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ANALOG-TO-DIGITAL SYSTEM FOR FILM RECORDS

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INTRODUCTION

As one employs the computer more and more for data reduction, one is led to consider the feasibility of on-line operation. There are at least two reasons why such a system may not be appropriate for a particular experiment: (1) the transient events of interest are on too short a time scale for even direct access storage (e.g. 275 nanoseconds for the fastest computers available) and/or (2) the cost of such a system is prohibitively high.

Both of these reasons have led us to develop an alternative to on-line monitoring for situations where feedback of digested data for purposes of control is not contemplated. The basic idea is to store the analog signal in the form of a film record. The film is then processed at the operator's leisure. The processing includes (1) preparation of a transparency suitably enhanced for scanning by a light spot scanner and (2) conversion of the analog scanning voltages into digital X-Y coordinates and automatic transferal to computer-compatible form (punched cards, magnetic tape or paper tape).

SYSTEM OPERATION

The system is shown in figure 1. The light spot from the Tektronix 561A oscilloscope is focused at the plane of the film. The focused spot is small enough to be blanked out by the trace on the film. A bias voltage tends to drive the spot vertically. If it strays from the line, the increased light at the photomultiplier tube produces a feedback voltage at the vertical plates to drive the spot back into the film trace and thereby reduce the light. Thus as the spot is driven horizontally across the film, it is forced to follow the signal recorded there.

The spot is moved across the film in equal discrete steps. The signal which generates this stepping is initiated by the digital voltmeter (DVM). The sequence of events is as follows. The relays in the multiplexer unit are assumed set so that the horizontal coordinate voltage is being fed to the DVM. The DVM samples this voltage and generates the "start" and "run" signals which are fed to the

IBM card punch. (In all that follows we will discuss the use of a card punch since this is actually what was utilized. The Hewlett-Packard 2547A coupler will, however, mate with many kinds of recording instruments and with more than one at a time.) The 2547A coupler converts the sampled signal and feeds it serially to the card punch. When all information (algebraic sign, four digits of data, and power of ten multiplier) is punched, an end-of-word (EOW) pulse is fed back from the punch. This signal is monitored by the multiplexer and causes relays to cut in in preparation for feeding the current vertical signal to the DVM. This relay shift also inhibits the passage of a horizontal step voltage at this time. The vertical voltage is now waiting to be sampled. When the DVM does so the same train of events as above occurs with the following two exceptions: (1) when the card punch finished punching the information it releases the card and feeds a new one so that only one set of coordinates appears on each card. (This is accomplished by means of a suitably punched program card and wired control panel on the card punch). (2) When the EOW pulse gets back to the multiplexer this time, the path is now open to pass the horizontal step voltage along to the 561A scope. The relays are now back in their original state, ready to record the next set of coordinates.

Since the film and spot generator must be completely enclosed in a light shield, we find it convenient to monitor the spot motion. This was done by putting a Tektronix 564 storage oscilloscope in parallel with the coordinate voltages of the 561A, allowing us to see at a glance whether or not the trace is being faithfully followed by the spot. There are three major reasons why the spot will lose the trace:
(1) faulty bias setting, either too large or too small,
(2) a steep slope together with too large a step size and
(3) improperly prepared trace, either not opaque enough, thick enough, or uniform enough. A photograph of the storage scope face can be taken at the end of the reading and compared with the original before computer processing of the deck of cards is undertaken.

ELECTRONIC DETAILS

Figure 2 shows the film reader electronics. The collector current from the photomultiplier plus the bias provides the discriminator input. The output feeds the vertical amplifier of a Tektronix 561A oscilloscope. The discriminator bias is set so as to drive the spot well beyond the trace on the film in the absence of the feedback loop.

The power supply provides regulated voltages for the discriminator and the photomultiplier. The discriminator (6BH6, ½6BK7) is a standard vacuum-tube operational amplifier adjusted near infinite gain by the resistor in series with the 6BK7 cathode.

Figure 3 shows the multiplexer and horizontal drive systems. Either the EOW trigger or a single push button trigger will drive the system, depending on the setting of toggle switch S_1. If S_1 is in the normal position the EOW pulse (a negative 5 volt, 12 microsecond, square pulse taken from the integrated circuit MC4C-8 on control card A16 of the 2547A coupler)[1] is fed through an emitter follower, T_1, amplifier, T_2, and another emitter follower, T_3, at which point it branches to provide both a trigger to fire the SCR, T_4, which causes relays R_1 and R_2 to close momentarily and a trigger to fire the univibrator, T_8 and T_9, through the emitter follower, T_7.

