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Airborne Electronic Ultra-Fast Scanning Spectrometer

Doran Baker
Utah State University

Allan Steed
Utah State University

AIRBORNE ELECTRONIC ULTRA-FAST SCANNING SPECTROMETER

Doran Baker and Allan Steed
Electro-Dynamics Laboratories
Utah State University
Logan, Utah

ABSTRACT

An all-electronic scanning spectrometer is described which is capable of scanning the 0.6 to 1 μ spectral region at scan rates of up to 10,200 scans/second at a resolution of better than 15 Å. An image dissector photoelectron multiplier tube is used as the detection device. The minimum detectable signal of the system is less than 1 x 10^{-6} w cm^{-2} $Å^{-1}$ at 0.8 μ. The instrument occupies a volume of less than half a cubic foot and is designed for operation in a KC-135 aircraft. Video magnetic tape recording is used, and a digital read-out method has been developed so that the data can be programmed into a computer.

INTRODUCTION

Studies of transient optical emission phenomena, such as explosions, electrical discharges, or projectile impacts, require an experimental measurement of power spectral density functions which are rapidly changing with time. In order to obtain such measurements from high-altitude nuclear bursts, where *a priori* knowledge about the spectral distribution of the emitted light was very limited, the Air Force Cambridge Research Center (AFCRC) developed the so-called Dispersion Units (McPherson, et al., 1961) to take measurements from aboard aircraft. These are fast-response photometers having flat optical bandpasses and sharp wavelength cut-offs.

Analysis of weapons test data with these and other instruments indicated a strong need for a system to complement the photometers by providing rapid spectral scans at moderate resolution. The new system, like the Dispersion Units, had to be capable of giving reliable absolute measurements with the data recorded electronically in a manner amenable to rapid automatic processing. This requirement provided the impetus for the development of the electronic scanning spectrometer described herein.

For some time, it has been possible to obtain very fast spectra using a slitless, streak spectrograph. Time resolutions of five microseconds are reported (Orville, 1966) for this device, which is essentially a shutterless movie camera affixed to dispersing optics. Spectrometers which use electro-optical detectors are much better for absolute irradiance measurement, dynamic range, and data transmission and processing; however, most scanning spectrometers are severely limited in speed of response by the necessity to move mechanical parts such as mirrors, slits, gratings, prisms, or filters.

The fastest mechanical spectrometers use a rotating mirror (Liberman, et al., 1966; Hill and Fellerhoff, 1966) or mirrors (Dolin, et al., 1966) to achieve scanning rates of up to about a thousand scans per second. Another technique has been to use a spinning Optical Coating Laboratory (1964) circularly-variable interference filter. The center wavelength of the optical passband is linearly related to the angular position on the circular filter.

The concept of a rapid electronic scanning spectrometer with no mechanical moving parts was suggested by Hervey Gauvin at AFCRC in 1955. His approach was to image a spectrum onto the face of a vidicon TV camera tube and then read out the time - resolved spectra electronically into a magnetic tape recorder. Although the technical feasibility of the approach was established, it was apparent that the technique could not readily be developed into an ultra-fast system, due to the signal storage requirements of conventional television camera pick-up tubes.

Subsequently, Doran Baker, of the same Laboratory, conceived the idea that the Farnsworth image dissector was the key to an

ultra-fast spectrometer with all-electronic scanning. The dissector does not have the storage time delays of the iconoscope, orthicon, or vidicon types of image tubes.

The development of the first fast-scanning spectrometer based on the image dissector was the joint effort of AFCRC (now AFCRL), ITT Industrial Laboratories, and the McPherson Precision Instrument Co. Two instruments with 1 kHz scanning rates in the 3300 to 5800 Å spectral region were integrated into KC-135 airborne instrumentation laboratories. Time-resolved spectra were successfully obtained from the 1962 high altitude nuclear detonations of Operation Dominic (Gauvin, et al., 1964). Essentially the same system has been partially described in the open literature (Harber and Sonnek, 1966).

