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320 Channel Optically Amplified 1550 nm Light wave Directly Modulated CATV Transport System Performance Improvement Using Optical Injection Technique

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***Abstract*—This paper proposed and successfully demonstrated 320 channel optically amplified 1550 nm light wave directly modulated high channel density CATV transport system. The optical injection technique increases the photon density of the modulation section and improves the overall performance of the fiber optical CATV system. Designed network demonstrates the improvement of transmission distance and channel density. Good performance in terms of output power, Composite Triple Beat (CTB), Signal to Noise Ratio (SNR), Composite Second Order (CSO) and Carrier to Noise ratio (CNR) has been observed by utilizing optical injection technique. Almost about 74 dBm Composite Second Order (CSO) has been achieved by utilizing 14 dBm optical injection techniques.**

Keywords: External Light Injection Technique, Cable TV, Optical Communication, High Channel density CATV system.

I. INTRODUCTION

Cable Television (CA-TV) is a shared cable system that uses a tree and branch topology in multiple households [1]. It originally stood for Community Cable Television System or Community Antenna Television [2]. In the places where signal from transmitter and receiver is limited due to the obstruction of mountain terrain, we can establish a large community antenna from which cables can carry media to individual homes. Whenever an optical signal transmits information, there is some loss in the transmission, hence there is some loss in data [3]. So the ultimate goal of the fiber optical cable television (CATV) transport systems should be increasing the fiber communication distance. In order to do that, the system has to be designed of minimum loss possible, and channel performance has to be increased as well. Besides these, nonlinear distortions [4], fiber dispersion effects can degrade the system performance as well as limit the maximum transmission distance [5]. External light injection technique can be employed in a radio fiber system to improve the bit error rate (BER) performance [6]. The external light injection technique can greatly enhance the frequency response of the laser diode [7]. It is expected to have good performances in analog fiber optical CATV systems [8]. This paper is based on directly modulated transport system which employs the external light injection technique on a cable television for 320 channels combined in WDM [9]. Transmission distance of 80 km is achieved under 1500 nm transmission window, with a CNR of 57 dBm, CTB of 54 dBm, CSO of 74 dBm. Using external light injection technique, the variation in output power is analyzed by changing input power from the externally modulated CW laser. A layout of CATV network in shown in figure-1:

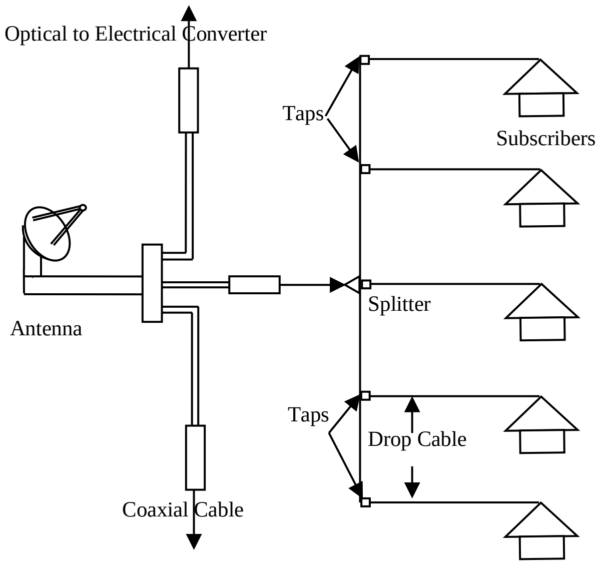

Fig. 1: Block Diagram of CA TV Network

II. NETWORK CONCEPT

A CATV network consists of three main parts as: the trunk, the feeder, and the customer drop [10].The trunk is usually intended to cover large distances of tens of miles. The feeder portion of the cable is used by the consumers for tapping signal [11]. It has maximum length of a few miles only because it is tapped off to feed subscribers, and that requires relatively high power levels [12]. The drop is the flexible cable which goes to the customer home. It is made of lower quality coaxial cable than that of the feeder or trunk [13].

