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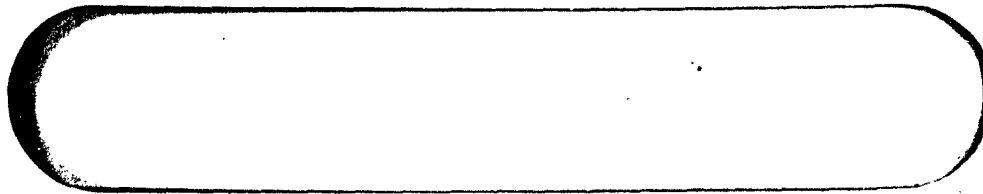
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**A REPORT ON
Millimeter Wave Research**

Contract Nonr687(00)

PREPARED BY BELL TELEPHONE LABORATORIES, INC.

ON BEHALF OF

WESTERN ELECTRIC COMPANY, INC.

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S I X T H R E P O R T
December 1952

A report on
MILLIMETER WAVE RESEARCH
Contract Nonr-687(00).
Period covered by this report
September to December 1952.

Prepared by Bell Telephone Laboratories, Inc.
On Behalf of
Western Electric Company, Inc.

Contains intelligence produced outside of the
work performed under contract Nonr-687(00)

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Edited by

S. E. Miller
J. R. Pierce

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ABSTRACT

This document reports progress in work of a research nature on millimeter wave measurements, tubes, crystals, circuit elements and propagation. The overall objective of this work is to put the millimeter wave art on a sound basis and to provide tools for the practical exploitation of this frequency range. In particular, this report describes the following work:

Progress has been made toward a 3 db directional coupler suitable for a balanced mixer.

A gas tube noise source has been constructed and will be tested.

Using a modified rectifier cartridge, conversion losses of 8.1 db at 5.4 millimeters and 7.6 db at 6.3 millimeters have been attained, and also an improvement in average performance. Bolometer beads mounted in a similar manner read 2 to 2 1/2 db low.

Work toward determining the loss of dielectric waveguide has been troubled both by a spurious mode of transmission, which has been eliminated, and by unduly high loss in commercially extruded polystyrene, which we hope can be remedied.

Propagation on a polyethylene-coated wire was investigated, but some trouble was encountered with propagation in the G-string mode.

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Work toward a circulator in dielectric guide is progressing.

Further progress has been made in constructing circular-electric guide sections of metal rings embedded in lossy material, which will kill other modes and allow bends. The experiments are being done at 9 kilomegacycles. The loss has been reduced from .042 db/meter to .038 db/meter, but this is still 1.15 to 1.20 times the theoretical loss. Preliminary tests were made on millimeter-wave spaced-ring line.

Further work was done on point-contact rectifiers with a view both to improving their performance and to using them at higher frequencies. Smaller pieces of silicon have been used and work has been done toward mounting them without soldering. Work is being done on both the cartridge and the silicon.

A disparity of losses between the right-hand and left-hand circularly-polarized waves in ferrite rods may be explained by the fact that one mode has a greater fraction of its energy inside the rod than the other.

The first hot measurements on the helix-type amplifier showed electronic interaction but no net gain. The tube was found to oscillate. An effort will be made to remedy this by proper addition of loss.

An effort is being made to fabricate circuits for spatial-harmonic amplifiers and oscillators by photo-etching

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and by grid winding techniques. No operating tubes have been completed.

The first 5.4 millimeter version of the spatial-harmonic amplifier gave 4 db gain at 5.4 millimeters and oscillated from 5.14 millimeters to 6.13 millimeters with a voltage sweep of from 4,000 volts to 1,800 volts.

The extradigitron structure was further investigated. A 45-wire resonant 3 centimeter oscillator was tested and cold tests have been made on backward-wave structures.

An analysis of propagation in ferrite-filled waveguides was extended.

The 5.4 millimeter reflex klystron program has progressed almost to the point of building and testing tuneable tubes.

Further measurements and circuit measurements have been made in connection with the close spaced tetrode. It is hoped to make a tube suitable for moderate bandwidths and frequencies by March 1953 and to arrive at some sort of design which will be suited to higher frequencies and broader bandwidths.

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1. Components and Measuring Techniques

1.1 Three-DB Matched Hybrid (N. J. Pierce)

The technique required to produce a photoengraved hole pattern in a thin copper sheet for use in a 3 db waveguide directional coupler has been worked out. This copper sheet is to be the common wall between two parallel waveguides. To accomplish this the sheet will be cemented between two polystyrene mandrels, after which the assembly and projecting edges of the foil are to be silver plated and then copper electroformed. The polystyrene mandrels may then be dissolved out to complete the fabrication.

A portion of this work has been carried out using Bell System funds as part of the radio research program.

1.2 Noise Source (W. W. Mumford)

A new waveguide circuit for matching the standard 0.074" x 0.148" I.D. waveguide to the discharge tube and a new design of discharge tube have both been completed. Tests are to be carried out in the near future.

A portion of this work has been carried out using Bell System funds as part of the radio research program.

2. Crystal Conversion Loss and Noise Figure Measurements (W. M. Sharpless)

Work has continued along the lines of investigating the first detector conversion losses of our millimeter wave receivers, together with an overall study of millimeter wave

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receiver noise figure improvements. Firm conversion loss measurements have now been made at a wavelength of 5.4 millimeters by the use of the power level measuring calorimeter and several standard crystals have been calibrated for reference.

Twenty new type Araldite insulated rectifiers have now been assembled and measured for conversion loss at both 5.4 and 6.3 millimeters. These units have shown our lowest measured conversion losses to date and average, in general, about as good as the best units we had a few months ago. The best unit to date has a conversion loss of 8.1 db at 5.4 millimeters and 7.6 db at 6.3 millimeters. Measurements at both wavelengths on a group of 30 rectifiers including both old and new type units show that the greater the loss at 6.3 millimeters, the greater will be the increase in loss in going to 5.4 millimeters. This difference becomes as much as 2 1/2 db on units having a conversion loss near 12 db at 6.3 millimeters. This gives further evidence of the importance of keeping the contact area and the resulting contact capacity as low as possible in our future units.

Direct power level measurements at 5.4 millimeters using a Western Electric Company 23A bolometer bead mounted in our new low loss Araldite insulated rectifier holder have shown that this device still indicates power levels 2 to 2 1/2 db below those measured by the calorimeter. Further work will be

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needed to uncover the losses still present in these units.

Some work is being done toward reducing the losses found in our present first detector contact rectifier designs. This effort is aimed at simplifying the rectifier circuit arrangement we now use by mounting the rectifiers directly in short sections of "adjustable" waveguide. Some of the results of this work should be available for the next report.

An investigation toward determining the best method of making noise measurements on our millimeter wave converters is continuing. From measurements made with balanced detectors and unbalanced detectors with narrow band beating oscillator filters, it appears that the noise output of a single rectifier may be measured correctly by the filter arrangement if a high level beating oscillator tube is available. Only one such tube is on hand, but by using this tube it is hoped that sufficient measurements can be made to correctly noise-rate a group of rectifiers. Having this information, the present plan is to try a simplified low frequency noise measuring scheme which, if successful, will greatly simplify the numerous measurements that will need to be made in conducting an exhaustive noise investigation.

A portion of this work has been carried out using Bell System funds as part of the radio research program.

