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A MULTI-RANGE ELECTRONIC APPARATUS FOR MEASURING AND RECORDING PHOSPHORESCENT DECAY

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ABSTRACT

The measurement of the decay time and photographic recording of curves showing decay periods of phosphors from 2×10^{-4} second to several hours is made with the apparatus described. Irradiation of the phosphor by ultraviolet light takes place exterior to the apparatus. A 1P22 or a 1P21 multiplier phototube, in connection with a direct-coupled amplifier and a 5-inch oscilloscope tube, gives a sensitivity sufficient to record the brightness as a vertical deflection. Horizontal deflection is produced by a time-sweep circuit triggered by a 1P28 multiplier tube. Another 1P28 tube is used to control the intensity of the spot on the screen, thus preventing overexposure at the starting point when the transient is recorded on film. A time scale is superimposed on the film by setting the vertical gain to zero and introducing a calibrated time pulse into the vertical amplifier during a given sweep. Multi-range time scales, low brightness sensitivity, and the convenience of recording transients are features of the apparatus.

PROBLEM STATUS

This is an interim report on a portion of Problem N01-02. Work is continuing.

AUTHORIZATION

NRL Problem No. N01-02.

A MULTI-RANGE ELECTRONIC APPARATUS FOR MEASURING AND RECORDING PHOSPHORESCENT DECAY

INTRODUCTION

The problem of measuring the decay time of phosphors, particularly those of low brightness, has afforded difficulty in several respects. Measurements of the decay characteristics of phosphors of high brightness excited by cathode rays have been extensively made, and apparatus for such measurements has been developed to considerable extent, since a need for information concerning the decay periods of materials used on screens in cathode-ray tubes has existed from the time of the introduction of these tubes into scientific and commerical work. Such methods of decay measurement, however, require that the phosphorescent material be placed in a high-vacuum chamber which adds to the difficulty in the procedure.

A photoelectric method utilizing a multiplier phototube has been developed whereby the phosphor is alternately irradiated and allowed to decay in repeating cycles which are indicated on a cathode-ray screen. [1] The method has the advantage of indicating both growth and decay of a phosphor, but depends on controlled chopping of a beam and is limited to a time range from 10^{-4} to 10^{-2} sec.

Another widely used method for decay measurements involves a rotating disc having the phosphorescent material applied around the periphery. Speed control of the disc is maintained by gears driven by a motor which rotates the disc at a known rate. At a fixed point near the disc, an exciting light is applied to the rim holding the luminous material. With a constant speed and an assumption of equilibrium conditions, it is possible to measure brightness in terms of distance from this fixed point, but the apparatus is somewhat cumbersome and not self-recording.

For extremely short periods of decay, other methods have been described. [2] By such methods, and with apparatus employing optical systems, even the time of fluorescence may be determined. Generally such short time intervals are encountered only in special work, and do not represent the decay periods of what are commonly known as phosphors.

In the apparatus described in subsequent pages of this report, an electronic method employs multiplier phototubes as indicators of brightness and also as pickup tubes for the triggering circuits. A single time-sweep, which may readily be photographed with a 35-mm camera on 36-exposure rolls of film, is produced on a cathode-ray screen. With the

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[1] W. DeGroot, Physica. 6:275-289, (1939).

[2] E. Gaviola, Physik, 42:853-861, (1927).

phototube located in front of the sample phosphor and the amplifier from this tube cut off or set to zero, a reference line may be traced which represents zero brightness. During this tracing period, a controlled time-pulse is introduced from an external oscillator and a calibrated time-axis is produced on the screen, and consequently on the film.

Since the apparatus has time axes with sweep periods ranging from 2×10^{-4} sec to several hours, it affords a convenient way to record decay curves of phosphors of comparatively low intensity. The time of extinction of light from a given phosphor is obtained as well as information on the manner in which the decay of light takes place. Thus it is possible to say when a phosphor becomes invisible to the human eye under described conditions. This apparatus may also serve as a wide-range instrument for research work in determining the relations between composition and decay rate. With information between luminous intensity and time recorded directly, studies can more readily be made of decay phenomena.

SCHEMATIC LAYOUT OF APPARATUS

The main electronic circuit is illustrated schematically in Figure 1. A 1P22 multiplier phototube is normally used to detect the radiant energy from the phosphor; if more sensitivity is desired, a 1P21 may be substituted. The anode of the tube (pin No. 10) is connected to the grid circuit of a 6SJ7 which serves as a conventional resistance-coupled amplifier controlling the vertical deflection plates DJ_1 and DJ_2 of the 5BP1 cathode-ray tube.

