Switched Blazed Grating for Optical Networking

Walter M. Duncan, Terry Bartlett, Benjamin Lee, Don Powell, Paul Rancuret and Bryce Sawyers
DLP™ Products Optical Networking, Texas Instruments Incorporated, P.O.B. 869305, MS8477, Plano, TX 75086

ABSTRACT
We describe applications of the Texas Instruments Switched Blazed Grating (SBG) as a high efficiency spatial light modulator for Digital Gain Equalization (DGE) in Dense Wavelength Division Multiplexed optical networks. The SBG is based on TI's DLP™ micro-mirror technology.

SPATIAL LIGHT MODULATION

The Switched Blazed Grating is of a class of modulators referred to as pixelated Spatial Light Modulators (SLMs). As the name implies, a spatial light modulator is a device capable of modulating the amplitude, direction and phase of a beam of light within the active area of the modulator. A pixelated spatial light modulator is comprised of a mosaic of discrete elements and can be constructed as a transmissive or reflective device. In the case of the SBG, the discrete pixel elements are micrometer size mirrors, and hence are operated in reflection. Each SBG consists of hundreds of thousands of tilting micromirrors each mounted to a hidden yoke. A torsion-hinge structure connects the yoke to support posts. The hinges permit reliable mirror rotation to nominally a +9 degree or –9 degree state. Since each mirror is mounted atop a SRAM cell, a voltage can be applied to either one of the address electrodes, creating an electro-static attraction and causing the mirror to quickly rotate until the landing tips make contact with the electrode layer. At this point the mirror is electro-mechanically "latched" in its desired position (see Figure 1). SBG are manufactured using standard semiconductor process flows. All metals used for the mirror and mirror substructures are also standard to semiconductor processing.

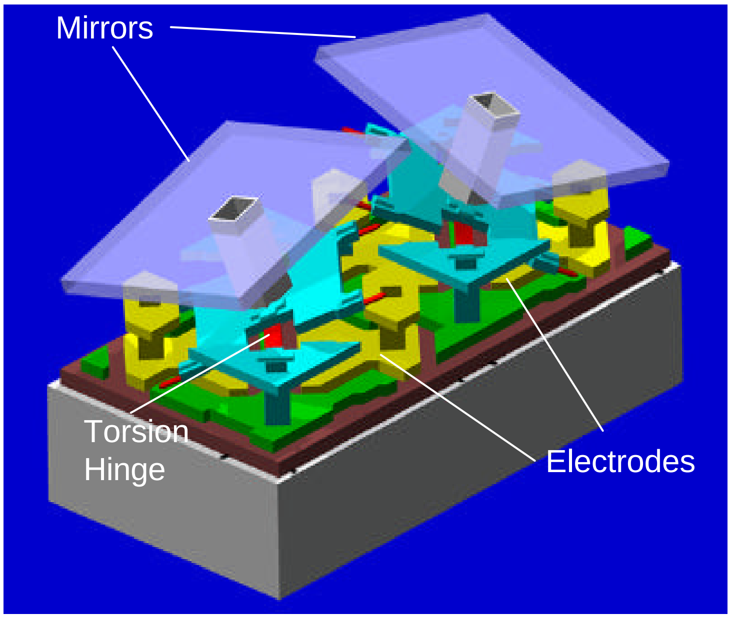

Figure 1. Schematic of two mirror-pixels comprising a typical SBG light modulator consisting of 1024 x 768 individually addressable mirror-pixels.

MODULATION OF COHERENT LIGHT

The total integrated reflectivity of a mirror array (i.e. reflectivity into all output angles or into a hemispherical solid angle) is a function of the area of the mirrors constituting the array, the angle of incidence and the reflectivity of the mirror material at a specific wavelength. (A consideration of second order effects on the integrated reflectivity would include weak effects such as light rays scattered from the mirror gaps.) To determine the power reflected into a small, well-defined, solid angle, one must know the pixel pitch or spacing in addition to the factors that control the integrated reflectivity (i.e. mirror area, angle of incidence and reflectivity). A pixelated reflector, the SBG behaves like a diffraction grating with the maximum power reflected (diffracted) in a direction θ_r, relative to the surface normal, determined by the pixel period, d, the wavelength, λ, and the angle of incidence, θ_i. Figure 2 depicts the optical layout in which the maxima in the reflectivity distribution function is governed by:

$$d(\sin\theta_r + \sin\theta_i) = n\,\lambda$$

where n is the order of diffraction. The condition in which the direction of incidence and diffraction are identical ($\theta_i = -\theta_r$) is referred to as the Littrow configuration, and equation (1) reduces to the well known Bragg equation,

