PROPOSAL
for
Development of a
20 INCH CATHODE RAY TUBE

Prepared for

AIR FORCE CAMBRIDGE RESEARCH CENTER
Electronics Research Directorate
Bedford, Massachusetts

232-Q-133

MAY 1958

GENERAL ELECTRIC

PROPOSAL
for
Development of a

20 INCH CATHODE RAY TUBE

Prepared for

AIR FORCE CAMBRIDGE RESEARCH CENTER
Electronics Research Directorate
Bedford, Massachusetts

232-Q-133 MAY 1958

Prepared by

Cathode Ray Tube
Department
Syracuse, New York

Electronics Laboratory
Electronics Park
Syracuse, New York

GENERAL ELECTRIC COMPANY

CONTENTS

I. ABSTRACT

This proposal contains a description of the suggested work to be performed on the development of a 20 inch spherical cathode ray tube. The objective of the proposed investigation includes the development of the associated deflection yoke which will permit a 300 degree total angle of deflection.

In order to obtain electron beam focus over the entire raster it will be necessary to overcome the difficulties arising from deflection defocusing. A method of compensation, which has enjoyed a measure of success in the development of triple beam color tubes, will be extended to determine its applicability to the problem of single beam deflection defocusing in the case of very large deflections.

Screening, sealing, and exhaust will follow along lines within known laboratory art. A selection of method will be made designed to accomodate the particular geometry of the spherical bulb.

The intent of the suggested effort is to produce a useable tube which will establish the feasibility of approach to the fabrication of products of this type. Thus, the assembly of the electron gun will proceed by modification of standard parts, and no attempt will be made to incorporate optimum gun design for minimum dynamic focus power. Also it is not expected that the screening in the feasibility study be of the quality currently available in commercial television receivers. Since the bulb fabrication and screening techniques are those of the laboratory and have not been reduced to a manufacturing routine, a useful rather than perfect screen is expected.

II. STATEMENT OF THE PROBLEM

The overall objectives of the investigations proposed below are the development of a 20 inch spherical cathode ray tube and the associated deflection yoke which will permit a 300 degree total deflection angle with electron beam focus over the total raster.

Of the many problems to be encountered in the development of such a tube, it is anticipated that the major difficulty will arise in connection with deflection defocusing. A method of compensation for deflection defocusing will be described which has proved effective for deflections as large as 160 degrees. Primary emphasis of the proposed program will be directed toward extending this method and establishing its limit of usefulness for deflection angles approaching the desired 300 degrees.

To achieve the desired focus of the electron beam for large deflection angles it will be necessary to establish techniques for providing the following items each approximately designed for the intended application:

(a) A sinusoidal conductor distribution on a symmetrical magnetic core.

(b) A second order corrective winding.

(c) A variable focus electron gun.

(d) Power supplies for the above three items, including dynamic voltage sources with the proper time of application interdependence. (The magnitude of the intended effort, however, will not permit optimum design of the electron gun for minimum dynamic focus power.)

In parallel with the development of the deflection yoke and electron gun, work will proceed on the technology involved in the construction and screening of the spherical bulb.

III. TECHNICAL BACKGROUND

The development of the 20 inch spherical tube with 300 degree deflection, as proposed in this program, will require a major increase in the angle of deflection in comparison with any commercial cathode ray tube now in use. Fortunately, however, a previous effort, pursued at the General Electric Electronics Laboratory on the development of deflection yokes for three beam color television tubes, has established a basis for the extension of the angle of deflection to the desired large value.

In the past effort alluded to above, an extensive analysis was made of the deflection paths and the deflection distortions of a practical type of (ring) yoke. The results and complete details of the analysis are given in the General Electric Technical Information Series report R56ELS-113 entitled, Deflection Distortions of the Ring Yoke as they Relate to the Convergence Problem of Triple Beam Color Tubes, by R. B. Gethmann.

A similar analysis, in somewhat abbreviated form, is given in IRE Transactions on Broadcast and Television Receivers, February 1958, also by R. B. Gethmann. A copy of the abbreviated analysis is included as Appendix of this proposal.

In the analysis, associated Legendre polynomials of half-order (or ring functions) are used to describe the field of a ring yoke, the fringe fields of which are included in the calculations of the beam paths. When the conductor distribution function is separated into a principal field and third order component it is shown that the raster and convergence distortions usually encountered are obtained. As a result of the fringing of the principal field, the forces encountered by the electron beam vary with the position of the beam in the deflection space giving rise to deflection distortions.

Techniques resulting from the analysis allowed sharp focus to be achieved, using a second order winding, in a demountable experimental set-up for beam deflections up to 160 degrees.

In the triple beam color tube it was necessary that three beams be deflected, converged and focused simultaneously. This required a relatively larger diameter electron beam bundle to be handled efficiently by the deflection system. In the program proposed here, considerable advantage will be realized from the fact that only a single beam is used. Thus, the effective bundle diameter is decreased in comparison with the color tube case and a much larger total deflection angle will be permitted. Even then, however, special coil design and special dynamic voltages, which are applied to the electron gun, will be required to produce a focus of the electron beam over the total raster.

Further remarks on the method and the application of the results of the analysis to the 300 degree deflection problem are given in Section IV, Proposed Technical Approach.

IV. PROPOSED TECHNICAL APPROACH

A. DEFLECTION YOKE

1. General Considerations

The study of beam convergence problems of a ring deflection yoke has demonstrated the fact that convergence and focus problems are closely related. In considering problems of this type, it must be remembered that an electron beam cannot be represented simply as a single ray or a single electron whose trajectory has zero cross-sectional area. A proper representation of the beam must include those electrons which are some distance from the central ray.

The beam distortions are better visualized if the beam is assumed to consist of concentric cylinders of rays. A cross-section of such a beam entering a deflection field would consist of a group of concentric circles. After the beam is deflected, the circles may be distorted into odd shapes, ellipses, triangles, and curved loops. When the beam is small compared to the yoke diameter and the deflection angle is small, these distortions are also small and are usually negligible.

In the spherical tube proposed here, the focus problem must be considered for the case in which the beam occupies an appreciable portion of the yoke opening. Thus, a major difficulty will arise in connection with deflection defocusing.

2. The Yoke Construction

In a cathode ray tube, the maximum angle of magnetic deflection is usually encountered when the electron beam is deflected into the glass of the tube neck in the vicinity of the yoke. In order that the beam be deflected in any direction, the yoke must surround the beam and have two sets of orthogonal windings. This fact prevents the use of other non-symmetrical arrangements for permitting an increase of deflection angle. The deflection angle can be increased if the yoke is reduced in length. The shape and size of the end turns on the existing television type of yoke prevents its use for deflections beyond 160 degrees total angle.

The shortest possible deflection yoke would be the ring yoke shown in Figure 1. It consists of a donut shaped core of high permeability on which is wound the yoke winding in the manner shown. If the beam is shielded from the magnetic field of the yoke for a portion of its path of entry into the yoke field, the beam can be deflected through a very large angle since it can be wrapped around the deflection yoke core.

The definitions of the ring coordinates shown in Figure 1 are given below. Derivation of the scalar magnetic potential in terms of these coordinates is presented in the Appendix.

$$\eta = \log\left(\frac{\overline{AP}}{\overline{BP}}\right)$$

θ = the angle between $\overline{AP}$ and $\overline{BP}$

ϕ = the angle from the deflection plane of the principal field to an arbitrary plane.

ω = the angle from the horizontal plane to the deflection plane.

$$x = \frac{\sinh \eta}{\cosh \eta - \cos \theta} \cos \phi$$

$$y = \frac{\sinh \eta}{\cosh \eta - \cos \theta} \sin \phi$$

$$r = \frac{\sinh \eta}{\cosh \eta - \cos \theta} = \sqrt{x^2 + y^2}$$

$$z = \frac{\sin \theta}{\cosh \eta - \cos \theta}$$

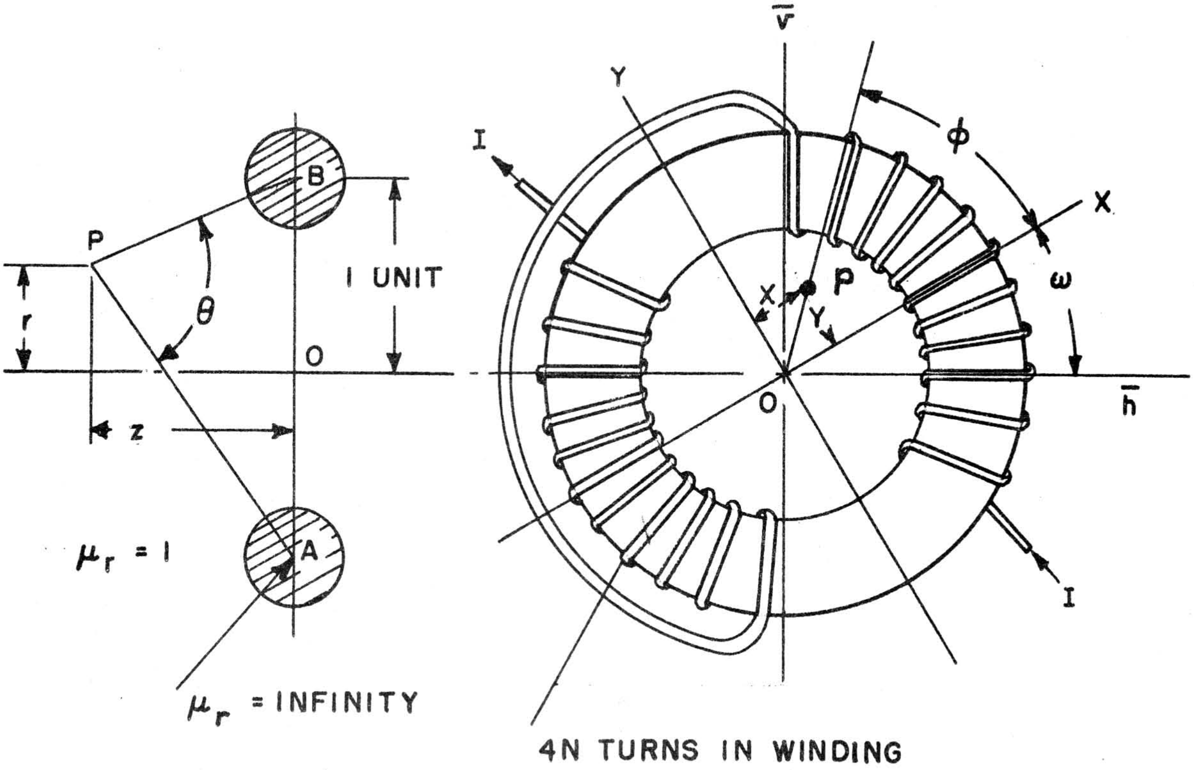


FIGURE 1

THE RING YOKE CORE AND ITS WINDING

By separating the winding distribution function into a Fourier series form, the first order term is found to be the most significant and provides the principal beam deflection.

When a ring yoke is made whose winding distribution function is simply this first order term, a very useful yoke is obtained. If the electron beam were to consist of a single ray directed along the yoke axis, this yoke would provide the 300° total deflection angle of interest. The beam, however, consists of large number of parallel rays which receive slightly different deflections because of their respective displacements from the central ray. This defocusing effect is most graphically depicted when the effects on those rays forming a circle of radius R prior to the entry of the beam into the deflecting field are considered.

The different deflections of para-axial rays are shown in Figure 2. Although the entrant beams were considered to be located on a circle of radius R, the final deflected pattern of this circle is seen to be elliptical. In this particular case, because of bulb shape, the maximum deflection angle is 110°; the deflection distortion problem is emphasized since the equivalent electron beam was one-half inch in diameter.

Fortunately, the smallest practical beam, about 1/16 inch in diameter, will be used in the proposed 300 degree tube; and, therefore, this effect will be reduced by a factor of 8.

It is natural to expect windings corresponding to other terms of the series, such as the third order term, to effect the beam distortions, as in fact they do. The third order term is useful in control of raster shape distortion and in convergence problems, but this term always introduces the triangular type of defocusing distortion shown in Figure 3.

