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A USEFUL SCHEME FOR GIGABIT LIGHTWAVE SYSTEMS

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Abstract

A useful scheme for Gbit lightwave systems is extended and analyzed. High capacity and long distance single mode fiber communication systems at the window of minimum loss are designed on the basis of 2-km germania-doped fiber segments connected in such a manner to periodically filter the chromatic dispersion. Both the chirp power penalty and the dispersion power penalty due to the fiber cutoff are considered. Simple relations relating the fiber capacity and the germania concentrations and the different operating wavelengths are obtained. Transmission systems employing either LEDs or DFB-LDs as sources and APDs as detectors are considered in the present study.

Introduction

Single mode fibers (SMFs) coupled to either light-emitting diodes (LEDs) or laser diodes (LDs) offer an economical, temperature stable, and reliable techniques currently being deployed in long-span multiGbit optical transmission systems [1-9] and are presently the subject of intensive researches for future deployment in the local network, subscriber loop, and long-haul systems. Recent experiments [2] have demonstrated the feasibility of LED-SMF systems for bit-rate-repeater spacing product up to 3 Gbit. km/sec.; while the use of distributed feedback laser diode (DFB-LD) and SMF, employing direct detection, yield product up to 500 Gbit. km/sec. Chromatic dispersion is a potential limitation at these products because of i) the broad spectral widths of LEDs and ii) the power penalty due to the fiber cutoff [1,2] i.e. power penalty due to dispersion and due to chirping in either LEDs or LDs [4,5].

In recent years also, Gbit transmission lines have been necessary for subscriber loops having a transmission distance of several kilometers, especially in broad band ISDN [9,10] and special CATV systems [9].

To realise transmission systems of high-bit-repeater span product, three important factors must be considered namely 1) high frequency response of optical sources, optical detectors, and electronic circuity, 2) spectral characteristics of optical sources, and 3) optical fiber dispersions [11,12] and loss characteristics [13]. To maximize the above product at certain spectral characteristics [1,14,15,16], systems are designed to operate at the dispersion-free window and minimum loss window where the first one is shifted to be at the same spectral position of the second using GeO_2-doped SMF.

Using an optical fiber as a high bandwidth channel is, by itself, insufficient to implement high capacity network. Ultimately, the capacity of the channel is limited by the processing speed of the associated electronic circuitry. The state-of the art in electronic technology today [17, 18] yields maximum processing speeds of approximately 1 GHZ.

However, in the present paper, we extended and investigate a useful scheme to maximize the bit-rate-repeater spacing product for any spectral characteristics. In this scheme we periodically employ two fiber segments of 2 km long of binary SMF (Silica (1-x)+ germania (x)) of different X's (germania percentage). Each pair of these segments periodically filter the chromatic dispersion at the end of 4 km distance. The germania concentrations X_1 and X_2 of the two segments are related, Fig.2-11. The correlation depends on the operating spectral characteristics.

2. Model and Analysis

The power budget of optical transmission systems is expressed as

$$P_t = P_r + \sigma L + n\,\sigma_c + m\,\sigma_s + \sigma_m \qquad (1)$$

where P_t is the average optical power of the optical source, L is the fiber length, P_r is the received average optical power at a bit error rate (BER) of 10^{-9}, σ is the fiber spectral loss [13], n is the number of connections, σ_c is the connector loss, m is the number of splices, σ_s is the splcing, and σ_m is the system margin. CSELT [1] derived the difference $P_t - P_r$ under the form

$$P_t - P_r = 10 \log \frac{B_m}{B_r} - P_d \tag{2}$$

where B_r is the bit rate of the system, B_m is a constant depending on the source-detector combination; and P_d is the dispersion power penalty due to the fiber cutoff given as [1].

$$P_d = C(B_r/F_t)^2 \tag{3}$$

where C approximately equals 1.25 and F_t is the fiber 3-dB bandwidth. This bandwidth is related to the chromatic dispersion as shown in numerical data. Gimlett and Cheung [2] derived a more accurate formula for P_d as

$$P_d = 5 \log [\, 1 + C_1 \sigma_t^2 B_r^2 + C_2 \sigma_t^4 B_r^4 + \ldots] \tag{4}$$

where C_1 and C_2 are constants. We adopt this "accurate" formula in our analysis; it will be evaluated for two exterme cases

$$P_d = 13\, B_r^2 \sigma_t^2 \tag{5}$$

for white receiver noise, and

$$P_d = 30\, B_r^2 \sigma_t^2 \tag{6}$$

for f^2- receiver noise.

The quantity σ_t^2 is the impulse response rms pulsewidth for the fiber [2].

$$\sigma_t^2 = L^2 (\Delta\lambda)^2 \left[\left(\frac{d\tau}{d\lambda}\right)^2 + \tfrac{1}{2} \left(\Delta\lambda \frac{d2\tau}{d\lambda^2} \right)^2 \right] \tag{7}$$

where τ is the group delay, λ is the operating wavelength, and $\Delta\lambda$ is the spectral width of the source. Based on the work of Ref. [15] τ is derived and modelled on the bases of Ref. [12] as

$$\tau\lambda^6 = \sum_{i=0}^{7} C_i(x, \Delta\lambda)\, \lambda^{2i} \quad (8)$$

where $C_{i,s}$ $(x, \Delta\lambda)$ are functions of both x and $\Delta\lambda$, see Appendix . This equation yields the variations of τ against the variations of x. At a certain value of x, depending on λ, τ possesses a zero value, above which the fiber possesses positive chromatic dispersion and on the other side it possesses a egative chromatic dispersion. The chrip power penalty of LD is derived [5] as

$$P_d = - 15.55 \log (1 - \Delta) \quad (9)$$

where

$$\Delta = 5.16\, T_p\, DB\, [\, 1 + \tfrac{2}{3}\, (D - T_p B) \quad (10)$$

where T_p is the pulse duration, and

$$D = L.\frac{\partial\tau}{\partial\lambda}.\delta\lambda\ Bq \quad (11)$$

where $\delta\lambda$ is the amount of wavelength excursion.

The use of Eq. (2) into Eq. (1) yields

$$10 \log \frac{B_m}{B_r} = \sigma L + n\sigma_c + m\sigma_s + \sigma_m + P_d \quad (12)$$

Walker [13] derived σ as

$$\sigma = a_1 \lambda^{-4} + a_2 + a_3 \times \exp(a_4/\lambda) + a_5 \quad \exp(-a_6/\lambda) \qquad (13)$$

where $a_1 = 0.95$, $a_2 = 0.2$, $a_3 = 7.7 \times 10^{-5}$, $a_4 = 4.9$,

$a_5 = 5 \times 10^{11}$, $a_6 = 48.0$

For L = 2 km, the above model is employed to calculate $B(x_1)$ and $B(x_2)$ where x_1 and X_2 yield numerically the same chromatic dispersion, but of different signs.

