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CHARACTERIZATION AND OPTIMIZATION
OF A SILICON VIDICON SPECTROMETER
THROUGH REAL-TIME MICROPROCESSOR CONTROL

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CHARACTERIZATION AND OPTIMIZATION OF A SILICON VIDICON
SPECTROMETER THROUGH REAL-TIME MICROPROCESSOR CONTROL

By

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ABSTRACT

CHARACTERIZATION AND OPTIMIZATION OF A SILICON VIDICON SPECTROMETER THROUGH REAL-TIME MICROPROCESSOR CONTROL

By

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A multiprocessor-controlled silicon vidicon spectrometer is described. The spectrometer incorporates a silicon-target vidicon with a fused-silica window to extend the usable instrument response into the near ultraviolet region. The spectrometer can monitor a 230 nm window in the range of 250 nm to 1000 nm with 1.0 nm resolution. Under computer control the wavelength window can be divided into between 16 and 4096 wavelength channels. The tube readout beam can be deflected to any channel at random or made to scan them sequentially at frequencies between 10 kHz and 1 MHz. To increase the target's integration time and enhance weak signals, the readout beam can be inhibited for a user-specified time interval.

The real-time signal-to-noise ratio (S/N) of the system is 3086. Signal averaging can be used to increase the S/N at the expense of time resolution. For a fixed data acquisition time, a combination of signal averaging and charge integration can be used to optimize the output response. The detector responds linearly to the incident light level over 4 orders of magnitude. The observed non-linearity of the vidicon is 1% at 90% of saturation.

Real-time control of the vidicon spectrometer is provided by a general purpose multiprocessor system based upon the Intel 8080A

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microprocessor. The development of this system not only illustrates the increased system capabilities of a multiprocessor system over those of a single processor system, but also provides design guidelines for an efficient and modular multiprocessor system. Specific examples of task allocation, efficient use of system resources, and utilization of the inherent bandwidth of available microprocessor static memory are provided in the documentation of the computer system used to control the vidicon spectrometer.

The vidicon spectrometer was applied to three basic types of dual-wavelength spectroscopy; dual-wavelength non-scanning spectroscopy, dual-wavelength scanning spectroscopy, and derivative spectroscopy. These dual-wavelength techniques are easily implemented with the vidicon spectrometer which, because of its multi-wavelength capability, requires only changes in the data processing software to achieve the various techniques. Realized advantages of the dual-wavelength mode of operation included continuous correction for scattering and sample settling and the elimination of the influence of an interfering component (Co^{+2}) in the analysis of a highly overlapping two-component mixture (Co^{+2} and Ni^{+2} in 2N HClO_4).

To Jean, Mom, and Dad

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CHAPTER 1

INTRODUCTION

The dominant technique for the measurement of electromagnetic radiation in the UV-VIS-IR region is the dispersive system based on the diffraction grating. The typical dispersive system decodes incident frequency information into an optical spatial array in the focal plane of the instrument, which is usually a monochromator or spectrograph. In the past, the two main detection systems used to measure the spectral intensities in the image have been the photographic emulsion (plate) and the photomultiplier tube in conjunction with an exit slit. Although the photographic plate is a multichannel detector capable of simultaneously recording thousands of lines during a single exposure, it has several severe disadvantages, namely; a nonlinear response, limited dynamic range, and tedious readout. Thus, even though the photomultiplier tube-exit slit combination is limited to measurement of one spectral resolution element at a time, it is the detection system of choice for the majority of spectrochemical measurements because of its wide dynamic linear range, sensitivity, and direct conversion of light intensity to an electrical signal.

Fortunately, this single-channel limitation is now being overcome by the utilization of electronic image sensors as spectroscopic detectors. These image sensors combine the desirable characteristics of photomultiplier tubes with a simultaneous multichannel capability. One type of electronic image sensor is the silicon-target vidicon. The most attractive features of this image detector for spectroscopic

applications are its broad spectral coverage (250-1100 nm), high quantum efficiency, linear response over a fairly wide dynamic range, low geometrical distortion, and reliability.

The design, characterization, and optimization of a multiprocessor-controlled silicon vidicon spectrometer are presented in this dissertation. The versatility of the computer-controlled instrument lies in the ability to change easily the scanning format by software changes rather than by hardware modifications. In addition to instrument control, the computer is used to implement several data processing options for signal-to-noise (S/N) enhancement.

Chapter 2 presents a thorough discussion of the operation of the silicon vidicon tube, as well as surveys of recent developments in vidicon tube technology and recent spectroscopic applications of the silicon vidicon tube. Chapters 3 and 7 discuss the operation and construction details, respectively, of the silicon vidicon spectrometer. The instrument can monitor a 230 nm window within a broad spectral range of 250 nm to 1000 nm. Spectral information within this 230 nm window is acquired simultaneously by the integrating diode array and read out sequentially by a scanning electron beam under computer control. Under software control, the user can specify the wavelength resolution (number of channels/scan), the scan frequency, vertical integration interval, detector integration time per scan, number of scans to be averaged for S/N enhancement, and the magnitude of the beam current.

A major objective of this research was the characterization and optimization of the performance of the silicon-target vidicon as a

spectroscopic detector. The experiments designed to obtain this information and the corresponding experimental results are discussed in Chapter 4. Characteristics examined included the multichannel spectral response, the wavelength linearity and response, and the signal dependence upon incident light level and integration time. Factors limiting the S/N and methods for S/N enhancement were also investigated.

Chapter 5 describes the application of the vidicon spectrometer to three basic types of dual-wavelength spectroscopy; dual-wavelength non-scanning spectroscopy, dual-wavelength scanning spectroscopy, and derivative spectroscopy. Because of the vidicon's multi-wavelength capability, the implementation of these dual-wavelength techniques with the vidicon spectrometer requires only changes in the data-processing software. Realized advantages of the dual-wavelength mode included continuous correction for scattering and sample settling and elimination of the influence of an interfering component in the analysis of a highly overlapping two-component mixture.

To provide real-time control of the instrument, a multiprocessor system was designed and built in our laboratory. Chapter 6 describes the development of the multiprocessor system and its advantages in real-time instrument control. Multiprocessor control of the vidicon spectrometer is also discussed in this chapter.

CHAPTER 2

OVERVIEW OF THE SILICON VIDICON TUBE IN ANALYTICAL SPECTROSCOPY

A. Introduction

The purpose of this chapter is to provide a clear perspective on the operation and application of the silicon vidicon tube as a spectroscopic detector. The first section explains in detail the theory of operation and signal generation of the silicon vidicon tube. Familiarity with this material is necessary to understand fully the following chapters on the design, characterization, and operation of the vidicon spectrometer developed in this research. The second section reviews recent developments in vidicon tube technology, including several unique imaging devices based upon a conventional vidicon tube. The last section surveys recent spectroscopic applications of the silicon vidicon tube to illustrate its usefulness as a multichannel detector in analytical spectroscopy.

B. Operation of the Silicon Vidicon Tube

The RCA C23246 silicon-target vidicon used in this research is a very high sensitivity photoconductive camera tube with extremely broad spectral response, high resolution, low residual signal, and low dark current characteristics. In electron-optics design, in mechanical construction, and in physical appearance, it is virtually identical to the standard vidicon photoconductive camera tube. However, whereas a standard vidicon tube has an evaporated photoconducting film as the

image sensing target, the silicon-target vidicon has a planar array of reverse-biased silicon photodiodes. The most obvious advantages of the silicon target over more conventional targets are its sensitivity, which results from an almost unity quantum yield throughout the entire visible and near infrared region, and its resistance to image burn-in or damage resulting from overexposure (1-9).

Figure 2-1 illustrates the silicon-target vidicon tube. The optical image is focused by a lens onto the substrate of the silicon photodiode array. This diode array has two distinct functions: 1) to convert the optical image into a corresponding electrical charge pattern, and 2) to accumulate and store the charge pattern until the electron beam and scanning mechanism read out the signal. The diode side of the array is scanned by an electron beam that has passed through the appropriate electron optics for focusing and deflection. When the scanning electron beam recharges the diodes, a current exists in the V_T circuit (Figure 2-1). This recharging current constitutes the video signal.

A silicon photodiode array typically consists of a matrix of 660 by 660 diodes; about 436,000 diodes within a 1.85 cm square. The substrate is nominally 10 Ω -cm n-type silicon with a diameter of 2.16 cm. The substrate in the area of the diode array is 5-50 μm thick, while the perimeter of the wafer is usually 100 μm thick to ensure a self-supporting structure (2,3,7). The diodes are islands of p-type dopant diffused through gaps in a silicon oxide insulating film (Figure 2-2). The diode array has a typical center-to-center diode spacing of 15 μm and an oxide hole diameter of 8 μm .

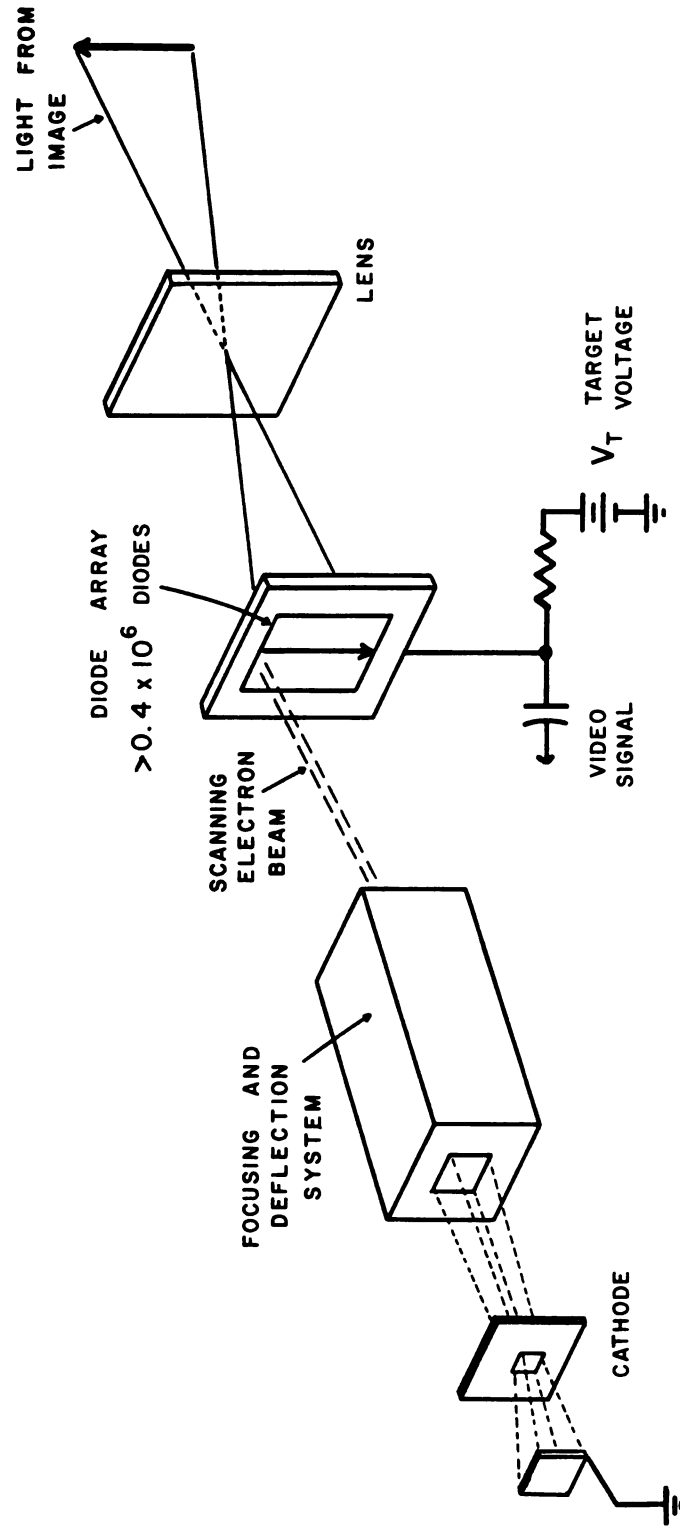


Figure 2-1. Schematic of a Silicon-Target Vidicon

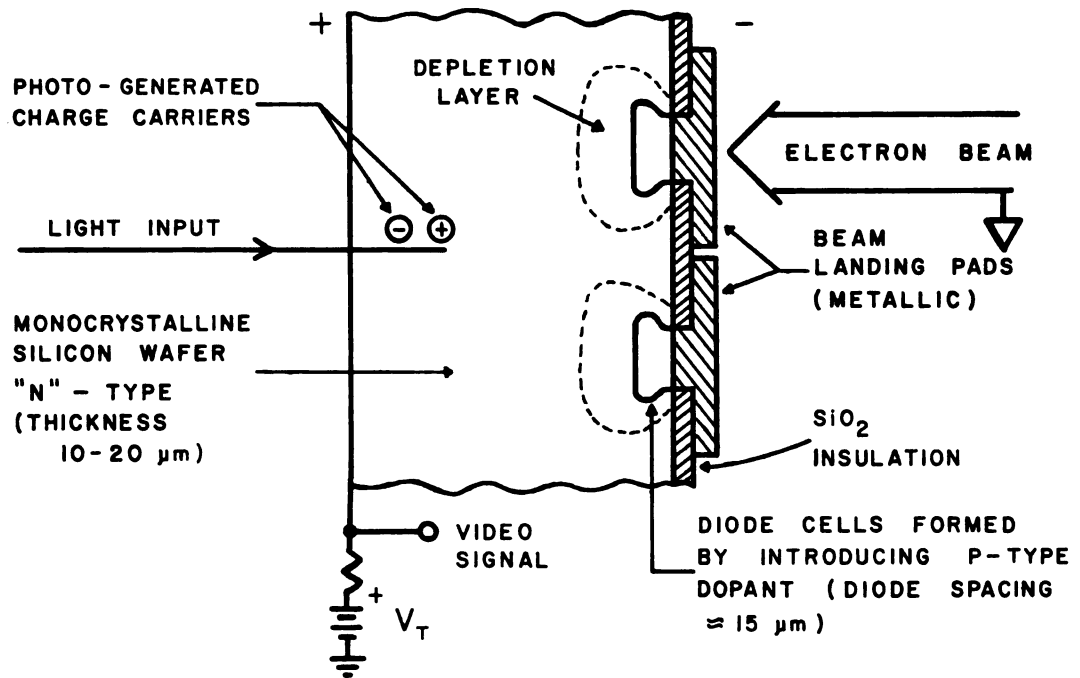


Figure 2-2. Silicon Vidicon Target Construction and Signal Production

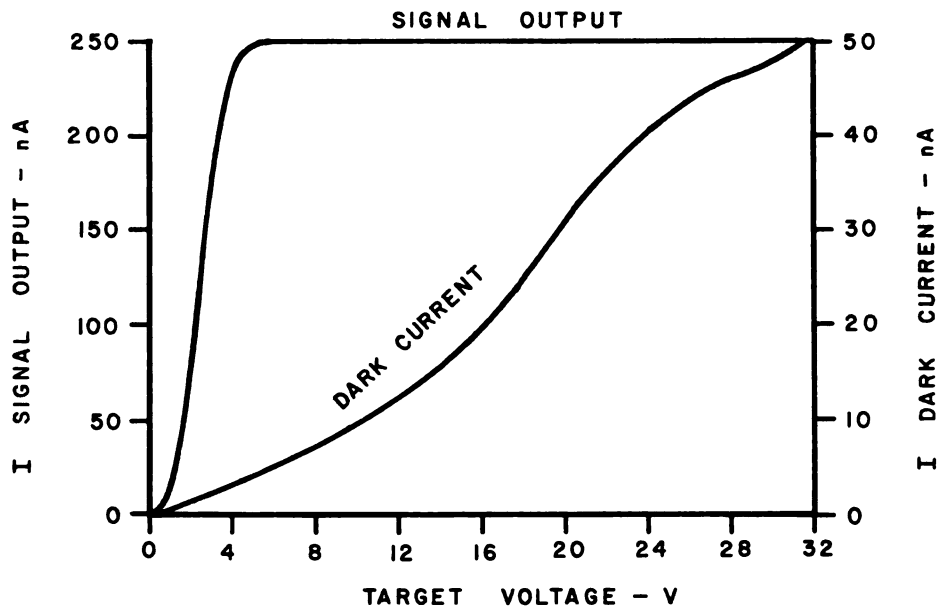


Figure 2-3. Signal Output and Dark Current vs Target Voltage at Constant Illumination

The silicon oxide film separates the diode matrix and prevents the scanning beam from landing outside of the diode and thereby finding a short-circuit path through the silicon. Unfortunately, if the oxide is exposed to the beam, it will accept and store electrons until it becomes negatively charged to the point where it will repel any further incident electrons from the beam, i.e. the openings into the diode centers will be closed off (1-3). In order to minimize oxide exposure to the scanning beam, RCA adds a pattern of raised conducting "beam-landing pads" to their vidicon targets (1) (see Figure 2-2). Precision fabrication of these metallic pads gives nearly complete shielding of the silicon dioxide from the scanning beam, while still isolating each diode pad.

In normal operation, the substrate of the diode array is biased positively with respect to the cathode of the electron gun. For an RCA silicon-target vidicon tube, the optimum bias (target) voltage is 8 volts (see Figure 2-3) (1,3). At this voltage the peak target current is approximately 750 nA. Higher target voltages result in excessive dark current and do not increase the sensitivity of the vidicon. Lower target voltages result in inefficient collection of the generated charge carriers, inability of the tube to handle reasonable levels of signal current, and lower resolution.

The electronic charge deposited by the electron beam places a reverse bias of 8 volts on the photodiodes as it scans over the array. This reverse bias creates a depletion width of approximately 5 μm with a 10 $\Omega\text{-cm}$ substrate and results in an effective charge storage capacitance for the target of approximately 2000 pF/cm² (1,2,7). Thus the diodes store electrons left by the beam as it charges them negatively

to the potential of the cathode of the electron gun. The insulating effect of the reverse-biased junction prevents the charges on the diodes from migrating within the target. Because the diodes have very low leakage currents (less than 0.1 pA per diode), they remain in the full reverse-biased condition throughout an entire frame period if illumination is absent.

When light is incident on the target, photons are absorbed in the n-type region, and an electron-hole pair is created for each absorbed photon. For visible light the majority of photo-generated carriers are created near the illuminated surface. As the creation of photo-generated carriers increases the minority carrier (hole) density above its thermal equilibrium value, illumination causes a net diffusion of holes towards the reverse-biased diodes. If the lifetime of the holes is sufficiently long and the illuminated surface has been treated to reduce recombination effects, a large fraction of the photo-generated holes will diffuse to the depletion region and contribute to the junction current. As long as the diodes remain reverse-biased, the light-induced junction current will continue to discharge the diode capacitance. In this manner a charge pattern develops on the diode array that is an electronic image of the optical image focused on the target.

The video output from each diode is created when the scanning electron beam returns to a diode and restores the original charge by re-establishing the full value of the reverse bias. If a fixed voltage of -8 V is applied to the cathode, the video output current from the target can be directly coupled to a current-to-voltage converter to

produce a position-encoded video output voltage (10) (see Figure 2-4). This arrangement maintains the necessary 8 V potential difference between the cathode and the target, while it eliminates the need for capacitive coupling between the target and the amplifier.

The electron beam is deflected across the target by two mutually perpendicular magnetic deflection coils. Typically, the scan pattern is a series of parallel lines that start in one corner of the target and end in the opposite corner (see Figure 2-5). Normally the rates of deflection for the two axes are 30-100 Hz and 15 kHz. In spectroscopic applications, the slow axis is usually positioned parallel to the wavelength axis in the focal plane of the monochromator.

The video output current, I , produced by a silicon vidicon is expressed by:

$$I = QeGA(N)^{\gamma}T_e/T_r \quad \text{in A}$$

where Q = quantum efficiency of the photosurface, dimensionless

e = electron charge, C

G = target gain ($G = 1$ for a silicon vidicon)

A = area of target scanned per output channel, cm^2

N = incident photon flux, quanta $\text{cm}^{-2} \text{sec}^{-1}$

γ = slope of the current vs luminous flux curve ($\gamma = 1$ for a silicon vidicon)

T_e = detector exposure time between readouts, s

T_r = active readout time per output channel, s (11).

If the photon flux is constant over the exposure time and the scan pattern is constant and reproducible, this equation reduces to

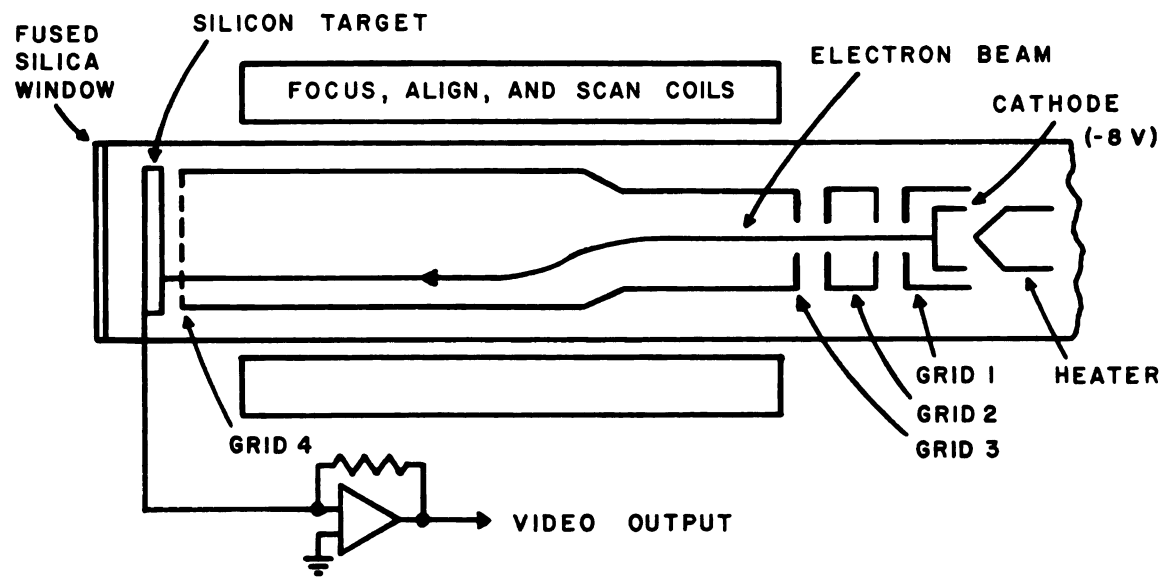


Figure 2-4. Silicon Vidicon Tube Geometry

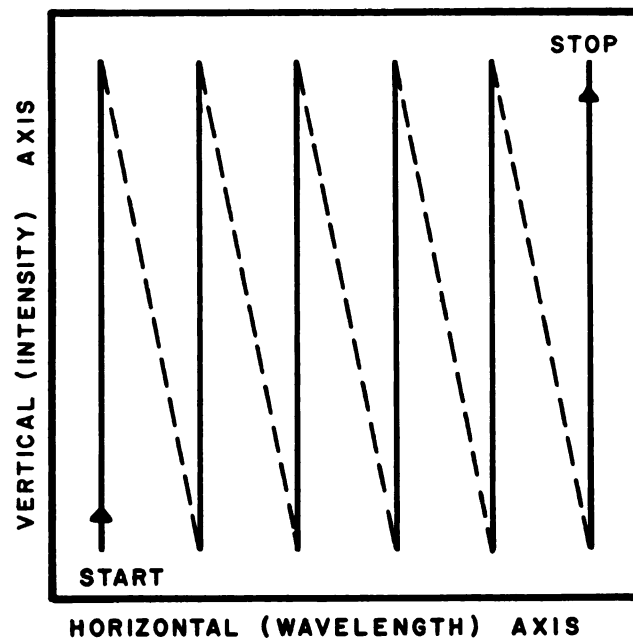


Figure 2-5. Beam Scan Pattern

$I = k(T_e/T_r)$, where k equals the constant $Q_e GAN$. Thus, the average output current of any given channel is directly proportional to the ratio of exposure time to readout time for a constant incident photon flux. This forms the basis for the charge integration technique for signal enhancement (see Chapter 4).

C. Recent Developments in Vidicon Tube Technology

In the past several years a number of excellent review articles have appeared in the scientific literature concerning the development of camera and storage tubes and self-scanned solid-state image sensors for pick up and reproduction of optical images (2,7,12-18). Because of the depth and breadth of coverage of these review articles with respect to currently available imaging devices, a review of imaging devices and their applications in spectroscopy is not included in this chapter. Thus, the following review covers only the more recent developments in vidicon tube technology.

1. Silicon-Target Vidicon

The concept of using a large-scale array of silicon photodiodes as a photosensitive target for a camera tube was first proposed at Bell Laboratories in 1967 (19). Since then, rapid advancements in silicon technology and large-scale integrated-circuit technology have led to arrays with more than 600,000 individual diodes on a silicon wafer (1). Continuing improvements in manufacturing efficiency and techniques have reduced the number and prominence of blemishes from faulty diodes and have resulted in lower-cost tubes. Also, the mechanical strength of the tubes has been increased by mounting the

target as a part of the faceplate assembly. The introduction of fused-silica and quartz windows has extended the response of the silicon vidicon into the UV to less than 250 nm. These ongoing improvements have helped to expand the usefulness of the silicon-target vidicon in existing applications and to extend its use into new areas.

One of the most recent developments with this type of tube is a reduced-blooming target that greatly reduces the highlight-blooming characteristic of the silicon-target tubes (1). (Blooming is a lateral spreading of a highlight image that occurs when the signal saturates a localized area of the diode array.) These tubes will eventually replace the standard silicon-target tubes and should offer extended dynamic ranges of 10^5 or more (12).

2. Focus-Projection-Scanning Vidicon

An important advance in the electron optics for high resolution cameras in recent years was the invention of the Focus-Projection-Scanning (FPS) vidicon (22-24). This vidicon combines the advantages of electrostatic deflection and magnetic focusing into one unique electron optics assembly. Inherent advantages of the FPS design include: optimized beam landing and edge focus, lower power requirements, higher beam current densities at the photoconductor, and smaller size and weight. Additionally, the FPS electron optics are compatible with any photoconductive target. Because FPS vidicons have 60 to 70 percent fewer internal parts than conventional magnetic vidicons and a correspondingly lower mass, they are extremely rugged devices.

3. Pyroelectric Vidicon

The search for improved cameras for thermal imaging has resulted in the development of the pyroelectric vidicon (PEV) (20,21). The pyroelectric vidicon is a low-cost, infrared-sensitive camera tube that operates at room temperature. It can image in any wavelength band within the 2-400 μm range and is compatible with all conventional television formats. Because the PEV responds only to changes in temperature, it is insensitive to any constant radiation incident upon it. However, a chopping and storage mode has recently been developed to enable the integrated signal from several frames to be displayed as a static image (20).

The pyroelectric vidicon is quite similar in appearance to the normal photoconductive vidicon. It differs in that the front window is usually germanium, which is opaque to visible radiation, but highly transparent in the 8-14 μm range. The most common target material for the PEV is TriGlycine Sulfate (TGS). The PEV uses a vidicon gun with a conventional thermionic cathode to provide a low velocity electron beam to sample the pyroelectric target. For the 8-14 μm region, the PEV has a typical minimum resolvable temperature of less than 1°C at 250 television lines (TVL). Successful areas of application of the PEV include infrared laser detection, forest fire mapping, security/surveillance, and medical diagnostics.

4. X-Ray-Sensitive Vidicon

Recently a new type of imaging tube for x-rays and γ -rays in the 80-keV and higher energy range was developed at Northwestern University

(25). The uniqueness of this x-ray-sensitive vidicon to the measurement of radiation lies in the vidicon's inherent ability to image low levels of radiation by charge integration in the target plate. The target plate for this tube consists of a layer of lead deposited on an aluminum substrate. The lead converts a portion of the incident radiation into photoelectrons. These photoelectrons travel through a low-density layer of cesium iodide deposited on the lead layer and create secondary electrons. An electric field across the cesium iodide layer causes the secondary electrons to be collected by the conductive backing of the target plate, which creates a charge pattern on the surface. A video output signal is created by scanning an electron beam, which neutralizes the charged array. There is no lateral spreading of the charge on the cesium iodide surface because of the high resistivity ($10^{17} \Omega/\text{cm}$) of the cesium iodide layer. In order to maximize the signal current for a given radiation energy, it is necessary to optimize the thickness of the lead layer and the thickness and density of the cesium iodide layer. Anticipated areas of application of this device include uptake scanning (visualization of the distribution of radioactive material in an organ or gland) and high-kV radiographic imaging.

5. Piezoelectric-Target Vidicon

Another interesting variant of the vidicon is the piezoelectric-target (quartz) vidicon that is used for visualizing ultrasonic images (26,27). The target of this vidicon consists of a mosaic of quartz crystals, which provide an electronic image of the incident acoustic

field distribution. Piezoelectric voltages are generated in the quartz target at all regions corresponding to the received acoustic image. As in the conventional vidicon, a charge pattern corresponding to the acoustic image is formed on the signal plate side of the target and subsequently neutralized by a scanning electron beam. A promising application for this imaging device is in the ultrasonic imaging of human anatomy.

D. Spectroscopic Applications of the Silicon Vidicon Tube

Imaging devices are finding steadily increasing application as multichannel detectors in analytical spectroscopy. During the past several years multichannel detectors, which employ either silicon vidicon or photodiode array detectors, have been used for atomic absorption (28-34), emission (10,11,18,33,35-56), and fluorescence (49,50,57,58) spectroscopy, molecular UV-visible absorption (10,18,32,55,59-82,91) and fluorescence spectroscopy (83-90), and Raman spectroscopy (92,93). This rapid expansion in the application of multichannel detectors has been aided by the availability of complete detector systems from several commercial companies, such as Princeton Applied Research, Nuclear Data, EMR, RKB, Quantex, Tracor-Northern, and Tektronix. Additionally, the detector heads and electronic components are also available on a modular basis from the following companies; Reticon, GE, Hamamatsu, EMI, AmpereX, ITT, RCA, Fairchild, Teltron, TI, and Westinghouse. Nieman (18) has written an excellent review on the historical development and application of imaging devices in analytical spectroscopy. Consequently, this review covers only

recent spectroscopic applications of the silicon vidicon tube.

Nieman and Enke (61) and Pardue et. al. (10,59) have recently developed and characterized computer-controlled vidicon spectrometers for molecular absorption and atomic emission spectrometry. The vidicon detector was found to be uniquely suited to multicomponent analysis and preliminary investigations of the kinetics of chemical reactions, including the detection of reaction intermediates with lifetimes as short as 10 ms (59). Recent applications by these authors include simultaneous multicomponent drug determinations (66,67), kinetic methods for simultaneous enzyme determinations (66,74), and reaction-rate methods of analysis (63,78-80).

More recently, Pardue and coworkers (60,81) have developed a vidicon based derivative spectrometer that simultaneously generates the normal spectrum and its first derivative. Electronic wavelength modulation is employed to generate the derivative spectrum. It is achieved by superimposing a low amplitude periodic waveform on the horizontal (wavelength) deflection signal. A phase-sensitive lock-in amplifier, referenced to the frequency and phase of the wavelength modulation waveform, generates a signal proportional to the first derivative of the optical spectrum incident on the vidicon detector. This instrument is currently being applied to the determination of bilirubin in biological fluids (60).

Ostertag (70) converted a commercial optical multichannel analyzer (PAR) into a pulse-operated system that fully synchronizes on an external event occurring even at low repetition rates. The optical spectra measured with this instrument are those of the luminescence of crystalline samples that have been excited by a

picosecond laser. Because of the low repetition rate of the measured events, a simultaneous background subtraction feature was added to provide automatic correction for long range drifts of dark current in the vidicon detector.

Silicon vidicon tubes have been used in an integrating mode for ground-based telescopic observation of celestial objects (77,94,95). Silicon vidicons are preferred over the intensified versions (SIT) because of the requirements for high photometric precision ($<1\%$) and IR sensitivity to relatively bright objects. The vidicons are mounted in vacuum-insulated boxes and cooled with dry ice to minimize the dark current and to extend the maximum usable integration time. At dry ice temperature, the accumulation of dark current in 1 hr is only 4% of full-scale saturation. To further minimize the accumulation of a background signal during signal integration, the filament current is turned off during integration, because backlighting of the IR-responsive silicon target by the cathode heater contributes a nonspatially uniform signal on the order of 1% of full-scale saturation in 1 min of warm operation at 6.5 V. Consequently, the integration time is limited by the intensity of the celestial object under observation rather than by the electronic background. Images of extended sources through the telescope agreed photometrically with photomultiplier measurements to about 1%.

The silicon vidicon tube is also a viable multi-wavelength detector for liquid chromatography (96). It offers the following advantages over single wavelength detectors: fingerprint spectral information to complement retention times, selection of wavelengths

which optimize sensitivity and resolution for each component, ability to resolve quantitatively overlapping chromatographic peaks, and the ability to detect impurities in chromatographic peaks. A preliminary application of this configuration (96) involved the analysis of pharmaceutical preparations (Sinutab II and Primatene tablets).

Similarly, a silicon intensified-target vidicon (SIT) was used as a multichannel detector for the identification of fluorescent liquid chromatographic petroleum fractions (58) and as a gas-phase fluorescence detector for gas chromatographic analysis of polyaromatic hydrocarbons (89). The SIT gave limits of detection about a factor of five times larger than those obtained with a photomultiplier tube.

To be useful in the clinical laboratory, multicomponent fluorescence analysis requires the rapid measurement of the fluorescence intensity at a variety of excitation and emission wavelengths. Because of the low light intensities often encountered in fluorescence spectroscopy, a SIT detector was used as the multichannel detector in a new video fluorometer (84,97). A complete set of emission and excitation spectra for perylene were obtained in less than 2 s at concentrations of 10^{-10} M. Another recent application of the video fluorometer involved a study of the fluorescence of the living brain and heart (57). As a quantitative tool, the video fluorometer is potentially of enormous value in measuring the damage in strokes and shock, as well as in basic studies of circulation and metabolism in the heart and brain.

Pardue and coworkers (55) and Morrison and coworkers (37,40) have used vidicon spectrometers for simultaneous flame-emission analysis of electrolytes in serum. Morrison's group combined first and second order diffraction lines to obtain analytical lines within the detector's

wavelength window, and used filters to partially absorb selected lines to equalize emission intensities. Results for control sera and clinical samples indicated an accuracy and precision of better than 2% (37). Simultaneous emission determinations of up to eight metals have been performed (10,11,36,43,45,58,49), but the S/N for the silicon-target vidicon is an order of magnitude lower than for single channel detection (11). Caruso and coworkers (48) demonstrated that a microwave induced plasma coupled to a vidicon detector has potential for simultaneous multielement trace analysis. Winefordner and coworkers (49) compared single channel and multichannel detection limits for eleven metals. The multichannel detection limit was an order of magnitude higher than the single channel detection limit. Busch, Howell, and Morrison (38) used spectral stripping to remove either molecular bands or undesired concomitant interferences from analytical lines of interest.

Simultaneous determinations of up to four elements (28,29,31,34) have demonstrated that the silicon vidicon is also a viable multichannel detector for atomic absorption spectrometry. The observed detection limits were an order of magnitude higher than for single channel detection. Multichannel detection allowed summation of the signal from several lines of the same elements for increased sensitivity (31). A random access vidicon echelle spectrometer provided both high resolution and wide spectral coverage for atomic absorption measurements (34). By using the random access mode of target interrogation to measure only the line intensities of interest, a reduction in computer time and memory space was realized, as well as greatly

simplified data reduction. For atomic absorption, the use of a non-integrating, electron-amplifier detector, such as an image dissector, would allow rapid signal modulation to eliminate interference from flame emission, and the electron amplification should improve S/N ratios to a level compatible with that of a photomultiplier tube (29).

The sensitivity characteristics of the ultraviolet-sensitized silicon vidicon and silicon intensified-target (SIT) vidicon tubes were compared in the ultraviolet-visible wavelength region (52). Flame emission detection limits for 23 elements were reported and compared to the best reported photomultiplier tube values. The results demonstrated that the silicon vidicon tubes are capable detectors in the visible wavelength region, and that the SIT vidicon tube provides detection power equivalent to commonly used photomultipliers in the visible spectral region. The image tube detectors' poor responsivity characteristics in the ultraviolet region limited their applicability to measurements in this spectral region. Winefordner and coworkers (87) demonstrated that while the silicon vidicon is not analytically useful for atomic fluorescence or molecular luminescence spectrometry, intensified image devices possess considerable analytical potential in molecular luminescence in the visible spectral region.

CHAPTER 3

OPERATION OF THE SILICON VIDICON SPECTROMETER

A. Introduction

The purpose of this chapter is to describe the basic operation of the microprocessor-controlled vidicon spectrometer as a general purpose, single-beam scanning spectrophotometer. Since all instrument control and data acquisition functions are under computer control, this chapter focuses primarily on the operating software that was developed for the vidicon spectrometer. The software and terminal interactions for operation of the instrument are discussed in the following section. Although the acquired spectral information can be processed locally by the micro, the stored spectra are usually transmitted to the mini-computer for final processing. Accordingly, details of the minicomputer software developed for post-processing of the acquired spectra are discussed in Section C. All programs relevant to this chapter are listed in Appendix A.

B. Real-Time Control and Data Acquisition

Real-time control and data acquisition in the vidicon spectrometer are provided by a multiprocessor system that was developed jointly with Erik M. Carlson (98) and Spyros Hourdakakis (99). The multiprocessor system not only provides real-time control of the vidicon detector's scan format and the data acquisition system, but also controls the monochromator wavelength drive, optical shutter, and the positions of

the sample and reference cells in the cell module. Details of the computer system architecture are presented in Chapter 6. Documentation of the design details of the electronic, mechanical, and optical components of the silicon vidicon spectrometer are presented in Chapter 7.

The vidicon detector is mounted on the faceplate of a GCA/McPherson EU-700 Czerny-Turner monochromator with the beam slow-scan axis parallel to the wavelength axis of the dispersed spectrum. The monochromator was modified so that the grating image is focused on the target of the vidicon tube. With the grating and optics used in this research, the target monitors a wavelength window of 230 nm. Since the vidicon's silicon target provides usable response from about 250 nm to 1000 nm, the detector's 230 nm wavelength window can be positioned anywhere within this broad spectral range. The wavelength control circuit divides the target into a user-defined number of parallel electronic channels. Information in each wavelength channel is read out by a scanning electron beam under computer control and integrated over the vertical trace by the data acquisition system to enhance the signal-to-noise ratio. Through the software the user can vary the above scan parameters to optimize the response of the vidicon spectrometer to the chemical system under study.

A new software package, CONVERS (100), was modified to run on a multiprocessor system (98) and was subsequently used as the software operating system for the vidicon spectrometer. This system is based upon an interpretive compiler and offers the advantages of high speed operation, excellent memory efficiency, stack manipulation, and a variety of high level constructs, i.e. the programmer can develop his

own individual modifications and additions to the language itself. Once software modules have been entered into the system software library, they can be called up and executed in one of two ways: the name of the software module can be entered at the terminal for immediate execution, or the module name can be included as a line of code in another software routine. Thus, once the assembly language routines for instrument control and data acquisition have been written, the programmer can develop his own instrument-specific high-level language by designing software modules that contain the desired sequence of assembly language module names.

In the vidicon spectrometer, the coordinator micro controls and coordinates all activities in the multiprocessor system, and all terminal interaction is with this micro. The software that was developed for the coordinator micro is outlined in Table 3-1. The order of these routines is consistent with the order in the program listing in Appendix A.

The power of the CONVERS language is evident in the following sequence of CONVERS commands that was used for characterization of the vidicon spectrometer:

VINIT
DATA
PLT
EVAL
WFILE

Although this command sequence contains only five CONVERS calls, these individual modules allow maximum flexibility in optimizing the response

Table 3-1. CONVERS Software for Operation of the Vidicon Spectrometer

Name	Function
TO1	Transfers data from Micro 0 (coordinator) to Micro 1 (communicator).
OPEN	Opens the shutter.
CLOSE	Closes the shutter.
SAMP	Selects the sample cell.
REF	Selects the reference cell.
TO2	Transfers data from Micro 0 (coordinator) to Micro 2 (vidicon micro).
DECBIN	5-digit BCD to 16-bit binary.
DECIN	Inputs a decimal number from the keyboard.
AXIS	Draws axes and tickmarks on the CRT.
CC	Checks for a Control C from the keyboard, then disables the graphics display and enables the alphanumeric display.
DIV	16-bit binary by 8-bit binary unsigned division.
BINDEC	16-bit binary to 5-digit BCD.
DECOUT	Outputs a decimal number to the CRT.

Table 3-1. (cont'd.).

WINOUT	Inputs/outputs monochromator position to/from keyboard/CRT.
POUT	Outputs current default scan parameters to the CRT and inputs new default values from the keyboard.
GON	Enables the graphics display and disables the alphanumeric display.
VSET	Initializes the vidicon scan circuits.
FSET	Initializes the fast adder circuits.
CLR8K	Clears the 8K data memory.
VINIT	Initializes the vidicon spectrometer.
WFILE	Writes current contents of data memory to a floppy disc file.
PLT	Plots choice of sample, reference, transmittance, or absorbance spectrum on the CRT.
EVAL	Outputs values of sample, reference, transmittance, and absorbance for selected wavelength channels to the CRT.
DATA	Initiates data collection.

of the vidicon spectrometer. The CONVERS routines resident in the other two micros are called as needed by the coordinator routines. Consequently, the routines in the two slave micros are completely transparent to the user.

The user initiates an experiment by entering VINIT from the keyboard. The coordinator then requests the current location of the monochromator. After the wavelength has been entered, the coordinator starts the operator dialogue routine (POUT). The CRT format for the operator dialogue is illustrated in Figure 3-1. It consists of a table of mnemonics, typical mnemonic default values, and an operator prompt (>). Table 3-2 explains the mnemonics and their functions. The user can change any or all of the mnemonic values by entering the mnemonic and its new value (see underlined portion in Figure 3-1). The processor checks the validity of each keyboard entry and updates the CRT display after each valid user response. If an illegal mnemonic or mnemonic value is entered, the processor outputs a question mark and waits for a valid input. If an entered mnemonic value is within the established boundary limits, but is not one of the discrete values allowed for that mnemonic, the processor selects the nearest allowed value and assigns it to the mnemonic. An entered mnemonic becomes the new default value for that mnemonic.

Although the number of wavelength channels (PTS) can vary from 16 to 4096, only values of between 64 and 512 points/spectrum are useful. Fewer than 64 points results in too little resolution for most applications, while more than 512 points requires excessive data storage and actually degrades the signal (see Chapter 4). The number of

WAV	550	FRQ	25
PTS	512	BEM	60
DLY	3	ACQ	6
BLK	1	GAI	1
BYT	3	BIT	12
AUG	100	INT	0
ADR	8192	CNT	1536
OPT	0	SRD	7

>(MNEMONIC) (VALUE) (CR)

Figure 3-1. CRT Format for Operator Dialogue

Table 3-2. Operator Dialogue Mnemonics

Mnemonic	Expansion	Function
ACQ	Acquire	Number of vertical intervals over which the signal is to be integrated. (The sum of ACQ and DLY can not exceed 10).
ADR	Address	Starting address for data storage.
AVG	Average	Number of scan frames to be averaged (1 to 4096).
BEM	Beam	Sets beam current by controlling voltage to Grid #1 (Grid voltage = $-0.59 \text{ V} \times \text{BEM}$).
BIT	Bit	Number of bits of precision in A/D output (12, 10, or 8).
BLK	Blanking	Enables blanking of scan during retrace and signal integration (0 - no blanking, 1 - blanking).
BYT	Bytes	Number of bytes of storage per data point (1, 2, or 3).
CNT	Count	Total number of bytes to be stored (CNT = BYT x PTS).
DLY	Delay	Number of vertical intervals to delay before starting data acquisition (ACQ + DLY < 10).
FRQ	Frequency	Scan frequency in kilohertz (FRQ = $1 \text{ MHz}/N$, for $N = 1$ to 100).
GAI	Gain	Controls time constant (gain) of the integrator (Gain increases with increase in GAI for GAI = 1 to 15).

Table 3-2. (cont'd.).

INT	Integration	Number of integration frames per scan frame (0 to 255).
OPT	Optimize	If set to '1', the computer optimizes the gain of the data acquisition system by selecting the largest integrator gain that does not cause the A/D converter to overrange.
PTS	Points	Number of wavelength channels (PTS = $4096/N$, for $N = 1$ to 256).
SRD	Sample Reference Dark	Specifies spectra to be collected ($S = 4$, $R = 2$, $D = 1$).
WAV	Wavelength	Current wavelength of monochromator.
END	End	Terminates operator dialogue.

wavelength channels also affects the time required to acquire a spectrum at a given scan frequency. For example, at 25 kHz the time required to acquire a spectrum ranges from 2.5 ms for a 64 point spectrum to 20.5 ms for a 512 point spectrum.

The scan frequency, which is programmable from 10 kHz to 1 MHz, also affects the data acquisition time. Since a high scan frequency was not a prerequisite for this research, a scan frequency of 25 kHz was used throughout this work as a satisfactory compromise between sensitivity (integration time between successive readouts by the scanning electron beam) and acquisition time.

For each spectrum acquired, the user can control three parameters to enhance the S/N: the number of bits in the A/D output, the number of spectral scans averaged, and the number of signal integrations per scan. Although faster conversion speeds can be obtained by "short cycling" (e.g. 4 μ s for 8 bits vs 10 μ s for 12 bits), the A/D quantization error is minimized by using the full 12-bit output of the converter. With a 12-bit converter output, the maximum S/N of the vidicon detector without signal averaging is measured to be 3086. (Maximum S/N is defined as the ratio of the maximum linear output level (~ 90% of saturation, see Chapter 4) to the root-mean-square (RMS) value of the observed background of a mercury lamp.) When time permits, signal averaging can be used to enhance the S/N by reducing random noise and converter quantizing noise (see Chapter 4).

The charge integration capability of the silicon vidicon target can be used to enhance weak signals by increasing the exposure time. The exposure time is increased by blanking the electron beam and

inhibiting the deflection circuits for an integer number of frames. Signal intensity increases linearly with exposure time until the accumulated signal approaches saturation (see Chapter 4). Since charge integration integrates the signals in all wavelength channels equally, this technique is limited by the most intense feature in a spectrum. If integration continues after an intense region has saturated, the signal from the saturated channels will spread into adjacent channels. For a fixed data acquisition time, a combination of charge integration and signal averaging will often maximize the output response.

The SRD mnemonic specifies the spectra that are to be acquired. A value of 7 results in the sequential acquisition of the sample, the reference (for absorption), and the dark spectrum under computer control. For a 512 point scan at a scan frequency of 25 kHz, all three spectra can be acquired in less than 10 sec. The ADR and CNT mnemonics are set by the computer and are not alterable by the user. Optimum beam current is achieved with BEM set to a value of 60. DLY and ACQ may be changed as desired.

The END mnemonic terminates the operator dialogue routine. Upon termination, the coordinator initializes the scan and data acquisition control circuits and clears the data memory. Next, the DATA command is entered to initiate data acquisition. Following completion of the data acquisition cycle, the PLOT routine can be used to plot the sample, reference, transmittance, or absorption spectrum on the CRT terminal. Alternately, the EVAL routine can be used to output to the terminal the sample, reference, transmittance, and absorbance values for specified

wavelength channels. Finally, WFILE outputs the sample, reference, and dark spectral data to the floppy disc. Prior to storing the spectrum on disc, WFILE allows the user to input the file name and file header text from the keyboard.

Although the acquired spectral information can be processed locally by the micro, stored spectra are usually transmitted to the minicomputer for final processing. The communication link between the microcomputer and the minicomputer was designed by S. Hourdakakis (99). The software written for this communication link (98,99) allows bidirectional transter of programs between the two computers.

C. Post-Processing of Spectral Information

Post-processing of the spectral output from the vidicon spectrometer is typically performed on the minicomputer to take advantage of the computational ability of the mini and to use the mini's peripherals. The data-processing software was written in FORTRAN IV and MACRO (assembly language) to run on a PDP 11/40 (Digital Equipment Corporation) with 32K words of memory, RK05 hard disc, floppy disc, CRT terminal, and line printer. Listings of the program and its sub-routines are included in Appendix A.

An example of a typical terminal interaction with the program is illustrated in Figure 3-2. The underlined portions are entered by the user. The program first requests the file specification, then looks up the specified file and outputs the file header text to the terminal. If the file is to be processed, the user specifies the normalization factor and indicates whether or not the background spectrum is to be

SRU VEDOFILE SPECIFICATION - #FL1:PCL325.DAT

PCL3 SPECTRUM .25M 122277
 512 PTS D/A-3/6 25 KHZ
 BEM = 60

PROCESS FILE ?YNORMALIZATION FACTOR [4, 64] : 8SUBTRACT DARK SIGNAL ?Y

DATA OUTPUT CODES:

0 = NOTHING
 1 = DARK
 2 = SAMPLE
 3 = REFERENCE
 4 = XT
 5 = ABSORBANCE
 6 = WRITE FILE
 7 = LOCATE
 8 = EVALUATE
 9 = ANOTHER FILE
 10 = EXIT
 11 = S/N

LIST : 0PLOT : 5THRESHOLD : 10

MIN = 0.0000000 AT POINT 5
 MAX = 788.0000000 AT POINT 239

SCREEN BOTTOM = 0.SCREEN TOP = 800.LINE PLOT = 0, POINT PLOT = 1 : CHOICE : 0

Figure 3-2. Program VEDO Terminal Interactions

subtracted from the sample and reference spectra. The upper limit on the normalization factor is equal to the number of signal averages. The lower limit represents the computer-selected prescaling factor that was required to fit the 24-bit data word from the micro into a 16-bit integer word at the mini. The normalization factor allows the user to specify the number of extra bits from signal averaging that are to be retained. Typically, half of the extra bits are retained for processing.

Next, the dark, sample, reference, transmittance, or absorbance spectrum can be selected for plotting on the terminal. Prior to plotting, the program searches out maximum and minimum intensity values in the spectrum and allows the user to scale the data as required for plotting. When plotting %T and absorbance, the user can input a threshold value which helps to reduce the distortion that can result at low intensities. At each data point the reference signal must exceed the sample signal by the threshold; otherwise, the point is assigned a value of 100% T or 0.0 A.

After plotting the desired spectrum, the S/N of the spectrum can be further enhanced by smoothing the data using quadratic/cubic Savitzky and Golay convolution functions (103). To limit the amount of signal distortion, the width of the smoothing function should be no wider than the full-width-at-half-maximum (FWHM) of the narrowest spectral feature (101).

The "locate" option uses the graphical input capability of the terminal to identify the channel number of a specific spectral feature. The data point of interest is selected with a movable cursor. The

program then outputs to the terminal the channel number of the selected data point and its corresponding values of sample, reference, %T, and absorbance. To ensure that the cursor did in fact select the desired point, the user can input the channel number to this routine and it will draw a vertical line from the baseline to the specified channel. Each time the "locate" option is called the spectrum is first plotted on the terminal. The "evaluate" option can be used to output the values of sample, reference, %T, and absorbance for specified channels without plotting the spectrum on the terminal.

The "write file" option records the spectrum on a user-specified file-structured storage medium for later plotting with MULPLT (102), a versatile and extremely powerful plotting package. The "S/N" option calculates the S/N and background RMS noise level of a spectrum. The "another file" option allows the user to specify another file for analysis. "Exit" returns control to the system monitor.

Several input/output conventions were adopted in designing the VEDO analysis software. All operator prompts that require a yes or no answer end with a question mark (?). Secondly, all prompts that require an integer response end with a colon (:). Thirdly, all prompts that require a real number input, i.e. require a number with a decimal point, end with an equal sign (=). By coding all of the prompts in this manner, user interaction with the program is greatly simplified in that the user is not required to remember the form of the response for each prompt. Rather, the user only needs to remember three basic programming conventions.

Examples of emission and absorption spectra recorded with the

vidicon spectrometer are given in Figures 3-3 thru 3-5. Figure 3-3 is the absorption spectrum of PrCl_3 in 1M HCl. Figure 3-4 is the emission spectrum of a lead hollow cathode lamp, and Figure 3-5 is the emission spectrum of the neon filler gas in the hollow cathode lamp.

