Low-Cost Laser-Based Wireless Optical Transceiver for 10-Mbps Ethernet Link

Phanumas Khumsat and Noppadol Wattanapisit
Department of Electrical Engineering,
Faculty of Engineering, Prince of Songkla Univesity,
Hat-Yai, Thailand

Karel Kulhavey
Twibright Laboratories
Praha, Czech Republic

***Abstract*— A low-cost full-duplex 10Mbps optical transceiver for free-space optical data communication is presented. The transceiver consists three main parts namely interface circuit, transmitter and receiver. The transmitter – based on a simple inverter circuitry, drives a laser diode emitting 635nm visible red beam. The 10-cm-diameter lens was employed for light collimation. Optical-to-voltage signal conversion is performed using a photodiode SFH203 incorporated with a single resistive followed by a low-noise amplifier deploying a dual-gate MOSFET. 10Mbps Ethernet link between two personal computers situated 300 meters apart has been experimentally verified.**

I. Introduction

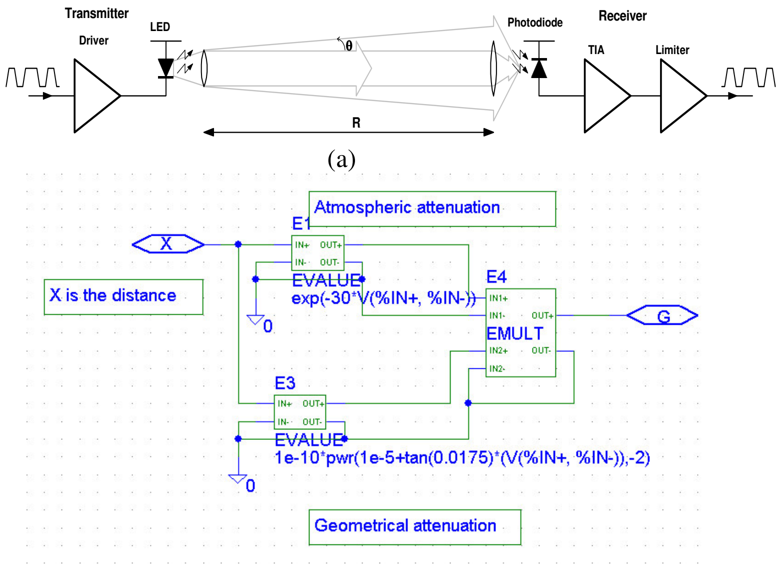
Free-space optics (FSO) or optical wireless comes into play as a feasible alternative for high bandwidth data networking to solve a "last-mile problem" in high-speed optical fibre link [1]-[5]. It is believed that FSO could bring best of both worlds of a high-bandwidth wire-line optic and a low-cost wireless radio. This paper presents design of front-ends for a full-duplex 10Mbps free-space optical transceiver which complies with IEEE 802.3 standard for Ethernet networking. It emphasizes on hardware implementation that utilizes low-cost, easy-to-find off-the-shelf components.

II. Free-Space Optic Basics

Fig.1a illustrates a simplified point-to-point free-space optical communication system linking. The receiving power P_{Rx} can be related to transmitting power P_{Tx} by [1, 2]

$$P_{R_x} = P_{T_x} \cdot \frac{R^2{}_{Rx}}{\left(R_{Tx} + \tan(\theta)\cdot R\right)^2} \cdot \exp(-\alpha \cdot R) \qquad (1)$$

where R_{Rx} and R_{Tx} are an optical receiver's and transmitter's radii, R link range (in km), θ is a beam divergence (in radians) and α is an atmospheric attenuation (dB/km). The receiving power is linearly proportional to transmitting power and receiving area while atmospheric condition does strongly affect link integrity as indicated by factor α in (1). Parameters P_{Tx}, A_{Rx}, and θ can be controlled by designers to enhance link range. This link characteristic of (1) can be effectively modelled using non-linear functions within PSPICE (Fig. 1b).