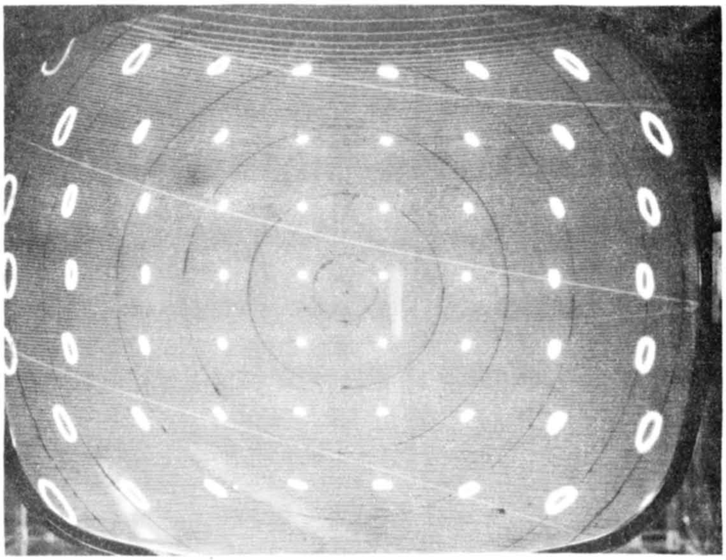


FIGURE 2

The deflection distortions of a cylindrical beam produced by the principal field of a ring yoke.

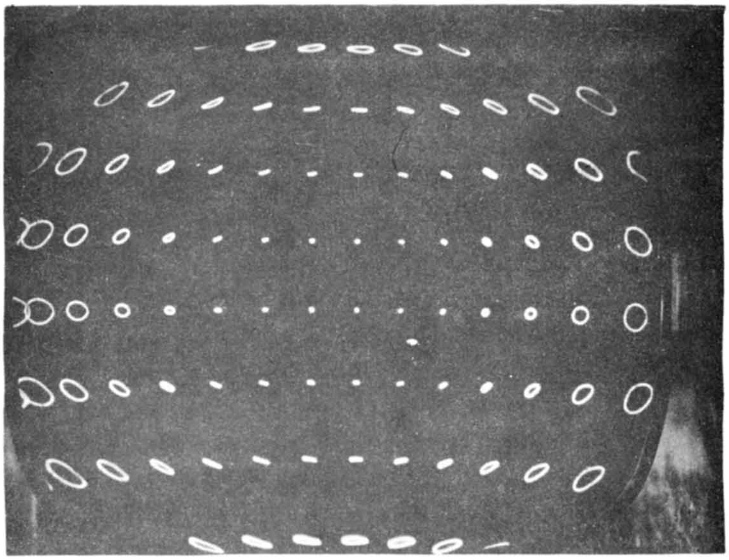


FIGURE 4

The pattern of Figure 2 corrected in the horizontal direction by a second order field.

Although the third order term can be used to improve the focus for the 45 degrees case of Figure 3, it also causes additional stretching of the beam elsewhere, particularly to 0 and 90 degrees. The third order winding is desirable since it can utilize the same current which energizes the first order winding. All higher order windings cause additional focal distortions and, therefore, are not desirable.

There remains the second order winding which varies as $\sin 2\phi$ or $\cos 2\phi$. Such a winding does not cause deflection of itself, but it does cause an elliptical type of distortion which, when correctly oriented, can be used to reduce the eccentricity of ellipses to 1. The resulting circular distortion is equivalent to a beam defocus. Thus, refocusing can reduce the circle to a point.

The photograph in Figure 4 shows the reduction of the ellipses on the horizontal line by such a field. The principal horizontal deflection current is a linear saw-tooth at 15,750 cps. The current in the second order winding is quadratic at the same frequency. This relationship is described by the equations:

$$\left.\begin{array}{lll} \text{Principal Winding} & i_1 & = I_1 t \\ \text{Second Order} & i_2 & = I_2 t^2 \end{array}\right\} \quad -T/2 \leq t \leq T/2$$

where T is the period of the saw-tooth wave.

With this technique , sharp focus was achieved in a demountable set up for a 160 degree beam deflection. Since the deflection distortion increases with at least the square of the deflection angle, a strong correcting field will be required for the 300 degree deflection.

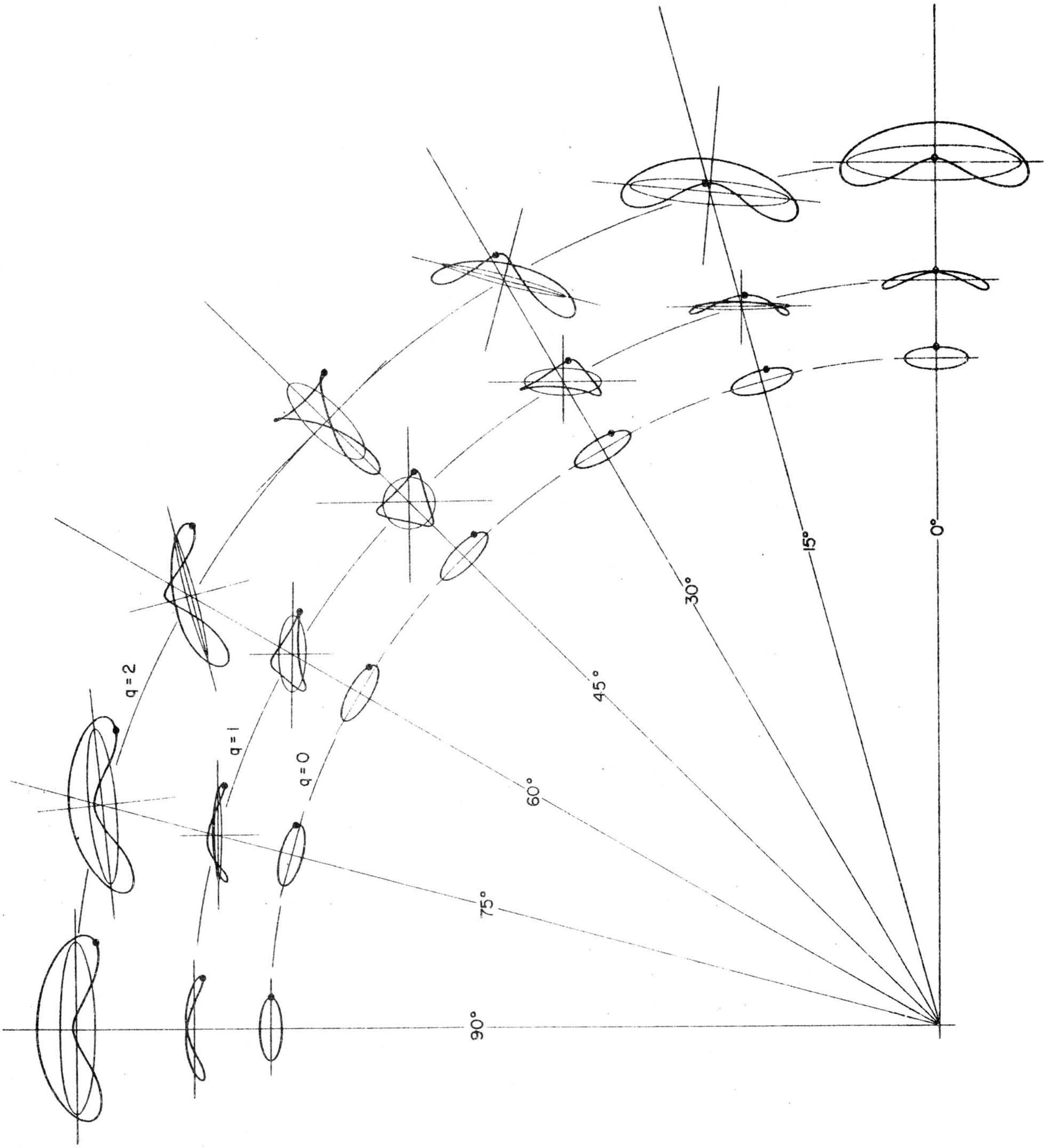


FIGURE 3

The effects on the distortive ellipses of Figure 2 ($q = 0$) produced by the addition of a third order field of strength q.

Figure 5 is a plot of the beam trajectory through the ring yoke field for 330 degree deflection. The figure shows that the beam comes near the ring core and near the turns producing the field. (In Figure 5, the horizontal and vertical coordinates are not pertinent to the discussion given here. The curves surrounding the ring core are lines of constant magnetic flux density.)

3. Further Comments

It was pointed out above that a technique is available for dealing with the problems of deflection defocusing. This method of compensation has proved effective for a 160 degree maximum deflection. Thus, a major portion of the effort will be directed toward establishing the usefulness of the approach for deflection angles as large as 300 degrees.

To achieve focus of an electron beam that is deflected through a large angle, it will be necessary to:

(a) provide a sinusoidal conductor distribution on a symmetrical magnetic core

(b) provide a second order corrective winding driven from a separate source

(c) provide a variable focus electron gun

(d) energize the above three elements with the required time related energy sources.

4. Yoke Cooling

Since the large maximum deflection angle requires that the yoke be placed near the center of the spherical bulb, there will be no possibility for the yoke to receive normal convection cooling. This condition, plus the fact that the large deflection angles will require

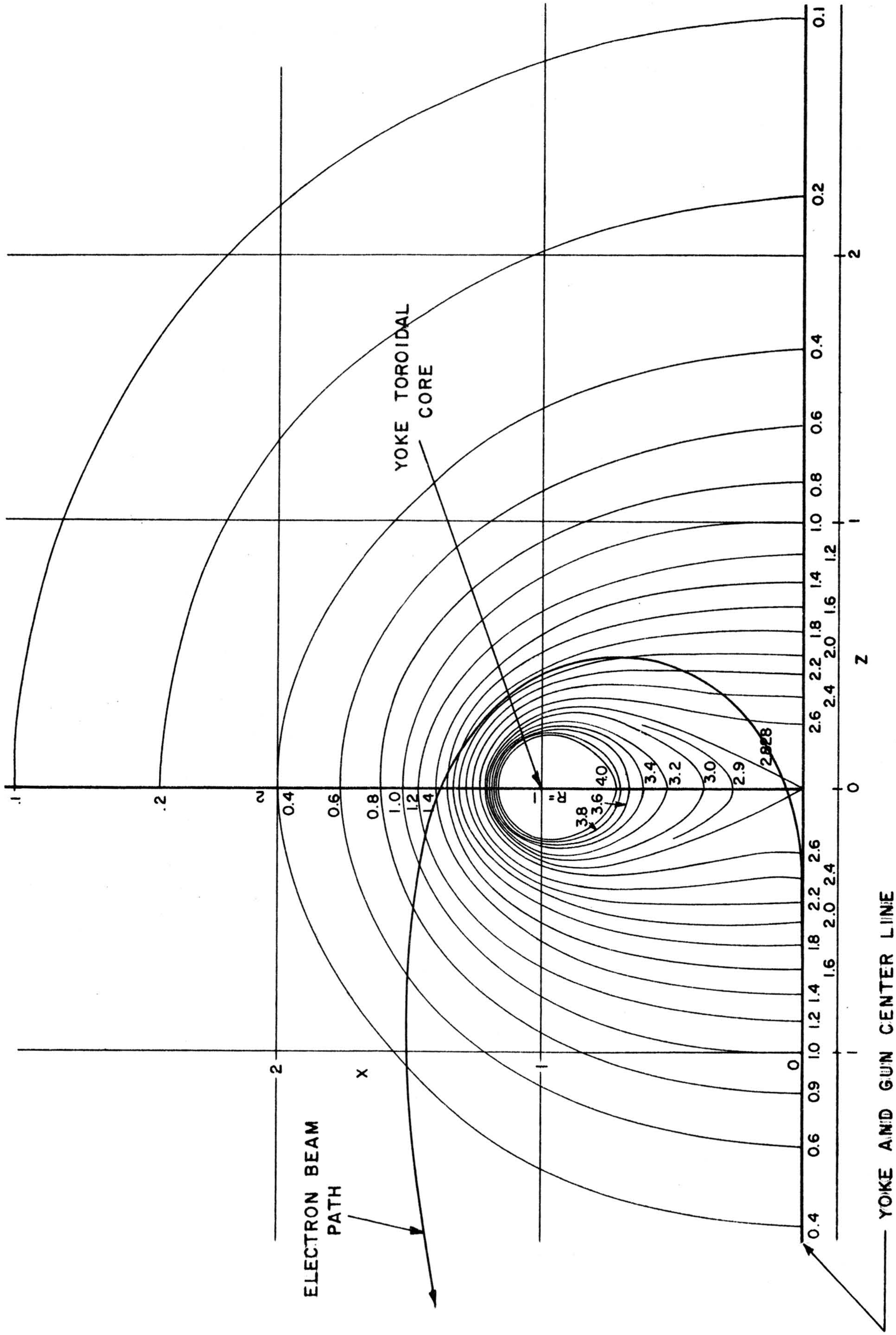


FIGURE 5

A typical electron beam trajectory at 300 degrees maximum deflection angle through the field of the ring yoke.

relatively larger deflection power than normal, make it mandatory that some type of cooling be supplied. At high sweep speeds, eddy current and hysteresis losses will contribute additional heating. The necessary cooling probably can be provided readily by a fan.

B. SCREENING

In parallel with the development of the deflection yoke and electron gun, work will proceed on the technology involved in the construction and screening of the spherical bulb.

