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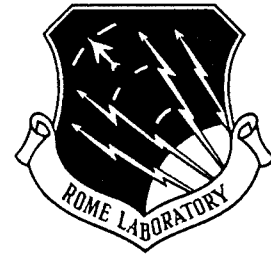
# HIGH SPEED LASER FACILITY

Joseph M. Osman and Brian DeVaul

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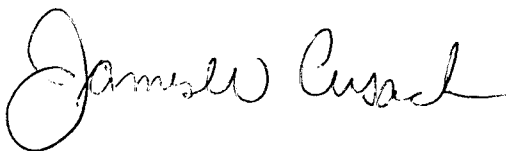*APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.*

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**Rome Laboratory**
**Air Force Materiel Command**
**Griffiss Air Force Base, New York**

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**13. ABSTRACT** (Maximum 200 words)
The current major limiting factor in digital optical computing is a fast, efficient, cascadable optical switch with which to build computers.  Candidates are not limited to the well known semiconductors and fabrication methods of electronics.  A novel facility to evaluate candidate devices has been constructed.  Multiline and tunable femtosecond and picosecond laser systems, as well as frequency mixing systems, are used as light sources.  The facility has at least picosecond source capability from 200 nm to 2 um.  The switch transfer function is evaluated in a pump-probe system with femtosecond and picosecond autocorrelators to measure dispersion, an Optical Multichannel Analyzer to measure absorption, a CCD or pyroelectric camera system to measure mode modification, and a multi-detector system to measure switching energy and insertion loss both in absorption and in reflection.  The switch or switching array under test is mounted in a 6 axis micropositioner system with a 0-20 goniometer, x, y and z translators, and a tilt goniometer.  Initial experiments on nonlinear interface optical switches are encouraging, as the selected broad bandwidth media has strong nonlinearity.

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# 1. Introduction

## 1.1. Purpose of the Facility

Planned Digital Photonics research in the Rome Laboratory Photonics Center includes development and evaluation of many candidate switches. The purpose of the High Speed Laser Facility (HSLF) in the Photonics Center is to develop test and evaluation expertise in the Photonics Center, to identify promising technological approaches towards switching for use in optical computing, to compare and contrast these differing approaches, to properly evaluate the products produced for the Mission Directorates of Rome Laboratory, and to provide technical advice to these Directorates for use in planning future technology thrusts.

## 1.2. Approach

The essence of Optical Switch Evaluation(OSE) for optical switches is what has been commonly referred to in the scientific literature as "pump-probe" laser spectroscopy. The actual process for evaluation depends of the type of device but any evaluation will entail measuring a coherent set of auto and cross correlation functions, with respect to the switch input and output signals, as well as over a range of operating parameters, e.g. temperature, wavelength, electrical biasing if appropriate. etc. The goal of our efforts will be to design and implement a modular system capable of performing the appropriate correlation measurement. We have initially designed a system for use with 542 and 800-850 nm radiation. Tests will include switching time, switching energy, insertion loss (absorption and reflection), bistability hysteresis, mode modification, $\chi^{(2)}$ and $\chi^{(3)}$. Also needed are measurements of polarization, wavelength, temporal, and angular dependencies of control, data, and output beams.

# 2. High Speed Laser Facility for Optical Computing

## 2.1. Advantages of Optical Computing

a) High bandwidth-The carrier frequency of a signal must be greater than the modulation of the signal. Light with a wavelength of 850 nm has a frequency of 353 THz. Laser light can already be modulated in the GHz range.

b) Two dimensional parallelism-It is very difficult to get photons to interact. Electrical signals interact by inductance and capacitance. The lack of beam to beam interference makes optics attractive for massively parallel computers[1].

c) Better impedance matching-Because the physical processes in optical devices are quantum in nature, they act as impedance transformers that allow efficient transfer of energy into the next device using free space or optical waveguide between devices[2]. In electronics small devices have small currents and thus are high impedance devices, while electrical transmission is low impedance in nature. This impedance mismatch is especially problematical when the required transmission lines are long or have high fanout, as would be required for a parallel electronic architecture.

d) Propagation at the speed of light-Optics does not require that the signal charge up transmission lines from one gate to the next. This takes some time, due to the RC time constants of the transmission lines, and leads to a large difference between the device switching time and the system clock rate in electronic computers[3].

e) Immunity to EMI-Beams of photons are undisturbed by electromagnetic fields caused by EMI or jamming.

Since many of these advantages are at the system level, individual optical switches do not necessarily have to surpass their electronic equivalent in every way[4].

## 2.2. Switch Requirements

The requirements for optical switches for optical computing include:

### 2.2.1 Cascadability

The output of one switch must have the proper intensity, mode, polarization, wavelength, pulsewidth and timing to switch the next switch. The very thing that makes optics attractive for parallel computation, the fact that light beams do not generally interfere with each other, means that making light switch light will require absorption of the light by a process that in some way changes the properties of a material and produces the proper switched output. Since most optical switches are quite inefficient, some means, such as an optical amplifier, is often needed to produce gain between switches. Since devices such as optical amplifiers are laser like, the transverse mode of the input light to the optical amplifier is critical. It also requires that there be no change of wavelength for resonant devices, so that the output of the switch will, if logically necessary, switch the next switch. If there is too much dispersion in the switch or switch/amplifier combination, the portion of the light in the broadened pulse that does not switch the next switch will be absorbed by the next switch and produce heat. In clocked systems, a device with an otherwise proper output that does not fit in the time window of the next clock pulse will cause a logic error.

### 2.2.2. Fanout

Every logical construction sufficient to make computers requires a fanout of at least two. Once again, optical amplification might be used to overcome the switching device's limitations. But optical computing, with its capability of performing large scale parallel computing, requires much larger fanout for one device to address many, as would often be required for parallel computing.

### 2.2.3 Logical Completeness

The ability to perform a set of Boolean logic functions complete enough for construction of a computer. In optical computing this is typically a NOR gate with logic inverted to the device. Devices that have a stable intensity threshold for switching can also perform an AND, with the combination of the two inputs driving the device over the threshold. OR'ing is easily performed optically by directing the outputs of the devices to be OR'ed into a single switch, thresholded such that any one input will cause the device to switch. Dual rail logic is often used, as an optical inversion is difficult to perform. Transmissive devices that change reflectivity after switching will have the transmitted light as the inverse of the reflected light, thus giving a dual rail output. Devices that cannot be set to perform an AND can instead be cascaded to perform an invert-OR-invert-OR, the logical equivalent to an AND, according to DeMorgan's rule.

### 2.2.4 Input/output Isolation

It is very difficult to cascade optical elements such that some light is not reflected back into previous stages. As more devices are cascaded together, this becomes more of a problem. Many of the proposed optical switching elements are two-port devices, which work just as well in reverse. It would then be possible to have competing processes occurring in the switch, eventually preventing switching action, or causing it to occur at an improper time. This can be prevented by using linearly polarized light and optical isolators, but this increases the complexity of the system. The reason this does not occur in electronics is because transistors are three-port devices. Power reflected back into the emitter or collector does not affect the transistor, as it is the base current that controls the device.

### 2.2.5 Spatial Isolation

In order to utilize the massive parallelism inherent in optics, devices will need to be packed closely together in arrays of large number. In these arrays, a device that is switching will have to be constructed

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far enough from its nearest neighbor such that it does not tend to make its nearest neighbor switch. There will be a minimum separation due to the ability of the system to deliver inputs consistently into the switches. The physical location of the output of a switch must also be invariable, so that the output always switches the proper next switch.

### 2.2.6 Low Switching Power

The ability to deliver large amounts of light to the massive numbers of gates required for a real computer is limited. Lasers are very inefficient converters of electricity to light. Every optical interface reflects some light, and all optical materials have some absorption. This problem can be alleviated to some extent by providing "power supply" light to place the switch near its switching threshold. Most optical computing architecture's feature stacked planes of logic devices, and getting the proper light levels into switches in such architectures will be difficult if many reflections and absorptions of the "power supply" light are occurring. The power required to switch is equal to the switching energy divided by the switching time, so there is a tradeoff between power and speed. In comparing energies between optics and electronics, the energy required to communicate the results to the next switch should also be considered [5]. There is a theoretical statistical limit to how low switching energy can be. You need approximately 1,000 photons to overcome random background thermal energy [6]. At 850 nm, for instance, this corresponds to a minimum switching energy of 0.2 fJ.[7] The maximum power a device can take, and hence its highest speed limit, is a function of the damage threshold of the material or the ability to remove heat from the device [8].

### 2.2.7 Switching Speed

Most optical nonlinearities switch on rapidly. The usual problem is that the separated charge carriers take some time to recombine, meaning that the switch off time, the time until the device is ready to switch again, is slower. In architectures that are massively parallel, overall system computational speed will come from the large number of computational channels, and individual switch speed will be less critical.

### 2.2.8 Stability and Reliability

A candidate switch must last for a long period of time and a large number of switching events. Many switches that use non-resonant effects, for example, only work with light intensities near their damage threshold [9].

### 2.2.9 Wish List

A wish list of device properties, as developed by S.D. Smith [10] is:

| 2-D Array $10^4$ - $10^6$ elements | Hold power/element 1 mW - 10 μW |
|---|---|
| Cycle speed 1 μs - 10 ns | Contrast >10:1 |
| Switch energy 1nJ - 10 nJ | Good throughput: T > 50% |
| Stability < 1% over hours | Makeable for various wavelengths |
| Uniformity 1-2% | Insensitive to small wavelength change |

Table 1. Optical Switch Wish List.

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| Boxcar Integrator System | Lock-In Amplifier System | Transient Recorder System | Optical Multichannel Analyzer | Beam Profile Analyzer |
|---|---|---|---|---|

Output Pulse Analysis Module

Switch Mounting Module (Temp Controlled)

Controlling Computers

Trigger Pulse Analysis Module (Delay Line)

Input Pulse Analysis Module (Delay Line)

Pulse Selection System

Non-linear Frequency Mixing System
0.205-0.47 μ, 1.2-1.8 μ

| 60-100 fs CPM Dye Laser 0.630 μ | 2 ps Dye Laser 0.4-1.00 μ | ps-fs F-Center Laser 1.53-1.66 μ | 10 W CO2 Laser 10 μ |
|---|---|---|---|

