High Sensitivity Optical Fiber Sound Detector

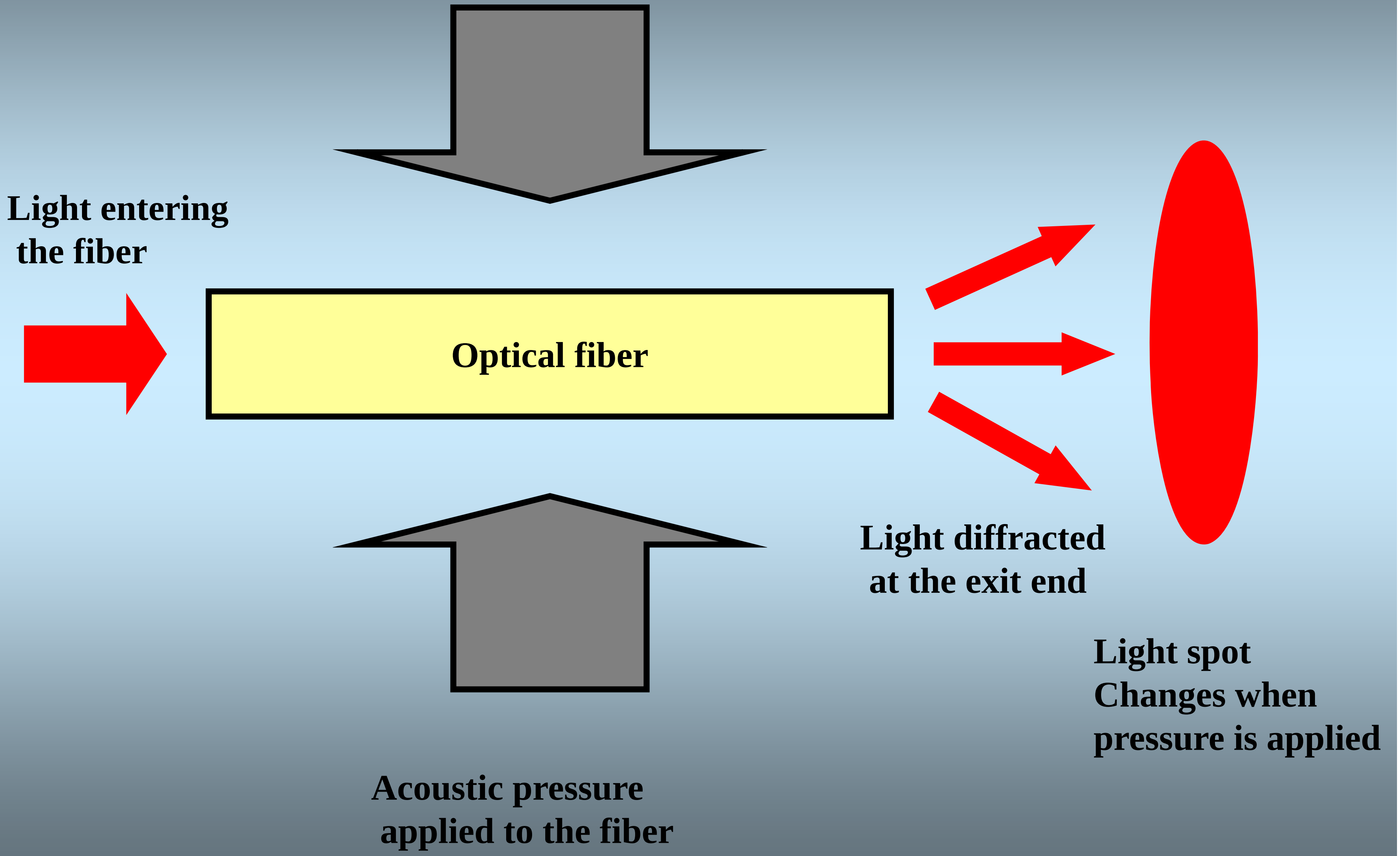
by

Aristides Marcano O. and N. Melikechi
Center for Research and Education in Optical Sciences and Applications (NSF-CREST), Delaware State University, 1200 N Dupont Highway, Dover, Delaware 19904
amarcano@desu.edu and melik@desu.edu

We propose a new design for an optical fiber sensor sensitive enough to detect sound of few decibels.

The device measures the changes of the diffraction pattern of light at the exit end of the fiber (phase sensitive sensor).

BASIC IDEA


Light entering
the fiber
Optical fiber
Light diffracted
at the exit end
Light spot
Changes when
pressure is applied
Acoustic pressure
applied to the fiber

Estimation of the sensor sensitivity

When light propagates through the fiber the additional phase that the wave front acquires is

$$\Phi = \frac{2\pi}{\lambda} nL$$

Where L is the length of the fiber, n the refraction index and l is the light wavelength

If the fiber is exposed to an acoustic field the refraction index changes due to the photo-elastic effect according to the equation

$$\Delta n = -n^3 pS(\vec{r}, t)$$

Where p is the unit-less photo-elasticity coefficient and S is the strain of the acoustic wave.

***Photoelasticity*, Volume 1 by Max Mark Frocht**

Then, the phase change due to the photo-elastic effect is

$$\Delta\Phi(t) = -\frac{2\pi}{\lambda} p n^3 L S(t)$$

This phase changes with time according to the time dependence of the acoustic wave

Now we can estimate the phase change amplitude generated by an acoustic wave of amplitude S_o

The acoustic amplitude can be written as

$$S_o = \left(2I_a / (\rho V_a^3)\right)^{0.5}$$

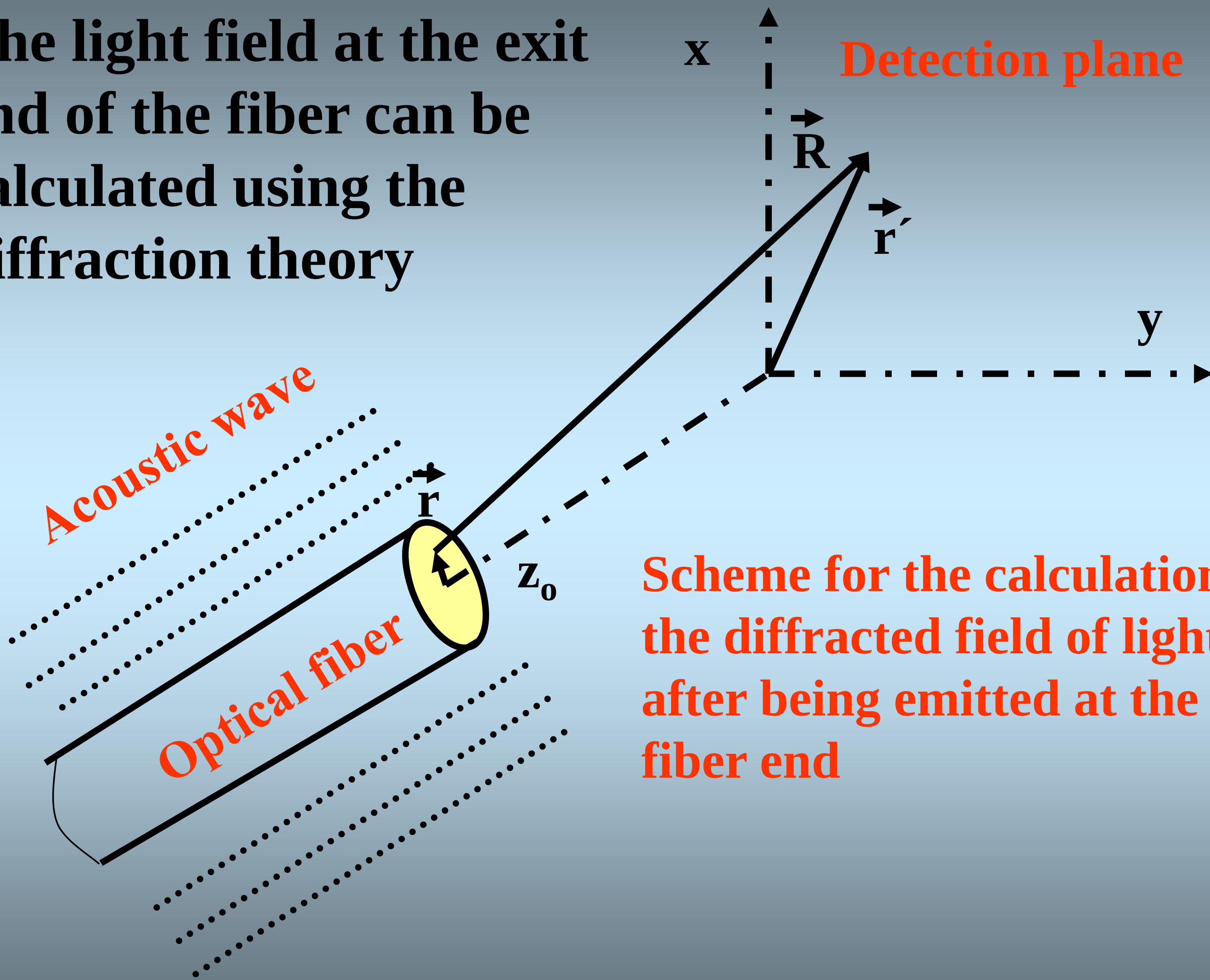
I_a is the acoustic intensity in W/m^2, for human voice is of the order of *10^{-8} W/m^2 (40 Db)*
V_a is the speed of sound waves in the fiber material and r the density of the material.
For the parameters (typical for glass) *$p=0.3$, $n=1.5$, $\rho=3$ g/cm^3 $V_s=3000$ m/s (see Hanbook of Chemistry and Physics, 33rd edition, Cleveland, Ohio)*, and for a fiber of *L=1 mts* we obtain a phase shift of