Let us first follow the branch through the SCR. The relays are shown in their normal position. Prior to triggering the 200 μfd condenser is charged to -12 volts through the 5 Kohm resistor. When relay R_1 closes the condenser is placed across the coil of R_3 and causes it to close. This rapidly

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[1] See page C-21 of the Operating and Service Manual for the Coupler.

charges the 10 μfd condenser via the 1 Kohm resistor, R_2-4[2], the 330 ohm resistor and R_3-2. This charge keeps R_3 from closing as R_1 and R_2 cut out after the SCR pulse decays. R_3 is kept in operation indefinitely by the now closed R_2-5, the 330 ohm resistor, and R_3-2. Now, the 200 μfd condenser is discharged via the 100 ohm resistor, R_3-7 and R_1-5 and hence in the succeeding operation the discharged capacitor comes in parallel with R_3 and cuts it out. Thus R_3 is switched in and out with succeeding pulses from the same source. We use this fact to connect the -12 volt supply alternately across another pair of relays (R_4 and R_5) to switch the vertical and horizontal signal to the DVM and to alternately apply the horizontal step to the horizontal amplifier of the 561A scope to drive the spot. The 10 megohm resistor in series with the vertical input damps out transients due to the sometimes large differences in voltage between the horizontal and vertical signals. The meter M_1 monitors the state of the multiplexer.

The other branch of the pulse at the output of T_3 drives the univibrator, T_8 and T_9. The output, a square

[2] R_2-4 means relay R_2, pin 4.

pulse whose length, τ is proportional to $R_m C_m$ is fed to T_{10} via the relays R_4 and R_5 so that it reaches its destination only on every other pulse. This signal causes T_{10} to conduct a current I_{10} for τ microseconds and thus causes a voltage drop at the 9 μfd capacitor of $\Delta V_{10} = I_{10}\tau/9$. The 9 μfd capacitor is charged by button switch "reset horizontal". In this way is the horizontal voltage source stepped down by equal amounts every other pulse. T_{11} is a MOS-FET with extremely high input impedance (>10^{14} ohms) which allows us to couple to the 9 μfd capacitor without depleting its charge measurably between pulses. The .47 μfd capacitor damps the horizontal drive sufficiently to prevent the spot from jumping off the film trace. Another MOS-FET, T_{12}, is used to allow us to monitor the horizontal position with meter M_2.

The sampling rate must be slow enough so that (1) the 200 μfd capacitor in the multiplexer has time to charge through the 5 Kohm resistor...about 1.5 seconds and (2) slow enough that the DVM can slide up or down its ramp to the new voltage for the maximum differences in horizontal and vertical signals we anticipate...again, about 1.5 seconds. Punching each word of six digits takes 1/3 second and release and feed of a card takes another second. Thus the punching of a complete X-Y record will take less than five seconds.

FILM PROCESSING

The film record (usually Polaroid) has to undergo some processing before it is suitable for use in this device. A negative is made from the original print (which can be then immediately returned to the experimenter for record keeping or other uses). The negative is projected by a standard enlarger on to a sheet of paper on which the curve is traced by hand. At this time all spurious "noise" can be (and must be) eliminated (e.g. illuminated scale lines, fiducial marks, light leaks). The drawing is now darkened and thickened with Inida ink and rephotographed with Polaroid Transparency Film (number 146L), care being taken that the final area encompassed by the trace is well within the linear portion of the lenses in the film reader. For the present system this means about a 50% reduction in size for traces which originally filled a piece of 4" x 5" film. This sacrifices some accuracy in reading, of course, and could be alleviated to some extent with some sophisticated optics.

Since the film can be loaded into the system with no fixed orientation with respect to the horizontal as defined by the 561A trace we require that all traces be accompanied by a base line trace of the scope making the data trace so that true voltages relative to a true zero line can be recorded.

This base line must not intersect the data line. A complete record will consist, then, of two decks of cards, one for the data trace and one for the base line trace.

Figure 4 shows the state of the signal at each stage of processing: original record, transparency of redrawn data as used in film reader, photo of the storage scope monitor of spot motion, and computer plot using cards generated by this sytem.

Figure 5 shows how one can read, by judicious alteration of the original trace, a signal with less than 100% duty cycle.

