Visible Light Communication for Advanced Driver Assistant Systems

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Abstract — VIsible light communication for advanced Driver Assistant Systems (VIDAS) is an outdoor application using the visible spectrum of light emitting diodes (LED). A simple traffic light set up based on LED traffic lights for traffic information transmission has been analyzed in this paper. Various important design parameters have been optimized through intensive investigation based on gain variation over 100 m of transmission range. This process is expected to simplify the front-end receiver design and enhance the performance of the receiver which is one of the most critical elements in a visible light communication (VLC) transceiver, especially in outdoor applications. Our design results show receiver adaptability for different packet sizes and different distances.

Keywords: HB-LEDs, VIDAS, VLC, wireless optical communication.

I. INTRODUCTION

Visible Light Communication Systems are a novel kind of optical wireless communication, using white and coloured LEDs. The use of visible light as a communication medium is still at a very early stage, compared to what has been achieved in areas like infrared and laser (free space optics). The VLC system using LEDs as light sources has many distinctive features and high potential to be a ubiquitous communication system. The VLC system is expected to undergo rapid progress, inspiring numerous indoor and outdoor applications. With recent advancement in high power coloured and white LEDs, the advantages of Infrared (IR) technology can be explored by VLC systems. In this system white and coloured LEDs can be used for data transmission [1,2] and at the same time provide lighting and signalling functionalities.

White and Coloured LED and High Brightness LEDs (HB-LEDs) devices are being used in large scale in indoor lighting, full colour displays, traffic lights, car lights etc. Fortunately, an intrinsic characteristic of LED is that it is a semiconductor, with high rate switching capabilities, making it possible to extend its usage to data transfer in wireless communications systems. These dual properties make them suitable candidates for traffic safety outdoor applications and a major motivation for project VIDAS.

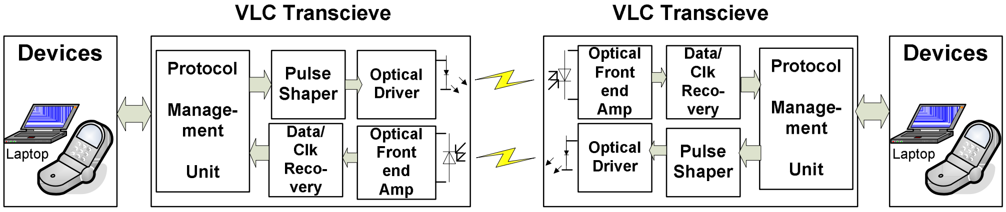

Fig.1. General Architecture for a full duplex VLC System

The present paper addresses the utilization of VLC in wireless Advanced Driver Assistance System (ADAS) which can be referred to as VIDAS. The VIDAS is an advanced outdoor application of VLC to reduce road accident and fatality by transmitting traffic information in advance to running vehicles. The VLC concept can be extended in car-to-car communication. There has been some work on the use of visible light as a communication medium. Akanegawa [3] discussed the use of LEDs for traffic lights. However, our work has differences in techniques of optimizing the design parameters; Pang [2] proposed an optical wireless broadcasting system based on control traffic lights using coloured high brightness LEDs.

This paper presents a brief introduction to VIDAS. Section II presents a conceptual VLC system architecture. The next section discusses optical link design while section IV explains the basic VIDAS system set-up and analysis of design parameters. Results and discussions are presented in section V and section VI concludes the paper.

II. VISIBLE LIGHT COMMUNICATION SYSTEMS

General System Architecture

In this section, we introduce a basic VLC transceiver system using LEDs and photo diodes. The block diagram representation of overall system architecture is shown in Figure 1. Devices such as laptop, mobile phones can be used for transmitting and receiving information signal. The transmitter part consist a modulator and a pulse shaper to switch the LEDs at the rate of data transmission (considering 1Mbps in our case). For optical wireless links, the most viable modulation is intensity modulation (IM) [4], in which the desired waveform is modulated onto the instantaneous power of the carrier. The optical driver is necessary to drive the emitter with sufficient power to obtain long distance communication. The optical signal is then detected and received by VLC receiving system front-end amplifier, whose gain is continuously adapted in order to reduce the effect of ambient and other background light sources. The most

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practical down-conversion technique is direct detection (DD). The modulation method used must offer high robustness to background light. Similarly, the detector is characterized by the parameter, field of view (FOV). For a larger service area, a receiver with a wider FOV is preferable. However, a wider FOV leads to performance degradation because all received signals, including mostly undesired signals, are processed simultaneously.

In addition the system will also need the protocol management unit and data/clock recovery block for the synchronization of received packets corresponding to the received power level.

The data rate in VLC systems is limited by the switching speed of LEDs transmitter. In the outdoor environment, such as VIDAS our aim is to develop a prototype VLC system able to transmit, with a data rate of 1Mbps and showing BER smaller than 10^{-6}. Long distance communication in this case is limited by the transmitted power and background light sources.

III. DESIGNING THE OPTICAL LINK FOR VIDAS

Designing a VLC system is multidisciplinary task as discussed before. Optical channel poses severe restrictions to system components such as necessary optical power and the necessary sensitivity and input dynamic range of the receiver front-end. Achieving high signal to noise ratio (SNR) is very challenging. High emitter power can not be considered because of power consumption and safety related issue. The receiver should have large light-collection area to minimize the path loss. At the same time it must be able to reduce the effect of intense ambient light and other noise source.

A. LEDs Emitter

LEDs traffic light consists of set of LEDs closely wired to fit into the standard traffic light dimension of 200mm or 300mm. Typically LEDs with half power angle (*hpa*) of 15^o to 45^o are used. The emitter is modelled using a generalized Lambertian radiation pattern ($Re(\varphi,m)$)[4]. This assumption allows the modelization of all single-lobe symmetrical emitters. '*m'* is the mode number of the radiation lobe, which specifies the directivity of the emitter and is given by the *hpa*:

$$m = \frac{-\ln 2}{\ln(\cos(hpa))} \qquad (1)$$

Assuming that P_t is the transmitted power, the radiation intensity is given by:

$$R_E(\varphi, m) = \frac{m+1}{2\pi} P_t \cos^m(\varphi); \varphi \in \left[\frac{-\pi}{2}, \frac{\pi}{2}\right] \qquad (2)$$

Figure 2 below shows the polar plot for different mode number of the radiation lobe. It is seen that as '*m*' increases the directivity of radiation increases.

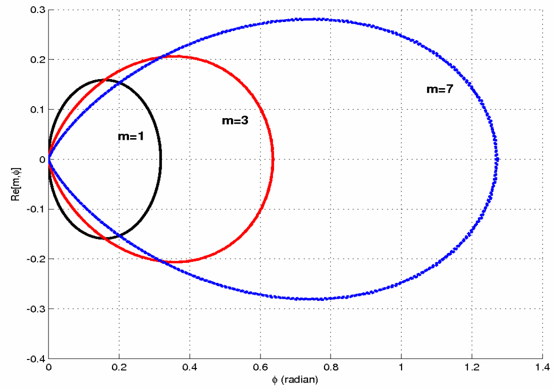

Fig.2. Radiation pattern as a function of '*m*' and '*φ*'

B. The Detector and Front End Amplifier

At the receiver a PIN photodiode converts the optical signal into an electrical current, which is further amplified by a front-end amplifier. In a LOS case, the influence of the directed light is very large which determines mainly the performance of the system. A bare detector achieves an effective signal-collection area of

$$A_{eff}(\sigma) = \begin{cases} A_d \cos(\sigma) & ;|\sigma| < FOV \\ 0 & ;|\sigma| \geq FOV \end{cases} \qquad (3)$$

where A_d is the detector physical area and σ is the angle of incidence with respect to the receiver axis.