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Older generation CATV systems used to have co-axial cables in the trunk and feeder portions of the network. Therefore, it experienced many problems related to (a) interference from spurious radiation, (b) distortions introduced by amplifiers and (c) limited bandwidth [14]-[16]. In order to increase communication distance and number of subscribers, necessary steps has been taken such as improving signal power, Signal-to-Noise Ratio, Carrier-to-Noise Ratio, Composite Triple Beat (CTB), and Composite Second Order (CSO) etc.

A. *CATV system without external light injection technique*

At the very beginning, a normal cable television system is designed. The whole system, as shown in figure 2, is connected through 50 km fiber optical cable. This length may be 50 km or higher if needed depending on the distance of subscriber's home.

The transmission system of this project is composed of CW laser and carrier generator connected to amplitude modulator (AM). The optical power is coupled into the EDFA-1 by a 2x1 optical coupler (as seen from figure-2), then connected through a single mode fiber (SMF). The received optical signal was split by a 1x2 optical splitter, passed through two rectangular optical band pass filters in order to select the appropriate wavelength, and detected both frequency bands using analog optical receivers.

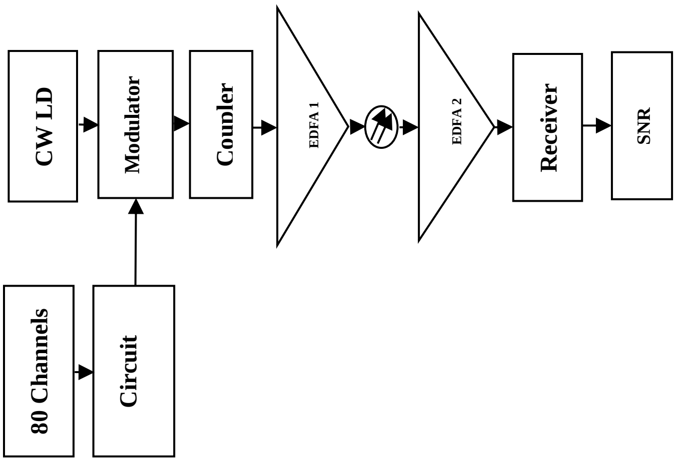

Fig. 2: Block diagram of basic CATV system without external light injection technique.

B. *CATV system with external light injection technique*

External light injection technique is coupled using a pump coupler. This external light injection technique adds extra power into the channel so that the desired minimum power is maintained even after reaching long distance. Light is injected in the counter propagation direction through an optical isolator and a 3dB optical coupler [17]. In the system the optical power was coupled into EDFA-1 by a 2x1 optical coupler in the same way as figure-2.

