

III. MODERN ELECTRONIC TECHNIQUES APPLIED TO PHYSICS AND ENGINEERING

A. DESIGN AND CONSTRUCTION OF A MICROWAVE ACCELERATOR

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Since the last progress report, primary emphasis has been on construction of additional lengths of accelerating cavity and the associated equipment necessary for operation. Primary design work has been finished on all components necessary for operation of the accelerator and most components are in the process of being assembled.

The following items include recent developments and design details which have not been mentioned earlier. Delivery on the 2-Mev Van de Graaff machine is expected at an early date. A pulsing circuit to modulate the electron beam from the Van de Graaff machine has been designed and built. Since this circuit is to be placed in the dome of the machine at high pressure, all component parts have been subjected to 400 lb/in² pressure to ensure that they have the necessary strength.

Machining work on the one-foot accelerator sections is essentially completed. Assembly and brazing of the parts are now in progress. The final design for the 20-foot accelerator tube has been slightly modified in that it has been divided into three sections which are isolated from each other rf-wise by short drift tubes which act as waveguides beyond cut-off. The primary purpose of this procedure is to allow for tuning each section to optimum frequency independently. Two tuners are being provided for each of the three sections and provisions have been made for a probe in each of these sections for measuring frequency and power level.

Two reports have been issued on certain aspects of the accelerator. They are:

RLE Technical Report No. 47, J.C. Slater, "The Design of Linear Accelerators", September 2, 1947.

RLE Technical Report No. 48, J.C. Slater, "Electromagnetic Waves in Iris-Loaded Waveguides", September 19, 1947.

III. B. ULTRASONICS RESEARCH PROGRAM

1. Mechanical Excitation of Second Sound in Liquid Helium II.

Staff: Dr. J. R. Pellam

Reflection of first sound in He II from a porous material should generate second sound. Experimentation was originally planned for 75 Mc/sec. Subsequent investigation has shown that absorption of second sound at this frequency would mask any existent effect. Accordingly, the test is to be made at 1 Mc/sec, where the absorption should be tolerable.

2. Low-Temperature Velocity Measurements of Second Sound.

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Apparatus is under construction for the measurement of the velocity of second sound at temperatures in the neighborhood of, and below, 1°K. Velocity data in this range are vital for determining whether the theory of Tisza or that of Landau describes the state of affairs in Helium II.

3. High-Frequency Ultrasonics.

Staff: R. A. Rapuano

Below 300 Mc/sec. Some work has been done on liquids in an effort to detect the breakdown of the f^2 dependence of attenuation. Examination of the equations of propagation of sound through viscous liquids indicate that with highly viscous liquids such as glycerine, the deviation of α/f^2 from a constant should be observable. Some measurements have been taken, but confirmation is being delayed because of crystal troubles.

Above 300 Mc/sec. It has been possible to excite crystals having a 15-Mc/sec fundamental at frequencies up to 1100 Mc/sec. Further progress depends upon the modification of present receiver equipment for stable operation above this frequency.

Many difficulties have prevented more work from being accomplished. The precision tank still has bearing troubles which, it is hoped, will be rectified soon. The last shipment of crystals received in June have proved to be very unsatisfactory. A new order has been placed.

III. B. ULTRASONICS RESEARCH PROGRAM

4. Ultrasonic Absorption in High Polymers¹.

Staff: Jean Hoopes

Ultrasonic measurements² in rubber solutions,³ in methyl ethyl ketone were begun, with the intention of investigating the variation of absorption with molecular weight of the rubber. In a 2 per cent solution, the attenuation varied with frequency in the same way as it did in the solvent, being only slightly higher. Measurements are to be made at higher concentrations and with different molecular weight fractions when samples are available.

Since for concentrations exceeding about 6 per cent the solutions behave like a gel, an auxiliary experiment was undertaken to determine whether ultrasonic behavior was discontinuous when a gelatinous liquid was allowed to set. Professor Mueller predicted that in the frequency range used (15 - 50 Mc/sec), a gel would have the ultrasonic characteristics of a liquid. This appears to be confirmed, in the case of a 3.5 per cent solution of pure food gelatin. The attenuation both before and after gelation follows roughly the α/f^2 law, being somewhat higher in the gel, but varying continuously during setting.