The power supply for the 1P22 is located in the main unit and the phototube itself is enclosed in a camera box with a shutter. This serves as a pickup box for light and is connected to the main unit through a shielded cable indicated by the dashed lines. Divider resistors R_D are placed in the camera box on the phototube socket and only three conductors are needed in the cable, which should be chosen to withstand reasonably high voltages. As a matter of experiment the best cable available (Tirex 3-conductor shielded) was used after the insulation had been tested at 3000 volts. Since the bank of six OA2 tubes, in connection with the filter and a full-wave rectifier using 2X2 tubes, develops approximately 900 volts, a safe cable to the pickup box is necessary.

As indicated in Figure 1, a cable connection is made between the 6SJ7 and the 5BP1 cathode-ray tube. This was made necessary because the separate power supply, cathode-ray tube, cabinet, and other parts of a conventional oscilloscope obtained in war surplus material were utilized. The separate units can be seen in Figure 2, where the main unit and the converted oscilloscope are shown side by side.

The necessity of several power supplies made the space problem one of prime interest. By using Stancor P-4077 transformers (T_3, T_4, T_5, and T_8) in half-wave rectifier circuits, an output voltage of about 650 volts was obtained in each case without excessive weight and space losses. The high voltage for the 1P22 tube, however, was supplied by a Thordarson T-19P57 transformer (T_1). A small power transformer (T_7) to supply plate voltage to the 6SJ7 was also needed, and a Stancor P-6010 was used. The power supply for the 5BP1 tube was obtained by using the transformer and other parts contained originally in a R.C.A. Model-160-B oscilloscope. This unit produced only half-wave rectification with moderate filtering, but the supply was adequate for the beam requirements of the cathode-ray tube.

The vertical amplifier and deflection circuit utilize two of the power supplies. Since voltage stabilization is desirable in phototube and resistance-coupled amplifiers, a bank of six OA2's were used to stabilize the potential supplied to the dynodes of the multiplier tube, a VR75 to stabilize the anode potential, and three OA2's to maintain a constant plate supply for the 6SJ7.

CIRCUIT CONSTANTS

RESISTORS

	Ohms	Watts
R_1	25k	25
R_2	20k	25
R_3	560k	1
R_4	67k	2
R_5	300k	1
R_6	100k	2
R_7	22k	1
R_8	100k	1
R_9	10k	2
R_{10}	47k	2
R_{11}	10k	1
R_{12}	100k	1
R_{13}	10k	2
R_{14}	470k	1
R_{15}	220k	1
R_{16}	0.8 meg	2
R_{17}	100k	1
R_{18}	27k	1
R_{19}	4k	25
R_{20}	112k	10
R_{21}	470k	1
R_{22}	15 meg	2
R_{23}	68k	1
R_{24}	10k	2
R_{25}	1 meg	1
R_{26}	90k	4
R_{27}	47k	1
R_{28}	120k	1
R_{29}	10k	2
R_{30}	18k	2
R_D	30k	1
R_DL	68k	½

POTENTIOMETERS

	Ohms	Watts
P_1	100k	1
P_2	100k	2
P_3	3k	3
P_4	3 meg	1
P_5	20k	3
P_6	25k	3
P_7	110k	2
P_8	200k	2
P_9	10k	3
P_{10}	100k	2

CHOKES

	Manufacturer	Number	Inductance (in henrys)
L_1	Stancor	C1080	15
L_2	Stancor	C1080	15
L_3	Stancor	C1080	15

CAPACITORS

	Farads	Volts
C_1 C_2	4	1500
C_3	4	1000
C_4	4	1000
C_5	4	1000
C_6	4	1000
C_7	16	450
C_8	4	1000
C_9	50	25
C_{10}	100 μμ	mica
C_{11}	12 μ	450
C_{12}	16	450
C_{13}	4	1000
*C_{14}		
*C_{15}		
C_{16}	3	500
C_{17}	0.5	550
C_{18}	16	450
C_{19}	270 μμ	mica
C_{20}	0.001 μ	mica
C_{21}	0.1	600
C_{22}	1	1000
C_{23}	10	600

TRANSFORMERS

	Manufacturer	Number
T_1	Thordarson	T - 19P57
T_2	Thordarson	T - 19F88
T_3	Stancor	P - 4077
T_4	Stancor	P - 4077
T_5	Stancor	P - 4077
*T_6		
T_7	Stancor	P - 6010
T_8	Stancor	P - 4077

*escued from surplus material in RCA oscilloscope 160B. Characteristics not given.

