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THERMAL ENVIRONMENTAL EFFECTS ON HIGH DATA RATE OPTICAL COMMUNICATIONS

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Abstract

Thermal environmental effects on high data rate optical communication (or powerful piused transmission) systems employing germania doped fibers are analyzed on a sensitivity basis. It is found that the environmental temperature (or the intrinsic temperature) has a considerable effect on the system capacity and introduces a thermal penalty controlled via both the percentage of germania and the operating wavelength.

1. Introduction

Single mode optical fibers are the dominant transmission media for long-haul high-bit-rate communication systems [1,2]. The transmission characteristics determining the information handling capacity, mainly the spectral loss and the chromatic dispersion, should be stable for the long term to ensure essential high reliability. Thus a major consideration for cable designers, is the effect of environment on fiber performance once the cable has been laid. A limited field and laboratory data about the effects of the environment on optical cable design were reported in Ref. [3].

Special emphasis is focused on both thermal-dispersion [2,4] and thermal loss [3] sensitivities as major environmental affecting parameters. It had been experimentally reported and slightly theoretically justified that the increase of the environmental temperature leads to high spectral loss and moves the zero-dispersion wavelength to higher values or in general alters the dispersion characteristics [5,6]. Thus, these two distinct mechanisms rely on accurate theoretical analysis to predict the effect of the survice environment on fiber performance especially its information handling capacity. In the present paper accurate model is casted taking into consideration the thermal variations of both the spectral loss characteristics and the dispersion charactristics in order to theoretically investigate the bit-rate thermal sensitivity of an optical beam launched into a single mode germania doped fiber.

2. Model and Analysis

Based on the estimated model of Walker [7] and the reported formula by

Jeunhomme [8], we fairly assume that the thermal dependent spectral loss $\sigma(\lambda, T, x)$ in the absence of OH absorption obeys the relation

$$\sigma(\lambda, T, x) = \sigma_I + \sigma_R + \sigma_{IR} + \sigma_{uv} \tag{1}$$

where

$$\sigma_I \equiv \text{intrinsic loss} \quad 0.2 \text{ dB/km} \tag{2}$$

$$\sigma_R \equiv \text{Rayleigh scattering loss}$$

$$= \left(\frac{0.75 + 66\ n}{\lambda^4} \right) \left(\frac{T}{T_o} \right) \tag{3}$$

$$\sigma_{IR} \equiv \text{infrared loss}$$

$$= 4.9 \times 10^{11} \exp \left[- \frac{48}{\lambda} \cdot \frac{T_o}{T} \right] \tag{4}$$

and

$$\sigma_{uv} \equiv \text{Ultraviolet loss}$$

$$= \frac{0.0132\ x}{1 + 733\ x} \exp \left(\frac{4.8}{\lambda} \cdot \frac{T_o}{T} \right) \tag{5}$$

where λ, T, x, Δn, and T_o are, respectively, the operating optical wavelength, the fiber temperature, the germania percentage, the core-clad refractive index difference, and the initial design temperature.

Through experimental study, Fleming [9] employed index measurements and correlated it to a three-term Sellmeir dispersion relations of the form

$$n^2 = 1 + \sum_{i=1}^{3} \frac{A_i \lambda^2}{\lambda^2 - \lambda_i^2} \qquad (6)$$

where n is the refractive index, and $A_{i,s}$ and $\lambda_{i,s}$ are functions of x.

The average thermal refractive index variations was reported [10] as

$$< \frac{dn}{dT} > = 1.5 \times 10^{-5} \, {}^{o}C^{-1} \qquad (7)$$

Therefore, we derived the following temperature-dependence relationship for $A_{i,s}$ as

$$A_i = A_{io} [1 + 0.005 (\frac{T - T_o}{T_o})] \qquad (8)$$

Injected power through the fiber, P, yields maximum obtainable temperature T which is linearly correlated under the form [11].

$$T - T_o = 3.54 P \qquad (9)$$

The chromatic dispersion (n, T, λ) including material, profile, and waveguide dispersions is handled through the model suggested by Adams [12].

The fiber bandwidth due to dispersion cutoff caused by material dispersion in single mode fibers is given by F_t [13] where

$$F_t = \frac{0.44}{\tau\ L} \qquad (10)$$

L is the cable length.

Based on the model of CSELT [13], El-Halafawy et al [14] derived a formula for the system bit rate, B_r, under the form:

$$B^2_r = 8\ F_t \log \frac{B_m}{B_r} \qquad (11)$$

where, $B_m = B_u \exp [- (\sigma L + \sigma_t)]$, B_u is the maximum allowable bit rate that depends on the source-detector combination, and σ_t accounts to the coupling, connecting and the marginal losses.

