# Experimental and theoretical study of crosstalk in WDM – CATV systems

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**Abstract**: Fiber nonlinearities are assessed theoretically and experimentally for WDM-CATV transmissions. For fixed channel number, twofold reduction of channel spacing or for fixed spacing, twofold increase of channel number, increases crosstalk by 3dB/ch and 1dB/ch, respectively.

**OCIS codes:** (060.2330) Fiber optics communications; (060.4370) Nonlinear optics, fibers

## 1. Introduction

Sub-carrier multiplexed (SCM) cable TV (CATV) networks currently use WDM technology to respond to the increasing bandwidth demand of broadband services such as video on demand, high definition TV and Internet access. Fiber-induced nonlinearities generate crosstalk between WDM channels to impair the performance of the system and limit its potential for upgrade to higher capacities. Experimental measurements of crosstalk [1,2] and a theoretical model [1] for two channels systems have been presented before, however no model or thorough measurements with realistic channel counts (8 channels or more) have been published so far. Moreover, the contribution of electrostriction to the crosstalk level can be significant [2] and the models described in the literature [1] do not include it.

In this paper, both experimental and theoretical results are presented for a typical 8-channel CATV system at 200, 100 and 50GHz spacing. We describe a model able to predict crosstalk accurately in a WDM, SCM system with any channel count including the contribution of electrostriction. The model was verified against our measurements and used to investigate the performance of WDM-CATV networks with various channel spacings and number of channels. Finally, we conclude that a 3dB crosstalk penalty is observed when the channel spacing is decreased, keeping the number of channels constant, while only 1 dB of increase is induced as the number of channels are increased with the same spacing.

## 2. Experiment

The experimental setup used is shown in Figure 1. Seven CW tunable sources were multiplexed, amplified in EDFA 1 and then externally modulated by a $LiNbO_3$ modulator driven by the tracking generator of a RF spectrum analyzer. A CW tunable source was used as the probe signal. The modulated and CW signals were combined, amplified in EDFA 2 and launched into 25 Km of single mode fiber. At the fiber output, a 0.6nm tunable grating filter was used to isolate the CW signal, which was then amplified in EDFA 3. A second filter (0.25nm bandwidth) was used between EDFA 3 and the Rx to limit the amplifier's ASE spectrum and improve the adjacent channel crosstalk. Variable attenuators were used to set the input powers to the fiber and Rx to 8dBm and –1dBm respectively. The shortest operation wavelength was set at 1550.92nm and the channel spacing could be selected to be 200GHz, 100GHz or 50GHz. The simultaneous transmission of the seven modulated signals in the presence of fiber nonlinearities, generates a modulation on the CW channel at the receiver end, which was detected and analyzed on an RF spectrum analyzer. The crosstalk was defined as the ratio of power of the CW channel after propagation, to the power of each modulated signal before transmission [1,2].

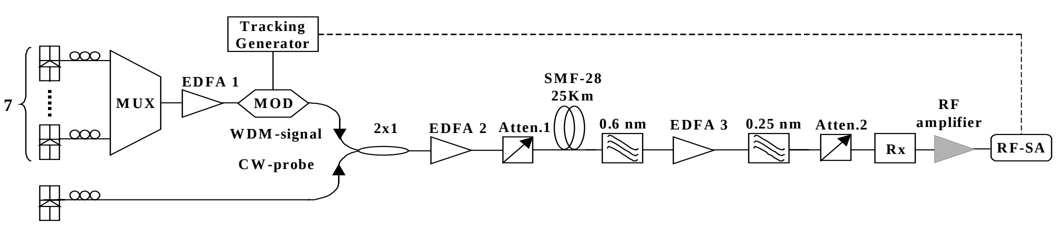


Fig. 1. Experimental setup

The crosstalk was then measured for several channels by varying the operation wavelength of the CW tunable source for channel spacings of 200, 100 and 50GHz. The results for the sixth wavelength are presented in Figure 2. The shapes of the measured crosstalk curves are similar to the ones obtained in [1] for a two-channel system and the electrostriction peaks identified in [2] are clearly visible.

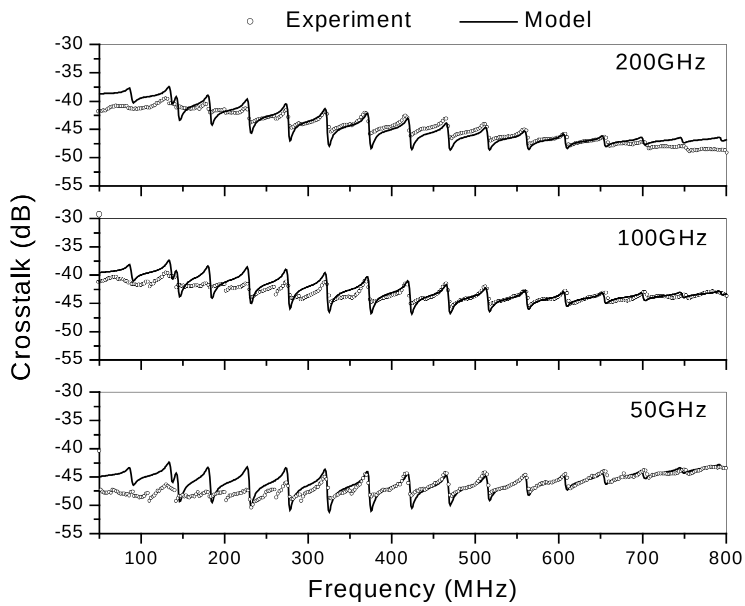


Fig. 2. Measured and calculated results for 200GHz, 100GHz and 50GHz spacing for the sixth consecutive channel.