(a)

(b)

Fig.1: A typical free-space optical system

III. Receiver Design

The key component is the receiver (Rx) is an inexpensive Si-PiN photodiode SFH203 [6] whose main task is to perform optical-electrical conversion. At 635nm the photodiode possesses a conversion efficiency of 0.434A/W which is considered to be sufficient for our application. The photodiode is combined with a resistor R_{tia} of 100kΩ and a low-noise amplifier implemented from a common-source dual-gate MOSFET BF988 [7] to perform an optical-to-voltage signal conversion as shown in Fig.2. The photodiode and MOSFET both inherit undesirable parasitic capacitance of 13pF, and a small-signal analysis of the current-to-voltage converter with low-noise amplifier renders a transimpedance gain of

The project is sponsored by Faculty of Engineering (general research grant) and Prince of Songkla University (new lecturer grant)

$$\text{gain} = -\frac{R_{tia}}{1 + sR_{tia}C_x} g_m R_D \qquad (2)$$

where BF988 contributes a transconductance g_m and C_x is the total capacitance at cathode of SFH203. Eq. (2) suggests that the parasitic capacitance inevitably gives unwanted lossy integrator (low-pass filter) ac-response characteristic. It thus needs a differentiator (or high-pass filter response) in a subsequent stage so that the original data pulses can be fully recovered. R_{tia} and R_D were designed to be 100kΩ and 560Ω respectively with corresponding g_m of 27mS by biasing the first and second gate terminals at 0V and 4V respectively via 2.2MΩ resistor and a resistive potential divider from a single voltage supply V_{DD}=12V.

An amplifier and differentiator can be effectively realized from a single IC NE592 with an appropriate capacitive feedback connected across the assigned pins as shown in Fig.2 where its small-signal input-output response is [8]

$$\text{gain} = \frac{1.4\times 10^4}{\frac{1}{sC} + 32} \qquad (3)$$

In this particular design the differentiating capacitor was chosen to be 270pF for 10Mbps data rate.

The last stage of the receiver circuit is a limiting amplifier implemented from discrete NPN 2N3904 forming a switching long-tailed pair driving an output 75-Ω load with 820Ω resistor employed to set bias tail current. This 75-Ω resistor load is specifically utilized in order to maximize power transfer to the interface circuit via a 75-Ω coaxial cable. The maximum signal-to-noise ratio is measured to be at 16.3dB corresponding to a bit-error-rate slightly better than 10^{-9}.

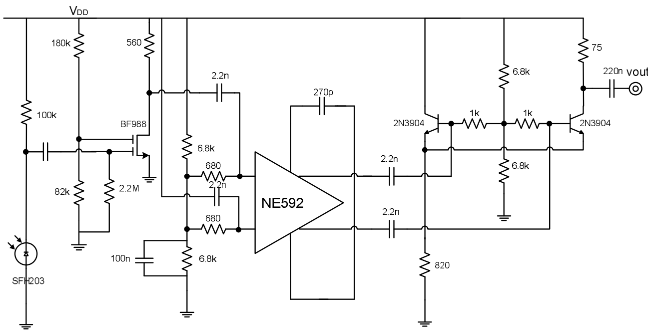
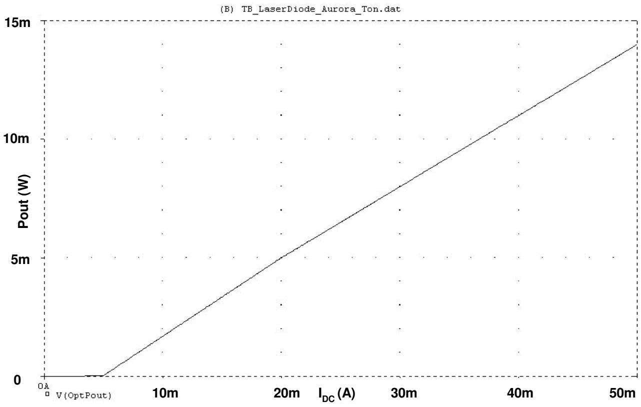


