Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [VLC channel modelling and constraints]
Date Submitted: [19th January 2009]
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Abstract: [A review of channel model and constraints that apply to the optical wireless channel]

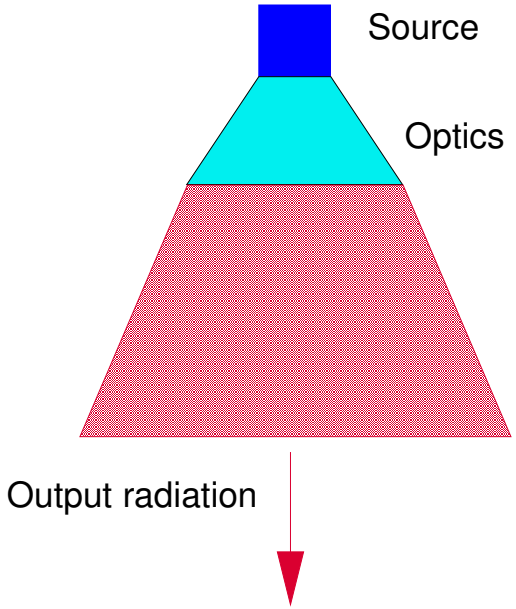
Purpose: [Provide information to the members of IEEE.802.15 TG-VLC]

Introduction

- VLC channel models
  - Constraints
  - Typical link budgets
- The optical channel
  - Modelling
  - Measurement
- Conclusions

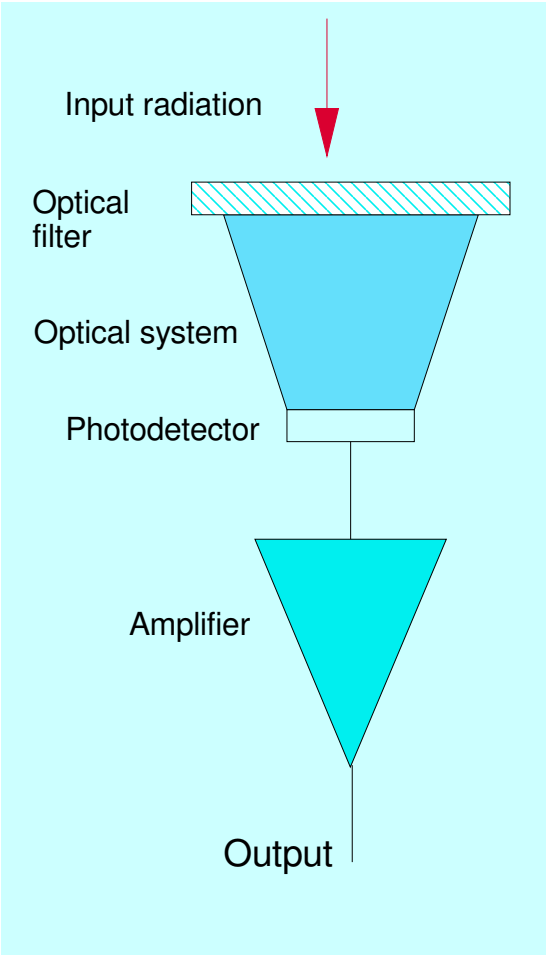
Components: transmitter

- Visible LED
  - Bandwidth constraint
    - ~10MHz or so
- Modulation electronics
  - Constraint at high bandwidth/powers



Optical receiver: introduction

- Receiver consists of
  - Optical filter
    - Rejects ‘out-of-band’ ambient illumination noise
  - Lens system or concentrator
    - Collects and focuses radiation
  - Photodetector (or array of detectors)
    - Converts optical *power* to *photocurrent*
      - Incoherent detection
  - Preamplifier (or number of preamplifiers)
    - Determines system noise performance
  - Post-amplifier and subsequent processing