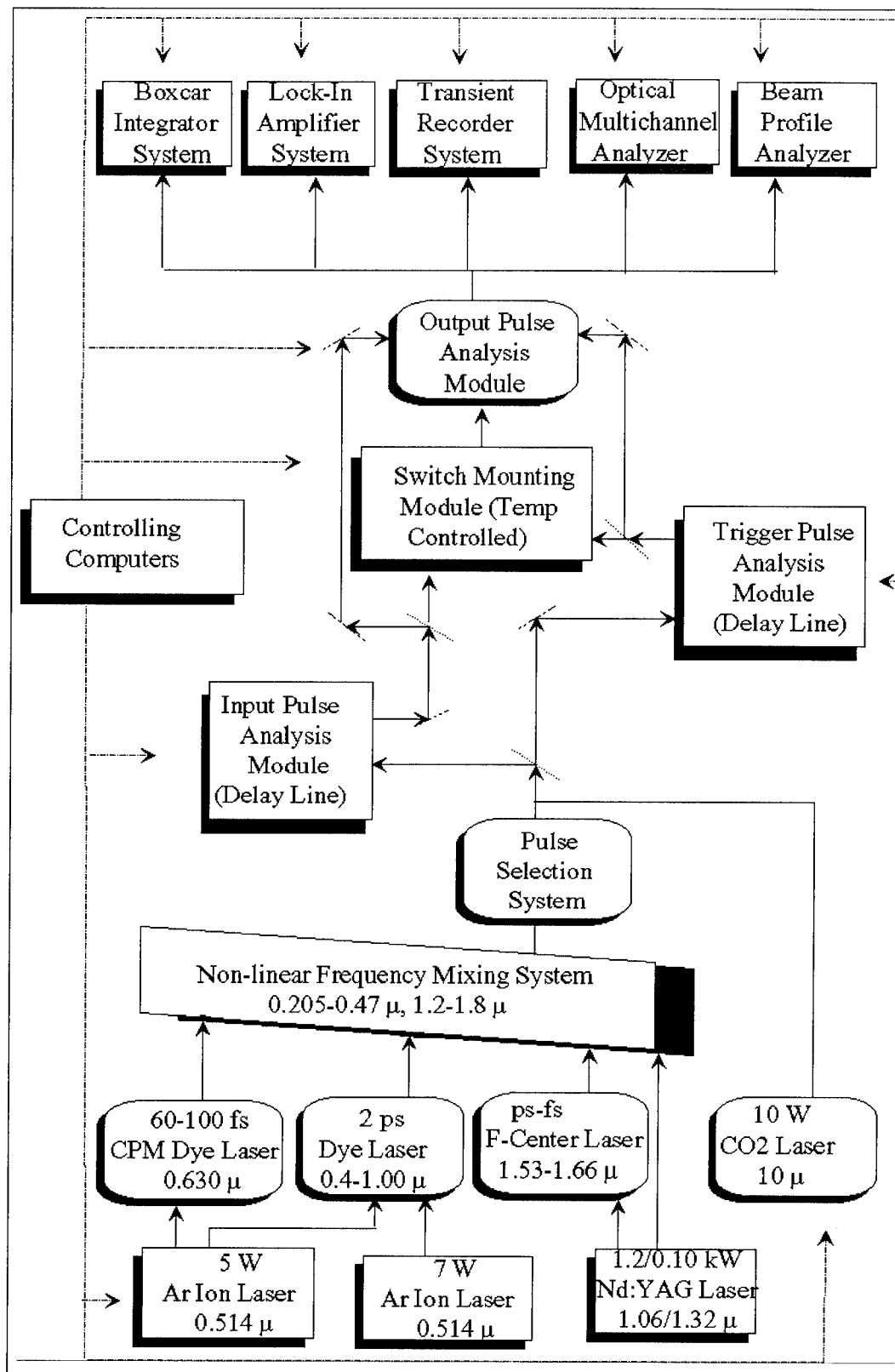| 5 W Ar Ion Laser 0.514 μ | 7 W Ar Ion Laser 0.514 μ | 1.2/0.10 kW Nd:YAG Laser 1.06/1.32 μ |
|---|---|---|

Figure 1. System Block Diagram

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## 2.3. Experimental Technique

### 2.3.1 System

Figure 1 shows the system block diagram. From top to bottom the components are: pump lasers, pumped lasers, light mixing, pump pulse analysis module (usually an autocorrelator), probe pulse analysis module ( also usually an autocorrelator), switch mounting module, output pulse analysis module, and other output analyzer. In general, fast light pulses are produced, split by a beam splitter into pump and probe pulses, seperately delayed and tested, spatially recombined, and sent through the switch under test. The output pulses can than be tested by a variety of test instrumentation. The same basic system, without a beamsplitter, can be used for reflectance, saturable absorption, photoluminescence, etc., by the addition of the proper components. The system was built with extra space between components to enhance its versatility. Appendix A gives a list of the system components. The design and initial measurements made with this system were presented by Joseph Osman, Brian DeVaul and Joseph Chaiken to the conference *Ultrahigh- and High-Speed Photography, Videography and Photonics '92* at the SPIE Annual Meeting-San Diego '92, and published in volume 1757 of the Proceedings of the SPIE.
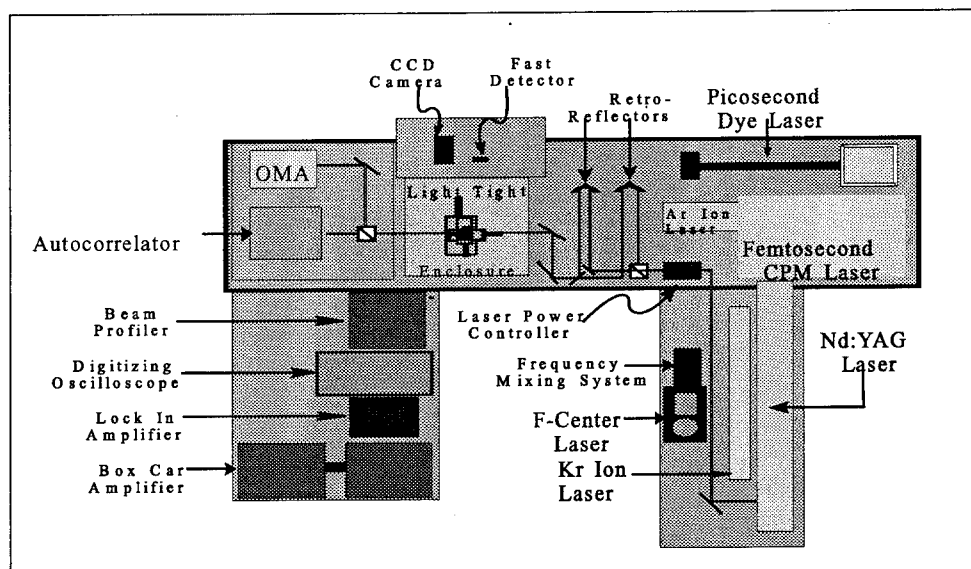


Figure 2. Physical Layout of the System.

### 2.3.2 Laser Systems

The primary emphasis on the laser systems is to have ultrafast pulse capability thru a broad wavelength range with emphasis on the following wavelengths:

830-850 nm for GaAs devices
1300 and 1550 nm for switches developed as fiber communication devices
400-600 nm for nonlinear organic material switches
10 μm for QWEST devices[11]

The fastest laser system is a Clark Instrumentation passively mode locked colliding pulse mode (CPM) dye laser, capable of producing 60-100 fs at 620 nm pulses. A Clark Instrumentation modification to replace the gain dye with a Ti:Sapphire gain medium has been delivered, but is not yet installed. This will give us a tunable CPM (~ 700-900 nm) with ~ 100 fs pulse capability. For 1550 nm pulses a Burleigh color center laser synchronously pumped by a mode locked Quantronix Model 4116-ML Nd:YAG laser

will give < 15 ps pulses tunable from 1530 nm to 1660 nm. For fs pulses at wavelengths less than 620 nm, the dyes of the CPM can be changed to produce pulses with wavelengths as low as 490 nm [12]. A Spectra Physics Model 375B dye laser can be synchronously pumped by a Spectra Physics Model 171-01 argon ion laser, a Model 171-09 krypton ion laser, or a Quantronix Model 4116-ML Nd:YAG laser to produce < 10 ps pulses from 333-1084 nm, depending on the dye used. We have dyes in stock at the HSLF to cover the wavelength range from 520-1000 nm. We also have a Spectra Physics Model 344 Cavity Dumper to use with the ps dye system. The Nd:YAG laser has a Q-switch and a second harmonic generator. The Quantronix Model 4116-ML Nd:YAG laser has a dual wavelength rod, and we have optics on hand to produce ~ 140 ps pulses at 1330 nm. Faster light pulses at 1300 nm will require use of the INRAD Autotracker II frequency mixing system and the Spectra Physics Model PDA-1 laser amplifier. We can pulse select all the above actively mode locked systems with a Quantronix pulse selector system, for which we have both visible and IR optics. We have various gratings on hand to permit fiber-grating pulse compression, if necessary. Fast pulses at 10 $\mu$m with our Laser Engineering 10 W cw grating tuned $CO_2$ laser will be difficult to achieve, with the leading candidates being passive modelocking via a bleachable absorber[13] and active "mode locking" by semiconductor surface reflection switching [14].

| LIGHT SOURCE | WAVELENGTH | PULSEWIDTH | POWER/ENERGY |
|---|---|---|---|
| Clark CPM dye laser | 620 nm-490 nm | 60-100 fs | 100 pJ |
| Clark Ti:Sapphire | 700-900 nm | 100 fs | 600 mW avg. |
| Burleigh color center | 1530-1660 nm | < 15 ps | 200 mW avg. |
| S-P 375B dye laser | 333-1084 nm | < 10 ps | 0.7 nJ |
| S-P 344 cavity dumper | 333-1084 nm | < 20 ps | 30 nJ |
| S-P 171-01 Ar ion laser | 458-514 nm | < 200 ps | 20 nJ / 4.6 W all lines |
| S-P 171-09 Kr ion laser | 647-676 nm | < 200 ps | 4 nJ / 4.6 W all lines |
| Quantronix 4116 Nd:YAG | 1064 or 1330 nm | 140 ps | 9 or 1.3 W avg. |
| Nd:YAG + SHG | 532 or 665 nm | 140 ps | 1 W or 144 mW avg. |
| Q-switched Nd:YAG | 1064 or 1330 nm | 900 ns or 225 ns | 3.0 or 1.2 mJ |
| INRAD UV frequency mixer | 204-470 nm | < 10 ps | low |
| INRAD IR frequency mixer | 1200-1800 nm | < 10 ps | low |
| S-P PDA-1 amplifier | 333-1084 nm | 6 ns | 10-40 mJ |
| Laser Eng. CO2 Laser | 9.2-10.9 $\mu$m | see text | 10 W CW |
| Quantronix pulse selector | visible & IR | | |

Table 2. Light Sources

### 2.3.3 Measurement of Parameters

<u>2.3.3.1 Switching Power</u>
The HSLF has several Antel 25 and 35 ps rise time photodetectors, which are coupled to a Tektronix 1 GHz analog oscilloscope through several 25 and 35 ps rise time sampling heads. Faster pulse intensities can be found using repetitive sampling with slower photodetectors, or by measuring the amplitude of autocorrelation or cross correlation peaks on a slower oscilloscope. The HSLF has one LeCroy Model 9450 dual channel digitizing oscilloscope and a LeCroy CAMAC digitizing system. For lower intensity measurements we have both visible and IR PM tubes. These can also be used in our EG&G PARC OMA III optical multichannel analyzer system, which currently uses a Model 1420 multichannel plate intensified linear diode array detector. We use an Ithaco 3970 lock-in amplifier system or a EG&G Model 4400 boxcar amplifier system for signal to noise enhancement. To ensure constant (to 0.2%) input intensity we have a Cambridge Research & Instrumentation laser power controller with integral power meter.
<u>2.3.3.2 Mode</u>
For transverse mode measurements the HSLF has a Spiricon LBA-100 laser beam analyzer with both a visible silicon CCD camera and a PbS near IR camera. For even longer IR measurements we have a 32x 32 $LiNbO_3$ pyroelectric array camera/framegrabber system. For longitudinal mode analysis we have a

Burleigh scanning Fabry-Perot system. For spot size measurements we have a Photon Beamscan II, capable of measuring spot sizes down to 5 μm with 2 μm resolution.

### 2.3.3.3 Polarization

To ensure that our input light has proper polarization, and to analyze our output light, we use Glan-Thompson polarizers. We have a limited supply of wave plates for retardation and rotation. We have access to a commercial liquid crystal broad wavelength range polarization control system, which we hope to test for extinction ratio, dispersion, mode modification, etc. If suitable, we plan to add several of these to our system.

### 2.3.3.4 Wavelenth

We can accurately determine wavelength from 0.4 to 4 μm using a Burleigh Wavemeter. The OMA system can also be used to determine wavelength.

### 2.3.3.5 Pulsewidth

In addition to the ps detector systems desribed in the Intensity section we have one commercial ps autocorrelator and two commercial fs autocorrelators. We have the crystals and PMTs to build 3 more autocorrelators, which we plan to permanently integrate into the sytem. We are currently developing internal time duration standards in order to perform time calibration of evaluation sub-systems already in place. Initially, we will implement a stand alone saturable absorber jet to measure the absorption recovery of saturable absorbers DQDCI and/or HITCI. We will determine if this results in a reproducible time standard using standard autocorrelation techniques. If that is not satisfactory, we plan to implement a standard using 2-photon spectroscopy of α-dicarbonyl [15].

