Integration of LED chip within patch antenna geometry for hybrid FSO/RF communication

J. Liao, A. Mirvakili, A. Boryssenko, V. Joyner and Z. Rena Huang

A free space optical (FSO)/radio frequency (RF) dual mode communication transmitter using a LED integrated within the geometry of a planar patch antenna on a shared substrate is demonstrated. An experimental FSO link is constructed with a bare die visible LED and a commercial silicon photodetector. The antenna radiating at a centre frequency of 10 GHz, provides a simultaneously operated backup RF channel for the FSO data communication link to enhance reliability. A date rate of 20 Mbits is achieved for the FSO data communication.

Introduction: With the rapid advancement of information technology, the traditional RF communication system no longer meets the data security, low power, and high bandwidth demands for the next generation of wireless communications. In recent years, there has been increasing interest in using solid-state lighting devices, namely light emitting diodes (LEDs) for high data rate indoor free space optical (FSO) communication [1, 2]. A hybrid RF/FSO system that combines the inherent advantages of both RF and FSO technologies is considered the solution for ubiquitous wireless data broadcast and networking for the future.

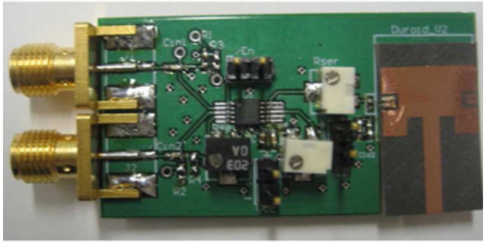
In this Letter, we report our prototype of an integrated LED/RF transmitter module, a core hardware designed as one of the possible options for the future hybrid FSO/RF wireless network. The prototype consists of a bare die LED with peak radiation at $\lambda = 660$ nm for high data rate FSO communication. The LED is placed on the same substrate within the geometry of the patch antenna to create a miniaturised LED/RF package. The RF channel can either work as the backup data link for FSO transmission or operate simultaneously with the FSO link to create redundancy and achieve carrier-grade reliability. Herein, we present the detailed analysis of the cross-channel coupling between the LED driver circuit and the electromagnetic radiation from the patch antenna.

RF/FSO transmitter: Prior work presented in [3, 4] demonstrated a RF/FSO package built upon a modified quasi-Yagi antenna. As the maximum directivity of the quasi-Yagi antenna is parallel to the substrate and requires a modification to radiate normally to the antenna PCB, a planar patch antenna with its main lobe orthogonal to the shared substrate is more suitable for the integration of surface-emitting LEDs.

The radiation element of a standard planar patch is modified to accommodate the co-integration of the LED chip as well as minimisation of the cross-channel coupling between the LED circuit and the antenna device. The length and width of a standard patch are tailored to excite the fundamental mode (TM_{010}) only [5]. A 3D full wave electromagnetic simulation package (HFSS from Ansoft) is used for the antenna design. The length of the patch is 8.20 mm, and the width is 11.86 mm. Two openings are cut along either the non-radiation edge or the radiation edge of the patch. Two contact pads (17 μm Cu film) of 1.5×0.5 mm are placed at the openings to accommodate the LED integration. The bare die LED (Epitex C660-30) is mounted to one of the contact pads using epoxy (SEC 1233 from Resinlab), and wire bonded to another pad, as shown in Fig. 1*a*. The bonding wire is 1 mil gold wire with an estimated length of 0.8 mm.

The substrate of the modified patch antenna is RT/Duroid 5880 with thickness of 0.8 mm, dielectric constant of 2.2 and loss tangent of 0.0009 at 10 GHz. The patch antenna is mounted to a four-layer FR4 PCB using Loctite Hysol 608 epoxy adhesive. The LED driver circuit is mounted on the PCB with output connections wire connected to the optical device bonding pads to deliver modulated current to the LED. The LED is DC-coupled to the driver circuit with a series resistor to dampen oscillations owing to parasitic inductances. The driver circuit chip (Micrel SY88922V) with a bipolar current-steering output stage offers differential input data control to reduce common-mode noise and operates up to 2.5 Gbits with separate modulation current control. With a power supply of 3.3 V, this driver module is capable of driving a peak current of up to 30 mA, which is suitable for the operation of the LED in this research. The photo of the RF/FSO transmitter is shown in Fig. 1*b*.

a



b

Fig. 1 *Photo of packaging of LED on patch antenna substrate, and FSO/RF transmitter board*

a Packaging of LED on patch antenna substrate
b FSO/RF transmitter board

Measurement results: The data rate of the FSO channel of the RF/LED transmitter is tested using a 100 MHz silicon photodetector. The differential inputs to the LED driving circuits are $2^{14} - 1$ pseudorandom bit sequences (PRBS) generated by a pulse pattern generator (Agilent 81110A). The modulated 660 nm LED output beam is collimated and coupled to the silicon photodetector with a communication distance varying from 10 cm to 2 m. The waveform and the eye diagram are displayed on an oscilloscope (Agilent DCA-J 86100C). The patch antenna is fed with a CW 14 dBm signal at 10 GHz from a high frequency analogue signal generator.

