I MICROWAVE AND PHYSICAL ELECTRONICS

A HIGH-POWER MAGNETRON RESEARCH

Staff Professor S T Martin
D L Eckhardt
J H Henry
V Mayper
R R Moats
W Rotman

Description of Project The purpose of this project is to explore the fundamental engineering problems which limit the power obtainable at microwave frequencies Several objectives have been established for investigation

(a) Establishing the suitability of output windows of mica steatite or other low-loss material

(b) Establishing the value of the sintered thoria cathode as an emittor for high-power tubes and a suitable technique and procedure for fabricating such cathodes

(c) Determining causes and limits of mode stability in the magnetron, at high-current levels

(d) A better understanding of the dynamics of the space charge, and its noise properties

(e) The production of a magnetron scaled to 10 7 cm from the AX-9 (a 3-cm rising-sun structure which has produced 1-Mw pulse power at 1/2 μsec) and determination of the limiting power obtainable from it

Status The assembly of the high-power tube referred to in part (e) above has not been completed because of metallurgical problems arising in the arc-welding of the kovar cup, in which the glass window has been sealed to a similar member brazed to the tube These problems have been traced to impurities in the kovar which boil out causing leaks and cracks in the weld A solution has been found which consists of prefiring the kovar parts in hydrogen for one-half hour at 1000°C Perfect leakless (to 10^{-8} mm of Hg) butt welds can then be made by arc-welding in an inert atmosphere The length of such welds has exceeded 12 inches Heating of the window during welding can be so controlled that, while strained it will not break Strains are removed during bake-out on the pumps

A pressurized test bench capable of working to 10 atmospheres is nearing completion This is necessary in order to establish the performance of the tube at high-power levels particularly where Rieke diagrams are desired

Work on the fabrication and assembly of mica windows has been held in abeyance since the last report because of a lack of materials a deficiency which has recently been corrected

Research on thoria cathodes, referred to in part (b) above has progressed to the point of fabricating several specimen pieces This work has been considerably accelerated by advice and information received from the Magnetron Development Laboratory under W C Brown at the Raytheon Manufacturing Company Techniques adapted from powder metallurgy appear quite promising Cathodes 0 5 in in diameter (before firing and having a wall thickness of about 0 050 in and approximately one inch long have been molded from thoria powder, thoria and tungsten, and thoria and tungstic oxide The mold is made from highly polished high-chrome, high-carbon steel (Crucible Steel Company, type HYCC) A mixture of the powder and 3 per cent (by weight) of carbowax, a water-soluble crystalline wax, is pressed at a pressure of 40 tons/sq in The piece is fired at 1800°C in hydrogen for one-half hour, resulting in a very strong hard ceramic Pieces made of pure thoria have a density of 9 2 g/cm^3, very nearly the theoretical value The above molding pressure and quantity of lubricant are not sufficient to prevent an undesirable variation in the density in the molded piece (ends are denser than the center), resulting in a variable shrinkage during firing Higher pressures and more lubricant will be tried to remedy this problem

Mode separation tests on brass models of X-band magnetron anode blocks as described in the Progress Report of April 15, 1947, have been completed, and the variation of frequency separation between the π-mode (n=9) and the n=8 mode as a function of slot widths has been found to be substantially as predicted by field calculations Oscilloscope patterns showing the detected radial component of the oscillating electric field inside the model anode block as a function of azimuth were studied, and the observed patterns compared with those predicted from field theory By making field computations at a radius approximating the mid-point of the rotating electrostatic probe reasonably good agreement between the calculated and observed fields was achieved Other apparent resonances not corresponding to any known resonance of the model anode were observed, and found to be the result of resonances in the coaxial line between the probe and the crystal detector Such a resonance increases the effective sensitivity of the probe to the point where the distribution of r-f energy in the anode structure at non-resonant frequencies can be observed

Work on the causes and limits of mode stability at high currents, referred to in part (c) above has been initiated This will consist of attempting to observe the conditions under which the magnetron shifts operation from the π mode to the next higher voltage mode under steady-state conditions Several 10 7-cm c-w rising-sun anode magnetrons the voltage-scaled equivalents of the high-power magnetron referred to in part (a), are being constructed for this experiment

