How To Build A Basic CCD Camera

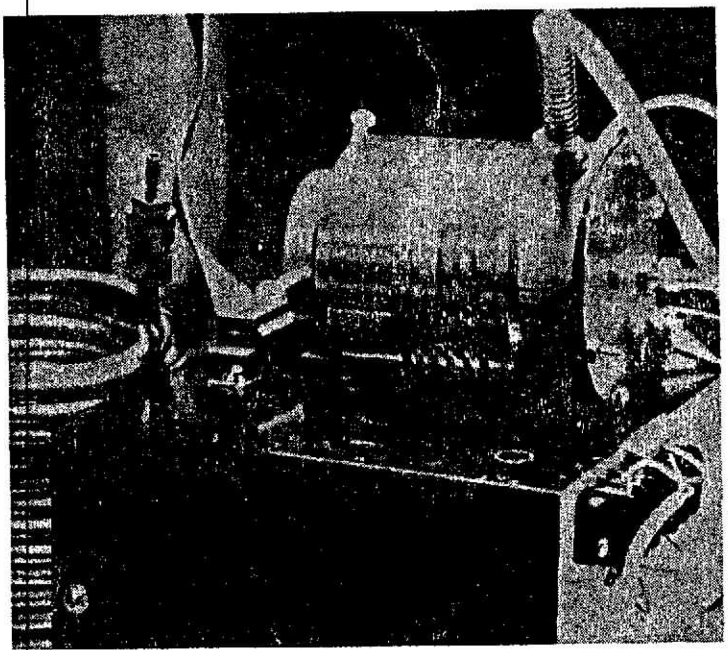
ELECTRONIC COMPONENTS 2392455.

TEXAS INSTRUMENTS AUST. (02) 878 9000

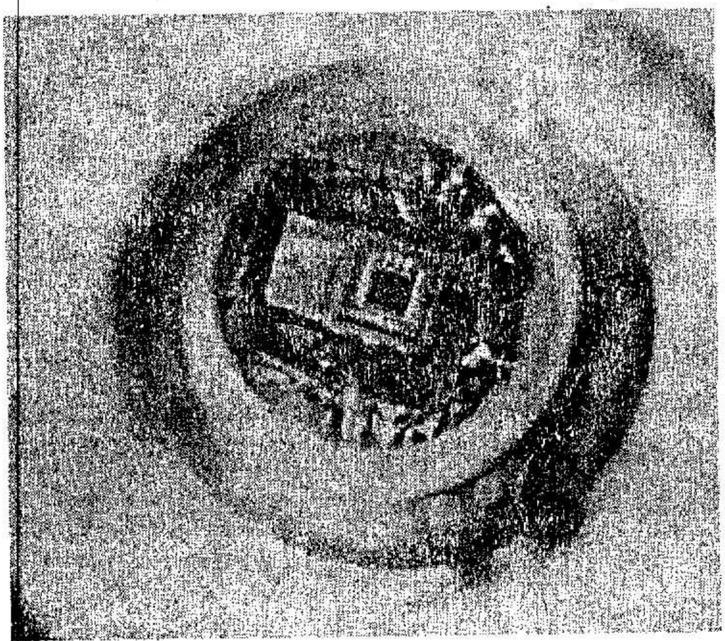
AGENTS ARE:- ADC (02) 5346200

*- TC211 ADC $46 each

85 Microns



Here is what the first version of the CCD camera looked like.



The TC-211 chip seen looking down the barrel of the camera.

The Texas Instruments TC211 area image sensor offers the amateur telescope maker an opportunity to experiment with CCD astronomy at a reasonable price. The sensors we purchased cost $35 a couple of years ago. Great references on building CCD cameras such as *CCD Astronomy* by Christian Buil and inexpensive image processing software like Richard Berry's AIP program give amateur astronomers an opportunity to construct CCD cameras and then extract the full content of the information recorded by the camera.

Construction of a CCD camera requires experience with many subjects but so does the construction of a telescope. We constructed our camera using Christian Buil's book as a reference guide (as one uses Texereau for telescopes) and the *Texas Instruments 1987 Optoelectronics and Image-Sensor Data Book* as a guide to the TC211 CCD chip. The TC211 chip differs from the Thompson chips which are described in Buil's book so we will provide some background on the TC211 operation.

The main goal of this article is to present an alternative computer interface. The need to use a dedicated digital Input/Output (I/O) card for control of the camera was an undesirable aspect of Buil's camera. However, the printer port, which is present on most PC computers (including lap-top) appeared to hold some promise of functioning for the task, and it was converted into a general camera interface. Its performance is lower, than that of a true digital I/O card but it's free.

