INITIAL PULSE MODULATION METHOD FOR SBS COUNTERACTING IN LONG DISTANCE OPTICAL FIBER CATV LINK

Marek Jaworski(1) **and** **Marian Marciniak**(2)

(1)*National Institute of Telecommunications, Department of Transmission and Fiber Technology,*
1 Szachowa Street, 04-894 Warsaw, Poland, E-mail M.Jaworski@itl.waw.pl

(2)*As (1) above, but E-mail: M.Marciniak@itl.waw.pl*

ABSTRACT

Analysis of Stimulated Brillouin Scattering in externally modulated lightwave long distance AM-CATV systems is presented. The SBS threshold power (P_{SBS} = 7 dBm) is the main limiting factor of transmission distance. Two methods of increasing the SBS threshold are compared: well known dithering method and new one called Initial Pulse Modulation Method, in which optical signal spectrum is widening and suppressed due to FWM in initial fiber with high normal dispersion and Kerr nonlinearity, e.g. DCF fiber. The simulations indicated good quality of the output signal (*CNR*>52 dBc, *CSO*<-60 dBc) for very long distance CATV link (up to 200 km).

INTRODUCTION

In optical fiber multichannel distribution systems (CATV – common antenna television) vestigial sideband amplitude modulation (AM-VSB) with subcarrier multiplexing (SCM) is used. Required high carrier to noise ratio (*CNR* > 52 dB) and low level of intermodulation distortions (*CSO* and *CTB* < -60 dB) is very difficult to obtain in systems with span of several tens of kilometers. Requirement of high transmissions quality causes that phenomena normally omitted in conventional telecommunication systems must be taken into account. Such undesirable phenomena are distortion – caused by nonlinearity of fiber appeared for high transmission power level, and multi-path interference (MPI) of signals directly coming to optical receiver and after double reflection. Fiber nonlinearity manifests itself in self-phase modulation (SPM) [1], stimulated Brillouin scattering (SBS) [2], and stimulated Raman scattering (SRS) [3]. Single wavelength CATV system is immune to SRS, contrary to WDM systems [3]. We attempt here to present comprehensive analyse of very long distance CATV link, underlying SBS phenomenon and measures to avoid it. Simulation model was used to evaluate CATV link properties, as shown at block diagram in Fig. 1. Module for increasing SBS threshold power (Fig. 2) is placed directly after light source and then external amplitude modulation is applied with additional phase modulation used to SPM compensation (prechirping) [4].

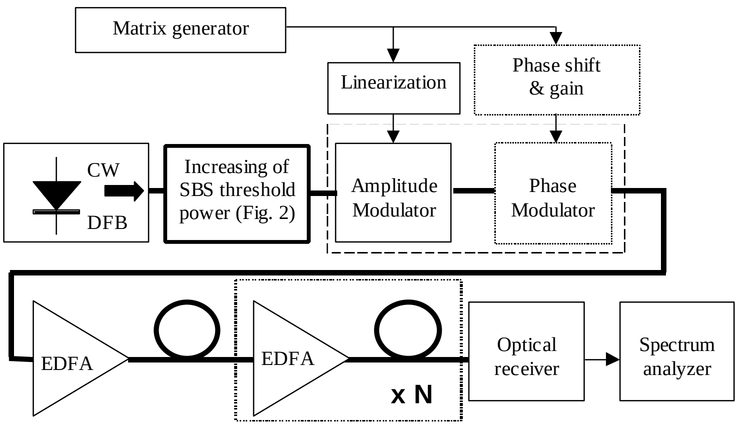


Fig 1. Block diagram of CATV link simulation model

INCREASING SBS THRESHOLD POWER

Stimulated Brillouin Scattering (SBS) takes place when high power, coherent optical wave propagates in optical fiber, which initiate propagation of acoustic wave. The acoustic wave creates patterns of periodically changing refractive index (fiber Bragg gratings). These gratings reflect the optical wave.

