# Closely Separated Dual Baseband Channel Generation and Separation for Provision of Broadcast Traffic in WDM-Passive Optical Networks

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*Abstract*— **The paper presents a scheme for the generation and optical separation of two independent high bandwidth baseband optical channels using a single laser and modulator that will enable simple provisioning of independent services in WDM passive optical networks.**

***Keywords : Wavelength division multiplexing, passive optical networks, optical access, subccarrier multiplexing, optical filtering***

## I. INTRODUCTION

Wavelength division multiplexed passive optical networks (WDM-PON) are considered to be the most suitable solution for access networks due to the virtual point to point connection between the service provider and the customers that enables large bandwidth connections, simple management and network security. However, this advantage of WDM-PON diminishes when it is used for the provision of independent broadcast services such as video or if another such independent service has to be overlaid onto the WDM-PON infrastructure. In this scenario, the proposed solutions are to use an additional set of wavelengths separated by the free spectral range of the arrayed waveguide grating or use time multiplexing schemes that shares each wavelength channel for the provision of the separate data streams [1]. Both these techniques can be costly and complicated to implement, especially when the different services are provided by different service providers.

In this paper a simple scheme is proposed that can optically generate and separate two independent optical channels using a single wavelength and a modulator that can be applied in WDM-PON for the provision of independent services. For example, the service provider that owns the infrastructure can easily lease the additional independent channel to another service without any complications. The channels are closely spaced such that they can pass through narrowband filters such as arrayed waveguide gratings and has fixed wavelength separation so changes in wavelength stability will not effect the close frequency separation. Further both channels are detected with conventional base-band receivers.

The scheme proposed here combines the two independent high speed data streams one as a baseband signal and the other as a low frequency subcarrier signal. Previously sub-carrier signals have been utilised to generate relatively low speed additional data channels such as control signals or labels in label switching networks [2-4], and also in multiple channel generation with high frequency subcarrier signals [5]. Most of these demonstrations have utilised high speed receivers and phase locked loops to detect the subcarrier signals. However, our scheme allows separate conventional baseband receivers for the independent data detection. The paper also presents the optimum bias conditions for this scheme to achieve equal bit error rate (BER) sensitivities for the two channels taking into account the different impairments of the individual channels.

## II. SCHEME FOR THE GENERATION AND SEPARATION OF TWO INDEPENDENT BASEBAND CHANNELS

A schematic of the scheme is shown in Fig. 1. The two independent 1 Gb/s baseband data streams are modulated onto a single optical source using a Mach-Zehnder modulator; one as a baseband signal and the other as a subcarrier signal at a frequency of 5 GHz in amplitude shifted keying (ASK) format [4-5].

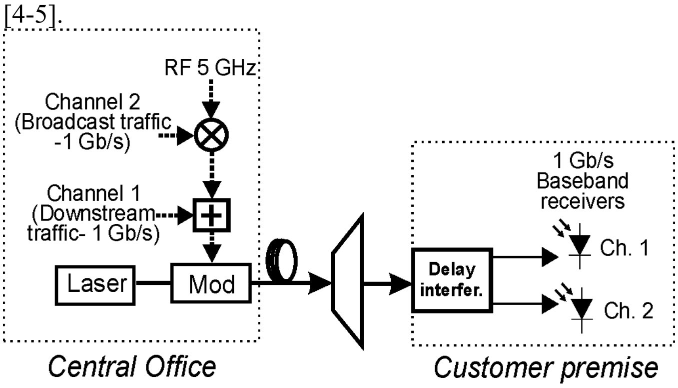

*Fig. 1: Schematic for dual 1 Gb/s baseband signal generation and separation.*

To obtain the two independent base-band signals after transmission, these signals are sent through a delay interferometer (DI) at the customer unit with a 100 ps differential delay that will separate the individual channels into its two output arms and enable baseband detection of the two data streams with two standard low frequency receivers. The data streams are independent of each other and does not require additional lasers or time demultiplxeing for service differentiation.

## III. RESULTS AND DISCUSSION

A series of simulations using a commercial software package with realistic parameter values were carried out to demonstrate the scheme. The amplitude of the signals was set in order to achieve similar receiver sensitivities for the two channels at a BER of $10^{-10}$ taking into consideration the different impairments each channel undergoes. This will be discussed in detail later. Hence, the amplitudes of the baseband signal and the RF signal were set at ~0.35 $V\pi$ and ~0.25 $V\pi$ respectively, where $V\pi$ is the half wave voltage of the modulator.