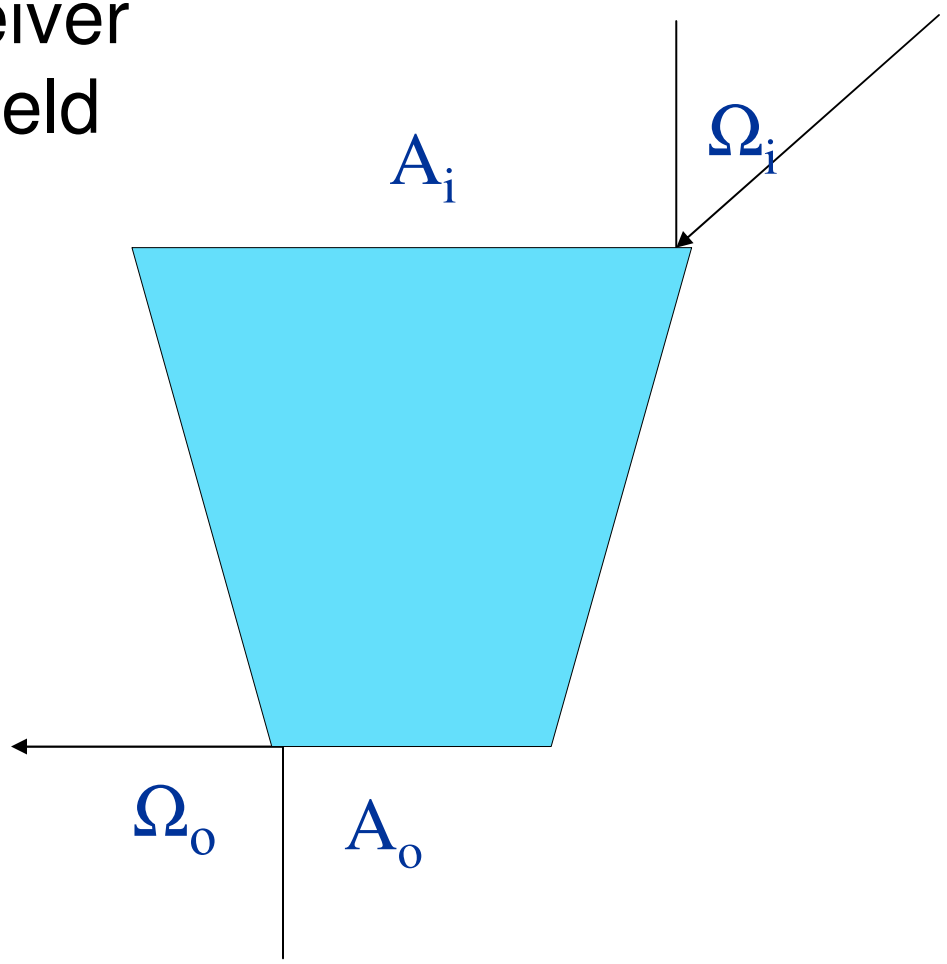


Optical receiver: constant radiance theorem

- Optical 'gain' of receiver limited by required field of view

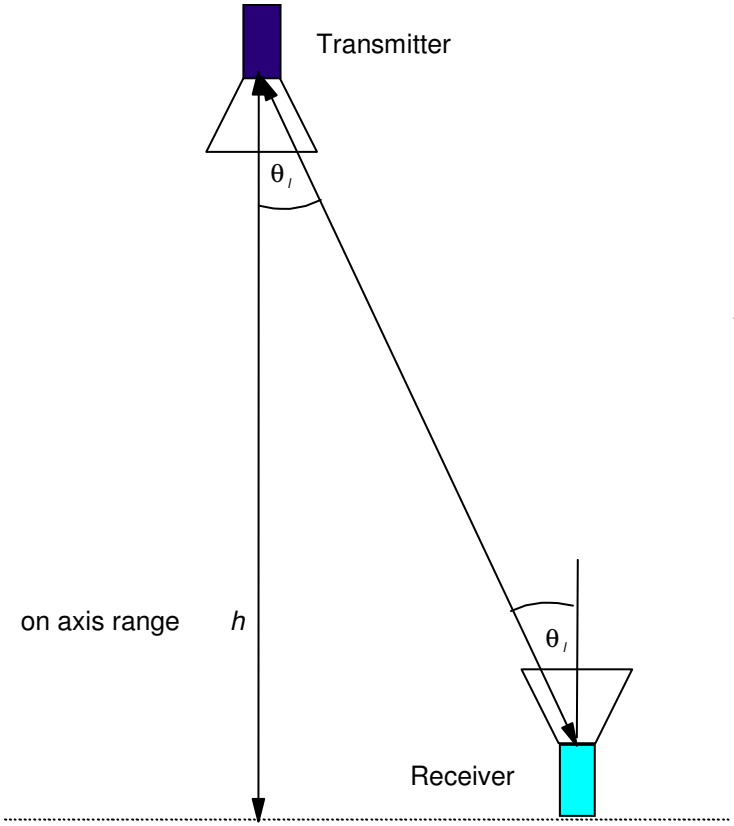
$A_i\Omega_i <= A_o\Omega_o$

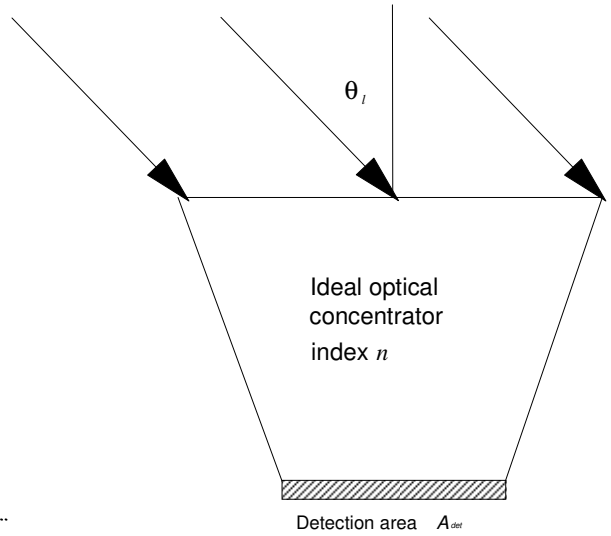
$A_i\Omega_i <= A_o 2\pi$



Channel model: Line of sight channels

- Transmitter emits Lambertian beam
- Worst case is at edge of coverage





Assumptions

- Lambertian source order *n*

$$I = \frac{(n+1)}{2\pi}\left(\frac{\cos(\theta_l)}{h}\right)^2 P_s \cos^n(\theta_l)$$