### 2.3.3.6 Timing

Device latency will be measured by cross correlation techniques, or if possible, by the high speed detector systems already described.

### 2.3.3.7 Nonlinearity

We have performed static measurements of the refractive index change vs. incident power of photorefractive cluster switches [16]. We also performed saturable absorption measurements of multiple quantum well bistable etalons [17]. To measure transient changes in both refractive index and absorption in the same time scale as the rest of our measurements, we have decided to add time division interferometry [18] capability to our system.

### 2.3.3.8 Spatial and Angular Uniformity

The switches are mounted on a 6 axis micropositioner system. These stages are ( listed from the optical table to the switch):

A translation stage for movement perpendicular to the plane of the table ( 1 μm/step resolution)

A 2Θ stage for the detector ( 0.01 °/step resolution)

A Θ stage ( 0.001 °/step resolution)

A linear stage for movement parallel to the table ( 1 μm/step resolution)

A linear stage for movement parallel to the table and perpendicular to the previous stage ( 1 μm/step resolution)

a tilt goniometer ( 0.001° /step resolution)

This stack allows us to place the light beam at the center of rotation of the stack, and then scan the face of the switch or switch array without moving the switch along the optical axis direction. This is particulary important in studying the spatial uniformity of a spatial light modulator (SLM). The Θ–2Θ stage allows us to measure angular dependencies of the switch using a CCD camera and software to measure beam walkoff under varying conditions. We have a thermoelectric controller to change or keep constant the temperature of the switch, if necessary.

## 2.4. Suitability of Switches for Different Architectures and Uses

Before and while the switch is evaluated, the tests involved must always be designed with its intended use in mind. After the switch has been evaluated, its suitability for use in a specific architecture can be mathematicaly modeled according to the methodology of Wherrett and Snowdon [19]. There are other uses for optical switches, such as sensor/eye protection [20] and photonic switching [21]. A candidate switch should, if possible, be evaluated for these other uses, in order to broaden the possible market for the switch.

## 2.5. Data Acquisition

### 2.5.1 ASYST Software for Laboratory Devices

The ASYST programming language offers GPIB and RS-232 control with graphics display, Lotus 1-2-3 compatibility, and data plotting. ASYST has more data acquisition specific commands than other languages such as BASIC. It also has the ability to create user defined words called "colon definitions" that execute a sequence of ASYST commands with one word. ASYST can be easier to use, but like all programming languages it takes time to learn.

A large portion of this section discusses topics covered in the manuals of ASYST. To better understand the software program, you may want to refer to the manuals while reading this section. Braces, [ ], are used to cite the manual and page number. The Roman numeral I represents the manual "Module I Tutorial (System, Graphics, Statistics)" and the letter N represents the manual "ASYST 3.10: Your Guide to ASYST's New Feature Enhancements." Words in *italic print* are commands or variables, while words in SMALL CAPITALS are DOS filenames.

```
═══════════════ GPIB DEVICE MAIN MENU ═══════════════

                                        DATE:  06/07/94


      KLINGER STEPPING MOTOR

      SPIRICON - LBA                 EXIT TO THE  'OK'  PROMPT
                 .
      LASER POWER CONTROLLER         EXIT TO DOS

      NON-LINEAR OPTICAL SWITCH




                         USAF PHOTONICS CENTER
                         GRIFFIS AIR FORCE BASE
                            ROME, NEW YORK


                                         by Brian DeVaul
```
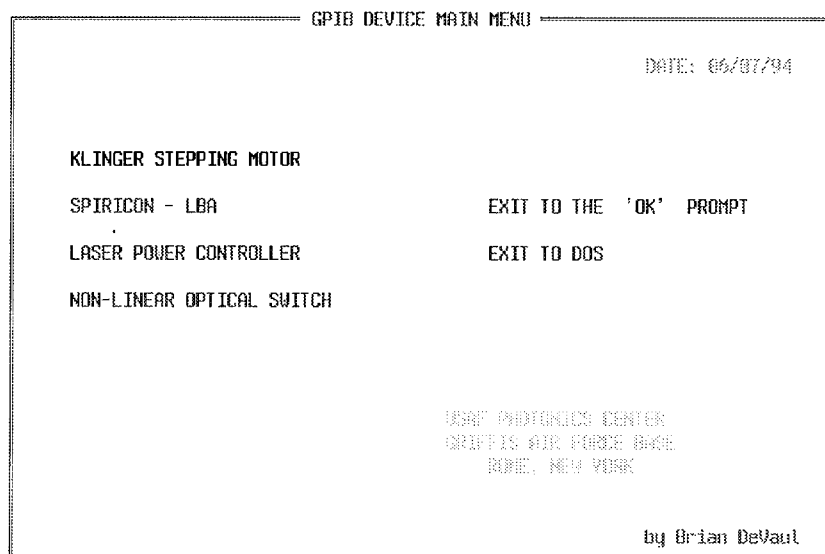
Figure 3. Main Menu for Device Automation

### 2.5.2 GPIB

In order for a lab device to talk to a personal computer the device usually has either a RS-232 or IEEE-488 interconnect. Because RS-232 can be rather difficult to configure we used the IEEE-488 interconnect whenever possible. The IEEE-488 port is connected to a personal computer through an

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interface called GPIB ( General Purpose Interface Bus ). The programming that has been done in ASYST has centered around communicating with laboratory devices using GPIB.

### 2.5.2.1 GPIB Board Configuration with IBCONF

The majority of GPIB boards being used at this facility are manufactured by National Instruments. The GPIB boards we currently have require configuration before they can be used. In order to use GPIB with ASYST or any other program, the GPIB board must first be configured before entering ASYST. For National Instruments a program called IBCONF.EXE is used to set parameters for the board and all the devices connected to it. For ASYST you will need to know the address of each of the devices on the board and each individual End Of String (EOS) character. If a device is not configured in IBCONF.EXE you may configure the board by reading the device manual for GPIB communication. Some devices have preset GPIB addresses that can not be changed, while others have dip switches to change their factory presets. Once you know the address, use IBCONF.EXE to set EOS characters (in Hex), time-out setting, interrupt setting, and the base I/O address. The GPIB board's manual should give the factory preset interrupts and I/O addresses (Figure 4). If the interrupt or I/O addresses are not available due to other programs already using them, then you will need to locate open interrupts or I/O addresses using DOS or utility programs such as Winsleuth or Quarterdeck Manifest. Ensure that all of the devices you intend to use are currently connected to the board with GPIB device cables. In IBCONF.EXE make sure that lines are drawn to connect GPIB0 (Figure 5). Software connection is made with function key F4. Save your configuration and reboot the computer to put these changes into effect. Remember your device addresses and EOS characters for configuration in ASYST.

```
 National Instruments                                IBM PC-AT

Board: GPIB0                          SELECT (use right/left arrow keys):

Primary GPIB Address          ↔ 0     0 to 30
Secondary GPIB Address ........ NONE
Timeout setting .............. T10s
EOS byte ..................... 00H
Terminate Read on EOS ........ no
Set EOI with EOS on Write .... no
Type of compare on EOS ....... 7-bit
Set EOI w/last byte of Write .. yes
GPIB-PC Model ................ PC2A
Board is System Controller .... yes
Local Lockout on all devices .. yes
Disable Auto Serial Polling ... yes
Disable Device Unaddressing ... no
High-speed timing ............ no
Interrupt jumper setting ...... NONE
Base I/O Address ............. 02E1H
DMA channel .................. 1
Internal Clock Freq (in MHz) .. 6

F1: Help      F2: Explain Field      F6: Reset Value      F9: Return to Map
```

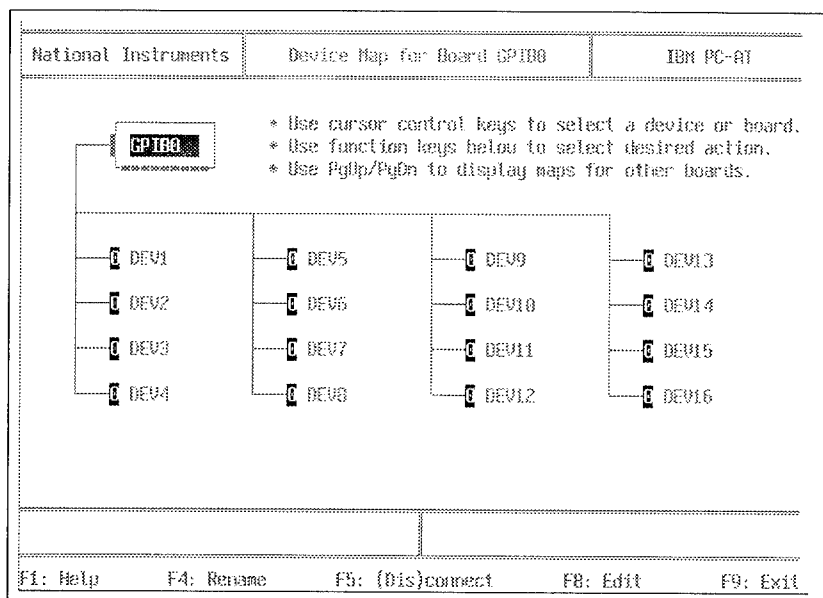Figure 4. IBCONF.EXE Controller Settings.

Figure 5. IBCONF.EXE Device Map.

## 2.5.3 ASYST Programming

ASYST uses special memory areas called stacks to perform its operations. The number stack manipulates numeric scalar and array variables, while the symbol stack is used for character string, true or false, and menu operations. The stacks use the variables on a last in, first out basis. ASYST also operates in polish notation. That is to say that the variables are placed before the operand instead of between them. Normally we would use 2 * 4 + 3, in polish notation it would be 2 4 * 3 +.

### 2.5.3.1 ASYST Configuration

Although it can be first run with ASYST.COM , other .COM files can later be made to run ASYST. To change its configurations press F2 at the OK, prompt in ASYST after executing the .COM file. This will bring up the Configuration Menu [I:1-16].

### 2.5.3.2 ASYST Hardware Specifications

At the ASYST configuration menu first select hardware configuration (Figure 6). ASYST is originally set up for a slow computer with monochrome monitor and IBM printer. Change the selections in the Hardware Configuration first so that you may make use of the selections when continuing the configuration process [I:1-18]. For instance, you cannot edit the color of the ASYST prompts unless your software is configured for a color monitor.
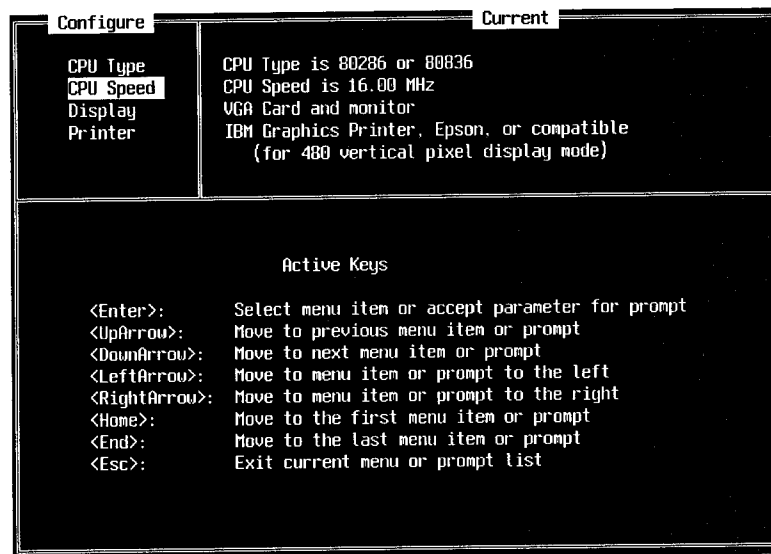
10

```
┌─ Configure ═══════════════════════════╗══ Current ══════════════╗
│                                                                   │
│   CPU Type          CPU Type is 80286 or 80836                    │
│   CPU Speed         CPU Speed is 16.00 MHz                        │
│   Display           VGA Card and monitor                          │
│   Printer           IBM Graphics Printer, Epson, or compatible    │
│                        (for 480 vertical pixel display mode)      │
│                                                                   │
│                                                                   │
│                                                                   │
│                          Active Keys                              │
│                                                                   │
│      <Enter>:        Select menu item or accept parameter for prompt │
│      <UpArrow>:      Move to previous menu item or prompt         │
│      <DownArrow>:    Move to next menu item or prompt             │
│      <LeftArrow>:    Move to menu item or prompt to the left      │
│      <RightArrow>:   Move to menu item or prompt to the right     │
│      <Home>:         Move to the first menu item or prompt        │
│      <End>:          Move to the last menu item or prompt         │
│      <Esc>:          Exit current menu or prompt list             │
│                                                                   │
└───────────────────────────────────────────────────────────────────┘
```

Figure 6. ASYST Hardware Configuration Menu.