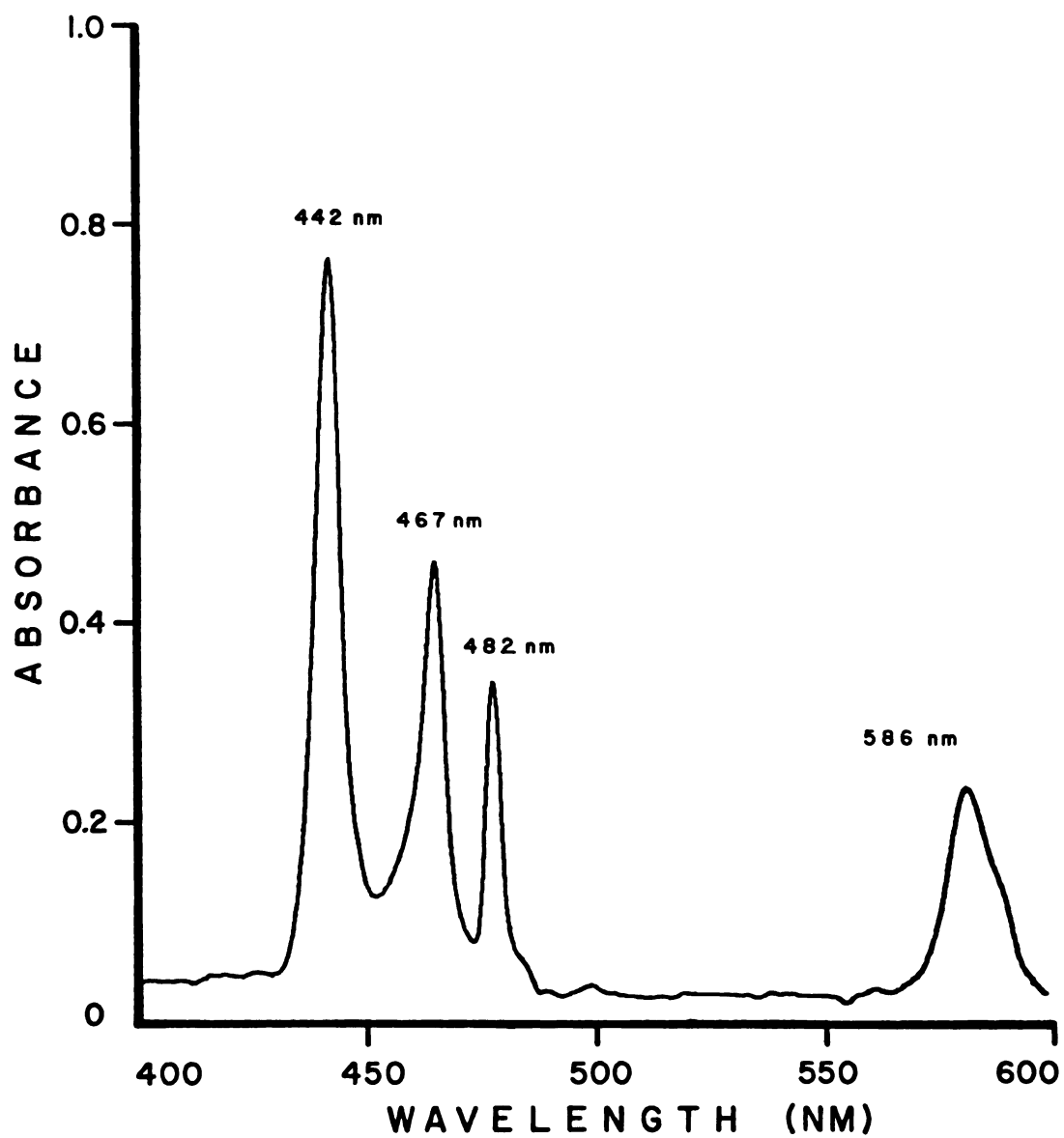


Figure 3-3. Absorption Spectrum of PrCl_3 (0.20M) in 1M HCl

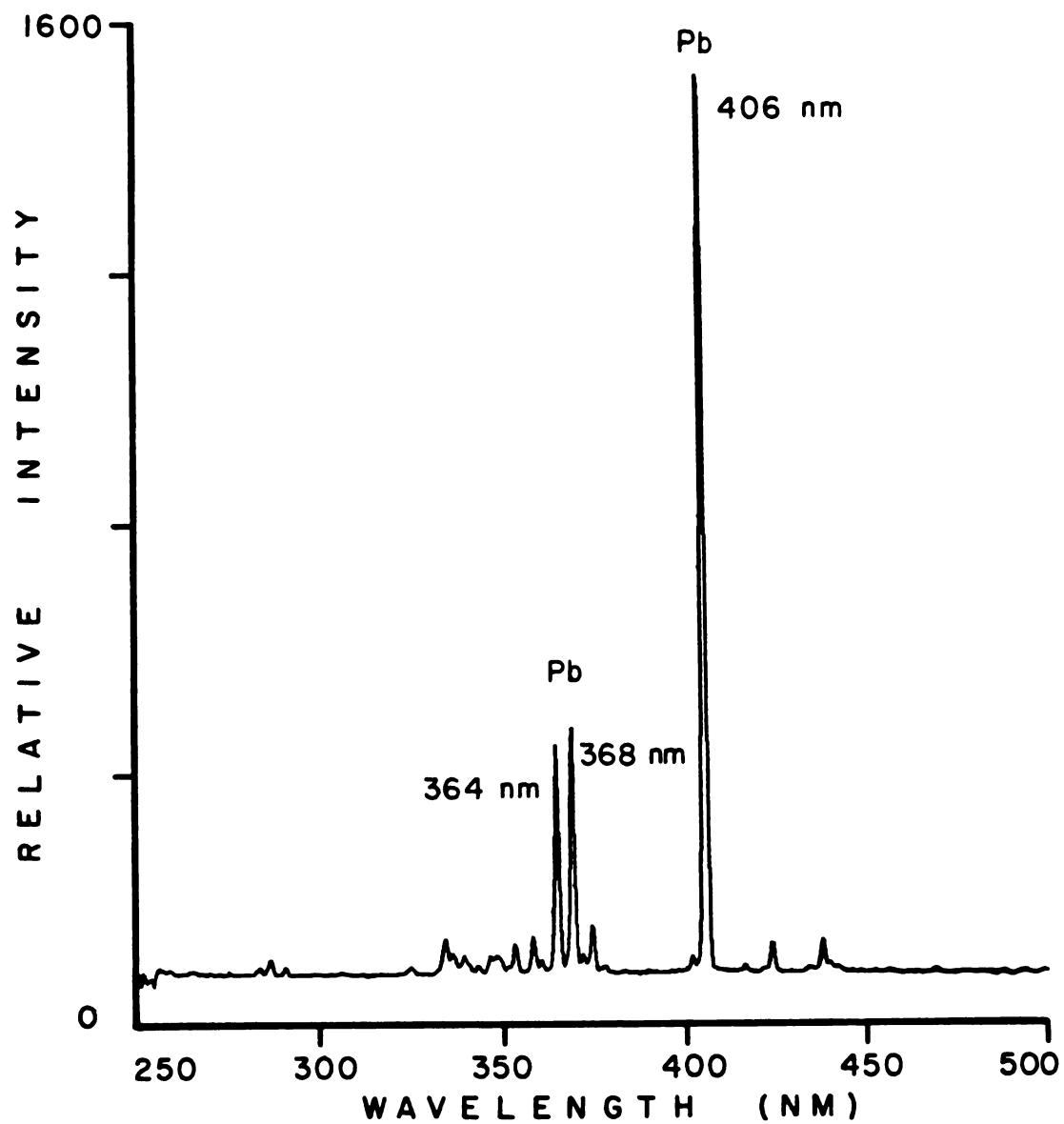


Figure 3-4. Emission Spectrum of a Lead Hollow Cathode Lamp

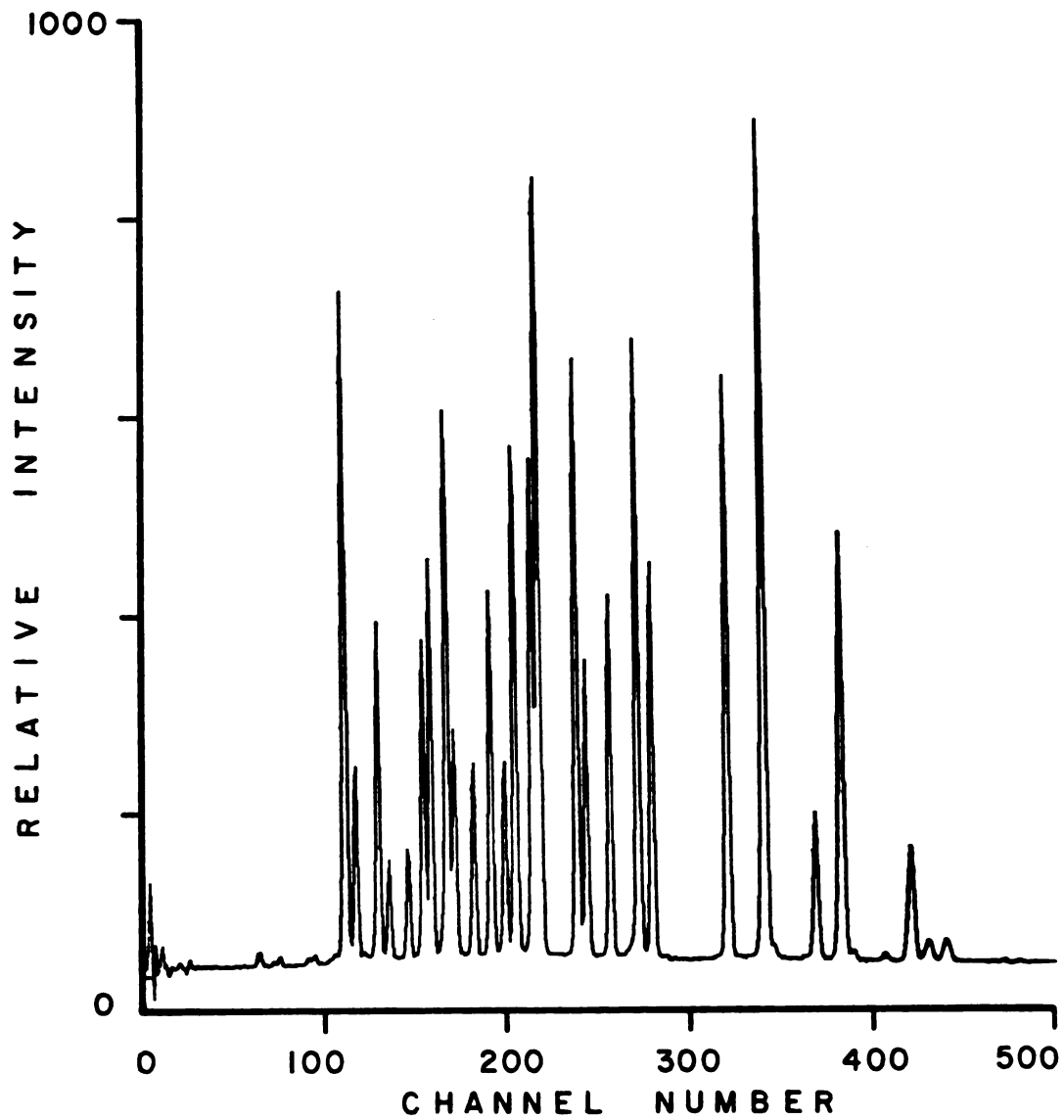


Figure 3-5. Emission Spectrum of Neon Filler Gas in a Hollow Cathode Lamp

CHAPTER 4

CHARACTERIZATION AND OPTIMIZATION OF THE SILICON VIDICON SPECTROMETER

A. Introduction

The microprocessor-controlled silicon vidicon spectrometer developed in this research is a powerful investigative tool for the analytical chemist. Microprocessor control of the instrument increases its versatility by allowing the scan format to be changed by software rather than by hardware modifications. Thus the computer can easily alter the operating parameters to optimize the performance of the instrument. This chapter describes the experiments used to characterize and optimize the performance of the vidicon spectrometer.

The vidicon detector's multichannel spectral response was examined to determine its uniformity of response within a selected wavelength window. Wavelength linearity and resolution were measured and resolution-limiting factors were identified. The relationships among the video output, scan rate, and beam current were studied and optimum values were established. The response of the detector to incident light intensity was evaluated, and the linear response region was identified. Charge integration was studied to evaluate its potential for signal-to-noise (S/N) enhancement. Next, the electronic background and random noise components of the video output were studied in order to determine their effect upon the maximum S/N of the system. Lastly, S/N enhancement techniques were evaluated.

B. Multichannel Spectral Response

The RCA C23246 silicon vidicon tube used in this research is a variant of the RCA 4532 family of silicon-target vidicons with a fused-silica faceplate for increased ultraviolet response. The active target area of the vidicon is 12.8 mm (horizontal) by 9.6 mm (vertical). The reciprocal linear dispersion of the monochromator is 18 nm/mm in the focal plane. Consequently, the vidicon detector can monitor a 230 nm wavelength window in the present system. The spectral response curves in Figure 4-1 and 4-2 (101) show that the vidicon's silicon target provides usable response from about 250 nm to 1000 nm. Thus the detector's 230 nm wavelength window can be positioned anywhere within this broad spectral range. Spectral information within the 230 nm window is acquired simultaneously by the integrating diode array and read out sequentially by a scanning electron beam under computer control.

As different areas of the active target area are illuminated by and respond to different wavelength resolution elements simultaneously, it is necessary to measure the uniformity of response across the active target area. This uniformity was experimentally determined for two different emission sources; a line source (436 nm emission line from a mercury lamp), and a continuous source (tungsten lamp, 546 nm).

The channel response of the vidicon detector to a narrow emission line was measured by monitoring the height of the 436 nm line from a mercury lamp as it was moved to different positions across the vidicon target. At each position data acquisition was delayed for several

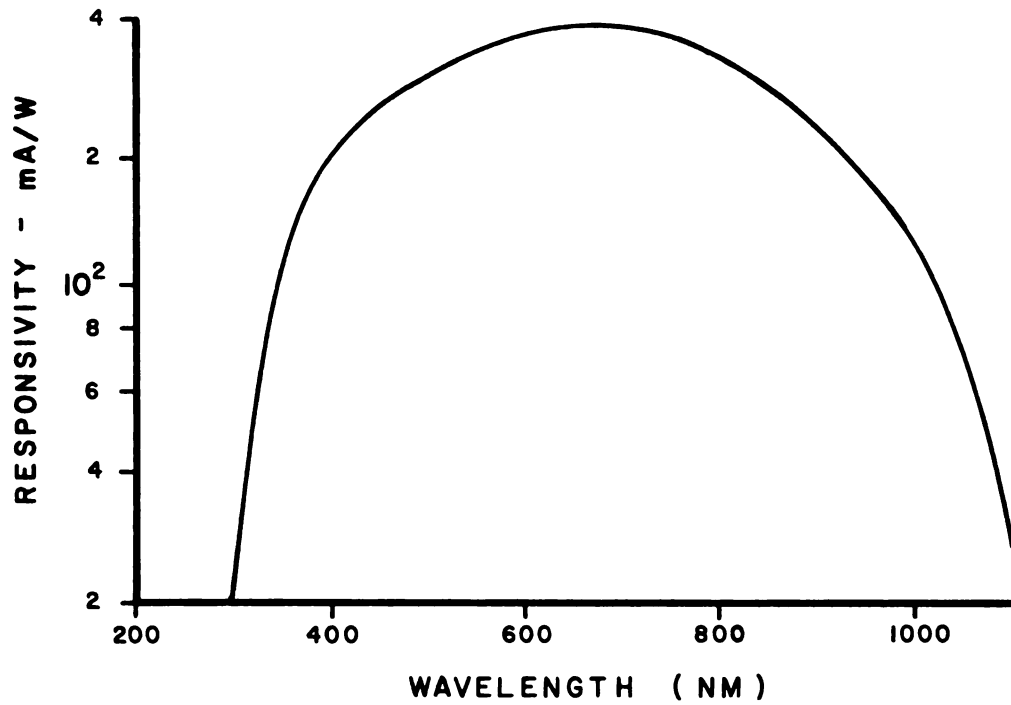


Figure 4-1. Responsivity of RCA C23246 Vidicon vs Wavelength

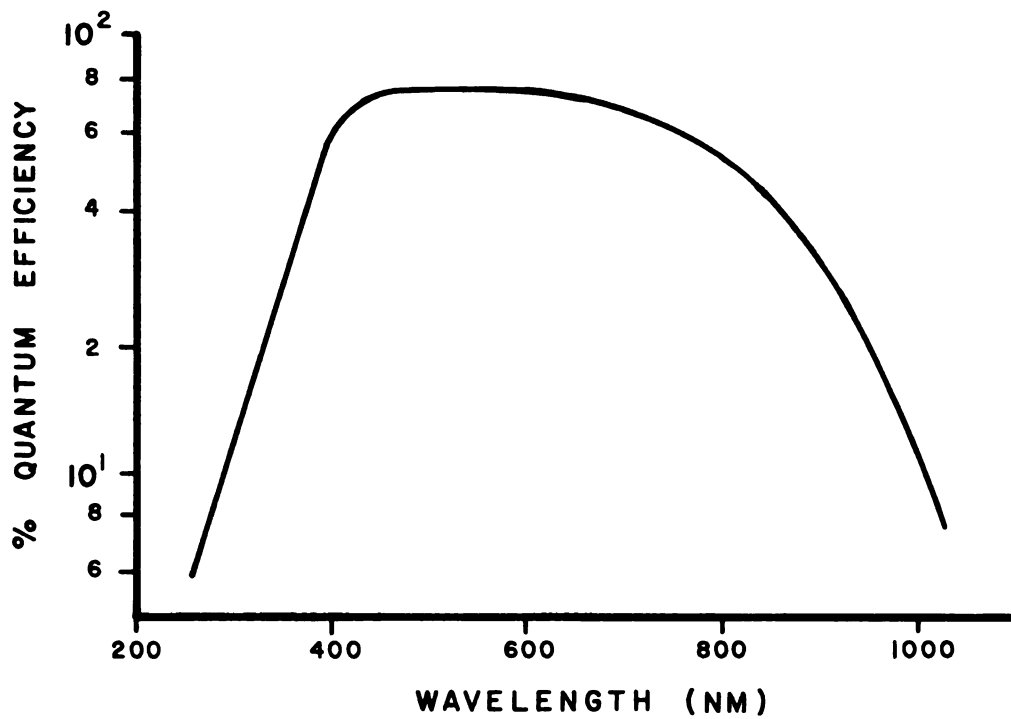


Figure 4-2. Quantum Efficiency of RCA C23246 Vidicon vs Wavelength

seconds to ensure that the detector output had reached a steady-state value. Target exposure and scanning were continuous throughout the experiment. The resulting response curves are shown in Figure 4-3. Peak heights, areas, and widths at half-height of the emission line at selected channels from this curve are listed in Table 4-1. At either

Table 4-1. Channel Response for a Line Source

Channel # (512)	Relative Peak Height	Relative Peak Area	Width at Half-Height(nm)
46	542	675	1.62
126	744	783	1.35
199	952	877	1.23
294	974	907	1.14
384	977	924	1.33
480	646	983	2.03

end of the target the observed peak profile broadened and the peak height decreased; however, the corresponding peak area increased as the emission line was moved from left to right. Busch, Howell, and Morrison (36) reported the same results using a commercial optical multichannel analyzer with an RCA 4532 UV-sensitive silicon diode vidicon. They suggested that part of the observed response could be accounted for by a lack of focus at the edges of the target. This lack of focus apparently results from placement of the flat vidicon target in the curved focal plane of the monochromator.

The channel response of the vidicon detector to a tungsten source is shown in Figure 4-4. The tungsten spectrum was moved across the

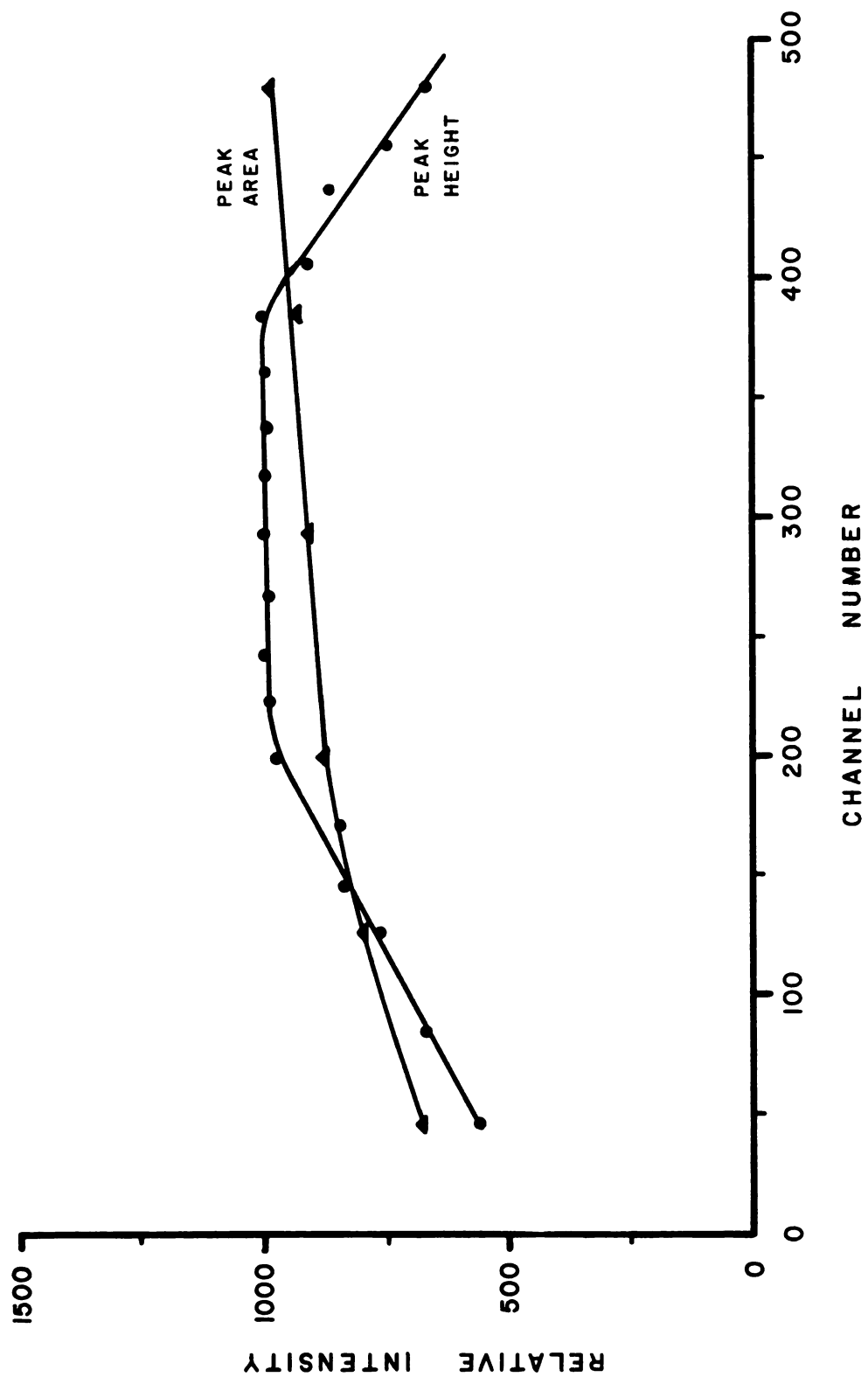


Figure 4-3. Channel Response of Vidicon Target to Hg 436 nm Line

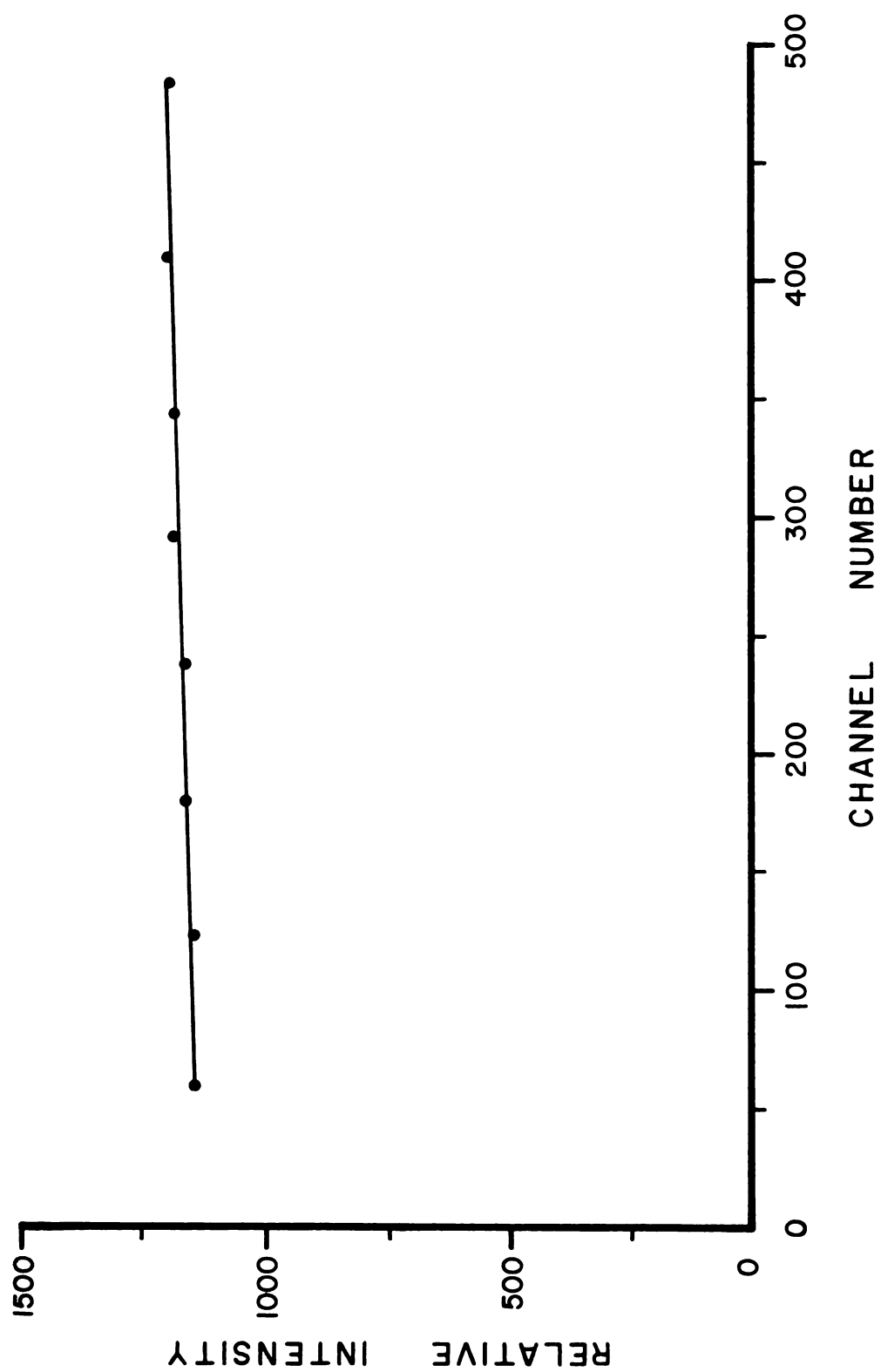


Figure 4-4. Channel Response of Vidicon Target to a Continuous Source

vidicon target and the response at 536 nm was recorded as a function of channel number. The observed response is linear across the entire target area. The intensity of the signal increased slightly across the target (6% higher at the right edge). This response curve suggests that the response of the silicon diodes to incident light is relatively uniform across the target.

The data obtained with the mercury and tungsten sources are apparently inconsistent, particularly with respect to the change in peak area with channel number. At this time it is not known whether the observed response is due to optical considerations or to the vidicon itself.

C. Wavelength Linearity and Resolution

1. Linearity of the Wavelength Deflection Circuit Elements

Wavelength scanning in the silicon vidicon spectrometer is accomplished by electronic deflection of the scanning electron beam rather than by more conventional mechanical systems that rotate either a mirror or grating. Consequently, the linearity of the wavelength axis is determined by the linearity of the analog deflection circuit elements. Wavelength linearity was measured by recording the positions of selected lines from the emission spectrum of a mercury lamp and from the absorption spectrum of a holmium oxide filter. A least squares line through the data points had a slope of 0.5109 ± 0.0019 nm/channel, an intercept of 332.9 ± 0.8 nm, a linear correlation coefficient of 0.99999, and a standard error of estimate of Y on X of 0.37 nm.

The least squares slope and intercept were then used to convert channel numbers to wavelengths. The results are shown in Table 4-2. The average wavelength error and percent deviation are 0.29 ± 0.19 nm and 0.13 ± 0.08 percent respectively. The limiting wavelength resolution for a 512 line scan is approximately 0.5 nm, so that the observed wavelength error is a result of wavelength quantization rather than any nonlinearity in the horizontal scan circuit elements.

2. Limiting Resolution of the Monochromator

The resolution of the vidicon spectrometer reflects its ability to distinguish adjacent adsorption bands or spectral lines as separate entities. The resolution is determined by the size and dispersing characteristics of the grating, the optical system of which the grating is a part, the slit width of the monochromator, and the horizontal (wavelength) resolution of the vidicon detector.

The fundamental resolution of a grating is

$$R_s = mN$$

where m is the order number and N is the total number of rulings (105). Thus in the vidicon spectrometer the resolving power of the grating (Bausch and Lomb certified precision 50 mm grating with 133.6 grooves/mm) is 6680 in the first order. At the mercury doublet wavelength of 577/579 nm, the smallest interval that can be resolved is $\Delta\lambda = (578 \text{ nm})/6680 = 0.09 \text{ nm}$. Since the maximum resolution of the vidicon detector is 0.5 nm for a 512 line scan, the resolving power of the grating does not limit the instrumental resolution.

The slit width of the monochromator also affects the resolution of

Table 4-2. Wavelength Linearity

Spectrum	Channel Number (512)	λ_{true} (nm)	λ_{calc} (nm)	$\lambda_{\text{calc}} - \lambda_{\text{true}}$ (nm)	% $(\lambda_{\text{calc}} - \lambda_{\text{true}}) / 230 \text{ nm}$
Hg	64	366.3	365.6	-0.7	-0.30
Hg	141	404.7	405.0	+0.3	+0.13
Ho	168	418.5	418.8	+0.3	+0.13
Hg	201	435.8	435.7	-0.1	-0.04
Ho	222	446.0	446.4	+0.4	+0.17
Ho	236	453.4	453.6	+0.2	+0.09
Ho	398	536.4	536.4	± 0.0	± 0.00
Hg	416	546.0	545.6	-0.4	-0.17
Hg	478	577.0	577.3	+0.3	+0.13
Hg	481	579.0	578.8	-0.2	-0.09

the instrument. The minimum spectral bandpass (width of a spectral line at half of its full height) that can be obtained with the vidicon spectrometer is a quantitative measurement of its resolution. This spectral bandpass is linearly dependent upon the slit width. Although resolution can be increased by decreasing the slit width, the light-gathering power of the monochromator and the sensitivity of the detector place a lower limit on the slit width. Sufficient light must reach the detector to enable spectral features to be distinguished from background noise.

Typically a monochromator has two slits; an entrance slit, which provides a narrow source of light to the dispersion optics to minimize overlap of monochromatic images, and an exit slit to select a narrow band of the dispersed spectrum for observation by the detector. In practice these slits are usually the same width so that the image of the entrance slit is just passed by the exit slit. However, in the vidicon spectrometer the exit slit has been replaced by the silicon target of the vidicon detector, which monitors a 230 nm window. Thus the limiting resolution will be a function of both the monochromator entrance slit width and the resolution of the vidicon target.

The experimental resolution of the vidicon spectrometer was evaluated by measuring the full width at half maximum (FWHM) of the 406 nm emission line from a lead hollow cathode lamp and the 436 nm emission line from a mercury lamp at a slit width of 25 μm . The resulting emission spectra are shown in Figures 4-5 and 4-6. The FWHM for these two lines were 1.26 nm and 1.28 nm respectively. Similar results have been reported by Ridder and Margerum (78). The

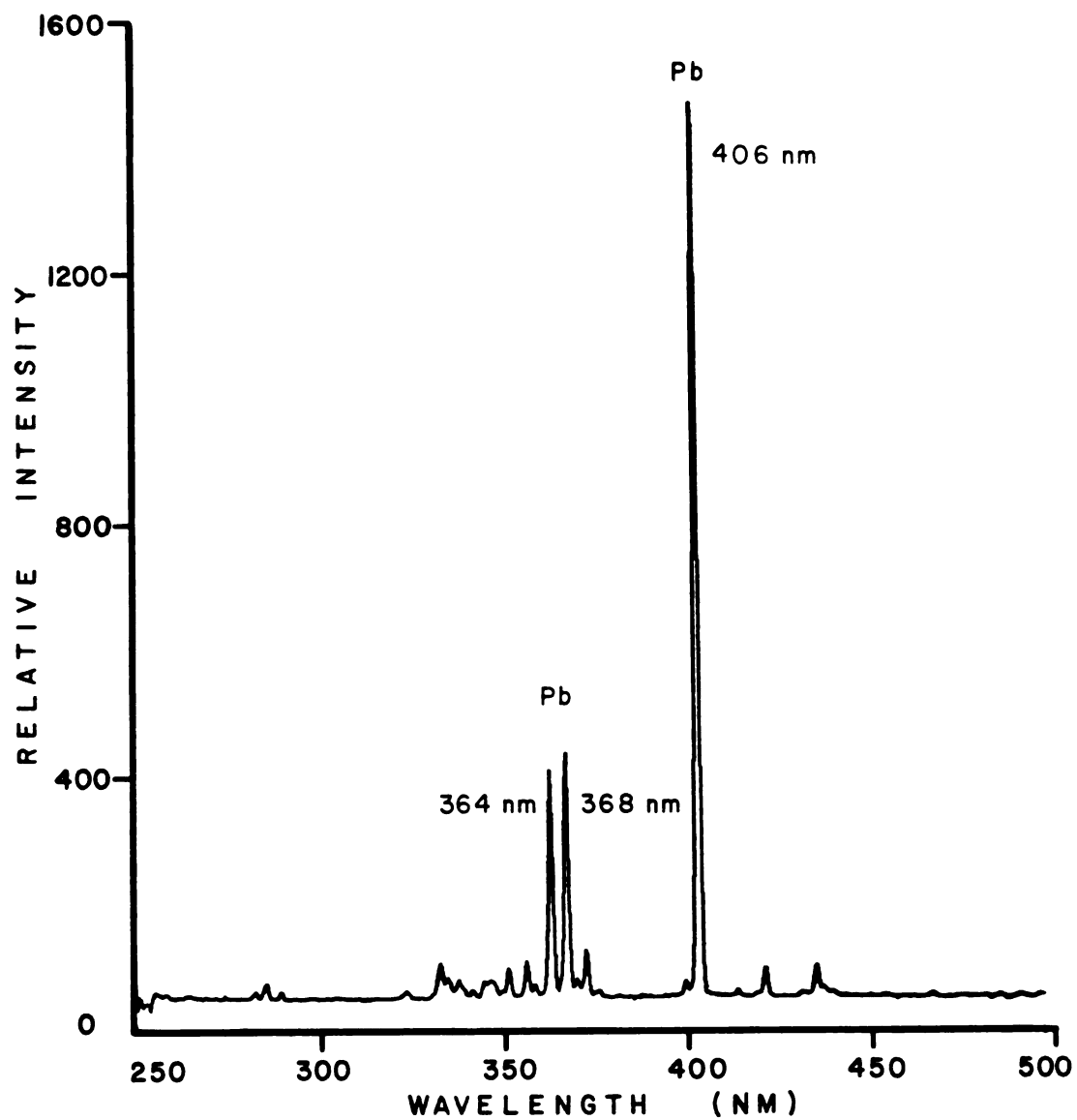


Figure 4-5. Emission Spectrum of a Lead Hollow Cathode Lamp

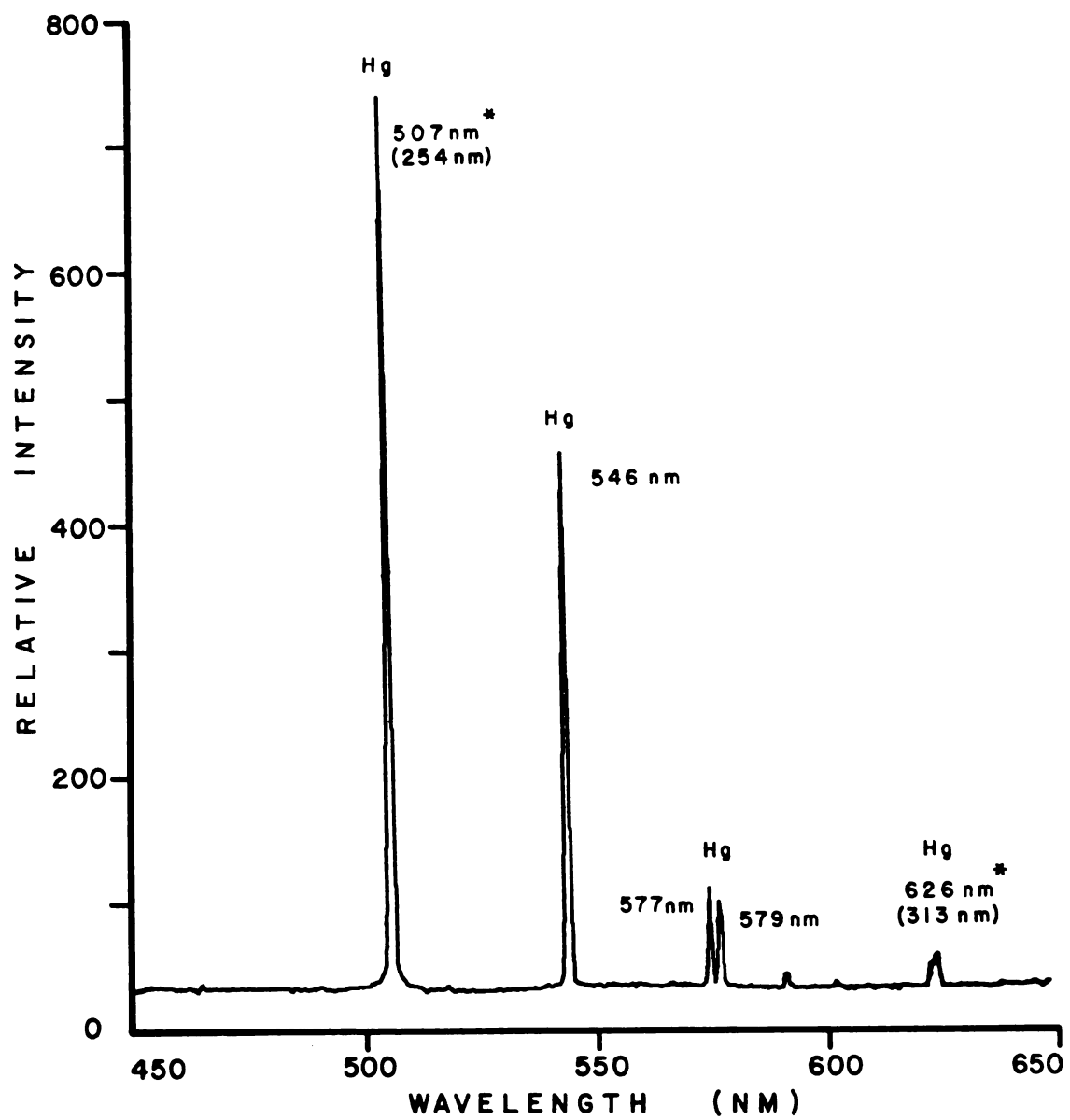


Figure 4-6. Emission Spectrum of a Mercury Lamp
(* - second order Hg line)

monochromator spectral bandpass at this slit width is 0.45 nm. Consequently, the resolution of the spectrometer is limited by the resolution of the vidicon detector itself.

The resolution of the vidicon spectrometer was increased by decreasing the slit width to 6 μm . The FWHM of the 436 nm mercury line at this slit width was 0.97 nm. However, the peak intensity at this slit width was approximately one-tenth of the intensity at 25 μm . Below 6 μm the peak was not distinguishable from the background noise. Therefore a slit width of 25 μm represents the usable lower limit for the optical system used in this research. Higher slit widths can be used, but only with a corresponding decrease in resolution. Resolution can be increased at the expense of wavelength coverage by using a grating with a larger resolving power (smaller reciprocal linear dispersion).

Another indication of an instrument's resolving power is the degree of separation between two closely spaced spectral lines. Figure 4-6 shows that the vidicon spectrometer attains baseline resolution of the 577/579 mercury doublet at a slit width of 25 μm . This doublet resolution further supports the observed resolution of 1.2 nm at a 25 μm slit width.

3. Resolution of the Vidicon Detector

If the scanning electron beam used for channel readout in the silicon vidicon had an infinitely narrow width, the resolution of the vidicon detector would be limited by the packing density of the diode array (approximately 900 discrete diodes per target width) (3).

Unfortunately, the electron beam has a finite width, and it is this beam width that limits the resolution of the vidicon detector (8). Since the reciprocal linear dispersion of the monochromator is 18 nm/mm, the vidicon's limiting spectral resolution of 0.97 nm implies a beam diameter of 0.054 nm. This value is in excellent agreement with previously reported beam diameters of 0.062 nm (34) and 0.051 nm (107).

The width of the electron beam was also measured using the approach of Nieman and Enke (61). The 456 nm emission line of a lead hollow cathode tube was focused on the center of the vidicon target and its height was recorded as the number of wavelength channels was varied from 64 to 512 by powers of two. Since channel exposure time is proportional to the number of channels in the spectrum, the observed intensity should increase as the number of channels is increased. The observed response is shown in Figure 4-7. The observed intensity increased linearly with the number of channels up to 256 channels per spectrum; however, the intensity decreased when the number of channels was increased to 512. When the step size between adjacent channels is smaller than the beam diameter, the beam overlaps a portion of the next adjacent position so that when this position is sampled a smaller signal is observed than for no overlap. Using this interpretation of Nieman and Enke, the experimental beam diameter is less than $1/256$ of the target width (0.050 nm), but substantially greater than $1/512$ of the target width (0.025 nm). Since the vidicon monitors a wavelength window of 230 nm, the detector's limiting spectral resolution according to this approach is approximately 0.90 nm. This value is in excellent agreement with the observed spectral bandpass of 0.97 nm at a slit width of 6 μm .

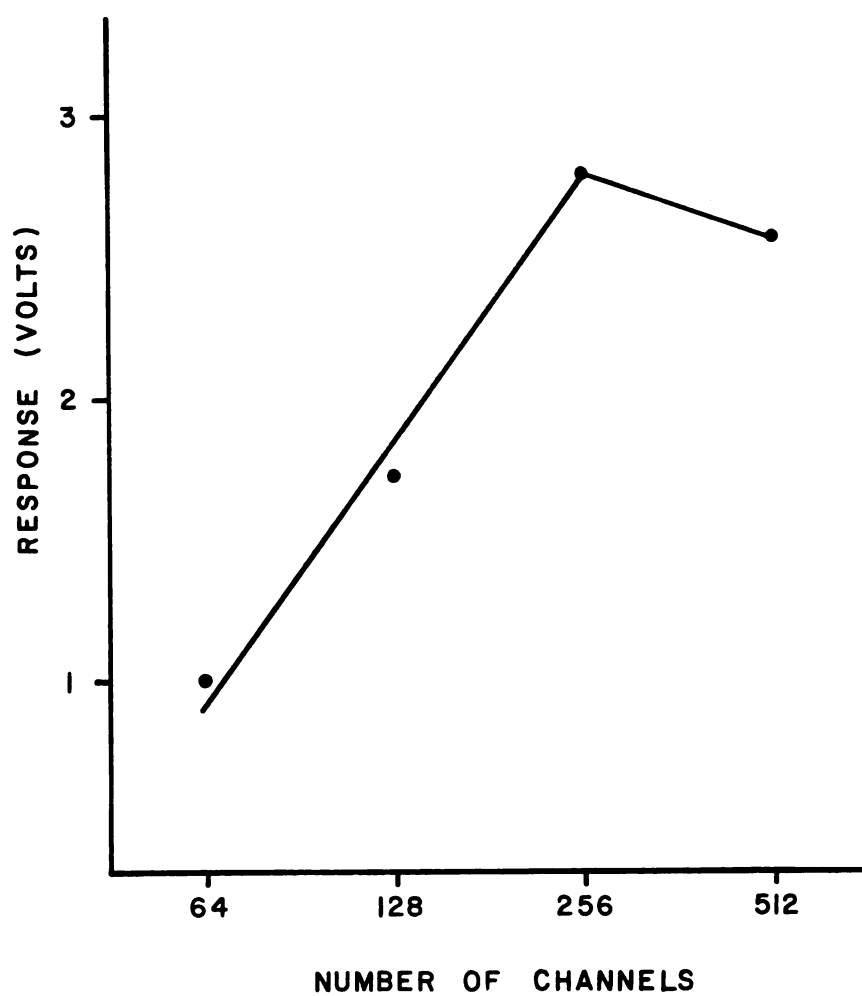


Figure 4-7. Vidicon Response vs Number of Wavelength Channels

This limiting spectral resolution of 0.97 nm applies only to the center portion of the target surface. The resolution of the vidicon decreases near the edges of the active target (see Section B). Consequently, the limiting spectral resolution near the edges would be greater than 1 nm.

D. Analytical Signal

The video signal from the vidicon detector consists of three parts; the analytical signal, electronic background, and random noise. These parts are illustrated in Figure 4-8, which shows three overlaid mercury emission spectra and their corresponding signal-to-noise ratios (S/N) for the 436 nm mercury line. Spectrum 1 represents 1 scan of the electron beam across the target, while spectrum 2 represents the average of 512 individual scans. For spectrum 3, the average of 512 scans of the background signal (shutter closed) was subtracted from the average of 512 scans of the observed signal (shutter open) to obtain a background-corrected spectrum. Signal-to-noise ratios for the 436 nm mercury line were calculated by dividing the peak intensity by the root-mean-square (RMS) background, which was calculated using 50 signal-free channels adjacent to the 436 nm emission line.

A comparison of spectrum 1 and spectrum 2 reveals that the effect of random noise on the signal-to-noise ratio is negligible compared to the effect of the electronic background, and that there is little advantage to signal averaging without background subtraction. However, when the background is subtracted from the video signal, a significant improvement in S/N is realized through signal averaging. Thus the

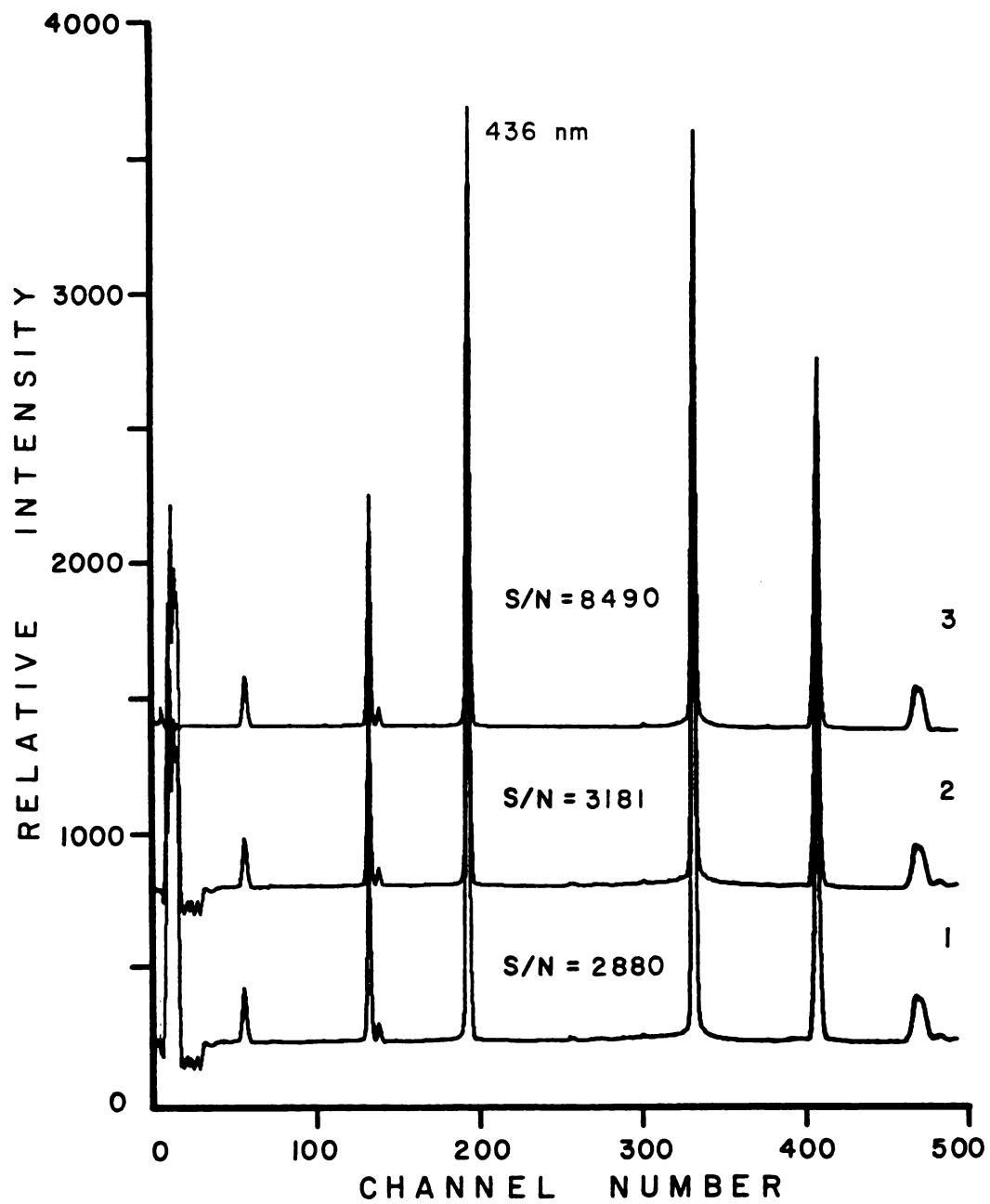


Figure 4-8. Components of the Vidicon Spectrum

electronic background is not only reproducible from scan to scan, but is successfully removed from the video signal by subtraction. The remainder of this section examines the factors affecting the analytical signal and its optimization. The following section examines the electronic background and random noise components.

1. Vidicon Detector Operating Voltages

The data sheet for the C23246 vidicon tube specifies a fixed voltage of +8 volts at the target; however, this requires that the target be capacitively coupled to the current-to-voltage converter. Instead, a fixed voltage of -8 volts was applied to the cathode and the target was connected directly to the summing point of the amplifier. This arrangement maintains the 8 volt potential between the cathode and target and permits a direct coupling between the target and amplifier (10). The remaining tube voltages were maintained at the recommended levels (see Table 7-1) (104).

The beam current of the vidicon is controlled by a negative voltage (0 V to -150 V) applied to Grid No. 1 from a high voltage amplifier (Datel AM301A high voltage, high speed FET OA with ± 140 V output swing, slew rate of 100 V/ μ s). The high voltage amplifier is interfaced to the microcomputer via an 8-bit digital-to-analog converter (Datel DAC-29 8-bit DAC with 5 μ s voltage settling time). Figure 4-9 shows the relationship between detector response to the 436 nm mercury emission line and Grid No. 1 voltage at a scan rate of 25 kHz. The observed response is a maximum at a grid voltage of -38 volts. This grid voltage was used for all subsequent measurements at 25 kHz.

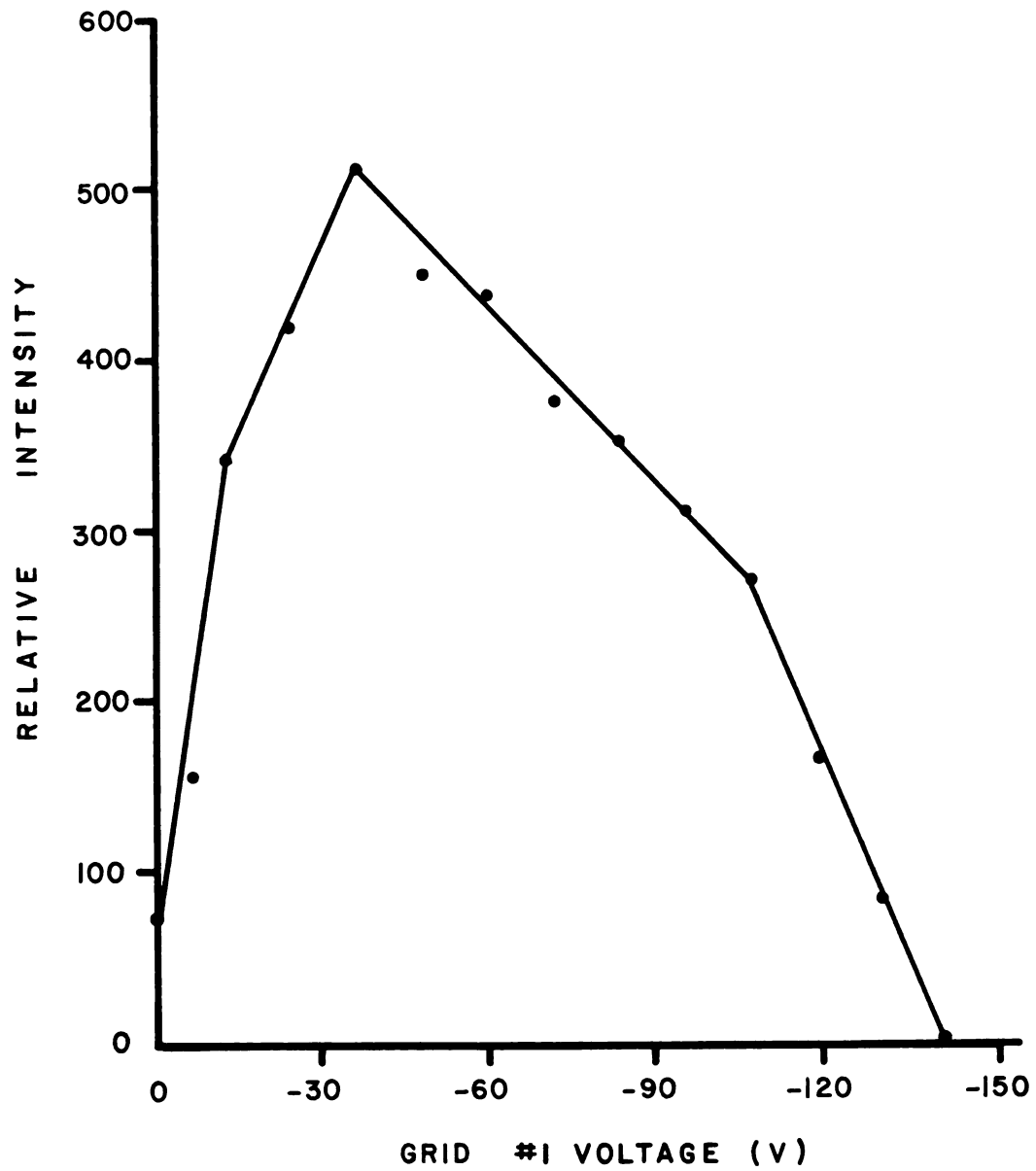


Figure 4-9. Vidicon Response vs Grid #1 Voltage

The optimum beam current was not observed to change with the scan frequency.

2. Response Near Saturation

The reverse-biased photodiodes in the vidicon target operate in the charge storage mode and hence are integrating type detectors. Between scans the reverse bias charge stored on the diodes can be discharged by either photo-generated charge carriers (light falling on the diode) or by thermally generated charge carriers (dark current). Thus the signal level necessary to re-establish reverse bias on the diodes during the next scan is a measure of the total light intensity and dark current integrated over the time between scans of the array. Unfortunately, these diodes have a saturation level (the reverse bias charge). If the total charge accumulated on a diode between scans reaches the reverse bias charge, the diode will saturate. Once saturated, the diode can not acquire additional charge so that all signal information between the time of saturation and recharge by the electron beam is lost. As non-linear response was expected near saturation (61), the response of the detector near saturation was measured to identify the linear response region.

The response near saturation was studied by measuring the transmittance of a neutral density filter ($T = 0.54$) as the intensity of the tungsten source was varied. The magnitude of the reference signal (no filter) was used as a measure of signal intensity. The results of this experiment are shown in Figure 4-10. The observed non-linearity is 1% at 90% of saturation. The detector's linear response thus extends to

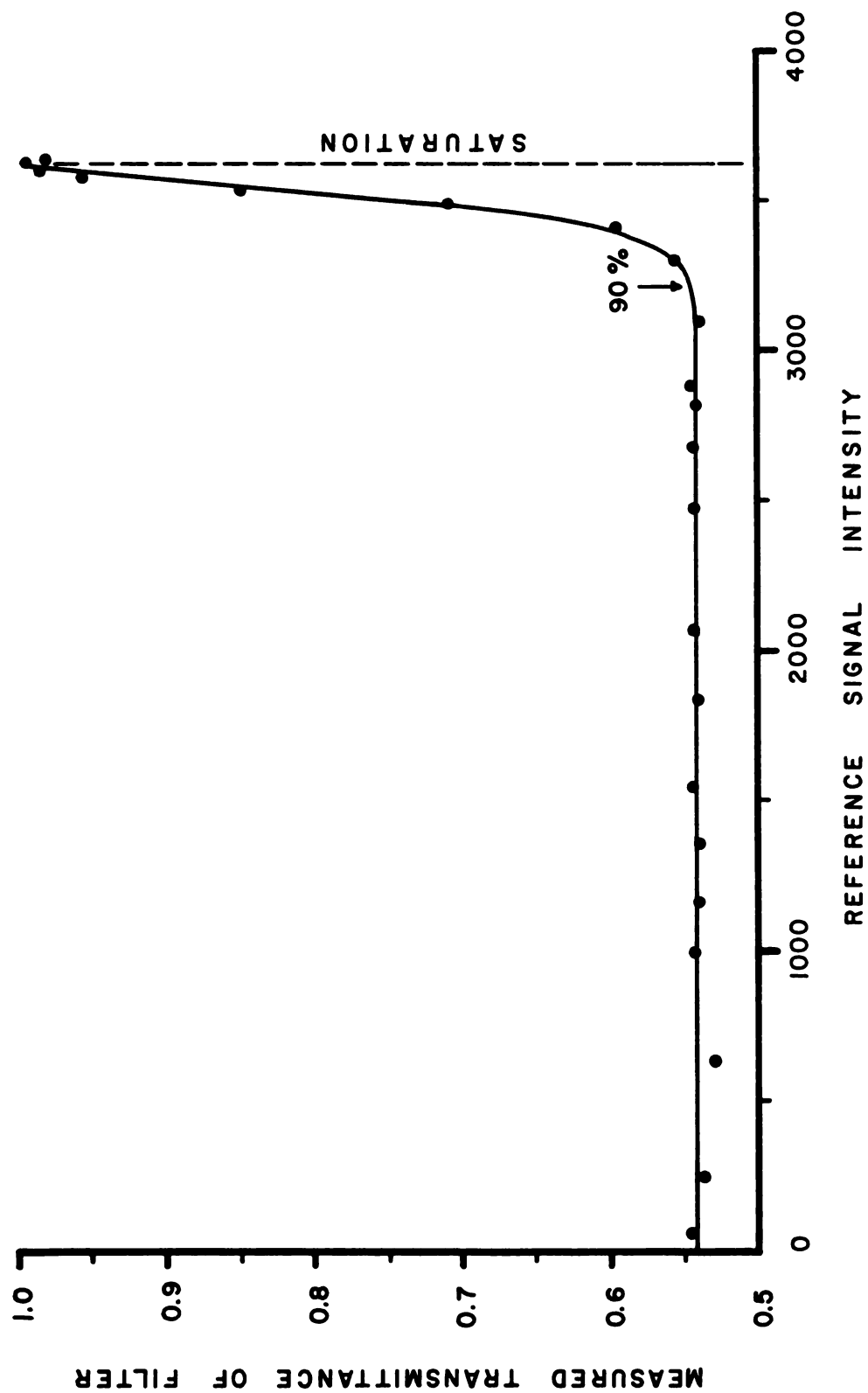


Figure 4-10. Vidicon Response Near Saturation

approximately 90% of saturation. In all subsequent experiments the amplifier gain was adjusted to keep all measurements within this linear response region.

