Agilent Technologies
Innovating the HP Way

Solid-State Optical Mouse Sensor with PS/2 and Quadrature Outputs

Application Note 1179

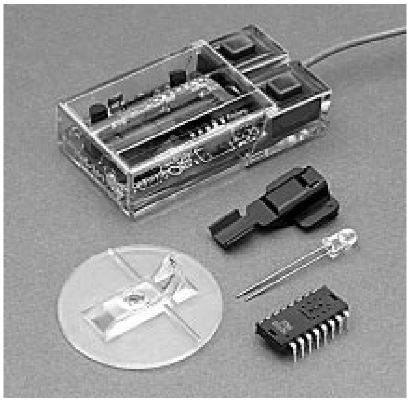
HDNS-2000
HDNS-2100
HDNS-2200

Introduction

The HDNS-2000 Application Note is intended to provide OEMs with a comprehensive overview on evaluating and integrating Agilent's Solid-State Optical Mouse Sensor and constituent components into PC, portable PC, and workstation mice.

Functional Description

The HDNS-2000 is a low-cost reflective optical sensor that provides a non-mechanical tracking engine for implementing a standard mouse. It is based on Agilent's optical navigation technology that measures changes in position by optically acquiring sequential surface images (frames) and mathematically determining the direction and magnitude of movement. The sensor is mounted in a plastic 16-pin optical DIP package and designed to be used with the HDNS-2100 (lens), HDNS-2200 (LED assembly clip), and HLMP-ED80 (5 mm red LED), providing a complete and compact tracking engine. This optical tracking engine has no moving parts and requires no precision assembly or optical alignment enabling high volume system assembly. The HDNS-2000 offers a PS/2 or quadrature output mode for interface flexibility. Resolution is 400 cpi at rates of motion up to 12 linear inches per second. The HDNS-2000 is comprised of three major functional blocks: an Image Acquisition System (IAS), Digital Signal Processor (DSP), and PS/2 or quadrature output converter. The IAS acquires images via the lens. These images are further processed by the DSP to determine direction and distance of motion. The DSP generates a stream of Δx and Δy relative displacement values that are then communicated to the output converter. This converter provides a PS/2 2 or 3-Button output, replacing existing mouse microcontrollers, or two-channel quadrature output, for direct interface to mouse microcontrollers.



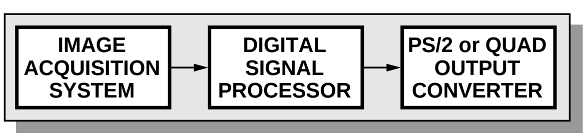


Figure 1. HDNS-2000 Block Diagram.

Features and Benefits

The HDNS-2000/2100/2200 system has many features and benefits that provide innovative solutions over traditional mouse mechanical tracking engines.

Superior Precision and Motion Tracking: Optical Navigation Technology
Users of conventional mice are often plagued with cursor track-

ing problems from environmental contaminants and mechanical wear on the system. Solid-State Optical Navigation technology provides superior precision and smooth navigation. It accurately tracks up to 12 linear inches per second at 400 cpi.

Robustness: Non-mechanical Surface-Tracking Engine
Agilent's Optical Tracking engine's quality and reliability is a benefit of its no-moving parts design—requiring no maintenance and providing high resistance to contamination.

Integration Flexibility: Compact Design
The compact size of the optical tracking system enables innovative mouse designs and allows easy integration into small areas. All components interlock for ease of assembly. Agilent also provides an IGES design file which describes base plate molding features to hold and align the HDNS-2100 lens into place in the user's final product.

Ease of Assembly: Modular Design
All components of the optical tracking engine interlock together as they are mounted onto the defined mounting features in the base plate of the mouse. This modular design provides a simple assembly that is compatible with high volume manufacturing processes and also ensures optical alignment.

Navigates over a Wide Range of Surfaces
Traditional mice typically require a pad for uniform contact with the mouse ball. Unlike traditional mice, Agilent's optical tracking engine does not physically make contact with the surface. It acquires sub-sequent images of the surfaces to calculate Δx and Δy relative dis-placement values. The naviga-tion requirements for the optical engine are a flat reflecting surface with random texture or pattern characteristics.

Component Description

The complete Optical Tracking engine consists of four components: (see Table 1 below).

Throughout this document, reference is made to the optical tracking engine which is comprised of the sensor, lens, clip, and HLMP-ED80 LED. All optical and electrical performance data in this document are based on using Agilent's complete Optical Tracking engine (HDNS-2000+ HDNS-2100+HDNS-2200+ HLMP-ED80 LED) over the recommended operating conditions.

These components interlock as they are mounted onto defined features in the mouse base plate. (Agilent provides base plate molding features via an IGES file.) Please contact your local Agilent representative to obtain this file.

HDNS-2000 (Sensor)
The HDNS-2000 contains the sensor IC housed in a 16-pin optical package designed for through hole mounting on the mouse printed circuit (PC) board. The sensor module mounts face down on the PC board. An aperture stop is provided via the lid on the package through which surface images are acquired via photocells on the IC. The features on the lid align the lens to the sensor.