For transmitted power higher than the SBS threshold power (approximately 7 dBm) the reflected power rapidly increases and consequently interferometric noise (MPI – multi path interference) increases. Scattering the optical spectrum can decrease spectral density. Unfortunately, when the transmitted spectrum is in order of tens of GHz modulation instability (MI) occurs in the case of fiber with anomalous (positive) dispersion. To avoid MI effect Non-Zero Dispersion Shifted Fiber ($NZDSF^{-}$) with slightly negative dispersion (e.g. -2 ps/nm·km) should be used. Two methods of increasing the SBS threshold are presented below: well known dithering method and new one called Initial Pulse Modulation Method.

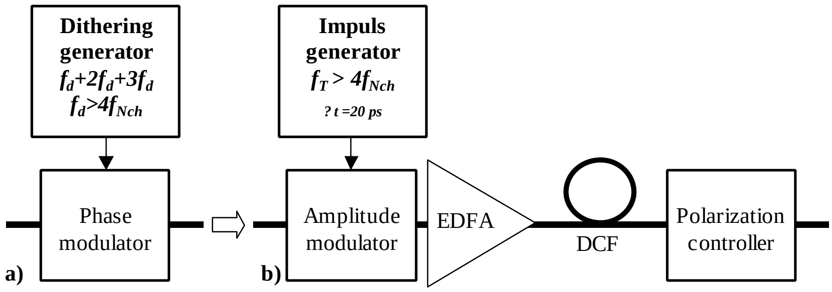


Fig. 2. Two methods of increasing SBS threshold power: a) optical phase modulation (dithering), b) initial pulse modulation and spectrum scattering by propagation in DCF fiber

A. Dithering Method

Wideband optical phase modulation (dithering) is well known method of increasing the SBS threshold power. External phase modulator or direct laser current modulation produces the dithering. Large value of index modulation *ß* creates many spectral lines (approximately 2·*ß*) placed symmetrically around the central line at frequency $?_0$, with span between them equals modulation frequency f_m. Making choice of the modulation frequency is very important. The frequency should be at least fourfold of signal maximum frequency (in the CATV system it is the highest subcarrier frequency) due to influence of triple beat intermodulation ($f_i + f_j - f_k$), and the frequency should not be too high due to interplay between GVD (Group Velocity Dispersion) and SPM (Self Phase Modulation).

Additional increasing of the SBS threshold can be achieved by multi-frequency modulation [2]. The main drawback of the frequency modulation (either single-tone or multi-tone) in long CATV link of total span higher then 100 km is spectrum fluctuations of the propagating power (Fig. 3). Origin of the fluctuations is Four Wave Mixing phenomenon (FWM), leading to increase of some spectral lines above SBS threshold power.