Fig. 2 shows the optical spectra of the modulated signal after optical separation by the DI. The top figure shows the separated optical carrier containing Channel 1 information and the bottom figure shows the separated optical subcarriers containing the Channel 2 information. As noted the optical power of the subcarrier signal is much smaller than that of the carrier signal, however they have similar BER sensitivity as shown in Fig. 4.

Fig. 3 shows the time domain traces of the generated signals, where figure 3(a) shows the optical intensity of the composite signal before transmission showing the two independent data streams, one modulated as a baseband signal and the other as a subcarrier signal at 5 GHz frequency. Figs (b) and (c) show the electrical output of the independent data channels after separation. The former shows the data stream from the sub-carrier and the latter shows the data stream from the carrier.

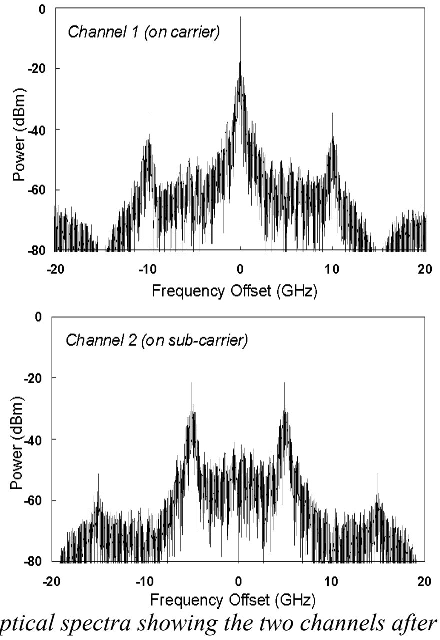

*Fig. 2: Optical spectra showing the two channels after separation with the delay interferometer. Channel 1 on the separated carrier (top) and Channel 2 on the separated subcarrier (bottom).*

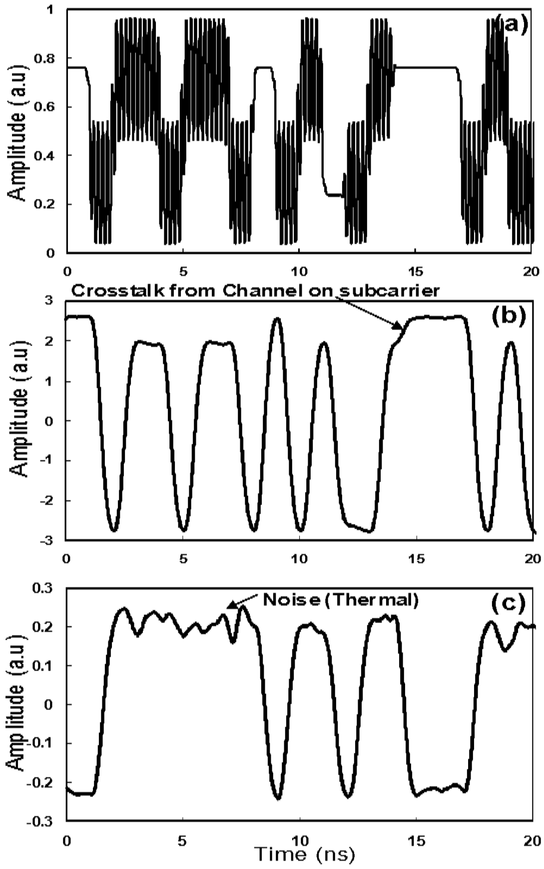

*Fig. 3: Time domain traces of (a) the composite optical signal, (b) Electrical output of Channel 1 on carrier signal and (b) Electrical output of Channel 2 on subcarrier signal.*

Fig. 4 shows the BER vs. total received optical power for the two independent data streams generated by the single laser. The optical power is measured before the DI and hence comprises of the total power of both channels. It is noted that the BER curves are different for the two channels even though the sensitivity at BER of $10^{-10}$ is equal. When an ASK modulated subcarrier signal is optically filtered, the detected carrier component shows an inverted copy of the data stream modulated onto the subcarrier due to the nonlinear operation of optical filtering [6]. This leads to crosstalk in the channel on the carrier from the channel at the subcarrier giving the observed error floor. However, this can be reduced by decreasing the amplitude of the RF signal. In this simulation, since the aim was to achieve similar BER sensitivity optimization of the bias for elimination of the error floor was not carried out. The observed error floor is well below the acceptable BER of $10^{-9}$. Further, the separated channel on the carrier has the majority of the optical power and hence the noise terms proportional to the optical power will be dominant. On the other hand the signal extracted from the subcarrier will have much lower optical power and will not be subjected to crosstalk from the channel on the carrier due to the optical filtering. This signal will be mostly thermal noise limited. Note, the thermal noise current in the simulation is assumed to be 10 pA/$\sqrt{\text{Hz}}$.