3. Linearity and Range

The response of the vidicon as a function of intensity should follow the relationship

$$\text{Response} \propto \text{Intensity}^{\gamma}$$

where γ is the gamma function (3). For the silicon diode vidicon, gamma is expected to approach unity. The linearity of the silicon vidicon was experimentally measured by varying the tungsten source intensity with combinations of neutral density filters and recording the corresponding A/D converter response. With no filter in the optical path (100% T), the gain of the data acquisition system was adjusted so that the converter received a full scale (+10 V) input when the vidicon target was at approximately 40% of saturation. The value of the observed converter response versus filter transmittance is given in Table 4-3. At two points the gain of the data acquisition system was increased to make use of more bits in the converter's response; all data were scaled to the original gain setting. The integration time was the same for all data points. A plot of $\log$ (converter response) versus $\log$ (% T) (Figure 4-11) shows that the vidicon's response is linear over nearly four decades. A linear least squares analysis of the linear portion of this response curve yielded a slope (γ) of 1.025 ± 0.005 , a linear correlation coefficient of 0.9997, and a standard error of estimate of Y on X of 0.024. Similar results have

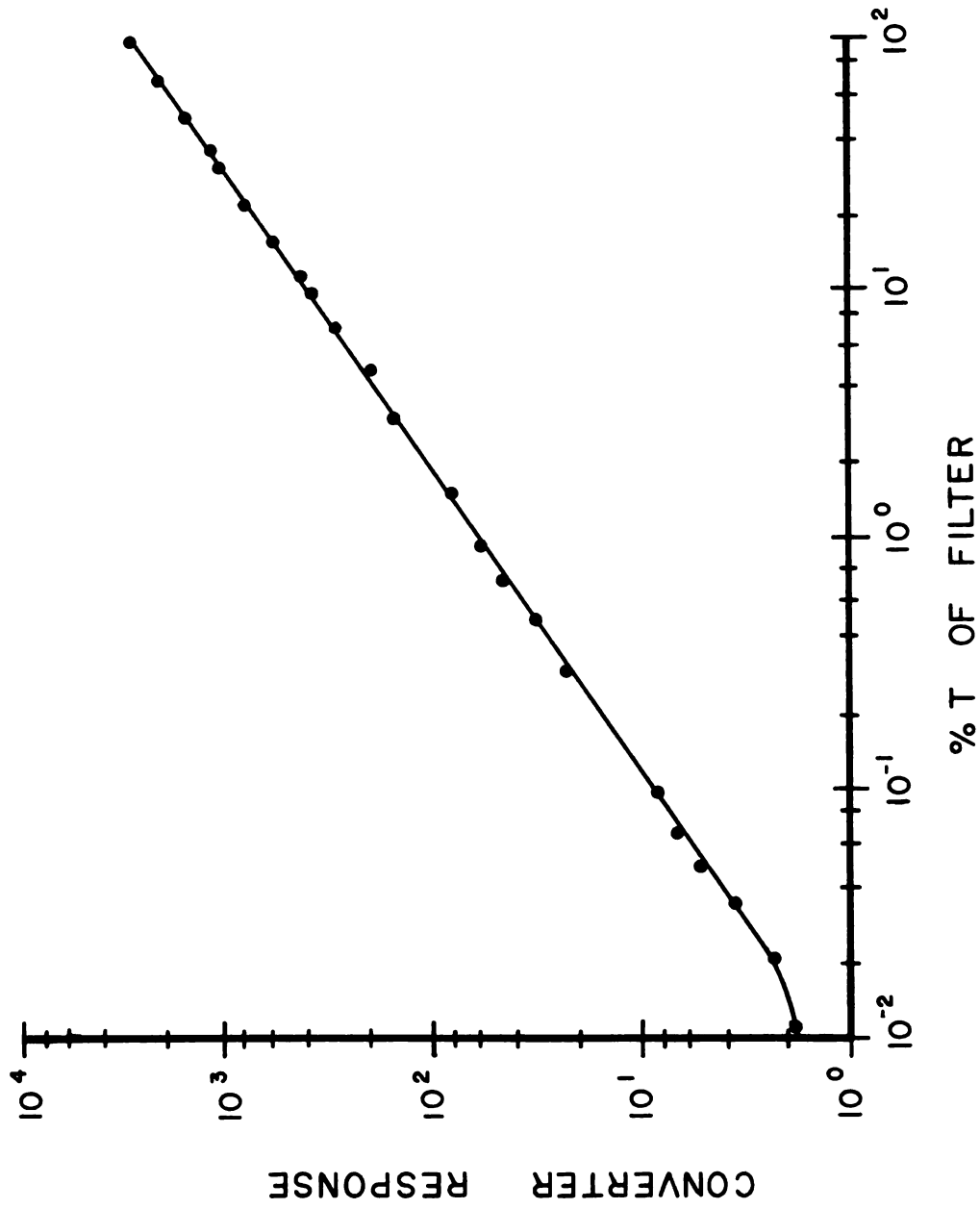


Figure 4-11. Vidicon Transfer Function

been reported by Milano et. al. (10).

Table 4-3. Vidicon Linearity and Range

Transmittance	Response	Transmittance	Response
1.0000	3032	0.0159	84
0.7079	2194	0.0100	60
0.5012	1584	0.0071	48*
0.3548	1175	0.0050	32
0.3162	1122	0.0031	24
0.2238	859	0.0010	8
0.1585	599	0.0007	7
0.1122	447*	0.0005	5
0.1000	387	0.0004	4
0.0708	303	0.0002	2
0.0501	203	0.0001	2
0.0316	159		

* amplifier gain change

4. Signal Enhancement with Charge Integration

The charge integration capability of the silicon vidicon target can be used to enhance weak signals by increasing the exposure time. Exposure time was increased by blanking the electron beam and inhibiting the deflection circuits for an integer number of frames (time required to record one spectrum). The scan circuit was then enabled, and the accumulated signal read out during one readout frame. The total number of exposure frames during which the charge accumulates is equal to the number of integration frames (scan time during which beam is inhibited) plus one (one readout frame). Intensity versus exposure frame data for three mercury emission lines (366.3 nm, 404.7 nm, and

435.8 nm) are listed in Table 4-4. One exposure frame is equivalent to an exposure time of 20 ms. A plot of log (signal intensity) versus log (number of exposure frames) (Figure 4-12) shows that all three curves have a linear region. The slopes and linear correlation coefficients of these linear regions are given in Table 4-4. As the accumulated signals approach saturation, non-linearity occurs. Thus signal intensity increases linearly with exposure time until the accumulated signal approaches saturation.

Charge integration integrates all wavelengths evenly. Consequently, this technique is limited by the most intense feature in a spectrum. Charge integration can be utilized only until the most intense feature saturates. If integration continues after an intense region has saturated, the signal from the saturated channels will spread into adjacent channels, in contrast to linear diode arrays (17).

Since dark current also increases linearly with exposure time, it places an upper limit on the number of integration frames that can be used for signal enhancement. For the present system the accumulated dark signal approaches saturation at an exposure time of approximately 3 seconds (150 frames). Cooling of the silicon diode array would significantly lower the dark current (77) and permit longer integration times for increased enhancement capability of weak spectral features.

E. Electronic Background and Random Noise

The two remaining components of the vidicon video output that need to be characterized are the electronic background and random noise. These two components are not related to the properties being measured

Table 4-4. Signal Enhancement with Charge Integration

Number of Exposure Frames	Signal Intensity (volts)		
	366.3 nm	404.7 nm	435.8 nm
1	0.024	0.092	0.231
2	0.048	0.184	0.470
3	0.069	0.284	0.718
5	0.123	0.482	1.241*
9	0.202	0.870*	1.702
17	0.386*	1.354	1.920
Log-log Plot			
Slope	0.978	1.031	1.044
σ_{slope}	0.014	0.006	0.008
Linear correlation coefficient	0.9996	0.99996	0.99994

* Last data point included in least-square fit

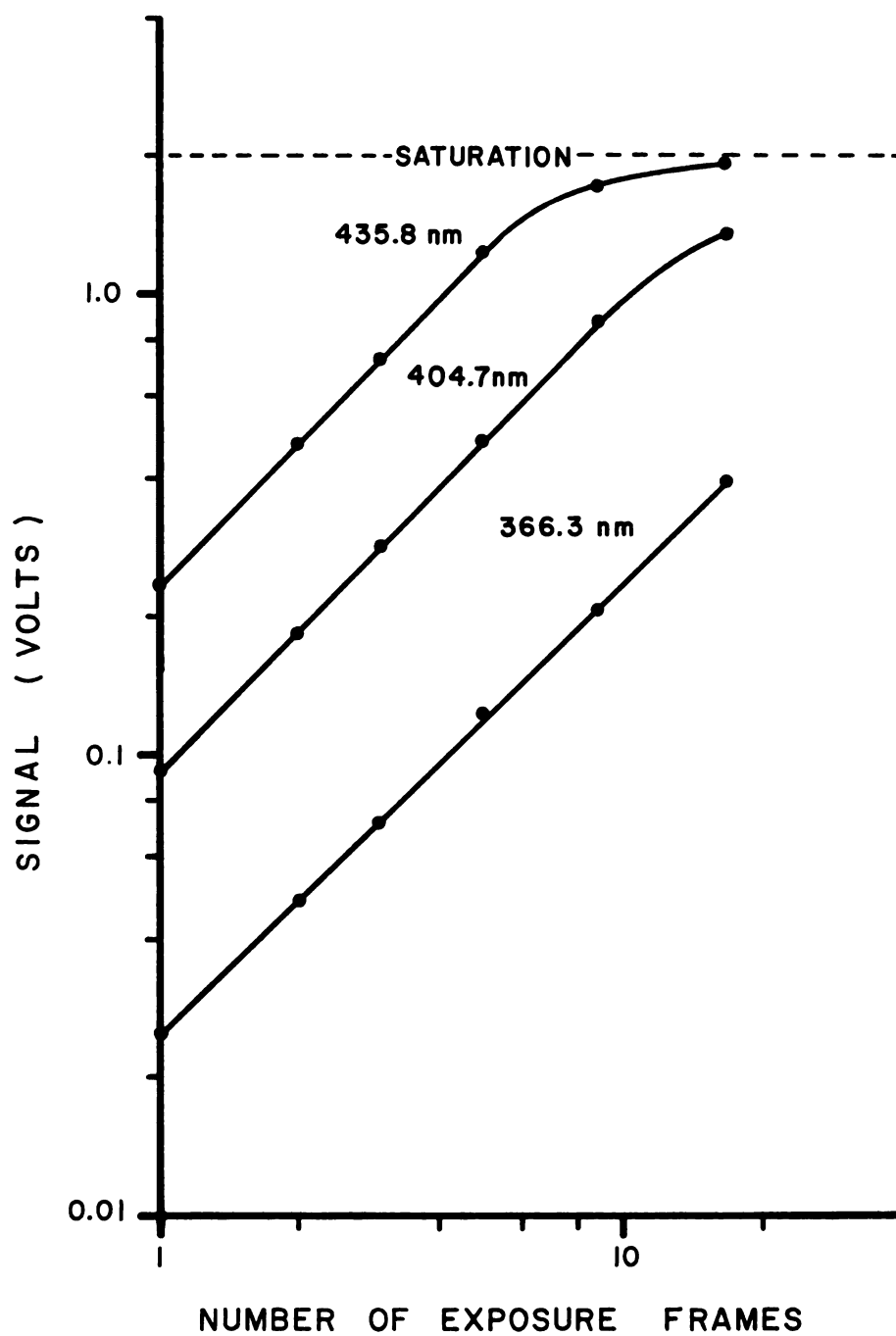


Figure 4-12. Vidicon Response vs Exposure Time

and must be removed from the composite signal. The electronic background is an operational characteristic of diode arrays and actually consists of two main components, dark current and fixed pattern noise (17). The dark current is a relatively constant DC signal and is the source of the overall level upon which the dynamic video signal is superimposed. The observed noise across the electronic background results from fixed pattern noise. Diode-to-diode dark current variations are the major source of fixed pattern noise and are reproducible from scan to scan. Random noise includes both photon noise and electronic noise from the preamplifier and the signal conditioning and sampling circuits.

Figure 4-13 illustrates the dark signals (shutter closed) recorded after 1 scan and after 512 signal averages. (The large noise spike in the first several channels is caused by the horizontal deflection coil during retrace.) Any random noise in the system should be a maximum without signal averaging (1 scan) and significantly reduced after 512 signal averages. A comparison of these two spectra shows that random noise is quite small compared to the electronic background and that the electronic background is a relatively constant and reproducible DC signal. Consequently, the electronic background can be removed from the composite signal by background subtraction.

A mercury emission spectrum was used to measure the S/N enhancement resulting from background subtraction. The test results are illustrated in Figure 4-14. For spectrum one, 512 scans were averaged. For spectrum two, the average of 512 scans of the dark current was subtracted from spectrum one to yield a background-corrected spectrum.

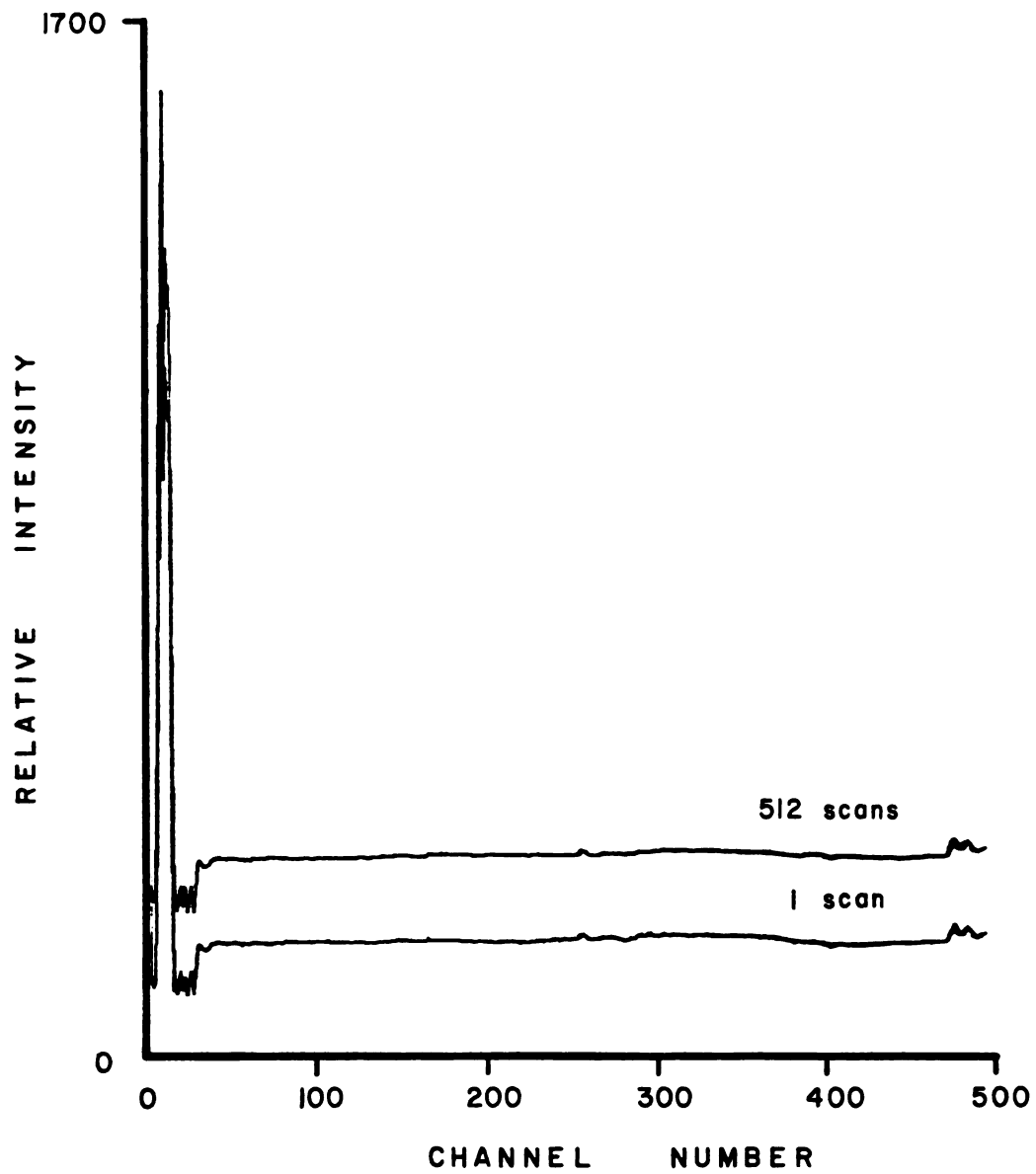


Figure 4-13. Vidicon Dark Signal

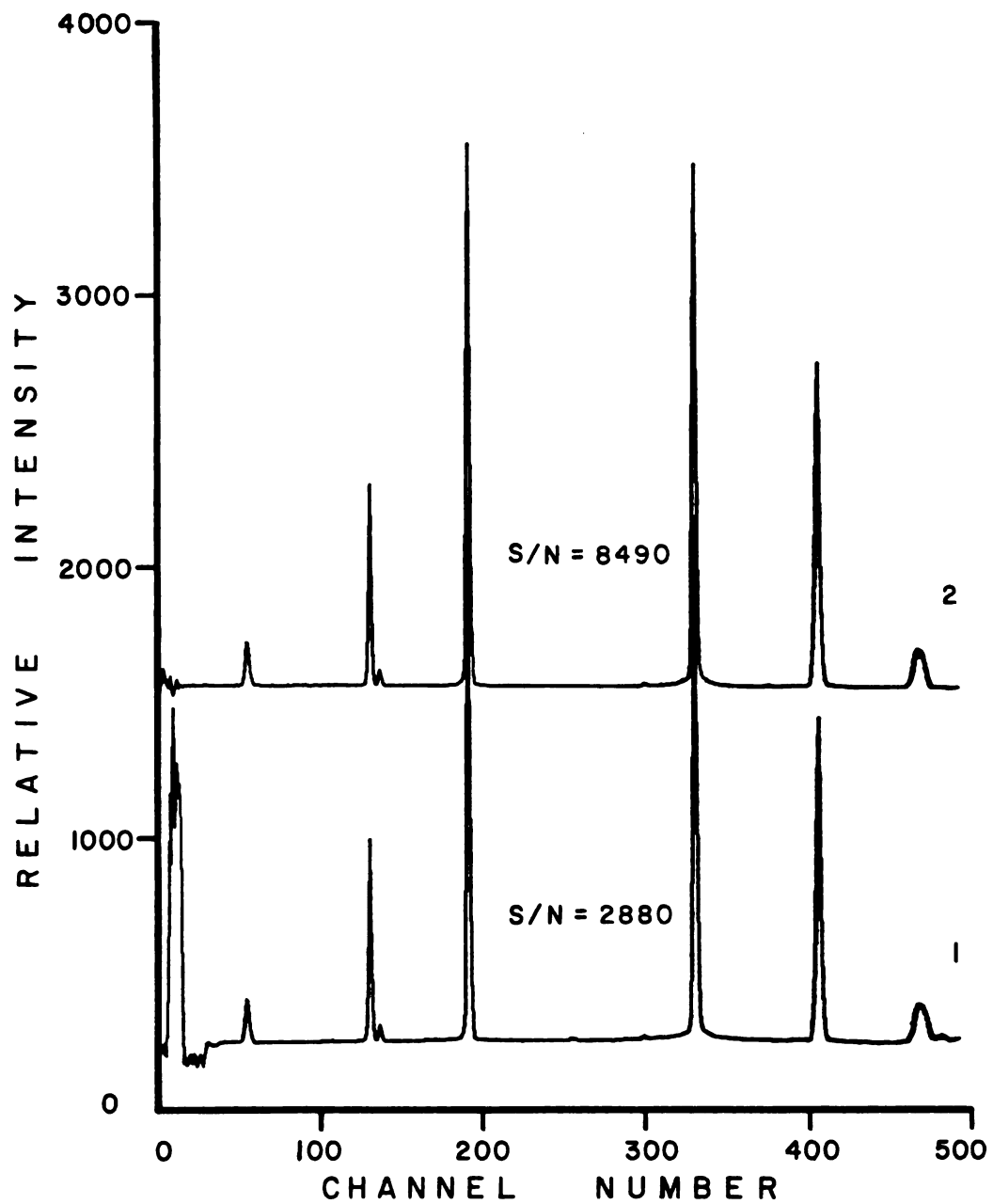


Figure 4-14. S/N Enhancement with Background Subtraction

Background subtraction not only removed the noise spike from the first several channels, but also noticeably improved the form of the baseline. This baseline improvement resulted in a significant increase in the S/N of the 436 nm mercury line.

When sufficient data acquisition time is available, signal averaging can be used to improve the real-time S/N of 3086 (4792 with background subtraction) by removing random noise from the output of the vidicon spectrometer. Figure 4-15 illustrates the improvement in maximum S/N achieved with signal averaging. (Maximum S/N is defined as the ratio of the maximum linear output level to the root-mean-square (RMS) value of the observed background, which was calculated using 50 signal-free channels adjacent to the 436 nm mercury emission line.) The lower trace shows the improvement in S/N without background subtraction; the upper trace the improvement in S/N with background subtraction. Signal averaging is observed to have limited utility in S/N enhancement when the background is not subtracted. The electronic background, which is not affected by signal averaging, limits the maximum S/N to approximately 4,200. However, the maximum S/N increases linearly with signal averaging when the background is subtracted. Thus, when used with background subtraction, signal averaging does successfully improve the maximum S/N by removing random noise from the video signal. Further, Figure 4-15 shows that good S/N data can be obtained with the vidicon spectrometer without the need for extensive signal averaging.

Since the data acquisition system is a digital system, quantizing noise can also limit the S/N of the system (108-111). Quantizing

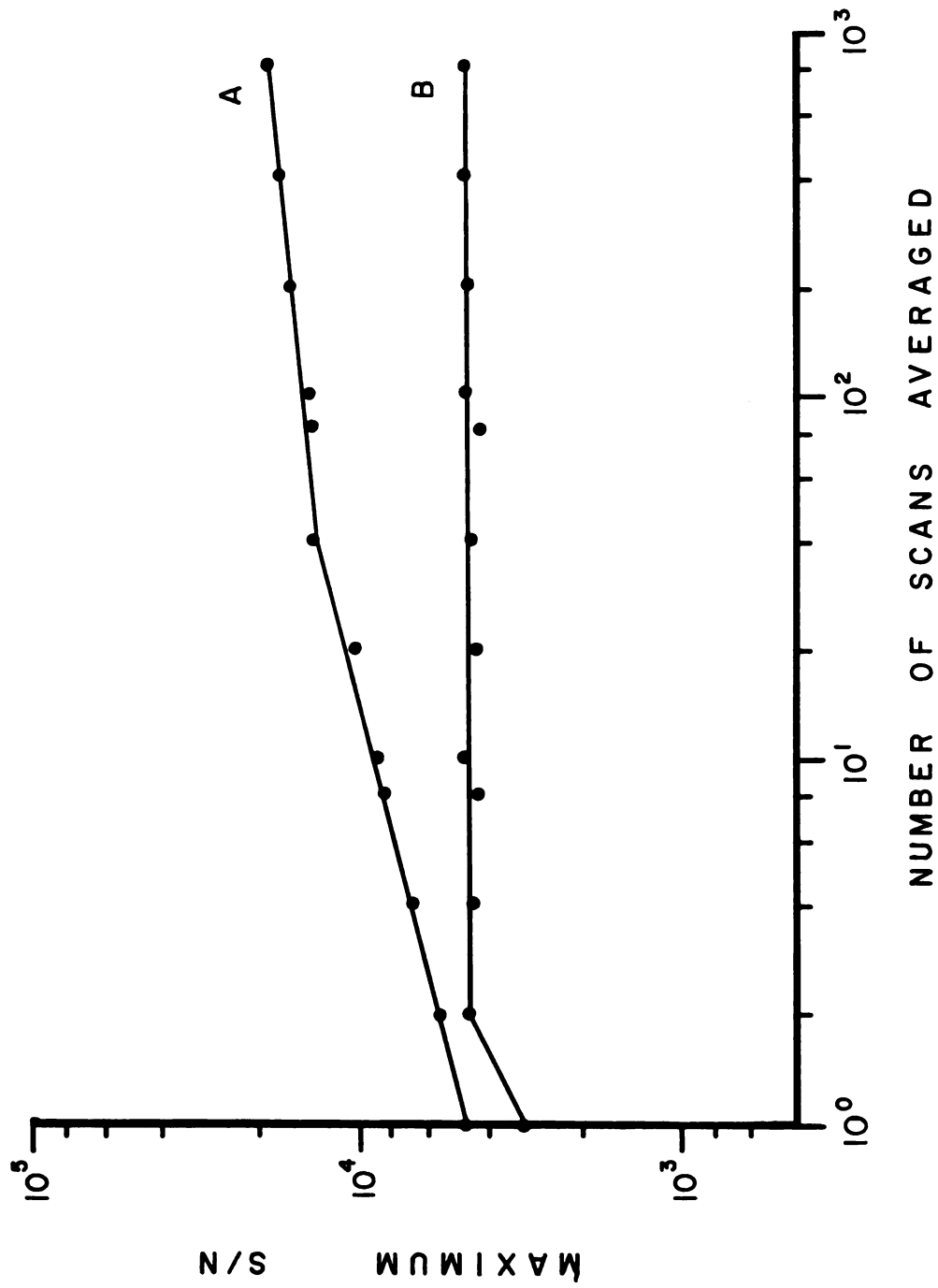


Figure 4-15. S/N Enhancement with Signal Averaging (A - with background subtraction, B - without background subtraction)

noise is a result of the finite resolution of the A/D converter (1 part in 4096 for a 12-bit converter). The effects of quantization on a signal are most serious when the converter is used to measure low level signals or when two quantized signals are subtracted to yield a small result. Consequently, quantizing noise is of concern in the vidicon spectrometer whenever the background signal is subtracted from non-signal containing portions of the video output. Fortunately, quantization effects can be time averaged away if a small amount of random noise is present on the signal (109). Such is the case in the present instrument. The random noise randomizes the quantization error and makes S/N enhancement by signal averaging possible. This averaging of the quantization error increases the effective bit resolution of the A/D converter. After 16 averages four extra bits are accumulated; however, only half of them are significant (108). Once the quantization error has been randomized, the precision of the resulting data depends essentially upon the square root of the number of scans averaged if white noise predominates (110,111). Thus in calculating the S/N for Figure 4-15 only one half of the extra bits accumulated through signal averaging were retained.

Finally, for weak signals charge integration (for signal enhancement) and signal averaging (for noise reduction) can be combined to increase the S/N for a fixed data acquisition time. Figure 4-16 shows three spectra in which the total data acquisition times were identical, but the relative times spent on charge integration and signal averaging were varied. The optically attenuated output of a mercury lamp served as the weak spectral source. Signal-to-noise ratios are given

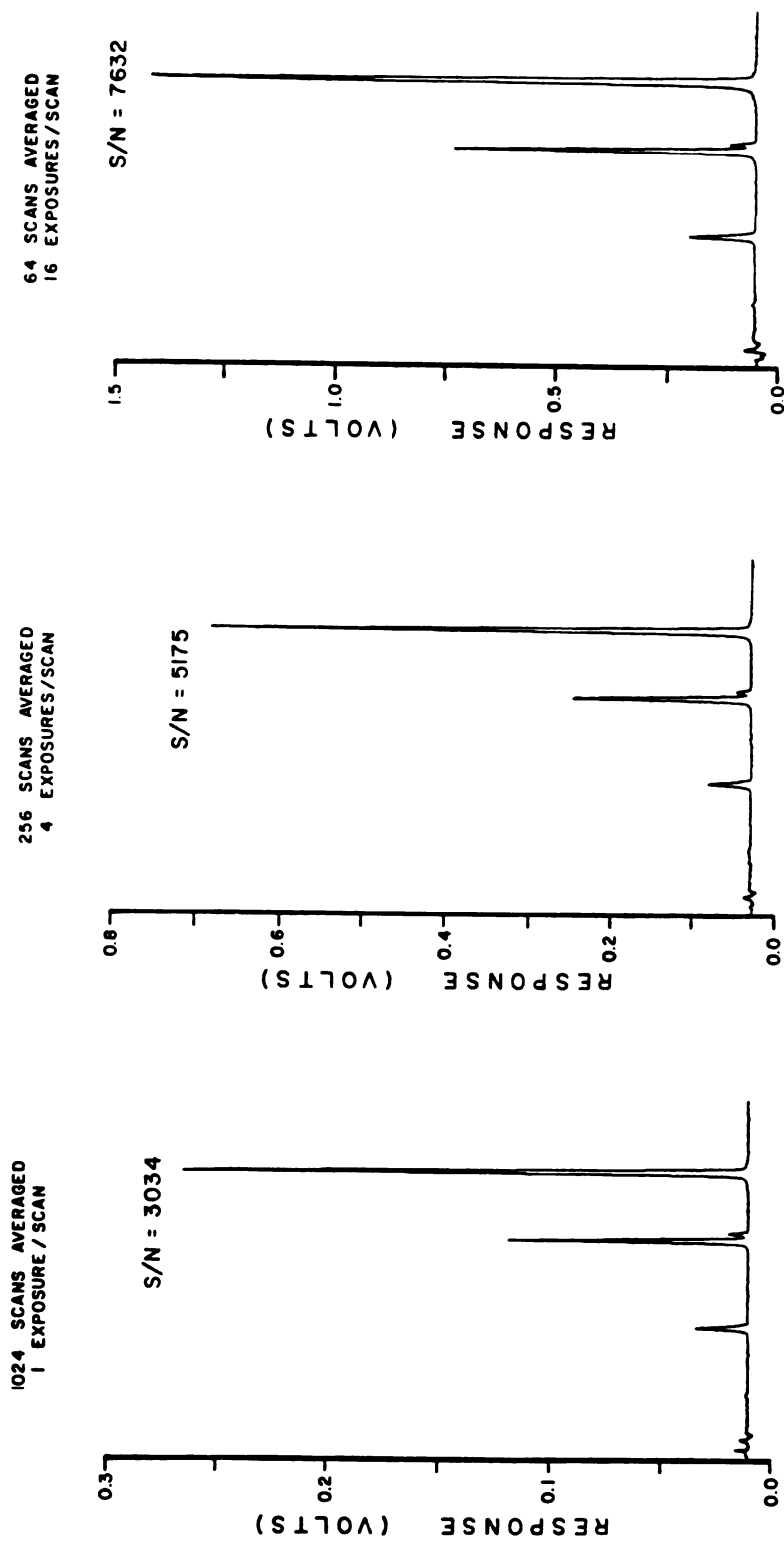


Figure 4-16. S/N Enhancement with Signal Averaging and Charge Integration

for the 436 nm mercury line. These spectra clearly demonstrate that a combination of these two S/N enhancement techniques provides a method for optimizing the output response for a fixed data acquisition time.

CHAPTER 5

DUAL-WAVELENGTH SPECTROSCOPY

A. Introduction to Dual-Wavelength Spectroscopy

Dual-wavelength spectroscopy was first proposed in 1951 by Chance (112) as a method for measuring small absorbance changes in turbid biochemical samples. In this method two monochromatic light beams of different wavelengths are alternately passed through a single cuvette, and the difference in absorbance at the two wavelengths is recorded as a function of time. One of the light beams (sample) is set at a wavelength that corresponds to an absorption peak of the substance under study. The second (reference) light beam is set at a wavelength at which the substance under study has little or no absorbance. Variations in light intensity at the reference wavelength reflect only scattering effects, if there is no absorbance change due to the substance under study. Thus, if the relative changes in scattered light are the same at the two wavelengths, the intensity at the reference wavelength provides continuous correction for scattering and sample settling. Consequently, this method allows the measurement of small concentration differences of single components in mixtures or the monitoring of small absorbance changes that would normally be hidden in a highly absorbing or scattering background.

The use of only one cuvette in the dual-wavelength method minimizes several errors that result from the use of two cells in the classical (single-wavelength) method. The errors in the dual-cell method result from differences in cell position, cell path lengths, cell reflectivity

losses, and from differences between the sample and reference solutions, such as turbidity and concentration (113). Because these errors are minimized in the dual-wavelength method, improved selectivity, sensitivity, and accuracy of analyte absorption measurement in the presence of severe spectral overlap can be obtained by using this technique (114,181).

There are two important restrictions that should be observed when applying the dual-wavelength technique (115). The reference wavelength should be chosen so as to minimize interferences from other absorbing components in the sample. Secondly, the two wavelengths should be closely spaced in order to minimize the effects of light-scattering differences. The second restriction is a result of the strong inverse fourth power wavelength dependence of Rayleigh scattering (116).

Of the various optical systems that have been designed for dual-wavelength spectroscopy, the most common is the time-division multiplexed system. In this system the two monochromatic light beams are alternately passed through the sample and onto a common photodetector. The output of the photodetector is then amplified, demultiplexed, and recorded. Vibrating mirrors (112,123,124), rotating chopper mirrors (113,117,120,125), acousto-optic devices (122), and air-turbine-driven mirrors (127) have been used to multiplex the two monochromatic light beams. An obvious advantage to these systems is that only a single detector is required, and it can be positioned quite close to the cell to ensure good collection efficiency. The disadvantages include the mechanical complexity of the chopper and a response time that is limited by the chopping rate (multiplex frequency).

More recently, dual-detector systems have been developed to provide faster response times for dual-wavelength applications. Chance et. al. (127) and Stewart (126) combined the two monochromatic light beams, passed them through the sample, isolated the two beams with a beam splitter and two interference filters, and detected them simultaneously with two photomultipliers. Woodruff and Shrader (128) used a Rowland circle to construct a dual-wavelength spectrometer with only one fixed grating and mobile exit slits and photomultiplier light sensors. Both of these approaches allow the two wavelength channels to be monitored independently and simultaneously. The primary advantage of this dual-detector approach is that the response speed is limited by the desired S/N value and not by a multiplex frequency.

There are three basic types of dual-wavelength spectroscopy that are commonly used; dual-wavelength non-scanning spectroscopy, dual-wavelength scanning spectroscopy, and derivative spectroscopy (156). In the dual-wavelength non-scanning mode, the sample and reference beams are fixed at different wavelengths. This mode is used in those analytical situations where an interfering substance overlaps the analyte or when the effect of turbidity must be minimized. The dual-wavelength scanning mode, in which the reference beam is fixed and the sample beam is scanned, is used to measure the spectral characteristics of a highly turbid sample when a suitable reference can not be prepared. The derivative mode provides the derivative function by scanning the two monochromators with a fixed small wavelength difference between them. These three types of dual-wavelength spectroscopy are discussed further in subsequent sections of this chapter.

Compensation of the effects of light scattering by turbid suspensions is probably the most important use of the dual-wavelength technique (112,124,125,127,129,130). This technique has also been used effectively to cancel signal disturbances caused by bubbles and various shock pulses in temperature-jump and flow experiments and to minimize the effects of lamp flicker and ripple (131,134,136). Other applications include spectroelectrochemical studies (138), stopped-flow measurements (131,134,137), sensitivity enhancement in inorganic spectrophotometry (113,133), simultaneous determination of mixtures or masking of diverse components (119-121,128), and multi-wavelength detection of liquid chromatographic effluents (132) and microwave atomic emission lines (139).

B. Dual-Wavelength Applications with the Vidicon Spectrometer

1. Introduction

Dual-wavelength techniques are easily implemented with the vidicon spectrometer because of its multi-wavelength capability. The vidicon spectrometer is similar to the dual-detector systems in that its wavelength channels are monitored independently and simultaneously by the photodiode array. However, as with the single-detector dual-wavelength systems, the response time of the vidicon spectrometer to time-dependent features is limited by a multiplex frequency (scan rate of the electron beam). The normal multichannel output of the vidicon spectrometer facilitates the selection of a suitable wavelength pair for the application of dual-wavelength techniques. In the remainder of this chapter, the performance of the instrument in three dual-wavelength modes (the

dual-wavelength non-scanning mode, the dual-wavelength scanning mode, and the derivative mode) is evaluated.

2. The Dual-Wavelength Non-Scanning Mode

In this method the radiant power incident on the sample is set at a wavelength that corresponds to an absorption peak of the substance under study, and the radiant power incident on the reference is set at a wavelength at which the substance under study has little or no absorbance. To the extent that relative changes in scattered light are the same at the two wavelengths, the intensity at the reference wavelength provides continuous correction for scattering and sample settling. This mode is implemented with the vidicon spectrometer by selecting two suitable wavelengths from an absorption spectrum of the sample and by using the difference in absorbance at these two wavelengths as the analytical signal.

The ability of this technique to compensate for scattering was evaluated by using neutral density filters to simulate scattering effects. In this case the turbidity change is the absorbance of the filter, and, for a good neutral density filter, this absorbance will be identical at all wavelengths. The spectral feature of interest was the 536 nm absorption band of a holmium oxide filter (see Figure 5-1). The sample wavelength was set at 536 nm and the reference wavelength at 563 nm. The sample and reference cuvettes in the sample compartment were filled with distilled water, and the holmium oxide filter was placed in front of the sample cell. Several neutral density filters were inserted into the light beam and the changes in absorbance were

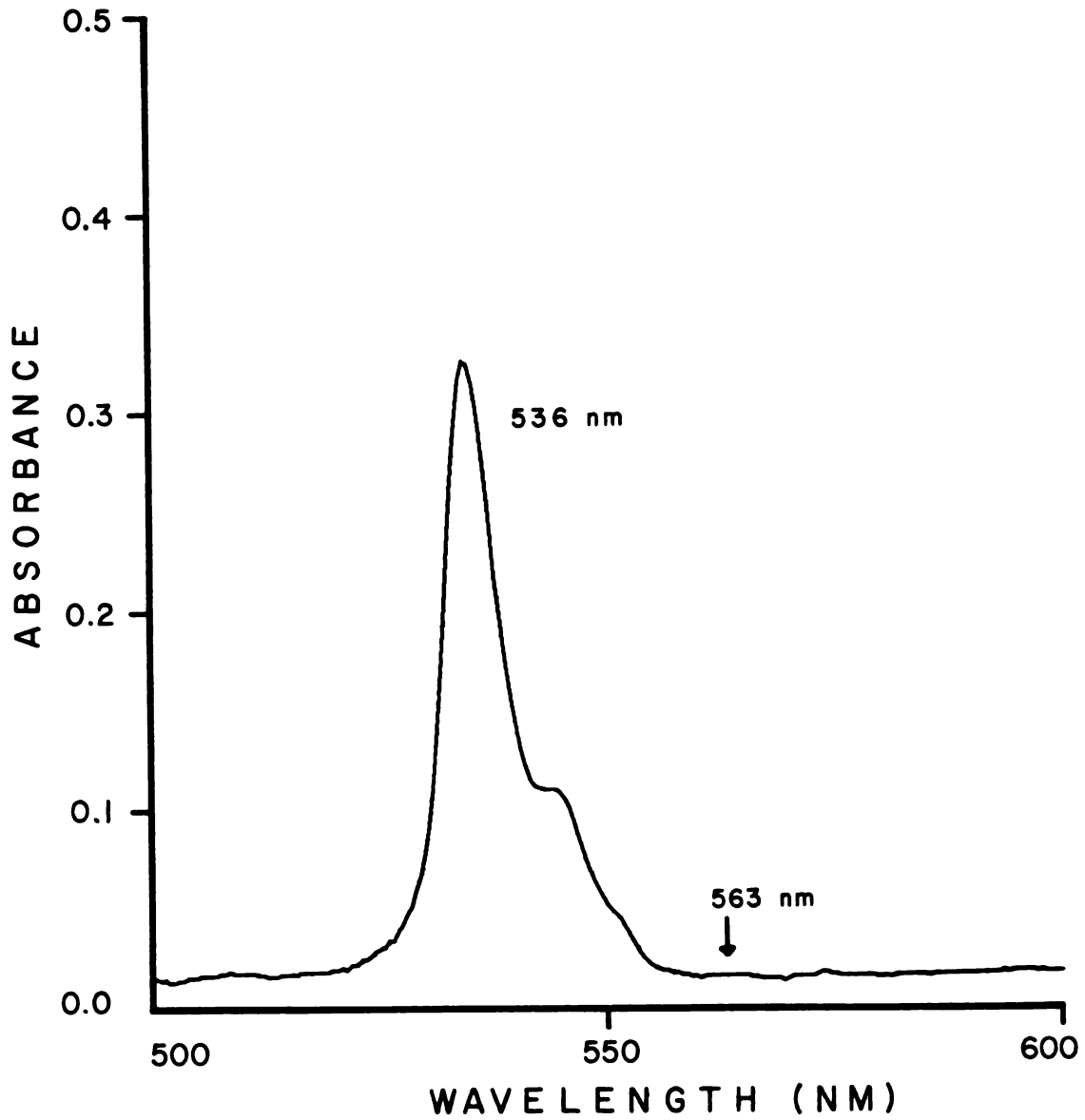


Figure 5-1. Absorption Spectrum of a Holmium Oxide Filter

recorded and tabulated (see Table 5-1). The average ΔA for these data is 0.298 ± 0.003 ($\pm 1\sigma$) absorbance unit.

Table 5-1. Dual-Wavelength Correction for Scattering

A (Neutral Density Filter)	A (536 nm)	A (563 nm)	ΔA
0.00	0.348	0.051	0.297
0.15	0.478	0.178	0.300
0.30	0.611	0.317	0.294
0.50	0.774	0.480	0.294
1.0	1.248	0.948	0.300
2.0	2.065	1.764	0.301

The data in Table 5-1 show that insertion of the neutral density filters into the beam caused changes of approximately 0.003 A (1%) in ΔA . Thus, the vidicon spectrometer corrected for 99% of the simulated "scatter" over a 2 absorbance unit range. The small variation in ΔA observed with the different neutral density filters may have resulted in part from non-uniformity of absorbance of the filters over the wavelengths of interest or from random errors in positioning the filters perpendicular to the beam.

Next, barium sulfate powder was added to the sample cuvette to simulate a sample with changing light-scattering properties. After the powder was added, data were collected at five minute intervals (see Table 5-2). The data for the 536 nm peak show that after a large initial deflection, the peak began approaching the original absorbance as the barium sulfate particles settled in the cuvette. In contrast,

Table 5-2. Dual-Wavelength Correction for Scattering and Sample Settling

Time, min	% Light Scattered	A (536 nm)	A (563 nm)	ΔA	% Error = $(\Delta A - 0.311)/0.311 \times 100$
0	0	0.331	0.020	0.311	± 0.0
1	92	1.384	1.098	0.286	- 8.0
5	83	1.088	0.787	0.301	- 3.2
10	72	0.902	0.594	0.308	- 1.0
15	60	0.720	0.409	0.311	± 0.0
20	43	0.566	0.254	0.312	+ 0.3

the dual-wavelength data show that the effect of the settling barium sulfate particles was almost eliminated in this mode. The observed dual-wavelength error, which increases with increased scattering, results from the wavelength dependence of scattering ($I_s \sim 1/\lambda^4$) (135). It is a function of both the wavelength separation of the sample and reference beams and the concentration of the light-scattering component. Thus, this error can be reduced by decreasing the sample turbidity and/or by decreasing the wavelength separation of the two analytical light beams.

The dual-wavelength non-scanning technique can also be used in the analysis of highly overlapping two-component mixtures to eliminate the influence of an interfering component. In this case the two wavelengths are chosen such that the absorbance of the interfering component at both wavelengths is identical ($\Delta A = 0$). Also, the sample wavelength must be at or near an absorbance maximum of the analyte to provide adequate sensitivity to the analyte. If these conditions can be met, the analyte can be analyzed directly and independently of the interfering component.

The determination of nickel in the presence of cobalt was used as a test of this application of dual-wavelength spectroscopy. The absorption spectra of the hexaquo Ni(II) ion (0.10 M) and the hexaquo Co(II) ion (0.17 M) in an approximately 2N perchloric acid solution are shown in Figure 5-2. These curves demonstrate that an analytical determination of nickel in the presence of cobalt necessitates the elimination (masking) of the absorption contribution from cobalt. The sample wavelength was set to the absorbance maximum for the

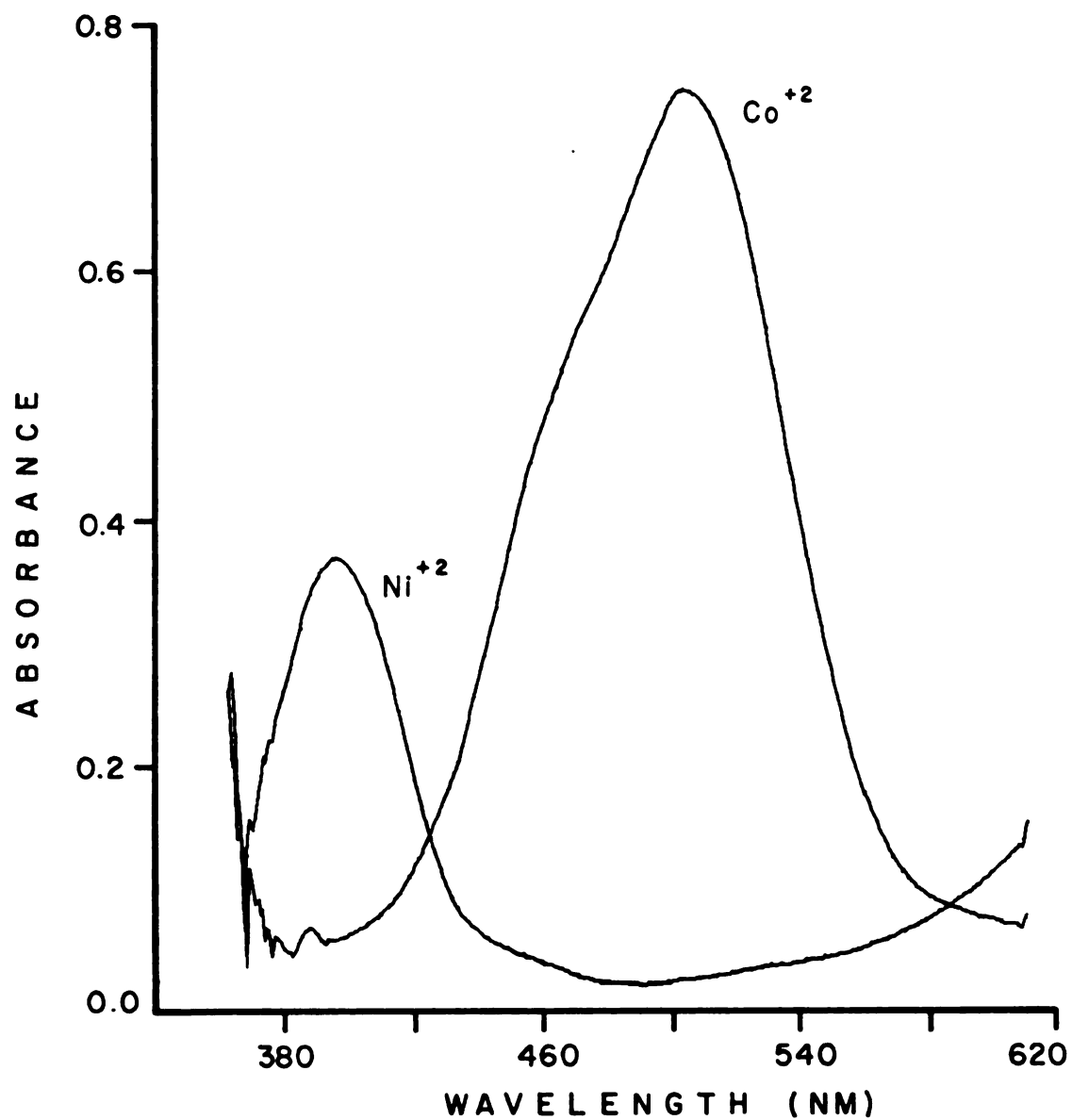


Figure 5-2. Absorption Spectra of Nickel (0.10M) and Cobalt (0.17M) in 2N HClO₄

hexaquo Ni(II) ion, 397 nm (Figure 5-2). Since the absorbance of the hexaquo Co(II) ion at 610 nm minimized changes in the difference of absorbance with changes in cobalt concentration, the reference wavelength was set at 610 nm.

Solutions were prepared by weighing out appropriate amounts of the metal salts (cobalt chloride and nickel nitrate), by dissolving them in 5 ml of concentrated (approximately 70%) perchloric acid, and by diluting to 25 ml with distilled water. The absorbance of each solution was then measured at 397 nm and 610 nm and the absorbance difference ($A_{397} - A_{610}$) was used as the analytical signal. Figure 5-3 illustrates the linear calibration curve (extrapolated to zero absorbance) that resulted from the measurement of the absorbance difference at the two wavelengths for varying amounts of Ni^{+2} . Table 5-3 lists the results obtained when 3 mg/ml of nickel were measured in the presence of varying amounts of cobalt. The data clearly show that over a cobalt concentration range of 0 to 15 mg/ml the dual-wavelength technique can successfully minimize the interference of

Table 5-3. Determination of Nickel in the Presence of Cobalt

Ni taken (mg/ml)	Co added (mg/ml)	Ni found (mg/ml)	Absolute Error (mg/ml)
3.0	0	3.0	0.0
3.0	3	3.0	0.0
3.0	5	3.1	+ 0.1
3.0	10	3.2	+ 0.2
3.0	15	3.3	+ 0.3

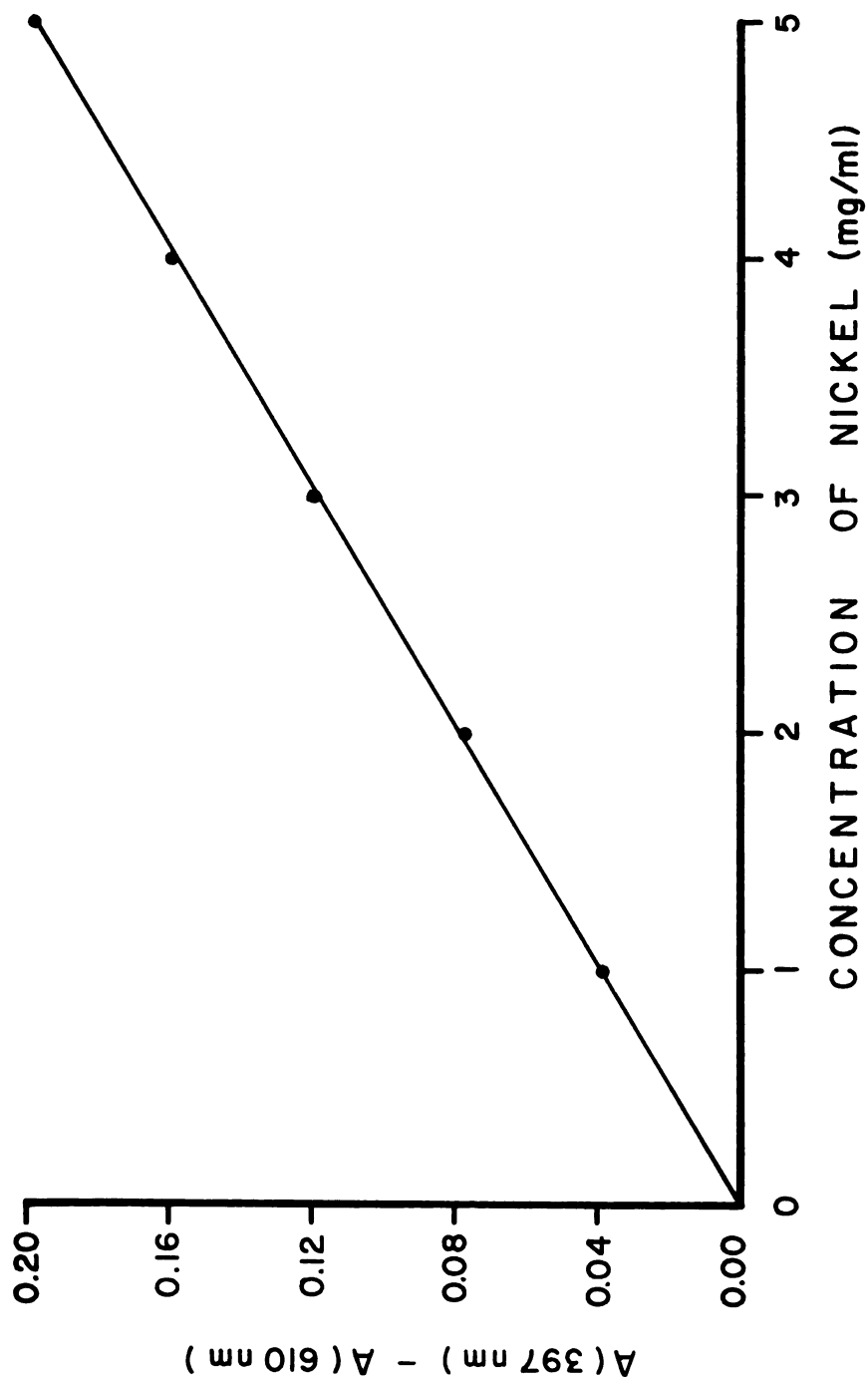


Figure 5-3. Calibration Curve for Nickel Determination

cobalt in the determination of nickel. The interference of cobalt was not completely eliminated because of a small absorbance difference between the two cobalt wavelengths.

3. The Dual-Wavelength Scanning Mode

The dual-wavelength scanning mode utilizes the same beam geometry as the dual-wavelength non-scanning mode. In the dual-wavelength scanning mode, however, the reference wavelength is stationary and the sample wavelength is scanned over a short wavelength interval. This mode permits the acquisition of spectral information, while retaining the advantages of dual-wavelength operation. Sellers et. al. (135) used this technique to study the reduction of a microsomal suspension in a turbid sample.

The dual-wavelength scanning mode can be implemented with the vidicon spectrometer by acquiring an absorption spectrum and then subtracting the absorbance at the reference wavelength from the absorption spectrum. As in the previous section, barium sulfate powder was used to simulate a sample with changing light-scattering properties caused by sample settling. A holmium oxide filter was placed in front of the sample cuvette and barium sulfate was added to the water in the cuvette. After the powder was added, the peak was scanned at five minute intervals. The resulting curves are shown in Figure 5-4 for the single-wavelength mode. After a large initial deflection, the peak began approaching the original trace as the barium sulfate particles settled in the cuvette.