Employing 2-fiber segments of germania percentages x_1 and x_2 as in Fig. 1 enables us to cancel the chromatic dispersion periodically at the end of 4-km distance

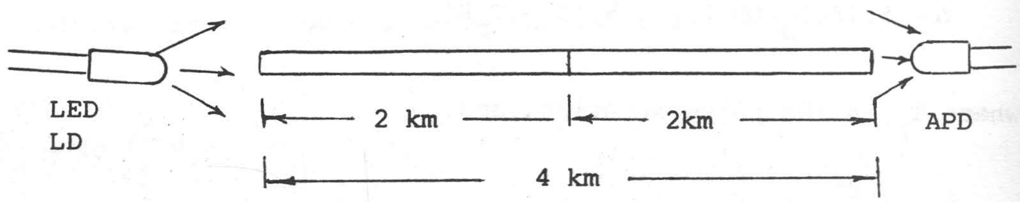

Fig. 1 The useful Schame

In fact, both the dispersion power penalty and the chirping power penalty are function of B^2, thus Eq. (12) may be recasted under the form

$$10 \log \frac{P_m}{P} = KP \qquad (14)$$

where P is the bit-rate repeater spacing product and P_m is the ultimate value of P. Both P_m and K are functions of L, x, λ , and Δλ

3. Numerical Data

Based on the data of Ref. [1] we have

$$\sigma_m = 2 \text{ dB}$$

$$F_t = 0.44/\tau_{ch} L$$

$B_m = 10^{12.7}$ bit/sec. for LD-APD combination

$= 10^{11.2}$ bit/sec. for LED-APD combination

Following the data of Ref. [9] we assume that

$$n\sigma_c + m\sigma_s = 4 \text{ dB}$$

while the data of Ref. [5] yields

$$10^{-10} \leq T_p \text{ (sec)} \leq 2 \times 10^{-10},$$

$$0.2 \leq \delta\lambda \text{ (nm)} \leq 0.5, \text{ and}$$

$$0.3 \leq \delta\lambda \text{(nm)} \leq 2 \text{ for LD.}$$

Also we have

$$20 \leq \Delta\lambda \text{ (nm)} \leq 60 \text{ for LED [3].}$$

Higher values for $\delta\lambda$ as well as smaller values for T_p are reported in Ref. [19] where

$$10^{-11} \leq T_p \text{ (sec)} \leq 2 \times 10^{-11}$$

$$5 \leq \delta\lambda \text{ (nm)} \leq 10$$

The germania percentage x , in the present calculations is assumed as

$$0 \leq x \leq 1.0$$

while the optical source wavelength is assumed as

$$1.3 \leq \lambda \text{ (}\mu\text{m)} \leq 1.6$$

4. Results and Discussions

In recent years a great deal of interest has been focused on the development of dispersion-shifted fibers operating in the low attenuation window [20-23] where such advantages must be weighted against a number of potentially adverse factors [20].

Line et al [21], and Marcuse [23] have suggested the possibility of equlizing pulse dispersion by connecting two or more fibers with opposite dispersion characteristics in tandem to cancel the effect of first-order dispersion. The anomalous dispersion characteristics of optical fiber recently reported [24] is proposed for use in equalization of fiber matereial dispersion [23].

In the present investigation, the theory of equalizing pulse dispersion by connecting two fibers with opposite dispersion characteristics to cancel (1) material dispersion (ii) waveguide dispersion, and (iii) profile dispersion is extended where such effects are deeply and accurately studied in connection with the fiber bandwidth, cutoff (dispersion) power penalty and the fiber spectral loss as a new scheme to maximize the system capacity.

Maximizing the system bit-rate, the variations of x_1 (germania percentage in the first segment) against the variations of x_2 (germania percentage of the second segment) are casted in Figs. 2 to 6 at different valuesof the operating wavelengths of LEDs, sources. The spectral with $\Delta\lambda$ of the optical source is displayed as a parameter. The ordered pairs (x_1, x_2 displayed on these Figures yield a system of maximum obtainable bit-rate at the assumed set of parameters where the chromatic dispersion produced by 2-km segment of germania percentage x_1 is concelled because of the chromatic dispersion produced by the 2-km segment of germania percentage x_2. This phenomenon is done periodically each 4-km distance. The spectral width of the operating source affects the value of ordered pairs (x_1, x_2) as shown in these Figures.

The same sort of variations but for LDS optical source are shown in Figs. 7 to 11.

The corresponding maximum obtainable bit-rates are displayed on Figs. 12 to 16 based on Eqs. 4 to 6 for LEDs Sources. The rates are approximately three orders of magnitude greater than the corresponding rates obtained when employing one segment along the span between the successive repeaters whatever the operating optical source.

The different bit-rate according to different penalties are portrayed on these Figures where the white receiver noise (Eq. (5)) yields higher values than the case of f^2-receiver noise (Eq. (6)). This is because Eq. (6) represents higher dispersion power penalty than that given by Eq. (5), but all the portrayed cases are of the same order of magnitude.

LD sources yields maximum obtainable bit-rates as clarified on Figs 17-21 based on Eq. (9) for different wavelengths and spectral widths.

5. Conclusions

The new scheme to maximize the system bit rate is modelled and theoretically investigated based on employing 2-fiber segments of germania percentages x_1 and x_2 which enable us to cancel the chromatic dispersion periodically at the end of each 4 km distance.

The suggeted model here, accounts the following:

a. Good and fast modeling of the spectral loss which accounts, the dependence of the loss and the operating wavelength, and the germania percentage.

b. Good and more accurate modelling of the chromatic dispersion with the same above parameters.

c. The different power penalties besides the system margin.

The following are the important conclusion of the present study.

i. As X_1 increases, X_2 decreases

ii. The obtained maximum bit rate is approximately 3 order of magnitude greater than that obtained when employing one segment.

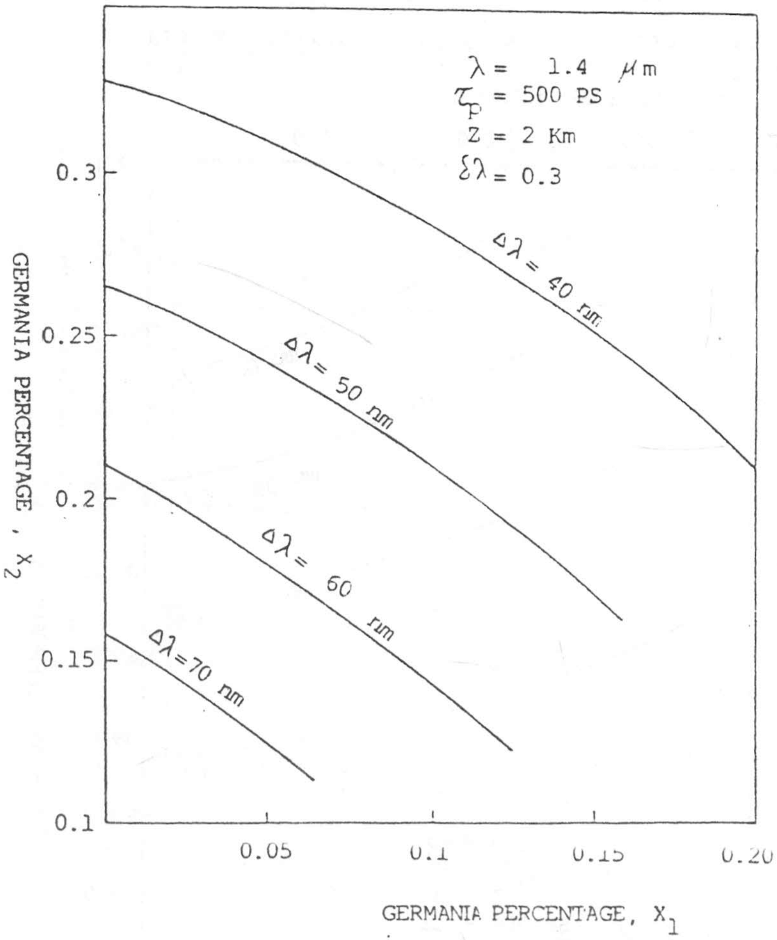

Fig. 2 Variations of X_1 against variations of X_2 at λ = 1.4 μm and assumed set of parameters of LEDs

