Project: IEEE 802.11bb Task Group

Submission Title: IEEE 802.11bb Reference Channel Models for Gas Pipelines

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Abstract: This contribution proposes LiFi reference channel models for gas pipelines.

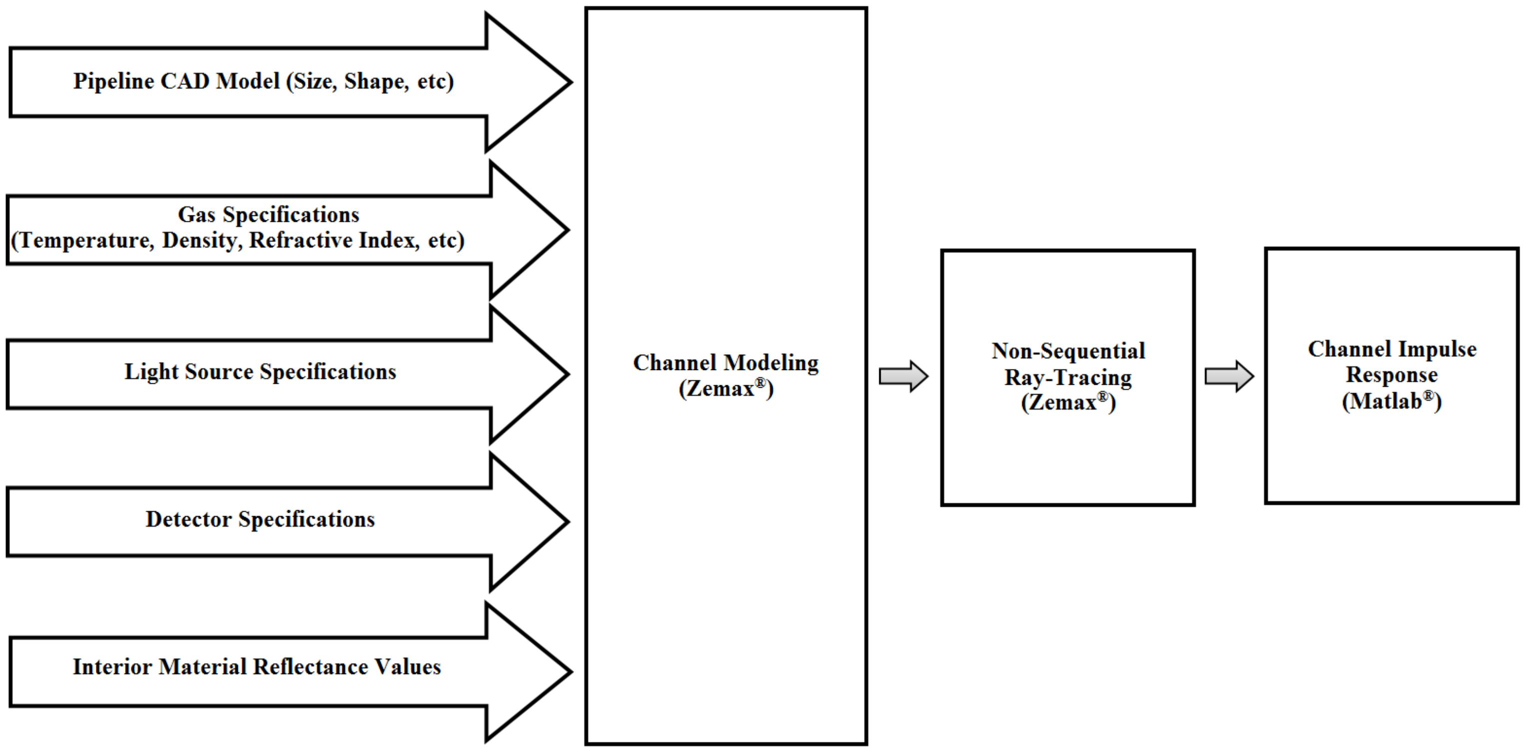
Purpose: To introduce reference channel models for the evaluation of different PHY proposals.