The generated photocurrent consists of desired signal current (proportional to the incident optical power); and noise component mostly dominated by shot noise current. Noise contributions are out of the scope of this work. However, future work will address noise problems and receiver front-end design in more details.

In order to meet the requirements of high sensitivity, gain and higher dynamic range transimpedance amplifiers (TIA) with switched feedback network or controlled feedback scheme as shown in fig. 3(a) and (b) are suitable candidates for the front-end receiver. In the design considerations of front-end the trade off between gain and dynamic range plays an important role.

There are two quantities which bound the dynamic input range: i) the front-end sensitivity - the minimum signal that can be recognized considering the presence of noise; and ii) the maximum output signal for which the front-end still exhibits an approximately linear response. The control circuit acts proportionally to the signal level, varying a set of multiple feedback resistors in order to obtain an easily controlled gain. This control scheme operates in such a way that it is effectively outside the signal path for the largest gains, achieving the lowest internal noise for very low input signals.

IV. TRAFFIC SYSTEM SET- UP FOR VIDAS

A simple system set-up of VLC for VIDAS is shown in Figure 4. The LED traffic light emitter is placed at height *h* above ground. The detector is moving towards the emitter with certain speed. The half-power semi angle of LED is 15^o. The receiver is installed on the centre of the vehicle front panel, and it has a vertical inclination of 'θ' and *FOV*. We assume LOS link between the first receiver and LED traffic light transmitter. U_{min} and U_{max} is the range of possible communication with U_{min} being near to traffic point while U_{max} is the starting point from where receiver starts receiving the traffic information. The involved system parameters are given in the table below:

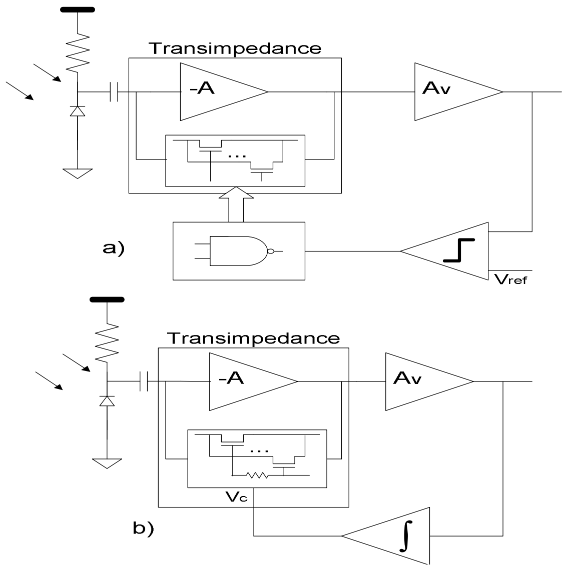

Fig. 3 a) Switched gain strategy b) Controlled feedback strategy

Table-I

Height of the traffic light (m)	h
Distance between emitter and receiver (m)	d
Distance in first lane direction (m)	x
Service area	[Umax,Umin]
Half-power semiangle	hpa = 15º
Angle of Irradiance	φ
Vertical Inclination of Receiver	0≤ϴ≤90º
Field of View of receiver	0º≤FOVc≤90º
Angle of incidence	σ

A. Channel Model

For a LOS configuration the incident power collected by the photodiode at the receiver end, depends on the transmitted power, on the geometry of the system traffic light to car, on the channel attenuation and on the receiver model. A simple model [4] for optical communication can be considered. The LOS case received signal is therefore given by:

$$I = P(t)\frac{m+1}{2\pi}\frac{\cos^m(\varphi)}{d^2}A_d\cos(\sigma)\partial\left(t-\frac{d}{c}\right) \qquad (4)$$

where *d* is distance between transmitter and receiver. The term *∂(t-d/c)* is the delay due to channel propagation. The above equation (4) can be written as function of (x, θ, h, ø) and simple manipulation results in:

$$Hn(\phi,\theta,x,h)=\frac{(m+1)}{2\pi}\left(\frac{\cos^m\left(\frac{\pi}{2}-\tan^{-1}(x/h)-\phi\right)\cos\left(\tan^{-1}(x/h)-\theta\right)}{h^2+x^2}\right) \qquad (5)$$

Optimizing *θ* and *ø* and taking the weighted average of these function and plotting the power loss over the range of *100m* distance, a loss of approximately *20 dB* is noticed as can be seen in Figure 5.

