Long Distance Transmission of 1550 nm CATV Signals on Different Optical Fiber Types

Ralph Radmacher, Juergen Seidenberg

Abstract — **1550 nm optical transmission is the preferred technology to span long distances in hybrid-fiber-coax networks. In order to achieve a good transmission performance, however, impairments induced by Stimulated Brillouin Scattering, Self-Phase Modulation and Chirp have to be avoided. This paper presents the results of investigations on impairments with respect to standard single mode fiber as well as advanced fiber types such as non-zero dispersion shifted fibers and wide band attenuation optimized fibers.**

Index Terms — **Hybrid-Fiber-Coax, Stimulated Brillouin Scattering, Self Phase Modulation, Chirp.**

I. INTRODUCTION

With the introduction of EDFAs and external modulated transmitters the analog transmission of CATV signals has made wide span transmission feasible. For very long distance applications the fiber loss can only be overcome by the use of optical amplifiers feeding at least 13 dBm into the standard single mode fiber. With these power levels several nonlinear mechanisms in the fiber become remarkable like Stimulated Brillouin Scattering (SBS), Self Phase Modulation (SPM) and in DWDM systems also Stimulated Raman Scattering (SRM), Cross Phase Modulation (CPM) and Four Wave Mixing (FWM). Additionally linear perturbations like Chirp-Dispersion-Interactions (CDI) degrade the transmission performance. All of these nonlinear and linear impairments depend on the spectrum of the optical transmitter signal and on optical and mechanical properties of the fibers. The transmission performance of CATV signals in terms of CNR, CSO and CTB has been investigated carefully on standard single mode fibers and 50 – 750 MHz frequency plans [1]. In this paper the transmission properties of 47 – 862 MHz systems obtained with some more advanced fibers like non-zero-dispersion-shifted (NZDS) fibers and wide band attenuation optimized fibers (WAOF) are compared with the performance achieved with standard single mode fibers (SMF).

II. MEASUREMENT SETUP

Fig. 1 shows the used measurement setup.
A professional tunable CATV headend is used to generate in total 44 PAL-B/G, 42 QAM64 and 36 FM-radio channels or the European Cenelec 42 channel AM-VSB frequency plan. The back-off of the FM-radio and QAM64 was –4 and –10 dB referred to unmodulated AM-VSB PAL-B/G channels. The professional headend was used instead of the widely used Matrix generator in order to have the flexibility to study the system performance either with unmodulated or modulated AM carriers and to use different frequency plans. This becomes important in determining the optical modulation index per channel (OMI) the total RMS optical modulation index OMI_{rmstot} for a requested bit error rate (BER) of the QAM64 channels.

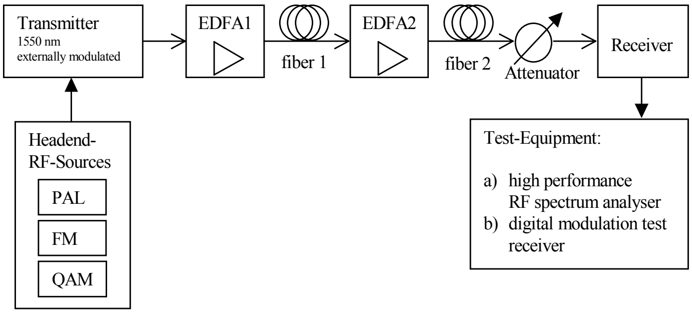

Fig. 1. Measurement setup for 2 sections of EDFA and fiber

For the long distance measurements the European CENELEC-42 frequency plan was used. This pure AM-VSB frequency plan with carriers between 47 and 862 MHz is currently seen to be the most difficult one to achieve good performance especially on CSO in the highest channel, especially regarding SPM and CDI.
The test equipment was a high performance RF spectrum analyzer for CNR, CSO and CTB measurements and a digital modulation test receiver, enabling MER, BER etc. measurements on the QAM64 channels.
The optical transmitter was an externally modulated 1550 nm DFB laser transmitter, with an intrinsic CSO/CTB of 71/69 dB for the given hybrid channel load.
The implemented SBS suppression capability could be tailored to the actual needs in order to minimize SPM.
EDFAs with very low noise (noise figures around 4.0 dB at 0 dBm input power) and low PDL + PMD have been used.
The p-HMT-FET optical receiver exhibited an input noise current of 3.8 pA/√Hz and negligible CSO and CTB contributions.
Three and four sections of EDFA + optical fiber have been used. The 100 km trunk network was suggested to consist of two or three sections with lengths of 33 and 50 km each, the final section, which represented the access network, was defined to use always 10 km of fiber.

