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# Low-Cost Interface for Light Communication Transceivers

**Natarajan Somasundaram[1]* ,Ramadass N[2].**

[1] Professor, Department of Electronics and Communication Engineering, VelTech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology, Chennai, Tamilnadu, India.
[2] Professor, Department of Electronics and Communication Engineering, Anna University, Chennai, Tamilnadu, India.

***Corresponding Author**

***Abstract:*** *With the latest advancements in wireless communication, many devices are networked leading to a drastic increase in the quantum of wireless data communicated. This leads to a growing demand for wireless bandwidth and secure channels without causing any interference and hazards. Light Communication is an emerging technique which can address the bottlenecks of existing wireless networks by providing a widest bandwidth, interference-free and secure operation. In order to implement light communication, a suitable platform satisfying the criteria of low cost and low power is desired. A light communication transceiver consists of a data source, digital light modulator and driver, light source, light sensor, digital demodulator and data storage. Digital modulator and demodulator can be implemented using any digital architecture. A two-wire interface is required, one to connect the light source, through appropriate driving circuit, to the modulator and another to connect the light sensor to the demodulator. A two wire digital interface compatible with any of the digital architectures and any of the light modulation schemes supporting standard data rates is designed and implemented.*

***Keywords:*** *Digital Interface, Full duplex Interface, Light Communication Port, Light Transceiver Interface, Two-wire Port.*

## INTRODUCTION

Wireless communication and digitalization has advanced to a great extent, where many sensors and devices are networked on a larger scale leading to increase in amount of data to be communicated across the network at a given instance of time (Chowdhury et al., 2018). Till date, wireless communication relies heavily on radio and microwave frequencies ranging from 3 KHz to 300 GHz with 3 major operational limitations such as limited bandwidth accommodating lesser devices or data, unsecured jamming-prone or eavesdropping-prone channel and interference with near-by devices. Also, they are attributed to adverse health effects on living body when exposed to the radio and microwave radiations (Larik et al., 2016; Sivani and Sudarsanam, 2012).
Light Communication is an emerging technique which can address the bottlenecks of existing wireless networks. It operates in the range from 300 THz to 800 THz offering a widest bandwidth. Light waves do not interfere with each other. Light communication cannot be jammed or tapped without blocking the transmission, confirming the security aspect. Lastly, it does not create hazardous health effect (Huaizhou et al., 2015).

Light Communication technology is shown in figure 1. Visible light LED or Infrared (IR) LED or LASER is the light transmitter and matching photodiode or phototransistor is the light receiver. Logic 0 is indicated as LED OFF and Logic 1 is indicated as LED ON. The data transmission rate (or flicker rate) is fast enough so that it is not apparent to human eye (Nan et al., 2015).

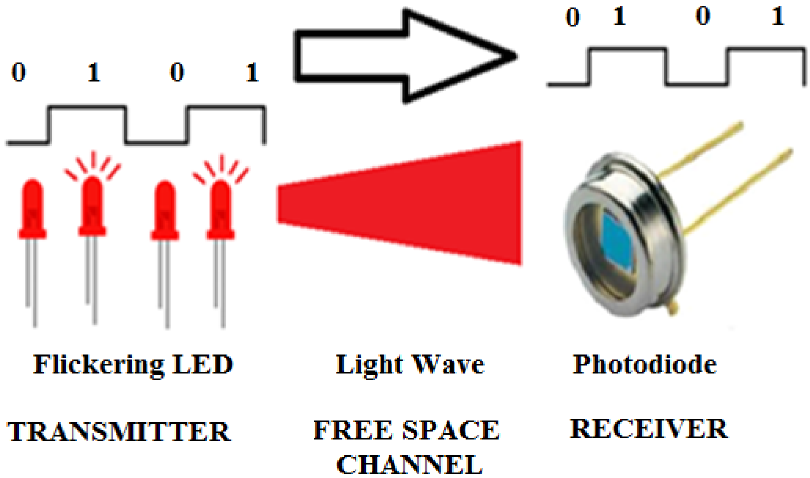


**Figure 1:** Light Communication Technology

**Light Communication Transceiver:**
The block diagram of a Light Communication Transceiver is shown in figure 2.

**1. Power Supply**

It is the prime component which powers both the transmitter and the receiver modules. It characterizes the performance metrics like transmission distance and responsivity. Distance is proportional to transmitter current. Responsivity is proportional to biasing current of receiver.