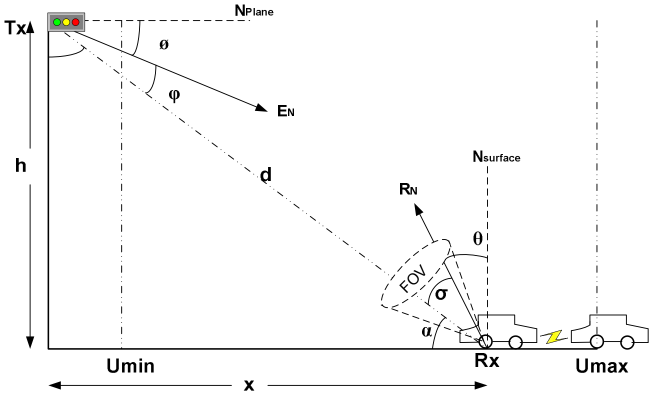

Fig.4. VLC scenario for VIDAS

B. Construction of the Service Area

Definition of service area (*SA*) and optimization of various parameters help in optimizing high performance front-end receiver. Let us assume: Data transmission rate (*Rb* = 1Mbps); packet size (*PS*=100Kb); average velocity of the running vehicles (*V*=50km/h). Vehicles travel approximately 1.39m of distance (call it as packet service area-*PSA*) which is equal to the time required to transmit one packet of data. It is also assumed that the data packet contains the same information i.e. *PS* contains whole information to be transmitted and it is repeated continuously.

If the vehicle starts receiving information from a distance of 100m from the traffic point in the first lane, we can notice the power variation in each PSA which is quite small, can be ignored. But in fact, as the vehicle approaches towards traffic light the power variation is considerable and the receiver must be able to adapt such variation to give necessary output. Since the *PSA* is very small, we can choose a larger unit of distance for the power variation over each 14m (10x1.39=approx 14m) call it as frame service area (*FSA*). The measured variation of power over this distance is given in table-II:

Table-II

FSA (m)	100-86	86-72	72-58	58-44	44-30	30-16	16-6
dB	1.3	1.4	1.9	2.7	3.2	5	3.1

Based on this information, it is possible to design a receiver either for varying packet size over a distance unit or adjusting the gain keeping fixed packet size. We see a sharp variation at very close to traffic point which is because of restricted minimum distance of information transmission. Since in the cases when vehicles stop at traffic point during red signal they maintain for certain distance of *3-4 m.*

V. RESULT AND DISCUSSION

The above analysis is valid and true for a fixed *PS* of *100kb* and adjusting receiver gain with such variation may not be practical. To overcome this, we refine our algorithm and try to find a fixed gain for varying distance. The distance measured in the beginning from the point when vehicle starts receiving is much larger than that near the traffic light.

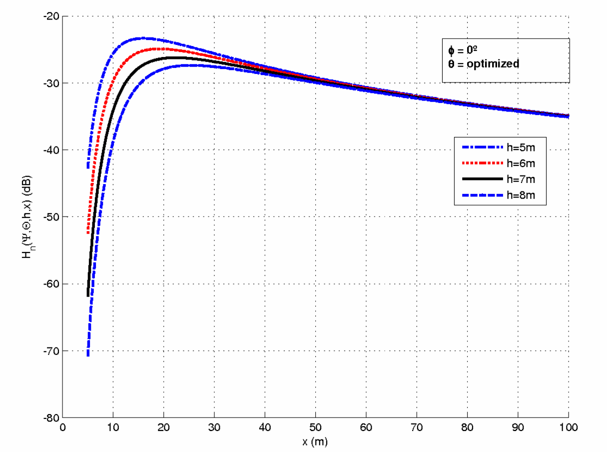

Fig.5. Gain variation over the distance for different values of *h* and optimized *Θ*