Two methods of screening will be evaluated within the scope of the suggested effort of the program. One approach for coating phosphor on the inside of the spherical bulb is that of vaporizing phosphoric acid inside and dusting the phosphor on in dry powder form. The technique is not new and has been used for a considerable time at General Electric to coat the inside of the cathode ray tubes whose inside surfaces are too complicated to screen by flow coating or settling.

The Gas Generator apparatus is shown in Figure 6. Referring to Figure 6, the acid is dropped, drop by drop, on the hot filament causing a dense cloud of smoke. A light draught of oxygen is introduced and blows the smoke into a clean bulb through the hose. The bulb at this point appears as if filled with tobacco smoke. The acid smoke is now flushed from the system and the condensed acid is dried. Dry phosphor powder is then shaken into the bulb in excess, rolled about until satisfactory coverage is achieved, and the excess poured out. The process may be repeated to improve distribution or eliminate holes.

The above method is straightforward and should prove to be a successful approach. However, an alternative method of screening which is particularly adapted to processing on irregular surfaces was used at

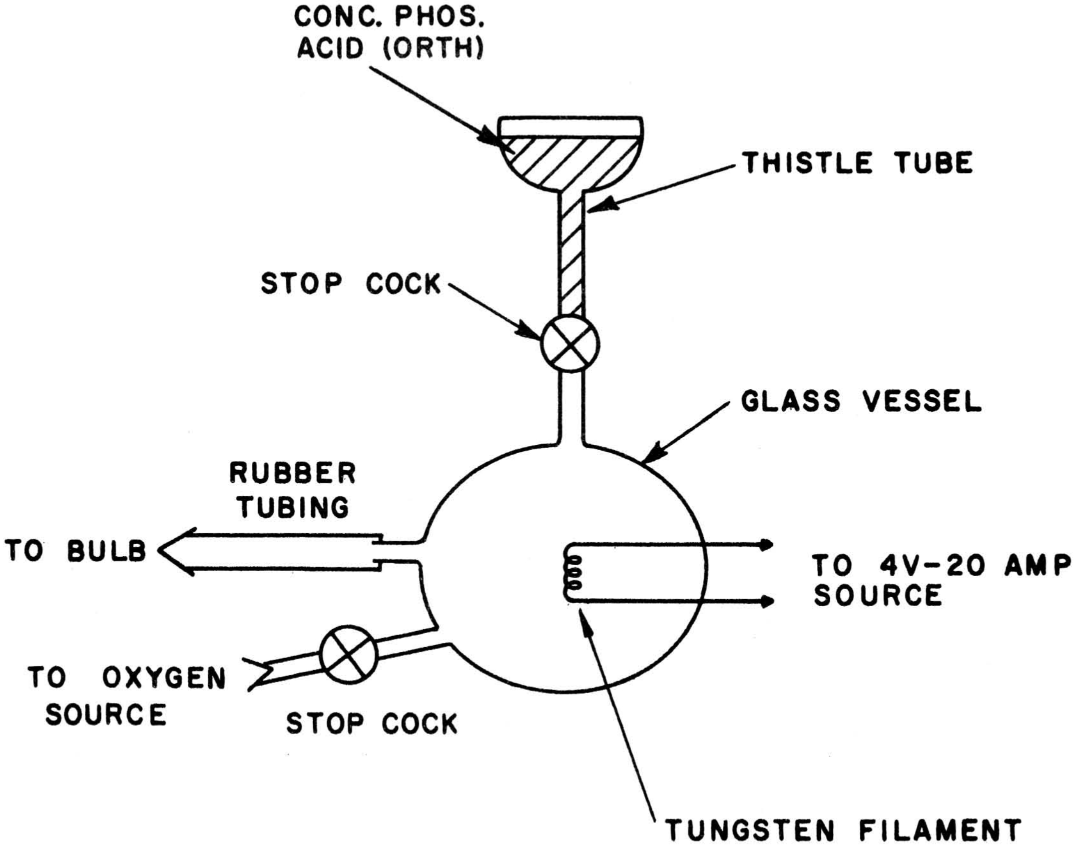


FIGURE 6

GAS GENERATOR SYSTEM

General Electric in laying down complex screens for tri-color television tubes. In this method, a polymerizable material, treated in such a way to make it photosensitive to ultraviolet light, is sprayed or flow coated on the surface to be screened. This material then acts as the binder for the phosphor in adhering to the glass. The phosphor may be applied in a slurry with the binder.

The particular technique chosen for screening will depend upon the difficulties encountered in connection with the geometry of the spherical bulb.

C. PROPOSED GENERAL DESIGN

When the design of the electron gun, shield, and the glass in the neighborhood of the deflection yoke are finalized, a completed 20-inch tube will be made. The proposed general design of the tube is shown in Figure 7.

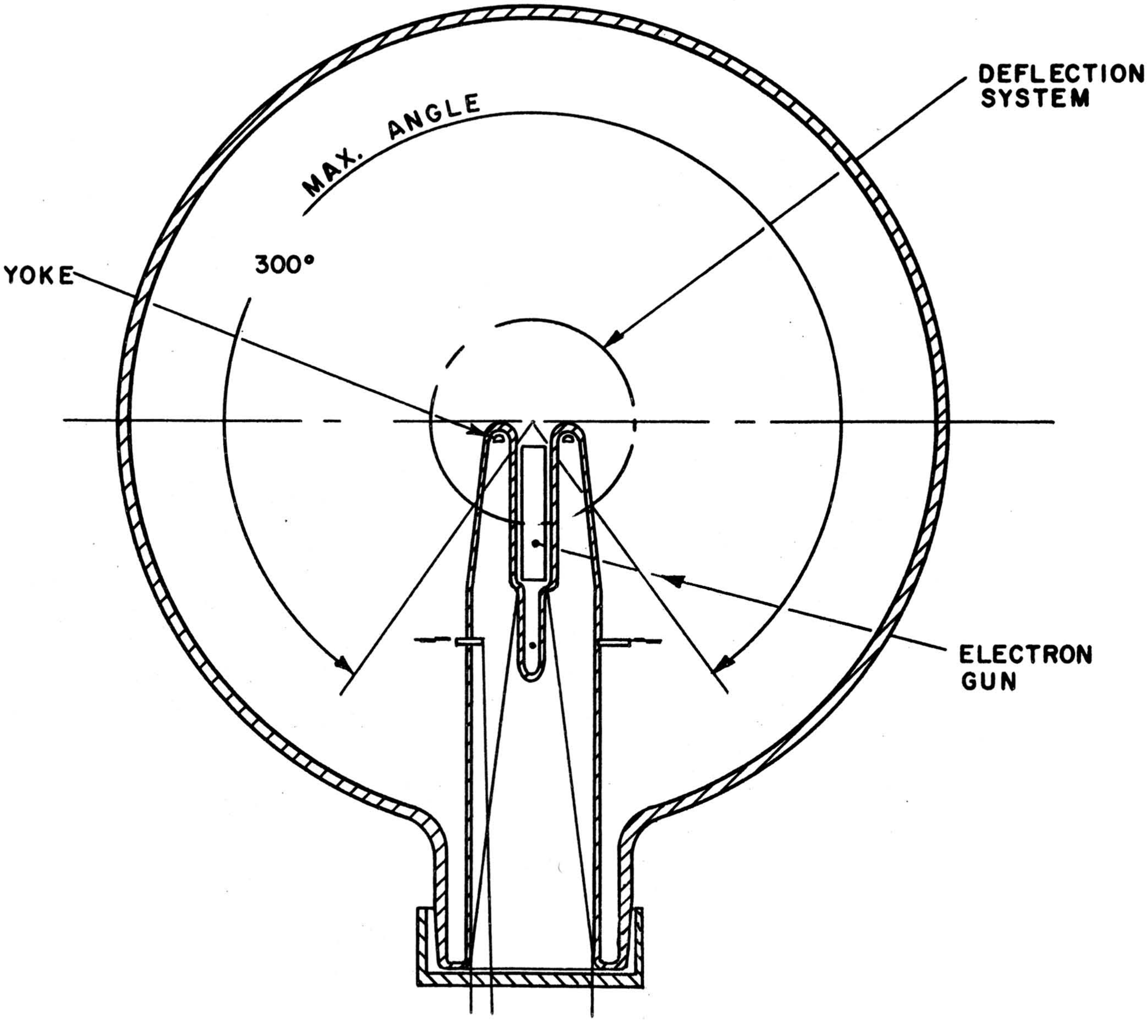


FIGURE 7

PROPOSED WIDE ANGLE DEFLECTION TUBE

V. TECHNICAL PROGRAM OUTLINE

As a consequence of, and in accordance with, the technical approaches described in Section IV, the best efforts of the General Electric Company will be applied to the following suggested scope of work which will serve as the basis for the proposed tube development. It is anticipated that effort will be applied for a period of twelve months in pursuing the objectives of the program.

A. ELECTRON GUN AND DEFLECTION YOKE

1.) The deflection yoke will be constructed in accordance with the approach described in Section IV. Very careful yoke construction will be necessary to provide the special field required. To aid in the design and construction of the deflection yoke and to study wide angle defocusing, a simple glass tube will be bent the desired amount and provided with a screen and an electron gun. At least four different deflection yokes must be constructed to determine the best method for construction of the precision yoke. The construction of tools to hold the conductors in the proper position will be necessary. Sinusoidal sweeps will be used to test the yoke.

2.) A special electrostatic gun will be selected or constructed to provide effective focus control on the electron beam for the dynamic focus function. It is anticipated that at least three different guns will have to be tried in order to obtain the proper internal shielding of the electron beam from the deflection yoke field.

3.) The proposed gun for the tube will be assembled from modifications of standard parts used in electrostatic guns. It is anticipated that the gun structure be such to show feasibility of approach but not designed for minimum dynamic focus power. After feasibility is shown, minimum power gun design would be an ideal extension of the effort and would warrant the required tooling costs if broad application is found for display of the type supplied by the spherical tube.

B. SCREENING, SEALING, AND EXHAUST

1.) The two methods of screening described in Section IV will be evaluated to choose the one more satisfactory for the intended purpose. The objective will be to produce the best phosphor screen commensurate with the level of effort of the program. As a result, uniformity over the entire bulb will be attained only to the degree necessary to show feasibility.

2.) Since the bulb is round and difficult to hold, a vacuum chuck will be designed and installed on a glass lathe. A special tailstock fixture will be designed to clamp the gun, yoke assembly in alignment. A skilled glass blower will join the two assemblies. A considerable amount of experimentation will be required to develop an annealing schedule to render the seal strain free and strong without damaging the screen or yoke and gun assembly.

3.) The Cathode Ray Tube Development Laboratory bench exhaust ovens will accomodate the size of bulb contemplated. Studies will be made to check the structural strength of the bulb with temperature. Cathode activation schedules will be developed. Since the bulb is new to the display tube art, a low pressure chamber will be used to test the complete structure to insure a safe mechanical design.

It is anticipated that mechanical difficulties in constructing the final prototype will involve a considerable amount of jig and fixture design. Special holders and handling devices will be installed in all the necessary laboratory equipment.

C. FINAL ASSEMBLY AND SHIPMENT

1.) Upon finalization of design of the electron gun, shield, deflection system, and the glass in the neighborhood of the yoke, a completed tube will be assembled.

2.) The completed tube will be tested with yoke, and shipment made of the final product.

D. REPORTS

Reports will be submitted as required and will include the following:

1.) monthly status reports

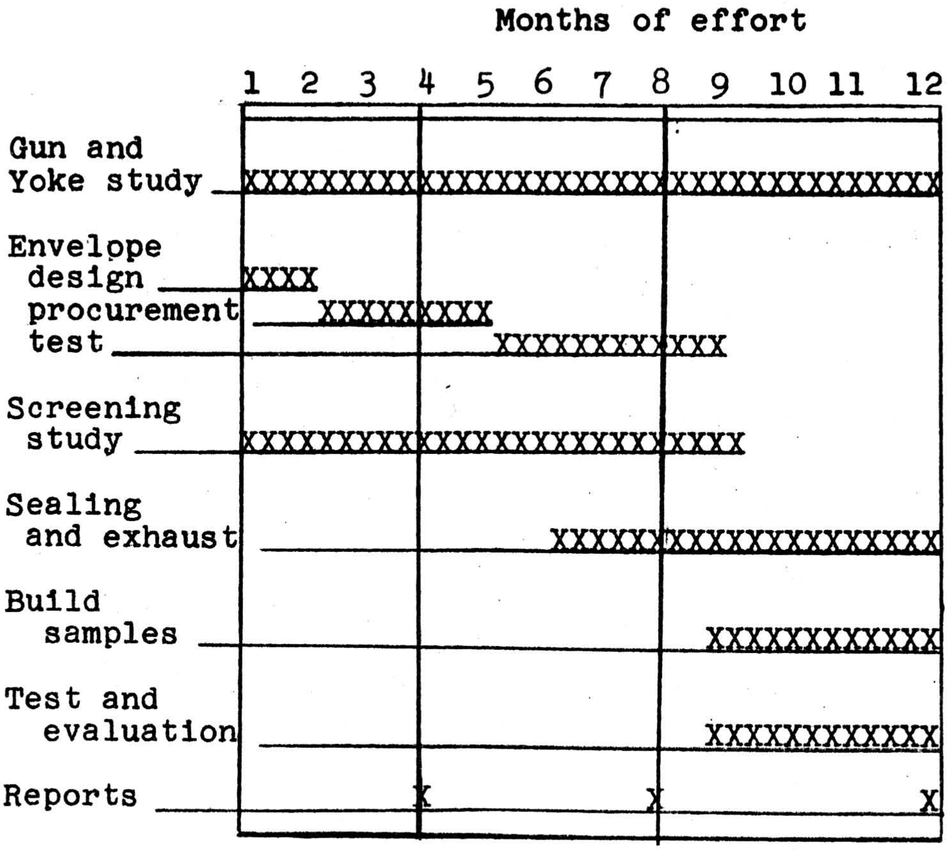
2.) quarterly technical reports

3.) a final comprehensive technical report.