$$\Phi_o = 2\times10^{-4}\,\mathrm{rad}$$

$$\Delta n = 10^{-12}$$

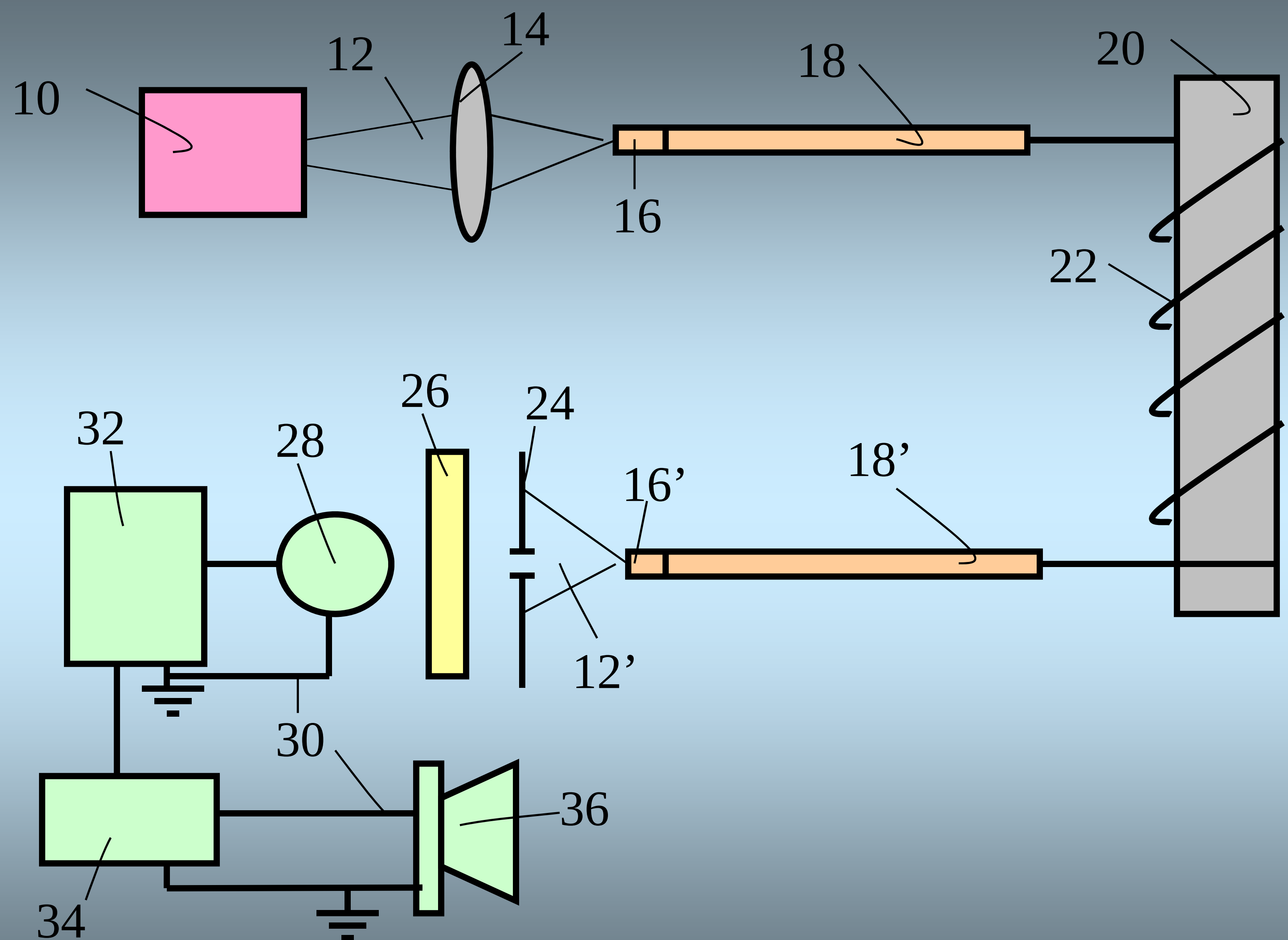
W. W. Rigrow and I. P. Kaminow, Proc. SPIE Vol. 1, 137 (1963)

The light field at the exit end of the fiber can be calculated using the diffraction theory



Scheme for the calculation of the diffracted field of light after being emitted at the fiber end

