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CSO/CTB PERFORMANCE IMPROVEMENT BY USING FABRY-PEROT ETALON AT THE RECEIVING SITE

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Abstract—An externally modulated NTSC 77-channel erbium-doped fiber amplifier (EDFA)-repeated system employing Fabry-Perot (FP) etalon at the receiving site to improve system performance was proposed and demonstrated. In comparison with conventional externally modulated fiber optical CATV transport systems, good performance of carrier-to-noise ratio (CNR), composite second order (CSO), and composite triple beat (CTB) were achieved for the full channel band over a 100-km single-mode fiber (SMF) transmission. Our proposed systems are suitable for the long-haul fiber optical CATV transport systems.

1. INTRODUCTION

The increasing promise of using fiber optical CATV networks for broadband communications stems from the fact that the introduction of 1550 nm technology has been enhanced. The advantages make 1550 nm transmission particularly attractive for long-haul fiber optical CATV applications. However, when multiple CATV channels are transmitted through a nonlinear device such as an optical amplifier, nonlinear distortions like composite second order (CSO) and composite triple beat (CTB) will be generated [1–3]. Dispersion accumulates rapidly over long-haul transmission; therefore, it is important that some ways be taken to reduce the fiber dispersion when transmitting CATV signals, leading to better CSO and CTB performance. Several ways have been proposed to improve CSO and CTB performance of systems. However, sophisticated optical single sideband modulation

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scheme and differential detection technique are required [4–6]. For a successful deployment of long-haul fiber optical CATV transport systems, the cost and complexity are obviously considerable concern. Fabry-Perot (FP) etalon, with an optical characteristic of narrow optical band-pass filter, can reshape the laser spectrum and reduce the spectral width [7–9]. It is expected to have good performance in fiber optical CATV transport systems. In addition, FP etalon can be very compact and low cost. In this paper, we proposed and demonstrated an externally modulated NTSC 77-channel erbium-doped fiber amplifier (EDFA)-repeated [10] system employing FP etalon at the receiving site to improve system performance. The function of FP etalon is to suppress the spectral width and to ameliorate the fiber dispersion, in which resulting in system with better performance. To the best of our knowledge, it is the first time to use FP etalon filter at the receiving site in externally modulated fiber optical CATV transport systems to improve system performance. In comparison with the conventional externally modulated fiber optical CATV transport systems, good performance of carrier-to-noise ratio (CNR), CSO and CTB were obtained in our proposed system over a 100-km single-mode fiber (SMF) transmission. Employing a simple FP etalon in fiber optical CATV transport systems is useful in real network, as it is simple, passive, and potentially low cost. Since our proposed system does not use sophisticated optical single sideband transmitter and differential detection technique, it reveals a prominent one with simpler and more economic advantages than that of conventional externally modulated transport system.

2. EXPERIMENTAL SETUP

Figure 1 illustrates two optically amplified AM-VSB transmission systems with three cascaded EDFAs. System I shows the conventional 77-channel fully loading externally modulated system. System II shows our proposed 77-channel fully loading externally modulated system employing FP etalon at the receiving site. The output power and noise figure of each EDFA used in systems I and II are $\sim 17\,\mathrm{dBm}$ and $\sim 4.5\,\mathrm{dB}$, at an input power of $0\,\mathrm{dBm}$, respectively. In System I, a total of 77 random phase continuous wave carriers from a multiple signal generator (MATRIX SX-16) are used to simulate analog CATV channels (channels 2-78; 6 MHz/CH) and fed into an externally modulated transmitter with an optical modulation index of $\sim 3.5\%$ per channel. The stimulated Brillouin scattering suppression ability of the externally modulated transmitter was $\sim 17\,\mathrm{dBm}$, so the launched optical power into the fiber should be kept at $\leq +17\,\mathrm{dBm}$ by

