Limitations of Dispersion Supported Transmission over Standard Single-Mode Fiber

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Abstract—Dispersion supported transmission (DST) is a new technique which combines intensity modulation (IM) and optical frequency modulation (OFM) to allow transmission spans beyond the usual dispersion limit. Using computer simulation, DST limitations are evaluated and optimum values for the frequency deviation and receiver bandwidth are determined. Finally, the maximum transmission distance is estimated for a power penalty of 1 and 2 dB.

I. INTRODUCTION

GROUP velocity dispersion (GVD) is the main limiting factor in high-bit-rate transmission systems operating over standard single-mode fibers. Moreover, parasitic OFM, known as “chirp,” occurring in directly modulated lasers decreases drastically the length of the transmission link.

Between several methods intended to overcome GVD limiting effect, DST is very attractive because of its relative simplicity and good capacity [1]. The DST principle of operation is mainly based on the interferometric conversion of an OFM signal into an IM signal across the dispersive fiber link [2]. Thus the light of the laser at a constant power level is switched between the two optical frequencies v0 and v1, representing the logical “0” and logical “1,” respectively. Due to GVD, the two optical frequencies travel with different velocities resulting in peaks and dips of the intensity with respect to the mean average power. These well-defined power fluctuations are filtered at the receiver and interpreted as logical “0” and “1” by a decision circuit. Experimentally, it turned out that an additional IM improves the transmission performances. Thus transmission of 10 Gbit/s in the 1550-nm bandwidth is switched between the two optical frequencies by an increase in the signal equal to the power penalty.

Nevertheless, this assumption is no longer valid for DST systems wherein it is necessary to adjust the receiver electrical bandwidth according to the total GVD [2]. This is why the receiver bandwidth is included in the expression of the power penalty given in (5).

II. TRANSMISSION SYSTEM MODEL

Assuming a monochromatic optical source with the linewidth significantly less than the transmission rate, the complex equivalent low-pass signal at the fiber input is expressed as

\[ x_{in}(t) = \sum_k \sqrt{a_k(r-1) + 1} \times P(t - kT) \exp(j2\pi a_k \Delta \nu t) \]

where \( a_k \) is 0 or 1, \( k \) is an integer, \( r \) is the power extinction ratio, \( P(t) \) is the pulse function with unity amplitude within the bit time and zero elsewhere, \( T \) is the bit duration, and \( \Delta \nu = \nu_1 - \nu_0 \).

The low-pass equivalent model for the single-mode fiber transfer function which isolates the GVD effect only is given by [4]

\[ H(f) = \exp \left[-j\pi DL \frac{\lambda_0 B^2}{c} \left( \frac{f - \nu_0}{B} \right)^2 \right] \]

where \( D \) is the GVD, \( L \) is the fiber length, \( c \) is the speed of light, \( \lambda_0 = c/\nu_0 \) is the wavelength related to \( \nu_0 \), and \( B \) is the transmission rate.

At the receiver side, the directly detected signal is expressed as

\[ y_d(t) = |F^{-1}[F[x_{in}(t)] H(f)]|^2 \]

and the filtered signal at the receiver output is

\[ y(t) = F^{-1}[F[y_d(t)] H_r(f)] \]

where \( F[ ] \) and \( F^{-1}[ ] \) denote the Fourier transform and its inverse and \( H_r \) is the transfer function of the receiver filter.

The GVD-induced power penalty in decibels is defined as follows:

\[ P_D(L) = 10 \log_{10} \left[ \frac{\Delta y(L)}{\Delta y(0)} \sqrt{\frac{\Delta f(L)}{\Delta f(0)}} \right] \]

where \( \Delta y \) is the eye-opening related to \( y(t) \) and \( \Delta f \) is the receiver electrical bandwidth, \( P_D \) expresses the degradation of receiver sensitivity, under the assumption that the receiver noise is unaffected by the signal. Therefore, at a given bit-error-rate (BER), GVD-induced eye closure is compensated by an increase in the signal equal to the power penalty.

In a previous approach, only the eye opening was taken into account in the power penalty evaluation, whereas the receiver bandwidth was kept constant [4]. Nevertheless, this assumption is no longer valid for DST systems wherein it is necessary to adjust the receiver electrical bandwidth according to the total GVD [2]. This is why the receiver bandwidth is included in the expression of the power penalty given in (5).

III. RESULTS AND DISCUSSION

Numerical simulations have been performed for DST transmission systems operating at \( \lambda_0 = 1550 \) nm over standard signal-mode fibers with \( D = 15 \) ps/\( nm \cdot km \).
The input waveform represents an NRZ-coded pseudorandom sequence of 128 bits intended to accurately simulate the intersymbol interference. The IM extinction ratio considered is $r = 1.5$. The final results have been obtained by averaging over 40 runs. The receiver baseband filter is a first-order Bessel low-pass filter. Excepting the case $\Delta \nu = 0$, the 3-DB bandwidth $\Delta f$ has been optimized for each pair ($\Delta \nu, L$) in order to minimize the power penalty. To facilitate comparisons and generalization the fiber length is referred to the quantity:

$$L' = \frac{\pi c}{\lambda_0^2 B^2 D}$$

and the frequency is normalized to the transmission rate.

The behavior of the power penalty was investigated for different fiber lengths with the frequency deviation varying between 0 and $2B$. Thus the optimum frequency deviation related to the power penalty global minimum was found to be $\Delta \nu_{D} = 0.96B$ if the fiber length exceeds $0.5 L'$. Therefore, the results reported in this letter have been obtained for $\Delta \nu = \Delta \nu_{D}$.

The DST power penalty as function of fiber length is shown in Fig. 1 with respect to the chirp-free conventional IM. The negative power penalty, effective between 0 and $0.64L'$ represents an improvement of the receiver sensitivity and is due mainly to an important decrease in electrical bandwidth.

The optimized receiver bandwidth is illustrated in Fig. 2. These surprisingly low values have been experimentally verified. Thus the bandwidths used in the two experiments reported in [3] are represented for comparison by filled triangles. The quite good agreement suggests that the optimum filter bandwidth is practically independent of $\Delta \nu$.

Finally, the relationship between transmission distance and transmission rate is illustrated in Fig. 3 showing the superiority of DST with respect to conventional chirp-free IM systems.

IV. CONCLUSIONS

GVD-induced limitations in DST transmission systems have been evaluated by computer simulation. It turn out that for a 1-DB power penalty the transmission distance is more than three times the one allowed by chirp-free IM systems. Moreover, simulation results show good agreement with available experimental data.

REFERENCES