

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

Introduction. The construction of a 10-Mw pulsed magnetron at 10.7 cm remains the focus of a group of related researches. These are:

- (1) The fabrication of a suitable output window for waveguide coupling of the magnetron, capable of sustained operation at an average power of about 10-20 kw.
- (2) The design and fabrication of a cathode free from the sparking or arcing troubles encountered with oxide cathodes at high voltages and high currents.
- (3) A study of the mechanism of mode jumping observed as the power output of a magnetron is increased.
- (4) Collateral with Item (3), a study of the buildup of oscillations in a given mode from the random noise generated by the space charge.
- (5) A study of the noise generated by the space charge in a cavity magnetron at voltages and currents below which coherence in the space-charge structure may be observed.

The production of a suitably evacuated high-power magnetron scaled from the AX-9 has not yet been achieved. The first tube failed on the pumps because of the development of a split in the kovar cup which supported the output window. Assembly of a second tube has been delayed pending the resolution of minor troubles with the hydrogen supply which has prevented fabrication of a leakless ceramic window for this tube. The problem is to reduce the concentration of oxygen and water vapor to the point where the titanium hydride brazing process, developed by the General Electric Company, is effective.

Progress on the items enumerated above is detailed in the sections below. In summary, all of these problems are in an intermediate stage of development and not yet advanced to the point where decisive conclusions may be reached.

1. Ceramic Windows

Staff: D. L. Eckhardt

Circular ceramic windows having a diameter of about $1\frac{1}{2}$ in. have been successfully brazed into both chrome iron and kovar. Eutectic silver

solder was used. Wetting of the ceramic was obtained by the use of titanium hydride. The seals were made with the ceramic in compression. They were tested over several cycles of heating to 450°C and 500°C, followed by cooling to room temperature. The vacuum continuously improved, finally giving no registration on an ionization gauge nominally calibrated to indicate a minimum pressure of 10^{-8} mm of Hg.

Windows $3\frac{1}{2}$ in. in diameter have been made without cracking but either the solder failed to wet a small portion of the seal, leaving a leak, or the metal surrounding it failed when stressed during evacuation. The latter defect is attributable to the flimsiness of the chrome iron obtainable, not to the seal. It has been observed that even though extreme precautions are observed to purify the hydrogen (passing it through calcium oxide, phosphorous pentoxide, hot magnesium, and hot copper, in succession), uniform results are not obtained in the resulting flow of solder on the ceramic. Usually a black, sooty surface is evident on the exposed part of the solder. The composition of this is unknown. It would appear from this experience that vacuum firing is preferable, in spite of the inconvenience of this procedure as compared to hydrogen furnace operation.

2. Thoria Cathodes

Staff: J. H. Henry

Work beyond that detailed in the last progress report has been held in abeyance since September. It will be resumed in January.

3. Mode Selection

Staff: R. R. Moats

A c-w rising-sun magnetron, designed as a voltage-sealed equivalent of the high-power 10.7-cm magnetron under construction, has been completed. Preliminary tests show the presence of at least two modes of operation at voltages lower than the threshold voltage for the π -mode, and that the voltage ranges for these two modes overlap. Both are surprisingly strong. In order to obtain stable operation throughout the range of currents required to cause the shift in mode of operation, pulsing will be required. Because of the requirements a 50-70 microsecond pulse has been determined the most satisfactory for the experiment and present effort is to assemble the necessary equipment.

4. R-F Buildup Time

Staff: Walter Rotman

As discussed in the last progress report, the transient behavior of

a QK-61 magnetron during the buildup of oscillations has been under investigation. A high-speed oscilloscope, the "Winterscope", allowing resolution of time intervals approximating 10^{-9} seconds has been employed to photograph voltage versus time of both the applied plate voltage pulse and the r-f voltage appearing across a suitable load. Figure 1 shows typical experimental results. Curve (a) is the rise of the plate voltage as a function of