The PC Parallel Printer Port

Our software was designed to

use LPT1 as the control port. Most systems have LPT1 located at the base port address 378 hex, but if you decide to build a system like ours, you should check their manuals for the address of their system. The printer port uses a 25 pin DB style female connector and a cable made with 25-lead ribbon. Up to fifteen feet of cable fitted with a male DB25 connector can be used to connect the camera to the computer.

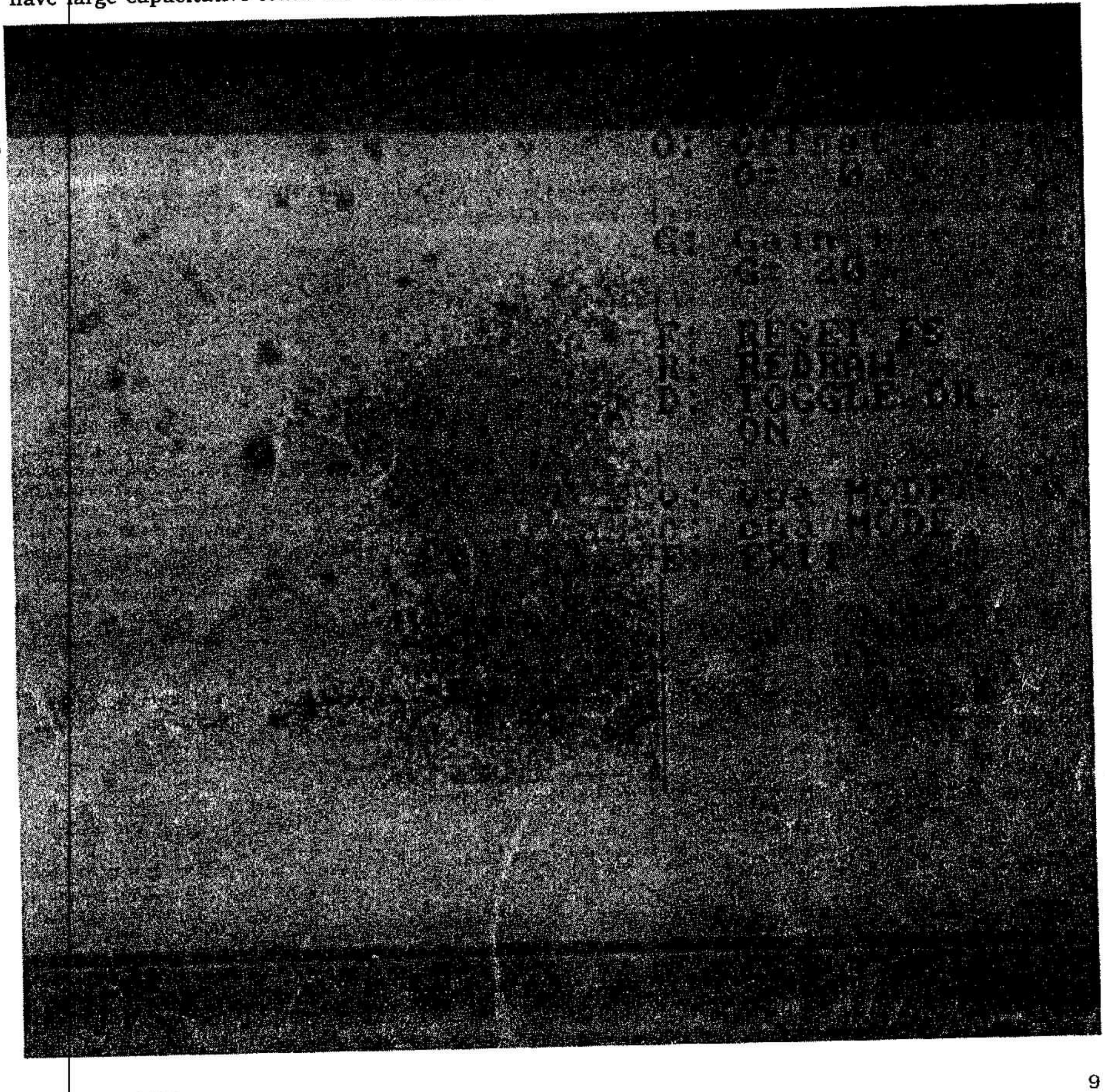
The data output latch of the printer port is used to generate the timing signals for the CCD chip. Data is written to the eight-bit data port which is at address 378 hex. Data bits zero through seven of the port are connected to pins 2 through 9. Most printer adapters have large capacitative loads on these data lines, which slow down the signals to reduce ringing and the generation of noise. The rise time of these lines must be restored with the use of Schmidt-triggered gates at the camera interface.

