TELECOMUNICAZIONI

Free space digital laser communication system based on microcontroller

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SUMMARY. – *Pulse code modulation (PCM) was chosen as the preferred system of practical application of optoelectronics signal to transmission of high quality voice signal based on microcontroller in free space is designed and constructed in this work. The microcontroller accepts a byte of data from an analog to digital converter ADC, and then it transmits it at a rate of 100 kbps via its RS-232 port. A laser diode that emits radiation at 650 nm of about 1 mW, was used as a source of optical carrier. At the receiver side, a BPX-65 PIN photodetector was used. The results show the microcontroller increase the system flexibility and make work easier in addition to BER less than 10^{-9} was achieved over 500 m path length at a wavelength 650 nm.*

1. Introduction

Unguided optical communication systems were the subject of a great research and development activity between 1960 and 1970. in the years following 1970, the effort devoted to optical fibers has entirely dominated this activity, and only a few highly specialized unguided applications were pursued. More recently with the development of applications in the space technology and the increasing importance of wireless (cordless) systems for mobile and interior communications, interest has been increased again. Unguided optical communication systems may also have a role in short links (between buildings, for example) when because of special local circumstances, it is difficult to run cables across the intervening space. In all these cases, optical links are competition with radio and microwave systems. It should be noted that even modestly safety requirements are satisfied (1). Free space laser communication systems have narrow optical beam paths, which are not accessible unless viewing directly into the transmitter path. Any potential eavesdropping will result in an interruption of the data transmission.

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Light emitters are a key element in any fiber optic system. This component converts the electrical signal into a corresponding light signal that can be injected into the fiber. The main types of emitters are the semiconductors diodes (that are the laser diode and the LED).

The energy loss of the propagating laser beam through the earth's atmosphere is mainly the absorption and scattering losses by the molecular species. the transparency of the atmosphere for the laser radiation is one of the most important parameters in the calculating the attenuation. This depends on the weather state and path length (range).

Atmospheric attenuation effect upon the irradiance may be described as in the following (2)

$$E = E_0 \exp(-\mu R)$$

where E_0 is the emergent beam irradiance at zero range, R is the path length in km, and μ is the sum of the scattering and absorption coefficients.

The Rayleigh scattering can be described by

$$y_{hR} = 4.56 \times 10^{-27} N_g \left(\frac{0.55}{\lambda}\right)^4$$

where $N_g = 2.55 \times 10^{19}$ cm^{-3} at sea level, and the Mie scattering is described by

$$\gamma_{pm} = \frac{3.91}{V}\left(\frac{\lambda}{550nm}\right)^z$$

where V is the visibility (in km), λ is the wavelength (in nm) and z is the size distribution of the scattering particles.

The transmittance through scattering is given by

$$T_s = \exp\left[-\left(\gamma_{gR} + \gamma_{pm}\right)R\right]$$

where R is the path length (Range), whereas the Transmittance through the absorption is given by

$$T_a = 0.7894\exp(-0.0026w)\,(658.6969\lambda - 2648.2 + 3948.2\lambda^3 - 2601.5\lambda^4 + 638.53)$$

where w is perceptible water content per unit path length

The atmospheric transmissivity can be factored as the product of the absorption and scattering transmisitivities:

$$T(R) = T_s \times T_a$$

The amount of the received power is proportional to the amount of power transmitted and the area of the collecting aperture. It is inversely proportional to the square of the beam divergence and square of the link length. It is also inversely proportional to the exponential of the product of the atmospheric attenuation coefficient (km^{-1}) and the link length (4).

The received power through the earth's atmosphere can be calculated as

[1] $$P_{rec} = P_t \frac{A_{rec}}{(\theta \times R)^2} \exp(-\mu R)$$

and $A_{rec}\pi(D^2/4)$ where A_{rec} is the receiver optics area, D is the receiver optics diameter and ı is the divergence of the laser beam in radians (4).

Obviously, the atmosphere is a good medium for transmitting visible light. Atmospheric transmittance can be considered excellent from 500 nm to 950 nm. The range of a laser communication system can be estimated by using Eq. 1.

