All-Sky Imaging System

for

Finnish Meteorological Institute

KEO Consultants October 4th, 1996

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<u>All-Sky Intensified Camera System</u>

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Introduction

This manual discusses the All-Sky Imaging Photometer built by KEO Consultants for the Finnish Meteorological Institute. This camera includes the following components:

- Optical System: This includes the lenses and image intensifier systems to put a final image on the CCD camera.
- CCD Camera: This camera system uses a PULNIX CCD camera that provides a CCIR video output and has real-time integrating capabilities. Because the CCD chip itself is not cooled, integration times are limited due to large dark-noise buildup to about a five second maximum exposure.
- Control System: This includes the filterwheel system, electronics for controlling the camera shutter, the intensifier power and gain, and a light-sensor system for protecting the image intensifier. This control system uses a standard RS-232 interface to communicate with any HOST computer system.

Each of these systems will be discussed in this manual as well as all technical information necessary for servicing and further engineering development.

Camera Optics: A Brief Overview

From the front lens of the camera to the rear, the optical components are:

- Front fisheye lens (Canon 15mm/F2.8) with 180° field-of-view. This lens should be focused at ∞ and the F-stop should be set at F4. (at F2.8, more light will enter the camera but will not be used by the following optics, and will only lead to scattered light in the system.)
- Shutter
- Telecentric optics in front of filterwheel. These lenses are between the shutter and the filter in the filterwheel, and ensure that the image falling on the filter is telecentric. This is necessary for narrow-band interference filters as the transmission wavelength is dependent on the incident angle.
- Re-imaging optics: The telecentric image at the filter (~ 42mm dia.) must be imaged onto the image intensifier (image dia. ~ 22mm). The Canon camera lens (85mm/F1.2) in front of the intensifier must have it's F-stop set all the way open (F1.2). The Canon lens is followed by a field-curvature corrector lens mounted just in front of the intensifier. [Note: The reduction of the 42mm/F4.0 image to 22mm requires the image intensifier lens to have a F number of ≤ F1.4]
- Relay optics: The output image from the intensifier (~ 22mm dia.) is relayed to the Pulnix CCD camera (~ 5.5mm dia.) via a Canon 100mm/F2.0 lens coupled to a Fujinon 25mm/F0.85 lens (4:1 reduction). The Canon lens should always be set at F2.0 and ∞ focus, and the Fujinon at F1.4 and focused manually. Opening up the Fujinon to F0.85 will increase coupling efficiency at the center of the image, but introduces significant vigneting at the edge of the image.

An optical schematic for this configuration is included in Figure 1.

The camera can be focused in the lab by setting the front lens at ∞ for far objects (>10 feet), and then adjusting the intensifier Canon 85mm/F1.2 lens until you get the best focus. Then focus the Fujinon 25mm/F0.85 lens. Iterate back and forth between focusing these two lens until optimum focus is achieved. You should be able to adjust the image 'through' focus, so that one can definitely determine the optimum focus settings.

KEO has determined through experience that the best way to critically focus the camera is by looking at a star field. Once the camera is set up to look at the night sky, remove one of the filters and take short white-light exposures to get good star images. One can also do this by taking longer exposures using the 4278Å, 5577Å or 6300Å filters, but the process will take longer.

Removing and adding new filters:

The fisheye lens, shutter and telecentric optics can be removed from the filterwheel housing in one piece. Simply remove the front cover of the filter wheel by unscrewing the 6 circumferential screws around the filterwheel housing. The filters are then accessible and there are two retaining screws (with nylon locking inserts) to hold them in place. [A piece

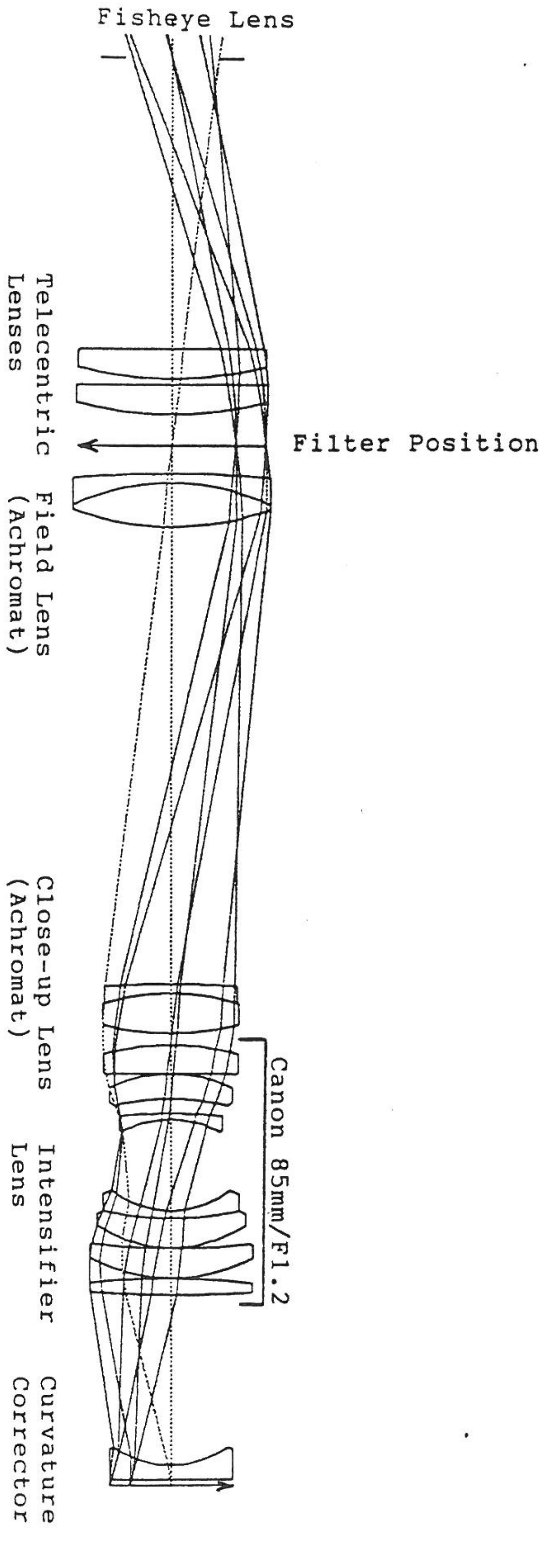


Figure 1: Optics Schematic (not to scale)

of scotch tape applied lightly to the filter can help pull them out of the filter housing.] Unused filter holes should probably be blocked, although it may be useful to leave one position open to facilitating focusing using a star field.

A word about field curvature and focusing:

All the optics designs require some compromise when designing systems with off-the-shelf optical components. The telecentric and reimaging optics results in some field curvature at the final image, so that the optimum focus for stars at the center of the image is different than the optimum focus for stars near the edge of the image.

KEO has installed a spherical correction lens in front of the CCD chip that is designed to correct the situation. Because no corrector lens will completely "flatten" out the image, KEO recommends optimizing the focus at about 45° elevation so that the zenith and the horizon are as little out of focus as possible.

A word about using CANON Lenses:

CANON lenses are removed by depressing the silver button at rear of lens and turning lens anti-clockwise. Note the small black plastic diaphragm adapter that is installed at the back of the lens. This is necessary for the f-stop adjustment ring to be operative. Vibration could loosen these diaphragm adapters so that they fall off. If there seems to be a problem with f-stop adjustment, check to see that they diaphragm adapters are in place.

A brief discussion of useful calibration procedures:

As one becomes familiar with using this instrument, there will be several calibrations that you will want to perform to further understand the instrument's characteristics and to be able to use the data quantitatively. A list of recommended calibrations is presented here.

- Temperature Controller Calibration: (Refer to the Athena Temperature Controller Manual). Once the instrument is installed, the Athena controller can be programmed to display in either °F or °C. An autotuning feature will determine the best PID loop parameters to accurately control the filterwheel temperature. A setpoint around room temperature should be selected and noted in you lab notes. KEO has autotuned each of the filterwheels in the lab without any filters installed. This process should be repeated once the instrument is installed in it's field location.
- Calibrate the light sensor sensitivity setting (VR4 on the control board) to switch the intensifier power on at an ambient light level roughly equivalent to civil twilight (or a solar depression angle of 6°).
- Use the calibrated light source that you use to calibrate your other photometric instruments to take long exposures at the different filter wavelengths to get a spectral calibration and overall quantitative calibration of the instruments. You will need to use the filter curves and the spectral response of your light source to correctly calculate these values.
- Get vigneting curves for the optics in the camera. Using a constant light source, take exposures with the source at equidistant positions from the front camera element, but at different elevation positions. Compare the output from these

different exposures at the same exposure time to get a vigneting curve for the optics. This will be important to "flatten" out the measurements of structures that span large parts of the field of view.

- Calibrate the center and radius of the image with respect to CCD pixels to get a spatial calibration of the instrument. The best way KEO has found to do this, is to take a bright image that clearly illuminates the edge of image. Image processing algorithms can also help to bring out this edge. Measure about 10 points around the edge of this image in CCD pixels, and then use different sets of three points from this data set to calculate an average radius and center.
- It is a good idea to take some long dark-noise exposures at the different intensifier gains and know what the dark noise contribution is.

