LETTERS

Optical Analogue Transmission of Multiple TV Channels in Single -Fiber Optical Communication Systems

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SUMMARY An investigation is made of the performance characteristics of frequency-division multiplexed transmission of TV signals using both electronic and optical power combining. Intensity-modulated light sources and avalanche photodiode detectors with optimized gains are considered. The allowable transmission loss, inter-repeater spacing and total transmission distance are investigated. Optical combining becomes more advantageous as the number of transmitted channels is increased. This technique might allow the use of optical analogue IM transmission in trunk line applications.

1. Introduction

Multiplexing schemes are employed to utilize the large bandwidth of modern optical waveguides. In the conventional technique, electrical signals are electronically combined to form a composite signal which modulates a light source whose output power is then launched into the fiber for transmission. In another modern technique, each electrical signal modulates a light source and the individual light sources are then optically combined for transmission [1],[2]. In the present work, we investigate the performance characteristics of frequency-division multiplexed transmission of TV signals using both electronic and optical power combining. Intensity-modulated light sources and avalanche photodiode detectors (APD) with optimized gains are considered.

2. Analysis

Assuming that the light incident on the APD is intensity-modulated by a composite signal which is the sum of n statistically similar signals, the S/N ratio at the post-detection amplifier input is given by [2],

$$\frac{S}{N}=\frac{\frac{1}{2}\left[\frac{\eta q}{h\nu}m\;P_R\right]^2}{\left(\frac{2\eta q^2}{h\nu}P_R+2qI_D\right)G^{x-2}B_n+\frac{4KT_N}{G^2R_L}B_n} \quad (1)$$

where ν is the optical frequency, G is the APD gain factor, m is the modulation factor for each signal, I_D is the dark current, P_R is the optical power incident on APD, B_n is the noise bandwidth, T_N is the receiver noise temperature, R_L is the load resistance and $x=2.5$ for silicon diodes [3],[4].

Equation (1) shows that G can be readily adjusted to optimize the S/N ratio. The optimum gain G_{OPT} can be readily shown to be given by the following expression,

$$G_{opt}=\left[\frac{8KT_N}{R_L(x-2)\left(\frac{2\eta q^2}{h\nu}P_R+2qI_D\right)}\right]^{\frac{1}{x}} \quad (2)$$

G_{opt} that gives the desired S/N ratio at minimum P_R will be considered as the optimum value. The corresponding S/N ratio is obtained by substituting Eq. (2) into Eq. (1),

$$\frac{S}{N}=\frac{0.6\,am^2}{C_1^{0.2}}\left[\frac{P_R^{2.5}}{bP_R+C_2}\right]^{0.8} \quad (3)$$

where $a=\frac{1}{2}\left(\frac{\eta q}{h\nu}\right)^2$, $b=\frac{2\eta q^2}{h\nu}B_n$

$C_1=\frac{4KT_NB_n}{R_L}$, $C_2=2qI_DB_n$

The minimum received power P_{RO} required to maintain a given S/N ratio is then readily derived from Eq. (3) and is obtained by solving the following nonlinear equation,

$$P_{RO}^{2.5}=Mb\;P_{RO}+C_2M \quad (4)$$

where $M=\left(1.65\frac{S}{N}\frac{C_1^{0.2}}{2}\right)^{1.25}$, $m=m_{max}/n$ and m_{max} is the maximum allowable modulation factor of the composite signal.

Using electronic combining, the maximum allowable transmission loss (in dB) is given by,

$$L=-10\log(P_{RO}/P_I) \quad (5)$$

where P_I is the average power launched into the fiber. Loss associated with couplers and splices is neglected. For optical combining, P_I is given by [2],

$$P_I=nP_{IO}10^{-\beta_n/10} \quad (6)$$

where P_{IO} is the average power delivered to the optical combiner by a single light source and β_n in the insertion loss in dB per channel due to the optical combiner. In the present work, use will be made of the following empirical expression for β_n [2],

$$\beta_n\simeq(n-1)\beta_2 \quad (7)$$

If repeaters are used to extend the transmission distance, we have the relation [5],

$$\left(\frac{S}{N}\right),\ \text{dB}=\left(\frac{S}{N_T}\right),\ \text{dB}+10\log n' \quad (8)$$

where S is the signal power received after passing through n' -1 repeaters, N_T is the total noise power and N is the noise power generated in a single repeater. Here it is assumed that all repeaters have transmission and detection circuitry which are identical to those of source and receiver.