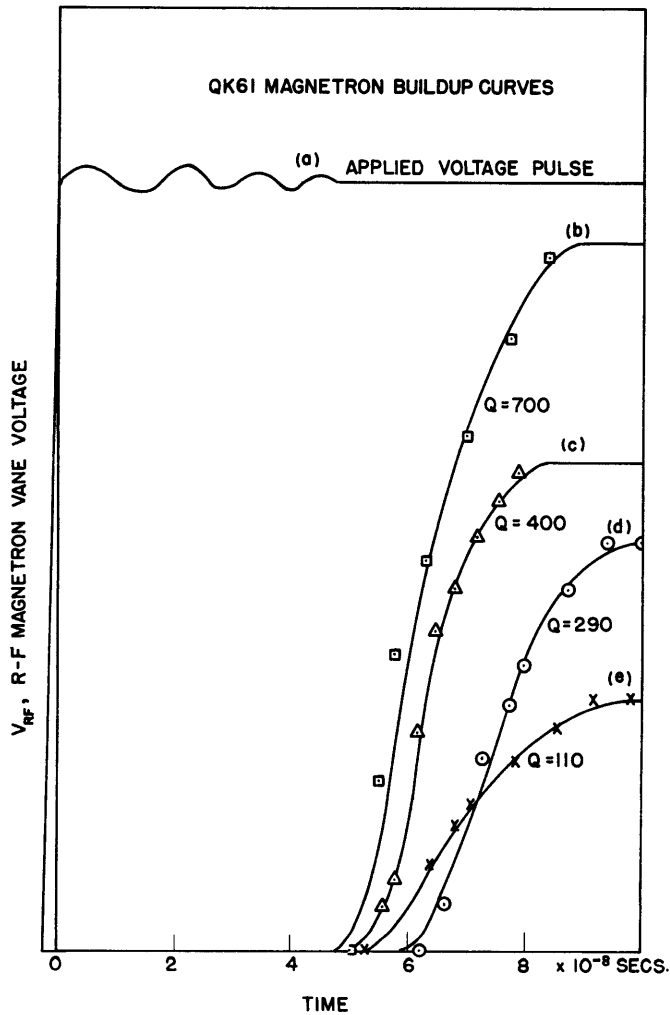


Figure 1. Voltage as a function of time. Curve (a) is the applied plate voltage. Curves (b), (c), (d) and (e) are the peak r-f voltage on the load for several different values of loaded Q.

time, and curves (b), (c), (d), and (e) are the rise of peak r-f voltage across the load as a function of time for several different loaded Q's. All are plotted in arbitrary voltage units.

A characteristic feature always observed is the apparently finite time of several hundredths of a microsecond before any appreciable voltage is detected at the load. The exact cause of this has not been determined experimentally. The different apparent starting times for the different

loaded Q's are not known to be significant -- they may merely represent the uncertainty of time measurement from one experiment to the other.

From such measurements, phenomenological quantities such as the electronic conductance of the space charge as a function of r-f voltage across, and current to, the magnetron vanes may be determined under transient conditions. These data are considered essential to an adequate understanding of the mechanism of mode selection and the starting characteristics of the magnetron.

5. Noise Generation in the Pre-oscillating Magnetron

Staff: V. Mayper

Further measurements have been made on the noise properties of the magnetron at voltages below oscillation at constant magnetic field with the eventual objective of a more complete understanding of the behavior of the space charge. All measurements have been made on a type QK61 10-cm, 16-cavity strapped magnetron.

It has been noted that there is a sharp break in the noise behavior (as well as in the V-I plot) with increasing voltage, at a value well below the Hartree voltage of the lowest discoverable mode (in this case, the π -mode). See Figs. 2 and 3. It is at the current that corresponds to this