IEEE 802.11bb
Reference Channel Models for Gas Pipelines

Outline

- Introduction
  - Overview of Channel Modeling Methodology
  - Modeling of the Pipeline
  - Modeling of Gas Specifications
  - Source Modeling
- Gas Pipeline under Consideration
  - Channel Impulse Responses (CIRs)
  - Effective Channel Responses
  - Channel Characteristics
- Conclusions

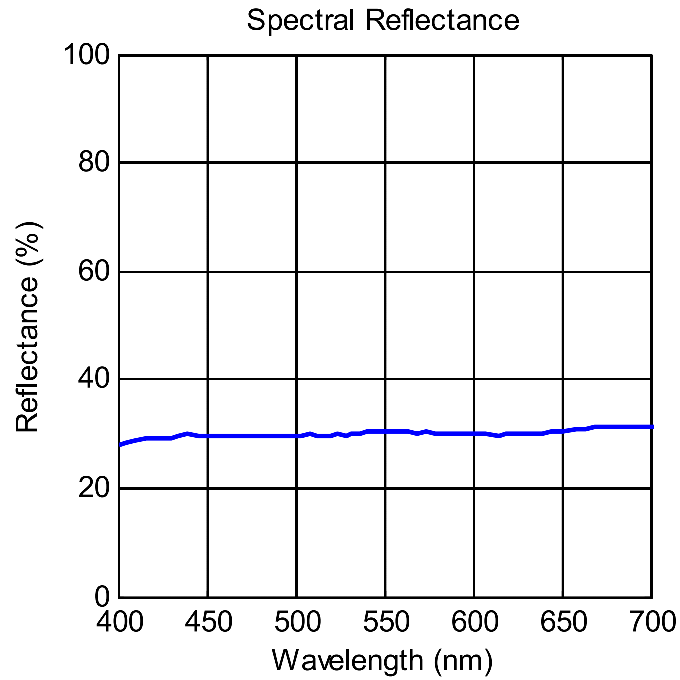
Overview of Channel Modeling Methodology[1]



[1] F. Miramirkhani, M. Uysal, O. Narmanlioglu, M. Abdallah, and K. Qaraqe, "**Visible light channel modeling for gas pipelines**", *IEEE Photonics Journal*, vol. 10, no. 2, pp. 1-10, 2018.

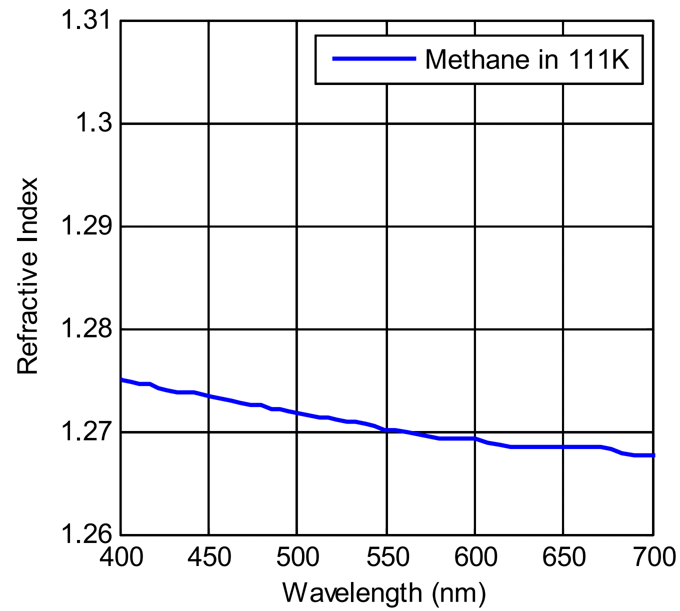
Modeling of the Pipeline

- Creation of 3D pipeline involves the selection of
  - Dimension and shape of the pipeline
  - Type and properties of materials
- The interior of pipeline is considered as carbon steel with spectral reflectance values shown in figure below.



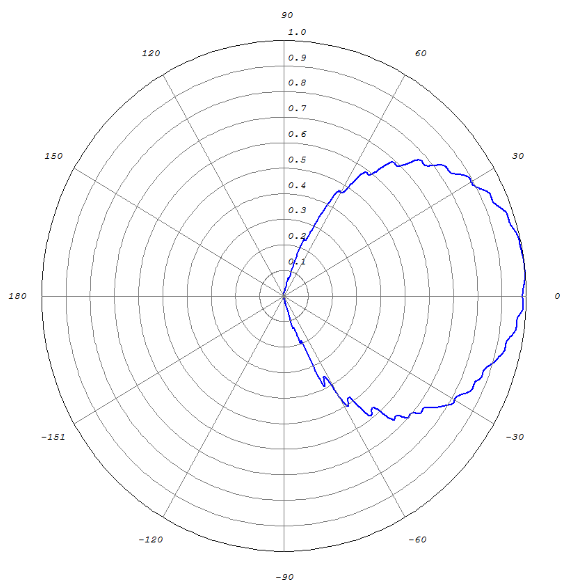
Modeling of Gas Specifications

- Natural gas is composed primarily of methane, but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon dioxide, sulfur compounds, and water may also be found in natural gas.
- Methane is by far the major component over 95% by volume for LNG [2]. Therefore, in our study, we assume the presence of only methane gas in the pipeline. Density, wavelength-dependent refractive index and transmission values of methane gas at 111 K can be found in [3] and [4].
- Through "**Table Glass Method**" [5] in Zemax®, we also define the density, wavelength-dependent refractive index and transmission value of gas in the pipeline. This allows the characterization of interaction of rays with the medium.