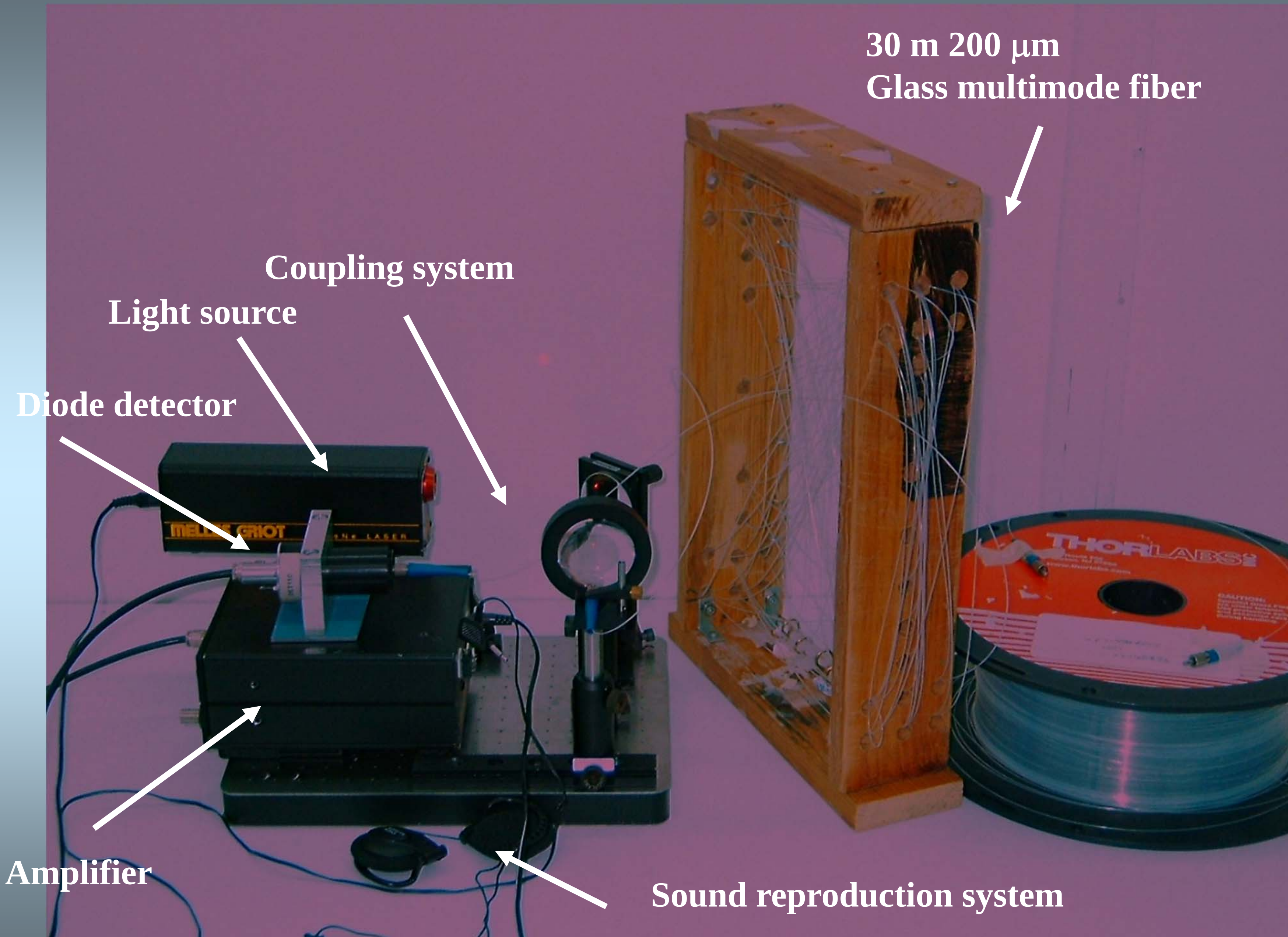
We locate a small aperture at some distance from the end of the fiber and measure the transmission through it. Changes in the light transmission of this aperture are proportional to the acoustic wave amplitude.



