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Performance Modeling of a Planar Waveguide Based Spectral Encoding System

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Abstract.

A planar waveguide based encoder/decoder system that produces and correlates N-bit complementary spectral codes was modeled to identify the key optical parameters affecting performance. The model is described and tolerances for the key parameters are presented.

Introduction.

There has been growing interest in the use of Code Division Multiple Access (CDMA) for optical communication networks. In a bulk optical test bed, we have demonstrated a method of spectral encoding and decoding that uses gratings and masks to take the correlation of complementary codes imposed on the input spectrum [1]. The use of bulk optics makes it susceptible to variations in components, particularly the gratings. It is also very sensitive to alignment errors and is not feasible for mass production. For these reasons, a similar system based on planar waveguide elements has been conceived. Computer models have been used to determine the key design parameters affecting performance in advance of chip fabrication.

Our testing of this encoding system takes advantage of Walsh codes: bipolar, orthogonal codes invented for wireless CDMA. Their key properties are that the autocorrelation (Θ_{JJ}) equals +1 (normalized), the correlation between a code and its complement is equal in magnitude but carries the opposite sign of the autocorrelation ($\Theta_{J\underline{J}} = -\Theta_{JJ}$), and the crosscorrelation between two different codes (Θ_{JK}) is exactly zero. The encoding scheme has been reported in detail previously [2].

Figure 1 is a schematic of the proposed planar waveguide based system. A broadband, incoherent source is demultiplexed into N channels using an arrayed waveguide grating (AWG). To compensate for a non-uniform input spectrum, each channel is then attenuated to ensure that all carry equal power. A series of 1x2 switches impose code **J** and its complement, $\underline{\mathbf{J}}$, on the spectra. The channels carrying the complementary spectral codes are then multiplexed into separate outputs, corresponding to data bits 1 and 0, respectively. The electrical data stream drives a 2x1 optical switch, sending the appropriate spectrum out to the network.

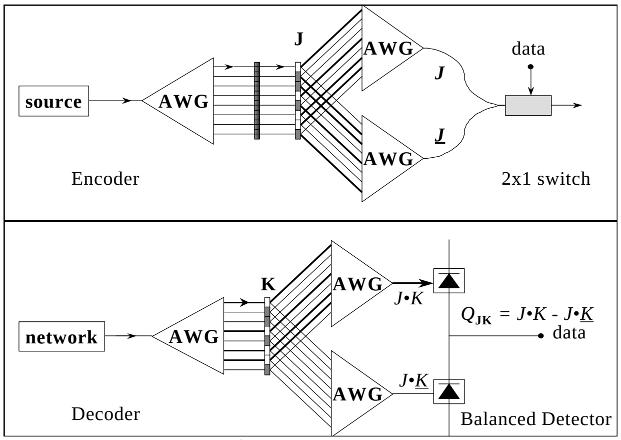

Figure 1. A schematic of an 8-bit encoding/decoding system.

The decoder is almost an exact duplicate of the encoder. The network signal is input, and its correlation with the decoding code **K** is produced at the output of a balanced detector, as shown in Figure 1.

Simulation

To simulate the integrated optical circuits described above, we represent each component of the system by a transfer function that operates on the spectrum or spectra it receives from the previous component. These functions include parameters that describe the effect of fabrication variations both between devices on the same chip and between chips. Each AWG has a central wavelength λ_0 (with possible variation $\delta\lambda_0$), with individual channel spacing of $\Delta\lambda$ (with variation $\delta\lambda_\Delta$), a transmission loss (Γ), and a flat background scattering level of β, as shown in Figure 2. We model each AWG channel passband as a Gaussian (down to the background) with a width defined by

$$\sigma^2 = [\,(\Delta\lambda + \delta\lambda_\Delta)\,/\,2\,]^2 \;/\; \chi,$$

where χ represents the power at which the passbands of adjacent channels overlap. Thus the passband for the *i*th channel is

$$P_i(\lambda) = \Gamma\,\{\,\beta + \exp[-\,(\lambda - \lambda_i)^2 / \sigma^2]\,\},$$

where

$$\lambda_i = (\,\lambda_0 + \delta\lambda_0\,) + i(\,\Delta\lambda + \delta\lambda_\Delta).$$

The array of attenuators includes an adjustment precision variable, δp. The model for the 2x1 switches contains an extinction ratio, η, between output ports.

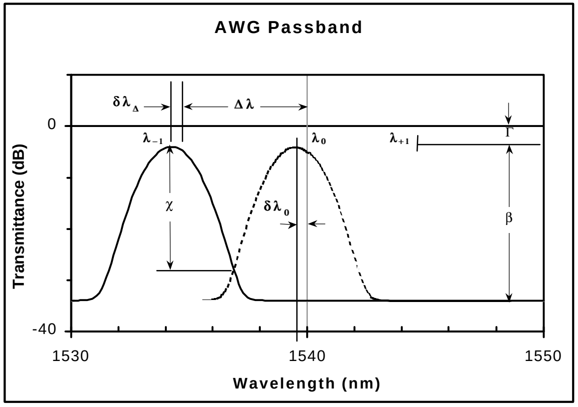

Figure 2. An illustration of three adjacent passband functions.

The ratio of crosscorrelation strength to autocorrelation strength is a good measure of the ability of the decoder to reject interference from other users, so the Cross to Auto Correlation Ratio (CACR) is defined as $\mathrm{CACR}_{JK} = \Theta_{JK} / \Theta_{KK}$. Theoretically, CACR = 0 for Walsh codes, but this cannot be achieved in practice. Past experiments with the bulk system have shown that a multi-user bit error rate of 10^{-9} can be achieved with a CACR ≤ 0.08 [3], which is the performance standard for this work.

Results.

For the initial characterization of the system, simulations produced the CACR as a function of each of the variables in Table 1, while all others were held at their ideal values. Fabrication tolerances were obtained for each variable by recording its value where the CACR exceeded 0.08. Spectral scale distortion ($\delta\lambda_\Delta$) was found to affect the CACR as strongly as the bulk system [2]. The tolerance for the scale distortion is +/-0.05 nm. This is small, but devices can be fabricated with $\delta\lambda_\Delta < 0.016$nm. The background level (β) also was found to have deleterious effects on the CACR, resulting in a tolerance of –26dB. It is notable that some code combinations performed better than others against rising β. Other results are shown in Table 1.

When values of all variables are set to be commensurate with what is currently technically feasible (listed in Table 1) [4], the CACR was found to be 0.011, indicating that reasonable bit error rates are within reach.

Summary and Future Work.

A bipolar spectral encoding scheme for optical CDMA communication based on planar waveguide technology has been computer modeled. The results indicate that it is possible to fabricate a chip having the encoding/decoding functionality with present fabrication capabilities.

Parameter	Ideal Value	Limiting Value	Feasible Value
Γ	0 dB	> 50dB	4dB
β	-150dB	-26 dB	-30dB
$\delta\lambda_0$	0 nm	> 0.5 nm	0.02 nm
$\delta\lambda_\Delta$	0 nm	0.05 nm	0.016nm
χ	-125 dB	-5 dB	-25dB
η	0	> 50dB	20dB
δp	10^{-14}	10^{-2}	10^{-2}

Table 1

While 8-bit codes were used in this work, larger code lengths are needed to support many users. The effects of closer channel spacing required by longer code lengths may cause wavelength scale distortion error to have an even more pronounced effect on performance, and must be explored. Also, testing the CACR against each variable with all others held at their "feasible values" will indicate which parameter will yield the highest improvement in performance.

Acknowledgements.

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