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3. Dielectric Waveguides (A. G. Fox, M. T. Weiss)

We are looking forward to the construction of an experimental dielectric waveguide of moderate length, perhaps 150 feet, which will have an attenuation of about 6 to 8 db and which will allow us to study the problems of support, alignment and shielding which would be encountered in any short length run of practical dielectric waveguide for outdoor use. In order to determine the proper size of dielectric rod to meet this attenuation requirement at 6.25 millimeter wavelength, attenuation measurements have been made on several of our available dielectric rods by direct insertion loss techniques. These measurements have yielded results which vary by as much as $\pm 20\%$. It was at first thought that this might be caused by variations in the cross sectional dimensions of our rods, and efforts were made to size these rods more accurately. Since this did not seem to cure the trouble, a measurement was finally made of the power level along a dielectric rod as a function of distance by means of a moving probe. This disclosed that the power level was fluctuating cyclically with distance. We believe that the cyclic variations in power level are due to the presence on the dielectric waveguide of some spurious mode in addition to the desired dominant mode. Although this spurious mode may have relatively small amplitude, it is nevertheless sufficient to cause the variations in insertion loss which were noted above. By eliminating the effect of this spurious mode we have obtained

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attenuation data that permit us to predict that a dielectric rod having cross sectional dimensions of .042" by .136" should give us the attenuation of around 5 db per hundred feet which we desire for our experimental waveguide.

In the meanwhile we have noted that the K-band attenuation of our 3/32" by 5/32" polystyrene rod extruded for us by Garrison Company is running nearly twice as high as rather crude homemade rods which have been built by slicing up sheet-stock and welding the strips end to end. We believe that this high attenuation must be due to contamination of the polystyrene by the extruder. We are currently hoping to persuade the Plax Corporation to extrude several hundred feet of oriented polystyrene rod in the new cross sectional dimensions, expecting thereby to obtain a purer product and one which is less likely to break when flexed.

With the objective of building an all dielectric waveguide circulator, two directional couplers have been built which couple .110" diameter round polystyrene rod to .052" by .168" rectangular cross section polystyrene rod so that 100% of a wave whose E vector lies parallel to the long side of the rectangular rod will be coupled to the round rod. These couplers will be used as polarization selective take-offs on either side of the ferrite element. Our problem now is to devise satisfactory means for matching polystyrene waveguide into the ferrite section. So far our efforts to build transitions from one size

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of dielectric rod to another have been only moderately successful. Even relatively long tapered transitions appear to scatter more power than might be expected.

Polyethylene rod containing a metal wire along the axis is easily obtainable by removing the metal braid from standard coaxial cable. Although the wire should have only a very small effect on the propagation of the dominant hybrid wave, it may offer some advantage in increased tensile strength where long spans are to be used. For this reason we have experimented briefly with such a structure and found as expected that satisfactorily low losses are obtainable provided the rod is quite uniform, but that it is relatively easy for the power to be coupled into the coaxial (G-string) mode by imperfections in the launching mechanism or by eccentricities of the axial wire.

4. Flexible TE₀₁ Waveguides (A. P. King)

4.1 Two-Inch Diameter Spaced-Ring Lines

The 2" diameter line, constructed with neoprene spacing washers as described in the preceding Quarterly Report, has undergone further investigation. The dissipation of TM₁₁ wave power in the radial line sections has been examined for neoprene resistivities (dc) of 3×10^3 to 10^9 ohms/cm³. The measured attenuation was found to have a maximum of 150 db/meter over a broad resistive range of 10^4 to 10^5 ohms/cm³.

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Lines built with neoprene washers show better alignment and stability of the copper rings than the earlier models constructed of a molded thiokol rubber jacket and show TE_{01} wave attenuation of .038 db/meter ($f = 9$ kmc) compared to the .042 db/meter previously reported. The .038 db/meter attenuation is 1.6 times greater than the theoretical attenuation of solid copper waveguide and 1.15-1.20 times the theoretical attenuation of a spaced-ring line of these proportions. It is expected that the newer lines having both lower TE_{01} wave attenuation and higher TM_{11} attenuation will show appreciably lower attenuation as TE_{01} bends.

The program is now well under way for the construction of longer sections, several feet in length, for TE_{01} bend tests.

4.2 Millimeter Sizes of Spaced-Ring Line

Plans for smaller diameter lines (0.4375" and 0.875") are also well along. For these smaller sizes, in which the assembly of the smaller components becomes more difficult, it is hoped that the neoprene spacing washer can be molded directly to the copper ring. Preliminary tests appear very encouraging.

5. Point Contact Rectifiers

5.1 Cylindrical Cartridge Units (R. S. Ohl)

A number of changes have been made in the millimeter rectifiers to improve their quality, most of which have been incorporated in the general experimental construction specifications. These specifications are revised from time to time to

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keep them up-to-date.

Some consideration has been given to the problem of making rectifiers suitable for use at wavelengths shorter than 5.4 millimeters. One of the dominant considerations is the fabrication and fastening of the silicon. It appears that the silicon dimensions will require further scaling down. We have succeeded in cutting activated silicon to a thickness of $1/128$ " and $1/64$ " square. While the $1/64$ " pieces will not be required at this time, we are nevertheless reassured to know that silicon can be cut to smaller sizes than the $3/64$ " square which is now being used.

In a practical sense it becomes increasingly more difficult to fasten silicon pieces by soldering when sizes smaller than $3/64$ " squares are to be used. The preparation of the metal back contact by the older process is equally as difficult. Therefore a contacting technique has been developed which is much less difficult to apply.

That gold will form a eutectic with silicon at 370°C . is well known.* Accordingly, a method was devised to apply gold to the silicon for a back contact. The silicon is first polished on both faces. One face is covered by a thick layer of evaporated gold just before the bombarding procedure. After

*J. W. Mellon V.6, 1930, p. 174.

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bombarding, to activate the unplated silicon surface, the gold on the back is found to have alloyed with the silicon to form a highly conductive and highly adherent junction. Such back contacts adhere firmly to the silicon throughout subsequent processing.

In order to avoid difficulties in soldering silicon in place, a method of fastening to its metal support by pressure alone has been developed.

The successful application of this method of fastening has required some study. Both the metal support and the silicon require special treatment. It was found that a tight connection can be obtained by the following procedure: Oxygen-free copper slugs are punched from sheet copper. They are annealed for 1/2 hour in air at 700 to 725° C. and allowed to cool slowly until very near to room temperature. The oxide is removed by pickling in dilute sulphuric acid. The slugs are pressed to size with the required square indentation in one face. Thereafter, they are again annealed as before, pickled in acid and tin electroplated. A piece of silicon may then be inserted in the square cavity and fastened by pressure in the sizing mould. The preferred physical state of the silicon is a square polished on both sides, one face of which has been gold plated as described above.

As a part of the problem of fastening the silicon by pressure, crushing tests were made of silicon wafers polished

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on both faces. The average crushing strength of 3/64" square was found to be about 226,000 psi. Similar tests were made on germanium yielding a value of 152,000 psi. These high values indicate that it should be possible to cold flow soft metal under pressure to permanently contact the silicon without cracking the semi-conductor.

It was necessary to design a new pin and insulation structure to correct certain faults in the coaxial electrical circuit. The new arrangement is designed to operate at 5.4 millimeters. The bakelite insulation is now .053" thick in place of .097". While the electrical behavior is much better the structure is somewhat weaker. In the present design the pin will withstand an axial force of 60 lbs. With the thicker insulation the critical axial force was 140 lbs. The crushing strength of the thinner bakelite washers is about 42,000 psi.