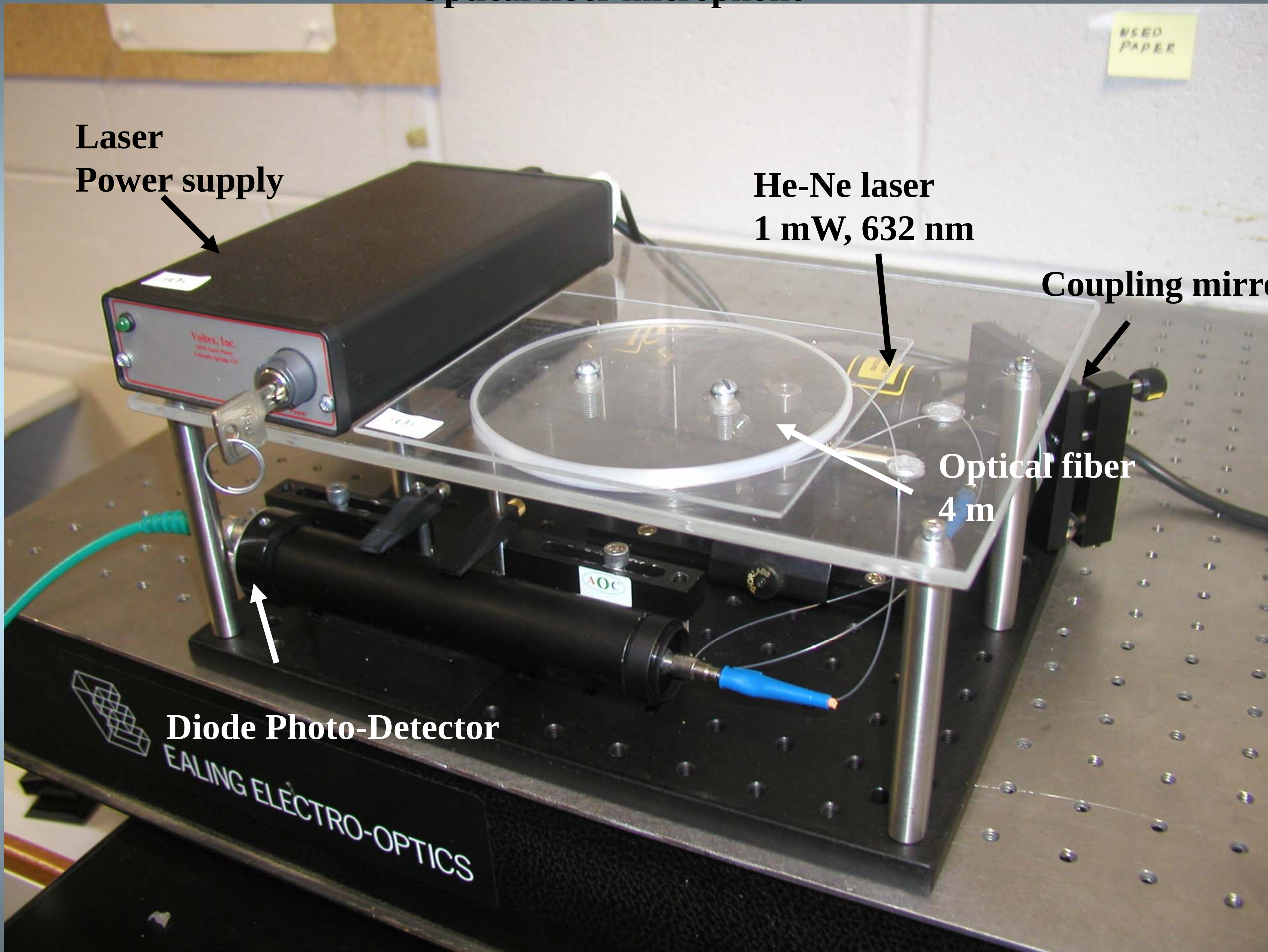
Scheme of the fiber optics microphone

Explanation toward the scheme of the optical fiber detector

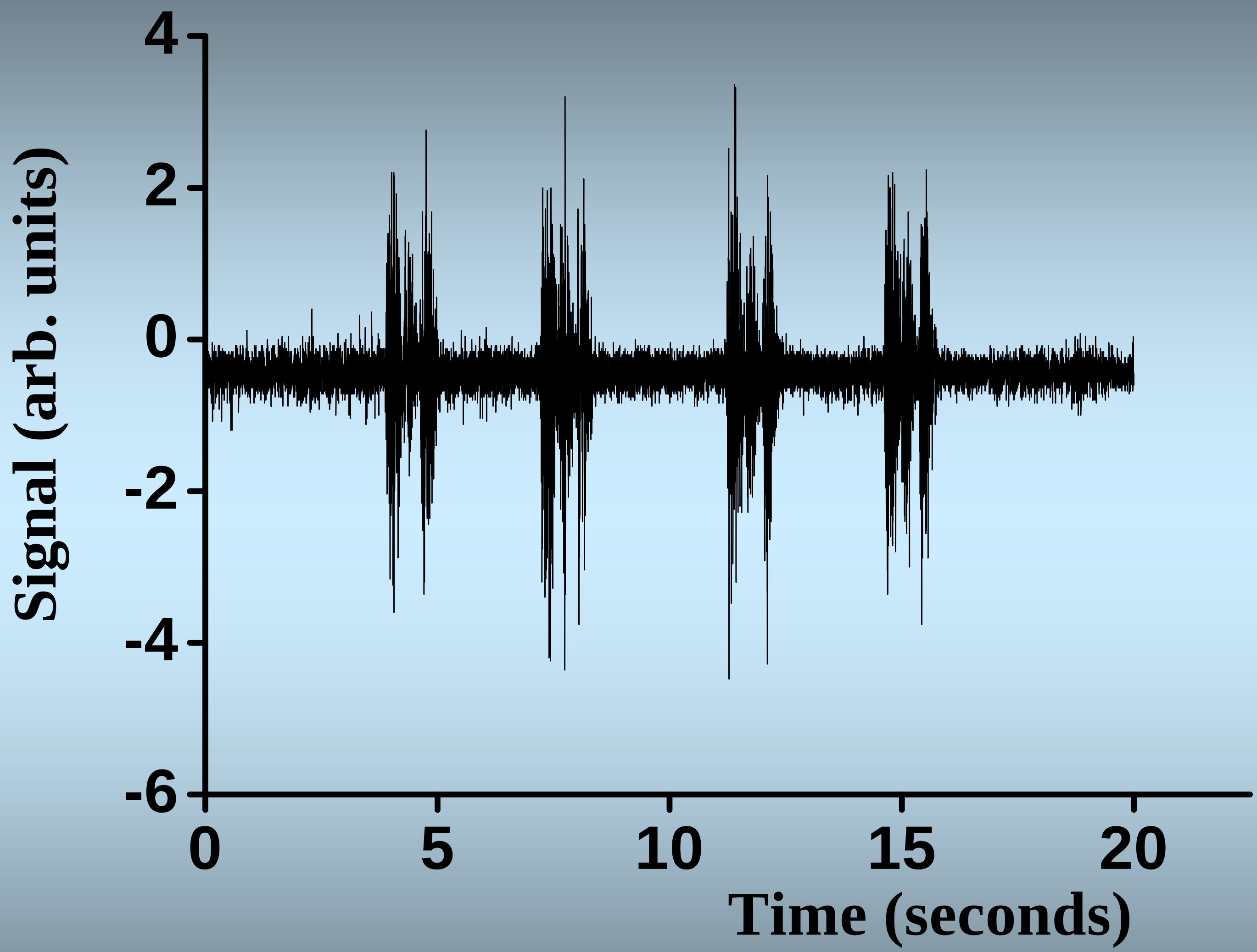
10 – Light source (low power He-Ne or diode laser)
12 – Light collected onto the optical fiber
14 – Coupling lens
16 – Optical coupler
18 and 18'– Isolated optical fiber
20 – Mechanical support for the optical fiber
22 – Active optical fiber
24 – Aperture
26 - Optical interference filter centered at the light wavelength
28 – Diode photodetector
30 – Connecting cables
32 – Current preamplifier
34 – Power amplifier
36 – Sound reproduction system


30 m 200 μm
Glass multimode fiber
Coupling system
Light source
Diode detector
Amplifier
Sound reproduction system
THORLABS

Optical fiber microphone

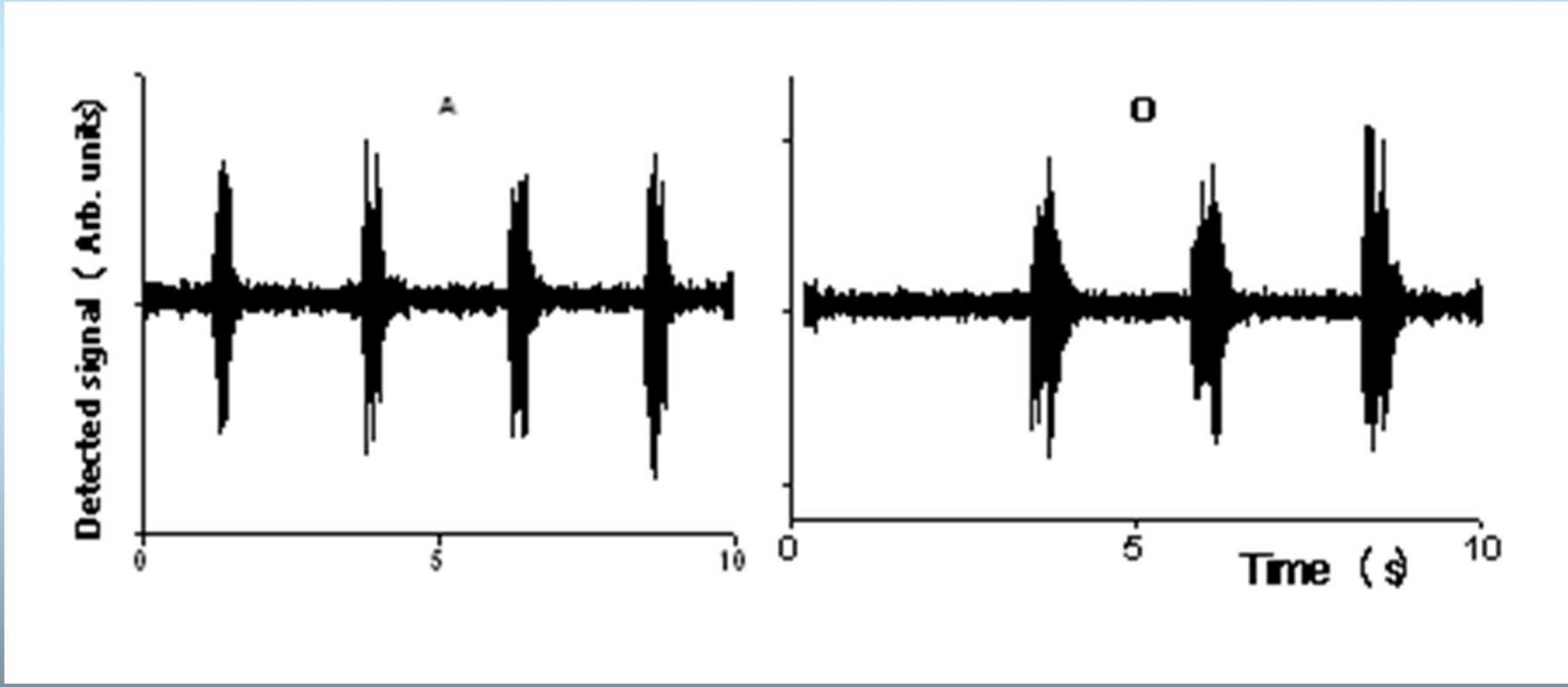


We have demonstrated that a 1-m long fiber with a coupled light beam of 1 mW (He-Ne light at 632 nm) can detect human voice with a signal-to-noise ratio of 10. Thus, the minimum phase change that can be detected with this system is of the order of 10^{-5} rad. This corresponds to an acoustic field more than 10 times smaller than the human threshold detection limit (10^{-11} W/m^2). Longer fiber should provide more sensitivity.

