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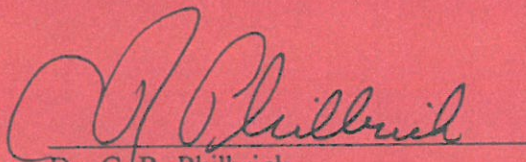
DEPARTMENT OF ELECTRICAL ENGINEERING

CHARACTERIZATION OF A FOURIER TRANSFORM
INTERFEROMETER

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FALL 1996

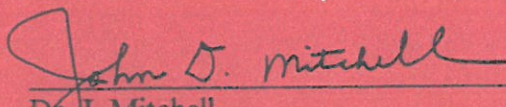
A thesis
submitted in partial fulfillment
of the requirement
for a baccalaureate degree
with honors in Electrical Engineering

Approved:



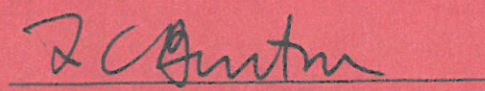
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ACKNOWLEDGEMENTS

I would like to thank Dr. C.R. Philbrick for his guidance and support; especially in light of the scope change for this thesis. I would also like to thank Jeff Huntington and Bill Durbin for their efforts in assisting me with the operation of the MIDAC Fourier Transform Interferometer. In addition, I would like to thank the United States Army, in particular Mr. Robert Gross, for loaning the MIDAC FTIR interferometer that is the basis of this thesis. Finally, I would to thank my family and friends for their tireless support and understanding.

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ABSTRACT

A MIDAC Fourier Transform Interferometer's (FTIR) capability to identify the existence of certain chemical species has been verified. Based on the Michelson interferometer, MIDAC's Plane Mirror Interferometer is capable of providing high resolution spectra in the infrared region, typical wavelengths of $2\mu\text{m}$ through approximately $14\mu\text{m}$. However, the instrument used here was modified to cover the 8 to $11\mu\text{m}$ region. The FTIR advantage is that it operates in the infrared region, known as the "molecular fingerprint region" where the absorption/emission spectra of a given molecular species provide a unique identification. Consequently the instrument can be used to identify the existence of various organic and inorganic molecules in the environment. In addition to being able to identify chemical species, spectra generated by the FTIR can be used to determine their concentration level. The FTIR provides a valuable method for companies and/or regulatory agencies (e.g., Environmental Protection Agency) to monitor the emissions of many pollution sources and determine whether or not compliance with regulated emission levels or discharge rates has been achieved.

INTRODUCTION

Issues concerning the current and future status of our nation's environment are the subject of an intense debate by the two 1996 presidential nominees. Both Bill Clinton and Robert Dole claim that they are going to take a tough stand against American companies that create pollution, robbing our children and future generations of a clean environment. Regardless of which nominee is elected President, the monitoring of pollution emission levels is an essential aspect of pollution regulation and control. Fourier transform interferometer (FTIR) techniques are rapidly becoming an extremely popular method of monitoring the emissions of various pollution sources.

This paper will address the theoretical basis for using an FTIR to determine the types and concentrations of chemical species being emitted by a source. In addition, a description of the basic FTIR design will be used to explain how this device is capable of generating a spectrum in the infrared region. Finally, the results of various experimental tests that characterize the device will be presented together with some caveats and cautions regarding the operation of an FTIR device.

BACKGROUND

FTIR Operating Principle

The operation of the FTIR system is based on the fact that almost every chemical species absorbs/emits energy in the infrared region of the spectrum. The vibration, stretch, and rotational energy states of molecules provide a unique set of wavelengths in this infrared region. In essence, each molecule's unique set of absorbed/emitted wavelengths provide all the necessary information required to identify the species, much as a fingerprint specific for each molecule. MIDAC's FTIR spectrometer simultaneously monitors wavelengths from approximately 8 μm to 11 μm in the infrared region and sends this information to a computer where it is stored. Finally, with the assistance of spectral analysis software, the spectrum of the stored data can be displayed. This spectrum can be used to identify compounds as well as concentration levels which are present in the monitored area.

There are essentially two types of spectra, emission and absorption, and hence an FTIR spectrometer can be applied in two ways to determine which compounds are present in the sample area. To understand the theory behind an emission spectrum it is essential to become familiar with Planck's radiation law. This law, in its quantified form, can be represented by the following equation [4],

$$I(\lambda, T) = (2\pi hc^2/\lambda^5)[e^{hc/\lambda kT} - 1]^{-1}. \quad (1)$$

In equation (1), h is Planck's constant ($\approx 6.626 \times 10^{-34}$ Js), T is the temperature (in Kelvin), and k is Boltzman's constant ($\approx 1.381 \times 10^{-23}$ J/K). A graphical representation of the

blackbody radiation (intensity, I) variation with wavelength and temperature as predicted by Plank's radiation law is shown below [1].

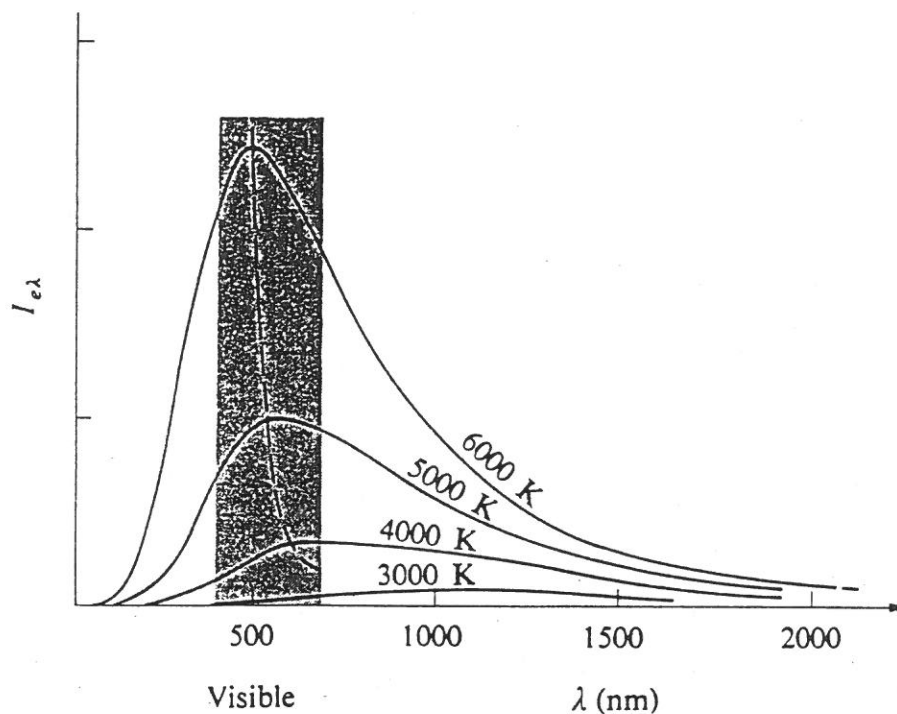


Figure 1. Blackbody radiation curves for several temperatures. Reference [1].

Based on experimental results, Plank's equation describes the radiated intensity at each wavelength for a source region at a specific temperature. An important observation to be made upon observing Figure 1 is that as the temperature of the radiating substance increases so does the intensity of the infrared radiation emitted by that source. Thus, in order to obtain high sensitivity when using an FTIR to monitor emission spectra, the radiating substance must be hot. Using FTIR to monitor emissions spectra is an excellent technique for monitoring the emissions of an automobile's exhaust system or pollution emissions of a smoke stack plume. In both these cases, the chemical species released by

the pollution source are hot.

The other application of an FTIR spectrometer is based on measuring the absorption spectrum. In order to use an FTIR to obtain these spectra, a strong infrared signal needs to be provided by a remote source. The infrared signal of this remote source passes through the desired sample area on its way to the FTIR spectrometer. Figure 2 displays the proper setup required to use the FTIR to measure absorption spectra.

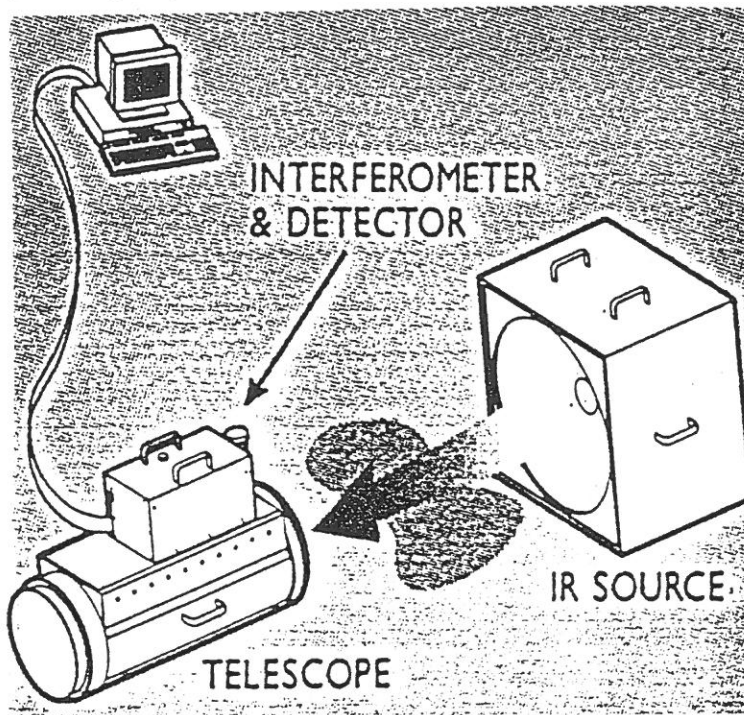


Figure 2. Proper setup to obtain absorption spectra from interferometer. Reference [5].

Utilizing the FTIR in the setup displayed in Figure 2 would produce a spectra containing the emissions of the strong infrared source minus any wavelengths in the infrared region absorbed by the sample area; hence the name absorption spectra. From the absorbed set of wavelengths, it is possible to identify the compounds residing in the sample area. This technique allows the detection of radiating substances without requiring the substance to

be hot as in the case of emission spectra.

Theory

The operation of a FTIR spectrometer is rooted in the principle of superposition of light waves. The principle of superposition basically states that light wave amplitudes are linearly additive. Suppose we have the electric fields of two wavetrains initially in phase and with the same frequency,

$$E_1 = E_{01} \sin(\omega t + \alpha_1), \quad (2a)$$

$$E_2 = E_{02} \sin(\omega t + \alpha_2). \quad (2b)$$

The principle of superposition requires the resulting disturbance, E_{Total} , to be nothing more than the linear addition of these waves,

$$E_{\text{Total}} = E_1 + E_2 \quad (3)$$

The intensity of the resulting field (refer to [1] for details) is obtained from the resulting disturbance from the interference of the two light waves (2a) and (2b),

$$I = E_{01}^2 + E_{02}^2 + 2E_{01}E_{02}\cos(\alpha_2 - \alpha_1), \quad (4)$$

$$\tan \alpha = (E_{01}\sin \alpha_1 + E_{02}\sin \alpha_2)/(E_{01}\cos \alpha_1 + E_{02}\cos \alpha_2). \quad (5)$$

The interference term, $2E_{01}E_{02}\cos(\alpha_2 - \alpha_1)$, is most significant in describing the way the two light waves combine to create a single disturbance. The resultant disturbance has the same frequency as the two original light waves but it has different amplitude and phase.

