REALIZATION OF ATMOSHERIC FREE-SPACE OPTICAL INFORMATION CHANNEL WITH UPRATED NOISE REDUCTION

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Abstract

Different methods of recovering a demodulated polarization modulation signal from atmospheric modulation noise are discussed. Negligible depolarization effects engendered by atmospheric propagation are used to advantage such that optical polarization modulation can be employed in transmission of information without serious interference by atmospheric modulation noise. Beam steering or beam deflection, beam spread, fluctuations in beam arrival angle, and beam scintillation contribute to atmospheric modulation noise impairing the performance of optical heterodyne receivers and throwing laser beams off target. The dual-path signal processing scheme minimizes these effects.

Keywords: atmospherics, light modulation, noise reduction, optical communication, optical polarization, signal processing, atmospheric optics, optical depolarization, optical heterodyning, photodiodes, transmission efficiency

I. FSO CHANNELS

The atmospheric free-space channel is a natural medium for outdoor optical wireless communication and has generated significant research attention in the past 10 years as a complement to radio-frequency (RF) links. The free space optical (FSO) atmospheric channel has a wide bandwidth and may support many more users than an RF channel. Most optical wireless links are based on intensity modulation with direct detection, the same technique that is used for state of the art fiber-optics communications. The availability of the optical components used in fiber optics makes outdoor optical links a cost-effective solution for high-rate voice and data communications. Communication in a FSO channel is achieved by a point-to-point connection of two optical transceivers in line of sight. An optical wave propagating through the air experiences random variations in phase and amplitude due to the effects of turbulence. This turbulence is caused by fluctuations in the refractive index of the medium as the latter experiences temperature gradients due to solar heating and wind.

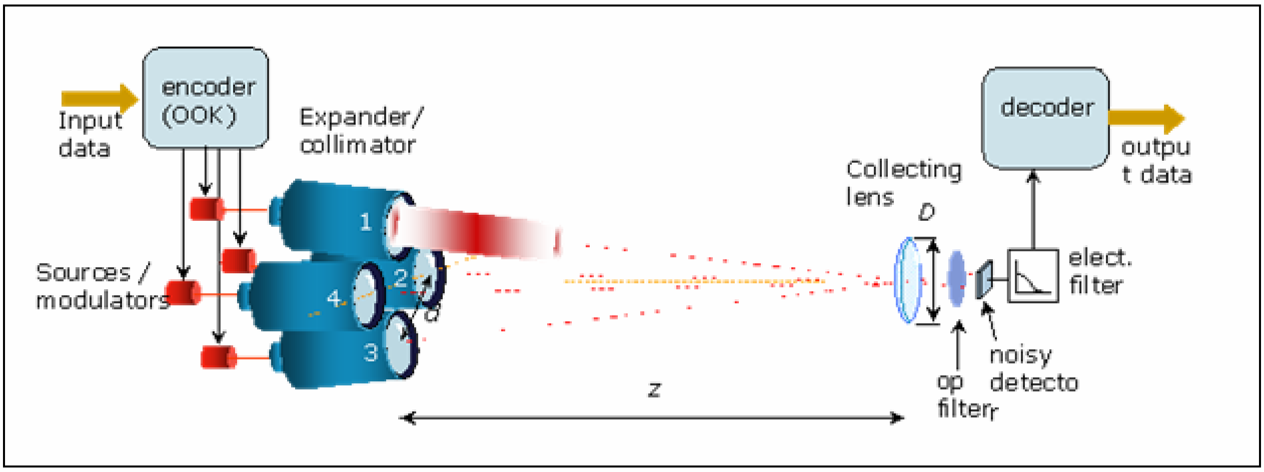

Fig. 1. Modulation and Coding for Optical Atmospheric Turbulent Channels

II. INTRODUCTION

A basic point-to-point FSO system, shown in figure 2 below, consists of transmitter, propagation path and receiver (the signaling is an ON–OFF keying (OOK), and a point detector is used). The typical optical transmitter involves a light source, the semiconductor laser of high launch power and wide bandwidth, and a telescope assembly designed using either lenses or a parabolic mirror. A low-density parity check (LDPC) encoded electrical stream carrying the network traffic modulates the light source beam. The modulated beam is then amplified and projected toward the receiver. On the receiver side, the receiver telescope compresses the modulated light signal, and the optical detector coverts it back into an electrical signal. The receiver commonly employs the trans-impedance design, a good compromise between the noise and bandwidth. A pre-amplified PIN photodiode or an avalanche photodiode are typically employed as optical detectors. During propagation, the modulated beam experience amplitude and phase variations coming from scattering, refraction caused by atmospheric turbulence, absorption, physical obstructions and building sway. The receiver electronics introduce noise, making the detection of the binary data subject to errors. After the photo-detection, the electrical signal is sampled and fed to an iterative LDPC decoder