Although all these calibrations will take a lot of time and care, KEO recommends doing them to get a full understanding of the capabilities of your instrument and to prepare your data for good quantitative analysis. These calibrations will pay off in the long run when it comes time to analyze the data you will take with this instrument.

Camera System

The camera system is built around the PULNIX TM-765 CCD camera with the following specifications:

- Video Output: CCIR standard video.
- CCD Size: 756x581, 11um pixels
- Power: 12VDC

The video is derived from the back panel of the camera via a BNC connector. Power for the camera is supplied for internally from the KEO control electronics, and the integrate and ground signals are brought out to the DB9 connector on the rear-panel of the camera chassis. Pin1 is camera ground, and Pin6 is the Integrate signal which can be interfaced to your frame-grabber system.

The integrate signal is held high for free running video (50Hz -- CCIR). When the integrate signal is brought low, blank video is outputted while the CCD chip is allowed to accumulated light. When the integrate signal is brought high again, the next frame outputted contains the integrated image.

Refer to the PULNIX camera manual for more information.

Centering the Image

The final image on the CCD chip is adjustable in the vertical direction to optimize the CCD image with the frame-grabber system. Figure 2 below shows how to adjust the CCD camera head.

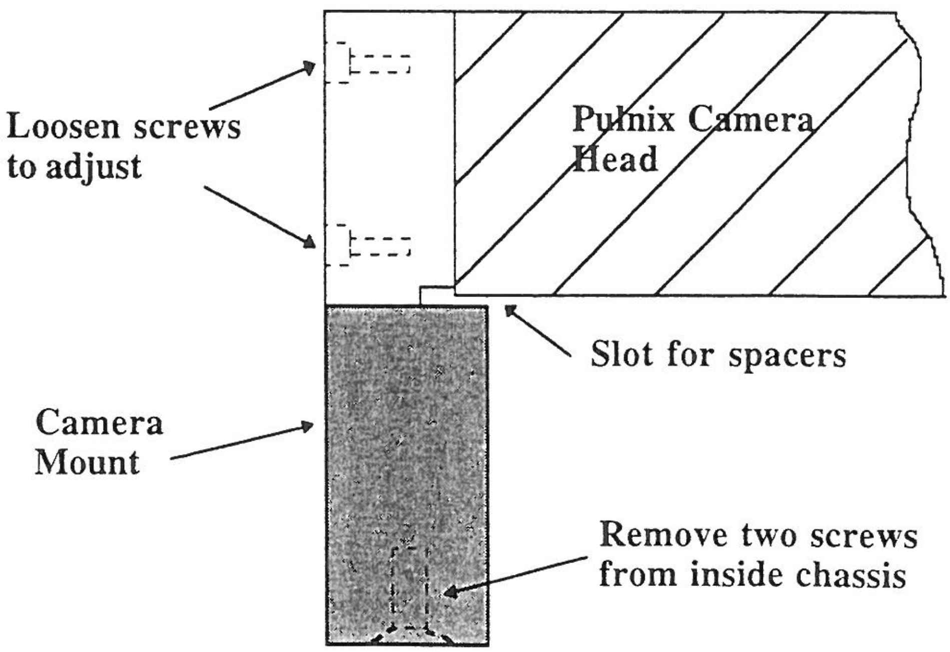


Figure 2. Adjusting the vertical placement of image

The Pulnix camera mounts to the vertical support with 4 pan-head screws. An O-ring seal compresses as the screws are tightened. Provision is made for ±0.3mm (25 pixels) vertical adjustment of the camera position, so that the image can be accurately centered on the CCD. To adjust, undo the two screws that hold the vertical support to the U-channel chassis. Remove the Pulnix camera/support assembly and then remove the C-mount lens from the camera head.

Loosen the four pan-head screws at the front of the camera. Insert various shim spacers (supplied, cut to size) into the slot at the back of the mount. Pressing down the camera onto the shim, tighten the screws. Trial and error will give the best centering of the image on the CCD.

Camera Control System

The imager needs control systems for the shutter, filterwheel and image intensifier. This section of the manual will discuss these systems while schematics and wiring documentation are included in the Appendix of this manual.

SMARTMOTOR System

Control for these instrument functions are provided via RS-232 serial communication. The RS-232 interface connects with a Servo-motor system connected to the filterwheel on the camera -- the Animatics SMARTMOTOR. The SMARTMOTOR system has an embedded processor with built-in EEPROM memory and is used to control the filterwheel system as well as the intensifier and shutter control systems.

KEO has built special hardware to interface between these two components. The advantages of this design are user flexibility to expand and re-program the system to meet new needs and the convenience of only having one small RS-232 interface cable to control the whole instrument. Because of the standard RS-232 interface, any terminal program, or programmed RS-232 communications can control the instrument.

KEO has provided an Windows-based control program called:

PRGTEST.EXE

that can be used to control the camera system via the SMARTMOTOR interface. This easy, menu-driven program allows you to control all functions of the camera system without having to learn the SMARTMOTOR control system. In addition, you can manually type in SMARTMOTOR commands via this program to get familiar with the system or to experiment with future development. **PRGTEST.EXE** was developed primarily as a test program and to facilitate with instrument calibrations.

SMARTMOTOR Development System

The SMARTMOTOR system comes with it's own development system that provides an easy way to view and modify the programs stored in it's EEPROM memory. For amore information explanation of the SMARTMOTOR and it's programming language, please refer to the Animatics SMARTMOTOR manual.

The SMARTMOTOR development system provided with this camera is DOS-based and so to use it, you must have a IBM-PC compatible computer available. Since all the SMARTMOTOR code has been provided for you by KEO Consultants, there really should be no need to use this development system unless you ultimately want to change things.

To install the SMARTMOTOR development system onto your DOS-based computer, use the SMARTMOTOR installation disk provided with your camera and type:

a:smartmin

This batch file will create a root directory:

deemed necessary. The HOME detector is interfaced to the SMARTMOTOR through it's I/O connector and uses Index pin A.

Temperature Control:

In addition, the filterwheel is temperature controlled. An Athena X16 temperature controller is provided at the rear of the instrument to control the temperature of the filters. Because the wavelength of the filters shifts with temperature it is important to maintain the filters at approximately room temperature, or somewhere around 22°C. Two AC heater pads are mounted symmetrically on the inside of the Filterwheel to maintain this temperature.

A manual for the ATHENA temperature controller is provided with the instrument. Using the setup controls, the display can be adjusted to read in °C or °F, and the filterwheel should be auto-tuned when finally mounted, so that the temperature controller can optimize the control feedback parameters used.

DIO-116 Parallel Interface:

The SMARTMOTOR uses an I^2C serial interface to control external devices. KEO has provided an I^2C parallel I/O board for this purpose. It is called the DIO-116 board and provides 8 bits latched TTL output, and 8 bits TTL input via this card. This board sits as a daughter board on the KEO Intensifier/Shutter Control board mounted inside the camera chassis and provides the interface to these devices.

The DIO-116 board is set up to use two adjacent port addresses and can be adjusted using the jumpers A1 and A2 providing four separate addresses. These boards can then be hooked up in series allowing the capability for 32 bits of latched output and 32 bits of input. This camera uses one DIO-116 module and it's address is set to 0 using the ports:

PORTA (Output) PORTB (Input)

Intensifier/Shutter Control Board

The Intensifier/Shutter Control Board built by KEO provides a flexible and expandable interface circuit to control two shutters and the image intensifier. In addition there are four auxiliary signals for additional functions to be added to the interface as well as an expansion connector for an optional manual control panel.

Power:

The only input power required by the board is 15VDC to 35VDC coming in on P1. This voltage becomes the starting voltage required by the shutter and should be optimized for the current shutter configuration. All other voltages needed for the board are derived by linear voltage regulators on the board.

In this particular system, 27VDC is used to control the filterwheel motor and used as an opening voltage for the shutter supplied with the system.

The Control Board creates three different voltages:

5V -- used for the CMOS circuitry on board (U9)
Vsh -- used as the holding voltage for the shutters (U8)
12V -- used for external components (U10)

All three of these voltage regulators can individually handle up to 1.5A, but keep in mind that the 24VDC power supply that powers these regulators can only supply 1.5A total. If more power is required for peripheral electronics, a larger power supply could be installed.

The 5V supply can be supplied by either the 5V regulator on board, or can be brought in via the parallel interface on P2 (pin 20). If the on-board regulator is used, then J5 should be installed, and if the external 5V supply is used J6 should be installed. ***Under no circumstances should both J5 and J6 be installed at the same time!!!***

The Finnish Camera System was delivered using the 5V supplied by the onboard voltage regulator. Hence J5 was installed, and J6 is left empty.

Vsh is used to create a holding voltage for the shutters and is set by adjusting the potentiometer VR5. This value should be set at about 1.5V above the desired holding voltage, as there are two diode drops that occur before the voltage reaches the shutter coil.

The Finnish Camera System was delivered with Vsh set at 7VDC.

12V is provided on the board for the convenience of the user in the event that some device is added to the system that requires 12VDC.

The Finnish Camera System used the 12VDC provided by this board to power the PULNIX TM-765 Camera which requires about 350mA of current.