**2. Transmitter**

It consists of a controller, driver and optical transmitter. The controller takes the data from data source, converts to binary in case of analog data and it is given to the modulation algorithm. The modulated binary data is fed into the optical transmitter through driver circuits. The optical transmitters can include IR LED or visible light LED or LASER array. The optical transmitter sends modulating binary data in form of IR or visible light. In the simplest form, ON-OFF Modulation is used, where binary digit 0 is represented as light "OFF" and 1 as light "ON".

**3. Receiver**

It consists of an optical receiver, signal conditioner and a controller. The optical receiver can include photodiode or phototransistor and must be compatible in terms of wavelength of light received. The light is converted to current or voltage and processed by the signal conditioning unit. The conditioned electrical signal is then demodulated and converted to binary data by the controller.

There are 2 controllers, one each for transmitter and receiver, shown in figure 2. This is for explanatory purpose but in reality, there will be a single transceiver controller handling transmission and reception. Driver and signal conditioning units can be considered as part of controller itself. Hence, the light communication transceiver consists mainly of power supply, controller, optical transmitter and optical receiver.

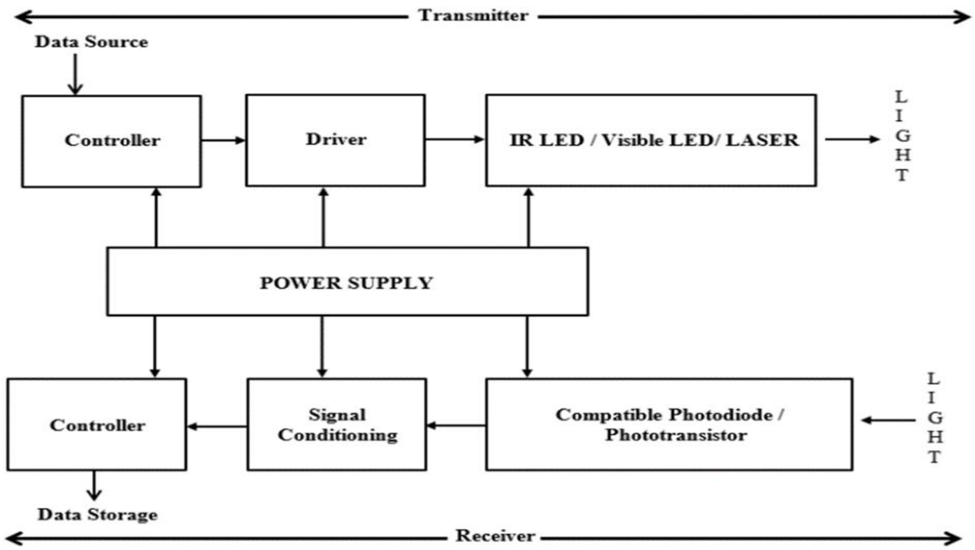


**Figure 2:** Block Diagram of Light Communication Transceiver

**Controller Interface:**

The interface between the controller module and optical module is not yet standardized. This interface must be compatible with any of the digital controller architectures and any of the light modulation schemes and support standard data rates. It is referred to as 2-wire transceiver interface comprising of 2 wires, one each for data transmission and data reception. The transceiver interface signals are Optical Output Port (OOP) and Optical Input Port (OIP), respectively, as shown in figure 3.