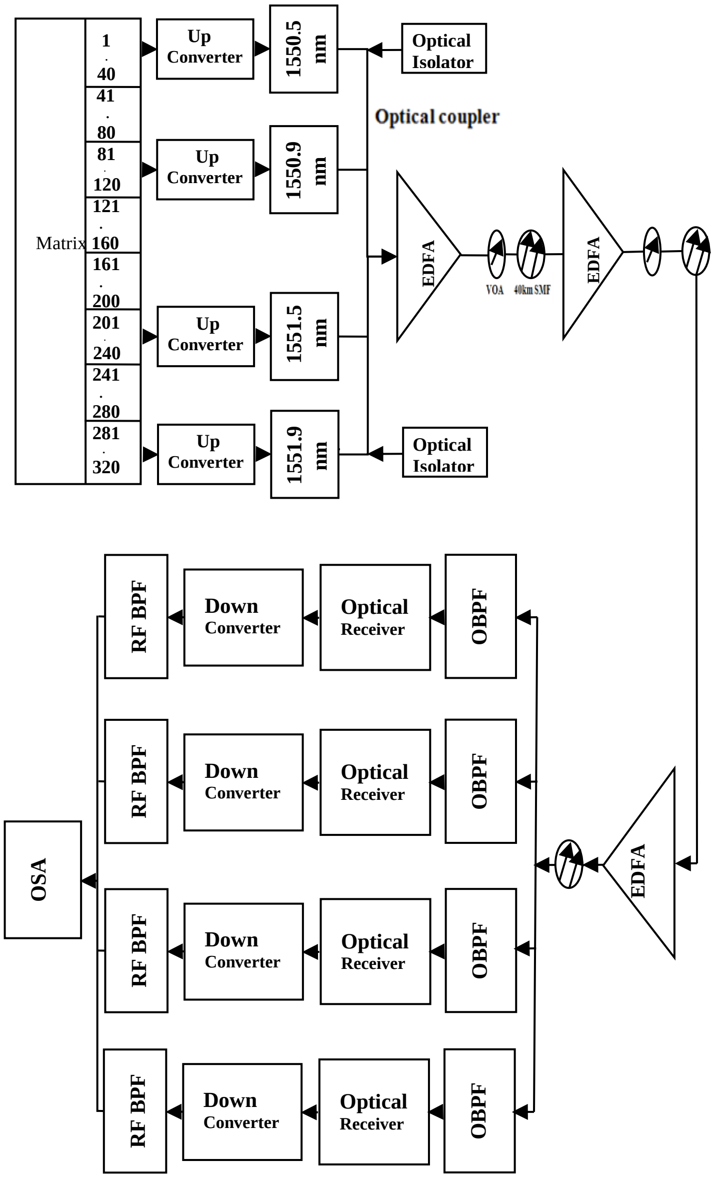

Fig. 3: Block diagram of directly modulated CATV system employing external light injection technique.

III. Results and Discussion

A. *CATV system without external light injection technique*

In case of no light injection, 30 dBm light source is used as the optical power. The CATV frequency bands are up-converted to the first microwave frequency bands (14.75 – 15.25 GHz) and then fed into the Continuous Wave (CW) laser diodes. The second CATV frequency bands are up-converted to the second microwave frequency bands (18.25 – 18.75 GHz) and then fed into the CW laser diodes. The central wavelengths of the two CW laser diodes are 1550.5 nm and 1555.7 nm, respectively. The electrical power as seen through electrical power meter visualize for a CATV system without light injection is 5.918 dBm. Since there is no external light injected, output power is small because of attenuation effect of fiber, non-linear distortions introduced by laser chirp.

*B. **Directly Modulated CATV system employing external light injection technique***

Directly modulated CA-TV System employing external light injection technique has been applied up to 320 channels to increase the available number of video channels. Light is injected in the counter propagation direction through an optical isolator and 3dB optical coupler. In case of two microwave frequency bands, CH 1-40 (555 - 720 MHz) and CH 41-80 (725 - 950 MHz) are directly fed into the up- converter and converted to the first microwave frequency band (14.75 - 15.25 GHz) first continuous wave (CW) laser diode, and (18.25 - 18.75 GHz) second CW laser diodes respectively, and central wavelengths of the first and second laser diodes are 1550.5 nm, 1550.7 nm respectively.

In third microwave frequency band CH 81-120 (555 -720 MHz) and CH 121-160 (725 - 950 MHz) are directly fed into the third and fourth respectively and frequency bands are up converted to the third microwave frequency band (19.20 - 19.70 GHz) and fed into the third CW laser diode. The fourth CATV frequency bands are up-converted to the fourth microwave frequency band (20.45 - 20.95 GHz) and fed into the fourth CW laser diode. The central wavelengths of the third and fourth laser diodes are 1550.9 nm and 1551.1 nm respectively.

For the remaining four microwave frequency bands, CH 161-200 (325 - 550 MHz), CH 201-240 (555 - 720 MHz), CH 241-280 (725 - 820 MHz), and CH 281-320 (825 – 950 MHz) are directly fed into the fifth, sixth, seventh and eighth up-converter, respectively. The fifth frequency bands are up converted to the fifth microwave frequency band (21.25 - 21.75 GHz) and fed into the fifth CW laser diode, sixth frequency bands are up-converted to the sixth microwave frequency band (23.25 - 23.75 GHz) and fed into the sixth CW laser diode. Seventh frequency bands are up converted to the seventh microwave frequency band (24.20 - 24.70 GHz) and fed into the seventh CW laser diode. The last eighth frequency bands are up-converted to the eighth microwave frequency band (26.45 - 26.95 GHz) and fed into the eighth CW laser diode. Central wavelengths of fifth, sixth, seventh and eighth laser diodes are1551.3 nm, 1551.5 nm, 1551.7 nm, and 1551.9 nm respectively.