E. PROPOSED TIME SCHEDULE

The objectives of the proposed program will be pursued for a period of twelve months. Over this period, the relative timing of the various aspects of the development will be in accordance with the work schedule chart given below:

WORK SCHEDULE



VI. PERSONNEL

The following key technical personnel will be assigned to pursue the objectives of the proposed program.

H. J. Evans

Mr. Evans received his MS in Physics from the University of Missouri in 1938. From 1939 to 1941, he was a graduate student at the University of Michigan.

From 1941 to 1943, Mr. Evans was a physicist with the Naval Ordnance Laboratory in Washington, D. C., where he did theoretical and developmental work on anti-magnetic mine devices.

From 1943 to 1944, Mr. Evans was an Assistant Professor of Physics at the University of Missouri. In addition to his teaching responsibilities, he worked on the development of a mass spectrometer and applications of the electron microscope. From 1944 to 1951, he was a physicist with the Radio Corporation of America. During this period he was engaged in work in dielectric and magnetic materials, and on various design problems involving cathode ray, power, and microwave tubes.

In 1951, he joined the Electronics Laboratory of General Electric, and since then has been involved in work on electron tubes, photoconductor and electroluminescent phosphor materials and devices, and solid state amplifying devices. Mr. Evans is currently Manager of the Thermionics component of the Electronics Laboratory.

F. F. Doggett

Mr. Doggett received his BS degree in Mechanical Engineering at Pennsylvania State College in 1942. From 1943 to 1946, he served as a commissioned officer in the U. S. Navy on engineering duty.

From 1946 to 1949, he was employed as a research and development engineer at the Baldwin Locomotive Works.

In 1952, Mr. Doggett received his BS in Electrical Engineering at Cornell University. From 1952 to the present, he has been employed as a design engineer in the Cathode Ray Tube Department of the General Electric Company. During this time he has designed tubes and electron guns for both entertainment and industrial applications.

R. B. Gethmann

Mr. Gethmann received his BSEE from the University of Michigan in 1940. In 1957, he was awarded an MSEE from Syracuse University. Mr. Gethmann joined the General Electric Company in 1940. During the war years, he was involved with several projects, the principal one being the design and development of an IFF system and equipment.

From 1945 to 1953, he was involved in a number of developments in commercial television. Some of these were: Advanced development of deflection yokes and sweep transformers, and the production problems concerned therewith; development of a toroidal deflection yoke; development of a technique for tuning sweep transformers by adjustment of leakage reactance; a unique design of permanent magnet and electron magnet for the focusing of cathode ray tubes; design of a cathode ray with internal permanent magnets which combined both focus and ion trap functions.

Mr. Gethmann came to the Electronics Laboratory in 1953. His initial work here was concerned with color television and included: the electron gun design of the vertical line structure tube; design of a workable, 3 beam electron gun and an electrostatic and magnetic convergence system. During this period he was also concerned with the design of a 120 degree deflection angle, color tube.

Since 1957, he has worked on an electroluminescent panel showing the speed with which the panel could be excited by the optics of a cathode ray tube.

Mr. Gethmann is the author of several papers and the holder of several patents in the field of electron optics.

P. H. Gleichauf

Dr. Gleichauf received his Ph.D. in Physics from Masaryk University, Brno, Czechoslovakia in 1939.

From 1939 to 1940, he was with the "Electrum" radio factory in Czechoslovakia in the development laboratory and in manufacturing. In 1945, [after the war] he was with "Always", manufacturer of radio components in Czechoslovakia, where he was in charge of development of paper and mica condensers. From 1946 until 1952, he was with the Westinghouse Research Laboratories in Pittsburgh, Pa., where he conducted basic research on high voltage breakdown over insulators. Other work carried out was on lightning arrestors using different gases and gas mixtures.

Since 1952, Dr. Gleichauf has been with the General Electric Company at the Electronics Laboratory. Much of his work has been in the fields of electron optics, principally in gun design, and electroluminescent displays.

Dr. Gleichauf is the author of several papers covering the field of high vacuum discharges and electron optics.

W. D. Rublack

Mr. Rublack received his BS degree in Chemistry in 1949 and his MS in Physical Chemistry from Queen's University, Canada in 1950. He instructed in Physical Chemistry for two years at the Royal Military College.

Mr. Rublack joined the RCA Monochrome Tube Division at Marion, Indiana, and worked there two years. In January 1954, he joined the Cathode Ray Tube Department of the General Electric Company as a development engineer on chemical processes.

Mr. Rublack has had wide experience in tube chemical processing including screens, binders, phosphor and metals evaporation.

VII. FACILITIES

A. THE ELECTRONICS LABORATORY

The Electronics Laboratory is an applied research and advance development organization. Its charter covers work in this entire field of electronics; its activity lies between that of fundamental research as conducted by the Company's Research Laboratory and that of product engineering within the Product Departments.

The principal objective of the Electronics Laboratory is to provide scientific and technical support to the Product Departments of the Defense Electronics Division.

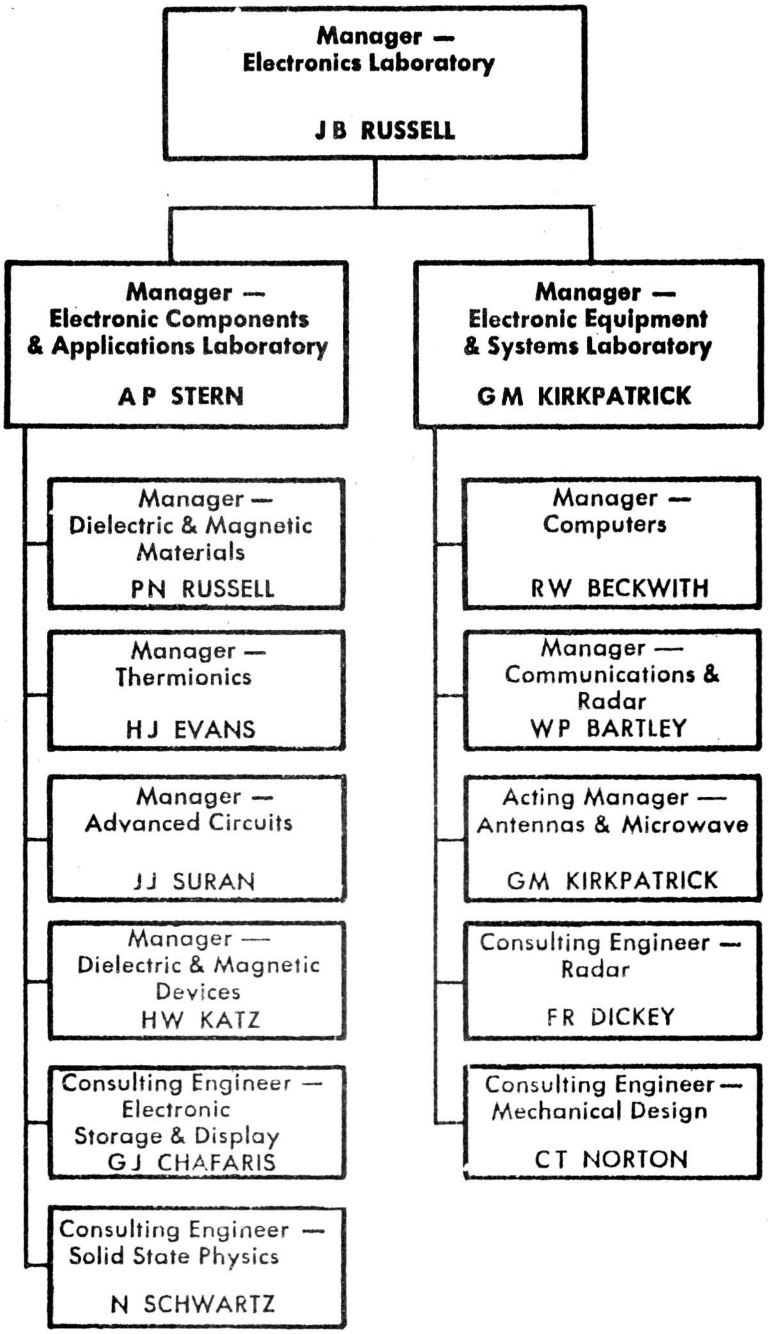
The Electronics Laboratory is located at Electronics Park, Syracuse, New York, and is an organizational component of the Defense Planning and Development Operation of the General Electric Company's Defense Electronics Division. Dr. John B. Russell, Manager-Electronics Laboratory, reports to General Haywood S. Hansell [USAF ret.] Manager-Defense Planning and Development Operation.

The Laboratory is organized and staffed to work on electronic systems, circuits, techniques, components, materials, and devices. Special competence is found here in microwave, communications, radar, data handling, information displays, advanced circuit techniques, solid state materials and devices, energy sources, and thermionics as well as in other areas of electronics. Laboratory personnel have educational backgrounds in electrical and mechanical engineering, mathematics, solid state physics, physics, chemistry, metallurgy, and ceramics.

The technical staff is complemented by a group of experienced supporting and service personnel, and by complete modern facilities including: drafting, reproduction, documents and general reference libraries, and model shop. Skillful artisans, specialists and technicians carry on these supporting functions so essential to Laboratory operation. Together with the professionals they form a complete and versatile team for applied research and advance development in electronics.

The engineers and scientists of the Electronics Laboratory have access to all other specially trained personnel within the General Electric Company, as well as to the facilities of other General Electric organizational components. Therefore, the Laboratory is in a good position to make use of the scientific and technical background of the General Electric Company.

The Laboratory is composed of two complementary operations: Electronic Components and Applications Laboratory and Electronic Equipment and Systems Laboratory. The following organizational chart indicates the sub-division of these Laboratories in technical areas.


Manager — Electronics Laboratory J B RUSSELL
Manager — Electronic Components & Applications Laboratory A P STERN
Manager — Electronic Equipment & Systems Laboratory G M KIRKPATRICK
Manager — Dielectric & Magnetic Materials PN RUSSELL
Manager — Thermionics HJ EVANS
Manager — Advanced Circuits JJ SURAN
Manager — Dielectric & Magnetic Devices HW KATZ
Consulting Engineer — Electronic Storage & Display GJ CHAFARIS
Consulting Engineer — Solid State Physics N SCHWARTZ
Manager — Computers RW BECKWITH
Manager — Communications & Radar WP BARTLEY
Acting Manager — Antennas & Microwave GM KIRKPATRICK
Consulting Engineer — Radar FR DICKEY
Consulting Engineer — Mechanical Design CT NORTON

B. THERMIONICS GROUP

The work of this group is directed toward applied research and development of dynamic devices and associated materials. Device and material development are intimately associated because processing of the components frequently alters the dynamic characteristics of the materials. Frequently, these devices incorporate active solid state elements with electron beams in vacuum closures. The electron beam may serve as a switch, as an energy transducer, as a probe, or as a means of measurement.

In this area work is progressing in the following fields:

Photoconductors and Electroluminescent Phosphors Material Development programs are in process which are intimately connected with device developments for infrared detectors and electroluminescent display panels. The objectives of development work in this field are: [a] to improve the phototconductor properties of speed, quenching and sensitivity, [b] to optimize the properties of photoconductors in specific applications, and [c] to develop materials and techniques for electroluminescent display panels and electro-optical devices.

The Electroluminescent Display Devices program is primarily concerned with the development of large visual display panels which may be used as light amplifiers or as display panels with storage. Included in this work are display panels with electrical and optical techniques for supplying input information. Applications include: [a] storage light amplifiers for military use; [b] half-tone amplifiers; [c] facsimile devices; [d] projection displays, and [e] flat displays with electrical inputs.