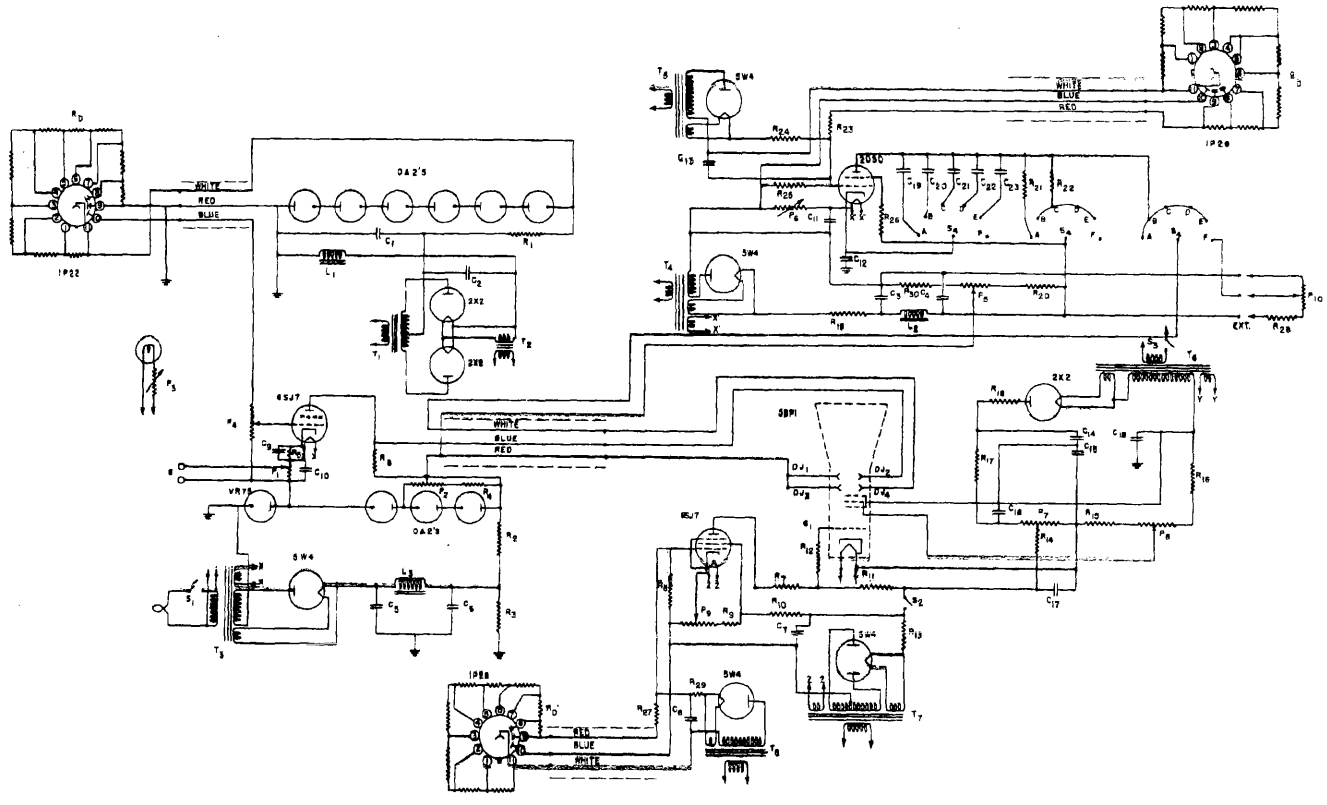

Fig. 1 - Main Schematic Diagram Showing All Units Except the Pulse Generator

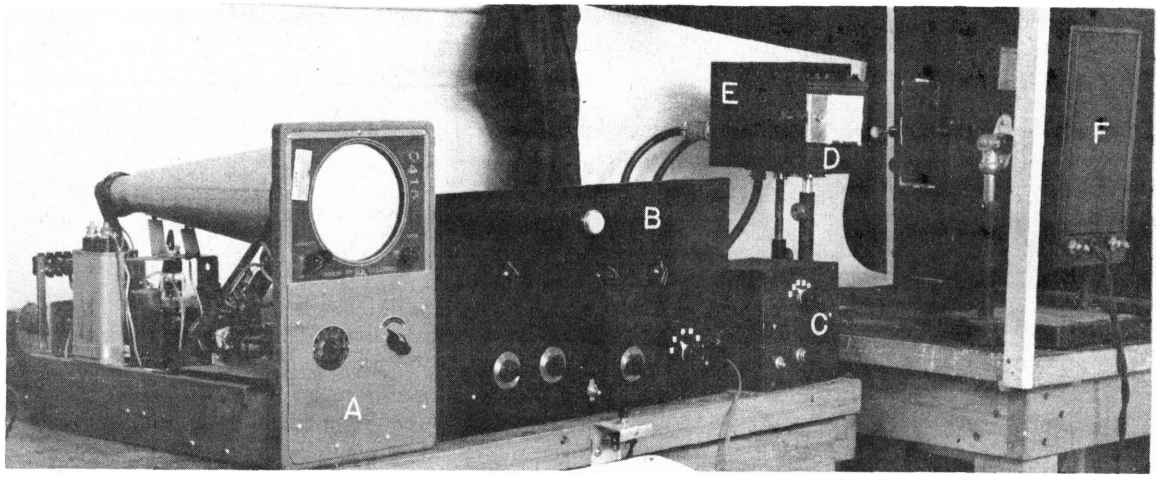

Fig. 2 - Photograph of Apparatus with Cabinets Removed
A- Oscilloscope Unit B - Main Unit C - Blocking Oscillator
D - Camera Box for 1P22 Tube E - Box for 1P28's
F - Hg Arc Lamp