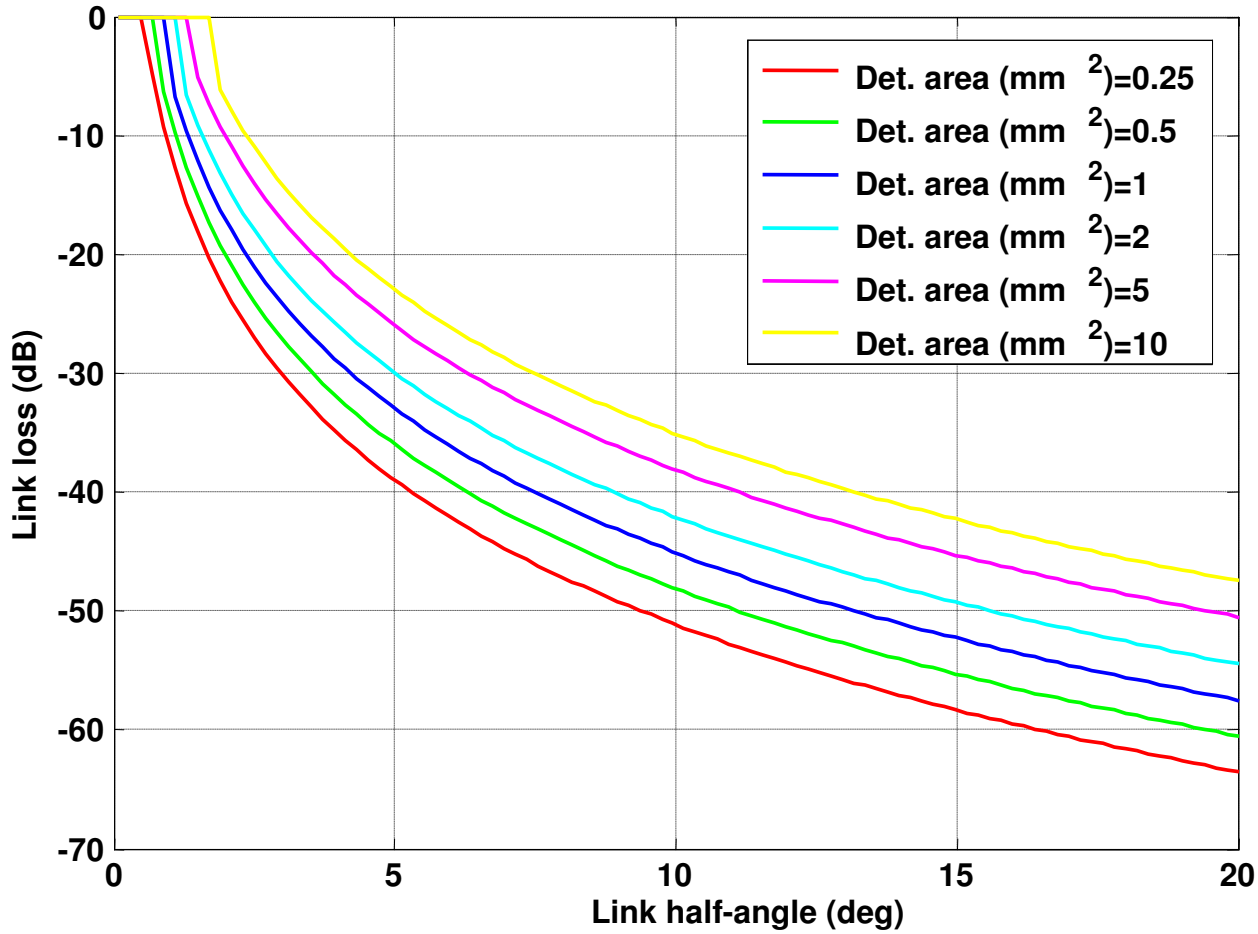
- Ideal optical concentrator index n_c, Detector area A_d, Collection area A_{coll}