The corresponding curves for the dual-wavelength scanning mode

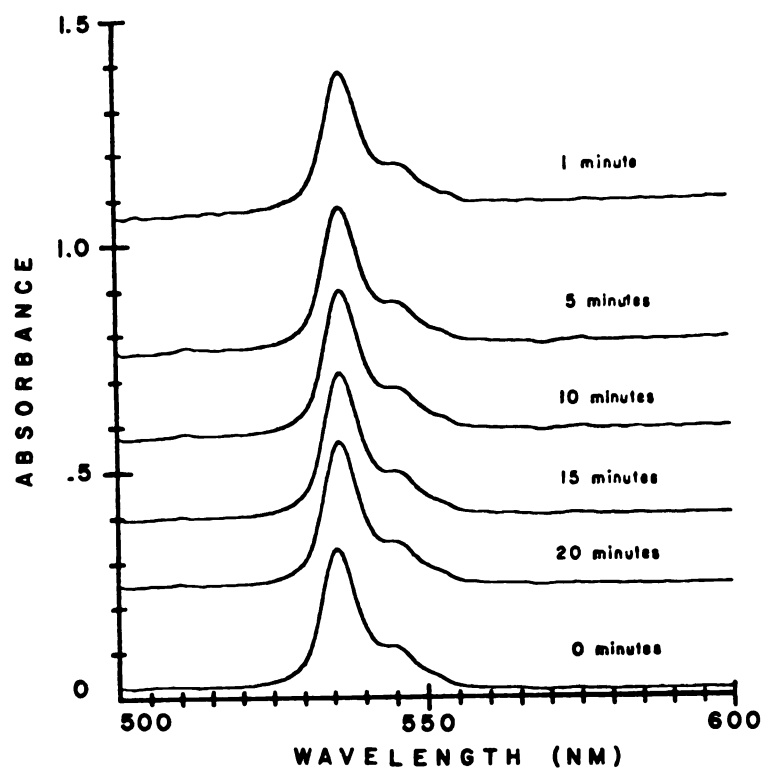


Figure 5-4. Effect of Sample Settling with Single-Wavelength Scanning

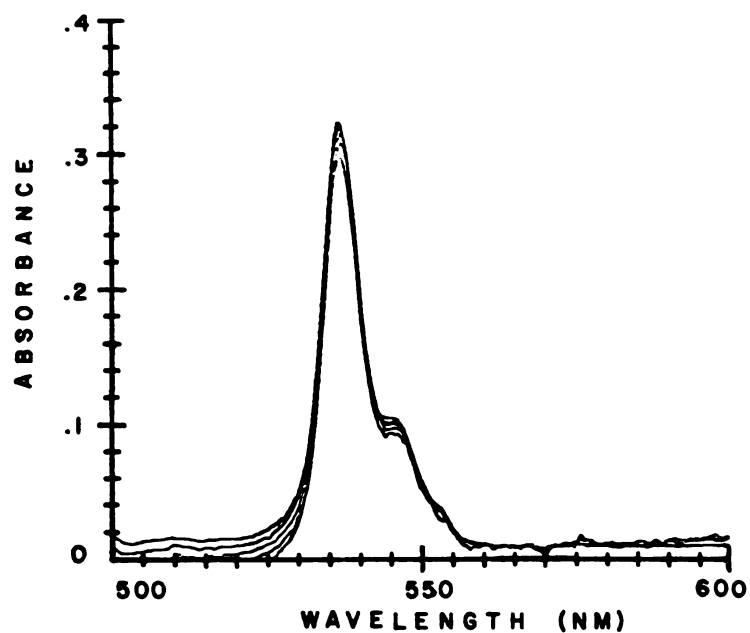


Figure 5-5. Dual-Wavelength Correction for Sample Settling

(Figure 5-5) show that the dual-wavelength scans are almost fully superimposed, and the effect of the settling barium sulfate particles was minimized. Unfortunately, this technique was not able to eliminate totally the effect of the sample settling because of the wavelength dependence of scattering (135). The observed correction error increases both with an increase in sample scattering and with an increase in the wavelength interval between the reference and sample beams.

4. The Derivative Mode

In the normal derivative mode, the beam geometry is identical to that of the dual-wavelength non-scanning mode, and a single cuvette is used. With single channel detectors, two monochromators are mechanically locked together at a fixed small wavelength difference. The monochromators are then simultaneously scanned across the wavelength interval of interest to produce a differential absorption curve. Sellers et. al. (135) found that a wavelength difference of 2 nm with a 2 nm bandpass results in differential absorption curves that closely approach the theoretical first derivative of a spectrum.

In 1955 Giese and French (140) published the results of their study of the behavior of the derivatives of hypothetical overlapping absorption bands. This paper clearly demonstrated the advantages in accuracy that could be gained by using derivative measurements in resolving overlapping bands. Advantages of the first-derivative of absorbance include the following: detection of absorption bands even if they completely overlap, resolution of small absorption bands

which lie on the steep portion of an absorption curve, precise location of very broad absorption bands, linear relationship of the differential coefficients at specific wavelengths to the concentration of the corresponding components, and the elimination of variations in turbidity or background.

The experimental approaches used to obtain derivative spectra fall into two general categories: those that operate on the light beam in the optical part of the spectrometer, and those that operate on the output signal of the spectrometer. The first category includes dual-wavelength spectrometry (112-114,118) and wavelength modulation with synchronous detection (142-145). The second category includes electronic differentiation (146-148,153), mechanical tachometers (149,150), and numerical differentiation (66,82,103,151,152,154).

In recent years the increased availability of on-line computer systems has made the use of numerical differentiation for producing derivatives of spectroscopic data more common. Once the spectroscopic data are in digital form, numerous algorithms are available for smoothing, averaging, or differentiating the original data (see references above). In order to use these techniques, the experimental curves must be continuous and the data must be sampled at uniform wavelength intervals (155). The digital output of the vidicon spectrometer meets these requirements and is well suited to the various post-processing techniques currently available.

The vidicon spectrometer simultaneously collects spectral information over a 230 nm window and outputs a user-defined number of uniformly spaced data points. These data can be subjected to any of

the various numerical differentiation techniques to calculate the first derivative. Pardue et. al. have used both Savitzky and Golay smoothing functions (66) and wavelength modulation of the horizontal sweep signal of a vidicon spectrometer (60,81) to generate the first derivative for atomic emission and molecular absorption processes. However, since the first derivative represents the slope at each data point, the first derivative of the vidicon output can be approximated by taking the difference between data points equally distant from the data point at which the slope is to be determined, e.g. the slope at the i^{th} data point is equal to $(i+n) - (i-n)$, where n is a user-specified integer. The value of n depends upon both the number of output wavelength channels and the form of the experimental curve. The first derivative of the acquired spectral data is obtained by repeating this calculation for all of the data points. Higher derivatives can be obtained by repeating this calculation the appropriate number of times.

This subtraction technique was qualitatively evaluated by calculating the first and second derivatives of the absorption spectrum of praseodymium chloride (Figures 5-6 thru 5-8) and the emission spectrum from a mercury lamp (Figures 5-9 thru 5-11). For each spectrum the number of wavelength channels was 512 and the integer increment for the derivative calculation was 2, i.e. the slope was calculated over a 2 nm interval at each point. The absorption spectrum of PrCl_3 (Figure 5-6) illustrates the high quality and resolution capability of the vidicon spectrometer. Figures 5-7 and 5-8 show the increased resolution obtained from the first and second derivative curves. Notice in

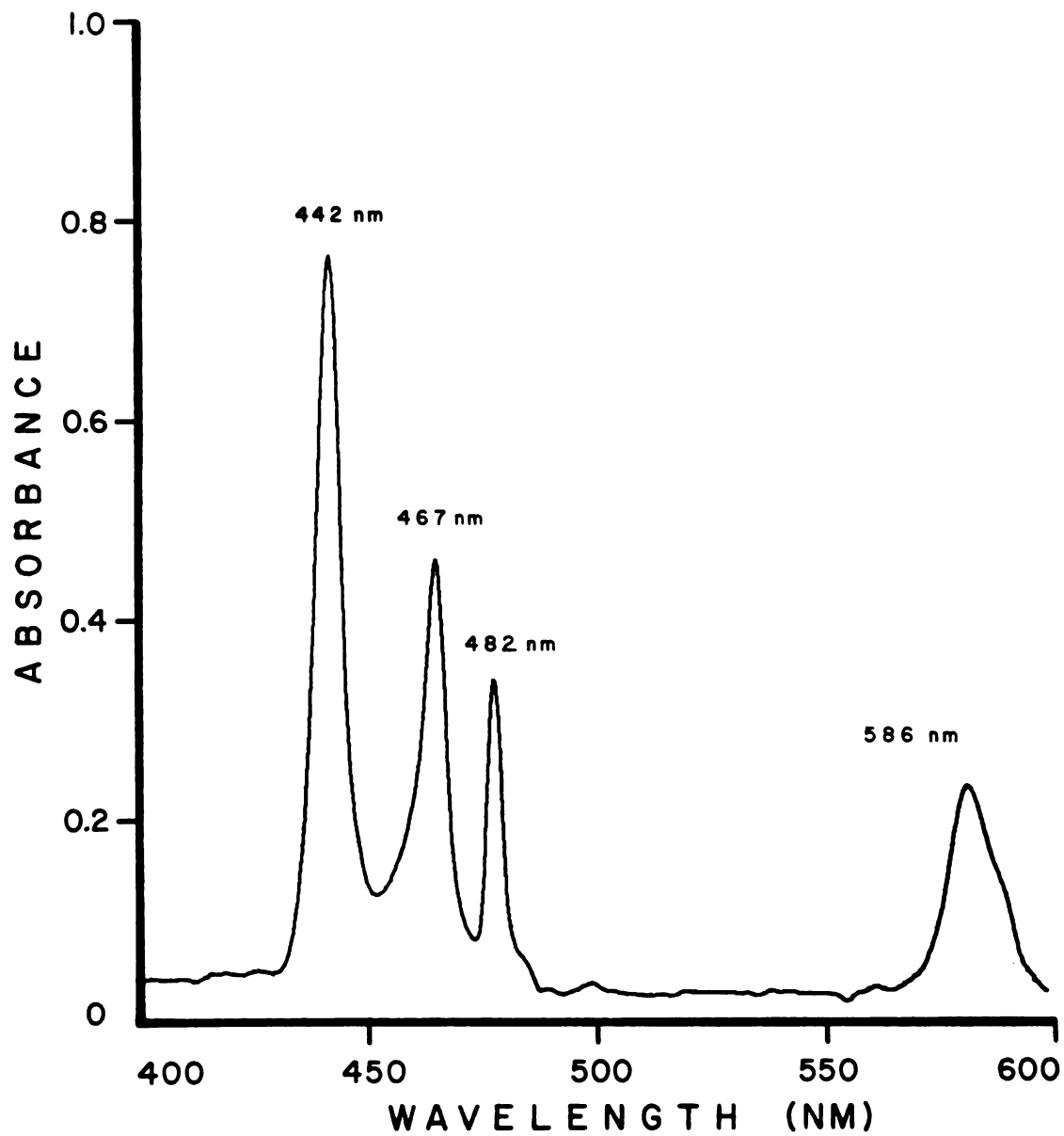


Figure 5-6. Absorption Spectrum of PrCl_3 (0.20M) in 1M HCl

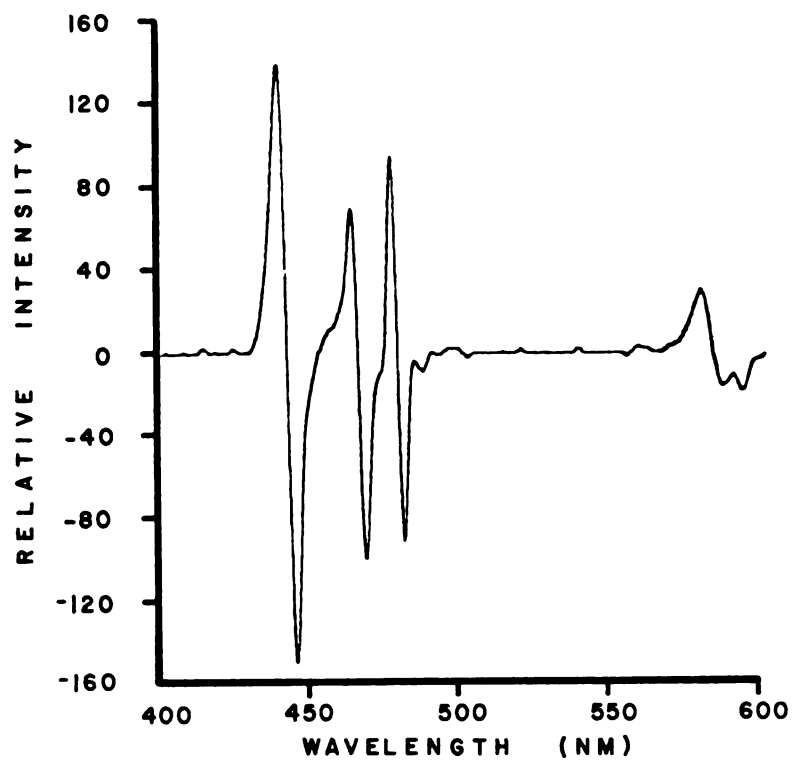


Figure 5-7. First Derivative of PrCl₃ Absorption Spectrum

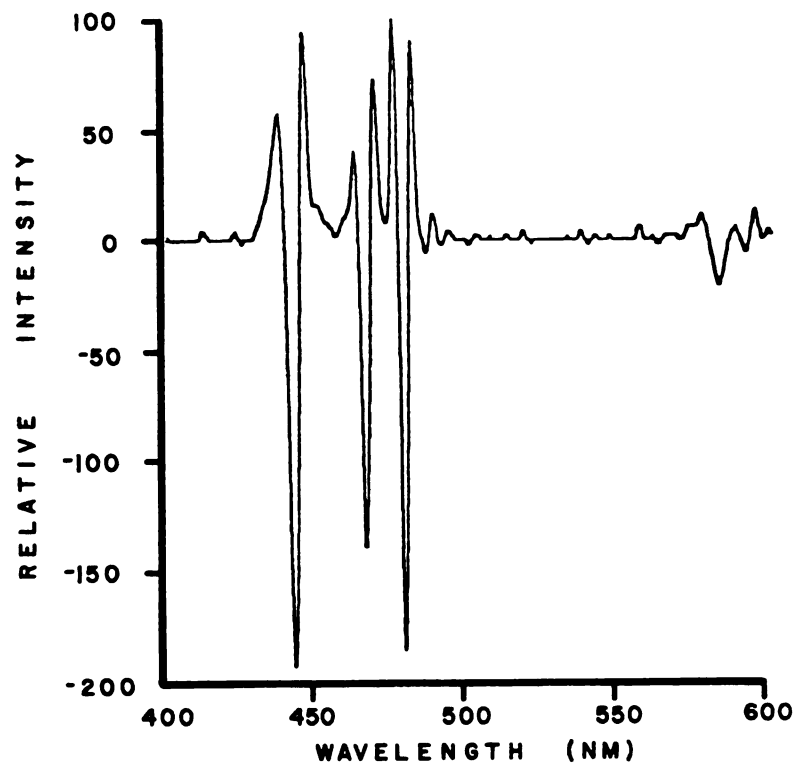


Figure 5-8. Second Derivative of PrCl₃ Absorption Spectrum

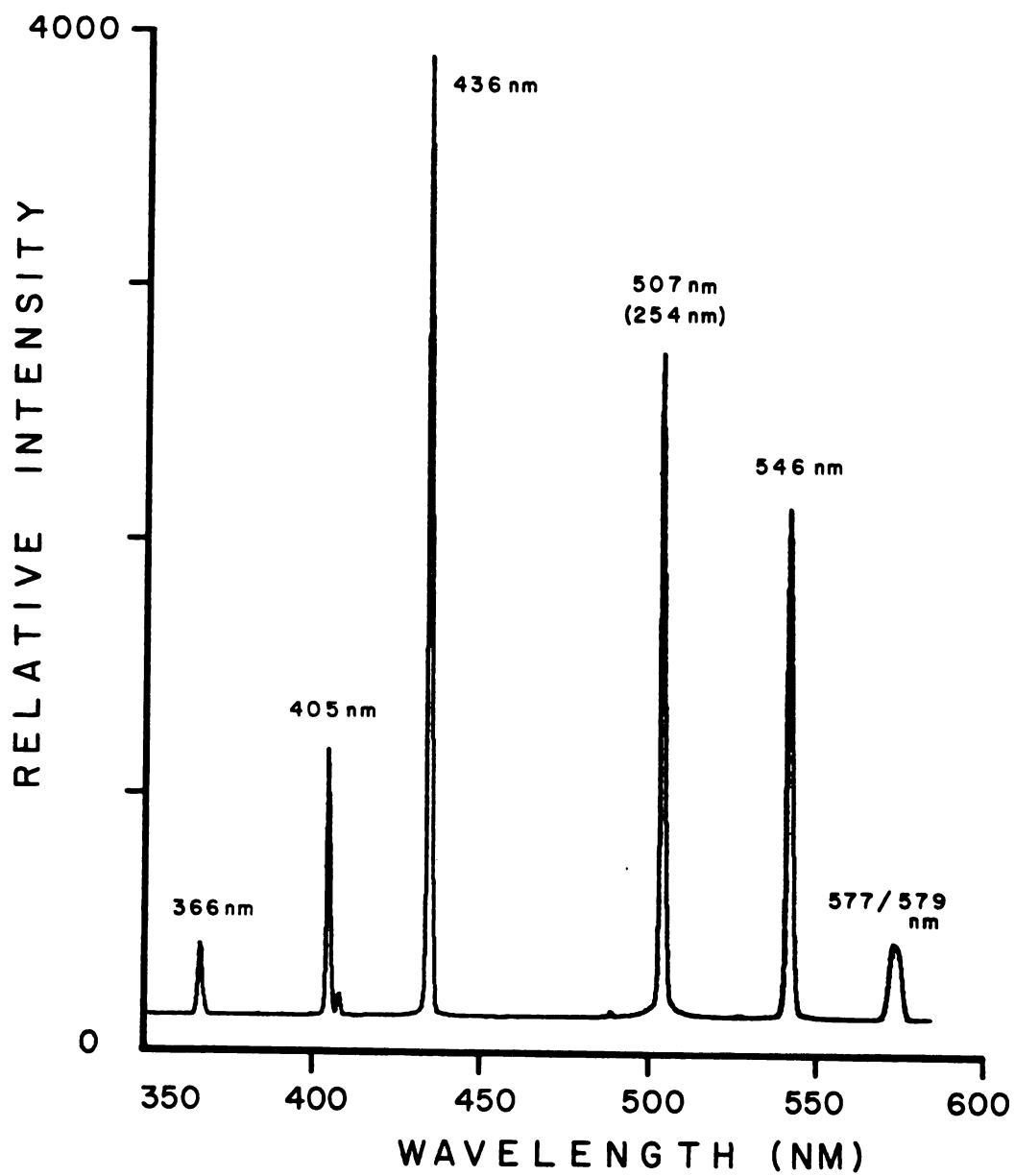


Figure 5-9. Mercury Emission Spectrum

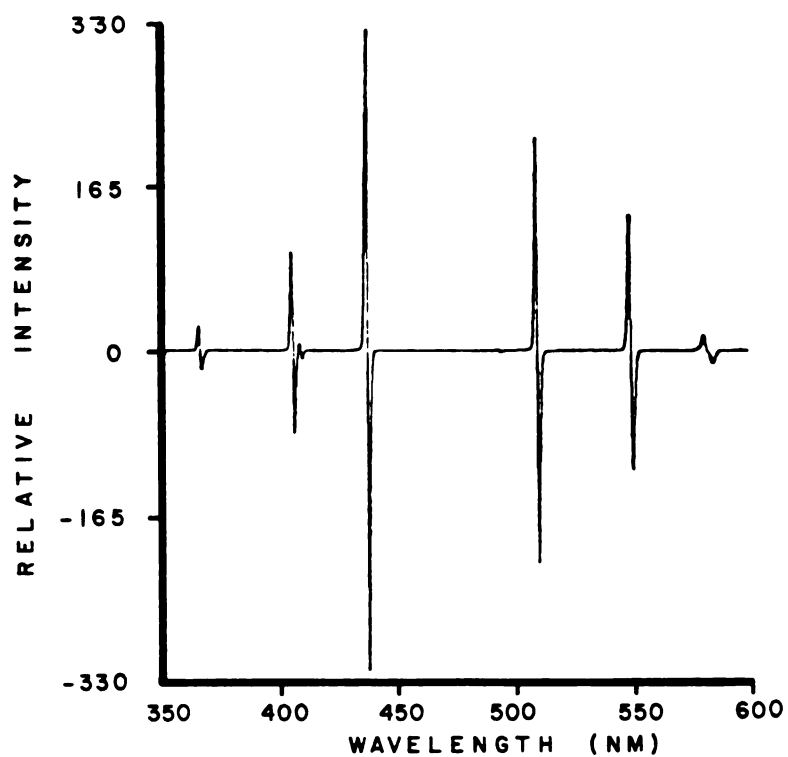


Figure 5-10. First Derivative of Mercury Emission Spectrum

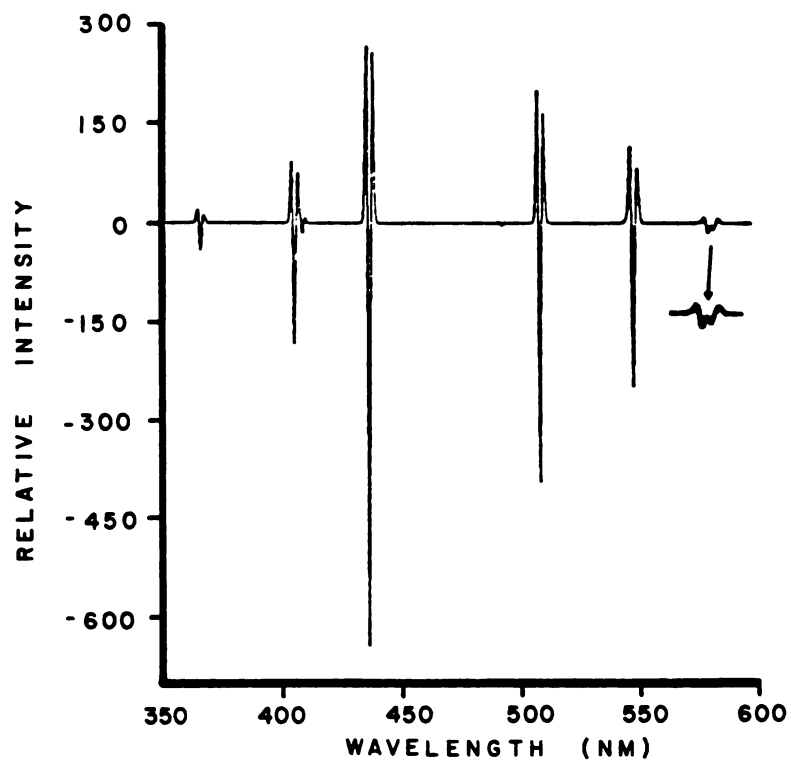


Figure 5-11. Second Derivative of Mercury Emission Spectrum

particular the resolution of the shoulder on the 586 nm absorption peak in the derivative curves. The mercury emission spectrum of Figure 5-9 further illustrates the excellent resolution obtained with a line spectrum. Although the vidicon spectrometer can not resolve the mercury 577/579 nm doublet when it is incident upon the target edge, the second derivative (Figure 5-11) clearly indicates the presence of two peaks in the doublet. Thus this numerical differentiation technique can be used to significantly improve the resolution of spectroscopic data.

One of the reported advantages of the first derivative method is the elimination of variations in turbidity or background (155). Also, because the wavelength channels used in evaluating the first derivative are only a few nanometers apart, the previously observed error due to the wavelength dependency of scattering should be essentially eliminated. The ability of the derivative mode to eliminate variations in turbidity and sample settling was evaluated by applying this technique to the scattering data reported earlier in this chapter. Figure 5-12 illustrates the results obtained when the derivative mode was used to correct for the "scatter" caused by insertion of several neutral density filters into the sample light path. Figure 5-13 illustrates the results obtained when the derivative mode was used to compensate for the effect of the settling barium sulfate particles in the sample cuvette. In both instances the derivative mode successfully eliminated the effect of variations in scattering in the sample. The derivative mode also eliminated the previously observed error that resulted from the wavelength dependency of scattering.

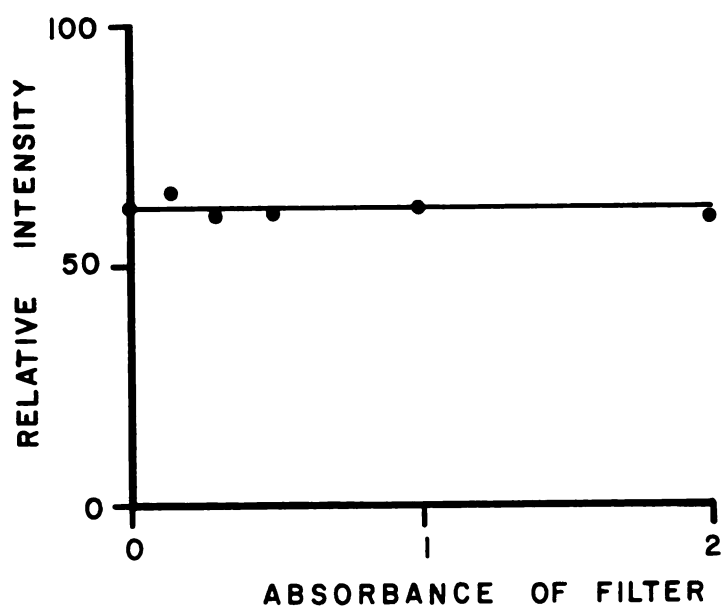


Figure 5-12. Intensity of First Derivative Signal vs Absorbance of Neutral Density Filter

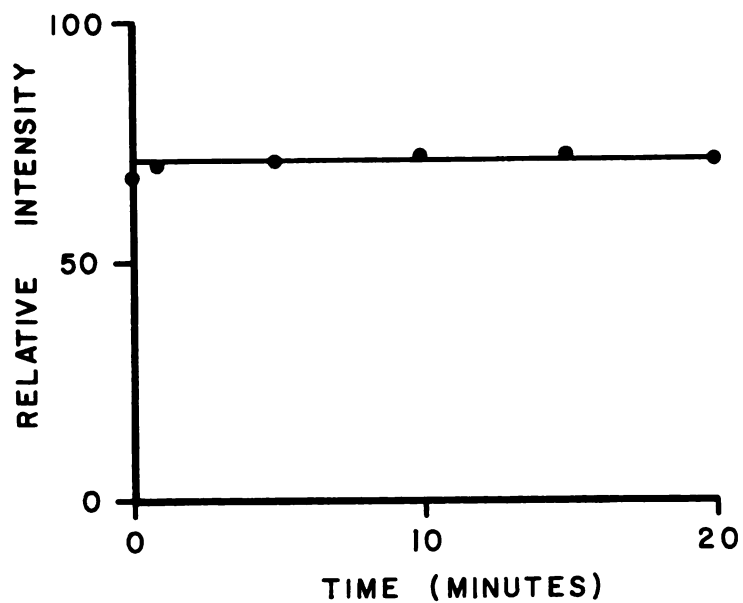


Figure 5-13. Intensity of First Derivative Signal vs Time During Sample Settling

C. Conclusions

Because of the multi-wavelength capability of the vidicon detector, successful implementation of the various dual-wavelength techniques on the vidicon spectrometer required only changes in the data processing software. No modifications were required in either the data acquisition hardware or software. Thus, the dual-wavelength techniques form powerful post-processing options that can be matched to specific data analysis requirements. This result is another excellent example of the power and versatility of the silicon vidicon tube as a spectroscopic detector in the UV-visible spectral region.

CHAPTER 6

COMPUTER SYSTEM ARCHITECTURE

A. Introduction

As microprocessor costs continue to fall and system designers become more familiar with them, microprocessors are being incorporated into many types of multiple processor systems (157-166). Advantages of multiple processor systems over single processors include higher throughput, improved real-time response, better system reliability, and modular expansion (158). At this point in time, however, the structures and organizations of multiprocessor systems have not been well defined. This is particularly true with respect to the implementation of multiple processor systems with the relatively new large-scale integrated (LSI) microprocessors. Current areas of research and development include task allocation, efficient use of system resources, sequencing and interaction between processors, and overcoming the physical and architectural limits of the microprocessors.

The first section of this chapter describes the logical development of a general purpose multiprocessor system based upon the Intel 8080A Microprocessor. The development of this system not only illustrates the increased system capabilities of a multiprocessor system over those of a single processor system, but also provides design guidelines for an efficient and modular multiprocessor system. The second part of the chapter describes the application of the multiprocessor system to the real-time control of the vidicon

spectrometer. In documenting the computer system used to control the vidicon spectrometer, specific examples of task allocation, efficient use of system resources, and utilization of the inherent bandwidth of available microprocessor static memory are provided.

B. Development of a Multiprocessor System

At the start of this research project it was not immediately obvious that a multiprocessor system was required for real-time control of the vidicon spectrometer. Rather, the need for a multiprocessor system slowly evolved during the design and specification of a suitable computer system for real-time instrument control. Although several single processor system configurations were considered, each one was subsequently rejected because of one or more performance limitations. Only the multiprocessor system was able to meet satisfactorily the design goals of standardization of design, software and hardware modularity, ease of expansion in both hardware and software, efficient use of system resources, and simplified programming.

1. Dedicated Minicomputer System

The first computer implementation considered was a dedicated minicomputer system (Figure 6-1). This system was based upon a Digital Equipment Corporation PDP 11/40 minicomputer with 32K of core memory. Standard peripherals include an extended instruction set (KE11-E), floating instruction set (KE11-F), Printronix Model 300 Line Printer (LP), Sykes Model 7250 Dual Flexible Disc Drive (FL), RK05 Decpack (DSC), and a Tektronix 4010-1 Computer Display Terminal (TRM). Also,

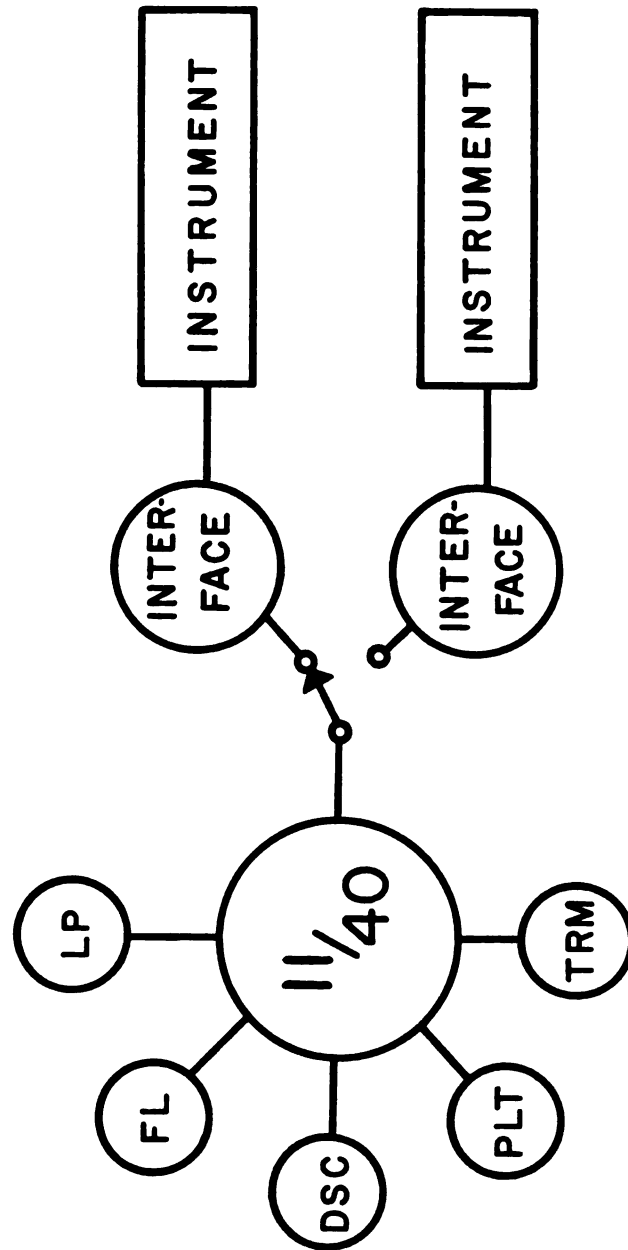


Figure 6-1. Dedicated Minicomputer for Instrument Control

a digital plotter (PLT) has been designed and interfaced to the minicomputer by workers in our laboratory (167). In this configuration one instrument at a time is operated through the minicomputer via its instrument-specific interface.

The dedicated minicomputer system does provide on-line real-time control of the instrument to which it is interfaced. While it is active, the instrument has the full attention of the minicomputer and its peripherals. There are, however, several distinct disadvantages to this system. Only one instrument can be active at one time. (Real time needs of instruments would be too demanding for time-share operation of the 11/40.) While the available response time and data acquisition speed capability of the mini may be used to service a specific instrument, effective use would not be made of the mini's computational capacity. Clearly, such a configuration seriously underutilizes the power of the mini and gives access to the peripherals only to the current user. A dedicated minicomputer system also requires an expensive minimal system, i.e. the minicomputer and its expensive peripherals, and different control logic for each subsystem. It also does not satisfy the design goal of modularity in software and hardware. As a result of these disadvantages, the dedicated minicomputer system approach was rejected.

2. Distributed System with Real-Time Microprocessor Control

The second system configuration that was considered is shown in Figure 6-2. In this system design a dedicated microcomputer is directly

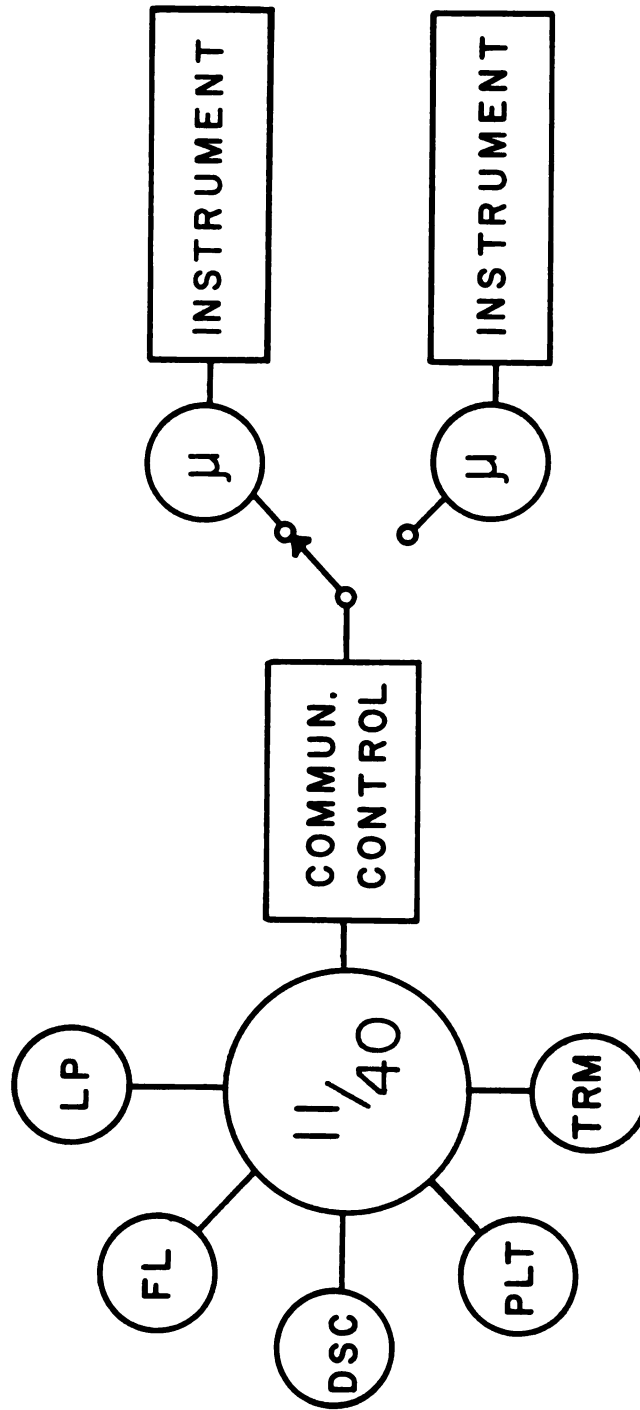


Figure 6-2. Dedicated Microcomputer for Instrument Control

interfaced to each instrument for localized real-time control. This configuration relieves the microsecond response requirement from the mini and, as a result, several instruments can be active at one time. Also, the minicomputer's expensive peripherals can be shared by several instruments in this configuration. A communication controller (99) is required to control the parallel communication link between the minicomputer and microcomputers and to resolve all bus conflicts.

Although this second system design is an improvement over the dedicated minicomputer system from the viewpoint of effective minicomputer utilization, it has several disadvantages with respect to instrument support. In the computer-controlled systems we are developing the microprocessor has to assume a variety of different tasks. This gives rise to two undesirable consequences; the interleaving of tasks makes hardware and software modularity difficult, and the microprocessor architecture (hardware and software) tends to mimic minicomputer architecture (i.e. large memory, advanced operating system, etc.) (159). Also, in those applications in which a fast minicomputer can barely keep up with the real-time control of an instrument, a single micro with its slower cycle time can not possibly maintain real-time instrument control. Consequently, this system configuration was also rejected due to the several obvious performance limitations.

3. Multiple Microprocessor System for Real-Time Control

The third and final system configuration that was considered is shown in Figure 6-3. In this design a multiprocessor system is used for real-time instrument control and data acquisition. This system is based on one "master" (coordinator) processor and two or more "slave"

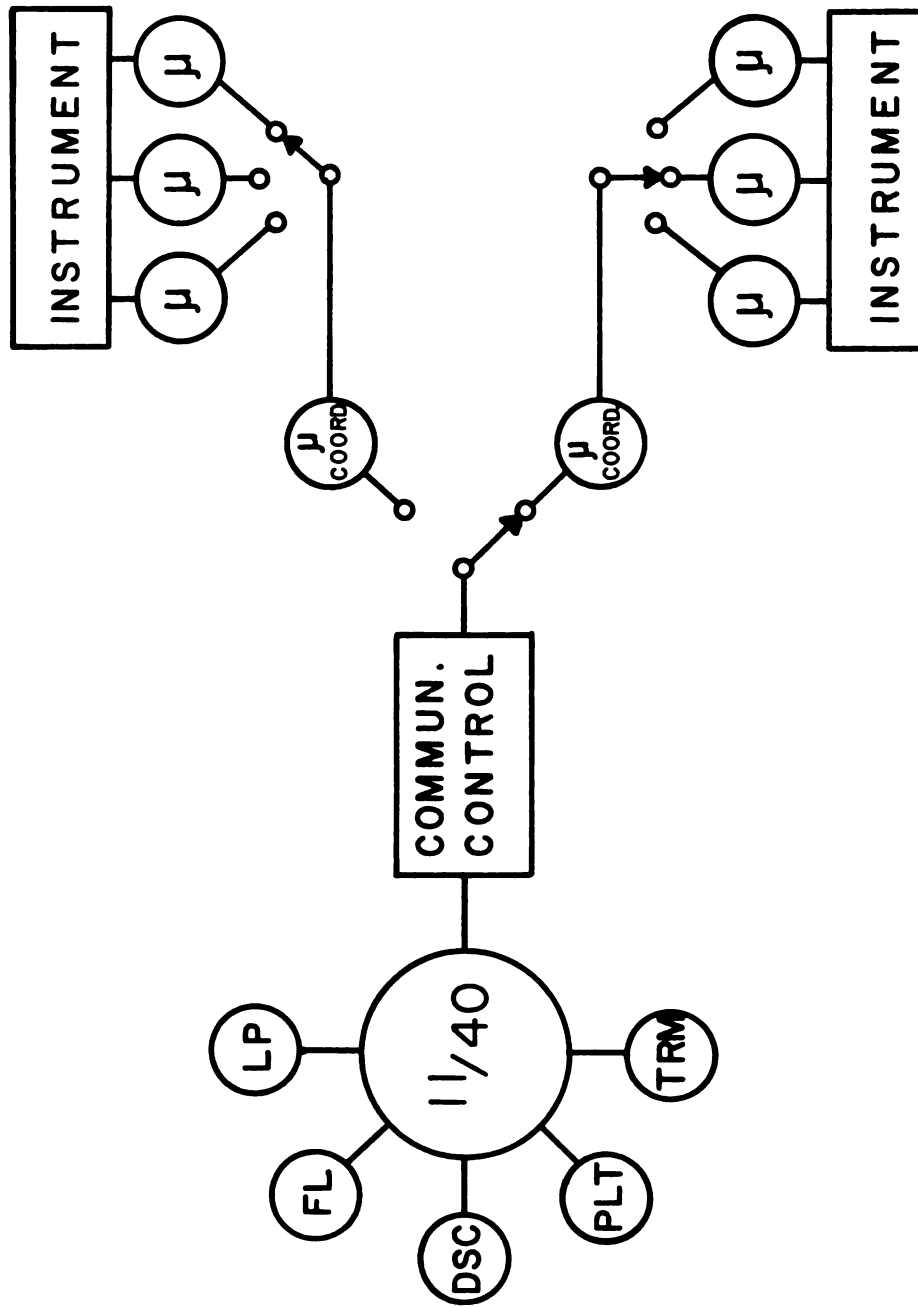


Figure 6-3. Distributed Multiprocessor System for Instrument Control

processors in a hierarchical relationship. The coordinator processor, which contains the system executive, controls or supervises the operation of the slave processors, which perform dedicated functions as part of the single partitioned system. This type of multiple processor system, often called a distributed system (157), uses a static allocation of tasks. Although a static allocation of tasks allows very simple, specialized program modules to be developed for each slave micro, this type of allocation requires that the tasks and their actions be known during system development so that the system processing load can be balanced.

One of the most powerful advantages of this system is its ability to execute logically divisible tasks simultaneously for subsequent correlation. This simultaneous execution of tasks significantly increases system speed and throughput. Other important advantages of the distributed system include standardization of design, modularity in both hardware and software, ease of expansion in both hardware and software, simplified programming, and the fastest possible response to multiple, asynchronous, real-time tasks (159).

The distributed system does have two major disadvantages. If the tasks and their actions are not fully known during system development, inefficient utilization of the processors and awkward segmentation of the system software can result. A second disadvantage of the static allocation of tasks is that the failure of any processor seriously degrades or even terminates system performance. The dedicated system can not dynamically shift tasks that have been assigned to a defective processor.

The advantages of the distributed system for real-time instrument

control far outweigh the disadvantages of the system. Consequently, this system was subsequently developed in our laboratory and applied to the real-time control of the vidicon spectrometer. However, before actually designing the system it was necessary to define the bus structure that would be used for system communication.

4. Interprocessor Communication

The majority of multiple processor systems that have been reported in the scientific literature have used a combination and/or modification of the five basic interconnection methods. These basic methods are the dedicated bus, multiporting, a single time-shared bus, multiple time-shared busses, and a crossbar matrix (157). Great care must be taken in selecting one of these bus structures for a particular application because the communication link used in a computer system is one of the most crucial factors affecting system performance.

The crossbar matrix is a method of connecting N active elements (processors and input/output elements) to M passive memory elements. Multiple simultaneous connections are possible if they are mutually exclusive. The main advantage of this structure is its high throughput. Unfortunately, the switch matrix that controls the $M \times N$ cross-points is necessarily complex, costly, and physically large. This structure also has a limited expandability because of the complexity of the switch matrix. The complexity and limited expandability of this structure eliminated it as a feasible communication link for our multiple processor system.

The multiported system uses multiple dedicated busses for communication. As illustrated in Figure 6-4, each passive element

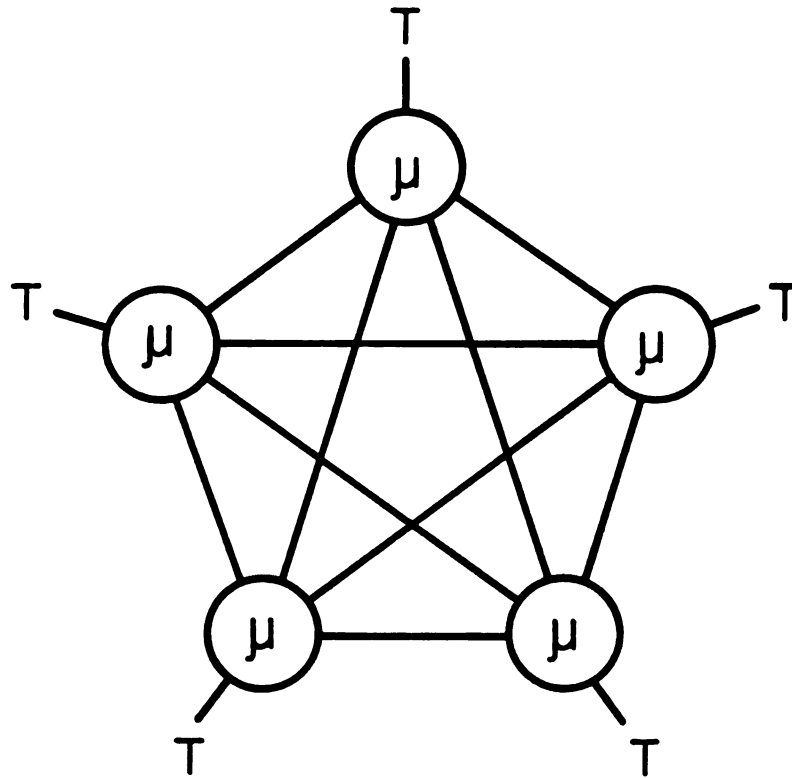


Figure 6-4. Multiported System

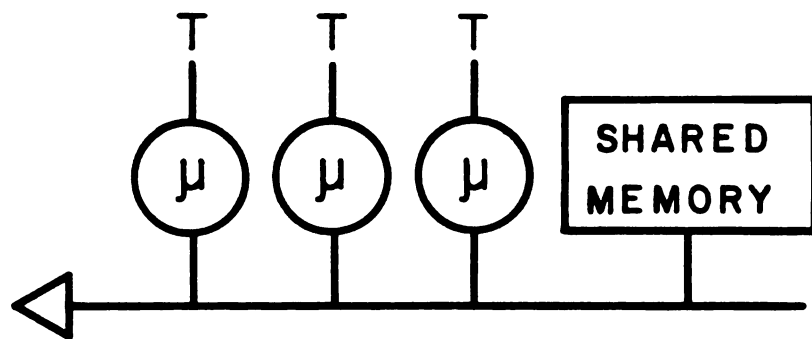


Figure 6-5. Single Time-Shared Bus System

(memory) has several ports, each tied to a different processor. Although the throughput of this arrangement is excellent, each passive device requires an arbiter to acknowledge requests from the multiple processing elements. In addition, the cabling and connector costs for a multiported system are large. The memory interface circuitry required also limits the expandability of this system. This system was rejected because of its complexity and cost. The multiple time-shared busses approach was also rejected for the same reasons.

In the single time-shared bus approach (Figure 6-5) the processors use common memory accessible on a common bus for instructions and data. Since the bus is a shared resource, an arbiter must be provided to resolve bus conflicts. The interference between processors requesting use of the bus is dependent upon the microprocessor instruction execution time, memory cycle time, and the number of processors sharing the bus. Advantages of a single time-shared bus include minimal interconnection costs and a high degree of modularity. Although it is very easy to expand this interconnection system, the addition of devices to the system bus increases bus contention. This increased bus contention and subsequent allocation overhead cause a corresponding decrease in individual processor throughput. Also, since the bus is the only data path in the system, a failure of the bus will result in loss of the total system. Consequently, this interconnection method was also rejected.

5. Dedicated Multiprocessor Bus System

A dedicated bus is either a permanent link between two devices or a bus used solely for one function (i.e. an address or data bus). It

is the least complex and easiest to configure of the five basic interconnection methods. Figure 6-6 illustrates an example of a dedicated bus system in which the bus serves as a communication link between the coordinator processor and the slave processors. In such a system each processor has its own local memory and can operate independently.

Figure 6-7 illustrates the dedicated bus system that was adopted for interprocessor communication in the multiprocessor system used to control the vidicon spectrometer. This method is a modification of the dedicated bus system in which the intercommunication bus is an extension of the coordinator's bus. A "bus switch" (98) is used to switch the local busses of the slave processors onto the coordinator's bus.

A block diagram of the multiprocessor bus system (Figure 6-8) shows the backplane bus (extension of the coordinator's bus) and three modules connected to the backplane; the coordinator and two slaves. The backplane bus includes a 16-line address bus, an 8-line data bus, and four control lines ($\overline{\text{MEMR}}$, $\overline{\text{MEMW}}$, DBIN, and RDY). In this system the slaves are fully functional microcomputers capable of independent operation; however, a user-defined portion of each slave's memory and task space resides in the address space of the coordinator. The coordinator thus has the capability to start and stop the slave processors, read and/or write status words to them, instruct them to begin execution of different portions of their resident programs, reprogram them, or even take complete control of a slave's memory and task.

If the coordinator wishes to take over control of the memory or task space of one of the slave processors, it simply sends the address

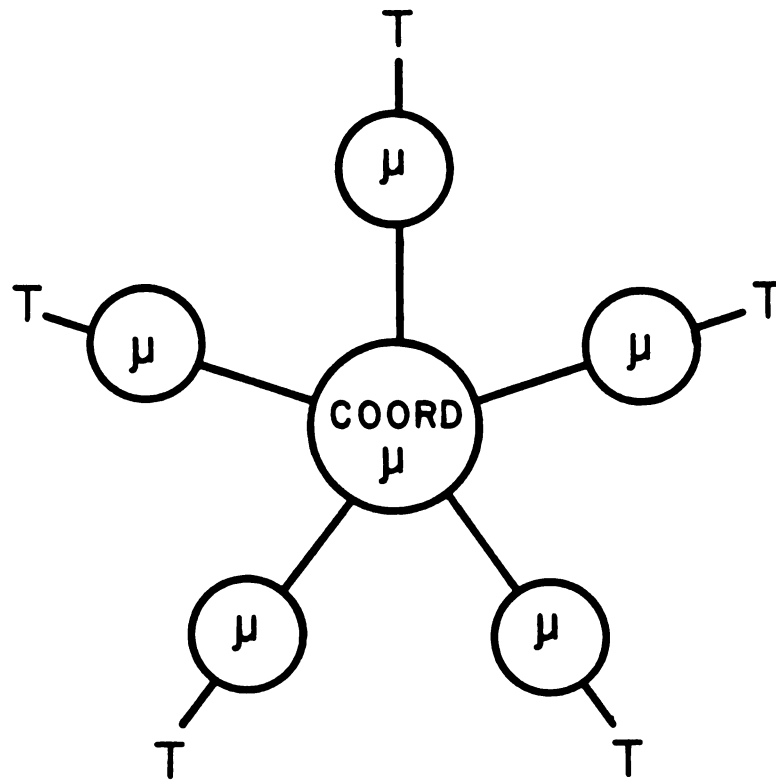


Figure 6-6. Dedicated Bus System

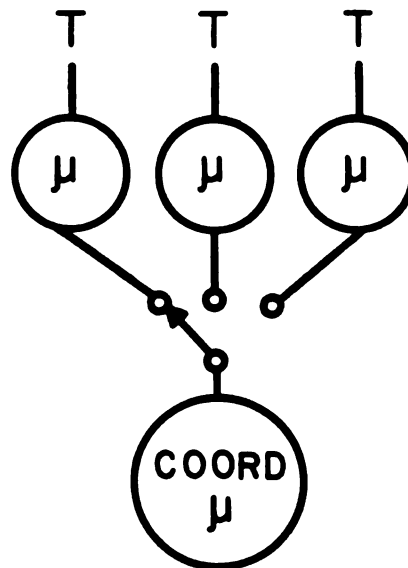


Figure 6-7. Dedicated Bus with Bus Switch

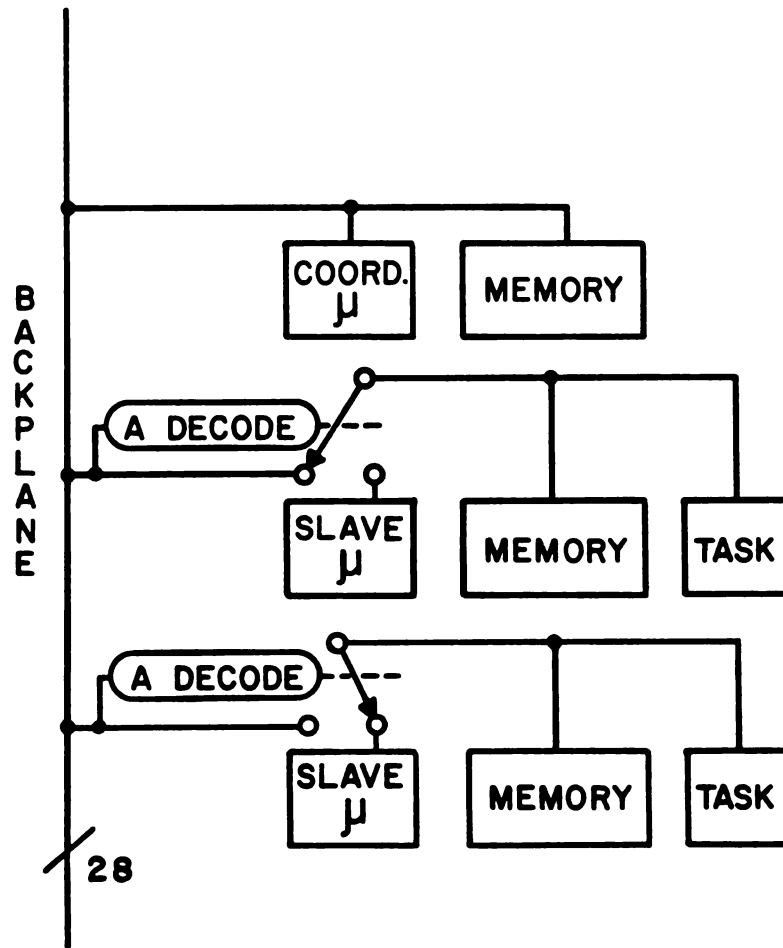


Figure 6-8. Block Diagram of Multiprocessor Bus System

of that slave's memory or task space down the backplane. The address decoding circuitry on the slave processor board recognizes its address and informs the processor that the coordinator desires control of the local bus. Upon completion of its current cycle, the slave processor goes on hold, and the address decoding circuit transfers (switches) control of the slave's bus to the coordinator. At this point the coordinator has complete control over the slave's memory and task. When the coordinator has finished with the slave's memory and task, it releases that address space and the address decoding circuit returns control of the memory and task to the slave.

This mode of communication works very well when communication between the processors does not need to exceed a speed of approximately 50 kilobytes/second, which is the maximum memory transfer rate achievable under processor (8080A) control. When faster communication is desired in the system, direct memory transfer (DMA) circuits must be used.