### 2.5.3.3 Selecting ASYST Overlays

ASYST has many sets of command words for different functions. Select only the overlays of command words for the functions that you will need (Figure 7). These overlays take up plenty of memory, so don't load overlays you will not use! If you are going to use the GPIB system you must load the GPIB master overlay and the overlay for your particular GPIB board [I:1-16]. Each of the driver overlays contains commands for more than one GPIB board. Choose only the driver overlay that contains your computer's GPIB board. For a list of supported GPIB boards and the driver overlays refer to Appendix D of the manual "Module 4 GPIB/IEEE-488." The "Help" overlay doesn't offer much help for the memory it takes up and we suggest not loading it. The "Editor" overlay is a simple ASCII text editor for altering user defined ASYST text programs. Although it is not needed, it is more convenient than leaving ASYST, loading another ASCII editor or word processor, and then returning to ASYST. If you plan on using the menu command words for driving your programs than you should load the overlay "Menu Tools." Other suggested overlays to load are "Data Files," and the "Lotus 1-2-3 File Interface" found in "File Overlays." This section is also important in minimizing the memory that these overlays use. After selecting the overlays you desire and press Escape, the program will ask if you want to permanently store them. Answer yes, otherwise the overlays you selected will not be loaded. Be sure of your choices or you may have to start all over.

```
┌─────Available Overlays─────┐┌─────Selected Overlays─────┐
│                            ││                           │
│ Editor                     ││ Editor                    │
│ Help System                ││ Data files                │
│ Array Editor               ││ Lotus 123 File Interface  │
│ RS-232                     ││ Statistics & Special Functions│
│ Algebraic Parser           ││ 3D Plotting               │
│ Menu Tools                 ││ Polynomial Operations     │
│ File Overlays              ││ Waveform Operations       │
│ Graphics Overlays          ││ Matrix & Curve Fit Functions│
│ Analysis Overlays          ││                           │
│ Data Acquisition           ││                           │
│ GPIB                       ││                           │
│ External Interfaces        ││                           │
│                            ││                           │
│                            ││                           │
│      Available Memory      ││                           │
│ Base Dictionary:    3146   ││                           │
│ Symbol Table:       14798  ││                           │
│ Overlay Memory:     2      ││ Type:  0 - for overlay description│
│ String Segment:     40786  ││        W - to find a desired word │
│ Array Memory:       15300  ││        <esc> - exit menu  │
└────────────────────────────┘└───────────────────────────┘
```

Figure 7. ASYST Overlay Selection Menu.

### 2.5.3.4 GPIB Board Configuration

After entering the board's bus number, which is usually zero, you can select which GPIB board your PC has from the highlighted list of choices. If your GPIB board is listed but not highlighted you must return to the Overlay Configuration and choose the correct driver overlay. Refer to Appendix D of the manual "ASYST Module 4 GPIB/IEEE-488" for a list of supported boards and their driver overlays. The program will then ask several questions for configuration depending on which type of GPIB board your computer uses. You will want to have ready the base address, interrupts, and controller address.

### 2.5.3.5 Memory Configuration

This configuration menu is very important (Figure 8). ASYST uses only conventional memory (except for tokens) which can fill up quickly with large programs and/or many overlays [I:11-24].

```
┌──────────────── Minimize System ────────────────┐
│                                                  │
│                                                  │
│   After a final system has been constructed by   │
│   loading in all needed overlays in the Overlay  │
│   Configuration menu, the size of the system     │
│   may be minimized. This will free up some space │
│   in the system for other areas of memory (those │
│   in the next menu). Note that once this is done │
│   to a system, no more overlays may be added     │
│   using the Overlay Configuration menu. (therefore,│
│   be careful not to minimize the original copy   │
│   of ASYST.) Also note that this minimization will│
│   not be available unless a Save is made when    │
│   leaving the main config menu.                  │
│                                                  │
│       Minimize System (Y/N): < Y >               │
│                                                  │
│       Leave room to load system transient overlays (Y/N): < Y > │
│                                                  │
│       Press 'Y' or 'N' and then press Esc to continue.│
│                                                  │
└──────────────────────────────────────────────────┘
```

Figure 8. ASYST Memory Configuration.

To get the most out of the ASYST memory configuration ensure that you have permanently loaded into memory only the overlays that you need from the Overlay menu. Then select 'yes' for ASYST to automatically minimize your system memory from the memory configuration menu. If you are sure you will not be needing any more overlays, do not allow room for loading transient overlays. Allowing room for one transient overlay takes up 36K of conventional memory space. Depending on your intended use the

target memory can be changed to suit your needs. As you program in ASYST you can check your memory usage at the OK prompt with *?memory*. If you find you're running out of room for one particular target memory, go back to the memory configuration menu to make changes in memory. Reassign memory according to your needs. You may want to delete all of your defined words before changing your memory, otherwise the memory configuration will be permanently saved with your currently defined word definitions. You may need to increase your conventional memory from DOS. This can be done by not installing devices such as FASTOPEN, SETVER, and MOUSE.COM in your CONFIG.SYS and AUTOEXEC.BAT files into memory. If you have a 386 you can use the DOS expanded memory manager, or a similar manager such as Quarterdeck's QEMM386, to load these and other devices into high memory.

### 2.5.3.6 Saving ASYST Configurations

You can save your configurations when you try to exit the configuration menu or type save FILENAME.EXT at the OK prompt. Both procedures create an .OVL and a .COM file to execute from the DOS prompt. You can save your configurations with your defined words or text programs loaded into memory. This saves time in loading them every time you enter ASYST from the DOS prompt. GPIB users keep in mind that if you were already initialized and "talking" to GPIB devices when you made the save, you still must re-initialize the GPIB bus when you run your saved program. A special note, all arrays and tokens are emptied during this save. Arrays keep their size, but not their data. Tokens lose size, data and place in memory if you had them put into expanded memory.

### 2.5.3.7 GPIB Device Configuration

Each GPIB device to be utilized by ASYST must be assigned. The program needs to know the EOS characters, I/O addresses, their user defined names, and whether the EOS characters are on or off. Next you'll need to initialize the GPIB bus. Initializing the bus takes three ASYST commands which we have shortened to one called init (see Appendix C - Short Commands). Since the GPIB board we was recently working with allows only ·16 devices we created a text file called GPIB3.XXX to assign all of the devices with their EOS character, address, and name (Appendix D - GPIB Device Configurations). This text file is automatically loaded by the main text file program and allows the GPIB Device Configuration file to be edited from an option given in the main menu.

### 2.5.3.8 Making Menus

In the latest version of ASYST, menu command words were added to create user defined menus for other users unfamiliar with the program [N:3-1]. Menus are subprograms of special command words. These exclusive menu commands are used only inside a menu definition.

```
HP8116A.MENU
    MENU.STATUS  HP8116A.STATUS
    MENU.BLOW.UP
    1  1  24  79  MENU.SHAPE
    0  11  MENU.COLOR
    15  MENU.PROMPT.COLOR
    1  1  "  CHANGE  PARAMETERS"  MENU.ITEM{ SGCP.MENU }
    3  1  "  EXECUTE  DESIGNED  PROGRAMS"  MENU.ITEM{ SGDP.MENU }
    5  1  "  ENABLE / DISABLE  FRONT  PANEL"  MENU.ITEM{ LOCK.OUT.SWITCH }
MENU.END
```

Figure 9. Example of a Menu Definition.

The menu is first declared using the command menu followed by the name of the menu to be defined. The menu definition begins with the name of the menu. The menu definition terminates when the menu reaches the menu command *Menu.End* (Figure 9). A menu is basically a text window with executable items for the user to choose from. The size and location of the menu is determined by the command *Menu.Shape* . Any predefined colon definitions, overlay commands, basic ASYST commands or other menus are executable in the menu by using the command word *Menu.Item*. This command also defines the location and text to be displayed as a menu option. Excluding the menu title and menu selections all other text can be displayed by a user defined colon definition executed by the menu command called *Menu.Status* . For GPIB device menus this command can be used to display current data from the device such as signal generator parameters in the program HP 8116A.XXX (Figure 10).

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```
: HP8116A.STATUS        1 FOREGROUND
  DISPLAY.DATA          2 FOREGROUND
  26 8 GOTO.XY ." CURRENT PARAMETER SETTINGS"
  0 8 GOTO.XY ." *********************"
  58 8 GOTO.XY ." *********************"
  1 10 GOTO.XY ." Amplitude:"          40 10 GOTO.XY ." Output Disabled:"
  1 11 GOTO.XY ." Offset:"             40 11 GOTO.XY ." Autovernier:"
  1 12 GOTO.XY ." Operating Mode:"     40 12 GOTO.XY ." High Level"
  1 13 GOTO.XY ." Control Mode:"       40 13 GOTO.XY ." Low Level:"
  1 14 GOTO.XY ." Trigger Slope:"      40 14 GOTO.XY ." Burst Number:"
  1 15 GOTO.XY ." Haversine(-90):"     40 15 GOTO.XY ." Repetition Rate:"
  1 16 GOTO.XY ." Waveform:"           40 16 GOTO.XY ." Sweep Start Freq.:"
  1 17 GOTO.XY ." Frequency:"          40 17 GOTO.XY ." Sweep Stop Freq.:"
  1 18 GOTO.XY ." Duty Cycle:"         40 18 GOTO.XY ." Sweep Marker Freq.:"
  1 19 GOTO.XY ." Width:"              40 19 GOTO.XY ." Sweep Time:"
  1 20 GOTO.XY ." Limit (on/off):"     40 20 GOTO.XY ." Complement (on/off):"
  11 FOREGROUND
```

Figure 10. Menu.Status example from HP8116A.XXX

As a special note the menu commands look decent in normal display, but appear slightly worse in graphics display mode.

### 2.5.3.9 Arrays and Tokens

ASYST arrays are very similar to arrays in any other programming languages [I:5-I]. They can have multiple dimensions and can be accessed one element at a time. These arrays can also be accessed one dimension at a time or you can change the entire array all at once by using the array name the same as you would a scalar variable name [I:18-1]. To access one dimension at a time you can use the ! character as a wild card variable with the ASYST command *XSECT* directly in front of the accessing braces ( ex. *XSECT [2, !, 5]* ). This creates a cross sectional view of the array. If a portion of a dimension is what you desire use the command *Sub* in front of the braces. However, you cannot use the ! character in a *Sub* command. ASYST also offers string arrays that are limited to two dimensions with one of the dimensions being the maximum character length of a string. Because ASYST does not automatically make use of expanded memory, tokens become an important tool for users to make use of a 286, 386, or 486 with expanded memory. Tokens are defined by taking the data and size of an already existing array. In the ASYST memory configuration, memory is allocated for unnamed arrays as well as a token heap. If you are using expanded memory the token heap size will not make a difference in your programming, but the size of the unnamed array heap can limit the maximum size of your arrays and your tokens. It would be more beneficial for users with expanded memory to increase the unnamed array memory allocation by decreasing the named array memory. This will allow for larger sized tokens in expanded memory. Keep in mind that when you enter a saved program from DOS all arrays are blank and your tokens have no size, data or place in expanded memory. You will then have reload tokens into expanded memory, define their size and load them with any necessary data.

### 2.5.3.10 Data Files

While ASYST has its own data file system, you can save data in a LOTUS 1-2-3 spreadsheet format (Figure 11), ASCII text file or into a BASIC data file. First let us discuss the ASYST data filing technique [I:17-1]. ASYST uses what it calls a file template to map out the structure of each data file. Data files contain only numeric arrays and comment statements. If you wish to store strings, you would need to use the comments. Keep in mind that comment statements have a maximum length of 64 characters. If you need to store strings of greater length, we suggest you convert your string arrays into integer arrays to be properly stored. This also means that upon restoring data you will have to convert the data from an integer array back into a string array. Once a file template is made it can not be changed with the exception of appending an array to the end of the file. If you desire to change the size of an array in the data file you must recreate the entire data file. The LOTUS 1-2-3 interface doesn't need a file template [I:17-23], but you must carefully decide which direction to write an array into a spreadsheet. Keep in mind there is only one array written to a spreadsheet at one time. If you want to write more than one string or numeric array, you must reset a pointer using *123WRITE.DOWN* and *123WRITE.ACROSS*. Data can be read from ASCII and DIF format files into ASYST strings, but ASYST does not let you write to BASIC or DIF files

interactively [I:17-19]. ASYST does offer a way to direct output to files to create ASCII text files. You can then edit these files by the ASYST text editor or any word processor.