There are various controllers available with various interfaces (Ashwin, Thakare and Chaudhar, 2013). The controller can be in the form of a Microprocessor (8-bit, 16-bit, 32-bit), Microcontroller (8-bit, 16-bit, 32-bit), Field Programmable Gate Array (FPGA) or a Programmable System on Chip (PSoC). The interfaces can be any one among Universal Asynchronous Receiver Transmitter (UART), Universal Serial Bus (USB), Inter Integrated Circuit (I2C) Bus interface or Serial Peripheral Interface (SPI).

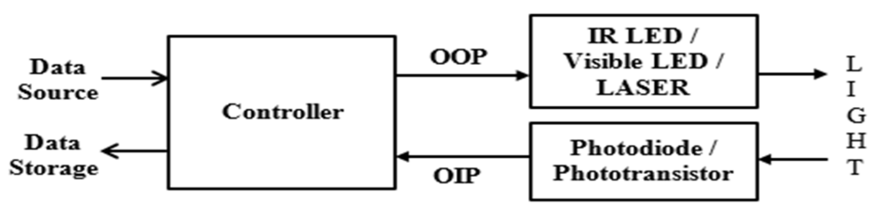


**Figure 3:** Light Communication Transceiver Interface

As can be seen from figure 3, any simple microcontroller with optional Analog-to-Digital Converter (ADC) and with driver circuit qualifies as a Controller. ADC is required only when the data is analog and it needs to be converter to binary. As suggested above, any of the interfaces can be used as an interface between Controller and optical transmitter. But it comes with a compromise that the Controller must have that interface on-chip or an off-chip interface chip is to be interfaced. When the interface is to be simplified, the proposed OOP and OIP interfaces can be used. The novelty of this interface lies in the simplicity of the Controller requirement. No complicated on-chip interface is required. Any Controller with an on-chip timer and a register qualifies for this interface implementation. The dataflow diagram of the proposed Light Communication transceiver OOP/OIP interface is shown in figure 4.

All Controller architectures will have clock circuitry, clock prescalar, timer, on-chip program and data memory, instruction decoder, register bank, Arithmetic Logic Unit (ALU) and other on-chip peripherals with external crystal oscillator as the clock source. The clock prescalar divides the clock frequency generated by the clock circuitry. The division factor depends on the Controller and it is different for variety of microcontrollers and/or FPGAs. The prescaled clock is fed as clock input to the timer. The timer will consist of three registers, namely Timer Register (TR), Mode Register (MR) and Control Register (CR). The MR defines the operating mode of the timer and CR controls the start and stop operation of the timer. The timer will generally work as an up counter. The value corresponding to required count is preloaded in TR. Upon receiving clock pulses from clock prescalar, TR is incremented by 1. When TR reaches the maximum count value and resets to 0, a clock pulse is generated. This clock pulse is used as clock for Light Communication transceiver output and input. Single bit, one after the other are sent on OOP from Register O at these clock pulses. Similarly, one bit after the other is read from OIP to Register I at these clock pulses.

**Light Modulation Schemes:**

The modulation process varies the characteristics of light according to the binary signal. The light characteristics which can be varied are light intensity, light wavelength and light duration (Faisal, Sajjid and Moazzam, 2018; Zekry et al., 2018).

**1. Light Intensity Modulation**

In this scheme, the intensity of light is varied in accordance with binary data. In the simplest case of light intensity modulation scheme, Logic 0 is indicated as LED OFF and Logic 1 is indicated as LED ON. The same discussion holds true for LASER also. In the complex scheme, a group of bits can be indicated as an intensity level in between fully OFF and fully ON. For example, a group of 2 bits as {00, 01, 10, 11} can be indicated as 0%, 25%, 50% and 75% intensity respectively.

**2. Light Wavelength Modulation**

In this scheme, the wavelength of light is varied in accordance with binary data. If a multi-spectral LED or LASER is used, each band can represent a group of bits. For example, using an RGB LED, a group of 2 bits as {00, 01, 10, 11} can be indicated as OFF, RED, GREEN and BLUE colour component respectively.

**3. Light Duration Modulation**

In this scheme, the duration of light is varied in accordance with binary data. For example, assuming a pulse duration of 1 ms, a group of 2 bits as {00, 01, 10, 11} can be indicated as 0, 0.25 ms, 0.5 ms and 0.75 ms respectively.

**4. Hybrid Light Modulation**

This scheme is a combination of the above schemes. For example, we can have a combination of light duration modulation coupled with light intensity modulation and likewise.

Any of the above mentioned light modulation schemes can be implemented on the Controller to make it operate as a Light Communication transceiver.

**Prototype Implementation:**

The adopted bit format for Light Communication transceiver prototype is shown in figure 5. One optical transceiver interface packet consists of 10 bits, out of which one bit is Sync bit, eight data bits B0 to B7 and one End bit. B0 is the Least Significant Bit (LSB) and B7 is the Most Significant Bit (MSB). The LSB and MSB can also be interchanged depending on the endianness of the Controller.

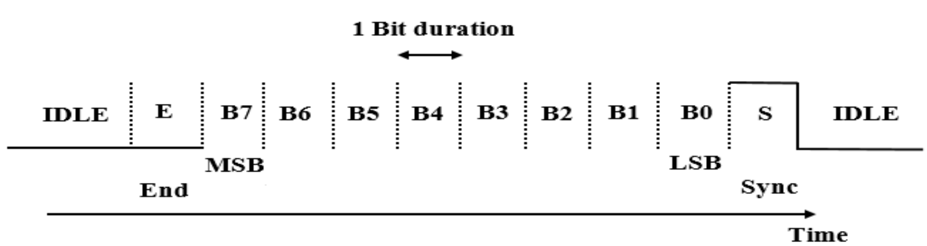


**Figure 5:** Light Communication Transceiver Interface Bit Format

The same bit format appears on both the transceiver interface signals OOP and OIP. Whenever no bit is transmitted on OOP, the signal line is in IDLE mode indicated by Logic 0 state electrically and LED/LASER OFF state optically. The transmission of a pack of eight bits starts with a S bit indicated by Logic 1 state electrically and LED/LASER ON state optically for one bit duration. The Sync bit is followed by LSB bit and transmission proceeds till MSB. The bit values are indicated by Logic 1 (or Logic 0) state electrically and LED/LASER ON (or OFF) state optically for one bit duration. The transmission of a pack of eight bits ends with an E bit indicated by Logic 0 state electrically and LED/LASER OFF state optically for 1 bit duration. The S bit and E bit are Sync and End bits, respectively. The same discussion holds true for OIP signal line.
The transceiver is parameterized by the following four equations:

$$1\,\text{timer tick duration} = \frac{\text{clock prescaler}}{\text{crystal frequency}} \quad (1)$$

$$\text{timer overflow ticks} = 2^{\text{timer length}} - \text{Timer Register (TR) value} + \text{overhead} \quad (2)$$

$$\text{bits per second} = \frac{1}{\text{timer overflow ticks} \times 1\,\text{timer tick duration}} \quad (3)$$

$$8\,\text{bits pack per second} = \frac{\text{bits per second}}{10} \quad (4)$$

For ½ bit duration sampling, (2) becomes

$$\text{Timer Register (TR) value} = 2^{\text{timer length}} - \frac{\text{timer overflow ticks}}{2} + \text{overheads} \quad (5)$$