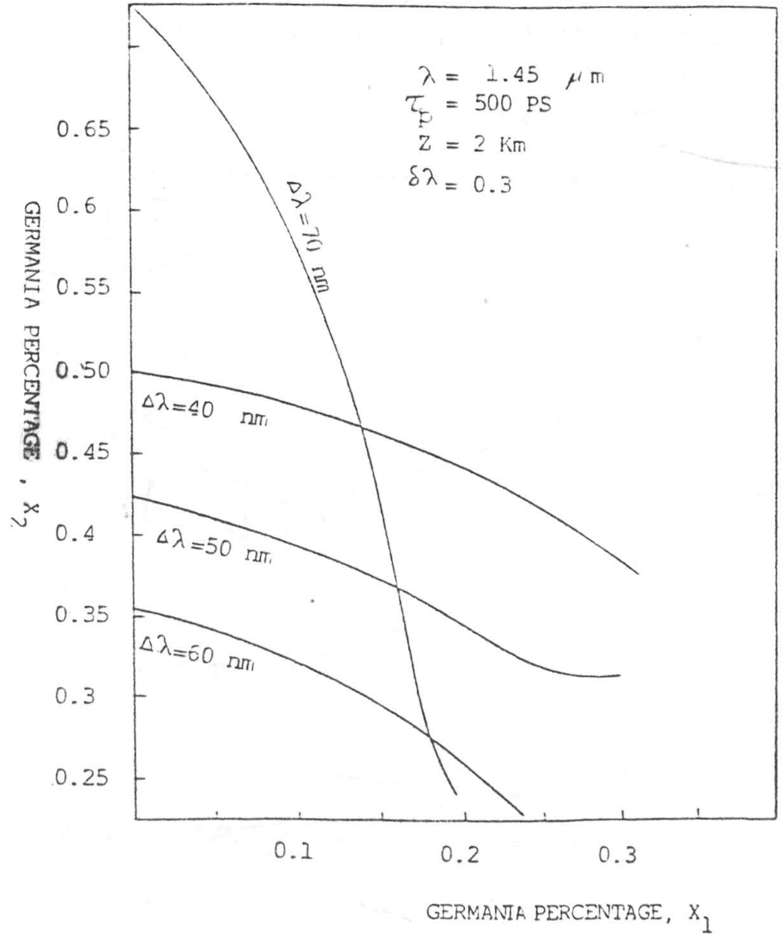

Fig. 3 Variations of X_1 against variations of X_2 at λ = 1.45 μm and assumed set of parameters of LEDs

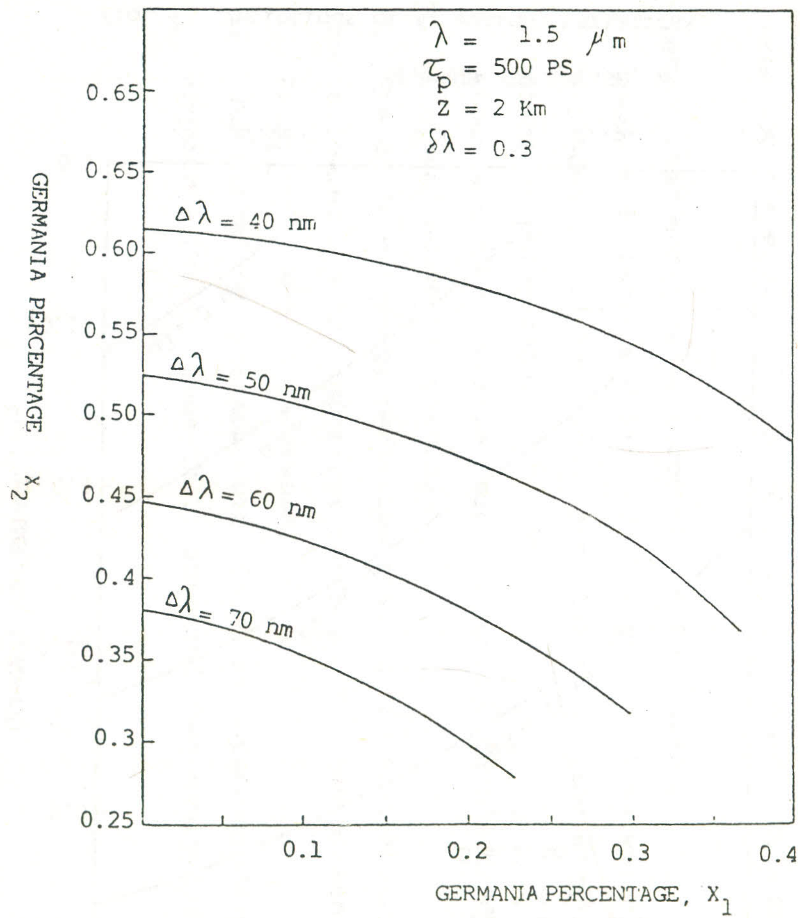

Fig. 4 Variations of X_1 against variations of X_2 at λ = 1.5 μm and assumed set of parameters of LEDs

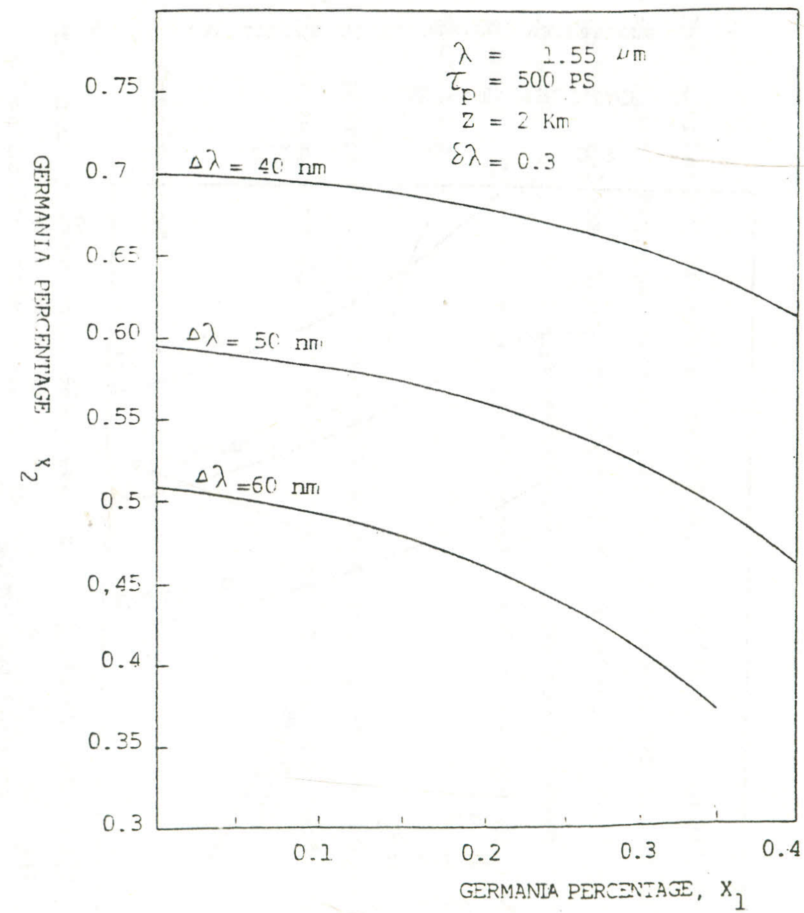

Fig. 5 Variations of X_1 against variations of X_2 at λ = 1.55μm and assumed set of parameters of LEDs