```
:  S123
     TOTAL       DATA123 XSECT[ ! , 1 ] :=
     DEGREES     DATA123 XSECT[ ! , 2 ] :=
     DATA123 SUB[ 1 , Q ; 1 , 2 ] EQUIV> DATA.123
     SGFILE MENU.EXECUTE                           \
     FILE.NAME DEFER> 123FILE.CREATE               \
     FILE.NAME DEFER> 123FILE.OPEN                 \
     1 1 123WRITE.ACROSS
     1 1 Q 2 123READ.RANGE
     DATA.123 ARRAY>123FILE
     123FILE.CLOSE  MENU.ESCAPE MENU.ESCAPE
```

Figure 11. Example of Lotus 1-2-3 Interface Commands.

### 2.5.3.11 Loops

As with any respectable programming language, ASYST offers loops to better organize tedious and repetitive portions of a program. ASYST *DO* loops have scalar variable counters that are useful in keeping track of where you are inside of a loop or nested loop [I:16-2]. The array manipulation and other various mathematical processes performed inside the loop at times require a counter. Here ASYST offers a counter without having to program the old method of ' N = N + 1 '. These counters, beginning with 'I' for the innermost loop, should not be redefined in a user defined program. In other words it is not advisable to create a variable or colon definition with a name of I, J, or K. If you view the programs you may notice the frequent use of loops to save room in the program file (Figure 11), neatly organize command lines, and best of all increase the speed of loading the program. ASYST offers indefinite loops for those of you who do not know the exact count on which to end [I:16-9]. These loops, *BEGIN-UNTIL* and *BEGIN-WHILE-REPEAT*, will continue until there is a false condition present in front of the *UNTIL* or *WHILE* commands. Although we have not yet had the opportunity to use this type of loop, we have mentioned it for future reference if you are in need of looping until a certain condition is met.