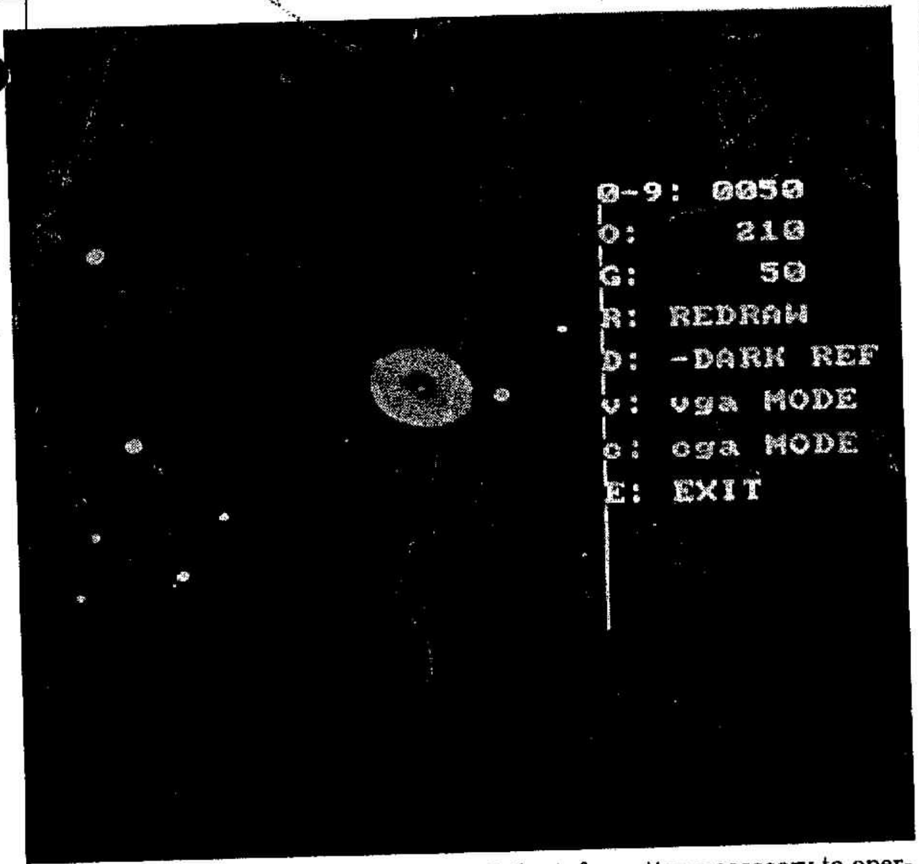
Unfortunately, the printer port does not have a complete 8-bit data-input system. The normal function of the data-input system is to determine the status of the printer. Four of these status input lines are used to read the ADC (Analog to Digital Converter) data. The status-port input address is 379 hex. Only bits seven through four are used for data. Obtaining eight-bit or twelve-bit data requires the use of a multiplexer at the camera interface. Data is restored through the use of logical *AND* which masks the lower four bits to zero. The four-bit data nybbles are then multiplied or divided to justify the nybbles before they are summed.

Computations are further complicated because bit seven is inverted. This bit is corrected with the XOR function which toggles the bit. As an alternative, the data line could be inverted by the camera hardware. On the DB25 connector, bit 7 connects to pin 10, bit 6 connects to pin 11, bit 5 connects to pin 12 and bit 4 connects to pin 13. Pins 18 through 25 on the DB25 connector are ground. The camera I/O interface and multiplexer circuitry are shown in Figure 1.