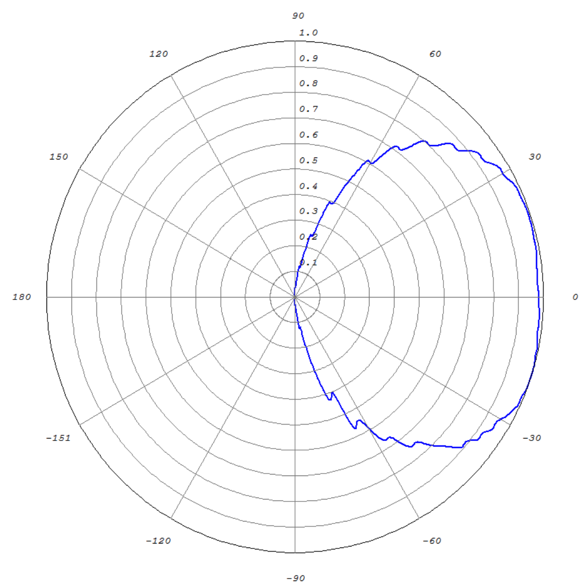


[2] B. G. Liptak, and K. Venczel, ***Analysis and Analyzers: Vol. II***, 5th ed., CRC Press, 2016.
[3] http://refractiveindex.info/?shelf=organic&book=methane&page=Martonchik-liquid-111K.
[4] J. V. Martonchik, and G. S. Orton, "**Optical constants of liquid and solid methane**," *Applied optics*, vol. 33, no. 36, pp. 8306-8317, 1994.
[5] Zemax 13 Release 2, Radiant Zemax LLC. [Online]. Available: http://www.zemax.com/os/resources/learn/knowledgebase/how-to-enter-glass-data-at-specific-wavelengths.

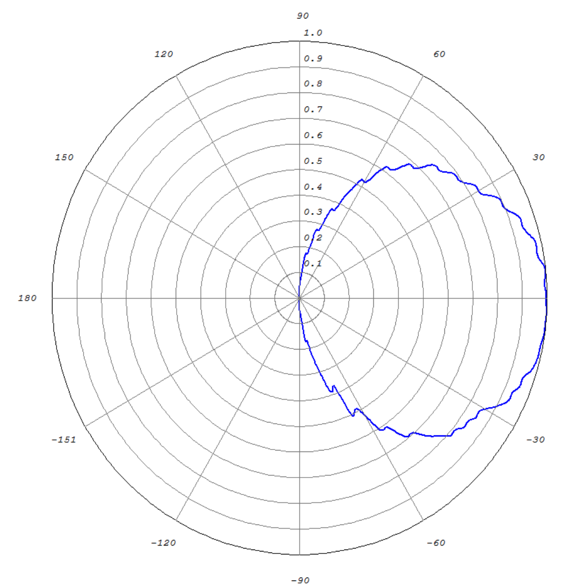
Source Modeling (1/2)



