Protected Multichannel Free Space Optics Communication System

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Abstract— **Protected Multichannel FSO communication system is described. FSO communication channel speckle distribution is considered. An Influence of both small and large size photodetectors is analyzed. Possibility to realize a protected channel of communication is presented. Sample of optical systems optimization is given. An Eyesafe wavelength optical band receiving module design is presented. Sensitivity and noise parameters are considered. Variable schematic decisions with different types of photodiodes are submitted. Technical solutions to optimize design are presented. Parameters of designed Photodetector module are given.**

Keywords-FSO system, FSO communication, Free Space Optics, APD, optical detection

I. INTRODUCTION

Nowadays free space optics (FSO) communication systems becomes more popular. Optical communication has several essential advantages comparing to classic data transferring through radio-channel. FSO communication does not require any resolution for wavelength range maintenance. Furthermore comparing with radio-band data transmission, optical transmission possesses significantly higher level of both noise immunity and communication security.

II. OPTICAL ARRANGEMENT OF THE FSO SYSTEM

One of essential problems during development of FSO system is coincidence of optical axes. Authors designed optical arrangement to solve the problem of triple optical axes coincidence. An architecture of the developed optical arrangement is presented at Fig. 1.

The main optical system represents a modification of the Hamilton system. The architecture design feature of described reflecting-refracting system is Mangin mirror using. Presented method allows to correct chromatism effectively without putting in the system heterogeneousness optical media. The system designed by authors involves quartz optical components only. Such decision allows to avoid an influence of thermo-optical aberrations. This method together with using of invar made structural elements gives a possibility to apply developed system at a wide temperature range. An obscuration value is around 25% of the area. Such decision allows effectively usage of obscured area to form an independent optical Subsystem inside. Same as the main system, the enclosed subsystem has a similar optical architecture. This system possessed the same level of an area obscuration, i.e. has 25% amount. Inside of the optical subsystem obscured part the third inner subsystem is located. The inner subsystem consists of three lenses. Media three- lenses system represents an objective with remanent chromatic aberration and intended to signal source collimation. Especial feature of all three described systems are diffraction image quality at the all possible FSO system operation wave range (from visible light to 1.5 μm). By means of chromatism special correction method application a focal plan displacement has not also happened for different wavelengths. This case the reflecting-refracting system relative aperture has ratio 1:3 and the ratio not be obligatory the same.

Parts of the optical system shown at. Fig.1. are following:

1 – receiving channel catadioptric lens;

2 – aiming and self-alignment channel catadioptric lens;

3 – transmitting channel lens objective.

Outer optical system is used to signal receiving. Enclosed reflecting-refracting system intended both to self-adjustment (aiming) of the FSO system communication channel and to observe an interception communication channel monitoring and thus to provide system hacking immunity. Simultaneously with the previous process at the real time mode a channel data transmission/receiving capacity has being analyzed and dynamic correction of both signal source and signal receiver is

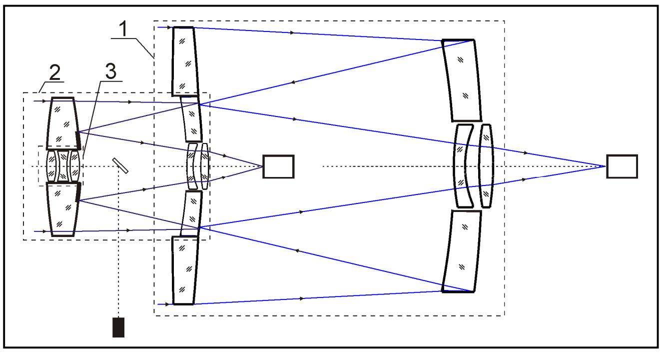

Figure 1. Architecture of FSO system optical arrangement

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happened. All three system objectives possesses essential fields of view, not deteriorated by aberrations. That kind of design allow to realize effectively a methodic of dynamic self-alignment for both transmitter and receiver at a wide operation range. This expands possibilities of communication channel operation at a wider range of a spatial angle. This feature is very important for application in outer space (astronautic) systems.

Using of three independent optical system gives a possibility to arrange geometry effectively together for a data transmission channel, data receiving channel and aiming channel. Simultaneously developed optical system architecture (embedded design) makes possible to create FSO system device with minimal possible size and weight parameters.

III. PHOTODETECTOR PROBLEM STATEMENT

One should design and optimize photodetector unit for FSO communication channel which could provide:

- eyesafe wavelength (1.54 μm) operation;
- possibility of operation at wide wavelength range from 0.8 to 1.7 μm (and using popular wavelength of 1.06 μm);
- switching between input wavelengths depends on external noise situation;
- as high as possible sensitivity level;
- as much as possible signal-to-noise ratio;
- depends on weather condition amplification adjustment;
- decision making circuit, which defines level of accepted signal.

Photodetector unit is intended to transfer input optical energy (from external space) into electrical signal on it's output. To design fast photodetector one can use either p-i-n-photodiode, or avalanche photodiode (APD) as an optoelectronic device. Other types of optical sensors like photoresistors, classical photodiodes, and pyrodetectors doesn't allow high speed operation. Photoelectronic multipliers significantly more intended for operation with radar systems and have some imperfections for example, bigger size, weight and high voltage supply requirements.

A. *Sensitivity of the System*

First problem of the system is a contradiction between bandwidth and sensitivity level of the module.

A simplified optical sensor circuit consists of photodiode (as a optical-to-electronic signal converter) and load resistor (as device, possessing either voltage or current containing information). This circuit bandwidth can be described by equation:

$$f = 1 / 2\pi RC \tag{1}$$

where C -- is photodiode capacitance,

R -- is resistance of the load.

Photodiode is current device, so it produced current for it's output. One should use resistor as a load (or using current-to-voltage converter circuit) to receive output voltage which can be handled by next stages.

Output voltage is defined by:

$$V_{OUT} = I_{PD} * R_{LOAD} \tag{2}$$

Generally to make signal band wider one should decrease resistance or capacitance value of the circuit. And it's necessary increase resistor value to improve sensitivity of the circuit. From one hand (bandwidth = data transmitting velocity) resistor should have low value. From the other hand to increase sensitivity (maximum operation distance) resistor should have high value. Thus we have a contradiction.

Classical solution of the problem (optimization value of the resistor) does not give an optimal result.

There are two circuits, which schematic can 'virtually' change parameters of the photodetector circuit. They are:

- transimpedance amplifier
- input capacity compensating amplifier.

Recent achievements in development of high speed operational amplifiers (OpAmp) allows choose one of schematic solutions mentioned above.

As current pin and avalanche photodiodes has small value of inner capacitance (units of picofarad) using of the transimpedance amplifier seems to be in preference.

B. *Using a Photodetector*

Photodetector is intended to transfer optical radiation power of the incident beam into electrical signal (current). The function of a photodetector is optical signal detection.

Output photocurrent can be described by following formula:

$$I_P = (q\eta\lambda / hc) E \tag{3}$$

where h – Planck constant

c – velocity of light

λ – wavelength

η – quantum efficiency of the detector

q -- charge of the electron

E -- optical radiation power.

Sensitivity of the photodetector can be defined by [ ]:

$$S = I_P / E = \eta q\lambda / hc \tag{4}$$

If one use an avalanche photodiode as a photodetector the inner multiplication rate M could be described by Miller's formula:

$$M = 1 / [1 - (V/V_{BR})^n] \quad (5)$$

Where n = 2…5

V_{BR} – avalanche breakdown voltage.

For typical values of the multiplication coefficient M=10…200 expression above can be simplified to:

$$M = V_{BR} / n (V_{BR} - V) \quad (6)$$

Typical Photodetector unit not limited by optical sensor only and consists of following parts:

a) Optical System, involving:

- Protective windows
- Immersion optics
- Optical Filters
- Diaphragms etc.

b) Optical sensor (photosensitive device)

c) Cooling system

d) Signal processing electronic modules (amplifiers, optimal filters, decision-making devices)

e) Auxiliary electronic modules

Sensitivity is one of main parameters of photodetector. Another parameter responsible for correct detection of input optical signal is noise level of the photodetector.

C. Signal-to-noise value consideration

The sensitivity of the Photodetector unit depends on inner noise of the electronic scheme components. Total noise of the

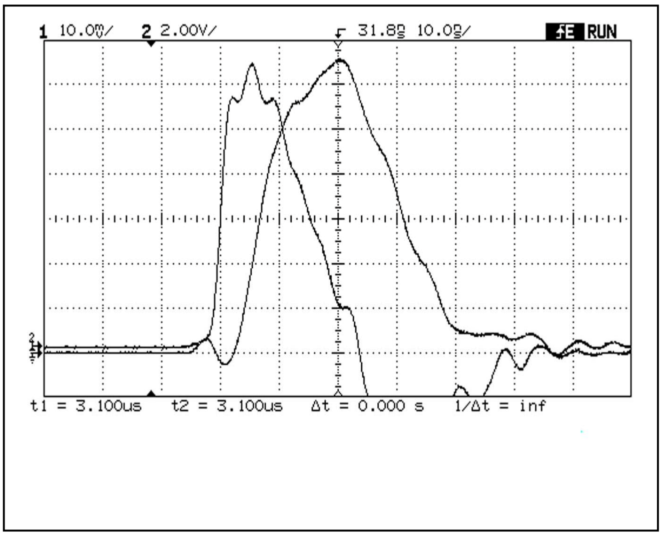

Figure 2. Current through Laser Diode and Simulator Output Optical Pulse.

device can be described by formula:

$$i_{n\Sigma} = (i_{nPD}^{\ 2} + i_{nAmp}^{\ 2})^{1/2} \quad (7)$$

where i_{nPD} -- noise current of Photodiode

i_{nAmp} -- noise current of Amplifier

When one use avalanche photodiode, the noise current can be calculated as:

$$i_{nAPD} = M\, i_{nPD} \quad (8)$$

where M – avalanche multiplication coefficient.

When transimpedance amplifier is used as part of the Photodetector, one could describe a noise current of the Amplifier stage as follow:

$$i_{nTIA} = (i_{nOPAMP}^{\ 2} + i_{nRT}^{\ 2})^{1/2} \quad (9)$$

where i_{nOPAMP} -- noise parameter of OPAMP used;

and noise of feedback resistor RT is:

$$i_{nRT} = (4kT\Delta f / R)^{1/2} \quad (10)$$

where k – Bolzmann constant,

T – absolute temperature (K)

R – value of the resistor (Ohms)

Δf – bandwidth (Hz).

Thus one can see that the sensitivity improvement question can be transferred into optimization of mutual noise values problem. Some noise components value depends on system bandwidth and other are independent. To reduce noise one should decrease input stage bandwidth. To raise the speed of data transferring increasing of the bandwidth is demandable. Thus we have a classical contradiction in our technical system which should be resolute by means of engineering optimization methods.

IV. PHOTODETECTOR MODULE DESIGN

Based on principles expounded above the photodetector unit was designed.

One of methods to find sensitivity level of the photodetector is to compare it with test device, possessed defined parameters. Based on laser diode and short current pulse generator simulator device was used as a signal source.

Parameters of Laser Diode current and Optical Power Output are shown at Fig.1.

Channel 1 presents Output Optical Pulse measured with Thorlabs 210 optical detector loaded at 50 Ohm input of Hewlett-Packard HP64325 Oscilloscope. Channel 2 demonstrates current flowing through emitting laser diode SFH495P at 890 nm wavelength.

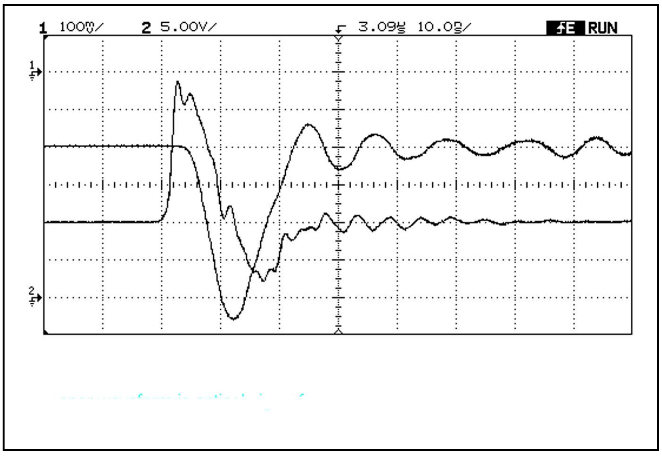

Figure 3. Current flowing through laser diode emitter and output voltage of Photodetector transimpedance stage

Timing characteristic of designed photodetector module is demonstrated at Fig.2.

One can suggest the damped harmonic motions after the falling edge of the Photodetector transimpedance stage output pulse demonstrates that operation of the amplifier occurs close to it's own frequency range limit.

V. Results

Based on principles described above a multiple wavelength Photodetector module was designed. Parameters of the device are following:

Sensitivity	better than 12 nW
Detector type	InGaAs APD, cooled
Operation wavelength	0.8 … 1.7 µm
Supply voltages	+12 V; -12 V; +180V
Gain sensitivity adjustment	±38dB
Output:	LVDS positive logic
Size	25 x 40 x 70 mm

VI. Conclusions

The improved architecture of free Space Optic System optical arrangement is developed using of modern design and optimization methods and procedures. Such architecture makes possible providing of a triple optical axes coincidence. Furthermore high sensitivity APD photodetector unit is designed. Parameters of designed photodetector module are given. The presented module optimized by using of inventive problem solving

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