APPLICATIONS

This device will be particularly useful for the following Radiation Project programs:

(1) Generation of X-ray spectra from current and voltage signals after processing by the ELECTREX[1] program.

(2) Development of electron energy spectrum.

(3) Determination of time history of radiation from time-resolved depth-dose records.

(4) Determination of time-resolved spatial radiation distribution.

(5) Electron energy and density distribution from calorimeter and Faraday cup information.

FUTURE DEVELOPMENTS

It would be very desirable to eliminate some of the time consuming steps involved with the film processing. An ideal solution would be to be able to record the signal directly on Polaroid transparency film which then could be used in the reader. We are exploring this and other prospects for improving the automation of the whole system.

REFERENCES

1. D. C. dePackh and J. T. Ulrich, "ELECTRAN-ELECTREX," Radiation Project Progress Report Number 7, to be published.

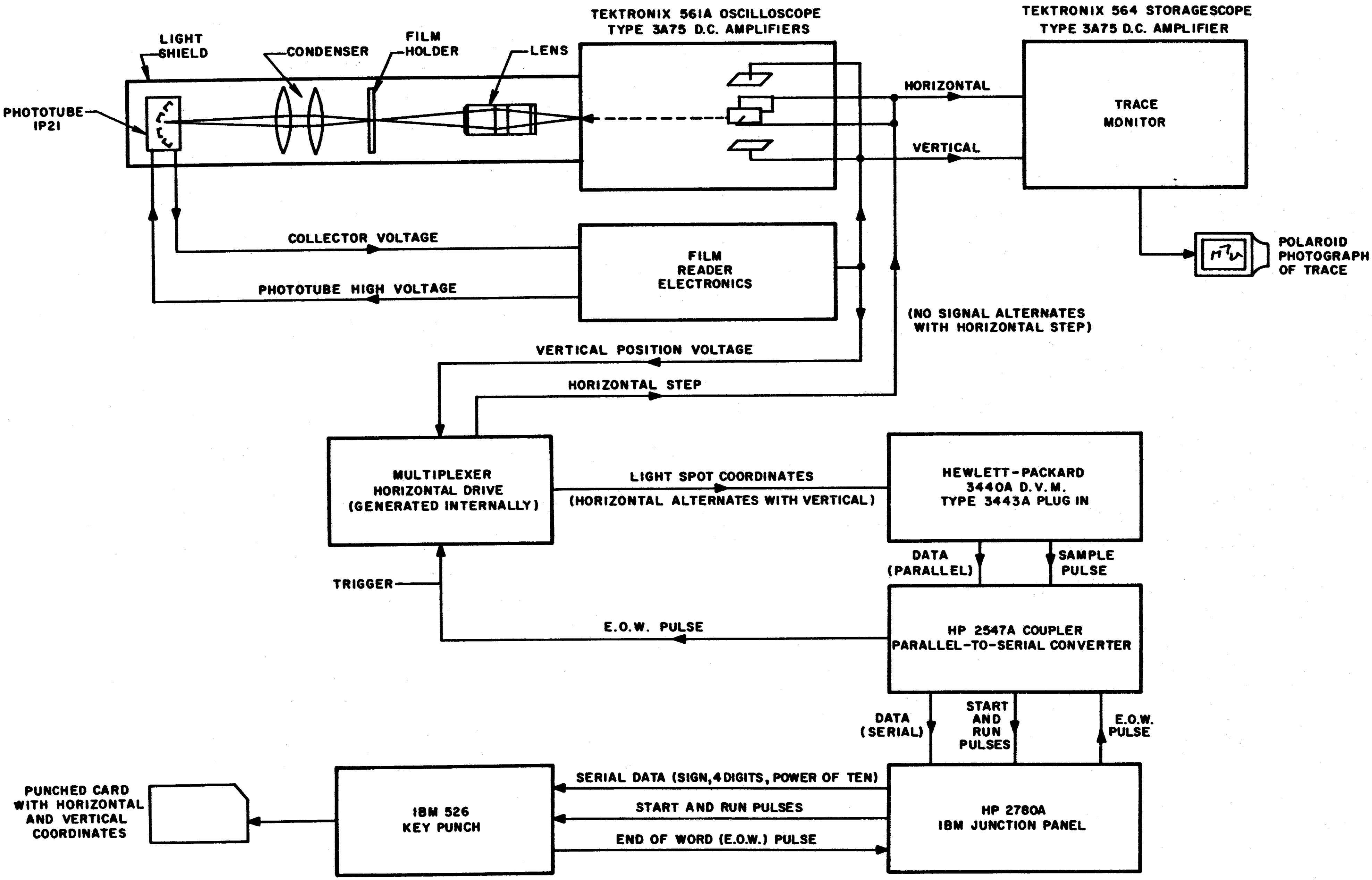

TEKTRONIX 561A OSCILLOSCOPE
TYPE 3A75 D.C. AMPLIFIERS
TEKTRONIX 564 STORAGESCOPE
TYPE 3A75 D.C. AMPLIFIER
LIGHT SHIELD
CONDENSER
FILM HOLDER
LENS
PHOTOTUBE IP21
HORIZONTAL
VERTICAL
TRACE MONITOR
COLLECTOR VOLTAGE
PHOTOTUBE HIGH VOLTAGE
FILM READER ELECTRONICS
POLAROID PHOTOGRAPH OF TRACE
(NO SIGNAL ALTERNATES WITH HORIZONTAL STEP)
VERTICAL POSITION VOLTAGE
HORIZONTAL STEP
MULTIPLEXER HORIZONTAL DRIVE (GENERATED INTERNALLY)
LIGHT SPOT COORDINATES
(HORIZONTAL ALTERNATES WITH VERTICAL)
HEWLETT-PACKARD 3440A D.V.M. TYPE 3443A PLUG IN
DATA (PARALLEL)
SAMPLE PULSE
TRIGGER
E.O.W. PULSE
HP 2547A COUPLER PARALLEL-TO-SERIAL CONVERTER
DATA (SERIAL)
START AND RUN PULSES
E.O.W. PULSE
PUNCHED CARD WITH HORIZONTAL AND VERTICAL COORDINATES
IBM 526 KEY PUNCH
SERIAL DATA (SIGN, 4 DIGITS, POWER OF TEN)
START AND RUN PULSES
END OF WORD (E.O.W.) PULSE
HP 2780A IBM JUNCTION PANEL