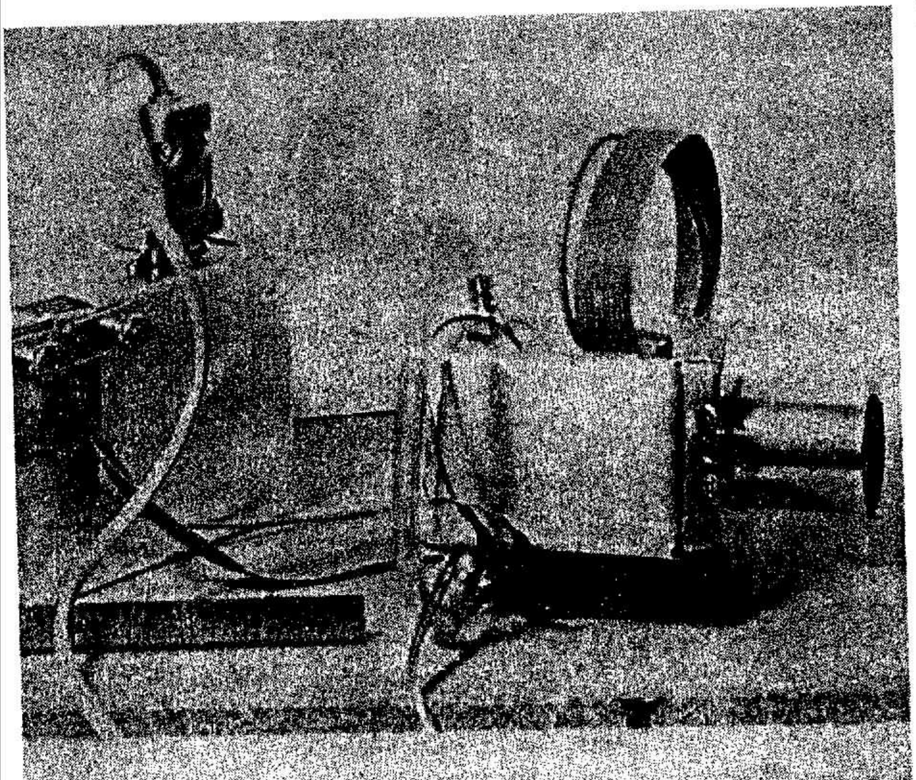
The TC211 CCD Chip

Texas Instruments uses a Virtual





The camera control software displays all the information necessary to operate the camera on the screen beside the last exposure that you have made. Both the CGA and VGA modes use 320-by-200-pixel graphics.



Here's the latest version of the camera and control electronics--a considerably tidier package than the first. Both the camera head and the control electronics fit into standart project boxes.

Phase process which simplifies the timing for the CCD. In our camera, only two clock signals are required to shift out the image data. We do not use the anti-blooming gate function.

The chip is organized as a 192 pixel by 165 line device. To obtain one image line from the chip, the IAG (Image Area Gate) input goes from a low state to a high state, the Serial Register Gate (SRG) input goes from a low state to a high state, the IAG input is set back to a low state and finally the SRG input is set back to a low state. Next, the line is read out with only SRG clocks. Pixels are shifted out by raising the SRG input to a high state then back to a low state.

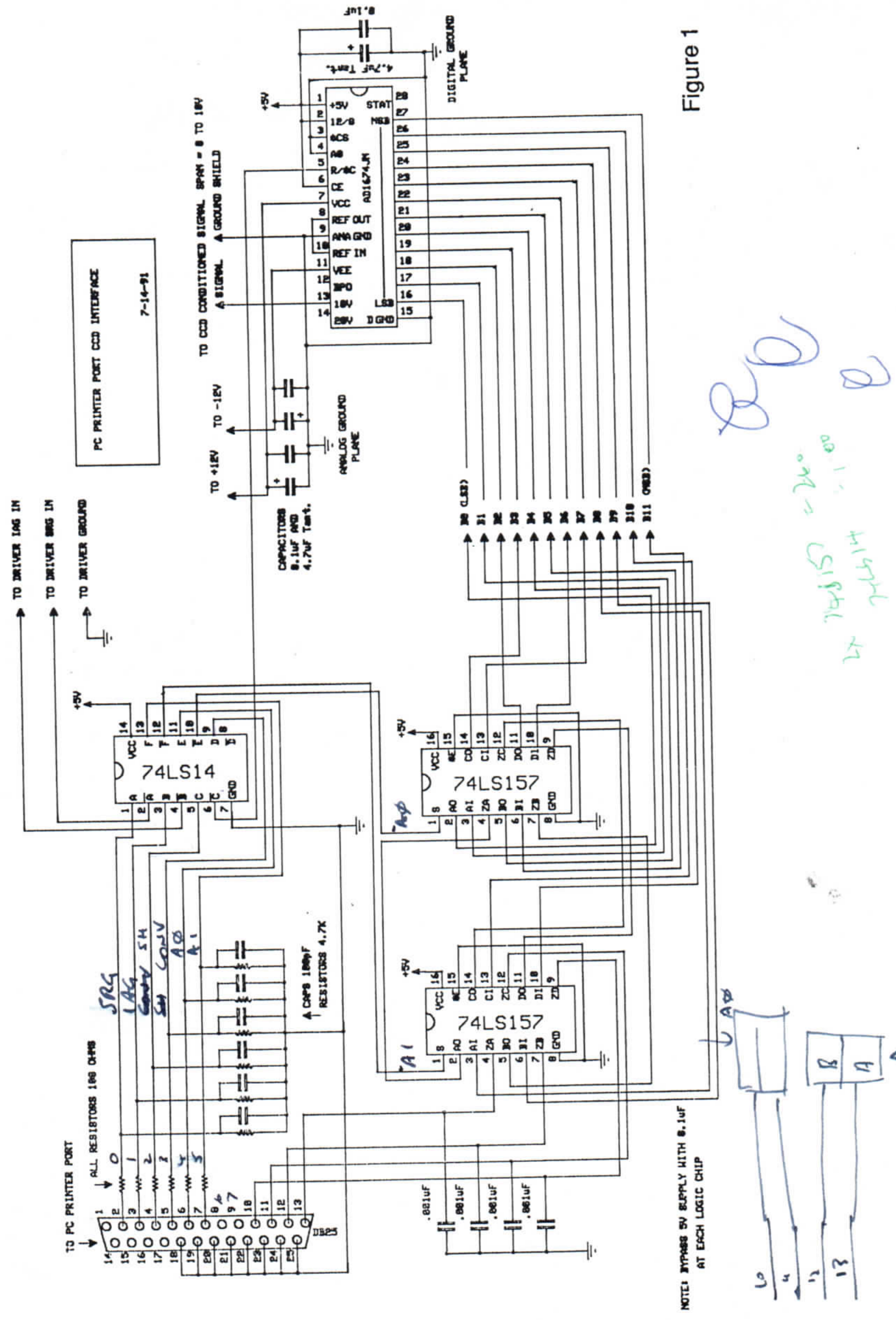
When the SRG input is in the high state, the output is in the reset state. It is not possible to obtain the reference level as with the CCDs described in Buil's book because the reset is internally connected to the SRG input. When the SRG input returns to the low state, the output holds the value of the shifted pixel.