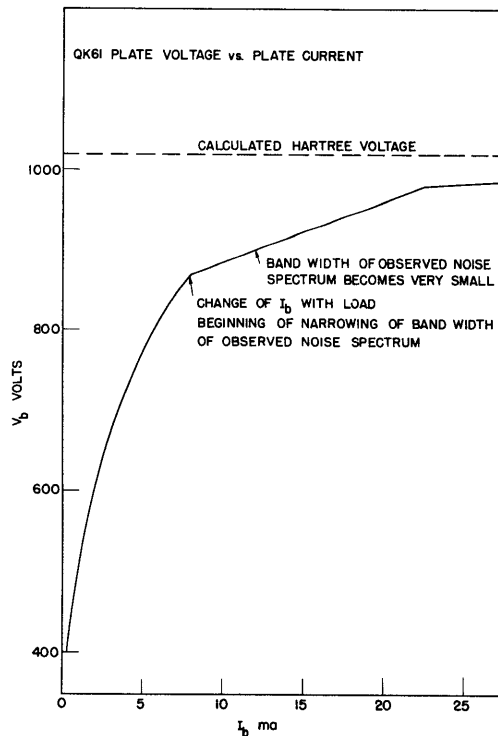


Figure 2. Principal features of magnetron plate voltage - plate current curve at constant magnetic field, in region below the onset of definite oscillation.

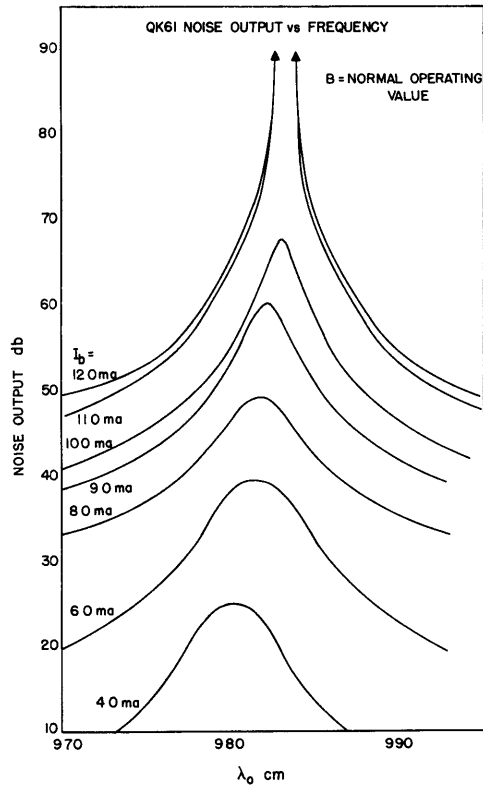


Figure 3. Noise power as a function of frequency in a QK61. Noise power reference level is that of a klystron, estimated to be about 20 db above a temperature limited diode at the same current.

voltage that, at constant magnetic field, changes in plate current with load become noticeable. Below this current (or voltage), the noise output increases exponentially with increasing plate current (an unknown fraction of this current is leakage to the end caps of the magnetron) and its frequency dependence may be represented by a constant-current noise generator in parallel with the equivalent parallel-tuned circuit of the loaded cold magnetron (see Fig. 4); above this current (or voltage) the noise output becomes less and less dependent on plate current (or voltage), and it becomes more and more peaked in frequency as if the equivalent tuned circuit were increasing in Q . This behavior continues up to and through the point at which definite oscillations can be detected; this latter point does not seem to be well-defined, but rather might be represented as the point at which the gradually narrowing bandwidth approaches infinity (or strictly, becomes limited by the non-linearity of the electronic conductance). The suggestion has been made that below the point of transition (in noise properties) the magnetron is acting purely as a d-c magnetron. Above this point phase focusing starts to produce the familiar spokes in the space-charge cloud. If one regards the magnetron as a form of tuned traveling-wave amplifier with its output run directly back into its input, then the bunches become merely a form of feedback mechanism, and the

