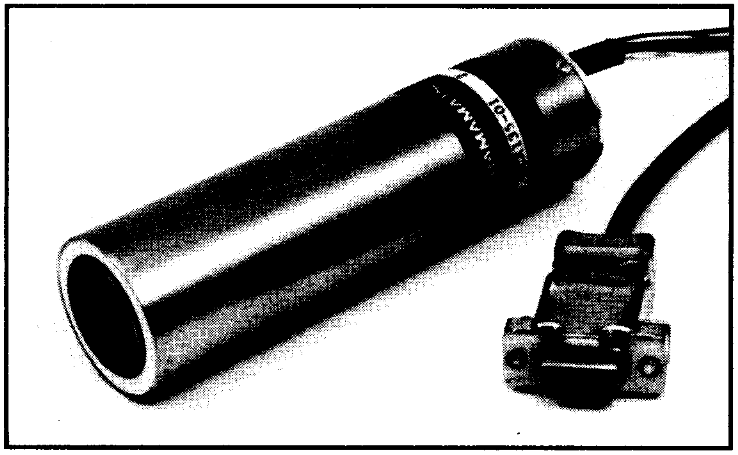
DEVELOPMENTAL

PMT Sensor Module with Embedded Microcontroller and RS-232-C Interface

PART NUMBER:

- **HC135-01**
  UV to Visible
- **HC135-02**
  UV to Near IR

After acquiring the light signal, photon by photon, the HC135 Series reports the result directly to a host computer.



The HC135 Series of low light level detectors combines the sensitivity of a photomultiplier tube with the intelligence of a micro-controller to provide a detector module of exceptional sensitivity, accuracy and flexibility. And since the detector interfaces directly to a personal computer, operating the detector is very simple.

The detector module acquires the signal by counting the photons as they enter the input window. This method is the most sensitive technique for light measurement. And since the HC135 integrates all of the necessary components for photon counting, the details of the technique do not have to be mastered by the user to enjoy the benefits. In fact, the detector is shipped with all adjustments pre-set by a rigorous calibration procedure. Two versions are available which differ in spectral response. The HC135-01 covers UV to 650 nm with very low background noise. The HC135-02 is suited for applications requiring measurement beyond 650 nm and into the near infra-red (850 nm). Both versions provide a large, 21 mm diameter active area for good light gathering ability.

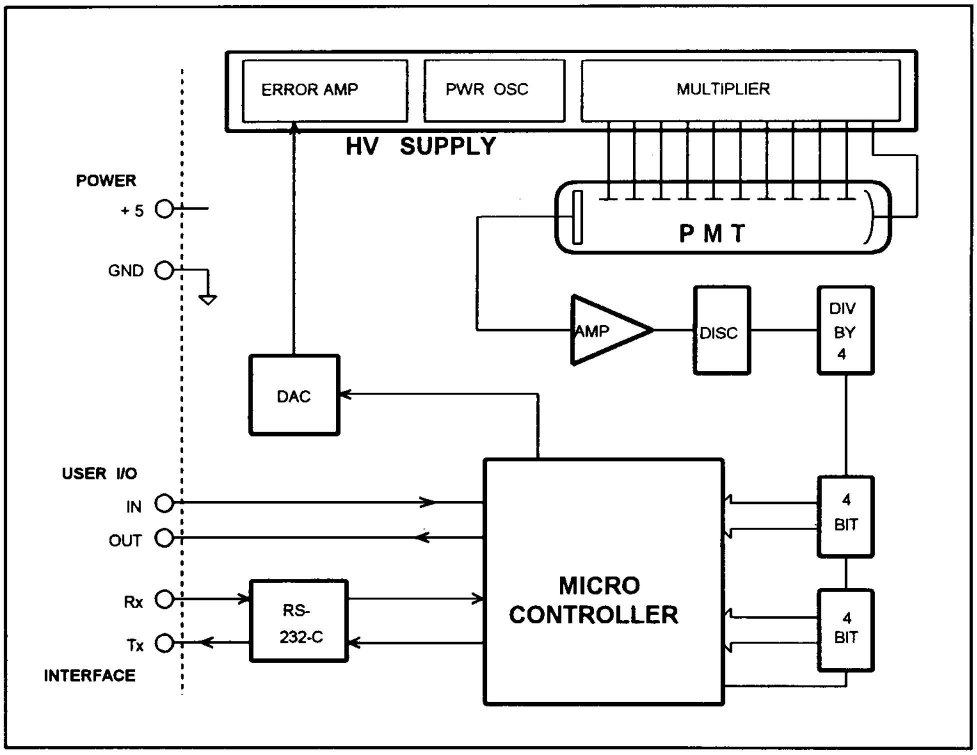
Included with the HC135 are the following resources:

1) A manual that describes the theory of operation, command sequences, programming tips, signal-to-noise calculations, and more.
2) Basic Language programs for IBM PC's and compatibles, on both 3.5" and 5.25 " diskettes, to allow immediate use of the detector.

FEATURES:

- Photon Counting for excellent sensitivity and accuracy.
- Fully self-contained operation.
- Light measurement sent to personal computer through serial port.
- Pre-set adjustments.

BLOCK DIAGRAM



APPLICATION CHECK LIST

1) HOST COMPUTER: An IBM PC or compatible is expected, but any computer that has an RS-232-C serial port that can be programmed to send commands and receive and interpret the returning data can be used. The serial port must be set to the following communications specifications:

9600 baud, no parity, 8 data bits, 1 stop

2) PROGRAMMING: This detector is supplied with a Basic Language program for IBM PC's or compatibles to exercise the unit and show capability. But, the user is expected to have sufficient experience with programming languages to write their own application.

3) LIGHT RANGE: Since the A/D conversion is done with photon counting, the high voltage is fixed during calibration. Therefore, the light range is fixed in terms of the number of detected photons per second per picoWatt at a given wavelength. Above 30 million counts per second, the circuitry saturates. Use the data from Figure 4 in this sheet to find if the light level you have at your wavelength, will require attenuation or is too high for this device.

CAUTION !!!

1) SUPPLY VOLTAGE: **Do not** exceed the maximum supply voltage of 6 volts. **Do not** reverse the supply potentials: Yellow goes to +5 and Black goes to ground. In either case, a mistake will blow a fuse. The unit will then require return of the unit for repair at Hamamatsu.

2) OVER EXPOSURE: This is a **sensitive** light detector that can be damaged by exposure to even subdued light. **Whenever the +5 power is on, the lights must be off!** When not in use, store with the protective cap in place or in darkness.

SPECIFICATIONS

MAXIMUM[1] RATINGS

	HC135-01	HC135-02	UNITS
Supply voltage[2]	+6.0		volts
Operating temperature	+5 to +50		°C
Storage temperature	-20 to +50		°C

GENERAL SPECIFICATIONS

	HC135-01	HC135-02	UNITS
Supply voltage	+4.75 to +5.25		volts
Spectral range	300 to 650	300 to 850	nm
Peak Wavelength	400	400	nm
Active area (diameter)	21		mm
Serial Interface[3]	RS-232-C		
Warm-up time	180		sec
Current consumption[4]	35		mA
Pre-scale factor[5]	4		
Size (less projections)	4.75 by ϕ1.375		inch
Weight (approximate, head only)	180		grams

TYPICAL PERFORMANCE SPECIFICATIONS

At peak wavelength, 25 °C

	HC135-01	HC135-02	UNITS
Responsivity	440,000	270,000	CPS/pW
Counting efficiency[6]	22	14	%
Equivalent Noise Input[7]	3X10E-17	5X10E-16	watts
Stability Baseline Responsivity	 11 +/- 0.1	 13 +/- 0.1	 %/°C %/°C
Dynamic range	2X10E6	2X10E5	
Linearity (0 to 2X10E7 CPS)	+/- 1		%