Parallel I/O:

The Intensifier/Shutter Control Board has an 8 bit In/8 bit Out parallel interface coming in on P2. The IN/OUT definitions are from the DIO-116/SMARTMOTOR's point of view. Thus an Output for the DIO-116 is really an input for the Intensifier/Shutter Control Board. The table below shows the I/O definitions for the Control Board

DIO-116 Outputs:

Shutter Control Signals:

SHTR1* and SHTR2* are negative going pulses that control the shutter outputs. On the initial down-going transition of these signals, a 50 msec pulse (determined by R1*C1 or R2*C2) switches the 24VDC onto the shutters. For the remaining duration of the low-state of SHTR1*, the voltage set by Vsh is switched onto the shutters. If more input power is necessary to open the shutters, a longer input pulse can be set by changing the R1*C1, R2*C2 combinations.

STROBE*:

The strobe pulse is a negative going pulse that clocks in the intensifier gain data into the input latches on U5. The signals REM:GAIN0 and REM:GAIN1 determine the gain setting for the image intensifier and should be set before setting the STROBE* signal low. The new gain state is clocked in on the negative going transition.

DIO-116	Intensifier/Shutter Control Board
OUT0	SHTR1*
OUT1	SHTR2*
OUT2	STROBE*
OUT3	REM:INT_POWER
OUT4	REM:GAIN0
OUT5	REM:GAIN1
OUT6	OUT:TTL0
OUT7	OUT:TTL1
IN0	GAIN0
IN1	GAIN1
IN2	INT_POWER:STS*
IN3	LIGHT_DET*
IN4	SH1:STATUS
IN5	SH2:STATUS
IN6	IN:TTL0
IN7	IN:TTL1
5V	5V
GND	GND

Figure 2. Parallel I/O Signal Definitions

Intensifier Power:

The intensifier power can be switched on and off remotely by this signal. A low state turns the power off, and a high state turns the power on. To actually have power applied to the image intensifier, the light detector must be in a valid state (dark enough for safe operation of the intensifier tube). There is no way to override this detector as long as it is connected to the Control Board.

REM:GAIN0 and REM:GAIN1

These are the bits that determine the gain state of the image intensifier. Valid values are thus 0 to 3 and adjust the intensifier gain over it's full range which is usually about 8:1. Gains are usually adjusted so that from maximum gain (3), each gain below this reduces the output by a factor of 2 (much like the f-stop in a camera lens).

OUT:TTL0 and OUT:TTL1

These are two undefined signals that can be used to control additional devices that may be added to the system at a later time. They are available on P3 which provides an interface via ribbon cable or daughter board configuration to an expansion circuit.

DIO-116 Inputs:

GAIN0 and GAIN1

These bits read the current status of the intensifier gain and are used to read the current intensifier gain to verify that it is set correctly. This feature is especially important when used with a 'Manual Control Panel'.

INT_POWER:STS*

This signal gives feedback to the actual current running through the image intensifier and thus give independent confirmation that the intensifier power is actually on. A 5Ω resistor (R11) is hooked up in series with the ground signal of the intensifier and the voltage across this resistor is amplified at U7.A to give an indication of intensifier current. Because this signal is buffered with an additional Schmidt Inverter (U1.F), the signal is active low. A HIGH signal indicates that there is no intensifier power present, and a LOW signal indicates that there is intensifier power present.

LIGHT_DET:STS

This signal reads the inverted value of the light detector amplifier (U7.B). This signal is used to enable or disable the intensifier power circuit. Thus, a HIGH signal indicates that it is **dark enough** to operate the intensifier, and a LO signal indicates that it is **too light** to operate the intensifier.

This signal must be adjusted in the field to meet the requirements of the instrument. KEO usually advises that the intensifier power is enabled at a solar depression angle of around 6° (civil twighlight). This adjustment is made by changing the value of the potentiometer VR4 until the light detector switches states.

SH1:STATUS and SH2:STATUS

Some have status switches installed in them. The Intensifier/Shutter Control Board provides the means to read the status of these switches and report them back to the host computer. This feature is useful to check that the shutter is working reliably.

The Finnish Camera System's Shutter does not have a status indicator, so these bits are not used on this system.

IN:TTL0 and IN:TTL1

These two undefined inputs to the host can be used to read additional devices that can be added to the system at a later date. They are available on P3 which provides an interface via ribbon cable or daughter board configuration to an expansion circuit.

DIO-116 Power:

5V and GND

GND must be connected between the Control Board and the Host. The 5V signal is optional. 5V for the control board can be derived from the onboard voltage regulator (U9), or from the host interface. Jumpers J5 and J6 must be set accordingly as described above under the POWER section. In some rare cases, the 5V derived on the Control Board might be used to power an interface card through this parallel I/O port. In this case, both J5 and J6 may be installed.

Shutter Driver:

There is provision for two shutter drivers on the Intensifier/Shutter Control Board. As described in the Parallel I/O section, both shutters are controlled by ACTIVE-LOW signals. A mono-stable vibrator (U2) creates a 50 msec pulse which is used to momentarily switch the 24VDC power to the shutter. This gives the shutter a powerful starting pulse to open it fully. After 50 msec, only the Vsh voltage is applied to the shutter providing a lower voltage holding current through the shutter coil.

The shutter circuit is set up for your camera to open at 24VDC and hold at about 5.5VDC which is typical operation voltages for the shutter provided. To get 5.5VDC on the shutter coil, Vsh must be adjust to about 7.0VDC as there are two diode drops between the voltage regulator and the shutter coil.

The provision for manual operation at a remote control panel is provided via P3, but if no control panel is connected, the jumper J1 must be installed to provide for REMOTE-ONLY operation. Your system was delivered with J1 installed.

In some cases shutters are designed to operate on a opening and holding voltage of 24VDC. The Control Board can be modified slightly to accommodate this case by removing U2 and shorting out pins (SH1) 4 and 6, (SH2) 12 and 10. This will switch in the starting voltage (24V) for the duration of the ACTIVE-LOW signal.

Shutter status capability is provided on the Control Board to accommodate shutters that have micro-switches mounted in them to signal a fully opened shutter. These switches can be interfaced to the host via buffers (U1.C, U1.D) and are ACTIVE-HIGH (i.e. they are high when the switches are closed/shutter is open). In addition, an LED can be brought out to the manual control panel via P3 to give a physical indication of the shutter status.

Intensifier Circuit:

The intensifier gain can be controlled remotely by the host or from the manual control panel via P3. Four gain settings are set via the potentiometers VR1 - VR3. The highest gain setting (3) does not use a potentiometer as it is always set to maximum gain. Gains can be calibrated by using a constant light source and adjusting the values of VR1 - VR3 so that their values cut the gain by 1/2 for each setting. The maximum dynamic range of gain adjustment for image intensifiers is usually on the order of 8-14.

Remote gains from the HOST must be clocked into a latch using the STROBE* signal. DATA is latched on the negative going transition. To program this interface, set the next data state with the STROBE* signal high, then set the STROBE* low and high again. This will clock in the next gain state.

For remote-only operation, J3 should be installed which keeps the input latch selected on the remote data rather than allowing manual selecting of remote/manual gain settings.

Intensifier Power:

Intensifier power can be controlled remotely by the host via the REM:INT_POWER line. This signal is ACTIVE-HIGH: a LOW state disables the intensifier power, and a HIGH state enables it. Intensifier power will only be enabled when *both* the POWER state is HIGH and the LIGHT_DETECTOR state is HIGH. This provides a safety mechanism for protecting the image intensifier tube which can be damaged easily.

Manual control of the intensifier power is available through P3, but J4 should be installed if the Control Board is going to be used in a remote-only configuration.

Current through the intensifier is monitored and returned via the INT:STATUS bit. Because this is buffered through a Schmidt Inverter for interfacing purposes (U1.F), this signal is ACTIVE-LOW: i.e. the intensifier has power when this signal is LOW, and does not have power when the signal is HIGH.

This status bit is useful in determining if the Intensifier circuit is working correctly and to confirm whether or not the Light Override has disabled the intensifier.

Light Detector:

A photoresistive light element is supplied with the camera and is mounted in a LEMO connector hanging off the front of the camera. This detector can be mounted anywhere in the dome or taped to the lens of the instrument. It should be in position to easily detect changes in ambient light level.

The photoresistive element is connected to a voltage follower (U7.B) and subsequently buffered through a Schmidt Inverter. This signal can be read by the host through the LIGHT_DETECTOR signal. A HIGH signal means that the ambient light level is dark enough to allow safe operation of the image intensifier, and a LOW signal means that there is too much light for safe operation.

The trigger point of this circuit is determined by adjusting the value of the potentiometer VR4. KEO recommends setting this potentiometer to enable the image intensifier around civil twighlight (or solar depression of 6°).

SMARTMOTOR Interface Details

An embedded program was developed for the SMARTMOTOR that allows the host to easily control both the filterwheel and the Intensifier/Control Board through the DIO-116 interface described above. The following section describes this system and the subroutines stored in the SMARTMOTOR EEPROM. Users should refer to the Animatics documentation for a deeper understanding of the SMARTMOTOR programming language and capabilities.