In the system the optical power was coupled into the pump coupler co-propagating. Power of the injected pump laser is fixed at 12 dBm, but it can be varied as needed. This system can be used to increase the power of the transmitted signal to a larger extent while maintaining the efficiency at the same time. Initially the simulation was carried out to determine how external light injection technique can improve sending signal of cable television system.

The graphical representation in figure-4 shows the maximum injected power is 12dBm. From this experiment, it can be considered that with the increase in injected power the output power of CA TV channel also increases.

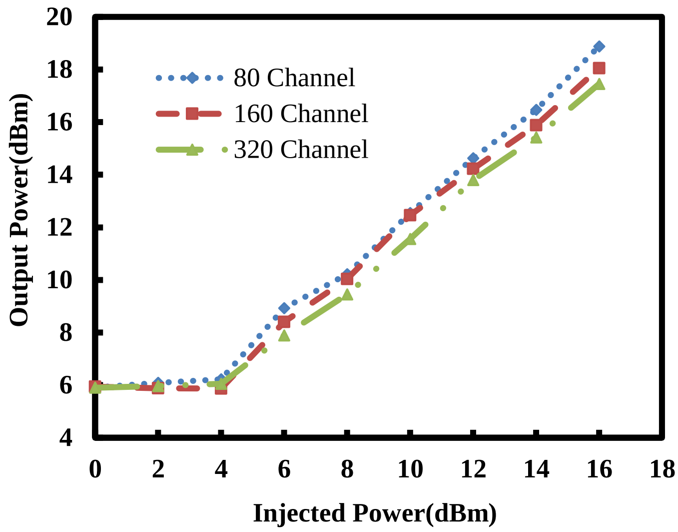

Fig. 4: Injected Power vs. Output Power. In case of varying the number of channel such as 80, 160, 320 channels, result shows that 80 channels output power is higher than that of 160 and 320 channels.

*C. **Effect of Length of the Transmission Line***

Transmission lines are used for connecting radio transmitters and receivers with their antennas, distributing cable television signals, trunk-lines etc. However, with increasing length of transmission lines, the desired signal strength reduces, adds noise and nonlinear distortion, so overall output power decreases. Data are collected from 80, 160, and 320 channels while keeping injected power fixed at 0 dBm and 28 dBm for 320 channels only.

A graph is included in figure-5 to show the effects of transmission distance and output power, the values for this experiment are taken by varying communication distance from 50 km to 80 km with an interval of 3 km.

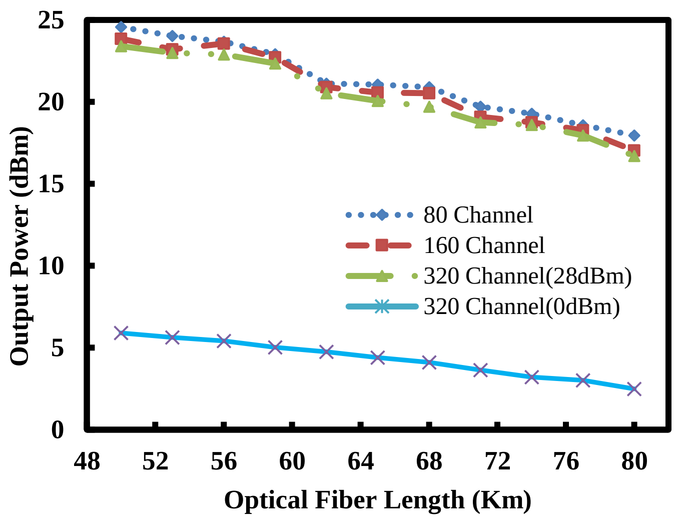

Fig. 5: Optical Fiber Length vs. Output Power. The difference between using injected power and without injected power is approximately 15 dBm output power for 320 channel design.