NOTES

1) Stresses above the "Maximum Ratings" may cause permanent damage to the device. Exposure to maximum conditions for extended periods may reduce device reliability.
2) The detector assembly is protected against overvoltage and reverse voltage by a fuse. If the fuse is blown, the unit must be returned to the factory for replacement.
3) The serial interface requires the following communication specifications:
   9600 baud, No parity, 8 data bits, 1 stop bit
   Alternate specs are not supported. No handshaking lines are monitored; CTS, DSR, DCD, and DTR are connected together. Connection to the host computer is via a 9 pin, female, D-subminiature connector.
4) If strong light is received by the input window while high voltage is applied, the current consumption increases. The detector assembly is protected against sudden failure by current limit circuits in the high voltage supply. However, exposure to strong light for more than 10 seconds can degrade performance of the tube. The equivalent noise input will increase and the cathode response may deteriorate, especially in the near infra-red wavelengths.
5) Restored to full count by microcontroller before being reported to host.
6) The ratio of measured counts to actual photon flux. The effects of photocathode quantum efficiency, electron-optic collection efficiency, dynode gain, and loss in the discrimination process are all included.
7) Measured with 1 second integration time at the peak wavelength.

Fig. 1
COUNTING EFFICIENCY

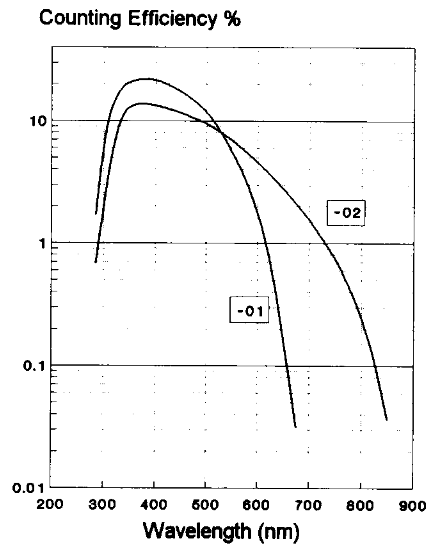


Fig. 2
SPECTRAL SENSITIVITY

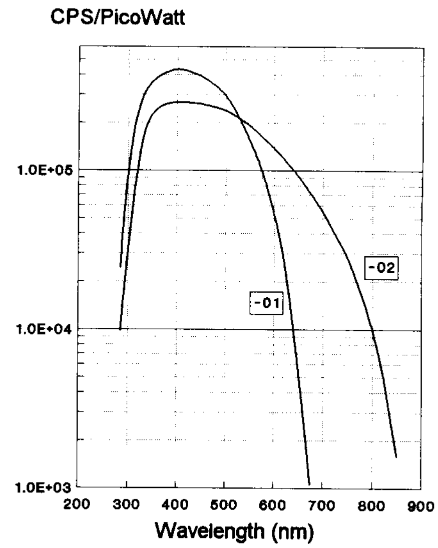


Fig. 3
EQUIVALENT NOISE INDEX

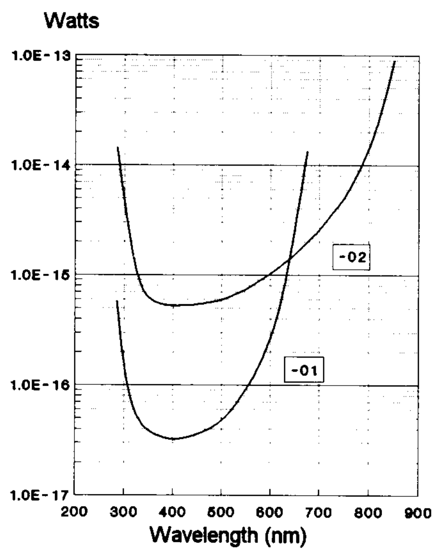


Fig. 4
MAXIMUM INPUT LIGHT

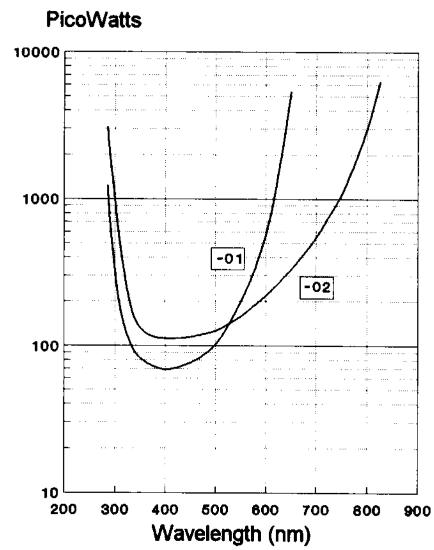


Fig. 5
LINEAR RANGE

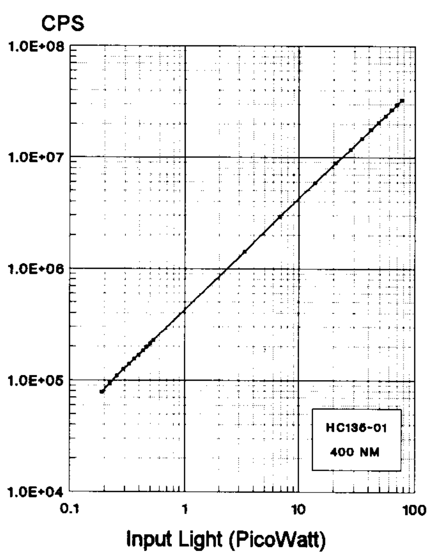
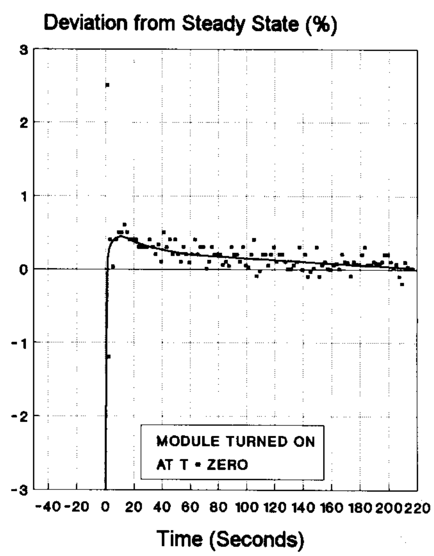


Fig. 6
STABILITY FROM TURN ON



THEORY OF OPERATION

The light signal from a photomultiplier tube takes the form of very high speed current pulses. In the HC135, these pulses are amplified and converted to digital pulses with a high speed amplifier and discriminator. Then, counting these pulses results in a very accurate A to D conversion.