Users should feel free to change the operating parameters of the filterwheel as well as any of the control routines stored in the SMARTMOTOR EEPROM. Software to develop and test applications for the SMARTMOTOR are supplied on a DOS-formatted floppy disk, along with the SMARTMOTOR program developed by KEO Consultants for your application.

Refer to the Animatics documentation for information about how to change the embedded software routines.

Description of FINLAND2.PRG

A simple control routine was developed for your application and is stored in the SMARTMOTOR EEPROM. This software automatically loads itself upon startup of the instrument and configures the instrument. To stop the program at anytime, the END command should be issued from the HOST. ***A listing of FINLAND2.PRG is included in the Appendix of this manual.***

Upon initializing the software (RUN), the motion parameters for the filterwheel are initialized:

```
AMPS = 100      ' Sets the maximum current to 1 AMP
MP              ' Sets the motor in absolute position mode
A=800           ' Sets acceleration to 800
V=600000        ' Sets Velocity to 600000
```

An output byte of 7 is STROBED into the Control Board, which sets both shutters to closed and the intensifier gain to 0 and the intensifier power to OFF.

Note that this guarantees that the control board state is in a SAFE mode of operation. Because the default state of the shutter is closed, and the additional safety of the light detector enabled, there is little chance of hurting the image intensifier.

Accelerations/Velocity/PID tuning:

Accelerations and velocities for the filterwheel were selected by trial and error and a medium speed was chosen to change the filterwheels. The servo-motor control system is capable of much higher performance, but the user should experiment with the adjustment of the tuning parameters to find the optimum system parameters for their applications.

Refer to the Animatics manual for definitions of units, motion control commands, and the servo tuning parameters to learn how to change these values.

KEO has tested the filterwheel and control software for over 2000 repetitions with no failures. The current parameter state should suffice for most applications.

Once the program has initialized the parameters for the system, a HOME command is issued (GOSUB5). When the unit is successfully HOME'd, the encoder position is calibrated and we can start issuing commands to the unit. An infinite loop is entered that just sits and waits for commands from the host. Any valid SMARTMOTOR commands may be issued by the host, but it is recommended that only the commands set forth in this manual be issued while the program is running.

*SMARTMOTOR communication is **case-sensitive**, so you must be careful when manually entering commands to preserve the case-states of the commands.*

To terminate FINLAND2.SM at any time, the command

END<cr>

must be issued. The program functions can easily be tested by hooking the SMARTMOTOR to any RS-232 port and using a terminal emulation software package. It is recommended that you use the KEO Software **PRGTEST.EXE** for initial testing as this will eliminate frustrating typing errors. To run this program, enter the Windows environment and run:

C:\SMARTMTR\KEO-PROGS\PRGTEST.EXE

Additionally, the DOS utility provided by Animatics

C:\SMARTMTR\TERM.EXE

is an excellent development and testing platform for the SMARTMOTOR system.

FINLAND2.PRG is based around the execution six subroutines that control the various functions of the camera system. SMARTMOTOR variables are set to set the command state of the subroutines and to hold the return results. The SMARTMOTOR variables for FINLAND2.PRG are set up as follows:

a	Holds contents of last read input (DINB0)
b	Holds contents of output register (DOUTA0)
c	Holds light detector status bit
d	Holds shutter status bit
e	Holds Intensifier Gain
f	Holds Intensifier Power status bit
g	Holds next filter position
h	holds present filter position

FINLAND2.PRG has the following subroutine definitions:

C0	Read_Light_Detector_State
C1	Shutter_Control
C2	Intensifier_Gain_Control
C3	Intensfier_Power_Control

C4	Filterwheel_Control
C5	HOME_Reset

Subroutines are terminated by emitting a LF character (#10) which is used by the host serial control to terminate the port read.

SMARTMOTOR Subroutine Descriptions

C0: Read Light Detector State

The command

```
GOSUB0
```

reads the input register and stores the result in variable **a**. Bit 3 of this register is masked out and stored in variable **c** and shifted to the LSB position. C0 returns with the string:

```
LIGHT:c                    ' where c is 0 or 1
```

C1: Shutter Control

The command

```
d=x
GOSUB1
```

where:

```
x  = -1                    ' just reads shutter state
x =  1                     ' opens the shutter
x =  0                     ' closes the shutter
```

controls the shutter state. If **d** == -1, then the shutter status bit is read and masked from register a and stored in variable **d**. If **d** == 16, it indicates that the shutter is open and C1 emits

```
SHTR:Open
```

If **d** == 0, then C1 emits

```
SHTR:Closed
```

Because your camera only has one shutter controlled by the Control Board, provision for only one shutter was included in your software package.

To open or close the shutter, the host would send the following commands:

```
d=1             ' Set shutter cmd to OPEN
GOSUB1          ' Operate shutter subroutine
.
.               ' get exposures, collect data, etc....
.
d=0             ' Set shutter cmd to CLOSE
GOSUB1          ' Operate shutter subroutine
```

Both calls to C1 will return the status of the shutter just as if the **d** == -1 parameter had been sent to the subroutine. The user can choose to ignore or use this return state based on their programming needs.

C2 Intensifier Gain Control

The command:

```
e=x
GOSUB2
```

where:

```
e=-1            ' just reads current Intensifier Gain
e= 0 - 3        ' sets the intensifier gain to e
```

controls the gain of the image intensifier tube. If e == -1, then the input register is read and the intensifier gain bits (B0-B1) are masked out and returned to the host:

```
GAIN:e
```

If an invalid gain was set in e (values other than 0 through 3), C2 returns:

```
GAIN:-1
```

To set the gain, for example, to 2, the following commands should be issued by the host:

```
e=2
GOSUB2
```

If everything is working correctly, the subroutine will return the following string to the host:

```
GAIN:2
```

C3: Intensifier Power Control

The command

```
f=x
GOSUB3
```

where:

```
x  = -1          ' just reads int. power state
x =  1           ' turns on intensifier power
x =  0           ' turns off the intensifier power
```

controls the intensifier power state. If f == -1, then the shutter status bit is read and masked from register a and stored in variable f. If f == 4, the intensifier power is OFF (remember the status signal is ACTIVE-LOW), and if f == 0, the intensifier power is on:

```
INTPWR:OFF       ' f == 4
INTPWR:ON        ' f == 0
```

To turn on/off the intensifier power, the host would send the following commands:

```
f=1              ' Set intensifier power to ON
GOSUB3           ' Operate int. power subroutine
.
.                ' do other stuff..
.
f=0              ' Set intensifier power to OFF
GOSUB3           ' Operate int. power subroutine
```

Both calls to C3 will return the status of the intensifier power. Remember that even after turning on the intensifier power from the host, the Control Board might still not enable the intensifier power if the Light Detector Bit is set LOW. This bit is checked by running C0.

C4 Filterwheel Control

The command

```
g=x
GOSUB4
```

where:

```
g = -1             ' reads the current filterwheel position
g = 1 through 7    ' sets the filterwheel to the position: g
```

commands the filterwheel to move to the selected position stored in **g**, or to read the current filterwheel position, if **g** == -1. C4 returns the current filter position to the host:

```
FILT:g
```

where **g** is a valid filter position between 1 and 7 (for your filterwheel system), or -1 if a non-valid filterwheel position command was issued.

NOTE: the filterwheel position is calculated from the current encoder state. There are 2000 encoder counts per motor revolution, and ten motor revolutions per filterwheel revolution. Thus, there are 2857 encoder counts per filter position. Therefore, the encoder position is always set so that the encoder is equal to the filter position * 2857. The servo loop should guarantee that the motor position is always locked onto the correct encoder position. When reading the filter position, C4 reads the current encoder position and divides by 2857 to get the filter number:

Appendix A

FINLAND2.PRG Program Listing (SMARTMOTOR)

```
'*****************************************************************'
'                                                                 '
' FINLAND2.PRG       9/30/96                                      '
'                    KEO Consultants                              '
'                    Cyril Lance                                  '
'                                                                 '
' Version: 1.2       Last Modified: 10/1/96                       '
'                                                                 '
'     Finnish Systems have a Seven Position Filterwheel:          '
'                                                                 '
'           2000 encoder counts/motor rev.                        '
'           10 motor rev./filterwheel rev.                        '
'           20,000 encoder counts/filterwheel rev.                '
'                                                                 '
'     So....          2857 encoder counts/filter position         '
'                                                                 '
' SMART-MOTOR embedded software for controlling the FINNISH       '
' camera electronics through the DIO-116 Parallel I/O board       '
' from the SMART-MOTOR to the Intensifier/Shutter Control         '
' board. Routines in the program are also included to            '
' control the position of the Filterwheel. A HOME reset          '
' code is included to home to the magnetic sensor, and then       '
' move a specified offset to the first FW position.               '
'                                                                 '
' Program loops, allowing input from user and then calls          '
' to the various subroutines.                                     '
'                                                                 '
' Variables used:                                                 '
'                                                                 '
'    a ==> Holds contents of last read input (DINB0)              '
'    b ==> Holds contents of output register (DOUTA0)             '
'    c ==> Holds Light Detector Status 0=Light, 1=Dark            '
'    d ==> Last read 'Shutter Status Bits' 0=closed, 1=open       '
'    e ==> Holds Intensifier Gain                                 '
'    f ==> Holds Intensifier Power Status 0=off, 1=on             '
'    g ==> Holds next filter position                             '
'    h ==> Holds present filter position                          '
'    j ==> Holds the HOME offset                                  '
'                                                                 '
' SUBROUTINES used:                                               '
'                                                                 '
'    CO ==> Read_Light_Detector_State                             '
'    C1 ==> Shutter_Control                                       '
```

```
'     C2 ==> Intensifier_Gain_Control                                   '
'     C3 ==> Intensifier_Power_Control                                  '
'     C4 ==> Filterwheel_Control                                        '
'     C5 ==> HOME_Reset                                                 '
'                                                                       '
'***********************************************************************'

SADDR1                    ' Identifies this as the motor #1

WAIT=1000                 ' Wait 0.25 sec for software resets
PRINT(#10)                ' clear communications buffer

' Initialize the motor variables and move around a bit to get the
' feeling that things are working!

AMPS=80                   ' Set the Maximum Current to about 1 Amp
MP                        ' Set the Motor to "Position Mode"

' Sets the Velocity and Acceleration of the motor

A=800                     ' Set Acceleration
V=600000                  ' Set Velocity

' Initialize the output port:  Shutters off, Int. Gain = 0

b=7                       ' Set Ouput bits, STROBE hi
DOUTA0,b
b=3                       ' Set STROBE low
DOUTA0,b
b=7                       ' Set STROBE hi to clock data
DOUTA0,b

' Initialize variables for SUBROUTINE calls

d=-1                      ' Shutter Parameter -- just read status
e=-1                      ' Intensifier Gain -- just read status
f=-1                      ' Intensifier Power -- just read status
g=-1                      ' Filter Wheel Report -- just report position

' HOME Initialization -- go to magnetic detector and slew to offset
' *** HOME Offset is defined in HOME routine!!!  Don't Change! ***

GOSUB5                    ' Find HOME Position, then slew to position #1

WHILE 1 LOOP              ' Program loops forever until user types "END"
END                       ' End of "MAIN" Program definition
```

```
'*******************************'
'                              '
' SUBROUTINE Defintions         '
'                              '
'*******************************'

' SUBROUTINE C0:  Read_Light_Detector_State( var c )

C0                        ' Read light status:  LO=light, HI=dark
  a=DINB0                 ' Get input BYTE (PORT B)
  c=a&8                   ' Mask out B3
  c=c/8                   ' Shift value to B0
  PRINT("LIGHT:",c)       ' Print value to screen
   PRINT(#10)
  RETURN                  ' Return to MAIN routine

' SUBROUTINE C1:  Shutter_Control( var d )    ' Uses Shutter #1

C1
  IF d==0                 ' Close the shutter
    b=b|1                 ' Close -- Shutter 1 bit HI (B0)
    DOUTA0,b              ' and output to DIO-116 PORTA
    WAIT=41               ' Wait 10 msec
    d=-1                  ' Set to read status
  ENDIF

  IF d==1                 ' Open the shutter
    b=b&254               ' Open -- Shutter 1 bit LO (B0)
    DOUTA0,b              ' and output to DIO-116 PORTA
    WAIT=41               ' Wait 10 msec
    d=-1                  ' Set to read status
  ENDIF

   IF d==-1
    a=DINB0               ' Read the input Byte (PORTB)
    d=a&16                ' Mask out Shutter 1 status

    IF d==16              ' If bit set, shutter is open
        PRINT("SHTR:Open",#13) ' Print status
        PRINT(#10)
    ENDIF

    IF d==0               ' If bit is not set, shutter is closed
       PRINT("SHTR:Closed",#13)
        PRINT(#10)
    ENDIF

  ENDIF                   ' Finished reporting status
```

```
  RETURN                    ' End of Subroutine C1

' SUBROUTINE C2:   Intensifier_Gain_Control( var e )

C2
  IF e>3                    ' Check for non-valid gain
      PRINT("GAIN:-1",#13)
     PRINT(#10)
   RETURN
  ENDIF

  IF e>=0                   ' Check for valid gain
    b=b&207                 ' Clear the output bits (B4-B5)
    e=e*16                  ' Shift gain over to B4-B5
    b=ble                   ' OR gain into output BYTE
    DOUTA0,b                ' and output to DIO-116 PORTA

    b=b&251                 ' Set the STROBE bit low (B2)
    DOUTA0,b                ' and output to DIO-116 PORTA

    b=bl4                   ' Set the STROBE bit high (B2)
    DOUTA0,b                ' and output to DIO-116 PORTA
    e=-1                    ' Flag to read intensifier gain

  ENDIF                     ' Intensifier gain has been set

  IF e==-1                  ' Flagged to read gain
    a=DINB0                 ' Get input BYTE (PORT B)
    e=a&3                   ' Mask out B0-B1
    PRINT("GAIN:")          ' Print value to screen
     PRINT(e)
      PRINT(#10)
  ENDIF

  RETURN

' SUBROUTINE C3:   Intensifier_Power_Control( var f )

C3
  IF f==1                   ' Command: Turn Power ON
    b=bl8                     ' Set the Int. Power bit (B3)
    DOUTA0,b                ' and output to DIO-116 PORTA
'      PRINT("Turning Int_Power on...",#13)
'     PRINT(#10)
    f=-1                    ' Set Flag to read power
  ENDIF

  IF f==0                   ' Command: Turn Power OFF
    b=b&247                 ' Clear the Int. Power bit (B3)
```

```
    DOUTA0,b                    ' and output to DIO-116 PORTA
'       PRINT("Turning Int_Power off...",#13)
'       PRINT(#10)
    f=-1                        ' Set Flag to read power
  ENDIF

   IF f==-1
    a=DINB0                     ' Get input BYTE (PORT B)
    f=a&4                       ' Mask out B2
    IF f                        ' INTSTS* --> Active Low...
       PRINT("INTPWR:OFF") ' Bit HI:  Power is OFF
    ENDIF
     IF f==0
       PRINT("INTPWR:ON")  ' Bit LO:  Power is ON
    ENDIF
     PRINT(#13)                 ' Print CR character
     PRINT(#10)                 ' Print LF character
  ENDIF

  RETURN                        ' Return to MAIN routine

' SUBROUTINE C4:   Filterwheel_Control( var g )

C4
  IF g==-1                      ' Request for present position
    h=@P/2857                   ' Update present position
     PRINT("FILT:")             ' and report the position
    Rh                          ' to the user
      PRINT(#10)
   RETURN
  ENDIF

  IF g>7
      PRINT("FILT:-1")
      PRINT(#13)
      PRINT(#10)
   RETURN
  ENDIF

  IF g<1
      PRINT("FILT:-1")
      PRINT(#13)
      PRINT(#10)
   RETURN
  ENDIF

  IF h==1                       ' Present Position is 2857
    IF g<5
      P=g*2857                  ' Next position = g*2857
```

```
    ENDIF
    IF g>=5
       i=g*2857
        i=i-20000
      P=i                          ' Move in opposite direction
    ENDIF
  ENDIF

  IF h==2                          ' Present Position is 5714
    IF g<6
       P=g*2857                    ' Next position is g*2857
    ENDIF
    IF g>=6
       i=g*2857
        i=i-20000
      P=i                          ' Move in opposite direction
    ENDIF
  ENDIF

  IF h==3                          ' Present Position is 8571
    IF g<7
       P=g*2857
    ENDIF
    IF g==7
       i=g*2857
        i=i-20000
      P=i
    ENDIF
  ENDIF

  IF h==4                          ' Present Position is 11428
      P=g*2857
  ENDIF

  IF h==5                          ' Present Position is 14285
    IF g==1
       i=2857
        i=i+20000
      P=i
    ENDIF
    IF g>=2
       P=g*2857
    ENDIF
  ENDIF

IF  h==6
  IF g<3
      i=g*2857
       i=i+20000
```

```
      P=i
    ENDIF
    IF g>=3
        P=g*2857
    ENDIF
ENDIF

IF h==7
    IF g<4
        i=g*2857
        i=i+20000
      P=i
    ENDIF
    IF g>=4
        P=g*2857
    ENDIF
ENDIF

' DEBUGGING PROMPTS
' PRINT("PRESENT: ")
' RP
' i=P
' PRINT("NEXT: ")
' Ri
'  PRINT(#10)

  G                               ' Make the filter move to next position
  TWAIT                           ' Wait until trajectory is finished
  h=g                             ' Reset the present filter position
  O=h*2857                        ' and reset the present origin

   PRINT("FILT:")
  Rh
    PRINT(#10)
  RETURN
```

