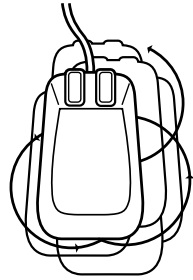


# Application Note

## Optoelectronics for Mouse and Shaft Encoder Applications

Figure 1

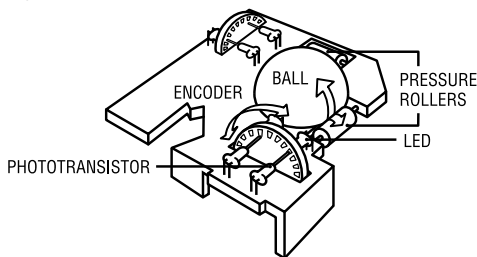


MOUSE

The mouse, a small hand-held device, usually with two or three buttons on top, is by far the most commonly used alternative input device for personal computers. As the mouse is moved, both direction and distance are sensed either mechanically or optically; software translates the mechanical movement of the mouse to a proportional movement of a pointer or cursor on the computer screen. The buttons on the mouse allow input without the use of the keyboard.

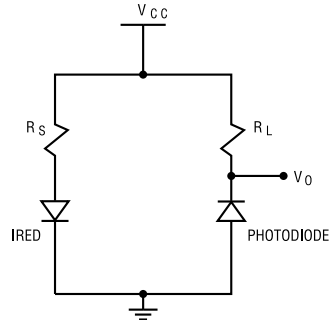
There are several different species of mice. There is the mechanical mouse, the optical mouse, and the optomechanical mouse. An optomechanical mouse is built around shaft encoders that use optoelectronic devices as the emitting and sensing component pairs. The movement of a rollerball at the bottom of the optomechanical mouse causes orthogonally placed shafts inside the mouse housing to rotate. This causes slotted encoder wheels to rotate, alternately blocking and opening the optical path between a light source and a sensor. The number of open/close cycles is proportional to the distance moved. The phasing of two channels on each encoder disc implies direction of motion.

Figure 2



OPTO - MECHANICAL MOUSE

Figure 3 IRED/PHOTODIODE CIRCUIT



In this configuration, the output voltage will be low when the optical path between the IRED and the detector is clear. The light falling on the photodiode will induce a current flow which will result in a reduction of voltage at  $V_O$  below  $V_{CC}$ . The reduction will be the amount of the current times the value of  $R_L$ . By proper selection of  $V_{CC}$  and resistor values, output voltage can be set as needed.

There are three considerations for this circuit:

1. Low values of  $R_S$  will cause the forward current in the IRED to be high. The resulting high radiant emission will consume energy and cause high temperatures in the IRED which will reduce its useable lifetime. However,  $R_S$  must be low enough to allow an irradiance level at the detector sufficient to induce useable photocurrents assuring a dependable "low" output level when the optical path is clear.

Degradation of IRED emission over time under various power dissipations has been studied extensively, and numerous articles on the subject have been published<sup>1</sup>.

2. High values of  $R_L$  will cause the output voltage ( $V_O$ ) to be low with a minimum of radiant energy on the detector. However, the value should be low enough to ensure that neither leakage currents in the detector nor photocurrent induced by ambient light will cause a false low signal when the optical path is blocked. Light energy leakage in the system has to be considered, as well as the leakage current/temperature relationship of the photodiode. Leakage current typically doubles for each 10°C temperature increase. A typical initial value is 1 nanoampere at room temperature.

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3. With Honeywell's SE5450 IRED and SD5421 photodiode these values can be expected:  $V_{CC} = 5V$ ,  $R_S = 35 \text{ Ohm}$ , and  $R_L = 50K \text{ Ohm}$ . A forward current of approximately 100mA in the IRED will result. If the optical path is short and clear, it will generate a photocurrent of greater than 100 $\mu$ A in the detector. The output voltage should be greater than 4.9V when the optical path is totally blocked, and less than 0.1V when it is totally clear.

Figure 4 TYPICAL MECHANICAL ARRANGEMENT  
LOW RESOLUTION ENCODER

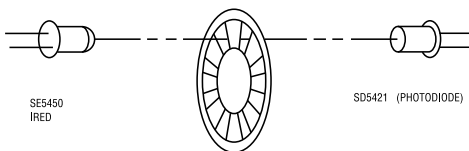
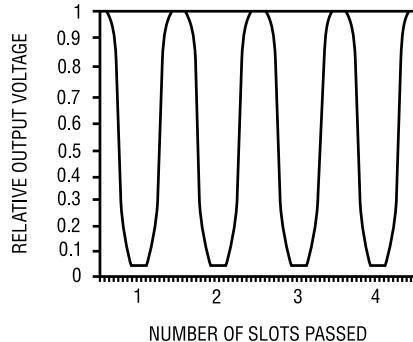


Figure 4 outlines the typical mechanical arrangement for this circuit. Figure 5 shows the typical output voltage pattern as a function of rotation of the encoder disc. Note that with this single channel device, only distance can be measured; no information about direction of motion is possible.

