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ATMOSPHERIC OPTICAL COMMUNICATIONS

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Abstract

This article contains a description of a digital atmospheric optical link (DAOL). DAOL may find LAN applications as bridger between buildings containing cable subnetworks or as temporary quick-connects for which cable runs are initially unavailable.

Keywords:
optical communications - space applications; atmospheric optical links; atmospheric optical network.

1. Introduction

The development in the social, economic and scientific spheres requires the progress of telecommunication networks, especially, computer networks (e.g. LANs). There is a packet communication with certain requirements concerning the bit rate, path length range and bit-error-ratio (BER) among the computers in the LANs. There are telecommunication networks built up that are used for information transmission or new connections are being built up, especially fiber-optic connections.

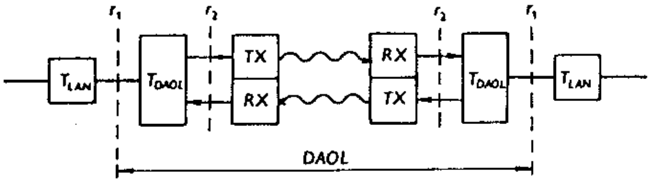

Fig.1.
Digital atmospheric optical link basic block scheme and its connection in the LAN.
(T_{LAN}, T_{DAOL} - terminals of the LAN and DAOL; r_1 - DAOL/LAN interface; r_2 - DAOL internal interface; TX - transmitting system; RX - receiving system.)

However, the present telecommunication networks are frequently insufficient (slow) for the use of computer communication and building fiber-optic links is inefficient or impossible. It such case it would be very acceptable to fill the communication network with a digital atmospheric optical link (DAOL) the basic block scheme of which is shown on Fig.1.

2. Optical, Mechano-Optical Design, Electro-Optical Design and Modulation

For the test of the DAOL function there was a simplex link assembled working with a direct intensive modulation and a direct detection. A digital signal is transmitted in such way that the logic "one" is identical with the optical source "switch on" and the logic "zero" is identical with the optical source "switch off". Then the optical signal is controlled with so-called "on-off" keying.

The source of optical power (OS) and transmitter antenna (TXA) are a part of the precise mechanical assembly with an optical cross staff and an azimuth/elevation control. The receiver antenna (RXA) with photodiode (PD) is similarly constructed.

The optical source can be LED (light emitting diode) or LD (laser diode). During the experimental test of the DAOL function the LED (λ= 840 nm) was used with the radiance I_{LED} = 6,4 mW/sr, 3-dB beamwidth φ_{OS} = 0,942 rad and the diameter of circular radiating area d_{OS} = 0,15 mm. The TXA has parameters: f_T = 118 mm and D_T = 30 mm. For β and φ_T angle (see Fig.2-a) results: β = 0,249 rad, φ_T = 1,3 mrad. The mentioned quantities have a substantial influence on the radiance intensity in the level of a receiving aperture.

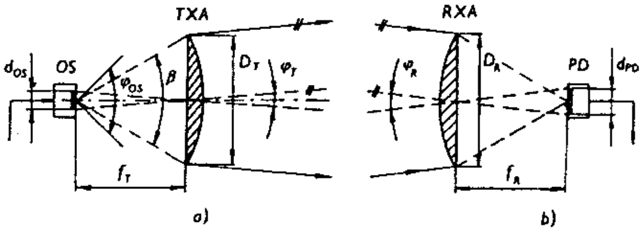

Fig.2.
Transmitter antenna (a) and receiver antenna (b).

The photodiode can be of the PIN type or the APD type (avalanche photodiode). The PIN photodiode was used with the responsivity S_I = 0,4 A/W (λ = 840 nm), the diameter of circular sensitive surface d_{PD} = 1mm and the noise equivalent power $NEP_1 = 0{,}7$ pW.Hz$^{-1/2}$. The RXA has the same parameters as the TXA, then $f_R = 118$ mm and $D_R = 30$ mm. For the RXA field of view (see Fig.2-b) results $\varphi_R = 8{,}5$ mrad. The above mantioned RX parameters have an influence on the level of the received optical power, on the receiver sensitivity threshold and on the received background power limitation. (Interference filter was not used.)

