Estimate of the Cost-Effective Number of Erbium-Doped Amplifiers in an AM-VSB Multichannel Optical Link

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ABSTRACT: We calculated the maximum distance of an HFC link by considering all noise mechanisms that contribute to CNR. Cost-effective solutions are limited to a small number of optical amplifiers in distances up to 120 km.

1. INTRODUCTION

Multichannel AM-VSB lightwave systems are used in hybrid fiber-coax (HFC) distribution networks to deliver simultaneous analog video and data channels to thousand of homes. Within the 50-750 MHz bandwidth these systems can carry up to 110 NTSC analog video channels using a single transmitter over a standard single-mode fiber. Along with the use of erbium doped fiber amplifiers (EDFA's) these systems allow the optical signal to reach several optical network units (optical-RF conversion equipment), after which the electrical signal is amplified in a cascade of RF amplifiers till the customer premises.

A particular application of such systems concerns the long distance (50 – 200 km) connection of sites, where a CATV operator wishes to transmit the signal without having to duplicate locally an entire headend with its several satellite antennas and RF modulators. Although such distances still appear to be reasonable for an optical link, the transmission is severely degraded by noise mechanisms, specially the signal-amplified spontaneous emission beat noise that accumulates in a cascade of optical amplifiers [1].

Literature is scarce on results concerning the maximum distance that an analog multichannel system can reach [3-5]. In this work we tried to answer that question by considering all noise mechanisms that affect system performance. Particularly, we have focused on the number of amplifiers needed to establish the link aiming a cost-effective solution for the connection.

2. Performance of AM-VSB systems with cascaded EDFA's

In analog systems, the carrier-to-noise ratio (CNR), CSO and CTB are the parameters designers use to calculate system performance. The HFC network is composed of two parts: the optical and coaxial paths. In order to achieve a 45-dB CNR (FCC recommendation) at the end of line (after the last RF amplifier), it is necessary that each of these paths present a CNR of at least 48-dB, as the logarithmic sum of both parts will deliver the recommended value [2]. We have taken this value to calculate the maximum distance the optical signal is allowed to travel.

For an AM-VSB video lightwave system with in-line EDFA's, the CNR calculation should include the several noise mechanisms that affect performance. Our model takes into account the contributions of relative intensity noise (RIN) of the transmitter, shot and thermal noise generated in the optical receiver, nonlinear distortion noise due to clipping of the laser and the signal-to-amplified spontaneous emission (ASE) beat noise of the erbium-doped fiber amplifiers. The other sources of noise generated by the optical amplifier such as the beating of the amplified spontaneous against itself and with shot noise were found to have no influence in the calculation. Nonlinear distortion (NLD) is caused by large excursions in modulation current. Instead of using CSO and CTB, we preferred an approach by [3] in which the carrier-to-NLD ratio is calculated as a function of the number of channels and the modulation depth per channel. This term is then considered in the total CNR calculation of the optical link, as shown below. It is important to note that there has been many approaches to the CNR calculation in analog links with in-line amplifiers. For example, [3] considers only the contributions of shot noise, NLD noise and signal-ASE beat noise. [4] takes into account the RIN of transmitter, shot and thermal noise in the receiver, the signal-ASE and ASE-ASE beat noise. This work has considered all these terms, from which the total CNR of the link is computed. For a cascade of optical amplifiers (see Fig. 1) the CNR is expressed as:

$$\frac{1}{CNR}=\left[\frac{1}{CNR_{RIN}}+\frac{1}{CNR_{NLD}}\right]+$$

$$+\left[\frac{1}{A\sum_{j}^{n}P_{inp\_Amp_j}}\right]+\left[\frac{1}{CNR_{shot}}+\frac{1}{CNR_{therm}}\right]$$

The first two terms in the above equation represent the relative intensity noise and the nonlinear distortion noise due the transmitter. The third term is the signal-ASE beat noise contribution of a cascade of n optical amplifier (A is a constant, which depends on the modulation index per channel, the photodetector responsivity and noise figure of the amplifier, and P_{input_Amp} is the optical input power to the jth amplifier). The fourth and fifth terms show the contribution of the shot and thermal noise in the receiver.