HDNS-2100 (Lens)
The HDNS-2100 provides the optical path for the system. It consists of several optical components: the imaging lens through which the sensor acquires surface images; integral light pipe through which the LED provides the surface illumination; and lensed prism to focus the LED light at the optimal angle of incidence. The features on the lens and integrated light pipe align with features on the base plate and clip. The lens also protects the sensor and LED from any contact ESD events that occur at the opening in the base plate.

HDNS-2200 (Clip)
The clip provides a snap-in mechanical housing for the LED. The LED must be inserted into the clip and the LED's leads formed prior to PCB loading. The HDNS-2200 holds the LED and aligns all of the components to the base plate. It interlocks to the top of the HDNS-2000 and light pipe of the HDNS-2100. The whole assembly then aligns to the base plate features. This design ensures optical alignment and requires no precision assembly.

Table 1. Optical Tracking Engine Components

Agilent Part Number	Name	Description
HDNS-2000	Sensor	IC in a 16-pin plastic package
HDNS-2100	Lens	Lens with integral light pipe
HDNS-2200	Clip	LED assembly clip
HLMP-ED80	LED	639 nm 5 mm LED

HLMP-ED80 (LED)

An LED is required to provide the illumination needed by the HDNS-2000 Sensor for proper tracking. Agilent recommends the use of the HLMP-ED80 639 nm radiometri-cally tested Precision Optical Performance AlInGaP (aluminum indium gallium phosphide) LED lamp in an untinted, nondiffused, 5 mm package. It incorporates second generation optics that produce well defined radiation patterns at a 30° viewing angle. The lamp is made with an advanced optical grade epoxy offering superior high tempera-ture and high moisture resistance performance. All optical and electrical performance data in this document are based on using the HLMP-ED80 LED over the recommended operating conditions.

Base plate

Agilent provides recommended base plate molding features to ensure optical alignment. Contact your local Agilent sales engineer to receive an IGES file containing the solid design of the base plate.

Mechanical Design Considerations

The distance from the surface of the HDNS-2100 lens foot ref-erence plane must be 2.4 mm to ensure proper operation. (See HDNS-2100 data sheet, dimension A in the Mechanical Assembly Requirements section.) Use standoff feet and adjust the base plate thickness to maintain this distance.

Design of the upper mouse case needs to include a molded feature to compress the spring clip on the HDNS-2200. This compres-sion from the upper mouse case and spring clip will secure all components together.

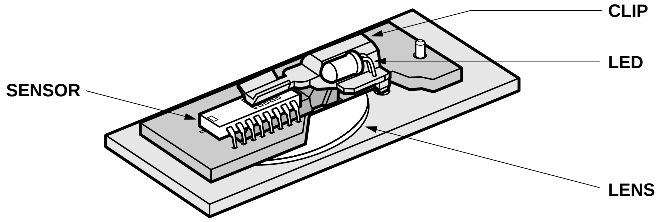


Figure 2. Assembly.

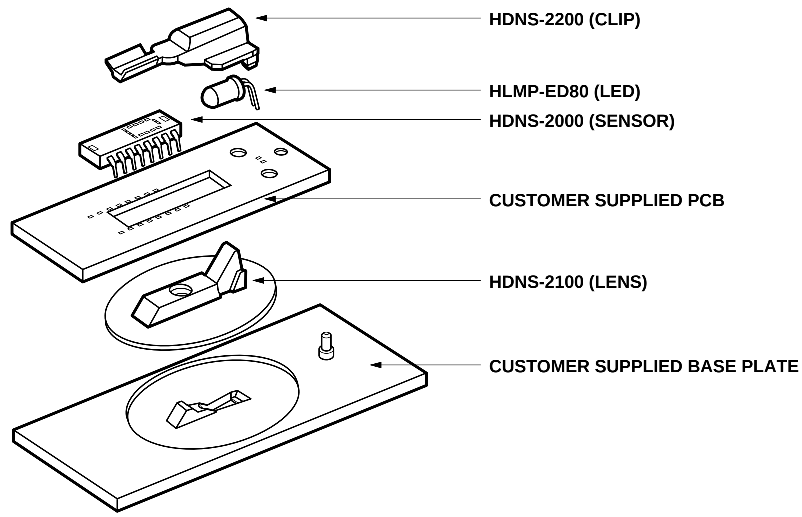


Figure 3. Exploded View Diagram.