' SUBROUTINE C5: HOME_Reset

```
C5
  V50000                          ' Slower Homing velocity
  A200                            ' Home Acceleration

  i=UAI                           ' Are we at the HOME bit?
  IF i==0                         ' move off it a little bit
      i=@P-500                    ' to guarantee that we're not already at HOME
     P=i
    MP                            ' Set move to "position" mode
   G                              ' Start the motor move, and
    TWAIT                         ' wait for the move to finish
```

```
ENDIF

MV                      ' Put motor in Velocity Mode
UAI                     ' Define the Encoder A bit as input

G                       ' Start slewing the motor
i=UAI                   ' Look at the HOME bit
WHILE i==1              ' Slew while this is not set (active_low)
  i=UAI                 ' and keep reading the HOME bit
LOOP

WHILE i==0              ' While the HOME bit is still set
  i=UAI                 ' keep reading the HOME bit
LOOP                    ' and keep moving until it is no longer set

A200                    ' Set a slow acceleration rate
V=-750                  ' Set the velocity to slow reverse
G                       ' and move backwards until beg. of HOME

WHILE i==1              ' While the HOME bit is NOT set...
  i=UAI                 ' keep reading the HOME bit
LOOP                    ' and keep moving until we reach the HOME bit again

A2000                   ' setup for a very quick stop
X                       ' and come to a stop using this acceleration
TWAIT                   ' wait until the motor has finished this decceleration
 WAIT=400               ' wait for things to settle

O=125                   ' Set this as offset origin

MP                      ' Put motor in Position MODE
V600000                 ' Normal slew velocity
A800                    ' Normal slew acceleration

P2857                   ' Setup to slew to position #1 from HOME
G                       ' Make the move
TWAIT                   ' Wait until the trajectory is over
WAIT=4000               ' Wait 1 sec for things to settle

h=1                     ' Set to current position
 PRINT("HOME:1")
 PRINT(#10)             ' Terminate communications buffer
RETURN

END             ' END of FINLAND2.PRG code
```

Appendix B

RS-232 Communication to SMARTMOTOR

The SMARTMOTOR has an RS-232 interface which is connected to a host computer via the DB-9 on the backpanel of our imagers. The filterwheel, image intensifier and shutter systems are all controlled by a set of commands issued by the host via the RS-232 interface.

Each SMARTMOTOR is individually addressed. Upon power-up, the SMARTMOTOR used in your camera system is given the address of #1. The SMARTMOTOR continually polls the RS-232 receive line and ignores all characters until it is addressed.

Addressing an individual SMARTMOTOR is achieved by sending out a high-order ASCII character:

ASCII Value	Motor Address
128	0 (All)
129	1
130	2
131	3
.	.
.	.
.	.

In our case, the Host must issue an ASCII character of value #129 (Decimal) before establishing a link with the SMARTMOTOR in the camera. Once this has been established, all commands issued from the Host as described in the preceding sections will be intepretted by the SMARTMOTOR.

Communication Protocol

The SMARTMOTOR communication is set up for:

9600 Baud, 8 bits, 1 stop bit, No Parity, No Flow Control

Note that all communication to the SMARTMOTOR is case sensitive!

Appendix C

Wiring and Cable Documentation

Internal Wiring:

AC Power

Signal Name	Rear Panel Bendix	Wire Color	Athena Temp. Controller	24V Supply
AC(Line)	A	Red	11 (L1), 2 (C)	AC(+)
AC(Neutral)	C	White	12 (L2)	AC(-)
Chassis Gnd	B	Green		GND

24VDC Power

Signal Name	24V Supply	Wire Color	Smart Motor DB11	Int./Shutter Brd P1
24V	Out(+)	Red	A1	1
Gnd	Out(-)	Black	A2	2

RS-232 Interface

Signal Name	Rear Panel DB9	Wire Color	Smart Motor DB11
Transmit	2	Red	3
Receive	3	Green	4
Gnd	5	Black/White	5

ANILINK Interface

Signal Name	Smart Motor AMP-MTE	Wire Color	DIO-116 AMP-MTE
5V	1	Yellow	1
Gnd	2	Green	2
Data	3	Red	3
Clock	4	Black	4

Intensifier/Shutter Controller Board Outputs

Signal Name	Int/Shtr Board DB-25	Wire Color	Light Detector LEMO FGG.0B	Shutter
PR(+)	11	Orange	1	
PR(-)	23	Black	2	
SH1(+)	6	Blue		1
SH1(-)	18	Green		2
			Intensifier LEMO FGG.1B	
P1	13	Red	1	
P2	24	White	2	
P3	12	Black	3	
P4	25	Green	4	

Filter Wheel Cable

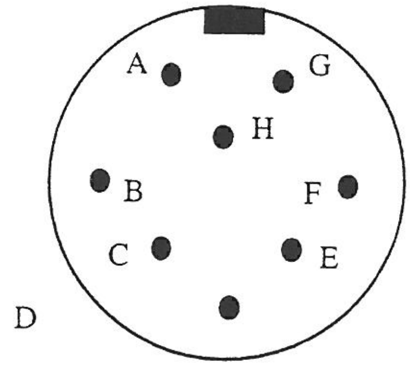
Signal Name	Filterwheel Bendix 8 pin	Wire Color	SMARTMOTOR I/O Connector	Athena Temp. Controller
Home(5V)	C	Red	6	
Home(Gnd)	D	Green	7	
Home(Out)	E	Yellow	1	
RTD(+)	A	Red		10 (RTD{+})
RTD(-)	G	Black		9 (RTD{-})
RTD(S)	H	Blue		8 (RTD{S})
AC(Line)	F	Blue		1 (N.O.)
AC(Neutral)	B	White		12 (L2)

Video Camera Cable

Signal Name	PULNIX Video Cable	Wire Color	External Cntrl. Rear Panel DB9	Int/Shtr Board P6
12V	2	Yellow		1
Gnd	1	Grey	1	2
Integrate	11	Blue	6	

Appendix D

Filterwheel Wiring Documentation



Filterwheel Connector

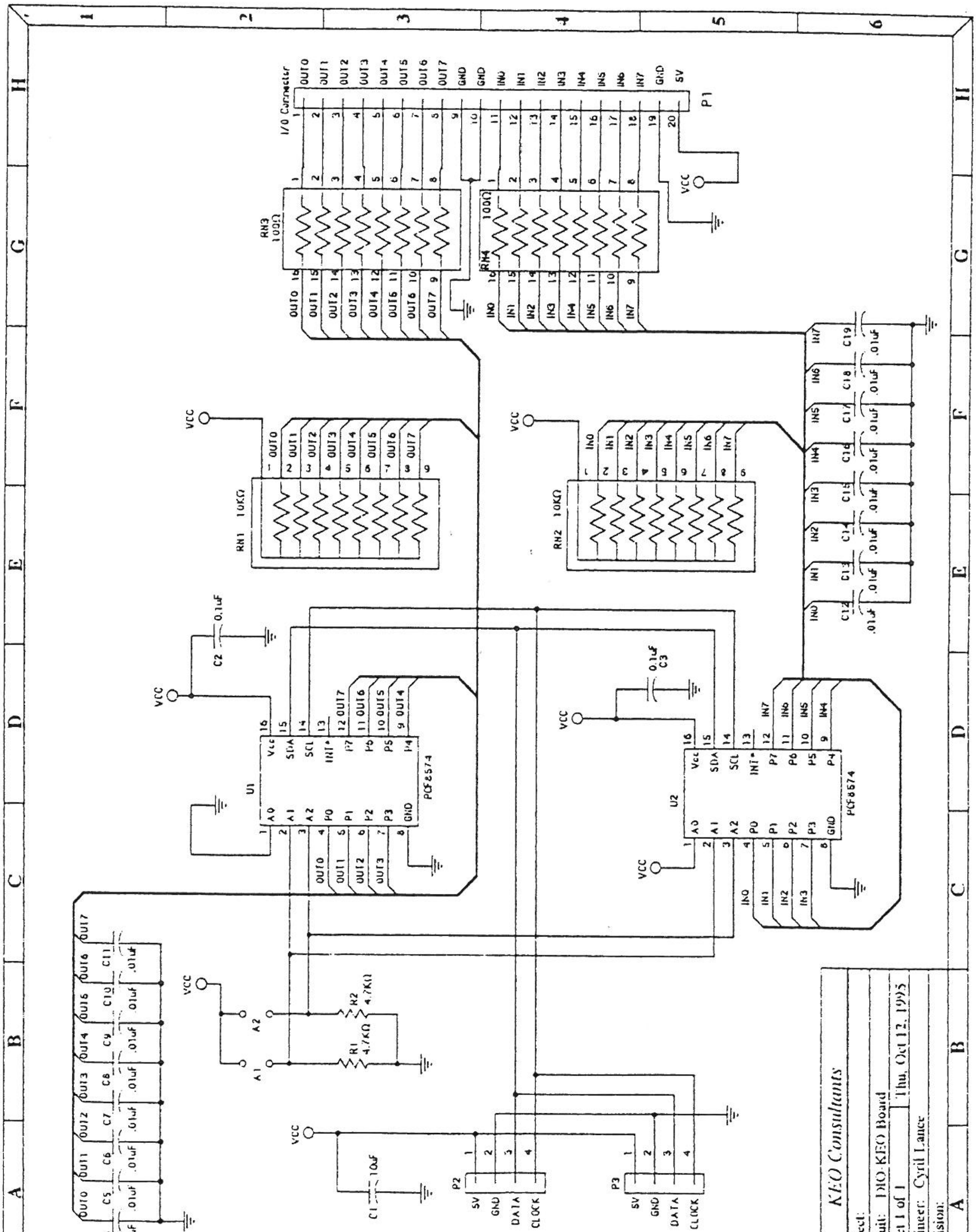
Signal Name	Pin
RTD(+)	A
RTD(-)	G
RTD(S)	H
AC(Line)	F
AC(Neutral)	B
5VDC	C
Gnd	D
Home	E

Note #1: AC(Line) and AC(Neutral) are connected to both Heater Pads in parallel. The total parallel resistance should be on the order of 150Ω.