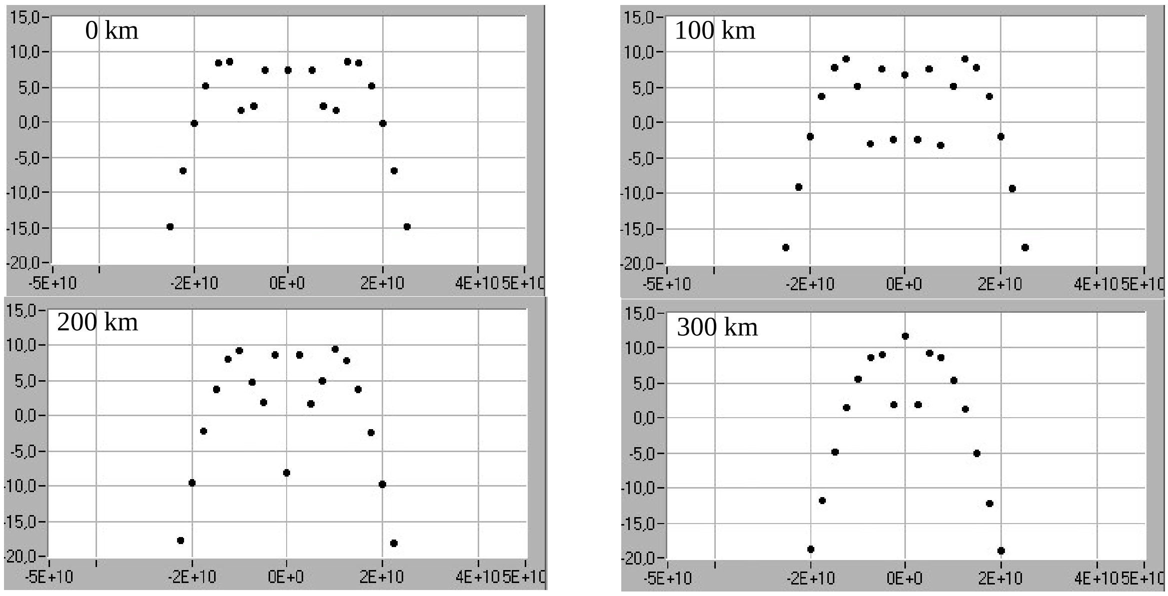


Fig. 3. Spectrum of optical power propagating in $NZDSF^{-}$ fiber after dithering (*ß* = 7.1).
Line parameters: P_{EDFA} = 17 dBm, L_{EDFA} = 50 km, *D* = -1 ps/nmkm, ? = 0,2 dB/km, ? = 1.3 $^{-}W^{-1}km^{-1}$

B. Initial Pulse Modulation Method

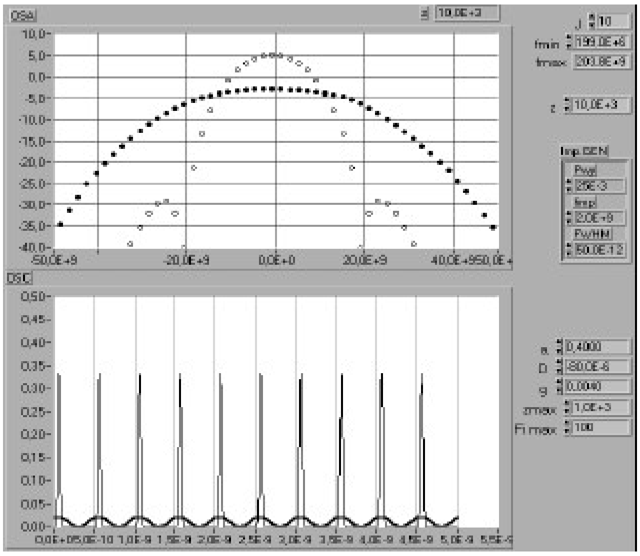


Fig. 4. Simulation of power propagation in initial DCF fiber.
a) Spectrum domain: circles - input, dots - output.
b) Time domain: thick line- output, narrow line - input.
z = 10 km, ? = 0,4 dB/km, ? = 4 $^{-}$W^{-1}km^{-1}, P_0 = 25 mW, ?t = 20 ps, T = 500 ps

To avoid these fluctuations we were looked for such a shape of optical spectrum propagating in NZDSF^{-} that is immune to deformation due to dispersion (GVD) and Kerr nonlinearity (SPM).