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Ralph Radmacher, Juergen Seidenberg, Bktel communications GmbH,
Bonnenbroicher Str. 2-14, 41238 Moenchengladbach, Germany,
tel.: +49 2166 27 2852, fax: +49 2166 27 2851,
Radmacher@BKtel.COM, Seidenberg@Bktel.COM

Standard single mode fiber was used showing a dispersion of 17 ps/nm/km at 1550 nm. Among the advanced optical fibers used for comparison were a NZDS fiber (Alcatel´s TeraLight optical fiber) with 8 ps/nm/km of dispersion at 1550 nm and a WAOF fiber (Lucent´s AllWave^{TM} optical fiber).

II. MEASUREMENT RESULTS

A. 100 km trunk network with standard SMF

Before measuring the transmission performance of a link as described in fig. 1 it is mandatory set the appropriate OMI. A lower OMI helps to improve CSO and CTB as well as BER, however, decreasing the CNR and MER. A higher OMI will improve the CNR and MER, but will degrade the other items. In general, with high performance optical transmission equipment, the BER becomes the limiting factor for OMI, that means, the maximum OMI and OMI_{totrms}. is given by the accepted BER.
Fig. 2 shows the measurement result on the BER as a function of OMI_{totrms}.

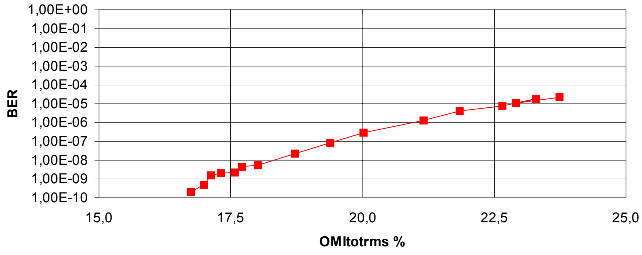

Fig. 2. BER as a function of OMI_{totrms}

The measured bit errors are due to clipping distortions in the optical transmitter. Externally or directly modulated transmitters show an almost identical BER vers. OMI_{totrms} behavior. For the subsequent measurements, the OMI_{totrms} was selected to be 19%, which gives a BER of 10^{-7}. This value is sufficient to achieve a bit error rate free transmission after the FEC circuitry of the set top box even taking into account further MER or BER degradations due to other network elements e.g. in the coaxial cable plant.

The main focus of the work was to investigate long distance transmission performance degradation because of SPM and CDI, which lead to poor CSO performance. Both, SPM and CDI, depend on the total accumulated dispersion of the optical link. CDI depends on the residual chirp of the optical modulator, SPM on the optical spectrum of the transmitter and the launched optical power. The spectrum is for purpose of suppressing Stimulated Brillouin Scattering broadened via an optical phase modulator, driven with microwave signals. Without phase dithering and with fiber input powers exceeding about 6 dBm SBS would strongly degrade or hinder the transmission. With phase dithering, fiber input powers of more than 13 dBm become feasible, hence, by taking into account a broadened optical spectrum. Unfortunately, the broader the spectrum the more SPM occurs. Therefore a tradeoff between SBS and SPM has to be found.
SPM and CDI have mainly an impact on CSO distortions, and almost no impact on CNR and CTB. For that reason in this paper only the CSO measurement results are presented.
Fig. 3 shows, the result, when the phase dithering is chosen to suppress SBS up to 17 dBm of fiber input power. Two sections of 50 km of standard single mode fiber (10 dB optical loss each) have been selected. The input power into each section has been varied between 13 and 16 dBm.