$$2d(\sin\theta) = n\lambda.$$

The tilt angle of the mirrors is also an effect that strongly controls the reflective power. The Fraunhofer diffraction directs the light into a ray with an angle equal to the angle of incidence ($\theta_i = \theta_r$). When the angle of the Fraunhofer diffraction is equal to a diffractive order, the SBG is said to be blazed, and greater than 88% of the diffracted energy can be coupled into a single diffraction order (Figure 3 illustrates the blazed condition.). Using this blazed mirror approach, insertion losses of about 1 dB can be achieved for the SBG. The diffractive behavior of the SBG is evident for both coherent and incoherent sources but is more obvious in coherent monochromatic sources as discrete well-resolved diffractive peaks are observed in the reflective power distribution.

Another consideration in using a pixelated modulator with a coherent monochromatic beam is the relationship between intensity and the number of pixels turned "on" or "off". In a typical single-mode fiber application, the gaussian beam from the fiber is focused onto the SLM by means of a focusing lens. The light, which is reflected or transmitted by the modulator, is then collimated and focused back into a single-mode fiber. By turning "on" various pixels in the spatial light modulator, the amount of optical power coupled into the receiving fiber for each wavelength is varied. The coupling of power into the output fiber, however, is not straightforward since it is dependent upon the power of the overlap integral between the modulated field and the mode of the output fiber [1]. Thus, the coupled power is given by:

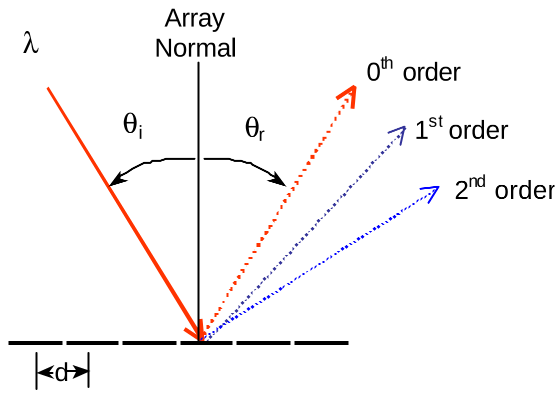

Figure 2. Incident light hitting a grating (SBG) with periodicity d and mirror-pixels inactive or "parked" at 0 degrees. In this example most of the incident light undergoes specular reflection and gets spread out over a number of low-irradiance orders.

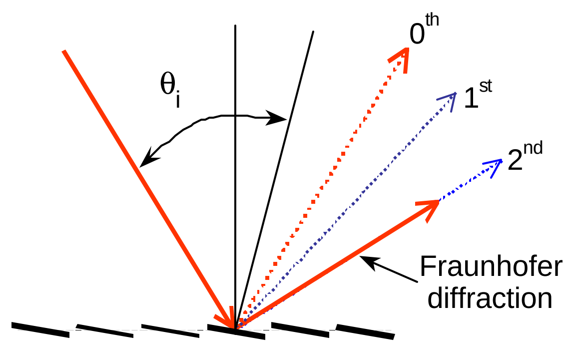

Figure 3. Incident light hitting SBG mirror-pixels under the "blazed" grating condition. Most of the diffracted radiation is concentrated in the second order producing a highly efficient coherent light modulator.

$$P_r = \left| \iint F_s(x,y) F_f^*(x,y)\,dxdy \right|^2$$

where $F_s(x,y)$ and $F_f(x,y)$ are the complex fields of the modulated signal and the fiber mode, respectively. It is important to note that the efficiency of the fiber coupling depends not only on the amplitude of the two fields, but on how well they are matched in phase. It can be shown that a similar relationship can be derived at either the input to the fiber, at the collimated beam, or at the spatial light modulator.

APPLICATIONS OF DLP™ IN OPTICAL NETWORKING

The SBG is suitable for applications where a series of parallel optical switches (e.g. 400 - 1x2 switches) are required. An illustrative optical system useful for processing DWDM signals and incorporates a SBG is depicted in Figure 4. An input/output medium (typically a fiber or array of fibers), a dispersion element (typically reflective), and the SBG comprise the optical system. Attenuation functions in the system illustrated are achievable by switching pixels between +1 and –1 states to control the amount of light directed to the output coupler (e.g. with mirrors in +1 state). Monitoring can be achieved by detection of the light directed into the –1 state. Shown in Figure 5 is the relative insertion loss of a Digital Gain Equalizer (DGE) filter system with alternate channels turned on and off. In this system minimum system insertion loss of about 5 dB have been demonstrated with approximately 34 dB maximum attenuation. Systems with polarization dependent losses of less than 0.2 dB have also been exhibited. Polarization dependent losses are limited by dispersive elements in these systems. With a ~15 microsecond switching speed, the SBG is well suited for dynamically balancing gain in optical networks. An Optical Add Drop Multiplexer can be configured using a optical system similar to the one shown in Figure 4 by adding a second output coupler collecting the light corresponding to the –1 mirror state. An optical performance monitor can also be configured similarly by placing a detector at the position of the output fiber in Figure 4. In this case the SBG mirrors are switched between states to decode wavelength and intensity signals arriving at the detector. A Digital Signal Processor (DSP) can be combined with the SBG to calculate mirror patterns, hence, perform Optical Signal Processing (OSP) on DWDM signals.