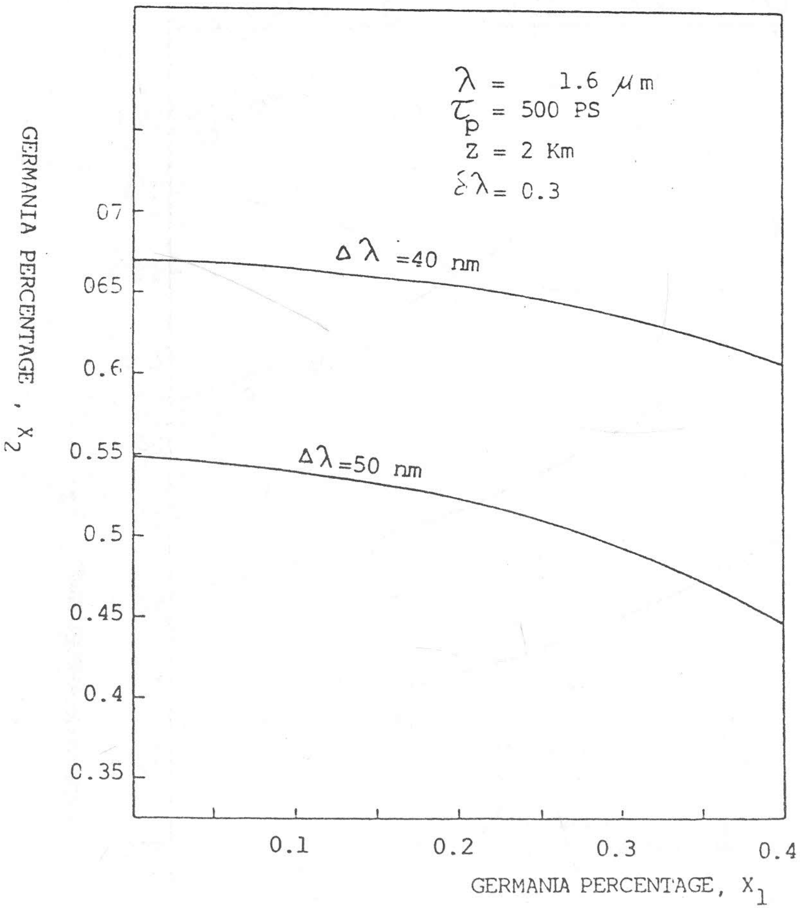

Fig. 6 Variations of X_1 against variations of X_2 at λ = 1.6 μm and assumed set of parameters of LEDs

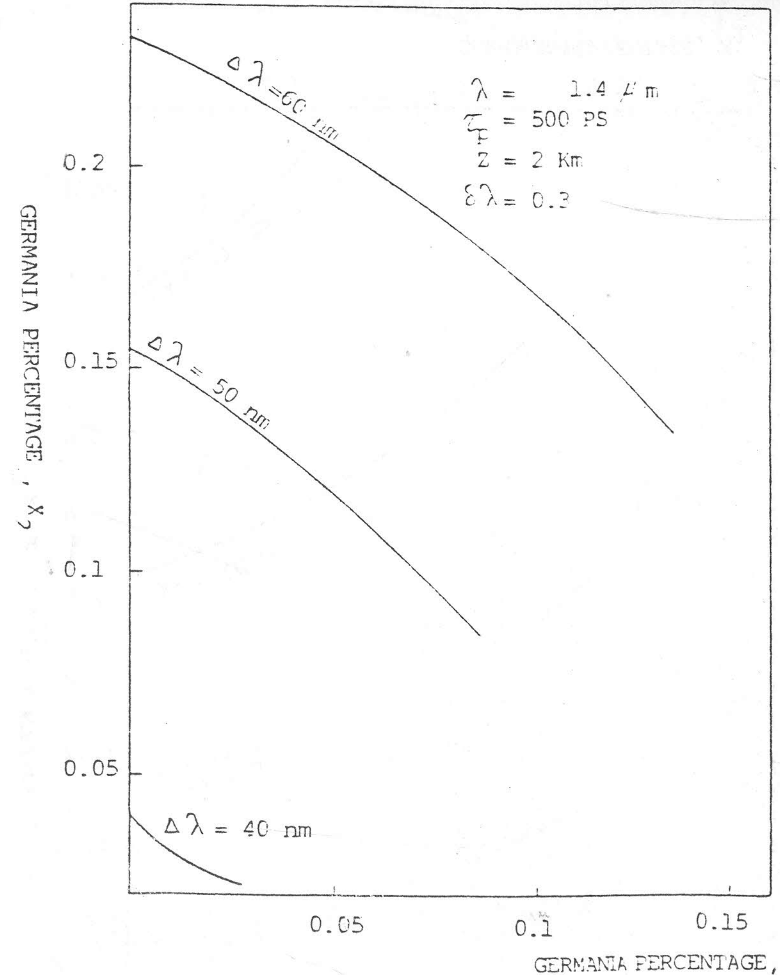

Fig. 7 Variations of X_1 against variations of X_2 at λ = 1.4 μm and assumed set of parameters of LDs

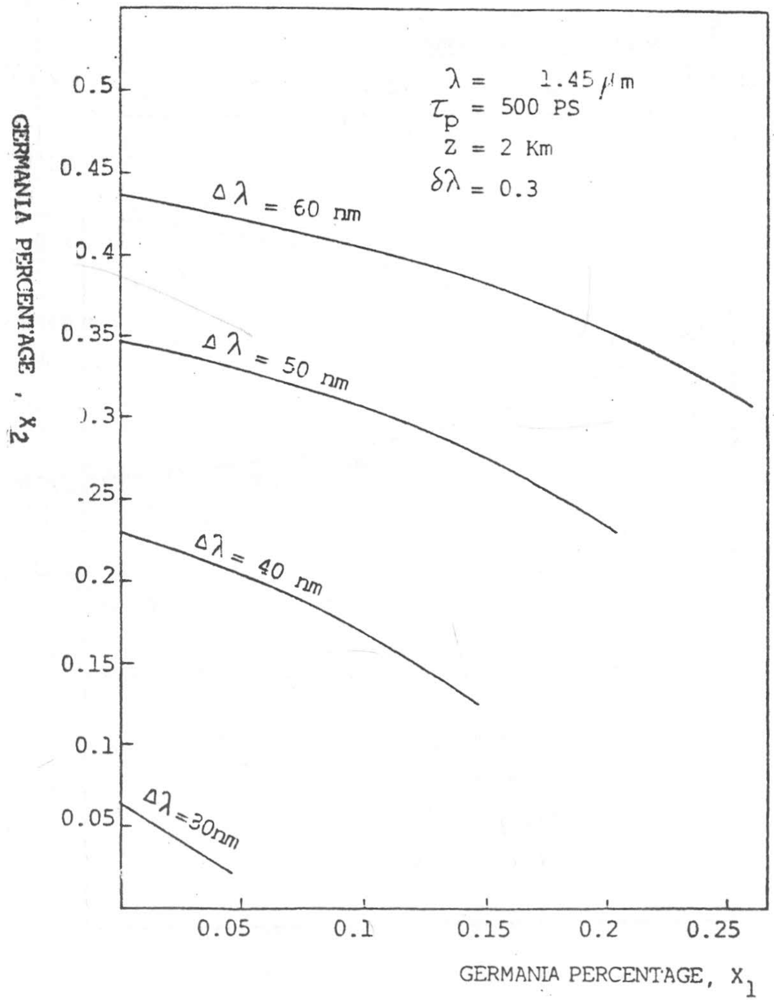

Fig. 8 Variations of X_1 against variations of X_2 at $\lambda = 1.45\,\mu m$ and assumed set of parameters of LDs