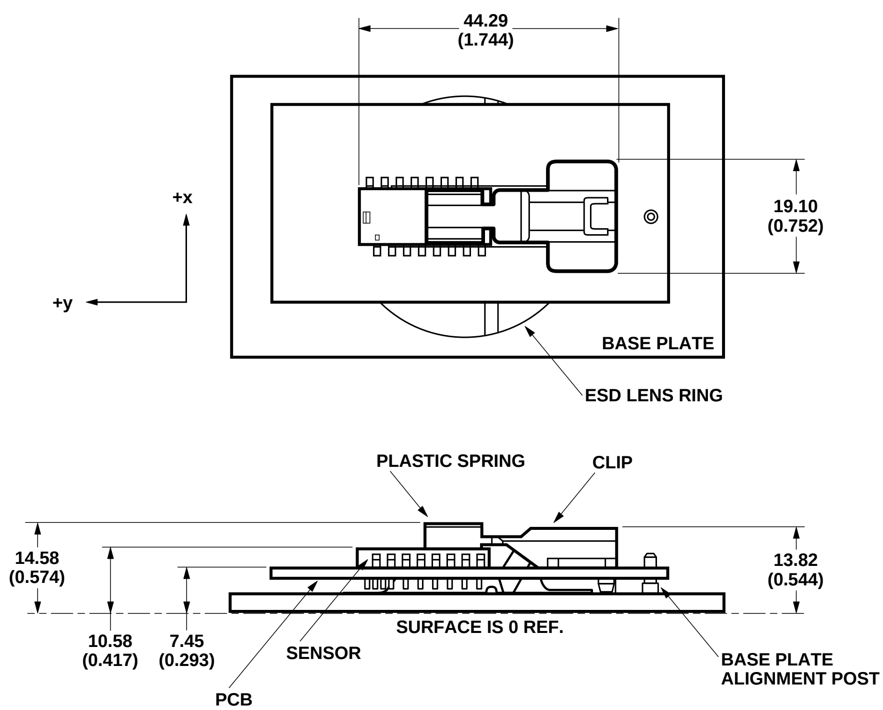


Figure 4. 2-D Drawing.

Assembly Considerations

PCB Assembly

- Insert HDNS-2000 and all other electrical components into PCB.
- Insert HLMP-ED80 (LED) into HDNS-2200 (LED assembly clip) and bend the leads 90 degrees.
- Insert HLMP-ED80/HDNS-2200 assembly into PCB.
- Wave Solder entire assembly in a no-wash solder process utilizing solder fixture as illustrated below. Solder fixture is needed to protect the sensor during the solder process. Fixture should be designed to expose leads to solder while shielding optical aperture from direct solder contact.

Mouse Mechanical Design and Assembly Considerations

- Remove protective kapton tape from optical aperture of HDNS-2000 sensor. Care should be taken to keep contaminants from entering the optical aperture.
- Place HDNS-2100 (Lens) onto the base plate.
- Insert PCB assembly over HDNS-2100 lens onto base plate alignment post to retain PCB assembly. HDNS-2000 aperture ring should self-align to the HDNS-2100 lens. The optical position reference for the PCB is set by the base plate and lens. Note that the PCB motion due to button press must be minimized to maintain optical alignment.
- Install mouse top case. The feature in the top case should press down onto the HDNS-2200 clip to ensure all components are interlocked to the correct vertical height.

Design Considerations for Improving ESD Performance

The flange on the lens has been designed to increase the creepage and clearance distance for electrostatic discharge. The table below shows typical values assuming base plate construction per Agilent supplied IGES file and HDNS-2100 lens flange.

- For improved ESD performance, the lens flange can be sealed (i.e. glued) to the base plate. Note that the lens material is polycarbonate and cyanoacrylate based adhesives or other adhesives which may damage the lens should not be used.

Circuit Design Considerations

Note: The application circuit diagrams are to be used as a guide when designing the electronic circuitry. Additional circuitry may be required or different component values may need to be used to minimize noise, counteract other electronic issues, or optimize LED performance.

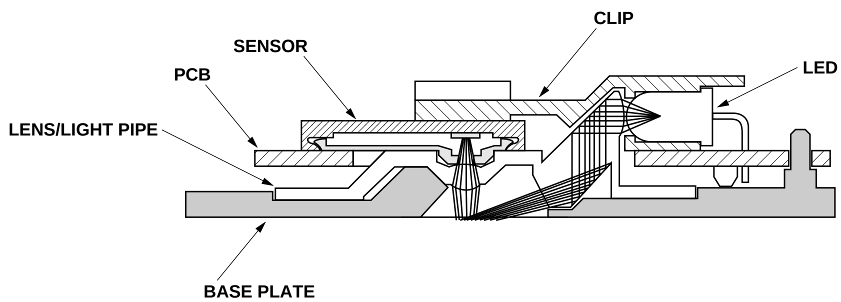


Figure 5. Optical System Drawing.

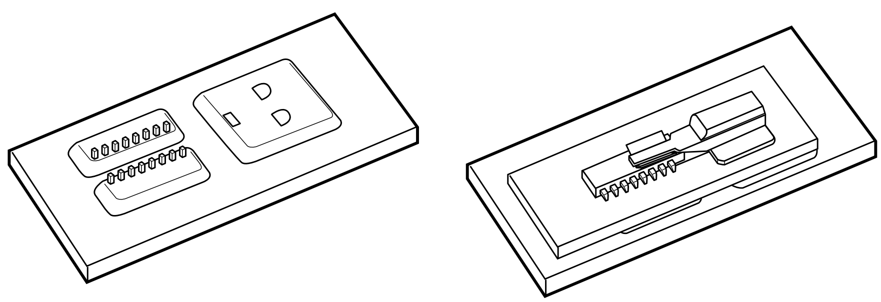


Figure 6. Example of Solder Fixture.

Table 2. Creepage and Clearance Distance

Typical creepage distance	16.0 mm
Typical clearance distance	2.1 mm

Electronic Design Considerations

The HDNS-2000 offers a standard 3-button PS/2 or quadrature output. In the 3-button PS/2 output mode, the sensor interfaces directly with the host, thereby eliminating the need for the mouse microcontroller. In the quadrature output mode, it emulates encoder phototransistor outputs for easy interface to existing mouse microcontrollers (e.g. PS/2, Serial, and USB mouse controller ICs).