For receiver, the bits received from optical receiver after signal conditioning has to be sampled in the middle of bit duration. In order to prototype the light communication transceiver signals, an 8051 microcontroller platform was selected.
The 8051 embedded C source code for transmission of eight bits pack on OOP signal line is shown in figure 6. The function send8bitpacket( ) takes an 8-bit data d and transmits it on OOP which is mapped on to pin P0.0 with the transmission clock provided by the function timer0func( ). T0H and T0L are values loaded into the timer registers. Here, simplest form of light intensity modulation scheme is used.
The 8051 embedded C source code for reception of eight bits pack on OIP signal line is shown in figure 7. The function receive8bitpacket( ) receives an 8-bit data d on OIP which is mapped on to pin P0.1 with the reception clock provided by the function timer0func( ). T0H and T0L are values loaded into the timer registers. Here, simplest form of light intensity modulation scheme is used. The incoming bits are sampled in the middle of bit duration. Once an S bit is detected, the Controller waits for middle of bit duration and samples subsequent bits thereon.

```c
#include <reg51.h>
#define S 1
#define E 0
sbit OOP = 0X90;

void send8bitpacket(unsigned char d)
{
    unsigned char i;
    OOP = S;
    timer0func(T0H, T0L);
    for(i = 0; i < 8; i++)
    {
        if(((d >> i) & 0X01) == 0X01)
            OOP = 1;
        else
            OOP = 0;
        timer0func(T0H, T0L);
    }
    OOP = E;
    timer0func(T0H, T0L);
}

void timer0init(void)
{
    TMOD = 0X01;
}

void timer0func(unsigned char T0H, unsigned char T0L)
{
    TL0 = T0L;
    TH0 = T0H;
    TR0 = 1;
    while(~TF0);
    TR0 = 0;
    TF0 = 0;
}
```

**Figure 6:** Light Communication Transceiver Interface Transmission Embedded C Code

```c
#include <reg51.h>
#define S 1
#define E 0
sbit OIP = 0X91;

unsigned char receive8bitpacket(void)
{
    unsigned char i, d;
    while(~OIP);
    timer0func(T0H, T0L);    //half-bit sampling
    if(OIP)
    {
        i = 0;
        do
        {
            timer0func(T0H, T0L);
            if(OIP == 0X01)
                d = d | (0X01 << i);
            else
                d = d | (0X00 << i);
            i++;
        }while(i < 8);
        timer0func(T0H, T0L);
    }
    return(d);
}

void timer0init(void)
{
    TMOD = 0X01;
}

void timer0func(unsigned char T0H, unsigned char T0L)
{
    TL0 = T0L;
    TH0 = T0H;
    TR0 = 1;
    while(~TF0);
    TR0 = 0;
    TF0 = 0;
}
```

**Figure 7:** Light Communication Transceiver Interface Reception Embedded C Code

In 8051 platform, the crystal oscillator frequency recommended is 11.0592 MHz and internal clock prescalar value is 12. Timer register is of 16 bit length[1]. Hence equation (1) becomes

1 timer tick duration = 1.085 μs (6)

The transceiver prototype was tested for 240, 480 and 960 packs of eight bits per second. When implementing this transceiver in software, compiler overheads are to be taken into account. By conducting various trials, the overheads have been identified for transmission and reception clock as shown in table 1.

**Table 1:** Overheads in Timer Overflow Ticks

| Bit Duration | Clock Overhead Ticks |
|---|---|
| 1 | 46 |
| 1/2 | 18 |

Equations (2), (3) and (4), and various values of eight bit pack per second as 240, 480 and 960 result in Tables 2 and 3.

**Table 2:** 8051 Timer Values for 1 Bit Duration Clock

| 8 bits pack per second | T0H | T0L |
|---|---|---|
| 240 | 0XFF | 0XAE |
| 480 | 0XFF | 0X6E |
| 960 | 0XFF | 0XCE |

**Table 3:** 8051 Timer Values for 1/2 Bit Duration Clock

| 8 bits pack per second | T0H | T0L |
|---|---|---|
| 240 | 0XFF | 0X52 |
| 480 | 0XFF | 0XB2 |
| 960 | 0XFF | 0XE2 |

## Conclusion:

8051 Embedded C code was written for prototyping optical transceiver interface signals. Keil IDE for 8051 was used to compile the code and perform the simulation. Implementation was done on 8051 circuit designed using Proteus Design Suite. The same was implemented on two 8051 development boards to test light transmission and light reception. It is found that it is feasible to implement a low-cost transceiver for light communication using a simple processor consisting of a timer and two registers.

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