Orientation Effects for LOS and NLOS OWC Characterisation Within Small Structures

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***Abstract*—This paper reports an experimental investigation of the orientation effect towards optical wireless channel parameters within small structures. The experiment has characterised the orientation effect of the line-of-sight (LOS) and non-line-of-sight (NLOS) infrared transmission when using different material and geometrical properties on significant infrared channel parameters. Two measurement setups were used, (1) the straight guiding structures, and (2) bending guiding structures, with three different bending angles (30º, 45º and 60º bend). In each of the measurement, the receiver/transmitter is rotated in the steps of 15˚ each time. The results revealed that the characteristic of the channel depends on the physical geometries, the orientation of the transmitter/receiver and also depend on reflection coefficient of the materials. The results are valid for both LOS and NLOS transmission.**

***Index Terms*—Optical Wireless Communication; Channel Characterisation; Frequency Response; LOS; NLOS.**

I. Introduction

Optical wireless communication (OCW) has become popular using both infrared and visible light [1]-[7], and the utilization of OWC within the vehicle data communication network give huge benefits associated with safety and mobility applications in different settings, especially for the vehicle control information which are transmitted remotely. Since automotive cabling is expensive, massive and may not be flexible for further expansions to the design [8], the signals are potentially be transmitted using wireless channels with high bandwidth, secure and reliable. Research focusing on intra-vehicular wireless communication has attained good response as reported in [9] focused on advanced intra-vehicular applications, which demand stable and reliable connectivity. Therefore, there is a growing level of interest to design OWC within the intra-vehicular system. With that in mind, the practicality and readiness of related technologies have been studied [10]-[15]. The development of steady and dependable wireless intra-vehicular communication networks and standards requires well-defined channel propagation in numerous scenarios [16]-[18].

The use of OWC technology within intra-vehicular settings was proposed by Green et al. [19][20] with an idea of using the vehicle chassis as a potential waveguiding structure, which is excluded from ambient light. A review by Higgins [21] focused on the characteristic of OWC channel within the cabin of a car, where he concentrated on the power and bandwidth distribution in various sections of the vehicle. A study on free-space optical communication links utilising the potential of guiding structures around a vehicle has been carried out by Rihawi et al. [22]. Unfortunately, these articles are based on scientific research and simulation models, so the approximation outcomes are principally not reliable in exploring the stability and trustworthiness of the system.

The outline of intra-vehicular OWC systems needs an in-depth knowledge of light propagation behaviour, especially in the small structures, e.g. hollow tubes. Focusing on the chassis of the vehicle, which will act as the channel waveguides, the transmission medium in this study is characterised by a set of samples for straight and bend tubes, with different geometrical shapes (rectangular and circular cross-sections) and various selected materials. This requires a thorough analysis of the channel within several investigational settings and using various optical configurations. This analysis overlooks a comprehensive knowledge of the channel behaviour, under different settings. In [22], Rihawi has simulated OWC systems which embedded the ray tracing techniques in the rectangular cross-section tubes and concentrated on the distribution of power and bandwidth as well as the path loss. This study reports the experimental investigation which involves various material and geometrical shapes.

This paper is organised as follows: Section II describes the sample studied which acts as the chassis of the vehicle, as well as the experimental setup. Section III reports the experimental findings and discussion. Lastly, concluding remarks are described in Section IV.

II. Experimental Setup

In order to demonstrate that OWC systems can work around bound corners, and to assess the performance of NLOS systems, the impact of diverse tube setups was set as (1) straight tubes, and (2) bending tubes with 30˚, 45˚ and 60˚ bending angles. The experimental environment for LOS transmission comprises of the straight rectangular and circular cross-section tubes at one-meter length as shown in Figure 1. The bend tube samples are as shown in Figure 2. Table I listed the metal tubes properties. This direct detection on-off keying (OOK) OWC system uses low-cost, off-the-shelf transmitter and receiver.

Figure 1: samples of straight tubes.