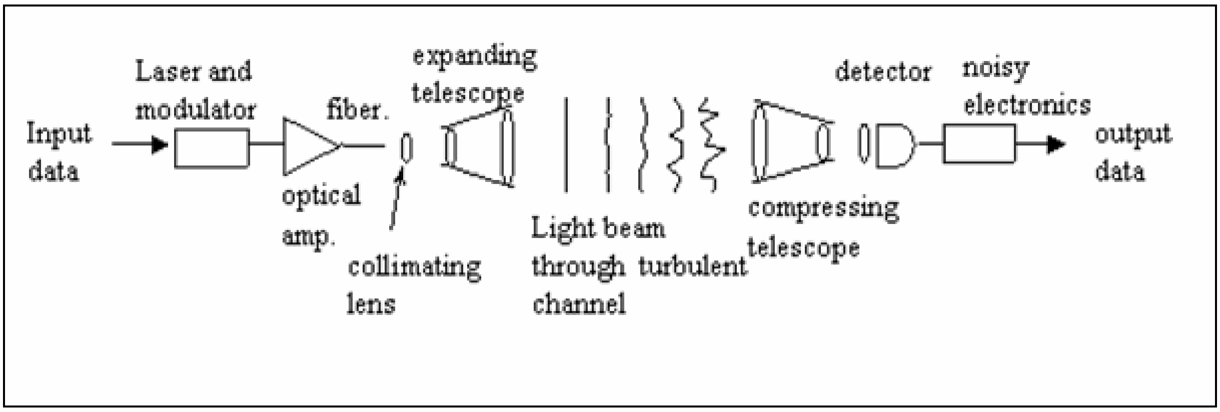

Fig.2. Point-to-point FSO system

III. NOISE REDUCTION IN FSO CHANNEL USING POLARIZATION MODULATION

Fluctuation of intensity of laser emission in the atmosphere leads distortion of amplitude modulated signal which is the simplest method of modulation. In order to compensate fluctuation of amplitude, it is necessary to developed FSO in which the level of multiplex noise is reduced through signal processing at the receiver. In this case polarization modulation is used since turbine does not depolarize optical wave.

Fig.3. Below shows a functional diagram of FSO with polarization modulation.

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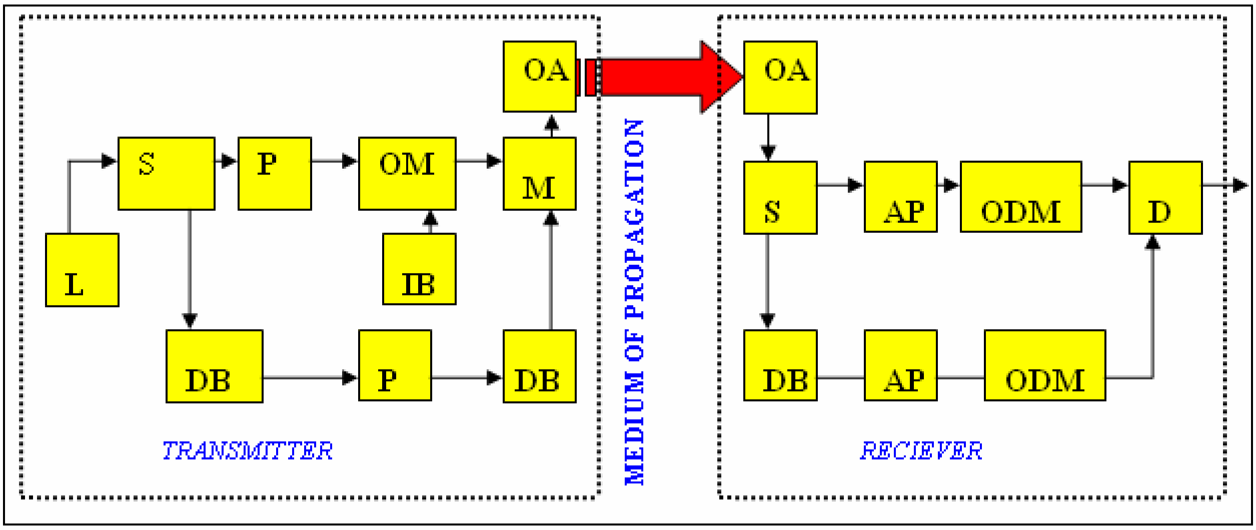