Prior to obtaining an exposure, the image area is cleared with 165 line shifts. An exposure is made by leaving the IAG clock low and toggling the SRG line from low to high. The chip does not have an image storage area and light will continue to strike the image while it is read out. This poses no problems for faint objects, but sub-second exposures require an external shutter.

When the exposure is completed, the image is read by 165 line shifts. Each line shift is followed by a serial readout. The serial register contains six dummy pixels which must be shifted out before the first pixel can be obtained. The 192 image pixels are then shifted out, converted to a digital format and stored. Another 12 pixels are present in the serial register after the image has been read out. These are dark reference pixels which are covered by a mask. Texas Instruments also sells a version of this chip without the mask and it contains 204 pixels by 165 lines.

Converting the Image to Digital

A twelve-bit Analog-to-Digital Con-verter (ADC) with an internal sample-and-hold amplifier converts the signal to one of 4096 levels. The output signal has a maximum peak-to-peak range of close to one volt. The specification indicates the saturation level is typically 600mV. The converter requires a signal which varies from zero to 10.0 volts.



PC PRINTER PORT CCD INTERFACE
7-14-91
TO CCD CONDITIONED SIGNAL SPAN = 0 TO 10V
SIGNAL
GROUND SHIELD
DIGITAL GROUND PLANE
ANALOG GROUND PLANE
0.1uF
4.7uF Tant.
AD1674JN
+5V
TO +12V
TO -12V
CAPACITORS 0.1uF AND 4.7uF Tant.
D0 (LSB)
D11 (MSB)
TO DRIVER IAG IN
TO DRIVER SRG IN
TO DRIVER GROUND
74LS14
74LS157
74LS157
CAPS 100pF
RESISTORS 4.7K
ALL RESISTORS 100 OHMS
TO PC PRINTER PORT
DB25
.001uF
NOTE: BYPASS 5V SUPPLY WITH 0.1uF AT EACH LOGIC CHIP