[2] $$\text{range} = \sqrt{\frac{4P_t\, A T(R) T_0}{D_s \pi \theta^2}}$$

where *range* is in kilometers, P_t is the laser emitted power, A is the area of receiving optics (lens or mirror), T_a is the transmissivity of the atmosphere, T_0 is te transmisssivity of the receiving optics, D_s is the detector sensitivity (minimum detectable signal). Aperture of receiving optics is 10 cm^2, assuming minimal atmosphere absorption and scattering (visual range = 100 km a very clear day) and average optics (T_0=0.85). From Eq. 1, one can notice the importance of keeping the laser beam divergence ı small. Halving the divergence doubles the range. Small divergence is quality to look for in a laser. Note also the importance of antenna area. Doubling the diameter lens gives half the range of that when using four times the diameter of the lens. A wireless light communication system with a laser diode as an optical source in transmitter and a PIN photodetector in the receiver used to do this.

2. System description

The block diagram of the implemented system is shown in the Fig. 1. The electrical signal comes from a microphone. Then it passes through a buffer which is an isolation and impudence matching stage. After that, the week signal is amplified by the operational amplifier. The amplified signal has a level of ±5*V* to be suitable for the input of the analog to digital converter (ADC).

The conversion process was implemented at a rate of 8 kHz, since the bandwidth of human voice is a bout 3.3 kHz. This process was controlled by the 8051 microcontroller. The ADC used in the work as a bipolar eight bit converter. The read/convert signal of the ADC which initiates the conversion process when its level is low (0 V) after the process ends the status signal goes high which is monitored by the microcontroller, so the microcontroller then make the read/convert pin of the ADC high (5 V). after that this byte of data is stored by the microcontroller and transmitted via the serial port of the 8051 microcontroller which is an RS- 232 standard. The setting of the RS-232 was 8-bit data, one start bit, one end bit and 19200bps for the baud rate. The setting first done at the beginning of the operation.

The output of the RS-232 is then converted into optical signal through the optical transmitter shown in Fig.2.

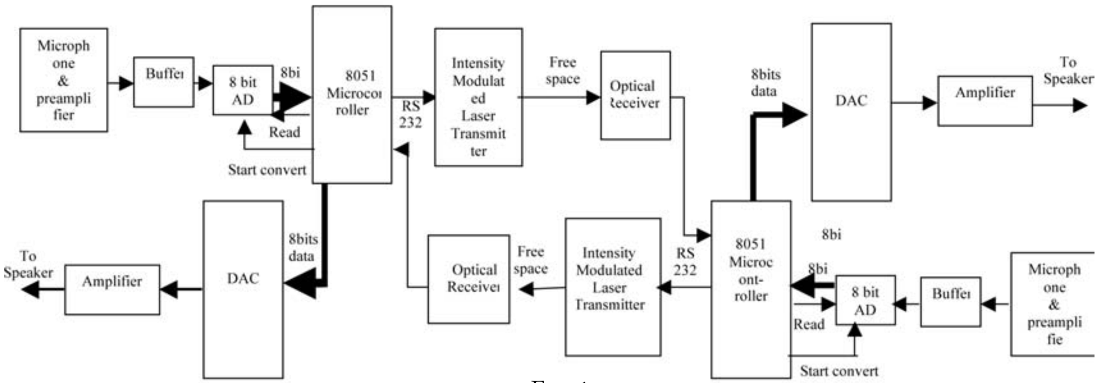

FIG. 1

A block diagram of the full duplex voice intensity modulated wireless optical communication system

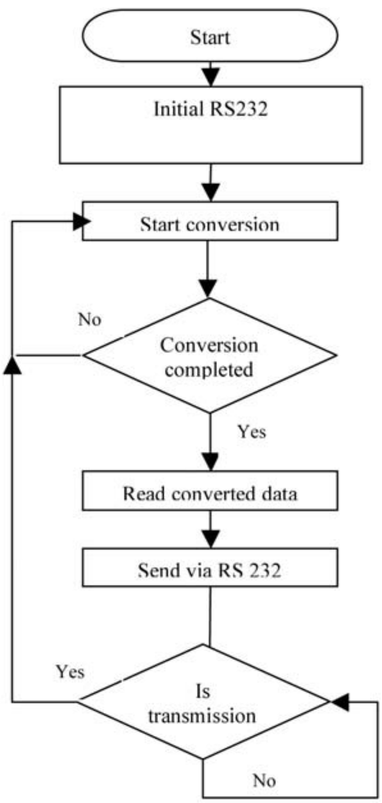

FIG. 2

Flow chart of the transmitter based on 8051 microcontroller

The transmitter shown is a digital optical transmitter that uses digital gates as a driver. The optical source used in the work was a laser diode that emits optical radiation at 632 nm. with maximum optical output power of 1 mW. The maximum current that passes through the laser diode can be calculated according to Eq. 1:

[3] $$I_d = \frac{V_{cc} - V_{\text{diode}}}{R_d}$$

where V_{diode} is the voltage drop across the laser diode which is about $1.6V$. The current through the diode was set at 120 mA which gives a power output of $1mW$.