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1. In collaboration with the Acoustics Laboratory.
 2. Using Roth's equipment pictured in the Progress Report for October 15, 1947, page 35, Fig. 1.
 3. Prepared by the Acoustics Laboratory

III. C. DEVELOPMENT OF FLASH TUBES.

Staff: Professor H. E. Edgerton

A Light-Integrating Meter For Measuring Short Flashes.

Design of the Meter. The measurement of the quantity of light produced by a flash from an electric-flash lamp involves the integration of instantaneous values of light over the duration of the flash. An elementary circuit that accomplishes this under certain conditions is given in Fig. 1. The measurement of light requires that the phototube current and instantaneous light be proportional:

$$i = kF$$

where k is a constant relating phototube current i and instantaneous flux F .

Figure 2 shows the general shape of the volt-ampere characteristics of a vacuum-type phototube, RCA 929, with strong illumination. Notice that the current and luminous flux can be proportional only for voltages above those indicated at the knee of the curve at the point A.

Should the instantaneous variation of luminous flux exceed that corresponding to the knee during a short, intense flash of light, the equation $i = kF$ will not be satisfied and the meter indication will not be a true measure of the integrated light. Gas-filled phototubes cannot be used since, because of the effects of the gas, the current may not be proportional to flux. The curves of Fig. 2 show that 100 volts is required on the phototube* if 36 lumens is the greatest instantaneous illumination that is to be experienced. For 145 lumens, the voltage should be about 200 volts. From this limited number of data it appears that the saturation current is approximately a function of the square of the phototube voltage.

A voltage proportional to the integrated light and thereby proportional to exposure is obtained across an integrating capacitor C . This voltage is

$$e_c = \frac{1}{C} \int_0^{\infty} i dt = \frac{k}{C} \int_0^{\infty} F dt \text{ volts.}$$

A vacuum-tube voltmeter with an indicating meter, M , is used to record the voltage without discharging the capacitor at a rate which interferes with the reading of the meter after the flash. The drift of the indicating meter after a flash reading will depend upon the grid current of the vacuum tube, the leakage current of the phototube, and the leakage of the circuit. The size of the capacitor C must be increased to such a value that the drift is inappreciable unless some method is provided to adjust the drift, such as

* RCA Type 929, S-4 surface of 0.5 square inch.

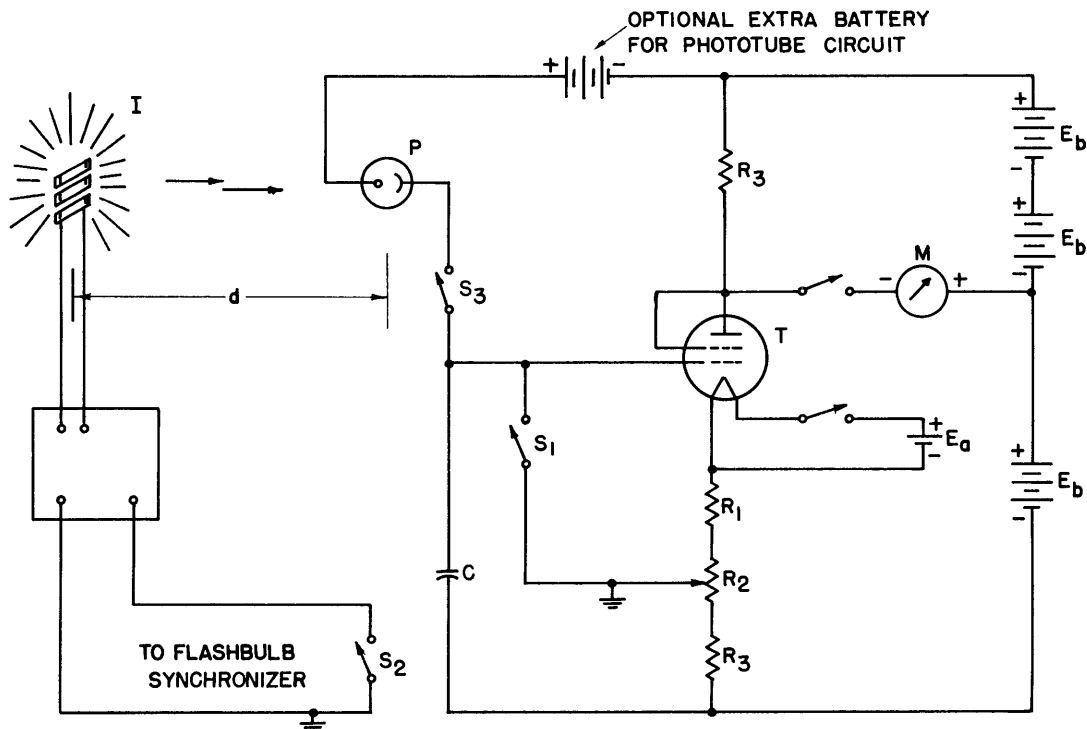


Figure 1. Elementary wiring diagram of a light-integrating meter.