Infrared Detectors work is devoted to the development of both quantum and thermal infrared detectors. The program includes both individual and camera-type detectors. A new vidicon type infrared camera tube with "bipole" target, invented at the Laboratory, modifies the requirement that the infrared sensitive target material must have high resistance; thus, infrared sensitive material, heretofore not applicable, may be used for camera devices.

The Solid State Amplifier program is devoted to amplifiers of the maser type and non-linear ferromagnetic type. This program is directed towards obtaining low noise amplifiers and mixers for use in military systems.

The Electron Optics programs on display devices and infrared detectors require special electron guns and deflection systems. Work in this field is directed towards supplying these needs and other special electron optical assemblies which require electron beams.

As a result of the current development programs, techniques have been acquired in: [a] special structures and assemblies for solid state devices; [b] specialized applications of high purity materials with specific additives for the development of dynamic components, and [c] highly specialized chemistry and materials technology which require unique processing.

C. INDUSTRIAL AND MILITARY CATHODE RAY TUBE SECTION

The Industrial and Military Cathode Ray Tube Section of the General Electric Company maintains a complete tube laboratory at Electronics Park, Syracuse, New York.

In this laboratory, equipment to assemble, process, and test cathode ray tubes is available. As a result, no extensive equipment modifications will be required to perform the necessary gun seal, exhaust, and screening operations anticipated under the proposed program. Also, trained laboratory technicians are available to perform the glass, chemical processing, and exhaust operations.

Deflection Distortions Contributed by the Principal Field of a Ring Deflection Yoke

by

Richard B. Gethmann

Thermionics Sub-Section
Electronics Laboratory
General Electric Company
Syracuse, New York

In this paper equations for the magnetic field of the ring yoke are obtained as solutions of the Laplace differential equation. The paths of axial and para-axial rays through this field are then calculated for the principal field of the ring yoke. Three types of distortions are shown to be contributed by this field.

A special 110 degree tube having a very thin neck in the vicinity of the deflection yoke which permits translation of the deflection yoke with respect to the electron beam was used to obtain experimental verification of the computed distortions.

Introduction

To achieve a more detailed understanding of the factors contributing to deflective distortions, an analysis was made of a simple ring deflection yoke. This type of yoke was selected because its magnetic field can be described by an infinite series whose first term is of principal significance. A practical ring yoke can be wound (with a simple sinusoidal winding distribution) which will establish a magnetic field described completely by this first term. Additional windings can also be added which produce fields corresponding to any of the subsequent terms of the series. This permits a detailed study of the effects of the winding distribution function upon the deflection distortions. Fortunately, these higher order fields are all zero on the yoke axis and are always negligible in the study of small angle deflections.

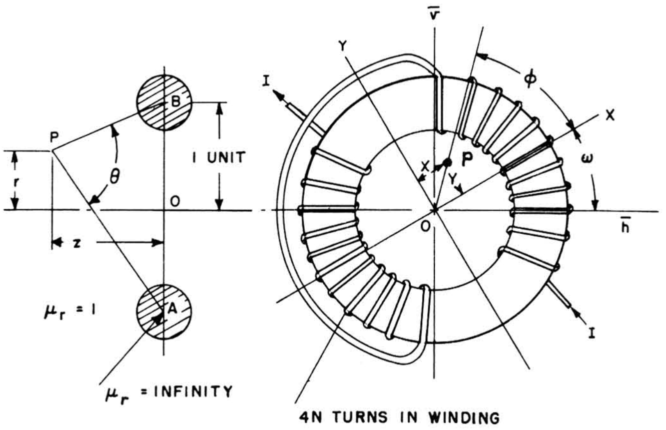
The determination of the deflection distortions of the principal first-order field is, therefore, of major importance.

A brief review of the solution Laplace differential equation for the field of the ring yoke and the subsequent application of a selective yoke geometry as the boundary conditions which lead to the simple field equation is given as a preliminary to the trajectory calculations.

Calculation of the Field of the Ring Yoke

Magnetic deflection yokes used with television picture tubes are energized by time-varying sawtooth-current generators -- the vertical windings at a 60-cycle rate, the horizontal at a 15,750-cycle rate. Although a perfect sawtooth requires an infinite number of harmonics, those above 500,000 cycles are not important. Because of the low impedance of the deflection yoke, the terms of Maxwell's equations that pertain to time variations may be neglected and the equations reduce to the Laplace differential equation. Solutions of this equation may be obtained in terms of any orthogonal set of functions. In general the solution will consist of an infinite sum of terms of the orthogonal set. This sum will converge most rapidly when a coordinate system is selected that roughly fits the boundaries. It would not be easy to fit the ring yoke boundary conditions into any of the usual coordinate systems, cartesian, cylindrical, or spherical.

If the coordinates shown in Fig. 1 are selected, an orthogonal set of functions known as ring functions is obtained. It provides a solution of the Laplace equations through the use of the separation of variables technique.



Ring Coordinants

$$\eta = \log\left(\frac{\overline{AP}}{\overline{BP}}\right)$$

π = the angle between $\overline{AP}$ and $\overline{BP}$

ϕ = the angle from the deflection plane of the principal field to the horizontal plane.

ω = the angle from the horizontal plane to the deflection plane.

$$x = \frac{\sinh\eta}{\cosh\eta - \cos\theta}\cos\phi$$

$$y = \frac{\sinh\eta}{\cosh\eta - \cos\theta}\cos\phi$$

$$r = \frac{\sinh\eta}{\cosh\eta - \cos\theta} = \sqrt{x^2 + y^2}$$

$$z = \frac{\sin\theta}{\cosh\eta - \cos\theta}$$

Fig. 1 – The ring yoke and coordinant system with definitions and the conversion equations.[1]

Since this is a steady-state field, it is convenient to use the scalar magnetic potential F (or mmf, magnetomotive force) which corresponds to the scalar electric potential. Thus, the Laplace equation is written as:

$$\nabla^2 F = 0 \tag{1}$$

The solution of this equation in general form as given by Hobson[2] is

$$\begin{aligned} F = &\sum_{m=o}^{\infty}\sum_{n=o}^{\infty} A_{mn}(\cosh\eta - \cos\theta)^{1/2} \\ &P^{m}_{n-1/2}(\cosh\eta)\ {\cos \atop \sin}\ n\theta\ {\cos \atop \sin}\ m\phi \\ &+ \sum_{m=o}^{\infty}\sum_{n=o}^{\infty} B_{mn}(\cosh\eta - \cos\theta)^{1/2} \\ &Q^{m}_{n-1/2}(\cosh\eta)\ {\cos \atop \sin}\ n\theta\ {\cos \atop \sin}\ m\phi \end{aligned} \tag{2}$$

This solution involves a double summation with respect to *m* and *n*. The sum involving *n* is eliminated by the selection of a circular core cross section. The terms involving *m* describe the effects of the conductor distribution function.

When $m = 1$ and $k = \tanh\eta$, Eq. (2) simplifies to

$$F = A_{10}\left(1 - \sqrt{1-k^2}\cos\theta\right)^{1/2} k\, F_{10}(k) \sin\phi \tag{3}$$

$$\text{where} \qquad F_{10} = \sum_{s=o}^{\infty} A_s\, k^{2s} \tag{4}$$

$$A_o = 1 \tag{5}$$

$$A_s = \left[\frac{s + m/2 - 1/4}{s + m}\right]\left[\frac{s + m/2 - 3/4}{s}\right] A_{s-1} \tag{6}$$

$$A_{10} = \frac{N_1\ I}{k_c\ F_{10}(k_c)} \tag{7}$$

---

[1] Wilhelm Magnus, and Fritz Oberhettinger, *Formulas and Theorems for the Special Functions of Mathematical Physics*, trans. J. Wermer (New York: Chelsea Publishing Co., 1949), p. 151.

[2] E. W. Hobson, *The Theory of Spherical and Ellipsoidal Harmonics* (London: Cambridge at the University Press, 1931), pp. 433-436.

This change of variable from η to k leads to a different coordinate system involving ϕ, θ, and k. Any point in space is described by its k, θ coordinants in the plane passing through it and the yoke axis; and the angle ϕ between it and the axial plane is shown in Fig. 2.

Equation (3) involves $\sin\phi$, therefore, F_{10} is zero on the $\phi = 0$ plane. Its plot on the $\phi = 90°$ planes is shown in Fig. 3. Pictorial drawings of this function are shown in Figs. 4 and 5. Surfaces of constant mmf are horn-like surfaces terminating at their ring core intersections. An equivalent number of ampere turns must be wound around the core to provide the mmf difference accumulated between successive shells of Fig. 5.

Having determined F and the constants resulting from the boundary conditions, the magnetic intensity H may now be obtained. Because the analysis can be made on the basis of static conditions, it is convenient to use the fictitious magnetic charge concept.[3] In this case Maxwell's second equation reduces to:

$$H = - \, grad \; F \tag{8}$$

Because of the special coordinant system some manipulation is required to obtain this gradient.

$$H = \bar{H}_x \, i + \bar{H}_y \, j + \bar{H}_z \, k \tag{9}$$

where

$$\bar{H}_x = \frac{N_1 \quad I}{k_c \;\; F_{10} \, (k_c)} \Big\{ (D_{10} - E_{10}) \sin\phi \cos\phi \tag{10}$$

$$\bar{H}_y = \frac{N_1 \quad I}{k_c \;\; F_{10} \, (k_c)} \Big\{ (D_{10} \sin^2\phi + E_{10} \cos^2\phi \tag{11}$$

---

[3] Edward C. Jordan, *Electromagnetic Waves and Radiating Systems*, ed. W. L. Everitt (New York: Prentice-Hall, Inc., 1950), p. 555.