The eye diagrams of the FSO data channel for a communication distance of 2 m at a date rate of 20 Mbits is shown in Fig. 2. Theoretically, a FSO data link can achieve more than 100 Mbits in a typical indoor environment [6]. The bandwidth of the FSO data link of this work is limited by the rise time of the Epitex LED device. For future work, a small area visible LED will be employed for high-speed testing of the indoor FSO communication link.

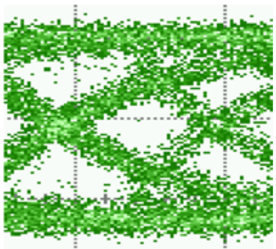


Fig. 2 *Measured eye diagram for 20 Mbits FSO data link at communication distance of 2 m when antenna simultaneously powered on at power level of 14 dBm at 10 GHz*

Cross talk analysis: As the LED is placed inside the patch antenna geometry, there is inherent electromagnetic coupling from the antenna radiation to the LED through the package leads, bonding wires, and contact pads located in the near-field region of the patch antenna. The antenna induced noise current is mainly affected by the position and dimension of the bonding wires and pads. In the analysis, a 0.8 mm length of the 1-mil gold bonding wire and 1.5×0.5 mm bonding pads are used for simulation.

Using Ansoft HFSS, we computed the coupling when the LED contact pads are placed at the non-radiation edge as well as the radiation edge of the patch. As the position of the contact pads affect the return loss of the antenna, the patch size is tuned to maintain a fixed resonance peak frequency. An induced noise current of 1.14 and 4.05 μA is observed in the optical circuits when the contact pads are placed along the non-radiation edge and radiation edge, respectively. This result agrees with the excited electric field distribution of the patch antenna, where the maximum E-field of 1.25×10^2 V/cm is obtained at the centre along the radiation edge, and the E-field goes to zero at the centre of the non-radiation edge. The LED is driven at 20 mA peak-to-peak modulation current, which is much larger compared to the antenna radiation induced noise. Fig. 3 plots the antenna radiation coupling to LED contact pads characterized by S-parameters, in which the antenna feed is named port 1, the centre of the non-radiation edge is port 2, and the centre of the radiation edge is port 3. These three ports for S-parameter modelling are labelled in Fig. 3*a*. Simulation results show parameter S_{21} is −25.86 dB at 10 GHz, resulting in 0.26% of the RF power being coupled into the optical driver circuit at the centre of the patch non-radiation edge. The coupling from antenna to optical port at the centre of the radiation edge (S_{31}) is −13.66 dB, which corresponds to 4.3% of the RF power being coupled into the optical driver circuit. Thus, the coupling from the antenna radiation has negligible effect on the LED transmitter at the centre of the non-radiation edge.

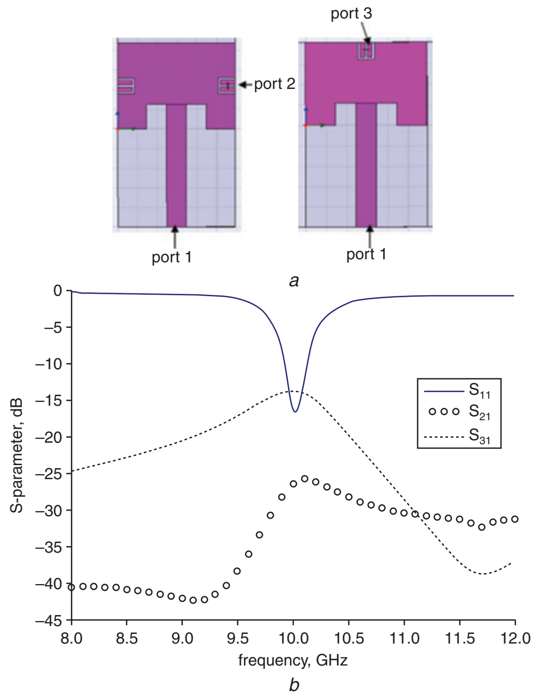


Fig. 3 *Schematics of HFSS model for S-parameter modelling, and crosstalk simulation results*

S_{11} is patch antenna return loss; S_{21} is crosstalk from antenna to optical driver circuit at patch non-radiation edge centre; S_{31} is crosstalk from antenna to optical driver circuit at patch radiation edge centre

Conclusion: To the best of our knowledge, this research presents the first successful demonstration of the integration of a bare die 660 nm LED within a patch antenna geometry on a shared substrate. A FSO data communication link at 20 Mbits with a signalling distance of 2 m is achieved while the RF antenna is simultaneously powered on at a power level of 14 dBm at 10 GHz. The coupling from the antenna radiation to the LED circuits is analysed, revealing that the induced noise current has a negligible effect on LED operation.

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One or more of the Figures in this Letter are available in colour online.

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