Suggested practical values are:

T = 1L4 vacuum tube (triode connected). Selected for low grid current.

C = Integrating capacitor with polystyrene or oil dielectric, 0.1 mfd.

M = 200 microampere d-c meter.

P = Type 929 phototube, RCA.

R_1 = 1000 ohms, 1 watt.

R_2 = 5000 ohms, variable wire-wound, 1 watt.

R_3 = 2×10^5 ohms, 1 watt.

R_4 = 1000 ohms, 1 watt.

E_a = 1.5-volt, 2FBP Burgess dry battery, or equivalent.

E_b = 45-volt W30 Burgess dry battery, or equivalent.

S_1 = Switch to charge integrating capacitor to initial condition for circuit balance. This switch is initially closed.

S_2 = Switch to flash the electric flashtube after S_1 is opened so that the integrating of current in C can be accomplished.

S_3 = Switch to open the phototube circuit after the flash is over so that average continuous light will not cause the meter to drift while the reading is being taken.

I = Standard flashtube for calibration.

Switches are arranged to operate in the sequence described either with a rotary or push button.

Note that R_1 , R_2 , and R_4 in series constitute a negative feed-back resistor of 7000 ohms. This connection tends to make the amplifier sensitivity independent of the triode characteristics.

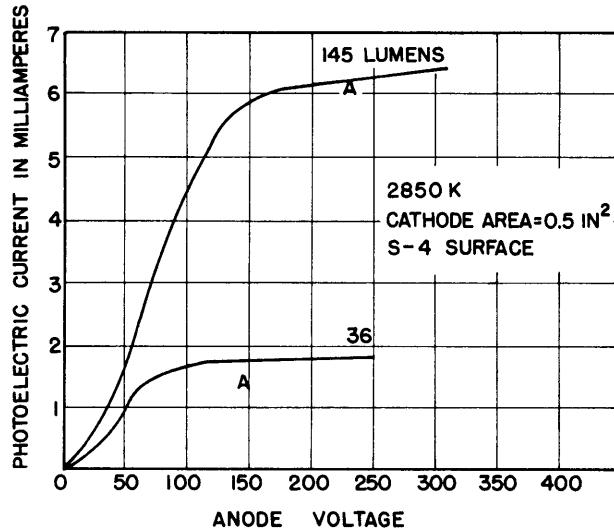


Figure 2. Characteristics of a 929 phototube.

grid current compensation.

In the practical design of an integrating light meter the capacitance for an uncompensated circuit is usually about 0.1 mfd when the meter drift is limited to less than a full-scale deflection in 30 seconds or so.

From the equation $i_c = C(de/dt)$, the time to drift to full scale, if the grid and leakage currents are assumed constant, can be given by

$$t_d = \frac{C e_c}{i_c}$$

where e_c = input capacitor voltage increment to produce a full-scale deflection, t_d = the time required for the meter to drift from zero to full scale, and i_c = the current that causes drift in the integrating capacitor C. Thus the drift time is a function of the grid and leakage currents and the integrating capacitor, once an amplifier design has been selected.