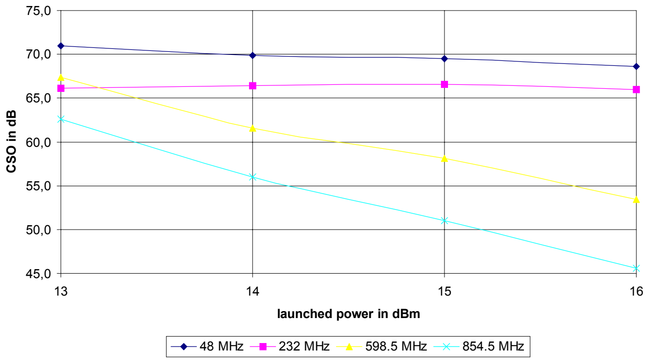

Fig. 3. CSO as a function of launched power into 2 x 50 km of standard SMF; SBS suppression capability fixed to 17 dBm

The CSO has been measured in 4 channels of the C42 frequency plan. As expected from theory, there is only a minor impact on the CSO in the lower frequency channels, whereas the CSO is worst in the higher frequency channels and with higher input power into the fiber sections. Due to the widely broadened spectrum of the transmitter in order to overcome the SBS problem, SPM is dominating the CSO in the higher channels. In order to achieve a good CSO for a 100 km C42 link, SPM has to be minimized, therefore requesting to operate with a less broadened optical spectrum and consequently less optical power launched into the fiber sections. A CSO of 62 dB can be obtained just with a launched power of less than 13 dBm into the fiber sections.

The resulting CNR contributions and accumulated CNR is shown in table 1:

network element	CNR contrib.	accum. CNR
1550 nm TX	62.3 dB	62.3 dB
1st EDFA at Pin = 6.5 dBm	59.1 dB	57.4 dB
2nd EDFA at Pin = 0 dBm	53.9 dB	52.3 dB
3rd EDFA at Pin = 0 dBm	53.9 dB	50.0 dB
Optical fiber	52.9 dB	48.2 dB
RX at Pin = +1 dBm	58.0 dB	47.8 dB

Table 1. CNR contributions and accumulated CNR in a 2 section 100 km trunk network followed by a 10 km access network

The first EDFA is used as a booster for the transmitter, the second EDFA is used as an inline amplifier, the third EDFA is suggested to be the distribution amplifier for the access network. The input powers of the EDFAs and the receiver have been adjusted using optical attenuators in order to simulate a total fiber loss of 0.25 dB/km, representing sufficient splice and connector loss in real life networks.

It can be seen, that the total accumulated CNR is only 47.8 dB (in 5 MHz). If higher values are requested, instead of a 2x50 km trunk network, a 3 x 33 km trunk network has to be planned.

Figure 4 shows the resulting CSO as a function of launched power for a 3x33 km trunk network.

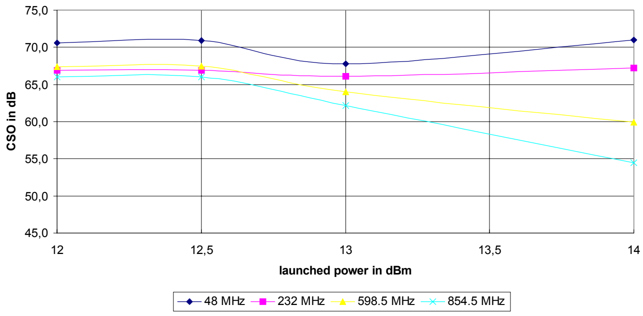

Fig. 4. CSO as a function of launched power into 3 x 33 km of standard SMF; SBS suppression adjusted to launched power

Also in this case, the limit to achieve 62 dB of CSO is a optical fiber input power of 13 dBm. The resulting CNR contributions and accumulated CNR are shown in table 2.

network element	CNR contrib.	accum. CNR
1550 nm TX	62.3 dB	62.3 dB
1st EDFA at Pin = 6.5 dBm	59.1 dB	57.4 dB
2nd EDFA at Pin = 4.3 dBm	57.3 dB	54.3 dB
3rd EDFA at Pin = 4.3 dBm	57.3 dB	52.6 dB
4th EDFA at Pin = 4.3 dBm	57.3 dB	51.3 dB
Optical fiber	52.9 dB	49.0 dB
RX at Pin = +1 dBm	58.0 dB	48.5 dB

Table 2. CNR contributions and accumulated CNR in a 3 section 100 km trunk network followed by a 10 km access network

With the 3x33 km trunk approach, the CNR of the total link can be improved to 48.5 dB.