The fiber bandwidth-thermal sensitivity using Eq. (10) is

$$\frac{dF_t}{dt} = - \frac{F_t}{\tau} \cdot \frac{d\tau}{dT} \qquad (12)$$

where

$$\frac{d\tau}{dT} = \frac{\partial\tau / \partial\lambda}{\partial n / \partial\lambda} \cdot \frac{\partial n}{\lambda\ T} \qquad (13)$$

Employing Eq. (10), the bit-rate thermal sensitivity is derived as

$$\frac{1}{B_r} \cdot \frac{\partial B_r}{\partial T} = \left(\frac{F^2_t}{B_m} \cdot \frac{\partial B_m}{\partial T} + \frac{B^2_r}{4F_t} \cdot \frac{\partial F_t}{\partial T}\right) \left(F^2_t + \frac{1}{4} B^2_r\right)^{-1}$$

The use of Eqs. (12) and (13) smplifies Eq. (14) as

$$\frac{1}{B_r} \cdot \frac{\partial B_r}{\partial T} = - (B_1 F_1{}^2 + B_2 B^2_r)\left(F^2_t + \frac{1}{4} B^2_r\right)^{-1} \qquad (15)$$

$$B_1 = L \frac{\partial \sigma}{\partial T} \; {}^{o}C^{-1}$$

and

$$B_2 = \frac{1}{4\tau} \cdot \frac{\partial \tau}{\partial T} \; {}^{o}C^{-1}$$

Equation (15) defines the relative bit-rate thermal sensitivity denoted by S_T^B. In the following part, we accurately investigate the variations of S_T^B against the variations of the affecting set of parameters $\{x, \;\; , T, \; n, P\}$ over a wide range of interest.

3. Results and Discussion

Experimentally, chromatic dispersion in single mode fibers was shown to have a direct dependence on temperature through a linear fashion [2]. Once an optical cables is installed, temperature changes surrounding the cable or produced by powerful optical pulses propagating through the fiber can have a significant impact on fiber performance, with especial emphasis on its pulse-carrying capacity. Such problem is accurately investigated through a well-casted model taking into account the thermal dependence of the fiber characteristics namely, the dispersion and the spectral loss.

The variables B_1 and B_2 are rewritten as

$$B_1 = L\left\{\frac{\sigma_R}{T} - \frac{4.8 \; T_o \; \sigma_{uv}}{\lambda \, T^2} + \frac{48 \; T_o \cdot \sigma_{IR}}{T^2}\right\}$$

or

$$B_1 = \frac{48L \; T_o}{\lambda T^2}\left\{\sigma_{IR} - 0.1 \, \sigma_{uv} + \frac{T\lambda}{48T_o} \, \sigma_R\right\} \tag{16}$$

and

$$B_2 = \frac{1}{4\tau} \cdot \frac{\partial \tau \;/\; \partial \lambda}{\partial n / \partial \lambda} \cdot \frac{\partial n}{\partial T} \qquad (17)$$

The variations of the system bit-rate, B_r, against the variations of the medium temperature T are portrayed in Figs. 1-2, while the variations of B_r against the variations of the operating optical wavelength λ are shown in Figs. 3-4. The variation of the sensitivity of B_r w.r.t. T against the variations of T are displayed in Figs. 5-6. Based on Figs. 1-6, it is clear that B_r possesses thermal penalty, which increases as the temperature increases. This thermal penalty decreases with the increases of the operating wavelength. In general, as the temperature increases, both the refractive index and the dispersion increase, yielding a reduced bandwidth and low bit-rates. This phenomenon occurs up to a certain wavelength after which the temperature rate of change becomes positive. Such operating wavelength is a function of T and x (germania concentration).

Another sort of variations of B_r against the variations of one or more of the affecting set of parameters $\{\lambda, x, T\}$ are clarified in Figs. 7-12 where, in general, B_r increases as T increases at $\lambda = 1.35\,\mu m$ but B_r increases as T increases at $\lambda = 1.55\,\mu m$ up to certain temperature; then as T increases, B_r decreases. The variations of the sensitivity $S_T^{B_r}$ assure these features, with the existence of a certain operating wavelength at which $S_T^{B_r}$ equals zero.