HORIZONTAL DEFLECTION CIRCUIT

The development of a horizontal sweep circuit which would meet all the requirements of the problem was most difficult. It was necessary to produce linearity of sweep non-recurrence of the trace after a single sweep, and wide time ranges which involved full trace periods of several hours to the shortest time possible within practical limits of such type of apparatus. The problem of holding the spot on the cathode-ray screen in a fixed position before trigger action took place was also difficult, since the curves to be measured were transient in nature and since all conventional trigger circuits depend on periodic pulses for smooth triggering.

At first, an attempt was made to trigger an 884 thyratron in a typical condenser-resistance circuit with a 917 phototube, but the results were not satisfactory. The 917 was not sensitive enough and the thyratron gave undesirable "jitter" on the screen before triggering took place.

The results of several efforts to produce a satisfactory horizontal sweep circuit are shown schematically in the upper right hand corner of Figure 1. A 1P28 multiplier tube is used to trigger a 2050 thyratron, which remains conducting as long as sufficient light is kept on the photo-cathode of the multiplier tube. Under such initial conditions, the No. 1 grid of the thyratron is kept at a positive potential with reference to the cathode. The magnitude of this grid potential depends upon the amount of light striking the 1P28 tube and on the setting of the potentiometer (P6) in the thyratron cathode circuit.

The grid No. 2 of the 2050 tube is connected through a 100-K resistor to the positive side of the power supply for the tube. This arrangement eliminates "jitter" by keeping the tube conducting or firing even while the potential on the plate drops to a few volts.

The instant that light is removed from the trigger tube, the potential on the No. 1 grid of the 2050 tube goes from a comparatively high positive to a slightly negative value, and

the thyratron becomes non-conducting. In such a manner the voltage or any chosen one of the condensers (C_{19}, C_{20}, etc.) is built up from the power supply through the resistors R_2, or R_{22} as seen from the gauged switching arrangement labeled A, B, C, D, E, and F. The time of sweep is determined by the r-c constant for each switch position except F. When the switch is in this position, any longer time of sweep may be obtained by rotating the potentiometer (P_{10}) mechanically. This potentiometer is contained in a separate motor-driven unit and is connected to the main unit by a cable with A-N connector. By taking into account the fatigue characteristics of the 1P22 or 1P21 pick-up tube,[3] periods of decay for several hours may be taken by leaving the shutter of the camera in front of the screen open in a darkened room.

A list of c-r constants and sweep periods is given in Table I. The time of sweep is considered to be the time it takes for the spot to move across about three-fourths of the screen depending somewhat upon the setting of the potentiometer (P_6).

TABLE I

Capacitance and Resistance Constants

Switch Position	Capacitance in farads	Resistance in ohms	Time of Sweep in seconds
A	270 $\mu\mu$f	470 k	0.001
B	0.001 μf	15 meg	0.02
C	0.1	15 meg	1
D	1.0	15 meg	7
E	10.0	15 meg	60
F	External Sweep		

TIME INDICATOR CIRCUIT

In the preceding discussion it was stated that the periods given in Table I were the approximate times of sweep for each switch position. To calibrate accurately the time axis, a periodic pulse (see Figure 3) is introduced into the vertical amplifier circuit from a cable-connected unit containing a multi-range blocking oscillator. An AN connector at G permits the external timing device to be connected at will into the potentiometer (P_1), which forms part of the cathode-bias resistance for the 6SJ7 amplifier tube.

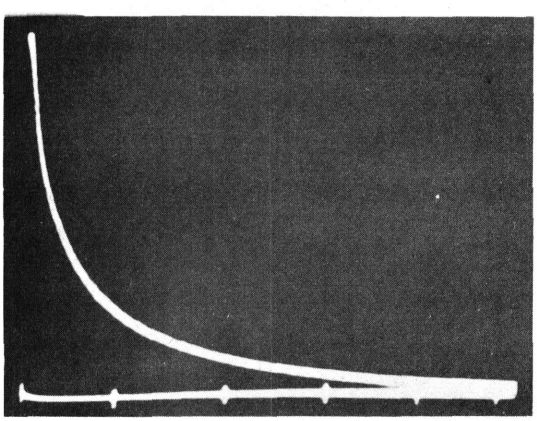

Fig. 3 - Typical Decay Curve and Reference Axis

In Figure 4 is given a schematic diagram of the blocking oscillator, which is contained in a separate cabinet. A conventional feedback oscillator is employed, with values of

[3] W. Engstrom, J. Optical Soc. Am. 37:420-431 (1947).

