Two Channel Optical Incremental Encoder Module

Technical Data

Features
- High Performance
- High Resolution
- Low Cost
- Easy to Mount
- No Signal Adjustment Required
- Insensitive to Radial and Axial Play
- Small Size
- 40°C to 100°C Operating Temperature
- Two Channel Quadrature Output
- TTL Compatible
- Single 5 V Supply

Description
The HEDS-9000 and HEDS-9100 series are high performance, low cost, optical incremental encoder modules. When used with a code wheel, these modules detect rotary position. The modules consist of a lensed LED source and a detector IC enclosed in a small C-shaped plastic package. Due to a highly collimated light source and a unique photo-detector array, the modules are extremely tolerant to mounting misalignment.

The two channel digital outputs and the single 5 V supply input are accessed through five 0.025 inch square pins located on 0.1 inch centers.

Standard resolutions for the HEDS-9000 are 500 CPR and 1000 CPR for use with a HEDS-

ESD WARNING: NORMAL HANDLING PRECAUTIONS SHOULD BE TAKEN TO AVOID STATIC DISCHARGE.
6100 codewheel or equivalent. For the HEDS-9100, standard resolutions between 96 CPR and 512 CPR are available for use with a HEDS-9120 codewheel or equivalent.

Applications
The HEDS-9000 and 9100 provide sophisticated motion detection at a low cost, making them ideal for high volume applications. Typical applications include printers, plotters, tape drives, and factory automation equipment.

Theory of Operation
The HEDS-9000 and 9100 are C-shaped emitter/detector modules. Coupled with a codewheel, they translate the rotary motion of a shaft into a two-channel digital output.

As seen in the block diagram, each module contains a single Light Emitting Diode (LED) as its light source. The light is collimated into a parallel beam by means of a single polycarbonate lens located directly over the LED. Opposite the emitter is the integrated detector circuit. This IC consists of multiple sets of photodetectors and the signal processing circuitry necessary to produce the digital waveforms.

The codewheel rotates between the emitter and detector, causing the light beam to be interrupted by the pattern of spaces and bars on the codewheel. The photodiodes which detect these interruptions are arranged in a pattern that corresponds to the radius and design of the codewheel. These detectors are also spaced such that a light period on one pair of detectors corresponds to a dark period on the adjacent pair of detectors. The photodiode outputs are then fed through the signal processing circuitry resulting in A, A, B, and B. Two comparators receive these signals and produce the final outputs for channels A and B. Due to this integrated phasing technique, the digital output of channel A is in quadrature with that of channel B (90 degrees out of phase).

Definitions
- Count (N) = The number of bar and window pairs or counts per revolution (CPR) of the codewheel.
- 1 Shaft Rotation = 360 mechanical degrees = N cycles
- 1 cycle (c) = 360 electrical degrees (°) = 1 bar and window pair
Figure 2. Mounting Plane Side A.

Figure 3. Mounting Plane Side B.

Figure 6. HEDS-5120 Codewheel.

Figure 5. HEDS-6100 Codewheel.

Mounting Considerations

NOTES:
1. THESE DIMENSIONS INCLUDE SHAFT END PLAY.
2. MAXIMUM RECOMMENDED MOUNTING SCREW TORQUE IS 5 IN-lbs (5.5 Nm).

DIMENSIONS IN MILLIMETERS (INCHES):

1.62 (0.064)
7.4 (0.29)
4.84 (0.19)
1.18 (0.04)
6.56 (0.26)
0.89 (0.035)
0.25 (0.010)
1.25 (0.05)
1.5 (0.06)
1.96 (0.08)
3.8 (0.15)
5.08 (0.20)
6.35 (0.25)
9.53 (0.37)
10 (0.40)
12.7 (0.50)
25.4 (1.00)
Figure 10–10  A photoconductor (photoresistor) cell.

Figure 10–17  The solar (photovoltaic) cell used as a light meter.

Figure 10–18  Cross-section construction of a semiconductor photovoltaic cell.
PHOTOTRANSISTORS AND PHOTODIODES

Electromagnetic radiation, such as light, can affect the p–n junction characteristics of a semiconductor device; thus, both diodes and transistors can be made sensitive to light. When used as light-sensitive transducers, they are generally referred to as photodiodes and phototransistors, and are used in fiber optic receivers, isolators, and light-sensitive relays.

The photodiode, as shown in the circuit and load line of Figure 10–25, is normally reverse-biased. The diode is constructed with a transparent window placed over the p–n junction, allowing light to fall on the junction. The reverse current flowing in the diode is directly proportional to the light intensity striking the junction. In effect, it is similar in operation to a photoconductive cell. However, the response time of the photodiode is much faster. At maximum light intensity, the current through the diode is a maximum, equal to V/R. When no light falls on the photodiode, the current is zero and the voltage across the diode equals V.