Note #2: There is an internal pull-up resistor of 10KΩ between pins C and E for the Hall-Effect Detector.

Appendix E

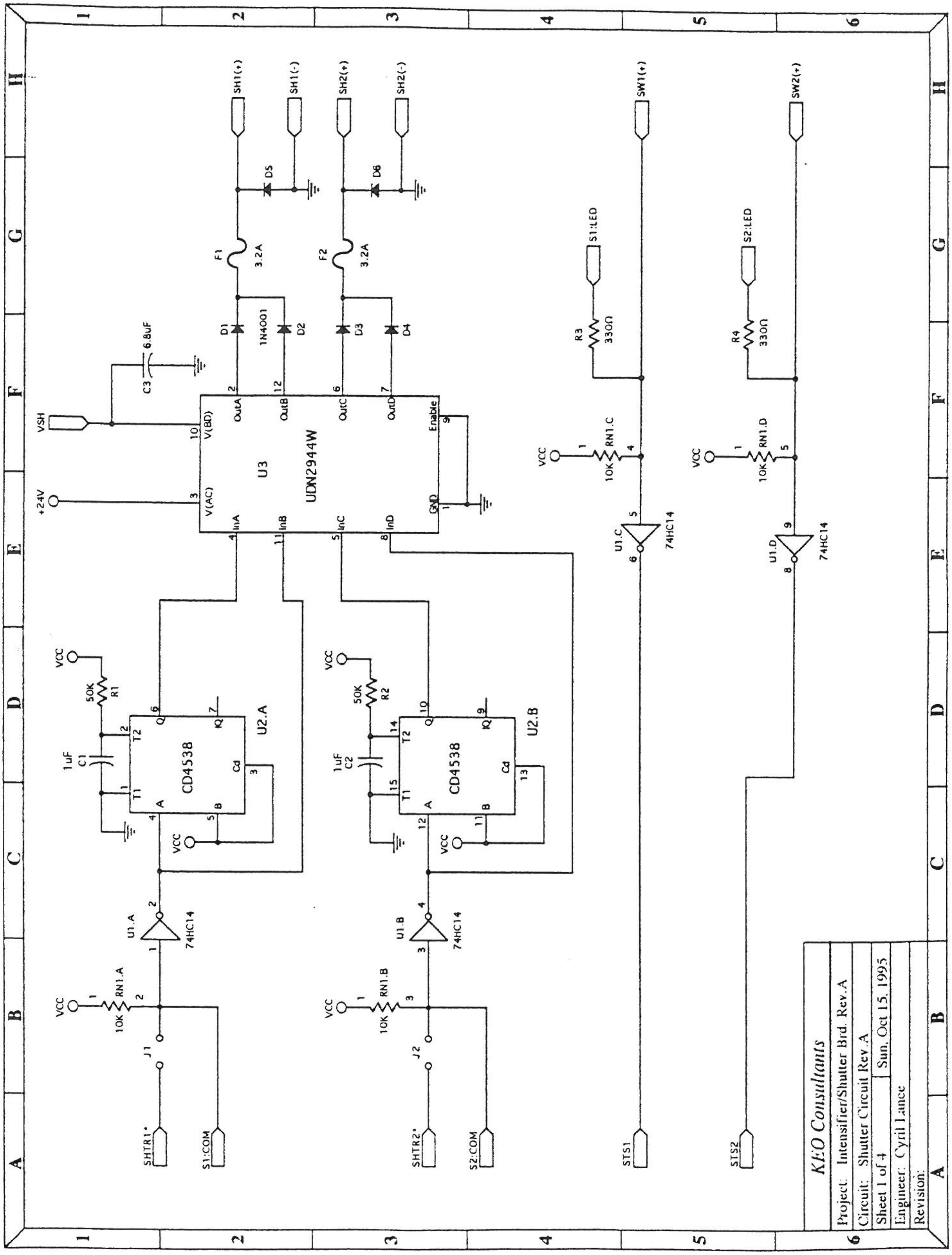
DIO-116 Parallel I/O Interface Schematic