Following are three application circuit diagrams for interfacing the HDNS-2000 using the PS/2 output (3-button mouse) and quadrature output (interface to PS/2 and USB mouse controllers). The PS/2 output mode enables the most cost-effective designs since only one integrated circuit (the HDNS-2000) is required. When an external microcontroller is added, additional flexibility is added since plug and play codes and other manufacturer customizations are feasible.

PS/2 mode vs. Quadrature Mode

Communications between the HDNS-2000 and an external microcontroller can use either the quadrature mode or PS/2 mode regardless of whether the mouse itself is a PS/2 mouse. Generally the quadrature mode is most appropriate when converting designs from opto-mechanical mice since the same microcontroller and program can be used. For new designs, the PS/2 interface may be more appropriate for communications between the HDNS-2000 and the microcontroller since only 2 signal pins are needed. The output mode is determined by the state of the MODE/XA pin at power-up reset. If the MODE/XA pin is tied high, the output mode is PS/2. If the MODE/XA pin is floating, the output mode is quadrature.

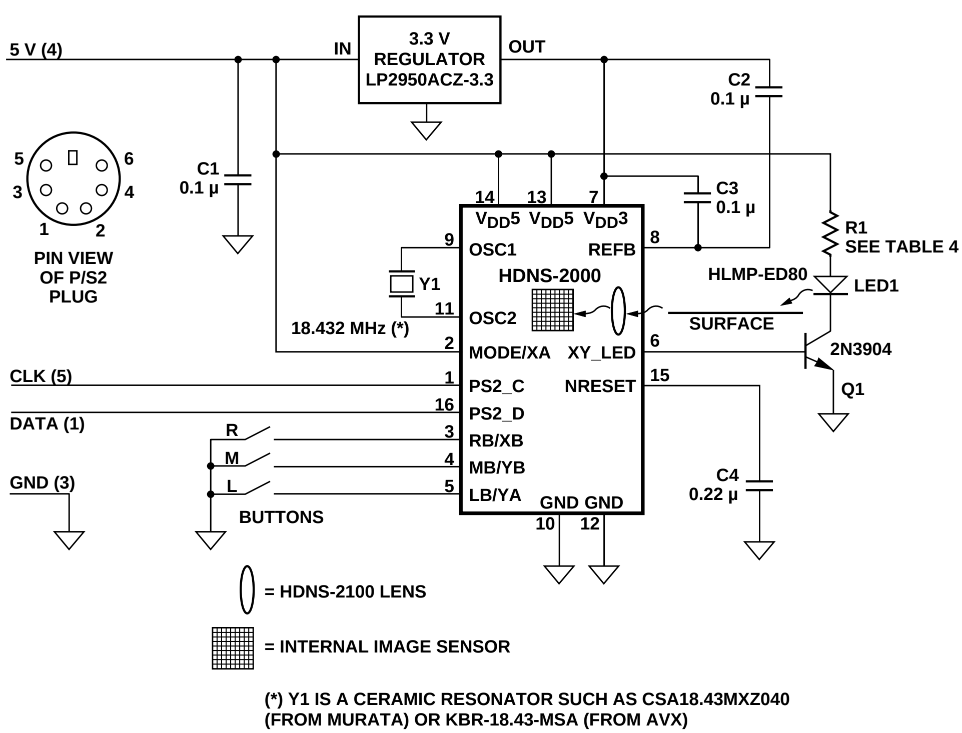


Figure 7. Typical Application using PS/2 Output.