The form of the grid current of a three-electrode vacuum tube appears as Fig. 3. For most tubes the cross-over point a of zero grid current is about -1 volt with respect to the negative end of the cathode. It is inadvisable to operate on the right-hand side of the cross-over point since the grid current increases rapidly on account of electrons that arrive at the grid with energy obtained from thermal processes at the cathode. Positive ion currents are responsible for the negative slope of the grid-current curve between the points b and c since the number of positive ions are directly a function of the plate current. To the left of point c the plate current is cut off and the tube serves no useful function. Therefore the portion of the characteristic that can be used falls between c and a. Point c as well as the entire curve depends upon plate voltage. A plate voltage is selected that is as low as possible, but still ample to produce plate current that is several times that of the maximum

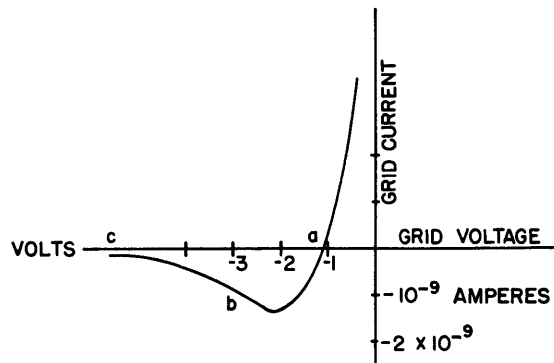


Figure 3. Typical grid current - grid voltage characteristic of a triode vacuum tube with the plate voltage held at a constant value.

reading of the meter. The usual practical value of grid bias is well to the left of point a for all operating conditions. The type 1L4 tube connected as a triode with the screen and plate connected, can be used with 45 volts on the plate, a plate current of 0.5 ma and a grid bias of -1.3 volt. A 200-microampere meter is used as an indicator. Under this condition the grid current is less than 10^{-9} ampere for selected tubes that have been aged for two days with 90 volts on the plates.

Design Test of the Instrument. Should the phototube voltage be less than that required for saturation (see point A, Fig. 2), the meter will read low. A simple test of the meter, with any flashing light source of known duration, is to vary experimentally the phototube voltage and plot the resultant meter reading. If the reading is constant as this voltage is increased, the operation is satisfactory. The limiting phototube voltage can be found by decreasing the phototube voltage until the meter reading begins to drop.

If a flashtube with a shorter flash is used, but of the same quantity of light, the break will occur at a higher phototube voltage.

Calculation of the Shortest Allowable Duration of Flash. The limiting time of flash can be calculated approximately as follows: Assume that the flash of light is of rectangular form of F lumens on the phototube cathode and of T seconds' duration. The quantity of light is

$$Q = \int_0^T F dt = FT$$

or

$$e_c = \frac{1}{C} kFT = \frac{1}{C} T.$$

The phototube current is kF amperes, and

$$i = \frac{C e_c}{T}.$$

From this it can be seen that the peak current through the phototube is a direct function of the integrating capacitance and the voltage required for full scale on the deflecting meter. Likewise the required phototube current for full-scale deflection increases inversely as the duration of the flash. A short flash will require a larger phototube current and a higher phototube voltage if a full-scale reading without error is to result.

A phototube circuit with 100 volts on the 929 phototube and with a peak flux of 36 lumens will produce a photoelectric current of 1.7 ma, as shown in the curve of Fig. 2. With $C = 0.1$ mfd and $e_c = 2.5$ volt (sufficient for a full-scale deflection of a 200-microampere meter) the preceding equation can be solved, by assuming a rectangular pulse of light, for

$$T = \frac{Ce_c}{i} = 147 \text{ microseconds} = \frac{1}{6800} \text{ second.}$$

The actual pulses of light from electric-flash tubes rise sharply to a peak and then decay with a form resembling an exponential.

With 200 volts on the phototube the current can be about four times greater and the time similarly decreases by 4 to 36 microseconds. By similar reasoning, a half-scale reading can be made with an 18-microsecond pulse with 200 volts on the phototube. The effective duration of practical flashtubes ranges from 50 to 1000 microseconds. As a general rule, the duration is longer for the more powerful lamps.

An approximate general expression for the necessary phototube voltage required to give an accurate integration of a rectangular pulse of light of duration T can be obtained if the phototube saturation current i is taken to be a squared function of the phototube voltage E .

$$i = KE^2$$

where K is a constant. This current, when substituted for the integrator capacitor voltage previously given, results in the following expression for the required phototube voltage:

$$E = \sqrt{\frac{Ce_c}{KT}}.$$

As a numerical example, the required voltage calculated for a one-microsecond flash is 1150 volts. This might cause a flashover in the phototube. If it is necessary to measure microsecond pulses, then a more sensitive amplifier or a smaller integrating capacitor should be used. Such a modification requires a smaller grid current in order to keep the meter drift time at a reasonable value. The phototube voltage becomes 240 if $e_c = 0.1$ volt and $C = 0.1$ microfarad. These are reasonable values that can be obtained

with a two-stage amplifier with grid current compensation.