*D. **Signal to Noise Ratio Analysis***

Signal to Noise Ratio (SNR) is defined as the ratio of signal power to the noise power, often expressed in decibels. If channel number is increased then it introduces non-linear distortion thus reducing output power that ultimately effects SNR. Since, the number of television channels are increasing day by day so SNR has to be analyzed. Measurement and analysis of SNR have been performed within 80, 160, and 320 channels. A total of eleven simulations were run to measure the signal to noise ratio within 50 km to 80 km at an interval of 3 km. During the analysis, input power was fixed at 30 dBm for every channel sets, but only for 80 channels injection power was changed to 0 dBm and 28 dBm. The graphical representation in figure-6 shows that, without external light injection technique output power decreases with the increase of transmission length, and also adds noise in the system that degrades SNR. However, the curve shows that signal to noise ratio is almost constant at optical lengths of 68 km, 71 km and 74 km for 80 channels, but for 160 channels it is constant at lengths of 68 km and 71 km. From these results, a conclusion can be drawn that the magnitude of SNR is inversely proportional to increasing optical length and increasing number of channels.

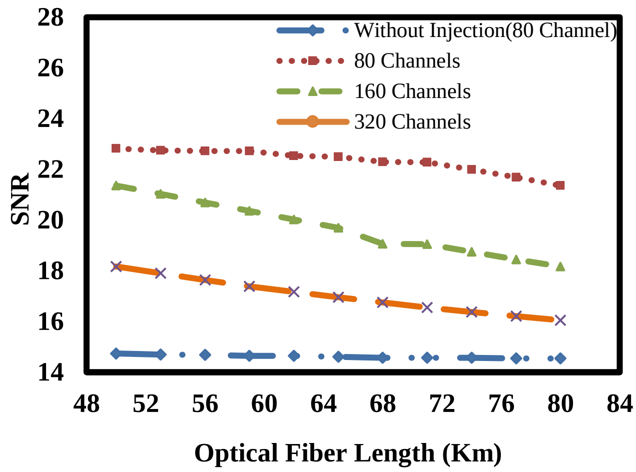

Fig. 6: Distance vs. Signal to Noise Ratio. SNR without light injection is at around 15 dB, and with light injection it is around 22 dB for 80 channels.

E. Distortion Analysis

Cable Television's transmission performances such video quality, audio synchronization, seamless buffering etc. are limited by the Composite Second Order (CSO) and Composite Triple Beat (CTB) because these distortions always occur in a CA TV transport system [18-19]. Frequency up-conversion technique has to be applied along with AM scheme to optimize the downstream transmission performances so that it will suppress unwanted noise and distortion. Designed 320 channel CATV signal can be broadcast to subscribers because the system meets the requirements of CNR, CSO, CTB demands (i.e. 43 dBm, 53 dBm, 53 dBm respectively) . The CNR value can be further improved by optimizing amplifier gain. Good performances of CSO/CTB are achieved for 12 dBm injection technique (≥74/54 dBm) and for 14 dBm injection technique (≥75/55 dBm). Up-conversion technique reduces CSO, CTB distortion and the constant power operation characteristic of AM scheme.

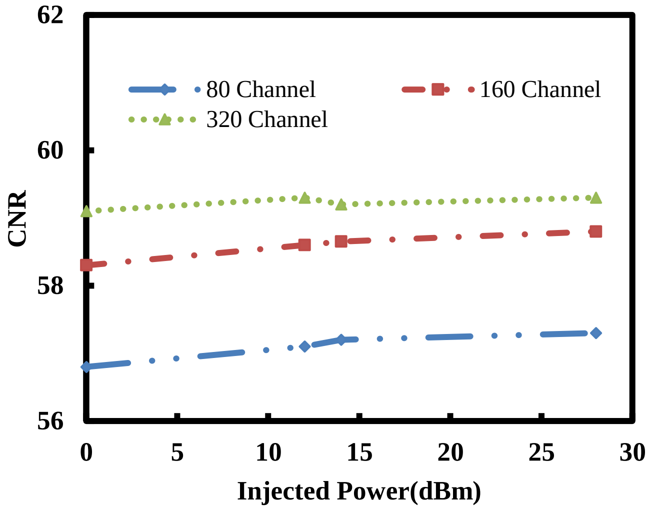

Fig. 7(a): Number of channel vs. CNR.