![Figure 10–25 Photodiode.](image)

By the addition of an additional p–n junction, a phototransistor has a sensitivity to light many times greater than that of a photodiode. A transparent window is placed over the phototransistor’s base area (the n-p-n junctions), allowing light to fall there. Figure 10–26 shows a family of collector curves for a typical phototransistor. As the light intensity increases (similar to an increase in base current in a conventional bipolar transistor), the collector current (I_C) increases, causing the transistor’s collector-to-emitter voltage (V_CE) to decrease, and vice versa. Consequently, I_C is directly and V_CE is inversely proportional to light intensity.

![Figure 10–26 Phototransistor collector characteristics.](image)
Figure 5.3: In this chapter we will discuss the sensors illustrated on this schematic of Rug Warrior's sensors and actuators: the near-infrared proximity sensors at top left, the three bumper sensors at top right and the shaft encoders, microphone, photoresistors and pyroelectric sensor shown in the center.
5.3 Light Sensors

Consider the circuit for the left photosensor in Figure 5.8. Here, two resistances form what is called a voltage divider. The total resistance in this circuit, \( R_T \), is the sum of the individual resistances: \( R_T = R + R_L \). According to Ohm’s law, the current, \( I \), through the circuit is \( I = V / R_T \). In order for the A/D converter in the microcontroller to measure a voltage, some current must flow into pin PE1. However, because the MC68HC11 has high-impedance inputs, the amount of current required is negligible compared to the currents in the rest of the circuit. In this case, the connection to PE1 can be ignored while analyzing the voltage divider. Thus, the voltage present on PE1 is:

\[
V_{PE1} = IR_L
\]

The resistance of the photosensor falls as the light level increases. This means that the voltage at PE1 decreases. Substituting for \( I \), we get:

\[
V_{PE1} = \frac{R_L}{R + R_L} \cdot V
\]

The 8-bit A/D converter in the MC68HC11 maps the variable voltage, \( V_{PE1} \), into the range 0 to 255. Although the mapping provided by the simple voltage-divider circuit is not logarithmic, as was recommended for light sensors in Subsection 5.2.2, a useful output can nevertheless be extracted. A good compromise between sensitivity and range will be achieved if the resistance, \( R \), is set to the same value as the resistance exhibited by the photosensor when exposed to the light level in the middle of the range of light levels in which the robot must operate.

Typically, photosensors are made from cadmium sulfide (CdS). Hamamatsu and Clarex manufacture CdS photosensors; often, photosensors can be purchased at electronic hobbyist stores. In addition, most of the
The Sharp detector responds to a modulated carrier put out by the near-infrared LED. This means that the programmer is responsible for blinking the LED in a certain pattern such that the detector will respond. This modulated carrier protocol increases the signal-to-noise ratio. A minimal circuit (only one IC is needed, a 74HC04 inverter), which achieves an interface of such a proximity sensor to a MC68HC11, is shown in Figure 5.12.

The Sharp detector responds to a carrier frequency of 40 kHz. A 40 kHz frequency means the LED is blinked on and off with a period of 25 microseconds (μs). According to the device specification, this signal should then be modulated at a lower frequency. The blinking should be on for 600μs and off for 600μs. Figure 5.13 gives the timing diagram and protocol for the emitter-detector pair.

The 40 kHz oscillator portion of the infrared emitter circuit in Figure 5.12 is implemented using two inverters, a capacitor, a resistor, and a transistor. This 40 kHz oscillator runs constantly while the Rug Warrior is on, but the LEDs blink only when pins PD2 and PD3 of port D are asserted. Thus, the programmer is responsible for turning these on and off 600μs each. The Sharp detector outputs a low signal when it detects reflected energy and a high signal when it detects nothing. Figure 5.13 shows the low signal asserted by the Sharp detector when an object reflects energy from the emitter back to the detector. The output of the Sharp detector is a digital signal, either 0 or 5 V. Consequently, pin PE4

Figure 5.13: The obstacle-detecting infrared beam has a 40 kilohertz (kHz) carrier modulated at 1667 Hertz (Hz). Note that the transmitted signal must be broadcast for several cycles before being acknowledged by the detector. Likewise, when transmission ceases, a few microseconds pass before the detector changes state. Both these delay times can depend on the signal strength.

of the MC68HC11 can be used in the normal digital input mode. The A/D converter capability is not necessary here.

The circuit that controls the emitters is a rather odd one. It is uncommon to have the outputs of inverters connected together. Normally, an AND gate would be used to allow signals PD2 and PD3 to modulate the oscillator output. (An AND gate outputs a high signal only when both inputs are high.) We chose instead the circuit shown here for practical reasons: It provides the same functionality as an AND gate, and it does not require adding another chip to the circuit.

The geometrical layout of the sensors has the detector mounted at the center-front of the robot and pointed straight ahead. The emitters are set one to each side and aimed slightly outward to the left and right. This saves having two detectors. Rug Warrior can get by with just one and yet still see to both left and right.