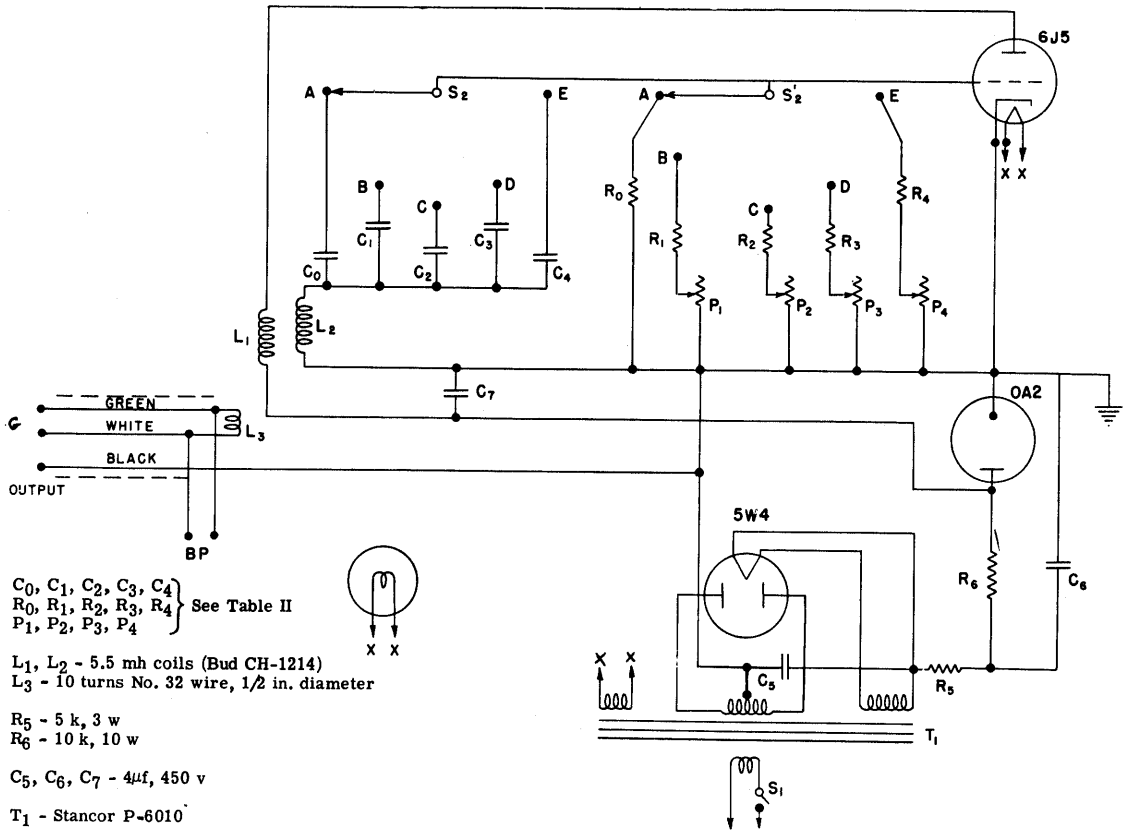

Fig. 4 - Schematic Diagram of Blocking Oscillator

R and C in the grid circuit so chosen that the tube (6J5) will oscillate until a negative voltage is built up on the condenser to a point where the bias becomes so great that oscillation stops. The time of stoppage depends upon the time it takes for sufficient electrons to flow back through the grid resistor. As a result the tube oscillates for a short time and then stops, giving a regular pulse as shown on the time axis of Figure 3.

The values of C and R in the grid circuit for the switch positions on the oscillator unit are given in Table II.

It is seen from the schematic diagram of Figure 4 and the R column of Table II that the grid resistance is made variable for all switch positions except A. This permits an easy re-calibration of the apparatus particularly on time scales where humidity and other effects are more liable to affect high value resistors.

The coil L_3 is coupled inductively to plate coil L_1 loosely enough so that loading the output circuit does not noticeably change the frequency characteristics of the oscillator. Two leads are connected to the binding posts BP located at the back of the oscillator box to facilitate calibration.

Calibrations on scales A, B, and C are made by comparing the output of the oscillator to the output of a heat-frequency oscillator (General Radio, Type 700-A) which produces a

TABLE II

Values of Capacitance and Resistance in the Grid Circuit

Switch Position	Capacitance in farads	Resistance in ohms	Pulse Rate per second	Period between Oscillations in seconds
A	240 $\mu\mu$f	189 k	5000	0.0002
B	0.005 μf	150 k + 200 k variable	500	0.002
C	0.1	390 k + 200 k variable	20	0.05
D	0.75	220 k + 0.5 meg variable	1	1.0
E	0.75	1.8 meg + 1.0 meg variable	1/5	5.0

sinusoidal wave of accurately known frequency. Such a comparison is easily made on a standard oscilloscope with a good internal sweep circuit.

