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RF Phase Distortion due to Crosstalk in an 8 Channel Wavelength Division Multiplexed Analog Delay Line

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Abstract — We present experimental results for crosstalk in an eight channel WDM dispersion managed 25 _s delay line. The total phase error produced by the crosstalk onto one channel from the other seven is measured.

INTRODUCTION

Analog fiber optics is being explored for microwave communications applications such as fixed wireless access (FWA) backhaul and for RF antenna arrays. In these systems it is important to consider distortions on the signal due to fiber nonlinearities and chromatic dispersion. In systems that employ wavelength division multiplexing (WDM), fiber dispersion and nonlinearities have been shown to produce crosstalk between two optical channels modulated at cable TV (CATV) frequencies [1]-[2], as well as at higher frequencies [3], primarily due to stimulated Raman scattering (SRS) and cross phase modulation (XPM). The magnitude of this crosstalk increases with the number of optical channels [4].

In steerable arrays and other antenna systems, WDM can be used to supply each antenna array element with a dedicated wavelength. Since all signals for the array pass through a common fiber, WDM offers the advantage of stabilizing the array against relative phase shifts over long lengths of fiber. For such systems, the phase error produced by the crosstalk must be considered. In this work we study the crosstalk between channels in an eight channel WDM system and measure the crosstalk induced phase error.

EXPERIMENTAL RESULTS

The system constructed and studied in this experiment is shown in Figure 1. Eight 200 GHz spaced DFB lasers are multiplexed onto a single fiber span using a commercial WDM. The DFB lasers areexternally modulated at frequencies from 0.05 to 20 GHz using quadrature-biased, 20 GHz bandwidth, Mach-Zehnder intensity modulators (MZM). The eight channels are transmitted along a 5 km (25 _s) span of Lucent Truewave™ non-zero dispersion shifted fiber with a negative dispersion (zero dispersion at 1590 nm). After the span, the eight wavelengths are demultiplexed and detected with 20 GHz bandwidth photodiodes.

The crosstalk amplitude was measured by modulating a single channel while detecting the RF power received at the photodiodes for all eight channels. As the modulation onto this channel is swept from 0 to 20 GHz, the RF power on each of the eight channels is measured using a network analyzer. The measured crosstalk onto channel 4 (_ = 1554.13 nm) from each of the other 7 channels (wavelengths ranging from 1549.32 nm to 1560.61 nm) is shown in figure 2. This nonlinear crosstalk represents the ratio of the RF power on the unmodulated channel (channel 4) to the RF power on the modulated channel. (channels1-3, 5-7). To compare with theory, the expected XPM and SRS crosstalk from channel 3 onto channel 4 was calculated based on models developed for CATV frequencies [1]. These calculations are plotted as solid lines in figure 2. Unlike CATV frequencies, where SRS is the dominant crosstalk mechanism, at higher frequencies XPM is the main source of crosstalk.

The crosstalk from each of the channels in the WDM delay line will produce errors in both the magnitude and phase of the signal transmitted along another channel. The reason for this is illustrated in figure 3. If the same frequency is modulated on each channel, a crosstalk vector will coherently (RF) add to the input signal vector, resulting in a vector with altered magnitude and phase. The phase, _c, between the crosstalk and signal is determined by the relative phase difference of the signals in the delay line. This difference is due primarily to differences in the fiber lengths for each channel before being multiplexed onto a single fiber, and differences in the phase of the RF signal input on each channel. The fiber lengths can be adjusted to randomize the phase difference between each channel, thereby minimizing the crosstalk induced phase error for predictable RF input signal phases. For systems with unknown RF signals, the maximum crosstalk must be considered. Therefore, the maximum phase error is examined by considering the case where _c = 90˚. Trigonometry yields the resulting maximum phase error:

_error,max = arctan[10^(Ac/20)] (1)

Where Ac is the amplitude of the crosstalk level in dB. Figure 4 shows a plot of the calculated maximum phase error for 2, 4, 8, and 16 channels with equal crosstalk.

To compare with this theory, the total phase error induced onto a single channel by the 7 other channels in the system shown in figure 1 is measured. The system is constructed such that the fiber lengths prior to the multiplexer have the same time delay to within < 100 ps. The same RF signal is applied to all 8 channels simultaneously. In order to measure the phase error without a priori knowing the phase between the signal and crosstalk vectors, the RF lines were set such channels 1-3, and 5-8 have the same RF delay prior to the fiber span to within < 2 ps, while the delay for channel 4 differs from the rest by 550 ps. This causes the phase between the signal and crosstalk vectors to change as the input frequency is swept from 0.05 – 20 GHz. Thus, _c varies periodically by 2π every 1.82 GHz. Hence the phase and magnitude of the resultant vector of channel 4 will oscillate as the input frequency is swept.

The measured phase error of channel 4 is plotted in figure 5 as a function of frequency. As the frequency is swept from 0.05 – 20 GHz, a sinusoidal variation with a period of ~1.8 GHz is seen in the phase measurement. Each maximum of this oscillation indicates the maximum phase error induced onto channel 4 at the corresponding frequency. The longer period variation seen in the phase signal is due to thermal drift in the 5 km fiber span. The phase error in figure 5 varies from 0.1° to 1°, while the crosstalk in figure 2 varies from –55 to –35 dB. However, this does not correspond to the 8 channel calculations shown in figure 4 for crosstalks of –35 dB. This is mainly due to the difference in crosstalk from each of the eight channels. For example, at 20 GHz one channel produces –35 dB of crosstalk, one produces –37 dB of crosstalk, and several channels produce < -45 dB of crosstalk, resulting in a lower total phase error.