Fig.3. FSO channel with polarization modulation

Non-polarized laser ray **L** splits into two at the splinter **S**. The first ray goes through the polarizer **P**, optical modulator **OM**, where it is being modulated according to the information signal from Information Block **IB** and then to the multiplier **M.**

The second ray directs to the deflection block **DB** and then to the polarizer **P**, which polarize it orthogonal to the first ray. After which to the deflection block **DB** again and then to the multiplier where the two rays multiplies and then emitted together through the optical antenna **OA**.

The receiver on the other side receives atmospheric ray which is composed of information signal $S(t)$ and multiplex noise $N_M(t)$ at the optical antenna **OA** . The noise modulated signal then proceed to the splinter **S** where it is split into two. After which the first ray goes through the directed polarization analyzer **AP** and then to the optical demodulator **ODM**, where $S(t)N_M(t)$ signal is separated. It further goes to the first input of the ray divider **D** which divides $S(t)N_M(t)$ with $N_M(t)$ and then separate information signal $S(t)$.

The main disadvantage of this system through its analysis shows that it has low noise reduction.

IV. FSO CHANNEL WITH SUPPRESSED MULTIPLEX AND ADDITIVE NOISE

It is necessary to have FSO system which suppresses not only multiplex noise but also additive noise. Additive noise can be suppressed by introducing a second **OA** at the receiver near to the first **OA** show on fig. 1 above. The second **OA** has to be completely identical to the first **OA** in all parameters but it is put in such away that information signal does do enter into its directional pattern. Taking into account that additive noise in FSO is induced mainly by emission scattering from different non-localized at the source space (background emission), we can assume that additive noise $N_A(t)$ at input of both **OA** is the same.

The laser ray that propagates through the atmosphere undergo modulation of information signal $S(t)$ and multiplex noise $N_M(t)$**,** then together with additive noise $N_A(t)$ proceed to the first **OA** and the splitter, where it is dived into two rays.

The demodulator after the directed polarization analyzer, isolate signal of this form

$$U(t)=S(t)\,N_M(t)+N_A(t), \qquad (4.1)$$

which then proceed to the first adder device.

The second ray, which has orthogonal polarization to the first ray, is isolate at the second polarization analyzer hence the output signal of the second demodulator will be the sum of noise since information signal was not received at the second antenna.

$$V(t)=N_M(t)+N_A(t) \qquad (4.2)$$

This sum of noise eventually proceeds to the second adder.

Along the circuit of the second **OA** include demodulator which isolate additive noise $N_A(t)$, phase shifter which shift its phase by 180° and ramose which feeds both adders in the main circuit with electrical signal equivalent to $N_A(t)$.

The result is that the output of the first adder is

$$U_1(t)=S(t)\,N_M(t). \qquad (4.3)$$

And the output of the second adder is

$$U_2(t)=N_M(t). \qquad (4.4)$$

Then both signals $U_1(t)$ and $U_2(t)$ are feed to the signal divider, where $U_1(t)$ is dived by $U_2(t)$ hence multiplex noise is also suppressed.

