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**PARALLEL INFORMATION PROCESSING  
(IMAGE TRANSMISSION VIA FIBER BUNDLE AND MULTIMODE FIBER)**

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## **Introduction**

Growing demand for visual, user-friendly representation of information inspires search for the new methods of image transmission. Currently used in-series (sequential) methods of information processing are inherently slow and are designed mainly for transmission of one or two dimensional arrays of data. Conventional transmission of data by fibers requires many fibers with array of laser diodes and photodetectors.

In practice, fiber bundles are also used for transmission of images. Image is formed on the fiber-optic bundle entrance surface and each fiber transmits the incident image to the exit surface. Since the fibers do not preserve phase, only 2D intensity distribution can be transmitted in this way. Each single mode fiber transmit only one pixel of an image. Multimode fibers may be also used, so that each mode represent different pixel element. Direct transmission of image through multimode fiber is hindered by the mode scrambling and phase randomization. To overcome these obstacles wavelength and time-division multiplexing have been used, with each pixel transmitted on a separate wavelength or time interval [1-2]. Phase-conjugate techniques also was tested in [3-5], but only in the unpractical scheme when reconstructed image return back to the fiber input end. Another method of three-dimensional imaging over single mode fibers was demonstrated in [6-9], using laser light of reduced spatial coherence. Coherence encoding, needed for a transmission of images by this methods, was realized with grating interferometer or with the help of an acousto-optic deflector.

We suggest simple practical holographic method of image transmission over single multimode fiber or over fiber bundle with coherent light using filtering by holographic optical elements. Originally this method was successfully tested for the single multimode fiber [10-11]. In this research we have modified holographic method for transmission of laser illuminated images over commercially available fiber bundle (fiber endoscope, or fiberscope).

## **Principle Of Holographic One-Way Direct Image Transmission**

In this section we will describe the basic principle of direct parallel image transmission, using holographic grating recording in photorefractive crystal  $\text{LiNbO}_3$ , doped by Fe.

First we remind basic features of image transmission over single multimode fiber, suggested and demonstrated in the paper [11]. This method was realized with the help of HeNe laser and a multimode fiber with  $70 \mu\text{m}$  diameter, numerical aperture of 0.17 and two meter long. After passing the optical fiber, the signal light wave  $E_s$  is mixed with another (reference) coherent wave  $E_r$  at the photorefractive crystal lithium niobate. The signal wave was also modulated by the amplitude mask(image) with transmission function  $T(x,y)$ . In this way dynamic hologram of the image and fiber wave was recorded in the crystal by photogalvanic mechanism of recording [11]. Retrieval of this hologram by the plane wave  $R$  (counterpropagating to the reference wave) lead to appearance of the diffracted wave  $D$ , that is phase conjugate to the signal wave. This phase conjugated wave propagate in the reverse direction via the fiber, speckle pattern is corrected and output wave reproduce input image.

The image formation may be explained in the following way: The probe signal beam excites  $N$  modes in the fiber, which form the resolution elements of the future image. Each of these  $n$  modes has its own propagation constant  $k_n$  and for this reason the beam has a speckle pattern at the fiber output. Then this beam is mixed in the crystal with the reference (pump) wave, modulated by the mask transmission. In our case diffracted, phase conjugated wave will be proportional to the transmission function  $T(x,y)$  and to the photogalvanic coefficient, that determine diffraction efficiency. Diffracted wave after propagating through the fiber into reverse direction is emitted from the fiber output end as a sum  $N$  eigen-modes with information about the image. This concept was confirmed by experimental demonstration of image transmission via commercial multimode fiber.

In this paper we use the same principle of holographic filtering with phase conjugated wave with more simple two wave scheme and using semi-permanent hologram. First we have recorded hologram of a fiber transmitting signal beam through the fiber and mixing it with the plane wave in the recording media: photorefractive crystal lithium niobate. Hologram recorded in the crystal may stay at room temperature at least several hours, so we may consider it as a fixed one. During retrieval, without changing optical scheme we introduce an image to the input end of the fiber bundle and block the reference beam.

In this case diffracted wave should be plane reference wave, modulated by the image. In other words, we have reconstructed image using hologram as a complex holographic filter, using simple two-wave mixing scheme.

### **Experimental Results With The Coherent Fiber Bundle**

In our experiments we have used commercial semi-rigid imaging fiber bundle (fiberscope) from Edmund Industrial Optics. This bundle incorporate six thousands of tightly packed individual fibers that are aligned coherently – both input and output ends retain position exactly opposite the other. Fiberscope length was about 10 cm, diameter 0.5mm with 25X eyepiece that offer a possibility of focusing of wide-angle image.

This fiberscope was placed in the signal wave leg of the traditional two scheme of hologram recording. Laser light from the diode-pumped solid-state CW laser (wavelength 532 nm, power up to 100 mW) was splitted in two beams, one was transmitted through fiberscope and thus forming a signal wave. Another, reference wave propagated in the free space and both beams recombine on the recording media : photorefractive crystal lithium niobate, doped with Fe. Variable beam-splitter was used to adjust optimal ratio of intensities for signal and reference waves. In our experiments we have used natural, unexpanded and unfocused laser beam (approximately 3mm in diameter). Eyepiece attached to fiberscope allow us to focus output signal beam on the crystal.

At the first reading stage hologram of fiberscope was recorded in the photorefractive crystal. On the reading-transmitting stage, reference wave was blocked and image ( Air-force resolution chart) was placed before input end of the fiberscope.

Diffracted beam in this scheme contain information about tested image. We have realized transmission of images with spatial frequencies of 21 /mm that was captured by the CCD camera attached to a beam profiler.

These preliminary experimental results demonstrate feasibility of the proposed concept of the holographic two-wave method of image transmission via fiberscope with coherent illumination.

### **Discussions and Conclusion**

Three-dimensional data transmission (like 3D-images) now is possible only with inevitable delay by in-series methods. Recently conceived method of parallel image transmission through multimode fiber is based on real-time holography using phase-conjugation principles. In this method image-bearing beam, aberrated by multimode fiber may be corrected by holographic complex filter. Holographic complex filter, working in real time, may be recorded in the photorefractive material with high diffraction efficiency.

First proof-of-principle experiment in 1991 (done in our group in the Institute of Physics, Kiev, Ukraine), proved feasibility of this idea for image transmission via multimode commercial fiber [1]. These encouraging experimental results allow us to be optimistic about possibility of development practical design for parallel information transmission.

There are several options based on the real-time holographic filtering, that are waiting for experimental testing and theoretical and computational

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