4. Conclusions

Environmental temperature (or the intrinsic temperature has a

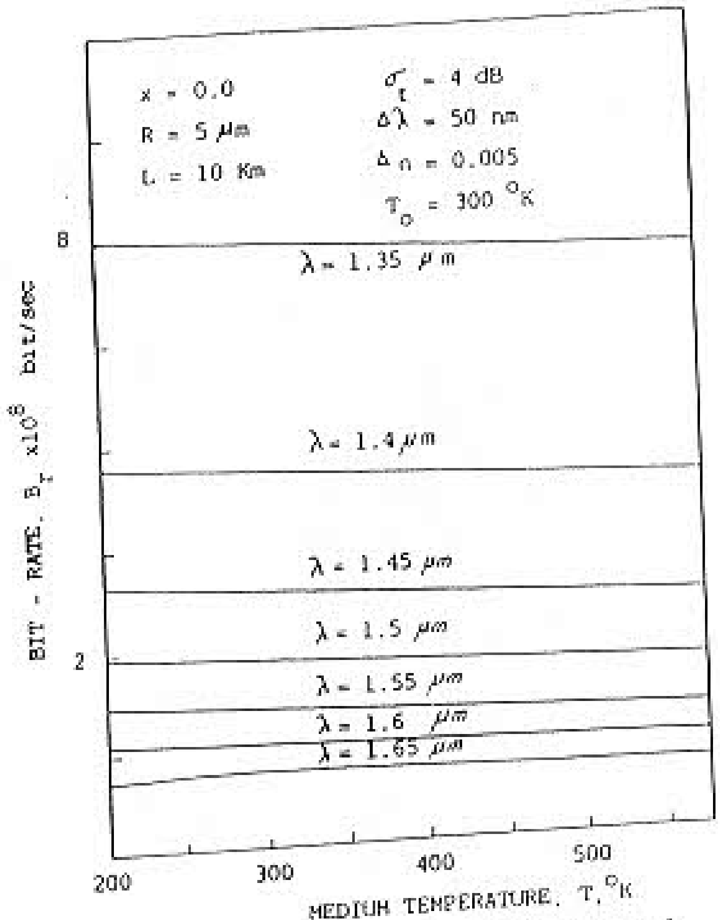

Fig. 1. Variations of B_r against variations of T at different value of λ and assumed set of parameters

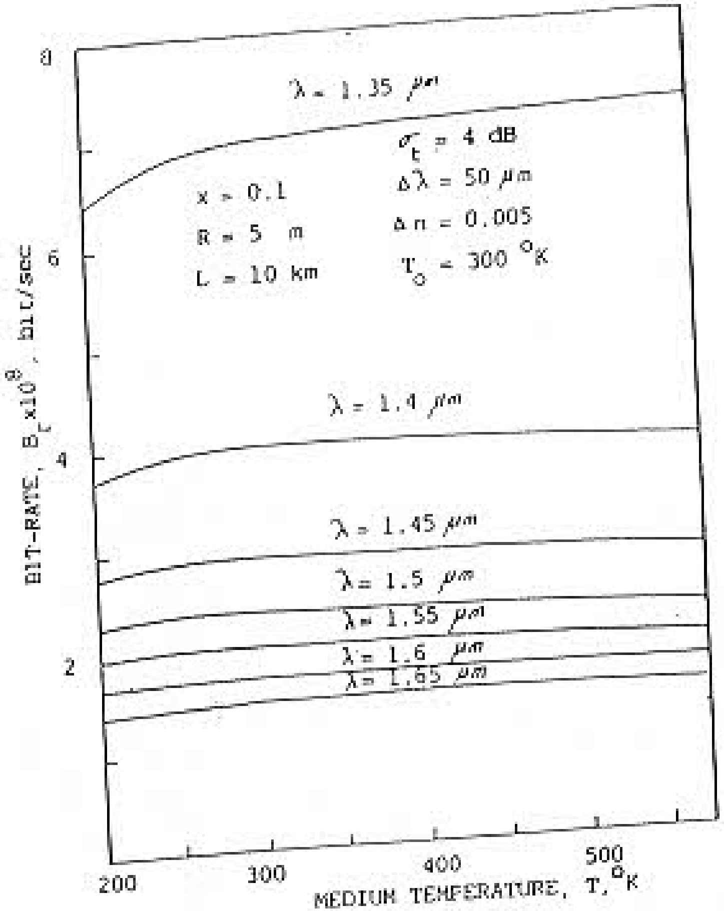

Fig. 2. Variations of B_r against variations of T at different value of λ and assumed set of parameters