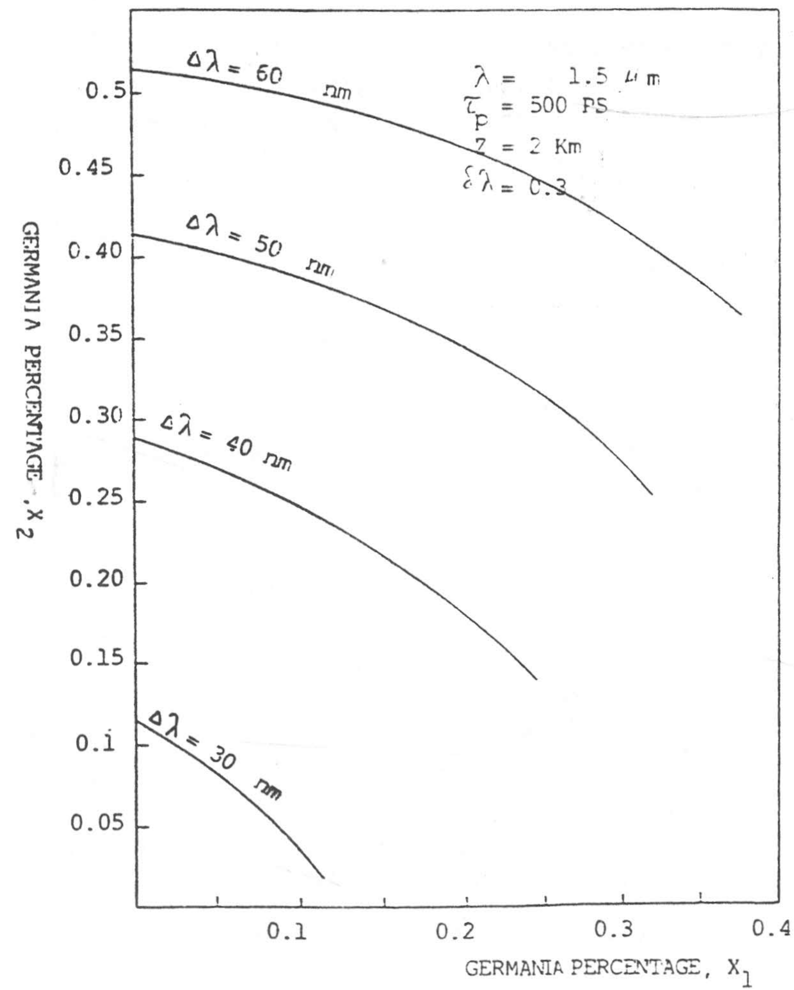

Fig. 9 Variations of X_1 against variations of X_2 at $\lambda = 1.5\,\mu m$ and assumed set of parameters of LDs

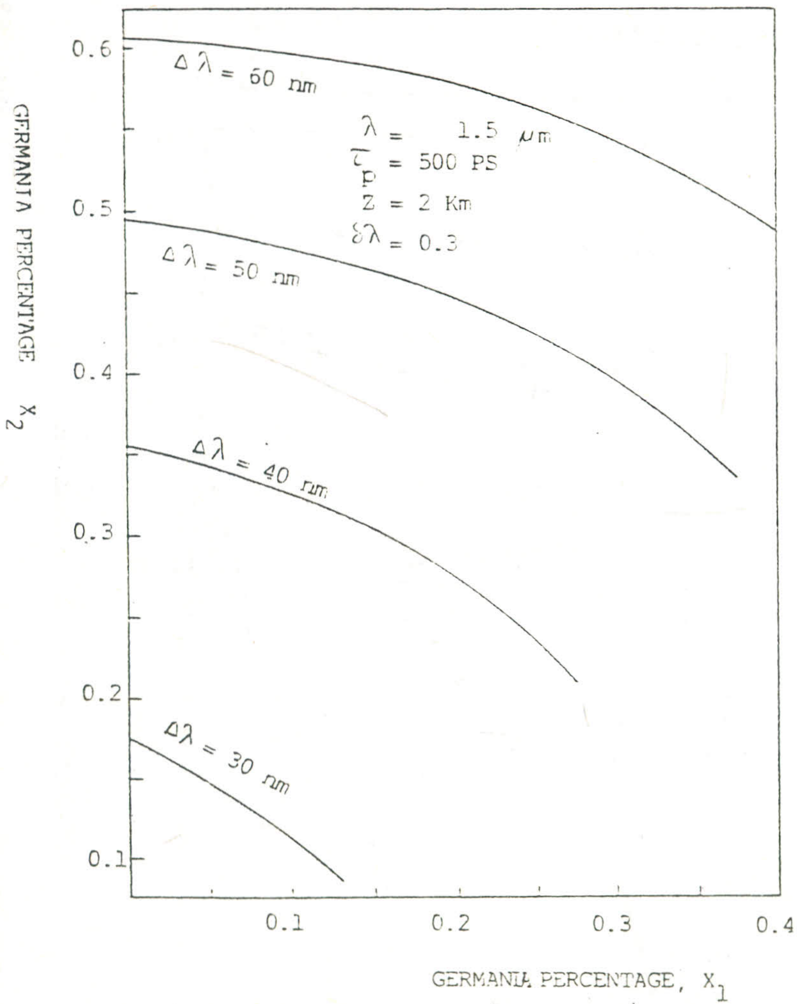

Fig. 10 Variations of X_1 against variations of X_2 at λ = 1.55 μm and assumed set of parameters of LDs

