

Spectral Slicing for Data Communications

M S Leeson¹, B Luo¹ and A J Robinson²

¹School of Engineering, ²Department of Physics,
University of Warwick, Gibbet Hill Road,
Coventry, CV4 7AL, UK

Abstract: *In short range data communications, the cost of terminal equipment is borne by the user so low-cost wavelength generation methods are desirable. One option is to use an optical filter to provide narrow slices of a broadband noise source producing an approach commonly known as spectral slicing (SS). This provides a cost-effective alternative to laser diode sources but introduces excess intensity noise due to the source incoherence. This paper addresses the bit error rate performance of SS systems and their capabilities. Consideration is given also to the impact of different modulation formats and performance improvement using error correcting codes.*

Introduction

Wavelength division multiplexing (WDM) is finding its way into access networks where the cost of expensive components is shared by a relatively small number of customers. One low cost option for implementing WDM is to use an optical filter to provide narrow slices of a broadband noise source, known as spectral or spectrum slicing (SS) [1]. Recent developments in, for example, superluminescent LEDs [2] have greatly increased slice output powers in recent years. However, the excess intensity noise in SS compared to laser diodes due to the source incoherence remains, producing a power penalty in exchange for the inexpensive nature of the source.

System Model

The SS system, shown schematically in Figure 1, is assumed to operate in the C-band and thus linear dispersion is dominant. The broadband optical source may be modeled as white Gaussian noise of two-sided power spectral density (PSD) $N_0/2$. Slices are taken from it with an unapodized arrayed waveguide grating (AWG) with impulse response $\propto \exp(-\alpha t^2)$ [3], where the parameter α is half the mean squared coherence time. This produces noise that is Gaussian but no longer white because of the effect of the filter on the PSD. The slices are assumed to be narrow in comparison with the approximately rectangular passbands of the WDM multiplexer (MUX) and demultiplexer (DEMUX), which then have a negligible effect on the Gaussian spectrum of the SS source. On-off keyed (OOK) data drives a polarization-insensitive intensity modulator of ideal extinction ratio such that the optical field has an envelope $s(t)$. The modulated signal travels through an optical fiber path of length z , having linear dispersion β_2 (here taken as -20 ps^2 per kilometer). A trade off between the dispersive spreading of the pulses generated using a wide filter, causing intersymbol interference (ISI), and the increasingly detrimental effect of the excess noise with narrowing filter bandwidth occurs.

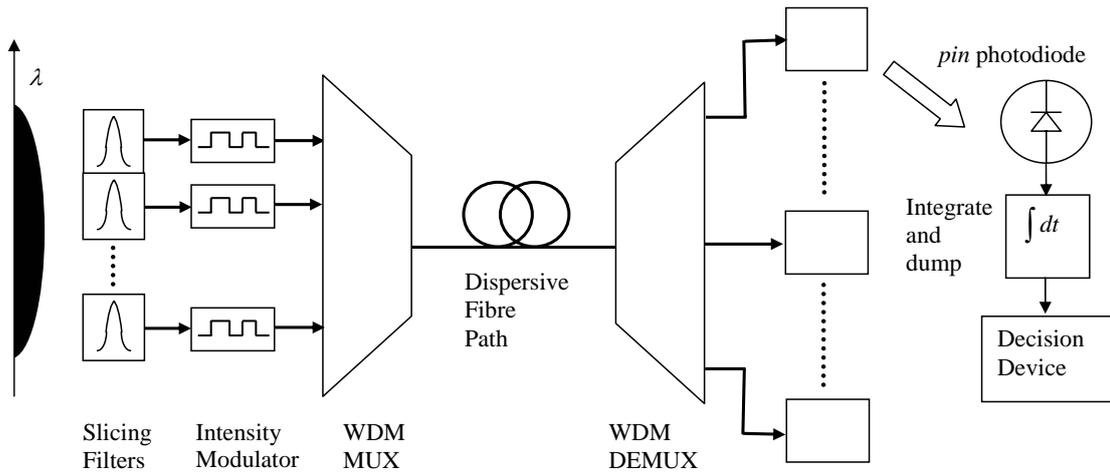


Figure 1: Schematic Representation of a Transmission System Employing Spectral Slicing.

For a bit time T_b , the current at the input to the decision circuit may be expressed as [4]

$$I = \frac{1}{2T_b} \int_0^{T_b} [x^2(t) + y^2(t) + \tilde{x}^2(t) + \tilde{y}^2(t)] dt + I_n \quad (1)$$

where $x^2(t), y^2(t), \tilde{x}^2(t)$ and $\tilde{y}^2(t)$ are independently identically distributed baseband Gaussian processes with variance σ^2 , equal to the photocurrent contributed by each of the two orthogonal polarizations. That is to say they represent the in-phase and quadrature components of each polarization of the sliced signal. The term I_n represents the thermal noise current induced in the electrical part of the receiver (here taken to be 255 nA). The mean signal photocurrent, σ^2 , is obtained from the photodiode quantum efficiency η , the electronic charge q , the mean number of photons per bit $\overline{N_p}$, and the bit rate R_b via $\sigma^2 = \overline{N_p} \eta q R_b$. Taking the amplitude of the modulating waveform to be Gaussian of the form $s(t) = \exp[-t^2/2T_o^2]$, where T_o is the half-width at the e^{-1} intensity points, permits a tractable expressions to be derived. The bit error rate (BER) is obtained using the saddlepoint approximation (SPA) [5] or the Gaussian approximation.

