# Evaluating the Sensitivity of a Fiber-Optic Displacement Sensor

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This study was undertaken to establish the sensitivity of the Model AT88NE1 reflectance-dependent fiber-optic displacement sensors (see Photo 1) manufactured by Philtec. Our interest lay in determining the smallest amount of vibratory motion that these devices could detect. It should be noted that their sensitivity is an issue entirely separate from that of their broadband S/N ratio, which we did not attempt to measure.

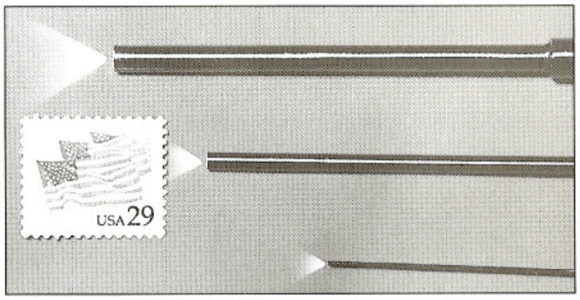


**Photo 1.** *Type 88N sensor tips are provided with fiber bundles as large as 3/16 in. dia. and as small as 0.006 in. dia. Although light rays diverge away from the sensor, they can be reflected back into the sensor tip from an area that is equal to that of the fiber-optic bundle.*

Specifically, we measured the smallest detectable signal from the detector when it was directed at a mirror whose position was oscillating at a specific frequency, as that displacement oscillation was decreased. To reduce the influence of the broadband noise spectrum on the detection limit, we used a frequency-specific (lock-in) amplifier for signal measurement.

The sensor used for these experiments was a standard unit except for one modification. There is a gain potentiometer on the standard unit, which is used to normalize the output to a maximum of 5 V for the target being measured. With the modification implemented, we were able to set up the sensor for our target mirror, adjust the gain pot for 5 V F.S., and then substitute a fixed-value resistor in place of the standard gain pot. This modification was implemented to increase the repeatability of the sensor electronics. The model number used to describe this modified unit was A88NE1S.

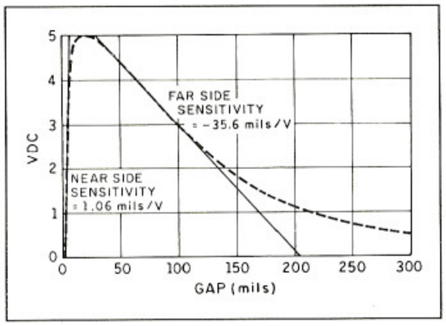


**Figure 1.** *The output voltage characteristic vs. gap is double valued. The region of maximum voltage output is referred to as the optical peak. The usable operating range includes linear ranges on both sides of the peak as well as operation at the peak itself, because the peak can be very flat in some models.*

## EXPERIMENTAL SETUP

The AT88NE1S fiber-optic displacement probe (see sidebar) delivers light through one-half of a fiber-optic bundle and measures the intensity detected in the other half. The resulting output as a function of the distance from the end of the bundle to a reflecting surface is shown in Figure 1. The detector operates at two distance ranges: the near side (with a linear response of ~ 1.968–3.936 mils), and the far side (~ 49.200–98.400 mils). The near side was selected for this study because the detector is 30 × more sensitive in this region.

The reflector was a front surface aluminized optical-quality mirror. The mirror was positioned by a PZ-80 piezo-driven actuator from Burleigh Instruments, Inc., (Fishers, New York), with a primary resonant frequency of ~ 5 kHz. The experimental setup is shown in Figure 2.

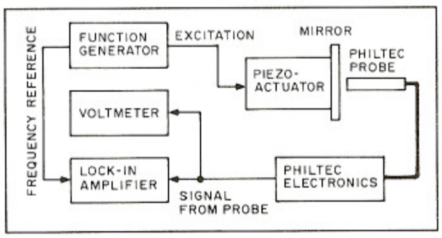


**Figure 2.** *The experimental setup allows a frequency-specific measurement of the mirror motion.*

## EXPERIMENTAL TECHNIQUE

The sinusoidal output from a function generator was used to drive the piezo actuator. The frequency reference from the function generator was input to the lock-in amplifier as its operating frequency. Before activating the oscillation signal, we adjusted the distance from reflector to detector to the detector's near side range such that the output from the detector was 2.50 V. The first set of measurements was performed by applying a fixed-amplitude sine wave to the actuator and varying the frequency of that sine wave.