Some exploratory work on the noise properties of the magnetron in its <u>pre-oscillating</u> state is being undertaken Its continuation depends on the character of preliminary results

B CATHODE RESEARCH

1 Cathode Interface Studies

Staff A S Eisenstein

Experiments described in the last progress report indicate that when thermionic emission currents are drawn from an oxide cathode, the flow of current through the interface and coating gives rise to a voltage, V_{ic} which appears between the base metal and vacuum surface of the coating Under pulsed conditions this voltage is not negligible as compared to the voltage V_a applied between the cathode base metal and the anode

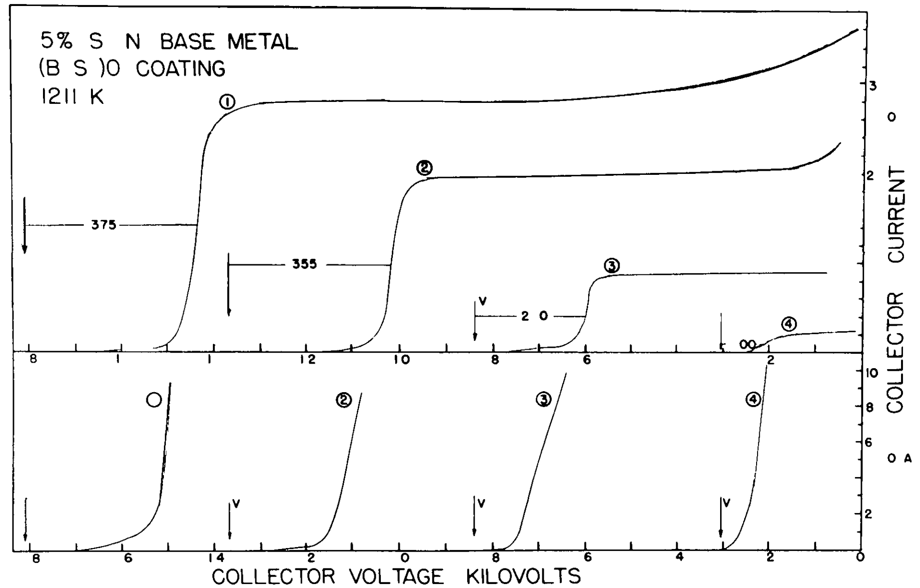

Figure 1 Retarding potential characteristics

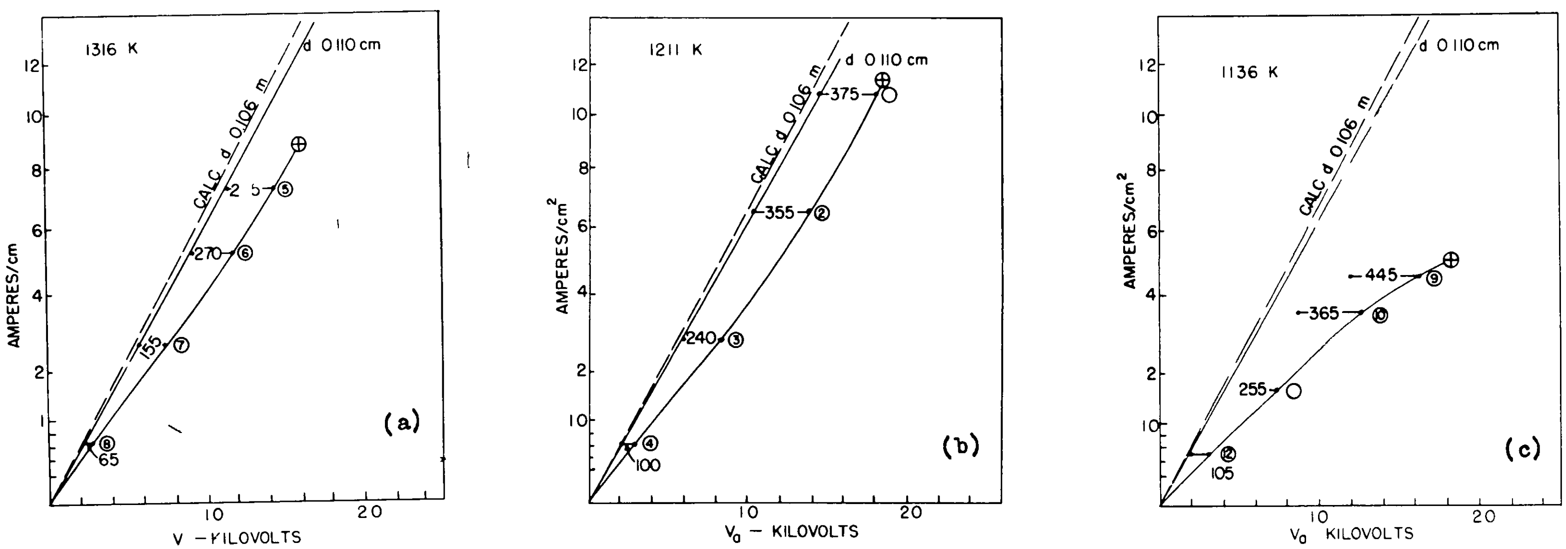

Figure 2 Voltage-current characteristics

Thus the experimental voltage-current characteristics of a diode show disagreement with the theoretical Langmuir-Child characteristic by a voltage displacement of V_{ic} The emission characteristics of cathodes having a Ba_2SiO_4 interface seem to show this effect

The actual voltage which appears between the vacuum surface of the coating and the anode (V_a-V_{ic}), may be computed from measurements of the potentials assumed by probes embedded in the coating at different depths A more direct method of determining this voltage has been devised Retarding potential measurements are made on electrons which pass through a small hole in the anode and are then collected by a suitable electrode As the cathode of the tube is pulsed negatively the average current which passes through the hole is measured as a function of the d-c retarding potential applied to the collector electrode Typical characteristics are seen in Fig 1 for the operating voltage-current conditions shown in Fig 2b Curve (1) of Fig 1 indicates the operating point as 1 81 kv and 11 amp/cm^2 As the collector voltage is made negative and approaches the potential of the coating surface the collected current suddenly drops to a small value The potential of the oxide surface with respect to the anode (V_a-V_{ic}) appears from curve (1) to be about 1 44 kv indicating an interface-coating