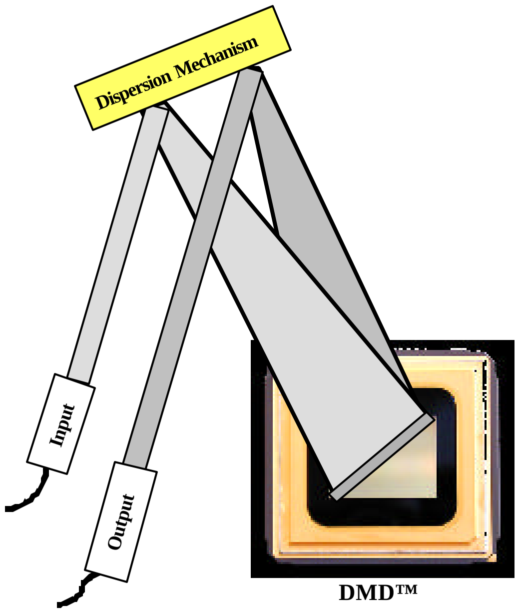

Figure 4. Depiction of the platform for SBG-based optical networking components.

SUMMARY

As a coherent light modulator, the SBG device can be used in DWDM optical networks to dynamically manipulate and shape optical signals. Systems exhibiting low insertion loss can be achieved by designing mirror arrays to meet blaze conditions such that the mirror tilt angle coincides with a diffractive order determined by the mirror pitch.

REFERENCES

1. R.E. Wagner, W.J. Tomlinson, ”Coupling efficiency of optics in single-mode fiber components,” *Applied Optics*, **21** (1982) 2671.

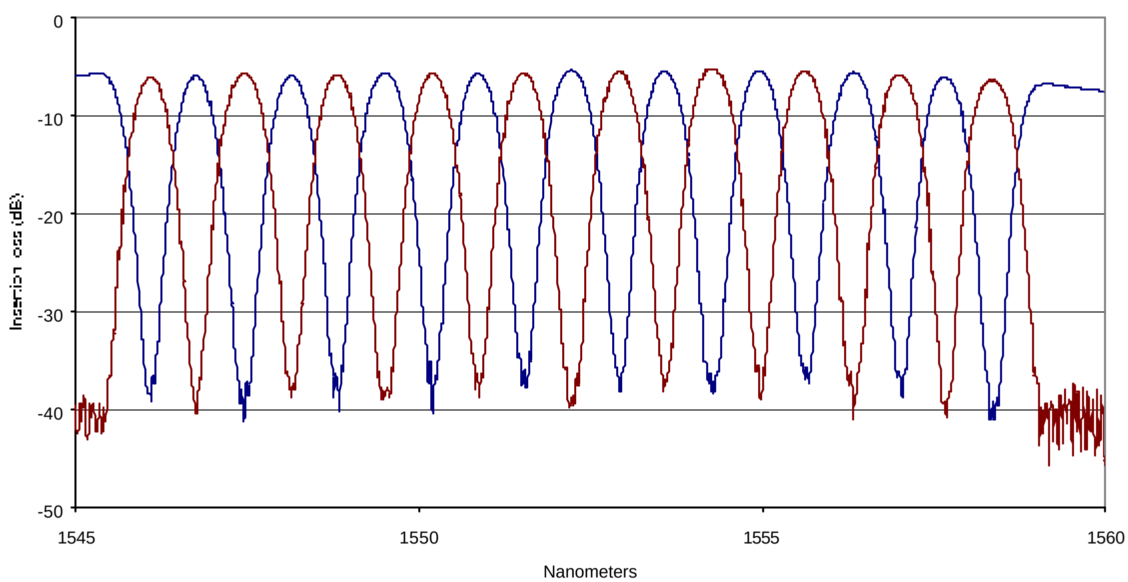

Figure 5: Insertion loss of DGE with alternate channels on and off.