Recently a 3-pound lot of Du Pont silicon has become available for millimeter rectifier use. From this lot of silicon one melt doped with .02% Boron was obtained. Some preliminary tests have been made with silicon from this melt made up in millimeter rectifiers. The material appears to be satisfactory but further tests must be made.

A new polishing machine intended to facilitate the fabrication of silicon was delivered, partly completed. It is being modified for satisfactory polishing.

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There have been indications that some of the variations in the quality of our rectifiers may be associated with ambient conditions. A possible method of evaluating the silicon surface state under various ambient conditions is to measure the surface contact potential with respect to some stable reference metal. A device for the measurement of surface contact potential differences (hereafter referred to as cpd) was constructed. It was found that platinum was a stable reference surface and that brass surfaces electroplated with tin were almost as good. All our measurements at this time are taken with respect to electroplated tin on brass, which is .235 volts positive with respect to pure solid tin and .855 volts positive with respect to platinum. Changes in the contact potential differences are observed with fresh chemically treated surfaces. For instance, pure tungsten sheet, after being cleaned with chloroform, is about .42 volts positive with respect to electroplated tin. This rises to .52 volts after electropolishing and remains at .50 after subsequent cleaning with HF. However, after exposure to air overnight, the polished tungsten contact cpd rose to .675 volts. This treatment is similar to that given tungsten points just before assembly in rectifiers.

Measurements of cpd of silicon surfaces are beginning to indicate a behavior trend. Du Pont doped silicon which has been soaked in dilute HF for 15 minutes shows evidence of a stabilized cpd of about .22 volts while the undoped material

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becomes stable at about .45 volts, although initially it has a value of about .20 volts. Oxidized silicon shows a value of about -.805 volts when oxidized on both faces. This work will be continued on a very limited effort basis for there appears to be some hope that the measurement of cpd may be helpful in obtaining a better control of the desired rectifier surface states.

The supply of millimeter rectifiers has been maintained.

A portion of this work has been carried out using Bell System funds as part of the radio research program.

5.2 New Type Crystal Rectifier (A. B. Crawford)

Consideration is being given to designs of crystal rectifiers in which the rectifier is mounted directly in the waveguide as opposed to the crystal cartridge in current use. None of these designs have progressed to the point of making comparative tests. Future developments in this work are given in the section on Crystal Conversion Loss and Noise Figure Measurements (Section 2).

6. Millimeter Wave Propagation (A. B. Crawford)

No work was done on this item during the period covered by this report.

7. Faraday Rotation (M. T. Weiss, A. G. Fox)

We have previously reported that many ferrites have rather large losses at low magnetic fields in the 10 kmc region.

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with the application of moderate magnetic fields in any direction,, longitudinal or transverse, this loss disappears, suggesting that domain wall motion may be the cause of this low field loss. Experiments with circularly polarized waves on ferrite pencils, however, show that the loss has a peak for the negative polarized wave rather than being independent of polarization as expected. (See the Fifth Report.) This loss asymmetry puzzled us for a time, but we now believe that it can be explained on the basis of the well known fact that μ for negatively circularly polarized waves should be higher than μ for positive waves. Since the ferrite pencil only partially fills the cross section of the metal waveguide, it will behave somewhat as a dielectric waveguide, in that part of the wave energy will be propagated within the ferrite while the remainder is propagated in the space around the ferrite. The higher the index of refraction of the ferrite, the greater will be the per cent of energy which is carried within the pencil, and the less will be carried in the space around it. Consequently, since the negatively polarized wave sees a higher index of refraction, more of its energy will travel within the ferrite than for the positively polarized wave. As a result, loss due to domain wall motion can be expected to be greater for the negatively polarized component.

8. Millimeter Wave Electronics (S. D. Robertson, A. Karp)

8.1 Helix Traveling-Wave Tube

The assembly of the first model of the helix amplifier.

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was completed. Before the tube was placed on the vacuum pump, measurements were made of the insertion loss of the 15 mil diameter tungsten helix and its associated coupling circuits. The measured insertion loss was found to be approximately 40 db at a wavelength of 5.4 millimeters, which checked closely with the calculated value. The standing wave ratios at the input and output waveguide connections were also measured and were found to be 3.2 db and 2.5 db respectively. These were regarded as quite acceptable. These measurements were made on a double-detection measuring set employing a calibrated IF attenuator. The measurements were found to be quite repeatable.

The tube was then pumped and outgassed for a couple of days. During this period a phase modulated, homodyne measuring set of the type recently developed by D. H. Ring was set up in order to measure the r-f characteristics of the tube. This measuring set uses a single 5.4 millimeter harmonic generator whose output power is divided by a directional coupler into two portions. One portion is fed to a balanced crystal detector to serve as a source of beating oscillator power. The other portion is modulated mechanically by a rotary phase shifter such that the signal emerging from the latter is shifted in frequency by 150 cycles. This signal is then applied to the input of the tube whose insertion loss or gain is to be measured. The output is then fed to the balanced detector where it beats with the original frequency and gives a 150 cycle signal in

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the output, which is then passed through a 150 cycle selective filter, an amplifier, an attenuator, and then applied to a calibrated output meter.

Before passing beam current through the helix, the cold loss of the tube was remeasured with the equipment described above. The measured loss was found to be 38 db at this time. Possibly the measuring set is not entirely linear. This may account for the discrepancy between this measurement and the earlier one.

The tube was then operated with typical results as follows:

E_{Helix}	1060 volts
I_{Cathode}	7 ma
I_{Helix}	1+ ma
$I_{\text{Collector}}$	1 ma
Magnetic Field	1080 gauss (critical)
R-F Insertion Loss	17 db

It will be noted that the electronic interaction between the beam and circuit reduced the insertion loss by 21 db. This is sometimes called "electronic gain."

During these tests the gun was not working well, which resulted in a current through the helix of only 1 ma instead of the 5 to 6 ma observed in earlier experiments. However, the 1 ma of current should have given a net gain of several db.

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It was observed that the curve of signal output versus beam voltage was very irregular. This led to a suspicion that the tube was oscillating at a longer wavelength. Such oscillation would act to overload the beam and reduce the output at the signal frequency. In order to search for the oscillation frequency, a simple broad-band crystal detector was connected to the output of the tube. The detector output was connected to an oscilloscope. When the helix voltage was swept a few hundred volts, evidence of oscillation was immediately observed. It should be pointed out that the signals observed on the scope were harmonics of oscillations occurring at wavelengths of at least 7.5 millimeters and perhaps longer. The tube does not have enough gain to oscillate at wavelengths near 5 millimeters, and the waveguide connectors cut off at 7.5 millimeters. The wavelength of one of the oscillation harmonics was measured and found to be 4 millimeters. This means that the fundamental frequency was 8 or 12 millimeters. The value of the wave velocity on the helix in the 8 to 12 millimeter range when correlated with the beam voltage for which the oscillations were maximum suggests that the fundamental oscillations were occurring at 8 millimeters. The 4 millimeter harmonic output was at a power level of the order of 1/2 milliwatt.

An attempt was made to increase the current through the helix. It was then noticed that the cold insertion loss of

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the tube had dropped and that the d.c. resistance of the helix had changed slightly. The tube was taken apart, and it was found that the helix had been burned through near the gun end.