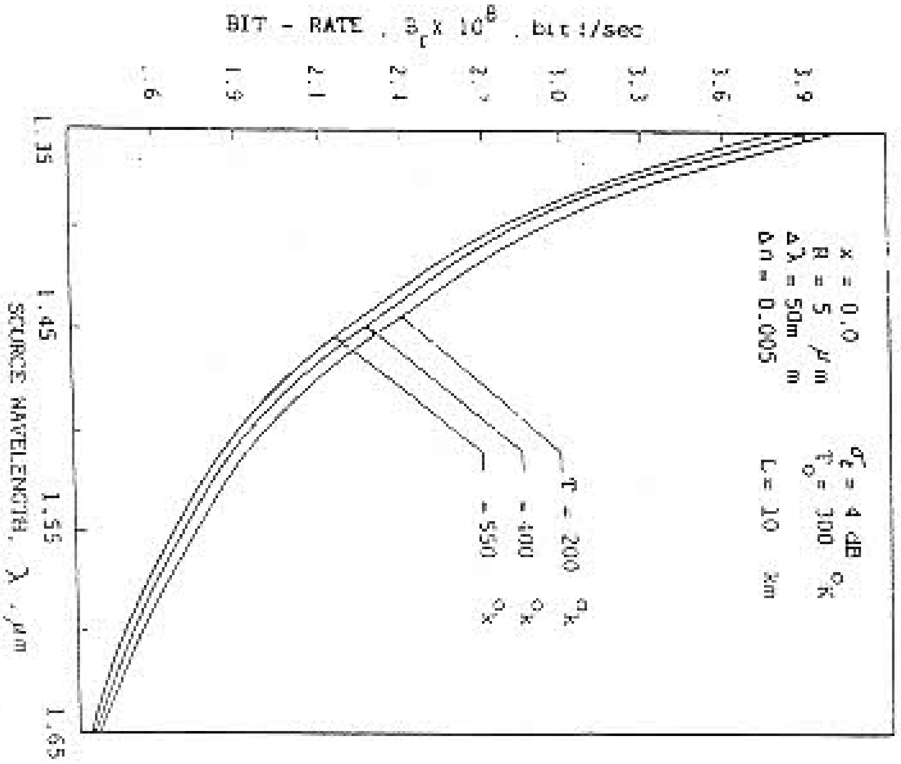

Fig.3. Variations of B_r against variations of λ at different value of T and assumed set of parameters

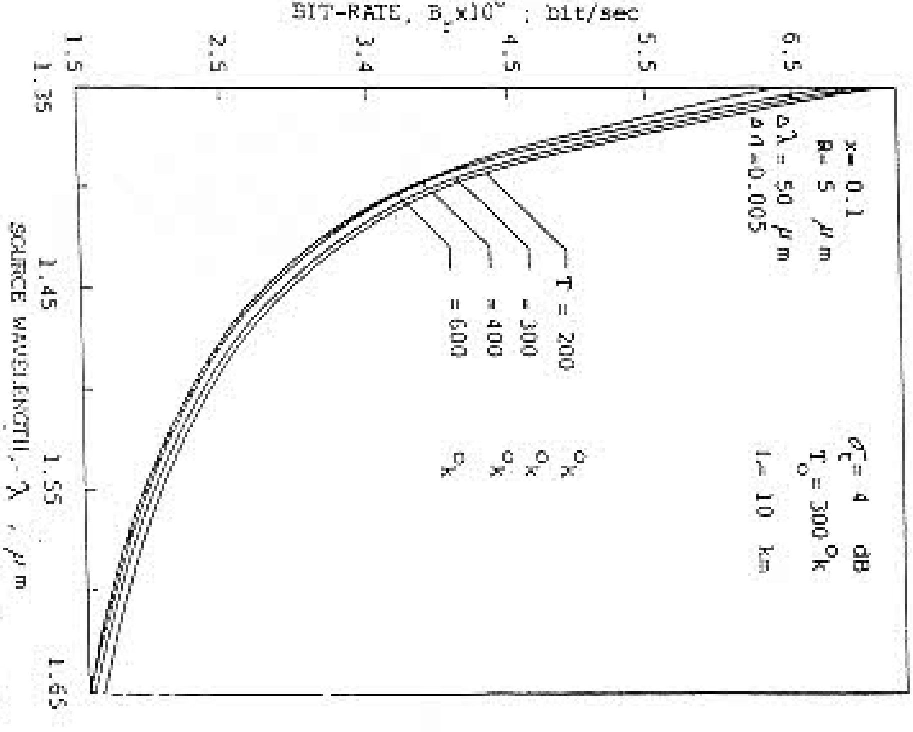

Fig.4. Variations of B_r against variations of λ at different value of T and assumed set of parameters.

