A remote monitoring system has been designed and developed for continuous monitoring of electrical energy consumption of a consumer from a remote station. The output pulse rate of digital energy meter, which is the measure of instantaneous energy consumption at the consumer end, is retrieved from the instrument via suitable optical coupling. The retrieved electrical pulses are sent from the transmitter end as optical pulses emitted from narrow beam visible laser (wavelength, $\lambda = 638$ nm) to the distant receiver end. The received optical pulses at the remote monitoring station are converted to equivalent electrical pulses and then the instantaneous pulse rate of the same (i.e. instantaneous frequency) is converted to equivalent instantaneous voltage via suitably designed frequency to voltage converter. Thus at any instant, the average value of the instantaneous voltage output of the receiver provides the measure of the instantaneous electrical energy consumption at the consumer end. The average voltage output is calibrated accordingly to provide direct measure of the instantaneous energy consumption. The system is tested for several transmitters to receiver distances to evaluate its ranging capability. A repeater circuit has also been proposed to increase the range of transmission and to construct beyond line of sight communication links.

**Keywords**
Free Space Optics, Instantaneous Electrical Energy Consumption, Remote Monitoring System, Smart Meter

**I. Introduction**
The foundation of basic concept of smart grid was emerged in the mind of electrical engineers towards the end of the 20th century [1]. Since the early 21st century, due to the great stipulation of electrical energy in most of the countries, the power consumption monitoring and control of grids as well as consumer ends have become almost indispensable. Some earliest deployments of smart grids include the Italian System Telegestore (2005), the mesh network of Austin, Tenas (since 2003) and the smart grid in Boulder, Colorado (2008) [2]. Smart grid system uses the benefit of modern advanced electronic communication technology for both way information transfer between power grid or consumer end and remote monitoring system. Remote power consumption monitoring system generally prefers wireless data communication instead of its guided (wired) counterpart. Radio frequency (RF) links are most common for communication between smart meters [3] and remote monitoring station. This is required in an electrical grid, which is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centres and distribution lines that connect individual customers [4]. A general layout of electricity network is shown in Fig. 1(a), where the voltages and depictions of electrical lines are typical for Germany and European systems. Smart meters, capable of transmitting measurement related data and receiving control instructions from the remote monitoring station and competent to respond according to the control instructions, have to be installed at each customer ends. The remote monitoring can control station can acquire the level of power consumption by the consumer from the transmitter data by the respective smart meter (forward link) and send complete or partial turn on or shut down commands to the customer and (smart meter) via the backward link; and the relevant smart meter can respond accordingly (Fig. 1(b)).

Free Space Optics (FSO), which is also synonymous with Optical Wireless or Laser com (i.e. Laser Communication), is an emerging technology using modulated Optical beams to set up short, medium or long range wireless data transmission [5]. FSO communication links transmit information by laser light generally in infrared (IR) spectrum through free space or atmospheric channel. Consequently these communication systems are immune to electromagnetic interference (EMI), jamming or wire-tapping. The FSO systems can be installed within considerably shorter span with much lower cost as compared to their wireless radio counter parts, making them worthy for short-term installations for events, military purposes and disaster recovery, thus due to the immense suitability associated with FSO communication systems (a few of those are already mentioned), the development and performance improvement of the same for several defense and civilians applications have attracted the attention of modern researchers now-a-days. Several advantages of FSO links over existing RF based point to point wireless communication systems have influenced the authors to design and implement the FSO communication links between the consumer smart meters and remote monitoring cum control station.
In this paper, the designed has been made and developed and finally experimentally realized for a remote monitoring system for continuous inspecting the total instantaneous electrical energy consumption in a consumer premises from a remote monitoring station. The output pulse rate of measuring digital energy meter, which is the measure of instantaneous energy consumption, is retrieved from the instrument via suitable optical coupling. The retrieved electrical pulses are sent from the transmitter end as optical pulses emitted from narrow beam visible red laser having wavelength of 638 nm to the distant receiver end. The received optical pulses at the remote monitoring station are converted to equivalent electrical pulses and then the instantaneous pulse rate of the same (i.e. instantaneous frequency) is converted to equivalent instantaneous voltage via suitably designed frequency to voltage converter. Thus at any instant, the average value of the instantaneous voltage output of the receiver provides the measure of the instantaneous electrical energy consumption at the consumer end. The average voltage output is calibrated accordingly to provide direct measure of the instantaneous power consumption.