Figure 5 OUTPUT VOLTAGE VS. ENCODER ROTATION  
LOW RESOLUTION ENCODER



High values of  $R_L$  cause high sensitivity to ambient light, high temperature induced leakage current, and thermal noise due to the  $4kT$  noise component of the resistor. The circuitry immediately following the detector must have an input impedance which is high compared to  $R_L$  in order for the output to behave as expected. Unless it is carefully shielded, this high input impedance stage may have noise problems.

Instead of a photodiode, a phototransistor is often used as detector in the encoder, with resulting much higher light current. Thus, the value of  $R_L$  can be reduced without compromising the signal characteristics at the output. Typically, much less emission is needed from the IRED, which is an additional advantage. The forward current can be greatly reduced to minimize power loss, heat generation and degradation rate of the IRED power emission overtime.

The transistor is a slower detector with a rise time of approximately 10 $\mu$ sec, a consideration to be kept in mind for high speed applications. For mouse applications speed is usually not a problem because the signal has a very low frequency. However, in other encoder applications a limitation of resolution or speed can pose a problem.

The circuit for a phototransistor encoder can be very similar to that of the photodiode version, but the component values will change significantly. For example, using the SE5450 with the SD5443 phototransistor, appropriate values might be  $V_{CC} = 5V$ ,  $R_S = 180 \text{ Ohm}$ , and  $R_L = 1K \text{ Ohm}$ . In this example, the IRED forward current will be approximately 20mA. The current in the detector should be sufficient to saturate it. The output voltage in the low (clear optical path) condition will be less than 0.2V. The lower limit on  $V_O$  is the saturation voltage of the phototransistor.

The component pairs described above have lenses with a diameter of approximately 0.150 inches. In order to assure a clean output signal, the optical path has to change from mostly clear to almost completely blocked. To accomplish this, the vanes and gaps of the encoder wheel have to be at least 0.150 inches wide (in other words, a 0.300" optical period), greatly limiting the resolution of the encoder or the number of pulses that can be encoded per revolution of the encoder wheel. The circumferential centerline of those openings and vanes is called the pitch diameter.) The resolution of the encoder can be determined by the following simple computation:

$$\text{Resolution in pulses/revolution} = \frac{\text{Pitch Diameter}}{\text{Optical Period}}$$

Unless the pitch diameter is very large, the number of counted pulses per revolution will be rather small and the resolution low.

When the emitter and detector are very close, as they are in the encoder application, the large lens will give the optical path a very large diameter. In this case, that is a negative effect. It is, therefore, common to use components with much smaller lenses. In fact, most medium resolution encoders use plastic package components with small lenses, such as the SEP8506 emitter and the SDP8406 detector.

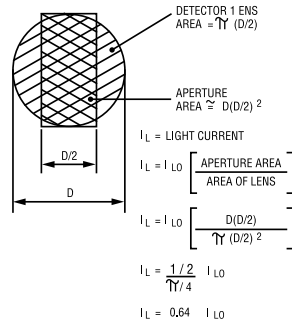
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Figure 6 LIGHT CURRENT REDUCTION EFFECT OF A LINE APERTURE OF WIDTH = D/2



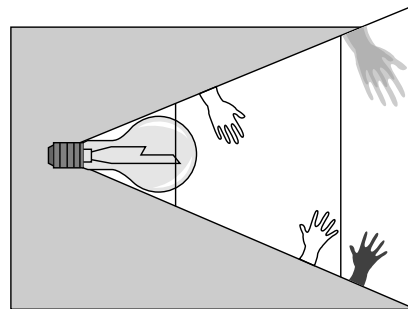
Another method to increase the resolution of an encoder is the addition of a stationary aperture in front of the detector lens. This reduces the photocurrent, but that trade-off is generally worthwhile. In fact, the trade-off is not strictly linear. To provide an example: If the aperture takes the form of a slit with a width equal to the radius of the lens when the slit is centered on the lens, the resolution is doubled at the expense of only 40% of the potential lightpath. (See Figure 6)

A logical progression from the single slit aperture is the use of an aperture with multiple slits. If slits and masking regions are equal in width, and the slit width is less than  $1/2$  the lens radius, no further reduction of light current will occur if the slit width is decreased and the number of slits is increased to keep total aperture area constant. At first glance, this appears to be the way to achieve unlimited resolution. Unfortunately, however, this is not the case. Quite the contrary, several serious problems occur if the slits become too narrow.