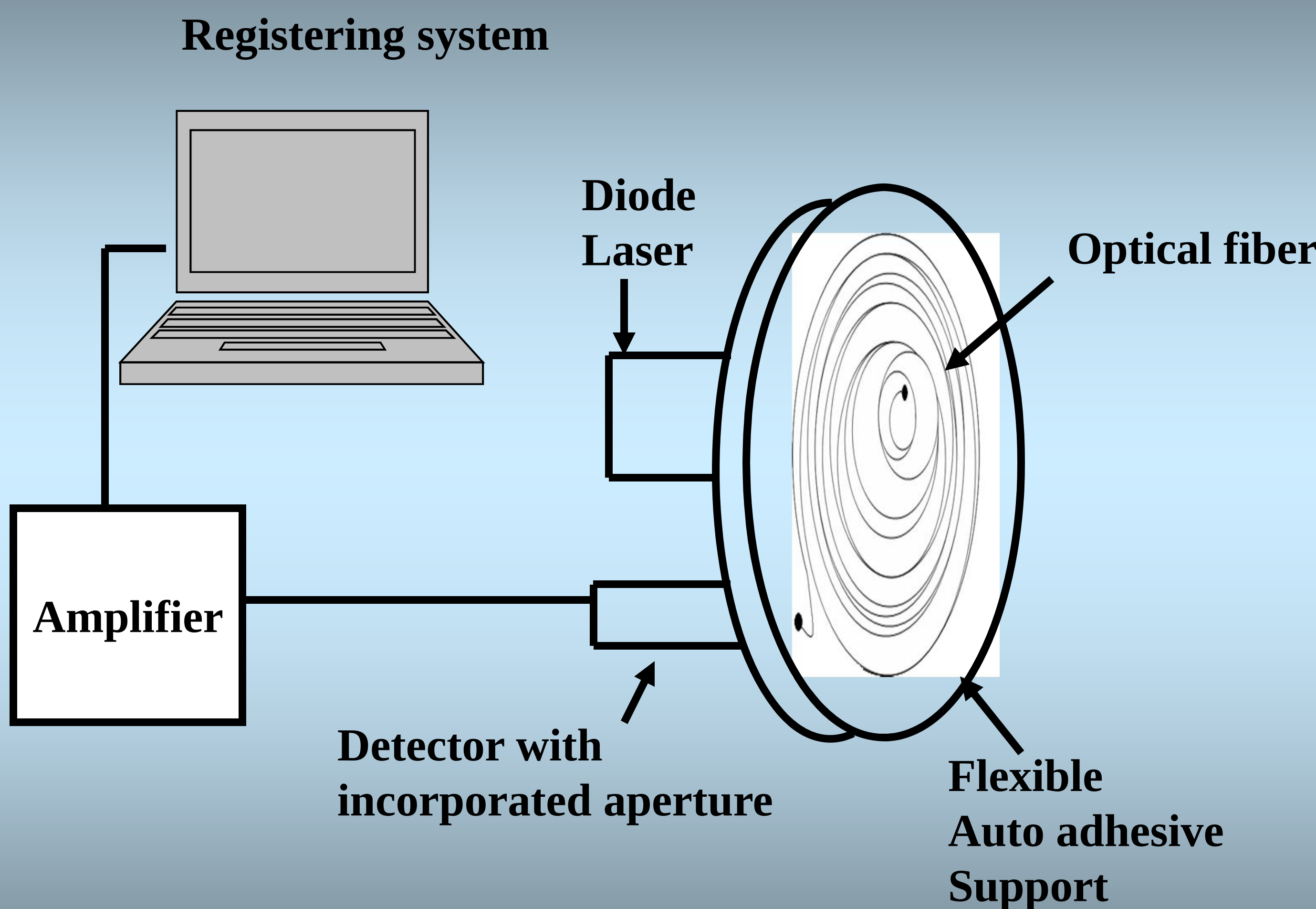


The register of the fiber detector of the word "FIBERPHONE" pronounced four times

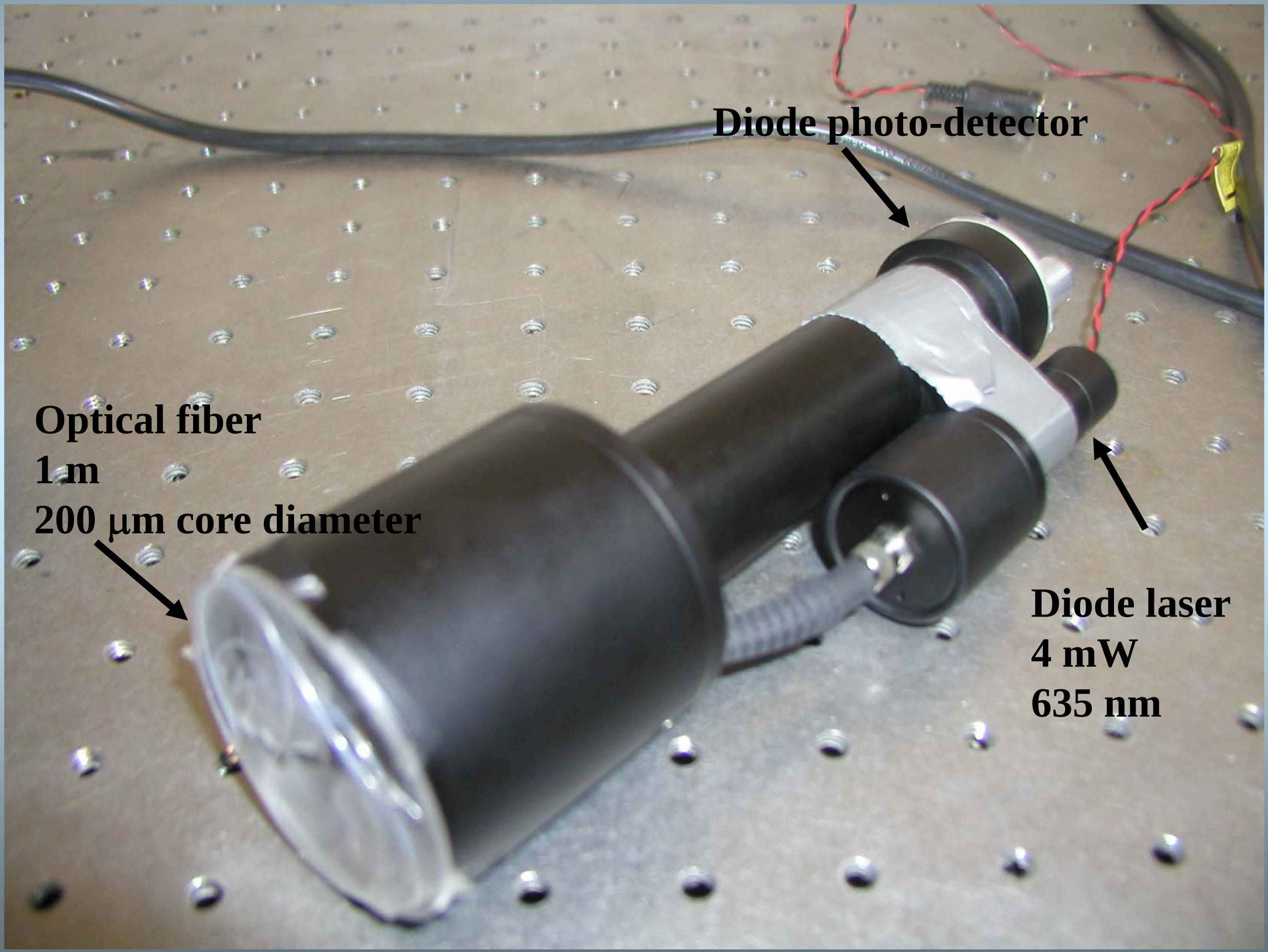
The register of the fiber detector of the letter A pronounced four times and letter O pronounced three times