Subsequent to the Fish Bowl nuclear test series, the need became apparent for a rapid scanning infrared system capable of achieving at least a 10 kHz scan rate with about a 15 Å resolution. Utah State University was contracted by AFCRL, under the direction of John Cahill, to design and develop this second-generation instrument, together with a data recording and read-out system which could cope with the very high rates. This paper describes the resulting airborne electronic spectrometer system which scans the 0.6 to 1.0 μ spectral region at a rate of 56 Å/μsec.

THE IMAGE DISSECTOR

The initial version of the device which subsequently came to be known as the dissector tube was patented in Germany by Dieckmann and Hell in 1925 (Hubbell, 1942). However, the young Utah inventor, Philo T. Farnsworth, developed the first practical cathode ray camera at his San Francisco laboratory in 1928 (Everson, 1959). Farnsworth called his tube a "dissector" because the word was descriptive of the process which took place in breaking down the optical image for electrical transmission. In 1935, Farnsworth greatly increased the sensitivity of his dissector tube by adding what he called a "multipactor." This electron multiplier or amplifier device is incorporated as an integral part of modern image dissector tubes. By this time, the iconoscope of Vladimir Zworykin (RCA) and the dissector of the Farnsworth Television Company had become the most important television cameras, but shortly thereafter the image dissector fell into disuse.

The principle of operation of the image dissector (Figure 1) is very similar to that of the photoemission multiplier tube. Photoelectrons are ejected from the back side

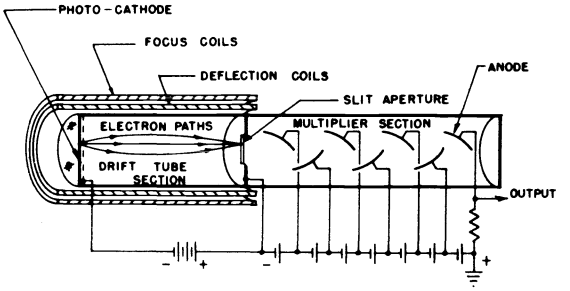

Figure 1. Image dissector tube and coil assembly.

of a translucent photocathode surface when light is incident upon the front side (Garson and Gardner, 1939). These electrons are accelerated away from the cathode and are focused into a secondary emission electron multiplier whose last dynode serves as the anode for the device. In the dissector, unlike the phototube, the optical image on the face of the tube is preserved as a photoelectron distribution image. An axial magnetic field is used to maintain the photoelectron distribution pattern as the latter drifts to the anode. An aperture, normally consisting of a circular hole in a plate, actually does the "dissecting" of the image when the whole electron image is swept across the aperture (Fink, 1957). Horizontal and vertical sweeping are accomplished either electrostatically or magnetically using deflection plates or coils, respectively, such as are used in common cathode ray tubes.

To maximize the throughput of the spectrometer, it was desirable to have a slit aperture instead of a circular hole for the scanning of a line spectrum displayed on the face of the tube from a grating monochromator. Since the old Farnsworth Television Company had long since been absorbed into ITT, the latter were engaged to fabricate the special electronic image dissectors required for both the early and the recent versions of the electronic rapid-scan spectrometer.

In the present instrument, magnetic deflection is used because it was economically more feasible for ITT to adapt their existing television technology in the development of the tube. Electrostatic deflection, though, offers the advantages of speed, sweep-circuit simplicity, and minimum image distortion.