It is essential to maintain good alignment between the aperture mask and the encoder wheel. If the slits in the aperture and the slits in the encoder wheel are not aligned with each other, the optical path is never completely blocked or totally clear. It is important that the energy passing through to the detector varies between high enough to give a good "clear path" output level and low enough to give a good "blocked path" output level. Slit width extremes will quickly reveal problems with the precision of mechanical components.

Even though the disc pattern and the aperture are well aligned, the shadow of the disc pattern is not sharply defined because of the close proximity of the radiation source. This phenomenon can be illustrated quite simply. Using a lamp as the light source cast the shadow of your hand on the wall. When the lamp is relatively distant the shadow is a good image of the hand. However, if the lamp is close the image will blur. In an extreme case, with the hand very close to the lamp and

Figure 7 EFFECT OF DISTANCE FROM DETECTOR TO MASK ON SHARPNESS OF IMAGE



far from the wall, it can be difficult to distinguish and count the number of fingers (see Figure 7). This is a good model to remind the designer that optimum signal clarity in a high resolution encoder will occur only if the radiation source is as far from the disc as practical, and the encoder is as near the aperture as possible. The distance between the aperture and the detector is far less important than the other dimensions.

The lens helps to overcome the problem caused by the proximity of the IRED. Not only does the lens concentrate the radiation where it is needed, it also makes it behave as if the source were farther away. That makes the shadow sharper than the encoder cases on the aperture. If the source were a true point source, the lens were a perfect imaging lens and the two properly related to one another, then the radiation would behave as if the source were at infinity, and the only disruption of the shadow would be from the diffraction effects. However, the emissions are from a distributed area, and there are many reflections and other limitations of the source. Therefore, attempts to use sophisticated, precision lenses do not generally have the desired effect. It is usually a better solution to move the IRED as far away as possible and place the encoder mask as near the aperture as practical.

Through proper design, manufacture, and selection of mechanical components it is possible to build a shaft encoder that provides the required number of high and low output levels per revolution. Of course, this is not the end of the story. Most often the slit width is small compared to the lens diameter, the slots and webs in the encoder disc have the same width as the aperture slit, implying a 50% mechanical duty cycle. The output voltage from a linear detector will be triangular. This may not be readily apparent, but consider this: The only time the optical path is completely open or closed is when the mask is exactly in phase or exactly out of phase with the aperture. At all other times some portion of the optical path is open.

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## Optoelectronics for Mouse and Shaft Encoder Applications

Figure 8 EQUIVALENT CKT SDP8601

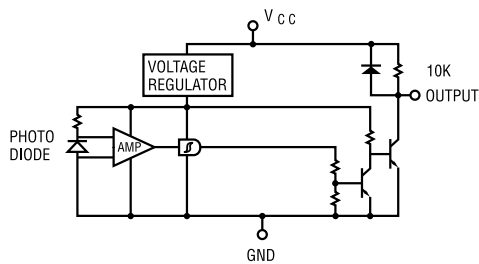


Figure 11 OBTAINING SPEED AND DIRECTION SIGNALS

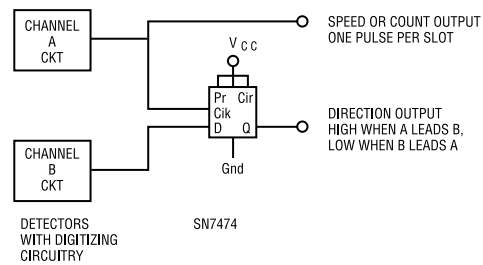
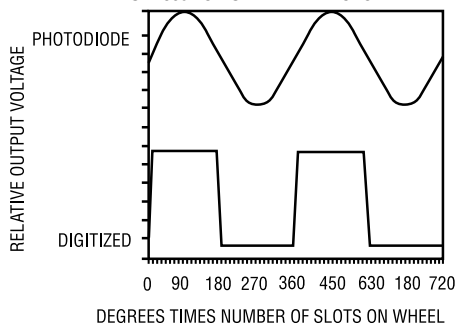
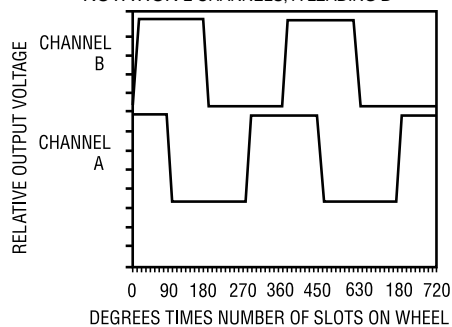