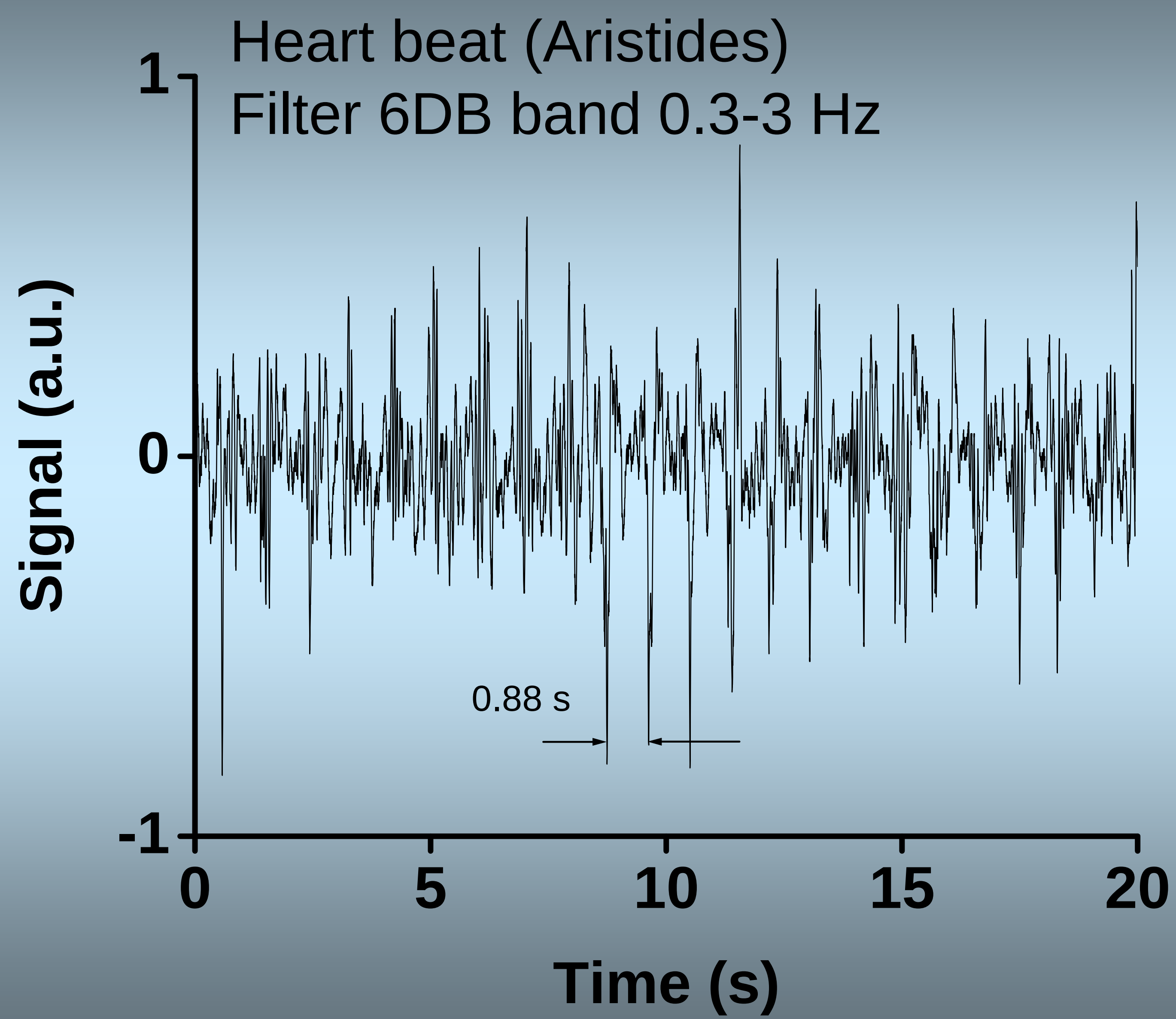


Optical fiber stethoscope for external use



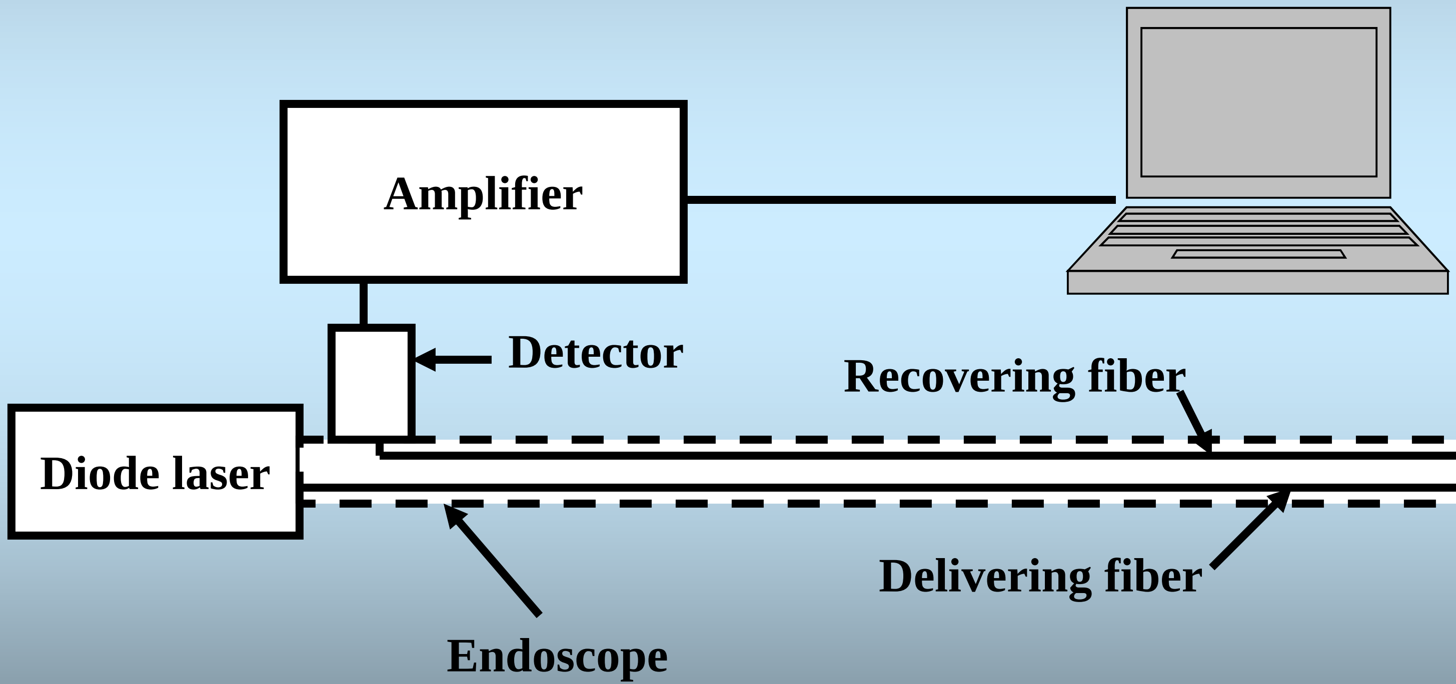
Optical fiber stethoscope





Heart beat (Aristides)
Filter 6DB band 0.3-3 Hz
1
0
-1
Signal (a.u.)
0.88 s
0
5
10
15
20
Time (s)