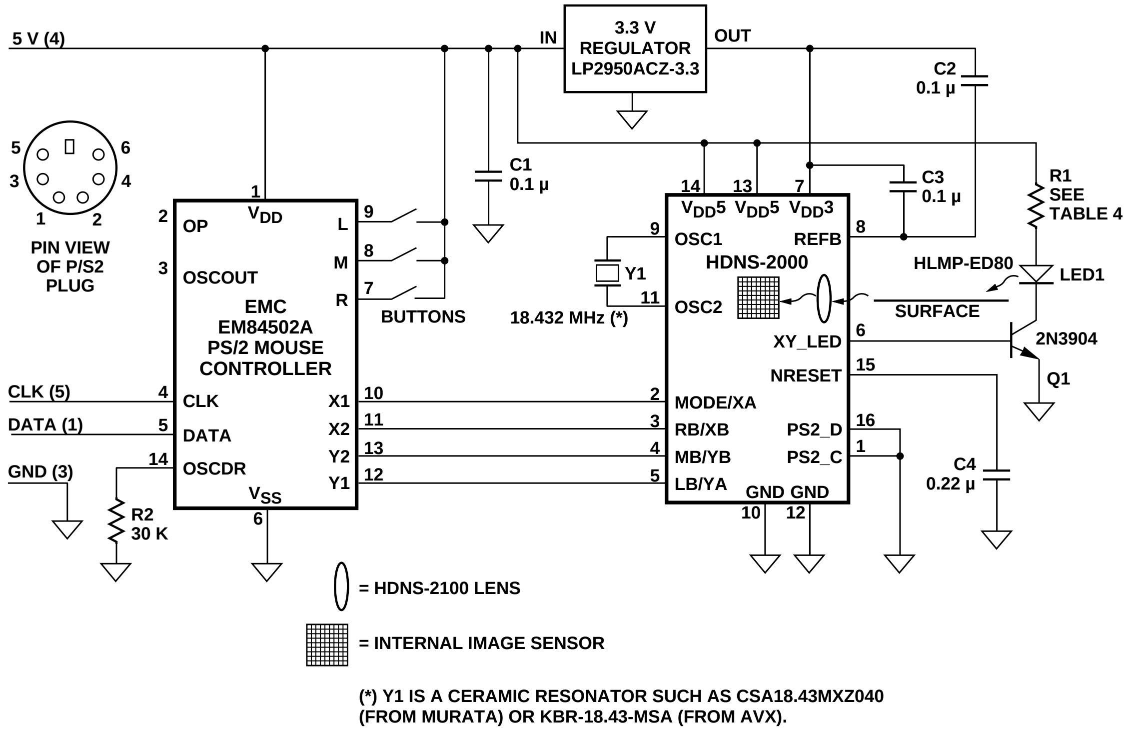


Figure 8. Typical Application using Quadrature Output Interfacing to PS/2 Mouse Controller.

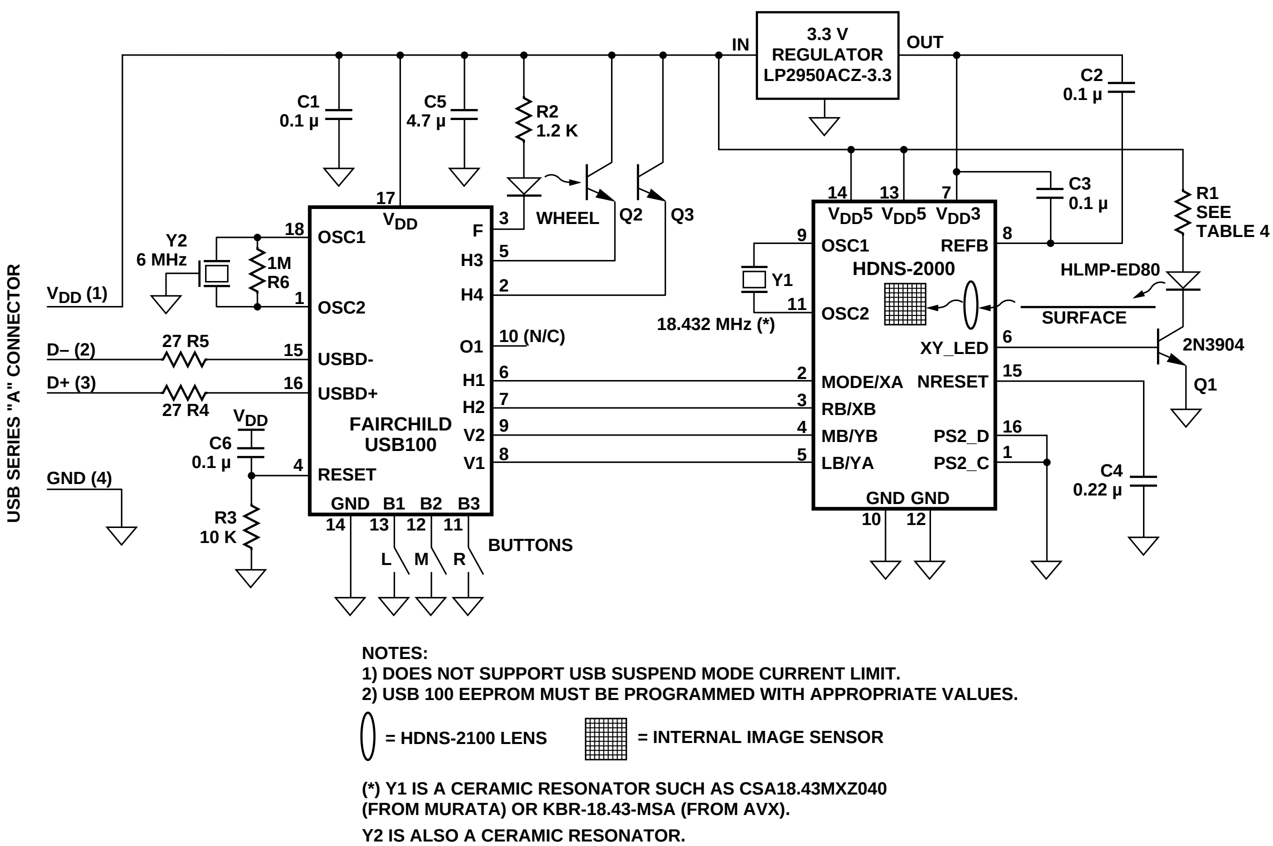


Figure 9. Typical Application using Quadrature Output Interfacing to USB Mouse Controller.