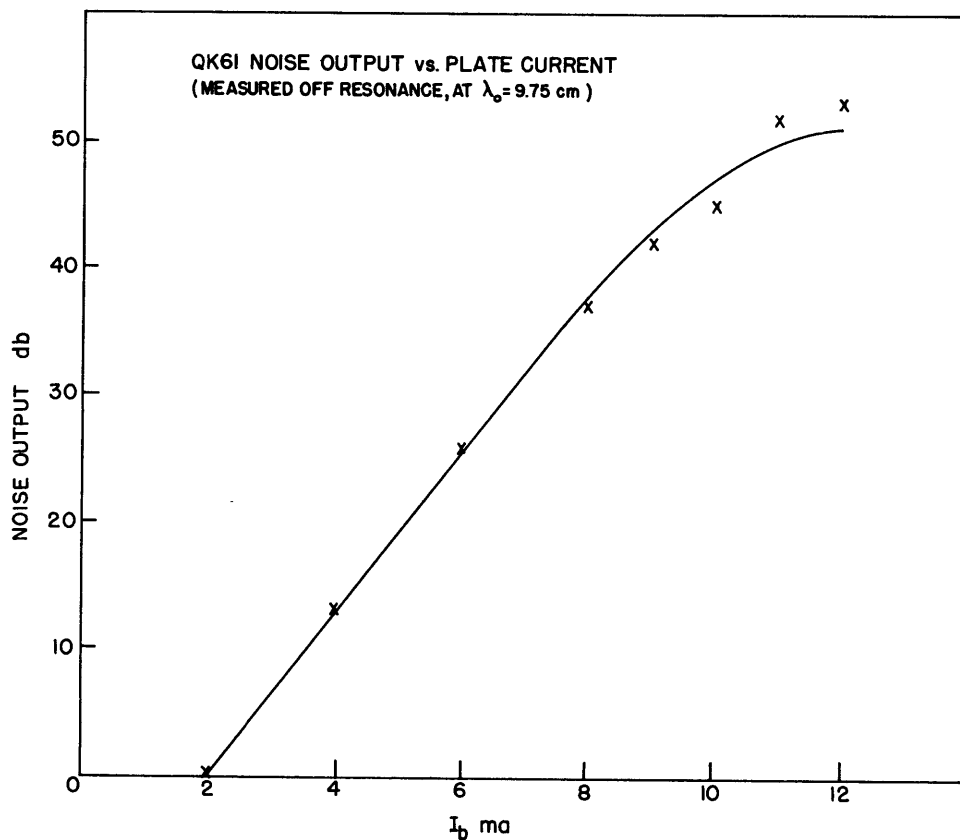


Figure 4. Noise power output as a function of plate current.

decrease in bandwidth is similar to that in a low-frequency regenerative feedback amplifier when the feedback voltage is increased.

The noise behavior with varying magnetic field is more complex, and shows peculiarities not as yet completely understood.

The actual mechanism of the noise production is uncertain. A defect of the experiment is the presence of end-cap leakage in the commercial magnetron used for the measurements; this factor is apparently quite variable in a given tube over a moderately long time, thus making measurements inconsistent and difficult to interpret. At present a tube is under construction which will eliminate this difficulty by having its end caps insulated from the oscillating cavity structure. It is expected that such a tube will be more consistent in its behavior, and that plate current readings will have more fundamental meaning.

I. B. CATHODE RESEARCH

1. Conductivity and Work Functions of Oxide Cathodes

Staff: G. W. Mahlman

Several experimental tubes have now been constructed which are designed to measure the photo-electric and thermionic work functions and the coating conductivity of an oxide cathode simultaneously. Only one of these, recently off the pumps, appears to be satisfactory in all respects. Several difficulties have been encountered in the construction and operation of these tubes. Cathodes having a coating weight exceeding 30 mg/cm^2 crack, in some cases so badly that the nickel sleeve beneath is readily visible. Badly cracked cathodes are rejected as unsuitable for coating conductivity measurements. Coatings of insufficient thickness result either in the shorting of the embedded probe to the nickel sleeve or in the probe's breaking through the coating, since the oxide coating shrinks about 30 per cent in the process of activation. Coating weights of $20\text{-}30 \text{ mg/cm}^2$ are the most satisfactory for the single probe measurements

Measurements were made on one tube of currents in retarding and accelerating fields. Schottky plots were straight with a slope of about two times the theoretical Schottky slope, over the range of temperatures $385\text{-}571^\circ\text{K}$, provided the power into the anode did not become too great. Too large currents or voltages caused an increase in emission with time over the straight-line portion of the Schottky plot. Reproducible retarding potential data yielded curves ($\log I$ vs. V/T , where I is tube current, V is collector voltage, and T is cathode temperature) whose slopes approached asymptotically the theoretical slope corresponding to the cathode temperature as measured by a thermocouple. The interpretation of these curves is otherwise doubtful at the present time. Tube leakage was excessive, and the probe was found to be open, so that no further work was done on this tube.