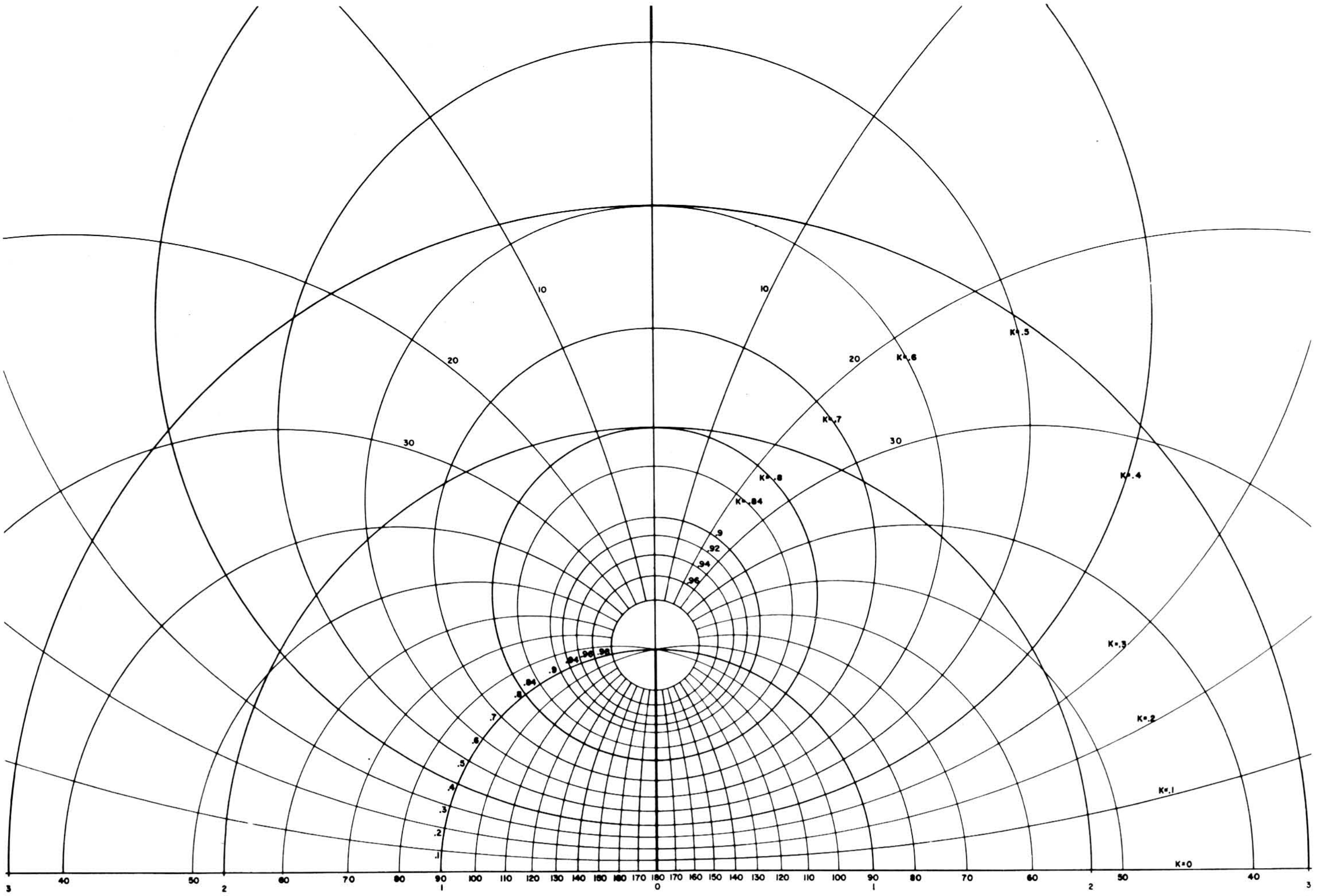


Fig. 2 – A plot of the ring coordinants k and θ on the axial plane

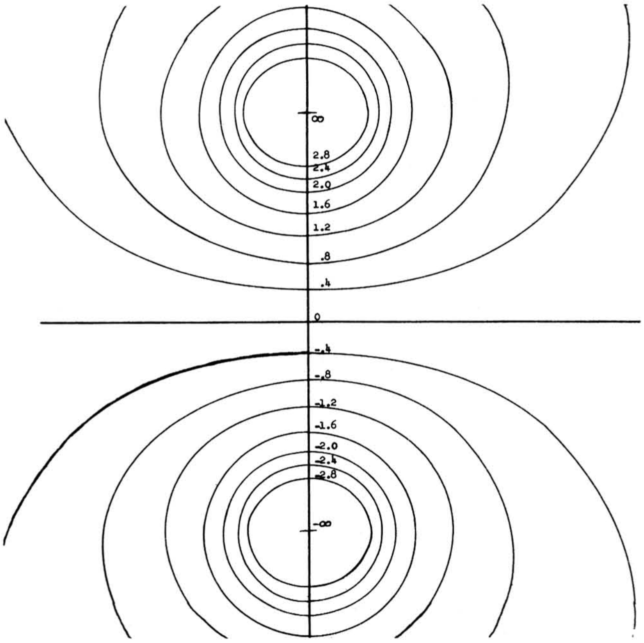


Fig. 3 – A plot of F_{10} on the $\phi = 90^\circ$ plane

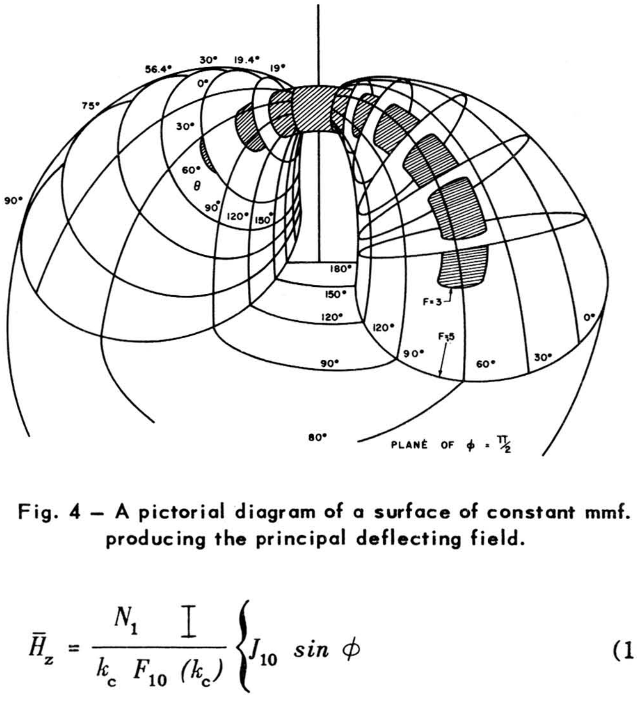


Fig. 4 – A pictorial diagram of a surface of constant mmf. producing the principal deflecting field.

$$\overline{H}_z = \frac{N_1 \quad I}{k_c \; F_{10}\,(k_c)} \left\{ J_{10} \; \sin \phi \right. \tag{12}$$

where

$$D_{10} = \frac{\sqrt{1-k^2}}{1 - \sqrt{1-k^2}\,\cos\theta}$$

$$\left[\left(\sqrt{1-k^2} - \cos\theta \right) \frac{F_{10}'}{F_{10}} - \frac{k^2}{2\sqrt{1-k^2}} \right] E_{10} \tag{13}$$

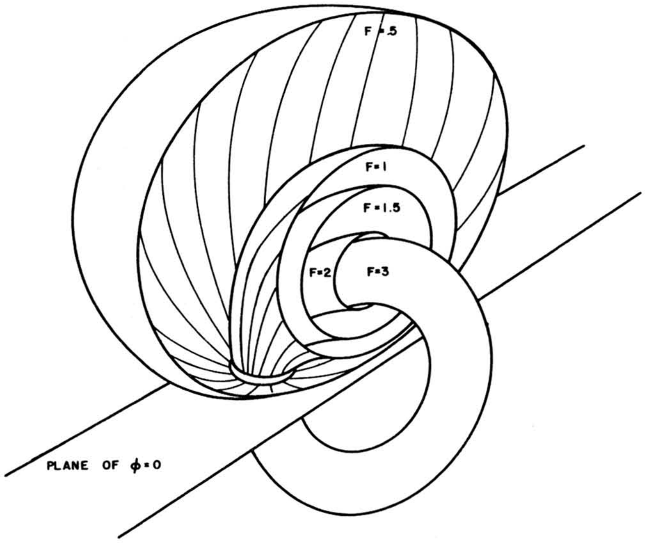


Fig. 5 – Another pictorial diagram of surfaces of constant mmf. producing the principal deflecting field.

$$E_{10} = (1 - \sqrt{1-k^2}\,\cos\theta)^{3/2} \quad F_{10}\,(k) \tag{14}$$

$$J_{10} = \frac{\sqrt{1-k^2}}{(1 - \sqrt{1-k^2}\,\cos\theta)}\, k \,\sin\theta \left[\frac{F_{10}'}{F_{10}} + \frac{1}{2} \right] E_{10} \tag{15}$$

$$\frac{F_{10}'}{F_{10}} = \frac{\sum\limits_{s=0}^{\infty} (2s+1)\, A_s \; k^{2s}}{\sum\limits_{s=0}^{\infty} A_s \; k^{2s}} \tag{16}$$

A_s was defined by Eq. (6). From these formulas, a plot of $\overline{H}_y$ was obtained for the $\phi = 0$ plane. It is shown in Fig. 6. Here, lines of constant magnetic intensity $\overline{H}_y$ are shown. In the central region and particularly for the value 2, the lines near the axis are parallel to the $z = 0$ axis and are, therefore, independent of r. In the remote regions, the lines are nearly circles about the origin. In the study of the deflections produced by the fields, these features are used to separate the problem into a principal deflection and additional, or corrective, error deflections. The plots of other fields are shown where they are needed to obtain the additional deflections.

Deflections Produced by the Principal Field

This field B_{10y} provides the principal deflection of an electron beam. Once beam's path through this field or a similar one is obtained, the small modifications of the final deflection angle contributed by the higher order fields or by positional changes, can be more easily determined.

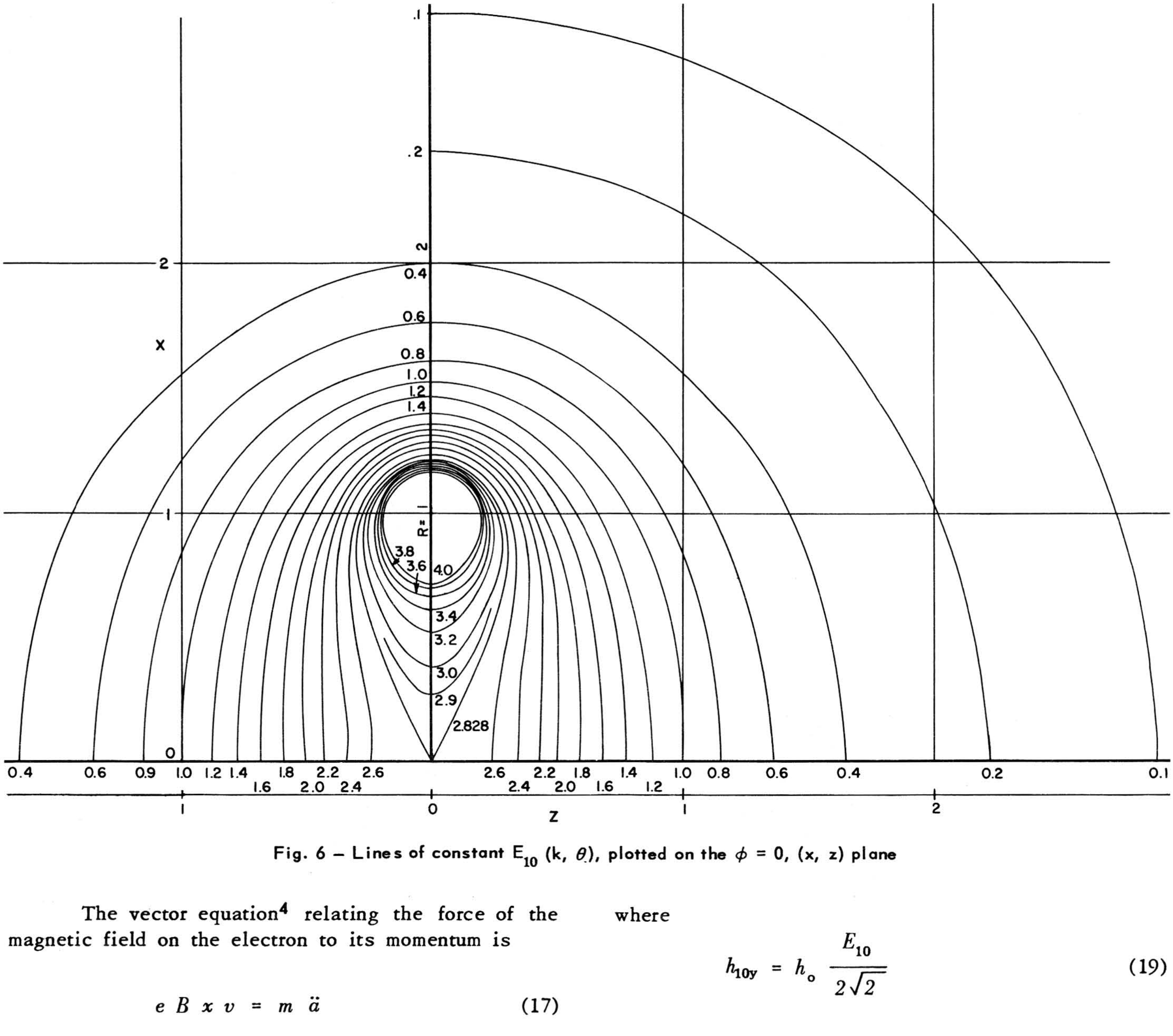


Fig. 6 – Lines of constant E_{10} (k, θ), plotted on the $\phi = 0$, (x, z) plane

The vector equation[4] relating the force of the magnetic field on the electron to its momentum is

$$e\,B \times v = m\,\ddot{a} \tag{17}$$

This equation may be expanded into three equations involving the three field components B_{10y}, B_{10x}, B_{10z}. When the analysis is restricted to the axial electrons in the plane, $\phi = 0$ only. The B_{10y} component remains. This fact eliminates one of the three vector equations. The remaining two can be manipulated to eliminate the parameter t, thus obtaining a single equation in which x is a function of z.

$$\frac{d^2x}{dz^2} = h_{10y}\left[1 + \left(\frac{dx}{dz}\right)^2\right]^{3/2} \tag{18}$$

where

$$h_{10y} = h_o\,\frac{E_{10}}{2\sqrt{2}} \tag{19}$$

Now h_o is the reciprocal of the radius of curvature of a beam located at $z = 0$, $x = 0$,

$$h_o = N_1\,I\,\frac{2\sqrt{2}}{k_c\,F_{10}\,(k_c)\,3.37\sqrt{V}} \tag{20}$$

Therefore it combines the effects of the currents and the beam voltage. If a mixture of co-ordinate systems is used, Eq.(9) simplifies to

$$h_{10y} = \frac{h_o}{(1 + z^2 + x^2)^{3/2}}\,F_{10}\,(k) \tag{21}$$

---

[4] Karl R. Spangenberg, *Vacuum Tubes*, ed. F. E. Terman (New York: McGraw-Hill Book Co., Inc., 1948) p. 398.

wherever k is small, $F_{10}(k)$ is nearly 1.