Because the FTIR deals with infrared wavelengths, which are longer wavelengths and lower optical frequencies than visible light, it is intensity that will be of particular concern because the high-gain photo-multiplier devices based on the photoelectric effect

are not available in this spectral region. In addition, a detector can be used to measure the intensity of the light, but it is difficult to measure the electric field strength of light using conventional detectors. Intensity (I) is proportional to the electric field wave amplitude factor squared, as given by equation (4), and provides an easily measured physical property. Another important observation can be made upon observing equation (4). Namely, the resulting intensity is not simply the sum of the two original intensities but rather there is an additional $2E_{o1}E_{o2}\cos(\alpha_2 - \alpha_1)$ term that is known as the interference term. The critical aspect of this interference term is its dependence on the phase difference between the two original light waves.

$$\text{Phase Difference} = \delta = (\alpha_2 - \alpha_1) \quad (7)$$

When the phase difference is equal to $0, \pm 2\pi, \pm 4\pi, \dots$ the resulting intensity is at a maximum and the two original light waves are said to have constructively interfered. Conversely, when the phase difference is equal to $\pm\pi, \pm 3\pi, \dots$ the resulting intensity is at a minimum and the two original light waves are said to have destructively interfered.

Fourier Transform Interferometers are based on the concept of multiple beam interference. In order for multiple beam interference to occur, a means of generating two waves having a fixed phase relationship with one another must be used. Currently, there are two ways of accomplishing this: wavefront splitting and amplitude division. Splitting of the wavefront was first described in 1802 by Thomas Young's double slit experiment. However, amplitude splitting is of particular importance in the case of an Fourier transform interferometry.

One of the simplest optical systems that accomplishes amplitude splitting, and is the basis of many FTIR spectrometers, is the Michelson interferometer. This optical system divides the amplitude of a wave via a partially reflecting/transmitting surface called a beamsplitter. The beamsplitter is the heart of the Michelson Interferometer and achieves the vital task of generating two in-phase waves that are traveling in different directions. After the original wave is split into two components, a phase shift is introduced into one of the waves by lengthening or shortening the optical path in one of the two legs of the instrument and the two waves are recombined at a partially reflecting surface. Figure 3 displays the Michelson interferometer as a spectrometer [2].

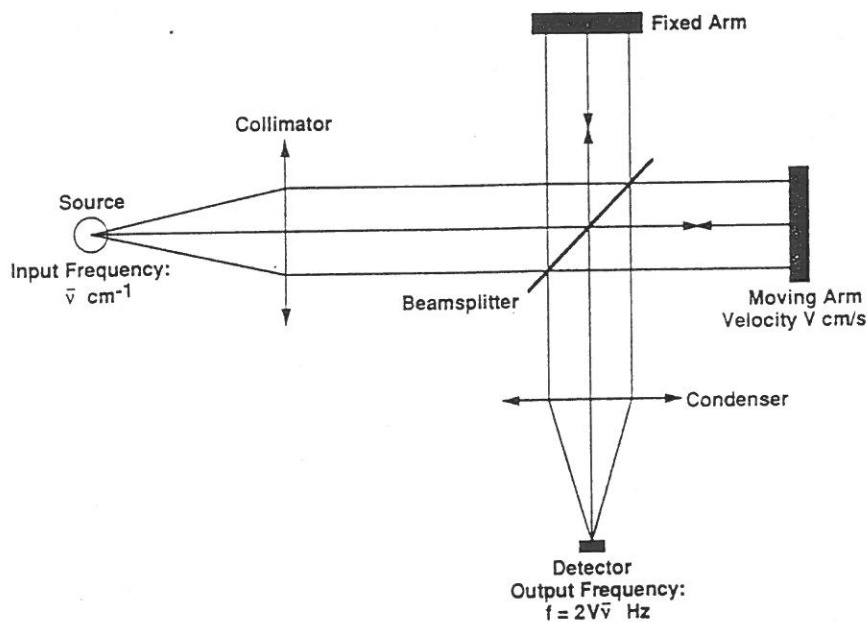


Figure 3. Michelson interferometer as a spectrometer. Reference [2].

The first element of the Michelson interferometer, shown in Figure 3, is the collimator which transforms the light waves from the source into parallel plane waves. These parallel wavefronts pass through a beamsplitter, which does exactly what its name implies; it equally divides the parallel wavefronts by sending half of the incident light towards a mirror located at the fixed arm and the other half to a mirror located at the moving arm. The design in Figure 3 shows that the mirrors located at the fixed and moving arm must be set perfectly perpendicular to the light beams. If this condition is satisfied, the two rectified wavefronts arriving back at the beamsplitter will still be plane and parallel. The beamsplitter now acts as a recombiner and the two plane and perpendicular wavefronts interfere by the principle of superposition. After the two wavefronts are recombined by the beamsplitter, they are focused by a condenser lens onto a detector which records the intensity of the recombined wavefront. The observed intensity is dependent on the path difference imposed between the light wave that traveled to the mirror at the fixed arm and the mirror located at the moving arm.

Noting that the velocity of the mirror attached to the moving arm is represented by V (cm/s) it becomes apparent that the path difference experienced by the two wavefronts is dynamic. As a result, the detector will see a light wave that varies periodically and indeed will be of sinusoidal form. This detected waveform will have an associated frequency, f , which is related to the frequency of the light waves emitted by the source and the velocity, v , of the mirror located at the moving arm,

$$f = 2 \frac{v}{\lambda} \quad (8)$$

In equation (8), ν is the frequency of the light emitted by the source in cm^{-1} (wave number, a unit commonly used in spectrometry to represent frequency), and v is the velocity at which the mirror attached to the moving arm is moving at in cm/s . Thus, the frequency of the waveform detected by the detector, f , has the unit of Hz (or s^{-1}).

The relationship between the frequency of the source and the detected wave modulation frequency generated by the Michelson interferometer provides the interferogram of the Michelson device. In essence, the interferometer shown in Figure 3 is a frequency transducer that converts the very large infrared optical frequencies of the source down to much more manageable frequencies for detection. In the case of an FTIR operating in the infrared region, the expected range of optical frequencies is 300 GHz to 300 THz. The optical frequencies of infrared light are very high and are well beyond the high frequency measuring capability of modern detectors. The Michelson interferometer, via the relationship given in equation (8), has the capability of converting these extremely high optical frequency values down to detectable frequencies that are within the range of conventional detectors. Theoretically, the Michelson Interferometer allows conversion to any desired frequency since the velocity (v) of the mirror attached to the moving arm can have any value desired by the user.

An additional benefit of the Michelson interferometer is that the relationship between optical frequencies and detected frequencies is a linear one. This simplifies the conversion required of the software used to display the FTIR spectra. It is the relationship displayed in equation (8) that allows the Michelson interferometer to function as a spectrometer.

Because typical sources, for example chemical species, emit and absorb a wide range of optical frequencies, a means of measuring the amplitudes of each of these electrical frequencies must be devised. As long as the velocity of the moving mirror is known, the input spectrum of the source is recoverable. The procedure employed to accomplish this is the Fourier transform [2].

Fourier transform techniques allow greater sensitivity stemming from the fact that the interferometer's detector monitors the entire spectrum of the source simultaneously rather than one frequency at a time. If the path difference introduced by the Michelson interferometer is represented by Δ (in cm) and the incident waveform has frequency ν (in cm^{-1}), the signal at the detector varies according to Δ ; i.e. the signal at the detector is represented by $I(\Delta)$,

$$I(\Delta) = I(\nu)\cos 2\pi\nu\Delta. \quad (9)$$

Thus, the interferometer converts a particular frequency component of the incident waveform into a variation in the intensity of the radiation that reaches the detector. As previously mentioned, the incident signal consists of intensities spanning a wide range of frequencies and the total intensity appearing at the detector is the sum of all these oscillating intensities,

$$I(\Delta) = \int_0^\infty I(\nu)\cos 2\pi\nu\Delta \, d\nu. \quad (10)$$

The problem is to determine $I(\nu)$, the variation of the incident intensity with respect to ν , which is the spectrum that the FTIR is to display. This is accomplished by applying the Fourier transform and is attained via the following relationship,

$$I(\nu) = \int_0^\infty I(\Delta)\cos 2\pi\nu\Delta \, d\Delta. \quad (11)$$

Figure 4 below illustrates the concept of the Fourier transform graphically [3].

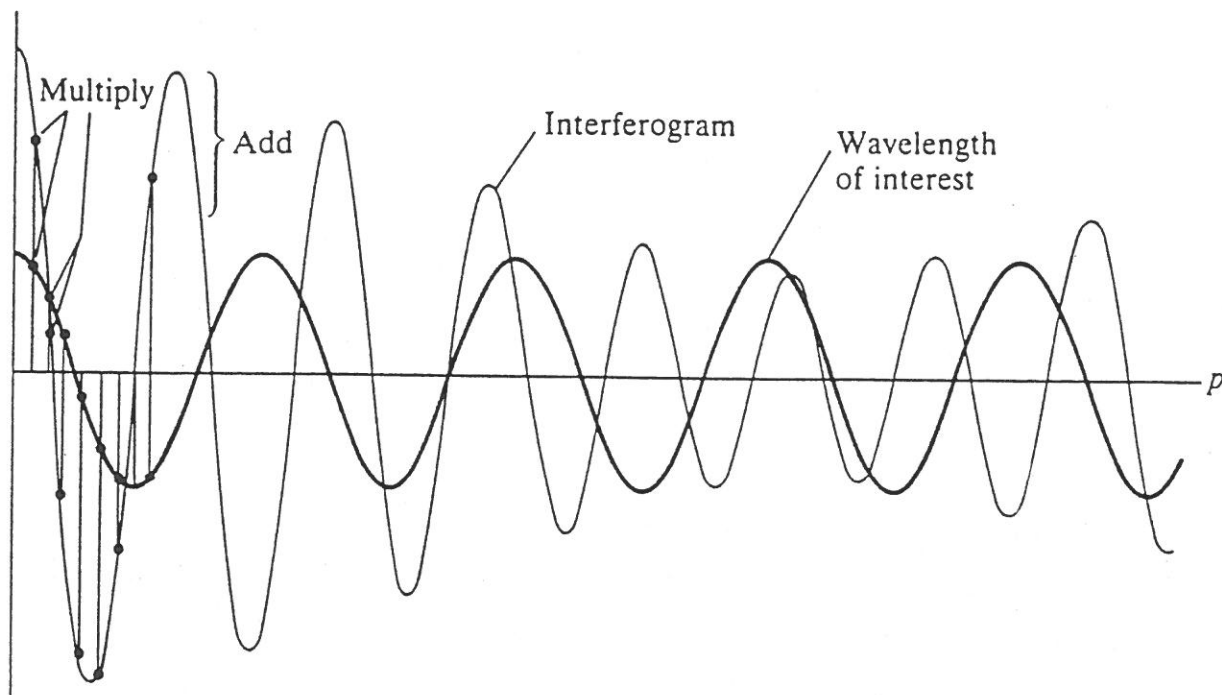


Figure 4. Illustration of the principle of a Fourier transform of an interferometer. Reference [3].

