Demultiplexer Crosstalk Rejection Requirements for Hybrid WDM System with Analog and Digital Channels

Keang-Po Ho and Shien-Kuei Liaw

***Abstract*—Hybrid WDM systems with both analog and digital channels are a natural choice for the video transmission applications. The effects of crosstalk in a hybrid WDM system are measured and analyzed in this letter. The required crosstalk rejection ratio is also provided with the assumption that the differences in received optical power among various channels are the same as their differences in receiver sensitivities.**

***Index Terms*— Crosstalk interference, hybrid WDM, video trunking, WDM.**

I. Introduction

WAVELENGTH-DIVISION-MULTIPLEXED (WDM) systems can utilize the vast bandwidth provided by a single-mode optical fiber. Most WDM systems distribute homogeneous traffic, for example, all channels transmitted Synchronous Optical Network (SONET) OC-48 (2.5 Gb/s) or OC-192 (10 Gb/s) signal. In video trunking or distribution, video signal may be transmitted using various formats, including analog amplitude-modulated vestigial-sideband (AM-VSB) subcarrier multiplexing (SCM), digital quadrature amplitude modulation (QAM) SCM, uncompressed pulse-code-modulated (PCM) video, compressed digital video, frequency-modulated television (FM-TV), etc. Hybrid WDM system with both analog and digital channels is a natural choice for the video transmission applications with analog and digital channels, especially in the trunking portion of the system.

Hybrid WDM systems had been demonstrated to transmit both FM-TV and 622 Mb/s baseband digital video [1], AM-VSB and PCM video [2], AM-VSB and 622 Mb/s OC-12 signal [3] (WDM in 1310 nm and 1550 nm), digital QAM-SCM and OC-48/OC-192 channels [4]–[5], and AM-VSB and OC-48 [6].

Fig. 1 shows an example of a generic hybrid WDM system. A WDM multiplexer combines a number of digital and analog channels at the transmitter and a WDM demultiplexer separates all channels at the receiver. Depending on the link budget, the fiber link in between may use EDFA's to compensate for fiber loss. Each WDM channel can transmit AM-VSB SCM channel, QAM-SCM channel, hybrid AM-VSB/QAM SCM channel, OC-48/192 channel, or other special digital or analog channels. Although WDM channels are almost transparent to the signal format, due to the differences in sensitivity requirement, hybrid WDM systems require special attention on EDFA operating point [2], [4]–[6] and crosstalk rejection in the WDM demultiplexer. While crosstalk rejection requirement in homogeneous digital WDM system was well studied [7]–[8], crosstalk rejection requirements for hybrid WDM system are analyzed based on experimental measured data in this letter.

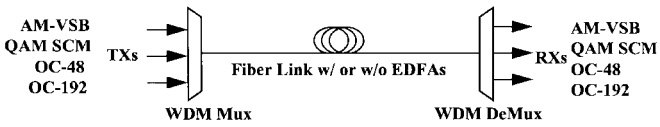

Fig. 1. Schematic diagram of a hybrid WDM system.

II. Crosstalk Rejection Requirements

Table I shows the sensitivities of signal having different format provided by our previous experimental measurements [4]–[6]. While AM-VSB SCM channel requires an input power around 0 dBm to achieve a CNR requirement of 55 dB, SONET OC-48 signal requires about −30 dBm to achieve a bit-error-rate (BER) requirement of 10^{-9}. Usually, the signal powers of different signal format in the fiber are adjusted according to their difference in sensitivity requirements such that no extra optical power and EDFA gain are wasted [2], [4]–[6]. For example, the optical power of OC-48 may be −30 dB lower than that of the AM-VSB SCM signal such that BER of 10^{-9} for OC-48 signal and CNR of 55 dB for AM-VSB signal can be achieved simultaneously. Because of the difference in optical power, besides the EDFA operating point [2], [4]–[6] must be adjusted accordingly, higher crosstalk rejection is required in the WDM demultiplexer.