These optical pulses then pass through the air toward the optical receiver. The optical receiver, which is responsible for converting these optical pulses into electrical equivalent pulses and removing the effects of the different noise sources through the transmission and obtaining an exact replica of the transmitted signal, contains an PIN photodetector of the type of BPX-65 with a rise time of 0.5 – 1 ns and a peak responsivity of 0.55 A/W.

The details of the optical receiver are shown in the Fig. 3. The detected optical signal is first converted into optical signal by the detector and then this weak signal is amplified by the amplifier stages. Then, the received serial bits are converted into bytes (parallel bits) by the software of the 8051 microcontroller at the receiver. These bytes are fed to the digital-to-analog converter to reconstruct the original signal (the voice). This signal is amplified and fed into a power amplifier and then into a speaker of $1W$. The flow chart of the programs of the transmitter and the receiver are shown in Figs. 2 and 3 respectively.

This work was designed, implemented and operated experimentally over a distance of separation between the transmitter and the receiver of 500 m. According to Eq. 2 the maximum distance of separation can be extended up to 7.94 km.

3. Results and discussion

The result of the Rayleigh scattering was calculated for a wavelength of 650 nm equal to 6.67×10^{-8} cm^{-1}, whereas the Mie scattering is equal to 1.159×10^{-5} when the visibility is 3 km and size distribution is 0.843. Then the transmittance through scattering equals to 0.99415 for 4500 m path length. The transmittance through absorption is equal to 0.65 when the relative humidity is 30% in Baghdad city, and the air temperature is 300°K, which gives $w = 0.01$ (perceptible water content per unit path length). The total transmittance is the scattering transmittance multiplied by absorption transmittance which is equal to 0.6461.

The power received of the system could be measured experimentally to calculate the optical signal-to-noise (S/N) ratio and bit error rate (BER). Figure 4 represents the BER as a function of power received for different values of the path length.

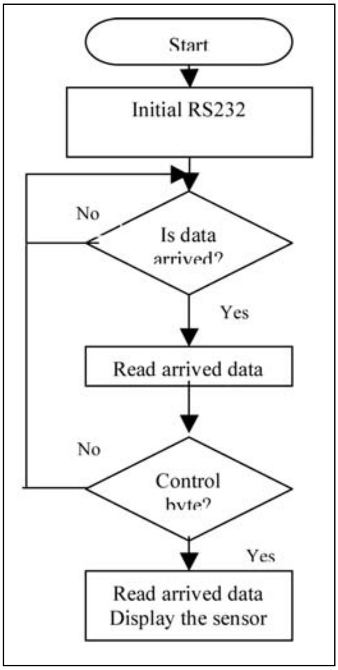

FIG. 3
Flow chart of the receiver

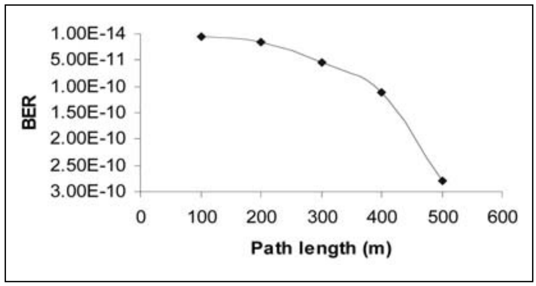

FIG. 4
Bit Error Rate as a function of path length

4. Conclusion

The performance of the free space digital laser communication system based on microcontroller was demonstrated and investigated experimentally. Free space laser communication based on microcontroller has been widely accepted as suitable for transmit high quality voice signal. In this work we calculated the BER of the system due to practical values of the received optical power. Experimental results have proven the experimental development here to attain a voice transmission using 500 m path length for a BER equal to 2.806×10^{-10}.

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