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# 3D IMAGING TRANSMISSION VIA THE OPTICAL HIGH FREQUENCY SYSTEM

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Abstract. *This paper presents an optical high frequency system for hologram transmission. The system consists of a microring resonator system incorporating an add/drop filter, where the large bandwidth signals are generated within the system. The input is a Gaussian pulse (i.e., with center wavelength at 1.55 μm). The other parameters used include the microring radii, coupling coefficient, and the linear and nonlinear refractive index. The results show that bandwidth expansion is achieved. The potential application of this system is the transmission of holographic 3D image displays on optical networks.*
**Keywords:** 3D images, Holographic display, 3D image transmission, Micro-optical device

1. **Introduction.** A three-dimension (3D) image is a visually realistic display of an object, which can be created by four methods: stereoscopic (with glasses), auto-stereoscopic, volumetric and holography (glasses-free) [1]. Presently, commercial products with 3D display capability are based on the stereoscopic technique, in which the 3D image is formed by the combination of the different images from the left and right eyes simultaneously to give a perception of depth [2]. 3D imagery has been developed to achieve visually realistic images. The best technique is the holographic image which eliminates the visual discomfort and eye fatigue resulting from viewing using 3D glasses [3,4]. Previous researchers have developed holographic displays [5-7]. These holographic three-dimensional displays have used photopolymers, holographic recording using a digital micromirror device, and real-time digital holographic microscopy that enables multiple reconstructed images. Elsewhere our research group has presented a technique using a conjugate mirror by PANDA ring circuit as a new type of holographic display application [8]. In that research holographic 3D images were created by using a micro-optical device; a PANDA ring conjugate mirror, which uses a volume pixel [9].

The major problem that has prevented the development of holographic 3D systems is the information storage capacity requirements. A 3D image requires a vast amount of data storage significantly larger than that required for a 2D image. A 2D image is broken down into micro sized pixels to be arranged and illuminated on a display. However, a holographic 3D image contains a huge amount of information, significantly greater than that required by a 2D image. The problem is therefore that a holographic 3D image needs a high bandwidth when it is transmitted over a network. There have been many network bandwidth expansion research projects, including [10,11]. The work reported in [10] was applicable to optical radio systems used in RFID applications and demonstrated a new optimized result in optical communication. The project in [11] applied to radio-over-fiber links using solitonic millimeter wave generated by a microring resonator for transmission on a network. However, about three-dimensional image transmission has not been implemented. Especially, the holographic 3D image display was generated by micro optical device system. This paper proposed a network bandwidth expansion technique on optical networks, enabling holographic 3D image transmission.

2. **Theoretical Background.** A Gaussian pulse propagating within a ring resonator has a constant light field amplitude ($E_0$) which is the combination of the terms attenuation constants ($\alpha$) and phase constants ($\phi_0$), where $L$ is the propagation distance (waveguide length). The microring resonator connects the multiple stages as shown in Figure 1. The input light field ($E_{in}$) of the Gaussian pulse is given by [12].

$$E_{in}(t) = E_0 e^{-\alpha L + j\phi_0(t)} \tag{1}$$

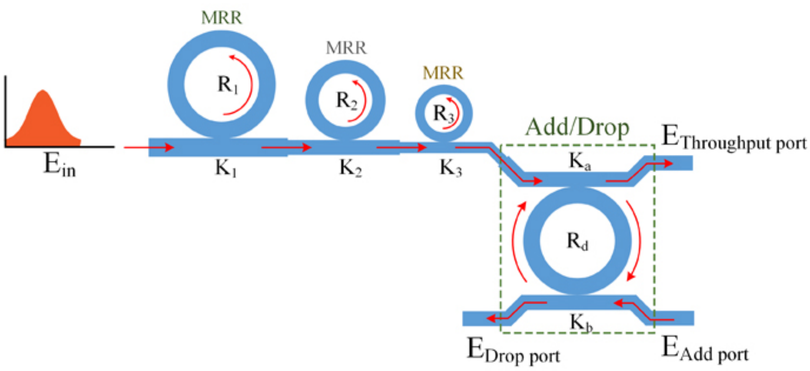


FIGURE 1. Schematic of optical high frequency system, where $R_s$: ring radii, $\kappa_s$: coupling coefficients, $\kappa_a$ and $\kappa_b$ are add/drop filter coupling coefficients

When light propagates within the nonlinear material (medium), the refractive index ($n$) of light within a medium is given by

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right) P \tag{2}$$

where $n_0$ and $n_2$ are the linear and nonlinear refractive indexes. $I$ and $P$ are the optical intensity and optical power. The effective mode core area of the device is given by $A_{eff}$. In this function, $A_{eff}$ is the effective mode core areas range of values for the microring and nanoring resonators [13].