Figure 1

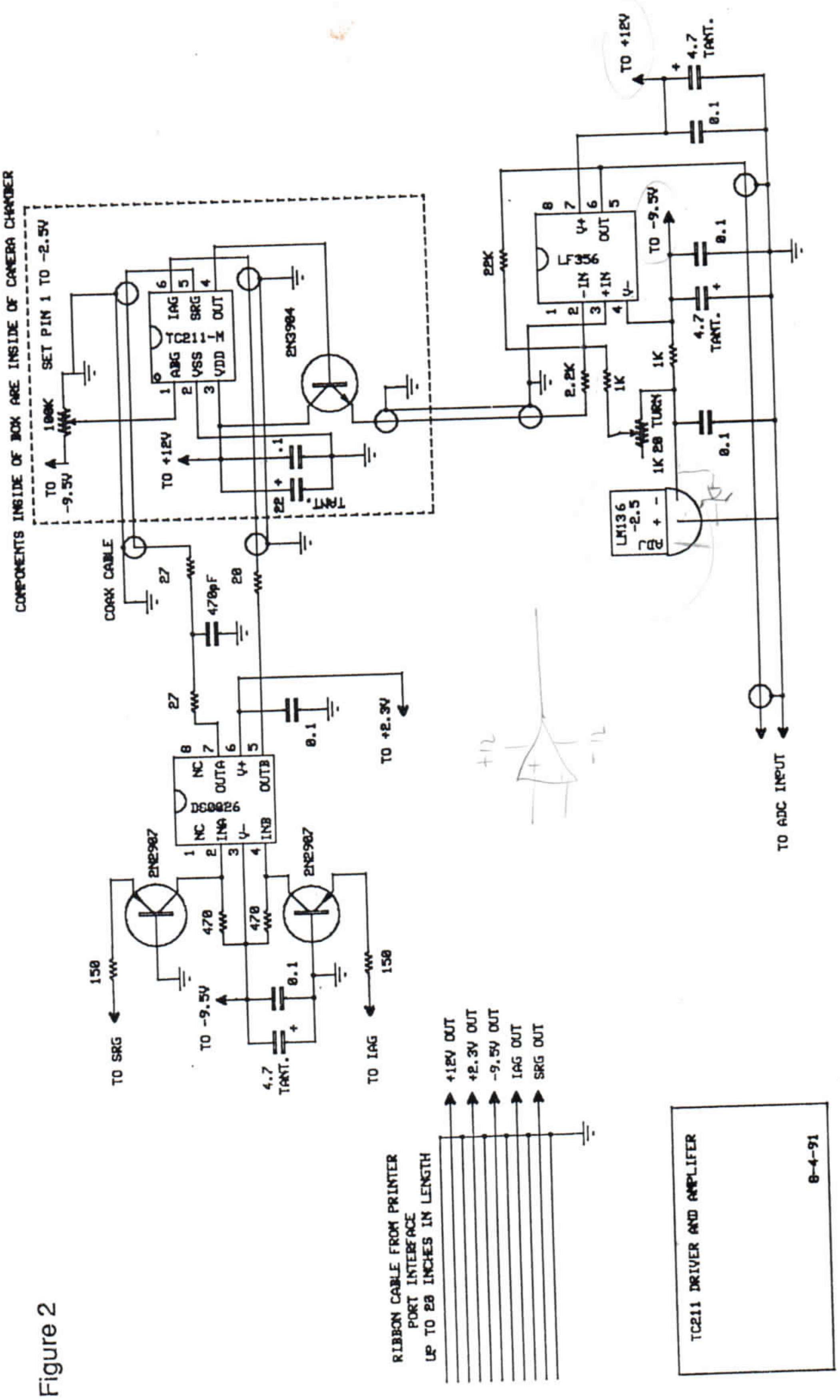
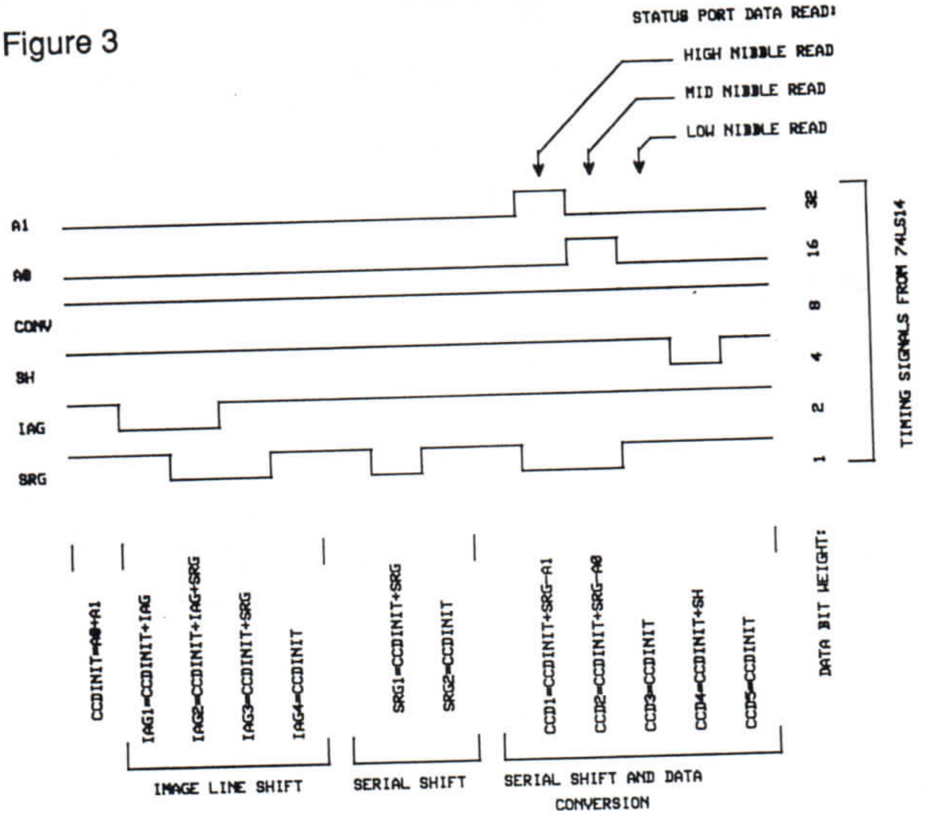