Here, we consider linear crosstalk from different wavelengths instead of homodyne crosstalk from the same wavelength [9]–[11]. For crosstalk from a digital into an analog channel, the power-spectral density of the digital signal is $S_d(f) = (R_{\rm det}P_d)^2\,{\rm sinc}^2(f/R)/R$ with $R_{\rm det}$ the photodetector responsivity, P_d the optical power, f the electrical frequency, and R the data rate of digital channel. The crosstalk interference from the digital channel into the

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TABLE I
SENSITIVITIES AND CROSSTALK REJECTION REQUIREMENTS

Signal Channel	Sensitivity (dBm)	Required Crosstalk Rejection† (dB)			
		OC-48	OC-192	AM-VSB SCM	64-QAM SCM
SONET OC-48	-30	15	25	45	27
SONET OC-192	-20	5	15	35	17
AM-VSB SCM	0	6	12	33	15
64-QAM SCM	-18	10	17	37	19

† Rounded to the nearest integer decibel.

analog channel is equal to $2\int_{f_-}^{f_+} S_d(f)\,df$ [3], where f_- and f_+ are the lower and upper end frequency of the video bandwidth of a CATV channel. The interference power is $2\int_{f_-}^{f_+} S_d(f)\,df \cong 2(R_{\rm det}P_d)^2(f_+ - f_-)/R$. Note that we approximate $\mathrm{sinc}(f/R) \approx 1$ for small f/R. For low frequency CATV channels (just higher than 54 MHz), the ratio f/R is very small for a digital channel with multigigabit data rate. The carrier power of an analog channel per channel is given by $1/2m^2(R_{\rm det}P_a)^2$, where m is the modulation index and P_a the optical power of the analog channel. The carrier-to-crosstalk-interference ratio (CCIR) from the digital channel to the analog channel can be evaluated as

$$\mathrm{CCIR} = 20\log(m/\gamma) + 10\log(R) - 66.2 - 6\ \mathrm{dB} \quad (1)$$

where $\gamma = P_d/P_a$ is the crosstalk level, and $66.2 = 10\log(4.2 \times 10^6)$ is the bandwidth $(f_+ - f_-)$ of the analog channel.[1] With the same argument, the CCIR from an analog to another analog channel can be evaluated as $\mathrm{CCIR} = -20\log(\gamma)$ for the same channel bandwidth and modulation index. CCIR from an AM-VSB to another AM-VSB channel should be modeled as composite triple beat (CTB) instead of Gaussian noise because the interference may be tones right on the top of the signal.

The degradation to analog signal can be evaluated by calculating the CNR using the CCIR. The CCIR must be 10 dB larger than the required CNR to ensure that the CNR degradation is less than 0.5 dB (exact value is $10\cdot\log_{10}(0.9)$). The effect of crosstalk to a digital channel must be evaluated by BER measurement [3], [7]–[9]. Fig. 2 shows the experiment setup to measure the effect of crosstalk to a digital channel. A 2.5-Gb/s directly modulated or 10-Gb/s externally modulated transmitter is used as signal channel and an AM-VSB SCM channel (80 channels, 4% modulation depth per channel), 2.5- or 10-Gb/s channel is used as the crosstalk interference, separately. The wavelengths of signal and crosstalk are different to eliminate homodyne or heterodyne beating of optical signal.

Fig. 3 shows power penalty to a digital channel as a function of crosstalk level. The power penalty is evaluated at a BER of 10^{-9}. While the measured penalties from a digital to another digital channel is larger than the theoretical studies [7], [8], it is consistent with other measurement result [9]. The power penalties of crosstalk induced from either a digital or an analog channel into a digital channel have insignificant difference in

[1]The bandwidth of NTSC TV is 4.2 MHz with a channel separation of 6 MHz. QAM or PAL may use larger bandwidth. Usually the correction factor is less than 1 dB.