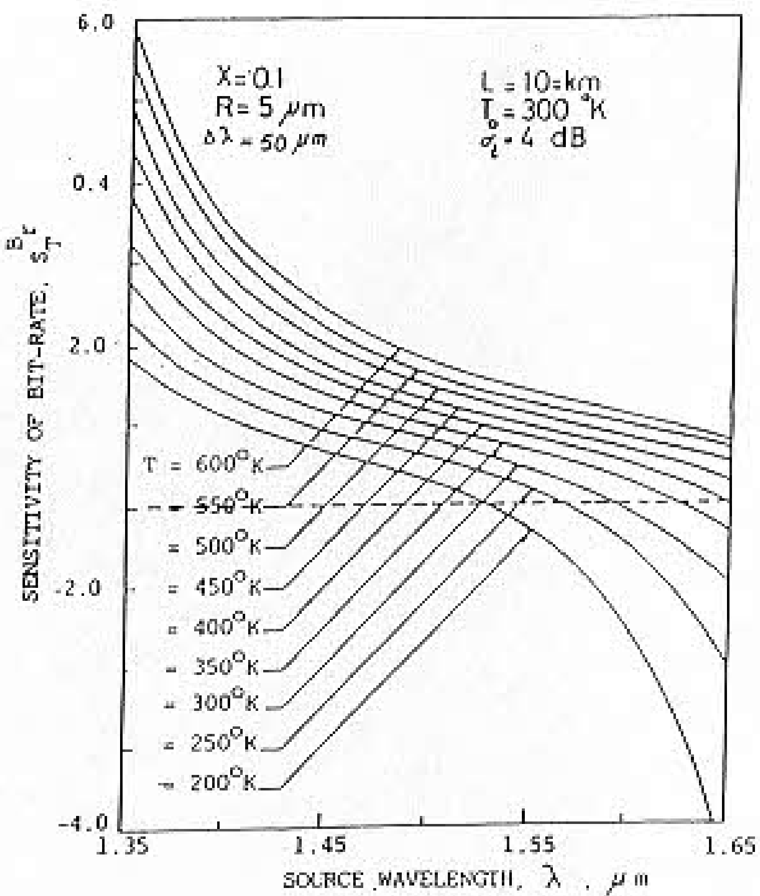

Fig. 5. Variations of $S_T^{B_r}$ against variations of λ at different value of T and assumed set of parameters

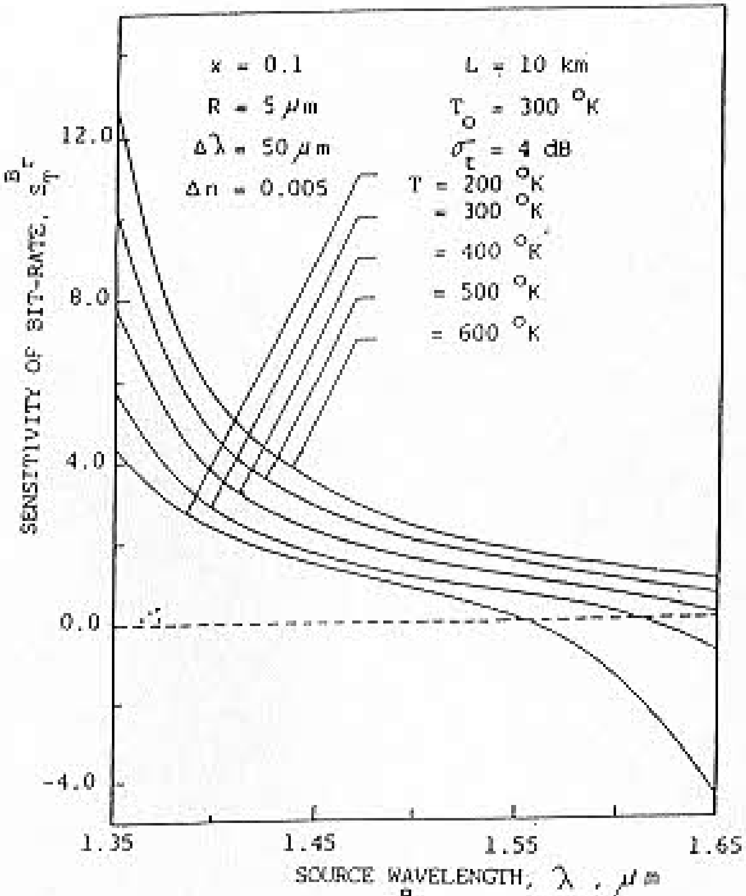

Fig. 6. Variations of $S_T^{B_r}$ against variations of λ at different value of T and assumed set of parameters