voltage V_{ic} of 375 volts This voltage is then used as a correction to the applied base metal-anode voltage, V_a, Fig 2b The resulting characteristic is seen to be in close agreement with the theoretical Langmuir-Child curve which was computed on the basis of a 0 106-cm anode-cathode spacing The experimental characteristic corresponds to a spacing of 0 110 cm

At a higher temperature Fig 2a similar results are obtained At a lower temperature however, Fig 2c points (9), (10) and (11) no longer agree with the d = 0 110-cm curve and the cathode is operating under non-space charge limited conditions At still lower temperatures values of V_{ic} have been observed up to 850 volts On the basis of Mutter's double-probe experiments which show most of the voltage as appearing across the interface and x-ray measurements of the interface thickness, it seems likely that voltage gradients across the interface may reach 10^6 volts/cm

An interesting and unexpected result of this experiment is the observation that a small number of electrons arrive at the anode with energies up to V_a This may be seen in the lower set of curves in Fig 1 It is presumed that at least part of these electrons are emitted from cracks in the coating Further studies of this phenomena are under way

2 The Interface as a Blocking Layer

Staff W E Mutter

No further progress to report at this time

3 Conductivity and Work Functions of Oxide Cathodes

Staff G W Mahlman

Standard diodes having cathodes of pure nickel (Wise No 1) and single platinum probes embedded in the oxide coating are being made to determine the feasibility of measuring the conductivity of the oxide coating by means of a single probe The pure nickel base metal presumably will not form any appreciable interface, hence a single probe should suffice to determine coating conductivity These experiments are preliminary to an experiment to determine conductivity and photoelectric and thermionic work functions of oxide cathodes The tube for such an experiment is still under construction

4 Spectral Emissivity of Tungsten

Staff Professor W B Nottingham
W E Mutter

The basic plan of this experiment is described in the progress report of October 15, 1946