Proper shape of optical spectrum can be realised by transmitting short periodical pulses through highly nonlinear fiber with high normal (negative) dispersion (Fig. 4). Pulses are quickly widening during propagation due to fiber dispersion, which means that time dependence of optical power diminishes. As a result, optical power at the fiber output is near constant, with only small component of pulse repetition frequency. Optical spectrum at the input of the fiber contains many lines – it is simply Fourier transformed spectrum of initial pulses and has quasi-Gaussian envelope with spectral components separated by f_T = 2 GHz. The components interfering each other due to Kerr nonlinearity (it is well known Four Photons Mixing process) and dispersion, producing new spectral components. The spectral bandwidth should be above 50 GHz to obtain stabile propagation. It is difficult to obtain such a wide bandwidth by electro-optical modulation. Additional, initial fiber was placed between pulse modulator and standard CATV amplitude modulator (Fig. 2b). The optical spectrum transmitted in DCF fiber, after initial transformation, stabilised their shape due to GVD and SPM interaction, if only input power is sufficiently high. Relatively smooth shape of the spectrum (in comparison with dithering method) leads to very stabile propagation in NZDSF^{-} fiber, even for high optical power levels (see Fig. 5).

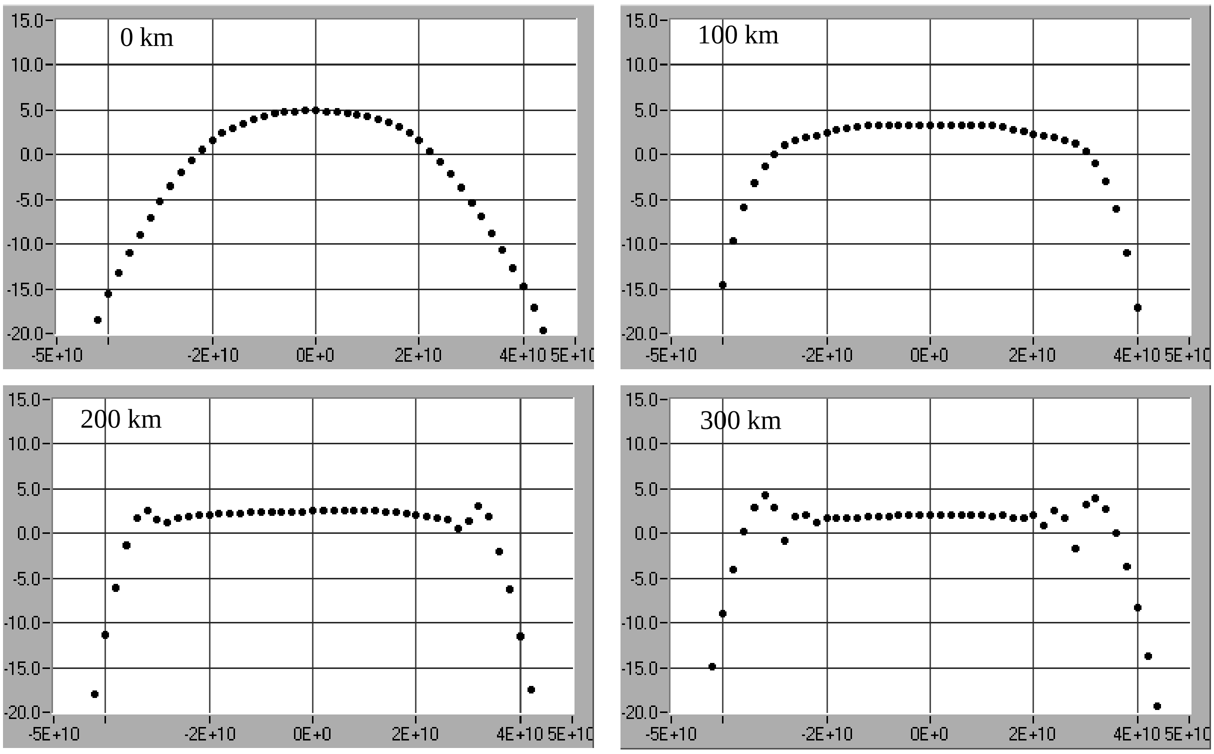
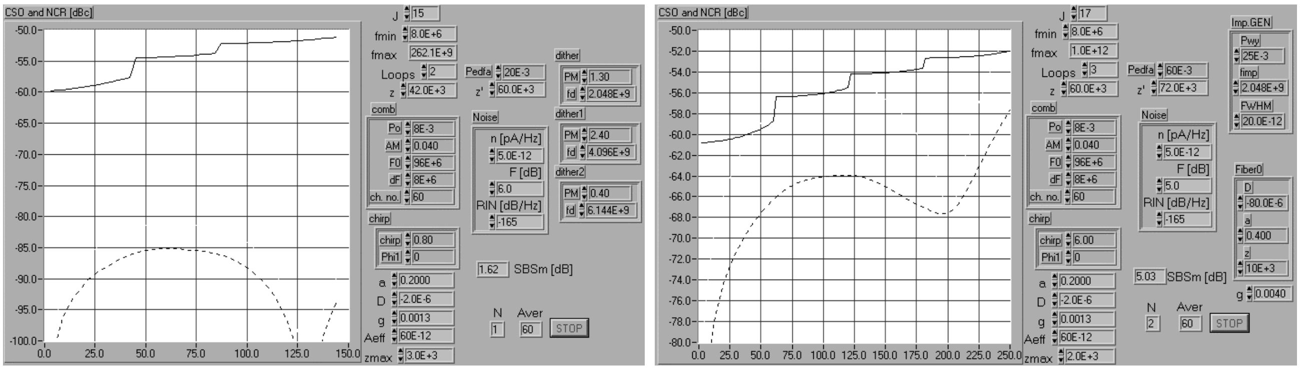