Table 3. HDNS-2000 Pinout

Pin	Name	PS/2 Mode	Quadrature Mode	Description
1	PS2_C	PS/2 Interface Clock	PS/2 Interface Clock	This input/output signal provides the clock for the PS/2 interface. It consists of an open driver and a pullup current (about 500 μA) to $V_{DD}5$. If desired, the PS/2 interface can also be used in quadrature mode. When not using the PS/2 interface, leave this pin unconnected.
2	MODE/XA	Select PS/2 mode	XA output	This input/output pin determines whether PS/2 mode or quadrature mode is activated. The state of the pin is sampled at the end of the reset interval after power-up. During the reset state, a weak pulldown current (about 30 μA) is active. To select PS/2 mode, tie this pin to $V_{DD}5$. To select quadrature mode, leave this pin floating during the reset interval and the internal pulldown will ensure the pin goes low. After reset this pin becomes one of the quadrature outputs (XA) if quadrature mode was selected. In PS/2 mode this pin should remain tied high after reset.
3	RB/XB	Right Button input	XB output	This pin is an input (Right Button) if using PS/2 mode and an output (XB) if using quadrature mode. XA and XB are the two quadrature 5 V CMOS outputs which encode motion in the X direction. When used as a button input, an internally generated pullup current holds the pin high unless an external switch to ground is depressed.
4	MB/YB	Middle Button input	YB output	This pin is an input (Middle Button) if using PS/2 mode and an output (YB) if using quadrature mode. YA and YB are the two quadrature 5 V CMOS outputs which encode motion in the Y direction. When used as a button input, an internally generated pullup current holds the pin high unless an external switch to ground is depressed.
5	LB/YA	Left Button input	YA output	This pin is an input (Left Button) if using PS/2 mode and an output (YA) if using quadrature mode. YA and YB are the two quadrature 5 V CMOS outputs which encode motion in the Y direction. When used as a button input, an internally generated pullup current holds the pin high unless an external switch to ground is depressed.
6	XY_LED	LED control output	LED control output	This output pin is designed to turn an external NPN switch on and off to control the LED. In the high state this pin is a current source which provides base drive to the NPN transistor. In the low state this pin actively discharges the base. This pin can also be used as a 5 V CMOS logic output as long as it is not connected to a DC load higher than Ioh.
7	VDD3	3.3 VDC input	3.3 VDC input	This is a 3.3 V supply input. A 0.1 μF bypass capacitor should be connected directly between this pin and the adjacent REFB pin.

Table 3. HDNS-2000 Pinout (Cont.)

Pin	Name	PS/2 Mode	Quadrature Mode	Description
8	REFB	Internal reference	Internal reference	This is an internal reference point which should be connected to a 0.1 µF bypass capacitor directly between this pin and the adjacent $V_{DD}3$ pin.
9	OSC1	Oscillator input	Oscillator input	This is an input which should normally be connected to a 2 terminal 18.432 MHz ceramic resonator. If desired, an external clock may be connected to this 3.3 V CMOS logic input.
10	GND	Ground	Ground	This is a ground return input for both supply inputs.
11	OSC2	Oscillator output	Oscillator output	This is an analog oscillator output which should normally be connected to a 2 terminal 18.432 MHz ceramic resonator. If external clock is provided on the OSC1 pin, then OSC2 should not be connected to anything. HP does not recommend using this analog output to drive external circuitry since load capacitance may prevent proper oscillator operation.
12	GND	Ground	Ground	This is a ground return input for both supply inputs.
13	$V_{DD}5$	5 VDC input	5 VDC input	This is a 5 V supply input.
14	$V_{DD}5$	5 VDC input	5 VDC input	This is a 5 V supply input.
15	NRESET	NRESET	NRESET	This input/output provides the power-up reset signal. Place a 0.22 µF capacitor from this pin to ground. An internal current source (about 10 µA) charges this capacitor during the reset interval to allow the oscillator and internal analog nodes to stabilize. An internal open drain driver holds this signal low until the internal oscillator begins to function. If the supply voltages are known to turn on in less than 100 µs, you may reduce the reset capacitor as low as 1000 pF.
16	PS2_D	PS/2 Interface Data	PS/2 Interface Data	This input/output signal provides the data for the PS/2 interface. It consists of an open drain driver and a pull-up current (about 500 µA) to $V_{DD}5$. If desired, the PS/2 interface can also be used in quadrature mode. When not using the PS/2 interface, leave this pin unconnected.

LED Drive Circuit

Another design choice is the method of LED drive. In all the following example schematics a series resistor sets the current through the LED. The LED current depends somewhat on supply voltage, temperature, and the forward drop of the LED. Agilent recommends matching the series resistor to the respective HLMP-ED80 LED intensity bin to ensure compliance with IEC 60825-1 AEL Class 1 (See Table 4).

Table 4. Nominal Resistor for Each LED Bin

LED Bin	Typical LED Current (mA)	Nominal Resistor (Ω) ± 1%
K	36	69.8
L	36	69.8
M	36	69.8
N	36	69.8
P	33	78.7
Q	28	93.1
R	25	113
S	21	137
T	17	169

More consistent current (and thus better performance on dark surfaces) can be maintained when the LED is driven from a constant current source. Designing a constant current source is straightforward but adds cost and components to the solution. The impact of current variations should be considered as part of a tradeoff between cost and performance.

Power Cycling Considerations

LED Strobing
The normal behavior of the HDNS-2000 is to turn the LED on for $^{2}/_{3}$ ms every 8 ms. When the LED is on, the IC determines whether motion has occurred since the last time the LED was on. If motion has occurred, then the LED stays on for at least 1 second and longer if there is continuing motion. If not, the LED continues to cycle on every 8 ms. When the LED is off, the 2 to 6 mA base drive from pin-6 is disabled, so the 5 V supply current drops by this amount plus the LED current draw.