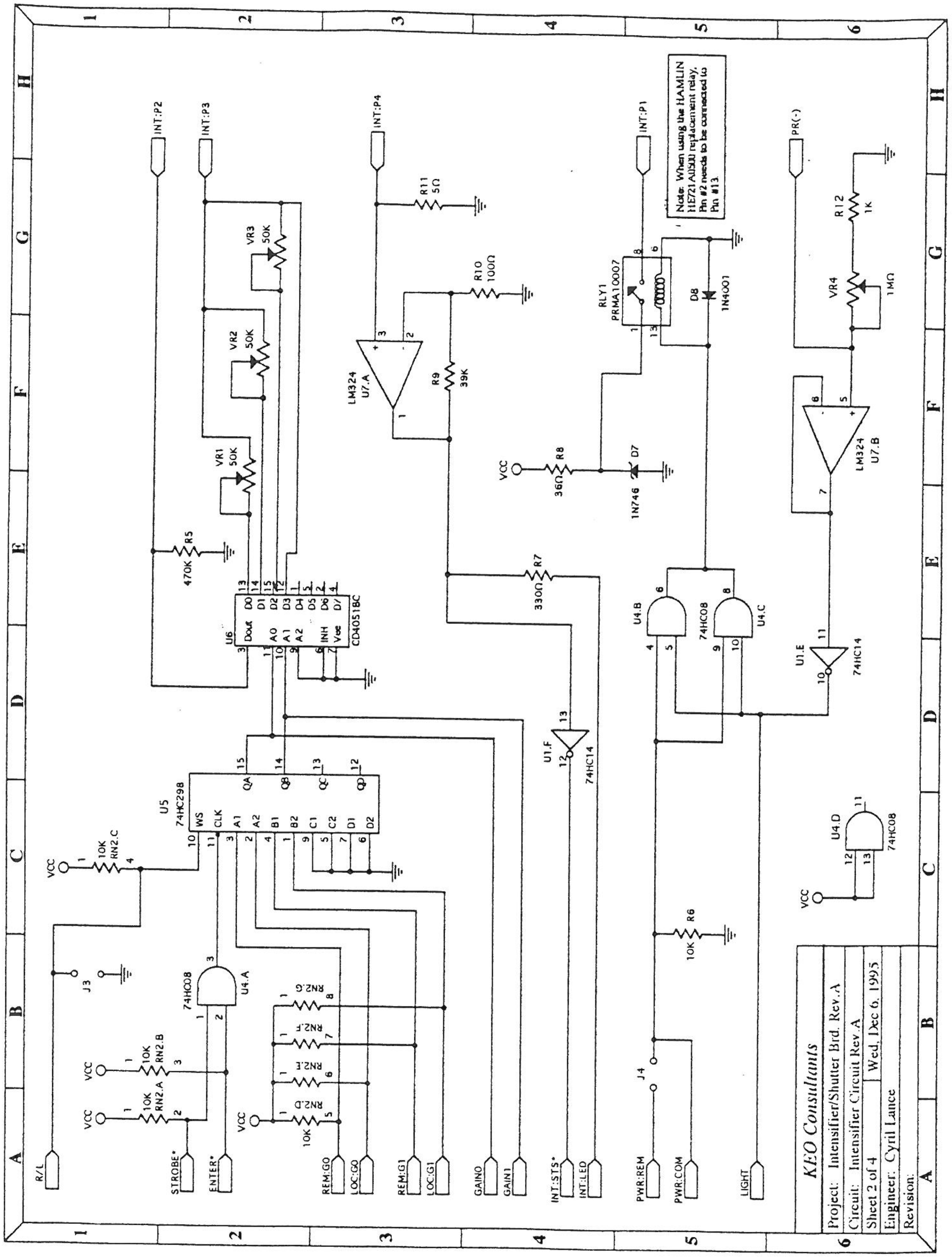


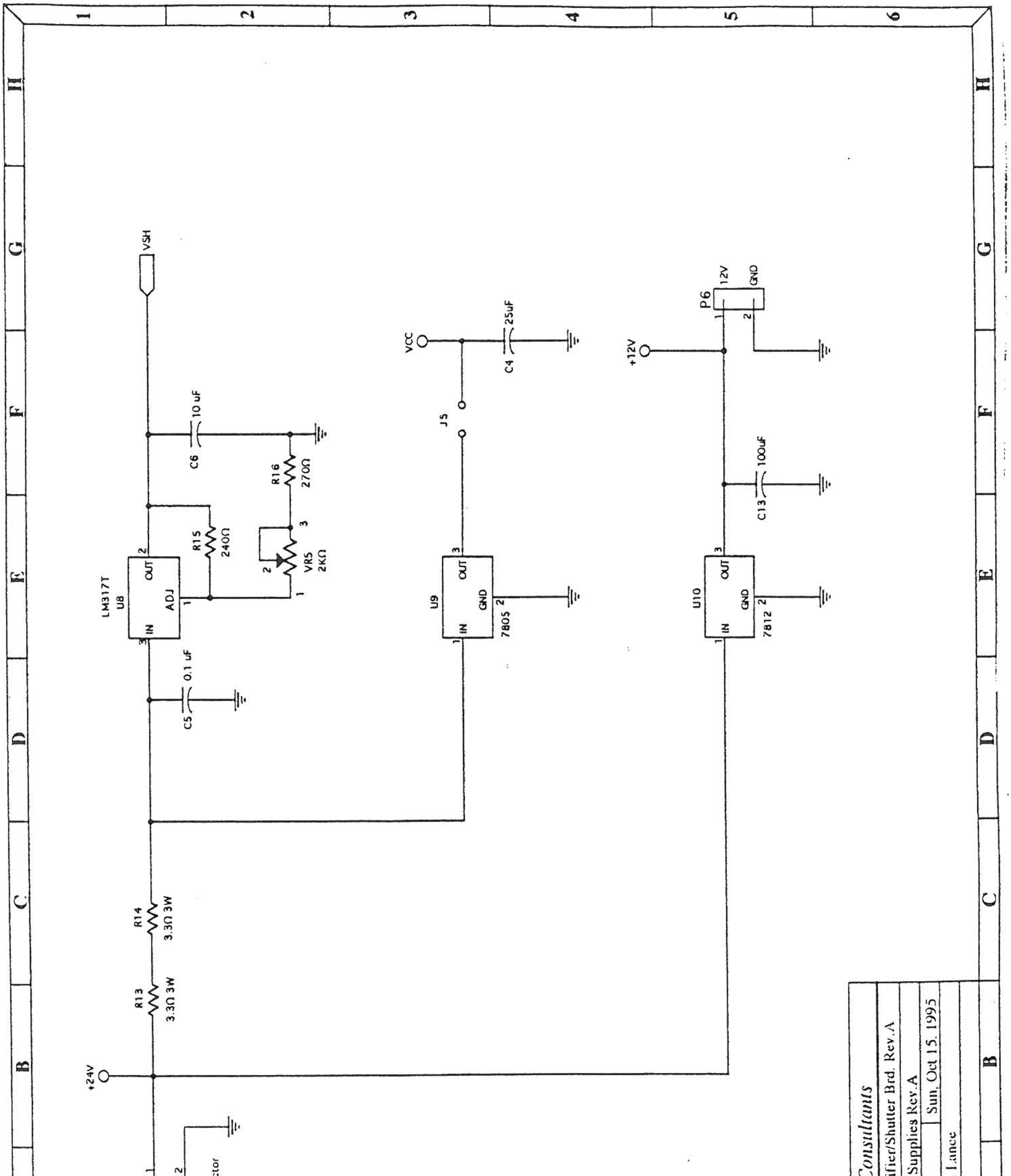
<u>Appendix F</u>

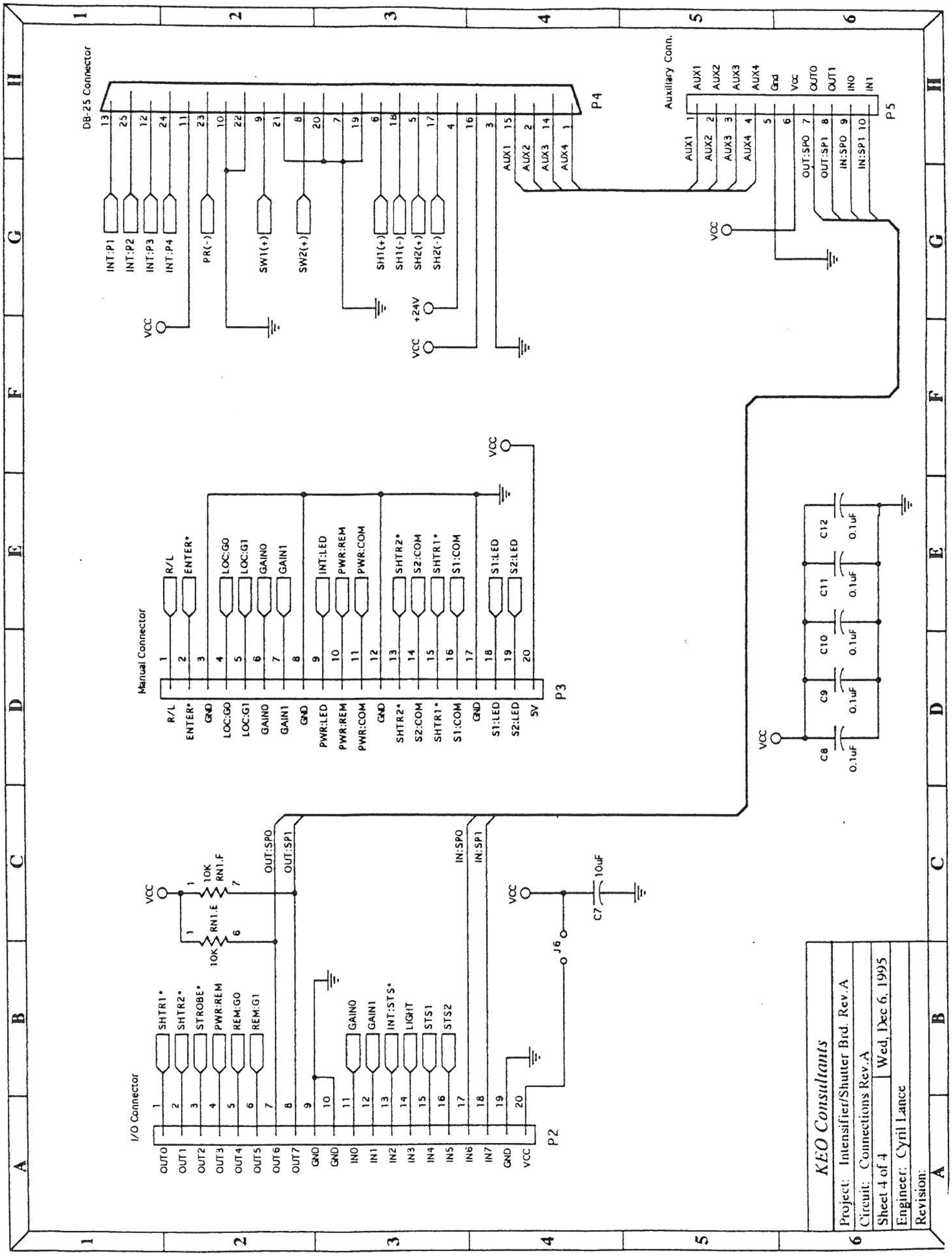
Intensifier/Shutter Control Board Schematics

Schematic #1:	Shutter Control Circuit
Schematic #2:	Intensifier/Light Detector Circuit
Schematic #3:	Power Supplies
Schematic #4:	Connector Schematic


KEO Consultants
Project: Intensifier/Shutter Brd. Rev.A
Circuit: Shutter Circuit Rev.A
Sheet 1 of 4
Sun, Oct 15, 1995
Engineer: Cyril Lance
Revision:
U3
UDN2944W
U2.A
U2.B
CD4538
74HC14
U1.A
U1.B
U1.C
U1.D
SH1(+)
SH1(-)
SH2(+)
SH2(-)
SW1(+)
SW2(+)
S1:LED
S2:LED
VSH
+24V
VCC
SHTR1*
S1:COM
SHTR2*
S2:COM
STS1
STS2
F1 3.2A
F2 3.2A
C3 6.8uF
1N4001
R3 330Ω
R4 330Ω
R1 50K
R2 50K
C1 1uF
C2 1uF
RN1.A 10K
RN1.B 10K
RN1.C 10K
RN1.D 10K
J1
J2


KEO Consultants
Project: Intensifier/Shutter Brd. Rev.A
Circuit: Intensifier Circuit Rev.A
Sheet 2 of 4
Wed, Dec 6, 1995
Engineer: Cyril Lance
Revision:
Note: When using the HAMLIN HE721A0500 replacement relay, Pin #2 needs to be connected to Pin #13.


KEO Consultants
Project: Intensifier/Shutter Brd. Rev.A
Circuit: Power Supplies Rev.A
Sheet 3 of 4
Sun, Oct 15, 1995
Engineer: Cyril Lance
Revision:
VSH
LM317T
U8
IN
OUT
ADJ
R15
240Ω
R16
270Ω
VR5
2KΩ
C6
10 uF
C5
0.1 uF
R14
3.3Ω 3W
R13
3.3Ω 3W
+24V
P1
24V
GND
Power Connector
VCC
C4
25uF
J5
U9
7805
GND
+12V
P6
12V
GND
C13
100uF
U10
7812


DB-25 Connector
P4
Auxiliary Conn.
P5
Manual Connector
P3
I/O Connector
P2
KEO Consultants
Project: Intensifier/Shutter Brd. Rev.A
Circuit: Connections Rev.A
Sheet 4 of 4
Wed, Dec 6, 1995
Engineer: Cyril Lance
Revision: