Advanced Large Distance Optical Free-Space Link on the Infrared Diode in Nanosecond Pulsed Mode

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***Abstract* — In the paper, the brief performances of wireless communication systems are represented and their disadvantages are considered. The infrared diode in nanosecond pulsed mode was investigated. The new multipurpose circuit of infrared transmitter block for wireless free-space communication systems is offered. Using modification of infrared diode and enhanced method of radiation, up to 100 Mbps transfer rate can be achieved.**

***Index Terms* — infrared transmitter, last mile, low cost, communication purposes**

I. Introduction

Now all over the world there is a large amount of wireless networks for the various purposes. Certainly, wireless solution basing of various equipment (radio-modems, radio-relay lines, microwave digital transmitters etc.) is common knowledge. But the number of complexities does not decrease yet. Frequency band is oversaturated and it is rather difficult to receive allowing for use of radio equipment. And the capacity of this equipment essentially depends on cost.

Certainly, a laser as a radiate element is possible to use for increase of distance. Some enterprises developed such equipment, herewith distance of connection up to 5 kms is provided at rate 2 Mbt/sec. Unfortunately, the use of lasers in such devices makes an equipment rather expensive, comparable with the cost of a good laser.

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In the paper, a light-emitting diode, as an electron device, capable to replace a laser is investigated. As far as the radiation power of the light-emitting diode in a continuous mode is small – about ~0.5 Wt, and in this case the distance of guaranteed connection does not exceed of hundred meters, the use of the light-emitting diode in nano-second pulsed mode with large signal repetition were offered by us. In this case the radiation power is increased in value, multiplied on repetition, that is up to 5–50 Wt and it will be comparable to laser power. The cost of light-emitting diode is thus essentially less.

II. Infrared Systems

Nowadays laser infrared (IR) link more and more are used. The laser link has a clear advantage of radio communication, when the matter concerns of organization of wireless bridges ("point to point") on 1-2 km distance. It has higher transfer rate (up to 155 Mbps and above), has a greater noise protection, a high secrecy, and does not require obtaining allowing for frequency band using. At the same time prices for equipment of laser link are quite comparable to the prices on a radio ones [1].

For maintenance of compatibility of infrared devices the association "Infrared Data Association" (IrDA) was established in 1993. The purpose of its creation was consolidation of efforts on development of the mobile communication market by means of infrared data transfer on small distances. Nowadays the systems on the IrDA standard provide data transfer with rate up to 4 Mb/sec, however the guaranteed by manufacturer distance of connection is very small.

Thus, laser link can be used for:

- creation of main and/or backup data link;
- several local networks joining up;
- solution of "last mile" problem [1];
- video observation systems and security television;
- service of mini-cellular link;
- an emergency communication, when the fast development is necessary.

Nowadays laser technology is developing in a way of transfer factor and distance raising that makes it especially perspective for application in high-speed communication systems. However common imperfection for the majority of modern systems is restricted operation conditions at a poor weather.

III. Problems and Solutions

The commercial models of existent IR-systems under the price characteristics are oriented for business class and western customer. The minimum price of such systems is approximately $3000...$10000, that makes their inaccessible to majority of individual customers. Problem of the IR-system creation with transfer rate up to 10 Mbps on distance from 300 up to 1000 meters at cost of components up to $100 is intensive considered on the Web. Hence, there is a need for such devices, which radio amateurs are ready to assemble by they own means and paying $100 for components!

Basic parameters of modern commercial laser links, influential to connection distance are following:

- average output power - 20...200 mW;
- transmit beam divergence - 0,5...10 mrad;
- receiver lens diameter - 100 mm;
- minimum received power - 0,1...2 mkW;
- communication range 1...2 km at a signal fading 6...10 dB.

At such characteristics the distance of link makes on average 1...2 km.

However, for an average device (fig. 1, dash line) at a small fog, meteorological optical range (MOR) is not less than 1 km, the connection will be steady on the distance not more then 1 km. But if the fog becomes denser the obtained signal will be lower than a threshold of sensitivity of the receiver (fig. 1, the dotted line with a point) and connection will become unstable or will be stopped. At MOR=0.5 km the signal level will make –14 dB relative to sensitivity. Such operation conditions are unacceptable for a reserve channel or emergency communication. In such cases it is necessary essentially to reduce distance of connection that is not always possible.

Expensive laser emitter, complex optical focus system and also the precision automatic mechanism of pointing and tuning at small beam divergence make expensive cost of devices.

Ways of operating distance increasing are following:

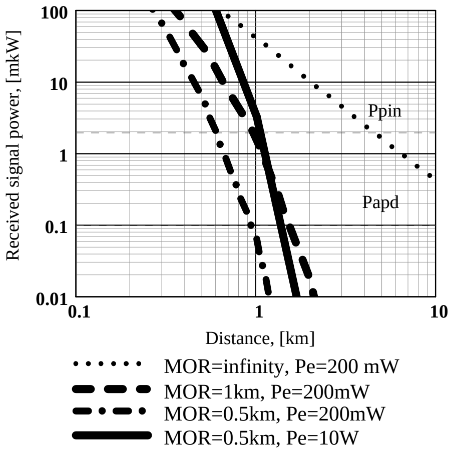

Fig. 1. Received signal power at receiver lens of the operation distance depending of fog density at: output power 200 mW, transmit beam divergence 10 mrad, receiver lens diameter 100 mm, sensitivity 2 mkW

1. The decrease of transmitter beam divergence allows to reduce losses of signal energy by transmission. But because of weather situation, natural conditions in atmosphere, the hunt effects of buildings etc. the beam divergence usually has limited to value 0.5 mrad, thus special tools of pointing (weapon sights) and device of automatic tuning already are required, that essentially has an effect to the price. At angle 10 mrad the special optical devices of pointing and automatic systems of tuning are not required, that essentially makes cheaper the system and installation time.

2. The increase of the reception lens diameter proportionally influences on mass and dimensions of the system, therefore the sizes are usual no more than 100...150 mm.

3. The increase of sensitivity of the receiver is limited to noise and hindrances.

4. But what about increase of output power of a signal? The use of more powerful laser emitters reduces also to essential high price of the system. So, for example, the laser diode with output power 4 W costs about $600.

IV. High Power Infrared Transmitter

The calculations were carried out and the conclusion was made from this. Cost of components can be essentially reduced if instead of the laser diode the infrared diode is used, which cost is lower 10...100 times, and also to simplify an optical part.

Transmitter and receiver of infrared pulses were developed. The general description looks as follows. On system source the information sequence of pulses is entered. Through matching device, necessary for agreeing of cable or communication link with transceiver input, the signal enters on pulse shaper. It creates the rectangular pulse of certain length and amplitude with steep-sided less than 10 ns front regardless of the form of source signal. Further the pulses gained by means of current generator and enter on infrared light-emitting diode. The optical system in a kind of assembling lens focuses the beam light radiated in the space. There is the similar optical system on the receiving target, focusing flow on photodiode. The photodiode current gains up to necessary level and acquires the necessary form on a pulse shaper.

The diode power in continuous mode is insignificant and makes 100...200 mW approximately. Using the IR-diode in the nanosecond pulsed mode with large porosity of signal, it is possible essentially increase of the emitted power, and consequently also operating distance. The advantage of such solution is universality of the system at switching modes of its operation on maximum distance or maximum transfer rate and also at a control of power in various meteorological conditions. So, for example, at short-term strong deterioration of visibility (strong fog or dense snow) the power of radiation can be increased (that is impossible for laser diode because of an optical strength of an output mirror is limited) unless the visibility will not be restored.

The IR-diode AL148A is offered to use as emitter. This diode has the following characteristics:

- constant direct current – 1 A;
- continuous emitted power – 200 mW;
- risetime of pulse – 30 ns.

As the optical system it is taken simple one-lens objective with 100 mm diameter of lens. The calculated and experimental data of the system shows that the operating distance of such system will make 1 km at 10 Mbps transfer rate and reserve 20 dB of the emitted power for fading in atmosphere (rain, snow, mist etc). Approximate cost of the system will make up to $30...$100. For example, an analog of such system WOCC-10MPD has the power reserve only 6 dB and price $3500 with the same other characteristics.

V. Advanced Features

The potential characteristics of the diode AL148A are quite a bit. The maximum pulse current of the diode can achieve to 300 A, at that the output pulse power will make about 50 W. Thus it is possible to essentially increase of operating distance of the IR-system.

For confirmation of theoretical accounts the mockup of the system was developed. The diode was used in pulsed mode with a large duty ratio of signal, so it emitted power has made 1 Wt. But because using of cheaper bad quality optical lenses with 50 mm diameter the beam divergence has made 40 mrad, as well at the receiver. Advantages of the mockup are direct corollary of it disadvantages: a large beam divergence. A disadvantage is large losses and therefore – decrease of distance, advantage – is simplicity of pointing and low requirement to the mount of devices. The operating distance of the system has made 0,5 km at good visibility, what has exactly coincided with calculation. Cost of half-package on components has made only $12.