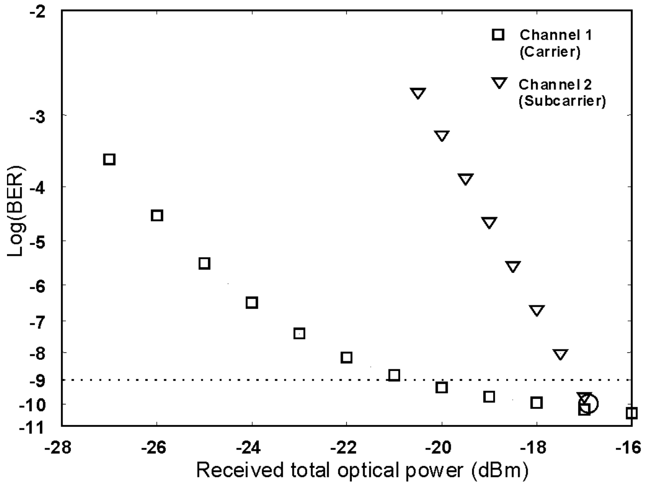

*Fig. 4: BER vs. total optical power (at the input of the DI before channel separation) for the two channels.*

Fig. 5 shows the BER vs. received optical power for a channel in a WDM passive optical network simulation. The two channels are transmitted through 20 km of single mode fiber and an arrayed waveguide grating with 40 GHz pass band. In this case the received optical power is measured after the separation of the channels and hence there is a large deviation in the optical power for the two channels. The results show no power penalty due to fiber transmission.

The consideration for the scheme includes the wavelength alignment with the DI. Simulation showed a wavelength deviation of +/- 1 GHz has to be maintained to be within 3 dB power margins. This can be easily achieved by electrical control of the DI path length. In another point of view, the subcarrier frequency can be set within the range of 4-6 GHz. The advantage of this technique is the fixed channel separation of the two data streams as opposed to using two independent wavelength sources, which can drift apart with respect to each other. Further, the channel bandwidth can be readily increased by larger subcarrier frequency and smaller differential delay for the DI. This will also ease the wavelength stability requirements.

## IV. CONCLUSION

The paper demonstrated a simple scheme to generate and separate two independent baseband channels using a single laser and modulator. The scheme transmits one channel at baseband and the other at a subcarrier frequency modulated as an ASK signal. At the receiver optical separation using a delay interferometer allows both channels to be detected independently using standard baseband receivers. The scheme is applied in a WDM-PON, where two independent services can be transmitted over an existing network. It also presented biasing conditions in order to generate the two signals with equal receiver sensitivity taking into account the different impairments of the channels.

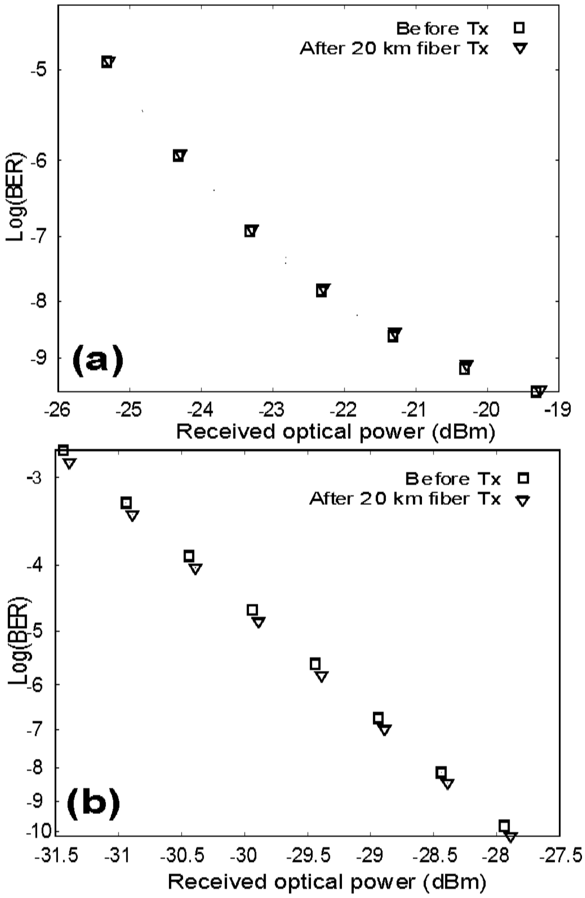

*Fig. 5: BER vs. received optical power (after channel separation) (a) for Channel 1 and (b) Channel 2 before and after20 km transmission in a WDM-PON network*

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