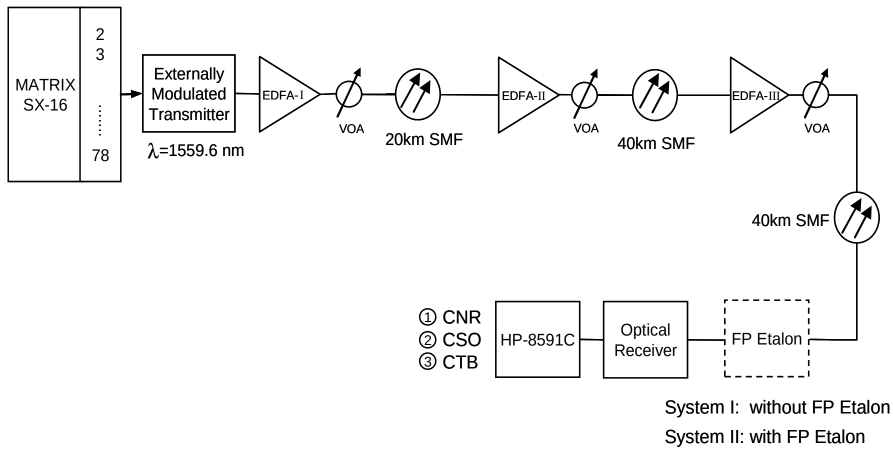


Figure 1. Two optically amplified AM-VSB transmission systems with three cascaded EDFAs:
System I: the conventional 77-channel fully loading externally modulated system.
System II: our proposed 77-channel fully loading externally modulated system employing FP etalon at the receiving site.

a variable optical attenuator (VOA) to avoid degradation caused by the stimulated Brillouin scattering effect. The effects of stimulated Brillouin scattering on system performance are examined using experimental result, as soon as the fiber injected power is increased beyond 17 dBm, a rapid degradation in CNR performance occurs. System link with a transmission length of 100 km consisted of three SMF spans ($20 + 40 + 40$ km, each with an attenuation of 0.24 dB/km, and a dispersion of 17 ps/nm/km). The VOA was also introduced at the start of each optical link, this would have resulted in less distortion since the optical power launched into the fiber would have been less. In order to transmit optical signal over a 100-km SMF, the optical power was amplified using three stages of EDFAs. The input power level of the optical receiver was adjusted to be 0 dBm using a VOA, with optical receiver's RF output level kept above 30 dBmV per channel. CNR/CSO/CTB CATV RF parameters were measured using an HP-8591C CATV analyzer over a 100-km SMF transmission. CNR, CSO, and CTB are used as figures of merit to evaluate the performance of the fiber optical CATV transport systems.

The difference between systems I and II is that system II employs a FP etalon at the receiving site to improve the system performance. The FP etalon has an optical input port and an optical output port.

The optical input port is connected with the end of 40-km SMF (the third fiber span), and the optical output port is connected with the optical receiver. The FP etalon is applied in front of optical receiver to compensate for fiber dispersion and to reduce spectral linewidth. One of the central wavelengths of the FP etalon is matched with the central wavelength of the externally modulated transmitter (1559.6 nm). In order to reshape the optical spectrum after a 100-km SMF transmission, the FP etalon exhibits free spectral range (FSR) of 100 GHz and narrow 3-dB bandwidth of 0.1 nm. ALL CATV RF parameters were also measured using an HP-8591C CATV analyzer over a 100-km SMF transmission.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The optical spectra with and without FP etalon at the receiving site are shown in Figure 2. It can be seen that originally the optical signal possesses a wide spectral linewidth of 0.363 nm; after the optical signal is coupled into FP etalon, the optical signal possesses a narrow one of 0.325 nm. By eliminating the redundant spectra of optical signal, this technique can enhance the spectral efficiency. Employing FP etalon at the receiving site not only offers high spectral efficiency but also ameliorates the dispersion by reducing the spectral width of optical signal. Wavelength misalignment between the transmitted optical wavelength and the FP etalon due to thermal effect, will change optical power level launched into the fiber and degrade system performance. To avoid wavelength misalignment due to temperature changes, the FP etalon used in this experiment is achieved by using athermal package.