The Gaussian pulse input as shown in Equation (1) is input into a nonlinear microring resonator. This is given in detail in [14]. The optical outputs of a ring resonator add/drop filter is given by Equations (3) and (4).

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_1) - 2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_2)e^{-\alpha L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{3}$$

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{4}$$

where $E_t$ and $E_d$ are the optical fields of the throughput and drop ports respectively. Details of the parameters in Equations (3) and (4) are described in [15] that the wave propagation constant is $k_n$ ($k_n = 2\pi/\lambda$) and the circumference of the ring is $L$ ($L = 2\pi R$; the radius is $R$). $\kappa_1$ and $\kappa_2$ are coupling coefficient of add/drop filters.

## 3. Methodology.

3.1. **The holographic 3D image display.** The 3D image is generated by the micro-optical device system. The device can be used to construct and reconstruct the 3D pixels using a micro-optical conjugate mirror. The conjugate mirror is formed by a semiconductor device, which is a tiny nonlinear optical device. By using a common laser as the input light beam, the object and reference beams can be formed by the reflected light beams from the PANDA ring throughput and drop ports. The interference between these two beams forms the 3D pixel by the four-wave mixing behavior coupled by the two nonlinear side rings. The 3D pixel is seen in the form of what we refer to as whispering gallery modes (WGMs) at the PANDA ring center, which is the real image, while the reconstructed images can also be obtained via the PANDA ring output port.

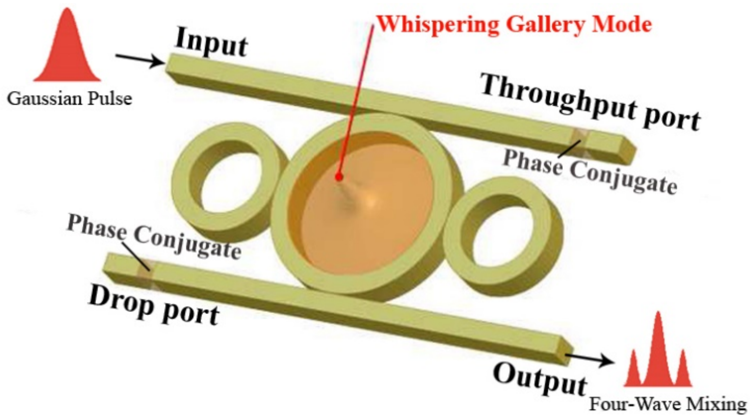


Figure 2. Schematic of whispering gallery mode output with 3D pixel (image)

The ring material is InGaAsP/InP which is the micrometer scale. The appropriate parameter for generated holographic 3D displays is a volume pixel, detailed in [8]. These 3D images are perfectly adjusted by the four-wave mixing results. By balancing the upper side band and lower band frequencies obtained, the perfect 3D image is seen.

3.2. **Transmission.** The holographic 3D images were constructed by the micro-optical device system. As shown in Figure 3, the output or four-wave mixing signal of the PANDA ring system is transferred to the Add port of the micro-optical device system. The four-wave mixing signal is then mixed with another signal (which we call the 'carrier signal') generated from the optical high frequency system (which will be discussed below). The mixing of both signals is transferred to the Drop port. The Drop port transfers these signals to a 3D display system, which extracts only the four-wave mixing signal from these signals. The system reconstructs the extracted signal to appear as a holographic 3D image on a display screen.

The key component illustrated in Figure 3 is the optical high frequency system (in the dotted-line rectangle) that generates the carrier signal. Three micro ring resonators of this system create a chaotic noise signal by breaking up, or chopping, the Gaussian pulse input signal. Each resonator has a different radius but each has the same coupling coefficient value ($\kappa$). The third ring resonator transfers the chopped chaotic noise signal to the input port of the Add/Drop filter. Then, the Add/Drop filter resonates the chopped chaotic noise signal to be the carrier signal. This carrier signal is transferred to the Drop port to be mixed with the four-wave mixing signal.