$$A_{coll} = \frac{{n_c}^2}{\sin^2(\theta_l)} A_{\det}$$

Line of sight channels: path loss

Link length (h) =3m

Concentrator index=1.5



Diffuse channel

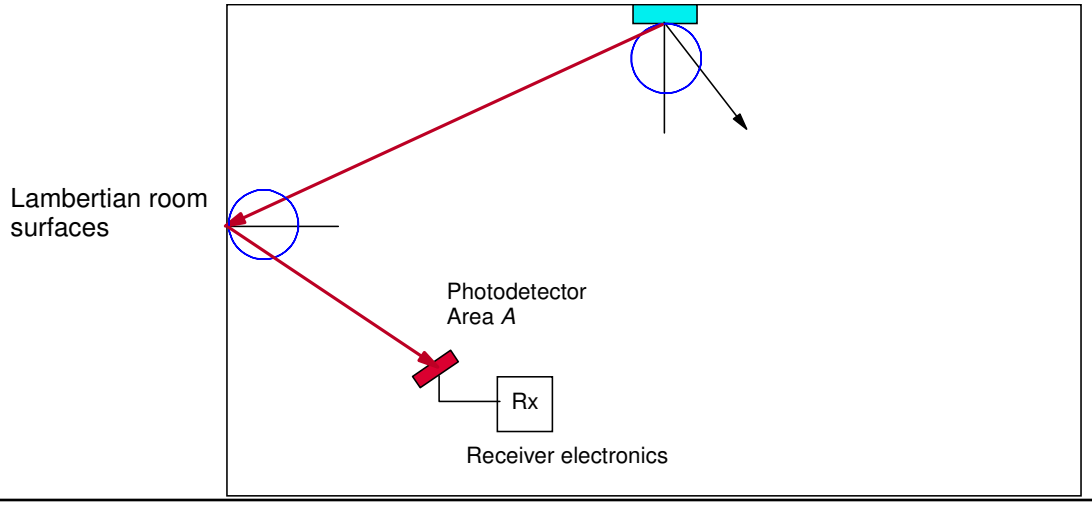
- Two considerations
  - Path loss
  - Dispersion
- Estimation of effects
  - Modelling
    - Ray-tracing
    - Models
      - Integrating sphere[1]
      - 'Impulse response'[2]
  - Measurement

[1]V. Jungnickel, V. Pohl, S. Nonnig, and C. von Helmolt, "A physical model of the wireless infrared communication channel," IEEE Journal on Selected Areas in Communications, vol. 20, pp. 631-40, 2002.

[2] J. R. Barry, J. M. Kahn, W. J. Krause, E. A. Lee, and D. G. Messerschmitt, "Simulation of Multipath Impulse-Response for Indoor Wireless Optical Channels," *IEEE Journal on Selected Areas in Communications*, vol. 11, pp. 367-379, 1993.

Diffuse channel characteristics: power

- For fully diffuse environment
  - Power received a function of 'bare detector' area and radiance within the coverage space only
- Typical losses
  - Literature indicates
    - 60-75dB/cm^2/Sr for propagation up to 4m or so rooms 28-30m^2
    - e.g. 1cm^2 detector (2π Sr field of view) Loss 52-68dB
    - Assume +40dBm modulation -30dBm received power level



Diffuse channel characteristics:bandwidth

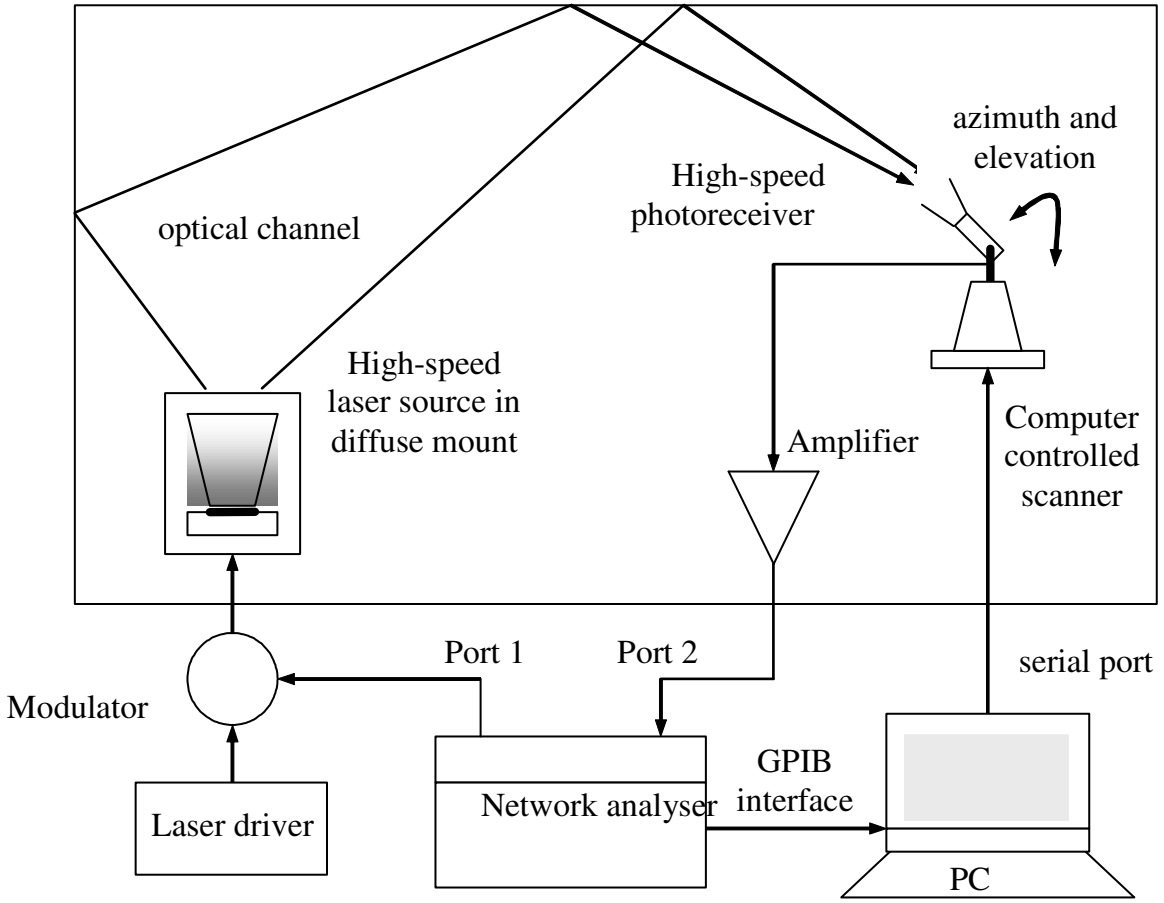
- Bandwidths: 'typical' results from literature
  - 'Rayleigh' type channel
    - All paths approximately same strength-no direct path
    - 10-20MHz for 'square' rooms in range 18-30 m^2
  - 'Rician' channels- case for VLC
    - Strong paths (either LOS or light from a single reflection)
    - Limitation dependent on relative path strength
    - Modelling by Heinrich Hertz Institute[1] indicates >90MHz for typical room