Results on the newest tube indicate an anomalous behavior in plots of probe voltage (with respect to the cathode) vs. probe current, but probe voltage vs. tube current plots are linear, and thus enable measurements of coating resistance to be made. It is planned to measure the variation of oxide-coating conductivity with temperature and work function of the oxide coating.

2. Spectral Emissivity of Tungsten

Staff: Professor W. B. Nottingham
W. E. Mutter

A number of measurements have now been made in the low-temperature range 1100° to 1600°K . It has been found necessary to regulate the output voltage of the d-c generator used to operate the tungsten source. This has

been done by controlling about 10 per cent of the field excitation current with a 6L6 tube. The generator voltage is bucked out by a battery and deviations from balance are indicated on a galvanometer. The light beam of the galvanometer plays on a phototube which supplies correction signals to the grid of the 6L6. The generator voltage may now be held constant to 0.02 per cent during the course of a measurement (about 15 minutes).

Figure 1 shows a typical curve of plate current of the 931A detector against distance of travel of the 0.005-in. square aperture of the monochromator along the axis of the image of the source. The peak corresponds to the passage of the aperture over the 0.0175-in. hole in the tubular light source. The current value "A" measures the power per unit area per unit range in wavelength from the miniature black-body cavity, while "B" measures the same quantity for the tungsten surface. The spectral emissivity for the wavelength for which the monochromator is set is then simply the ratio B/A.

The values of emissivity obtained are about 5 per cent high compared to Worthing and Forsythe's¹ data at $\lambda = 6650$ and 4670 , the only wavelengths at which data are available. Since all expected errors would lead to high emissivities, the design of the experiment has to be carefully considered.

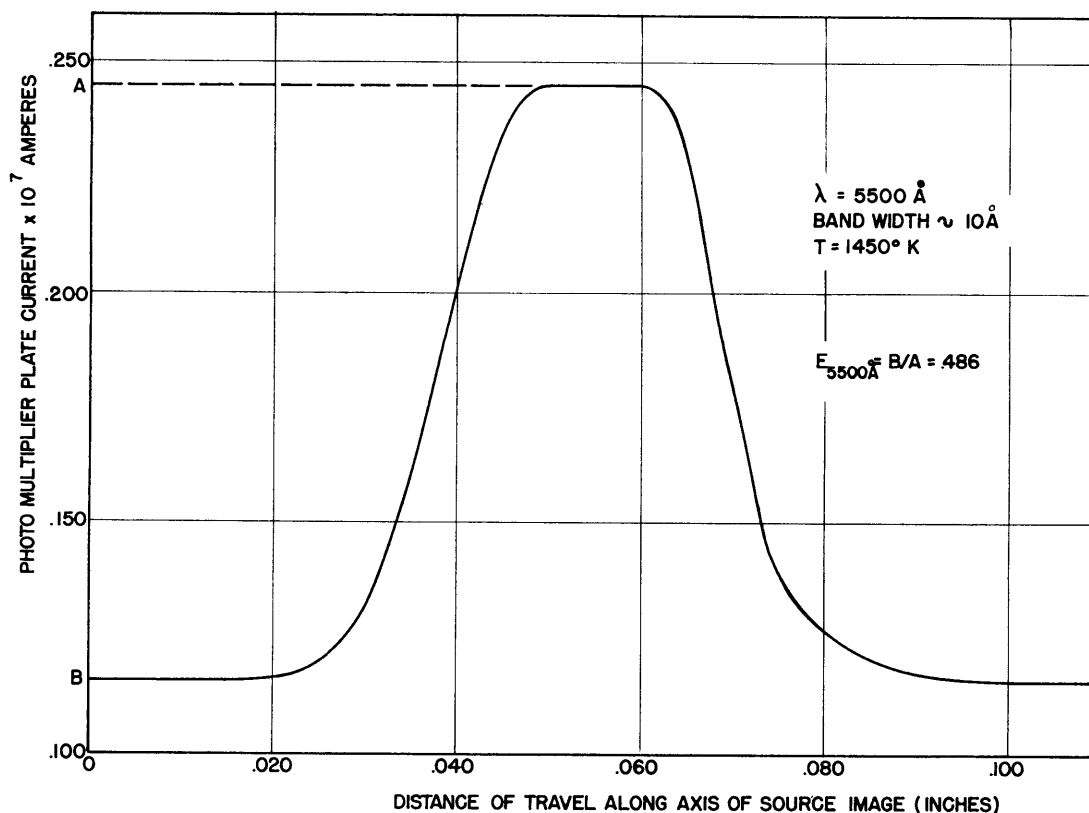


Figure 1.