```
     121 1 DO                     \ REPLOT PICTURE PIXEL BY PIXEL
     121 1 DO
          DATA2 [ J , I ] COLOR
          I 2 * 396 + M := M 1 + Y :=
          J 2 * L :=
          348 L - N := N 1 - Z :=
            M N P!   M Z P!
            Y N P!   Y Z P!
     LOOP
     LOOP
```

Figure 12. Example of a DO LOOP from LBA.XXX.

## 2.5.4 Instrumentation-Specific Device Automation

### 2.5.4.1 Cambridge Research Institute - Laser Power Controller

A laser power controller offers the ability to change the output power of the laser beam without changing any of the parameters of the laser itself. This device is also controllable over a GPIB bus to allow the computer to change the output level and take test measurements. Although the laser power controller has a dip switch to change its GPIB address, the dip switch is inside the controller. We used its factory set address of 8 to avoid disassembly of the controller. The other devices we used either have factory settings other than 8, or are easily changed. CRI offers their laser power controller with different options built into it. It a helpful note is to make sure which type you are using in order to correctly program for the specific parameters it has. We are using a model that can change the percent power or keep the transmissibility at a

specified amount. Our experiment calls for the control of the output power. Control of the device can be difficult at times with an erratic laser beam. If you try to specify a power level where the percent amount of transmission can peak at times over 100%, than the controller will be in error and leave the power level at its present state. Ensure that when you wish to communicate with the controller that a laser beam is present. If the laser beam isn't going through the controller your communication will cause a system crash and you will need to restart the ASYST program by using Control-Break.

### 2.5.4.2 Hewlett Packard - HP8116A Signal Generator

The Signal generator is an easy device to communicate with and is helpful in programming for an oscilloscope, but has not yet played a part in our experiments. However, if we ever need to use it we'll have a program ready to help us in the lab. Like most GPIB ready devices, the GPIB address is defined by a dip switch on the back panel of the device.

Although communicating with the signal generator can be simple, the number of different parameters adds length to the program. The basic use for the program is to save particular parameter settings to be restored at later dates quickly and easily.

### 2.5.4.3 Ithaco - 385EO Lock-in Amplifier System:

Although our experiment hasn't yet called for a lock-in amplifier, another experiment we are currently conducting does need the use of a lock-in amplifier. The Ithaco does some calculating of data for you, but it is only accessible through the GPIB bus. The front panel of the lock-in amplifier limits its use, but a computer can alter more parameters and offer better control over the device. The GPIB address is located on the back panel of the 385EO which is an option device for the lock-in amplifier. The most difficult part of programming for the lock-in amplifier was figuring out the data format. Ithaco sends a numeric code that describes the output data. The data may come in 64 different combinations of 7 formats. Displaying which formats are currently being used is cumbersome to say the least. We had to make sure that if all formats were being used the length of display wasn't longer than the length of available screen space. This makes displaying the data itself rather arduous. We also had to limit the amount of data to 10 different sets at a time.

### 2.5.4.4 Klinger - MC4/MD4 and Stepping Motors:

The Klinger controls various motorized stages for different laboratory needs. Two rotational stages control the rotational angle of the substrate and the detector. Two linear stages in the X and Y directions are used to align the film directly over the center of rotation of the two rotational stages. A Klinger stepping motor has also been used to control the height of all of stages in the Z direction. The GPIB address for the motors is on the back of the Klinger motor controller. It is an easily changed dip switch setting.

The program displays the counters of the four axes of one controller, and offers moving a motor to a specified count. We have made changing the stepping rate or speed of the motor more accessible than through the front panel of the controller. In the program we were faced with the problem of inputting a letter designating a particular controller and changing it to an integer such as A-1, B-2, C-3, etc. Inside the colon definition for *CHOOSE.CONTROLLER* the user inputs a letter and *"UPPER* insures that the letter is capitalized. we then change the ASCII letter to its numeric counterpart. Since the upper case ASCII characters start at 65, we then subtract 64 from the decimal character. Now an 'A' will be seen as 1 and a 'B' as 2 and so on. The useful note to make here is that for some reason unknown to us, ASYST would not correctly recognize the letter directly following an input statement. This causes a slight problem, but we were able to work out a simple solution. After the input statement the letter is saved into a variable, *KD*. we tried to take the ASCII value of the variable *KD*, but it would always be returned with the ASCII value of K. In order to get around this irritating snag, we put the ASCII command and the variable *KD* into a string. We then used *"EXEC* to execute the commands inside the string, and it worked.

### 2.5.4.5 Spiricon - LBA-100 Laser Beam Analyzer:

The laser beam analyzer uses a camera to show the intensity of the beam across a square area. The analyzer measures both total and peak power in Watts, Joules, or relative power. A screen plot is made from the data collected in the camera with various colors representing different intensity ranges. The GPIB address for the laser beam analyzer is driven through its own internal software. The address can easily be changed or viewed by using the Spiricon's menu system. The difficult task in programming for this device is the large amount of string space needed to transmit the profile from the analyzer into the ASYST

program. The profile is an array of 120 x 120 pixels with a measured intensity between 1 and 255. This means a string of over 14,400 bytes long. Make sure you have the available memory before considering to download the laser beam profile. Reproducing the profile is even more difficult. The only known way to reproduce the profile is pixel by pixel. Although it can be easily programmed, the display routine is rather slow. We have also had trouble with sending the profile back to the analyzer. To date we have not yet succeeded. The laser beam analyzer is great by itself, but communicating with an IBM PC can be troublesome.

### 2.5.4.6 Newport - 835 Optical Power Meter:

The power meter was the easiest device to program. When the Spiricon camera system became temporarily inoperable, a power meter replaced the Spiricon LBA to measure the total power. An attenuator was attached to the power meter to measure power above 2 milliwatts when the laser's power was increased for higher intensity measurements reflected from the substrate. The GPIB address is set once again by a dip switch on the back panel. However, this dip switch includes an option for talk/listen and talk only. The talk only option can be found at dip switch number 6. This allows for the device to continuously send data into the GPIB bus. Since our experiment only needed to record the reading from the meter, we placed the meter in talk only mode. This way it continuously sends out it's current reading out into the GPIB bus. Whenever we need a power reading we can execute a GPIB Read from ASYST into string variable. Because of the small amount of programming for this device, we did not make a separate sub program devoted to it. To date you can find it's use in the 'Joe' program for the Non-Linear Optics testing.

## 2.5.5 Automated Device Configuration

As we increase the number of devices on the GPIB bus and in the program, we notice the amount of available program memory quickly decreases. ASYST constricts your conventional memory and tokens can only offer a little help. We have designed a way to easily change which devices are loaded into memory. The program is configured with only the device menus that are needed. The program is then re-saved on to the hard drive with a different name for fast loading from DOS. This keeps devices that are not being used from taking away your precious memory. Whenever the main menu program is initially loaded a menu configuration option is offered. Through this menu you can select the separate menus that you want, or don't want loaded. You can also change the GPIB device characteristics such as name, end of string character code, and GPIB device number. Mouse support is also configured. All of these settings can than be saved under a new name to be opened from DOS. The entire program is reloaded, but the menu configuration option will have been deleted. When you finally leave the current program, you can enter the saved ASYST program with the name that it was saved under. You'll notice that it won't have to take time to load the program, because it was already loaded when it was saved. The menu options will be only those that you had selected earlier. This process makes the programming more versatile to the demands of the laboratory. Although it is easy to use and may not appear to do much, it is extremely complex and hard to program.

## 2.5.6 Evaluation of ASYST

### 2.5.6.1 Advantages to ASYST

The use of ASYST has centered on its GPIB control. The GPIB bus allows control of different devices from one computer. This makes laboratory control easier. The GPIB bus is manipulated effectively in ASYST. The new menu commands make the programs more user friendly. Designing similar menus in higher level languages would take many hours to program. The menus allow for other people to easily operate our experiment without hours of technical program training. One advantage that we favor is the colon definitions. These definitions are similar to macros, but are easier to create and modify with an ASCII text editor. ASYST also offers statistical analysis, mathematical computations, and graphical analysis that takes time to program in any higher level language.

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2.5.6.2 Disadvantages of ASYST

ASYST (version 3.1) doesn't make use of expanded memory available in IBM 386 and 486 PCs except in tokens. Tokens help a little, but plenty of conventional memory could be saved for calculations and data manipulation if the entire program was loaded into expanded memory. If more conventional memory was freed the processing time would increase and so would the maximum size of any arrays. ASYST says that a new version will be coming out soon making better use of expanded memory. Instead of making a DOS window, ASYST makes its own interface. This limits the amount of DOS commands available inside ASYST and some of the commands are used differently. It is usually easier to exit to DOS rather than use the DOS interface commands. Although we were pleased with the ASYST menu commands in the normal display mode, the menu display in graphics mode did not work as well. Hopefully, in the next version these problems will be solved.

# 3. Nonlinear Interface Optical Switch Development

## 3.1. Introduction to Nonlinear Interface Optical Switches

The Nonlinear Interface Optical Switch (NIOS) consists of 2 layers: one of an ordinary linear dielectric and a second thin nonlinear layer consisting of dielectric with an intensity dependent index of refraction, *i.e.*, an optical Kerr effect medium. This nonlinear layer has an index of refraction at weak input intensities which is slightly lower than the linear medium. When used for optical computer switching, all input beams are at or near the critical angle for total internal reflection (TIR). The beams are adjusted so that with no control beam or pulse, the data beam will undergo TIR, but when a control beam is present, the change in the nonlinear medium's index of refraction will lead to a transmission of the data beam through the interface. The transmitted beam gives C AND D, the reflected gives the EXCLUSIVE OR of C and D. These are sufficient to build a complete set of logic gates for a computer. When used for high power laser switching or eye/sensor protection, the device is structured such that light above a certain threshold causes the device to undergo TIR.
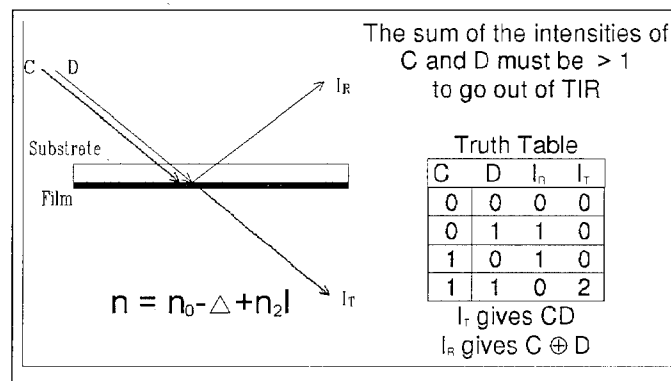


The sum of the intensities of C and D must be > 1 to go out of TIR

Truth Table

| C | D | $I_R$ | $I_T$ |
|---|---|-------|-------|
| 0 | 0 | 0     | 0     |
| 0 | 1 | 1     | 0     |
| 1 | 0 | 1     | 0     |
| 1 | 1 | 0     | 2     |

$I_T$ gives CD
$I_R$ gives C $\oplus$ D

$n = n_0 - \triangle + n_2 I$

Figure .13 NIOS Schematic & Truth Table.

First proposed by Kaplan in 1977[22], they are currently under development at Penn State, where the nonlinear medium is a liquid crystal layer[23], the University of Iowa, where the nonlinear medium is an aqueous microparticle suspension[24], and BDM Corporation, which also uses microparticle suspensions.[25] The University of Iowa group has published suggested architectures for NI switches using two simple logic primitives : the Interaction gate with crossover and the Priese gate with crossover. These are thermodynamically reversible gates[26]. The Iowa group has also made a study of enhancements to switching due to proper saturation of the nonlinear medium[27]. All these group's switches have large nonlinearities, but very low switching speeds.

In general, the major advantages of this type of switch over other types are that, because they do not use a resonator, they are capable of extremely fast response times if fast nonlinearities can be used, and if the nonlinearity itself is not a resonant nonlinearity, they can switch data signals of broad spectral bandwidth [28].

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The switches we are developing are made by Professor Joseph Chaiken of the Syracuse University Chemistry Department. They are made of nonstoichiometric tungsten trioxide cluster material. Tungsten oxides are tough refractory materials able to withstand high temperatures, and are familiar as the most common material used to make magnetron anodes. Bulk tungsten trioxide ($WO_3$) is a photorefractive material. It is also photochromic and electrochromic. We hope that the cluster material, by drastically decreasing the charge carrier travel distance, will speed up the nonlinear effect due to photorefraction, especially the recombination time. The change in reflectivity due to photochromic effects must also be investigated. The exact mechanism involved that makes the material photochromic is still controversial [29], and the speed of color change involved has not been measured. By looking at the change with our ultrafast pump-probe system, we may be able to eliminate some mechanisms on time scale considerations. By annealing cluster material, we could produce memory, which would be integrable with the switches.

The material is produced by pulsed laser fragmentation and deposition of fragments of an organometallic precursor in Prof. Chaiken's laboratory. By varying the wavelength, pulse duration, and gases present in the chamber, Prof. Chaiken can vary the stoichiometry much easier than previous groups making similar materials, who commonly used high temperature sputtering.

The largest known nonlinearities available in a material system that can be integrable is in quantum confined semiconductors such as CdS in zeolites or semiconductor doped glasses. These nonlinearities are fast to switch on, but slow to switch off, because the matrix the semiconductor microcrystallites are in cannot be tailored for the fast carrier combination required. Nonstoichiometric cluster switches have the microcrystallites on the surface as a thin film, and Dr. Chaiken at SU has the capability of tailoring not only the microcrystallites, but also the matrix they are embedded in. The large nonlinearities mean changes will be easier to discern experimentally, making it easier to separate the effects of changes in switching parameters.

In October, 1992 S.U. began the initial phase of ESCA analysis of $WO_3$ films at RL/ERD to determine the best oxygen ratio for optical nonlinearity.

## 3.2. Reflection Studies Using Method of Abeles

We measured reflectivity vs. incident angle for both film on substrate (light striking substrate first) and substrate alone at a constant wavelength and intensity. In the film on substrate case, the reflections from the air-film interface cannot be separated from the reflection at the film-substrate interface. The tangent of the angle of incidence at which the two (film on substrate and substrate alone) have equal reflectivity gives the index of refraction of the film. If the shape of such a curve is a function of the power of the incident light, then one of the materials in the three phase system is photorefractive and switching is possible. We used a succession of higher powers and looked for changes of the nonlinear film index of refraction vs. change in intensity.

The initial task in nonlinear interface optical switch development was to determine the low light intensity index of the nonlinear film, so we could get the proper matching substrate. We initially used a method of Abeles[30]. Using mode-locked 514 nm pulses of 100 ps duration obtained from an argon ion laser, the beam was first polarized and sent through a Laser Beam Controller (LBC). A beam-splitter then split the laser beam into two separate beams of unequal intensity. Mirrors redirected the two beams to become nearly parallel and close together before entering the light tight enclosure. Upon entering the enclosure the beams reflect and refract from the surface of the substrate. The reflected beams are measured by a photodetector connected to a power meter. The beam diameter was 100 μm in diameter.
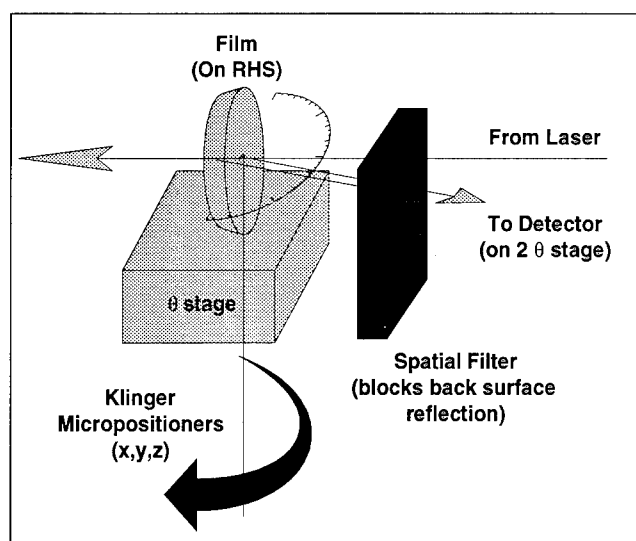
Figure 14. Setup for Reflectivity Measurements.

We found that the measured indices were quite different than those obtained by other methods. In the example shown in Figure 15, the crossing angle was 59.73 °. The tangent of 59.73 ° is 1.713. This is too low for the film index when other measurements are compared. A literature search of reflection studies using this method of Abeles found that they are not accurate if the difference in index between film and substrate is larger than ± 0.3 [31]. Our substrate index is 1.49. We also found that any absorption in the film leads to error[32]. According to Prof. Chaiken, a 200 nm thick film has 92 % transmission. We did see changes in the index as the incident power changed.
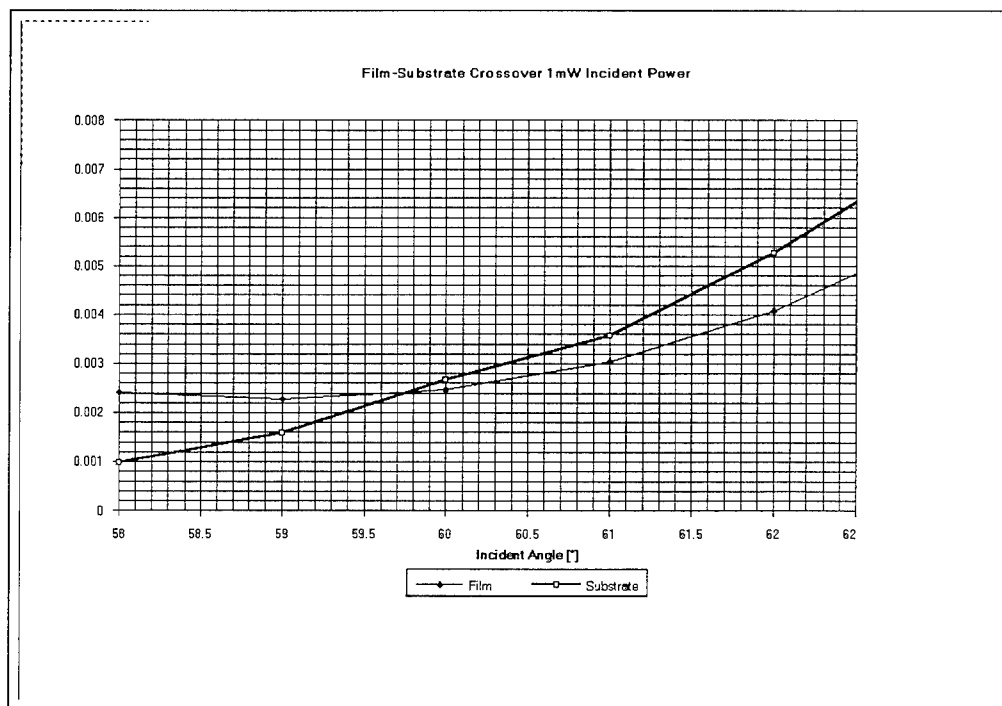


Figure 15. Film-Substrate Crossover Plot.

We also looked for changes in the shape of the curve. Small changes in the intensity of an input beam can result in comparatively large changes in the transmitted beam angle due to self-channeling of beams in

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nonlinear medium[33]. We did see some changes in the shape of the curve which were repeatable over several runs, but they were not repeatable from day to day.
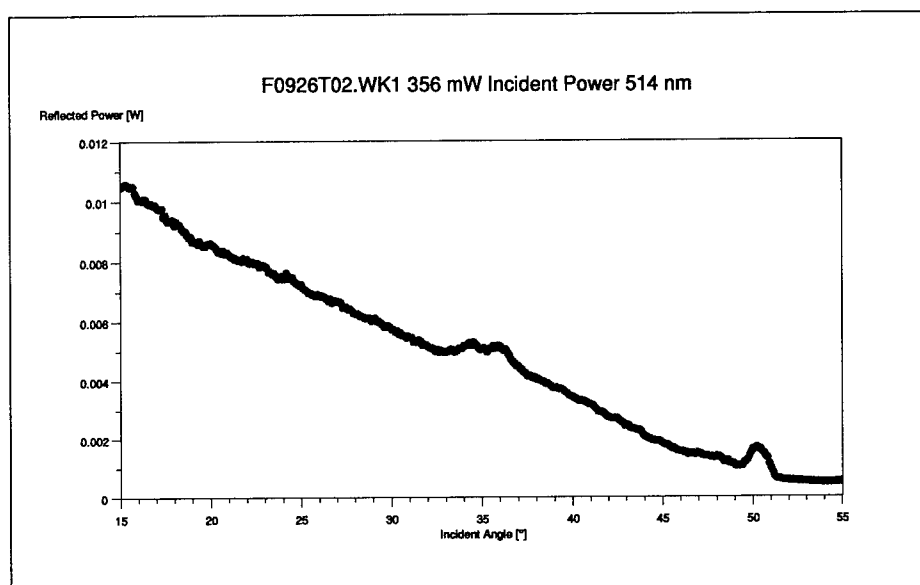


Figure 16. Anomalistic Curve.

## 3.3. Fresnel Model Analysis of WO₃ Films

We decided to develop a Fresnel equations model to get film index change as function of measured reflectance. This was a model from first principles, and followed the theory in Born and Wolf [34].
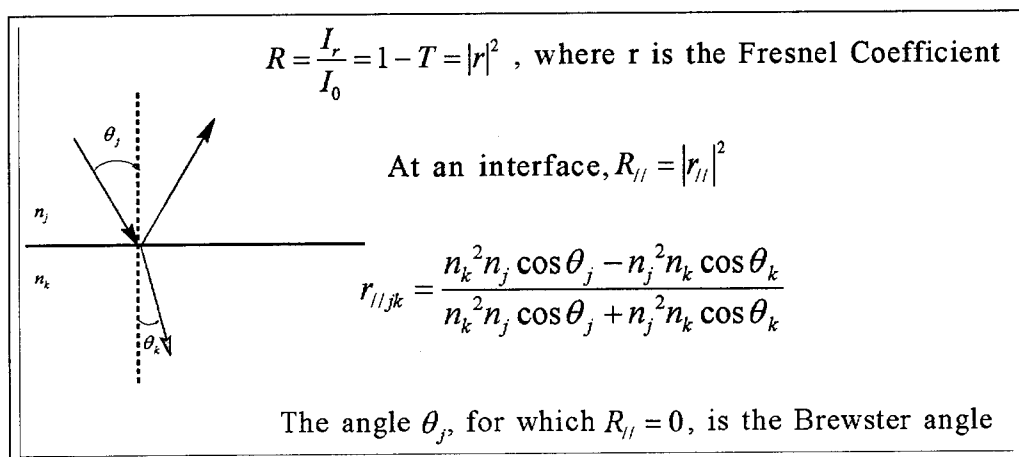
$$R = \frac{I_r}{I_0} = 1 - T = |r|^2 \text{ , where r is the Fresnel Coefficient}$$

$$\text{At an interface, } R_{//} = |r_{//}|^2$$

$$r_{//jk} = \frac{n_k^2 n_j \cos\theta_j - n_j^2 n_k \cos\theta_k}{n_k^2 n_j \cos\theta_j + n_j^2 n_k \cos\theta_k}$$

$$\text{The angle } \theta_j, \text{ for which } R_{//} = 0, \text{ is the Brewster angle}$$

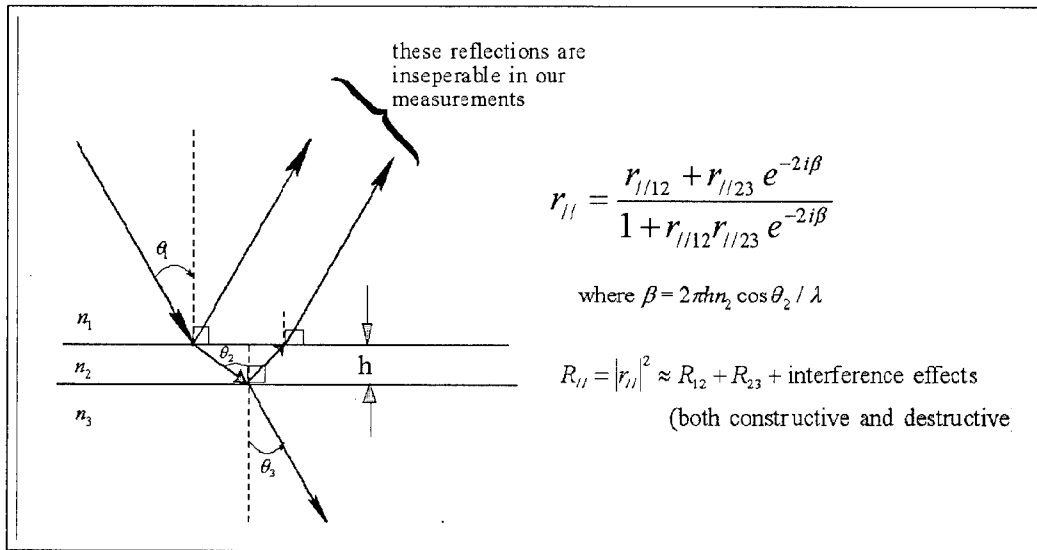Figure 17. Single Interface Fresnel Model.

Figure 18. NIOS Fresnel Model.

We used MathCAD for our model. Putting the Born and Wolf theory into MathCAD was the senior project of Vincent Guerriero. Because of the nature of sines and cosines, the index cannot be calculated from the reflectance, instead, reflectances can be found from indices, and the problem can be solved iteratively. The following page shows the Mathcad program FRSBACK3.MCD.