What is illustrated in Figure 4 is that the intensity for each path difference, $I(\Delta)$, is multiplied by the value $\cos 2\pi\hat{\nu}\Delta$ and all these products are added together. The absorption/emission spectrum of the FTIR consist of various path differences weighted by a $\cos 2\pi\hat{\nu}\Delta$ term. Each frequency in the $\cos 2\pi\hat{\nu}\Delta$ term is an integer multiple of the harmonic frequency. When the results of this computation are plotted against $\hat{\nu}$ (cm^{-1}) the absorption spectrum is obtained [3].

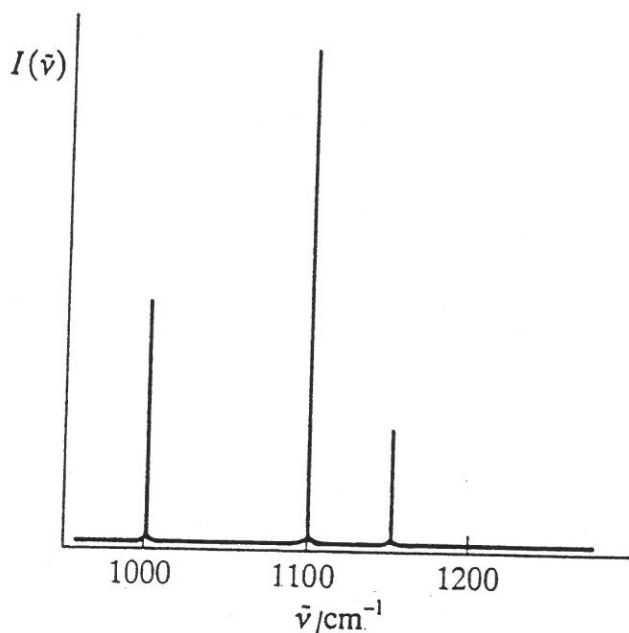


Figure 5. Absorption spectrum of the sample. Reference [3].

Unfortunately, equation (11) cannot be solved by the transform exactly as it is stated. First of all, the use of an integral sign in (11) assumes that the path difference (Δ) is known for infinitesimally small intervals. In other words, it assumes that an infinite number of samples were taken by the FTIR. However, the FTIR is a real device that is only capable of determining the path difference at discrete intervals, which is all that is needed. Thus the integral appearing in equation (11) needs to be replaced by a summation sign. Secondly, the interferogram is produced by a real instrument and can only be generated over some finite range of path differences. Hence, the integration from 0 to ∞

shown in (11) is unrealistic and needs to be replaced by a finite path distance range of 0 to L.

These limitations require the use of the discrete Fourier transform. This operation requires the FTIR to sample the interferogram at equal intervals ($\delta\Delta$). In addition, this discussion assumes that the first sample occurs at position $\Delta = 0$. The required number of samples (N) is given by equation (12),

$$N = 1 + L/\delta\Delta. \quad (12)$$

In equation (12), the maximum path difference is represented by L. As a result of this sampling process, the output of the Discrete Fourier Transform is a set of N spectral intensities that are equally spaced in frequency ($\delta\sigma$). The resulting equations are:

$$I(m\delta\Delta) \equiv \sum_{k=0}^N F(k\delta\sigma) \exp(i2\pi k \times \delta\sigma \times m\delta\Delta), \quad (13)$$

$$I(n\delta\sigma) \equiv \left(\frac{1}{N}\right) \sum_{j=0}^N I(j\delta\Delta) \exp(-i2\pi j \times \delta\sigma \times n\delta\Delta). \quad (14)$$

The use of the Discrete Fourier Transform provides results that closely mimic those given by the Fourier Transform [equations (10) and (11)].

Figure 6 shows a "generic" configuration of a Fourier transform interferometer. Some of the components appearing in this diagram warrant a discussion. The entrance aperture, shown in Figure 6, is placed to provide control of stray light. The diagram assumes that the reflecting coating is located on the front face of the beamsplitter. This

placement of the reflecting coating results in the transmitted beam making three passes through the material that comprises the beamsplitter while the reflected beam will make only one pass through the beamsplitter en route to the detector. As a result of this discrepancy and in an attempt to maintain consistency, it is common practice to insert an uncoated element of material and thickness identical to that of the beamsplitter in the path of the reflected beam to ensure equality. This element is referred to as a compensator.

An additional observation needs to be made with regard to the alignment of the two arms of the interferometer. Unlike the original Michelson interferometer, shown in Figure 3 where the fixed and moving arm were required to be perpendicular to each other, the fixed and moving arm are no longer perpendicular to each other. The advantage of this arrangement is that the shallower the angle between the two arms, the smaller the required beamsplitter and compensator. These elements tend to be the most expensive and limiting elements of an interferometer. As a result, the design shown below is more cost effective [2].

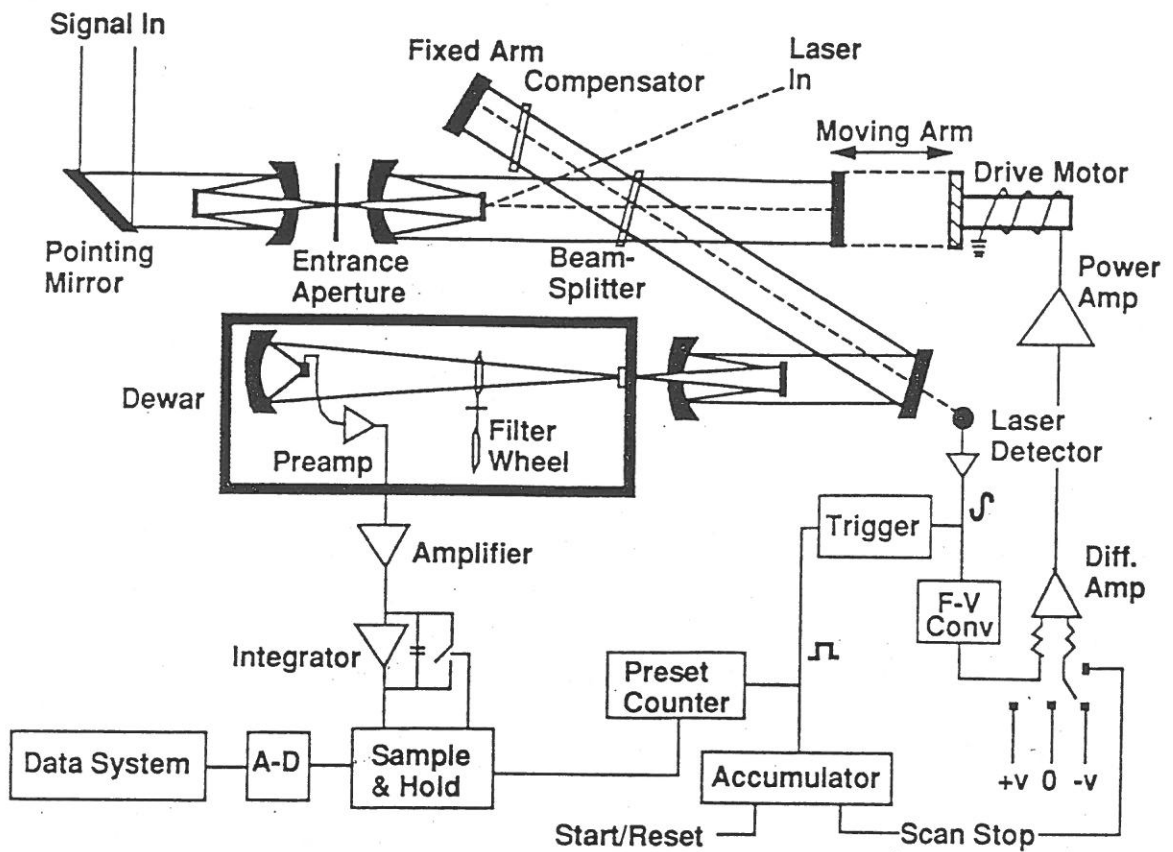


Figure 6. A generic Fourier transform interferometer. Reference [2].

EXPERIMENTAL RESULTS

Experimental Tests

MIDAC's Model M2400 - ZnSe was the FTIR used to experimentally identify the existence of certain chemical species in the surrounding environment. The instrument was set up in the Electrical Engineering Laser Remote Sensing Laboratory at the Pennsylvania State University. Appendix A shows the electrical schematics of the interferometer and

Appendix B describes the assembly and operation of the device. This device is a plane mirror Michelson interferometer that uses a liquid N₂ cooled MCT detector. However the FTIR used in these experimental tests has been modified to monitor wavelengths of approximately 8μm through 11μm in the infrared range instead of the typical 2μm through 14μm range typical of other ZnSe interferometers produced by MIDAC. The spectrum shown in Figure 7 is a spectrum of the background noise associated with the experimental setting and demonstrates the range monitored by the modified Fourier transform interferometer.