Scales D and E were calibrated by connecting the binding post BP to the vertical deflection circuit of the standard oscilloscope and determining the pulse rate with a stop watch.

It is important to mention that any time pulse may be introduced into the AN connector on the main circuit at the point G (see Figure 1). Longer periods than those afforded by the oscillator can be obtained more conveniently from mechanically driven generators. Such a generator is now under construction.

CIRCUIT FOR CONTROLLING SPOT INTENSITY

After the apparatus was built and tested, it was found that when a camera was used to make a permanent record of the trace, over-exposure at the initial or rest point was objectionable. To aviod this, a special circuit was used, employing a 1P28 multiplier tube to control the grid circuit of a 6SJ7.

On the schematic diagram of Figure 1 the intensity control circuit may be seen in the area below the 5BP1 tube, connected to the cathode-ray tube in such a way that the voltage on the first grid (G_1) may be varied by a fluctuation of the plate current of the 6SJ7 tube. This plate current is in turn controlled by the 1P28 phototube. When some of the light from the source used to irradiate the phosphor falls on the 1P28 (see Figure 7), the potential is made more negative on grid G_1. At the instant this light is cut off, the 1P28 triggers the 6SJ7 so that little or no plate current flows. The potential between grid No. 1 and the cathode-ray tube snaps back to normal and the spot comes on the screen.

The action of the intensity control circuit may be varied by adjusting the potentiometer (P_9) or completely cut out by opening the switch (S_2).

OPERATION

A comparison of Figures 5, 6, and 7 with the photograph in Figure 2 will show the general location of the controls. The camera boxes, containing the multiplier tubes (Figure 7) and the arc lamp, are ordinarily enclosed in a tent made of black cloth so that light from the arc does not interfere with the photography. Thw switch SW is a push-button