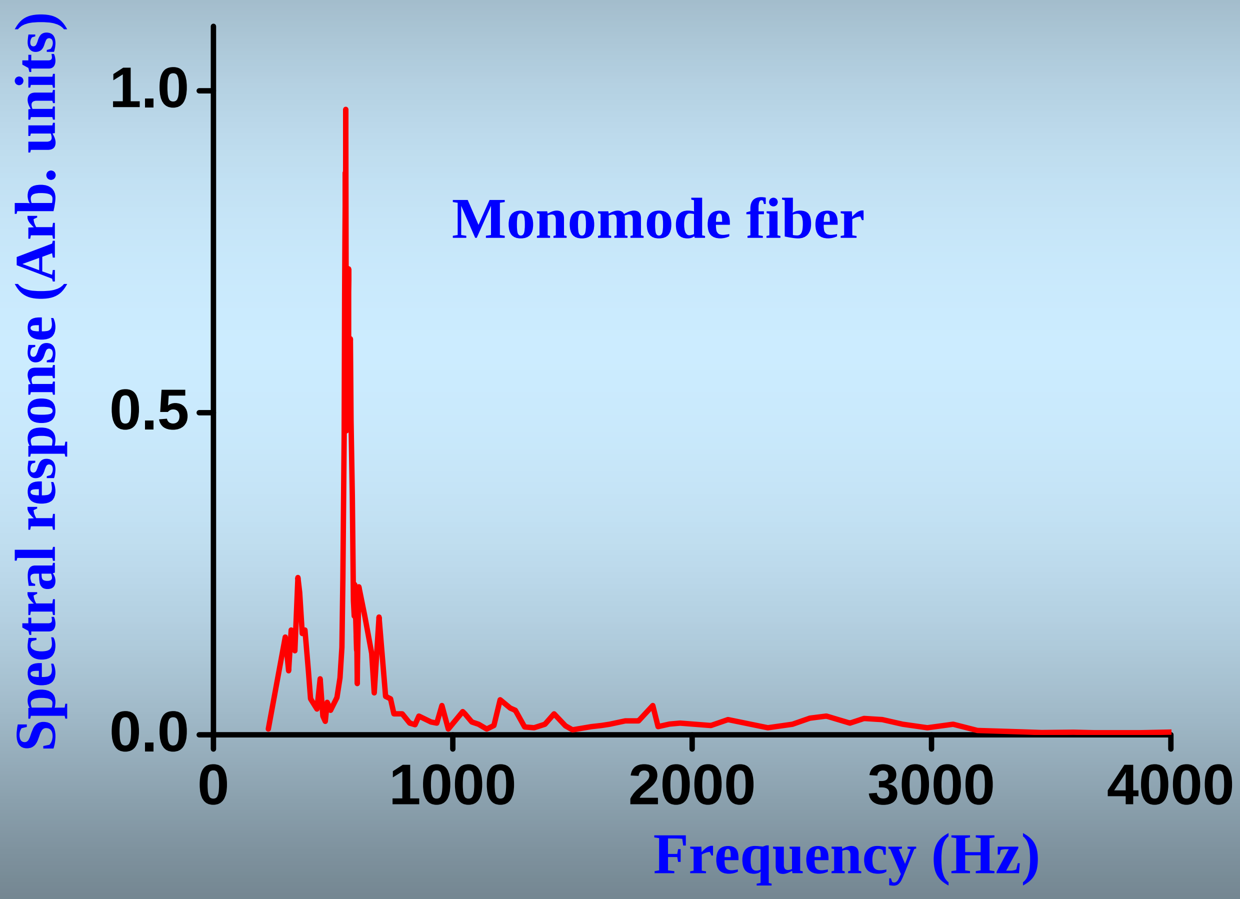
Fiber optics stethoscope for internal use



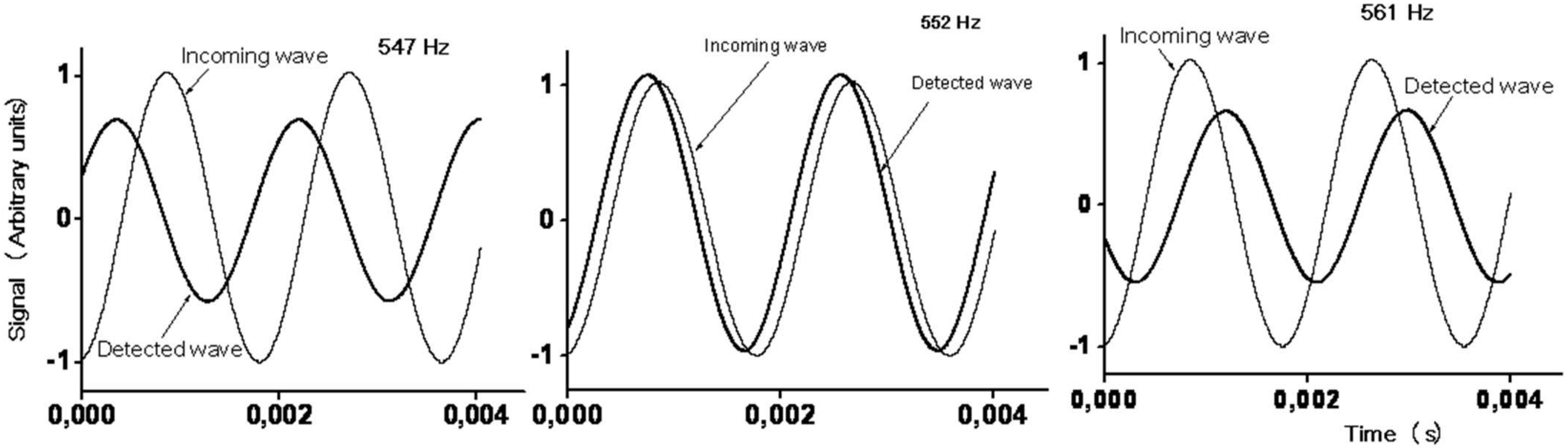
We have studied the spectral response of the device

Monomode and multimode fibers were used

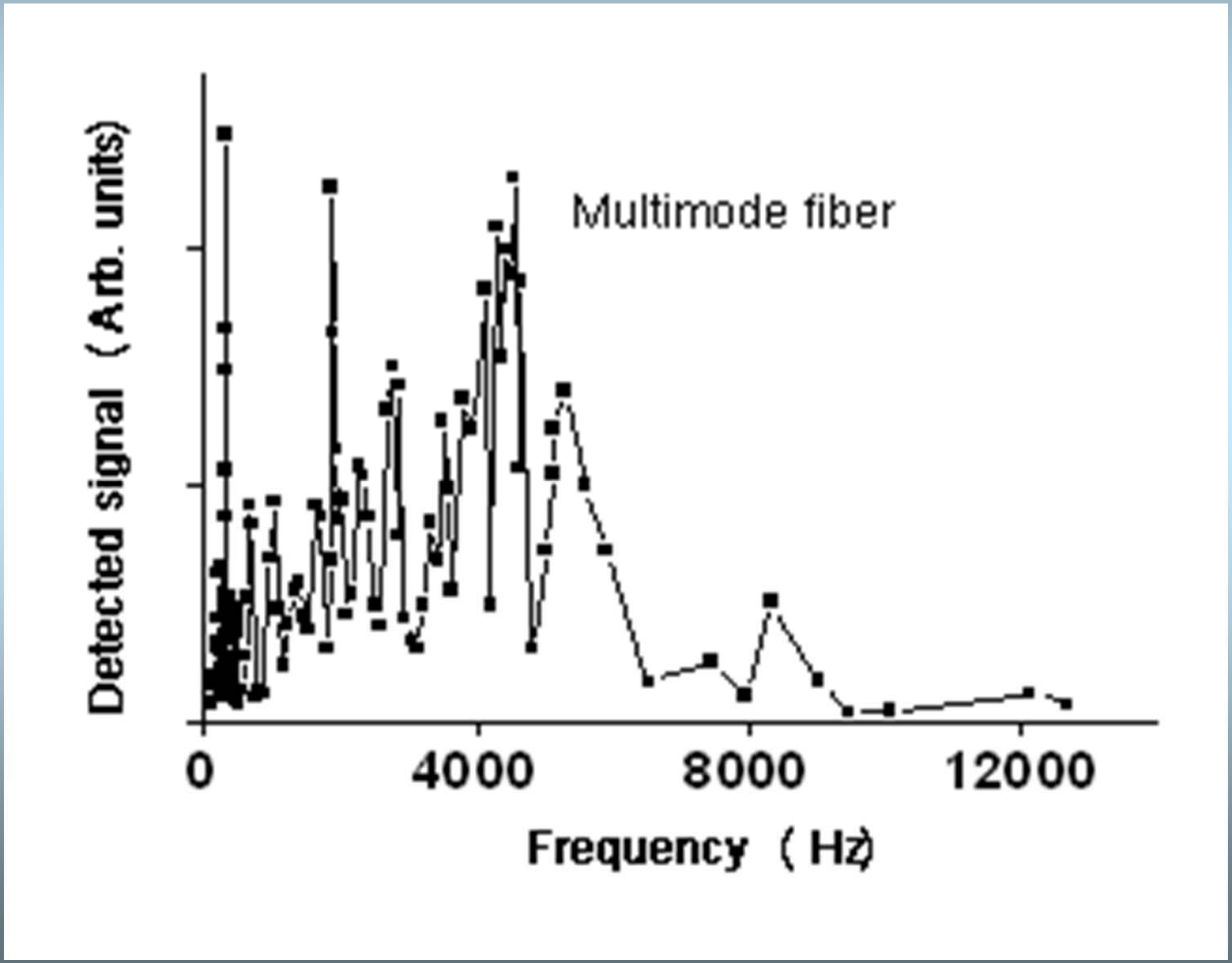
Spectral response of an 8-μm diameter 2-m long monomode glass fiber