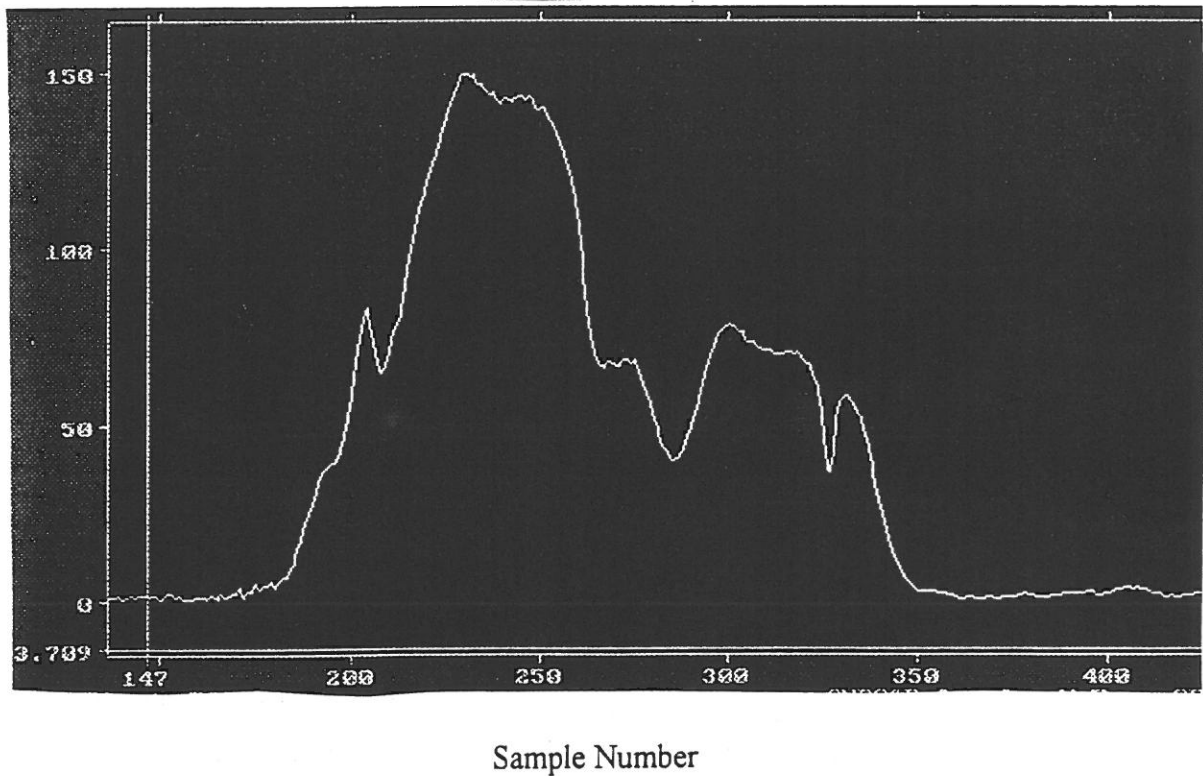
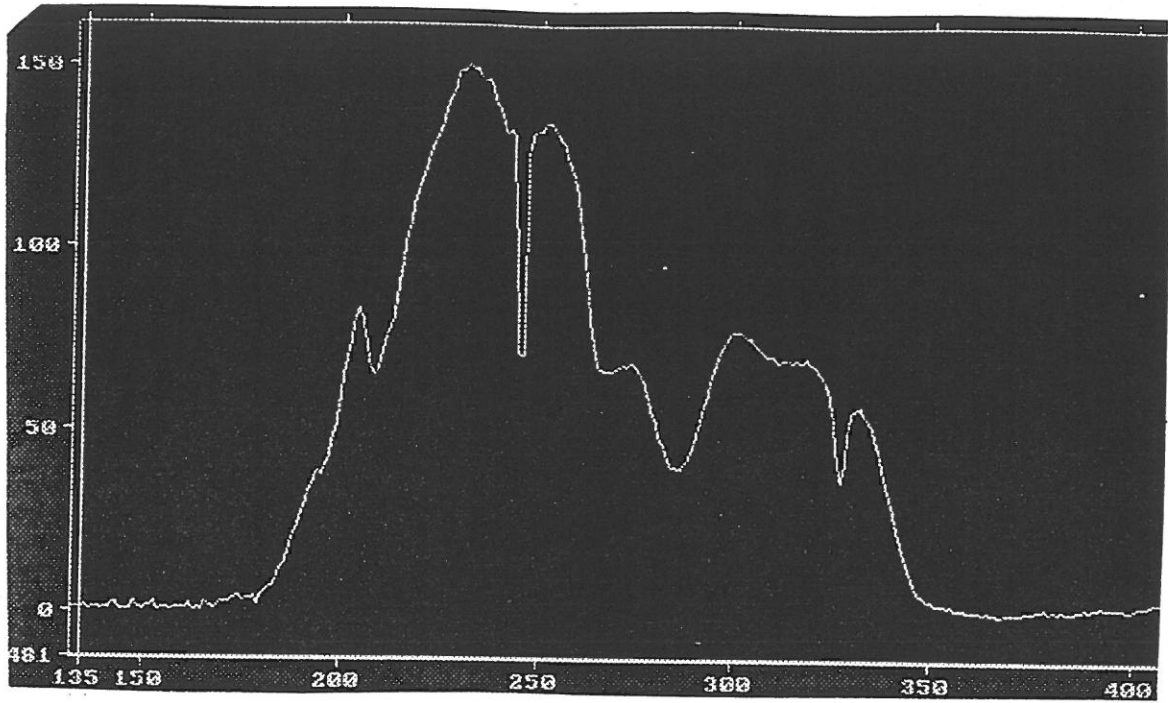


Figure 7. Background spectrum generated by FTIR.

The spectrum shown in Figure 7 was obtained using Galactic Industry Corporation's Labcalc. Labcalc plots the spectrum with sample number displayed on the horizontal axis. Because of the way Labcalc plots the spectrum, the horizontal axis must be multiplied by 3.858 to convert sample number to wavenumber in cm^{-1} . The spectral range of the FTIR is approximately 750cm^{-1} to 1300cm^{-1} which correspond to wavelengths of $7.7\mu\text{m}$ to $13\mu\text{m}$. The smaller range of monitored wavelengths was required to allow certain modifications to the components that comprise the interferometer. These modifications include a larger detector surface area and higher detector sensitivity. A ceramic hot plate was used as the infrared source in the experimental tests to obtain absorption spectra of the chemical species.

Sulfur hexa-fluoride, SF_6 , was chosen as the chemical specie to be experimentally tested. This specie was selected because its infrared spectrum has a single emission/absorption line that lies in the middle of the monitoring region of the Fourier transform interferometer. An experimental setup similar to Figure 2 was used to obtain the following absorption spectrum of SF_6 .

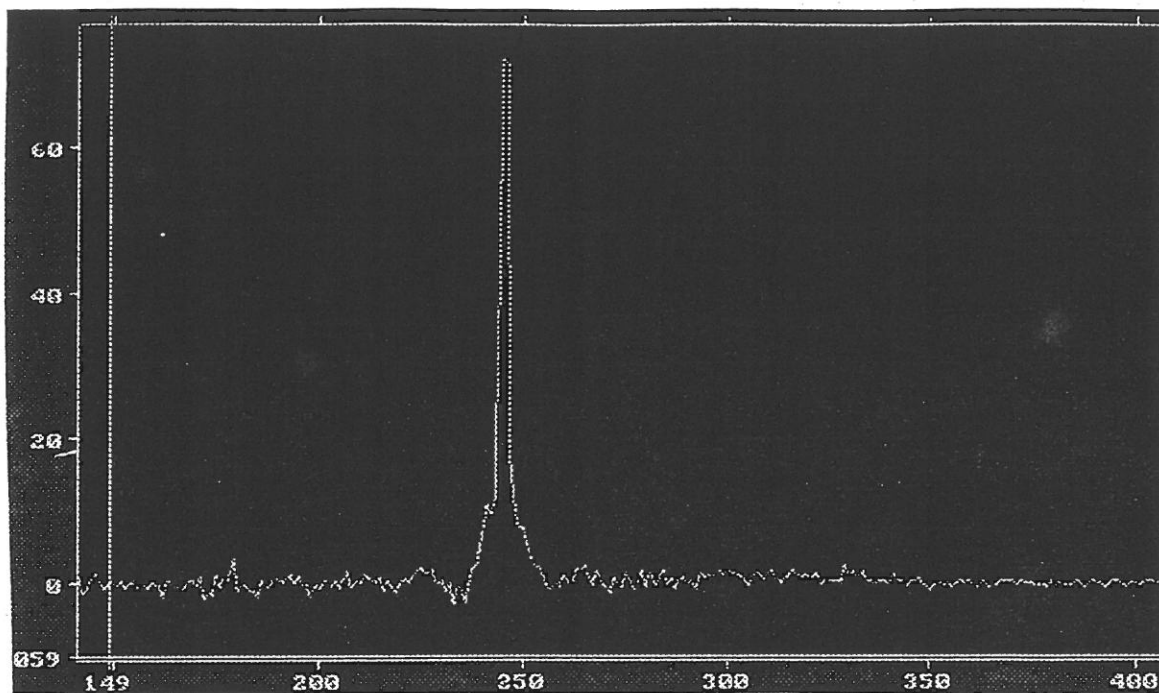


Sample Number

Figure 8. Absorption spectra of sulfur hexa-fluoride.

Comparing the spectra displayed in Figure 8 with Figure 7 it becomes readily apparent that the SF_6 absorption line, which is known to correspond to 950 cm^{-1} (sample number 245 in Figure 8), is detected. This frequency corresponds to a wavelength of approximately $10.5 \mu\text{m}$. The line width of the absorption spectra of the SF_6 chemical species is approximately 7 cm^{-1} which is considerably greater than the manufacturer specification of a 0.5 cm^{-1} resolution. Possible sources of this discrepancy are addressed in the sources of error section. The spectrum shown in Figure 9 was obtained by taking the difference of the spectra shown in Figure 7 and 8. This spectrum clearly displays the absorption line

associated with SF₆.



Sample Number

Figure 9. The absorption line associated with sulfur hexa-fluoride.

The slight variations evident in the spectrum shown in Figure 9 are caused by the drift in the spectra that occurs between scans of the FTIR as well as other sources of error to be discussed in the following section.

Sources of Error

There are many sources of error that can occur when using a Fourier transform interferometer to monitor the emission/absorption spectra of a chemical species. These errors distort the spectra generated by the FTIR and cause discrepancies between

predicted and achieved results. Possible sources of error include, but are not limited to, finite resolution, phase errors, beam divergence through the interferogram changing as a function of wavelength, mirror misalignment, poor mirror drive, sampling errors, and background noise [6]. Errors due to finite resolution, sampling errors, and background noise will be addressed.

In the theory section, it was mentioned that the Fourier transform [defined in equation (11)] could not be solved exactly by the FTIR. One of the limitations of the FTIR is that in a real device an infinite number of samples cannot be considered. As a result, the FTIR can only generate an interferogram over a finite range of path differences (0 through L). This limitation corresponds to multiplying the ideal interferogram, based on an infinite number of samples, by a boxcar function. A boxcar function, $B(x)$, has a value of 1 for $0 \leq x \leq L$ and is 0 elsewhere. Multiplying the ideal interferogram, $I(\Delta)$, see equation (10), by the boxcar function in the time domain is the same as convolving the Fourier Transform of the Boxcar function with $I(\nu)$, the Fourier Transform of $I(\Delta)$, in the frequency domain. The Fourier transform of the boxcar function, $B(\nu)$, is given by,

$$B(\nu) = \text{sinc}(2\pi\nu L). \quad (15)$$

The frequency domain representation of the boxcar function, the sinc function, is shown below in Figure 10.

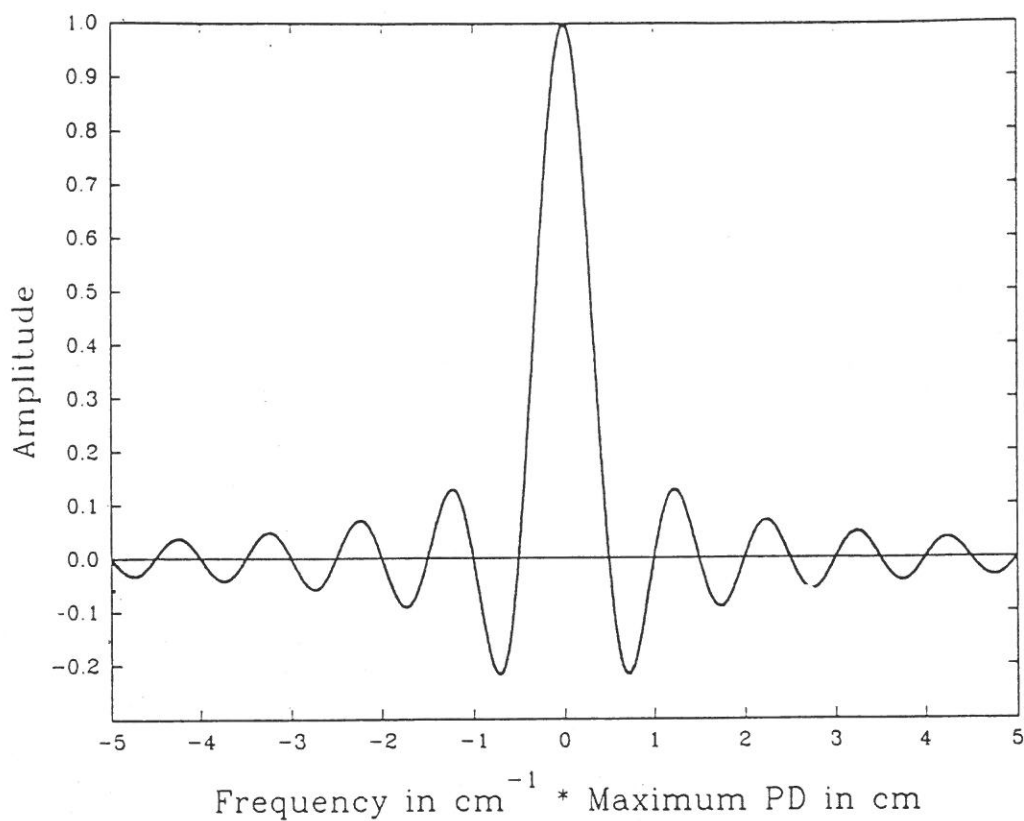


Figure 10. Frequency domain representation of the boxcar function. Reference [2].