3. The DAOL range and BER

It is suitable for an expression of the received optical power to start from the model that is shown on Fig.3. [1].

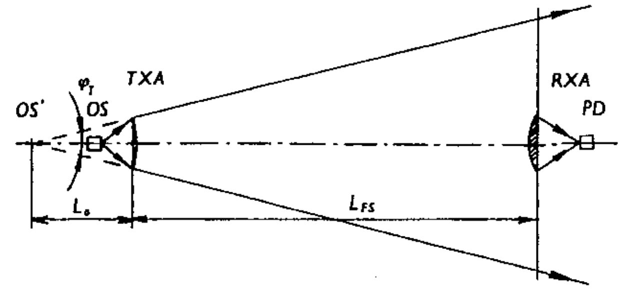

Fig.3.
The DAOL model for a power budget.

OS' is a virtual optical source with a real source radiance located in the point of the intersection of a beam axis with extended lines determinating beamwidth. The subsidiary length $L_O = D_T f_T / d_{OS} = 23{,}6$ m. As illustrated by Fig.3, the subsidiary length L_O locates the position of a virtual source OS' from which a virtual cone of radiation with an apex angle φ_T is issued to replace the real sources in far-field range calculations. Let us select the path length range (DAOL range) with regard to possible applications: $L_{FS} = 200$ m. The review of a power budget of the DAOL system is listed in Tab.1.

Parameter	Notes	Value
LED *optical power*	$10\log(0.25\pi\varphi_{OS}^2 I_{LED})$	7 dBm (5 mW)
LED-TXA *loss*	$20\log(\beta/\varphi_{OS})$	-11,6 dB
TXA *attenuation*	$10\log(\phi_2/\phi_1)$	-0,5 dB
Free-space loss	$20\log[L_O/(L_O+L_{FS})]$	-19,7 dB
RXA *attenuation*	$10\log(\phi_2/\phi_1)$	-0,5 dB
PIN *received optical power*	sum of previous numerical values	-25,3 dBm (3 μW)

Tab.1.
The DAOL power budget. ($L_{FS} = 200$ m; ϕ_2, respectively ϕ_1 are optical powers on output, resp. input of optical systems TXA and RXA; $D_T = D_R$; the atmosphere effects are excluded.)

In order to consider the level of the received optical power on PIN it is necessary to express the receiver sensitivity threshold $\phi_{P,min}$ and the carrier to noise ratio *(C/N)*. The receiver sensitivity threshold is expressed with the equation $\phi_{P,min} = NEP.B^{1/2}$, where NEP is noise equivalent power of the receiving system (RS) that relates to the unit bandwidth and B is a bandwidth. The receiving system parameters are: $NEP = 6{,}7$ pW.Hz$^{-1/2}$ ($\lambda = 840$ nm) and $B = 20$ MHz. The receiver sensitivity threshold results $\phi_{P,min} = 30$ nW (-45,3 dBm).

We designate the carrier to noise ratio *(C/N)* by means of the diagram which is shown on Fig.4 [2].

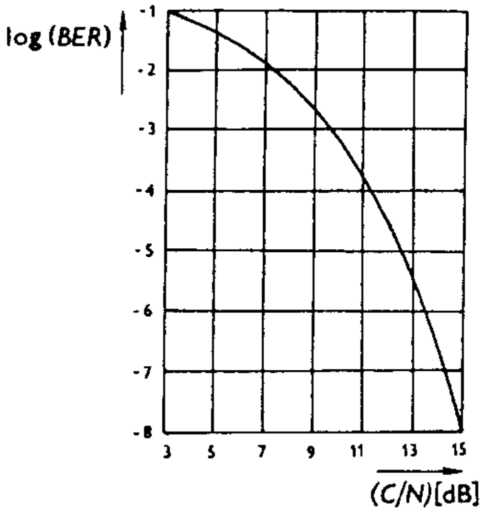

Fig.4.
BER versus (*C/N*) for "on-off" keying.