An obstacle-detection program can be written very easily in C using the sleep function, as the following code fragment shows. PD2 is asserted and a sleep period begins. After 600μs, PE4 is polled and its state is saved in the variable val. Then PD2 is deasserted and the program waits another 600μs. Next, we poll PE4 again and store its value in val. If an obstacle is detected if the detector output is low when the emitter is on and high when the emitter is off. The function ir.detect() should be called as often as necessary to keep the variable ir.status updated. A similar loop is repeated for the other LED.
Figure 5.14: A Hamamatsu S3599 near-infrared receiver contains an on-chip frequency generator, which drives a near-infrared LED for correlated detection.

```c
int ir.status = 0; /* Global var for IR detection status */

void ir.detect() {
    int val.off, val.on;
    /* Intermediate vars for IR detection */
    bit.set(port.D,0b000000100); /* Turn on one emitter */
    sleep(0.000600); /* Wait for 600μs */
    val.on = peek(port.E); /* Get value of detector */
    bit.clear(port.D,0b000000100); /* Turn emitter off */
    sleep(0.000600); /* Wait for 600μs */
    val.off = peek(port.E); /* Get value of detector */
    if ((val.off & val.on & 0b000000100) == 0b000000100 )
        ir.status = 1; /* Obstacle detected */
    else
        ir.status = 0; /* No obstacle detected */
}
```

Common fluorescent lights put out a great deal of noise, to which the IR detector is sensitive. Using the turn-on, test, turn-off, test strategy just outlined will help to eliminate spurious obstacle detections due to noise.

Hamamatsu makes some very convenient-to-use optical sensors, ranging from photocells and near-infrared emitters and detectors to position-sensitive devices, photodiode arrays, and triangulation-based near-infrared rangefinders. One very simple implementation of a near-infrared proximity detector uses the Hamamatsu S3599 light-modulation photo IC. This detector contains an on-chip oscillator to drive an accompanying LED and also an integrated correlating receiver. This means the entire system can be built in a very small package. (The discrete-component 40kHz oscillator of the previous example is extraneous here.) Figure 5.14 illustrates a sample circuit.

5.3.3 Pyroelectric Sensors

One of the most useful sensors for endowing your robot with a means of interacting with humans is a pyroelectric sensor. A pyroelectric sensor is the essential component in certain types of motion-detecting burglar alarms. The output of a pyroelectric sensor changes when small changes in the temperature of the sensor occur over time. The active element in such a sensor is typically a lithium tantalate crystal. Charge is induced as the crystal is heated. Inexpensive pyroelectric sensors are optimized to detect radiation in the 8-10 μm range (the range of infrared energy emitted by humans) and require no cooling to produce a useful signal. This makes them suitable for use in motion sensors and security alarms.

Pyroelectric sensors are sold by a number of companies. Figure 5.15 depicts a dual-element sensor with integrated amplifier, the 442-3, sold by Eltec. The package is shown in the can with the window at the left. To the
Because the near-infrared energy emitted by the LED can penetrate thin white paper, it is important to take into consideration what is behind the striped paper pattern. Two pieces of plain, white paper discs backing the striped wheel should be enough to make the white segments adequately opaque so that the beam will be reflected back to the detector. Figure 5.28 illustrates 32-, 48-, and 64-count encoder patterns. You can photocopy these patterns and use them to construct your own reflective shaft encoders.

The photoreflectors we have chosen for Rug Warrior are the Hamamatsu P306201s. We have chosen these devices because they have circuitry integrated in the package to amplify and condition the output of the phototransistor. The only interface components required for connecting to the MC68HC11A0 are two resistors: one for pulling up the phototransistor's open-collector output and one for limiting the current through the LED, or reading the shaft-encoder data into Rug Warrior's control system. We have chosen to take advantage of the timer-counter hardware connected to the MC68HC11A0's port A. Port A's 8 pins have various input capture and output compare registers associated with them, which are able either to mark the time that events happen on those pins or to initiate events at preprogrammed times. We use PA7 and PA0 as the port A pins to accept the input from the left and right shaft encoders, respectively, as shown in Figure 5.29.

A pulse accumulator function is associated with PA7 making it easy to count the pulses produced by the left shaft encoder in software. It would have been more convenient if the MC68HC11A0 designers had included two of these features on their chip (newer versions of the MC68HC11 do have more features for reading shaft encoders and for pulse width modulating motors), but since we do not have that luxury, we connect the right shaft encoder to the PA0 pin and use its input capture function to count the pulses.

Figure 5.30 illustrates a simple open-loop control scheme, where a motor is given a speed command and the shaft encoders are used simply to monitor its velocity. Later, in Chapter 7, we will use other portions of port A's timer system, output pins PA5 and PA6, to drive the motors, and we will also discuss how to use shaft-encoder feedback data to implement software a velocity controller. In this section, however, we concentrate on describing how to get the shaft-encoder sensor data into the microprocessor.

Reading Shaft Encoders

In order to use the shaft-encoder sensors in some sort of velocity control scheme for Rug Warrior, we must first interface the photoreflectors to the