Convolving in the frequency domain, the ideal spectrum $I(\nu)$ with the boxcar function results in a "smeared out" version of the ideal spectrum $I'(\nu)$ [2]. As a result, any spectral structure of the emission/absorption spectrum of a compound which is sharper than the width of the sinc function will be lost. This limitation demonstrates the importance of spectral resolution. Spectral resolution is defined as a measure of the ability of the spectrometer to reproduce the incident spectrum [6].

Sampling errors characterize an additional source of error introduced by real FTIRs. Proper control of the interferogram's sampling rate represents a critical element in the operation of the FTIR. Interferogram sampling is based on the Shannon sampling

theorem. This theorem states that a spectrum whose non-zero values are limited to the frequency range $\nu_1 \leq \nu \leq \nu_2 \text{ cm}^{-1}$ can be exactly reconstructed from samples of that spectrum if the spectrum is sampled at intervals of the path difference Δ (in cm), which is expressed,

$$\Delta \leq 1/[2(\nu_2 - \nu_1)]; \quad \nu_2 > \nu_1 \geq 0. \quad (16)$$

The expression given by equation (16) is valid only if $\nu_2/(\nu_2 - \nu_1)$ is an integer.

Sampling an interferogram in the time domain results in repetitions of the spectrum in the frequency domain. Each frequency domain repetition of the spectrum is assigned and identified by an alias number. If the sampling interval differs from the path difference Δ defined in equation (16) aliasing will result. Aliasing is the phenomenon of reflecting frequency components of the spectrum that fall outside the boundaries of a given order back into the spectrum. Thus, deviations of the sampling interval from the path difference described in (16) will result in distortion of the spectrum generated by the FTIR. The sampling rate, that is the intervals between samples, of the FTIR has some inherent variability. Thus, it is extremely difficult for the FTIR to consistently have an interval between samples that exactly satisfies the condition given in (16). As a result, some amount of distortion due to aliasing results in the spectrum generated by the FTIR.

The ability to exactly reconstruct a spectrum from its samples, as predicted by the Shannon sampling theorem, is based on the assumption that an ideal bandpass filter is used to extract the portion of the spectrum corresponding to the desired alias order. Unfortunately, ideal filters cannot be achieved. The optical filters used in a FTIR do not have the sharp cutoffs required to satisfy the Shannon theorem. Thus an optical filter of

bandwidth $\Delta\nu$ will have measurable transmittance for frequencies well beyond its cutoff frequencies. This shortcoming, like an inexact and varying sampling frequency, results in aliasing and introduces another distortion component into the spectrum of the FTIR. A frequency domain plot of the transmittance curve for a typical band-pass filter used in a FTIR is shown below [2].

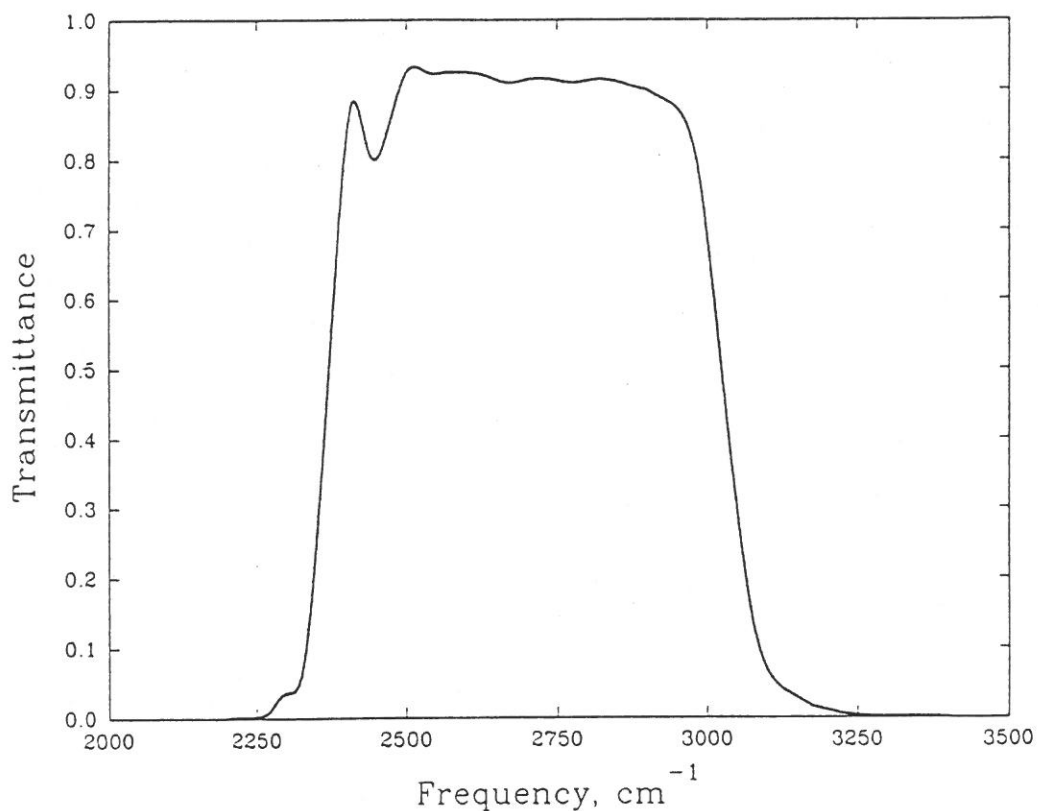


Figure 11. Transmission curve of a typical filter used in a FTIR. Reference [2].

A third source of distortion that corrupts spectra generated by an FTIR is background noise. Background noise creates a contrast problems inherent in the fact that the desired emission/absorption spectrum of the compound is overlaid on top of and hence

corrupted by the background noise. In extreme cases the intensity of background noise can be orders of magnitude greater than that of the desired signal. Background noise typically originates within the sensor and its immediate environment.

FUTURE WORK

The Fourier transform interferometer has been characterized by analyzing the emission spectra of a few chemical species in a controlled setting. This characterization of the FTIR barely touches the applications in which this device can be used. Future experiments should focus on monitoring the emission spectrums of smoke stack plumes or car exhausts. These pollution sources are ideal because they are hot enough to emit a measurable amount of radiation in the infrared range. Thus, a separate external infrared source is not needed as in the case of monitoring absorption spectrums.

CONCLUSION

The Fourier transform interferometer (FTIR) is a powerful device that can be used to identify and monitor the existence of organic or inorganic chemical species in the environment. This device makes use of the fact that each compound emits/absorbs frequencies in the infrared range that are unique to that species. In essence the infrared region provide the "fingerprint" region of various chemicals.

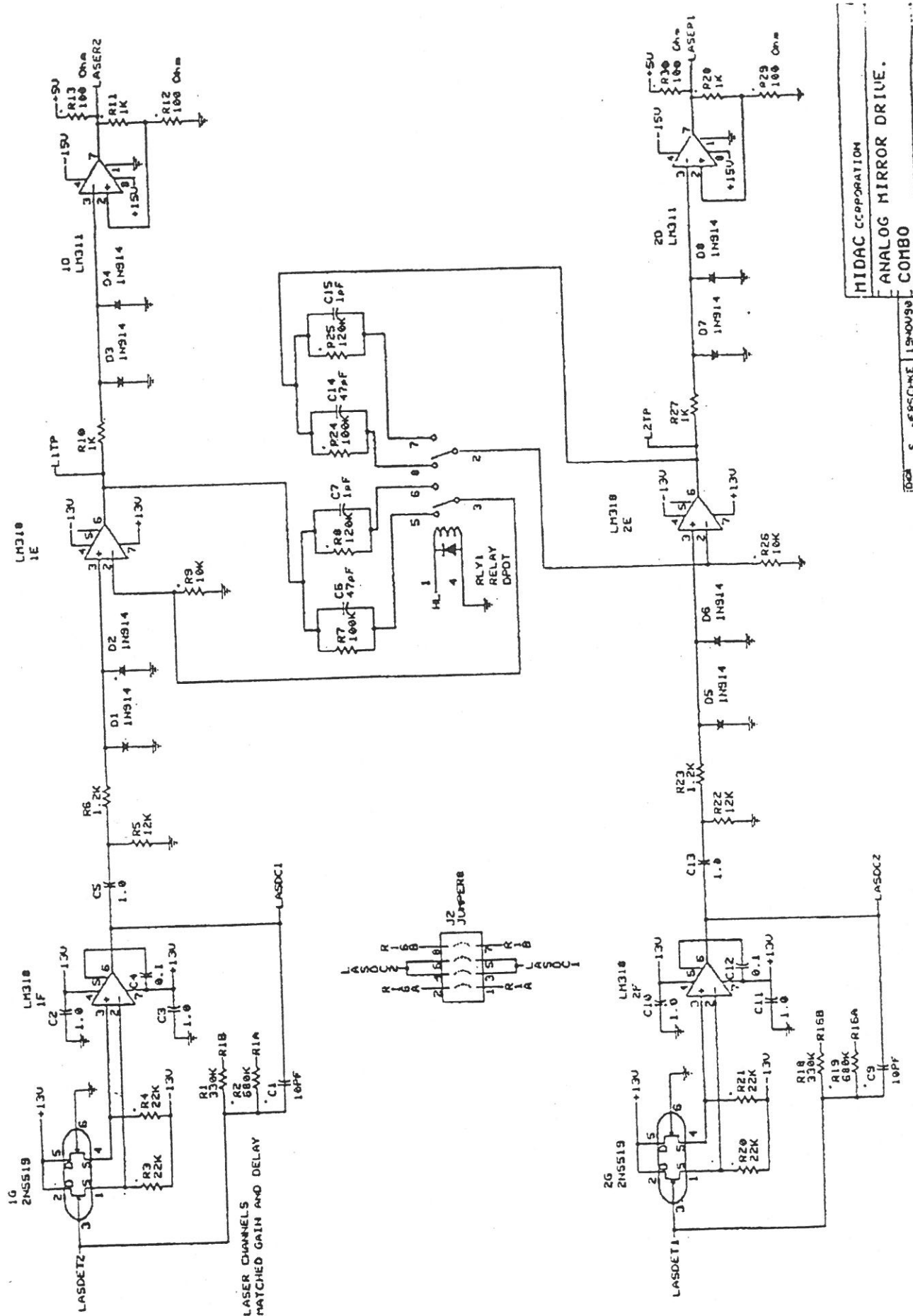
A brief description of the theory associated with the FTIR design and verification of its ability to identify the existence of compounds in the environment have been included in this paper. The Fourier transform interferometer was successfully set up and an absorption spectrum was obtained from the laboratory instrument. Instrument operation was verified by using sulfur hexa-fluoride as the chemical species in the experimental tests. Line width of the absorption spectra was used to estimate the resolution of MIDAC's Fourier transform interferometer and this experimentally obtained value was compared to the manufacturer's specifications. Additionally, possible sources of errors have been identified.

