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Electronic Scanning Microscope for a Spectrographic Plate Comparator

M. L. Kuder

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A scanning microdensitometer has been constructed for the purpose of analyzing spectrographic plates. The instrument facilitates reading the data and increases the speed and accuracy over other methods.

A small section of the plate is scanned at one time and converted to a magnified X–Y plot of density versus wavelength displayed on the screen of a cathode ray oscilloscope. The display includes an electronically produced fiducial line which is used as a reference point for measurements of line position. An alternate type of display may be used which includes the superposition of the mirror image trace on the original trace. This is preferred in some cases for setting on unsymmetrical lines.

Resolution to better than 0.001 millimeter on the plate is consistently obtained, and the fiducial line remains stable to this precision for several hours. Provision is made for observing up to five adjacent spectrograms on a single plate.

1. Introduction

Wavelength measurements of spectral lines may be made by accurately comparing the relative positions of the images recorded on a spectrograph plate. If the lines are sharp and distinct they may be scaled by an operator using a visual microscope having a suitable arrangement of cross hairs and a calibrated lead screw for advancing the spectrograph plate. However, if the lines are faint, unsymmetrical or superimposed on other lines, visual reading is difficult.

Greater accuracy and convenience is obtained by the use of a scanning microscope used as a microdensitometer to convert the image densities into analog values, these being presented as a display on a cathode ray oscillograph. The use of such a display of density versus wavelength in analyzing spectrograph plates is not new.[1] However, an electronic scanning microscope (figs. 1 and 2) has been devised which incorporates certain refinements in the principles of operation of a device of this type. The instrument shown was engineered to rapidly scan spectral lines (on a plate) and convert them into a magnified X–Y coordinate plot, which is displayed on a cathode ray screen. This device produces an unusually stable and sharply defined display of the X–Y plot of densities versus wavelength.

An electronically generated fiducial index has been integrated into the sytem in such a way that unusual stability has resulted in respect to the wavelength position which it indicates. This fiducial index appears on the cathode ray screen display superimposed upon the X–Y plot of the spectral pattern. The integrated generation of a fiducial index makes it possible to manipulate any of the normal controls of the oscilloscope without engendering any relative motion between the fiducial index and the X–Y plot.

The overall stability of the display together with the relative stability of the fiducial index line is sufficient to insure wavelength position readings within an accuracy of 0.001 mm or better when interpolating these wavelength positions from spectral lines of a parallel track on the same plate. In order to obtain absolute measurements of wavelength it is customary to record the spectrum of a standard source on an adjacent track on the same spectrograph plate. This makes it more convenient and more accurate to obtain a measurement of the relative positions of unknown spectral lines for accurate interpolation of their absolute wavelength.

The photographic density of the spectral lines as recorded on the plate may be read directly from the oscilloscope since d–c amplification of the scanned signal is employed throughout. The determination of ordinate deflection versus density calibration of the oscilloscope is not difficult, since the instrument yields the same deflections for static densitometer readings. Thus, with or without scanning, a standard density step wedge may be inserted in place of the spectrograph plate when calibrating the ordinate deflection representing densities. The instrument as presently designed yields a linear relationship between light intensities and ordinate deflections. This will ordinarily make it difficult to read photographic densities much above 2.2 with any degree of accuracy. For densities below 2.2 it is possible to obtain density readings with an accuracy of approximately 5 percent.

[1] A photoelectric setting device for a spectrum plate comparator, by F. S. Tompkins and M. Fred, J. Opt. Soc. **41**, p. 641 (Sept. 1951).