It should be noted at this point that CSO induced by SPM in principle can be compensated with CSO induced by CDI [2], however, only for one output of the Mach-Zehnder modulator of the optical transmitter, since CDI induced CSO distortions are only in proper phase to cancel SPM induced CSO if originating from the right output. There are, however, two disadvantages in this approach. First, the required chirp, which can be either generated by a debiasing of the Mach-Zehnder modulator or an intrinsic different Mach-Zehnder-modulator design will disable the use of the second output at least for medium and long distance transmissions. Second, the compensation of CSO induced by SPM with CSO induced by CDI only works for one distance perfectly, that means especially for point-to-point links. In ring type networks, the most frequent application of 1550 nm trunking today, the compensation only works for one ring outlet, the signal performance at the other outlets would be degraded significantly.

B. 50 km trunk network with advanced SMF

The availability of more advanced fiber types, requests to check whether the results obtained by applying the standard SMF can be transferred to new types of SMF.

For that reason an investigation has been started to investigate optical fiber networks with new fiber types.

A fiber type, where the results to be achieved are expected to be very similar to the standard SMF is the Lucent AllWave™ fiber. The major difference of this fiber is the significantly lower loss at the OH^--absorption-peak at 1383 nm. All the other properties such as effective area and dispersion are about the same as the standard SMF. For that reason it is expected that the nonlinear effects (SBS and SPM) will be very similar.

One of the new advanced NZDF is Alcatel´s TeraLight fiber. This fiber exhibits a significant lower dispersion at 1550 nm of only about 8 ps/nm/km compared to the 17 ps/nm/km of the standard SMF. The effective area, however, has been reduced from 80 μm^2 to only 65 μm^2 . The attenuation of 0.205 dB/km at 1550 nm is slightly higher than the standard SMF

The lower dispersion gives less SPM and CDI induced CSO to be expected. The reduced effective area will, however, increase SBS and SPM.

For comparison, the standard SMF, the AllWave fiber and the TeraLight fiber have been investigated in the set-up as shown in fig. 1. For simplicity, however, with only one section of EDFA and 50 km of fiber. The results are given in table 3 below. Measurements have been performed on both outputs of the optical transmitter, which comprise opposite optical chirp and in 4 channels of the C42 frequency plan.

	CSO in dB with output 1 / 2 measured at			
fiber type	48 MHz	232 MHz	598.5 MHz	845.5 MHz
no fiber	70.3/69.3	66.9/64.8	67.0/68.6	68.1/66.8
standard	69.9/68.6	67.7/65.5	66.8/69.5	65.0/65.1
AllWave	69.6/68.9	67.4/65.8	66.9/69.6	65.3/65.7
TeraLight	69.6/69.2	67.5/65.9	68.3/66.7	66.6/61.4

Table 3. CSO measured using both outputs of the transmitter with 50 km of different fiber types.

The line “no fiber” gives the intrinsic CSO performance of the link consisting of transmitter, EDFA, attenuator and receiver.

For all fiber types the CSO was measured to be about the same (+/- 1 dB) in the 2 lower frequency channels. For the two higher frequency channels the CSO obtained with the AllWave fiber is about the same as with the standard SMF. There is a small CSO drop in the higher channels for both outputs, which means that CDI induced CSO is very low and SPM is the major reason for CSO.

For the link using the TeraLight fiber the situation is different: For the 2 higher channels, the CSO with output 1 of the transmitter improves, whereas the CSO with the other output degrades, especially in the highest channel. The explanation comes from SPM. Because of the smaller effective area of the TeraLight fiber, SPM is stronger than in all other links. Since SPM always has the strongest impact on the higher frequency channels, at 845.5 MHz the CSO change becomes clearly evident. By chance, the SPM induced CSO distortions compensate the intrinsic distortion (output 1 at 598.5 MHz) in one case. The most important impact, however, can be seen with output 2 at 854.5 MHz, where the CSO drops by about 4 dB compared to the standard SMF.

III. CONCLUSION

Long distance transmission of 1550 nm CATV signals can be achieved with good transmission performance by properly choosing the appropriate OMI to enable the transmission of simultaneous AM-VSB PAL/NTSC and QAM-signals. BER is a major factor in this selection process.

Fiber nonlinearities play an important role in 100 km span trunk links especially in upper frequency channels. By adjusting the SBS suppression capability of the transmitter accordingly, very good transmission quality can be achieved.

Several advanced optical fibers have been introduced for terabit digital links and metropolitan networks in the past 2 years. In this paper some initial results for 2 advanced fiber types have been presented.

It appears, that analog transmission has different requirements on the optimum fiber properties than terabit digital links.

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