The FTIR provides a simple and relatively accurate method of providing pollution monitoring. FTIR instruments are expected to become a vital device in the Environmental Protection Agency's (EPA) attempt to determine whether or not compliance is being achieved by industries.

REFERENCES

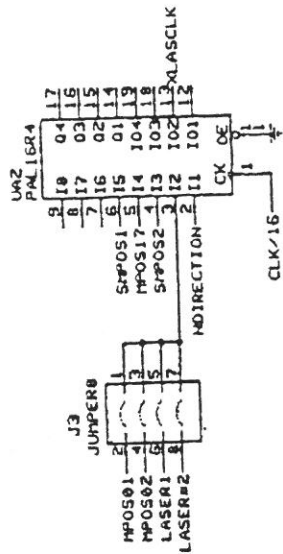
- [1] E. Hecht, *OPTICS*. Reading, Massachusetts: Addison-Wesley Publishing Company, 1987.
- [2] R. Beer, *REMOTE SENSING BY FOURIER TRANSFORM SPECTROMETRY*. New York, New York: John Wiley & Sons, Incorporated, 1992.
- [3] P.W. Atkins, *PHYSICAL CHEMISTRY*. New York, New York: W.H. Freeman and Company, 1990.
- [4] R.A. Serway, *PHYSICS FOR SCIENTISTS AND ENGINEERS*. Philadelphia, Pennsylvania: Saunders College Publishing, 1990.
- [5] MIDAC Corporation's Product Brochure. Irvine, California: MIDAC Corporation, 1995.
- [6] P. Griffiths, *FOURIER TRANSFORM INFRARED SPECTROMETRY*. New York, New York: John Wiley & Sons, 1986.

APPENDIX A
Circuit Schematics of the FTIR

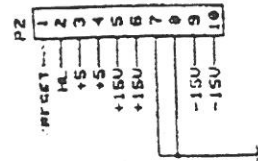
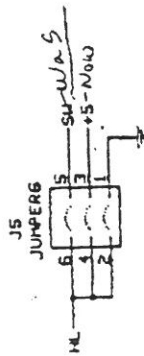


MIDAC CORPORATION
 ANALOG MIRROR DRIVE.
 COMBO
 DESIGNED BY
 101354

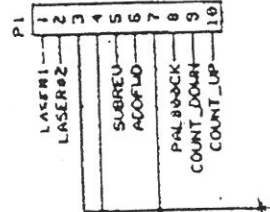
Doc# S. -ERSCHE 15-00050
 BY G. KISHIDA 17-PR51



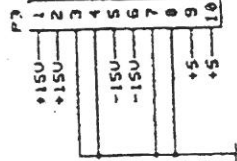
PAL EQUATIONS IN
PAL916.EQU FILE OR
PAL917.EQU (DATA IN BOTH DIRECTIONS) FILE



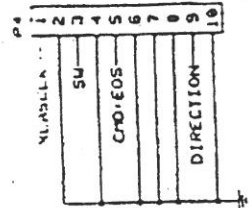
RESET AND POWER
PIN AND SOCKET CONNECTION
TO ANALOG BOARD



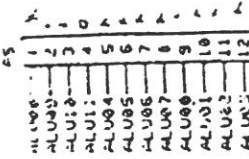
COUNT, CONTROL, AND LASER
PIN AND SOCKET CONNECTION
TO ANALOG BOARD



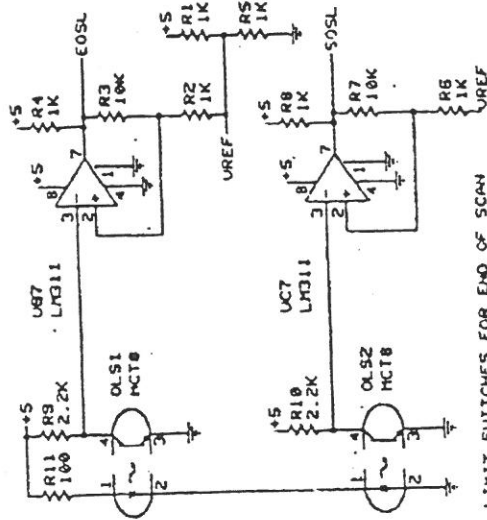
POWER INPUT CONNECTOR
PIN HEADER FOR IDC



I/O CONNECTOR TO COMPUTER
PIN HEADER FOR IDC



PIN AND SOCKET CONNECTION
TO ANALOG BOARD



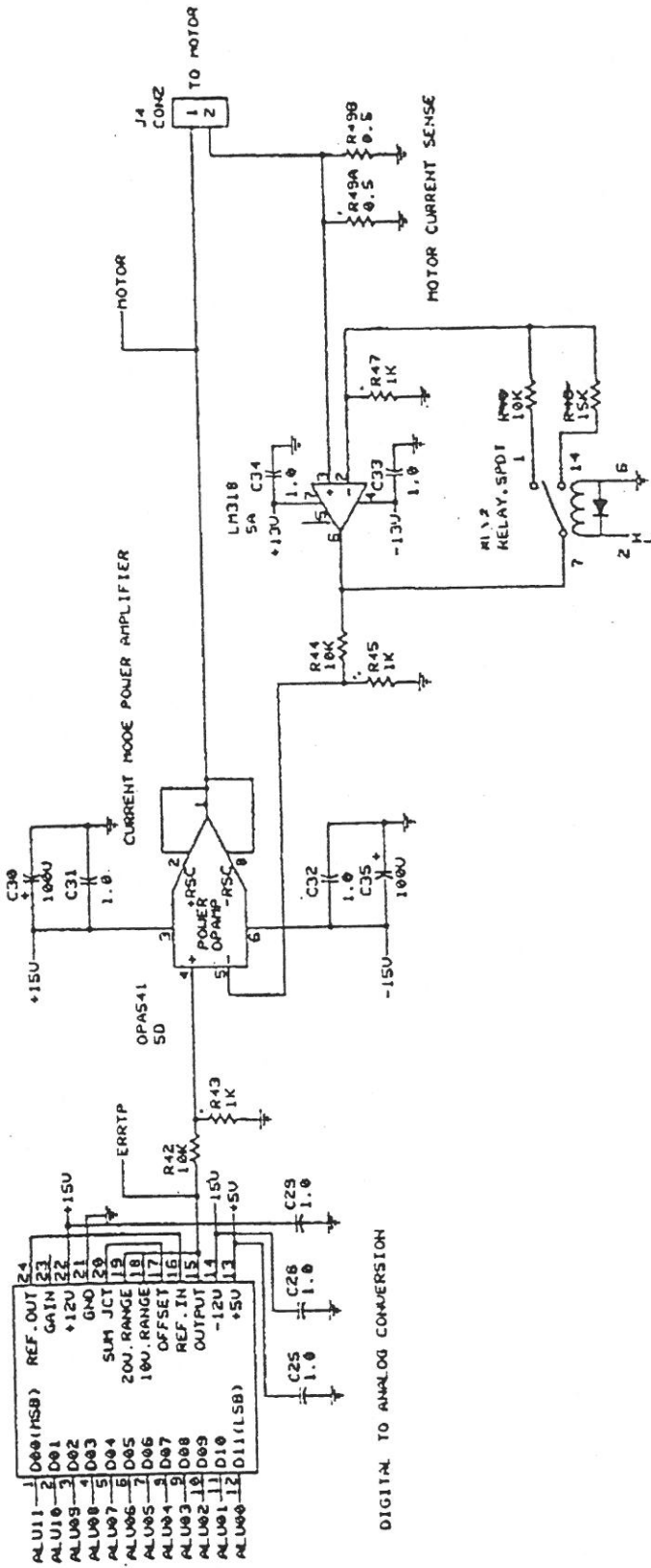
OPTICAL LIMIT SWITCHES FOR END OF SCAN

FOR S. VERSCHEE 19POL90
 FOR G. KISHIDA 17POL91
 DATE 8/87

MIDAC CORPORATION
 DIGITAL MIRROR DRIVE,
 COMBO

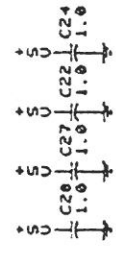
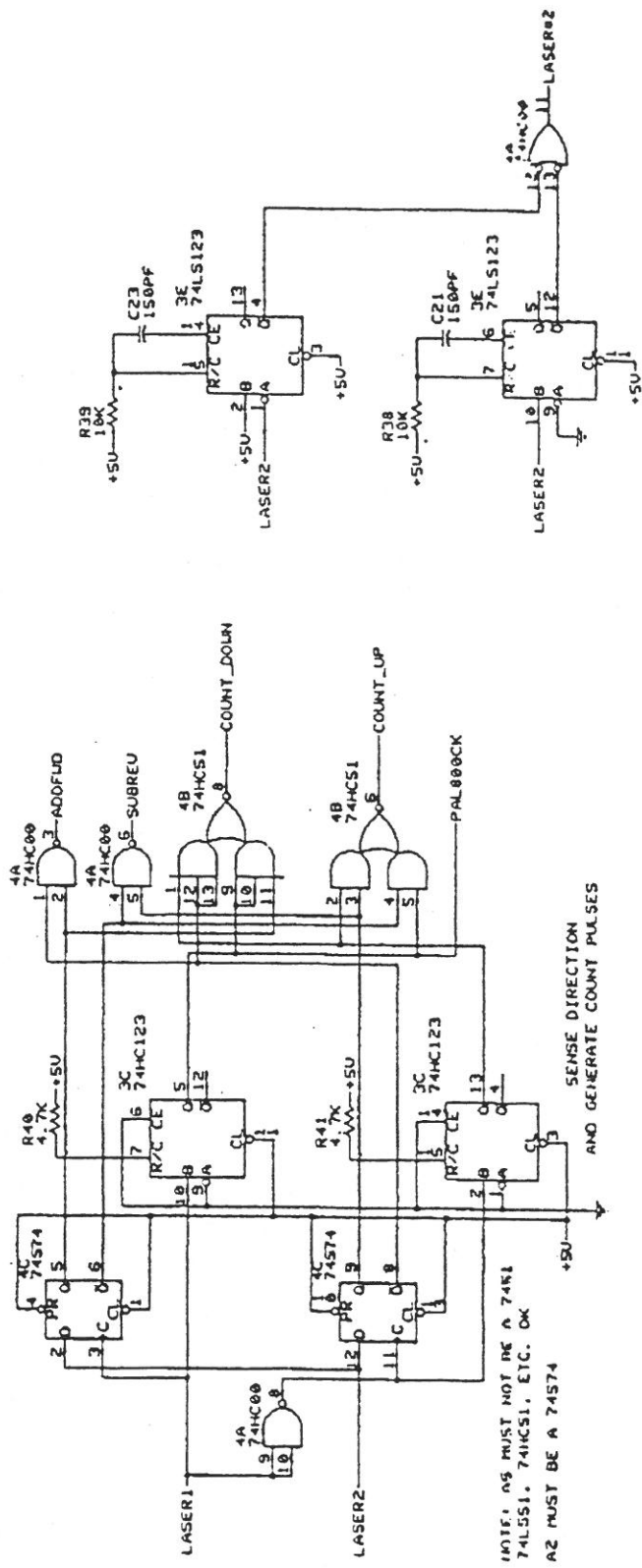
101357