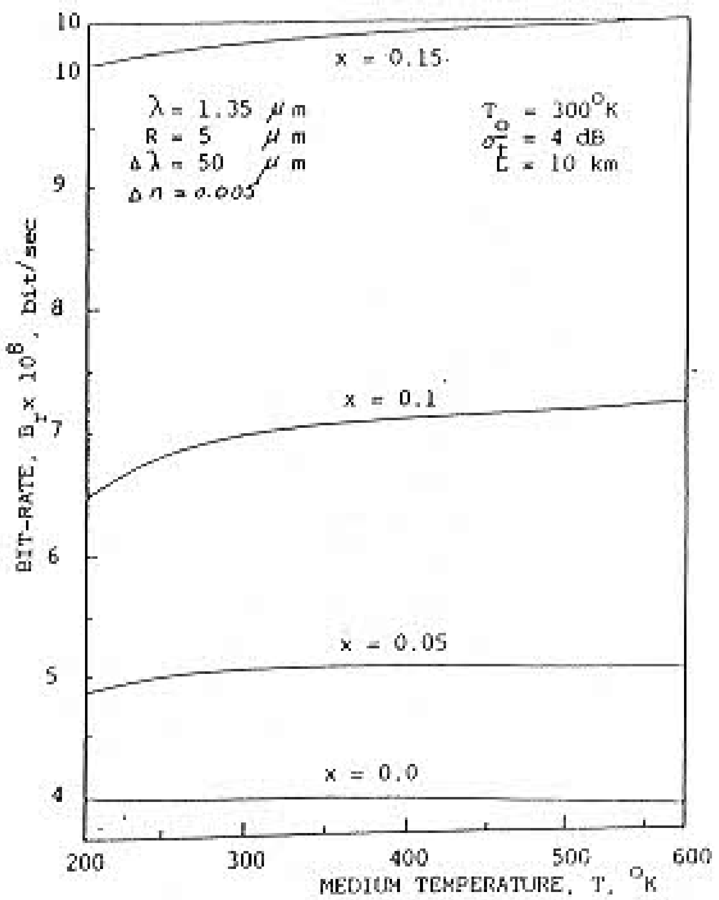

Fig. 7 Variations of B_r against variations of T at different value of X and assumed set of parameters.

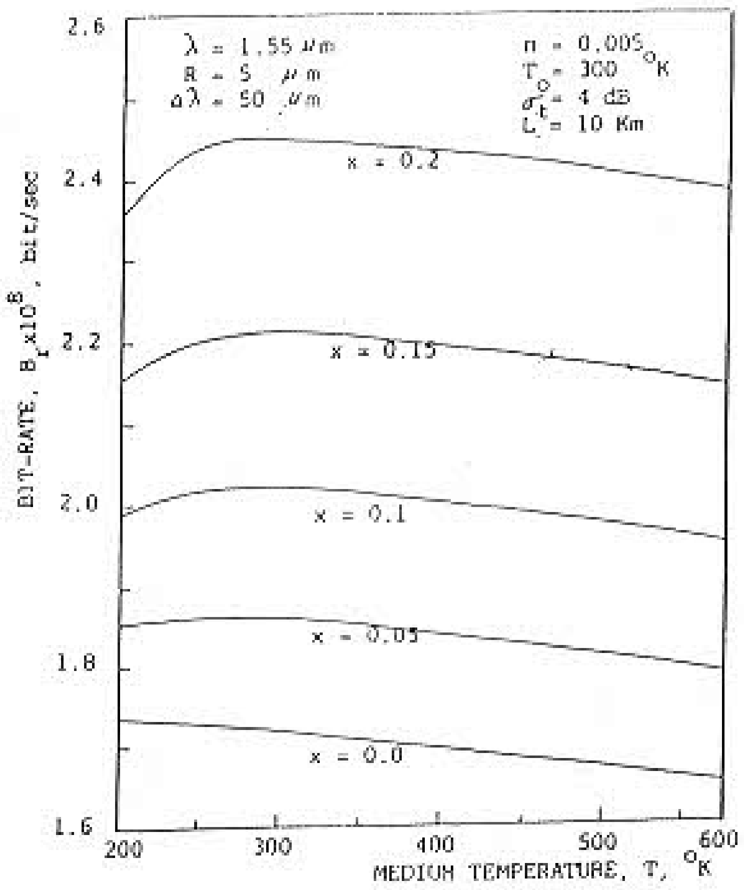

Fig. 8 Variations of B_r against variations of T at different value of X and assumed set of parameters