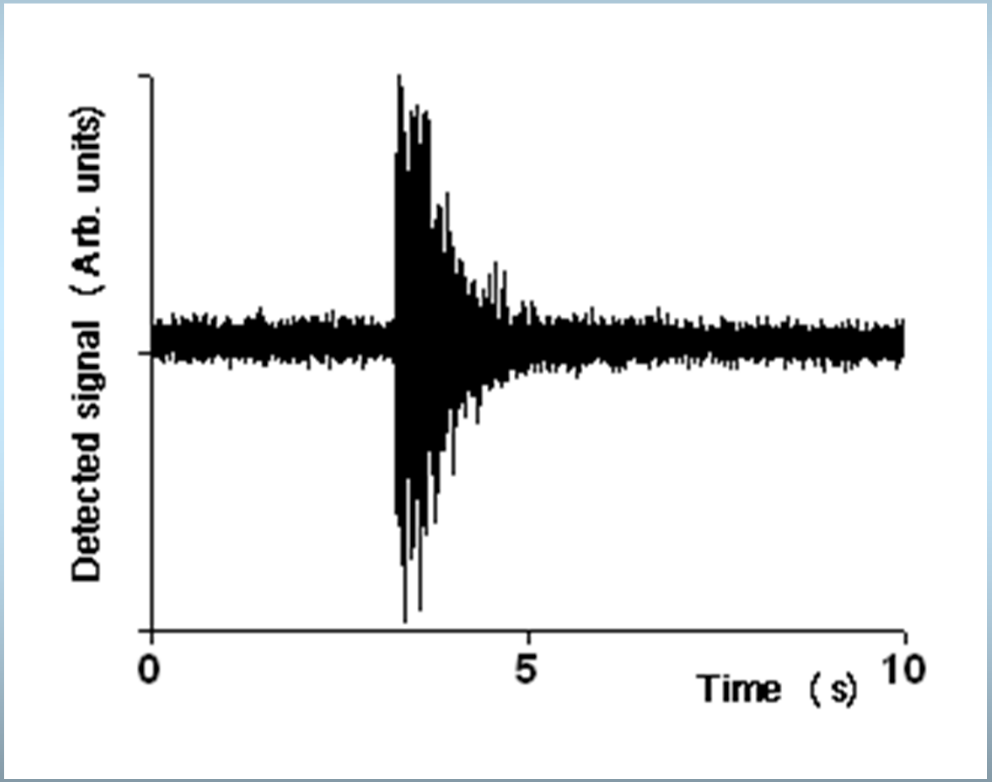
Impinging and detected by the monomode fiber acoustic wave for three different frequencies as indicated



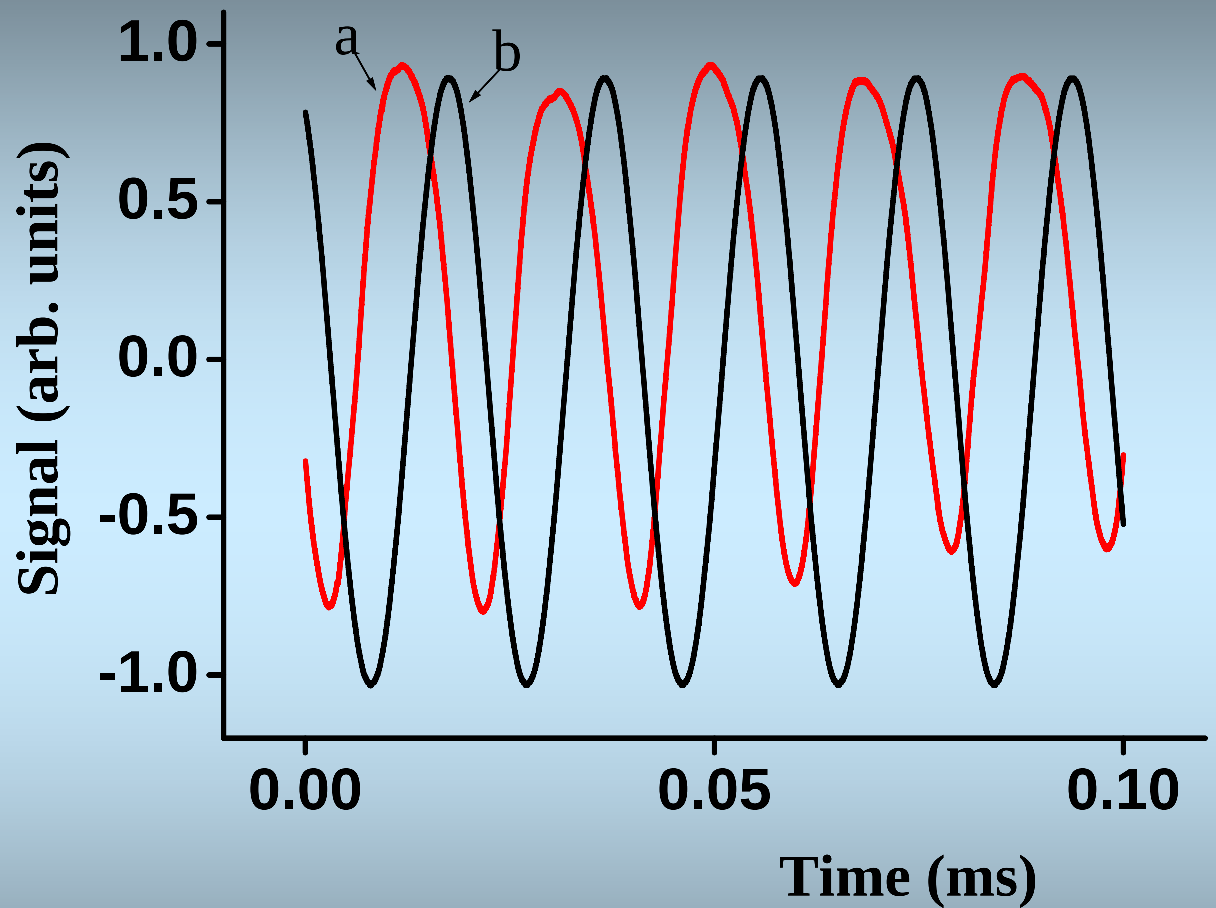
Acoustic spectral response of 1-m long 200-mm diameter multimode glass fiber



The signal detected when touching the optical fiber



Ultrasound can be detected as well



High frequency signal as registered by the detector (curve a). For comparison we show also the excitation signal (curve b)

Advantages

1. Phase detector – high sensitivity

2. Simplicity – no special requirements for the fiber

3. Distributed optical fiber sensing – large structure monitoring

4. Low cost – works with conventional low cost technology

5. Real time vibration effects monitoring

6. Versatility and universality

Possible applications

1. High sensitivity microphones
2. Alternative communication system
3. Alarm systems of large facilities
4. Monitoring of large structures
5. Stethoscope of new design, including for internal monitoring
6. Measuring flow of liquids through a pipe.
7. Pressure sensor

CONCLUSIONS

We have demonstrated a new type of optical fiber detector based on the phenomena of light diffraction at the exit end of the fiber. The sensitivity is large enough to detect human voice clearly. A preliminary study of the spectral response of the detector is presented. We show that detector can work using monomode and multimode fibers although they acoustic spectral response are different. The detector can be also used for the registration of ultrasound. In general, the described device can be use not only for acoustic field detections. Any effect able to induce changes in the refraction index of the fiber will give similar response.

Thank you!