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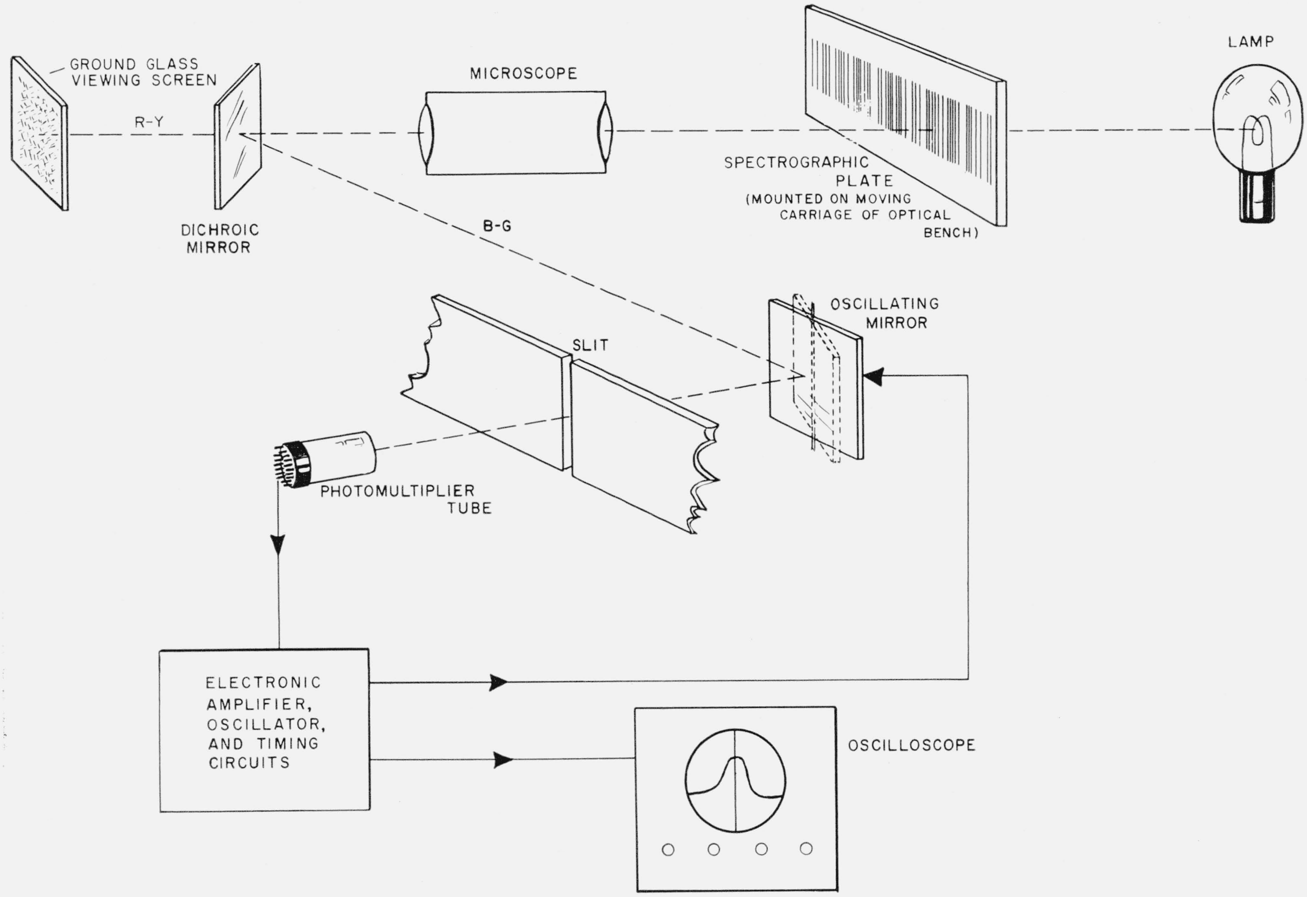

Figure 1. *Optical system.*

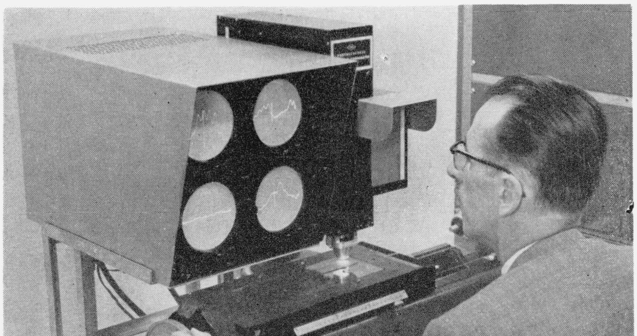

Figure 2. *Operator's view of assembled microscope, with the electronic controls on the right.*

2. Electronic Scanning Microscope

2.1. Operational Goals

Basically, an ordinate-line scanning microscope will provide video signals for a density versus wavelength display on a cathode-ray tube. In order that such a display may be useful for making measurements of a spectrograph-plate, it must first be stable and free of drift. Secondly, for precision measurements, the display should have a "generated" fiducial index which is related electronically in a very stable fashion to the optical axis of the microscope. Centering-drift of the oscilloscope will then be relatively unimportant. Direct-current amplification of the ordinate or density signal is essential for making absolute density estimates from the display. In order to make precision wavelength measurements the spectrograph plate should preferably have a pair of coherently exposed "standard" spectra (on the two outside tracks) such as thorium and iron. Using premeasured lines of these standard spectra, precise interpolation of the adjacent spectral tracks may be accomplished. In this procedure the electro-optical fiducial-index is used in conjunction with the micrometer lead screw for making precise settings on selected lines of the parallel spectral tracks. Interpolation between the unknown and the standard is then accomplished by calculations from the micrometer lead-screw readings used to advance the spectrograph plate under the microscope. If the oscilloscope displays a highly magnified image (of the plate) which is very stable and free of noise, it is possible to resolve the settings more acutely, more rapidly, and with less eye strain than is possible with the conventional optical microscope.

2.2. Optical Scanner

The optical scanning portion of the instrument (figs. 1 and 2) consists of a special low-power microscope with a magnification of approximately 10 diameters. Immediately behind the objective lens a dichroic mirror is inserted which splits the image beam into essentially equal parts of the visible spectrum. The red-yellow portion of the spectrum is delivered via bent optics to a viewing ground glass screen. The blue-green portion of the microscope beam is reflected from a vibrating mirror which is part of an electro-mechanical-optical transducer. Thence the oscillating beam impinges upon a slit of approximately 0.125 mm width and 13 cm length. Behind this slit five end-on photomultipliers are mounted, each of which receives the light from the lines of adjacent spectra on the same spectrograph plate.

A miniature DuMont 6365, end-on photomultiplier was selected for this application because its small size permits close stacking behing the common slit and also because the 6365 yields a better signal to noise ratio than some other older types that were tried. Also the "dark noise" is probably reduced by keeping the unilluminated portion of the photocathode to a minimum. The ideal photocathode might be one which was only a little wider than the slit aperture in front of it. Individual separation adjustment of the photomultiplier tubes is provided along the slit aperture to compensate for differences in separation of the parallel spectral tracks.

The vibrating mirror causes the 10 times magnified image of the spectrum to traverse the slit aperture before the photomultipliers. This mirror scans the image through a very small angle in sinusoidal fashion and sweeps over a maximum of approximately 0.5 mm on the spectrograph plate, with a slit-scanning resolution of 0.0005 in. or 12.7 μ. The electromagnetic mirror transducer shown in figure 3 consists of a miniature dynamic-speaker movement which imparts a push-pull movement to one edge of the mirror while the other edge of the mirror is affixed to a flexure plate made of phosphor-bronze. This transducer is self-resonant at approximately 400 cycles and is driven electrically at a frequency slightly below resonance. It is excited by a sine wave source of moderately constant frequency derived from a high-Q LC-circuit oscillator followed by a push-pull power amplifier. A gain control in this amplifier provides adjustment of the amplitude of vibration and hence of the scanning width on the spectrograph plate. A tilt adjustment has been provided for aligning the slit with the images of the spectrograph plate lines. If an identical spectral line (standard) is provided on the two outside tracks of the spectrograph plate, the slit may be readily and precisely aligned by adjusting the slit for coherent oscillograms of the scanning signals of these two outside tracks, as they are viewed on two separate oscilloscopes.

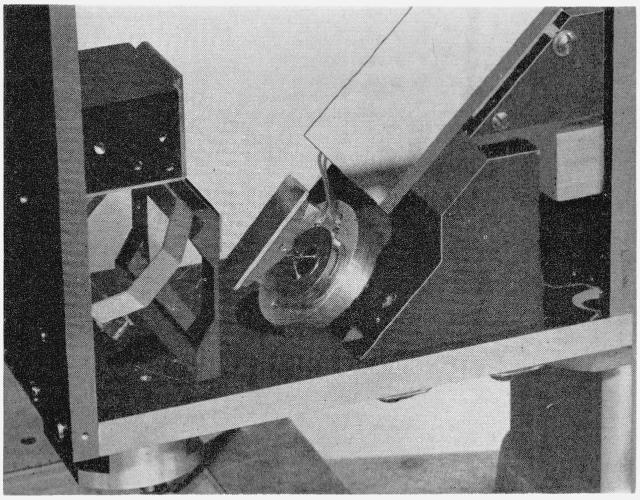

FIGURE 3. *The electro-magnetic mirror transducer.*

2.3. Programed Oscilloscope Sweep

The oscilloscope sweep as well as the source for the vibrating mirror transducer originates with the 400-cycle oscillator. In the block diagram, figure 4, this oscillator (1) is shown as the prime source for the network of electronics. This oscillator signal is fed through a paraphase amplifier which splits the signal into two signals which are mutually 180° out of phase. These two opposite phased signals of 400 cycles each pass through a pair of cathode follower impedance changers (3 and 5) which in turn feed into a pair of asymmetric clamps (4 and 6), which alternately clamp off first one and then the other of these two opposite-phased signals. These two asymmetric clamps are alternately turned "off" and "on" by the binary counter in such a manner as to pass exactly one cycle of each phase signal in sequence to the cathode follower (7). Each cycle passed by the asymmetric clamp is turned "on" at the peak of the sine wave and "off" at the next peak. The binary counter (12) is synchronized by means of the phase shifter (10) and the Schmitt trigger (11) to accomplish this precise timing for clamping the sine wave sweep signal at the crest of the sine wave. This paraphase sweep signal

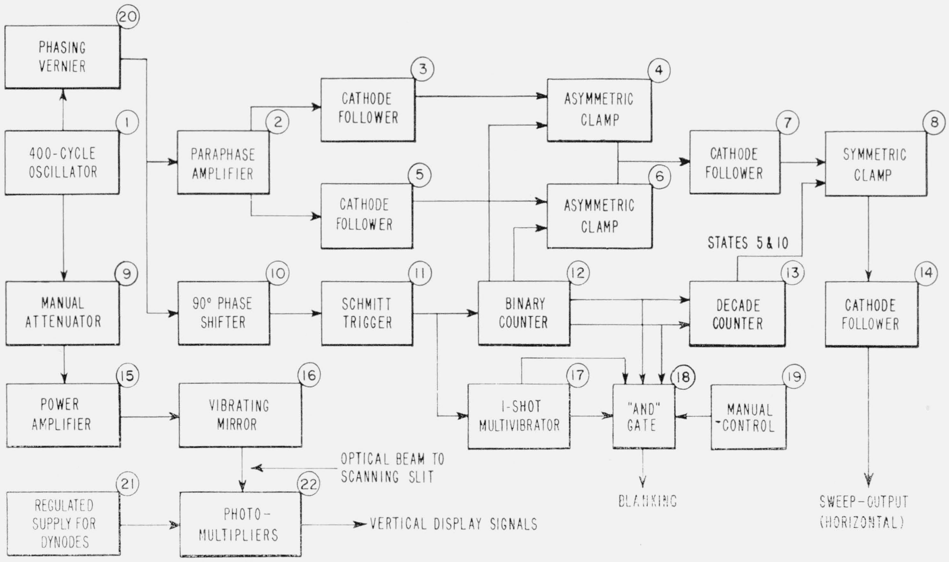

FIGURE 4. *The block diagram of the electronic system.*

presented on alternate sweeps has the property of generating a mirror image presentation of the scanned area of the spectrograph plate. The mirror image may be superimposed on the normal image. See figure 5 for oscillogram of this complex sweep signal.

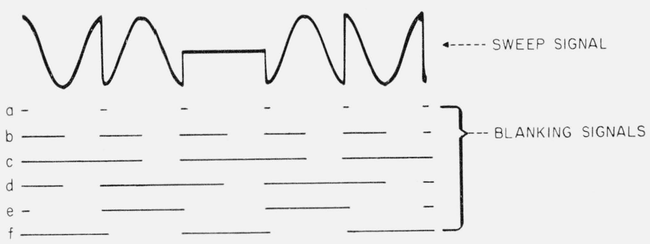

FIGURE 5. *Paraphase sweep-signal, and blanking signals.*

(a) Flyback blanking only.
(b) Flyback and retrace blanking for dual-presentation.
(c) Flyback, retrace, and mirror image blanking.
(d) Flyback, retrace, and normal image blanking.
(e) Flyback, and normal image blanking.
(f) Flyback, and mirror image blanking.

The binary counter also drives a decade counter (13) which in turn operates the symmetric clamp (8). The symmetric clamp has the property of collapsing the output signal precisely to the center of the sine wave for exactly 1 out of every 5 cycles. It is this collapse of the sine wave sweep signal to its exact center or zero voltage position which results in the generation of a stable fiducial line on the oscilloscope. During this single collapsed sweep interval the vibrating mirror transducer goes through its normal gyrations causing the vertical deflection of the oscilloscope to proceed in the normal manner with its signals from the photomultiplier. The normal deflection signals from the photomultipliers then plot the vertical fiducial line on the oscilloscope during this single collapsed sweep.

It will be noted that the same 400 cycle oscillator (1) feeds the power amplifier (15) through the manual attenuator (9). This latter link provides the necessary power to operate the vibrating mirror transducer (16) which of course vibrates synchronously with the sweep signals since they both operate from the same primary signal source. A manual attenuator (9) permits the selection of any width of scanning of the spectrograph plate from approximately $\frac{1}{2}$ millimeter down to zero, by adjustment of the transducer driver amplitude. The vibrating mirror transducer is a-c coupled to the amplifier through an impedance matching transformer which also has the property of eliminating any d-c component from the amplifier which could tend to cause a d-c drift in the central position of the vibrating mirror. Also, since the transducer is driven by a coil in a magnetic field, there are no moving components in the vibrating mirror system to accrue residual magnetism which would tend to affect the stability of the central position of the mirror. The choice of a high (400 cycle) scanning frequency permits a relatively rigid flexure-plate mount for the mirror, further insuring mechanical stability for positioning the nominal or central position of the mirror during its vibrating cycle, which precisely corresponds to the static position of the mirror when the transducer is at rest. The symmetric clamp (8) thus plots a stable fiducial line representing the rest position of the vibrating mirror. Since the symmetric clamp (8) is a high-impedance circuit which is sensitive to loading it is followed by the cathode-follower (14) to prevent any disturbance of this clamping circuit.

2.4. Selective Blanking

With the 400 cycle oscillator source (1), coming through (2), (3), (4), (7), (8), and (14) used directly for the oscilloscope sweep, a single pattern is traced during one-half of the cycle going from a peak to a trough of the 400 cycle source, while another (backward) retrace of the same pattern results from the other half of the 400 cycle signal which corresponds to the returning traverse of the mirror to its starting point. This retracing of the pattern during the last half cycle of the sine wave corresponding to the return sweep of the mirror is useful for checking phase shift in the system but is generally undersirable for measurement observations, since it tends to broaden the trace and reduce acuity. Any change in separation of the retrace pattern with respect to the normal trace is a sensitive indication of relative phase shift between the motion of the vibrating mirror and the oscilloscope electrical sweep. Any such phase shift can be manually nulled (compensated) rendering the retrace coincident with the nominal trace by adjustment of the phasing vernier (20).

During the normal "reading" operation of the instrument it is usually desirable to eliminate the retrace pattern. This is accomplished by the one-shot multivibrator (17) providing a blanking signal to the oscilloscope during one-half of the sine wave sweep. The result is a steady-state "single" sweep or unilateral display of the density versus wavelength in the scanned zone. However, a dual or bilateral display of the same X-Y plot may be presented in superimposed fashion, while maintaining blanking of the retraces. The use of the paraphase sinusoidal sweep makes such a dual display possible with coherent superimposition. Subsequently when the spectrograph plate micrometer screw is moved, the mirror image presentation moves in the opposite direction with respect to the normal presentation. This provides another convenient mode of matching selected components of the pattern as they merge together at the center of the sweep. This method of matching the "mirror" image with the "normal" image is particularly useful when trying to "set" on an unsymmetrical line. With this method it is possible to estimate an equal energy (spectral) distribution on either side of the fiducial line with much better visual discretion than with a single presentation.

Control signals taken directly from the binary counter (12) are used to operate the "AND" gate (18) through manual selection provided by (19), permitting the operator to select either the normal or the mirror image presentation or both. An ON-OFF control for the one-shot multivibrator (17) permits the operator to select or reject the retrace pattern for both of the two paraphase sweeps. Whenever the one-shot multivibrator (17) is in the OFF position permitting viewing of the retrace it is not turned completely off but rather is returned to a minimum time interval (see fig. 5a) which is just sufficient to blank the flyback which occurs during the transition between the alternate sweeps.

2.5. Typical Spectrum Patterns

Some typical patterns for the spectra of thorium are shown in the illustrations figures 6 to 10. Tompkins and Fred (see footnote 1) demonstrated this type of oscilloscope display, in 1951, using a revolving prism as the scanning element. These are Zeeman patterns which have typical symmetry. However, the spectral illustrations show an insufficiently small portion of the Zeeman pattern to reveal its symmetry. In figure 6a a portion of a Zeeman spectrum is shown first, in the "normal" single oscillogram form as resolved by this instrument; and secondly, in 6b, it is shown as it appears with the "mirror-image" oscillogram superimposed.

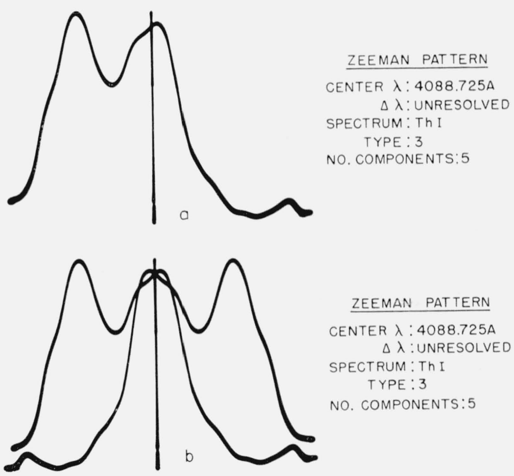

FIGURE 6a. *Portion of Zeeman pattern shown in "normal" presentation.*

FIGURE 6b. *Zeeman pattern of 6a shown as it appears in dual presentation (with mirror image superimposed).*

The latter is the "dual presentation." Figure 7 shows the instrument's ability to resolve some typical fine magnetic-splitting component (Zeeman) spectral lines with a minimum of noise in the oscillogram signal. The oscillograms shown in all the illustrations are unretouched photographs taken directly from the instrument's oscilloscope screen. The spectrograph plates used for these presentations were made with a dispersion factor of 0.881 A/mm.

In figure 8b, the resulting oscillograph pattern of figure 8a representing the density versus wavelength of spectral lines has been superimposed upon a

FIGURE 7. *Zeeman pattern, showing fine splitting components resolved without "noise".*

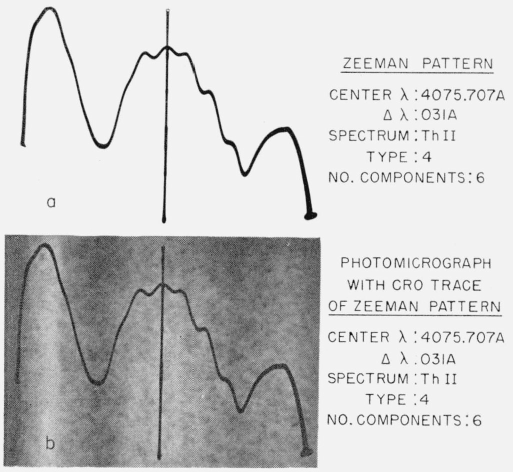

FIGURE 8. *Portion of Zeeman pattern showing (a) oscillograph presentation only, and (b) oscillograph presentation with superimposed photomicrograph of corresponding spectrograph plate.*

photomicrograph of the portion of the spectrograph plate which represents this scanning study. An examination of this photomicrograph concurrently with the associated oscillogram shows the remarkable integrating ability of the scanning system to eliminate the effect of the graininess of the spectrograph plate itself. This is not surprising when one considers that the scanning is accomplished with a line scanner rather than a point scanner. For with the line scanner each horizontal element scanned looks at a much larger equivalent vertical portion of the spectrograph plate than is shown in these photomicrographic illustrations.

2.6. Auxiliary Instrumentation

When the operator tries to read very faint lines or grossly overexposed spectral lines he will find it rather difficult to obtain sufficient amplitude on the vertical deflection of the oscilloscope for adequate resolution. This condition will tempt the operator to increase the vertical gain of the oscilloscope to the point where portions of the pattern will deflect off the face of the oscilloscope. While this mode of operation does yield a better resolution for spectral lines representing very small increments of density, it makes it necessary to repeatedly re-center the display for practically every advancement of the spectrograph plate under the comparator lens. Nevertheless, this mode of operation seems to be highly necessary to enable the reading of very faint lines and very saturated lines but it becomes a most inconvenient procedure, because of the need for frequent re-centering of the display image. This inconvenience may be overcome with an electronic attachment.

In order to avoid constant resetting of the gain and centering controls, automatic electronic centering of a sampled segment is provided. A sampling system raises or lowers the signal trace so that the segment of interest appears in the screen's center regardless of the amplitude or complexity of the signal waveform. An auxiliary piece of equipment provides such automatic vertical centering of the image continuously and simultaneously for all four oscilloscopes. A block diagram of the electronic circuitry which accomplishes this useful automatic centering is shown in figure 9. The principle of