C. Multiprocessor Control of the Vidicon Spectrometer

As illustrated in Figure 6-9, the multiprocessor system has been used for real-time control of the vidicon spectrometer. This system requires three processors; a coordinator micro, and two slave micros. The coordinator micro supervises the operation of the slave processors and coordinates all activities in the multiprocessor system. The communication microprocessor at the top of the figure controls communication with the system peripherals; CRT monitor, ASCII keyboard, floppy disc, and communication link to the minicomputer. The vidicon

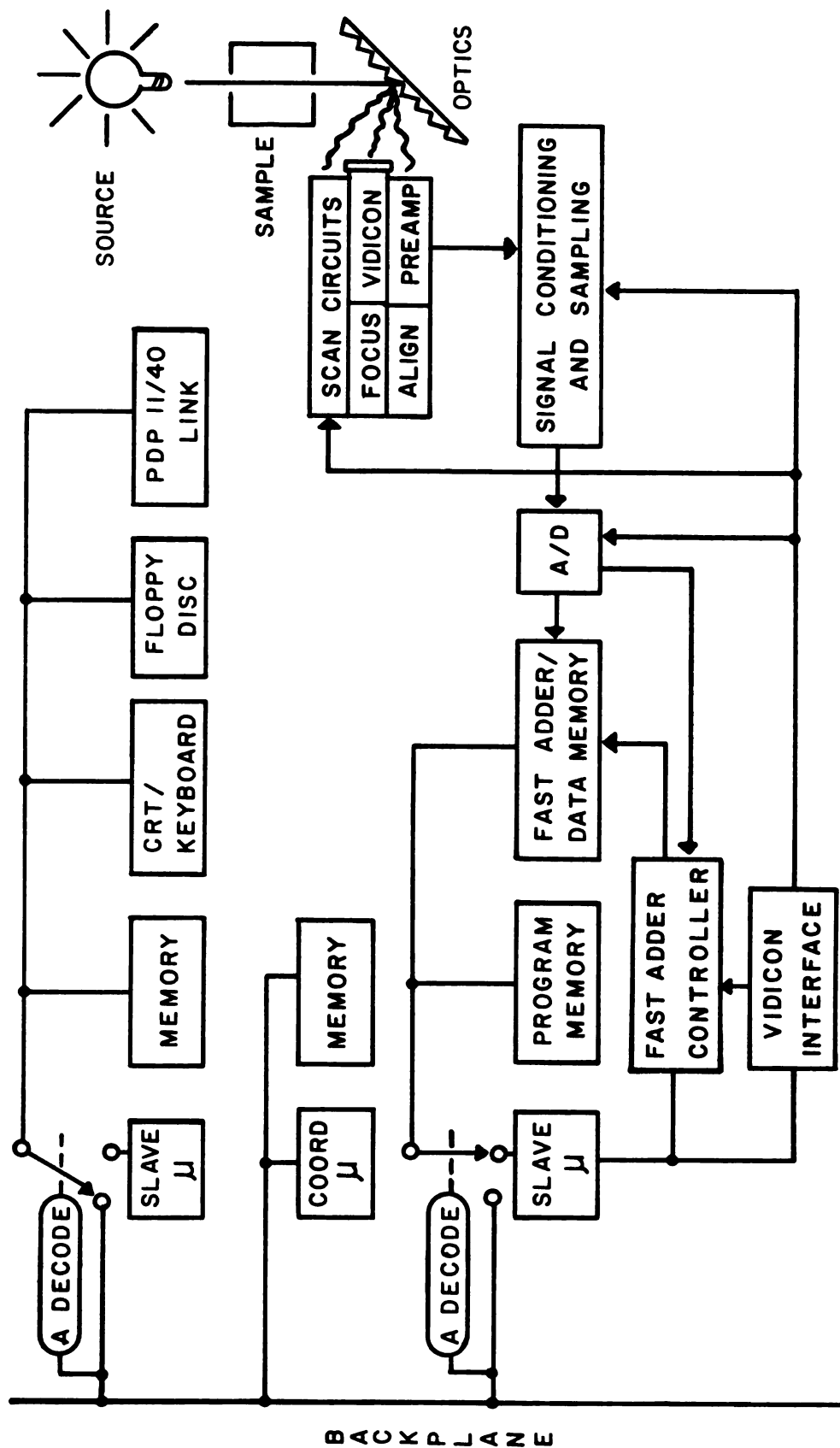


Figure 6-9. Block Diagram of Vidicon Spectrometer System

microprocessor at the bottom of the figure controls the spectrometer; monochromator wavelength drive, sample cell module, optical shutter, vidicon scan circuits, and the data acquisition system.

The three microprocessors and their dedicated I/O interfaces are contained in a standard BUD card rack (168). The card rack has 12 card slots with 58-pair connectors. A backplane was soldered to the lower 40 pair of connectors to buss them across the width of the rack. The upper 18 pair of connectors were not bussed, but instead were left open for wire wrapping. A typical micro card is a 6 x 8 inch double-sided wire wrap board with holes on 0.1 inch centers. A block diagram of a microprocessor board, the vidicon spectrometer, is included in Chapter 7. The rack power supply was built by the Michigan State University Electronics Shop (169).

All of the micros have their own local memory for the storage of data and task-specific program modules. In addition, a user-defined portion of the memory and task space of the two slave micros resides in the address space of the coordinator for control and communication. A new software package, CONVERS (100), was modified to run on a multi-processor system (98) and was subsequently used as the software operating system. The executive for this system resides in the coordinator micro.

The communication micro controls communication between the multi-micro system and the operator (CRT/keyboard), local bulk storage (floppy disc), and the 11/40. Memory mapping is used to interface these peripherals to the communication micro. The primary advantage of the memory mapping technique is that all instructions that operate on

memory locations can be used in I/O, i.e. the accumulator is not the only transfer medium in memory mapped I/O.

An Electronic Warehouse Model EW-100 ASCII Encoded Keyboard (170) provides operator input to the multiprocessor system. It is interfaced to the bus of the communication micro via an Intel 8212 8-bit I/O Port (174). The display system consists of a Ball 9 inch CRT Data Display (172), a Matrox MTX-1632SL 16 x 32 ASCII Character Video Random Access Memory for alphanumeric capability, and a Matrox MTX-256²-1 Graphic Display (171) for graphic capability. The two Matrox units interface directly to the micro bus as memory units. They provide composite video, TTL video, horizontal synchronization, and vertical synchronization outputs that can be used to drive a CRT display. The MTX-1632SL is a slave unit that uses the synchronization outputs from the MTX-256²-1 unit to ensure proper synchronization between the alphanumeric and graphic displays. The Persai Model 1070 Intelligent Diskette Controller (173), which is based upon a dedicated 8080 microprocessor, also interfaces directly to the communicator's bus. The diskette controller has a factory interface for the Model 270 Dual Diskette Drive (173) and a PROM-resident file management program that greatly simplifies use of the floppy disc unit for information storage and retrieval. Communication between the multimicro system and the PDP 11/40 is provided via a parallel link designed by S. Hourdakís (99). An MDB-1710 General Purpose Interface Module (175) was used to interface the communication link to the minicomputer.

The vidicon microprocessor at the bottom of Figure 6-9 provides real-time control fo the vidicon spectrometer, including;

GCA/McPherson Alternating Cell Module Model EU-721-11 (176),
GCA/McPherson EU-700 Czerny-Turner Monochromator (176), optical
shutter, vidicon scan circuits, and data acquisition system.
Documentation on the design details of the spectrometer circuits
are presented in Chapter 7. Chapter 3 presents an overview on
the routine operation of the vidicon spectrometer.

CHAPTER 7

DOCUMENTATION OF SYSTEM DESIGN

A. Introduction

The purpose of this chapter is to provide documentation of the design details of the electronic, mechanical, and optical components of the silicon vidicon spectrometer. This documentation may be used either to duplicate the instrument or to compare the results obtained with it to the results obtained with similar instruments. Additional documentation is included in Appendix B to aid in the repair or modification of the vidicon spectrometer.

An overview of the complete vidicon spectrometer system was presented in Chapter 6. In contrast, this chapter discusses in detail the vidicon slave micro, the electronic circuits used to control the vidicon scan format, and the data acquisition system. A block diagram of the vidicon circuits discussed in this chapter is shown in Figure 7-1.

B. Scan Control Micro

1. Introduction

The primary function of the scan control micro is to provide real-time control of the vidicon detector's scan format. This section describes the design of the scan micro and the scan circuits. Details of the micro's real-time clock and interrupt circuit, a dedicated microprocessor for number processing, and the shutter control circuit

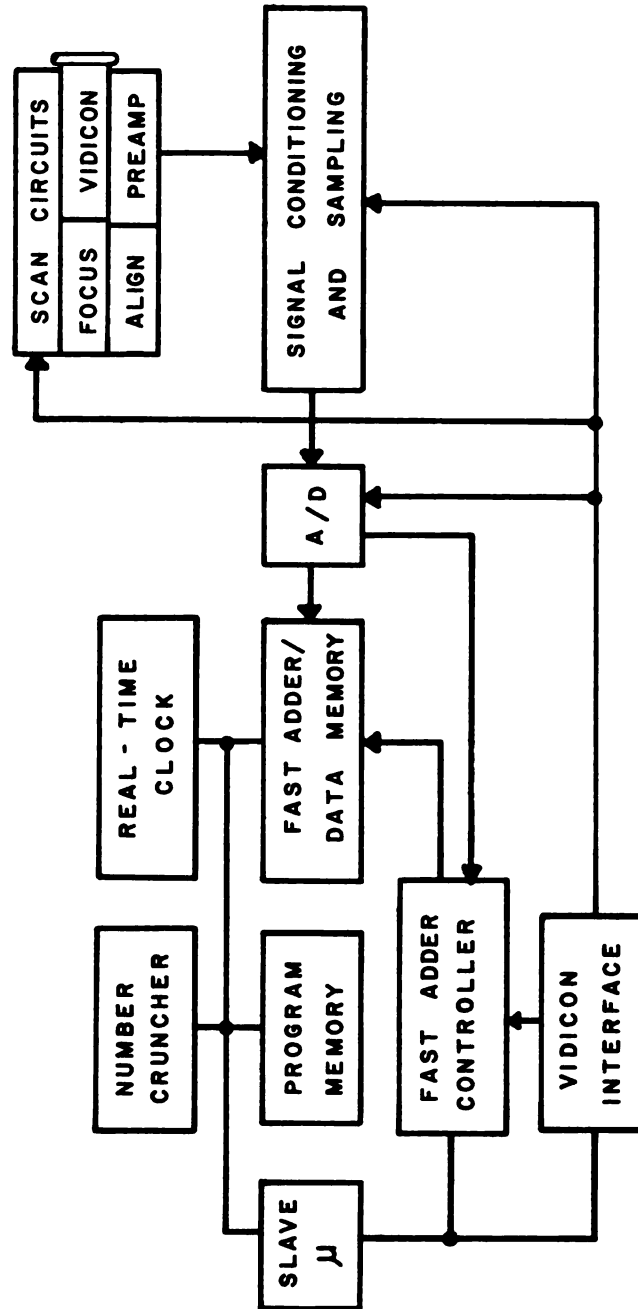


Figure 7-1. Block Diagram of Vidicon Control Circuits

are also included in this section.

2. Slave Micro Design

A block diagram of the scan control micro is shown in Figure 7-2. The basic micro consists of an Intel 8080A Microprocessor (single chip 8-bit N-channel microprocessor with 2 μ s instruction cycle time), 8224 Clock Generator (controlled by an 18.0000 MHz crystal), 8228 System Controller, and 2102A-4 Static RAM (1K x 1) (174). A bus driver is also required to interface the static memory's data out lines to the microprocessor's 8-bit bi-directional data bus.

In order to utilize the full 64K memory address capability of the 8080 microprocessor, an Intel 8205 1-of-8 Decoder (C1) was used to decode address lines A13-A15. When C1 is connected as shown in Figure 7-2, an active low signal that is exclusive in nature and that represents the value of the input address lines is available at one of the C1 outputs. Thus C1 provides eight 8K "chip selects". C2 is used to further decode the lowest 8K of memory space into eight 1K memory "chip selects" for the local memory (2102A-4 1K static RAM).

The control, data, and address lines on the left side of Figure 7-2 provide communication between the scan control micro and the coordinator micro. These signals originate from the coordinator micro and permit it to reset the slave micro, start or stop program execution, read or write status words to the slave, or even completely reprogram the slave micro.

Communication between the coordinator and the scan control micro involves the transfer of control of the slave's local bus to the

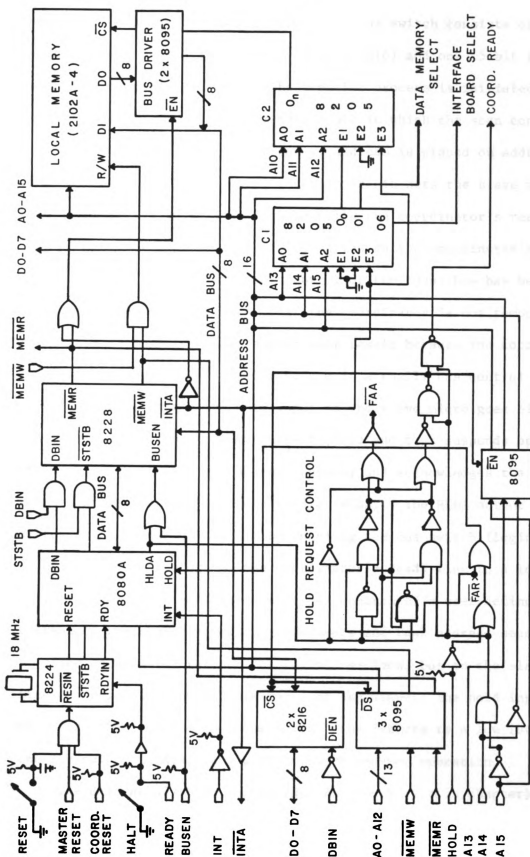


Figure 7-2. Vidicon Slave Micro

coordinator via the bus switch (98). The bus switch consists of one 8-bit bi-directional data bus driver (2 x 8216) and one 15-bit tri-state line driver (3 x 8095). The transfer process is initiated when the coordinator addresses the memory space in which the scan control micro resides. When the proper memory address is placed on address lines A13-A15, the hold request control circuit sets the slave micro's hold input (HOLD) to a logic '1' and pulls the coordinator's ready line (Coord. Ready) low (logic '0'). A low on the coordinator's ready line halts the coordinator until control of the local bus has been transferred to the coordinator. If the coordinator is not temporarily halted, an incomplete data transfer will result because the coordinator will start the data transfer before it actually has control of the slave's memory. After the hold input to the slave micro goes high, the slave micro completes its current cycle and then suspends operation, floats its data and address busses, and acknowledges the hold request by generating hold acknowledge (HLDA). The HLDA output completes the transfer of control by enabling the bus switch (logic '0' at $\overline{DS}$ and $\overline{CS}$) and returning the coordinator's ready line to a logic '1'. At this point the coordinator has control of a user-defined portion of the scan control micro's memory and task address space.

The coordinator returns control of the local bus to the slave micro by releasing the address space of the slave. The hold input to the micro then returns to a low level, HLDA returns to a low level, the bus switch is disabled, and the micro resumes operation.

The data acquisition system (see Section C of this chapter) can also generate a hold request to the scan control micro. Consequently,

the hold request control circuit was designed to accept only one hold request at a time. Once this circuit has latched a hold request, it will not recognize another request until the current one has been terminated and HLDA has returned to a low level. $\overline{FAA}$ is the hold acknowledge signal sent to the data acquisition system in response to a hold request. The lockout circuit is necessary because of the internal timing sequence of the 8080 microprocessor. Without this circuit HLDA from a previous hold request could pass control of the local bus to the requesting device at the same time that the scan control micro was resuming bus control. The result of such a conflict would be the logical 'AND' of information placed on the bus by the two bus controllers. This would lead to very unpredictable and undesirable results.

The control, data, and address lines at the top of Figure 7-2 ($\overline{STSTB}$, DBIN, $\overline{MEMW}$, $\overline{MEMR}$, DO-D7, AO-A15) and the READY and BUSEN control lines are used to interface the scan micro to the hardware front panel (see Appendix C). When it is connected to the micro, the hardware front panel provides the operator with complete hardware control of the micro and its peripheral circuits. This hardware control capability is important not only in testing the micro and its peripheral circuits during the construction phase, but also for later trouble-shooting of non-functional circuits.

3. Analog Scan Circuits

The analog scan circuits used in the vidicon spectrometer include the vidicon tube and deflection assembly drive circuits and their power supplies. The silicon vidicon tube (RCA C23246), deflection

assembly (Cleveland Electronics VYLFA-959), magnetic focus and alignment circuits, horizontal and vertical drive circuits, and the preamplifier are contained in a small aluminum box mounted directly to the front of the monochromator (Heath EU-700) with an XY translation stage (Newport Research Corporation Model 400). All circuits within this detector module are shielded from one another by 1/16 inch aluminum panels connected to chassis ground. Power for these circuits and for the vidicon tube is obtained through shielded cables from the power supply. The destination, voltage, and current requirements for the power supply are listed in Table 7-1. Design details of the power supply and the magnetic focus and alignment circuits are given in Appendix B.

The magnetic focus and alignment control circuits are adjustable current sources. These control circuits are controlled by potentiometers located inside the detector module. As the focus and alignment were observed to be quite stable with time, there is no need to readjust these controls once their settings have been optimized.

The vertical deflection drive circuit (Figure 7-3) is based on conventional television scan circuitry (177). Typical waveforms for this circuit are illustrated in Figure 7-4. The line sync input is derived from a crystal-controlled programmable clock. The line sync is buffered, differentiated, and applied to the base of the 2N3906 PNP transistor. The transistor is normally held in saturation, but the differentiated square wave momentarily brings it out of saturation. Flyback action of the 22 mH choke raises the resulting voltage pulse to approximately 50 volts peak-to-peak at the transistor collector. This

Table 7-1. Analog Power Supply Requirements

Destination		Voltage	Current
Tube pin 1	Heater	+6.3 V	+0.1 A
2	Grid 1, beam current	-38 V	
3	Grid 4, decelerator	+340 V	
5	Grid 2, accelerator	+300 V	
6	Grid 3, beam focus	+290 V	
7	Cathode	-8 V	
8	Heater	0 V	
Tube target flange (target bias)		0 V	
Magnetic focus		+24 V	+45 mA
		-24 V	-45 mA
Alignment		+15 V	+90 mA
		-15 V	-90 mA
Vertical deflection circuit		+5 V	+250 mA
		-40 V	-0.5 A
Horizontal deflection circuit		+15 V	+0.5 A
		-15 V	-0.5 A
Preamplifier		+15 V	+200 mA
		-15 V	-200 mA

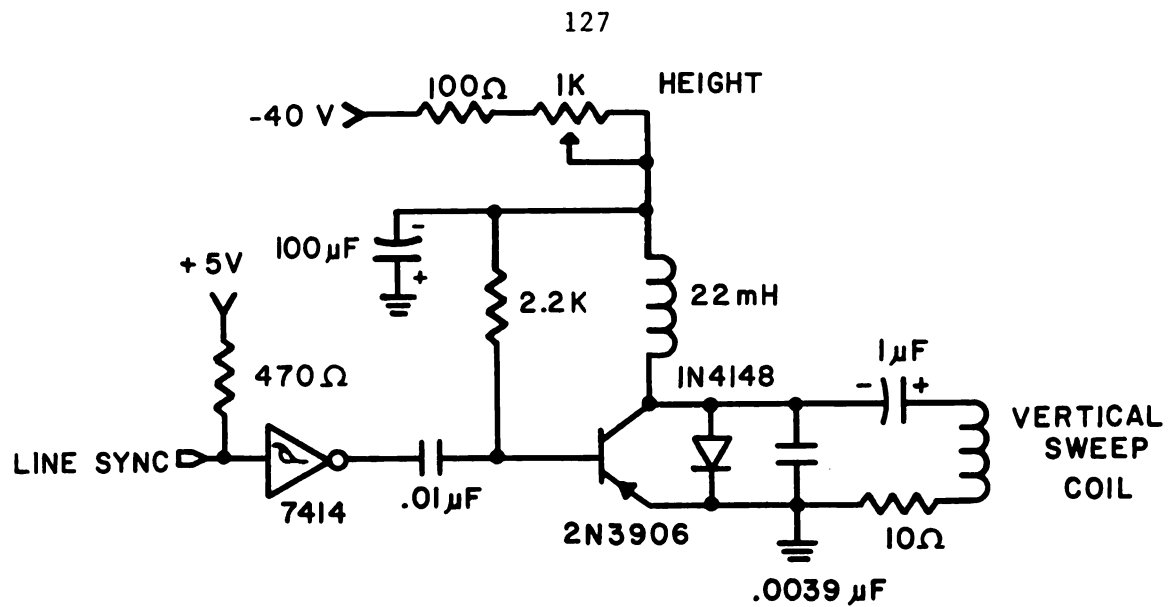


Figure 7-3. Vertical Deflection Drive Circuit

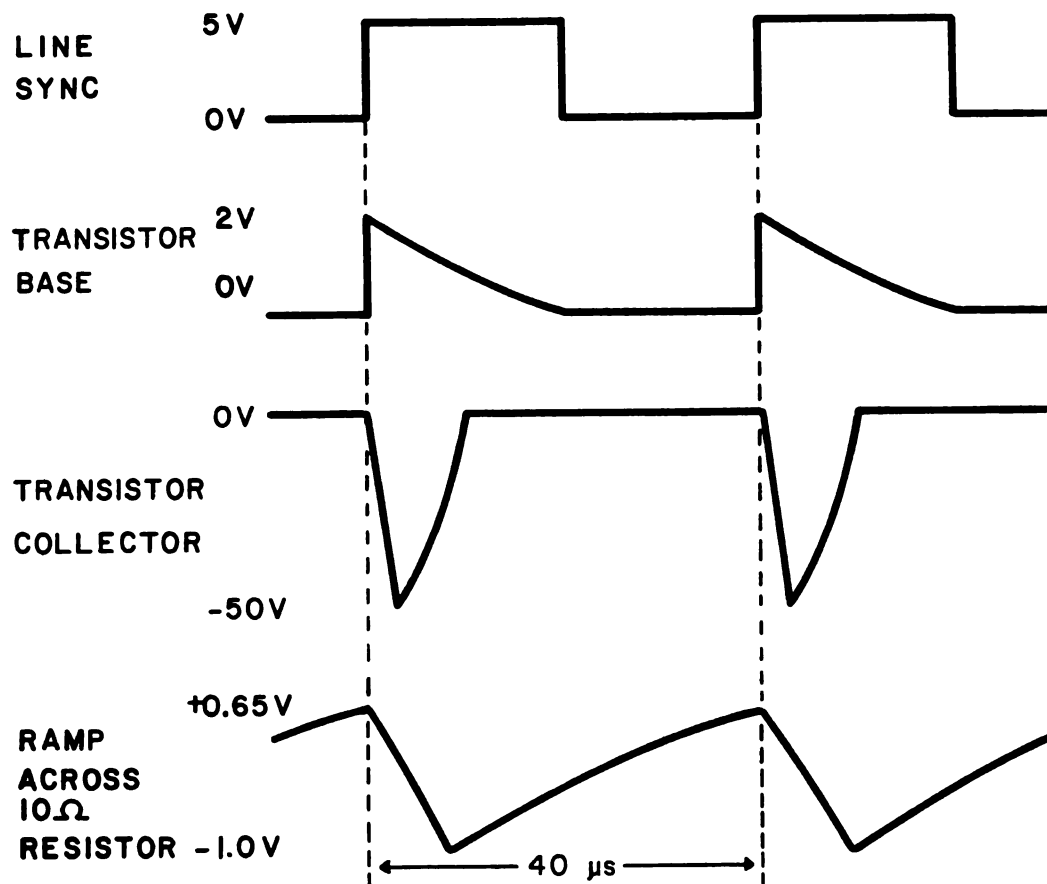


Figure 7-4. Vertical Deflection Circuit Waveforms (25 kHz)

voltage pulse is applied to the vertical deflection coil through the 1 μF capacitor. The coil requires a pulse waveform of this type to generate a current ramp through its windings because of its inductive reactance. The 1N4148 diode serves as a conventional damper, while the 0.0039 μF capacitor is used as a coil ringing capacitor. The 10 Ω sense resistor is used to monitor the current ramp through the coil. This current ramp does not need to be linear; however, it must be consistent from line to line.

The horizontal deflection drive circuit (Figure 7-5) drives the scanning electron beam to the selected wavelength channels of interest. Consequently, it must be both linear and reproducible. In order to obtain a linear current ramp through the deflection coil, the coil was included in the feedback loop of a National Semiconductor LH0042 operational amplifier. A Burr-Brown 3553 buffer amplifier was used to increase the coil drive capability of the circuit. Current sensing was provided by placing a 10 Ω resistor in series with the coil, while a 1 k Ω resistor in parallel with the coil suppressed coil ringing. A 0.1 μF feedback capacitor was used to compensate for reactive loading of the amplifier by the coil. This drive circuit produces a linear current ramp through the coil at frequencies up to 1 MHz. Two potentiometers are included for adjustment of the amplitude and centering of the deflection waveform. Typical waveforms for this circuit are shown in Figure 7-6.

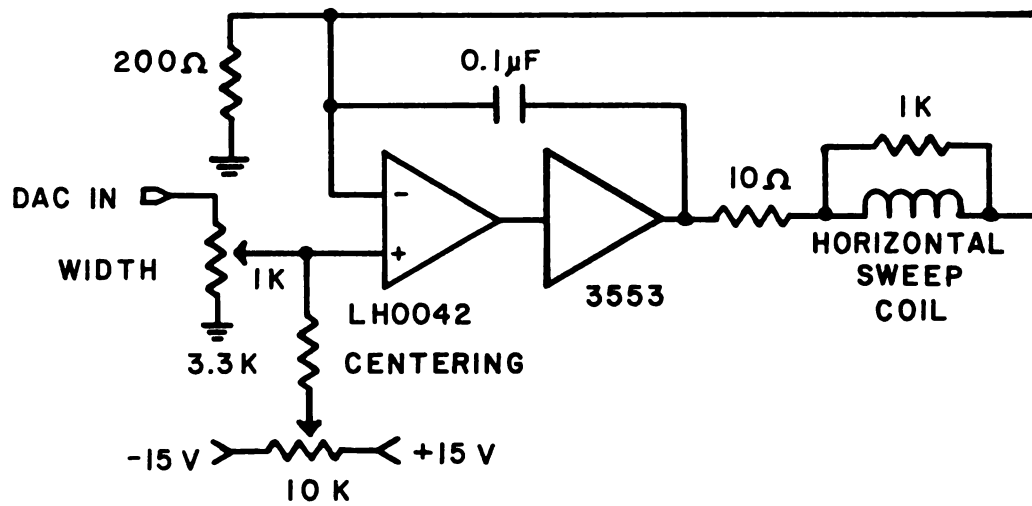


Figure 7-5. Horizontal Deflection Drive Circuit

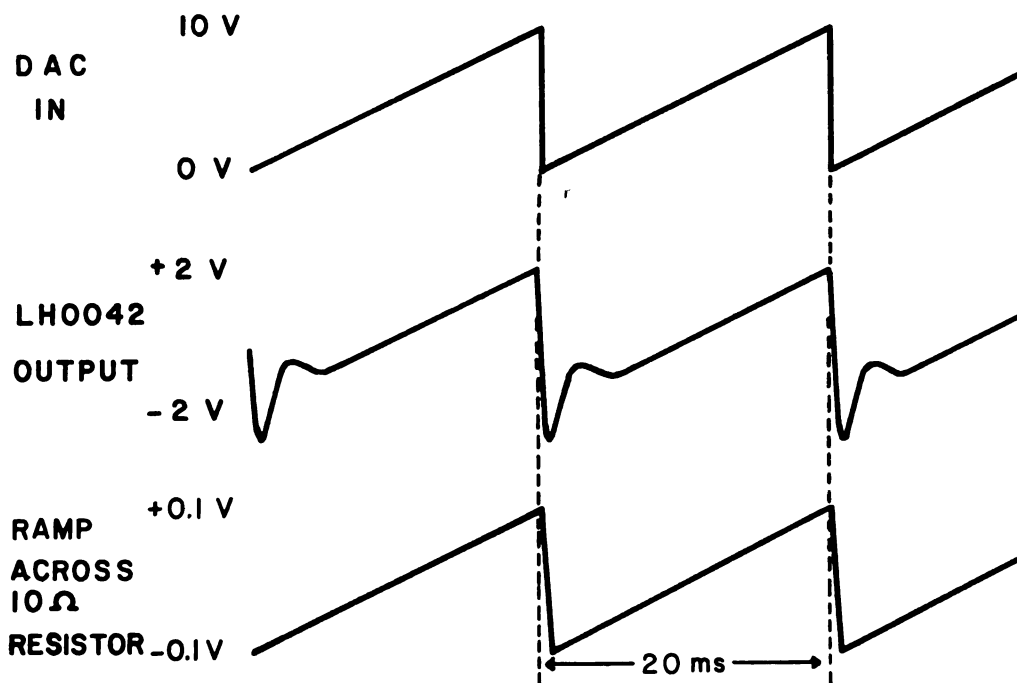


Figure 7-6. Horizontal Deflection Circuit Waveforms (25 kHz)

4. Digital Control and Interface Circuits

The control and interface circuitry consists of the horizontal (wavelength) and vertical (intensity) deflection circuits. These circuits not only control the scan format of the vidicon detector, but also provide timing signals to the data acquisition circuits.

The vertical deflection circuit (Figure 7-7) generates the line sync signal, which is the basic timing and synchronization signal for the vidicon detector. The line sync is derived from a 10 MHz crystal-controlled oscillator and a digital prescaler. This prescaler consists of a programmable $\div N$ counter (for N from 1 to 256) and a $\div 10$ counter. The prescaler thus generates two output waveforms, line sync and $\times 10$ line sync. Line sync provides the clocking waveform to the vertical deflection drive circuit (Figure 7-3) and the horizontal deflection circuit (Figure 7-8). It also initiates the timing sequence that controls the sample conditioning and sampling circuits (Figure 7-12). The $\times 10$ line sync waveform provides 10 clock pulses per line sync pulse.

A new vertical scan trace is initiated by the rising edge of line sync. This rising edge enables the count-down input to the $\div N$ delay counter by setting the Q output of FF1 to a logic '1'. When the counter is enabled, it counts a preselected number of $\times 10$ line sync pulses and then underflows. The borrow output (B) disables the counter input by clearing FF1, reloads the counter, resets the integrator by clearing FF2, and triggers delay monostable MS1. The output of MS1 sets flip-flop FF3. FF3 enable the integrator and the count-down input to the $\div N$ integrate counter. This counter counts a preselected number of $\times 10$ line sync pulses and underflows. The borrow output of the integrate

Figure 7-7. Vertical Deflection Circuit

counter disables the counter input by clearing FF3, reloads the counter, and triggers delay monostables MS2 and MS3. MS2 generates a 50 ns pulse that initiates an A/D conversion. MS3 provides a 200 ns delay before MS4 discharges the integrator by setting flip-flop FF2. This circuit not only allows the computer to select the scan frequency, but also allows it to specify the vertical interval that is to be integrated during the data acquisition process.

The line sync signal is also gated with two other signals, line sync inhibit and selective readout. These signals are used in the random access mode of target interrogation. In this mode the computer interrogates only those wavelength channels of immediate interest by inhibiting the oscillator-based line sync, positioning the readout beam at the desired wavelength channel, and generating a line sync pulse by pulsing the selective readout line. Although the circuits have been designed to permit random access scanning, this mode has not been implemented because of the slow cycle time of the 8080A microprocessor.

The wavelength deflection circuit (Figure 7-8) generates an analog output that is used by the horizontal deflection drive circuit to drive the electron beam to the wavelength channel of interest. This circuit consists of a hardware adder circuit with programmable increment and a high speed D/A converter (Datel DAC-12HYBC high speed 0 to +10 V converter with a 300 ns current settling time). Although the D/A converter has an internal amplifier for voltage output, an external high speed operational amplifier (Datel AM-100 fast settling FET OA with 400 ns settling time) was used to achieve a faster settling time. Either the 12-bit output of the adder circuit or a 12-bit random

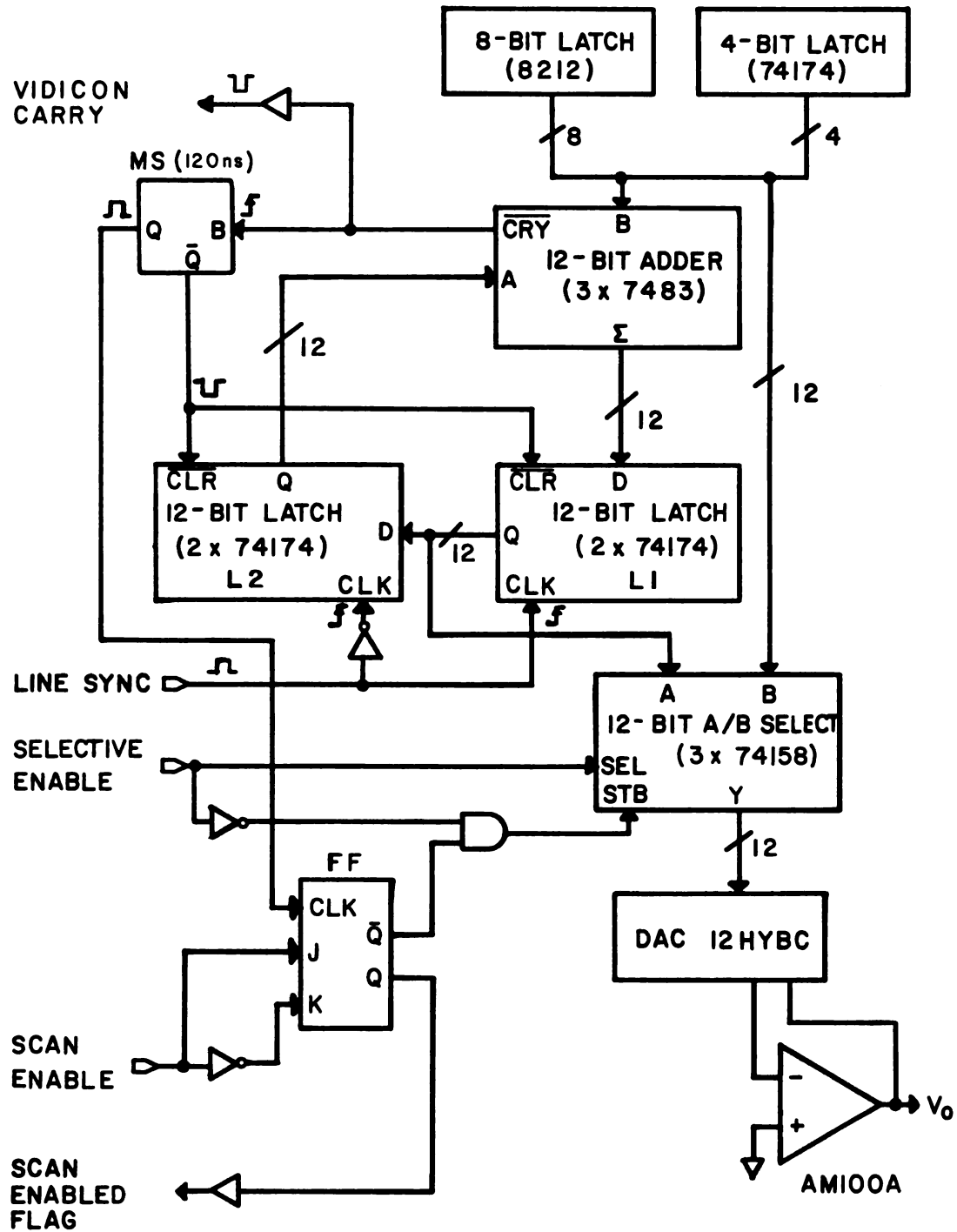


Figure 7-8. Horizontal Deflection Circuit

access address determines the wavelength channel to which the beam is deflected. A logic '1' applied to the selective enable input enables the random access mode of scanning. The number of wavelength channels per scan is $4096/N$, where N is the 8-bit programmable increment.

The hardware adder circuit is clocked by the line sync signal from the vertical deflection circuit. The rising edge of line sync causes latch L1 to latch the 12-bit output of the adder. The output of L1 is connected to latch L2 and a 12-bit 2-to-1 multiplexer. The falling edge of line sync causes latch L2 to latch the output of L1 and apply it to the hardware adder. The adder adds the output of L2 to the programmable increment and applies the sum to L1. Thus the wavelength address is updated every line sync until the adder overflows. When the adder overflows, the adder carry pulse clears latches L1 and L2 (resets the wavelength), sends a scan completed signal (vidicon carry) to the computer, and triggers monostable MS. This monostable generates a scan synchronization pulse that clocks the scan enable flip-flop (FF). If scan enable is a logic '1' when the flip-flop is clocked, the DAC input is enabled. If scan enable is not a logic '1', then the DAC input is disabled (set to 0 volts). This scan enable control is necessary to synchronize data collection with wavelength scanning after the readout beam has been disabled and blanked during charge integration. A scan enabled flag signals the computer when the wavelength deflection circuit is enabled.

5. Real-Time Clock and Interrupt System

A versatile real-time clock and interrupt system (Figure 7-9) has been designed for the 8080A microprocessor to allow accurate interval timing. This system features a flexible time base, hardware or software triggering of the clock, and vectored interrupts.

The real-time clock consists of a Mostek 5009P Counter Time-Base Circuit (178) and the Intel 8253 Programmable Interval Timer (179). The counter time-base serves as a programmable prescaler with frequency division ranges from 1 to 36×10^8 . The interval timer has three programmable 16-bit counters, one of which is used as the real-time clock. The count-down sequence of this counter is initiated by either a hardware or software trigger pulse. The clock input to the real-time clock circuit is a 1 MHz square wave signal derived from the crystal-controlled 2 MHz micro clock signal (ϕ_{2TTL}).

At the end of the timing interval, the borrow output of the interval timer sends an interrupt request to the priority interrupt controller by clocking flip-flop FF1. If the interrupt system has been previously enabled, the controller will generate an interrupt if the priority of the requesting signal is greater than the priority in a software-controlled status register. The interrupt controller also issues vector information along with each interrupt to identify the service routine. Requesting level priorities are assigned by the designer. $\overline{R7}$ is the highest priority input to the 8214 and $\overline{R0}$ the lowest.

The vidicon carry output from the wavelength deflection circuit also generates an interrupt request by clocking flip-flop FF2. This

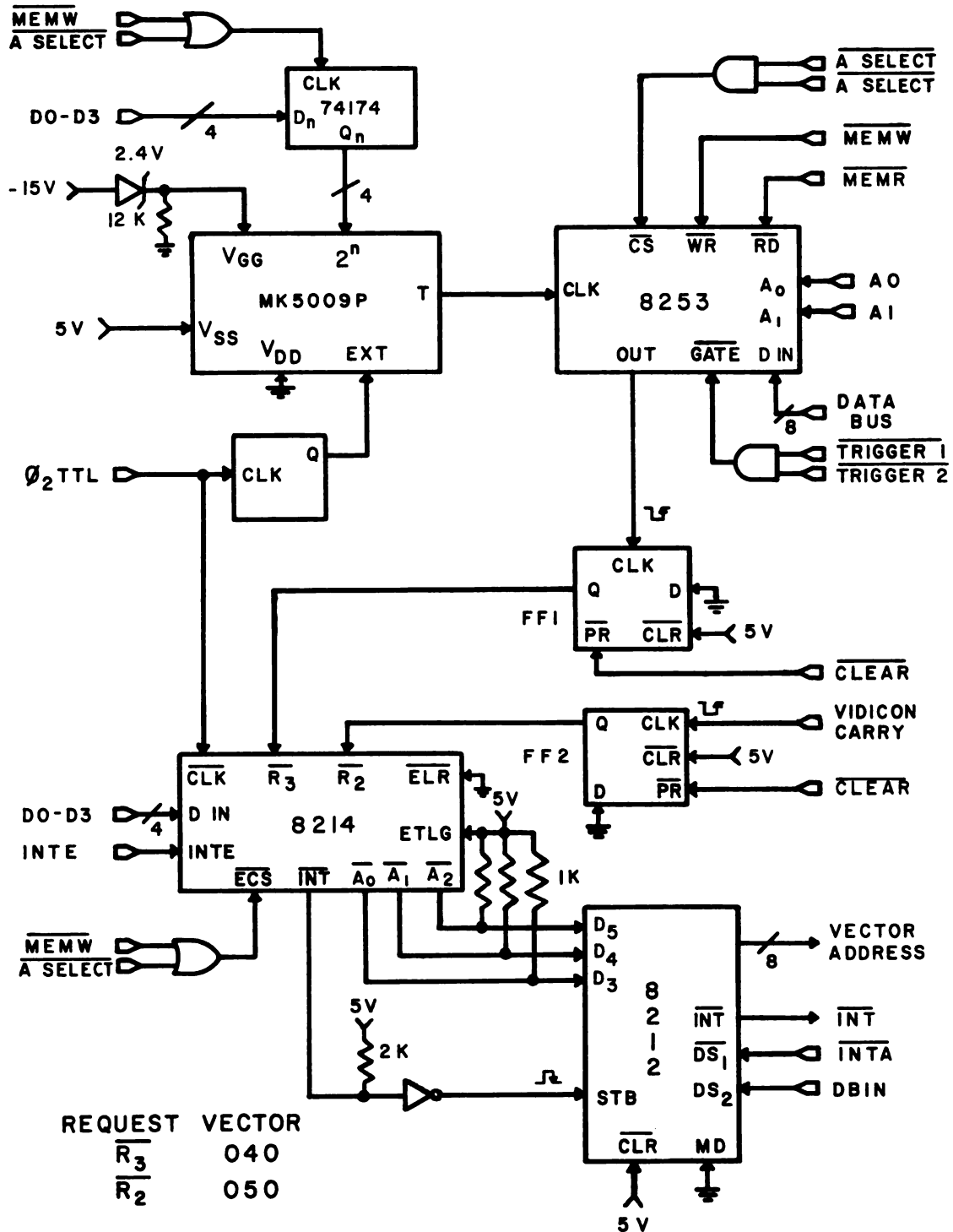


Figure 7-9. Real-Time Clock and Interrupt System

interrupt request is generated at the completion of each frame. The vidicon carry interrupt request has a lower priority than the interval timer so that it may be disabled without affecting interrupts from the timer. Thus the micro can use either vectored interrupts or software polling of the scan completed flag (see Appendix B) to count the number of scans completed during signal averaging.

6. Dedicated Microprocessor for Number Processing

The National Semiconductor MM57109 MOS/LSI Number-Oriented Microprocessor (180) is used in this microprocessor system for number processing applications in place of user-written number processing software. Figure 7-10 shows the interface circuit used to interface the 57109 to the 8080A bus as a peripheral device.

Although the 57109 is a MOS device, all but two of its signal inputs (HOLD and POR) will respond properly to TTL logic levels if the processor is operated from supplies of +5 V and -4 V. The two non-TTL compatible signal inputs are driven by RCA 3140 operational amplifiers. These amplifiers are used as comparators to convert TTL logic levels to MOS compatible levels. A logic '1' applied to the POR input resets the processor. A logic '1' applied to the HOLD input halts the processor. This input must be high when the ready line (RDY) goes high unless a 6-bit instruction is present in the instruction latch (L1).

Prior to using the 57109, the microprocessor first resets the cruncher (microprocessor refers to the 8080A - cruncher refers to the 57109). When it is ready to input a 6-bit instruction the cruncher sets the ready flag (INRDY). The microprocessor then writes an

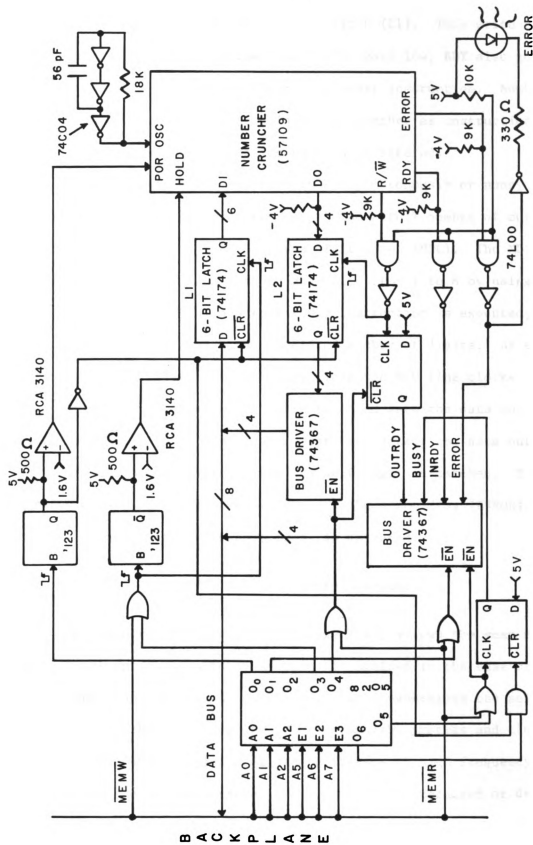


Figure 7-10. Interface for 57109 Number-Oriented Processor

instruction into the 6-bit instruction latch (L1). This write cycle also pulses the HOLD input low. When HOLD goes low, RDY also goes low and the cruncher reads and performs the 6-bit instruction. Numbers are entered one BCD digit at a time into the cruncher as instructions. When INRDY goes high the next instruction is entered.

Although data can be entered either synchronously or nonsynchronously, they are output synchronously. The actual number of output digits is determined by the mantissa digit count (MDC). The MDC is initially 8, but it can be set to any value from 1 to 8 by using the SMDC instruction. When an output (OUT) instruction is executed, the cruncher sequences through the specified number of digits. As each digit is output on the data out (DO) lines the $R/\overline{W}$ line clocks the digit into a 6-bit data output latch (L2) and sets the data out ready flag (OUTRDY). The microprocessor must then detect the data out flag and read the latched digit before the next digit is latched. Time between digits is approximately 140 μ s. The error flag (ERROR) is set high if an arithmetic or output error is detected.

7. Shutter Control Circuit

The shutter control circuit (Figure 7-11) allows the scan micro to control the optical shutter. A logic '1' applied to the base of the 2N6043 NPN transistor turns on the transistor, energizes the solenoid, and opens the shutter. A logic '0' reverses the process and closes the shutter. The 400 Ω resistor eliminates bursts of high frequency noise that had been observed whenever the solenoid was energized or de-energized. The 40 V zener diode protects the transistor from harmful voltage transients. The solenoid is mounted inside the sample compartment

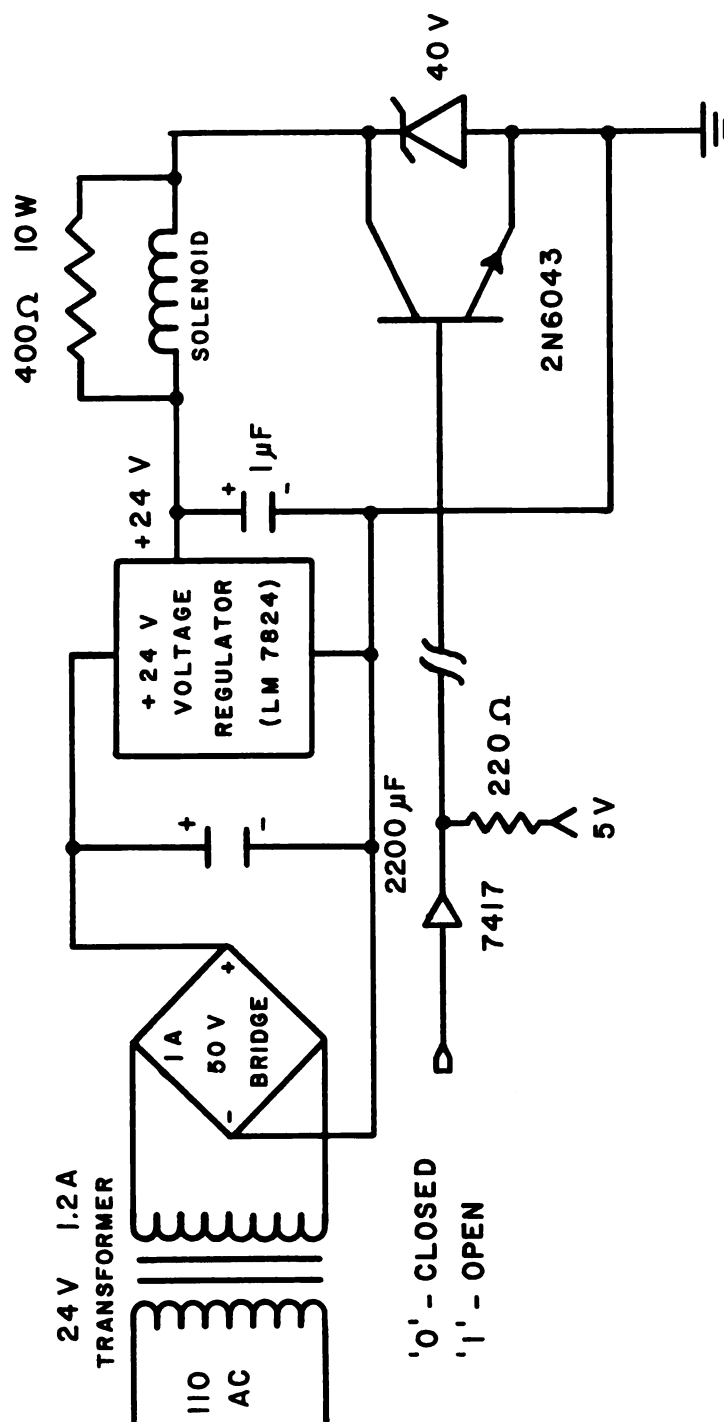


Figure 7-11. Shutter Control Circuit

of a Health Alternating Cell Module Model EU-721-11 and is attached directly to the shutter.

C. Data Acquisition System

1. Introduction

The data acquisition system for the vidicon spectrometer consists of the analog conditioning and sampling circuits, hardware adder for signal averaging, and the digital control circuits. The design details of these circuits and the timing of a data acquisition cycle are discussed in this section.

2. Analog Conditioning and Sampling Circuits

The analog conditioning and sampling circuits are illustrated in Figure 7-12. The preamplifier consists of a current-to-voltage converter (OA1) with a measured 3dB point of 88 kHz and a x10 buffer amplifier (OA2 and OA3). The buffer amplifier produces a video signal capable of driving the 100 Ω twisted-pair shielded cable connection to buffer amplifier OA4 on the signal conditioning and sampling board. The preamplifier is located in a small aluminum box with the vidicon tube, deflection assembly, and drive circuits (see Section B.3.). It is connected to the vidicon target by a 4 cm length of 50 Ω coaxial cable. The length of this connection was minimized because of the high speed and low level of the vidicon detector video output.

The signal conditioning and sampling board is located in the micro rack (see Chapter 6). It consists of a buffer amplifier (OA4), integrator (OA5), sample-and-hold amplifier (Datel Model SHM-IC-1

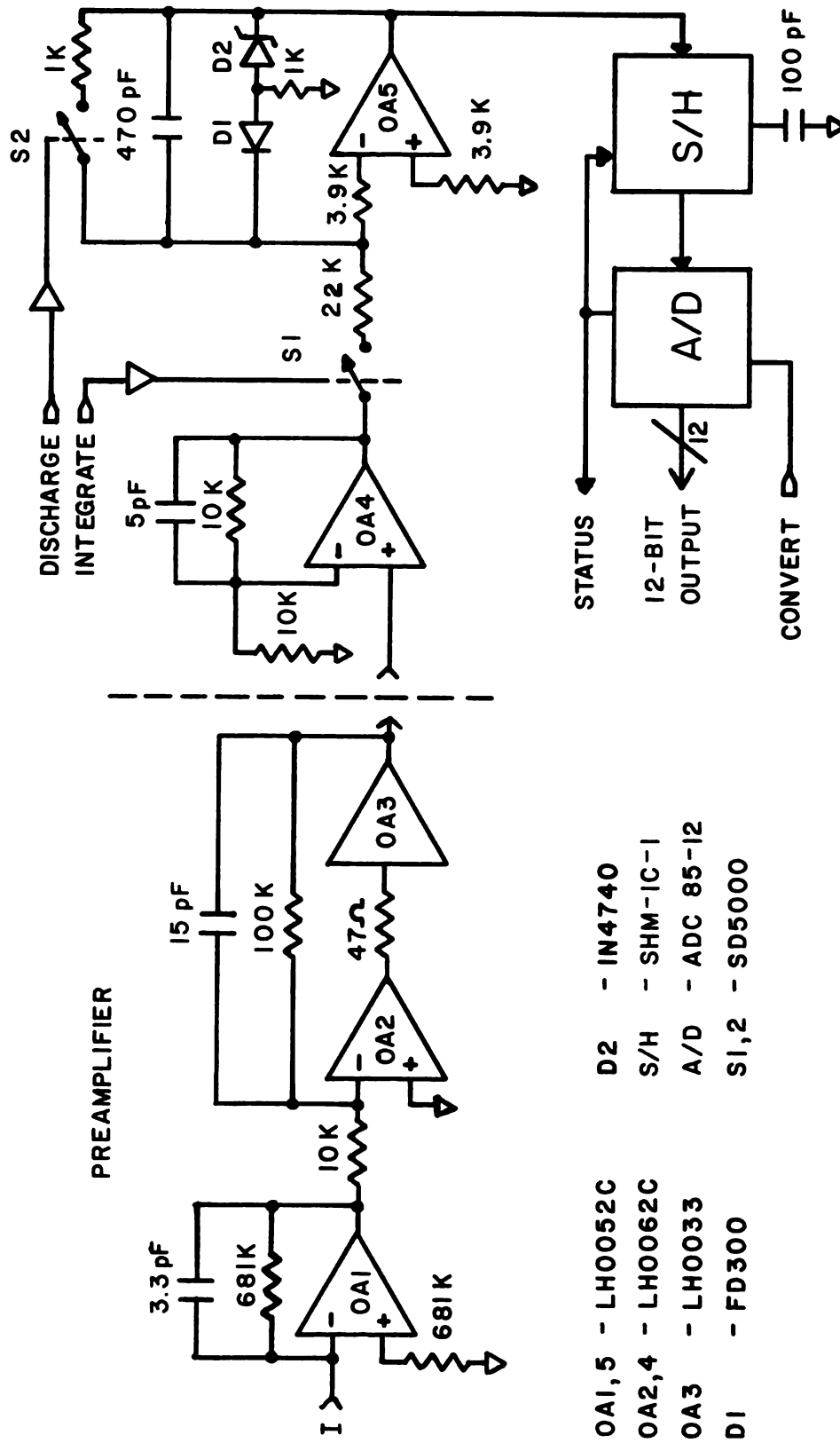


Figure 7-12. Analog Conditioning and Sampling Circuits

integrated circuit sample and hold with an acquisition time of 2 μ s and a hold mode droop of 500 mV/s), and 12-bit analog-to-digital converter (Burr-Brown ADC85-12 12-bit successive approximation A/D converter with 10 μ s conversion speed). The integrate, discharge, and convert commands are generated by the data acquisition control circuit (see Section C.4.).

The 1 k Ω resistor in series with the discharge analog switch (S2) protects the switch from damage by limiting the discharge current. Diodes D1 and D2 limit the integrator output to +10.6 V. D1 is included because of its very low leakage current when off (1 nA). It also ensures that the diode loop is open under negative input conditions, although this condition should never occur. The 1 k Ω resistor between the two diodes keeps the anode of the switching diode (D1) near ground unless the zener diode (D2) is conducting. This resistor thus maintains the low leakage current advantage of the switching diode. Without this resistor, leakage current from the zener diode could turn on the switching diode. The 3.9 k Ω resistor at the inverting input of the integrator (OA5) protects the amplifier input from discharge transients.