1. A. G. Worthing and W. E. Forsythe, *Astrophysical J.* **61**, 146 (1925).

Measurements with different size holes opening into the black-body cavity of the present source yield the same results. This indicates that the approximation to a true black-body radiator achieved in the source design is satisfactory. Emissivity values obtained by the standard pyrometric method (at $\lambda = 6650\text{\AA}$) correspond to those of Worthing and Forsythe within $\frac{1}{2}$ to 1 per cent. Thus the surface state of the tungsten is probably comparable to that of their source. It appears that the high values obtained are caused by a background illumination arising from the scattering of light from the walls of the glass envelope containing the source. This difficulty is being eliminated by improvement of the optics of the system as well as by a redesign of the envelope.

3. Electron Emission in Accelerating and Retarding Fields

Staff: Professor W. B. Nottingham
C. S. Hung

All experimental equipment including well-regulated power supplies and an electrometer setup has been completed. Minor changes and repairs of the experimental tube, however, have only now been made and experimental work will be undertaken soon.

C. IONIZATION GAUGE RESEARCH

Staff: Professor W. B. Nottingham
L. Sprague

During the past quarterly period, the ionization gauge that was described previously, has been tested and shortly after the first tests were begun, the gauge became inoperative, because of the loss of a connection lead. Prior to this, a study of the phenomenon of gas absorption on a filament within the tube showed that the gauge design was probably working successfully and really measuring the ionization as distinct from some of the spurious currents that make accurate readings in the neighborhood of 10^{-8} mm pressure impossible with conventionally designed ionization gauges. This phenomenon of gas absorption and subsequent measurement was one pointed out to us by Dr. Apker of the General Electric Company. More details concerning the usefulness of this test will be made available in the next report.

D. PROPERTIES OF CATHODE-RAY TUBE SCREENS

Staff: Professor W. B. Nottingham
W. T. Dyall

Investigations of persistence characteristics of cathode-ray tube phosphor screens has continued through this quarterly period. A technical report covering tubes having P7, P14, and P4 type screens is now being written.

E. DETERMINATION OF EMISSION PROPERTIES OF SINGLE CRYSTALS

Staff: Professor W. B. Nottingham
C. J. Marcinkowski
M. K. Wilkinson

According to present plans, the thermionic emission will be measured by a photometric method, using the light produced by electron bombardment of a fluorescent screen. A promising method of depositing uniform coatings of phosphor inside a glass tube has been developed. Tube components, including several polished filaments of tungsten specially processed for large crystal growth, are being prepared.

F. TRAVELING-WAVE AMPLIFIER TUBES

Staff: Professor L. J. Chu
L. A. Harris

The last quarterly period has been devoted to a study of the problem of producing and maintaining a narrow high current density electron beam. This phase of the work has been completed, and it is felt that adequate electron beams for the traveling-wave tube can be obtained with the Pierce electron guns that were studied. Work is now going forward on the actual construction of two complete tubes. Many of the components have been completed and the remainder are under construction.

The electron-gun study indicated that a strong longitudinal magnetic field should be applied over the entire length of the tube. Accordingly, a large air-core electromagnet has been designed for this purpose and is now being built.

The auxiliary waveguides and tube supports to fit inside the magnet and to provide for accurate alignment of the tube are being designed.

In addition, numerical calculations, based on previous theory,¹ have been carried out. These provide design data for obtaining the helix dimensions for maximum gain at various wavelengths.

1. L. J. Chu and J. D. Jackson, "Field Theory of Traveling-Wave Tubes", RLE Technical Report No. 38, April 28, 1947.