VIII.   TUBE RESEARCH AND DEVELOPMENT

A.   MAGNETRON DEVELOPMENT

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1.   Testing and Design of High Power 10.7-Cm Magnetrons

Progress during the last quarter has been very limited because of vacation schedules and construction problems. Several attempts to carry a tube through processing failed because of leaks developing in the ceramic window seal, in the gold diffusion seal, or because of broken ceramic windows.

B.   MICROWAVE TUBES

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1.   Noise and Space Charge Waves

a.   Multivelocity electron flow in a temperature-limited diode at high frequencies

An analysis has been made of the temperature-limited flow in a diode with infinite external a-c impedance, taking into account the velocity distribution of the electrons emitted at the cathode.   Each velocity group (electrons emitted with the same velocity from the cathode) is treated separately; the interaction among different velocity groups is taken into account.

The fundamental equation has been developed under the following assumptions: (a) one-dimensional flow; (b) infinite external a-c impedance of the diode, i.e. no externally applied a-c field; (c) continuity of the electric field (short range collisions are neglected); (d) small signal theory and no reversal of electron motion.   All quantities are functions of c, the emission velocity, and x, the distance along the diode.

The fundamental equation is

$$\frac{\partial^2 J_1(c,x)}{\partial x^2} + \left(\frac{3}{v_0(c,x)} \frac{\partial v_0}{\partial x} + \frac{2j\omega}{v_0(c,x)} \right) \frac{\partial J_1(c,x)}{\partial x}$$

$$+ \left(\frac{2j\omega}{v_0^2(c,x)} \frac{\partial v_0}{\partial x} - \frac{\omega^2}{v_0^2(c,x)} \right) \frac{\partial J_1(c,x)}{\partial x} = \frac{e}{m} \frac{I(c)}{\epsilon v_0^3} \int\limits_{\substack{\text{all velocity} \\ \text{groups}}} J_1(c,x)\, dc \qquad (1)$$

with the following notation: $J_1(c,x)$ = a-c density per unit velocity; $v_0(c,x)$ = d-c velocity of the velocity group emitted with the velocity c from the cathode at the point x; ω = angular frequency; $I(c)$ = d-c density per unit velocity.

If there is no acceleration, it can be shown that Eq. 1 is equivalent to the expression obtained by Haeff (1) and Bohm and Gross (2).   With the assumption of an $e^{j(\omega t - \gamma z)}$ dependence and slight manipulation involving an integration with respect to $c = v_0$ one gets

$$\int \frac{-\frac{e}{m} \frac{\rho_0(v_0)}{\epsilon}}{(v_0 \gamma - \omega)^2}\, dv_0 = 1 \qquad (2)$$

which is the mentioned expression.

Equation 1 has been solved under the assumption of a constant accelerating field and under approximations which are valid for values of frequency, current, acceleration and velocity spread satisfying the following restricting conditions

$$\omega \frac{c}{a} < 1 \tag{3}$$

$$\frac{e}{m} \frac{J_o}{\epsilon a^2} \sqrt{2ax} < 1 \quad . \tag{4}$$

J_o = total d-c convection current density; a = d-c acceleration. As an example one may mention that all of these conditions are satisfied for a temperature-limited gun under the following operating conditions: $0 < x < 1$ cm, f = 5×10^3 Mc/sec, T = cathode temperature = 1700°K, v = cathode anode potential = 16 volts.

The solution of Eq. 1, subject to the mentioned approximations, has been used to compute the output convection current as a function of the shot noise at the cathode. For this purpose North's assumptions (3) have been used: (a) independence in the emission of one velocity group of the other velocity groups; (b) the noise convection current at the cathode due to the fluctuation in one velocity group is assumed to be

$$d\overline{(i^2)}_s = 2eI \frac{mc}{kT} e^{-\frac{mc^2}{2kT}} dc \quad .$$

With these assumptions the resulting expression for the mean-square fluctuations of the output convection current becomes

$$\overline{(I^2)}_s = 2eI \Delta f \left(1 - \frac{e}{m} \frac{|J_o|}{a^2} \sqrt{2ax} \left[1 - \sqrt{\frac{\pi kT}{axm}} \right] \right) \quad .$$

It can be observed that the fluctuations approach the full shot value in the absence of space charge. The space charge introduces a reduction in the output noise current which is rendered less and less efficient the greater the velocity spread of the electrons at the cathode. The noise current is independent of frequency if all terms involving $\omega \cdot c/a$ raised to a higher power than the second are neglected.

H. A. Haus

References

1. A. V. Haeff: Proc. I. R. E. 37, 4, 1949

2. D. Bohm, E. P. Gross: Phys. Rev. 75, 1851, 1949

3. B. J. Thompson, D. O. North, W. A. Harris: RCA Rev. 4, 441, 1940

b.   Experimental study of noise on electron beams

After some modifications of the apparatus described in the last report, a maximum standing wave ratio of almost 15 db has been obtained, with intercepted current less than about 0.3 percent.   On examination of the gun parameters (the gun was designed in 1948), it was discovered that the beam diameter is limited by thermal velocities rather than space charge forces.

A new, higher current gun is now being installed in the apparatus.   The effect of thermal velocities on the beam diameter will be relatively small.   The perveance of this gun is 0.5×10^{-6}, its half-angle of convergence is 13°, and its beam diameter is 0.075 inch.