Sensitivity Results

The SS system is assumed to operate at a wavelength of 1550 nm, and the spectral slice and slice power spectral density are taken as Gaussian waveforms as above. To accommodate ISI, pulses either side of the received pulse are considered, with the sequences 010 and 101 representing the worst case scenarios. A bit rate of 2.5 Gbps and a photodiode of efficiency 70% are also assumed.

OOK

Using OOK, the 10^{-9} sensitivity of a single WDM channel as a function of the slice full width at half maximum (FWHM) appears as depicted by the black symbols on Figure 2.

The appearance of a minimum is apparent for the 15 km results, and operation at approximately 0.35 nm FWHM is optimum.

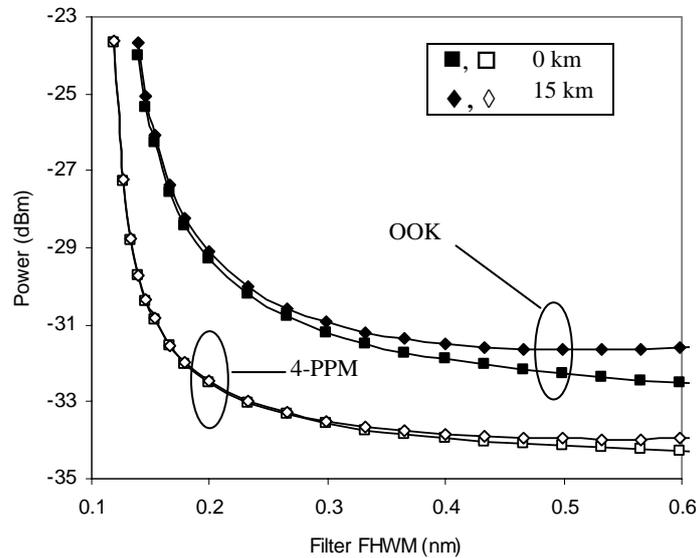


Figure 2: Sensitivity of SS as a function of slice width in the presence of dispersion [6], [7]

Pulse Position Modulation (PPM)

Digital PPM uses a single pulse, representing M bits (the PPM coding level), to convey information by its position, and the format exchanges bandwidth for receiver sensitivity. The SS-PPM system considered uses maximum likelihood detection (MLD), i.e. integration over each time slot. Assuming perfect extinction, only thermal noise is present in the off state and the Gaussian approximation may be employed to compare the relative performance of PPM and OOK. The 10^{-9} sensitivity of 4-PPM is shown by the white diamonds and squares on Figure 2. It may be observed that this modulation scheme offers an improvement in sensitivity of approximately 3 dB.

Forward Error Correction (FEC)

Recent work in Japan [8] has illustrated that substantial benefits accrue for SS by the use of FEC codes. As an example, a preliminary Monte Carlo simulation of a (15, 11) Hamming code applied to a slice width of ~ 0.07 nm is shown in Figure 3. It may be seen that even this simple code offers a benefit of several dBs, and this area is one for further study using more powerful codes.

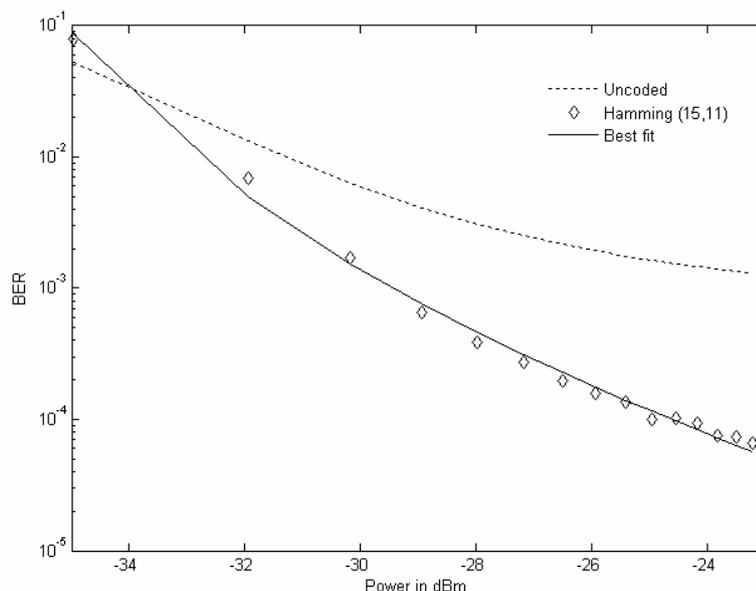


Figure 3: BER for SS system with and without FEC

Conclusions

SS lightwave systems have been considered for high speed data communications. The appearance of an optimum slicing width of ~ 0.35 nm for a bit rate of 2.5 Gbps has been illustrated. PPM has been shown to offer a 3 dB sensitivity advantage for SS over OOK. The emerging area of FEC for SS has been introduced with promising initial results and the prospect of considerable further work.

References

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