Practice and the calculations show that at small additional expenditures with better lenses will essentially rise of efficiency of the given system in many times. It is caused by decrease of a beam divergence up to 10 mrad and increase of reception lens diameter up to 100 mm.

As a result of researches the following characteristics of transmitter were achieved:

- pulse length – 100 ns;
- output-pulse frequency – 500 kHz;
- risetime of pulse – not more than 40 ns;
- falltime of pulse – not more than 40 ns;
- pulsed current of diode – 10 A;
- pulsed power of radiation – 5 Wt.

Main characteristics of receiver are following:

- risetime of pulse front – 5 ns;
- upper border of passband – 200 MHz;
- target voltage – 3 V.

Prospective distance of this device at rate 500 kbits/sec is near 1 km in conditions of bad visibility.

The main restriction on distance and rate of transfer information is introduced the characteristics of infrared light-emitting diode - risetime and maximum average diffuse power. Communication distance is connected with the radiation power, which is a direct proportional average diffuse power as follows:

$$R = k \cdot \sqrt[\alpha]{P_{out} \cdot Q}\,, \qquad (1)$$

where *k* is a factor, take into account of receiver sensitivity and additional losses; *a* takes into account a spreading of light in the space, *a*=2…3; *Q* is signal repetition.

From (1) it is visible that for increasing of distance it is necessary to increase the signal repetition *Q*:

$$Q = \frac{1}{\tau \cdot f_T}\,, \qquad (2)$$

where τ is a length of radiate pulse; f_T is output-pulse frequency (equivalent of transfer rate).

To increase of pulse repetition (2) it is necessary to reduce f_T, that will be equivalent of rate reduction, or reduce of the radiate pulse length, which is limited of the diode characteristics: it is necessary that the radiation time will be in several times more than risetime. Thus, the main system characteristics are determined by diode parameters basically. It is necessary to use of light-emitting diodes with the maximum ratio risetime – radiation power.

Advanced circuit of transmitter lets easily to vary of its parameters such as operating distance and transfer rate at various meteorological conditions (table 1).

Usage of the diode in the transmitter scheme with accumulative capacity [2] allows effectively to regulate the emitted power controlling a supply voltage at the last cascade from 5 up to 40 V (fig. 2). Thus, at a strong fog (MOR=0.5 km and less), using the given solution, it is possible to boost the emitted signal power up to 10 Watts, that will provide an indispensable signal level on the receiver (fig. 1, solid line). However at increasing the pulse power it is necessary to increase a porosity of the signal that entails data rate reduction.

TABLE I
PARAMETERS OF INFRARED LINK

Maximum transfer rate (kbps)	Operating distance (km)		Maximum theoretical distance (km)
	fading 20 dB	fading 6 dB	
10000	1	5	10
640	2	10*	20
64	3.5	17*	35

For example, system installed on 3.5 km distance with reserve of the emitted power 20 dB for fading in atmosphere (such as strong rain, snow or fog), at good weather can be fluently turned in fast transfer rate mode – 10000 kbps and 6 dB fading – by decreasing supply voltage of driver and increasing of signal duty ratio and vice versa.

So, using given high power transmitter with cheap IR-diode AL148A (it cost about $2), price of infrared system is only about $100. The calculations and experimental data of the system shows that the operating distance of such system will make 1 km at data rate up to 10 Mbps and reserve of the emitted power up to 35 dB for fading in atmosphere (rain, snow, fog etc).

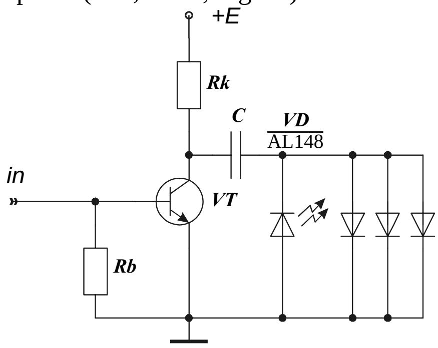

Fig.2. The last cascade of the high power transmitter

VI. Conclusion

Usage of the IR-diode AL148A in the offered scheme is an effective solution of the last mile problem. Basic merits of a designed system are its cheapness, simplicity of installation, which is not requiring special tools for development.

The developed circuit of infrared transmitter is universal block both for various types of communication as for Ethernet interface, and analog phone lines, at much less cost in comparison with its analog.

Using modification of diode AL148A and enhanced method of radiation, 100 Mbps and above transfer rate can be achieved and also longer distance.

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