As shown in the block diagram on page 2, the pulses are pre-scaled by a factor of four before counting. This aids in extending the dynamic range without using excessive power. After pre-scaling, the counting is performed by two 4-bit CMOS IC's and eight bits of counting internal to the microcontroller.

Precise counting intervals of ten milliseconds are provided by the crystal-controlled counter/timer circuitry in the microcontroller. Since the total count can be recorded and reset every ten milliseconds, the maximum rate of photon detection is 65,536 times 100 times the pre-scale factor, or approximately 26 million photo-electrons per second.

The block diagram also shows the use of the Cockcroft-Walton high voltage supply. This is used to limit current consumption and prevent unwanted temperature rise of the assembly. The supply is set by a D/A converter, allowing computer control of the setting.

To produce a design of this sort, two calibrations must be done accurately: the selection of the *high voltage operating point* and the value of the *dead time*. Both of these calibrations are performed at the factory.

The determination of the high voltage is done by reading the count rate as the high voltage is varied over it's useful range. As the voltage is increased, the count rate reaches a nearly constant value, called the plateau. This voltage is noted and programmed into the microcontroller for use during measurements.

The concept of dead time is based on the probability of two light photons to be detected simultaneously and counted as one. This probability increases with higher light levels and is alleviated by use of high speed photomultipliers and circuits. The degree of overlap in the HC135 is small and the resulting error in linearity is corrected through use of a simple theory which is based on the dead time of the detector. The dead time is measured during production and programmed into the microcontroller. The measured count for each ten millisecond interval is corrected before reporting to the host.