According to CCIR REC 614 recommendation the *BER* for a digital links shall be not greater than 10^{-6} for at least 98% of any month. For $BER = 10^{-6}$ we get $(C/N) = 13{,}5$ dB from Fig.4 diagram.

After finishing the power budget results a link margin (atmospheric effects are excluded):

PIN *received optical power* - ($\phi_{P,min}$ + *C/N*) = 6,5 dB

4. The Atmospheric Effects

The atmosphere influence on the DAOL activity consists in its pollution (gasses/aerosols attenuation) and turbulence (wind influence and local temperature non-homogenity) [3]. The gasses/aerosols attenuation is described with the $\alpha_{1,ext}$ [dB/km] (atmosphere attenuation coefficient) and strength of the turbulence of the atmosphere is described with C_n^2 [m$^{-2/3}$] (structure parameter of the refractive index).

The review of approximate values of α_{ext} ($\alpha_{ext} = \alpha_{1,ext}.L_{FS}$; $L_{FS} = 200$ m) as a function of the strength of atmospheric pollution (atmospheric turbulence is excluded) is shown on Tab.2.

The review of approximate values of α_{turb} [dB] (attenuation caused by the atmospheric turbulence) as a function of the strength of turbulence is shown on Tab.3. (atmospheric pollution is excluded).

Strength of atmospheric pollution	Visibility	$\alpha_{1,ext}$	α_{ext}
	[km]	[dB/km]	[dB]
Extremely clean	200	-0,07	-0,01
Clean	20	-0,74	-0,15
Haze	2	-7,35	-1,47
Dense fog	0,2	-73,5	-14,7

Tab.2.

Approximate values of α_{ext} ($\lambda = 840$ nm, $L_{FS} = 200$ m) as a function of the strength of atmospheric pollution.

Strength of turbulence	C_n^2 [$m^{-2/3}$]	α_{turb} [dB]
Weak	$6{,}4.10^{-17}$	-0,1
Medium	$1{,}6.10^{-15}$	-0,5
Strong	$2{,}5.10^{-13}$	-7,5

Tab.3.

Approximate values of α_{turb} ($\lambda = 840$ nm, $L_{FS} = 200$ m) as a function of the strength of turbulence.

The experimental test of the DAOL function passed under the conditions of a pure, medium turbulent atmosphere and total atmospheric attenuation ($\alpha_{ext} + \alpha_{turb}$) did not exceed the expected value during the measuring.

5. Conclusion

The strong dependence of connection quality parameters on the weather state is usually introduced with DAOLs, but at the same time, it is stated in a number of publications that their real possibilities are not fully appreciated (e.g. [1]). The dependence on the weather of the DAOLs was substantially reduced with a digital transmission and a special coding technique. The fall of a connection quality under the admissible level comes only under the extreme atmospheric conditions (strong rain, dense snowing etc.). The limited usability of atmospheric optical links has its analogy in the limited serviceability of air-lines: in spite of their dependence on weather conditions they are supposed to be developed and not to be cancelled. With a statistic evaluation of the DAOL usability - considering the atmosphere influence - we get acceptable results, with regard to their use in LAN systems.

6. References

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About author, ...

Otakar Wilfert was born in Česká Třebová, Czech Republic, in 1944. He received the M.E. degree in electrotechnical engineering and the Ph.D. degree in aplied physics, both from Military Academy of Brno, Czech Republic, in 1971 and 1984, respectively. He is currently the Associate professor in the Department of Radioelectronics at the Technical University of Brno. Mr. Wilfert is a member of Czech Photonics Society. Research and pedagogical interests: optoelectronics, optical communication, atmospheric optical links.