DAC1200
5G

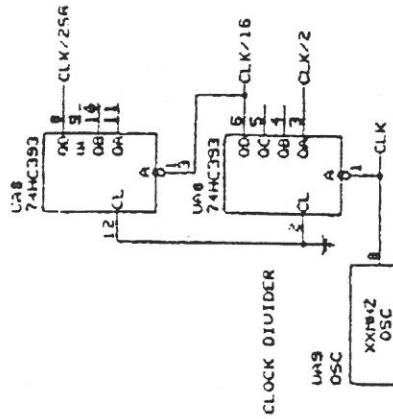
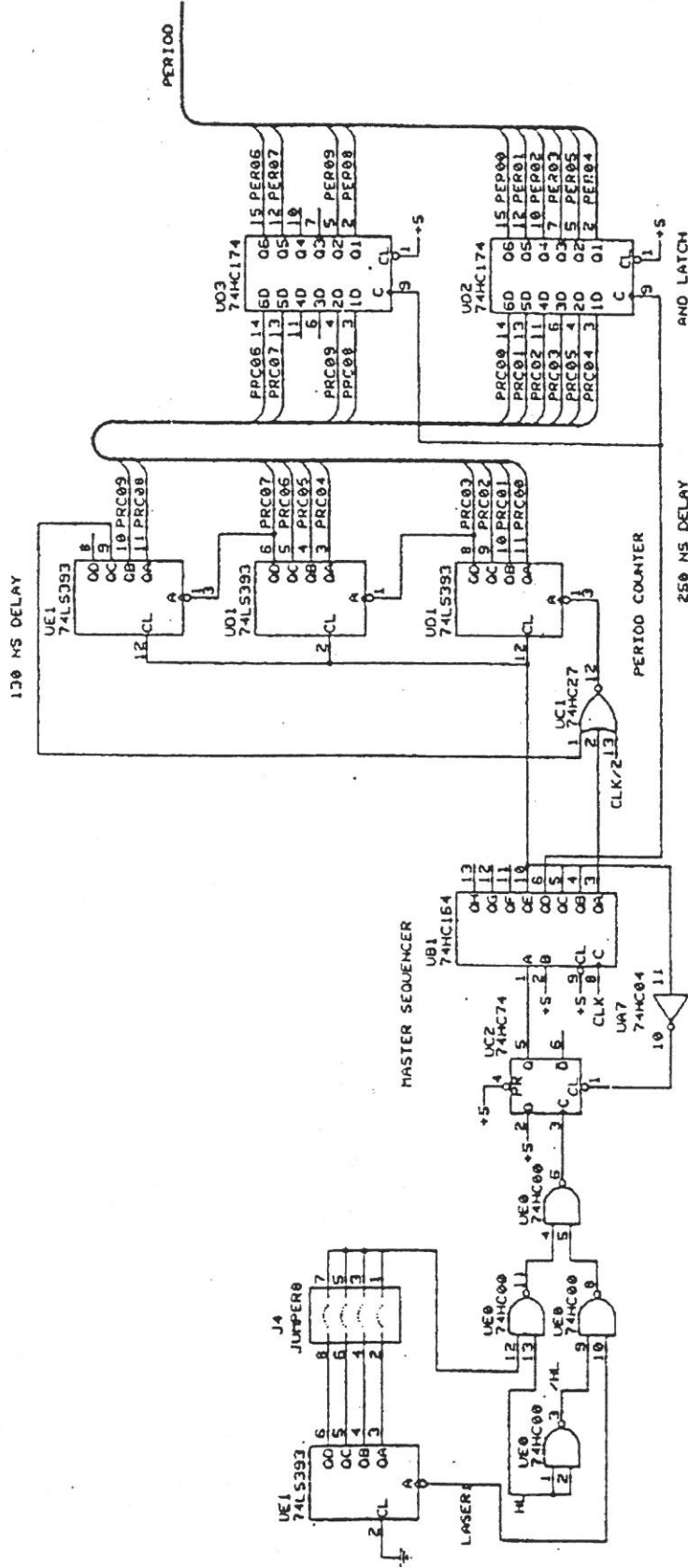


DIGITAL TO ANALOG CONVERSION

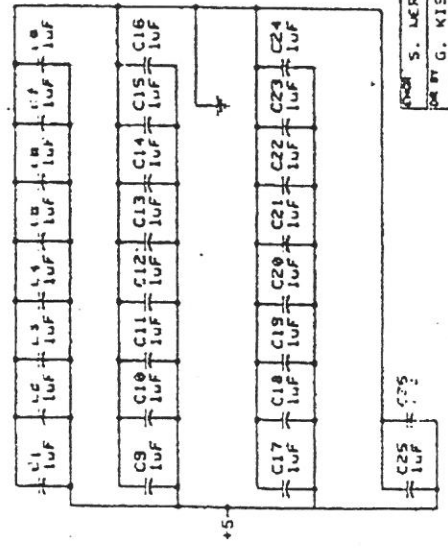
MIDAC CORPORATION	
ANALOG MIRROR DRIVE,	
COMBO	
DATE	101354
DESIGNED BY	S. WERSCHKE
DESIGNED BY	G. KISHIDA
DATE	19NOV90
DATE	17APR91



MIDAC CORPORATION	
ANALOG MIRROR DRIVE.	
DESIGNER: S. UERSCHEKE	DATE: 10/NOV/80
CHECKED BY: G. KISHIDA	DATE: 17/APR/81
PROJECT NO: 101354	REV: 1 B

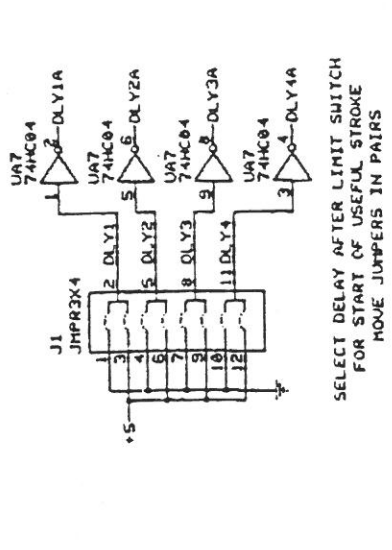
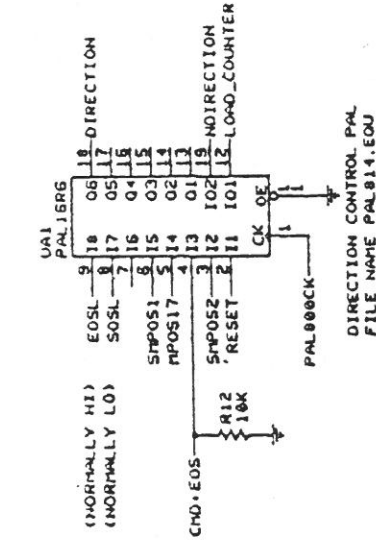


4.0 MHz OSC -> 3MHz LASER
 AN EXCELLENT CHOICE FOR JTGOS DETECTORS
 (APPLIES FOR H-9. IE LOW SPEED)

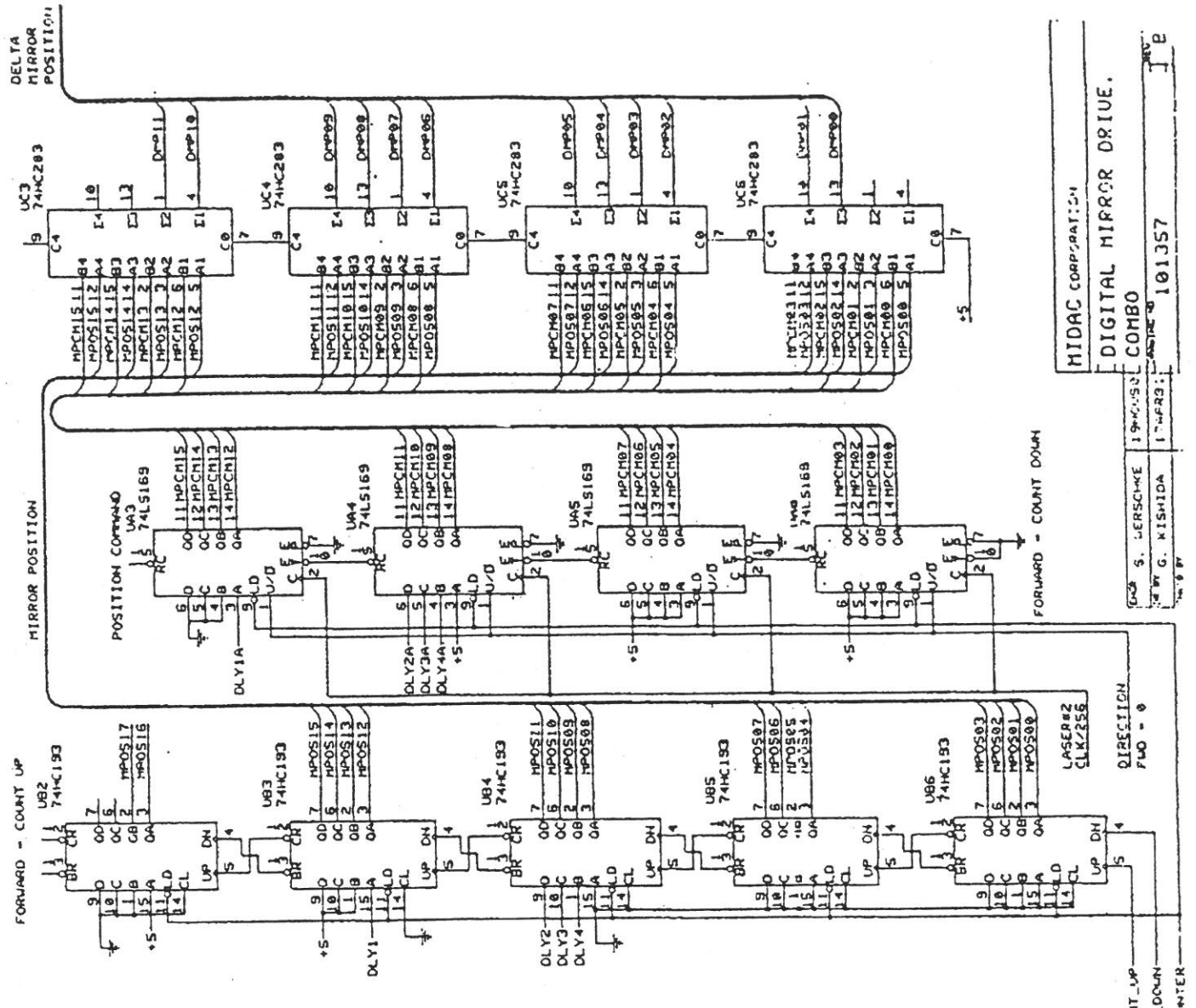
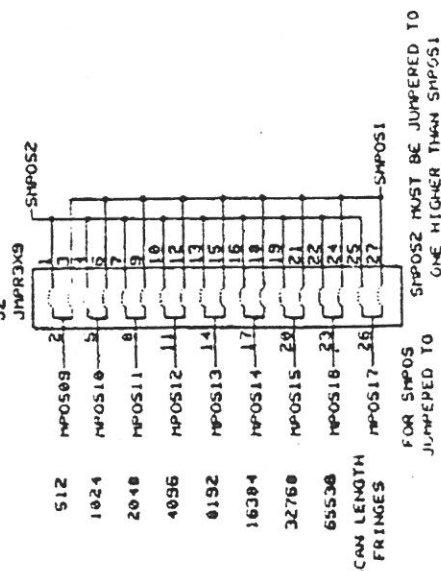