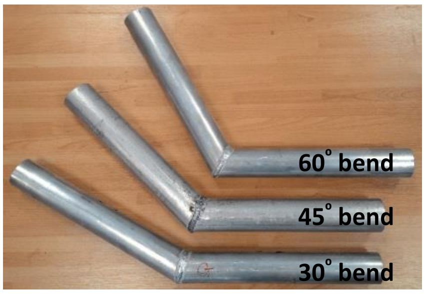

Figure 2: samples of bend tubes.

Table 1
Tubes Sample and Parameters

Items	Material	Dimension	Measured reflection coefficient
C	Circular mild steel tube	35 mm diameter	0.3
D	Square aluminum 6082 tube	40 mm x 40 mm	0.3
E	Square aluminum 6082 tube	20 mm x 20 mm	0.3
F	Circular aluminum tube	20 mm diameter	0.4
G	Circular galvanized aluminum tube	35 mm diameter	0.2
H	Square mild steel tube	40 mm x 40 mm	0.1
I	Free space	(controlled environment)	

III. Findings and Discussion

The study focused on straight and an angled metal tube. Three criteria were reflected to quantify the characteristic of the transmission channel: the frequency response, the optical power, and the optical path loss.

A. *Frequency Response*

Frequency responses of the transmission channel were based on the frequency profiles achieved at 0.5 meters and one-meter separation distances. The LOS link between the transmitter and the receiver was developed to ensure highest received signal could be detected and remained in the same positions throughout the measurement procedure. The outcomes for the transmission at 0.5 metre and one-metre separation distances were determined, as in Figure 3 and Figure 4 respectively. The plot illustrates that the power intensity decreased with an increment of the transmission angle. Comparable trends were found for both setups. Promising received signal was obtained for less than 15˚ transmission angles. As the orientation angle expanded, the optical power detected weakened fundamentally. The optical power intensity is good for the materials with highest reflection coefficient and for smaller cross-sections tube, and vice versa.

Therefore, insignificant misalignment within the LOS setting resulted in a significant loss of optical power. The combination of the reflection coefficient and geometrical property of the material both are assumed to be a critical measure in influencing the detected optical intensity at the desirable end.

If the measured angle is θ, then, the received optical power density, $P_{d_{rec'}}$ could be assumed as:

$$P_{d_{rec'}} \approx A.e^{-k^{\theta}} \text{ watts/cm}^2 \tag{1}$$

where the constants *A* and *k* can be determined for the case of each material and each geometry (the geometry to include the length of the tube and the tube diameter).

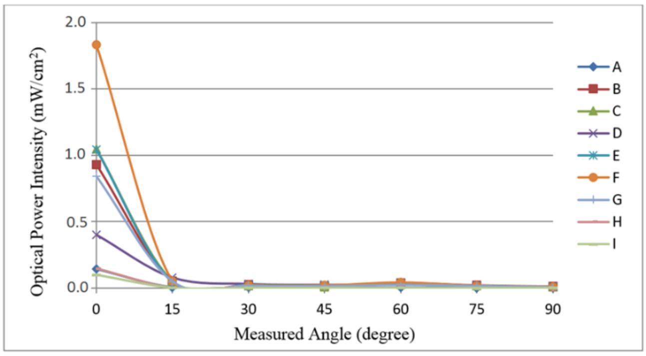

Figure 3: Received power against transmission angle at 0.5-metre separation

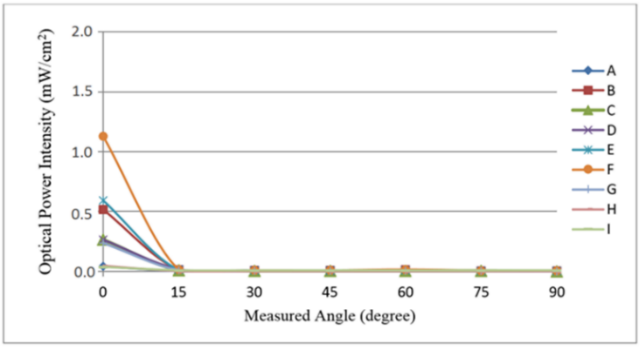

Figure 4: Received power against transmission angle at 1-metre separation

Figure 5 and Figure 6 plot the path losses at 0.5 meter and one-metre separation distance. The path losses have very similar curves for both distances. The path loss increased significantly as the transmitter/receiver angle widen up to 15˚. Then, insignificant increment occurs according to the increase in the distances.