Fig.2: *Receiver circuit schematic*

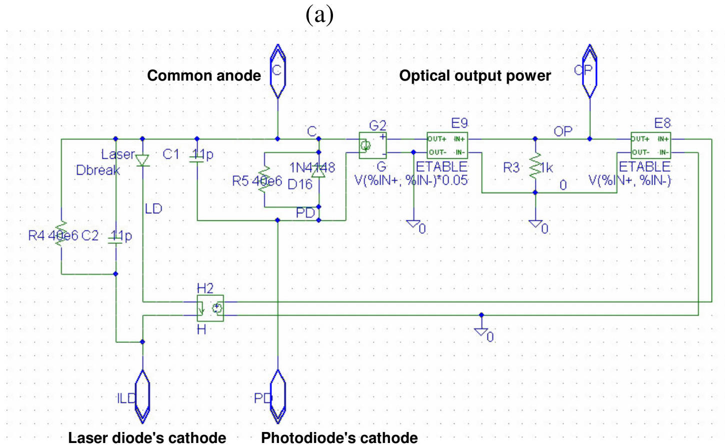
IV. TRANSMITTER DESIGN

The laser diode was chosen a transmitter's light source and it has been taken from a low-cost easy-to-find red laser pointer. It was characterized and found to have a threshold current of 5mA and emitting optical power of 5mW at 20mA. The laser emits a visible red beam with a wavelength of 635nm. This laser diode has also been modeled in PSPICE for simulation purpose as shown in Fig.3.

Two-stage inverter implemented with three 74HC04 chips at supply voltage of 5V drive the laser diode via 75Ω (Fig.8) which sets maximum current swing to 40mApp (the laser diode's forward voltage ~2V). The front part of the transmitter incorporates a limiting amplifier based on a conventional long-tail pair structure with capability of 75-Ω matching to the interface circuit.



(a)



(b)

Fig.3: Laser diode characteristic (a) and its corresponding behavioral model (b)

V. TRANSMITTER AND RECEIVER TESTING

10-MHz square wave was applied to the transmitter's input in order to check whether the circuits can handle 10Mbps data rate. The results are as shown in Fig.4 indicating that the 10MHz square wave can be correctly recovered at the receiver's output (transmitter and receiver was 200cm apart without collimating lens).

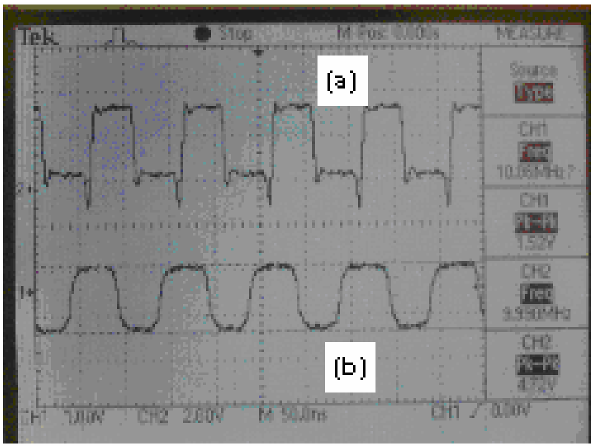
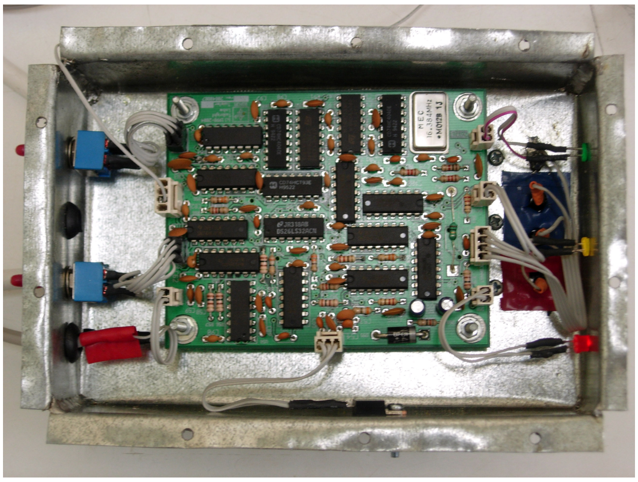


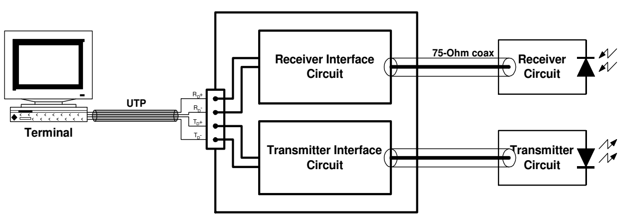
Fig.4: *Measured receiver's output voltage (b) compared with the transmitted signal (a) at 10MHz.*

VI. Interface Circuits

Interface circuit provides signal conditioning and generating some specific signals in order to comply with IEEE 802.3 standard. It can be divided into two major parts: (a) circuit that interfaces with transmitter and (b) circuit that interface with receiver as shown in Fig.5.