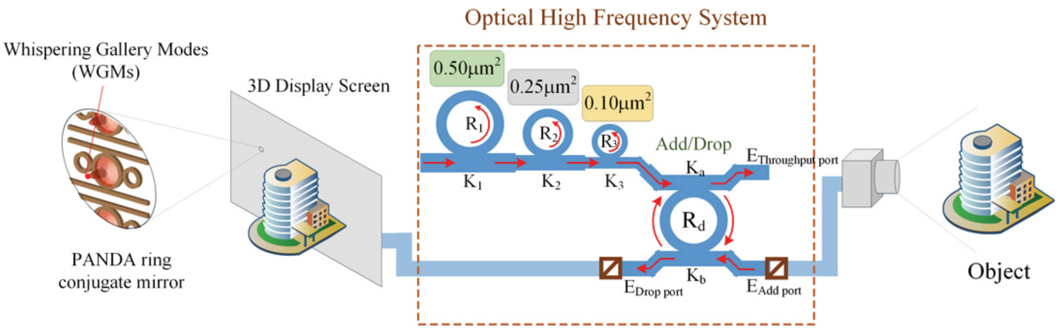


FIGURE 3. Schematic of optical high frequency system for holographic 3D image display

Our approach is described by all the steps in the optical high frequency system described above, which create bandwidth expansions that are capable of transmitting 3D images over the optical network.

4. **Experiments and Results.** Experimental simulations were programmed with MATLAB for optical high frequency systems. A Gaussian pulse with center wavelength ($\lambda$) at 1.55 $\mu$m and peak power at 5 W was input into the system. Suitable parameters used included a ring radii $R_1 = 15$ $\mu$m, $R_2 = 10$ $\mu$m, $R_3 = 5$ $\mu$m and $R_d = 50$ $\mu$m. The static parameters of the system are $A_{eff} = 0.5$ $\mu$m$^2$, 0.25 $\mu$m$^2$ and 0.1 $\mu$m$^2$ for the microring resonators, respectively, $\alpha = 0.01$ dBmm$^{-1}$, $\gamma = 0.1$ and coupling coefficient ($\kappa$) of the microring resonator $\kappa_1 = \kappa_2 = \kappa_3 = 0.5$ and $\kappa_a = \kappa_b = 0.5$. The linear refractive index is $n_0 = 3.34$ (InGaAsP/InP). The nonlinear refractive index is $n_2 = 4.27 \times 10^{-17}$ m$^2$/W.

The results of the three rings and Add/Drop filter device are shown in Figure 4. The Gaussian pulse input signal is shown in Figure 4(a). The output of the first ring ($R_1$) is shown in Figure 4(b), the second ring ($R_2$) in Figure 4(c) and the third ring ($R_3$) in Figure 4(d). The output of the three rings is the chaotic signal which is chopped into the