While the tube was apart, the measuring equipment was improved by constructing a 2-db noise figure i-f amplifier, and a new waveguide attenuator.

H. E. Rowe, A. L. McWhorter

c.   Traveling wave tube design

The continuously pumped system described in the last report is almost complete, and it will be placed in operation soon.

C. E. Muehe, Jr.

2.   1-Mev Pulsed Electron Source

The high voltage tube shown in Fig. VIII-1 was assembled and outgassed, but the filament failed during activation of the cathode.   After the opening and resealing process, the 8.5-inch diameter glass envelope cracked.   Reconstruction of the envelope has caused a delay in the project.

The single wire, double spiral filament has proved to be impractical in this tube because of the stringent heater current and power requirements.   While 24 watts are

Fig. VIII-1
High voltage cathode ray tube

required to heat the cathode, the filamentary current must be kept below 1 amp, in order
to avoid excessive heating and voltage drop in the secondary winding of the pulse trans-
former. These conditions require either a very long or a very thin filament. The small,
0.0034-inch diameter, 11.5-inch long filament in the original design had too small a
surface area for radiation of the required power at a reasonable temperature. There-
fore, it is now planned to use a 0.0053-inch diameter, 28.5-inch long coiled-coil tung-
sten filament.

Other components of the high voltage pulsed system have been completed.

A. W. Boekelheide

3.   Spiral Beam Oscillator

This oscillator, pictured in the Quarterly Progress Report, July 15, 1951, has been
found to operate in any cavity mode having a transverse electric field on the axis of the
cylinder. In general, the magnetic field is the value required for cyclotron resonance
at the frequency mode in question, although one cavity mode can be obtained at two mag-
netic fields, cyclotron value and one-half the cyclotron value. This may be of impor-
tance if higher frequency tubes are to be built.

The power output in all modes has ranged from tenths to tens of milliwatts. Under
one set of conditions with the beam voltage held constant the power output varied as the
seventh power of the beam current. The entire behavior of this oscillator is drastically
affected by residual gas pressure; in particular the data on power output vs. beam cur-
rent were not reproducible unless the pressure in the cavity was considerably lower
than 10^{-6} mm Hg.

Neither the reflector voltage nor the diameter of the reflector electrode has any
major qualitative effect on the operation of the oscillator, except that the power output
increases as the diameter of the reflector decreases. One tube used an axial 60-mm
wire as reflector; its oscillations were not stable but came in randomly-spaced, 2-μsec
bursts.

If the reflecting field is eliminated by connecting the reflector electrode to the
anode (i.e. to the cavity) the device can be made to oscillate by applying the cathode
voltage in pulses ranging from 1 to 400 μsec long. To date this type of operation has
been erratic and unstable. It indicates that the energy to sustain oscillations may be
derived from the radial d-c field between the beam and the cavity. The failure to oper-
ate without a reflecting field at higher pressures or continuous wave is presumed to be
due to the cancellation of the space charge field by positive ions.

J. E. Thomas, L. Stark, L. D. Smullin

4.   Oscillator Magnet Gaussmeter

The gaussmeter described in the Quarterly Progress Report, July 15, 1951, has
been built. The only deviations from the original plan are that vee jewels and pivots

were used, and the probe diameter reduced from 0.28 inch to 0.25 inch.

The gaussmeter has been tested over the range of 1 to 8000 gauss and approximately obeys the law $B = kf^2$ where k = constant, and f = audio frequency.   In the region from 15 to 1250 gauss the agreement is very good and $k = 6.69 \times 10^{-3}$ gauss-sec^2/cy^2.   From 1 to 15 gauss there is a slight departure from the law given above, but if one assumes the values of k to hold in the 1 to 15 gauss region, the error will never be more than 0.3 gauss.   From 1250 to 8000 gauss k is within less than 15 percent of the above value. However, k could not be accurately measured since accurately known fields were not readily available in this region.   The upper operating limit of the gaussmeter is not known.   The slight departure from $B = kf^2$ which occurs from 1 to 15 gauss is known to be due to the amplitude of oscillation of the magnet increasing to such a value that the resonant frequency of the magnet shifts slightly downward.   (This behavior is exactly analogous to the simple pendulum with large swings.)

The repeat accuracy of the gaussmeter is about 2 percent at 1 gauss, 0.6 percent at 10 gauss, and 0.2 percent from 100 to 8000 gauss.   The long term accuracy will be determined principally by how constant the moment of the magnet remains as it ages.   If it does change, it will be necessary to recalibrate the gaussmeter at one field alone since this sets the rest of the calibration curve.   The loaded Q of the system is about 100 over the whole range, where Q is $f/\Delta f$, and Δf is the frequency variation between half-scale deflections of the bridge circuit.

The temperature coefficient of the gaussmeter has been measured.   At a constant magnetic field of 600 gauss the resonant frequency decreases 0.02 percent/°C in going from 0 to 50°C.

The audio voltage applied to the bridge is a constant 20 mv.   The bridge unbalance at resonance varies from about 0.5 to 1 mv.   A simple three-stage amplifier detector indicates the bridge output voltage on a microammeter.   Except for a slight readjustment of the amplifier gain, the only knob one need touch over the entire range of magnetic fields is the oscillator frequency control.

This device has proved especially useful in measuring solenoidal magnetic fields.

Construction details will be described in a forthcoming technical report.

<div align="right">J. M. Houston</div>