A second helix of copper-plated and sintered tungsten was installed and cold tested. The results were very erratic. This helix was removed and found to have a shorted turn near one end.

A third helix is now being prepared for test. This helix is also copper plated in order to reduce the cold loss. An attempt will be made to eliminate the oscillations by placing attenuating material near enough to the helix to raise the long wavelength attenuation substantially without increasing the loss appreciably at the operating wavelength.

8.2 Spatial-Harmonic Tubes

8.21 Amplifier Tube

The construction of a spatial-harmonic amplifier tube employing a photographically etched circuit element is nearly completed. The millimeter wave circuit, which was called Model IV in the scaled-up version described in the last Quarterly Report, consists of a ridged rectangular guide of the same overall dimensions as RG-98/U, whose upper broad wall is made of a sheet of molybdenum containing a series of resonant slots. This sheet, which is .002" thick, is made in two identical halves each having about 80 slots cut along one edge. The slots are .045" deep and .0056" wide, and are spaced

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55.5 to the inch. Additional slots of varying lengths at each end are utilized for tapering in and out.

These slotted sheets are being turned out by B. A. Diggory, using a photoengraving process, and a few pairs which appear to be quite uniform and clearly cut will be gold plated and sintered. When a pair of slotted sheets is clamped into the tube assembly, a longitudinal gap between opposing rows of plots, .015" wide, is obtained. This gap will permit thermal expansion without buckling, and in particular the first circuit is being set up in the gun-and-magnet assembly used with the above mentioned helix tube so that the .015" diameter beam may be focussed through the gap. In this assembly the waveguide bends out of the way of the gun and collector and the ridge is tapered out before connecting the input and output to RG-98/U waveguides.

8.22 Backward-Wave Oscillators

8.221 Tape-Helix Tube

Since the plan has succeeded at lower frequencies, it appears worth a try to make a tape-helix backward-wave oscillator out of the existing helix-amplifier setup with its dense .015" diameter beam. Accordingly, helices having 92 T.P.I. of .0055" x .001" gold plated molybdenum ribbon are being prepared so that they may be substituted for the original helix in the assembly.

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8.222 Wound-Over Ridged Guide Oscillator

A millimeter-wave-sized version of the circuit called Model III in the last Quarterly Report was fabricated. It consists of gold plated molybdenum wire that was rolled down to a .0055" x .001" cross section and wound at 96 T.P.I. on an especially prepared copper plated molybdenum base and sintered so as to form a ridged-guide whose broad wall contains over 100 regularly spaced transverse slots .090" long.

A gun of simple design with a directly heated thoria cathode was assembled and tested in a magnetic field in a demountable, water-cooled envelope. As planned, a ribbon beam with approximately 1 A/cm^2 current density and a cross section about .025" x .090" was obtained when the magnetic field was sufficiently strong.

The circuit was placed in the envelope with the gun, and an output coupling (gun end) and circuit termination (collector end) added, and in a first attempt to obtain oscillations the tube was placed between makeshift conical magnetic pole pieces and fired up. Only negligible collector current and no oscillations were obtained, although various means of correcting for the misalignment of the pole pieces - which was great enough to be apparent to the naked eye - were tried.

Consideration of the smallness of the region that usable spatial-harmonic fields occupy - it does not extend for more than .002" on either side of the tapes - indicates that

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a magnetic field that is straight and aligned with the circuit with a precision of at least 1 part of 1,000 will be required. It will thus be necessary to solve this problem of obtaining a satisfactory magnetic field before the tube can be fired up again.

8.23 Other Spatial-Harmonic Devices

Some time has been devoted to the problem of devising a slow wave circuit for a traveling-wave tube using the circular electric mode in a circular guide. There has come to mind one scheme which appears to be of relatively simple construction and to have a few other promising features. A scale model is being constructed so that passive measurements may be made.

8.3 Open-ended Cavity for Reflex Klystrons

These paragraphs are concerned with the cut-off guide-with-post cavity that was last mentioned in Section 10.3 of the Fourth Report. Since that time the tunable, seamless, 4,000 mc model with a round cornered cross section was completed and tested. This model was intended to supply further data on electrical characteristics and for trying out an unusual construction technique.

Some copper foil was clamped between mandrels of low melting point alloy and trimmed so that after electrodepositing a thick layer of copper over all, machining away the excess, melting out the mandrels, cleaning, polishing,

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and adding flanges and tuning mechanism a tunable cavity with flexible side walls was obtained. Although this technique works, it is already, at 4,000 mc, a difficult job. It is, furthermore, difficult to insure adhesion of the foil to the electrodeposited copper after a few cycles of flexing.

The intrinsic Q , (Q_0), and the ratio of external to intrinsic Q , (Q_E/Q_0), which is an index of the degree of coupling, were measured in the range 3,900-4,220 mc with the help of E. D. Reed. Coupling was achieved by locating the flange end of the cavity at a distance of $1 \frac{3}{8}$ " from the post center line and immediately joining on, by means of its choke flange, a length of standard guide. (The cut-off guide cross section is approximately $1/4$ " x 1", which is centered in the $7/8$ " x $1 \frac{7}{8}$ " cross section of the standard guide.) Q_0 , which was of the order of 2500 (the fixed tuned brass model with 4 seams had $Q_0 \approx 1500$), increases somewhat as the cavity gap opens up to tune to higher frequencies. At 3900 mc Q_E/Q_0 is 4.56 - rather loose coupling - and only an 8% increase of frequency, to 4220 mc, sees the coupling increase to the tight value corresponding to $Q_E/Q_0 = 2.77$. Since one generally desires a klystron where Q_E/Q_0 is nearly constant over the band, it appears that anything less than a more complicated coupling arrangement will be inadequate. No further work is contemplated on this subject.

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9. Spatial-Harmonic Tube (C. F. Quate, R. M. Rogers)

After changing the design of the tube to include an external collector kovar-to-glass seals rather than moly-to-glass and a redesign of the cathode structure we have been successful in activating and sealing off two tubes in this period. The first tube incorporates a beam forming electrode of a Pierce gun design rather than a grid. This has proved unsatisfactory as a current control since a large bias on the electrode distorts the optics to the extent that only 1.4 ma can be transmitted to the collector. With this current a net gain of 4 db was measured at 5.4 millimeters, which agrees with the measured gain in the 6.25 millimeter tube at this current level. As a backward-wave oscillator, 1 ma to the collector is quite sufficient; and we are currently using this tube as a sweeping test oscillator. The tube oscillates from 5.4 millimeters to 6.13 millimeters when we sweep the beam voltage from about 4,000 volts down to 1,800 volts. Using 6.25 millimeter waveguide we observed oscillation from about 6.0 millimeters to 7.0 millimeters as we swept the beam voltage from 2,000 volts to 1,000 volts.

The second tube incorporated a fine wire grid for current control. However, shortly after it was activated and sealed off the pump, it developed a leak; and we were unable to obtain data on this tube.

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The initial r.f. tests on the ceramic window which used a sheet of ceramic at an angle across the guide gave an insertion loss of about 7 db, which is excessive. Other geometrics are now under consideration in an effort to reduce the loss and still allow for a metal-to-ceramic seal.