[1] J. Grubor, Randel-S, Langer-Kd, and Waleski-Js, "Broadband Information Broadcasting using LED-based Interior Lighting," *To be published in the Journal of Lightwave Technology,*

Diffuse channel characterisation

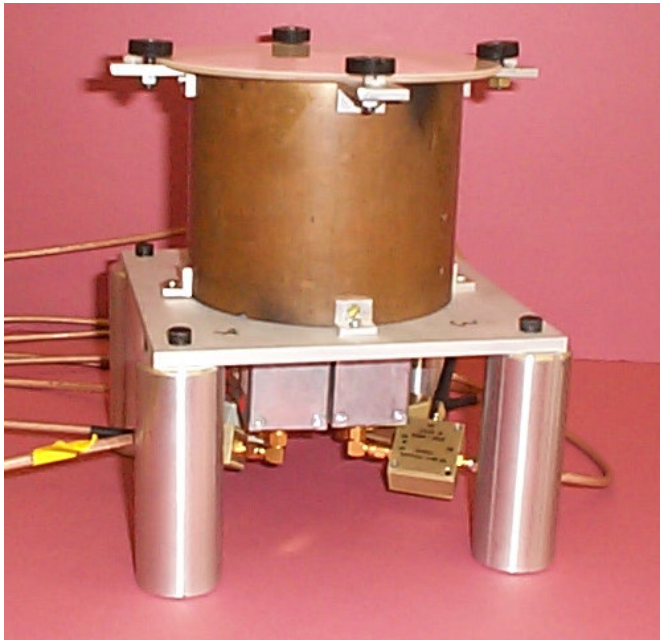
- Require impulse/frequency response
  - Position dependent
- Measurements
  - Typically use swept frequency source
  - Receiver
  - Network analyser
    - Amplitude and phase
    - Bandwidth
    - Multipath effects