The analysis on the straight tube confirmed that the link demonstrates a considerable susceptibility to the orientation of the transmitter/receiver. The substantial variation between power received and path loss detected within the tubes, at orientation between 0˚ up to 15˚ angles, was identified. No signal was detected for the transmission at more than 15˚ orientation. Based on the setting and material selection, this proved that the field of view of the orientation is limited to 15˚ only.

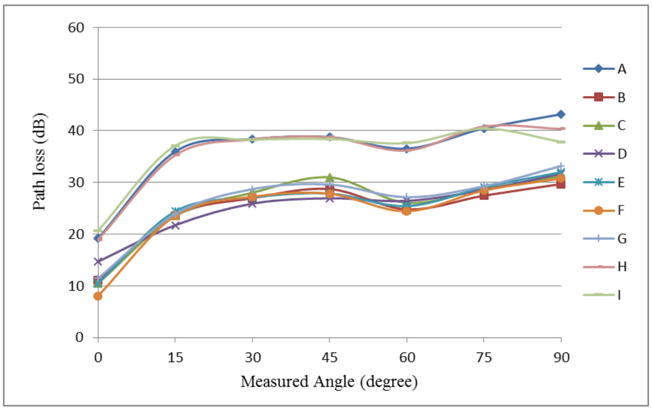

Figure 5: Path loss at a 0.5-metre distance.

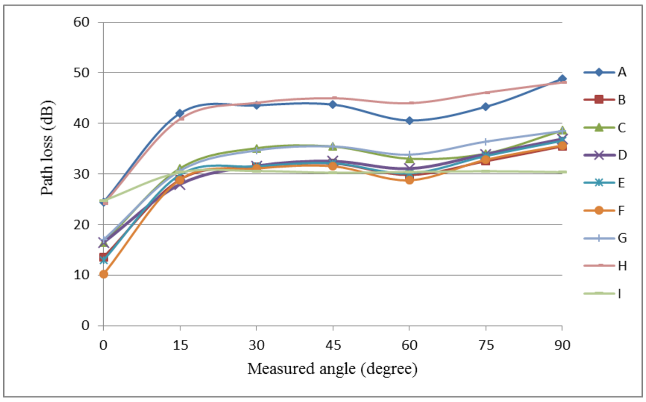

Figure 6: Path loss at a 1-metre distance.

The study focused on aluminium and steel bent tubes, as to imitate a real chassis of the vehicle. A simple experiment, prior to the angle selection stage, was undertaken to establish likely parameters, especially angles and choice of particular materials. Based on the results, three tube configurations, with 30˚, 45˚ and 60˚ bending angles, were selected and fabricated as in Figure 2.

The estimated number of reflections within 20 mm and 40 mm tubes is made based on the geometrical shape of the tubes and Snell's law. Table II lists the estimated number of reflections in each tube.

Table II
Tubes Sample and Parameters

	30˚ bend	45˚ bend	60˚ bend
20 mm tube	8	14	25
35 mm tube	5	8	14
40 mm tube	4	7	12

Figure 7 to Figure 9 shows the normalised response for respective tubes with 0.5 meters and one-meter length. The normalised responses based on the standard dB formula of 20 $\log_{10}(P_r/P_t)$ and were normalised to their respective peak values.

By referring to Table I and the measurement data, the frequency responses of the signal transmitted through tubes E, D, F and G, was manageable to measure. The noise level was higher at the receiver for the rest of the samples, and almost no signal was detected in some of the tubes, although, with the aid of a lense.