10. Extradigitron (D. Hagelbarger, J. W. Sullivan, L. R. Walker)

A 45-wire 3 centimeter model tube was built which had a starting current of 0.7 ma into an optimum load and a maximum power output of 300 milliwatts. As in earlier tubes, reflex operation reduced the starting current but proved harmful at higher levels. The power limitation is due to moding, which arises because the wavelength of the cavity mode was not chosen to have the best value. Another 45-wire tube is being built to have a greater voltage separation between the wire modes in the region of 3.5 centimeters. This can be done by using shorter wires.

Satisfactory helices for 5.4 millimeters have been wound, using a double winding of iron wire and copper wire of equal diameter, side by side and in contact.

11. Backward-Wave Oscillator (D. Hagelbarger, J. W. Sullivan, L. R. Walker)

Work on our 1,000 mc model indicated that it might be possible to match into the extradigitron structure with its cavity removed, or in other words into the wire modes, over a satisfactory bandwidth. However it was difficult to reproduce

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these results at X-band and it appears that this matching operation is too critical to be satisfactory. It is not planned to pursue this further in this form. A modified extradigitron circuit is being considered. In this case the wires are not connected to a common shorting base but are attached to another parallel strip line similar to the usual one. The structure is now symmetrical and admits the possibility of matching by tapering.

12. Propagation in Waveguides Containing Ferrites (H. Suhl and L. R. Walker)

This work, which is carried on partly under a waveguide research program using Bell System funds, has been followed through to the point where one has a rather complete description of the modes of propagation of cylindrical guide containing a ferrite. The properties of the ferrite are for definiteness supposed to be given by Polder's theory, which, whether correct in detail or not, provides a good qualitative description of the behavior.

13. Millimeter Wave Low Voltage Reflex Klystron (E. D. Reed, L. B. Luckner, F. P. Drechsler)

13.1 General

The millimeter tube effort in the last quarter consisted of

- a), completing the design of assembly tools and jigs,
- b) receiving, inspecting and processing of tube parts,
- c) proving-in of tools and assembly techniques.

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- d) completing beam-pulsing equipment,
- e) additional electrical measurements on full scale cavity model and
- f) planning and ordering waveguide test equipment.

These activities fully occupied our assembly force so that no further work was done on the demountable fixed frequency 6.25 millimeter reflex klystron.

13.2 Preparation for Assembly of First 5.4 Millimeter Tube

The design of this tube was shown and described in the last report. Except for the cavity block all parts have now been received and processed and are ready for incorporation in the first tubes to be built. Some subassemblies such as bulb-and-tuner assembly, G2-diaphragm-repeller housing assembly, stems, etc. have also been prepared. The only remaining bottleneck is the cavity block. Our present hubbing tool, the original purpose of which was to prove the feasibility of hubbing, was made with machinery lacking the required precision and is dimensionally slightly incorrect. The resulting impressions therefore require excessive machining, a process which not only is very time consuming but also mars some of the cavity surfaces. There is hope, however, of getting a number of good parts in the near future. The problem is currently being attacked by two precision shops independently. One, an outside supplier, has succeeded in making a die insert which is almost right and will require only minor touching up to

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give us a dimensionally perfect impression. At the same time the Precision Room at Murray Hill Model Shop has undertaken to deliver six finished cavity blocks to us by the middle of January. Work is progressing in the meantime to establish and prove in all other assembly techniques.

Tests have been made on the tuning mechanism using a sensitive dial-gage to measure diaphragm motion. Its performance may be judged from the curve of Fig. 1, which shows that the change in grid separation of about $1\frac{1}{2}$ mil, which is required to tune over a 10% band, will be achieved by about four revolutions of the tuning screw. Final judgment on the adequacy of this tuning scheme cannot, of course, be made before its performance within a working tube has been observed, but the preliminary test described shows promise.

Barring any major setbacks, the first 5.4 millimeter tube should go to the pump in January. Present plans call for initial operation under pulsed conditions in order to avoid possible grid burnouts and to reduce cavity losses due to the presence of white-hot tungsten grids. A simple pulse unit has been constructed and tried out. It is capable of delivering 50 microsecond pulses of a magnitude ranging from 300-600 volt to the focusing anode.

13.3 Q-Measurement on Full Scale Cavity Tester

The last Quarterly Report described a 5.4 millimeter tunable cavity tester which confirmed the cavity dimensions

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PERFORMANCE OF MECHANICAL
TUNER

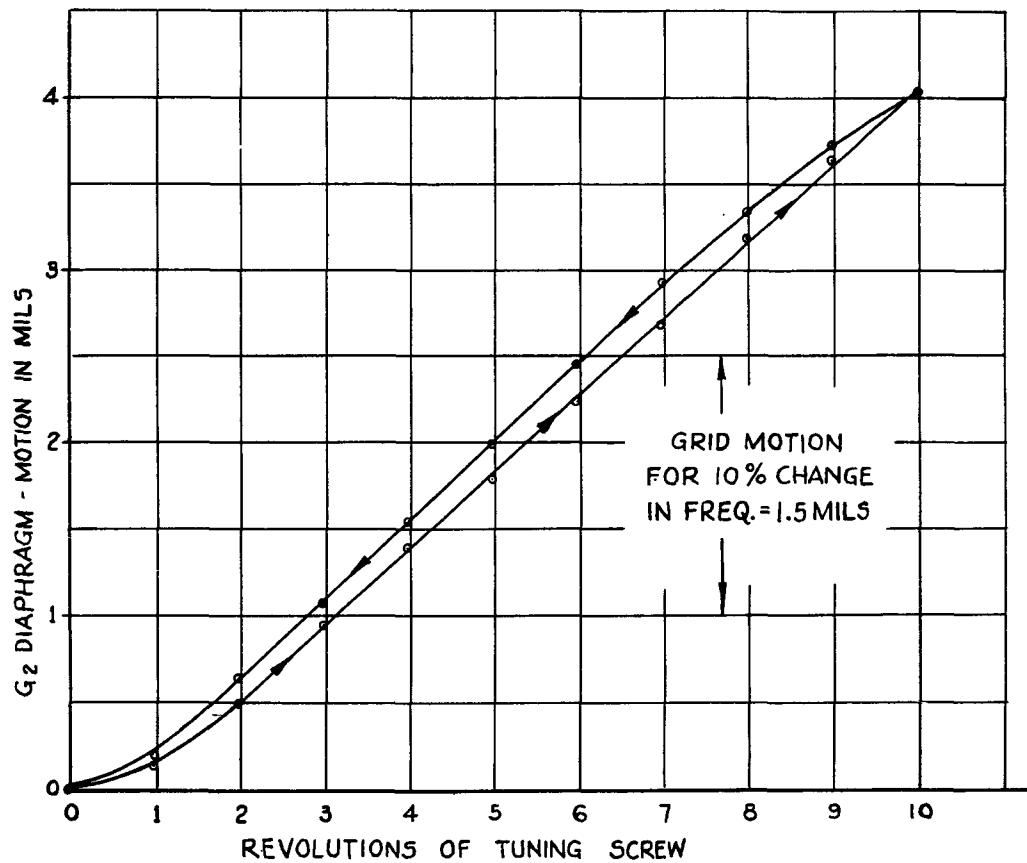


FIGURE 1

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INCORPORATED, NEW YORK

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obtained by scaling from 4,000 mc brass models. This cavity tester was taken to Holmdel and its Q determined using Mr. Ring's equipment. The value of internal Q was found to equal 470, which is appreciably lower than the theoretical value of 800 obtained by scaling Q measured on 4,000 mc brass models to 55,500 mc. As was also pointed out in the last report, this 5.4 millimeter cavity model was made using a dimensionally imperfect hubbing tool, thus necessitating a number of corrective machining operations which resulted in a fairly rough cavity surface. The experiment will be repeated as soon as a hubbing tool becomes available which will yield smooth resonator walls.