Diffuse channel characterisation



Transmitter

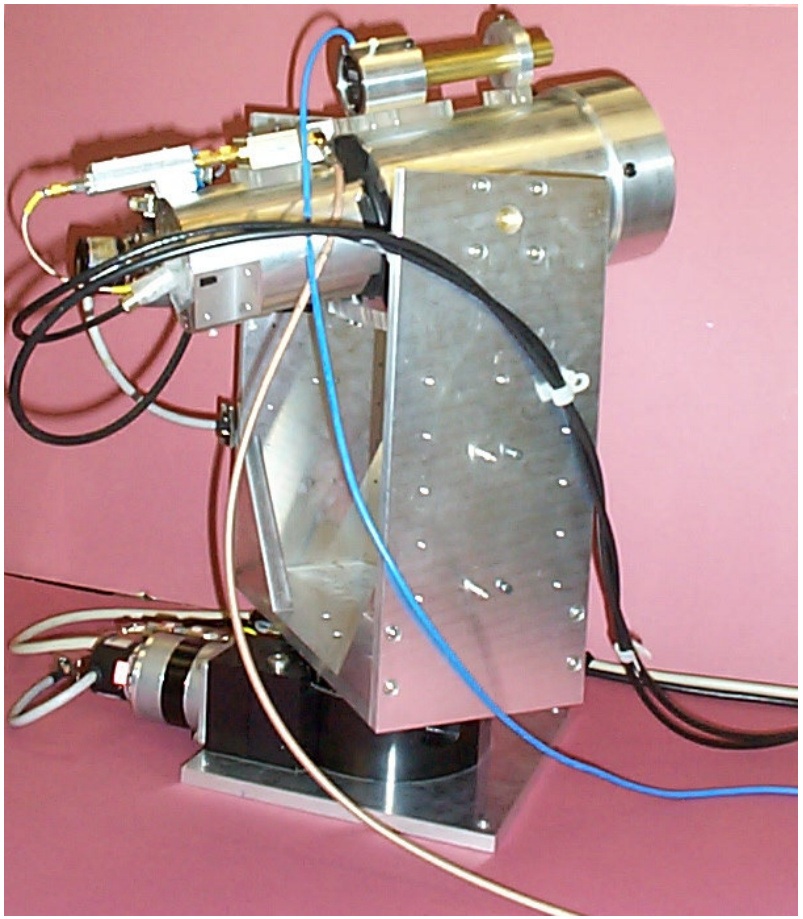
- Four semiconductor laser diodes biased by four laser diode constant drivers
- Operating wavelength of 820 nm
- Near Lambertian source
- Transmit power after the diffuser of +14.5 dBm