Power-up Delay
After the 3.3 V and 5 V supplies are turned on, there is a delay before the HDNS-2000 accurately reports motion. This delay is approximately 40 ms but depends on the efficiency of the LED and the reflectance of the target. The worst case value for power up to data sheet specified accuracy levels is 70 ms. For optimum movement accuracy, all movement reported within 70 ms of power-up should be ignored. However, to optimize response time, this data may be used.

PS/2 Power-up ID
500 ms after power up, the PS/2 data line transmits AA00. In a power cycling application that uses PS/2 500 ms after power up, the PS/2 data line transmits AA00. In a power cycling application that uses PS/2 mode, sending any PS/2 command except reset prior to 500 ms after power-up can defeat this delay. However, no PS/2 command should be sent until after the NRESET pad rises above 1.5 V (about 30 ms when using the recommended 0.22 µF capacitor).

Bypass Capacitor Location
Hewlett-Packard recommends that any power switching circuit be placed external to the 0.1 µF bypass capacitors used on the 3.3 V and 5 V power supply pins. In other words, these capacitors should always remain attached to the HDNS-2000. Since they will have to be charged and discharged during each power cycle, some additional current will be consumed. However, the average value of this current will be under 100 µA for any power cycling rate slower than 60 Hz.

Power Switch Resistor Drop
When selecting FET switches (or equivalent) to turn the HDNS-2000 power on and off, be sure to calculate the I*R voltage drop across the switch. The HDNS-2000 requires 3.3 V ± 5% and 5 V ± 10% for normal operation.

Leakage into Inputs
When the power to the HDNS-2000 is off, any pull-up resistors on I/O pins (such as the PS/2 pads) can cause current to flow into the I/O pins through on-board ESD protection diodes. Therefore, for lowest current in the off state, make sure the supply to the pull-up resistors is also shut off or ensure that the I/O pins are in the logic low state.

Printed Circuit Board Layout

The reference is pin-1 hole on the PCB. The LED and Clip holes are held to this dimension to ± 0.1 mm.

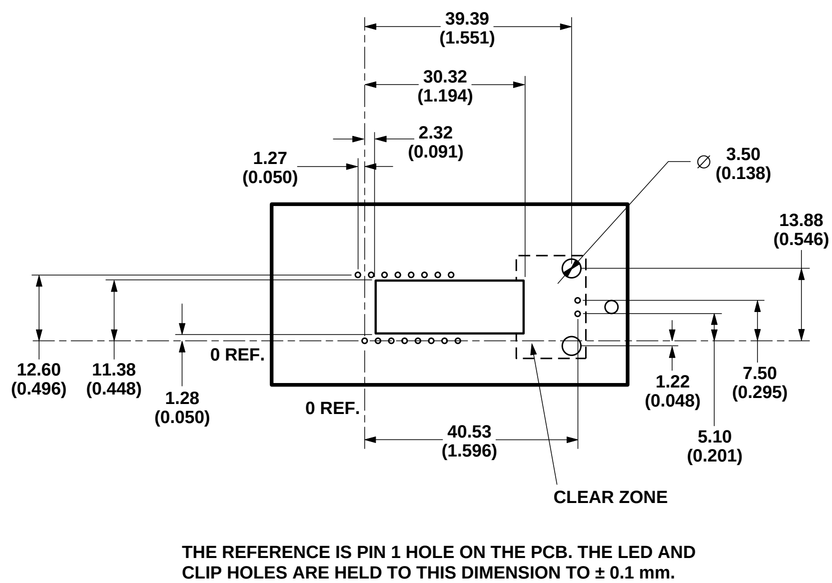


Figure 10. Recommended Hole Cutouts and Dimensions.

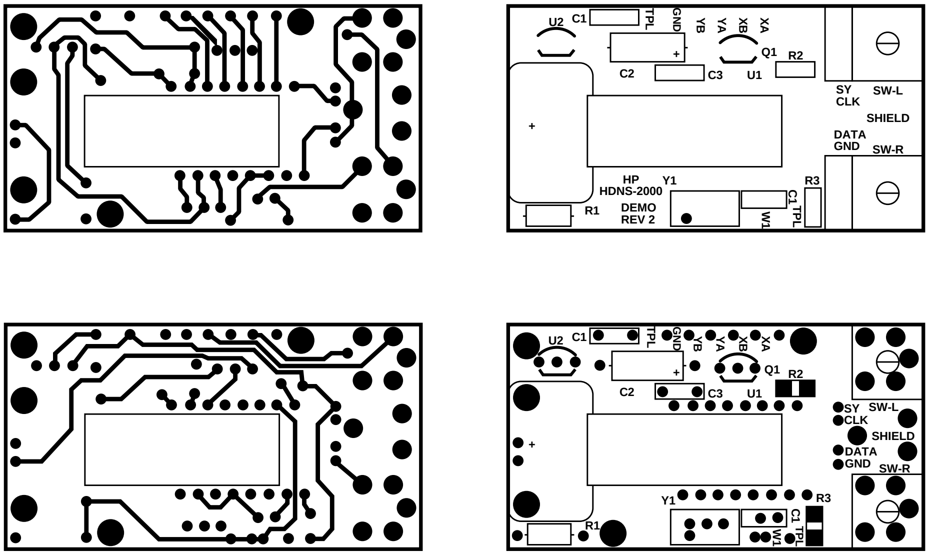


Figure 11. Example Printed Circuit Board Layout.