13.4 Waveguide Test Equipment

Considerable effort was spent collecting information, redesigning and ordering the components for a waveguide test setup. These include attenuators, directional couplers, wave-meters, a harmonic generator, etc. Since none of these items are available commercially, complete sets of drawings and engineering information had to be gathered and supplied to our machine shops. All parts are now on order, some have already been received and the balance is expected early in January. The major portion of the design information was made available by Mr. Ring of the Holmdel Laboratory and all components are interchangeable with equivalent units now in use with other groups at the Laboratories.

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14. Very Close Spaced Broad-Band Tetrodes (C. T. Goddard, N. C. Wittwer, E. J. Walsh)

14.1 Job Status

Most of the parts for the M1843 broad-band tetrode are now on order. It is expected that the first samples will be assembled some time in March 1953. In addition to completing the design of the above tube, effort has been concentrated on mechanical and circuit properties of the basic structure and its vacuum enclosure. Studies of the electrical properties of conventional enclosures are continuing through the medium of large scale models and by high frequency measurements of Bell System broad-band electron tubes. The latter studies are being charged to Bell System funds.

14.2 Electrical Studies

Measurements of input conductance of a 10:1 scale model have been attempted by direct substitution, by susceptance variation and by a voltage divider technique. In each of these three methods the tube input is resonated, which requires a determination of the equivalent shunt resistance of the tuning inductance. These values of shunt resistance were found to be the order of one fifth to one tenth of the input resistance of the tube predicted from earlier measurements. Since the measurement of the Q of the tuning coils on the Q meter made these methods at best no better than a straight Q measurement of the model tube, they have been abandoned in favor of the Q meter

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technique. The studies have been further complicated by oscillations which are difficult to suppress without affecting the true values of input resistance.

Q meter type measurements on a stable structure are now in progress but complete families of curves are not yet available.

In preparation for direct high frequency measurements on M1843 tetrodes a study of techniques using the General Radio admittance meter has been completed. Measurements were made of the input conductance of Western Electric 404A vacuum tubes in the range 90 to 250 mc. Good agreement was found with theoretical values of input conductance and the technique appears to be directly adaptable to the M1843. Since 404A tube performance is an item of telephone interest, all work on this phase of study has been charged to Bell System funds.

The results of a study of interstage networks for use with the M1843 tetrode were reported in the last Quarterly Report. The problem of obtaining large impedance transformation over frequency bands in excess of one octave indicates that operation of the tube at frequencies of the order of several hundred megacycles would simplify the network problem of attaining superior broad-band performance. Insufficient time remains under the present contract to permit the construction of tubes in this frequency range, but some study of means of adapting the basic structure to higher frequencies has been

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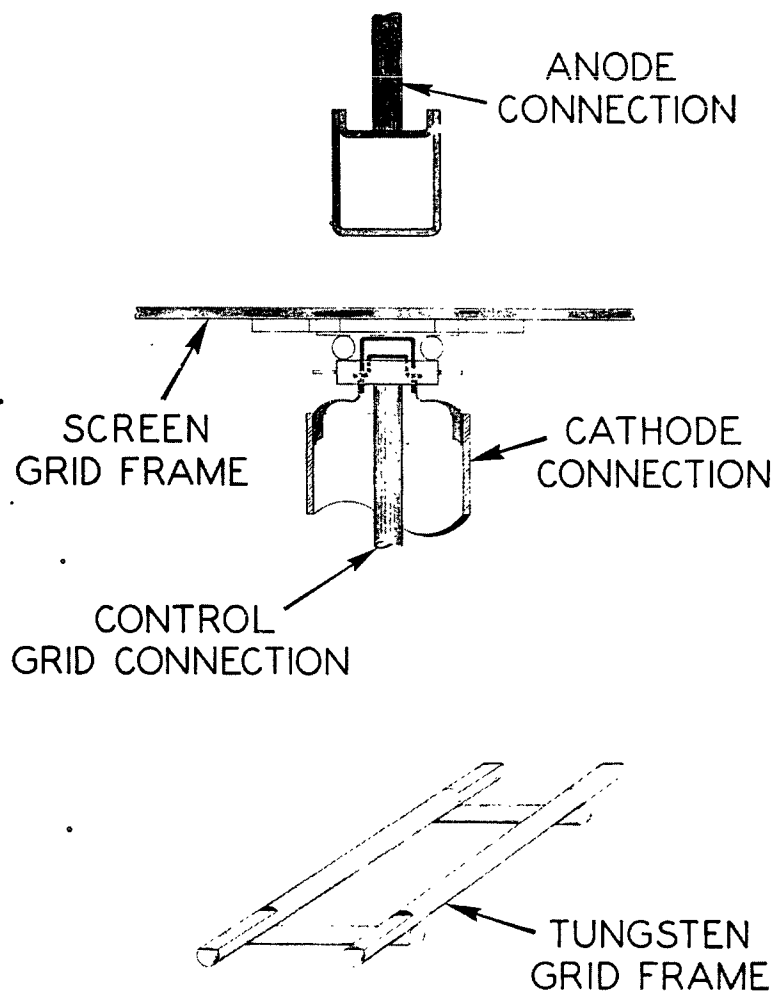
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initiated. The inherent superiority of tetrodes over triodes in gain and bandwidth, previously reported, has directed attention toward adaptation of the tetrode to a grounded cathode structure having a minimum of cathode circuit impedance. Design factors which minimize coupling between the electron stream and the control grid circuitry will reduce both input loading and induced grid noise at high frequencies. The incorporation of a coaxial shielded input connection is desirable in this respect and will also help in raising the frequency of input circuit resonance.

The results of a preliminary study of methods suitable for attaining the above goals are shown in Figures 1, 2, and 3. Figures 1 and 2 show a desirable means of obtaining low impedance r.f. connections to the M1843 tetrode electrodes for adaptation to the enclosures shown in Figure 3. The structures show both the all tungsten control grid frame and a ceramic grid frame which appears to possess some desirable features. Three possible enclosures are shown in Figure 3. The enclosure of Figure 3A would be desirable for use where all elements of the interstage network are to be external to the tube. The all metal envelope of Figure 3B could be utilized where a part or all of the interstage network is to be within the vacuum enclosure. The vacuum enclosure of Figure 3C was designed for tetrode use in another department of the Bell Laboratories. A few vacuum envelopes of this type were con-