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57-53 [L-14]

3. Computed Results

The following parameter values are used in the present work, $R_L = 100\ K\Omega$, $I_D = 1$ nA, $\eta = 0.5$, $B_n = 4.2$ MHz, Noise figure $NF = 7$ dB, $m_{max} = 0.8$ and $\nu = 3.53 \times 10^{14}$ Hz. For high quality transmission, a S/N ratio of 54 dB is assumed. The following parameters are then readily computed, $a = 0.059$, $b = 0.46 \times 10^{-12}$, $C_1 = 2.8 \times 10^{-18}$, $C_2 = 1.34 \times 10^{-21}$ and $M = 2.6 \times 10^4 n^{2.5}$. The minimum received power P_{RO} is calculated by solving Eq. (4) for different numbers of channels. The maximum allowable loss is then calculated using Eq. (5)—(7). An approximate value of 0.3 dB was assumed for β_2 [2]. The maximum allowable transmission loss is shown in Fig. 1 as a function of the number of TV channels that are transmitted, no repeaters are assumed. It is noticed that the decrease of loss for the multiple light source case is more gradual than that for the single light source case. For $n = 10$ channels and $P_{IO} = 10$ mW, the maximum transmission loss is 23 dB for the multiple light source case, this compares to 16 dB for the single light source case. Systems for optical analog IM transmission of 10 TV channels using multiple sources therefore appear to be practical for distances longer than 11 km (a fiber loss of 2 dB/km is assumed), this compares to about 8 km for the single light source case.

If repeaters are to be used, the separation distance between repeaters as function of their number is calculated by assuming a given number of repeaters which is then used to calculate the S/N ratio at each repeater using Eq. (8). The result is then used to calculate the factor M and consequently P_{RO} as given by Eq. (4). Then the repeater separation and total transmission distances can be readily calculated for a given optical fiber. A S/N_T ratio of 40 dB is assumed[5]. The procedure is repeated for electronic and optical power combining. Table 1 lists the separation distance d and total transmission distance D in km for the case of 10

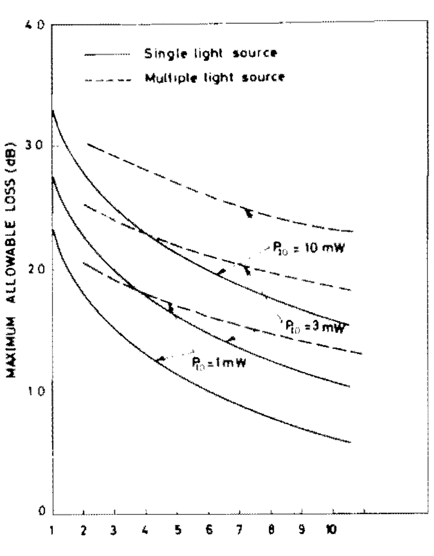

Fig. 1 Maximum allowable loss versus number of channels.

Table 1 Interrepeater spacings and transmission distances (10 repeaters).

n	2	4	10
	P_{IO} =	1 mW	
d (km)	10.4 (11.8)	7.9 (10.5)	4.6 (8.2)
D (km)	114.1 (129.1)	87.1 (115.1)	50.3 (90.4)
	P_{IO} =	10 mW	
d (km)	15.4 (16.8)	12.9 (15.5)	9.6 (13.2)
D (km)	169.1 (184.1)	142.1 (170.1)	105.1 (145.1)

repeaters, 2, 4 & 10 TV channels are considered. Numbers between parentheses are those for the optical power combining. It is noticed that as the number of transmitted signals is increased, optical combining becomes more advantageous over electronic combining regarding the separation and total distances. These distances are clearly decreased as the number of transmitted channels is increased. Using 10 mW light sources, 10 TV channels can be transmitted by optical power combining for 145 km using 10 repeaters which are 13.2 km apart. This is to be compared with a transmission for only 105 km using the same number of repeaters which are separated by 9.6 km, if electronic power combining is used instead.

4. Conclusions

The presented results show that for optical analogue IM transmission of multiple TV channels in an RF subcarrier FDM scheme, use of multiple light sources with an optical power combiner is advantageous compared to the use of a single light source and electronic power combiner, provided the loss introduced by the optical combiner is small. For a given number of repeaters, a larger allowable loss, a larger interrepeater spacing and total transmission distance are achieved using optical combining. As the number of transmitted channels is increased, optical power combining becomes more advantageous. The above considerations might allow the use of optical analogue IM transmission with multiple light sources in trunk line applications. Experimental verification is needed before practical systems can be implemented.

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