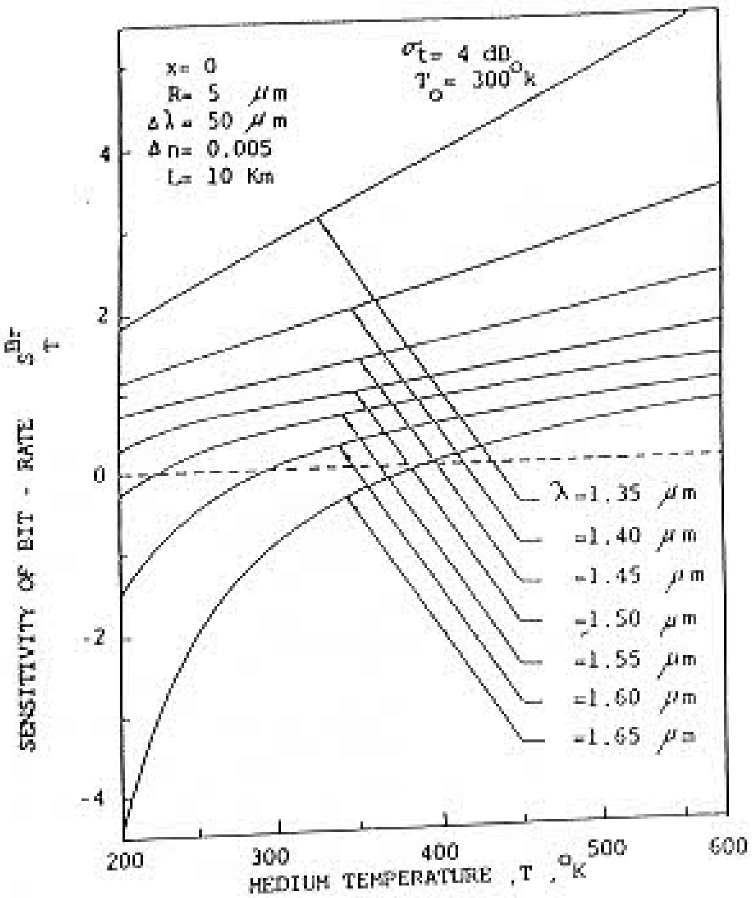

Fig .9 Variations of S_T^{Br} against variations of T at different value of λ and assumed set of parameters.

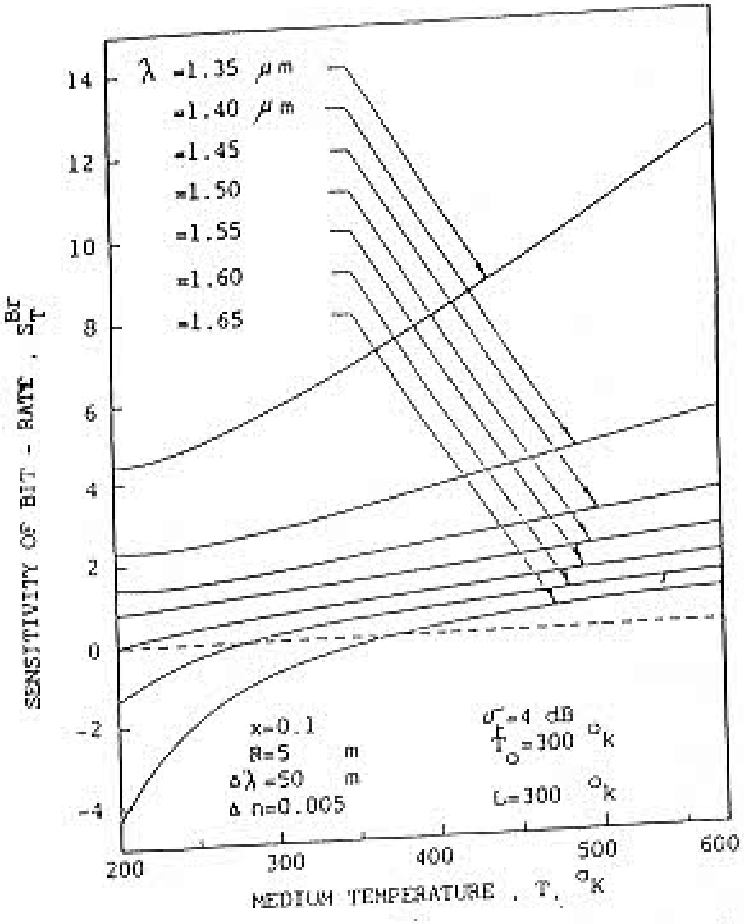

Fig 10. Variations S_T^{Br} against variations of T at different value of λ and assumed set of parameters.