### 3. Model

In order to assess the transmission impairments due to fiber nonlinearities, a model was developed that includes the effects of stimulated Raman scattering (SRS), cross phase modulation (XPM), polarization dependent loss (PDL) and electrostriction. The model can predict crosstalk levels for different channel numbers and wavelength spacings and as well as fiber parameters. The effects of SRS, XPM and PDL have been modeled following the work by Phillips et al. [1] and Wang et al. [3]. Electrostriction-induced acoustic interactions were included according to the theory introduced by Dianov et al. [4], Pilipetskii et al. [5], and Buckland and Boyd [6] as a modification of the nonlinear refractive index. Specifically, the electrostrictive frequency response was numerically calculated and added at the nonlinear refractive index with a multiplication factor of 1.5. The required acoustic eigenfrequencies were derived from Shelby et al.[7] by numerical calculation. The contribution of multiple modulated channels was calculated by squaring and then adding the modulation depths induced by each of them on the probe signal. The redundant sum of the squared modulation depths expressed in dB is defined as the crosstalk of the probe channel and is described analytically in terms of the fiber-induced nonlinearities by equation 1. Finally, the angle between the probe's and the modulated channels' polarization state could be varied, while the modulated channels were considered to be co-polarized.

$$C_{total} = 10\log\left[ \sum_{i=1, i\neq probe}^{N} \left(m_{depth,i}\right)^2 \right] \equiv 10\log\left[ \sum_{i=1, i\neq probe}^{N} \left(m_{SRS,i} \pm m_{XPM,i} + m_{PDL,i}\right)^2 \right] \quad (1)$$

The crosstalk model was used to calculate the crosstalk level for an eight-channel system, with varying channel spacing and similar parameters to the experimental setup described previously. The results can be seen in Figure 2. Good agreement between model and experiment is observed, especially in the sub-carrier frequency range between 500 MHz and 800MHz, where digital services are provided in CATV networks and WDM is used. This indicates that the models used for electrostriction and for the impact of multiple modulated channels were appropriately included in the overall crosstalk model.

Calculations were then used to predict the crosstalk level for 8, 16 and 32 channel systems at 200, 100 and 50GHz spacing. Figure 3 shows the crosstalk level at the worst case polarization between the probe and signal channels for the third channel on each channel plan. A detailed investigation of these results in the 500 to 800MHz range shows that the crosstalk level increases by 3 dB when the channel spacing is reduced by a factor of two and the total number of channels is kept constant. Moreover, the crosstalk level increases by 1dB when the number of channels is doubled but the spacing is kept constant. Consequently, if more channels are required in a system, it is preferable that these are added at the same spacing at the expense of bandwidth, rather than interleaved within the original wavelength span.

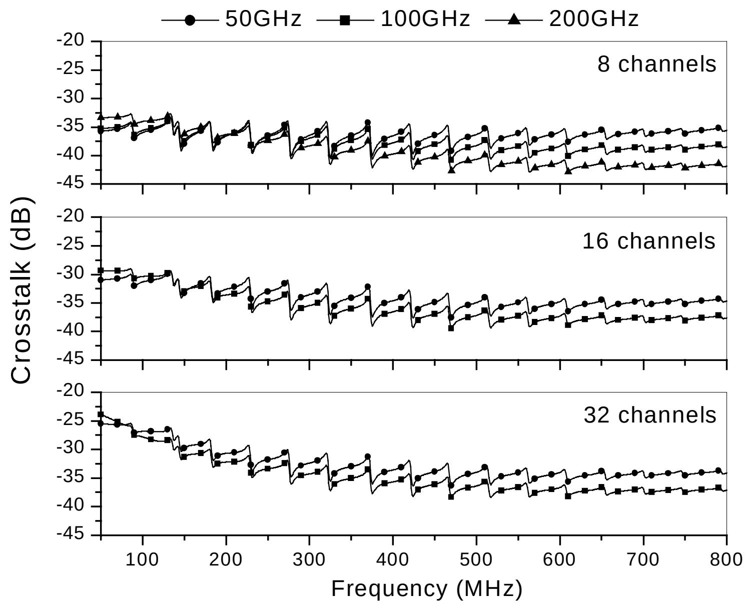


Fig. 3. Predicted model results in worst case scenario for 8, 16 and 32 channels and for different channel spacings.

## 4. Conclusions

The crosstalk level of an eight-channel WDM CATV system was measured at 50, 100 and 200GHz channel spacings. A complete model including the effects of electrostriction and multiple modulated channels was developed and verified against the experimental data. This model can be used to design and engineer CATV WDM networks and predict the crosstalk level for any number of channels at any channel spacing. For example, using the model we found that the crosstalk level increases by 3 dB when the channel spacing is reduced by a factor of two and the total number of channels is kept constant. Moreover the crosstalk level increases by 1dB when the number of channels is doubled but the spacing is kept constant.

## 5. References

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