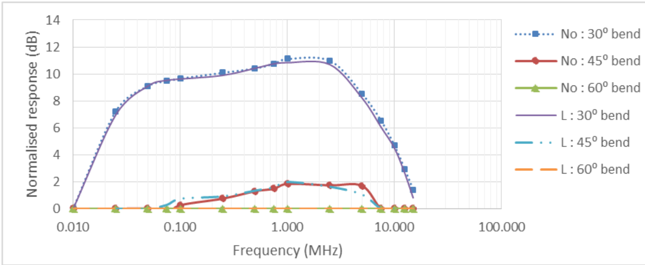

Figure 7: Relative response of square aluminium tube

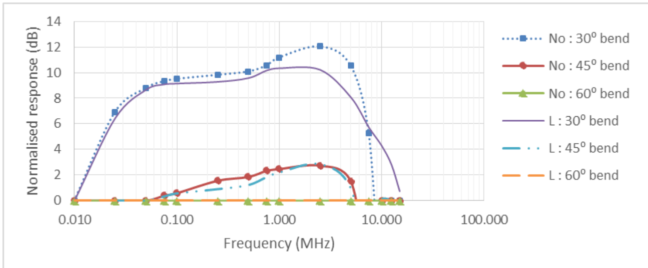

Figure 8: Relative response of circular aluminium tube

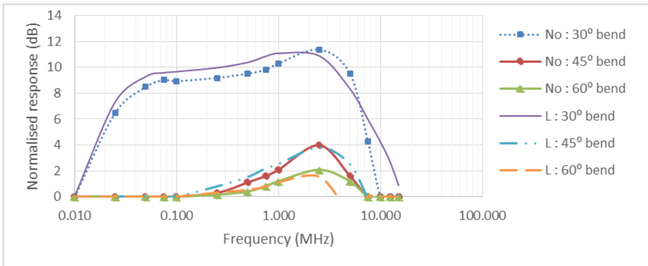

Figure 9: Relative response of circular galvanised aluminium tube

The bandwidth of the designed experiments reduced drastically as the bending degrees increases. At 60˚ bent, no signals were detected except for G. The transmission through 20 mm square aluminium tube is the worst, where no signal was detected for bending angle exceed 30˚. Clearly, the shape of the frequency response at smaller bending angle is almost identical, and the only difference is in the amplitude of the received signal.

B. Received Optical Power and Path Loss

Figure 10 tabulates the received optical signal against the number of reflections within the tubes. It is clearly seen that, as the number of reflections increased, the received optical power reduced. The highest optical power received is within the 20 mm circular aluminium tube at the 45˚ bend. The optical power received was at the lowest value within the 60˚ bend tubes.

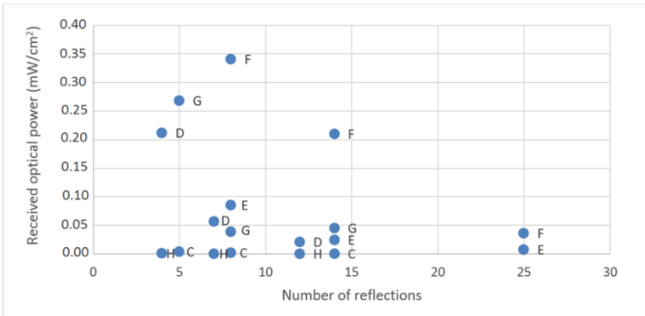

Figure 10: Received optical power plotted against several reflections.

Figure 11 and Figure 12 tabulate the received optical power at 30˚, 40˚ and 60˚ bends using the power meter and the photometer respectively. Figure 13 and Figure 14 plots the path loss at 30˚, 40˚ and 60˚ bends. The measurement demonstrates that the path loss increases as the transmission angle increases. The lowest path loss is for the 20 mm circular aluminium tube. Unfortunately, the received power is too low. The highest received optical power is through D, F and G, at almost the same level. Further, the path loss is the lowest in F, with the measured value of 13.71 dB, followed by G (16.16 dB) and (D (16.64 dB). The path loss increased as the bending angle increased. This concludes that the path loss depends on the dimension, the geometrical shape of the tubes and also the material reflection coefficient, as previously discussed.