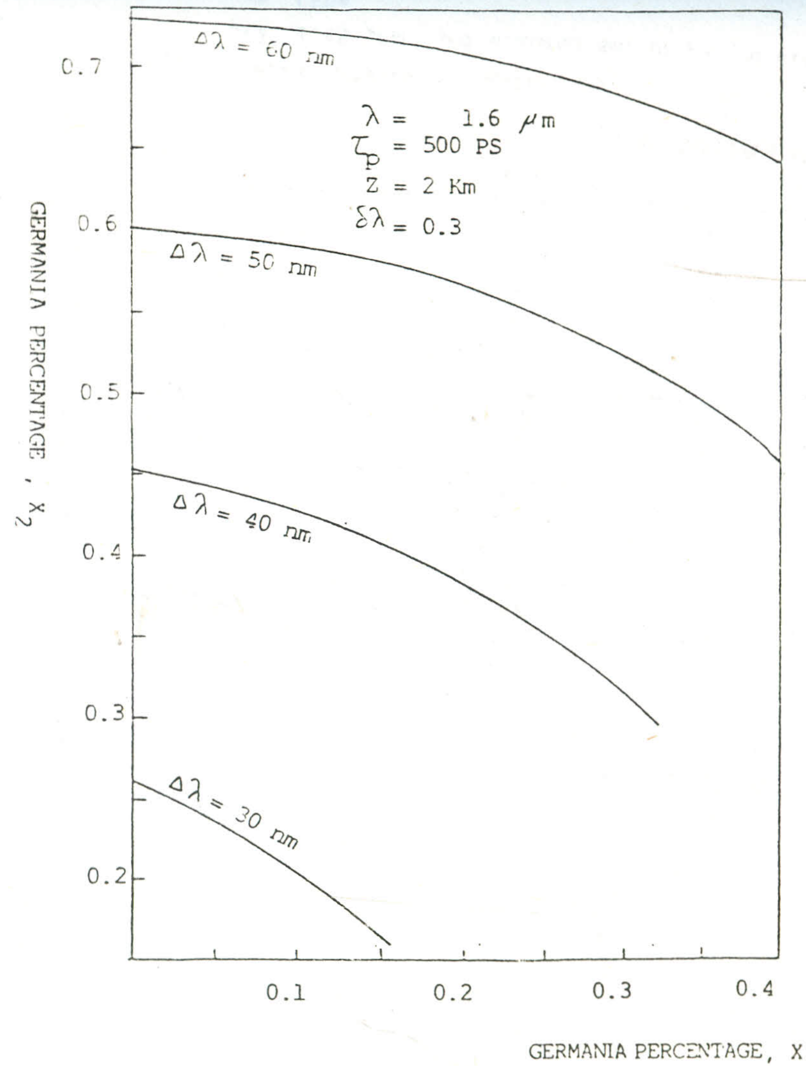

Fig.11 Variations of X_1 against variations of X_2 at λ = 1.6 μm and assumed set of parameters of LDs

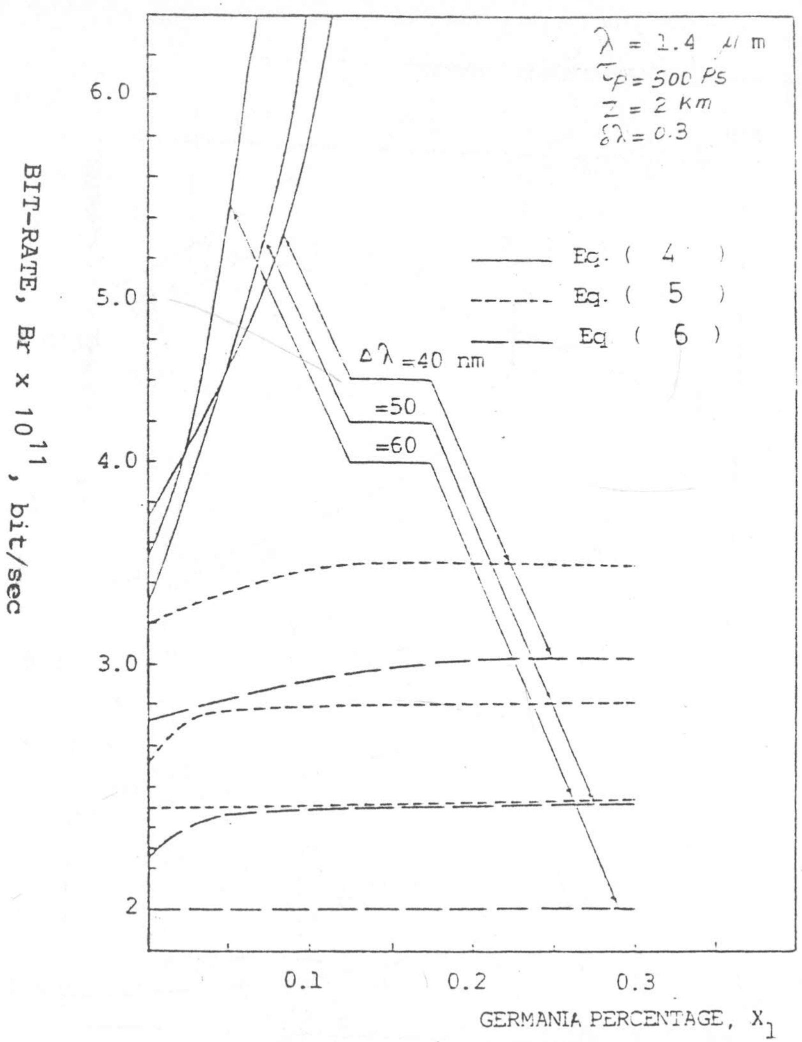

Fig.12 Variations of B_r against variation of X_1 at $\lambda = 1.4\,\mu m$ and assumed set of parameters of LEDs

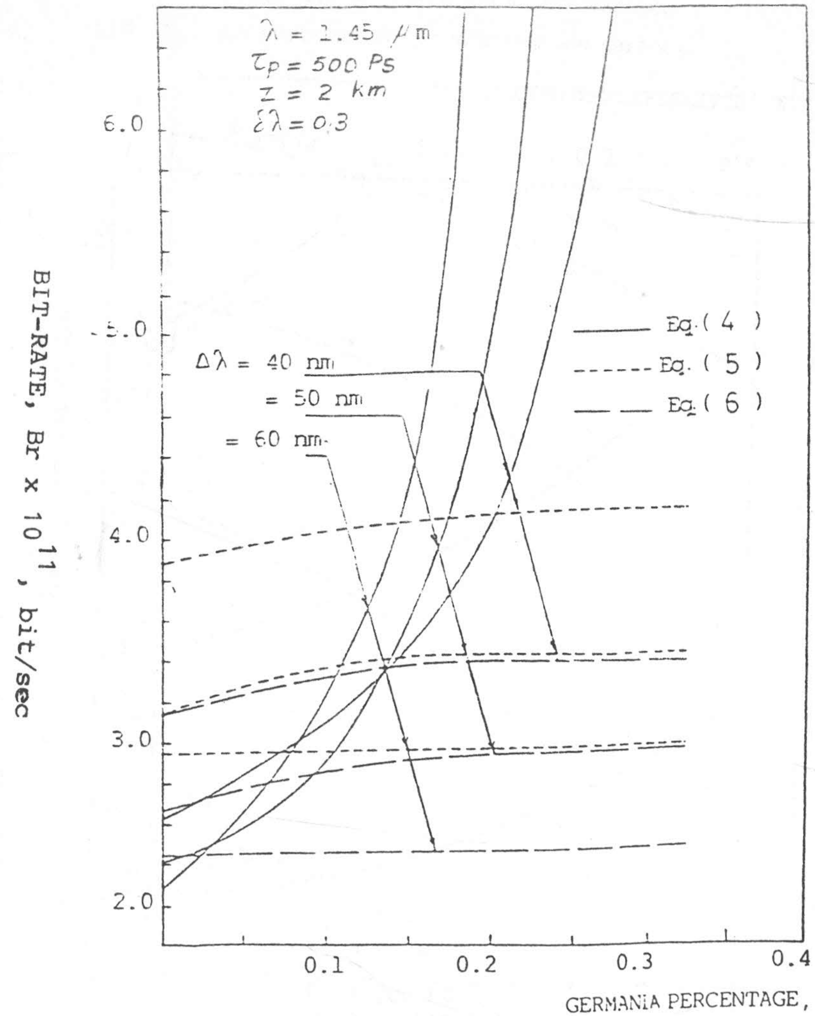

Fig.13 Variations of B_r against variation of X_1 at $\lambda = 1.45\,\mu m$ and assumed set of parameters of LEDs