Component Placement

Two components warrant special attention during PCB layout. These are C3 (the 0.1 µF capacitor between pins 7 ($V_{DD}3$) and 8 (REFB) and Y1 (the ceramic resonator between pins 9 (OSC1) and 11 (OSC2). C3 should be placed as close as possible to pins 7 ($V_{DD}3$) and 8 (REFB) in order to minimize the inductance of this path. This will reduce both the supply noise inside the HDNS-2000 and the radiated emissions from the mouse. Y1 should be placed close to pins 9 (OSC1) and 11 (OSC2) in order to minimize parasitic capacitance on the oscillator traces. The region around pin 9 (OSC1) should be kept clean and free of debris which might cause DC leakage currents over 1 µA. Finally the inductance of the path from pins 10 and 12 (GND) to the ground wire (or shield if it exists) in the mouse cable should be minimized by keeping the distance short and the trace wide. This will help reduce radiated emissions from the mouse.

Lumination Considerations

Illumination of the surface is critical to the function of the HDNS-2000 sensor. Proper illumination of the scanned surface has several benefits. It maximizes the variety of surfaces on which the sensor functions and the velocity and accuracy with which the HDNS-2000 sensor tracks motion. Optical and electrical specifications and performance are based on using Agilent's optical tracking engine with the HLMP-ED80 LED over the recommended operating conditions. Improperly designed illumination and optics will reduce the accuracy of the sensor and the variety of surfaces on which it will function.

The illumination system must deliver a minimum light output for the sensor to function properly on the full range of surfaces. The brighter the illumination, the wider the range of surfaces on which the sensor will function. Light output is dependent upon the choice of LED drive circuitry and LED brightness bin variations (see Table 5 below).

Table 5. Light Output Requirements

Surface	Min. Light Output W/m^2
White bond paper	10
Black bond paper	55

If the illumination is too bright, eye safety must be considered. The resistor values in Table 4 have been selected to meet IEC60825-1 AEL Class 1 eye safety regulations. Class 1 eye safety regulations define the maximum acceptable light output of the optical tracking engine illumination system. The acceptable range of light output is bounded on the high end by safety limits and is bounded on the low end by satisfactory function of the mouse.

Surface Characteristics

The HDNS-2000 sensor works on a wide variety of surfaces. The sensor uses microscopic features of the surface to register motion. These features may come from fine texture in the surface and/or from color contrast. The sensor acquires surface images and compares successive images to determine motion.

Surfaces with texture and/or pattern features work well with the sensor. Examples of problematic surfaces include mirrors, glass, some half-tone printing surfaces, and 3-D mouse pads.

Frequently Asked Questions

What's new about this optical mouse sensor vs. previous optical mice?
Agilent's Optical Tracking Engine does not require a mouse pad in order to track motion. The sensor acquires subsequent images of the surface to calculate relative motion displacement values. Other optical mice in the market place require special mouse pads that reflect light off of a grid pattern onto photo-detectors to track motion.

What are the advantages of an optical tracking engine over a mechanical tracking engine?
An optical tracking engine is more reliable than a mechanical tracking engine due to the fact that there are no moving mechanical parts that can break down or require periodic cleaning.

Will this mouse require periodic dust cleaning?
Occasional cleaning of the base plate hole opening may be necessary. However, no disassembly is required.

Will water condense inside the sensor? If so, is that OK?
By design, the package is not sealed. It allows condensation to evaporate.

How much current is allowed in the LED while still meeting eye safety laws?
See Table 4.

Can the assembled components survive 15KV air-discharge ESD tests?
Yes, they will, since the HDNS-2100 lens creepage distance precludes direct discharge to the sensor.

Will I have trouble meeting FCC/IEC emissions requirements since the product has an 18 MHz clock?
Agilent internal testing demonstrated that the BBM-2000 evaluation unit's emissions were below FCC Class B limits. Customer's results depend upon PCB layout and other construction details.

Is it possible to meet USB suspend mode current limits using this sensor?
Powering down the LED and sensor may be necessary.

How much current is needed in the LED for adequate performance?
See Table 4 and 5.

Is a fixed resistor LED drive acceptable given LED variations?
Some performance degradation will occur. HP recommends matching the resistor to the LED bin. See Table 4.

Can an IR or other color LEDs be used?
Yes, see Illumination considerations and HDNS-2000 data sheet.

What shape feature is needed in my base plate? Will Agilent provide a CAD model file for the necessary base plate features?
Agilent provides recommended base plate molding features to ensure optical alignment. Contact your local Agilent sales engineer to receive an IGES file containing the solid design of the base plate.

How precisely does the lens have to be aligned relative to the sensor?
The lens and sensor are self-aligning. See Mechanical Considerations section.

What soldering process is recommended?
A "no-wash" wave solder process is recommended.

Does the sensor work on every surface?
The sensor works on a wide variety of common surfaces. See Surface Characteristics section.

How do I get samples?
The HDNK-2000 Sample Kit is available. See your local Agilent field representative or http://www.agilent.com/view/sensors for more details.

Product Support

Questions should be addressed to your local Agilent field sales representative. Additional information is available on http://www.agilent.com/view/sensors.

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