Some care is required in selecting a suitable integrating capacitor since some capacitors have leakage and others have absorption effects that are serious. It has been found that polystyrene and mica capacitors have very desirable characteristics. Mica cannot easily be made in large capacitance sizes and is difficult to obtain. Polystyrene capacitors are made by a limited number of manufacturers, such as the General Radio Company of Cambridge, Massachusetts. Certain types of oil capacitors can be used with success as integrating elements.

The spectral sensitivity of the 929 phototube peaks in the blue and has a cut-off in the green. Thus it measures mainly the blue light. This is not a serious disadvantage since most photographic film, even the panchromatic types, also has a sensitivity peak in the blue. For color photography the flashtubes that are used are mainly filled with xenon gas at high pressure for high-efficiency use. The meter should then be calibrated experimentally with a xenon lamp under conditions that are known to produce a suitable color-photograph result. Fortunately xenon flashtubes are of about the same color temperature regardless of the energy loading, and therefore the light meter can be used for comparison purposes with great success even if only sensitive to blue light.

Maximum Sensitivity of the Meter. The example given previously ($e_c=2.5$ volts, $C=0.1$ mfd.) will have a maximum reading of the meter corresponding to 36 lumens for 147 microseconds when a phototube voltage of 100 volts is used; thus the reading corresponds to

$$\text{Light} = 36 \times 147 \times 10^{-6} = .0053 \text{ lumen-second}$$

with a tungsten source having a color temperature of 2850° Kelvin.

Xenon lamps have an equivalent "color temperature" of from 6000 to 9000 and therefore because of the proportionally greater blue light, require less than half as much visual light in lumen-seconds to produce the equivalent phototube current in the 929 phototube. For this reason a xenon flashtube will produce a full-scale reading of the meter with about .0026 lumen-second of incident light.

The projected area of a 929 phototube cathode is about 0.5 square inch, so the phototube cathode has a light density of about .005 lumen-second per square inch when used to measure the light from a xenon flashtube. We will now calculate the distance from a standard flashtube that will give this deflection for calibration purposes. A standard FT-214 flashtube (General Electric Company) flashed from 30 mfd at 2000 volts emits some 2000 lumen-seconds and has an intensity I of 200 horizontal candle-

power seconds with a duration of about 150 microseconds. The number of lumen-seconds per square inch at a distance d in inches is

$$L = \frac{I}{d^2} = 0.005 \text{ lumen-second per square inch,}$$

from which

$$d = \sqrt{\frac{I}{L}} = 200 \text{ inches} = 16.7 \text{ feet.}$$

Calibration of the meter can be accomplished directly by this method using a standard flashtube operated under specified conditions.

Negative Feedback Self-bias Connection. Amplifiers with self-bias resistors have voltage calibrations that are relatively independent of the tube constants. This independence of calibration is gained at the expense of sensitivity in the conventional circuit design. However, for this special type of amplifier with a floating input capacitor, as used for light measurement, the advantages of self-bias can be gained without a loss of sensitivity. As long as the product of capacitance C and the voltage necessary for full-scale deflection e_c is constant, the light necessary for full-scale deflection of the meter and the drift time will not be changed. The drift time is also proportional to the same product.

A suitable design with degeneration by means of a cathode resistor is one that reduces the gain by a factor of five. Such a design will decrease the influence of tube characteristics by a factor of about the same value. Figure 1 shows an amplifier with a cathode resistor of about the value mentioned above.

Light Attenuation. Several methods appear to be useful for extending the range of the instrument. One of these is the conventional camera diaphragm. A diffusing disc is required back of the diaphragm in order to diffuse the light before it strikes the phototube cathode. If this is not done, the illuminated area of the cathode can become a small spot when the hole is small and this is undesirable since phototube cathodes are not uniformly sensitive over their surfaces and space-charge effects may be present due to local intense emission. A second method is the use of holes in a disc in front of the phototube and a diffuser. A third method involves the use of a pair of polaroid sheets which can be rotated with respect to each other. An "aperture" or any other calibration can be marked on the polaroid moving mechanism or on the meter scale. The transmission of crossed polaroid discs is a function of the square of the cosine of the angle between the axes of the two discs.