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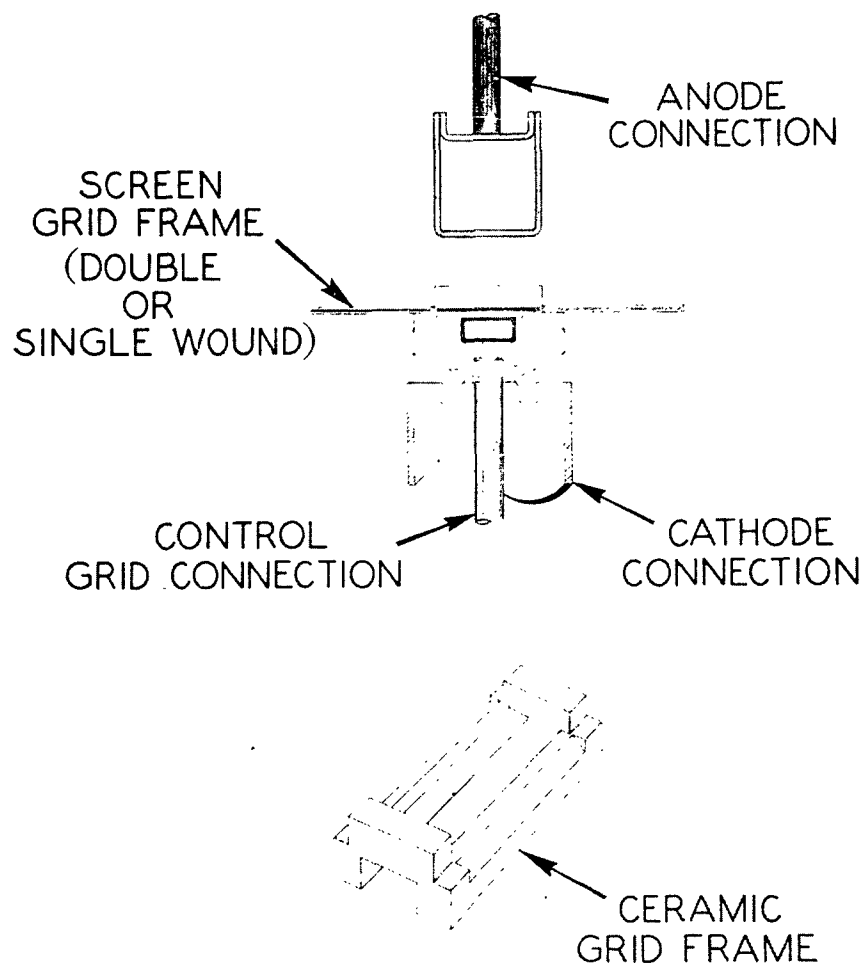
HIGH FREQUENCY TETRODE PRELIMINARY CONSIDERATIONS

FIG. 1

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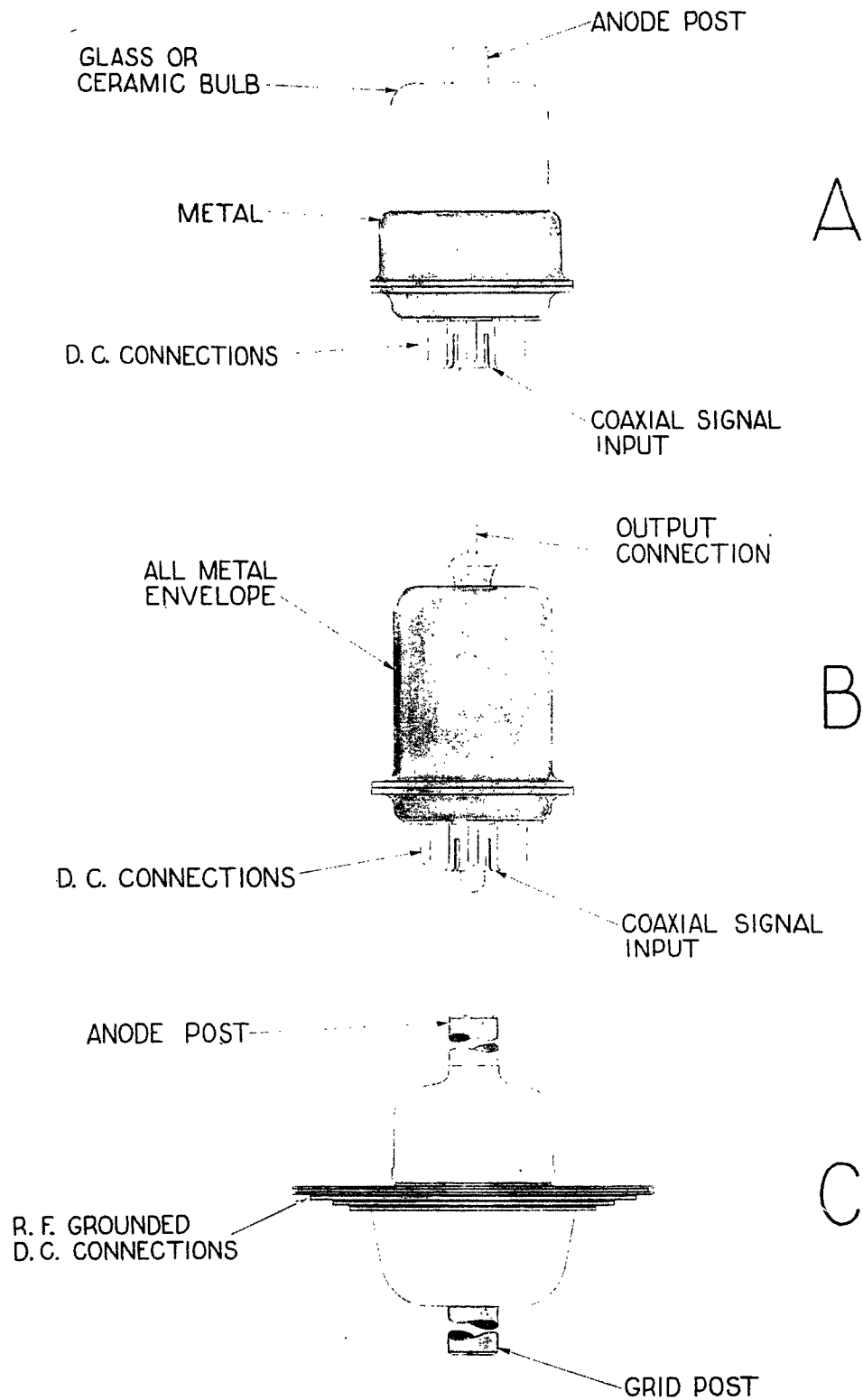
HIGH FREQUENCY TETRODE PRELIMINARY CONSIDERATIONS

FIG. 2

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FIG. 3

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structed on Bell System funds about a year ago.

Details of internal bypassing of cathode and screen grid to the metal bulbs to combine the internal and external structures of Figures 1, 2 and 3 have been analyzed but are not shown. The omission is intentional to emphasize that a considerable amount of effort would be required to capitalize on the ideas expressed here.

14.3 Mechanical Problems

All large tetrodes assembled in the past have been characterized by short life. This problem has been discussed at length in previous reports. The difficulties have been attributed at various times to an inability to obtain or maintain flat cathodes, to poor control of spacings or variation of spacing during life, to a lack of tension in grid wires or to a high operating grid temperature. In order to pinpoint the source of trouble the first two of the above items have been studied during the past quarter.

A total of forty diodes were constructed for test. These tubes are identical in assembly to the large tetrode except that the control grid wires were replaced by a solid steel plate for the diode anode. Four lots of ten tubes each were assembled, having spacings of .0005 and .0010, .0015, and .0020". The cathodes used were obtained by surface grinding one side of our regular "commercial" rectangular cathodes. Measurements of capacitance made after assembly and during life

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have been used as a means of assessing control of product quality. The results indicate that we are able to fabricate a tube with input spacing tolerances of approximately $\pm .001$ " and that a random change in spacing of this same magnitude occurs during life. The cathodes used were of better quality than had been used in earlier tetrodes. Three of the forty diodes showed intermittent shorts when tapped, and it appears that these were due to metallic particles trapped in the structure during assembly.