So

$$h_{10y} = \frac{h_o}{(1 + z^2 + x^2)^{3/2}} \tag{22}$$

When $x = 0$ and $k = 0$

$$h_{10y} = \frac{h_o}{(1 + z^2)} \tag{23}$$

In the area of particular interest h_{10y} can be approximated by two equations -- Eq. (23) pertaining to the initial deflection and that occurring within the immediate vicinity of the yoke and out to $z = z_1$, and Eq. (22) is used to obtain the deflection in the region beyond $z = z_1$. These equations are identical on the axis where $x = 0$ and are good approximate formulae wherever k is small. The location of these regions with respect to the ring yoke and the electron beams is shown in Fig. 7.

This separation of the field into two regions is a convenient concept for it is in the first region that the

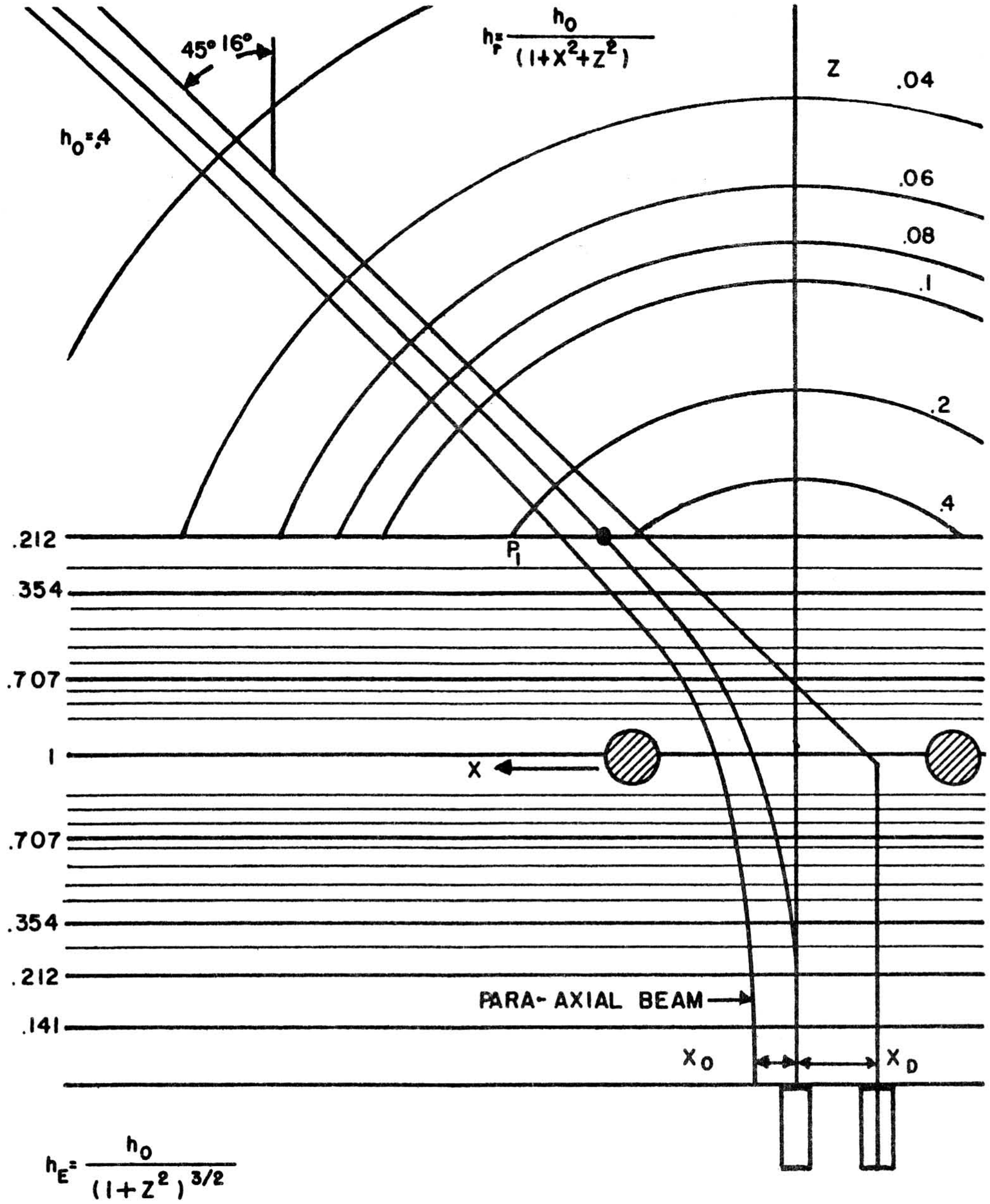


Fig. 7 – Lines of constant h_e and h_r and several beam paths for $h_o = 0.4$

major deflection of the beam is encountered. Here also the effects of the higher order fields may be significant. In the second or remote region, it is essentially the field of a magnetic dipole located at the origin.

By a combination of graphical and analytical techniques, the approximate paths of the beam through these regions were obtained for several values of h_o. These are shown in Fig. 8.

This assumed field of Fig. 7 was subtracted from the field of Fig. 6 to yield an error field $h_{10y}-he$. The value of this error field as encountered along an assumed path was used to obtain the exact deflection angle. The calculated deflection angle of a beam entering the yoke field on its axis is given by the equation

$$\psi = 108.1\ h_o + 30\ h_o^3 \text{ degrees} \qquad (24)$$

The position of the center of deflection also is obtained as

$$X_d = 2.2\ h_o^2 \text{ radial units} \qquad (25)$$

To obtain experimental verification, a yoke was wound having a sinusoidal conduction distribution. Even though its core cross section was not identical to the circular section required for exact duplication of the mathematical case, a similar equation was obtained.

$$\psi = 108.1\ h_o + 36.2\ h_o^3 \qquad (26)$$

Deflection Distortion as Additive to the Principal Deflection

The deflection of an electron ray (element of a beam) passing through a general ring deflection yoke can be separated into its vector components.

$$\psi = (\psi_c + \beta_x)\ \overline{\psi} + \beta_y\ \overline{\omega} \qquad (27)$$

where

$\overline{\psi}$ is the vector direction defined by the angle between the yoke axis and the final beam direction as obtained for an axial ray

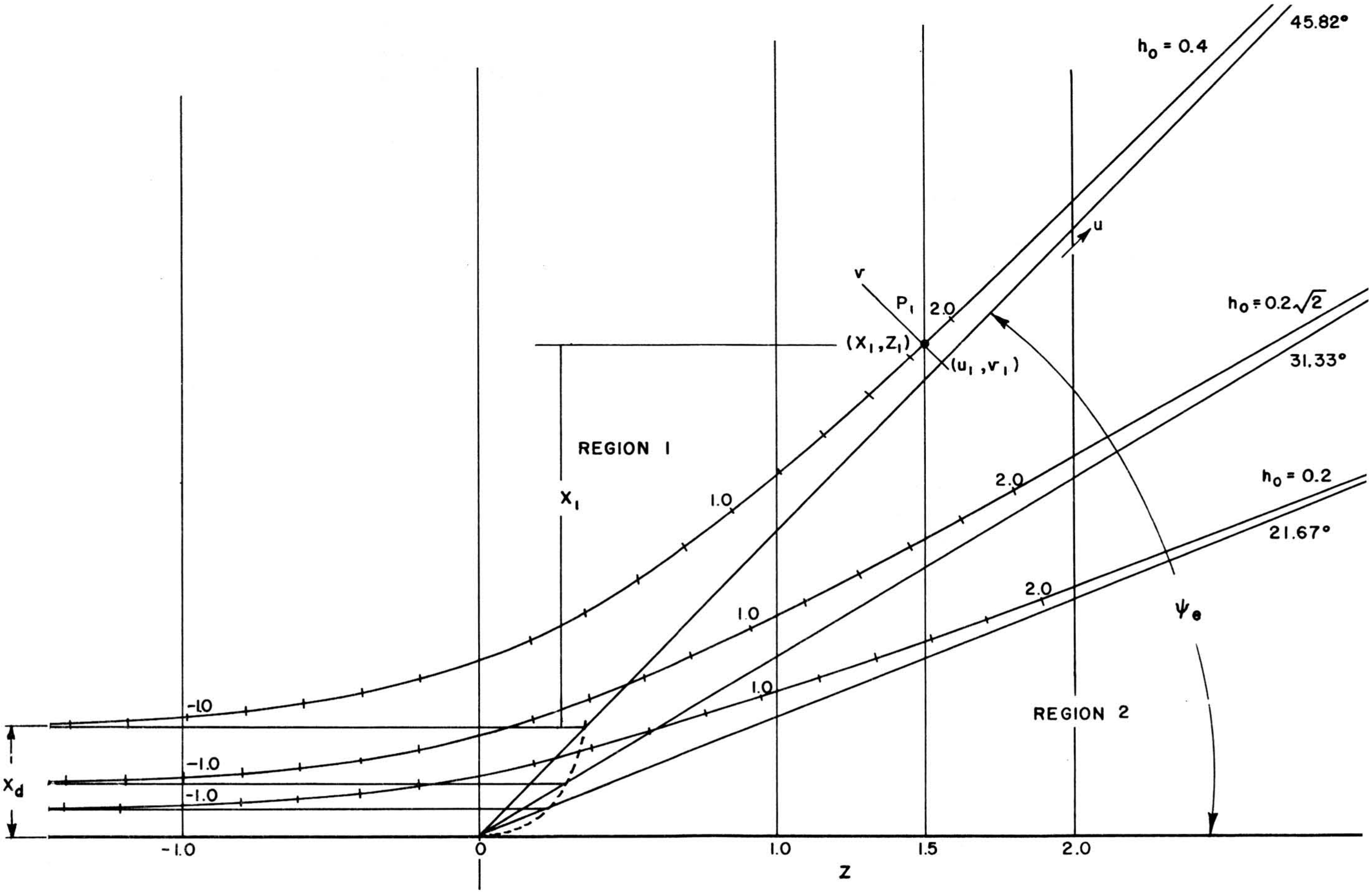


Fig. 8 – Selected beam paths determined by the assumed fields

$\overline{\omega}$ is the angular vector direction at right angles to $\overline{\psi}$

ψ_c is the deflection angle of the central axis ray

ψ is a function h_o and z_o, provided the picture screen is sufficiently remote from the deflection yoke.

When the beam at z_o (Fig. 9) is displaced a distance r_o in the plane intersecting the $\phi = 0$ plane on the axis, and making an angle $\omega_o - \omega$ with respect to it; the field encountered along the beam path will differ from the h_{10y} field, thus causing added deflections β_{10x} and β_{10y}. Now the position of the entrant beam is

$$x_o = r_o \cos(\omega_o - \omega) \tag{28}$$

$$y_o = r_o \sin(\omega_o - \omega) \tag{29}$$

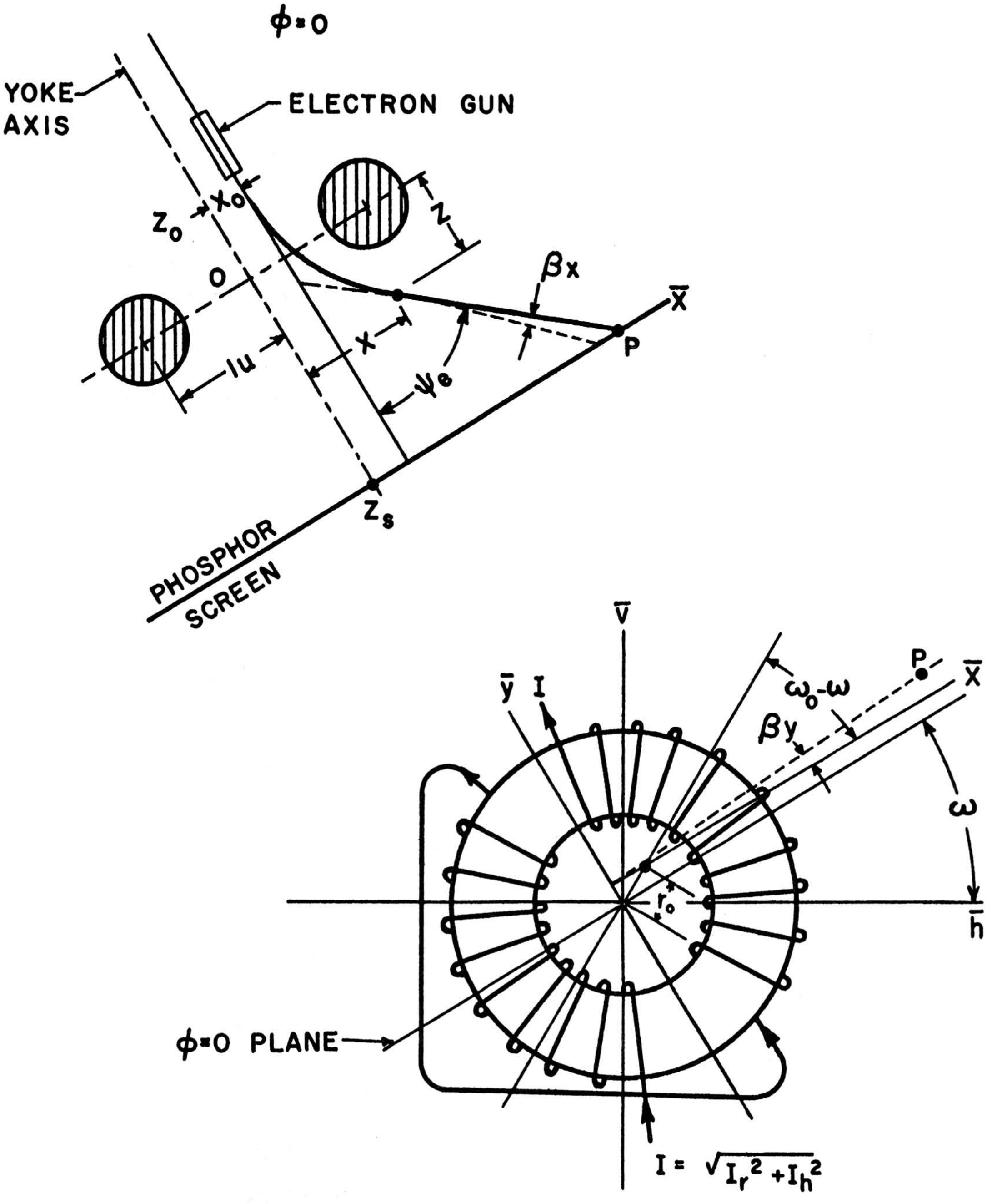


Fig. 9 – The deflection geometry of a ring yoke showing the constants used in the discussion of the deflection of a para-axial beam.