Figure 9 OUTPUT VOLTAGE VS. ENCODER ROTATION WITH SPD8601 OR SIMILAR DETECTOR



The triangular signal is often harder to process than a digital pulse. Therefore, it is common to place a schmitt trigger circuit in the output of the detector. Then the output becomes a string of pulses with clean leading and trailing edges which are suitable for almost any digital circuit interface. Such a circuit can easily be built from separate components, but Honeywell offers detectors with this function built-in. The SDP8601, for example, contains a voltage regulator, a photodiode, a linear amplifier, a schmitt trigger stage, and an output transistor with a 10K Ohm collector pull-up resistor to  $V_{CC}$ . Figure 8 is a schematic of the SDP8601. Figure 9 shows the effect on the output waveform.

Figure 10 OUTPUT VOLTAGE VS. ENCODER ROTATION 2 CHANNELS, A LEADING B



Obtaining a clean digital pulse train output and an appropriate number of pulses per revolution is a major step toward the solution of the design problem. In most applications, and especially in mouse applications, it is critical to encode the direction of rotation. A single channel encoder is not sufficient. The common solution is to use a second, duplicate channel that is 90 degrees out of phase with the first. In one phase option, for example, the first channel output will lead the second channel output for one direction of rotation and lag it for the other. Figure 10 shows the ideal relationship between the output signals. Figure 11 is a sample circuit that uses the phase difference to generate a logic high for one direction and a logic low for the other.

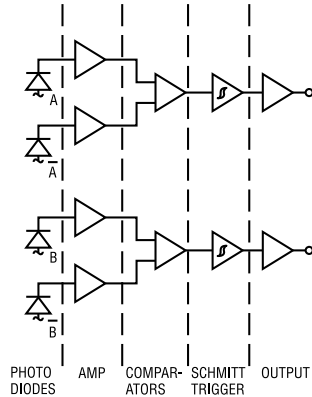
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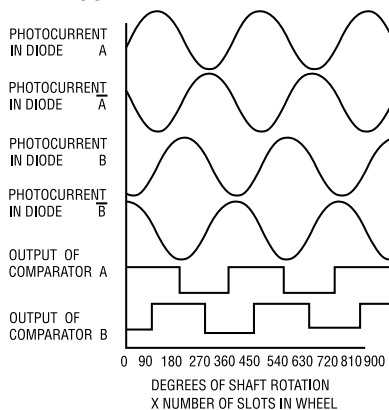
## Optoelectronics for Mouse and Shaft Encoder Applications

Figure 12 CIRCUITRY FOR A DIFFERENTIAL MODE ENCODER



When the aperture slits are fairly wide the resolution will be relatively coarse, which is typical of mouse applications. In this case it is sufficient to use individual components and design their nominal locations as needed to obtain the phase relationship described above. Ideally, the phase shift between the output signals from the two channels is 90 degrees, but it is enough to assure that the first channel is always high as the second one goes high when the shaft is rotated in one direction and, when the shaft is rotated in the other direction, the first channel is low when the second channel goes high. With increasing resolution this is harder to accomplish. Remember that the variation in the optical path has to be less than  $\frac{1}{2}$  the width of a slit to assure that the  $\pm 90^\circ$  phase relationship will be maintained.

Figure 13 TIMING CHART FOR DIFFERENTIAL MODE ENCODER



As the relative positions of the optical paths become more critical it is desirable to use a single housing holding all components. The apertures are molded or machined into the housing. Their relative positions are known within the tolerances that can be attained with the respective technique used to manufacture the housing. This, however, is a rather inflexible approach. The aperture gives optimum results only when it is matched with a certain encoder mask of the appropriate diameter and a certain number of slits.

As increasingly higher resolutions are demanded, the realization of the encoder becomes more difficult. One successful approach is to place both detector channels on one semiconductor element, where their relative position can be fixed with the same precision as other elements within the integrated circuit. Even the aperture can be made an integral part of the semiconductor. Two of the primary variables, the relative position of the detector channels and the aperture, can thus be precisely controlled. The alignment of these apertures to the disc pattern and the sharpness of the projected image, however, are still unimproved.

Another approach is to use differential detector in a common channel. This allows reliable detection of much smaller signals. Using two detectors and an operational amplifier in a differential mode allows detection of variations regardless of the absolute value of the signal, and at very low contrasts. Figure 12 shows a basic circuit arrangement. Figure 13 is a timing chart for the signals in the circuit.

### SUMMARY:

This article describes the use of optoelectronic components for simple shaft encoders. Design considerations for shaft encoder circuits and component selection are given.

Honeywell Optoelectronics offers a broad line of standard components optimized for shaft encoder applications. Custom designs and optoelectronics assemblies are also available.

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