3. Digital Control Circuits

This section describes the design details of the digital circuits that control data acquisition and signal averaging in the vidicon spectrometer. Because of its slow cycle time the 8080A microprocessor is unable to directly control the transfer of data into memory during a data acquisition cycle. Consequently, a direct memory access (DMA)

controller circuit was developed for data acquisition and signal averaging. This controller circuit uses the Hold feature of the 8080 to acquire the system bus and generates the control signals required to allow the hardware adder to access or deposit data directly from or to memory. The controller uses the ϕ_2 (2 MHz TTL) clock of the 8080 system for timing so that individual memory read or write cycles require only 500 ns.

The fast adder (F.A.) controller circuit (Figure 7-13) is the hardware sequencer for the DMA data acquisition system. Prior to the start of data acquisition, the microprocessor loads the 4-bit byte count (# bytes of precision - 1) latch and the 16-bit starting memory address latch. The micro then sets the start scan (1 bit in the scan control register, see Appendix B) input to a logic '1'. Next, data acquisition is synchronized with the scanning electron beam by the vidicon carry signal, which clocks the start scan flip-flop (FF1). Finally, the F.A. circuit is enabled by a line sync pulse, which sets the F.A. enabled signal to a logic '1' by presetting flip-flop FF3 and enables the F.A. request flip-flop (FF2).

Once the F.A. circuit has been enabled by the micro, data acquisition and signal averaging proceed under hardware control independent of the microprocessor. A data acquisition cycle is initiated by the falling edge of the A/D status line. This falling edge, which indicates that the converter has completed a conversion, triggers monostable MS1. This monostable sends a hold request (F.A. request) to the micro. The data acquisition cycle starts when the F.A. controller receives a hold acknowledge ($\overline{\text{FAA}}$) from the micro.

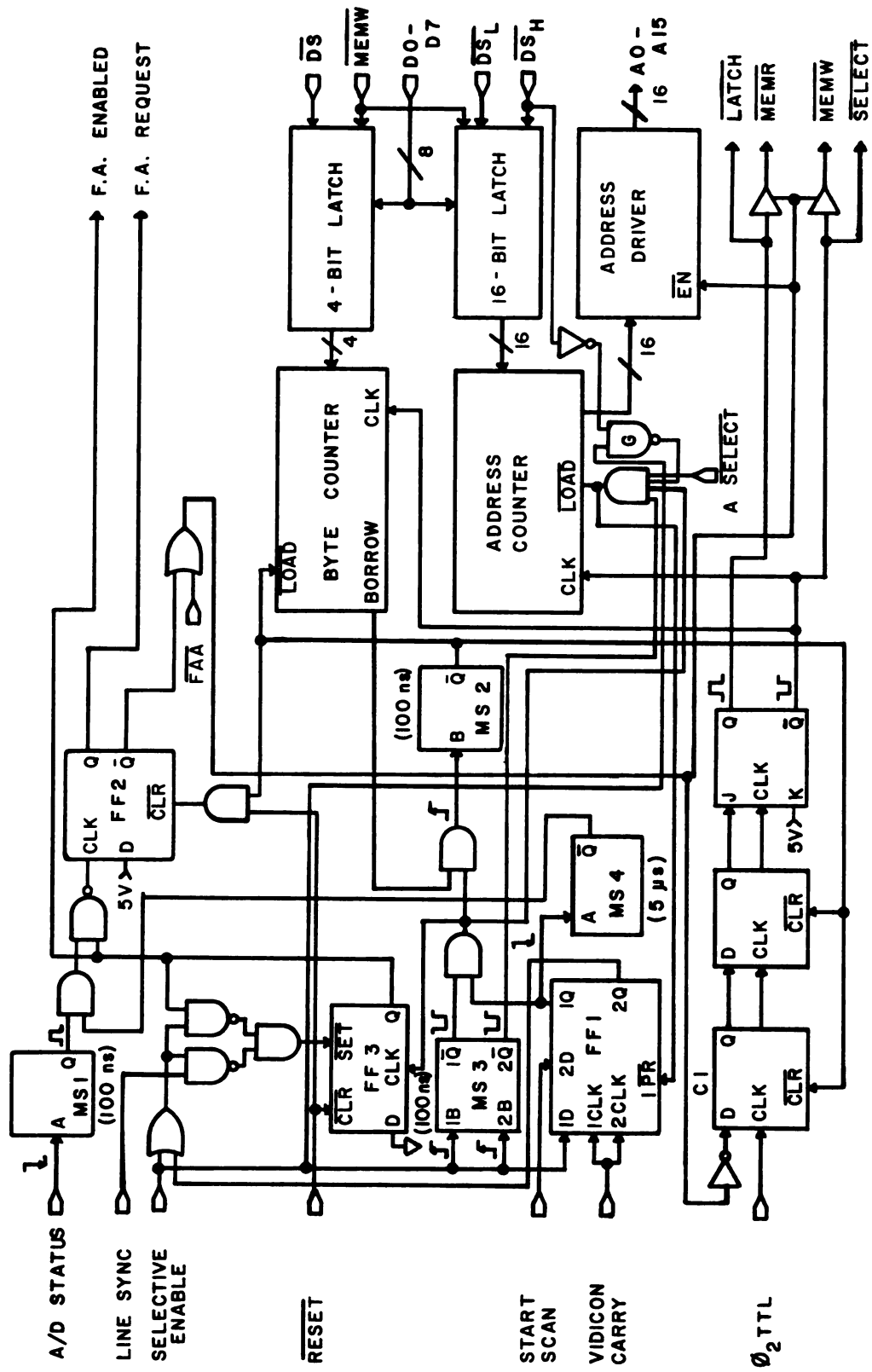


Figure 7-13. Fast Adder Controller Circuit

Timing waveforms for a triple-precision (24-bit) data acquisition cycle are shown in Figure 7-14. The $\overline{\text{FAA}}$ signal from the micro enables the controller clock (Cl), the address bus driver, and the $\overline{\text{MEMR}}$ and $\overline{\text{MEMW}}$ drivers. This clock provides the timing for the data acquisition cycle; alternate 500 ns memory read ($\overline{\text{MEMR}}$) and memory write ($\overline{\text{MEMW}}$) pulses, corresponding data latch ($\overline{\text{LATCH}}$) and memory select ($\overline{\text{SELECT}}$) pulses, and clocking of the byte and address counters.

A data acquisition cycle continues until the required number of data bytes have been averaged, at which time the byte counter underflows. The borrow output from the byte counter triggers monostable MS2. This monostable disables the F.A. controller clock, disables the memory read and write lines, reloads the byte counter, and releases the F.A. request to the micro. This data acquisition cycle, which requires less than 4 μs for a triple-precision average, is repeated each time the converter completes a conversion.

At the end of every wavelength scan a vidicon carry signal is generated by the wavelength deflection circuit. This signal not only clocks the start scan signal every frame (one wavelength scan) to synchronize the enabling and disabling of the F.A. circuit, but also reloads the address counter with the starting address contained in the address latch. The address counter must be reset at the beginning of each frame for signal averaging. However, the address counter must not be reset at the end of a frame until the last F.A. cycle is completed. Circuit timing was adjusted to properly synchronize these signals.

The F.A. controller also has a selective enable input (1 bit in the scan control register, see Appendix B) for random access interrogation of the vidicon target. The rising edge of selective enable

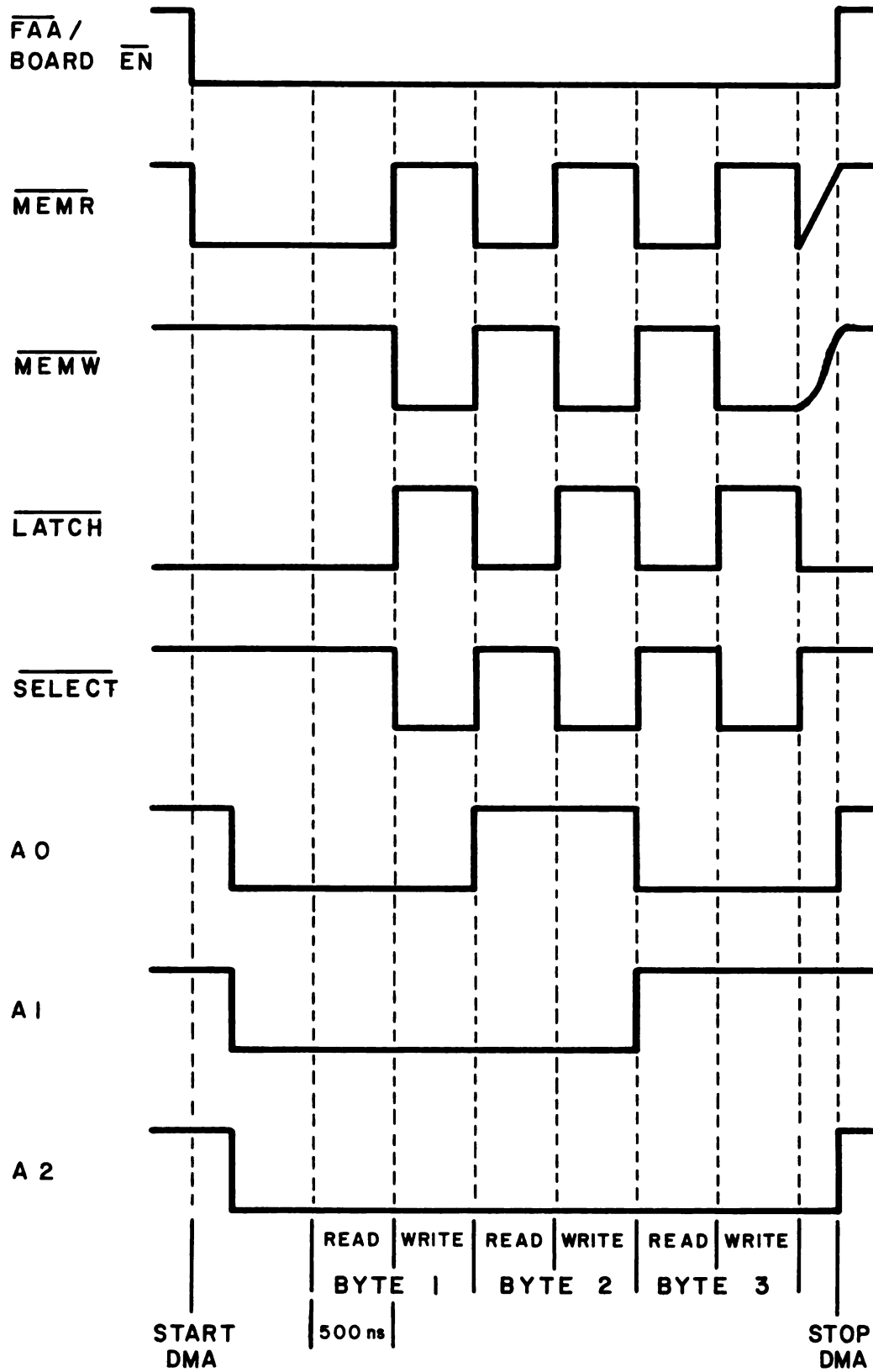


Figure 7-14. Fast Adder Timing Waveforms

triggers monostable MS3, which loads the address and byte counters. A logic '1' at selective enable enables the line sync input to flip-flop FF3 and enables gate G. Gate G is used in the random access mode to load the address counter whenever the high byte of a new address is loaded into the 16-bit address latch ($\overline{DS}_h$ pulsed low). After the address has been loaded into the address latch, line sync is pulsed high to initiate a data acquisition cycle. Thus a data acquisition cycle in random access scanning requires the micro to load the address latch with a 16-bit address and to pulse line sync. As mentioned earlier, random access scanning has not been implemented because of the slow cycle time of the 8080A microprocessor.

4. Hardware Adder for Signal Averaging

The fast adder circuit (Figure 7-15) performs the actual data acquisition and signal averaging. The timing signals for the fast adder originate on the F.A. controller board and are illustrated in Figure 7-14. At the completion of an A/D conversion, the falling edge of the A/D status line triggers monostable MS. This monostable clocks the inverted output of the A/D converter (converter's output is complementary straight binary) into a 12-bit latch and clears control flip-flops FF1 and FF2 to select the lower 8 bits for the first average. At the same time data from the corresponding memory location is read into an 8-bit data latch. These two 8-bit numbers are added by an 8-bit hardware adder, the sum is written back into the same memory location, the carry is latched by flip-flop FF3, and the memory address is incremented. The next byte is then read from memory into the 8-bit latch and added to the upper 4 bits from the A/D conversion

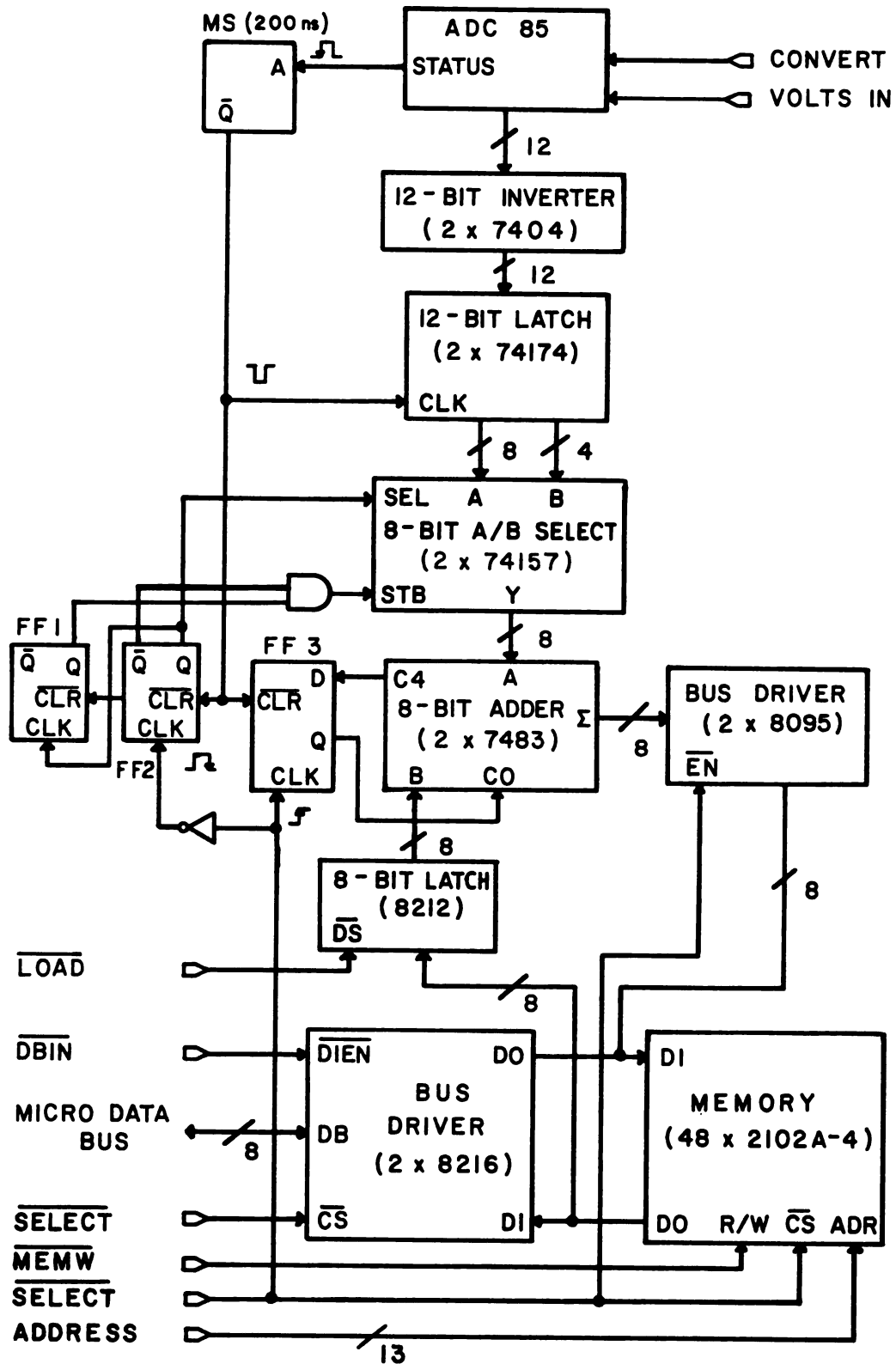


Figure 7-15. Fast Adder Circuit

together with the carry from the previous addition. This sum is written back into memory and the memory address is again incremented. Finally, the triple-precision addition is completed by adding the remaining byte in memory to the carry from the second addition and storing the sum in memory.

At a typical scan frequency of 25 kHz a data point is acquired every 40 μ s. Since a triple-precision data acquisition cycle requires less than 4 μ s, the micro is only slowed down approximately 10% at a scan rate of 25 kHz. Thus the micro can count the number of signal averages completed, monitor the quality of the incoming data, or perform any other desired function at about 90% of full speed.

D. Optical Configuration

The dispersion system used in the vidicon spectrometer was a GCA/McPherson EU-700 Czerny-Turner Monochromator (176). The vidicon detector was mounted in front of the monochromator with a Newport Research Corporation Model 400 XY Translation Stage. The exit slit was covered, the second folding mirror removed, and the rear focusing mirror moved forward to focus the grating image onto the window of the vidicon tube. The original monochromator grating was replaced with a Bausch and Lomb precision certified grating with 133.6 grooves/mm. The reciprocal linear dispersion of this system is 18 nm/mm. The width of the active vidicon target is 12.8 mm, so that the target monitors a wavelength window of approximately 230 nm.

APPENDICES

APPENDIX A

Program Listings


```

                LHL D      40014
                MOV      B,C
                MOV      A,H
                ORI      100
                MOV      H,A
:20            DCX      H
                POP      PSW
                MOV      M,A
                DCR      B
                JNZ      .20
                DCX      H
                MOV      M,C
                MOV      A,H
                ANI      37
                MOV      H,A
                SHLD     40014
                POP      B
                POP      PSW
                POP      H
>>

<< DEC BIN      ;DECIMAL TO BINARY CONVERSION
                PUSH     H
                PUSH     B
                PUSH     D
                PUSH     PSW
                OFF      ; CHARACTERS
                MOV      B,A
                LXI      H,0
:10            MVI      D,0
                OFF      ;GET A DIGIT
                MOV      E,A
                CPI      12
                JNC      .30
                DAD      D
                JC       .30
                DCR      B
                JZ       .20
                MVI      C,11
                MOV      E,L
                MOV      D,H
:15            DAD      D
                JC       .40
                DCR      C
                JNZ      .15
                JMP      .10
:20            PUSH2    ;PUT THE RESULT ON THE STACK
                POP      PSW
                POP      D
                POP      B
                POP      H
                STC
                CMC
                RET
:30            DCR      B
:40            MOV      A,B
                ON       ; CHARACTERS LEFT
                POP      PSW
                POP      D
                POP      B
                POP      H
                STC
                >>
<< DEC IN      ;INPUT DECIMAL NUMBER
                PUSH     PSW

```

```

:10  STRING      ;INPUT ASCII STRING FROM TTY
      XRA        A
      ON         ;ASCII => OCTAL MODE
      ASCII      ;CONVERT TO BCD
      DECBIN     ;CONVERT TO BINARY
      JC         .20 ;ERROR FLAG SET?
      POP        PSW
      RET
:20  CLEAN      ;REMOVE GARBAGE FROM THE STACK
      WHAT      ;SEND A '?' TO TTY
      JMP        .10 ;TRY AGAIN
>>
<< MOVIT      ;COORD ROUTINE TO CHANGE WAVELENGTH
      PUSH      H
      PUSH      B
      MVI       H,11
      LXI       B,.25
:10  LDAX       B      ;GET CHARACTER
      ON         ;AND PUSH ON STACK
      INX       B      ;INCREMENT ADDRESS POINTER
      DCR       H      ;AND DECREMENT CHARACTER COUNT
      JNZ       .10    ;JUMP IF MORE TO DO
      MESSAG     ;OUTPUT MESSAGE
      DECIN     ;INPUT NEW WAVELENGTH
      POP2
      SHLD      40024 ;STORE IN SLAVE 2
      SETUP 2   WAV
      RUN 2
:20  FLAG 2
      JZ        .20    ;JUMP IF NOT
      LDA       40036 ;ELSE GET STATUS
      ANA       A
      JZ        .30    ;JUMP IF NO ERROR
      STC       ;ELSE SET CARRY
      POP       B
      POP       H
      RET       ;AND RETURN
:30  STC
      CMC       ;IF NO ERROR CLEAR CARRY
      POP       B
      POP       H
      RET       ;AND RETURN
:25  15,12,127,101,126,40,75,40,10 ;MESSAGE
>>
<< AXIS      ;AXIS ROUTINE FOR COORD
      PUSH      H
      PUSH      PSW
      LHL      40113 ;GET POSITION OF AXES
      PUSH2     ;ON STACK
      MVI       A,2
      ON         ;NUMBER OF BYTES ON STACK
      T01      ;TRANSFER TO COMMUN.
      SETUP 1   AXIS
      RUN 1
      XRA       A      ;DRAW AXES
      ON         ;A=0
      LHL      40115 ;0 TO STACK
      PUSH2     ;GET X Y INCREMENTS
      LHL      40113 ;TO STACK
      PUSH2     ;AXES
      MVI       A,5
      ON         ;BYTE COUNT
:10  FLAG 1
      JZ        .10    ;CHECK COMMUN.
      T01      ;JUMP IF NOT READY
      T01      ;TRANSFER TO COMMUN.

```



```

      SETUP 1 TICMRK
      RUN 1      ;DRAW TICKMARKS
:20   FLAG 1
      JZ        .20
      POP       PSW
      POP       H
>>
<< CC      ;CHECK FOR C
      PUSH     PSW
      PUSH     H
      MVI      L,1      ;BYTE COUNT
      MVI      H,3      ;CONTRL C
      PUSHE2
      T01
      SETUP 1 CC      ;SEND TO COMMUN.
      RUN 1      ;RUN CHECK PROGRAM
:10   FLAG 1
      JZ        .10      ;CHECK FLAG, JUMP IF NO CONTRL C
      MVI      A,17
      STA      36500      ;ENABLE ALPHA, DISABLE GRAPHICS
      POP      H
      POP      PSW
>>
<< DIV      ;16-BIT BY 8-BIT UNSIGNED DIVISION
      ;SAVE STATUS AND REGISTERS
      PUSH     PSW
      PUSH     H
      PUSH     D
      PUSH     B
      OFF
      MOV      B,A      ;GET DIVISOR
      POP2
      MVI      C,21      ;GET DIVIDEND
                        ;BIT COUNTER
:10   XRA      A
      MOV      D,A
      MOV      A,L
      RAL
      MOV      L,A      ;ROTATE LOW BYTE
      MOV      A,H
      RAL
      MOV      H,A      ;ROTATE HIGH BYTE
      DCR      C      ;DECREMENT COUNTER
      JZ        .30
      MOV      A,D
      RAL
      JNC      .20
      SUB      B
      JMP      .10
:20   SUB      B
      JNC      .10
      ADD      B
      JMP      .10
:30   MOV      A,H      ;COMPLEMENT HIGH BYTE OF QUOTIENT
      CMA
      MOV      H,A
      MOV      A,L
      CMA
      MOV      L,A      ;COMPLEMENT LOW BYTE
      PUSHE2      ;QUOTIENT ON STACK
      MOV      A,D
      ON
      POP      B      ;REMAINDER ON STACK
      POP      D      ;RESTORE STATUS AND REGISTERS
      POP      H
      POP      PSW
>>

```



```

<< BINDEC                                ;16-BIT BINARY TO 5 DIGIT BCD
      PUSH      H
      PUSH      B
      PUSH      PSW
      MVI       C,5                       ;INITIALIZE BCD DIGIT COUNTER
      MOV       B,C
:10   MVI       A,12                       ;DIVISOR FOR 10
      ON
      DIV       ;DIVIDE BINARY NUMBER BY 10
      OFF      ;GET REMAINDER
      PUSH      PSW                       ;AND SAVE
      DCR       C                       ;DECREMENT BCD COUNT
      JNZ      .10                      ;JUMP IF MORE LEFT
      POP2     ;GET QUOTIENT
      MOV       C,B
:15   POP       PSW                       ;REINITIALIZE BCD COUNTER
      CPI      0                       ;IS IT A ZERO?
      JNZ      .25                      ;NO, REST OF DIGITS ARE SIGNIFICANT
      DCR       B                       ;YES, DECREMENT COUNT
      DCR       C
      JNZ      .15                      ;JUMP IF MORE TO DO
      INR       C
      INR       B
      JMP      .25
:20   POP       PSW
:25   ON
      DCR       C
      JNZ      .20
      MOV       A,B                       ;GET NUMBER OF NON-ZERO DIGITS
      ON
      POP       PSW                     ;AND PUT ON STACK
      POP       B
      POP       H
>>
<< DECOU                                ;OUTPUT DECIMAL NUMBER
      PUSH      PSW
      BINDEC   ;CONVERT BINARY NUMBER TO DECIMAL
      MVI       A,1
      ON
      ASCII    ;CONVERT TO ASCII CHARACTERS
      MESSAG   ;OUTPUT
      POP       PSW
>>
<< WINOUT                                ;INPUT(0)/OUTPUT(1) MONO LOCATION
      PUSH      PSW
      PUSH      H
      PUSH      B
      OFF      ;GET MODE
      MOV       L,A                       ;AND STORE IN L
      MVI       H,11                     ;BYTE COUNT
      LXI       B,.20                   ;STARTING ADDRESS OF MESSAGE
:10   LDAX      B                       ;GET CHARACTER
      ON
      INX       B                       ;PUSH ON STACK
      INX       B                       ;INCREMENT ADDRESS
      DCR       H                       ;DECREMENT BYTE COUNT
      JNZ      .10                      ;JUMP IF MORE
      MESSAG   ;OUTPUT MESSAGE
      XRA       A                       ;A=0
      CMP       L                       ;MODE=0?
      JNZ      .15                      ;NO, JUMP
      DECIN    ;YES, INPUT CURRENT WAVELENGTH
      POP2     ;AND STORE IN SLAVE 2
      SHLD     40017
      POP       B
      POP       H

```

```

      POP      PSW
      RET
:15    LHL    40017    ;GET CURRENT POSITION
      PUSH2
      DECOUT      ;OUTPUT CURRENT WAVELENGTH
      POP      B      ;AND RETURN
      POP      H
      POP      PSW
      RET
:20    15,12,127,101,126,40,75,40,10
>>
<< POUT      ;DIALOGUE ROUTINE
      PUSH    H
      PUSH    B
      PUSH    D
      PUSH    PSW
:3      LXI    H,15401
      PUSH2
      MESSAG      ;PAGE CRT
      LXI    H,0
      SHLD    .50    ;INITIALIZE BYTE COUNT POINTER
      LXI    D,.40    ;ADDRESS OF MNEMONIC TABLE
      MVI    B,0      ;INITIALIZE MNEMONIC COUNTER
:5      MVI    C,3      ;3 BYTES/MNEMONIC
      CALL    .20      ;OUTPUT MNEMONIC AND ITS VALUE
      LXI    H,4401
      PUSH2
      MESSAG      ;OUTPUT TAB
      MOV     A,B
      CPI     20      ;ALL MNEMONICS OUTPUT?
      JZ      .10      ;YES, JUMP
      MVI     C,3
      CALL    .20      ;NO, OUTPUT NEXT ONE
      CRLF
      MOV     A,B
      CPI     20      ;MORE LEFT?
      JNZ     .5       ;YES, JUMP
:10     CRLF
      CRLF
      LXI    H,37001 ;OUTPUT '>'
      PUSH2
      MESSAG
:11     STRING      ;INPUT MNEMONIC
      LXI    D,.40    ;ADDRESS OF MNEMONIC TABLE
      LHL    50      ;ADDRESS OF STACK
      CLEAN      ;CLEAN STACK
      MOV     A,M      ;GET BYTES
      CPI     3        ;=3?
      JZ      .13      ;YES, JUMP
:12     WHAT      ;NO, OUTPUT '?'
      JMP     .11      ;AND INPUT AGAIN
:13     INX
      XCHG
      LXI    B,3
:14     INR      B      ;INCREMENT MNEMONIC COUNTER
      PUSH    D
      CALL    361      ;CALL SYSTEM COMPARE ROUTINE
      POP     D
      MOV     A,B
      JZ      .15      ;JUMP IF MATCH FOUND
      CPI     21      ;COMPARE ALL MNEMONICS?
      JZ      .12      ;YES, OUTPUT '?' AND INPUT AGAIN
      JMP     .14      ;NO, COMPARE NEXT IN TABLE
:15     CPI     21      ;COMPARE WITH 'END'
      JNZ     .16      ;JUMP IF NOT END ON INPUT

```

```

      POP      PSW
      POP      D
      POP      B
      POP      H
      RET      ;RETURN
:16  MOV      A,B
      DCR      A
      STA      .50
      INR      A
      LXI      H,.41 ;ADDRESS TABLE ADDRESS
      CALL     437 ;CALL JUMP TABLE ROUTINE
      DECIN    ;INPUT DECIMAL NUMBER
      XCHG
      POP2
      XCHG
      MOV      M,E ;PUT 1ST BYTE IN MEMORY
      CALL     .30 ;1 OR 2 BYTES?
      JC       .32 ;JUMP IF ONLY 1 BYTE
      INX      H
      MOV      M,D ;TRANSFER 2ND BYTE
:32  SETUP 2 POUT2
      RUN 2
:34  FLAG 2 ;CHECK TO SEE IF MICRO 2 IS FINISHED
      JZ       .34 ;LOOP IF NOT
      JMP      .3 ;GO DO AGAIN
:20  LXI      H,20040 ;PUT TWO SPACES ON STACK
      PUSH2
      MOV      A,L
      ON
:21  LDAX     D ;AND ADD ANOTHER
      INX      D ;GET MNEMONIC
      ON
      DCR      C
      JNZ      .21 ;JUMP IF MORE CHARACTERS
      INR      B
      MVI      A,6 ;BYTE COUNT TO STACK
      ON
      MESSAG
      LXI      H,20001 ;OUTPUT MNEMONIC
      PUSH2
      MESSAG ;OUTPUT SPACE
      PUSH     D
      PUSH     B
      MOV      A,B
      LXI      H,.41 ;ADDRESS OF ADDRESS TABLE
      CALL     437 ;CALL JUMP TABLE ROUTINE
      MOV      A,M ;GET BYTE
      MOV      E,A
      CALL     .30 ;1 OR 2 BYTES?
      JNC      .22
      MVI      D,0
      JMP      .24
:22  INX      H
      MOV      A,M ;GET 2ND BYTE
      MOV      D,A
:24  XCHG
      PUSH2
      DECOUT    ;OUTPUT DECIMAL NUMBER
      POP      B
      POP      D
      LXI      H,.50
      INR      M
      RET
:30  PUSH     H
      PUSH     D

```

```

LXI      H, .51
XCHG
LHLD     .50
DAD      D
MOV      A, H
CPI      2
POP      D
POP      H
RET
:40      127, 101, 126, 106, 122, 121, 120, 124, 123, 102, 105, 115, 104, 114
        131, 101, 103, 121, 102, 114, 113, 107, 101, 111, 102, 131, 124
        102, 111, 124, 101, 126, 107, 111, 116, 124, 101, 104, 122, 103
        116, 124, 117, 120, 124, 123, 122, 104, 105, 116, 104
:41      40024, 40117, 40120, 40104, 40122, 40123, 40124, 40035, 40037
        40125, 40026, 40034, 40102, 40100, 40126, 40127
:50      0, 0
:51      2, 1, 2, 1, 1, 1, 1, 1, 1, 2, 1, 2, 2, 1, 1
>>
<< CON          ;ENABLE GRAPHICS - DISABLE ALPHA
        PUSH     PSW
        MVI      A, 21
        STA      36500
        POP      PSW
>>
<< SUBTR          ;SUBTRACT UNSIGNED 16-BIT NUMBERS
        PUSH     H          ;SAVE REGISTERS
        PUSH     D
        POP2      ;GET SUBTRAHEND
        XCHG
        POP2      ;GET MINUEND
        MOV      A, L
        SUB      E          ;SUBTRACT LOW BYTES
        MOV      L, A
        MOV      A, H
        SBB      D          ;SUBTRACT HIGH BYTES
        MOV      H, A
        PUSH2     ;ANSWER BACK ON STACK
        POP      D          ;RESTORE
        POP      H
>>
<< VSET
:10      FLAG 2
        JZ      .10
        SETUP 2 VSETUP      ;MODIFY VIDICON SCAN FORMAT
        RUN 2
>>
<< FSET          ;INITIALIZE FAST ADDER CIRCUIT
:10      FLAG 2
        JZ      .10
        SETUP 2 FASET
        RUN 2
>>
<< CLR8K          ;CLEAR 8K DATA MEMORY
:10      FLAG 2
        JZ      .10
        SETUP 2 CLRMEM
        RUN 2
>>
<< VINIT          ;COORD INITIALIZATION OF MICRO 2
        PUSH     H
        PUSH     PSW
        SETUP 2 VINIT2
        RUN 2          ;RUN INITIALIZATIONPROGRAM ON 2
:10      FLAG 2          ;DONE?
        JZ      .10      ;NO, JUMP

```

```

XRA      A
ON
WINOUT   ;ELSE 0 ON STACK
SETUP 2 AUTO ;REQUEST CURRENT MONOCHROMATOR POSITION
RUN 2
:20 FLAG 2 ;MONOCHROMATOR BACK UNDER MICRO CONTROL
JZ .20 ;DONE?
POUT ;NO
VSET ;USER I/O
FSET ;SET UP NEW SCAN FORMAT
:40 FLAG 2 ;SET UP NEW DATA ACQUISITION PARAMETERS
JZ .40
LHLD 40024 ;GET NEW WAVELENGTH
PUSH2
LHLD 40017 ;CURRENT WAVELENGTH
PUSH2
SUBTR ;ANY DIFFERENCE?
JC .47
POP2 ;GET ANSWER
MOV A,H
ORA L ;ANSWER=0?
JZ .55
JMP .50
:47 POP2 ;CLEAN STACK
:50 SETUP 2 WAV ;REPOSITION MONOCHROMATOR
RUN 2
:60 FLAG 2
JZ .60
:55 POP PSW
POP H
>>
<< WFILE ;OPEN FILE ON FLOPPY - COORD
PUSH H
PUSH B
PUSH D
SETUP 1 WFILE1
RUN 1
:10 FLAG 1
JZ .10
CALL .40 ;GET ADDRESS OF 1'S STACK
LDAX D ;GET STATUS
INX D
ANA A
JNZ .30 ;JUMP IF FILE NOT OPENED
LXI H,60000 ;ADDRESS OF DARK
CALL .42 ;TRANSFER BLOCK OF DATA
LXI H,65252 ;ADDRESS OF REFERENCE
CALL .42 ;TRANSFER
LXI H,72524 ;ADDRESS OF SAMPLE
CALL .42 ;TRANSFER
SETUP 1 CFIL1
RUN 1
:15 FLAG 1
JZ .15
STC
CMC
:20 POP D
POP B
POP H
RET
:30 XCHG ;UPDATE COMMUN'S STACK
MOV A,H
ANI 37
MOV H,A
SHLD 20014

```

```

      STC                ;SET CARRY IF FILE NOT OPENED
      JMP      .20       ;AND JUMP TO EXIT
:40   LHL      20014      ;GET ADDRESS OF STACK
      MOV      A,H
      ORI      40        ;ADJUST ADDRESS FOR COORD
      MOV      H,A
      XCHG                ;HL -> DE
      RET
:42   PUSH     H          ;SAVE DATA ADDRESS
      LHL      40100      ;GET TOTAL BYTE COUNT
      PUSH     H          ;AND SAVE
      INX      H
      INX      H
      INX      H
      DCX      D
      LDA      40037      ;GET BYTES/DATA WORD
      STAX     D
      DCX      D
      LDA      40027      ;NUMBER OF SIGNAL AVERAGES - HIGH BYTE
      STAX     D
      DCX      D
      LDA      40026      ;SIGNAL AVERAGES - LOW BYTE
      STAX     D
      DCX      D
      MOV      A,H
      STAX     D          ;SEND BYTE COUNT TO MICRO 1
      DCX      D
      MOV      A,L
      STAX     D
      DCX      D
      MVI      A,5
      STAX     D          ;SEND OF BYTES
      XCHG
      MOV      A,H
      ANI      37         ;RE-ADJUST ADDRESS
      MOV      H,A
      SHLD     20014      ;UPDATE MICRO 1'S STACK
      SETUP   1 TSF
      RUN      1
:44   FLAG     1
      JZ       .44
      CALL     .40        ;GET CURRENT ADDRESS OF 1'S STACK
      POP      H          ;GET BYTE COUNT
      PUSH2    A,100      ;NUMBER OF BYTES/TRANSFER
      ON
      DIV
      OFF      .55       ;GET REMAINDER
      STA      .55
      POP2     .56       ;GET QUOTIENT
      MOV      A,L
      STA      .56
:46   LDA      .56
      ANA      A
      JZ       .50       ;JUMP ON ZERO
      DCR      A          ;ELSE DECREMENT COUNT
      STA      .56
      MVI      B,100
      MOV      C,B
      JMP      .52       ;JUMP TO TRANSFER ROUTINE
:50   LDA      .55       ;GET REMAINDER
      ANA      A
      JNZ      .51       ;JUMP IF NON-ZERO
      POP      H          ;ELSE CLEAR STACK
      RET            ;AND RETURN

```

```

:51      MOV      B,A
          MOV      C,A
          XRA      A
          STA      .55      ;CLEAR REMAINDER
:52      POP      H          ;GET ADDRESS OF DATA
          DCX      D
:53      MOV      A,M          ;GET DATA
          INX      H
          STAX     D          ;AND TRANSFER
          DCX      D
          DCR      B          ;DECREMENT COUNT
          JNZ      .53      ;LOOP IF MORE
          MOV      A,C
          STAX     D          ;TRANSFER BYTE COUNT
          PUSH     H          ;SAVE DATA ADDRESS
          XCHG
          MOV      A,H
          ANI      37          ;ADJUST ADDRESS
          MOV      H,A
          SHLD     20014      ;UPDATE STACK ADDRESS
          SETUP 1 TSF1
          RUN 1
:54      FLAG 1
          JZ       .54
          CALL     .40          ;GET CURRENT STACK ADDRESS
          JMP      .46          ;GO FOR MORE
:55      000
:56      000
>>
<< PLT          ;PLOT SAMP,REF,A,T ON CRT - COORD
          PUSH     H
          PUSH     B
          PUSH     D
          PUSH     PSW
          CRLF
          LXI      D,.60      ;MESSAGE ADDRESS
          MVI      B,21      ;BYTE COUNT
          MOV      C,B
:5       LDAX     D          ;GET BYTE
          ON
          INX      D
          DCR      C
          JNZ      .5          ;LOOP IF MORE BYTES
          MOV      A,B
          ON          ;COUNT TO STACK
          MESSAG     ;OUTPUT MESSAGE
:10      STRING    ;INPUT MNEMONIC
          OFF      ;GET BYTE COUNT
          CPI      1          ;1 BYTE?
          JZ       .15        ;YES
          ON          ;NO, REPLACE
          CLEAN     ;CLEAN OFF STACK
:12      WHAT      ;OUTPUT '?'
          JMP      .10        ;GO GET ANOTHER
:13      OFF      ;GET CHARACTER
          CPI      123        ;S?
          JNZ      .16        ;NO
          LXI      H,72524    ;YES, GET S ADDRESS
          JMP      .100
:16      CPI      122        ;R?
          JNZ      .17        ;NO
          LXI      H,65252    ;YES, GET R ADDRESS
          JMP      .100
:17      CPI      124        ;T?
          JNZ      .20        ;NO

```

```

      MVI      D,0      ; YES, D=0
      JMP      .22
:20    CPI      101      ; A?
      JNZ      .12      ; NO
      MVI      D,1      ; YES, D=1
:22    LXI      B,.61    ; MESSAGE ADDRESS
      MVI      H,15     ; COUNT
      MOV      L,H
:25    LDAX     B        ; GET BYTE
      ON
      INX      B
      DCR      L
      JNZ      .25      ; LOOP IF MORE
      MOV      A,H
      ON
      MESSAG
:27    DECIN                      ; INPUT THRESHOLD
      POP2
      MOV      A,H
      CPI      0        ; H SHOULD BE 0
      JZ       .30
      WHAT                      ; NOPE, OUTPUT '?'
      JMP      .27      ; AND TRY AGAIN
:30    MOV      A,L
      STA      40133     ; STORE THRESHOLD FOR XT CALC
      SETUP 2 XT
      RUN 2
:23    FLAG 2
      JZ       .23
      MOV      A,D
      ANA      A        ; PLOT XT OR A ?
      JZ       .37      ; JUMP IF XT
      SETUP 2 A        ; ELSE CALCULATE A
      RUN 2
:35    FLAG 2
      JZ       .35
      LHLD     40134     ; GET STARTING ADDRESS OF A DATA
      MOV      A,H
      ORI      100      ; ADJUST ADDRESS FOR COORD
      MOV      H,A
      JMP      .40
:37    LXI      H,600000 ; STARTING ADDRESS OF XT DATA
:40    PUSHE2                      ; SAVE ADDRESS
      CALL     .65
      POP2                      ; STARTING ADDRESS
      MVI      C,0
:45    MOV      A,M      ; GET DATA POINT
      CMA
      STA      36202     ; STORE IN Y POSITION
      MOV      A,C
      STA      36201     ; STORE C IN X POSITION
      INR      C
      MVI      A,1
      STA      36200     ; TURN ON DOT
      LDA      .62      ; GET INCREMENT
      MOV      B,A
:47    INX      H
      DCX      D
      MOV      A,D
      ORA      E
      JZ       .50      ; JUMP TO EXIT IF FINISHED
      DCR      B
      JNZ      .47
      JMP      .45      ; GO GET ANOTHER
:50    POP      PSW      ; EXIT

```

```

      POP      D
      POP      B
      POP      H
      RET
:60      120, 114, 117, 124, 40, 133, 123, 54, 122, 54, 101
      54, 124, 135, 40, 76, 40
:61      15, 124, 110, 122, 105, 123, 110, 117, 114, 104, 40, 75, 40
:62      0
:63      0                      ; BYTES/DATA WORD
:64      0                      ; X-POSITION
:65      LHLD      40120          ; GET OF POINTS
      MOV      D, H
      MOV      E, L
      XRA      A
      CMP      L                ; L=0?
      JZ       .66
      INR      H
:66      MOV      A, H
      STA      .62
      RET
:100     PUSH2          ; SAVE ADDRESS
      LDA      40037
      STA      .63            ; GET BYTES
      CALL     .65            ; GET INCREMENT FOR PLOTTING
      LDA      .63            ; GET BYTES
      MOV      C, A
      LDA      40136          ; POINTS TO SKIP
      MOV      B, A
      DCR      C
:105     ADD      B
      DCR      C
      JNZ      .105
      STA      .136
      LXI      B, 0
      MOV      C, A
      MOV      A, E
      SUB      C
      MOV      C, A
      MOV      A, D
      SBB      B
      MOV      B, A
      POP2          ; ADDRESS IN HL
      LDA      .136
      STA      .64            ; INITIALIZE X POSITION
      MOV      E, A
      MVI      D, 0
      DAD      D
      PUSH     H
      PUSH     B
      INX      H
      MOV      D, M            ; GET INITIAL YMAX
:101     DCX      B            ; DECREMENT COUNT
      LDA      .63
:102     INX      H
      DCR      A
      JNZ      .102
      MOV      A, M            ; GET NEXT BYTE
      CMP      D                ; D>E?
      JC       .103            ; YES
      MOV      D, A            ; NO, GET NEW YMAX
:103     MOV      A, B
      ORA      C
      JNZ      .101            ; LOOP 'TIL DONE
      MVI      E, 1
      MOV      A, D

```

```

      LXI      D, .100 ; MNEMONIC TABLE ADDRESS
      MVI      H, 13 ; BYTES
      MOV      L, H
      CALL     .75 ; OUTPUT PROMPT
:10  STRING   ; INPUT RESPONSE
      OFF
      CPI      1 ; 1 BYTE?
      JZ       .15 ; YES, JUMP
      ON       ; NO
      CLEAN
      WHAT
      JMP      .10
:15  OFF      ; GET BYTE
      CPI      131 ; Y?
      JNZ      .31 ; NO, EXIT
      CRLF
      LXI      D, .105
      MVI      H, 24
      MOV      L, H
      CALL     .75
      DECIN    ; CHANNEL NUMBER
      DECIN    ; CHANNELS
      CRLF
      LXI      D, .110
      MVI      H, 20
      MOV      L, H
      CALL     .75
      CRLF
      POP2
      MOV      B, H
      MOV      C, L
      POP2
      PUSH     H
:20  XCHG
      CALL     .70 ; ADJUST ADDRESS
      LXI      H, 72524 ; SAMPLE ADDRESS
      CALL     .60 ; OUTPUT SAMPLE
      CALL     .65 ; TAB
      POP      H
      PUSH     H
      XCHG
      CALL     .70
      LXI      H, 65252 ; REFERENCE ADDRESS
      CALL     .60
      CALL     .65
      POP      H
      PUSH     H
      DCX      H
      XCHG
      LXI      H, 60000 ; XT ADDRESS
      CALL     .55 ; OUTPUT XT
      CALL     .65
      POP      H
      PUSH     H
      DCX      H
      XCHG
      LHLD     40134 ; POINTER TO A ADDRESS
      MOV      A, H
      ORI      100 ; ADJUST ADDRESS FOR COORD
      MOV      H, A
      CALL     .55 ; OUTPUT A
      LXI      H, 20040
      PUSH2
      MVI      A, 2
      ON

```

```

MESSAG
POP      H
PUSH     H
PUSH2
DECOUT           ;OUTPUT SPACES AND CHANNEL
CRLF
DCX       B
MOV       A,B
ORA       C
JZ        .30    ;EXIT IF DONE
LHLD     40120   ;TOTAL NUMBER OF POINTS
PUSH2
POP       H
PUSH     H
PUSH2
SUBTR           ;TOTAL POINTS - CURRENT CHANNEL
POP2
MOV       A,H
ORA       L
JZ        .30    ;EXIT IF AT LAST CHANNEL
POP       H
INX       H
PUSH     H
JMP      .20
:30      POP     H           ;CLEAN OFF CHANNEL
:31      POP     B
          POP     D
          POP     H
          POP     PSW
          RET           ;RETURN
:53      DAD     D
          MOV     E,M
          MVI     D,0
          XCHG
          PUSH2
          DECOUT
          RET
:60      DAD     D
          MOV     E,M
          INX     H
          MOV     D,M
          XCHG
          PUSH2
          DECOUT
          RET
:63      LXI     H,4401    ;TAB
          PUSH2
          MESSAG
          RET
:70      LDA     40037    ; BYTES /DATA WORD
          DCR     A
          DCX     D
          MOV     H,D
          MOV     L,E
:72      DAD     D
          DCR     A
          JNZ     .72
          XCHG
          RET
:75      LDAX   D
          ON
          INX     D
          DCR     H
          JNZ     .75
          MOV     A,L

```



```

      STAX      B      ;MOVE CURSOR AND WRITE DOT
      STAX      B
      STAX      B
      NOP
      NOP      ;DELAY
      NOP
      NOP
      NOP
      ORI       300    ;REVERSE DIRECTION
      STAX      B      ;MOVE BACK
      STAX      B
      STAX      B
      STAX      B
      STAX      B
      STAX      B
      NOP
      NOP      ;DELAY
      NOP
      NOP
      ANI       77     ;CLEAR UPPER BITS TO REVERSE
      STAX      B      ;MOVE BACK
      STAX      B
      STAX      B
      POP       PSW
      POP       B
>>
<< TICMRK      ;DRAW TICK MARKS ON X AND Y AXES
      PUSH     PSW    ;SAVE STATUS AND REGISTERS
      PUSH     H
      PUSH     D
      PUSH     B
      LXI      D,16202 ;SET UP Y ADDRESS
      MVI      L,21   ;CODE TO WRITE DOTS IN HORIZONTAL
      OFF
      OFF      ;CLEAR OFF BYTE COUNT
      OFF      ;GET X-CURSOR POSITION
      STA      16201  ;WRITE
      MOV      H,A    ;AND SAVE
      OFF      ;GET Y-CURSOR POSITION
      STAX     D      ;WRITE
      MOV      B,A    ;AND SAVE
      OFF      ;GET Y INCREMENT
      MOV      C,A    ;AND SAVE
      CPI      0      ;>0?
      JZ       .30    ;NO, JUMP TO NEXT AXIS
:10  MOV      A,B      ;GET CURSOR
      SUB      C      ;SUBTRACT INCREMENT
      JC       .20    ;JUMP ON BORROW
      STAX     D      ;POSITION CURSOR
      TICK     D      ;DRAW SINGLE TICK MARK
      JMP      .10    ;LOOP
:20  MOV      A,B      ;GET CURSOR AGAIN
      STAX     D      ;AND REPOSITION
:25  ADD      C      ;ADD INCREMENT THIS TIME
      JC       .30    ;JUMP ON CARRY
      STAX     D      ;POSITION CURSOR
      TICK     D      ;DRAW SINGLE TICK MARK
      JMP      .25    ;LOOP
:30  MOV      A,B
      STAX     D      ;REPOSITION
      OFF      ;GET X INCREMENT
      MOV      C,A    ;AND SAVE
      CPI      0      ;>0?
      JZ       .40    ;NO, EXIT
      MVI      L,41   ;NEW CURSOR MOVE COMMAND
      DCX      D      ;DECREMENT ADDRESS POINTER
      MOV      A,B    ;GET Y CURSOR

```

```

      MOV      B,H      ;EXCHANGE CURSORS
      MOV      H,A
      MOV      A,B      ;GET X CURSOR
      JMP      .10      ;RETURN
:40    POP      B        ;RESTORE
      POP      D
      POP      H
      POP      PSW
>>
<< CC      ;COMMUN. CHECK FOR REQUESTED CHARACTER
      PUSH     PSW
      PUSH     H
      POP2
      READ     ;GET CHARACTER IN H,1 IN L
:10    READ     ;INPUT CHARACTER
      CMP      H        ;COMPARE WITH DESIRED CHARACTER
      JNZ      .10      ;JUMP IF WRONG CHARACTER
      POP      H
      POP      PSW
>>
<< WFILE1   ;OPEN FILE FOR WRITING - MICRO 1
      PUSH     PSW
      PUSH     B
      PUSH     D
:5     MVI      A,52
      CRT      ;OUTPUT '*'
      LINE     ;INPUT COMMAND STRING
      JC       .25      ;CLEAN STACK JUMP ON C
      FCMD     ;SEND COMMAND STRING TO FLOPPY
      CPI      3        ;3 -> FILE OPEN FOR WRITING
      JNZ      .5       ;ELSE JUMP BACK
      LXI      B,.50    ;GET ADDRESS OF MNEMONICS
      MVI      D,93     ;GET BYTE COUNT
:10    LDAX     B        ;GET MNEMONIC
      INX      B        ;INCREMENT ADDRESS
      CRT      ;OUTPUT TO CRT
      DCR      D        ;DECREMENT BYTE COUNT
      JNZ      .10      ;LOOP 'TIL DONE
:15    LINE     ;INPUT COMMAND STRING
      JC       .30      ;CLEAN STACK JUMP ON C
      OFF      ;GET BYTE COUNT
      MOV      B,A
:20    OFF      ;GET ASCII CHARACTER
      CPI      15       ;IS IT A CR
      JNZ      .22      ;NO
      CALL     1123      ;YES, OUTPUT
      MVI      A,12     ;GET CODE FOR LF
:22    CALL     1123      ;OUTPUT TO FLOPPY
      DCR      B        ;DECREMENT BYTE COUNT
      JNZ      .20      ;JUMP IF MORE
      MVI      A,15
      CALL     1123      ;OUTPUT CR
      JMP      .15      ;GET ANOTHER COMMAND STRING
:25    MVI      A,1      ;1 = ABORT FILE OPENING
      JMP      .35      ;JUMP EXIT
:30    MVI      A,3
      CALL     1123      ;OUTPUT EXT TO FLOPPY
      XRA      A
:35    ON
      POP      D
      POP      B
      POP      PSW
      RET
:50    111,116,120,125,124,40,124,105,130,124,40,55,40
      34,103,40,124,105,122,115,111,116,101,124,105,123,15
>>

```

```

<< CFIL1      ;CLOSE FILE - MICRO 1
      CALL     1171 ;SEND EOT
      CALL     1106 ;GET ACK OR NAK
      CPI      6    ;ACK?
      JNZ      .10  ;JUMP IF NO
      CALL     1106 ;ELSE READ EOT
      RET      ;AND RETURN
:10    CALL     1106 ;READ ERROR MESSAGE
      CPI      4    ;EOT?
      JNZ      .20  ;JUMP IF NO
      RET      ;ELSE EXIT
:20    CRT      ;OUTPUT TO SCREEN
      JMP      .10  ;JUMP FOR MORE
>>
<< TSF        ;TRANSFER FROM STACK TO FLOPPY
      OFF      ;GET BYTE COUNT
      MOV      B,A
:10    OFF      ;GET BYTE
      CALL     1123 ;TRANSFER A TO FLOPPY
      DCR      B    ;DECREMENT BYTE COUNT
      JNZ      .10  ;JUMP IF MORE
>>
<< TSF1       ;OUTPUT DATA TO FLOPPY - MICRO 1
      OFF      ;GET BYTE COUNT
      MOV      C,A
      MOV      B,A
:10    OFF      ;GET BYTE
      PUSH     PSW  ;AND PUT IT ON STACK
      DCR      C
      JNZ      .10
:20    POP      PSW
      CALL     1123
      DCR      B
      JNZ      .20
>>

```

```

;
; MICRO2.CON
;
; JIM HORNSHUI NOVEMBER 1, 1977
;
; CONVERSE LIBRARY FOR VIDICON MICRO
;
<< ON ;CONTENTS OF REG A ON STACK
    PUSH H
    LHL D 14
    DCX H
    MOV M,A
    SHL D 14
    POP H
>>
<< OFF ;CONTENTS OF STACK TO REG A
    PUSH H
    LHL D 14
    MOV A,M
    INX H
    SHL D 14
    POP H
>>
<< PUSHE2 ;CONTENTS OF H0L TO STACK
    PUSH D
    XCHG
    LHL D 14
    DCX H
    MOV M,D
    DCX H
    MOV M,E
    SHL D 14
    XCHG
    POP D
>>
<< POP2 ;2 BYTES FROM STACK TO H0L
    PUSH D
    LHL D 14
    MOV E,M
    INX H
    MOV D,M
    INX H
    SHL D 14
    XCHG
    POP D
>>
<< CELL ;ROUTINE TO MOVE CELL
    POP2 ;GET COMMAND WORD
    XCHG ;AND PUT IN DE
    LXI H,120000 ;ADDRESS OF OUTPUT LATCH
    MOV M,D ;SEND OUT SELECT COMMAND
    INX H
:10 MOV A,M ;GET STATUS OF CELL COMPARTMENT
    ANA E
    JNZ .10 ;IF STATUS NOT 0, WAIT FOR CELL
>>
<< SREF ;SELECT REFERENCE CELL
    PUSH PSW ;SAVE STATUS AND REGISTERS
    PUSH H
    PUSH D
    LDA 21 ;GET CURRENT STATUS
    ANI 6 ;SET REFERENCE BIT
    STA 21 ;UPDATE STATUS
    MOV H,A ;SET UP COMMAND WORD
    MVI L,2