The envelope for the tungsten black-body source has been redesigned to facilitate replacement of filaments Water cooling has also been provided for the input leads The original filament, formed from 0 0018 in tungsten foil, buckled on heating because of failure of the expansion joint A second filament was made from sintered tungsten tubing, but this cracked during assembly Filaments are now being made from the original foil, and it is believed that with an improved expansion joint and better filament-forming dies, this type of filament may be operated successfully

A compact vacuum tube electrometer setup using the Victoreen VX-41 miniature electrometer tube has been built Although this equipment may be used to some extent in the emissivity work, it will be available for measurement purposes wherever needed

Some preliminary tests have been made to estimate the range of wavelengths over which emissivity measurements may be made A 931A photomultiplier circuit designed by Professor Nottingham was used For a given source temperature the long wavelength limit arises from the falling spectral response of the S4 photocathode while on the short wavelength end, the limitation arises primarily from the rapidly decreasing spectral emissive power of the source and the poor transmission of the glass bulbs With a tungsten ribbon filament operating at approximately 1600°K and a monochrometer aperture 0 008 in by 0 010 in (bandwidth about 10A in the ultraviolet and 150A in the red) it was found that the emergent light intensity could be measured within 1 per cent at 3500A and at 6300A In spite of the poor response characteristic of the 931A photomultiplier, there is still enough photoelectric current generated from radiation at 8000A to be measured with an accuracy of about 10 per cent Close to the same accuracy is found at the wavelength 3200A

The electronic equipment used with the 931A tube for these tests has been developed recently in connection with a project not sponsored by the Research Laboratory of Electronics The performance of the equipment has turned out to be so satisfactory and capable of giving such quantitative measurements at very low levels of light flux that plans are now under way for duplication of the equipment for RLE purposes It is for that reason that a brief description of the equipment is offered here In order to achieve the accuracy of measurements desired extremely stable power supplies are required New circuits using old principles have been designed for a 250-volt supply, a 300-volt supply, and the photomultiplier supply with a range of 250 to 1000 volts The low-voltage supplies have an internal resistance of the order of 1 ohm and the compensation for line voltage variations from 105 to

125 volts is practically perfect For very slow variations in line voltage, the circuit is very slightly over-compensated, while for variations that take place so rapidly that the heaters of the tubes involved do not change temperature appreciably, the circuit is slightly under-compensated The high-voltage supply for the 931A tube is practically perfect'y compensated at all voltages within the limits specified

The indicator system itself has built into it potentiometers and very accurately calibrated resistors As a consequence, accurate measurements can be made over a range of radiation flux values that extends through at least five orders of magnitude Although the total weight of the equipment as it is now designed is approximately 100 pounds, it is broken into three boxes so that it becomes easily portable and can be used in a very wide variety of experiments The first application to which the equipment will be made, as soon as the RLE version is completed will be that of the investigation of the spectral emissivity of tungsten

5 Electron Emission in Accelerating and Retarding Fields

Staff Professor W B Nottingham
C S Hung

Although this work has been interrupted for a few months, it is well under way again and a new tube for the investigation of this subject will be available shortly

C IONIZATION GAUGE RESEARCH

Staff Professor W B Nottingham

The ionization gauges of a new design and a conventional design are now on a vacuum system and are being compared over the entire range of pressures suitable for ionization gauge measurements No conclusions have yet been drawn concerning the results of these experiments

D PROPERTIES OF CATHODE-RAY TUBE SCREENS

Staff Professor W B Nottingham
W T Dyall

The specialized equipment referred to in the April 15 Progress Report has now been reconnected and is practically ready for operation As soon as the preliminary standardization runs have been made it is anticipated that a full-time program will be carried on for the next quarter for the evaluation of special properties of cathode-ray tube screens

E DETERMINATION OF EMISSION PROPERTIES OF SINGLE CRYSTALS

Staff Professor W B Nottingham
C J Marcinkowski
M K Wilkinson

The work on the above subject has been temporarily discontinued, but will be renewed actively sometime in October