SPECTROMETER SYSTEM

The overall operation of the airborne fast-scanning spectrometer is shown in the block diagram of Figure 2. The light from

the radiating source to be measured is dispersed by a fixed-grating slit monochromator. The resulting live spectrum is displayed on the face of the image dissector. The electrical output from this image tube is then

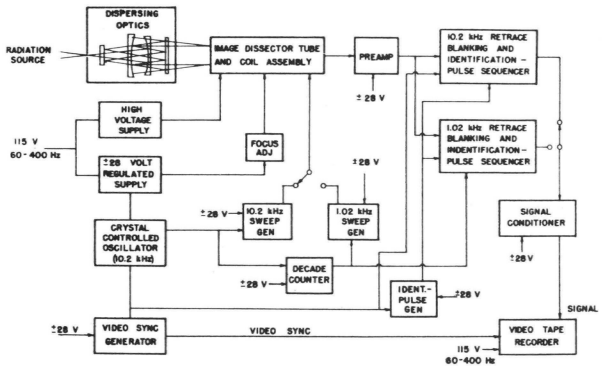

Figure 2. Block diagram of electronic ultra-fast scanning spectrometer system.

signal conditioned to make it suitable for analog storage by a video magnetic tape recorder. The optics, image dissector tube with associated coil assembly, and necessary electronics are contained in the 5 x 7 x 24-inch aluminum housing shown in Figure 3. The instrument is designed to be shock mounted in a KC-135 aircraft. Both the high and low voltage supplies are external to this housing, but can be located inside the housing in subsequent instruments. The system operates from an external 115 V, 60 or 400 Hz power source. The spectrometer weighs 25 lbs, exclusive of power supplies and tape recorder.

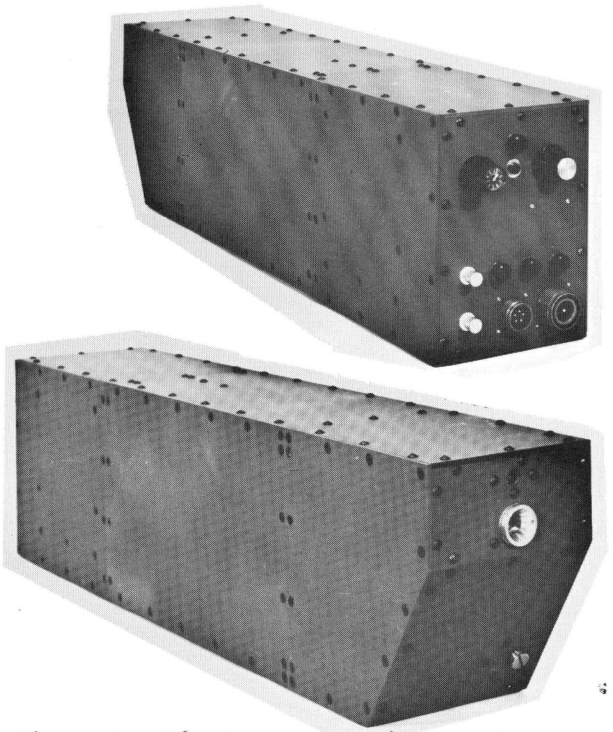

Figure 3. Electronic scanning spectrometer.

Dispersion Optics and Detector

Modified Czerny-Turner dispersing optics are used in the spectrometer. The entrance slit is 76 mm long with an adjustable width which can be closed down to about 25 microns. The grating is a Bausch and Lomb 35-53-04-35 which has 600 lines per mm and is blazed at 7500 Å. The field of view is 7.5 x 14° full angle with the greater angle in the vertical direction. This specific field of view was chosen so as to coincide with that of the Dispersion Units. The optics are aligned to display a 4000 Å bandpass (normally 6000-10,000 Å) across a 1-inch detector surface.

The detector is an ITT F4011 image dissector which has an S-1 photocathode response and an internal aperture slit 76 mm long and 50 microns wide. The linear dispersion on the photocathode is 165 Å/mm. With these optics and detector, it is possible to achieve better than 15 Å resolution throughout the spectral bandpass when scanning at 10.2 kHz. This gives a spectral scan rate of 56 Å/μsec.

All of the optical components including the image dissector tube are mounted on a rigid, specially flattened 3/8-inch aluminum plate to insure ease of alignment and focus. The physical arrangement of these components is shown in Figure 4.