OPERATING CHARACTERISTICS

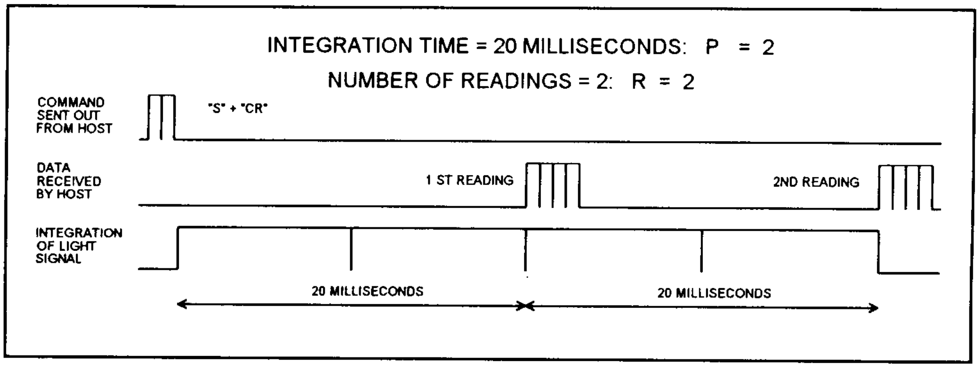
When the HC135 is started up by applying +5 volts, default values are set for basic operation. The number of ten millisecond intervals to be summed is set to 100, meaning that the integration time is one second. The number of readings to be taken for each request is one. So, the only necessary commands to issue are: 1) set the high voltage ON to the pre-programmed value by sending "D" + "CR", and 2) request a reading by sending "S" + "CR". The result will be returned as four bytes, one second later.

As the command summary shows, commands can be issued to decrease the integration time in ten millisecond steps or cause a sequence of readings to be taken for each "S" issued. The timing diagram indicates the general way in which the host activity occurs. The delay after receipt of the "CR" before counting begins is about 150 microseconds.

Once the command is issued to take a reading, the host must be ready to receive the data as it is sent. The HC135 does not buffer the readings. Once the readings are collected, the data usually needs conversion to printable ASCII decimal digits. That is, each byte sent by the HC135 is a portion of a 32 bit value in binary format.

Several software features have been incorporated to enhance reliability. First, each command and each argument issued by the host is

TIMING EXAMPLE



tested for validity. A two byte code is returned that should be tested by the user's program for best reliability. If the light level is too high for the counters, an overflow condition occurs and the data is in error. This condition is flagged by setting the most significant bit of the most significant byte to one. And finally, the design incorporates a watchdog timer to exclude the possibility of loss of program control.

SIGNAL-TO-NOISE PERFORMANCE

Since the HC135 uses photon counting, the noise analysis can be based on Poisson statistics, where the S/N ratio is the square root of the signal count. If the light signal applied to the detector has light power **P(λ)** at wavelength λ, the detector will provide a signal count of:

$$N_{sig} = \frac{CE(\lambda)\ P(\lambda)\ \lambda}{100\ h\ c} \quad (cps)$$

CE(λ) = counting efficiency (%)
h = 6.62X10E-34 (Js)
c = 2.998X10E8 (m/s)

The counting efficiency depends on the ability of the photocathode of the photomultiplier tube to convert the light to a photo-electron (known as the quantum efficiency), the collection efficiency of the electron optics, the noise figure of the dynodes, and the loss in the discrimination process. Most of the loss is due to quantum efficiency, especially at longer wavelengths. Figure 1 shows the variation of the counting efficiency with wavelength.

If the detector generates a dark signal of N_{dark} counts per second, and if the measuring time is **T** seconds, the signal to noise ratio can be calculated as:

$$S/N = \sqrt{\frac{N_{sig}^2\ T}{N_{sig} + 2\ N_{dark}}}$$

If the above equation is set equal to one, we can solve for the light level needed to give an S/N ratio just equal to the noise. This light level is known as the Equivalent Noise Index and is graphed in Figure 3.

For light levels where the signal counts are at least several times the dark count value, the S/N ratio reduces to:

$$S/N = \sqrt{N_{sig}\ T}$$

For the HC135-01, the typical dark count is 100 per second; for the HC135-02, it is 10,000 per second.

This analysis shows the importance of good counting efficiency at the wavelength of interest and of low dark count. Longer measuring time enhances the S/N ratio. And, additional improvement can be obtained from keeping the detector near room temperature, since the dark count increases sharply with higher temperature.