COMPONENTS INSIDE OF BOX ARE INSIDE OF CAMERA CHAMBER
SET PIN 1 TO -2.5V
TC211-M
2N3904
TO +12V
TO -9.5V
COAX CABLE
470pF
TO +2.3V
DS0026
2N2907
TO SRG
TO IAG
4.7 TANT.
LF356
22K
2.2K
1K
1K 20 TURN
LM136 -2.5
TO ADC INPUT
RIBBON CABLE FROM PRINTER PORT INTERFACE UP TO 20 INCHES IN LENGTH
+12V OUT
+2.3V OUT
-9.5V OUT
IAG OUT
SRG OUT
TC211 DRIVER AND AMPLIFER
8-4-91

Figure 2

Figure 3



PARALLEL PORT TIMING FOR TC211 CCD

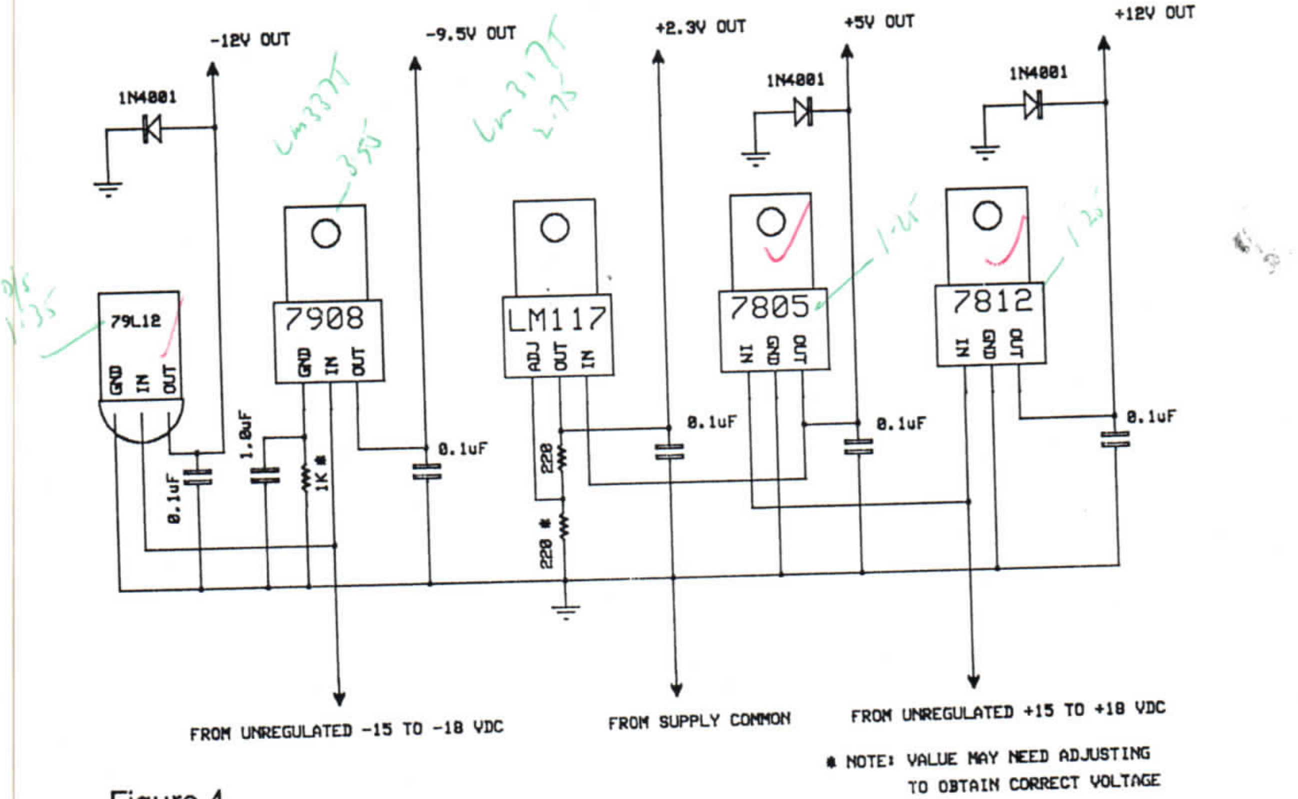
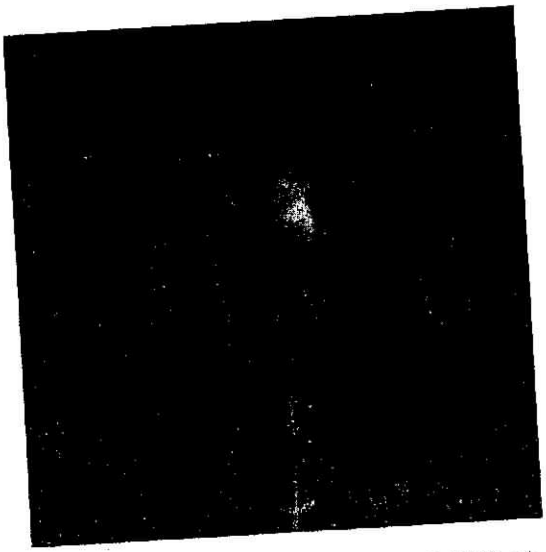


Figure 4

This image of M27 is a 2-minute exposure with a 6-inch f/5 Newtonian reflector. Because the TC-211 is so small, M27 fills an appreciable fraction of the field even with a short-focus telescope.