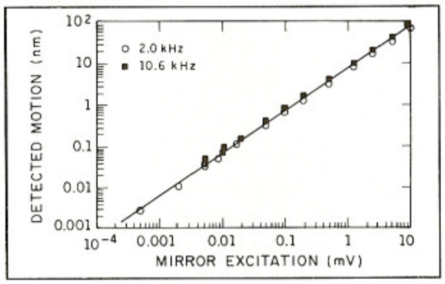


**Figure 3.** *The detected motion at low amplitudes shows the sensitivity of the measurement system, including the Philtec probe. The mirror excitation voltage is linearly related to the motions of the mirror.*

## Series 88 Fiber-Optic Displacement Sensors

*Gerald J. Philips, Philtec, Inc.*

The Series 88 fiber-optic displacement sensors detect the intensity of light reflected from a target surface. The basic elements of these devices (see Figure 4) are a sensor tip; a cable in which light-conducting glass fibers are arranged in bundles; and an optoelectronic amplifier. Inside the amplifier, the fibers are grouped into transmit and receive bundles. At the sensor tip, transmit and receive fibers are mixed and grouped into various geometric arrangements to create different sensor responses to target motion.

Noncollimated light is coupled into the transmit fibers at the amplifier end. At the sensor tip, light rays diverge from each transmit fiber, and are reflected off the target surface and into the adjacent receive fibers (see Figure 5). The Series 88 detectors do not use collimated light because all the light would be reflected back into the transmit fibers instead of into the receive fibers.

The detectors perform with high accuracy when the angle of light rays incident on the target surface is equal to the angle of reflection off the target, a condition that exists when the surface is smooth and reflective. Dull finishes and rough or textured surfaces tend to scatter light rays at random angles, i.e., the angle of incidence does not equal the angle of reflection. Such light scattering reduces the accuracy of these sensors.

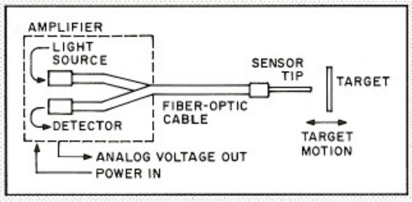


**Figure 4.** *Type 88N sensors are reflectance-dependent devices that are commonly used to measure target motions that move or vibrate toward and away from the sensor tip. The same portion of the target surface is continuously present in front of the sensor tip.*

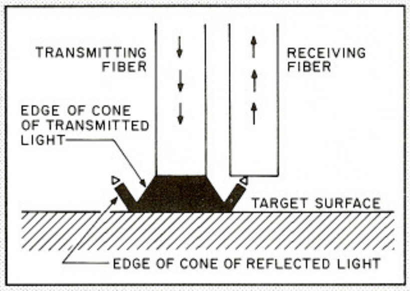


**Figure 5.** *Light-transmitting fibers generate rays of light that illuminate adjacent receiving fibers. The Series 88 sensors do not use collimated light; to do so would cause all the light to be reflected back into the transmit fibers instead of into the receive fibers.*

The primary mechanical resonance of the actuator resulted in a peak near 4 kHz. Based on initial testing, two frequencies were chosen for further study: 2.0 kHz (below the primary resonance) and 10.6 kHz. The second frequency was selected because a resonant peak resulted in an amplitude response nearly identical to that below the primary resonance. Hence, the amplitude response is nearly identical at these two frequencies.

For the second part of this investigation, the amplitude was reduced until the signal was no longer reliably detectable. This procedure was repeated for the two chosen frequencies. The very low signal response, however, was measured only at 2 kHz; the results are shown in Figure 3.

The testing revealed the detector to be very sensitive. The smallest detectable signal was 200 nV, corresponding to a motion of 2 pm. For the signal magnitude to be measured with 5% accuracy, it would have to be 50 × greater. A motion of 1 Å can therefore be measured. The nature of the application would, of course, determine whether the detectability limit (1 pm), or the lowest accurately measurable signal (0.1 nm) is the probe's more important characteristic.

No attempt was made to determine which component of the experimental setup resulted in the measurement limit determined. Candidates include the lock-in amplifier's ability to measure submicrovolt signals; the detector's ability to reproducibly produce such signals; and the actuator's mechanical stability at such small motion levels. At any rate, the measurements indicate a detection level at least as sensitive as that stated above.

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