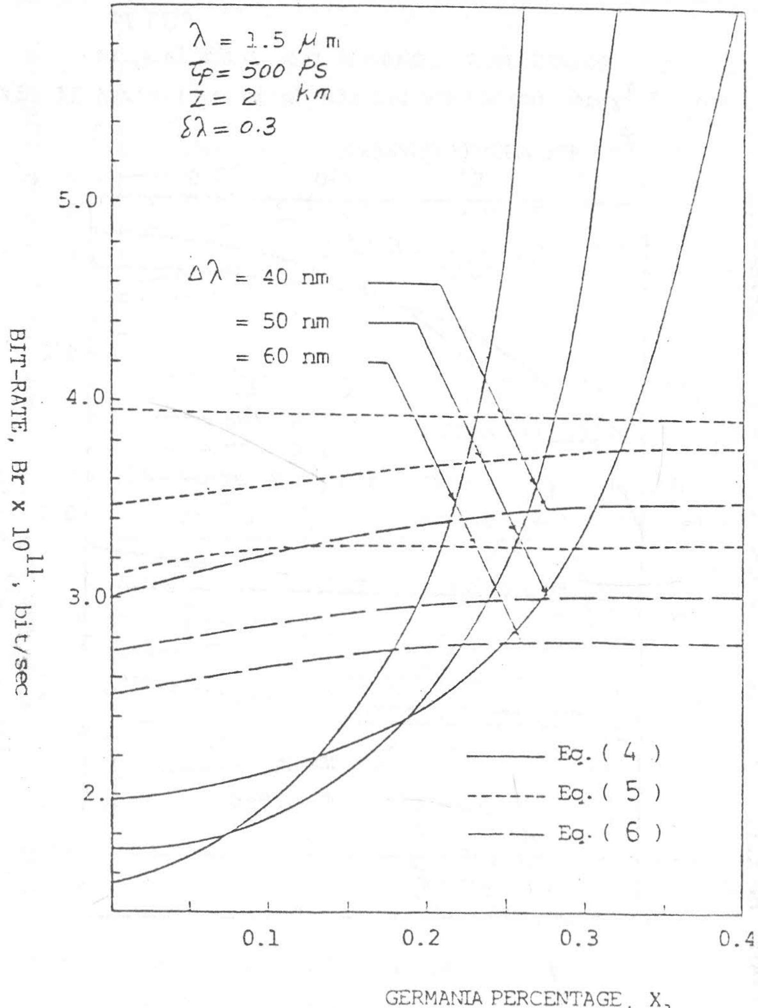

Fig. 14 Variations of B_r against variation of X_1 at $\lambda = 1.5\,\mu m$ and assumed set of parameters of LEDs

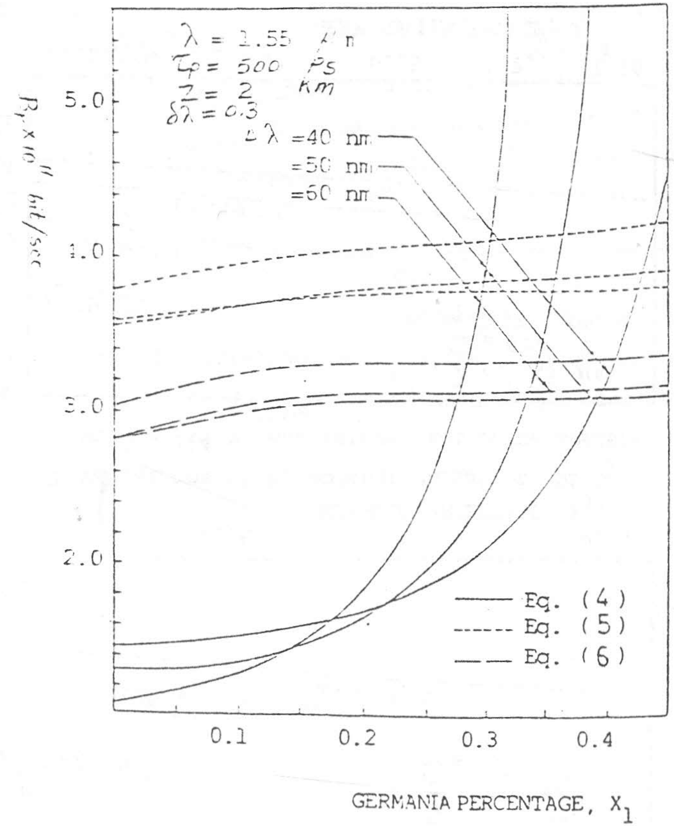

Fig. 15 Variations of B_r against variation of X_1 at $\lambda = 1.55\,\mu m$ and assumed set of parameters of LEDs

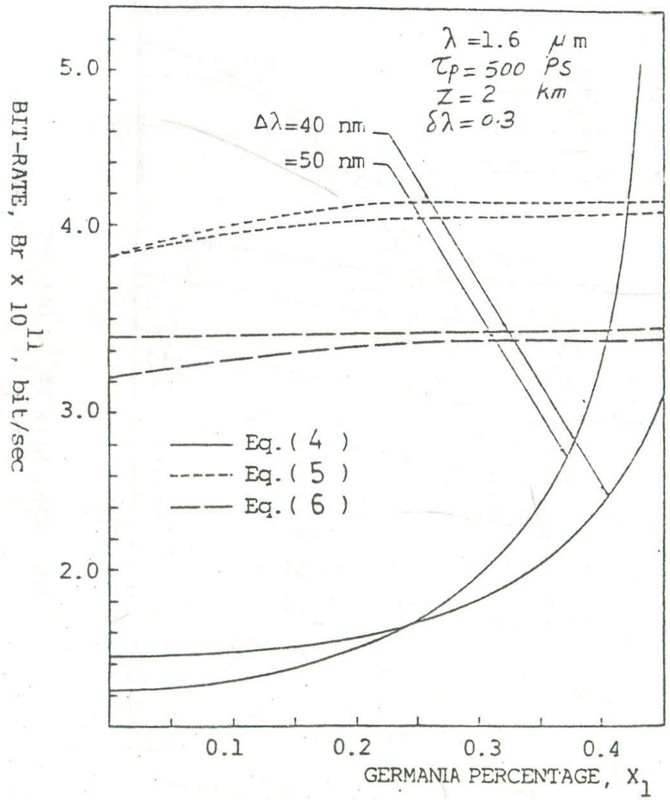

Fig. 16 Variations of B_r against variation of X_1 at $\lambda = 1.6\,\mu m$ and assumed set of parame of LDs

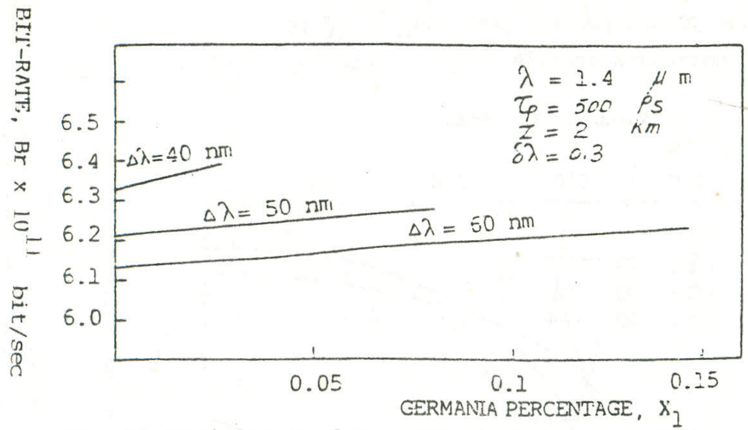

Fig. 17 Variations of B_r against variation of X_1 at $\lambda = 1.4\,\mu m$ and assumed set of parameters of LDs