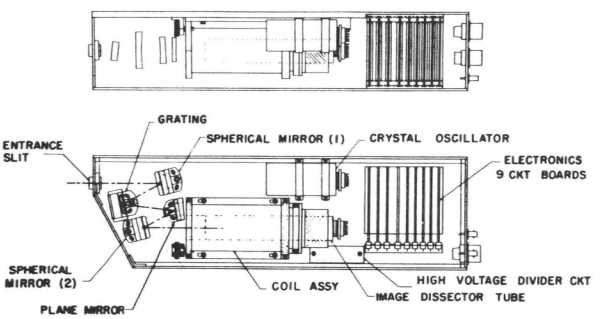

Figure 4. Physical layout of electronic scanning spectrometer.

Electronics

The system was designed with four orders of dynamic range so that irradiances in the range of about .002 to 20 w cm^{-2} μ^{-1} could be measured. This is accomplished using a logarithmic video amplifier. The high im-

pedance current output from the image tube is presented to the record amplifier as a low impedance voltage.

Timing for the entire system is supplied by a crystal-controlled oscillator with a 10.2 kHz output. This waveform is used to trigger the scanning sweep circuits and also to provide synchronization for the video tape recorder. The spectrometer is designed to scan at both 10.2 and 1.02 kHz, and the two magnetic sweep generator circuits are contained in the electronics section. A circuit is also included which makes it possible for the instrument to change scan rates automatically from 10.2 to 1.02 kHz at a preset time after the initiation of a burst of light. This is accomplished using a light-activated SCR and a delay circuit. The SCR is positioned near the optical entrance slit of the instrument.

Since the scan rate is high and it is desired to scan for a considerable length of time, it is very useful to have some form of scan identification to aid in data read-out. This is accomplished in this system by sequencing into the signal train a series of six pulses preceding each spectral scan. The height of each pulse represents a decimal number from zero to nine. With six pulses, it is possible to identify up to a million spectral scans before repeating the sequence. The height of each pulse is converted into binary form when the spectral information is passed through an analog-to-digital converter. Direct binary coding was considered, but there is insufficient time between scans to include the necessary number of pulses. A sketch showing these identification pulses in relation to the rest of the signal train is shown in Figure 5.

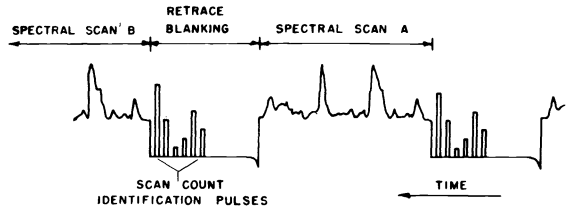

Figure 5. Location of scan identification pulses on signal train.

Recorder

The electronic frequency response (-3 dB) of the recorder must extend from the scanning frequency (f_{scan}) of the spectrometer up to

$$f_c = \frac{0.35}{D} \frac{\lambda_2 - \lambda_1}{\Delta\lambda} f_{scan}$$

where $\lambda_2 - \lambda_1$ is the optical spectral bandpass, $\Delta\lambda$ is the optical resolution, and D is the duty cycle of the spectrometer (≈70%). In order to store the data from scanning a 4000 Å wide spectral region at a rate of 10.2 kHz with a 15 Å resolution, the recording system must have a bandwidth of about 1.4 MHz. Efforts now underway to increase the spectrometer resolution will make a further demand on the frequency response of the recorder.

The only practical electronic recorders to meet these demands are video magnetic tape recorders with rotating heads. The instrument selected was an Ampex VR660B, which is a standard, portable TV broadcast recorder with an upper frequency response of 3.5 MHz. Information is recorded along diagonal tracks across a 2-inch tape by two recording heads positioned 180 degrees apart on a rotating disk. The electronics section of the spectrometer contains all the necessary circuitry to present the proper format and synchronization to the video recording system.