II. Design and Implementation of the Transmitter and Receiver Circuits

The schematic of the proposed transmitter circuit is shown in Fig. 2. Basically the transmitter circuit is consisting of four units, such as (i) power supply unit, (ii) optical pulse sensing circuit, (iii) pulse reshaping circuit and (iv) laser driver circuit. The power supply unit uses one centre tap step down transformer (TR1: 230 V, 50 Hz (primary), 16V – 0 – 16V, 50 Hz (secondary), 500 mA maximum secondary current), bridge rectifier (consisting of 4 diodes: 1N4004), shunt capacitor filters, positive 12 V (IC7812) and negative 12 V (IC7912 regulators. The power supply unit provides ±12 V DC bipolar regulated supply; however, only +12 V DC supply is required for the present transmitter circuit, but the −12 V DC supply is kept in the designed system for the further enhancement. The optical pulse sensing circuit is basically an inverting amplifier made of IC741 op-amp, designed to operate at saturation mode to ensure the undistorted recovery. A high speed Silicon PIN diode (BPW34) suitably reverse biased with 4.7 KΩ pull up resistor is used for optical pulse sensing from the energy meter blinker. A bistable multivibrator circuit made of IC555 timer is used to reshaping and smoothening of the electrical pulses (equivalent to the sensed optical pulses from the blinker) obtained from the output of the optical pulse sensing circuit. Capacitor coupling is used between the optical pulse sensing circuit and pulse reshaping circuit. Finally a laser driver circuit made of CL100 bipolar junction transistor and suitable resistors (1 KΩ base resistor to provide sufficient base current during on-state and 560 Ω collector pull up resistor in series with the laser diode to ensure high on-state collector current through it). Red laser ML520G71 is used as the optical transmitter which is supposed to emit narrow beam red (λ = 638 nm) light pulses through the appropriate optical arrangement as shown in fig. 2.

The schematic of the proposed receiver circuit to recover the transmitted optical pulses via laser beam at the distant monitoring station is shown in fig. 3. The receiver circuit is consisting of three different units, such as (i) power supply unit, (ii) optical pulse sensing circuit and (iii) frequency to voltage converter (F to V converter) unit. The power supply unit is the ±12 V DC bipolar regulated supply, similar as that of the transmitter. Again the receiver optical pulse sensing circuit which is used to convert the optical pulses from the transmitted laser beam to equivalent electrical pulses is similar as the optical pulse sensing circuit at the transmitter end. The above said circuit is coupled with the F to V converter circuit via capacitor coupling. The F to V converter
A circuit based on IC555 timer based bistable multivibrator is used to convert the instantaneous pulse rate of the received pulses to equivalent instantaneous voltage. Finally that instantaneous voltage rectified and properly filtered to get the average value of it, which can be measured via digital voltmeter at the output. Thus at any instant, the average value of the voltage output displayed in the voltmeter is the measure pulse rate of the digital energy meter blinker at that instant; which intern leads to the remote monitoring of the amount of electrical energy consumption at the transmitter end at any instant of time, since the pulse rate of the energy meter blinker at any instant is the measure of the energy consumption at that instant.

PCB layouts of the designed transmitter and receiver circuits are sketched via “EAGLE 5.10.0 Light” software. After obtaining the layouts, both the PCBs are prepared and then the components are carefully soldered on those PCBs. Finally the FSO transmitter and receiver modules are made ready to carry out the experimental measurements.

![Fig. 2: The Proposed Transmitter Circuit](image1)

![Fig. 3: The Proposed Receiver Circuit](image2)

### III. Experimental Measurement

Both the indoor (absence of sunlight) and outdoor (presence of sunlight) experimental measurements have been carried out in SKFGI, Mankundu, WB, India. During each and every measurement, the transmitter laser and receiver PIN diode are carefully aligned to avoid any experimental error corresponding to misalignment [6]. For simplicity, the blinker of the energy meter is constructed artificially by means of a BJT based LED driver circuit and a low power green LED. The LED is made blinking at different pulse rates by providing square wave of 50% duty cycle of different frequencies from signal generator to the LED driver circuit. That blinking green LED is optically coupled with the PIN diode of the transmitter circuit. Initially the frequency response of the trans-receiver system (i.e. \(20 \log_{10}(V_{pp}/V_{max})\) vs. \(f_{p}\); where \(V_{pp}\) is the peak to peak amplitude of the received pulse, \(V_{max}\) is the maximum value of the peak to peak amplitude of the received pulse) is obtained in absence of sunlight (i.e. dark indoor condition) for different transmitter to receiver distances (\(L_d\)) and experimental set up is shown in fig. 4 for \(L_d = 1\) m.