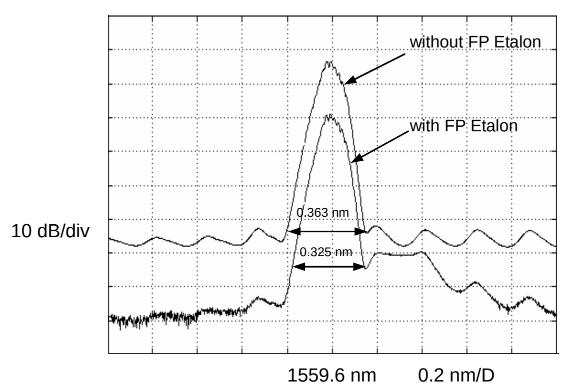
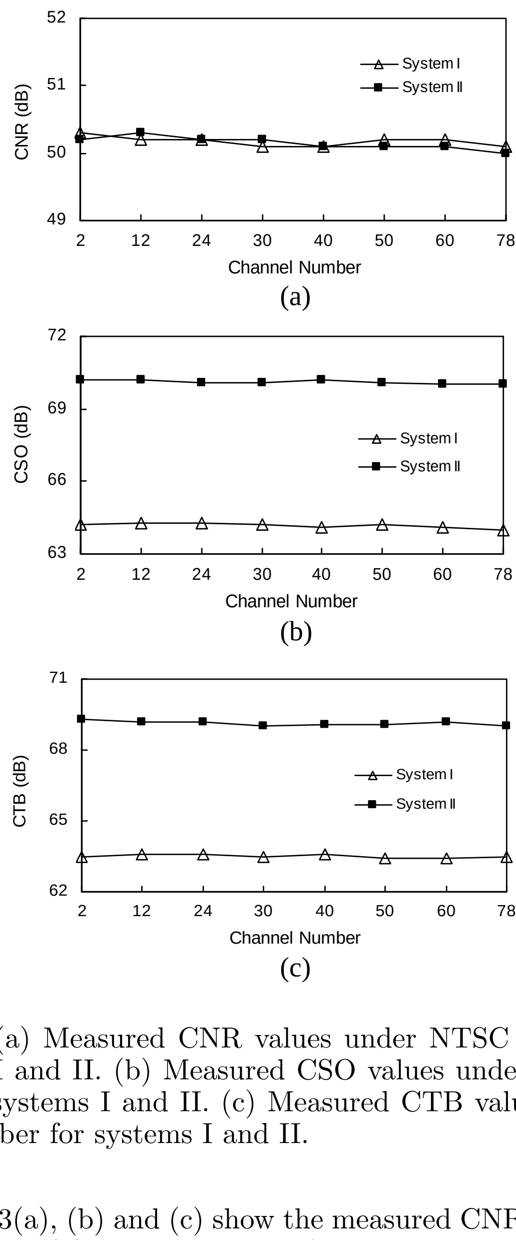


Figure 2. The optical spectra with/without FP etalon at the receiving site.



(a) (b) (c)

Figure 3. (a) Measured CNR values under NTSC channel number for systems I and II. (b) Measured CSO values under NTSC channel number for systems I and II. (c) Measured CTB values under NTSC channel number for systems I and II.

Figures 3(a), (b) and (c) show the measured CNR, CSO and CTB values under NTSC channel number for systems I and II, respectively. They indicate that the CNR values (≥ 50 dB) of systems I and II are almost identical. In the presence of optical amplifier, the photodiode (PD) is primarily limited by the shot noise and signal-amplified spontaneous emission (ASE) beat noise. The resultant CNR at the

PD with the optical amplifier can be expressed as [11]:

$$CNR^{-1} = CNR_{shot}^{-1} + CNR_{S-ASE}^{-1} = \frac{4hv}{m^2 P_{in} G}\left[1 + 2n_{sp}(G-1)\right] \quad (1)$$

where CNR_{shot} is associated with the optical receiver, CNR_{S-ASE} is associated with the EDFA, $h\nu$ is the photon energy, m is the OMI, P_{in} is the EDFA optical input power, n_{sp} is the spontaneous emission factor, and G is the gain of the EDFA. It is clear that, from Equation (1), CNR depends critically on the EDFA optical input power P_{in}. CNR values of systems I and II are almost identical due to the same optical input power levels of EDFA.