DATA PROCESSING

Once the data are recorded, the formidable problem presents itself of how to read out the spectral information from the magnetic tape into a usable form. It is necessary to program the information into computer language by passing it through an analog-to-digital converter. The difficulties in doing this are: (1) There are no analog-to-digital converters capable of converting data at the required 1.4 MHz rate, and (2) the VR660B recorder is not capable of playing back the data at a slower rate because of major difficulties in trying to reduce in synchronism both the rotating head speed and the tape speed of the video recorder.

A method of reading out the data has been devised, however, using a specially modified oscilloscope (HP H19-175A) with a delay generator plug-in unit (1781B) and a display scanner plug-in unit (H031751A). A block diagram of this system is shown in Figure 6.

The system operates as follows: The motion of the tape is stopped with the recorder on "playback" so that one diagonal track of the video tape is repeatedly scanned by the heads which rotate at their normal speed. A signal is thus produced at the recorder output containing 170 individual spectral scans which are repeated every 1/60-th of a

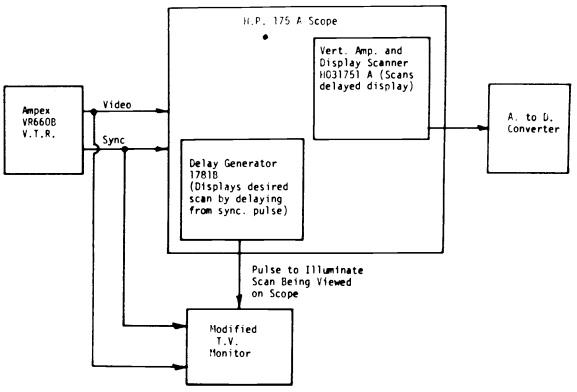

Figure 6. Block diagram of read-out system.

second. This signal is then fed into the H19-175A oscilloscope. A synchronization pulse derived from the record-head switching circuitry is also fed into the input. These pulses indicate the start of the diagonal track being scanned and are used to activate the delay generator in the scope.

As an example, consider the read-out of the spectral information of the 50-th scan from a particular diagonal track on the tape. The delay generator is adjusted so that the main sweep of the oscilloscope is armed just prior to the appearance of this scan in the repeating signal described above. The main sweep of the oscilloscope is then triggered by the negative pulse (Figure 5) which precedes the 50-th scan, making it possible to display this individual scan across the entire scope face every 1/60-th of a second. The H031751A plug-in unit makes it possible to manually or automatically read out the repeating spectral scan appearing on the scope face. This spectral information appears at the scope output in form suitable for analog-to-digital conversion or X-Y plotter display.

The TV monitor (Conrac 17/c) shown in Figure 6 is used to assist in locating spectral information of interest. With the recorder repeatedly scanning a single diagonal track, all 170 spectral scans appearing on that track are displayed on the monitor, one below the other, in intensity modulation form. With the data displayed in this manner, it is easy to determine where rapidly changing spectra occur. This display is of great help in deciding what information should be digitally read out.

Spectrum of a Xenon Flash

Figure 7 shows a sequence of spectral scans taken during a single flash of a xenon photo-flash lamp. The information was taken using the ultra-fast scanning spectrometer and recorded with the video tape recorder. Information was read out using the sampling oscilloscope described above and an X-Y plotter. On the first scan the initiation of the flash can be seen. The second scan shows the continuum build-up over the entire spectral range. Subsequent scans show the xenon line structure emerging as the brightness of the flash decays. By the 18-th scan