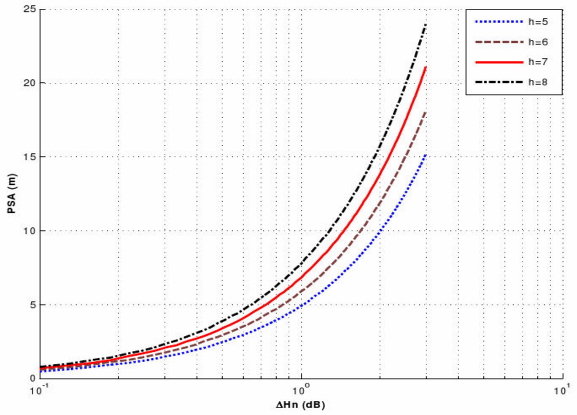

Fig.6. Service área vs gain for different values of traffic height '*h*'

Alternatively it can also be said that the designed receivers should be capable of receiving different packet sizes over the distance which is given by:

$$PS = \frac{(PSA * Rb)}{V}(PSA * Rb) \tag{6}$$

The Figure 6 illustrates this. In addition to this the figure also represents plots for different values of the height of the traffic light. It is seen that the suitable height can be chosen from this results. It is a useful recommendation for future installation of LEDs based traffic light.

Though the measured gain variation over the distance is not large (<20dB) but considering the noise level during day and night and different time of the day, the noise variation is very large. The front end receiver has to adapt these changes.

Our results suggest the optimized parameters especially receiver orientation (angle θ) and the emitter orientation (angle $ø$) which are 81.4^o and 8.6^o respectively. However, presently LEDs based traffic lights are designed with 0^o of emitter orientation. Therefore, we can optimize our receiver orientation but it can serve as a recommendation for manufacturers to make suitable changes in their design in the future. Therefore, the optimized value of receiver still remains the same with reduced gain variation over the distance.

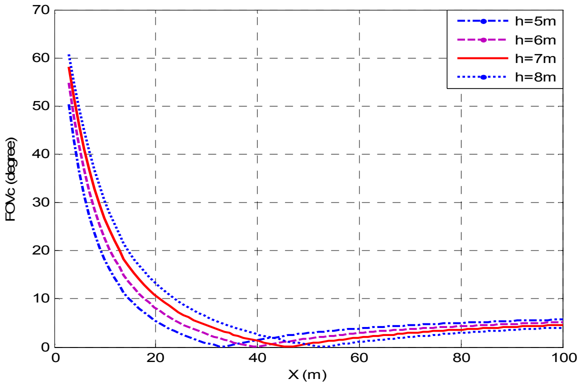

Fig.7. Critical values of *FOV* for different '*h*' over distance

The receiver is characterized by its FOV and there is a critical value of FOV (*FOVc*) which specifies minimum value for selected height of traffic light and distance of information transmission. This is shown in the Fig. 7.

Another interesting parameter to discuss is *hpa* which decides the mode number of radiation lobe in turn the directivity of emitter. It can be seen that the smaller the *hpa* the higher the value of '*m*'. A value of 15^o of *hpa* corresponds to m=20 which is selected as a compromised value in our design. It is also to be noted that most common available LEDs have *hpa* between 15^o-45^o.

VI. CONCLUSION

Various design parameters for a simple set-up of VIDAS have been analyzed in this paper. Analytical and simulation results suggest that we can have different approaches when designing a front-end. However, if a varying packet size is considered, the approach might simplify the design of front-end. As the VLC applications in outdoor especially in traffic light is at very early stage, the important recommendations will prove to be useful for manufacturers and city administrator responsible for installation of traffic lights. Although some of the design challenges have been simplified in this paper, a number of complex issues remain. It is expected that our continuous efforts will bring suitable solutions to this technology.

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