Thus, the location of the displaced beam as a function of z is

$$x = r_o \cos(\omega_o - \omega) + x(z) \tag{30}$$

$$y = r_o \sin(\omega_o - \omega) \tag{31}$$

Now these deflections are functions of $(h_o, \omega, r_o, \omega_o)$, where h_o and ω include the magnitude of the resultant of the currents in the two windings and the effective angle of deflection, while r_o and ω_o describe the location of the entrant ray. Numerical calculations of β_x and β_y were obtained for a series of entrant rays. A composite picture of these results is shown in Fig. 10.

The circle with points a_1, b_1, c_1, a_2, c_2, a_3, b_3, and c_3 shows the position (r_o, ω_o) of the yoke axis relative to the entrant beam at b_2. If the difference function h_{10y}-h_e were zero everywhere, the beam would arrive at point b_2 on the picture screen regardless of the yoke position. As a result of the deflections β the beams arrive at the indicated points of the after-deflection diagram, and the circle of yoke motion is transformed into an ellipse of spot motion. The bending of the ellipse is probably due to arithmetic errors. The para-axial deflections involve more extensive computations and, therefore, are less accurate.

Experimental verification of these results has been obtained from a special 110 degree tube and yoke setup which permits this translation of the yoke. A time exposure of a dot pattern taken while the yoke was moved about a circular orbit resulted in photographs, such as Fig. 11a of the entire picture screen and 11b, an enlargement of one of the ellipses. The smaller ellipse (b) was generated when the diameter of the circle was reduced by one-half. The photograph clearly shows that the size of the ellipse is a function of the deflection angle and thus, ultimately of h_o. Fig. 11b shows the linear relationship with respect to r_o. These data are combined in the empirical formulae.

$$\beta_\psi = 0.1745\,(1 + 0.85\,h_o^2)\,h_o^2\,r_o \cos(\omega_o - \omega) \tag{32}$$

$$\beta_\psi = -4.1 \times 0.1745(1 + .85\,h_o^2)\,h_o^2\,r_o \sin(\omega_o - \alpha) \tag{33}$$

which, together with the following formulae, completely defines the position of an electron beam when deflected by a simple first order ring yoke.

$$h_o = \frac{2\sqrt{2}\;N_1}{3.37\sqrt{V}}\sqrt{l_h^2 + l_v^2} \tag{34}$$

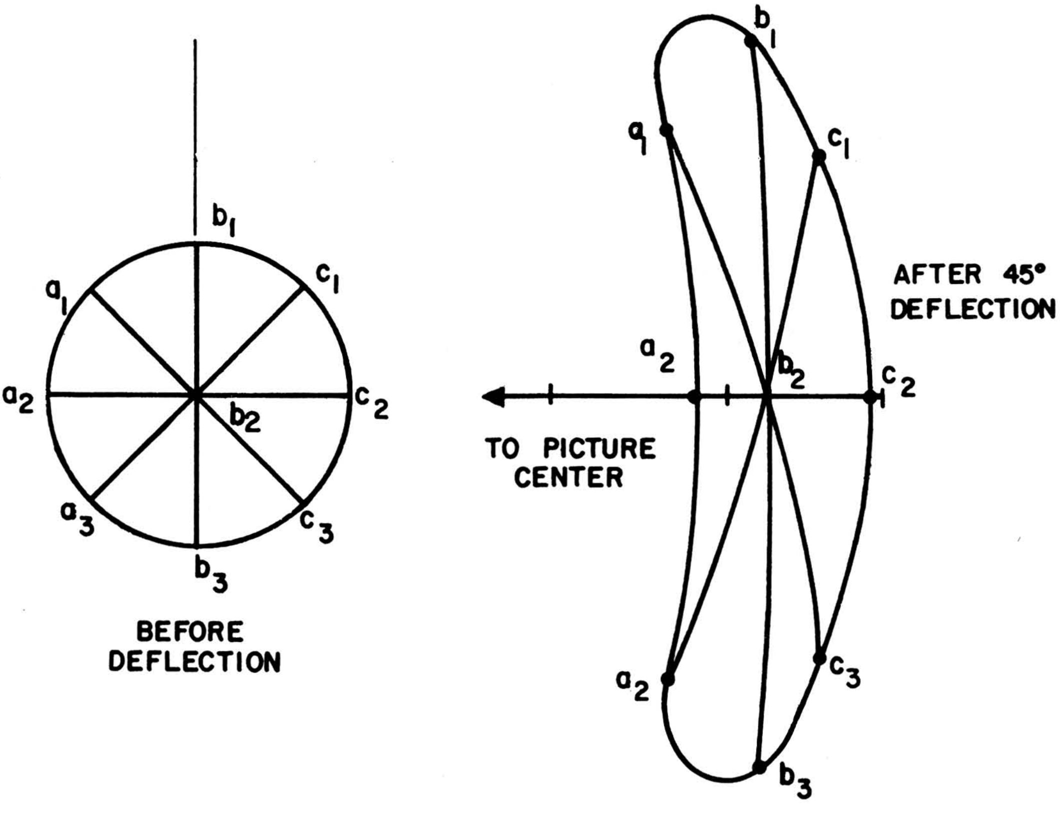


Fig. 10 – Calculated deflection distortions for a first order ring yoke

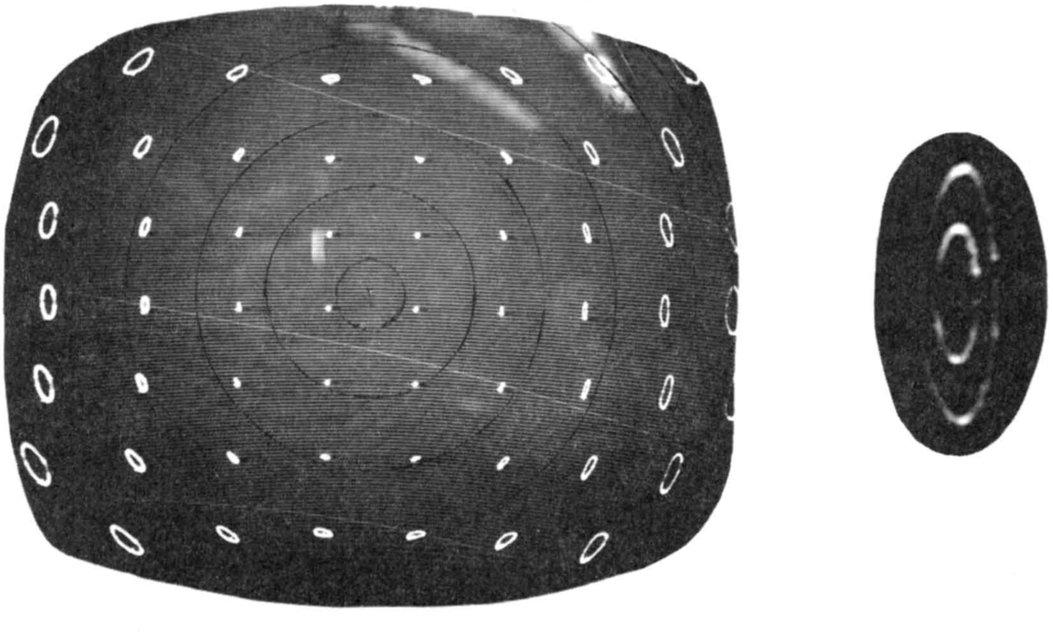

(A) (B)

Fig. 11 – A photograph of a tube showing the deflection ellipses caused by a circular yoke motion and an enlargement of patterns for $r_o = 9.22u$ and $r_o = 0.11u$.

$$\cos \omega = \frac{I_h}{\sqrt{I_h^2 + I_v^2}} \tag{35}$$

$$\psi_c = 1.887\, h_o\,(1 + 0.278\, h_o^2)\ \text{radians} \tag{36}$$

$$D\,(\psi_c, \omega) = \frac{l_o}{\cos \psi_c} \tag{37}$$

$$D(\psi_c, \omega) = R\left\{\sqrt{1 - 1 - \frac{l_o^2}{R}\sin^2 \psi_c} - \left(1 - \frac{l_o}{R}\right)\cos \psi_c\right\} \tag{38}$$

The function $D\,(\psi_c, \omega)$ is determined by the tube screen, geometry and position, as the distance from the center of deflection to the tube screen. It would be a function involving ω for a cylindrical tube screen. Formulae for flat and spherical cases are shown, as Eqs. (37) and (38) respectively, where l_o is the distance between the screen and the center of deflection, as measured along the beam axis. Some results obtained for a flat screen are shown in Fig. 12.

Such lines, obtained with the conventional crosshatch pattern are frequently used for convergence tests of a three-beam color tube. A distortion of a perfect square thus obtained is known as a pin-cushion distortion and results from the deflection geometry and the lack of a linear relationship between the current and the deflection angle. A spherical screen can provide some correction of this condition. Complete correction would be obtained when the spherical center and deflection center are identical. However, such a picture is not pleasing in appearance and is not acceptable.

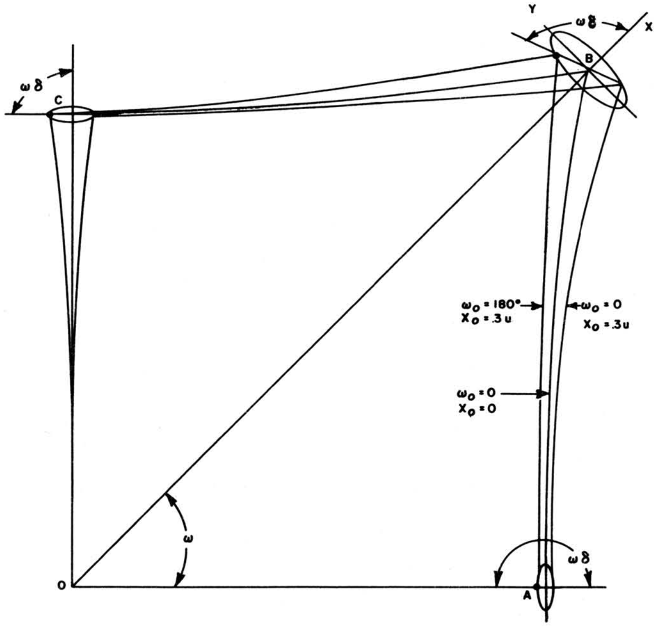


Fig. 12 – The square raster calculated for a first order ring yoke for the axial and two para-axial yoke positions and showing the pincushion distortion.

Conclusions

The principal deflecting field of the ring yoke contributes three types of deflection distortions: a raster distortion that increases with the square of the deflection angle and is modified by the geometry of the tube and screen; a stretching effect which leads to spot ellipticity and is equivalent to the astigmatism and curvature of the image field of optics[5]; and a rotational effect that is important in the convergence problems of the in-line triple beam color tube.

Practical deflection yokes can be made which produce fields identical to the principal deflecting field of the ring yoke. Core cross-sectional geometries other than circular when would with the sinusoidal conductor distribution will have similar distortions. However, the coefficients of these distortions will be modified by the change.

◆

---

[5] G. Wendt, "Systemes de Deviation Electronique et Luers Aberrations", *L'Onde Electrique,* February 1953, pp. 93-106.