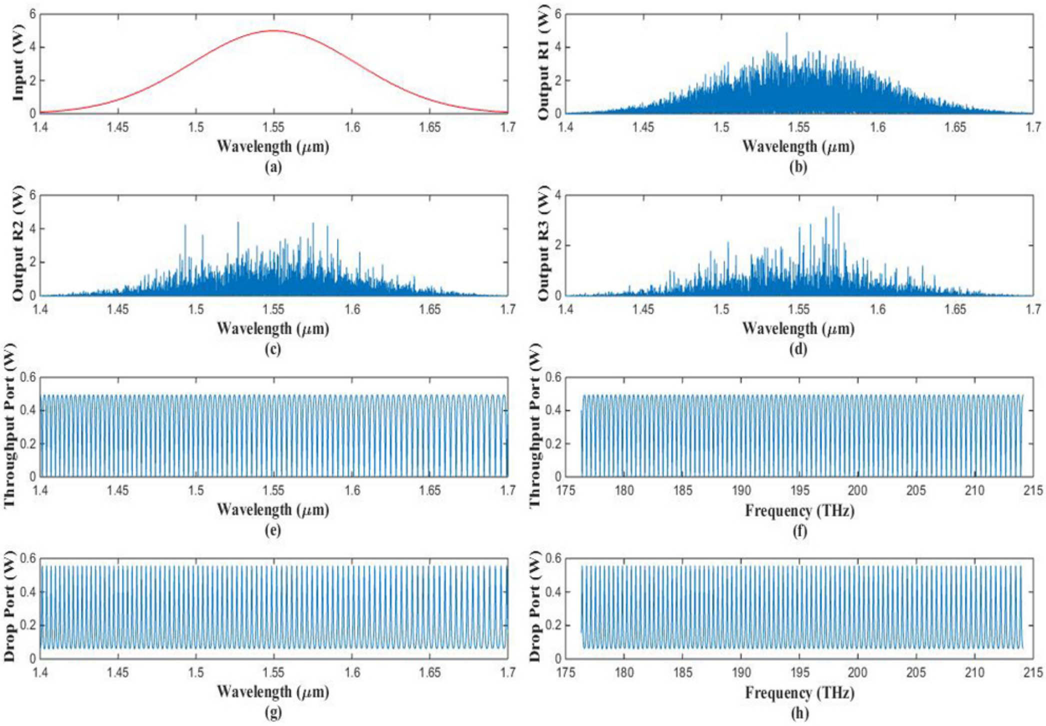


FIGURE 4. The output of ring resonator system with center wavelength at 1.55 $\mu$m

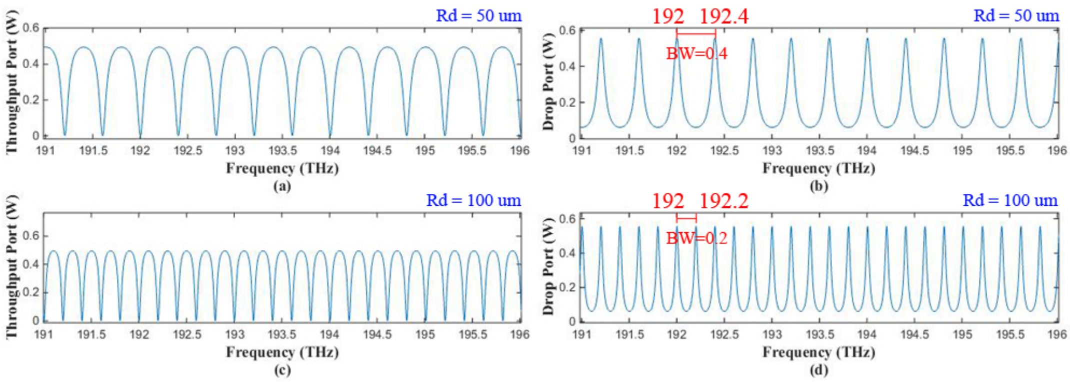


FIGURE 5. The bandwidth THz frequency expansion

smaller signal spreading over the spectrum (i.e., board wavelength). Then the chopped signal of the microring resonator is transferred to the Drop port of Add/Drop filter. The wavelength of the signal output obtained at the Throughput port is shown in Figure 4(e) and the output frequency at the Throughput port is shown in Figure 4(f). The wavelength of the signal output obtained at the Drop port is shown in Figure 4(g) and the output frequency at the Drop port is shown in Figure 4(h).

For the output at the Throughput port and Drop port shown in Figures 5(a) and 5(b), the ring radius ($R_d$) of the Add/Drop filter is 50 $\mu$m. The expansion has a bandwidth of 0.4 THz. The bandwidth can be adjusted by adjusting the parameter of the ring radius. When the ring radius is increased to 100 $\mu$m, the bandwidth decreased to 0.2 THz, as shown in Figures 5(c) and 5(d). The result obtained a high enough bandwidth to transmit the holographic 3D images.

5. **Conclusions.** We have proposed a technique of hologram transmission through an optical high frequency system. This system demonstrated that bandwidth expansion was obtained. The expanded bandwidth was at a THz frequency which is a sufficiently large bandwidth to enable 3D hologram transmissions via the optical network. The adjusted ring radii of the Add/Drop filter device can be controlled, with an increase in high frequency and a greater bandwidth being achieved. Future work will search the optimal parameter of optical high frequency system for transmitting 3D images.

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