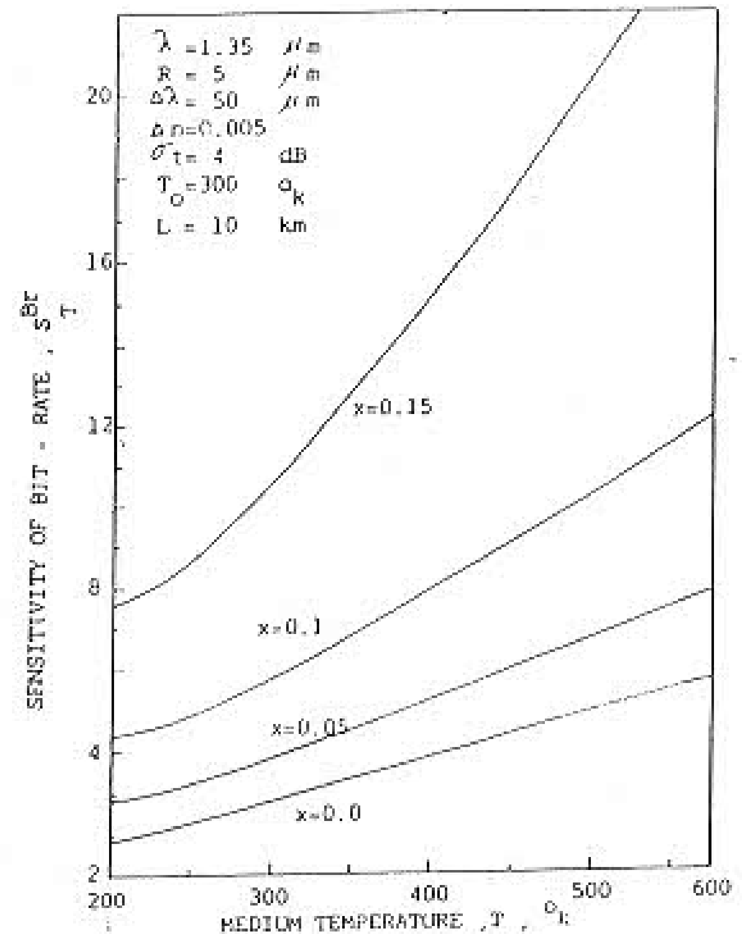

Fig .11 Variations of S_T^{Br} against variations of T at different value of x and assumed parameters

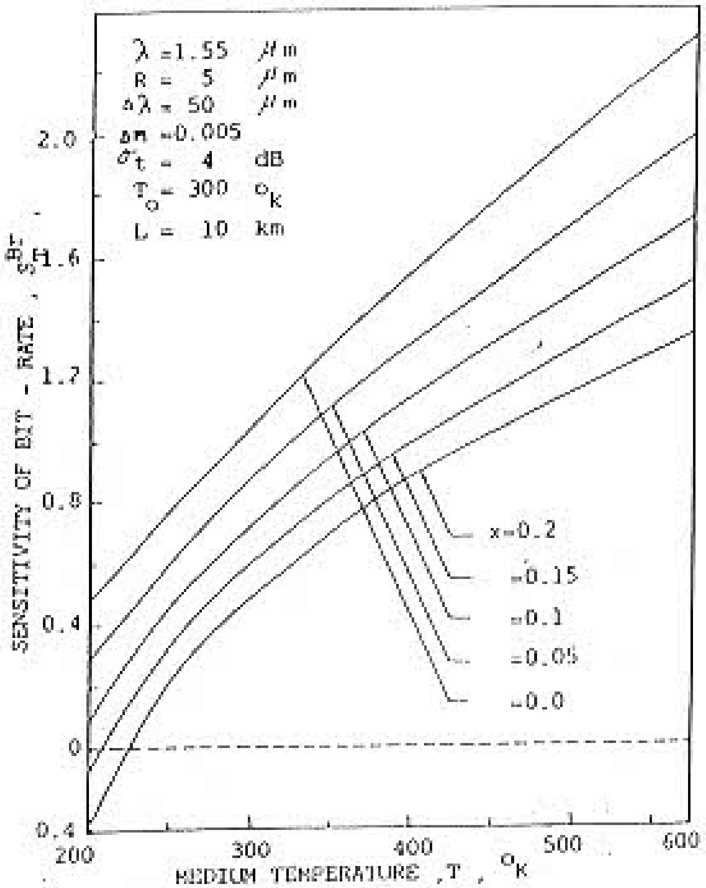

Fig .12 Variations of S_T^{Br} against variations of T at different value of x and assumed parameters.

considerable effect on the system capacity and introduces a thermal penalty controlled via the variables: The germania percentage and the operating wavelength. There is an operating optical wavelength at which the thermal sensitivity vanishes. Such wavelength is a function of the variables: The medium temperature and germania percentage. The obtained results assure the impact of employing hard thermal resistive jaket to reduce what is called thermal penalty.

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