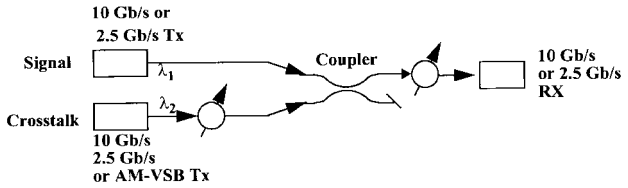

Fig. 2. Experimental setup to evaluate power penalty due to analog and digital crosstalk to digital channel.

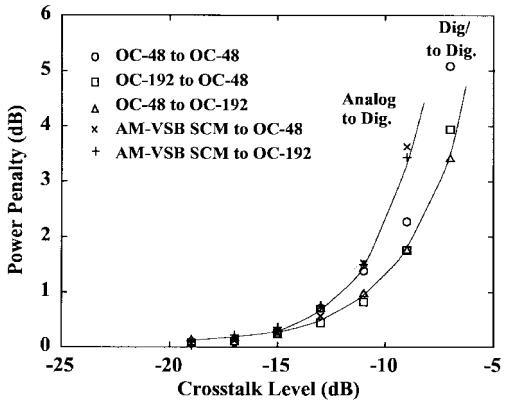

Fig. 3. Power penalty to a digital channel as a function of crosstalk level for crosstalk from analog and digital channel.

low crosstalk level (crosstalk less than −13 dB). However, analog crosstalk induces larger penalty than digital crosstalk in high crosstalk level (crosstalk larger than −10 dB). For example, for a crosstalk level of −9 dB, analog crosstalk induces 3.5-dB power penalty, but digital crosstalk induces only 2 dB of power penalty. An analog channel induces a BER floor of 10^{-9} with a crosstalk level of about −8 dB, but a digital channel induces the same BER floor with a crosstalk level of about −6 dB. For a power penalty less than 0.3 dB, a crosstalk level less than −15 dB is acceptable as indicated in Fig. 3.

The optical powers in the hybrid WDM system for different signals can be adjusted according to their differences in receiver sensitivities, for example, an AM-VSB channel is 18 dB more powerful than a QAM-SCM channel, 20 dB more powerful than a OC-192 channel, 30 dB more powerful than a OC-48 channel. Under this assumption, Table I shows the crosstalk rejection requirements between different signal formats. We assume that AM-VSB and QAM-SCM channel require a CCIR of 65 dB and 38.5 dB, respectively, and have an $m = 4\%$ modulation index. The CCIR of 65 and 38.5 dB are 10 dB more than the required CNR of 55 dB and 28.5 dB for AM-VSB and 64-QAM (for a BER of 10^{-9}) signal. Note that the CCIR requirement of 65 dB for AM-VSB channel is the same as the CTB requirement of −65 dBc. The crosstalk rejection requirements from a digital channel to an analog channel is calculated according to (1). The crosstalk rejection requirements from an analog to another analog channel is calculated by $\mathrm{CCIR} = -20\log(\gamma)$.

From Table I, while a crosstalk rejection of 6 dB is required from OC-48 to AM-VSB channel, a crosstalk rejection of 45 dB is required from AM-VSB to OC-48 channel due to

the high optical power of AM-VSB channel. If the filtering characteristic of the WDM demultiplexer port of the OC-48 channel is represented as a bandpass filter, a crosstalk rejection requirement of 45 dB implies that the AM-VSB channel must be located at a wavelength in which the transfer function is more than 45 dB down from that of the OC-48 channel. Several empty WDM channels (equivalent to a large guard band in frequency division multiplexing system) can be used between the OC-48 and AM-VSB channel to reduce the crosstalk level [6].

III. Conclusion

Crosstalk rejection ratio is studied for the design of hybrid WDM systems. A crosstalk level less than -15 dB is acceptable for crosstalk from a digital into another digital or from an analog into a digital channel. Assuming that the differences in received optical powers for a hybrid WDM system are the same as their differences in receiver sensitivities, the required crosstalk rejection ratio is provided.

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