The phase error due to crosstalk is an important consideration when constructing phase sensitive WDM systems such as RF antenna arrays. The maximum phase error produced by interchannel crosstalk in an eight channel 25 _s delay line was measured. Phase errors of 1° and less were observed for the system.

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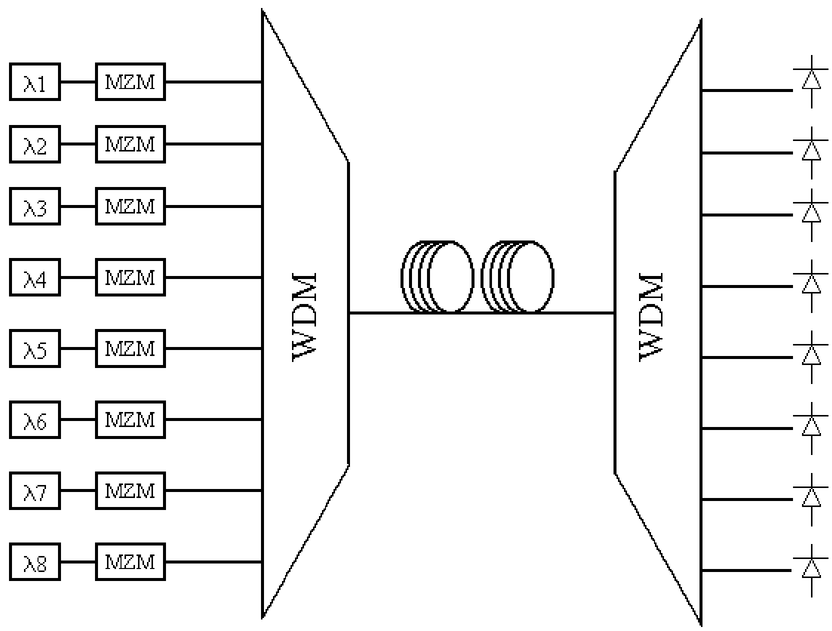

Figure 1. Eight channel WDM RF delay line.

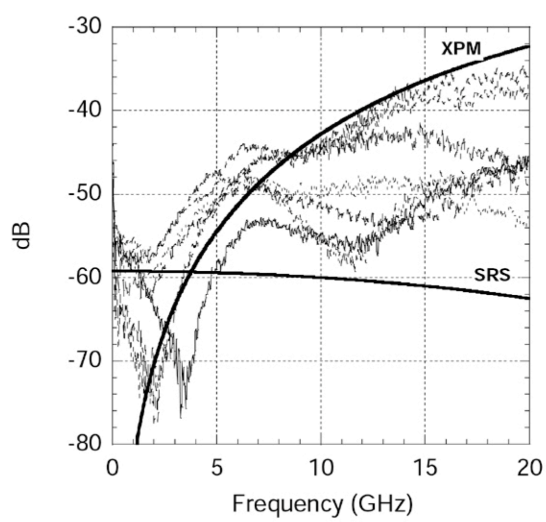

Figure 2. Crosstalk onto channel 4 due to modulation of channels 1-3,5-8. The solid lines show the calculated XPM and SRS crosstalk from channel 3 onto channel 4.

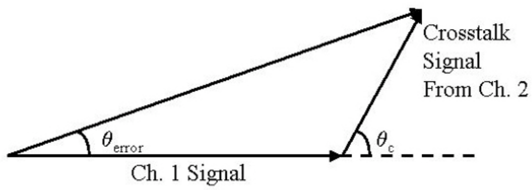

Figure 3. Vector representation of crosstalk induced variations in signal amplitude and phase.

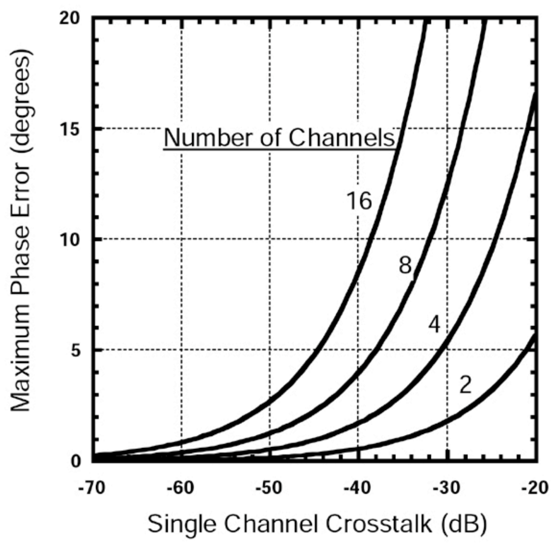

Figure 4. Calculated maximum phase error for 2, 4, 8, and 16 channels with crosstalk of equal magnitude.

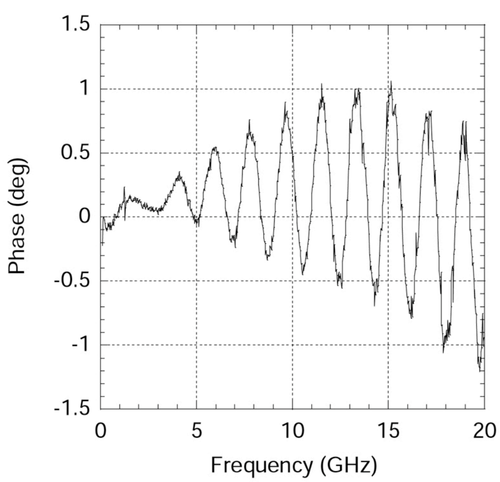

Figure 5. Measured S21 phase response from channel 4 with an equal amount of optical and microwave power on channels 1-3,5-8.