Figure 1

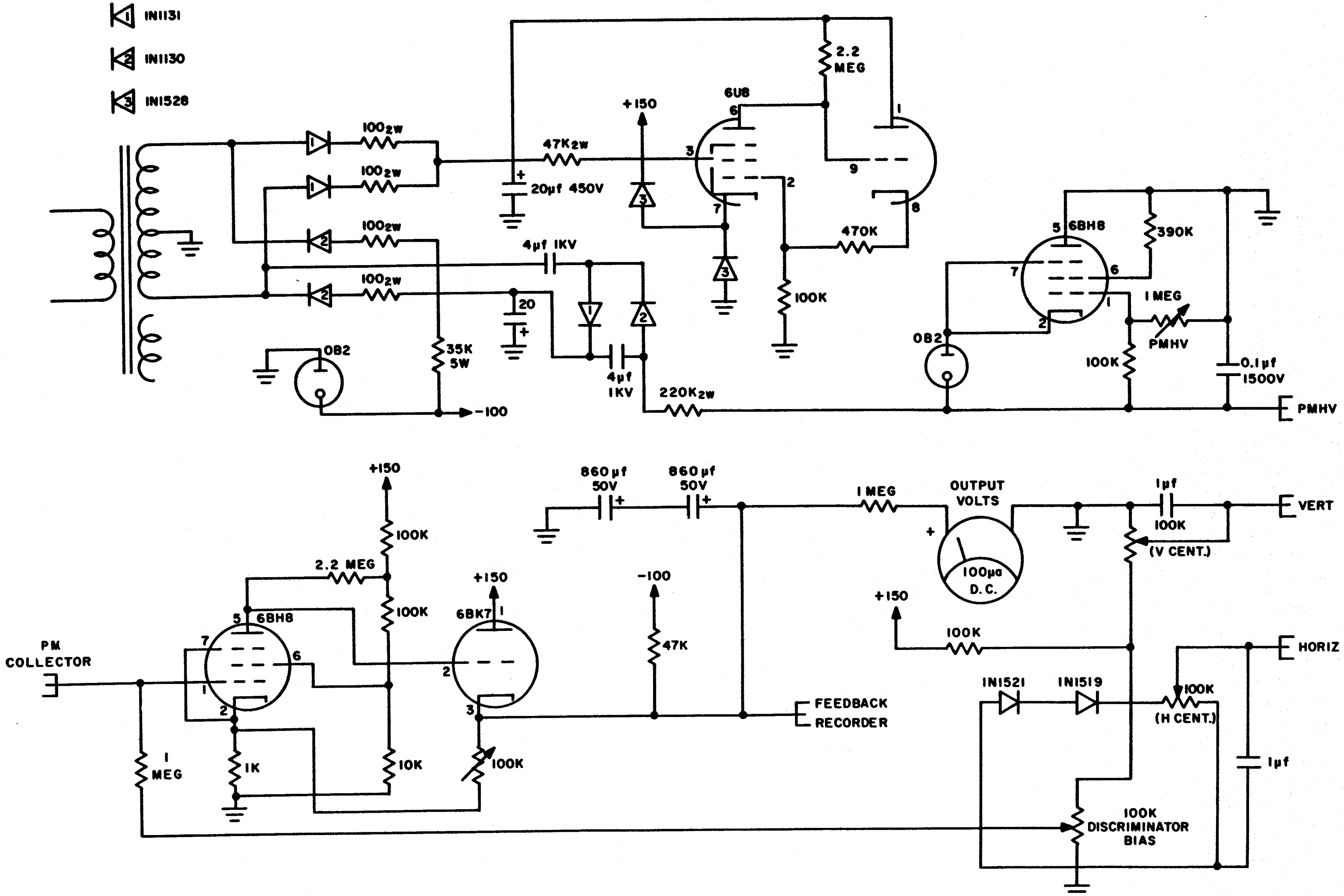