Here is the planetary nebula NGC 6543 at the focus of a 10-inch Meade SCT. The raw image has been rescaled with a power-law of 0.4 and sharpened with a 3x3 unsharp mask, and then zoomed to double size.

An amplifier with a gain of -10.0 was used to scale the output voltage. To allow and correct for the DC offset drift of the system, the reset level for the amplified signal should be set about 100mV above zero. The reset level can be converted and used for a reference point. Otherwise, set the zero integration time dark readout level just above zero. The amplified dark level is about 1.5 volts above the reset level. The CCD circuitry is shown in Figure 2.

The AD1674 converter is connected for stand-alone mode operation. Conversion is started after the data output (SRG goes low) is allowed to slew to the new level and settle (about five microseconds). Conversion is initiated by a high to low transition on the R/C input to the converter. The data outputs are only present after the conversion is completed (10 microseconds minimum) and if R/C is in the high state. Data is read after the SRG input is set to the high reset state and the conversion is completed. The data is read in three nybbles which are accessed through a two-bit address control of the multiplexer circuits. The address is sent out the printer port and the data nybble is obtained by a subsequent input of the status port.

Programming the control interface is simplified if constant terms are used. We assigned the control pins bit-location weights shown below:

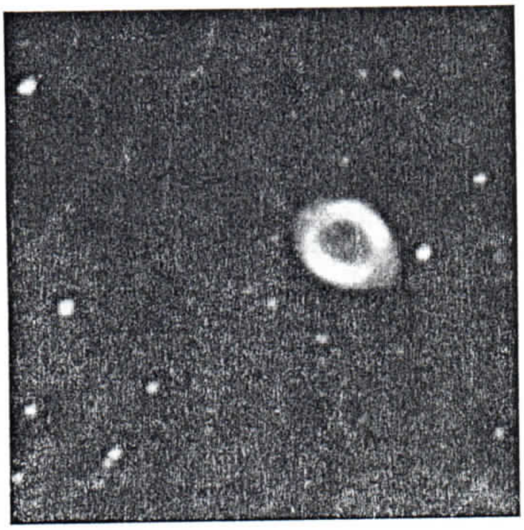
SRG = ~~1~~ 32
IAG = ~~2~~ 16
SH = 4 (sample/hold and convert)
CONV = 8
A0 = ~~16~~ 1
A1 = ~~32~~ 2

(We did not use CONV. COVN and SH can be used on systems with separate sample/hold and ADC modules.)

The data lines from the printer port are inverted by the interface. The correct timing polarity is obtained by adding a constant to set a low logic level and subtracting the constant to obtain a high logic level. The SRG and IAG lines are inverted by the drivers and positive level logic is used on these lines.

The control lines are all set to an initial state called CCDINIT=A0+A1. To pulse the SRG input to the CCD chip high then low, the sequence CCDINIT+SRG; CCDINIT would be sent to the printer port. The SH logic input to the converter is normally in the high state.

A prime-focus image of Saturn through the 10-inch f/10 Meade stopped down to 4 inches aperture. This image was shuttered with a special software routine that uses the chip in a half-frame mode.



This image of the Ring Nebula with the 6-inch f/5 telescope is among the first we took. To prepare it for printing, the image was exponentially scaling to show detail in both the bright and dark parts of the image.

To pulse the SH line low, the sequence CCDINIT+SH; CCDINIT would be sent to the port. The address control inputs to the multiplexer are normally in the low state due to the inverted logic.

To set the address line A0 high the value CCDINIT-A0 is sent to the port. A general timing sequence for the three basic operations: line shift, serial shift, and serial data conversion, are shown in Figure 3.

A simple program that uses MicroSoft QuickBASIC 4.5 to drive the interface is available from the authors. It uses an integral machine code driver for slower machines but includes a driver written in QB for reference. If you request the program, please send a 5.25-inch formatted diskette and a stamped, self-addressed diskette mailer.

Miscellaneous

The interface and CCD circuitry require little power. Well-filtered ±15VDC at 150mA is needed. The regulated voltages are obtained with the circuitry shown in Figure 4. The cooling system requires most of the power. Our system uses a Cambion model 801-2003-01-00-00 Peltier cooler which is operated at 3 amps and 5 volts. The back of the camera is an integral water jacket which is pumped by an electric fuel pump. A separate 12-volt 1-amp supply is used for the pump. The TC211 is specified for operation at -10C minimum, but we operate it down to the specified minimum storage temperature of -30C.

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References:

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