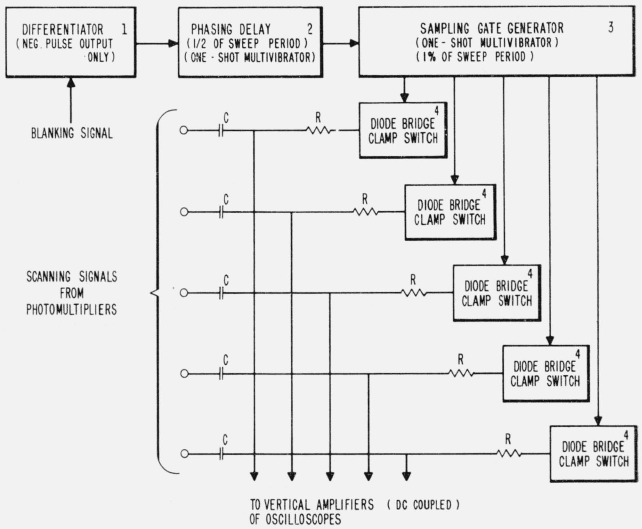

FIGURE 9. *Automatic image centering device.*

operation of this device is relatively simple and consists of the following technique. The leading edge of the blanking signal from the sweep generator circuitry is fed into a differentiator (1) which selects the negative transition of the blanking signal and provides a sharp pulse at that time. This negative pulse triggers a one-shot multivibrator phasing delay (2) which in turn provides a pulse output which occurs at the time the sweep is crossing the fiducial index line. This delayed pulse from (2) is used to trigger the sampling gate generator (3). The sampling gate generator is another one-shot multivibrator which generates a very short pulse whose duration is approximately 1 percent of the sweep period or sweep length. This sampling gate pulse operates a multiplicity of diode-bridge clamp-switches (4). The diode-bridge clamp-switches in turn provide for momentary grounding of the d–c return end of the a–c coupling resistor (R) only during the time of the sampling gate. The five a–c couplings shown are conveying the output of the five photomultiplier signals to the d–c amplifiers of the corresponding oscilloscopes. Grounding the d–c return resistance of these a–c couplings only when the sweep is crossing the fiducial line causes that part of the display image to always come to ground potential. This makes it possible to initially set the vertical centering of the oscilloscope so that the beam is vertically centered for a zero voltage or grounded input. The resultant displays obtained with this attachment under these conditions will always produce a trace which crosses the fiducial line at the center of the CRO tube, regardless of the magnitude or position of the balance of the display. The diode-bridge clamp effectively provides a d–c return for the a–c coupling at only one point in a repetitive pattern of an asymmetric signal. Since the signal is repetitive, the grounding for a brief instant at the same repetitive phase time will result in the generation of a bias on the load end of the a–c coupling condenser. After a time of about 5RC/d (d denotes duty cycle) a steady state bias voltage is established on the load end of the coupling condenser, and the pulse current thru "R" falls to zero. Thus on subsequent repetitions of the trace, the vertical signal passes thru a zero voltage point as it crosses the fiducial line during the gate-pulse interval. The time required for reaching a steady-state display after advancing the spectrograph plate is conveniently made about 0.2 sec.

Figure 10 shows a detailed schematic of the clamp-switch. The diode-bridge clamp-switch is actuated by a pair of coherent pulses of opposite polarity which are repetitive at any convenient rate. These pulses generate a bias voltage on the bridge end of these coupling condensers (C) which is nearly equal to the peak value of the control pulses. If these two control pulses come from a relatively low impedance driving source, a relatively high peak current will flow in the diodes for the brief time of that pulse, thus providing a very low resistance in all directions around the bridge. This results in the a–c signal being clamped to ground with the relatively low forward resistance of two diodes. In the interim between the control pulses all of the diodes are biased off by the accrued rectified bias charge on the coupling condensers (C). So long as this accrued bias on C exceeds the peak amplitude of the a–c signal to be clamped no clipping disturbance of the a–c signal will occur during the unclamped interval.

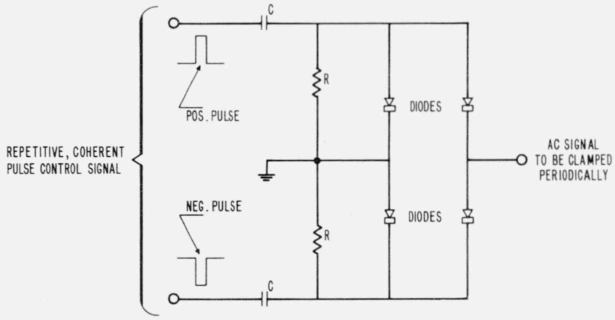

FIGURE 10. *Diode-bridge clamp-switch.*

The author thanks Herbert D. Cook and Louis A. Marzetta for their many helpful technical suggestions, and Paul Allison for his contribution of skilled craftsmanship in the fabrication of mechanical parts.

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