Fig. 5. Spectrum of optical power propagating in NZDSF^{-} fiber after initial pulse modulation.
Line parameters as in Fig. 3

SIMULATIONS

The lightwave CATV link simulation was performed in order to evaluate usefulness of the proposed compensation method (Fig. 1). Noise parameters (carrier to noise ratio - *CNR*) and distortion parameters (composite second order - *CSO*) were simultaneously monitored. The *CSO* was measured in the next channel to the highest subcarrier. The simulation was performed for system with 60 subcarriers with random phases. Due to the random nature of the input signal, the *CSO* is calculated as average result of 60 simulations. Composite triple beat (*CTB*) is not calculated here, because in lightwave CATV systems *CSO* distortions are dominant. The nonlinearity of transmission fiber was taking into account and Split Step Fourier Method (SSFM) was used. The main parameters of simulated CATV link are shown in Fig. 6.

Special utility software was prepared to control simultaneously noise (*CNR*), intermodulation distortions (*CSO*), and margin of transmitted power for the SBS threshold, related to the CATV link length. The results of simulation are shown in Fig. 6. Lower line depicts *CSO* distortions and higher line shows noise parameter *CNR*. *SBSm* value shows how much (in dB) transmitted level is lower then SBS threshold. Fig. 6 shows that the main source of *CNR* deterioration is EDFA amplified spontaneous emission (ASE).



a) b)

Fig. 6. Simulation results of 60 channels CATV link with two methods of increasing SBS power threshold: a) dithering method, b) initial pulse modulation method

In the case of dithering method maximum output EDFA power is limited to 20 mW, due to narrow and sharp optical spectrum (Fig. 3), and consequently distance is noise limited to 120 km. In the case of Initial Pulse Modulation Method high output EDFA power (up to 60 mW) can be used. Maximum distance is limited by the Kerr nonlinearity, which can be partially compensated by prechirping [5].

CONCLUSIONS

SBS is the main limiting factor of CATV link span. The new method of SBS counteracting was proposed. In the method optical signal spectrum is widening and suppressed due to Four Wave Mixing in the initial fiber (with high normal dispersion and Kerr nonlinearity, e.g. DCF fiber). The amplified output signal is then launched at standard amplitude modulator of CATV transmitter. The simulations indicated good quality of the output signal (*CNR*>52 dBc, *CSO*<-60 dBc and *CTB*< -65 dBc) for very long distance CATV link (up to 200 km).

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