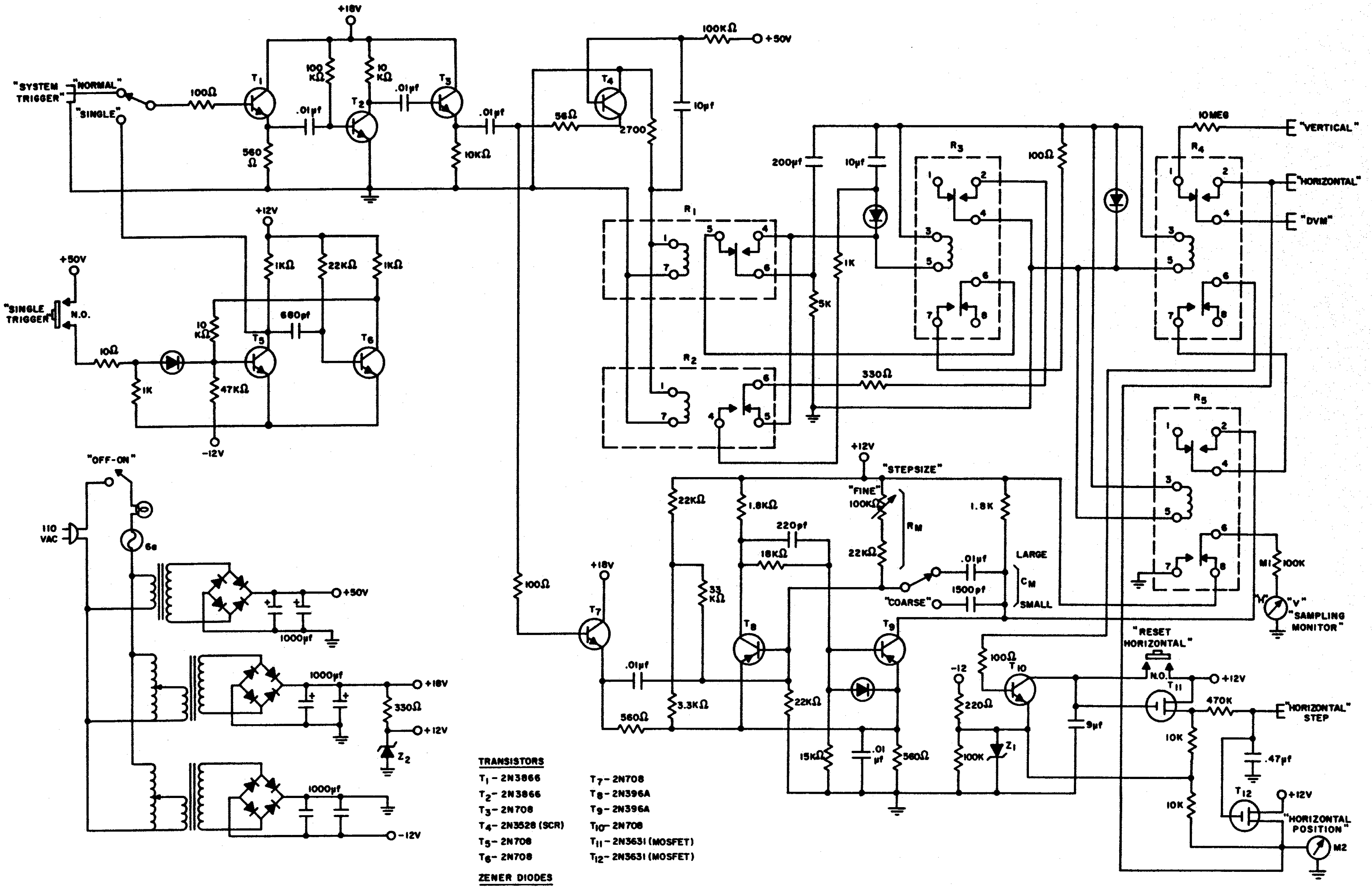