(a)



(b)

Fig.5: *Transceiver interface (a) PCB and (b) connection to Tx, Rx*

VII. Simulation and Experimental Results

To assist the design, the complete FSO system ranging from transistor-level circuits, laser diode, photodiode to the free-space behaviour in (1) were modelled and simulated within PSPICE as schematically depicted in Fig.8.

The receiver circuit housed inside an optical loupe with 10-cm-diameter lens can be viewed in Fig.6. The system test set-up (as illustrated in Fig.7) connects two personal computer situated 300-metre apart linking between two buildings and the results have confirmed its successful operation, file transfer, on-line games, remote access, Ethernet video link). Note that the transmitters and receivers were housed inside optical loupes, while the interface circuit (powered by 12V supply unit) was situated near the computer. Besides employing two long shielded 75-Ω coaxial cables for signal connection between T_x, R_x and interface circuit, these cables were also used to supply 12V and ground to T_x, R_x via the outer shield which runs along the total length of the cable.

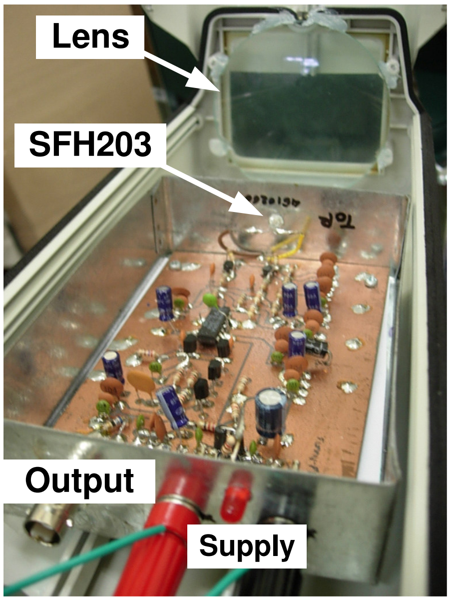


Fig.6: *FSO receiver prototype inside an optical loupe*

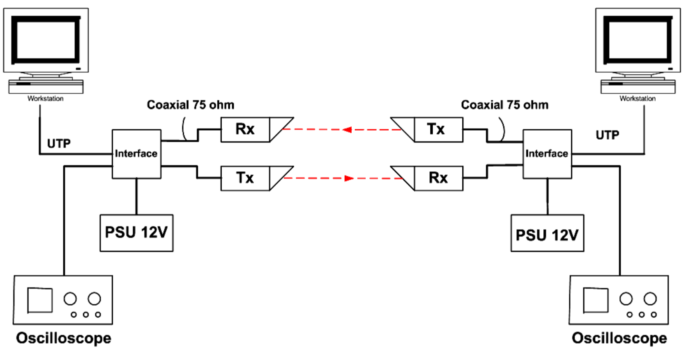


Fig.7: *Transceiver test set-up*

VIII. Conclusion

A low-cost full-duplex 10Mbps free-space optical transceiver complying with IEEE802.3 standard for Ethernet networking has been demonstrated and successfully verified at a distance of 300 metres. The system has been implemented from easy-to-find off-the-shelf components. Further improvement can be done by employing fully differential circuit structure to lower common-mode noise and enhance the overall signal-to-noise ratio.

References

[1] S. Bloom, "The Physics of Free-Space Optics," Air Fiber white paper, available online at http://www.airfiber.com

[2] H. A. Willebrand and B. S. Ghuman, *Free-Space Optics: Enabling Optical Connectivity in Today's Networks*, SAMS publishing, 2002.

[3] C. C. Davis et al, "Flexible Optical Wireless Links and Networks," *IEEE Communications Magazine*, March 2003.

[4] A. Acampora, "Last Mile by Laser," *Scientific American*, July 2002.

