondary electrons by collision. These secondary electrons are then trapped by the magnetic field as before, and the process repeats. Thus the action is cumulative and the current builds up to a steady value limited by the impedance of the power supply.

This ion source has run for long periods of time with little attention and is very stable and reproducible. The adjustments and dimensions are very un-critical. A few hundred volts and a few hundred gauss are typical. In fact,

\* On military leave.

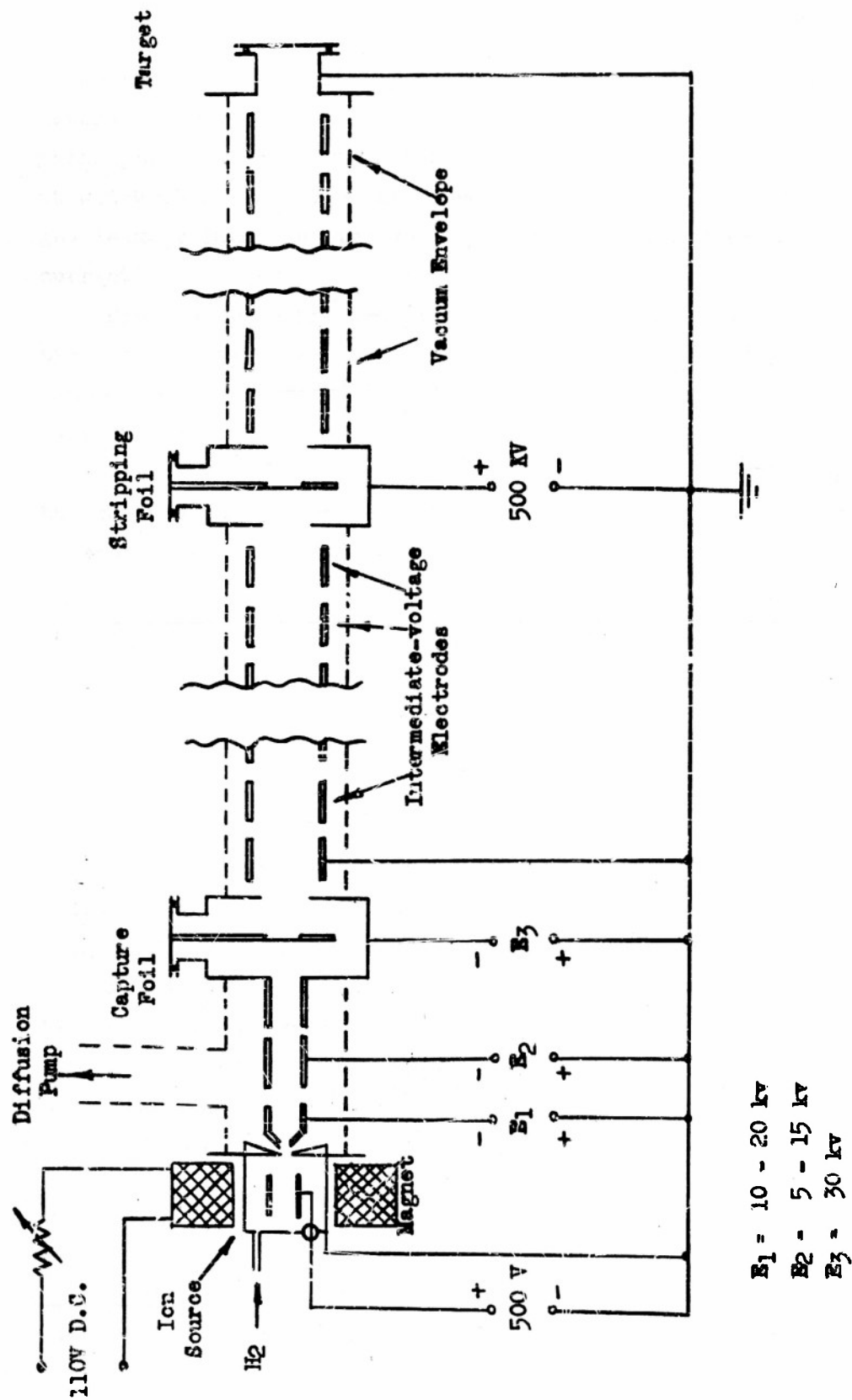


Fig. 1 Charge-Exchange Accelerator  
Schematic Diagram

the only special precaution required is to make the cathodes out of a good secondary-electron-emitting material. Ordinary soft aluminum is ideal. The natural film of oxide is a good secondary emitter and is very durable. The principal advantage over other types of ion sources is the low gas pressure at which it operates, roughly ten to one-hundred times lower. This reduces the gas leakage into the high-voltage parts of the system and allows larger beam currents.