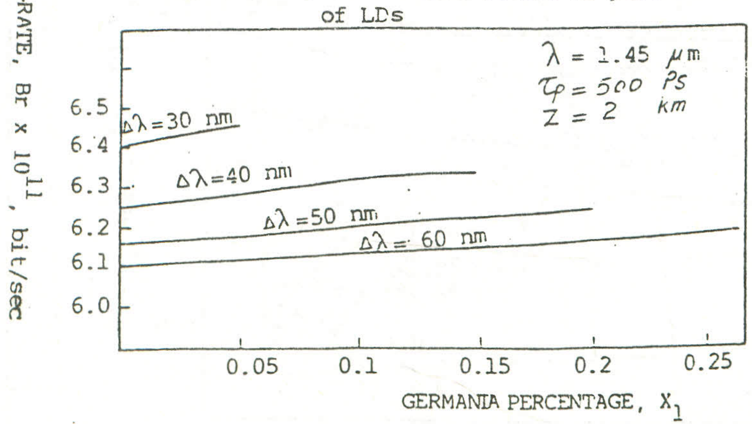

Fig. 18 Variations of B_r against variation of X_1 at $\lambda = 1.45\,\mu m$ and assumed set of parameters of LDs

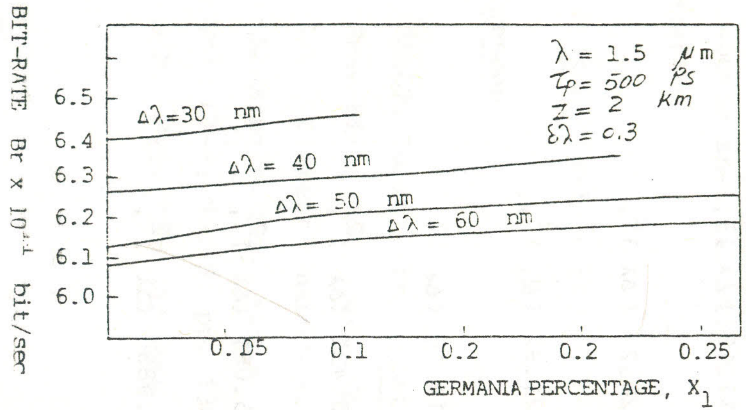

Fig.19 Variations of B_r against variation of X_1 at $\lambda = 1.5 \mu m$ and assumed set of parameters of LDs

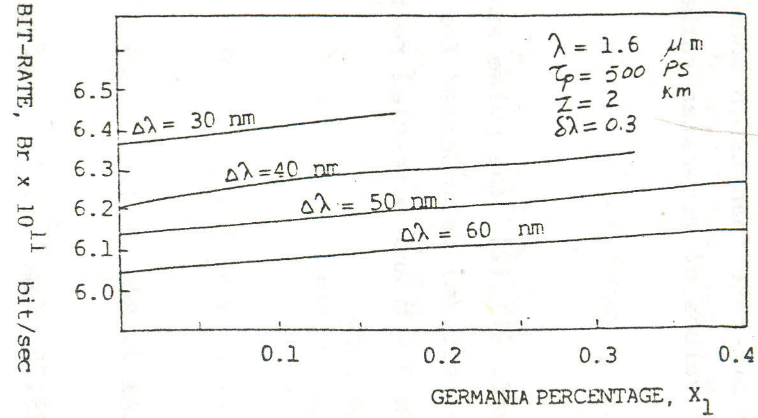

Fig.21 Variations of B_r against variation of X_1 at $\lambda = 1.6 \mu m$ and assumed set of parameters of LDs

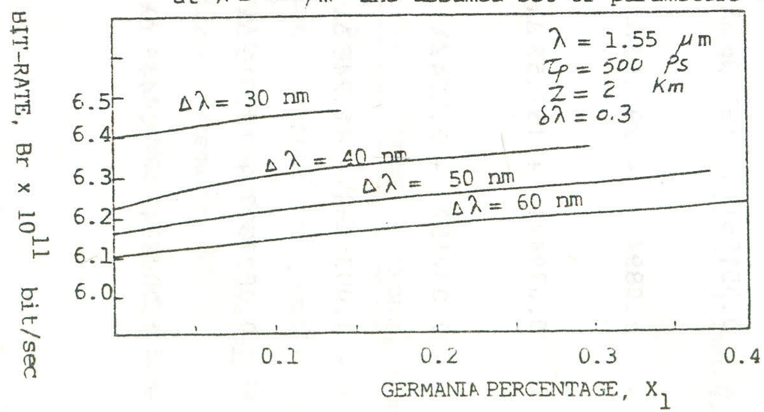

Fig. 20 Variations of B_r against variation of X_1 at $\lambda = 1.55 \mu m$ and assumed set of parameters of LDs

iii. LD,S optical sources yields higher bit-rate than LED,S sources.

iv. White receiver noise yields higher values of bit-rates rather than the case of f^2-reciver noise.

Appendix A

In Ref. [15], and on the basis of Ref. [11,12], the pulse spreading τ due to chromatic dispersion(τ in pico - sec./m) is modelled for single mode germania doped fiber of radius 5 μ m and core-clad refractive index differences Δn = 0.005 under the form

$$\tau\lambda^6 = \sum_{i=0}^{7} C_i (x, \Delta\lambda)\lambda^{2i}$$

where $C_i (x,\Delta\lambda) = a_i (\Delta\lambda) \exp (b_i (\Delta\lambda). x)$,

$$a_0 = - 0.0075933 - 139.03\,\Delta\lambda - 29.78\,(\Delta\lambda)^2,$$

$$a_1 = 0.051561 + 197.86\,\Delta\lambda + 312.18\,(\Delta\lambda)^2,$$

$$a_2 = - 0.0894 - 293.53\,\Delta\lambda - 426.22\,(\Delta\lambda)^2,$$

$$a_3 = 0.070421 + 157.55\,\Delta\lambda + 321.92\,(\Delta\lambda)^2,$$

$$a_4 = - 0.032152 - 2.324\,\Delta\lambda - 114.19\,(\Delta\lambda)^2,$$

$$a_5 = - 0.0035584 - 41.246\,\Delta\lambda - 25.499\,(\Delta\lambda)^2,$$

$$a_6 = 0.0027927 + 13.016\,\Delta\lambda - 15.081\,(\Delta\lambda)^2,$$

$$a_7 = - 0.00038473 - 1.3446\,\Delta\lambda - 1.9885\,(\Delta\lambda)^2,$$

$b_0 = 1.7052 \exp(0.0075525\, \Delta\lambda)$,

$b_1 = 2.2668 \exp(-0.090382\, \Delta\lambda)$

$b_2 = 2.0255 \exp(0.025884\, \Delta\lambda)$,

$b_3 = 1.7501 \exp(0.067739\, \Delta\lambda)$,

$b_4 = 2.3157 \exp(-0.86932\, \Delta\lambda)$,

$b_5 = 1.9527 \exp(-0.075858\, \Delta\lambda)$,

$b_6 = 1.9292 \exp(0.031259\, \Delta\lambda)$, and

$b_7 = 1.9204 \exp(-0.0060029\, \Delta\lambda)$.

The source spectral with $\Delta\lambda$ satisfies the following two-sided bounded inequality

$$0 \leq \Delta\lambda \text{ (nm)} \leq 50.$$

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