COMMAND SUMMARY

ACTION	COMMAND	ARGUMENT	RESPONSE
Set the numbei of 10 msec intervals to sum. Same as integration time for 1 reading.	P # C_R	# is between 1 and 100	VA, BC, BA
Set a sequence of readings, where each reading uses the integration time set with the P command.	R # C_R	# is between 1 and 255	VA, BC, BA
Change the high voltage applied to the tube.	V # C_R	# is between 0 and 1200. Two bytes are to be sent.	VA, BC, BA
Set the output of the user digital output line.	O # C_R	# is 0 or 1	VA, BC, BA
Start the reading sequence.	S C_R	none	4 bytes of data per reading
Re-set the default high voltage to the tube	D C_R	none	VA, BC

EXAMPLES

To set the integration time to 330 milliseconds, 33 10 millisecond intervals must be summed by the microcontroller. The command is:

P 33 C_R, or 50 21 0D in hexadecimal

To set a sequence of 10 readings, the command is:

R 10 C_R, or 52 0A 0D in hexadecimal

To turn off the high voltage, the command is:

V 00 C_R, or 56 00 00 0D in hexadecimal

To return the high voltage to the proper operating value (the value pre-programmed during production of the unit), send:

D C_R, or 44 0D in hexadecimal

NOTES

A command with an argument is tested by the microcontroller. An acknowledgement is returned having two bytes:

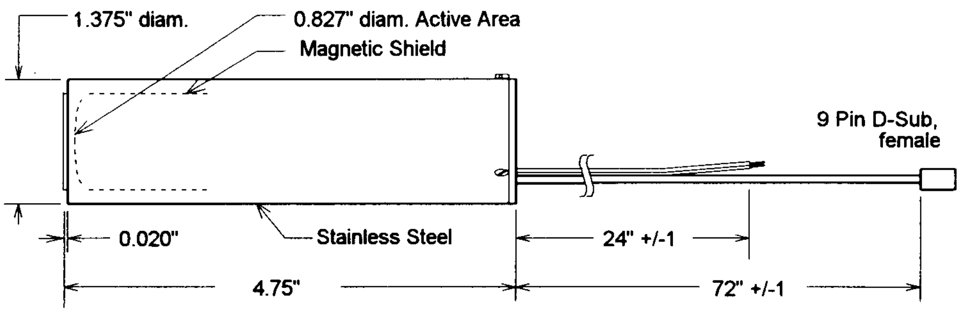
BC means the command is bad
BA means the argument is bad
VA means the command is valid

The command, S, starts the reading process. The result is 4 bytes of data; i.e. a 32 bit value. If the microcontroller detected an overflow of it's counter, it sets the most significant bit to 1. Note that, if another character is accidentally sent, the microcontroller will only send 2 bytes: BC.

When the unit first receives power, it loads default values for the programmable features. These default settings are:

P = 100 for 1 second integration time
R = 1 so each S command returns only one reading.
V = high voltage turned off.
O = 0 or set to ground.

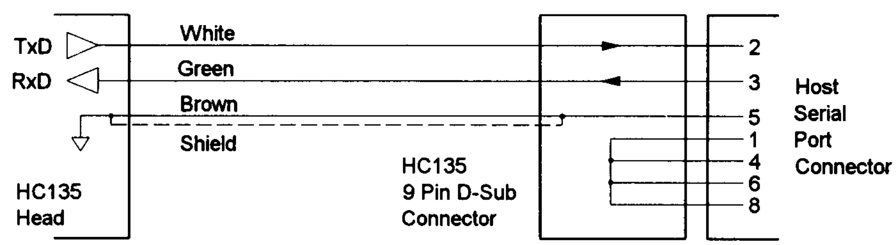
DIMENSIONAL OUTLINE



LEAD DESIGNATIONS

Yellow	26 ga., 19/36	XLPVC	+5 volts
Black	26 ga., 19/36	XLPVC	Ground
White/Orange Stripe	26 ga., 19/36	XLPVC	User line, TTL output
White/Purple Stripe	26 ga., 19/36	XLPVC	User line, TTL input
Black, shielded cable	26 ga., 3 conductor		RS-232-C interface

RS-232-C SERIAL INTERFACE



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