Transmitter assembly

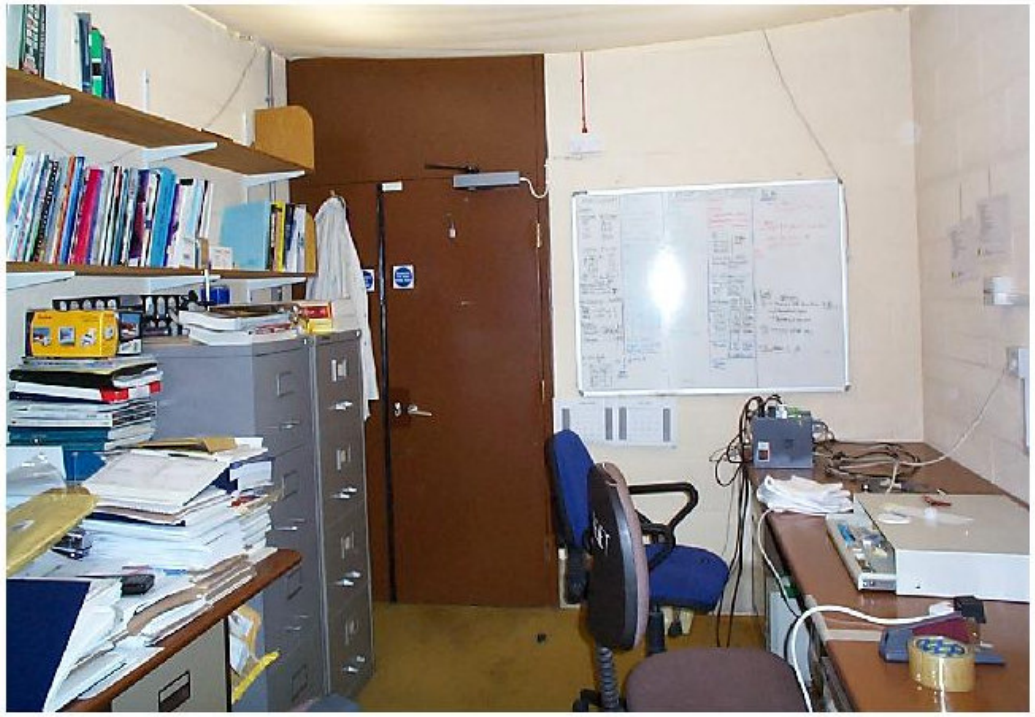
Receiver

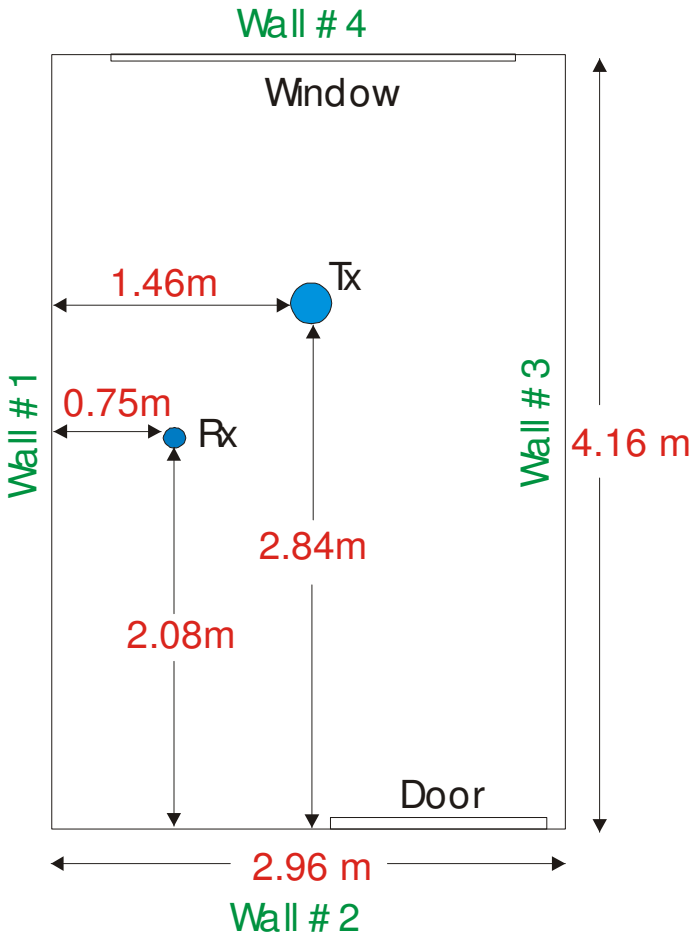
- Field Of View (FOV) 5 degrees
- Detectors
  - Photomultiplier Tube (PMT)
  - (Photek PMT110)
  - Diameter 10mm
  - Responsivity of 18 mA/W at 820nm
  - High bandwidth, low noise, large
  - detector area
- DC power meter with the same FOV



Receiver scanning optical system

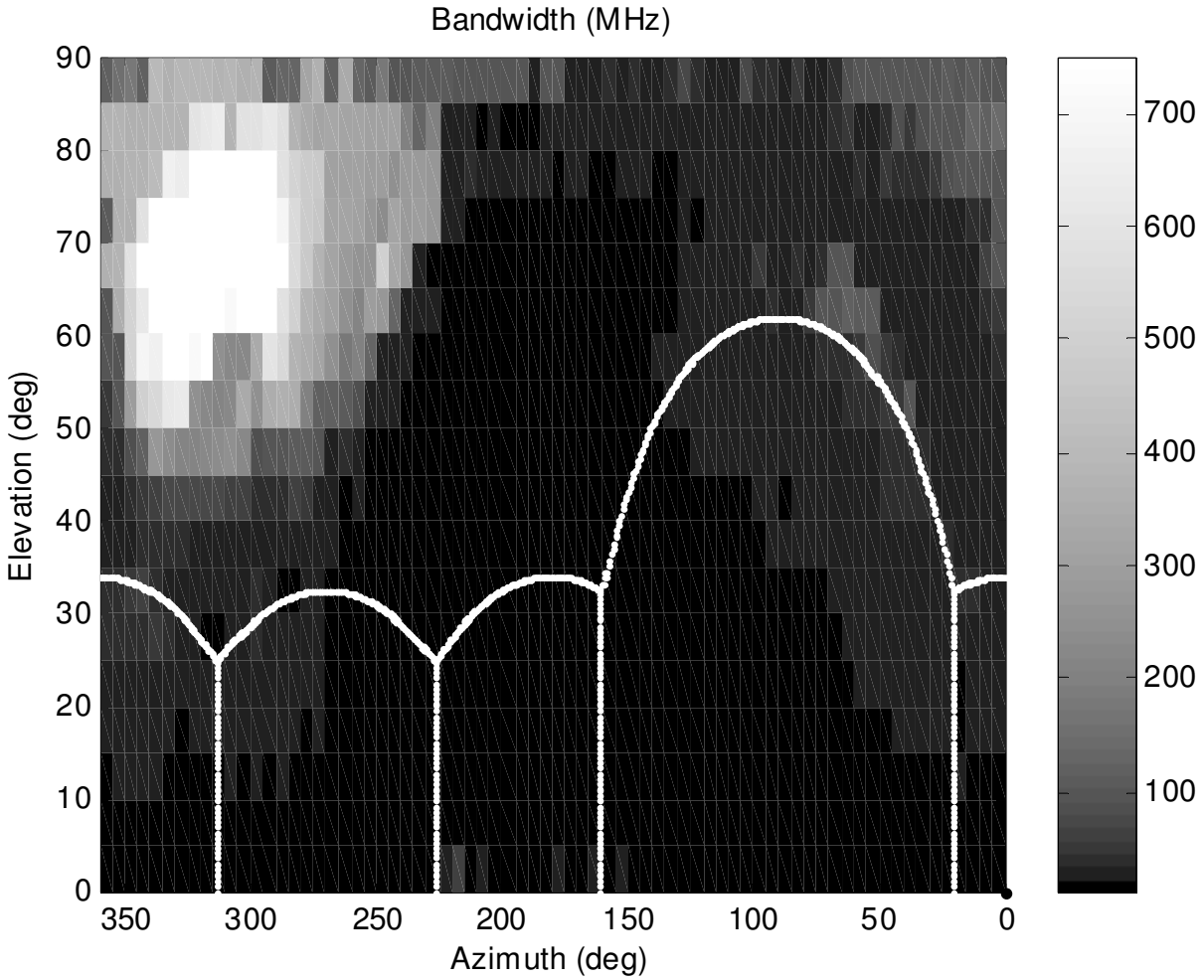
Indoor Diffuse Channel Measurements example