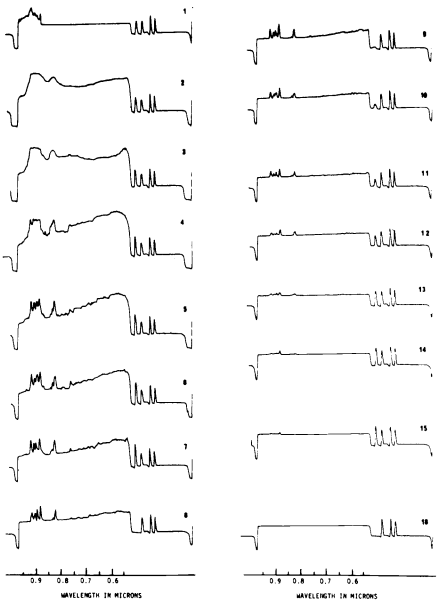

Figure 7. Spectral data of xenon photoflash lamp taken with electronic scanning spectrometer.

the intensity of the flash is no longer observed at any wavelength. The scan rate was 10.2 kHz showing that the entire flash lasted only about 1.8 msec. Figure 8 shows the 6-th scan of the sequence expanded, showing the near-infrared line structure of xenon.

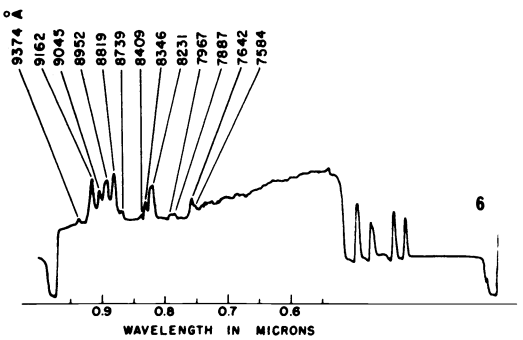

Figure 8. Single scan of xenon photo-flash.

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REFERENCES

1. Dolin, S.A., H.S. Kruegle, and G.J. Penzias, "Model 501 Rapid Scanning Spectrometer," Technical Specification Sheet, The Warner and Swasey Company, New York; 1966.

2. Everson, G., "The Story of Television, The Life of Philo T. Fransworth," W.W. Norton and Company, New York; 1949.

3. Fink, Donald, "Image Dissector (Non-storage) Tube," Television Engineering Handbook, McGraw-Hill, New York, pp. 5-52 to 5-55; 1957.

4. Gauvin, H.P., et al., "High Altitude Nuclear Detonation Optical-Infrared Effects," Operation Dominic, Fish Bowl Series, DASA POR-2035, Air Force Cambridge Research Laboratories, Bedford, Massachusetts; Sep., 1964.

5. Harber, R.A., and G.E. Sonnek, "Spectral Analysis Using the Electronic Scanning Spectrometer," *Applied Optics*, Vol. 6, No. 6, pp. 1039-1043: June, 1966.

6. Hill, R.A., and R.D. Fellerhoff, "A Dual Recording, Variable Range, Rapid-Scan Spectrometer; Comparison of Simultaneously Recorded Stark-Broadened Hα and Hβ Line Profiles," *Applied Optics*, Vol. 5, No. 7, pp. 1105-1110; July, 1966.

7. Hubbell, R.W., "Four Thousand Years of Television," G.P. Putnam's Sons, New York; 1942.

8. Larson, C.C., and B.C. Gardner, "The Image Dissector," *Electronics*, Vol. 12, No. 10, pp. 24-27; Oct., 1939.

9. Liberman, I., C.H. Church, and J.A. Asars, "A High Resolution Rapid Scanning Spectrometer," Scientific Paper 66-1C1-BPLAS-P6, Westinghouse Research Laboratories; May 2, 1966.

10. McPherson, P.M., N. Sclar, B.R. Linden, W. Brouwer, and A.T. Stair, Jr., "Photo-detecting Instrument with Flat Wavelength Response," *J. Opt. Soc. Am.*, Vol. 51, No. pp. 767-773, July, 1961.

11. Orville, R.E., "Time-Resolved Slitless Spectrum of a Lightning Stroke," *Science*, Vol. 151, pp. 451-452; Jan., 1966.