```
Iteration of Fresnel Equations to Obtain Reflectance Values.
```

$x := 1 .. 50$      x is the range variable. MathCad's max is 50.

$n2_1 := 2.55$      the initial value for the index of the film that gives us the reflectances we observed from F812RMP2.XLS at 40° incident angle.

$n2_{(x+1)} := n2_x + .001$      this is the increment for the index values.

$n1 := 1$      Index of Refraction of first medium (air).

$n3 := 1.489392$      Index of third medium (substrate).

$\theta1 := 68$      Angle of Incidence on the first boundary measured from the normal.

$\theta1\rho := \theta1 \cdot \dfrac{\pi}{180}$      Conversion from degrees to radians.

$\theta2_x := asin\left(\dfrac{n1}{n2_x} \cdot sin(\theta1\rho)\right) \cdot \dfrac{180}{\pi}$      Application of Snell's Law to achieve refracted angle from first boundary

$\theta2\rho_x := \theta2_x \cdot \dfrac{\pi}{180}$      Conversion from degrees to radians.

$\theta3_x := asin\left(\dfrac{n2_x}{n3} \cdot sin\left(\theta2\rho_x\right)\right) \cdot \dfrac{180}{\pi}$      Iteration of Snell's Law once again provides us with the refracted angle from the second boundary.

$\theta3\rho_x := \theta3_x \cdot \dfrac{\pi}{180}$      Conversion from degrees to radians yields

$r12_x := \dfrac{\left(n2_x\right)^2 \cdot cos(\theta1\rho) - n1 \cdot n2_x \cdot cos\left(\theta2\rho_x\right)}{\left(n2_x\right)^2 \cdot cos(\theta1\rho) + n1 \cdot n2_x \cdot cos\left(\theta2\rho_x\right)}$      Formula used to calculate the coefficient of reflectivity at the 12 boundary.

$r23_x := \dfrac{\left(n2_x\right)^2 \cdot cos\left(\theta3\rho_x\right) - n2_x \cdot n3 \cdot cos\left(\theta2\rho_x\right)}{\left(n2_x\right)^2 \cdot cos\left(\theta3\rho_x\right) + n2_x \cdot n3 \cdot cos\left(\theta2\rho_x\right)}$      Similiar process to obtain c.o.r. at the 23 boundary.

$h := .0000002$      Thickness of thin film.

$\lambda := .000000514$      Wavelength of incident light.

$B_x := \dfrac{2 \cdot \pi \cdot h \cdot n2_x \cdot cos\left(\theta2\rho_x\right)}{\lambda}$

$r_x := \dfrac{r12_x + r23_x \cdot exp\left(-2i \cdot B_x\right)}{\left[1 + \left(r12_x \cdot r23_x \cdot exp\left(-2i \cdot B_x\right)\right)\right]}$      Complex Coefficient of Reflectivity.

$R_x := \left(\left|r_x\right|\right)^2$      Reflectance

Figure 19. Mathcad Program FRSBACK3.MCD.

The results are multivalued, so another method must be used to find the approximate index to select the proper region of solutions. We used previous results of Michael Casey in his Ph.D. thesis [35] to get a first approximation.

Brian DeVaul used the algorithm in the MathCAD program to write the model in ASYST, the data aquisition language we use. This allowed us to view the results as soon as the data was collected. These methods gave us an index in the region of 2.2.
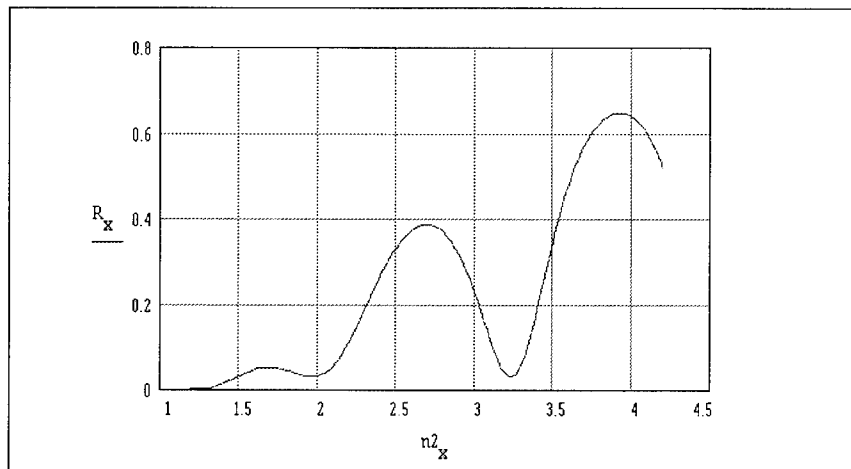
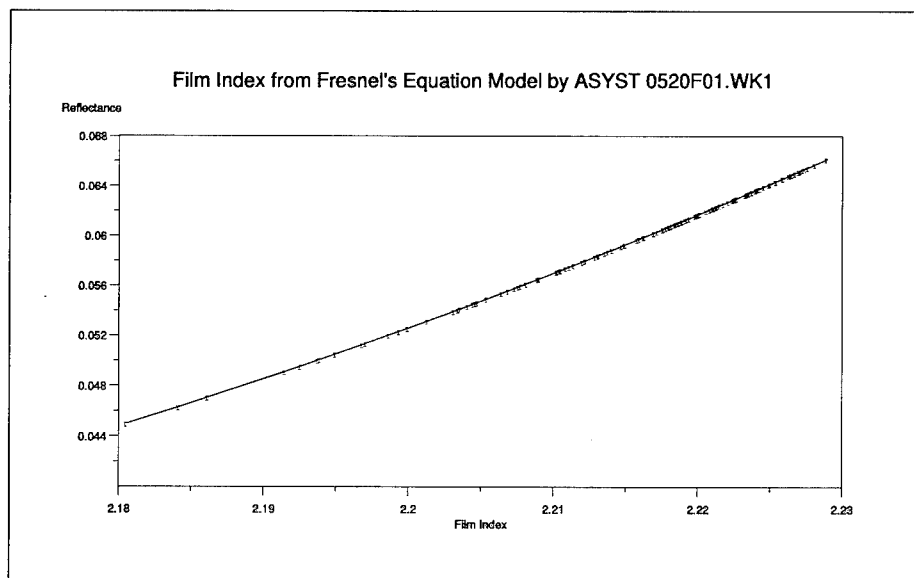Figure 20. Model Results from Mathcad-Reflectance vs. Index.



Figure 21. Model Results from ASYST-Reflectance vs. Index.

We output from our MathCAD model fifty R vs. n2 pairs over our measured reflectance range. We put these into RS/1, a mathematical spreadsheet program, and fit to a third degree polynomial. The polynomial coefficients were used with measured reflectance values to construct the following Excel chart. The large nonlinearity shown was encouraging. Now that we knew the film index from these results, we ordered ZnSe substrates to more closely match the film index.
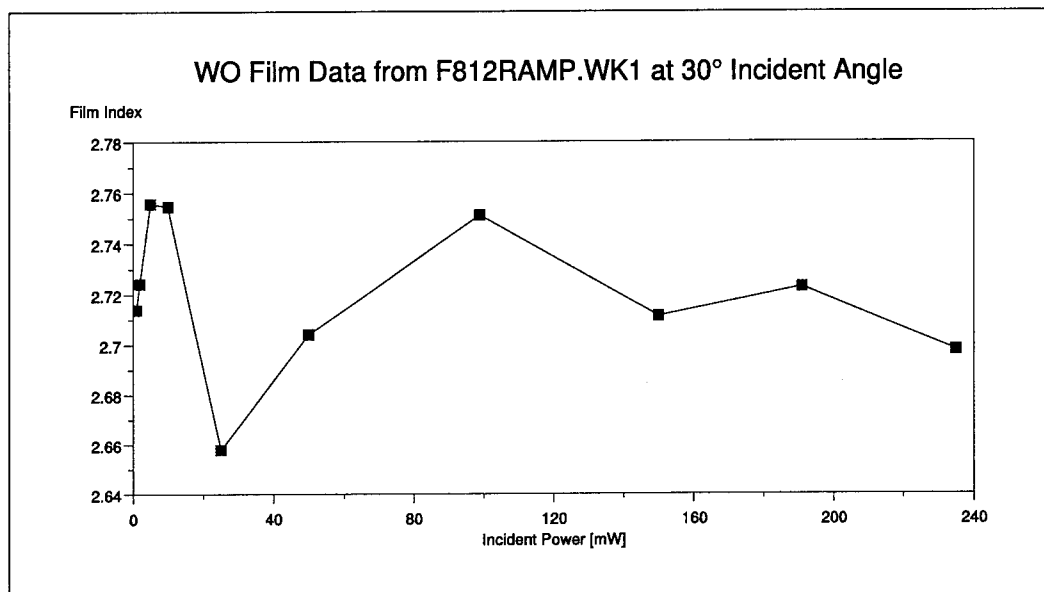
24

Figure 22. Film Index vs. Incident Power.

## 3.4.    Data Acquisition

### 3.4.1 Data Acquisition Program

Up to this point we have discussed some of the basic elements of the GPIB device programs. Another program has been written that incorporates most of these device programs to operate our optical switch testing. This program centers around a nested loop. First data is recorded from either the laser beam analyzer or the power meter and then the Klinger rotational stages are moved to another angle. An option has recently been added to allow the program to collect data and then change the power of the laser beam. With this option the rotational stages remain at their current position. The program started out to be simple, but it has quickly grown to accommodate different testing methods. For instance, the program now can collect data for a range of angles, automatically save the data, change the Z axis, and repeat the procedure (Figure 23). Changing the Z axis lets us collect data from a different location on the optical switch. Outside of this nested loop the user can quickly change the angular position of the substrate, change the power of the laser beam, view a graph of the latest collected data, and save the data in different formats.