[5] Lightpointe, "Optical Wireless Solutions Based on Free-Space Optics (FSO) Technology," Lightpointe white paper, available online at http://www.lightpointe.com

[6] SFH203 datasheet, available on line at http://www.infineon.com

[7] BF988 datasheet, available on line at http://www.semiconductors.philips.com

[8] NE592 datasheet, available on line at http://www.semiconductors.philips.com

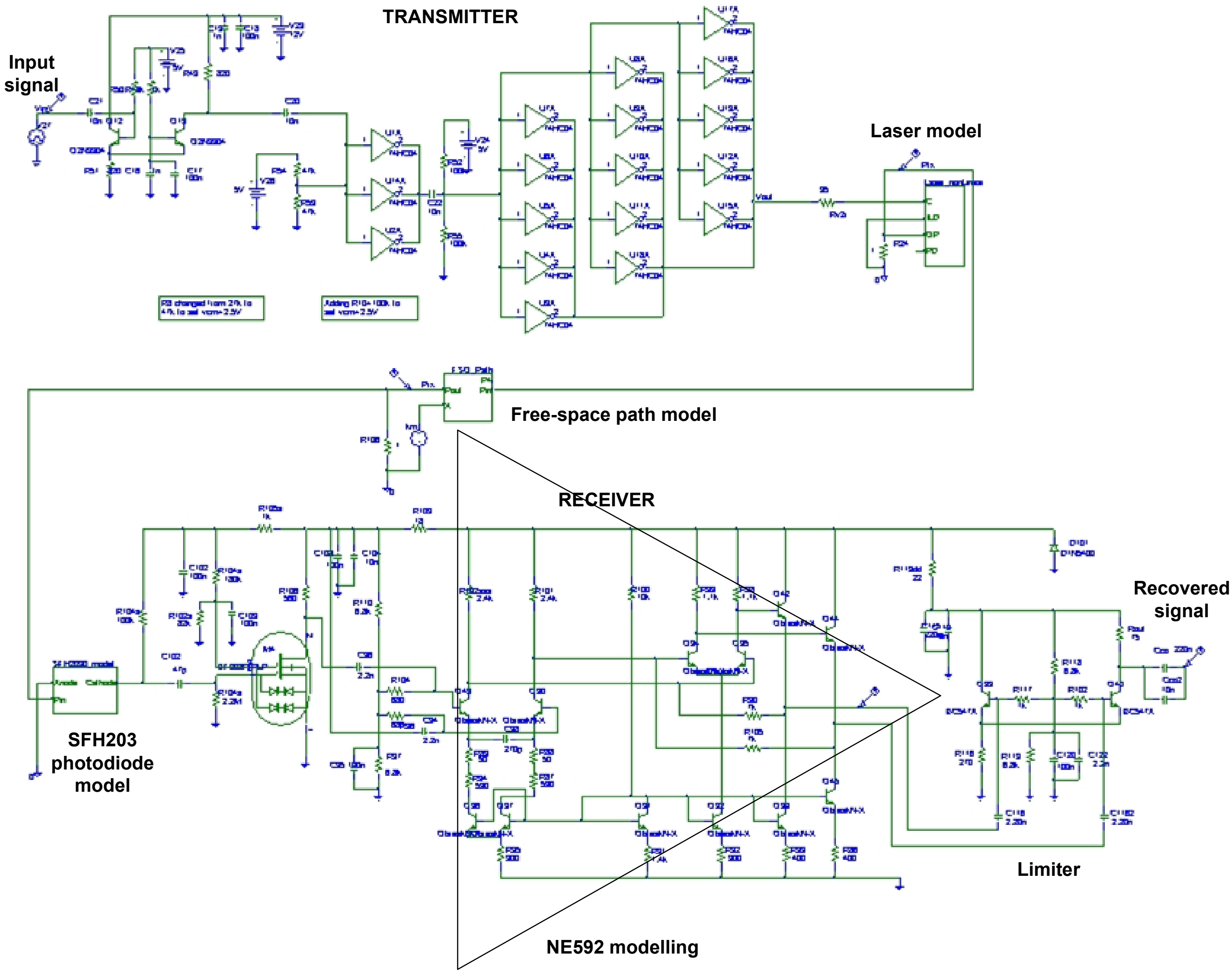


Fig.8: PSPICE schematic capture of the implemented FSO system