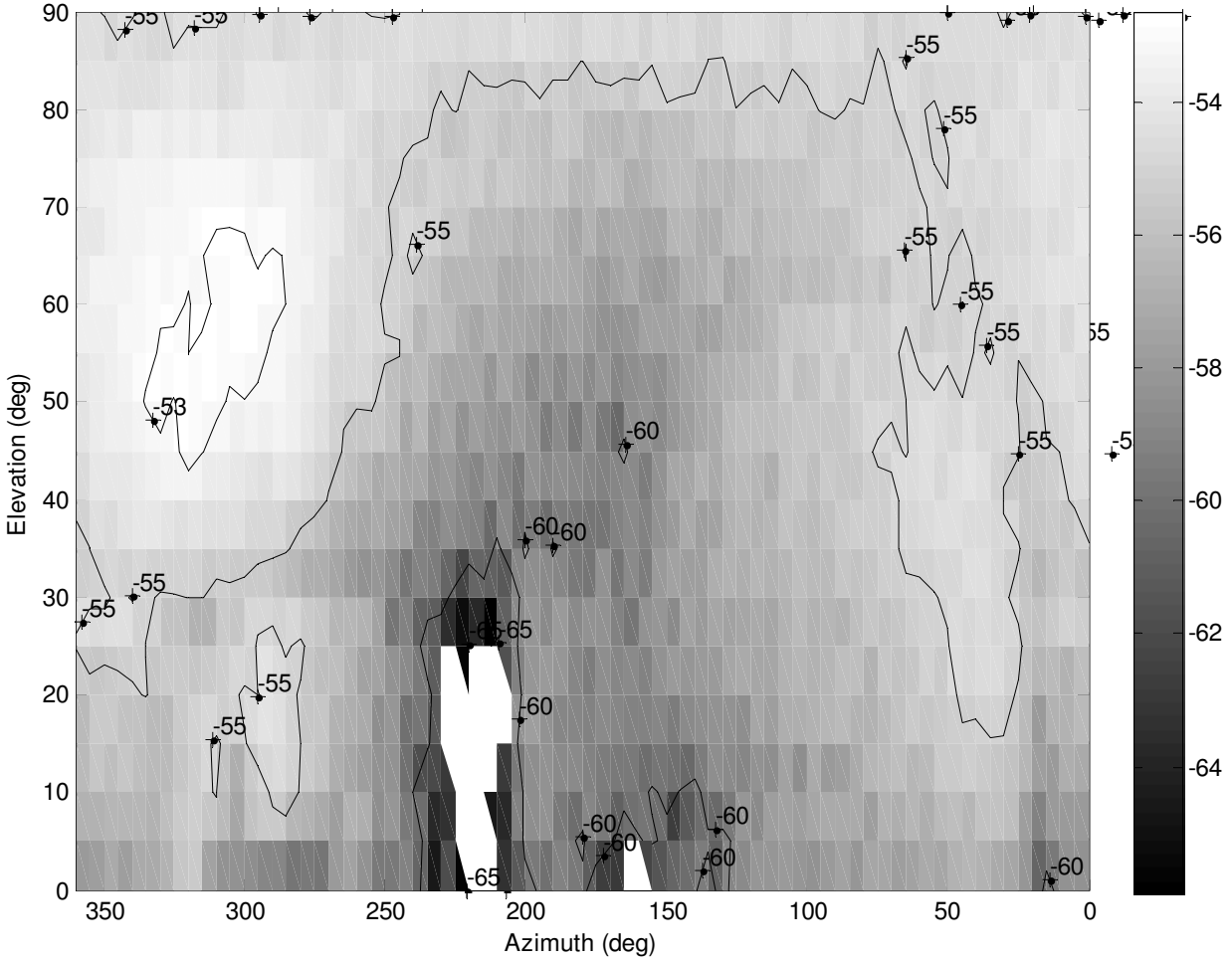
Schematic diagram of the measured room

Results: Bandwidth



Bandwidth map of typical space

Results: Path loss



Loss map of typical space (dB/cm^2/Sr)

Questions for channel model

- Which channel do we want to use
  - LOS
    - Can always ‘see’ a light
      - High SNR
      - Bandwidth ~90MHz
      - Requires LOS
  - NLOS
    - Can work in shadow
      - Possible bandwidth of ~20MHz or so
      - Low received power
      - Robust-should work in any direction
- Combination
  - Might require data rate adaptation

Conclusions

- VLC
  - Link budget constraints
    - Relatively straightforward to obtain figures for typical transmitter power and receiver sensitivity
  - Channel
    - Combination of LOS and diffuse offers robustness
      - Variable data rate
- Possible next steps
  - Survey of transmitter/receivers to obtain worst case
  - Measurements