```

```

                PUSH2                ;AND PUT ON STACK
                CELL                ;CALL ROUTINE TO MOVE CELL
                POP                  ;RESTORE STATUS AND REGISTERS
                POP                  D
                POP                  H
                POP                  PSW
>>
<< SSAMP                ;SELECT SAMPLE CELL
                PUSH                PSW                ;SAVE STATUS AND REGISTERS
                PUSH                H
                PUSH                D
                LDA                21                ;GET CURRENT STATUS
                ORI                10                ;SET SAMPLE BIT
                STA                21                ;UPDATE STATUS
                MOV                H,A                ;SET UP COMMAND WORD
                MVI                L,1
                PUSH2                ;AND PUT ON STACK
                CELL                ;CALL ROUTINE TO MOVE CELL
                POP                  ;RESTORE STATUS AND REGISTERS
                POP                  D
                POP                  H
                POP                  PSW
>>
<< DELAY                ;PROGRAMMABLE DELAY ROUTINE
:10             DCR                C
                RZ
:20             DCR                B
                JZ                .10
                JMP                .20
>>
<< SOPEN                ;ROUTINE TO OPEN SHUTTER
                PUSH                H
                PUSH                B
                PUSH                PSW
:10             LXI                H,120004
                MOV                A,M                ;GET STATUS
                ANI                2                ;TEST BIT 1
                JNZ                .20                ;IF BIT 1=1, ALREADY OPEN
                STA                120007            ;OPEN SHUTTER
                MVI                A,6
:15             LXI                B,177777
                DELAY                ;DELAY FOR SHUTTER
                DCR                A
                JNZ                .15
                JMP                .10                ;DOUBLE CHECK
:20             POP                PSW
                POP                B
                POP                H
>>
<< SCLOSE                ;ROUTINE TO CLOSE SHUTTER
                PUSH                H
                PUSH                B
                PUSH                PSW
:10             LXI                H,120004
                MOV                A,M                ;GET STATUS
                ANI                2                ;IF BIT 1=0, ALREADY CLOSED
                JZ                .20                ;CLOSE SHUTTER
                STA                120007
                MVI                A,6
:15             LXI                B,177777
                DELAY                ;DELAY FOR SHUTTER
                DCR                A
                JNZ                .15
                JMP                .10                ;DOUBLE CHECK
:20             POP                PSW
                POP                B
                POP                H

```

```

>>
<< STEP                                ;ROUTINE TO STEP MONOCHROMATOR
PUSH PSW                                ;SAVE STATUS AND REGISTERS
PUSH H
PUSH D
PUSH B
POP2                                     ;GET COUNT
XCHG                                     ;PUT IN DE
OFF                                     ;GET STATUS
MOV B,A
:10 LXI H,120000;OUTPUT LATCH ADDRESS
MOV A,B
INR A
MOV M,A
LXI B,107403;SET UP BC FOR DELAY ROUTINE
DELAY ;CALL PROGRAMMABLE DELAY
DCR A
MOV M,A
LXI B,107403
DELAY
MOV B,A
INX H
MOV A,M ;GET STATUS
ANI 4 ;TEST REVERSE LIMIT
JZ .20 ;JUMP IF NOT AT LIMIT
XRA B ;ELSE CHECK FOR FORWARD MOTION
ANI 4
JNZ .30 ;IF STILL REVERSE, EXIT ON ERROR
:20 DCX D ;DECREMENT COUNT AND TEST IF = 0
MOV A,E
ORA D
JNZ .10 ;NO, CONTINUE
POP B ;YES, EXIT WITHOUT ERROR
POP D
POP H
POP PSW
STC ;SET CARRY
CMC ;CLEAR CARRY(ERROR FLAG)
RET ;AND RETURN
:30 POP B
POP D
POP H
POP PSW
STC ;SET CARRY(ERROR FLAG)
>>
<< DOWN                                ;DECREMENT MONOCHROMATOR WAVELENGTH
PUSH H
POP2 ;GET COUNT
LDA 21 ;GET MONOCHROMATOR STATUS
ANI 12 ;CLEAR FORWARD BIT
ON ;AND PLACE STATUS ON STACK
PUSH2 ;ALSO COUNT
STEP ;MOVE MONOCHROMATOR
JC .10 ;RETURN ON ERROR
ON ;STATUS BACK ON STACK
LXI H,200
PUSH2
STEP ;TAKE ADDITIONAL 128 STEPS DOWN
JC .10 ;RETURN ON ERROR
ORI 4 ;SET FORWARD BIT
STA 21 ;UPDATE STATUS
ON ;AND PUT ON STACK
LXI H,200
PUSH2
STEP ;STEP UP 128 STEPS

```

```

                STC                ;SET CARRY
                CMC                ;CLEAR CARRY
                POP                H
:10            RET                ;SET CARRY(ERROR FLAG)
                POP                H
>>
<< UP          ; INCREMENT MONOCHROMATOR WAVELENGTH
                PUSH PSW          ;SAVE STATUS AND REGISTERS
                PUSH H
                POP2              ;GET COUNT
                LDA 21            ;GET MONOCHROMATOR STATUS
                ORI 6             ;SET FORWARD/EXTERNAL ENABLE BITS
                STA 21            ;UPDATE STATUS
                ON                ;AND PLACE ON STACK
                PUSH2            ;PLACE COUNT ON STACK
                STEP             ;MOVE MONOCHROMATOR
                POP H            ;RESTORE
                POP PSW
>>
<< SUBTR       ;SUBTRACT UNSIGNED 16-BIT NUMBERS
                PUSH H          ;SAVE REGISTERS
                PUSH D
                POP2            ;GET SUBTRAHEND
                XCHG            ;GET MINUEND
                POP2
                MOV A,L          ;SUBTRACT LOW BYTES
                SUB E
                MOV L,A
                MOV A,H
                SBB D            ;SUBTRACT HIGH BYTES
                MOV H,A
                PUSH2            ;ANSWER BACK ON STACK
                POP D            ;RESTORE
                POP H
>>
<< WAV         ;MOVE TO NEW WAVELENGTH
                PUSH H          ;SAVE STATUS AND REGISTERS
                PUSH B
                PUSH D
                PUSH PSW
                LHL 17           ;GET OLD WAVELENGTH
                XCHG
                LHL 24           ;GET NEW WAVELENGTH
                SHLD 17          ;UPDATE WAVELENGTH
                PUSH2            ;AND PLACE ON STACK
                XCHG
                PUSH2            ;OLD WAVELENGTH ON STACK
                SUBTR           ;SUBTRACT
                JC .20           ;JUMP IF CARRY DURING SUBTRACTION
                UP              ;INCREMENT WAVELENGTH
:10            XRA A            ;CLEAR A
                STA 36           ;CLEAR ERROR LOCATION
                POP PSW          ;AND RETURN
                POP D
                POP B
                POP H
                RET
:20            POP2            ;GET ANSWER
                MOV A,L          ;COMPLEMENT AND INCREMENT COUNT
                CMA
                ADI 1
                MOV L,A
                MOV A,H
                CMA

```

```

ACI      0
MOV      H,A
PUSHE2   ;COUNT BACK ON STACK
DOWN     ;DECREMENT MONOCHROMATOR
JNC      .10 ;JUMP IF NO ERROR
MVI      A,1
STA      36 ;STORE ERROR CODE IN LOC 36
JMP      .10

>>
<< AUTO ;MONOCHROMATOR UNDER MICRO CONTROL
        PUSH    PSW
        LDA     21 ;GET STATUS
        ORI     2 ;SET EXTERNAL ENABLE BIT
        STA     21 ;UPDATE STATUS
        STA     120000
        POP     PSW

>>
<< MAN ;PUT MONOCHROMATOR ON MANUAL
        PUSH    PSW
        LDA     21 ;GET STATUS
        ANI     14 ;CLEAR EXTERNAL ENABLE BIT
        STA     21 ;UPDATE STATUS
        STA     120000
        POP     PSW

>>
<< CLRMEM ;CLEAR 8K DATA MEMORY
        PUSH    PSW
        PUSH    H
        PUSH    D
        LXI     H,20000 ;MEMORY STARTING ADDRESS
        SHLD    120011 ;INITIALIZE MEMORY POINTER
        SHLD    102 ;INITIALIZE MEMORY POINTER
        LXI     D,0
:10      MVI     M,0 ;CLEAR MEMORY
        INX     H ;INCREMENT MEMORY ADDRESS
        INX     D ;AND COUNTER
        MOV     A,D
        ANI     100 ;TEST BIT 15
        JZ      .10 ;JUMP IF STILL MORE MEMORY
        POP     D
        POP     H
        POP     PSW

>>
<< DIV ;16-BIT BY 8-BIT UNSIGNED DIVISION
        ;SAVE STATUS AND REGISTERS
        PUSH    PSW
        PUSH    H
        PUSH    D
        PUSH    B
        OFF     ;GET DIVISOR
        MOV     B,A
        POP2    ;GET DIVIDEND
        MVI     C,21 ;BIT COUNTER
        XRA     A
:10      MOV     D,A
        MOV     A,L
        RAL     ;ROTATE LOW BYTE
        MOV     L,A
        MOV     A,H
        RAL     ;ROTATE HIGH BYTE
        MOV     H,A
        DCR     C ;DECREMENT COUNTER
        JZ      .30
        MOV     A,D
        RAL
        JNC     .20

```

```

SUB      B
:20      JMP      .10
SUB      B
JNC      .10
ADD      B
JMP      .10
:30      MOV      A,H      ;COMPLEMENT HIGH BYTE OF QUOTIENT
CMA
MOV      H,A
MOV      A,L
CMA      ;COMPLEMENT LOW BYTE
MOV      L,A
PUSH2    ;QUOTIENT ON STACK
MOV      A,D
ON        ;REMAINDER ON STACK
POP      B      ;RESTORE STATUS AND REGISTERS
POP      D
POP      H
POP      PSW
>>
<< BINDEC      ;16-BIT BINARY TO 5 DIGIT BCD
PUSH      H
PUSH      B
PUSH      PSW
MVI      C,5      ;INITIALIZE BCD DIGIT COUNTER
MOV      B,C
:10      MVI      A,12      ;DIVISOR FOR 10
ON
DIV        ;DIVIDE BINARY NUMBER BY 10
OFF        ;GET REMAINDER
PUSH      PSW      ;AND SAVE
DCR      C      ;DECREMENT BCD COUNT
JNZ      .10      ;JUMP IF MORE LEFT
POP2      ;GET QUOTIENT
MOV      C,B      ;REINITIALIZE BCD COUNTER
:15      POP      PSW      ;RECOVER REMAINDER
CPI      0      ;IS IT A ZERO?
JNZ      .25      ;NO, REST OF DIGITS ARE SIGNIFICANT
DCR      B      ;YES, DECREMENT COUNT
DCR      C
JNZ      .15      ;JUMP IF MORE TO DO
INR      C
INR      B
JMP      .25
:20      POP      PSW
:25      ON        ;PUT REMAINDER ON STACK
DCR      C
JNZ      .20
MOV      A,B      ;GET NUMBER OF NON-ZERO DIGITS
ON        ;AND PUT ON STACK
POP      PSW
POP      B
POP      H
>>
<< POUT2      ;MICRO 2 I/O ROUTINE
PUSH      D
PUSH      H
PUSH      B
PUSH      PSW
LDA      117      ;CALCULATE SCAN FREQUENCY
LXI      H,1750    ;1000KHZ
CALL     .40      ;DIVIDE 1000KHZ BY DESIRED FREQ
JP       .10      ;JUMP IF BIT 7 NOT SET
INR      L      ;ELSE BUMP COUNT
:10      MOV      A,L      ;AND SAVE

```

```

MOV      B,A
LXI      H,1730
CALL     .40      ;DIVIDE THIS TIME BY COUNT
JP       .15
:15      INR      L
MOV      A,L
STA      117      ;STORE  ACTUAL FREQ FOR POUT
MVI      H,0
MOV      L,B
PUSH2
BINDEC           ;GET BCD DIGITS
POP2
MOV      B,L      ; DIGITS
XRA      A
CMP      H      ;1ST  DIGIT A 0?
JNZ      .5      ;NO,  JUMP
MVI      H,12     ;YES,  MAKE IT A 10
:5      DCR      H      ;DECREMENT
MOV      A,H
DCR      B
JZ       .20      ;JUMP IF ONLY 1 DIGIT
OFF           ;ELSE GET NEXT DIGIT
CPI      0      ;=0?
JNZ      .7      ;NO,  JUMP
MVI      A,12     ;YES,  MAKE IT A 10
:7      DCR      A
RAL
RAL
RAL
RAL
ANI      360      ;MASK OFF LOWER 4 DIGITS
ORA      H      ;ADD  1ST DIGIT
:20     STA      110      ;DEPOSIT
XRA      A
STA      .43      ;INITIALIZE COUNTER
LXI      H,10000  ;4096 -> HL
PUSH2
LHLD     120      ;NUMBER OF POINTS REQUESTED
MOV      D,H
MOV      E,L
:23     XCHG           ;DE->HL
PUSH2
XCHG           ;HL->DE
SUBTR
JC       .24
LXI      H,.43    ;BUMP COUNTER
INR      M
:24     JMP      .23      ;GO SUBTRACT AGAIN
POP2
LDA      .43
CPI      5      ;5 IS MINIMUM INCREMENT
JNC      .22
MVI      A,5      ;MAKE IT A 5
:22     STA      111      ;STORE INCREMENT
LXI      H,10000
CALL     .40
JP       .25
INX      H
:25     SHLD     120      ;STORE  POINTS FOR POUT
MOV      D,H
MOV      E,L
DAD      H      ;DOUBLE WORD COUNT
LDA      37      ;NUMBER OF BYTES
SUI      2
JZ       .26      ;JUMP IF 2

```

```

:26  DAD      D
      SHLD    100      ;STORE WORD COUNT
      LHLD    122      ;H - ACQ : L - DLY
      DCR     L
      DCR     H
:27  MOV      A,H
      ADD     L
      CPI     11      ;ACQ+DLY<11?
      JC      .32      ;YES, JUMP
      XRA     A
      CMP     L
      JZ      .31
      DCR     L      ;DECREMENT AND TRY AGAIN
      JMP     .27
:31  DCR     H
      JMP     .27
:32  MOV      A,H
      RAL
      RAL
      RAL
      ANI     360
      ORA     L
      STA     105
      INR     L
      INR     H
      SHLD    122      ;UPDATE FOR POUT
      LDA     124      ;ADJUST BLANKING
      STA     112
      ANI     60      ;KEEP ONLY D4 D5
      MOV     B,A
      LXI     H,106
      MOV     A,M
      ANI     317      ;CLEAR D4 D5
      ORA     B      ;AND SET THEM
      MOV     M,A
      LDA     125      ;SET UP CONVERTER
      CPI     12      ;10 BITS
      JZ      .41
      JC      .42
      XRA     A
:45  STA     23
      LDA     37      ;GET NUMBER OF BYTES
      CPI     3      ;=3?
      JZ      .46      ;YES, EXIT
      LHLD    26      ;GET NUMBER OF SIGNAL AVERAGES
      MOV     A,H
      ORA     L
      CPI     21      ;NUMBER OF AVERAGES < 17 ?
      JC      .46      ;YES, EXIT
      MVI     L,20
      MVI     H,0
      SHLD    26
:46  POP     PSW
      POP     B
      POP     H
      POP     D
      RET
:40  PUSH2
      ON
      DIV
      OFF
      POP2
      ANA     A
      RET

```

```

:41      MVI      A,15
        JMP      .45
:42      MVI      A,26
        JMP      .45
:43      0
>>
<< DIV3      ;24-BIT X 16-BIT UNSIGNED INTEGER DIVISION
                ;SAVE STATUS AND REGISTERS
        PUSH     PSW
        PUSH     H
        PUSH     D
        PUSH     B
        POP2
        MOV      C,L      ;GET DIVISOR
                        ;LOW BYTE TO REG C
        MOV      B,H      ;HIGH BYTE TO REG B
        POP2
        MVI      A,31     ;ADDRESS OF 3-BYTE DIVIDEND
        STA      .25      ;BIT COUNT
        XRA      A
        MOV      E,A
:10      MOV      D,A
        MOV      A,M      ;ROTATE DIVIDEND LEFT ONE BIT
        RAL
        MOV      M,A
        INX      H
        MOV      A,M
        RAL
        MOV      M,A
        INX      H
        MOV      A,M
        RAL      ;MSB OF DIVIDEND INTO CARRY
        MOV      M,A
        DCX      H
        DCX      H
        LDA      .25
        DCR      A      ;DECREMENT BIT COUNT
        JZ      .30      ;IF A=0, JUMP TO EXIT
        STA      .25      ;ELSE STORE COUNT AND CONTINUE
        MOV      A,E
        RAL      ;MSB OF DIVIDEND INTO REMAINDER LOW BIT
        MOV      E,A
        MOV      A,D
        RAL
        MOV      D,A
        JNC      .20      ;JUMP IF BORROW ON SUBTRACTION POSSIBLE
        MOV      A,E
        SUB      C      ;SUBTRACT LOWER BYTES
        MOV      E,A
        MOV      A,D
        SBB      B      ;SUBTRACT HIGH BYTES
        JMP      .10      ;LOOP
:20      MOV      A,E
        SUB      C      ;SUBTRACT LOW BYTES
        MOV      E,A
        MOV      A,D
        SBB      B      ;SUBTRACT HIGH BYTES
        JNC      .10      ;JUMP IF NO BORROW
        MOV      D,A      ;RESTORE D
        MOV      A,E      ;ELSE ADD DIVISOR BACK
        ADD      C
        MOV      E,A
        MOV      A,D
        ADC      B
        JMP      .10      ;AND LOOP
:25      000      ;STORAGE LOCATION FOR BIT COUNT
:30      MOV      A,M      ;GET QUOTIENT AND COMPLEMENT

```

```

CMA
MOV      M,A
INX      H
MOV      A,M
CMA
MOV      M,A
INX      H
MOV      A,M
CMA
MOV      M,A
INX      H
PUSH2    ;ADDRESS OF NEXT DATA WORD ON STACK
XCHG
PUSH2    ;REMAINDER ON STACK
POP      B      ;RESTORE STATUS AND REGISTERS
POP      D
POP      H
POP      PSW
>>
<< NORM2    ;NORMALIZE DATA - MICRO 2
PUSH     H
PUSH     D
PUSH     B
PUSH     PSW
LDA      127    ;GET MODE
RAR      ;BIT0 -> CARRY
JNC      .15    ;SKIP DARK IF NO CARRY
PUSH     PSW
LXI      H,20000 ;STARTING ADDRESS OF DARK
CALL     .40    ;NORMALIZE
POP      PSW    ;GET A BACK
:15      RAR      ;BIT1 -> CARRY
JNC      .20    ;SKIP REFERENCE IF NO CARRY
PUSH     PSW    ;SAVE A
LXI      H,25252 ;STARTING ADDRESS OF REFERENCE
CALL     .40    ;NORMALIZE
POP      PSW    ;GET A
:20      RAR      ;BIT2 -> CARRY
JNC      .25    ;SKIP SAMPLE IF NO CARRY
LXI      H,32524 ;STARTING ADDRESS OF SAMPLE
CALL     .40
:25      POP      PSW
POP      B
POP      D
POP      H
RET
:40      LDA      37    ;GET NUMBER OF BYTES
CPI      3        ;=3?
JZ       .43      ;YES, JUMP
XCHG     ;NO, 16-BIT DATA(ADDRESS->DE)
LHLD     120      ;GET NUMBER OF POINTS
MOV      B,H
MOV      C,L
:41      LDAX     D      ;GET LOWER DATA BYTE
MOV      L,A      ; IN L
INX      D        ;INCREMENT MEMORY POINTER
LDAX     D        ;GET UPPER DATA BYTE
MOV      H,A      ; IN H
PUSH2    ;PUSH ON STACK
LDA      26      ;GET NUMBER OF AVERAGES
ON       ;PUSH ON STACK
DIV      ;NORMALIZE
OFF      ;GET REMAINDER
POP2     ;GET NORMALIZED DATA
ANA      A        ;BIT7 = 1?

```

```

      JP      .42      ;NO. JUMP
      INX     H        ;YES, INCREMENT ANSWER
:42   MOV     A,H
      STAX    D        ;RETURN NORMALIZED DATA TO MEMORY
      DCX     D
      MOV     A,L
      STAX    D
      INX     D        ;SET MEMORY POINTER TO NEXT DATA WORD
      INX     D
      DCX     B        ;DECREMENT COUNT
      MOV     A,B
      ORA     C
      JNZ     .41      ;JUMP IF MORE TO DO
      RET      ;ELSE RETURN
:43   XCHG    ;HERE FOR 24-BIT DATA(HL->DE)
      LHLD    120      ;GET NUMBER OF POINTS
      MOV     B,H
      MOV     C,L
      LHLD    26        ;NUMBER OF AVERAGES
      XCHG    ;DATA ADDRESS TO HL
      PUSH2   ;TO STACK
:44   XCHG    ;NUMBER OF AVERAGES TO HL
      PUSH2   ;TO STACK
      XCHG
      DIV3
      POP2    ;NORMALIZE
      DCX     B        ;CLEAR OFF REMAINDER
      MOV     A,B      ;DECREMENT COUNT
      ORA     C
      JNZ     .44      ;JUMP IF MORE TO DO
      RET      ;ELSE RETURN
>>
<< SUBTRD      ;SUBTRACT DARK FROM SIGNAL - MICRO 2
      PUSH    H
      PUSH    B
      PUSH    D
      PUSH    PSW
      LXI     D,25252 ;ADDRESS OF REFERENCE
      CALL    .30
      LXI     D,32524 ;ADDRESS OF SAMPLE
      CALL    .30
      POP     PSW
      POP     D
      POP     B
      POP     H
      RET
:30   LXI     B,20000 ;ADDRESS OF DARK
      LHLD    120      ;JUMBR OF POINTS
      PUSH    H
:32   LDAX    D        ;GET LOW BYTE
      MOV     L,A
      INX     D
      LDAX    D        ;HIGH BYTE
      MOV     H,A
      PUSH2   B
      LDAX    B
      MOV     L,A
      INX     B
      LDAX    B
      MOV     H,A
      PUSH2   B
      SUBTR
      POP2    ;POP ANSWER
      JNC     .35
      LXI     H,0

```

```

:35  MOV    A,H
      STAX  D      ;CORRECTED DATA BACK TO MEMORY
      DCX   D
      MOV   A,L
      STAX  D
      INX   D
      INX   D
      INX   B
      LDA   37      ;NUMBER OF BYTES/DATA WORD
      CPI   3      ;=3?
      JNZ   .40     ;NO, JUMP
      INX   D
      INX   B      ;YES, INCREMENT COUNTERS
:40  POP    H      ;GET COUNT
      DCX   H
      MOV   A,H
      ORA   L
      RZ      ;RETURN IF DONE
      PUSH  H
      JMP   .32

>>
<< XT      ;CALCULATE XT - MICRO 2
      PUSH  H
      PUSH  B
      PUSH  D
      PUSH  PSW
      LHLD  120     ;NUMBER OF POINTS
      PUSH  H
      LXI   H,20000 ;ADDRESS OF XT DATA
      SHLD  .22
      LXI   D,25252 ;REFERENCE ADDRESS
      LXI   B,32524 ;SAMPLE ADDRESS
:5   LDAX   D
      MOV   L,A
      INX   D
      LDAX  D
      MOV   H,A
      PUSH2 ;REFERENCE TO STACK
      LDAX  B
      MOV   L,A
      INX   B
      LDAX  B
      MOV   H,A
      PUSH2 ;SAMPLE TO STACK
      SUBTR
      JNC   .10     ;JUMP IF R>S
      POP2  ;CLEAN OFF STACK
      DCX   D
      DCX   B
      MVI   A,377   ;T = 255 IF S>R
      JMP   .15
:10  LDA   133      ;GET THRESHOLD
      MOV   L,A
      MVI   H,0
      PUSH2
      SUBTR      ;SUBTRACT THRESHOLD
      POP2      ;AND ANSWER
      JNC   .12
      DCX   D
      DCX   B
      MVI   A,377   ;IF R-S<THR, THEN T = 255
      JMP   .15
:12  LDAX  B
      MOV   H,A
      DCX   B

```

```

LDAX    B
MOV     L,A
SHLD    131      ;STORE SAMPLE IN SCRATCH PAD
XRA     A
STA     130      ;SET UP SAMPLE X 256
LXI     H,130    ;ADDRESS OF SCRATCH PAD
PUSH2
LDAX    D
MOV     H,A
DCX     D
LDAX    D
MOV     L,A
PUSH2
DIV3
POP2
POP2
LDA     130
:15     LHL      .22      ;REFERENCE TO STACK
MOV     M,A      ;DIVIDE (SAMP X 256)/REF
INX     H
SHLD    .22      ;CLEAR OFF REMAINDER
INX     D
INX     D
INX     B
INX     B
LDA     37        ;AND ADDRESS
CPI     3         ;GET XT
JNZ     .20       ;ADDRESS OF ANSWER
INX     D
INX     B
:20     POP      H        ;NUMBER OF BYTES/DATA WORD
DCX     H         ;=3?
MOV     A,H
ORA     L
JZ      .25       ;NO, JUMP
PUSH    H         ;YES, INCREMENT COUNTERS AGAIN
JMP     .5
:22     000,000
:25     POP      PSW
POP      D
POP      B
POP      H
>>
<< VSETUP      ;SET UP VIDICON SCAN PARAMETERS
PUSH    H
PUSH    B
PUSH    D
PUSH    PSW
MVI     C,7
LXI     H,140000 ;STARTING ADDRESS OF INTERFACE BOARD
LXI     D,104    ;STARTING ADDRESS OF PARAMETER STORAGE
:10     LDAX    D      ;GET SCAN PARAMETER BYTE
MOV     M,A
INX     H
INX     D
DCR     C
JNZ     .10       ;JUMP IF MORE PARAMETERS
LDA     21
STA     120000    ;UPDATE MONOCHROMATOR STATUS
POP     PSW
POP     D
POP     B
POP     H
>>
<< FASET      ;SET UP FAST ADDER CIRCUIT

```

```

PUSH    D
PUSH    H
PUSH    PSW
LXI     D,120010;STARTING ADDRESS OF F.A.
LDA     37      ; BYTES OF PRECISION
DCR     A
STAX    D
INX     D
LHLD    102      ;ADDRESS OF NEXT AVAILABLE MEM LOCATION
XCHG
MOV     M,E      ;LOW BYTE OF ADDRESS
INX     H
MOV     M,D      ;HIGH BYTE OF ADDRESS
INX     H
LDA     35
MOV     M,A      ;F.A. STATUS
INX     H
MOV     M,A      ;INITIALIZE BYTE AND ADDRESS COUNTERS
LDA     21
STA     120000   ;UPDATE MONOCHROMATOR STATUS
POP     PSW
POP     H
POP     D

>>
<< VINIT2      ;INITIALIZE MICRO 2
VSETUP      ;SET UP DEFAULT SCAN PARAMETERS
MAN         ;MONOCHROMATOR ON MANUAL CONTROL
SCLOSE      ;CLOSE SHUTTER
SREF        ;SELECT REFERENCE CELL
FASET       ;INITIALIZE FAST ADDER CIRCUIT
CLRMEM      ;CLEAR DATA MEMORY

>>
<< A          ;CALCULATE A - MICRO 2

PUSH    H
PUSH    B
PUSH    D
PUSH    PSW
LHLD    120      ;GET NUMBER OF POINTS
PUSH    H
LXI     D,20000  ;ADDRESS OF XT DATA
DAD     D        ;STARTING ADDRESS OF A DATA IN HL
INX     H
SHLD    .30      ;STORE
SHLD    134
:10     LXI     H,.40 ;STARTING ADDRESS OF A TABLE
LDAX    D        ;GET XT
INX     D
MOV     C,A
MVI     B,0
DAD     B        ;GET ADDRESS OF A IN TABLE
MOV     A,M      ;GET A
LHLD    .30
MOV     M,A
INX     H
SHLD    .30
POP     H        ;NUMBER OF POINTS
DCX     H
MOV     A,H
ORA     L
JZ      .20      ;EXIT IF DONE
PUSH    H
JMP     .10      ;ELSE CONTINUE
:20     POP     PSW
POP     D
POP     B

```

```

POP      H
RET
:30      000,000
:40      377
          360,322,300,264,252,242,234,226,221,214,210,204,201,176,173
          170,165,163,160,156,154,152,150,146,144,143,141,137,136,134
          133,132,130,127,126,125,123,122,121,120,117,116,115,114,113
          112,111,110,107,106,105,105,104,103,102,101,101,100, 77, 76
          76, 75, 74, 74, 73, 72, 72, 71, 70, 70, 67, 66, 66, 65, 65
          64, 64, 63, 62, 62, 61, 61, 60, 60, 57, 57, 56, 56, 55, 55
          54, 54, 53, 53, 52, 52, 51, 51, 51, 50, 50, 47, 47, 46, 46
          46, 45, 45, 44, 44, 44, 43, 43, 42, 42, 42, 41, 41, 41, 40
          40, 40, 37, 37, 36, 36, 36, 35, 35, 35, 34, 34, 34, 33, 33
          33, 32, 32, 32, 32, 31, 31, 31, 30, 30, 30, 27, 27, 27, 27
          26, 26, 26, 25, 25, 25, 25, 24, 24, 24, 23, 23, 23, 22
          22, 22, 22, 21, 21, 21, 21, 20, 20, 20, 20, 17, 17, 17, 17
          16, 16, 16, 16, 15, 15, 15, 15, 15, 14, 14, 14, 14, 13, 13
          13, 13, 12, 12, 12, 12, 12, 11, 11, 11, 11, 11, 10, 10, 10
          10, 10, 7, 7, 7, 7, 7, 6, 6, 6, 6, 6, 5, 5, 5
          5, 5, 4, 4, 4, 4, 4, 3, 3, 3, 3, 3, 2, 2, 2
          2, 2, 2, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0
>>
<< DATCOL      ;SIGNAL INTEGRATION AND AVERAGING
          PUSH   PSW
          PUSH   H
          PUSH   B
          PUSH   D
          LHL D
          MOV    C,L
          MOV    A,C      ; OF INTEGRATIONS
          STA    .25
          MOV    B,H      ;F.A. STATUS IN REG B
          LHL D
          XCHG      ; OF AVERAGES IN DE
          LXI     H,106    ;ADDRESS OF VIDICON STATUS
          CALL    .10      ;CHECK SCAN FLAG
          CALL    .10      ;CHECK AGAIN FOR SYNC
:50      XRA      A
          CMP     C      ;ANY INTEGRATIONS?
          CNZ     .20      ;YES, GO INTEGRATE
          MOV     A,B      ;GET F.A. STATUS
          ORI     20      ;SET F.A. START SCAN BIT
          MOV     B,A
          STA     120013    ;SET UP F.A. SCAN ENABLE
          CALL    .10      ;START SCAN ON FLAG
          DCX     D      ;DECREMENT OF AVERAGES
          MOV     A,E
          ORA     D
          JNZ     .50      ;JUMP IF MORE TO DO
          MOV     A,B
          ANI     17      ;CLEAR SCAN BIT OF ADDER
          STA     120013
          CALL    .10      ;ADDER STOPS ON FLAG
          LDA     120016    ;CHECK ERROR FLAGS
          ANI     3      ;CLEAR NON-ERROR BITS
          ON      ;PUSH FLAGS ON STACK
          STA     120017    ;CLEAR ERROR FLAGS
          POP     D      ;RESTORE
          POP     B
          POP     H
          POP     PSW
          RET      ;RETURN WITH DATA IN MEMORY
:10      PUSH     H
          LXI     H,140011
:12      MOV     A,M      ;GET FRAME FLAG

```

```

      ANI      200      ;TEST BIT 7
      JZ       .12      ;LOOP TIL FLAG
      DCX      H
      MOV      M,A      ;CLEAR FLAG
      POP      H
      RET      ;RETURN
:20  MOV      A,B
      ANI      17      ;CLEAR F.A. SCAN BIT
      MOV      B,A
      STA      120013
      MOV      A,M      ;GET VIDICON STATUS
      ANI      376     ;CLEAR SCAN BIT
      MOV      M,A
      STA      140002
:22  CALL     .10      ;INTEGRATION STARTS ON FLAG
      DCR      C      ;DECREMENT INTEGRATION COUNT
      JNZ      .22      ;LOOP IF MORE INTEGRATIONS
      MOV      A,M      ;ELSE, RETURN FOR READOUT
      ORI      1      ;SET SCAN BIT
      MOV      M,A
      STA      140002 ;ENABLE SCAN CIRCUIT
      LDA      .25
      MOV      C,A      ;RESTORE INTEGRATION COUNT
      RET
:25  000      ;INTEGRATION COUNT STORAGE
>>
<< DDAT2      ;DARK DATA - MICRO 2
      PUSH     H
      PUSH     PSW
      LXI      H,20000
      SHLD     102
      FASET
      SCLOSE   ;INITIALIZE ADDER
      DATCOL   ;CHECK SHUTTER
      OFF      ;COLLECT DATA
      LXI      H,36    ;GET STATUS
      ORA      M
      MOV      M,A
      POP      PSW
      POP      H
>>
<< RDAT2      ;REFERENCE DATA - MICRO 2
      PUSH     PSW
      PUSH     H
      LXI      H,25252
      SHLD     102    ;STORE STARTING ADDRESS
      FASET    ;INITIALIZE ADDER
      SOPEN    ;CHECK SHUTTER
      SREF     ;SELECT REFERENCE CELL
      DATCOL   ;COLLECT DATA
      OFF      ;GET STATUS
      LXI      H,36
      ORA      M
      MOV      M,A
      POP      H
      POP      PSW
>>
<< SDAT2      ;SAMPLE DATA - MICRO 2
      PUSH     H
      PUSH     PSW
      LXI      H,32524
      SHLD     102    ;STORE STARTING ADDRESS
      FASET    ;INITIALIZE ADDER
      SOPEN    ;CHECK SHUTTER
      SSAMP    ;SELECT SAMPLE CELL

```

```

        DATCOL      ;COLLECT DATA
        OFF         ;GET STATUS
        LXI         H,36
        ORA         M      ;OR STATUS WITH MEMORY
        MOV         M,A    ;STORE STATUS
        POP         PSW
        POP         H
    >>
    << DATA2      ;COLLECT DATA - MICRO 2
        PUSH        H
        PUSH        B
        PUSH        PSW
        XRA         A
        STA         36     ;CLEAR ERROR LOCATION
        LDA         127    ;GET MODE
        RAR         ;BIT0 -> CARRY
        JNC         .15    ;SKIP DARK IF NO CARRY
        PUSH        PSW
        DDAT2       ;COLLECT DARK
        POP         PSW
    :15 RAR         ;BIT1 -> CARRY
        JNC         .25    ;SKIP REFERENCE IF NO CARRY
        PUSH        PSW
        RDAT2       ;COLLECT REFERENCE
        POP         PSW
    :25 RAR         ;BIT2 -> CARRY
        JNC         .35    ;SKIP SAMPLE IF NO CARRY
        SDAT2       ;COLLECT SAMPLE
    :35 POP         PSW
        POP         B
        POP         H
    >>

```

NOVEMBER 21, 1977

**** COMPILER WITH /ON SWITCH ****

```

BYTE IFILE(24),IBUFF(256),ANS,Y,NN(2),NM(2)
BYTE JWORK(2460)

```

```

DIMENSION ISAMP(819), IREF(819), IDARK(819)

```

DIMENSION IWORK(819)

EQUIVALENCE (ICNT,NN),(NBYT,NMD)

DATA Y / 'Y' /

CHECK TO SEE IF FILE EXISTS OR ERROR

CALL FORPIP (IFILE,IMODE)

```
IF ( IMODE.EQ.1) GOTO 20
```

WRITE(6,902)

GOTO 10

OPEN FILE FOR UNFORMATTED BINARY READ

IERR=0

CALL UNFMO(IERR, IFILE, 0, 1)

```
IF( IERR.EQ.0) GOTO 25
```

WRITE(6,933) IERR

GOTO 40

READ 256 BYTES FROM FILE

1 BYTE=256

IERR=0

CALL UNFMRW(IERR, IBUFF, IBYTE)

```
IF( IERR.NE.1) GOTO 30
```

WRITE(6,904)

GOTO 40

OUTPUT ASCII TEXT TO TERMINAL

NEND=0

INDEX= 1

CALL TEXT(Ibuff, Ibyte, Index, Nend)

```
IF(NEND.EQ.1) GOTO 35
```

```
IF( IBYTE.EQ.0) GOTO 25
```

ALL TEXT OUTPUT - SEE IF FILE IS TO BE PROCESSED

WRITE(6,905)

READ(6,906) ANS

IF(ANS.EQ.Y) GOTO 50

CALL UNFMC(IERR)

WRITE(6,907)

READ(6, 906) ANS

IF(ANS.EQ.Y) GOTO 10

CALL EXIT

```

C
C      BEGIN PROCESSING DATA - DARK FIRST
C
50      DO 55 I=1,819
          IREF(I)=0
          ISAMP(I)=0
          IDARK(I)=0
55      CONTINUE
          ICODE=1
          GOTO 100
60      ISCALD=1
          NAVG=0
          CALL REPACK( IDARK, JWORK, ICNT, ISCALD, NAVG)
C
C      PROCESS REFERENCE DATA NEXT
C
          ICODE=2
          GOTO 100
70      ISCALR=1
          CALL REPACK( IREF, JWORK, ICNT, ISCALR, NAVG)
C
C      PROCESS SAMPLE DATA LAST
C
          ICODE=3
          GOTO 100
80      ISCAL=1
          CALL REPACK( ISAMP, JWORK, ICNT, ISCAL, NAVG)
          GOTO 120
C
C      DATA PROCESSING ROUTINE
C
100     IF( IBYTE.EQ.0) CALL RFILE( IBYTE, IERR, INDEX, Ibuff)
          NN(1)=Ibuff( INDEX)
          INDEX=INDEX+1
          IBYTE=IBYTE-1
          IF( IBYTE.EQ.0) CALL RFILE( IBYTE, IERR, INDEX, Ibuff)
          NN(2)=Ibuff( INDEX)
          INDEX=INDEX+1
          IBYTE=IBYTE-1
          DO 110 I=1, ICNT
              IF( IBYTE.EQ.0) CALL RFILE( IBYTE, IERR, INDEX, Ibuff)
              JWORK(I)=Ibuff( INDEX)
              INDEX=INDEX+1
              IBYTE=IBYTE-1
110     CONTINUE
          GOTO (60,70,80), ICODE
C
C      PROCESSING COMPLETE - CLOSE INPUT FILE
C
120     CALL UNFMC( IERR)
          IF( IERR.NE.0) WRITE (6,934) IERR
          NBYT=0
          NM(1)=JWORK(3)
          NPT=( ICNT-3)/NBYT
C
C      NORMALIZE DATA BUFFERS
C
          MAX=MAX0( ISCAL, ISCALD, ISCALR)
          WRITE(6,929) MAX, NAVG
          READ(6,909) NORM
          IF( NORM.LE.MAX) NORM=MAX
          IF( NORM.GE.NAVG) NORM=NAVG
          IF( NORM.EQ.0) NORM=1
          SCALS=FLOAT( ISCAL)/FLOAT( NORM)
          SCALR=FLOAT( ISCALR)/FLOAT( NORM)

```

```

SCALD=FLOAT(ISCALD)/FLOAT(NORM)
DO 130 I=1,NPT
S1=FLOAT(ISAMP(I))+32767.
R1=FLOAT(IREF(I))+32767.
D1=FLOAT(IDARK(I))+32767.
S1=S1*SCALS+0.5
R1=R1*SCALR+0.5
D1=D1*SCALD+0.5
ISAMP(I)=INT(S1-32767.)
IREF(I)=INT(R1-32767.)
IDARK(I)=INT(D1-32767.)
130 CONTINUE
C
C BEGIN OUTPUT SECTION
C
WRITE(6,932)
READ(6,906) ANS
IF(ANS.EQ.Y) GOTO 111
ICODE=1
GOTO 402
C
C SUBTRACT DARK SIGNAL
C
111 DO 993 I=1,819
IWORK(I)=0
993 CONTINUE
DAVC=0
DO 400 I=1,NPT
DAVC=DAVC+FLOAT(IDARK(I))
400 DAVC=DAVC/FLOAT(NPT)
FSPOS=32767.
FSNEG=-32767.
DO 410 I=1,NPT
S=ISAMP(I)
R=IREF(I)
D=IDARK(I)
S=S-D+DAVC
R=R-D+DAVC
IF((S-FSNEG).LT.0) S=FSNEG
IF((S-FSPOS).GT.0) S=FSPOS
IF((R-FSNEG).LT.0) R=FSNEG
IF((R-FSPOS).GT.0) R=FSPOS
ISAMP(I)=INT(S+0.5)
410 IREF(I)=INT(R+0.5)
WRITE(6,908)
1 WRITE(6,917)
READ(6,909) IA
ICODE=1
IF(IA.LT.0) GOTO 402
IF(IA.EQ.0) GOTO 2
301 GOTO (190,201,202,203,204,500,600,700,800,
1899,860,820,840),IA
402 WRITE(6,908)
GOTO (1,2),ICODE
200 WRITE(6,910) (IWORK(I),I=1,NPT)
GOTO 1
2 WRITE(6,928)
READ(6,909) IA
ICODE=2
IF(IA)402,1,301
C
C DARK
C
190 DO 191 I=1,NPT
191 IWORK(I)=IDARK(I)

```

```

C      GOTO (200,300), ICODE
C
C      SAMPLE
C
201    DO 211 I=1,NPT
211    IWORK(I)=ISAMP(I)
      GOTO (200,300), ICODE
C
C      REFERENCE
C
202    DO 212 I=1,NPT
212    IWORK(I)=IREF(I)
      GOTO (200,300), ICODE
C
C      XT
C
203    WRITE(6,911)
      READ(6,909) ITH
      THR=ITH
      DO 213 I=1,NPT
      R=IREF(I)
      S=ISAMP(I)
303    IF((R-S)-THR) 304,312,312
312    T=1000.*(S-DAVG)/(R-DAVG)
      IWORK(I)=T
      IF(1000-IWORK(I)) 304,304,305
304    IWORK(I)=1000
305    CONTINUE
213    CONTINUE
      GOTO (200,300) ICODE
C
C      ABSORBANCE
C
204    WRITE(6,911)
      READ(6,909) ITH
      THR=ITH
      DO 214 I=1,NPT
      R=IREF(I)
      S=ISAMP(I)
306    IF((R-S)-THR) 310,313,313
313    T=(S-DAVG)/(R-DAVG)
      IF(1.-T) 310,310,308
308    IF(T) 310,310,309
309    IWORK(I)=-1000.*ALOG10(T)
      GOTO 311
310    IWORK(I)=0
311    CONTINUE
214    CONTINUE
      GOTO (200,300) ICODE
300    CONTINUE
      M=0
      M=M+1
      N=NPT
C
C      FIND MINIMUM AND MAXIMUM AND SCALE FOR PLOTTING
C
3    PMIN=IWORK(M)
      PMAX=IWORK(M)
      JMIN=M
      JMAX=M
      DO 8 I=M,N
      T=IWORK(I)
      IF(T-PMIN) 5,6,6
5      PMIN=T
      JMIN=I

```

```

6      IF(PMAX-T) 7,8,8
7      PMAX=T
      JMAX=I
8      CONTINUE
      WRITE(6,912) PMIN, JMIN
      WRITE(6,913) PMAX, JMAX
      WRITE(6,914)
      READ(6,915) SMIN
      WRITE(6,916)
      READ(6,915) SMAX
      YSCALE=600./(SMAX-SMIN)
      XSCALE=1000./FLOAT(NPT)
      WRITE(6,918)
      READ(6,909) IAM
      NCODE=0
      IF(IAM.NE.0) GOTO 17

C
C      LINE PLOT
C
870    IX=XSCALE*FLOAT(MD
      IY=(FLOAT(IWORK(1))-SMIN)*YSCALE
      IF(IY.GT.600) IY=600
      IF(IY.LT.0) IY=0

C
C      ERASE SCREEN, GO TO GRAPHICS MODE, DRAW AXIS,
C      TICK MARKS, AND DARK VECTOR TO FIRST POINT
C

      CALL T4010(0)
      CALL T4010(5,10,10)
      CALL T4010(1,IX,IY)
      L=M+1
      DO 18 I=L,N
      IX=XSCALE*FLOAT(I)
      YI=(FLOAT(IWORK(1))-SMIN)*YSCALE
      IF(YI.GT.600.) YI=600.
      IF(YI.LT.0) YI=0.
      IY=YI
      CALL T4010(2,IX,IY)
18     CONTINUE

C
C      RETURN TO ALPHA MODE AND HOME
C

      CALL T4010(1,0,780)
      CALL T4010(3)
      GOTO 19

C
C      POINT PLOT
C
17     CONTINUE
      CALL T4010(0)
      CALL T4010(5,10,10)
      DO 9 I=M,N
      IX=XSCALE*FLOAT(I)
      YI=(FLOAT(IWORK(1))-SMIN)*YSCALE
      IF(YI.GT.600.) YI=600.
      IF(YI.LT.0) YI=0.
      IY=YI
      CALL T4010(6,IX,IY)
9      CONTINUE
      CALL T4010(1,0,780)
      CALL T4010(3)
19     IF(NCODE.EQ.1) GOTO 850
      WRITE(6,919)
      READ(6,909) ISIZE
      IF(ISIZE.LE.0) GOTO 2

```

```

      IF( ISIZE.LT.5) GOTO 15
      IF( ISIZE.GT.25) GOTO 15
      M=( ISIZE+1)/2
      N=NPT-M
      CALL SMOOTH( IWORK,NPT, ISIZE)
      GOTO 3
15    WRITE(6,925)
      GOTO 19
C
C    ROUTINE TO OUTPUT DATAFILE TO STORAGE DEVICE
C
500   WRITE(6,920)
      READ(6,901) IFILE
      CALL ASSIGN(4, IFILE,24, IERR)
      WRITE(4,926) N
      IF( IA.LE.3) GOTO 506
      DO 510 I=M,N
      X=FLOAT( I)
      Y=FLOAT( IWORK( I))
      WRITE(4,927) X,Y
510   CONTINUE
      GOTO 511
506   DO 507 I=M,N
      X=FLOAT( I)
      Y=FLOAT( IWORK( I))+32767.
      WRITE(4,927) X,Y
507   CONTINUE
511   END FILE 4
      GOTO (1,2), ICODE
C
C    LOCATE
C
600   WRITE(6,931)
      READ(6,906) ANS
      NCODE=1
      IF( IA.NE.0) GOTO 17
      GOTO 870
850   IF( ANS.NE.Y) GOTO 602
      CALL T4010(4, IX, IY)
      XI=FLOAT( IX)/XSCALE
      I=INT(XI)
      WRITE(6,930) I
      LOC=I
      GOTO 702
602   WRITE(6,921)
      READ(6,909) LOC
      IF( LOC.LE.0) GOTO 602
      IF( LOC.GE.NPT) GOTO 602
      IX=XSCALE*FLOAT( LOC)
      IY=0
      CALL T4010(1, IX, IY)
      YI=(FLOAT( IWORK( LOC))-(SMIN+5.))*YSCALE
      IY=INT(YI)
      CALL T4010(2, IX, IY)
      CALL T4010(1,0,780)
      CALL T4010(3)
      GOTO 702
604   WRITE(6,922)
      READ(6,906) ANS
      IF( ANS.EQ.Y) GOTO 600
      GOTO (1,2), ICODE
C
C    EVALUATE
C
700   WRITE(6,923)

```

```

702      READ(6,909) LOC
        IF(LOC.LE.0) GOTO 700
        IF(LOC.GT.NPT) GOTO 700
        S=ISAMP(LOC)
        R=IREF(LOC)
        S=S-DAVG
        R=R-DAVG
        T=S/R
        A=-ALOG10(T)
        WRITE(6,924) S,R,T,A
        IF(NCODE.EQ.1) GOTO 604
        GOTO (1,2),ICODE
800      GOTO 10
C
C      CALCULATE DERIVATIVES
C
820      WRITE(6,941)
        READ(6,909) ISTEP
        ISTEP=ISTEP/2
        ISTART=ISTEP+1
        IEND=NPT-ISTEP
        WRITE(6,943)
        READ(6,909) IORD
824      DO 825 I=ISTART, IEND
        IDARK(I)=IWORK(I+ISTEP)-IWORK(I-ISTEP)
825      CONTINUE
        DO 827 I=ISTART, IEND
827      IWORK(I)=IDARK(I)
        IORD=IORD-1
        IF(IORD.GT.0) GOTO 824
839      GOTO (200,300), ICODE
C
C      DUAL WAVELENGTH SCANNING
C
840      WRITE(6,942)
        READ(6,909) ICHAN
        JCHAN=IWORK(ICHAN)
        DO 844 I=1,NPT
844      IWORK(I)=IWORK(I)-JCHAN
        GOTO (200,300), ICODE
C
C      CALCULATE S/N AND STANDARD DEVIATION
C
860      WRITE(6,935)
        READ(6,915) SATD
        WRITE(6,936)
        READ(6,909) IPEAK
        WRITE(6,937)
        READ(6,938) IST, IEN
        SUM=0.
        SUMSQ=0.
        DO 865 I=IST, IEN
        SUM=SUM+IWORK(I)
865      SUMSQ=SUMSQ+IWORK(I)**2
        XMEAN=SUM/FLOAT(IEN-IST+1)
        DEV=(SUMSQ/FLOAT(IEN-IST+1))-(XMEAN**2)
        DEV=SQRT(DEV)
        XMEAN=XMEAN*(10000./4096.)
        DEV=DEV*(10000./4096.)
        SNM=SATD/DEV
        SNP=IWORK(IPEAK)/DEV
        WRITE(6,939) SNM,SNP,XMEAN,DEV
        GOTO (1,2), ICODE
899      CALL EXIT
C      *****

```

```

900  FORMAT('FILE SPECIFICATION - ')
901  FORMAT(24A1)
902  FORMAT(' *** FILE ERROR ***')
904  FORMAT(' READ ERROR ')
905  FORMAT('SPROCESS FILE ?')
906  FORMAT(1A1)
907  FORMAT('S ANOTHER FILE ?')
908  FORMAT(' DATA OUTPUT CODES: '/' 0 = NOTHING '/'
1' 1 = DARK '/' 2 = SAMPLE '/' 3 = REFERENCE '/'
2' 4 = %T '/' 5 = ABSORBANCE '/' 6 = WRITE
3 FILE '/' 7 = LOCATE '/' 8 = EVALUATE '/'
4' 9 = ANOTHER FILE '/' 10 = EXIT '/'
5' 11 = SN '/' 12 = DERIVATIVE '/'
6' 13 = DUAL WAVELENGTH SCANNING '/')
909  FORMAT(15)
910  FORMAT(/(1X,7(17,4X)))
911  FORMAT('THRESHOLD : ')
912  FORMAT(/' MIN = ',F,' AT POINT ',15)
913  FORMAT(' MAX = ',F,' AT POINT ',15,/)
914  FORMAT('SCREEN BOTTOM = ')
915  FORMAT(F10.4)
916  FORMAT('SCREEN TOP = ')
917  FORMAT('$LIST : ')
918  FORMAT('$LINE PLOT = 0, POINT PLOT = 1 : CHOICE : ')
919  FORMAT('$LENGTH OF SMOOTH IS ')
920  FORMAT('$OUTPUT FILE NAME - ')
921  FORMAT('$POINT TO LOCATE IS ')
922  FORMAT(/,'$LOCATE ANOTHER POINT ?')
923  FORMAT('$POINT TO EVALUATE IS ')
924  FORMAT(10X,' S',18X,' R',18X,' T',18X,' A',/
12X,F,5X,F,5X,F,5X,F)
925  FORMAT('ORANGE OF SMOOTH IS 5 TO 25 POINTS!')
926  FORMAT('NU',15)
927  FORMAT('RD',2(E15.7))
928  FORMAT('$PLOT : ')
929  FORMAT('$NORMALIZATION FACTOR [' ,15,' ,',15'] : ')
930  FORMAT('$ POINT NUMBER IS ',15,/)
931  FORMAT('$GRAPHICAL INPUT ?')
932  FORMAT('$SUBTRACT DARK SIGNAL ?')
933  FORMAT(' ERROR WHILE OPENING FILE - IERR = ',15)
934  FORMAT(' ERROR WHILE CLOSING FILE - IERR = ',15)
935  FORMAT('$SATURATION LEVEL = ')
936  FORMAT('$PEAK LOCATION IS ')
937  FORMAT('$INTERVAL FOR RMS NOISE IS ')
938  FORMAT(2(15))
939  FORMAT('$MAXIMUM S/N = ',F10.2,5X,
1' PEAK S/N = ',F10.2,/' MEAN = ',F10.2,5X
2' STANDARD DEVIATION = ',F12.4,/)
940  FORMAT('$SAMPLE OR REFERENCE ARRAY [S/R] : ')
941  FORMAT('$CHANNEL WIDTH IS [EVEN ] : ')
942  FORMAT('$REFERENCE CHANNEL IS ')
943  FORMAT('$ORDER OF DERIVATIVE IS ')
END

```

```

C          VGVEDO.FTN
C
C          JIM HORNSHUB          NOVEMBER 28, 1977
C
C          PROGRAM TO EVALUATE AND DISPLAY SPECTRAL DATA COLLECTED
C          BY THE CG ENKE VIDICON SPECTROMETER
C
C          FOR USE ONLY ON THE DEPARTMENTAL PDP 11 COMPUTER
C
C          ** COMPILE WITH /ON SWITCH **
C
C          CALLS SUBROUTINES: VECTOR, SMOOTH, FORPIP, UNFM, TEXT, RFILE, REPACK
C
C          BYTE IFILE(24), IBUFF(256), ANS, YES, NN(2), NM(2), JWORK(2460)
C          DOUBLE PRECISION S1, R1, D1
C          DIMENSION ISAMP(819), IREF(819), IDARK(819)
C          DIMENSION IWORK(819)
C          EQUIVALENCE (ICNT, NN), (NBYT, NM)
C          COMMON /VECTOR/XSCALE, YSCALE, IDEV
C          COMMON /VTEK/XUPPER, YUPPER, NIBS
C          INTEGER PMODE
C          DATA YES /'Y'/
10      WRITE (6,900)
C          READ (6,901) IFILE
C          IMODE=0
C
C          CHECK TO SEE IF FILE EXISTS OR ERROR
C
C          CALL FORPIP (IFILE, IMODE)
C          IF (IMODE.EQ.1) GOTO 20
C          WRITE(6,902) IMODE
C          GOTO 10
C
C          OPEN FILE FOR UNFORMATTED BINARY READ
C
C          IERR=0
C          CALL UNFMO(IERR, IFILE, 0, 1)
C          IF(IERR.EQ.0) GOTO 25
C          WRITE(6,903) IERR
C          GOTO 40
C
C          READ 256 BYTES FROM FILE
C
C          IBYTE=256
C          IERR=0
C          CALL UNFMRW(IERR, IBUFF, IBYTE)
C          IF(IERR.NE.1) GOTO 30
C          WRITE(6,904)
C          GOTO 40
C
C          OUTPUT ASCII TEXT TO TERMINAL
C
C          NEND=0
C          INDEX=1
C          CALL TEXT(IBUFF, IBYTE, INDEX, NEND)
C          IF(NEND.EQ.1) GOTO 35
C          IF(IBYTE.EQ.0) GOTO 25
C
C          ALL TEXT OUTPUT - SEE IF FILE IS TO BE PROCESSED
C
C          WRITE(6,905)
C          READ(6,906) ANS
C          IF(ANS.EQ.YES) GOTO 50
C          CALL UNFMC(IERR)
40      WRITE(6,907)