As a result of the above tests it appears that major mechanical studies may now be turned to grid wire tension and grid operating temperatures.

In the course of these studies a means was developed for the measurement of flatness of surfaces. The measurement of flatness of cathodes or control grid planes is particularly difficult by conventional means because the fragility of the surfaces precludes any procedure in which the surface is physically contacted by a measuring probe. The matte surface resulting from surface grinding or from the application of cathode coating discourages measurements in which the wavelength of light is used as a reference standard. However, a non-contacting method using a beam of light and the geometrical type of "interference" pattern obtainable with a grating was found to be satisfactory.

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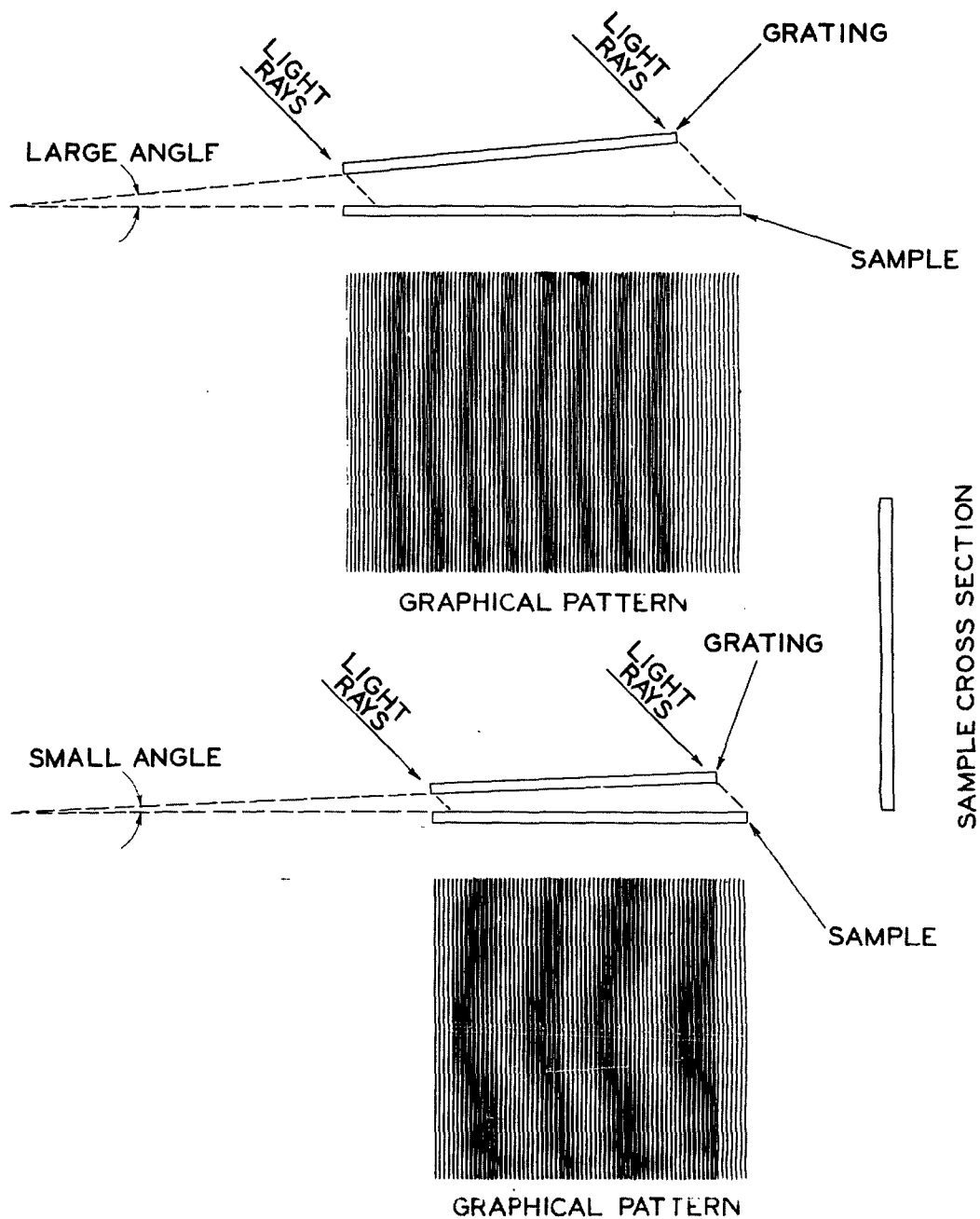
A graphical demonstration of the method of surface flatness measurement developed is shown in Figure 4. A cross section of the sample to be tested is pictured at the right edge of the figure. The departure from flatness of one surface is clearly visible. Two graphical patterns are shown, each pattern being developed by the geometrical arrangement of the sample, a ruled grating and a source of parallel light as shown immediately above the patterns. The shadows of the individual ruled lines of the grating are not straight lines as may be seen at the right edge of the graphical pattern. If the observer looks at these shadows through the grating from above he will see the graphical pattern indicated. The dark shadow bands provide a linear magnified picture of the cross section of the sample surface.

An analysis of the geometry of the system demonstrates that the dark bands are distorted by an amount equal to the distance between adjacent dark band centers when the surface departure from flatness is equal to the spacing between grating lines for an incident light angle of 45 degrees. This relation is independent of the angle between the grating and the sample surface. The angle may be adjusted to any convenient small value to permit a simple determination of the ratio of dark band distortion to the distance between dark band centers. A report describing methods of obtaining quantitative measurements of flatness is in preparation.

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GRAPHICAL DEMONSTRATIONS OF FLATNESS MEASUREMENT



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FIG. 4

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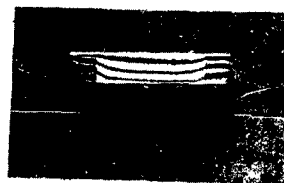
The application of the grating method to flatness measurements is shown in Fig. 5. The grating used was 50 per cent opaque and was ruled 400 lines per inch. The coated commercially flat cathodes used in almost all tubes prior to October 1952 were found to contain longitudinal valleys the order of one mil deep. These are clearly visible in the lower pictures. The two top pictures show variations in coating thickness and excessive longitudinal bowing of the commercially flat sample. The technique is being extended to permit an accurate measurement of coating thickness, which is the order of .0005" on all cathodes. The superiority of the surface-ground cathode is obvious. Such cathodes were used in the diode testers described above.

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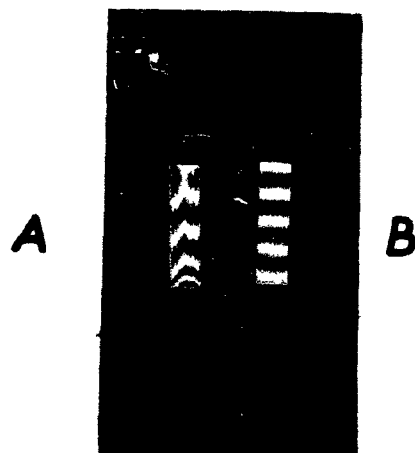
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A



B



A

B

A COATED COMMERCIALY FLAT CATHODE
B COATED SURFACE-GROUND FLAT CATHODE

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FIG. 5

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