As to CSO/CTB performances, the CSO/CTB values ($\geq 70/69$ dB) of System II can be improved significantly. The improved results seen are due to the use of FP etalon to decrease the linewidth of the optical signal, in which leading to the reduction of the fiber dispersion. CSO/CTB distortions can be stated as [12]:

$$CSO = 10\log\left[\frac{mD\lambda_c^2 Lf}{4c}\sqrt{16(\Delta\tau)^2 + \frac{4\lambda_c^4 L^2 \pi^2 f^6}{c^2}}\right] + 10\log N_{CSO} + 6 \quad (2)$$

$$CTB = 10\log\left[\frac{9m^2 D^2 \lambda_c^4 L^2 f^2}{4c}\left(4(\Delta\tau)^2 + 4\pi^2 f\right)\right] + 10\log N_{CTB} + 6 \quad (3)$$

where D is the dispersion coefficient, λ_c is the optical carrier wavelength, L is the fiber length, f is the RF frequency, $\Delta\tau(\propto \Delta\lambda)$is the fiber dispersion, $\Delta\lambda$ is the spectral width, N_{CSO} and N_{CTB} are the product counts of CSO and CTB. The use of FP etalon lets the spectral width to change from a broad width into a narrow width, leading in lower fiber dispersion. Then there would be significant reductions in the CSO/CTB distortions. From the experimental results we can see that large CSO and CTB improvements of 6 and 5.5 dB have been achieved compared to System I (without FP etalon).

4. CONCLUSION

We proposed and presented an externally modulated NTSC 77-channel EDFA-repeated system employing FP etalon at the receiving site to overcome fiber dispersion. In comparison with the conventional externally modulated fiber optical CATV transport systems, good performance of CNR/CSO/CTB were achieved over a 100-km SMF transport. Employing a simple FP etalon in fiber optical CATV transport systems is useful in real networks, as it is simple, passive, and potentially low cost. Our proposed systems are suitable for the long-haul fiber optical CATV transport systems.

REFERENCES

1. Singh, S. P. and N. Singh, "Nonlinear effects in optical fibers: Origin, management and applications," *Progress In Electromagnetics Research*, PIER 73, 249–275, 2007.
2. Gebretsadik, H., H. T. Foulk, N. C. Frateschi, W. J. Choi, S. V. Robertson, and A. E. Bond, "Linearised integrated SOA-EA modulator for long-haul and FTTH CATV applications at 1.55 μm," *Electron. Lett.*, Vol. 40, 1016–1017, 2004.
3. Lee, C. C. and S. Chi, "Repeaterless transmission of 80-channel AM-SCM signals over 100-km large-effective-area dispersion-shifted fiber," *IEEE Photon. Technol. Lett.*, Vol. 12, 341–343, 2000.
4. Singh, S. P., R. Gangwar, and N. Singh, "Nonlinear scattering effects in optical fibers," *Progress In Electromagnetics Research*, PIER 74, 379–405, 2007.
5. Lu, H. H., W. S. Tsai, C. Y. Chen, and H. C. Peng, "CATV/radio-on-fiber transport systems based on EAM and optical SSB modulation technique," *IEEE Photon. Technol. Lett.*, Vol. 16, 2565–2567, 2004.
6. Piehler, D., X. Zou, C. Y. Kuo, A. Nilsson, J. Kleefeld, G. Garcia, J. D. Ralston, and A. Mathur, "55 dB CNR over 50 km of fiber in an 80-channel externally-modulated AM-CATV system without optical amplification," *Electron. Lett.*, Vol. 33, 226–227, 1997.
7. Ghafoori-Fard, H., M. J. Moghimi, and A. Rostami, "Linear and nonlinear superimposed Bragg grating: a novel proposal for all-optical multi-wavelength filtering and switching," *Progress In Electromagnetics Research*, PIER 77, 243–266, 2007.
8. Yoon, Y., J. Shim, D. Jang, J. Kim, Y. Eo, and F. Rhee, "Transmission spectra of Fabry-Perot etalon filter for diverged input beams," *IEEE Photon. Technol. Lett.*, Vol. 14, 1315–1317, 2002.
9. Song, D. Y. and J. S. Lee, "Angle-tuned Fabry-Perot etalon filter having Gaussian transmittance curves," *IEEE Photon. Technol. Lett.*, Vol. 12, 1186–1188, 2000.
10. Rostami, A. and A. Salmanogli, "Investigation of light amplification in Si-nanocrystal-Er doped optical fiber," *Progress In Electromagnetics Research B*, Vol. 9, 27–51, 2008.
11. Ovadia, S., *Broadband Cable TV Access Networks: Form Technologies to Applications*, Prentice-Hall, 2001.
12. Way, W. I., *Broadband Hybrid Fiber/Coax Access System Technologies*, Academic Press, 1998.