```

```

      READ(6,906) ANS
      IF(ANS.EQ.YES) GOTO 10
      CALL EXIT
C
C      BEGIN PROCESSING DATA - DARK FIRST
C
50    DO 55 I=1,819
      IREF(I)=0
      ISAMP(I)=0
      IDARK(I)=0
55    CONTINUE
      ICODE=1
      GOTO 100
60    ISCALD=1
      NAVG=0
      CALL REPACK( IDARK,JWORK, ICNT, ISCALD,NAVG)
C
C      PROCESS REFERENCE DATA NEXT
C
      ICODE=2
      GOTO 100
70    ISCALR=1
      CALL REPACK( IREF,JWORK, ICNT, ISCALR,NAVG)
C
C      PROCESS SAMPLE DATA LAST
C
      ICODE=3
      GOTO 100
80    ISCAL=1
      CALL REPACK( ISAMP,JWORK, ICNT, ISCAL,NAVG)
      GOTO 120
C
C      DATA PROCESSING ROUTINE
C
100   IF( IBYTE.EQ.0) CALL RFILE( IBYTE, IERR, INDEX, Ibuff)
      NN(1)=Ibuff( INDEX)
      INDEX=INDEX+1
      IBYTE=IBYTE-1
      IF( IBYTE.EQ.0) CALL RFILE( IBYTE, IERR, INDEX, Ibuff)
      NN(2)=Ibuff( INDEX)
      INDEX=INDEX+1
      IBYTE=IBYTE-1
      DO 110 I=1, ICNT
      IF( IBYTE.EQ.0) CALL RFILE( IBYTE, IERR, INDEX, Ibuff)
      JWORK(I)=Ibuff( INDEX)
      INDEX=INDEX+1
      IBYTE=IBYTE-1
110   CONTINUE
      GOTO (60,70,80), ICODE
C
C      PROCESSING COMPLETE - CLOSE INPUT FILE
C
120   CALL UNFMC( IERR)
      NBYT=0
      NN(1)=JWORK(3)
      NPT=( ICNT-3)/NBYT
C
C      NORMALIZE DATA BUFFERS
C
      MAX=MAX0( ISCAL, ISCALD, ISCALR)
      WRITE(6,929) MAX,NAVG
      READ(6,909) NORM
      IF(NORM.LE.MAX) NORM=MAX
      IF(NORM.GE.NAVG) NORM=NAVG
      IF(NORM.EQ.0) NORM=1

```

```

SCALS=FLOAT(ISCALS)/FLOAT(NORMD
SCALR=FLOAT(ISCALR)/FLOAT(NORMD
SCALD=FLOAT(ISCALD)/FLOAT(NORMD
DO 130 I=1,NPT
S1=FLOAT(ISAMP(I))+32767.
R1=FLOAT(IREF(I))+32767.
D1=FLOAT(IDARK(I))+32767.
S1=S1*SCALS+0.5
R1=R1*SCALR+0.5
D1=D1*SCALD+0.5
ISAMP(I)=INT(S1-32767.)
IREF(I)=INT(R1-32767.)
IDARK(I)=INT(D1-32767.)
130 CONTINUE
C
C BEGIN OUTPUT SECTION
C
WRITE(6,912)
READ(6,906) ANS
IF(ANS.EQ.YES) GOTO 111
ICODE=1
GOTO 402
C
C SUBTRACT DARK SIGNAL
C
111 DO 993 I=1,819
IWORK(I)=0
993 CONTINUE
DAVG=0
DO 409 I=1,NPT
409 DAVG=DAVG+FLOAT(IDARK(I))
DAVG=DAVG/FLOAT(NPT)
FSPOS=32767.
FSNEG=-32767.
DO 410 I=1,NPT
S=ISAMP(I)
R=IREF(I)
D=IDARK(I)
S=S-D+DAVG
R=R-D+DAVG
IF((S-FSNEG).LT.0) S=FSNEG
IF((S-FSPOS).GT.0) S=FSPOS
IF((R-FSNEG).LT.0) R=FSNEG
IF((R-FSPOS).GT.0) R=FSPOS
ISAMP(I)=INT(S+0.5)
410 IREF(I)=INT(R+0.5)
WRITE(6,908)
1 WRITE(6,917)
READ(6,909) IA
ICODE=1
IF(IA.EQ.0) GOTO 4
IF(IA.LT.0) GOTO 402
301 GOTO (190,201,202,203,204,500,600,700,800,899,820,840), IA
402 WRITE(6,908)
GOTO (1,2,4), ICODE
200 WRITE(6,910) (IWORK(I), I=1,NPT)
GOTO 1
2 WRITE(6,928)
READ(6,909) IA
ICODE=2
IF(IA) 402.1,301
4 WRITE(6,932)
READ(6,909) IA
ICODE=3
IF(IA) 402.2,301

```

```

400      WRITE(5,910) (IWORK(I), I=1,NPT)
        GOTO 4
C
C      DARK
C
190      DO 191 I=1,NPT
191      IWORK(I)=IDARK(I)
        GOTO (200,300,400),ICODE
C
C      SAMPLE
C
201      DO 211 I=1,NPT
211      IWORK(I)=ISAMP(I)
        GOTO (200,300,400),ICODE
C
C      REFERENCE
C
202      DO 212 I=1,NPT
212      IWORK(I)=IREF(I)
        GOTO (200,300,400),ICODE
C
C      %T
C
203      WRITE(6,911)
        READ(6,909) ITH
        THR=ITH
        DO 213 I=1,NPT
        R=IREF(I)
        S=ISAMP(I)
303      IF((R-S)-THR) 304,312,312
312      T=1000.*(S-DAVG)/(R-DAVG)
        IWORK(I)=T
        IF(1000-IWORK(I)) 304,304,305
304      IWORK(I)=1000
305      CONTINUE
213      CONTINUE
        GOTO (200,300,400) ICODE
C
C      ABSORBANCE
C
204      WRITE(6,911)
        READ(6,909) ITH
        THR=ITH
        DO 214 I=1,NPT
        R=IREF(I)
        S=ISAMP(I)
306      IF((R-S)-THR) 310,313,313
313      T=(S-DAVG)/(R-DAVG)
        IF(1.-T) 310,310,308
308      IF(T) 310,310,309
309      IWORK(I)=-1000.0*ALOG10(T)
        GOTO 311
310      IWORK(I)=0
311      CONTINUE
214      CONTINUE
        GOTO (200,300,400) ICODE
300      CONTINUE
        M=0
        M=M+1
        N=NPT
C
C      FIND MINIMUM AND MAXIMUM AND SCALE FOR PLOTTING
C
3      PMIN=IWORK(M)
        PMAX=IWORK(M)

```

```

JMIN=M
JMAX=M
DO 8 I=M,N
T= IWORK( I)
IF(T-PMIN) 5,6,6
5 PMIN=T
JMIN= I
6 IF(PMAX-T) 7,8,8
7 PMAX=T
JMAX= I
8 CONTINUE
XSCALE=FLOAT(N)/12.0
YSCALE=ABS(PMAX-PMIN)/9.0
WRITE(6,918)
READ(6,909) PMODE
PMODE=PMODE+2
C
C INITIALIZE VECTOR GENERAL AND DRAW AXES
C
XUPPER=12.0
YUPPER=9.0
IDEV=1
CALL VECTOR(0.,0.,0)
Y=ABS(PMAX-PMIN)
CALL VECTOR(0.,Y,1)
CALL VECTOR(0.,0.,2)
X=FLOAT(N)
CALL VECTOR(X,0.,2)
CALL VECTOR(0.,0.,1)
C
C PLOT DATA FILE
C
DO 420 I=M,N
X=FLOAT( I)
Y=FLOAT( IWORK( I))
Y=ABS(Y-PMIN)
IF(PMODE.EQ.3) CALL VECTOR(X,Y,1)
CALL VECTOR(X,Y,2)
420 CONTINUE
CALL VECTOR(X,Y,4)
19 WRITE(6,919)
READ(6,909) ISIZE
IF( ISIZE.LE.0) GOTO 2
IF( ISIZE.LT.5) GOTO 15
IF( ISIZE.GT.25) GOTO 15
M=( ISIZE+1)/2
N=NPT-M
CALL SMOOTH( IWORK,NPT, ISIZE)
GOTO 3
15 WRITE(6,925)
GOTO 19
C
C ROUTINE TO OUTPUT DATAFILE TO STORAGE DEVICE
C
500 WRITE(6,920)
READ(6,901) IFILE
CALL ASSIGN(4, IFILE,24, IERR)
WRITE(4,926) N
IF( IA.LE.3) GOTO 507
DO 510 I=M,N
X=FLOAT( I)
Y=FLOAT( IWORK( I))
WRITE(4,927) X,Y
510 CONTINUE
GOTO 511

```

```

507      DO 506 I=M,N
          X=FLOAT(I)
          Y=FLOAT(IWORK(I))+32767.
          WRITE(4,927) X,Y
506      CONTINUE
511      END FILE 4
          GOTO (1,2,4),ICODE
C
C      LOCATE
C
600      WRITE(6,931)
          READ(6,906) ANS
850      IF(ANS.NE.YES) GOTO 602
          CALL VECTOR(X,Y,-1)
          I=INT(X+0.5)
          WRITE(6,930) I
          LOC=I
          GOTO 702
602      WRITE(6,921)
          READ(6,909) LOC
          IF(LOC.LE.0) GOTO 602
          IF(LOC.GE.NPT) GOTO 602
505      X=FLOAT(LOC)
          Y=0.
          CALL VECTOR(X,Y,1)
          Y=FLOAT(IWORK(LOC))
          Y=ABS(Y-PMIN)
          CALL VECTOR(X,Y,2)
          CALL VECTOR(X,Y,4)
          GOTO 702
604      WRITE(6,922)
          READ(6,906) ANS
          IF(ANS.EQ.YES) GOTO 600
          GOTO (1,2,4),ICODE
C
C      EVALUATE
C
700      WRITE(6,923)
          READ(6,909) LOC
702      IF(LOC.LE.0) GOTO 700
          IF(LOC.GT.NPT) GOTO 700
          S=ISAMP(LOC)
          R=IREF(LOC)
          S=S-DAVG
          R=R-DAVG
          T=S/R
          A=-ALOG10(T)
          WRITE(6,924) S,R,T,A
          IF(IA.EQ.6) GOTO 604
          GOTO (1,2,4),ICODE
800      GOTO 10
C
C      CALCULATE DERIVATIVES
C
820      WRITE(6,941)
          READ(6,909) ISTEP
          ISTEP=ISTEP/2
          ISTART=ISTEP+1
          IEND=NPT-ISTEP
          WRITE(6,943)
          READ(6,909) IORD
824      DO 825 I=ISTART,IEND
          IDARK(I)=IWORK(I+ISTEP)-IWORK(I-ISTEP)
825      CONTINUE
          DO 827 I=ISTART,IEND

```

```

827      IWORK(1)=IDARK(1)
        IORD=IORD-1
        IF(IORD.GT.0) GOTO 824
        GOTO (200,300,400),ICODE

C
C      DUAL WAVELENGTH SCANNING
C
840      WRITE(6,942)
        READ(6,909) ICHAN
        IV=IWORK(ICHAN)
        DO 845 I=1,NPT
845      IWORK(I)=IWORK(I)-IV
        GOTO (200,300,400),ICODE
899      CALL EXIT
C      *****
900      FORMAT('SFILE SPECIFICATION - ')
901      FORMAT(24A1)
902      FORMAT(' FORPIP FILE ERROR - MODE = ',I4)
903      FORMAT(' ERROR WHILE OPENING FILE - IERR = ',I5)
904      FORMAT(' READ ERROR ')
905      FORMAT('SPROCESS FILE ?')
906      FORMAT(1A1)
907      FORMAT('SANOOTHER FILE ?')
908      FORMAT(' DATA OUTPUT CODES: '/' 0 = NOTHING '/' 1 = DARK '/'
1' 2 = SAMPLE '/' 3 = REFERENCE '/' 4 =  $\pi$ T '/' 5 = ABSORBANCE '/'
2' 6 = WRITE FILE '/' 7 = LOCATE '/' 8 = EVALUATE '/'
3' 9 = ANOTHER FILE '/' 10 = EXIT '/' 11 = DERIVATIVE '/'
4' 12 = DUAL WAVELENGTH SCANNING '/' )
909      FORMAT(I5)
910      FORMAT(/(1X,7(17,4X)))
911      FORMAT('STHRESHOLD : ')
912      FORMAT('SSUBTRACT DARK SIGNAL ?')
915      FORMAT(F10.4)
917      FORMAT('SLIST [KB] : ')
918      FORMAT('SLINE PLOT = 0, POINT PLOT = 1 : CHOICE : ')
919      FORMAT('SLENGTH OF SMOOTH IS ')
920      FORMAT('SOUTPUT FILE NAME - ')
921      FORMAT('SPOINT TO LOCATE IS ')
922      FORMAT(/,'SLOCATE ANOTHER POINT ?')
923      FORMAT('SPOINT TO EVALUATE IS ')
924      FORMAT(10X,' S',18X,' R',18X,' T',18X,' A',/
12X,F,5X,F,5X,F,5X,F)
925      FORMAT('ORANGE OF SMOOTH IS 5 TO 25 POINTS!')
926      FORMAT('NU',I5)
927      FORMAT('RD',2(E15.7))
928      FORMAT('SPLOT : ')
929      FORMAT('SNORMALIZATION FACTOR [',I5,',',I5'] : ')
930      FORMAT('SPOINT NUMBER IS ',I5,/)
931      FORMAT('SGRAPHICAL INPUT ?')
932      FORMAT('SLIST [LP] : ')
941      FORMAT('SCHANNEL WIDTH IS [EVEN] :')
942      FORMAT('SREFERENCE CHANNEL IS ')
943      FORMAT('SORDER OF DERIVATIVE IS ')
      END

```

```

; SUBROUTINE REPACK ( IDAT,IBUFF,ICNT,ISCALE,NAVG)
;
;       IDAT   = DATA ARRAY ADDRESS
;       IBUFF  = BUFFER ARRAY ADDRESS
;       ICNT   = BYTE COUNT
;       ISCALE = SCALING FACTOR
;       NAVG   = NUMBER OF SIGNAL AVERAGES
;
; MACRO SUBROUTINE TO REPACK AND SCALE VIDICON DATA
;
;       JIM HORNSHUB                NOVEMBER 20, 1977
;
; .TITLE REPACK
; .IDENT /V1.2/
; .PSECT REPACK
; .GLOBL REPACK
;
; .SBTTL DEFINITIONS
;
R0 = %0
R1 = %1
R2 = %2
R3 = %3
R4 = %4
R5 = %5
SP = %6
PC = %7
;
; .MCALL .F4DEF
; .F4DEF 0
;
; .PAGE
; .SBTTL MAIN
;
REPACK:  MOV     R0,-(SP)           ;SAVE REGISTERS
        MOV     R1,-(SP)
        MOV     R2,-(SP)
        MOV     R3,-(SP)
        MOV     R4,-(SP)
        MOV     2(R5),R0         ;DATA ARRAY ADDRESS
        MOV     4(R5),R1         ;BUFFER ARRAY ADDRESS
        MOV     6(R5),R2         ;BYTE COUNT
        MOV     (R1)+,N1         ;NUMBER OF AVERAGES TO CALLING PROGRAM
        MOV     (R1)+,N2
        MOV     N1,6(R5)
        SUB     3,R2             ;ADJUST BYTE COUNT
        CMPB    3,(R1)+         ;3 BYTES/DATA WORD?
        BEQ     SCALE           ;BRANCH IF YES
        LOOP:   MOV     (R1)+,N1 ;ELSE REPACK 2-BYTE DATA WORDS
        MOV     (R1)+,N2
        MOV     N1,R3
        ADD     100000,R3        ;GET REPACKED DATA
        MOV     R3,(R0)+        ;CONVERT TO 2'S COMPLEMENT
        SUB     2,R2             ;AND PUT IN DATA ARRAY
        BNE     LOOP           ;DECREMENT BYTE COUNT
        EXIT:   MOV     (SP)+,R4 ;LOOP 'TIL DONE
        MOV     (SP)+,R3        ;RESTORE REGISTERS AND EXIT
        MOV     (SP)+,R2
        MOV     (SP)+,R1
        MOV     (SP)+,R0
        RTS     R5              ;** EXIT FROM SUBROUTINE **
;
SCALE:   ADD     2,R1            ;MSB OF 1ST DATA WORD
        MOV     0,N5
        MOV     (R1),N5         ;GET 1ST BYTE
        LOOP1:  CMPB    (R1),N5 ;LOOK FOR LARGER BYTE

```

```

        BLOS      ON          ;BRANCH IF N5>(R1)
        MOV      (R1),N5
ON:      ADD      3,R1        ;BUMP ADDRESS
        SUB      3,R2        ;AND BYTE COUNT
        BNE      LOOP1      ;LOOP 'TIL DONE
        MOV      1,R2        ;INITIALIZE R2
        MOV      N5,R0
        BEQ      ON2        ;BRANCH IF R0=0
        MOV      0,N5
LOOP2:   ASL      R2          ; X 2
        DEC      N5
        ASR      R0          ; / 2
        BNE      LOOP2      ;LOOP 'TIL R0=0
ON2:     MOV      R2,010(R5)  ;SCALE FACTOR TO CALLING PROGRAM
        MOV      4(R5),R4    ;BUFFER ADDRESS
        ADD      3,R4
        MOV      06(R5),BYTCNT ;BYTE COUNT
        SUB      3,BYTCNT
        MOV      2(R5),R3    ;DATA ARRAY ADDRESS
        MOV      N5,R2
AGAIN:   MOV      (R4)+,N1
        MOV      (R4)+,N2
        MOV      (R4)+,N3
        MOV      N3,R0      ;HIGH DATA WORD IN R0
        MOV      N1,R1      ;LOW DATA WORD IN R1
        ASHC     R2,R0      ;SHIFT BY R2
        ADD      100000,R1   ;CONVERT TO 2'S COMPLEMENT
        MOV      R1,(R3)+   ;AND PUT IN DATA ARRAY
        SUB      3,BYTCNT
        BNE      AGAIN
        JMP      EXIT
;
; .EVEN
N1:      .BYTE 0
N2:      .BYTE 0
N3:      .BYTE 0
N4:      .BYTE 0
N5:      .BYTE 0
N6:      .BYTE 0
BYTCNT:  .WORD 0
;
        .END REPACK

```

```

; SUBROUTINE TEXT (IBUFF,IBYTE,INDEX,NEND)
;
;       IBUFF = BUFFER ARRAY ADDRESS
;       IBYTE = BYTE COUNT
;       INDEX = ARRAY INDEX
;       NEND  = ETX FLAG
;
; SUBROUTINE TO OUTPUT HEADER TEXT TO TERMINAL
;
;       JIM HORNSHUE                NOVEMBER 20, 1977
;
; .TITLE TEXT
; .IDENT /V1.0/
; .PSECT TEXT
; .GLOBL TEXT
;
; .SBTTL DEFINITIONS
;
; R0 = %0
; R1 = %1
; R2 = %2
; R3 = %3
; R4 = %4
; R5 = %5
; SP = %6
; PC = %7
;
; .MCALL .F4DEF,.INIT,.WRITE,.WAIT,.RLSE
; .F4DEF 0
;
; .PAGE
; .SBTTL MAIN
;
TEXT:  MOV     R0,-(SP)           ;SAVE REGISTERS
      MOV     R1,-(SP)
      MOV     R2,-(SP)
      MOV     R3,-(SP)
      MOV     R4,-(SP)
      MOV     2(R5),R4         ;GET ADDRESS OF BYTE ARRAY
      MOV     4(R5),R3         ;AND BYTE COUNT
      MOV     BUFF,R2          ;R2->LINE BUFFER HEADER
      MOV     TBUFF,R1         ;R1->TEXT BUFFER
      MOV     R1,6(R2)         ;SET DUMP POINTER IN HEADER
      CLR     R0               ;INITIALIZE COUNT
LOOP:  DEC     R3
      CMPB    3,(R4)           ;CHECK FOR ETX
      BEQ     WRITE            ;BRANCH ON ETX
      MOVB    (R4),(R1)+       ;BYTE TO TEXT BUFFER
      INC     R0               ;INCREMENT BYTE COUNT
      CMPB    15,(R4)          ;CR?
      BNE     LOOP1            ;NO
      MOVB    12,(R1)+
      INC     R0
LOOP1: CMP     R3, 0
      BEQ     OUT              ;BRANCH ON ZERO BYTE COUNT
      ADD     1,R4
      BR      LOOP             ;ELSE CHECK NEXT BYTE
WRITE: MOV     1,4(R5)         ;SET RETURN ETX FLAG
OUT:   CMP     R0, 0           ;HEADER TEXT?
      BEQ     OVER            ;BRANCH IF NOT
      MOV     R0,4(R2)         ;SET ACTUAL BYTE COUNT
      MOV     TTY,R0           ;R0->TTY LINK BLOCK
      .INIT R0
      .WRITE R0,R2
      .WAIT R0

```

```

OVER:  .RLSE R0
        MOV     R3, @4(R5)      ;BYTE COUNT TO CALLING PROGRAM
        COMB    R3
        INC     R3
        INC     R3
        MOV     R3, @6(R5)      ;ARRAY INDEX TO CALLING PROGRAM
        MOV     (SP)+, R4        ;RESTORE REGISTERS FOR EXIT
        MOV     (SP)+, R3
        MOV     (SP)+, R2
        MOV     (SP)+, R1
        MOV     (SP)+, R0
        RTS     R5              ; ** EXIT FROM SUBROUTINE **

TTY:    .WORD 0                  ;KEYBOARD LINKBLOCK
        .RAD50 /KB/              ;LOGICAL DEVICE NAME
        .BYTE 1, 0              ;WORDS TO FOLLOW/UNIT NO.
        .RAD50 /KB/              ;PHYSICAL DEVICE NAME

BUFF:   .WORD 0                  ;MAX BYTE COUNT
        .BYTE 6, 0              ;STATUS/MODE =DUMP UNFORMATTED ASCII
        .WORD 0                  ;ACTUAL BYTE COUNT
        .WORD 0                  ;DUMP POINTER

TBUFF:  .BLKB 300                ;TEXT BUFFER
        .END TEXT

```

C
C
C
C
C
C
C
C
C
C
C

SUBROUTINE RFILE (IBYTE, IERR, INDEX, Ibuff)

IBYTE = BYTE COUNT
IERR = ERROR FLAG
INDEX = BYTE POINTER FOR BUFFER ARRAY
IBUFF = ADDRESS FOR BUFFER ARRAY

SUBROUTINE TO REFILL Ibuff WITH VIDICON DATA

JIM HORNSHUB

NOVMBER 20, 1977

** COMPILE WITH /ON SWITCH **

SUBROUTINE RFILE (IBYTE, IERR, INDEX, Ibuff)

IERR=0

IBYTE=256

CALL UNFMRW (IERR, Ibuff, IBYTE)

INDEX=1

RETURN

END

C
C
C
C
C

SMOOTH.FTN

JIM HORNSHUB

NOVEMBER 1, 1977

DIGITAL SMOOTHING SUBROUTINE

C

```

SUBROUTINE SMOOTH(IRAY,NRAY,ISIZE)
  DIMENSION NORM(11),IWEIGH(13,11),IRAY(819),IBUF(26)
  DATA NORM/35,21,231,429,143,1105,323,2261,3059,805,5175/
  DATA IWEIGH/-3,12,17,10*0,-2,3,6,7,9*0,-21,14,39,54,59,
    18*0,-36,9,44,69,84,89,7*0,-11,0,9,16,21,24,25,6*0,-78,
    2-13,42,87,122,147,162,167,5*0,-21,-6,7,18,27,34,39,42,
    343,4*0,-136,-51,24,89,144,189,224,249,264,269,3*0,-171,
    4-76,9,84,149,204,249,284,309,324,329,2*0,-42,-21,-2,15,
    530,43,54,63,70,75,78,79,0,-253,-138,-33,62,147,222,287,
    6343,387,422,447,462,467/

  DO 3 I=1,ISIZE
    IBUF(I)=IRAY(I)
    IB=(ISIZE-3)/2
    IC=(ISIZE+1)/2
    XNORM=NORM(IC)
    IA=IC-1
    LSTPNT=NRAY-IA
    DO 1 I=IC,LSTPNT
      IBUF(ISIZE)=IRAY(I+IA)
      PNT=FLOAT(IWEIGH(IC,IB))*FLOAT(IBUF(IC))
      DO 2 J=1,IA
        P1=IBUF(IC+J)
        P2=IBUF(IC-J)
        WGT=IWEIGH(IC-J,IB)
        PNT=PNT+WGT*(P1+P2)
      2 PNT=PNT/XNORM
      DO 4 J=1,ISIZE
        IBUF(J)=IBUF(J+1)
      4 IRAY(I)=PNT+.5
    1 RETURN
  END

```

```

;
; T4010 WRITTEN BY TOM ATKINSON AND JIM HORNSHUB FOR THE
; C.G.ENKE RESEARCH GROUP
;
; 18-JUN-73
;
; SUBROUTINE FOR GRAPHIC I/O WITH TEKTRONICS 4010
; 0 - ERASE SCREEN, ALPHA MODE, HOME(0,780)
; 1 - GRAPHIC MODE, CONSTRUCT DARK VECTOR
; 2 - CONSTRUCT LIGHT VECTOR
; 3 - RETURN TO ALPHA MODE
; 4 - GRAPHIC INPUT WITH CROSS-HAIRS
; 5 - PLOT AXIS AND TICK MARKS
; 6 - GRAPHIC MODE, POINT PLOT
; 7 - GRAPHIC INPUT WITHOUT SCALE SHIFT
;
;
; FOR MODE 5 OPERATION CALL T4010(IMODE,IXDIV,IYDIV)
; IMODE = MODE OF OPERATION
; IXDIV = NUMBER OF X DIVISIONS DESIRED
; IYDIV = NUMBER OF Y DIVISIONS DESIRED
;
; FOR ALL OTHER MODES CALL T4010(IMODE,IXCORD,IYCORD)
; IXCORD = INTEGER VALUE OF X COORDINATE (0-1000)
; IYCORD = INTEGER VALUE OF Y COORDINATE (0-600)
;
; THIS SUBROUTINE SHIFTS THE SCREEN ORIGIN TO (10,10)
; FOR ALL PLOTTING AND GRAPHIC INPUT EXCEPT FOR MODE 7.
;
;
; .TITLE T4010
; .SBTTL PRELIMINARIES
; .IDENT /T4010/
; .PSECT T4010,REL,RW,I
; .GLOBL T4010
; .PAGE
; .NLIST TTM
;
; R0=%0 ; REGISTER DEFINITION
; R1=%1
; R2=%2
; R3=%3
; R4=%4
; R5=%5
; SP=%6
; PC=%7
;
; MASKR5=177740 ; MASKR5 = .NOT.000037
; MASKS5=176037 ; MASKSR = .NOT.001740
; TXCSR=177564 ; T4010 TRANSMITTER COMMAND, STATUS REG
; TXBUF=177566 ; T4010 TRANSMITTER DATA REGISTER
; RVCSR=177560 ; T4010: RECEIVER COMMAND, STATUS REG
; RVBUF=177562 ; T4010: RECEIVER DATA REGISTER
; CSK=33 ; T4010: ERASE, GO TO ALPHA MODE, AND
; CL=14 ; T4010: RETURN TO HOME (0,780)
; CS0=37 ; T4010: GO TO ALPHA MODE
; CSN=35 ; T4010: GO TO GRAPHICS MODE
; CZ=32 ; T4010: STARTS CROSS-HAIR WHEN
; ; PRECEDED BY CSK
;
; .PAGE
; .SBTTL MACROS
;
; .MCALL .F4DEF

```

```

;
; .F4DEF 0 ; ASSIGN R5 CONVENTION TO MACROS
;
; .MACRO INPUT,DUMMI,DUMMY
DUMMI: TSTB RVCSR ;TEST BIT7, IS DATA READY
BPL DUMMI ;BRANCH IF NOT READY
MOVB RVBUF,DUMMY ;DATA TO CPU
.ENDM
;
; .MACRO COORD,HI,LO,VALUE
CLR R0
MOVB HI,R0 ;HI BYTE->R0
BIC MASKR5,R0 ;MASK OFF RIGHT 5 BITS
ROL R0 ;ROTATE R0 5 TIMES TO LEFT
ROL R0
ROL R0
ROL R0
BIC MASKS5,R0 ;MASK OFF BITS5-9
CLR R1
MOVB LO,R1 ;LO BYTE->R1
BIC MASKR5,R1 ;MASK OFF BITS 0-4
ADD R1,R0 ;ADD HI/LO BYTES
MOV R0,VALUE
.ENDM
;
; .NLIST ME
;
; .PAGE
; .SBTTL MAIN
T4010: MOV R0,-(SP) ; SAVE REGISTERS
MOV R1,-(SP)
MOV R2,-(SP)
MOV R3,-(SP)
MOV R4,-(SP)
MOV 2(R5),R4 ; IMODE ADDRESS -> R4
MOV (R4),R0 ; IMODE VALUE -> R0
TST R0 ; TEST IF >0
BCE L0 ; YES, CONTINUE
JMP ERR ; NO, RETURN
L0: CMP 7,R0 ; IMODE .GT. 7 IS ILLEGAL
BEQ ADD2 ; ADD 2 TO GET OVER JUMP IN TABLE
BEQ ADD2 ; BYPASS JUMP
BEQ ADD1
BCE L1
JMP ERR
ADD2: ADD 2,R0
BR L1
ADD1: INC R0
L1: ROL R0 ; MULTIPLY BY TWO
ADD AJT,R0 ; CONSTRUCT JMP ADDR
JMP (R0)
JTABLE: BR ERASE
BR GRAPH1
BR VECTR2
BR ALPHA
BR GIN
JMP AXIS
JMP PTPLT
JMP GIN
ERASE: MOV CSK,R0
JSR R5,OUTPUT
MOV CL,R0
JSR R5,OUTPUT
JMP EXIT

```

```

GRAPH1: MOV      4(R5),R4
        MOV      (R4),XNUM
        ADD      12,XNUM
        MOV      6(R5),R4
        MOV      (R4),YNUM
        ADD      12,YNUM
        JSR      R5,GRAPH
        JMP      EXIT
VECTR2: MOV      4(R5),R4
        MOV      (R4),XNUM
        ADD      12,XNUM
        MOV      6(R5),R4
        MOV      (R4),YNUM
        ADD      12,YNUM
        JSR      R5,VECTR
        JMP      EXIT
ALPHA:  MOV      CS0,R0
        JSR      R5,OUTPUT
        JMP      EXIT
GIN:    BIC      100,RVCSR
        MOV      CSK,R0
        JSR      R5,OUTPUT
        MOV      CZ,R0
        JSR      R5,OUTPUT
        INPUT    AGAIN,R0
        INPUT    AGN1,H1X
        INPUT    AGN2,LOX
        INPUT    AGN3,H1Y
        INPUT    AGN4,LOY
        COORD    H1X,LOX,XCORD
        COORD    H1Y,LOY,YCORD
        MOV      2(R5),R0
        MOV      (R0),R1
        CMP      7,R1
        BEQ      GINNS
        SUB      12,XCORD
        SUB      12,YCORD
GINNS:  MOV      4(R5),R0
        MOV      XCORD,(R0)
        MOV      6(R5),R0
        MOV      YCORD,(R0)
RECSR:  BIS      100,RVCSR
        JMP      EXIT
AXIS:   MOV      1762,XNUM
        MOV      12,YNUM
        JSR      R5,GRAPH
        MOV      12,XNUM
        JSR      R5,VECTR
        MOV      1142,YNUM
        JSR      R5,VECTR
        CLR      R0
        MOV      1762,R1
        MOV      4(R5),R2
        MOV      (R2),R3
        TST      R3
        BNE      YES
        CLR      XDIV
        BR       AX1
YES:    DIV      R3,R0
        MOV      R0,XDIV
AX1:    CLR      R0
        MOV      1142,R1
        MOV      6(R5),R2
        MOV      (R2),R3
        TST      R3

```

;SHIFT ORIGIN TO (10,10)

; SET TO ALPHA MODE

;NON-SCALED GRAPHIC INPUT
;SHIFT DATA BACK TO ORIGIN (0,0)

;RESET INT ENBL BIT

;ARE X DIVISIONS REQUIRED
;YES, CONTINUE
;NO, SET XDIV=0

;ARE Y DIVISIONS REQUIRED

```

        BNE      AX2          ;YES, CONTINUE
        CLR      YDIV
        TST      XDIV        ;ARE X DIVISIONS REQUIRED
        BNE      XTICK       ;YES DRAW TICKS
        JMP      EXIT        ;NO, EXIT
AX2:    DIV      R3,R0
        MOV      R0,YDIV
        MOV      12,XNUM
XTICK:  TST      XDIV
        BEQ      YTICK
XNEXT:  ADD      XDIV,XNUM
        MOV      12,YNUM
CMP     1762,XNUM
        BMI      LASTX
        JSR      R5,GRAPH
        MOV      20,YNUM
        JSR      R5,VECTR
        JMP      XNEXT
LASTX:  MOV      1762,XNUM    ;DRAW FINAL TICK MARK AT 1000
        JSR      R5,GRAPH
        MOV      20,YNUM
        JSR      R5,VECTR
YTICK:  MOV      12,YNUM
        MOV      12,XNUM
        TST      YDIV
        BNE      GO
        JMP      EXIT
GO:     ADD      YDIV,YNUM
        CMP      1142,YNUM
        BGE      CONT
LASTY:  MOV      1142,YNUM    ;DRAW FINAL Y TICK MARK AT 600
        JSR      R5,GRAPH
        MOV      20,XNUM
        JSR      R5,VECTR
        MOV      12,XNUM
        JMP      EXIT
CONT:   JSR      R5,GRAPH
        MOV      20,XNUM
        JSR      R5,VECTR
        MOV      12,XNUM
        JMP      GO
PTPLT:  MOV      4(R5),R4
        MOV      (R4),XNUM
        ADD      12,XNUM      ; ADD OFFSET BIAS
        MOV      6(R5),R4
        MOV      (R4),YNUM
        ADD      12,YNUM
        JSR      R5,GRAPH
        JSR      R5,VECTR
        JMP      EXIT
ERR:
EXIT:   MOV      (SP)+,R4      ; RESTORE REGISTERS
        MOV      (SP)+,R3
        MOV      (SP)+,R2
        MOV      (SP)+,R1
        MOV      (SP)+,R0
        RTS      R5          ; AND RETURN
        .PAGE
        .SBTTL SUBROUTINES
;
; SUBROUTINE GRAPH: DRAW VECTOR ON SCREEN
;
GRAPH:  MOV      CSM,R0
        JSR      R5,OUTPUT
VECTR:  MOV      YNUM,R0      ; DO UPPER Y

```

```

        JSR      R5,ROT5          ; ROTATE 5 RIGHT
        BIC      MASKR5,R0        ; MASK OFF RIGHT 5 BITS
        BIS      40,R0           ; INSERT UPPER Y TAG
        JSR      R5,OUTPUT        ; SEND UPPER Y BYTE
        MOV      YNUM,R0         ; DO LOWER Y
        BIC      MASKR5,R0        ; MASK OFF RIGHT 5 BITS
        BIS      140,R0          ; INSERT LOWER Y TAG
        JSR      R5,OUTPUT
        MOV      XNUM,R0         ; DO UPPER X
        JSR      R5,ROT5          ; ROTATE 5 RIGHT
        BIC      MASKR5,R0        ; MASK OFF RIGHT 5 BITS
        BIS      40,R0           ; INSERT UPPER X TAG
        JSR      R5,OUTPUT
        MOV      XNUM,R0         ; DO LOWER X
        BIC      MASKR5,R0        ; MASK OFF RIGHT 5 BITS
        BIS      100,R0          ; INSERT LOWER X TAG
        JSR      R5,OUTPUT
        RTS      R5

;
; SUBROUTINE ROT5: ROTATE R0 RIGHT 5 TIMES
;
ROT5:   ROR      R0
        ROR      R0
        ROR      R0
        ROR      R0
        ROR      R0
        RTS      R5          ; RETURN

;
; SUBROUTINE OUTPUT: OUTPUT 1 BYTE TO TERMINAL
;
OUTPUT: TSTB     TXCSR           ; IS TERMINAL BUSY?
        BPL     OUTPUT          ; STATUS REGISTER POS MEANS BUSY
        MOV     TXCSR,-(SP)      ; SAVE CURRENT TERM TRANS STATUS
        CLR     TXCSR           ; BE SURE INTERRUPT IS OFF
        BIS     200,R0          ; SET BIT 8 OF BYTE
        MOV     R0,TXBUF        ; SEND IT OUT
OUT1:   TSTB     TXCSR           ; TERMINAL BUSY?
        BPL     OUT1
        MOV     (SP)+,TXCSR      ; NO RESTORE STATUS
        RTS      R5            ; RETURN

HIX:   .BYTE 0
LOX:   .BYTE 0
HIY:   .BYTE 0
LOY:   .BYTE 0
        .EVEN
XCORD: .WORD 0
YCORD: .WORD 0
XDIV:  .WORD 0
YDIV:  .WORD 0
XNUM:  .WORD 0
YNUM:  .WORD 0
AJT:   .WORD JTABLE            ; ADDR OF JTABLE
        .END      T4010

```

APPENDIX B

Supplementary Documentation of System Design

Table B-1. Peripheral Addresses for Vidicon Micro (octal)

Address	Bit	Function	Comments
120000		Monochromator status register	
	D0	pulse out ()	Monochromator steps 0.1 A per pulse
	D1	external enable	0 - manual control, 1 - micro control
	D2	direction select	0 - reverse, 1 - forward
120001	D3	cell position	0 - reference, 1 - sample
		Monochromator status	
	D0	sample cell	0 - cell selected and in position
	D1	reference cell	0 - cell selected and in position
120002	D2	reverse limit	1 - at lower wavelength limit
	D3	forward limit	1 - at upper wavelength limit
120003		Flag to coordinator	1 - active
		Hold and interrupt register	
	D0	hold enable	1 - enables micro to go into hold state after setting flag to coordinator
	D1	frame interrupt enable	1 - enables interrupt at end of scan
120004		Shutter status	
	D1	shutter flag	0 - closed, 1 - open
120007		Shutter flip-flop	A pulse here changes state of shutter

Table B-2. Data Acquisition Addresses for Vidicon Micro (octal)

Address	Bit	Function	Comments																								
120010		Number of bytes of precision	1, 2, or 3 bytes/data word																								
120011		Low byte of starting address for data storage																									
120012		High byte of starting address for data storage																									
120013	D0 D1 D2 D3 D4 D5	Scan control register R1 gain resistor R2 gain resistor R3 gain resistor R4 gain resistor start scan selective enable	Cleared on Reset 1 - active 1 - active 1 - active 1 - active 1 - enables data acquisition 1 - enables selective integration																								
120014		Initialize	Initializes byte and address counters																								
120015	D0 D1 D2 D3 D4	A/D status register <u>A</u> select <u>B</u> select <u>12</u> bit select <u>10</u> bit select <u>8</u> bit select	<table><tr><th><u>A</u></th><th><u>B</u></th><th><u>12</u></th><th><u>10</u></th><th><u>8</u></th><th>#bits</th></tr><tr><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>12</td></tr><tr><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>10</td></tr><tr><td>0</td><td>1</td><td>1</td><td>0</td><td>1</td><td>8</td></tr></table>	<u>A</u>	<u>B</u>	<u>12</u>	<u>10</u>	<u>8</u>	#bits	0	0	0	1	1	12	1	0	1	1	0	10	0	1	1	0	1	8
<u>A</u>	<u>B</u>	<u>12</u>	<u>10</u>	<u>8</u>	#bits																						
0	0	0	1	1	12																						
1	0	1	1	0	10																						
0	1	1	0	1	8																						

Table B-2. (cont'd.).

120016	D0 D1	A/D status A/D overflow status error	1 - active 1 - active
120017		Clear	Clears A/D error flags

Table B-3. Vidicon Control Addresses for Scan Micro (octal)

Address	Bit	Function	Comments
140000		Beam current	Grid No. 1 voltage = $0.59 V \times N$, for $N = 1$ to 256
140001	D0-D3 D4-D7	Delay Integrate	Number of vertical intervals skipped Number of vertical intervals integrated
140002		Scan status register	
	D0	scan enable	1 - scan enabled
	D1	line sync inhibit	0 - line sync inhibited
	D2	74LS158 select	0 - scan enabled
	D3	74LS158 strobe	1 - scan enabled
	D4	beam mode select A	beam on (1,1), beam off (0,0), blanking (1,0)
	D5	beam mode select B	
140003		Reset	Resets vidicon scan circuits
140004		Frequency select	Frequency = $1 \text{ MHz}/N$, for $N = 1$ to 256
140005		Wavelength increment	Number of channels = $4096/N$, for $N = 1$ to 256
140006		Wavelength increment	Extra wavelength bits for selective integration
140007		Vertical scan pulse	Vertical scan enable for selective integration
140010		Clear	Clears frame flag

Table B-3. (cont'd.).

140011		Scan status flags	
	D0	scan enables	1 - scan enabled
	D7	scan completed	1 - scan completed, 0 - scan in progress

Table B-4. Backplane Connections for Vidicon Slave Micro

Pin	Side A (wirewrap)	Side B (component)
1	D0	D4
2	D1	D5
3	D2	D6
4	D3	D7
5	A0	A2
6	A1	A3
7	Board select	$\overline{\text{MEMR}}$
8	$\overline{\text{INTA}}$	$\overline{\text{MEMW}}$
9	INT	Integrate enable
10	Discharge enable	A/D convert
11	DBIN	Line sync
12		Vidicon carry out

Table B-5. Backplane Connections for Fast Adder Board

Pin	Side A (wirewrap)	Side B (component)
1	A select	A0
2	B select	A1
3	12 select	A2
4	10 select	A3
5	Line sync	A4
6	A/D status flag	A5
7	R1	A6
8	R2	A7
9	R3	A8
10	R4	A9
11	Integrate	A10
12	Convert pulse	A11
13	Adder reset	A12
14	A/D overflow flag	Memory board select
15	Clear error flag	8218 $\overline{\text{LATCH}}$
16	$\overline{\text{DIEN}}$	Average $\overline{\text{SELECT}}$
17	$\overline{\text{CS}}$	2102 R/W ($\overline{\text{MEMW}}$)
18	8 select	Vidicon carry out
19	$\overline{\text{MEMR}}$	A/D status error
20	Scan flag	
33	D7	D6
34	D5	D4
35	D3	D2
36	D1	D0

Table B-6. Backplane Connections for Memory Board

Pin	Side A (wirewrap)	Side B (component)
1	A/D input - Bit 12	A0
2	11	A1
3	10	A2
4	9	A3
5	8	A4
6	7	A5
7	6	A6
8	5	A7
9	4	A8
10	3	A9
11	2	A10
12	1	A11
13	Adder reset	A12
14	A/D overflow	Memory board select
15	Clear error flag	8212 $\overline{\text{LATCH}}$
16	$\overline{\text{DIEN}}$	Average $\overline{\text{SELECT}}$
17	$\overline{\text{CS}}$	2102 R/W ($\overline{\text{MEMW}}$)
18	$\overline{\text{MEMR}}$	A/D status error

Table B-7. 3M Connector Pin Assignments

Pin	Signal	Pin	Signal
1	A0	18	D1
2	A1	19	D2
3	A2	20	D3
4	A3	21	D4
5	A4	22	D5
6	A5	23	D6
7	A6	24	D7
8	A7	25	DBIN
9	A8	26	$\overline{\text{MEMW}}$
10	A9	27	$\overline{\text{MEMR}}$
11	A10	28	ϕ_2^{TTL}
12	A11	29	Ready
13	A12	30	$\overline{\text{FAA}}$
14	A13	31	FAR
15	A14	32	Reset
16	A15	33	INTE
17	D0		

APPENDIX C

Front Panel Documentation

APPENDIX C

Front Panel Documentation

The hardware front panel provides the operator with complete hardware control of the micro and its peripheral circuits. This hardware control capability is important not only in testing the micro and its peripheral circuits during the construction phase, but also for later trouble-shooting of non-functional circuits. Figure C-1 illustrates the signal interaction between the front panel and the micro-processor. The front panel generates all of the control signals (DBIN GATE, $\overline{\text{MEMW}}$, $\overline{\text{MEMR}}$, READY, $\overline{\text{STSTB}}$, $\overline{\text{BUSEN}}$) needed to assume full control of the micro. The logic that generates these signals will be discussed later in this appendix. Data from the micro is buffered by bus driver B1 and displayed with an 8-digit 7-segment LED display (D3). Status information on the data lines is latched by latch L1 when $\overline{\text{STSTB}}$ is pulsed low and displayed with individual LED's (D2). Keyboard input is driven down the micro data bus by bus driver B2. A single 16-digit 7-segment display (D1) is used to alternately display the keyboard output and the current memory address (see Figure C-2).

Data and address information are input from the front panel via a surplus keyboard of unknown origin. Since this keyboard does not output a standard keyboard code, it was necessary to design the front panel around the keyboard output code. Table C-1 illustrates the keyboard output code for 16 keys and the value or function assigned to each key. Bit M4 is used to distinguish a number from a control function.

Figure C-1. Block Diagram of Front Panel Input/Output

Table C-1. Keyboard Output Code

Key	M ₁	M ₂	M ₃	M ₄ [*]	S	N ₁	N ₂
None	1	1	1	1	1	1	1
0	1	0	1	1	0	1	0
1	1	1	0	1	0	1	1
2	1	0	1	1	0	1	1
3	1	0	0	1	0	1	1
4	0	1	1	1	0	1	1
5	0	1	0	1	0	1	1
6	0	0	1	1	0	1	1
7	0	0	0	1	0	1	1
HLT	0	0	0	0	1	1	1
SS	0	0	1	0	1	1	0
EXM	0	1	0	0	1	1	0
DEP	0	1	1	0	1	1	0
EXM NXT	1	0	0	0	1	1	0
DEP NXT	1	1	0	0	1	1	0
CLR	1	1	1	0	1	1	0
RUN	1	1	1	0	1	0	1

* M₄: 1 - number, 0 - control function

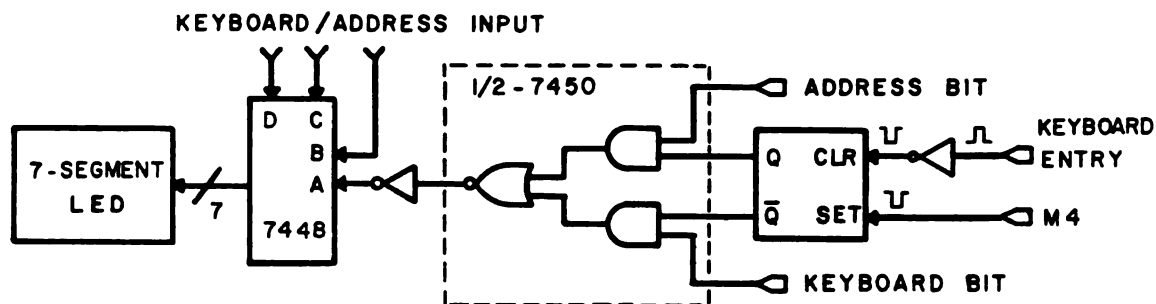


Figure C-2. Keyboard/Address Display Logic

The keyboard interface is illustrated in Figure C-3. When an octal address or data word is entered at the keyboard, the corresponding bit pattern for each entered digit is clocked into a 6-digit shift register (3 x 74164). The shift register outputs are then multiplexed onto the data bus at the appropriate time either to examine a specified memory location or to deposit a data word in memory. To deposit a word in memory, LOW BYTE ENABLE is set to a logic '1' to enable the lower 8 bits from the shift register, bus driver B2 is enabled ($\overline{DS1}$ set to logic '0' and DS2 to logic '1'), and $\overline{MEMW}$ is pulsed low to write the data into memory. To examine a desired memory location, the front panel places a jump instruction on the data bus by setting JMP ENABLE to a logic '1' and enabling bus driver B2. Next, the micro's ready line is returned to a logic '1' to start the micro. The micro then reads the jump instruction, which causes it to look for a 16-bit memory address. Normally the micro would read the next two memory locations to obtain the jump address; however, the front panel disables the micro's memory input and places the user-specified jump

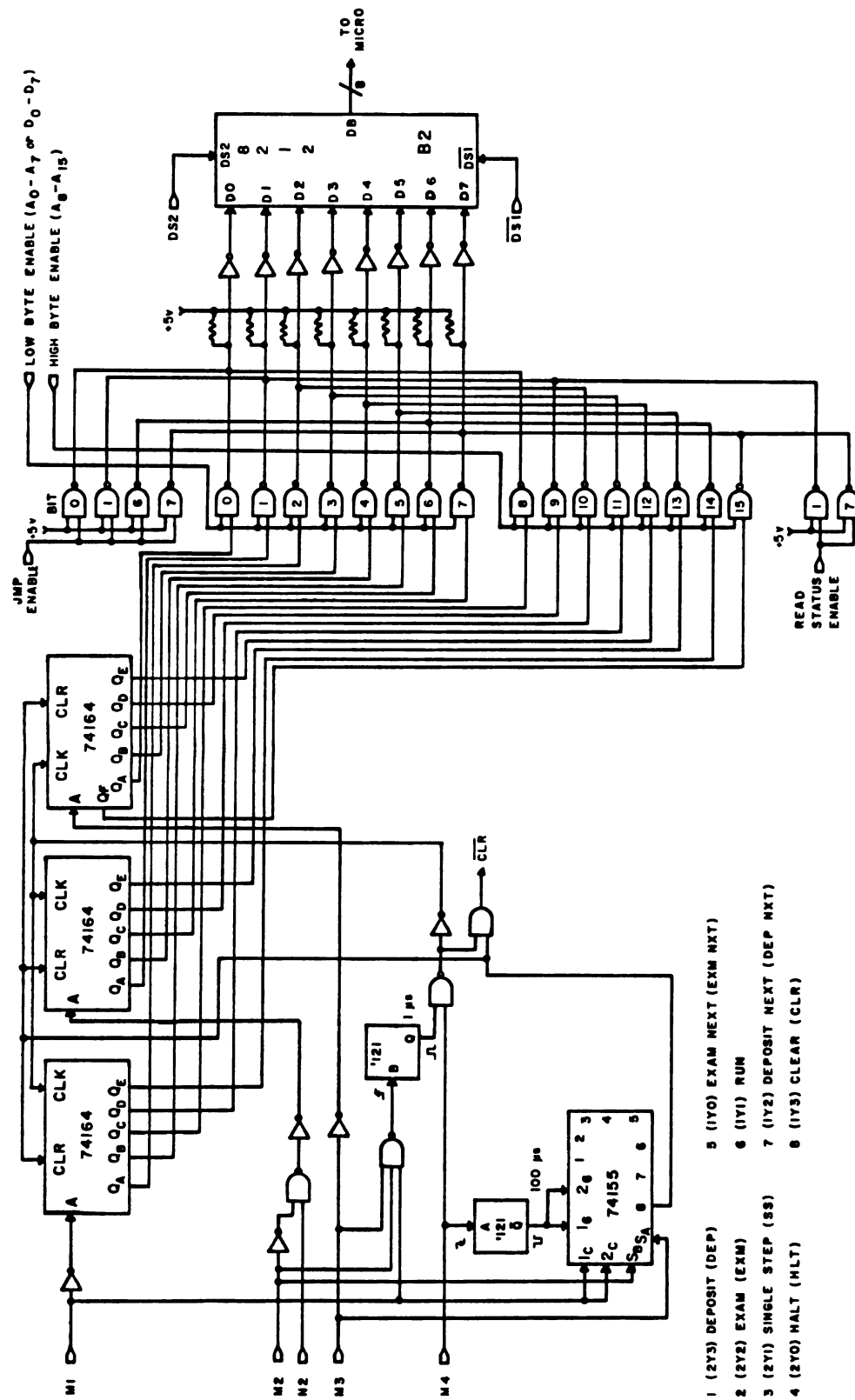


Figure C-3. Keyboard Interface

address on the data bus by pulsing LOW BYTE ENABLE and HIGH BYTE ENABLE at the appropriate times. After the micro has input the address and completed a jump to the desired address, the front panel returns the ready line to a logic '0' to halt the micro. At this point the front panel displays the address and data of the specified memory address.

The exam next (EXM NXT) function requires that the micro access the next sequential memory location. To exam the next location, the front panel disables the memory, places a NOP instruction on the data bus, and raises the ready line to a logic '1' for one instruction cycle. The micro then reads and executes the NOP, increments its memory address, and halts at the next memory location. The deposit next (DEP NXT) function combines the exam next and deposit functions. For single stepping (SS) through programs, the front panel again lets the micro run for only one instruction cycle at a time; however, in this mode the micro reads and executes the code in its memory instead of code supplied by the front panel. The clear (CLR) function writes a zero byte (NOP) into the current memory location.

In order to latch the status bits output by the micro, the front panel was interfaced directly to the micro bus. Consequently, the system controller (8228) is between the front panel and memory. The system controller is a bi-directional bus driver controlled by the status output from the micro. When the micro halts, the controller is in the input mode, i.e. driving data to the micro. Therefore, in order to deposit data into memory from the front panel the direction of the system controller must be reversed. The front panel does this by

placing a NOP instruction on the data bus and pulsing $\overline{\text{STSTB}}$. This operation strobes a new status word into the system controller and forces it to reverse direction. After depositing a byte of data into memory, the direction of the system controller must again be reversed to read the contents of the current memory location. The system controller is returned to the input mode by enabling READ STATUS ENABLE, enabling bus driver B2, and pulsing $\overline{\text{STSTB}}$. This sequence accompanies each deposit and deposit next instruction.

The function keys are decoded by the keyboard interface. When a function key is depressed, the 74155 generates a 100 μs pulse that initiates the selected function. Figure C-4 illustrates the control and timing circuit used to generate the necessary control signals for front panel control of the micro and its peripherals as described above.

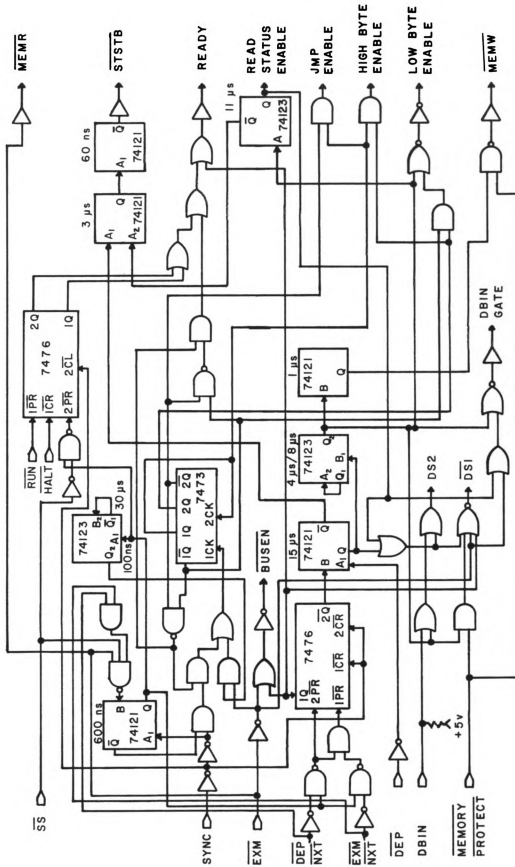


Figure C-4. Front Panel Control Logic

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