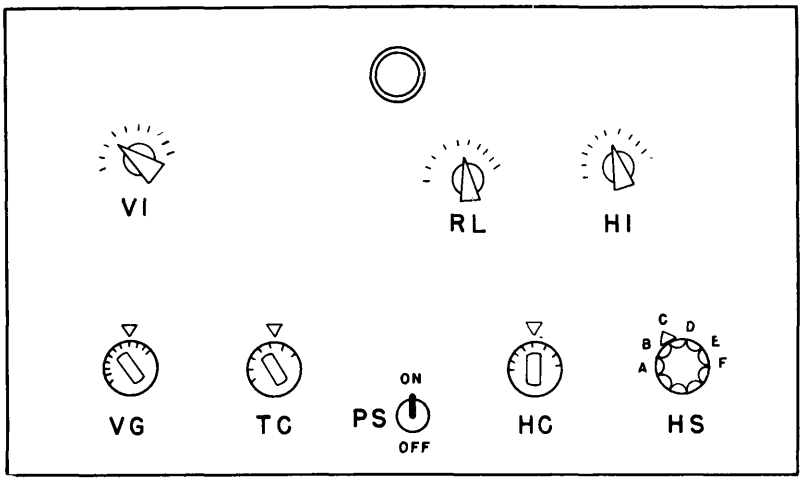

Fig. 5 - Front View of Main Unit

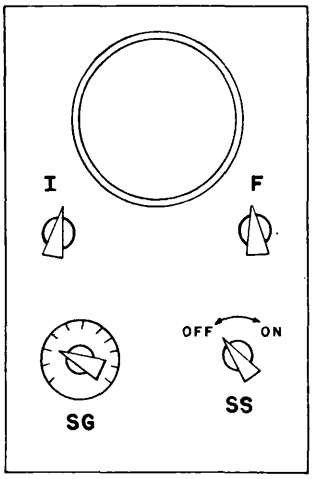

Fig. 6 - Front View of Converted Oscilloscope

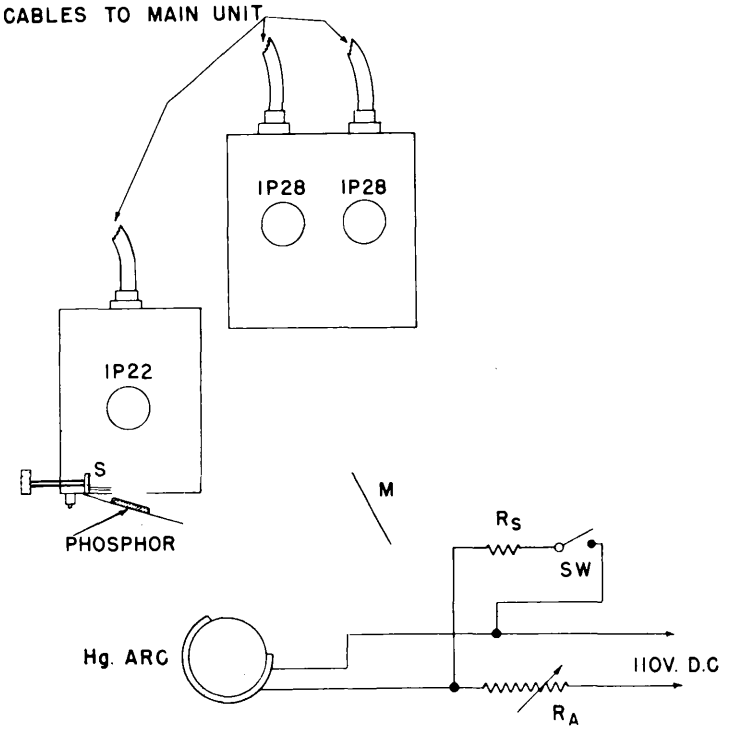

Fig. 7 - Layout for Irradiation of Sample Phosphor and Trigger Tubes

type and shorts out the arc to initiate the triggering and tracing action of the apparatus.

A shutter S between the sample phosphor and the vertical pick-up tube 1P22 may be opened or closed, but the front of the box containing the 1P28 tubes is left open. A front-surfaced mirror (M) is located so that some of the light from the arc is reflected toward the phosphor with very little entering the camera box directly. The mirror is also located so that light from the arc falls directly on the 1P28 trigger tubes.

The controls indicated on the drawings of Figures 5 and 6 are identified on the schematic diagram of Figure 1 by Table III.

All cable connections between the various units utilize AN connectors in such a way that the possibility of making a wrong connection is removed. Good connections between all units are necessary before optimum performance is obtained.

TABLE III

Controls

Identifying letters	Schematic diagram	Description
PS	S_1	Main power switch
TC	P_1	Amplitude control for time pulse
VG	P_4	Gain for vertical amplifier
RL	P_3	Rheostat for pilot lamp
VI	P_2	Vertical setting for starting point
HC	P_6	Bias control for horizontal sweep
HI	P_5	Horizontal setting for starting point
HS	S_4	Selector switch for horizontal sweep rate
I	P_7	Main intensity adjustment Also power switch for oscilloscope unit
F	P_8	Beam focus
SG	P_9	Auxiliary intensity adjustment with light on 1P28 tube
SS	S_2	Switch for connecting or disconnecting trigger circuit from grid G_1

The steps suggested in operating the apparatus are as follows:

1. Turn switch SS to "off" position.
2. Cut on power switches I and PS.
3. Tilt and start arc lamp with shutter S closed.
4. Set switch HS to desired range.
5. Adjust intensity I and set spot to starting point by adjusting VI and HI.
6. Focus by turning F, and press the shorting switch SW to get best focus for entire sweep.
7. Place white paper over the sample phosphor and open shutter S. Start arc.
8. Adjust NG for desired vertical deflection.
9. Make several trial sweeps, adjusting HC, until the trigger circuits work to give a trace similar to Figure 8 (without time pulses).
10. Remove white paper and note decay of phosphor.
11. Focus camera on screen and photograph trace.
12. Close shutter S and start blocking oscillator unit on desired scale. Adjust TC.
13. Trace reference axis.

If the initial spot is overexposed on the film, the switch SS may be closed and the spot made practically extinct by adjusting SG. This must be done with the arc lamp on the spot held at a fixed position on the cathode-ray screen. A number of firings may be necessary before the best overall adjustment is obtained. It is recommended that several tracings be made both for the reference axes and for the decay curves before a photograph is attempted.

A Zeiss Contax camera using Kodak Photoflure film (PF 135) gives all the speed needed for photographing the traces on the screen. A Speed-O-Copy attachment serves at present as an aid in focussing the camera, but a permanent camera holder is being developed.

RESULTS AND PRESENT STATUS OF THE PROBLEM

Some interesting photographs have been made of various phosphors. Scintillations or "noise" fluctuations may be seen in the photographs of Figures 9 and 10. These seem to be