V. NOISE REDUCTION IN FSO USING SPACE DIVISION CHANNEL

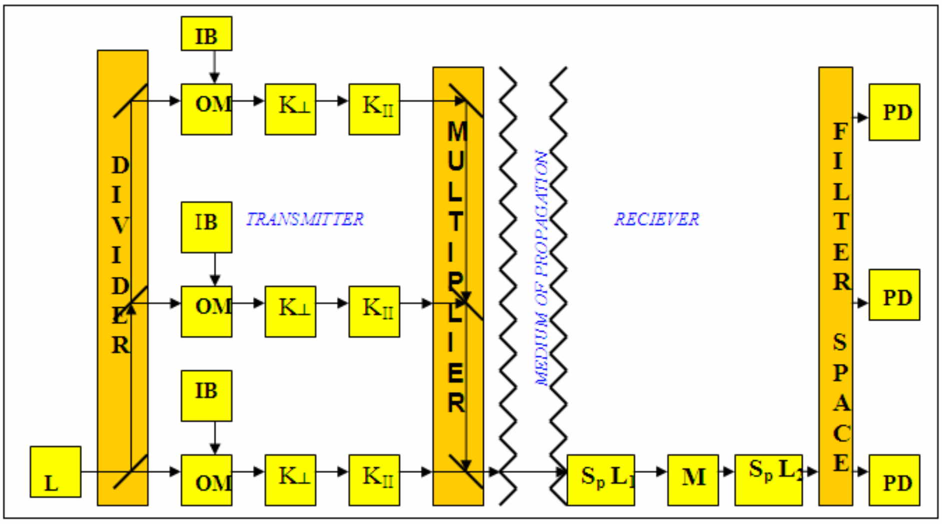

Fig.4. FSO using space division channel

Multiplex noise of atmospheric turbine brings about transfer of noise between different channels of FSO. Space division channel can be used in FSO as shown in fig. 3 so as reduce this effect.

Its main feature is that it has two mutually perpendicularly connected optical space coder which phase-modulate the information signal from the source. The transmission factors of the two coders are orthogonal function.

The laser ray is divided into **N** rays according to the number of channels. Every ray then goes through modulator **OM**, where information signal from the source **S** is modulated and then through the two space coders $K_{\perp}$ and K_{II}, which are mutually perpendicularly connected. Phase modulation is done by a given law on the space along the ***X*** and ***Y*** coordinates respectively. After that the rays are combined by the multiplier and then the general ray is emitted to the atmosphere.

The ray in the receiver device undergoes double Fourier transformation which is performed by the spherical laser **S$_p$L**, according to Fourier-spectra at the focus of the given plane lens. Matrix **M** is a double space matched holographic filter. The entire filters matrixes are written on a single hologram at two different incident angles of reference ray.

Transmission factor of each of the filter matrix takes the form as:

$$K_i(w_x, w_y) = C\frac{T_i^*(w_x)T_i^*(w_y)}{W(w_x, w_y)}, \tag{4.1}$$

where $T_i^*(w_x), T_i^*(w_y)$ – complex space spectra which is the multiple of transmission factor of coders $K_{\perp}$ and K_{II}; $W(w_x\ w_y)$ – spectra space of power spectral density of noise; ***X*** and ***Y*** – instant coordinate; ***C*** –constant.

Filter with such a transmission factor matching the i-th coder $K_{\perp}$ and K_{II} theoretically has maximum signal to noise ratio (**SNR**).

After matrix **M** the overall ray received is divided into **N** rays with deviation angle from optical axis equivalent to different angles φ_i of reference ray in recording filter. More so every single ray forms a channel and these channels are separated in that manner due to use of matching filter, this means that transmission noise between the channels has a limited theoretical minimum level.

Then the spherical lens **SpL** performs inverse Fourier transformation on the filtered **N** rays, and the result is that light dots are formed on the focus plane which is at the rear/ back focus.

These light dots are the different channels and present realization of two space function of mutual correlation between joint function of transmission factor of coders $K_{\perp}$ and K_{II} and the transmission factor of different i-th channel of matching space holographic filter from the matrix. These channels are later separated by filter space and the rays are received at the photodiode **PD** along these channels.