IN1131
IN1130
IN1528
100 2W
47K 2W
20µf 450V
+150
6U8
2.2 MEG
470K
100K
4µf 1KV
20
35K 5W
0B2
-100
4µf 1KV
220K 2W
6BH8
390K
1 MEG
PMHV
100K
0.1µf 1500V
PMHV
+150
860µf 50V
860µf 50V
1 MEG
OUTPUT VOLTS
100µa D.C.
1µf
100K
(V CENT.)
VERT
2.2 MEG
100K
6BH8
6BK7
-100
47K
+150
100K
HORIZ
PM COLLECTOR
1N1521
1N1519
100K
(H CENT.)
FEEDBACK RECORDER
1 MEG
1K
10K
100K
1µf
100K DISCRIMINATOR BIAS

Figure 2



TRANSISTORS

- T_1 - 2N3866
- T_2 - 2N3866
- T_3 - 2N708
- T_4 - 2N3528 (SCR)
- T_5 - 2N708
- T_6 - 2N708
- T_7 - 2N708
- T_8 - 2N396A
- T_9 - 2N396A
- T_{10} - 2N708
- T_{11} - 2N3631 (MOSFET)
- T_{12} - 2N3631 (MOSFET)

ZENER DIODES

- Z_1 - 1N1521
- Z_2 - 1N1605

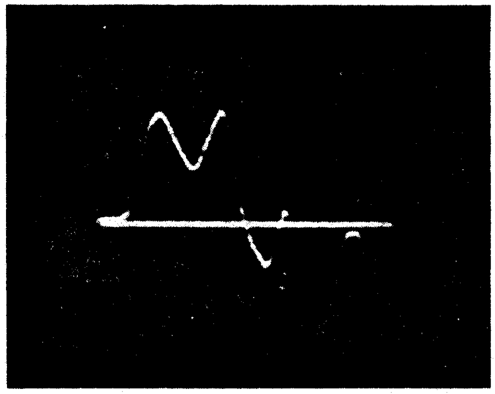
RELAYS

R_1 & R_2 - POTTER-BRUMFIELD PW5L5
R_3, R_4 & R_5 - POTTER-BRUMFIELD FC11D

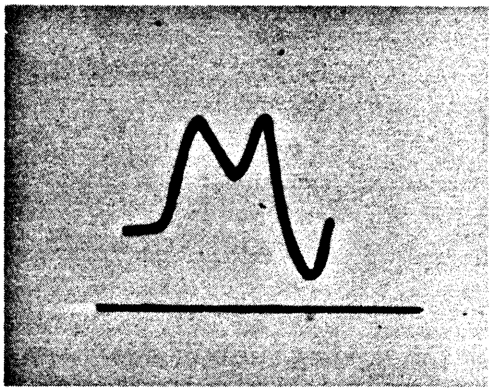
METERS

M_1 - 0-100μADC
M_2 - 0-10VDC

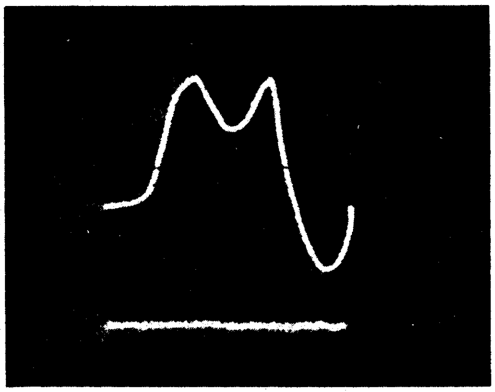
Figure 3



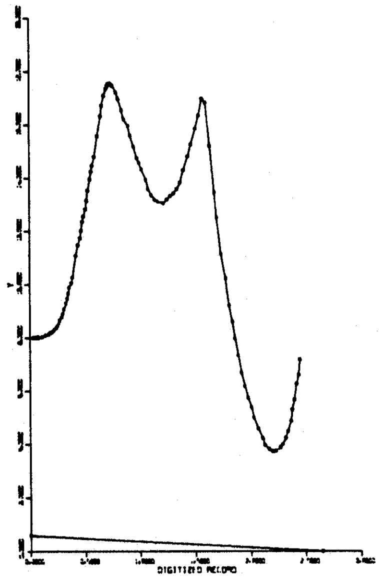
Original Record



Redrawn Transparency

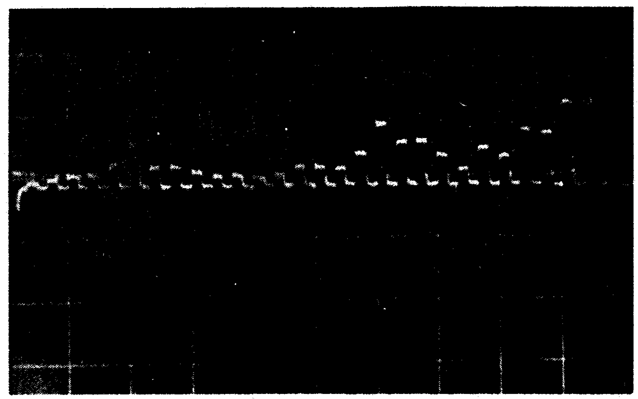


Storage Scope Monitor

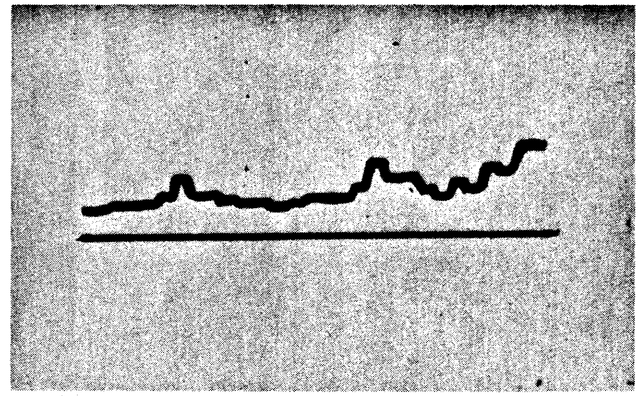


Digital Plot

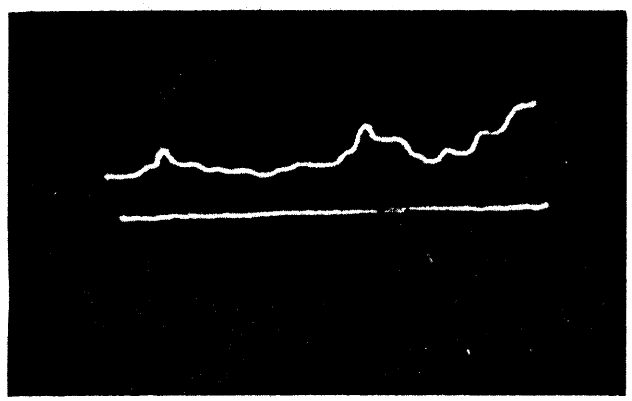
Figure 4



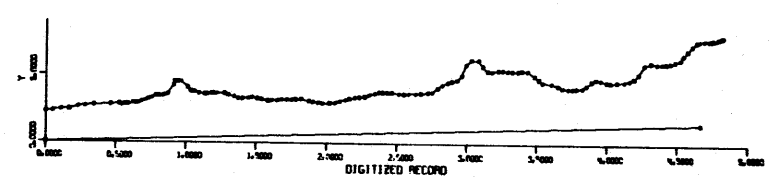
Original Record



Redrawn Transparency



Storage Scope Monitor



Digital Plot

Figure 5