The frequency response of the FSO trans-receiver module in the absence of day light for different transmitter to receiver ranges (i.e. 1, 10, 30 and 50 m) are shown in fig. 5 (a). It can be observed from fig. 5 (a) is that, the 3 dB bandwidth (BW) of the system decreases significantly as the distance increases. This is due to the highly dispersive nature of the air medium, which is more pronounced at higher frequencies, i.e. when the pulse width becomes shorter. Also the incident optical power density on the PIN diode detector decreases significantly especially for longer distances, since the
diverging nature of the transmitted laser beam is observed due to inadequate optical arrangement at the transmitter end. That is why performance degradation of the system is obvious for longer range of transmission. The frequency response of the system is also obtained in presence of day light (outdoor condition) but not shown in the present paper. However the direct exposer of the Si PIN diode at the receiver end is avoided by using suitable optical filtering arrangement. Variations of the 3 dB BW of the system with transmitter to receiver distances during both day (BW_d) and night (BW_n) times are separately obtained from the respective frequency response plots and shown in fig. 5 (b). It is noteworthy from fig. 5 (b) that, in the presence of sunlight, the BW of the system slightly decreases; this is due to the interference of sunlight with the laser beam at the detector end. In fig. 5 (c), the bar graphs represent the decrement of bandwidth (ΔBW = BW_n − BW_d) due to the presence of sunlight during day time for different transmitter to receiver distances. It can be observed from fig. 5 (c) that, the performance degradation of the system due to sunlight interference is more pronounced for longer transmitter to receiver distances.

Finally the average values of the receiver output voltage (V_av) are measured for different transmitted pulse rates (f_p) via digital multi-meter (kept in voltmeter mode) and the corresponding plot of the V_av vs. f_p are shown in fig. 6. Linear region of the graph (Fig. 6), i.e. up to f_p = 2 KHz represents the functioning region of the system. Since the inverting amplifier, i.e. the optical pulse sensing circuit in the receiver circuit is designed to operate in saturation mode and the linear region of the graph remains well below the upper cut-off frequency of the system up to 50 m (maximum L_d = 50 m under consideration), that is why received pulses are always have the saturation value (i.e. V_pp = V_max) within these range. That is why, no change in V_av vs. f_p plots has been observed for the transmitter to receiver distance up to 50 m. If practically the energy meter at the consumer end (i.e. at the transmitter end) has the specification of x pulses/KWh, then at any instant of time transmitted or received pulse rate of f_p is equivalent to energy consumption (EC) = (3600f_p/x) at that instant. Generally most commonly used standard energy meters in India...
have the specification of 3200 pulses/KWh. Thus the scale of the EC is shown in the upper side x-axis of fig. 6 for energy meters having 3200 pulses/KWh specification. Using this scale, EC at the consumer end at any instant of time can be obtained from the average value of the voltage output shown in the voltmeter at the receiver end (i.e. at the remote monitoring station). The system is capable of scrutinizing up to 2.25 MWh instantaneous energy consumption (i.e. up to \( f_p = 2 \) KHz); limitation in high frequency operation of F to V converter used in the present design is responsible for that. However, since this system is designed for monitoring of domestic energy consumption, thus 0 – 2.25 MWh instantaneous EC range is quite adequate.

Moreover, the circuit same as the transmitter circuit (Fig. 2) may be used as regenerative repeater for beyond line of sight simplex FSO links. The PIN diode will sense the optical pulses coming from the transmitted laser beam, converted to equivalent electrical pulses and finally the same is reshaped before retransmitted in forward direction via red laser beam once again. Thus the range of the system can be increased as much as required by using a number of regenerative repeaters within the communication path. Even the laser beam propagation path can be suitably directed in any direction by using one or more regenerative repeaters; thus line on sight limitation of FSO links can be easily avoided.

**IV. Conclusion**

An attempt has been made to design and experimentally realize a remote monitoring system based on simplex FSO link for continuous scrutinizing the total instantaneous electrical energy consumption in a customer residence from a distant station. The average voltage output at the receiver end is scaled accordingly to provide direct measure of the instantaneous energy consumption at the consumer end. The proposed system is capable of monitoring up to 2.25 MWh instantaneous energy consumption at the consumer end; which is fairly adequate for domestic energy consumption. The system is tested for several transmitters to receiver distances to evaluate its ranging capability. A repeater circuit has also been proposed to increase the range of transmission and to construct beyond line of sight communication links.

**References**