VI. NOISE REDUCTION IN FSO USING ADAPTIVE METHOD

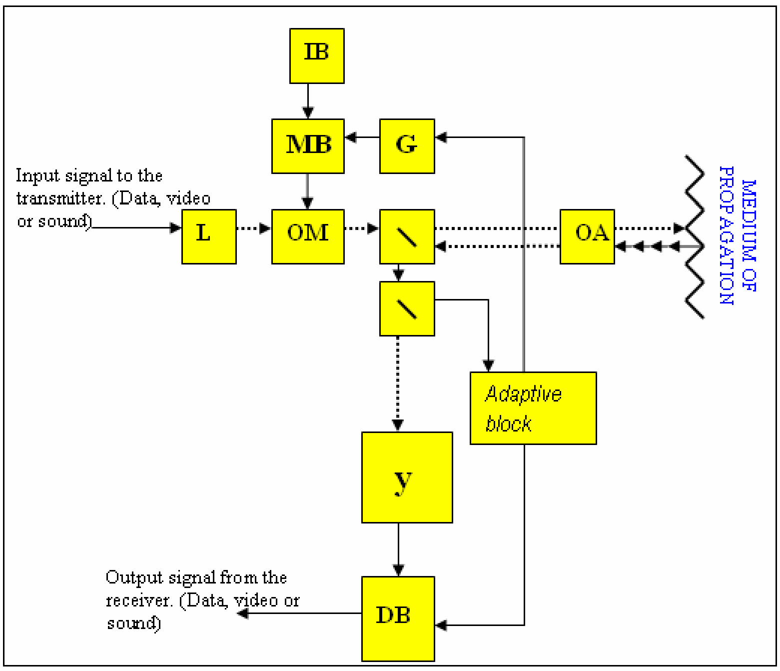

Fig. 5. Receiver- transmitter block

Adaptive method is necessary in order to up-rate noise reduction in FSO. This kind of method is often used in transmission of discrete or digital information. Fig. 5 shows duplex optical communication system.

This system consists of two identical receiver-transmitters. The main elements include:

- Optical modulator **OM** which modulate laser ray according to the information signal from the memory unit **MU**. This is to ensure that modulation frequency does not depend on the frequency of discrete signal from the source. Frequency modulation depends on the type of frequency generator **G**, which gives the frequency at which information from memory unit is read
- Decisive block **DB** in the receiver makes decision according to a given optimal criterion on its registered pulses. The signal from adaptive block also proceed to this same decisive block as shown on fig. 6

How the adaptive block works.

Fig.6. aside shows components of adaptive block. Part of the energy received from laser emission proceeds to the autocorrelator **AC**, where autocorrelation phase (or amplitude) space function **B(ρ)** of optical field at the receivers aperture is measured. Then the signal equivalent to **B(ρ)** proceeds to signal transformer **ST**, where the function of spectral plane fluctuation of atmospheric refractive index is determined.

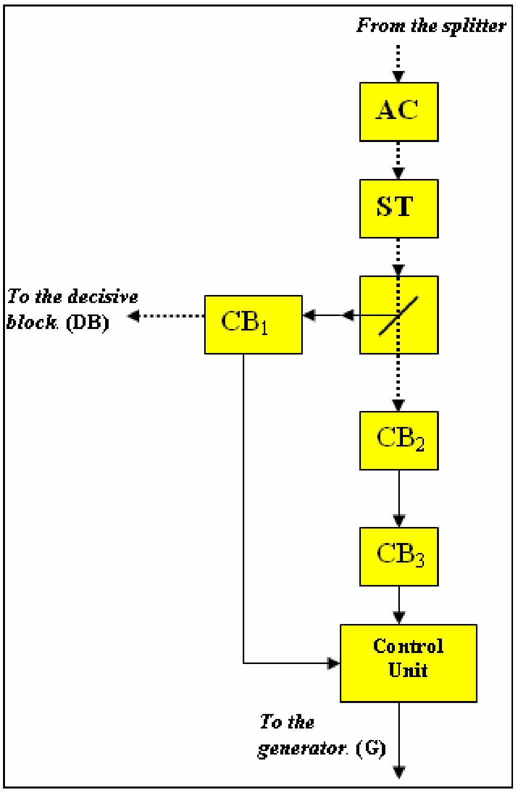

Fig.6. Components of adaptive block

After splitting at the splitter the signal proceed to the computing block **CB** where the mean intensity of the received laser emission is calculated which is feed to the computing block CB_1 and then also to the decisive block.

The other part of the spitted signal proceeds to the computing block CB_2 with its output equivalent to fourth order of coherent function $\mathbf{\Gamma_4}$ which in turn proceed to the computing block CB_3 where signal to noise ratio **SNR** of the receiver's output is calculated with the known coherent function $\mathbf{\Gamma_4}$ and mean intensity.

The calculation of **SNR** is the main work of adaptive block.

SNR then proceed to the control unit **CU** where control signal for tact frequency $\mathbf{f_T}$ is produced. Tact frequency is then feed to the control input of the generator **G**.

VII. CONCLUSION

Therefore, based on information about the condition of the medium of propagation which leads to continuous distortion of information signal in the process of duplex communication, the adaptive block generates signal which controls information transmission rate and threshold level of detection according to the measured parameters of medium of propagation of which in this case it is presented through the mean value of optical pole intensity at the receiver's antenna aperture and signal to noise ratio **SNR** at the input of the receiver.

Hence, adapter is used in the receiver for the threshold level detection, and also in the transmitter for information transmission rate, that is changing the base of transmitted signal. This makes adaptive method much more reliable than any other method discussed since the atmospheric condition keeps on changing and so it the receiver requires automatic adjustment in order to correct randomly distorted received signal.

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