```
: MOVE.SETUP        \ THIS ROUTINE CALCULATES THE CURRENT SUBSTRATE ANGLE
  MC4A " DW" GW    \ FROM THE COUNTERS OF THE TWO ROTATIONAL STAGES,
  D.W GR D.W 3 20 "SUB 0 "NUMBER V := SS.CLEAR   \ THEN CALCULATES THE
  MC4B " DZ" GW                          \ NEEDED POSITIONS FOR A
  D.W GR D.W 3 20 "SUB 0 "NUMBER X := SS.CLEAR   \ DESIRED ANGLE.
  X 5 * V + 1000 / RX :=                 \ RX = CURRENT ANGLE
                \ MC4B "Z" IS THE DETECTOR AND MUST BE POSITIONED AT
                \ AN ANGLE TWICE THE SIZE OF MC4A "W" ( THE SUBSTRATE).
                \ THE MC4B "Z" AXIS STAGE IS 100 COUNTS PER DEGREE
                \ THE MC4A "W" AXIS STAGE IS 1000 COUNTS PER DEGREE
                \ THEREFORE THE COUNT DIFFERENCE IS 1/5.
  13 FOREGROUND
  25 21 GOTO.XY ." INPUT THE NUMBER OF DEGREES FOR THE SETUP"
  11 FOREGROUND 7 BACKGROUND
  50 5 GOTO.XY CLRSCR 1 10 "SUB "TYPE
  50 5 GOTO.XY "INPUT SS ":= SS 0 "NUMBER KMD.N := SS.CLEAR
  MC4A          \ CALCULATE FROM PREVIOUS POSITION THE NEW POSITION
  RX 2 * KMD.N - 1000 * V := V "." SS ":= " PW" SS "CAT SS ":= SS GW
  MC4B KMD.N RX < IF RX KMD.N := THEN
  KMD.N RX - 200 * U := U "." SS ":= " PZ" SS "CAT SS ":= SS GW
  STACK.CLEAR SS.CLEAR
  13 FOREGROUND  0 BACKGROUND
  25 21 GOTO.XY ." WAIT FOR THIS MESSAGE TO DISSAPEAR      "
  11 FOREGROUND ;
```

Figure 23. Colon Definition from JOE.XXX.

Changing the angle of the substrate requires some calculation. The rotational stage holding the detector is located beneath the stages holding the substrate. This means that for every degree that the detector moves, the substrate must also move the same amount. Because we need to measure the reflected beam, the detector must be at an angle twice the angle of the substrate. For a desired substrate angle , the detector must move to a position of 2. The substrate then must move an angle in the negative direction. To accomplish this feat, the current angle is first calculated from the current axis positions. For our setup the "W" axis on the first controller operates the substrate rotational stage. The second controller operates the detector rotational stage on the "Z" axis. To add to the complexity, the rotational stage for the substrate (MC4A "W") moves at a rate of 1000 steps per degree. The detector stage (MC4B "Z") moves at the rate of 100 steps per degree. After the current angle $RX$ is calculated, the desired angle is then input by the user as $KMD.N$. The desired position of the stage is calculated from the difference between the previous angle and the desired angle with an adjustment based upon the type of stage. The rest of the colon definitions are similar to definitions found in the device specific programs. Because we had taken the time to develop programs for each individual device, we can now easily program for combinations of different devices with some of the necessary colon definitions already defined.

### 3.4.2 Future Use of ASYST in Optical Switch Evaluation

Our evaluation setup will be measuring the transmitted and reflected light from the switch with an EG&G Optical Multi-channel Analyzer (OMA) and an Inrad Autocorrelator. The OMA system will analyze the spectrum of the light to include the wavelength. A GPIB connection will be made from the keypad of the EG&G spectrograph. The computer will then control the scanning of the grating inside the spectrograph., which is receiving the transmitted or reflected laser beam. The autocorrelator will then be connected to a LeCroy 9450 Oscilloscope. The oscilloscope will be able to save wave forms, find deviations, full width at half maximum with the background light subtracted, and separate between the two peaks of the split laser beam. The computer will then be connected through GPIB to the Oscilloscope for data extraction and further analysis.

## 3.5.    Future Experiments

Our test plan for the tungsten trioxide switches involves a cycle of testing for nonlinear switching behavior, changing the stoichiometry, and then retesting. As nonlinear switching behavior is observed, we will investigate how changes in the material change switching behavior.

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A parallel experiment is to put the input beam through the substrate layer first, then the film (i.e. turn the switch over), rotate the switch until TIR just occurs, then increase intensity until a transmissive beam occurs. This latter configuration is also a nearly zero background measurement and in practice is less sensitive to photorefractive effects at the film-air interface. This will allow us to compare our results with published models[36]. We could then use the results to determine the direction of changes in the material needed to optimize the Kerr coefficient.

Once the nonlinearity is optimized, then the switch can be evaluated in the typical pump probe method in which a pulse of light is used to set up the nonlinearity and a later pulse, the probe/data arrives delayed to map out the switch transfer function.

Using a pump-probe system, we could determine the time parameters of nonlinear processes involved, then optimize the pulse length to produce best switching- low threshold energy with usable contrast and fanout.

After the material is optimized,we could investigate contrast enhancement due to soft saturation [37].

Later, we could integrate a simple logic primitive on a single substrate, either an Interaction gate with crossover or a Priese gate with crossover [38], and test the device for cascadability, switching speed and switching energy.

# 4.

# Conclusions

A novel facility to evaluate optical switches for optical computing has been built. Initial experiments on nonlinear interface optical switches are encouraging, as the selected broad bandwidth media has strong nonlinearity.

# Appendix: Resources on Hand

## Light Sources

Quantronix 4116 Nd:YAG Laser-ML, QS, SHG
Quantronix Pulse Selection System-with both IR and visible optical heads
Clark CPM-1 Colliding Pulse Mode-Locked Dye Laser
Clark NJA-1CP Mode Locked Ti:Sapphire Conversion Package
(2) Clark GDC-1 Gain Dye Circulators
Clark AC-1 Interferometric Autocorrelator
Spectra Physics 171-09 Argon Ion Laser
Spectra Physics 171-01 Krypton Ion Laser
Spectra Physics 375B Dye Laser
Extra recirculators for 375B Dye Laser
Spectra Physics 409 Autocorrelator
Spectra Physics 342A Mode Locking System
Spectra Physics 435 Mode Locker Stabilizer
Spectra Physics 344 Cavity Dumper for 171/375B Laser
Spectra Physics PDA-2 High Gain Laser Amplifier
Burleigh Color Center Laser System -1.5 Å
ILS 10 W grating-tuned $CO_2$ Laser System
INRAD Autotracker II Frequency Mixing System with both UV and IR optical heads
Laser Precision Rm-6600 two channel Universal Radiometer
Coherent 2000 Power/Energy Meter
(2) Coherent Labmaster Power/Energy Meters
CRI LPC Laser Power Controller
NESLAB HX-750 Refrigerated Recirculator - 16 gpm @ 60 psi

## Device Mounting, Modulation and Power Systems
16 axes of Klinger Precision Micro Control Positioner Systems
ILX LDS-7000 Turn Key Laser Diode System
(6) Meadowlark Variable Retarders with D1040LC Digital Interfaces
Newport EOS N21080-1 SAS Acousto-Optic Modulator System
HP 66000A 8 channel Modular Power System Mainframe
(3) HP 66102A DC Power Modules

## Data Acquisition and Analysis Systems
IBM PS/2 Model 70A21 25 MHz 386 computer running Viewdac for automated data acquisition & analysis
25-35 ps rise time Antel photodetectors
Antel photodetector supplies
Oriel PMT Detector system w/vis & IR PM tubes
Graseby S390 8 channel Universal Optometer with three silicon detectors
EG&G PARC OMA III Optical Multichannel Analyzer with gated, MCP intensified silicon detector
Instruments SA HR-320 0.32 M Spectrograph
EG&G/ARC Model 1235 0.28 M Spectrograph
Ealing 204P Black Body Source
Burleigh Wavemeter-visible & IR
Burleigh Scanning Fabry-Perot-visible & IR
Spiricon Silicon, PbS (near IR) and Pyroelectric (far IR) Beam Profile Systems
Unisys 16 MHz 386 computer for Spiricon/OMA III
Photon Beam Scan II Beam Size Measurement System
Tektronix 7104 Analog 1 GHz Oscilloscope with 7S11 Sampling Unit and 7T11A Sampling Sweep Unit
Tektronix 350 + ps rise time sampling heads
EG&G PARC 4402/4420 Box Car Averager System with two sampled and two gated heads
EG&G PARC 1302 Fast Pulser
(2) EG&G PARC 115 Wide band Preamplifiers
Ithaco 3970 Lock-In Amplifier System
LeCroy 9450 two channel 350 MHz Digital Oscilloscope
LeCroy CAMAC Transient Recorder System

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