Protons are extracted from the ion source through a small hole in one of the cathodes as shown in Fig. 1. The voltage  $E_1$  is adjustable to control the ion current. The voltage  $E_2$  is used as a focusing adjustment and is normally less than  $E_1$ . The energy with which the protons strike the capture foil is determined by  $E_3$  which should be about 30kv. The negative ions emerging from the capture foil are accelerated by the 500 kv. potential, reconverted to protons at the stripping foil, and accelerated again by the same potential, arriving at the target with 1 m.e.v. kinetic energy as explained in the first report.

The construction, assembly, and testing of the 500 kv. power supply has been completed. It consists of a 16-stage cascade rectifier using 16 type 5825 tubes which have a peak inverse rating of 60 kv. The circuit is the one first published by Greinacher<sup>(1)</sup> in 1921 and used by Cockroft and Walton in 1930. The rectifier is one foot by two feet, and is four feet high; it is insulated with lucite throughout. Each pair of tubes with associated equipment is assembled in one section fabricated of lucite. These sections are then stacked up to give whatever voltage is desired. The insulation is air since it is more convenient than oil in this voltage range unless there are unusual space restrictions. The sectionalized unit construction is used because of its ease of servicing. Perhaps the most unusual feature of this rectifier is the use of r-f filament heating with ferrite-core transformers for high-voltage d-c isolation. More details of the filament-heating system will be given later.

J.R. Woodyard

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1. Greinacher, H., Zeitschrift Fur Physik, Vol. 4, pp. 195-205, Jan. - Mar. 1921.

## 12. MAGNETIC RECORDING OF BINARY INFORMATION

University Sponsored Research

Prof. Albert S. Hoagland

The following summary indicates an area of research which has been recently completed. Present work is directed toward an evaluation of decoding techniques in reading and the use of magnetic switches for a magnetic drum memory.

The study is primarily concerned with the development of a useful mathematical description of the process of magnetic recording of binary information. More explicitly, those relations are developed which describe the transfer, by means of a suitable transducer, of binary information in the form of a current-time function to a surface spatial magnetization state and the reverse transfer to a voltage variation in time. The analytical work is supplemented by correlated experiments on a digital computer magnetic drum memory.

The general features of a binary magnetic memory system are covered. The analysis is limited to the longitudinal type of magnetic recording, and a macroscopic point of view is taken of magnetism. The physical questions which arise have a natural separation into two categories, time-dependent and geometrical. The former class is treated using linear theory. In the associated experimental work an anomaly was discovered in the behavior of one magnetic-head material. This results in an interesting phenomenon, referred to as the Spike Effect. The system geometry is introduced into the analysis in the form of an idealized model. By this means a significant quantity in binary magnetic storage, "writing definition", is simply related to the geometrical parameters and the E-H surface characteristic. Reading is similarly analyzed to obtain the functional form of the geometrical dependency of the output voltage upon the recorded magnetic surface state.

The over-all storage process is then qualitatively considered, reading being viewed from a low-pass filter transmission concept based upon the previous development. The bandwidth and gain of this wavelength filter are explicitly expressed in terms of the geometrical parameters, and the resolution on reading appears as less precise than the corresponding definition in writing. Drum modulation is shown to be dependent only upon the absolute variation in the separation distance.

A.S. Hoagland

### 13. ADMINISTRATION

In connection with work under Contract Number N7-onr-29529 Cmdr. G. Hunter, Lt. C.B. Sharpe and Mr. M.C. Long, all from Office of Naval Research, Washington, D.C. visited this Laboratory. Dr. G.F.W. Mulders and Mr. A.J. Morris, San Francisco Office of Naval Research, also visited here.



## 14. REPORTS

### 14.1 REPORTS ISSUED:

Under Contract Number N7-onr-29529

R.W. Bickmore, Part I - Flush-Mounted Omni-Directional Annular-Slot Antennas

G.L. Matthaei, Part II - Matching Networks for Annular Slot Antennas

Series No. 60, Issue No. 107

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D.J. Angelakos, Flush-Mounted Cardioid-Pattern Antennas

Series No. 60, Issue No. 108

F.D. Clapp, Semi-Flush-Mounted Cardioid-Pattern Antennas

Series No. 60, Issue No. 109

### 14.2 REPORTS UNDER PREPARATION:

Under Contract Number N7-onr-29529

R.W. Bickmore, Radiation Patterns Synthesis with Annular Apertures

J.J. Epis, Corner Reflector Standard Gain Antennas for 800 to 1600 Megacycles

A.M. Serang, An Analysis of a Side-Cutlet Tee for Impedance Measurements

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