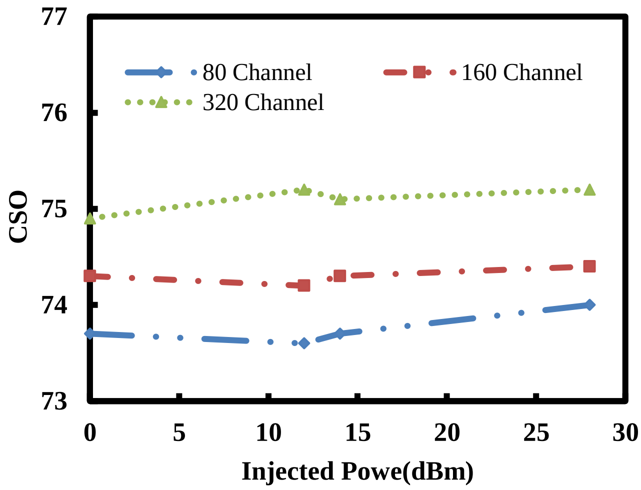

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Fig. 7(b): Number of channel vs. CSO.

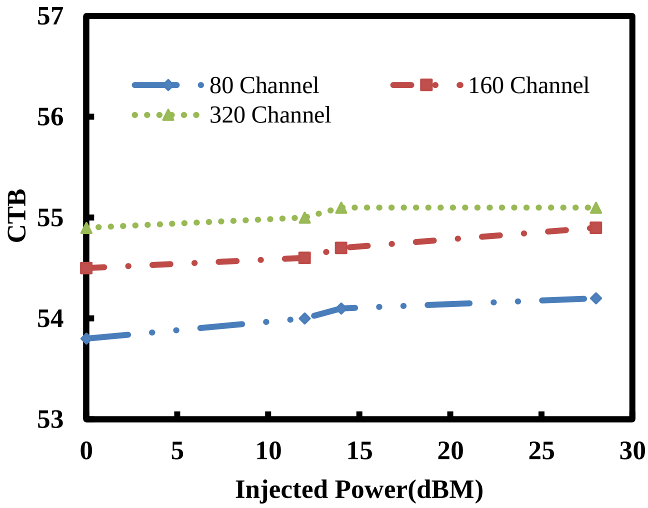

Fig. 7(c): Number of channel vs. CTB.

From these three figures, it is clear that the measured CNR, CSO and CTB values are affected by the injection power level. When the injection power is 0 dBm (i.e. without injection) the CNR, CSO and CTB values are limited at around 56, 73, and 53 dBm, respectively. Whenever the injection power is increased to 12 dBm, the CNR, CSO and CTB values are increased by 1.5, 2, and 1 dBm respectively. So a conclusion can be drawn that, the CNR, CSO, CTB performances with 14 dBm light injection technique are better than that of 12 dBm light injection technique, and without light injection technique both. Reduction of chirp can be obtained by an injection locking.

IV. Conclusion

Ongoing investigations on cable television with external light injection technique and effects on increasing number of frequency bands have been presented in this project. Firstly, we included the results of output power by simulating normal cable television network. Secondly, external light injection technique was applied to observe improvement of signal efficiency due to external light injection technique. Thirdly, the number of channels were increased by manipulating frequency bands in order to evaluate the receiving power of external light injection technique. The proposed system in this paper meets the demands of fiber optical CATV system at the optical node, and has an upstream performance of ≥58/74/54 dBm for CNR/CSO/CTB respectively with 14 dBm light injection technique. Our features are designed in such way that it can be successfully adopted in commercial CA TV network that will increase the number of channels as well as improve picture quality of each channel.

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