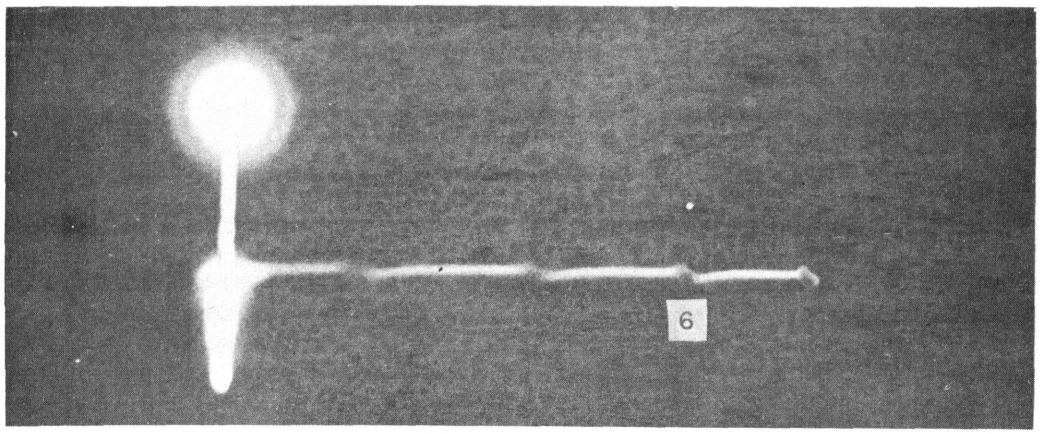

Fig. 8 - Fast Trace with Diffusing Surface
Placed over Phosphor to be Tested

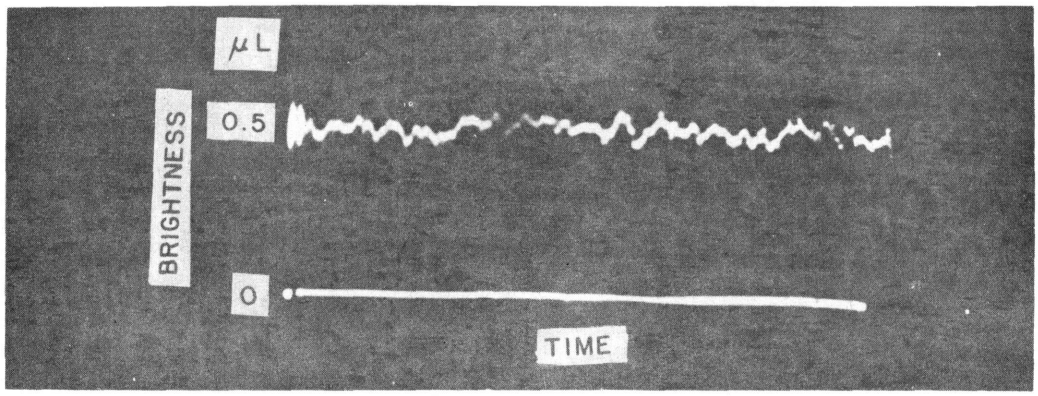

Fig. 9 - Evidence of Scintillations with Reference
Line Traced Under Dark Conditions

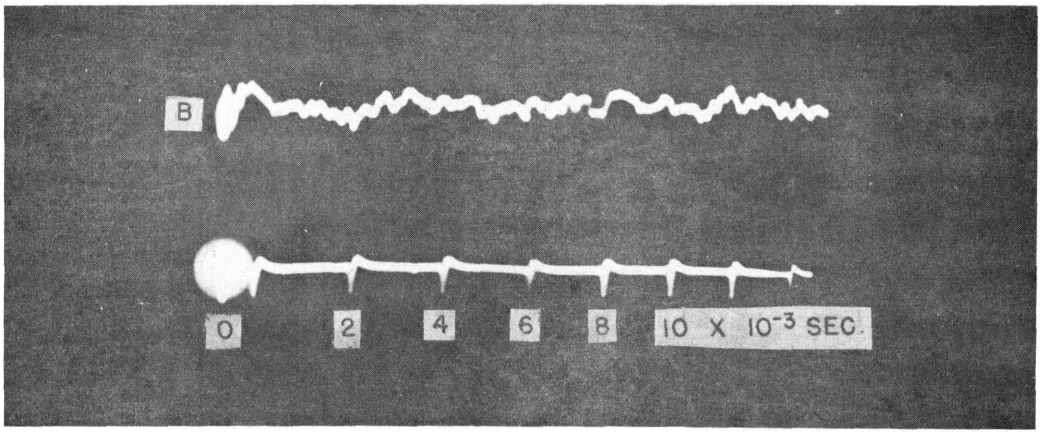

Fig. 10 - Scintillation Trace with Time Axis

more noticable in phosphors of coarser grain, but the type of binder or adhesive seems to be in some way connected with these fluctuations.

In addition to possible basic experiments with the apparatus, appreciable work has yet to be done in providing a more satisfactory photographic arrangement and in completing the sweep and timing apparatus for much slower speeds. A gear train to rotate the potentiometer P_{10} (see Figure 1) is being designed for several sweep speeds up to 3 hours. Also another slow-pulse generator is being built to give time calibrations below those of the blocking oscillator described above. No further changes of importance seem to be needed in the main portion of the apparatus. The fastest sweep has been set at approximately 1 millisecond for the complete trace and time markings 0.0002 sec apart are easily recorded. If higher operating speeds are needed, perhaps no circuit changes would be involved, but it is possible that the whole apparatus could be redesigned with shorter leads and other design features whereby capacitive and inductive effects in the connections themselves could be reduced. The main feature of the apparatus described is the multi-range advantage which gives decay curves of phosphors differing very widely in decay periods.

* * *

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