MIDAC CORPORATION
 DIGITAL MIRROR DRIVE,
 COMBO
 101357

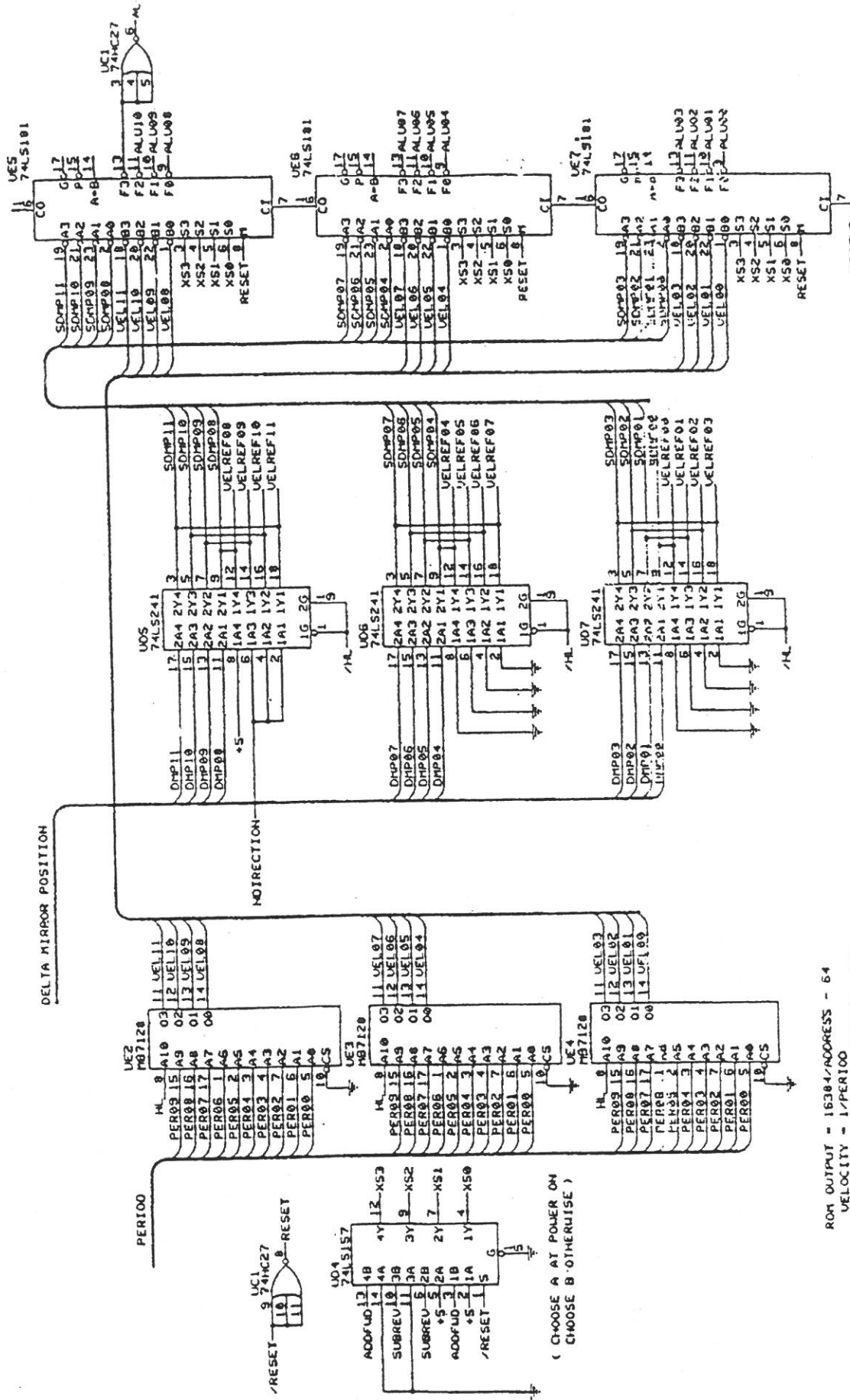
DESIGNED BY S. WERSCHKE
 DRAWN BY G. KISHIDA
 CHECKED BY J. W. HARRIS



SELECT DELAY AFTER LIMIT SWITCH
FOR START OF USEFUL STROKE
MOVE JUMPERS IN PAIRS



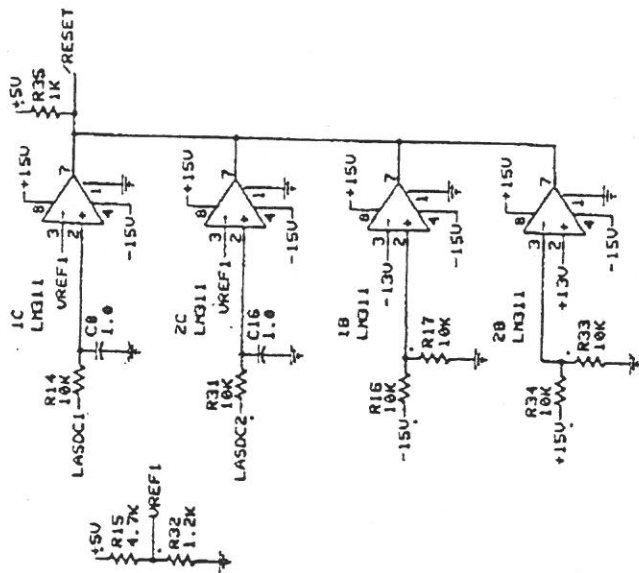
MIDAC CORPORATION
DIGITAL MIRROR DRIVE.
COMBO
S. LERSCHKE 19-H-52
G. NISHIDA 17-FR0
101357



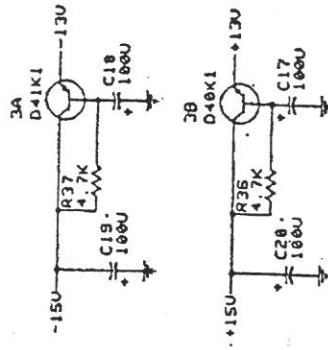
ROM OUTPUT = 16384/ADDRESS - 64
 VELOCITY = 1/PERIOD
 NOMINAL INPUT = NOMINAL OUTPUT - 256
 (FOR 1L-0, IE LOW SPEED)

COMBINE POSITION AND VELOCITY TERMS

MIDAC CORPORATION	
DIGITAL MIRROR DRIVE.	
5 - ERSCHKE	17-PP-11
5 - MISHIOA	17-PP-11
101357	



POWER ON AND LASER OUT
RESET GENERATOR



POWER FILTERING

PIN AND SOCKET CONNECTIONS TO LOGIC BOARD

P3	1	ALU08
	2	ALU09
	3	ALU10
	4	ALU11
	5	ALU04
	6	ALU05
	7	ALU06
	8	ALU07
	9	ALU00
	10	ALU01
	11	ALU02
	12	ALU03

ALU BUS TO DAC

P2	1	LASER1
	2	LASER2
	3	GND
	4	GND
	5	SVAREU
	6	RODFLO
	7	GND
	8	PAL800CK
	9	COUNT_DOWN
	10	COUNT_UP

COUNT, CONTROL, AND LASER

J3	1	-13U
	2	LASDET1
	3	-13U
	4	LASDET2
	5	
	6	
	7	
	8	
	9	
	10	

DETECTOR CABLE

J1	1	MOTOR
	2	ERRTP
	3	GND
	4	GND
	5	LASER1
	6	LASER2
	7	L2TP
	8	L1TP
	9	LASDC2
	10	LASDC1

TEST POINTS

FOR S. UERSONKE	15H0U90
BY G. KISHIDA	17APK91
DATE	101354
REV	B

HIDAC CORPORATION

ANALOG MIRROR DRIVE,
COMBO

APPENDIX B

Assembly of the FTIR and GENINTER Functionality

ASSEMBLY OF THE FTIR

Components:

- 1) MIDAC's FTIR
- 2) Power Supply
- 3) 25-Pin Ribbon Cable
- 4) GENINTER Data Acquisition Software

Assembly:

- 1) Connect the Power Supply to the FTIR and plug into an outlet
- 2) Connect one end of the 25 pin cable to the FTIR and the other to the PC port
- 3) Switch the FTIR switch to the Standby Position (A loud buzz sound should occur)
- 4) When an audible decrease in the noise emitted by the FTIR occurs, switch the switch to the On Position
- 5) Go to the MIDAC subdirectory on the PC and type:
midac filename.dat
note: The filename must consist of 3 Letters followed by 4 Numbers in order for GENINTER to accept it as a valid name (Ex. tst0001.dat)
- 6) You should now see an interferogram on the screen of the PC
- 7) If the interferogram is inconsistent with expected results view GENINTER's gen.opts file. This file should have the following values:

video support = off
size of igram = 4
input buffer size = 8192
error code three = off
spectra = on
center = positive
seconds between scans = 0

GENINTER Functionality

The order of displays in GENINTER are:

- 1) Interferogram
- 2) Spectra
- 3) Initiate Collect Data Screen

[+] key allows you to move to the next display

[-] key allows you to move to the previous display

For Interferogram:

[right arrow] allows you to zoom in

[left arrow] allows you to zoom out

For Spectra:

[up arrow] allows you to zoom in

[down arrow] allows you to zoom out

For Interferogram and Spectra:

[page up] allows you to increase gain by 1

[page down] allows you to decrease gain by 1

Note: For best results set gain as high as possible but be sure to avoid any errors codes