Fig. 2A shows the noise contributions that shape the CNR considering at first only one amplifier between the transmitter and receiver. Values considered in the calculation were 0.04 for the modulation index per channel, a load of 80 channels and a noise figure of 7dB for the optical amplifier. As one can see, the sum of the signal-ASE beat noise, RIN and NLD limit the maximum CNR, delivering a maximum value of 51 dB as the optical input power to the receiver increases. To the left the curve is limited by the shot and thermal noises, which also imposes the minimum limit of optical power in the receiver for obtaining the 48-dB CNR required in the link. Fig. 2B shows the behavior of CNR versus the optical input power to the receiver when more EDFA's are added to the cascade. One clearly sees that the maximum value of CNR lowers as the number of amplifiers increases. Calculations showed that its was possible to insert up to 9 amplifiers in the link and still get the 48-dB for the CNR, considering a 0 dBm input power to the receiver. The method used to compute the curves of Fig. 2B considers that the input power to each amplifier is the same and that the amplifiers work in the saturated condition

3. RESULTS

For calculation of the maximum link distance, the configuration used considered the first amplifier as a booster and its optical input power (P_{IN1}) fixed at +6 dBm (equal to the output power of the transmitter). This condition establishes the maximum CNR value of the link. All amplifiers were taken to work in the saturated regime, so that their output remains constant (P_{out} = +18 dBm). Optimization was performed by varying the input power (that is, the distance between amplifiers) to the next amplifier up to the point where the 48-dB CNR begins to decrease. Fig. 3 shows the distance the optical signal may reach as the number of amplifiers increase in the cascade. It is interesting to note that after the third amplifier the distance covered by the signal does not worth the addition of further amplifiers in the link. That is, the solution is not cost-effective.

4. CONCLUSION

By considering a 48-dB CNR value for the optical path of an HFC network we have determined a maximum number of optical amplifiers in the link. Results show that for a cost-effective solution not more than 3 amplifiers should be used for the total distance between transmitter and receiver does not present a considerable extension as the number of amplifiers increases.

5. REFERENCES

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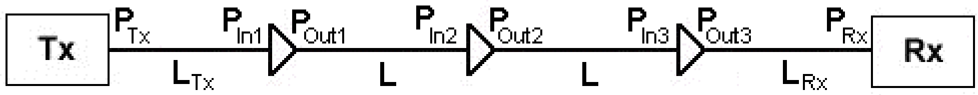

Fig. 1. Cascade of optical amplifier

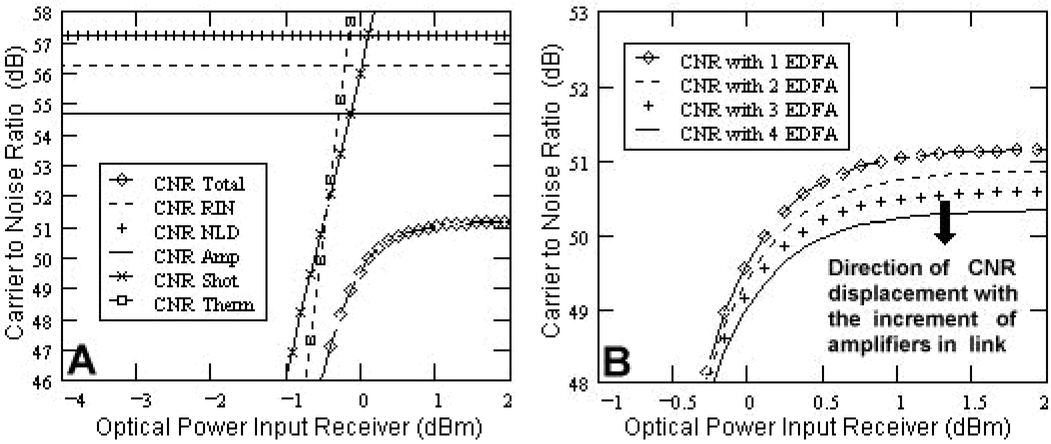

Fig. 2. (A) shows the most significant contributions to the total CNR of the link.
(B) shows CNR values curve for increasing number of optical amplifiers.

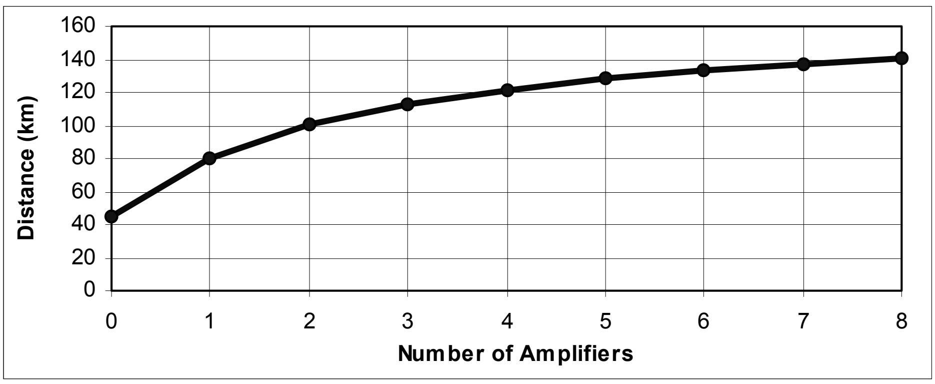

Fig.3. Maximum distance of the link versus the number of optical amplifiers