I F CONSTRUCTION OF 5-MM OXFORD TYPE TUBE

Staff N G Parke

Experiments on the version of the 60,000-Mc reflex velocity-modulated tube discussed in the last progress report showed conclusively that with proper gun alignment it was possible to get almost all of the beam current through the 14-mil reentrant gap in the cavity However all three tubes tested showed a rapid fall-off in beam current during the three-hour period required to bring the beam voltage up to its operating value The most reasonable explanation for this was the fact that the tube had a ground-glass seal using stopcock grease This precluded a 450°C bake-out As a result, when the beam voltage exceeded 1200 volts the gas coming out of the bottom electrode of the cavity contributed to a destructive positive-ion bombardment of the cathode Thus none of the three tubes was able to reach the estimated 4-ma starting current for oscillation To overcome these difficulties, the tube has been completely redesigned and has assumed a less engineered and more experimental appearance The new design has the following interesting features

(1) The gun may be aligned during operation by three thermal aligning struts

(2) The cavity is thermally tuned by a single strut

(3) The reflector is hollow and positioned by a small ceramic sleeve

(4) The gun is positioned by an accurate jig while being spot-welded to the aligning mechanism

(5) The whole mechanism is enclosed in a $2\frac{1}{2}$" x 7" glass envelope and will be baked out as long as necessary at 450°C

Parts for five tubes have been completed and the assembly of one tube is nearly complete

G TRAVELING-WAVE AMPLIFIER TUBES

1 Theoretical Considerations

Staff Dr L J Chu
J D Jackson

A paper under the title "Field Theory of Traveling-Wave Tubes" was published recently as RLE Technical Report No 38 The material was presented at the I R E Electron Tube Conference at Syracuse New York and the Second Annual Congress of the Canadian Association of Professional Physicists, London Ontario

For a narrow beam it has been shown in this report that the a-c convection current bears a linear relationship with the axial electric field E_z

$$I_z = \left[\frac{j\omega \frac{e}{m} I_o}{v_o^3 \left(j\frac{\omega}{v_o} - \gamma \right)^2} \right] E_z$$

where I_o is the d-c beam current

v_o is the d-c electron velocity

$\gamma = \alpha + j\beta$, the propagation constant

The rate of increase of power along the tube is equal to the time average of the product $-E_z I_z$ which can be equated to $-\alpha E_z^2/Z$ where Z is the ratio of $2P/|E_z|^2$ The result is a cubic equation

$$\alpha\left[\frac{e}{m}\frac{\omega I_o Z}{v_o^3} - (\alpha^2 + \overline{\Delta\beta}^2)^2\right] = 0$$

where $\Delta\beta = \beta - \omega/v_o$ From this equation, we get

$$\alpha_1 = 0$$

$$\alpha_2 = -\alpha_3 = \sqrt{\left[\frac{e\omega I_o Z}{m v_o^3}\,\Delta\beta\right]^{\frac{1}{2}} - (\Delta\beta)^2}$$

The maximum value of α_2 is obtained by differentiating α_2 with respect to $\Delta\beta$, assuming that Z and v_o are constant

$$\alpha_{max} = \frac{\sqrt{3}}{2}\left(\frac{e I_o Z\omega}{2m}\right)^{\frac{1}{3}} \frac{1}{v_o}$$

This is the formula obtained by Pierce and Kompfner

2 Experimental Studies

Staff Professor J B Wiesner
L A Harris

Description of Project The purpose of this project is to build traveling-wave tubes for X-band operation, and to study their characteristics

Status Several tubes have been constructed since publication of the last progress report Of these one tube had a very small gain when used on S-band This gain, however, was much smaller than the cold insertion loss, so that there was no net gain

A study of the problem of coupling energy from the waveguide to the helix indicates that the waveguide holes through which the tube projects must be made much smaller With the present size of hole used a considerable radiation takes place and the presence of the glass envelope aggravates this situation

The other factor which prevents the tube from operating as desired is the lack of sufficient beam current along the axis of the helix Because the helix and tube must be made smaller, and because the beam current must be increased considerably, efforts will be directed principally at producing an electron gun which will meet these requirements Once this is achieved, it appears likely that the traveling-wave tube may be made to function with reasonable success