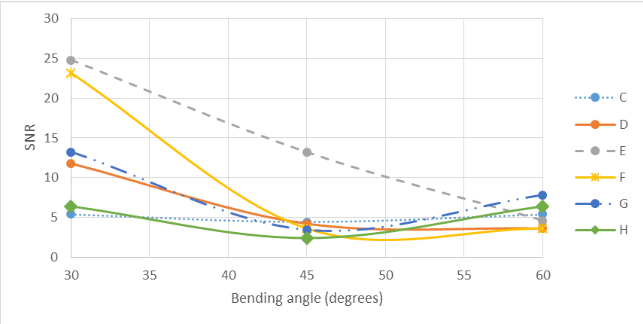

Figure 11: Signal to noise ratio (measured using a power meter)

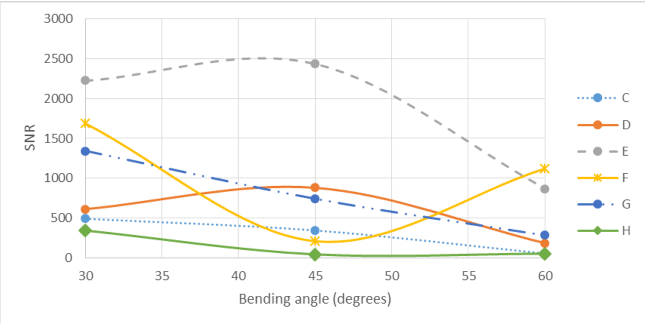

Figure 12: Signal to noise ratio (measured using photo meter)

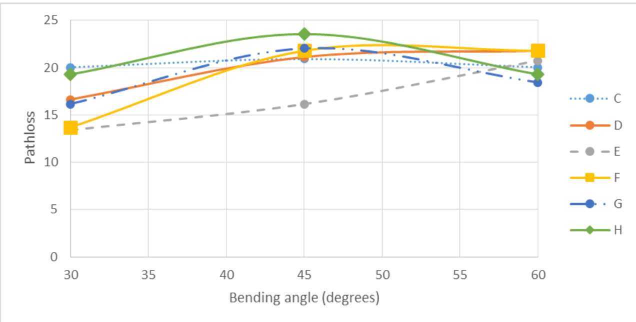

Figure 13: Calculated path loss (based on measurement using power meter)

IV. Conclusion

This paper investigates the properties of the NLOS transmission channel of OWC system focusing on the transmission within straight and bent tubes. The influencing factors were examined in detail integrates the frequency response, optical power received and the path loss.

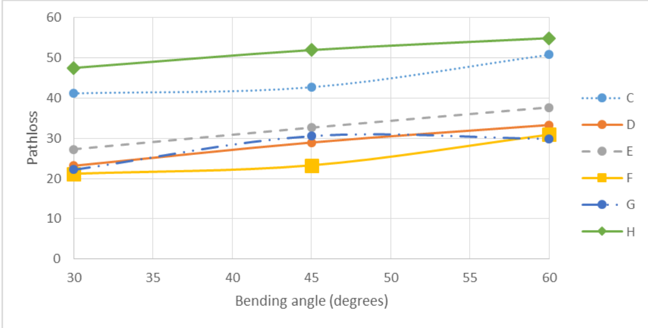

Figure 14: Calculated path loss (based on measurement using photo meter)

The study shows that good transmission is likely to occur within the tubes with transmitter or receiver orientation angle less than 15˚. By means of the orientation angle increases, the signal power detected at the receiving end decreases. As expected, the detected signal power is high for 20 mm square aluminium tube and 20 mm circular aluminium tube. This shows that the smaller tube size in addition to high reflection coefficient properties will have lowest path loss. Path loss is higher at 45˚ and 90˚ orientation angles.

The outcomes are exceptionally unique, with a remarkable sensitivity level to the orientation degree of the transmitter and receiver. There are significant outcomes between the optical received signal at various angles within straight and bent tubes. The effects are valid for the frequency responses and path losses in both testing environments. As the bending angle expanded, the frequency response reduced significantly and the path loss increased.

The findings have also confirmed that the channel properties do not exclusively rely on the dimension and shape of the tubes, but also the reflection coefficient properties. As the number of reflection increases at larger bending angles, the received power is reduced although the tube diameter is small. Small size tube and small bending angle result in higher detected optical power. But then again, bending angle plays the most critical factor in this context. It is expected that the OWC performance in various tubes can be improved by finding the relationship between the tubes geometries with a material with better reflection coefficients.

Acknowledgement

The author would like to thank Centre for Telecommunication Research & Innovation (CeTRI), Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka for the facilities used to complete this project.

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