Emission pattern of
white Cree Xlamp MC-E

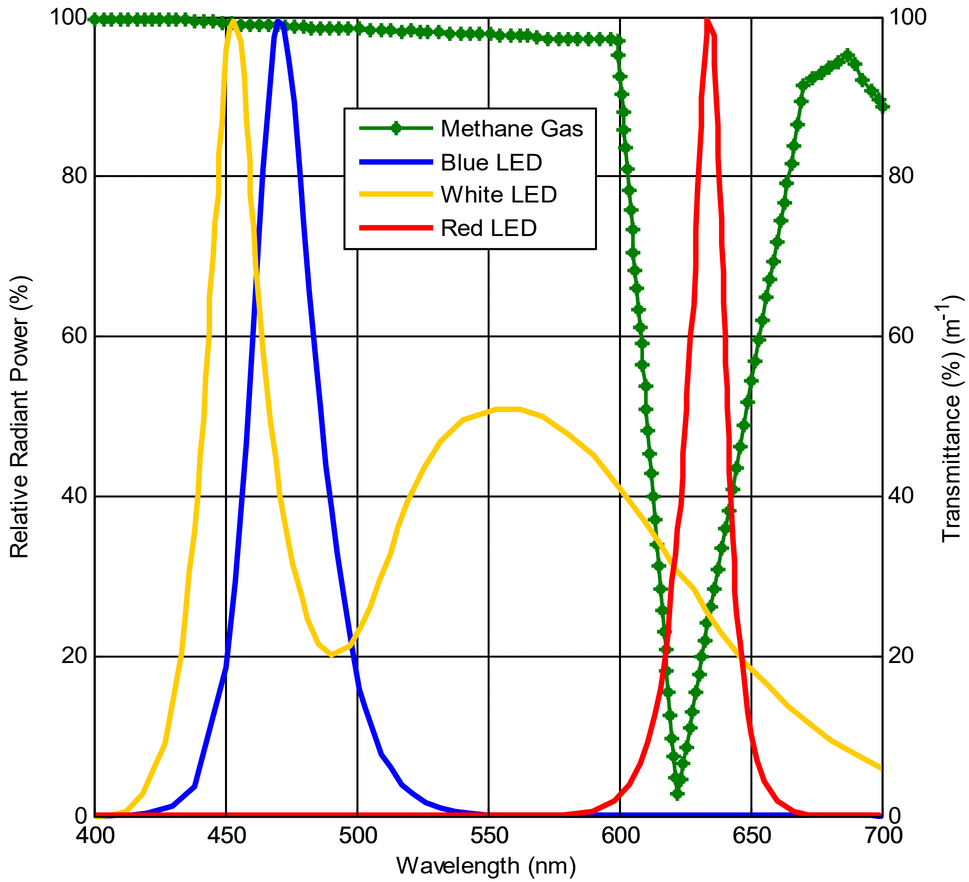


Emission pattern of
blue Cree Xlamp XP-C



Emission pattern of
red Cree Xlamp XP-C

Source Modeling (2/2)



Channel Impulse Response (CIR)

- Based on Monte Carlo Ray Tracing.
- Sobol sampling is used for speeding up ray tracing.
- The Zemax® non-sequential ray-tracing tool generates an output file, which includes all the data about rays such as the detected power and path lengths for each ray.
- The data from Zemax® output file is imported to MATLAB® and using these information, the multipath CIR is expressed as

$$h(t) = \sum_{i=1}^{N_r} P_i \delta(t - \tau_i)$$

P_i = the power of the i^{th} ray
τ_i = the propagation time of the i^{th} ray
$\delta(t)$ = the Dirac delta function
N_r = the number of rays received at the detector

Effect of LED Response

- In addition to the multipath propagation environment, the low-pass characteristics of the LED sources should be further taken into account in channel modelling.

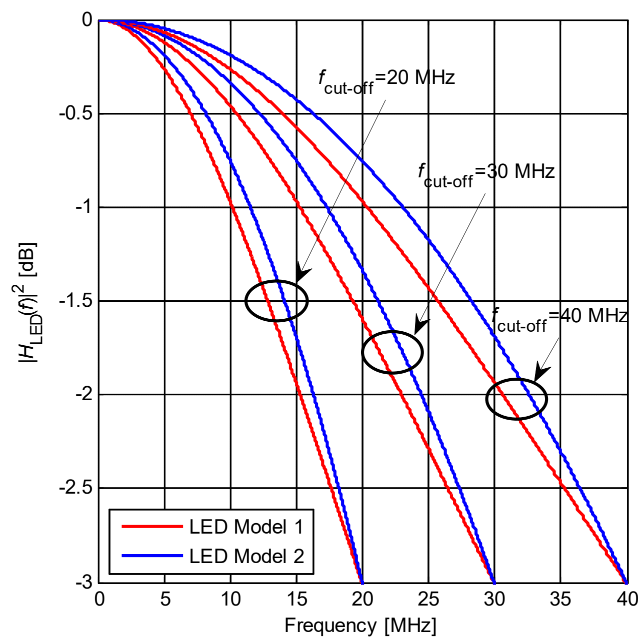
LED Model 1 [6]

$$H_{\mathrm{LED}}(f) = \frac{1}{1 + j\dfrac{f}{f_{\text{cut-off}}}}$$

LED Model 2 [7]

$$H_{\mathrm{LED}}(f) = e^{-\ln\left(\sqrt{2}\right)\left(\frac{f}{f_{\text{cut-off}}}\right)^2}$$

$f_{\text{cut-off}}$: 3 dB cut-off frequency of the LED

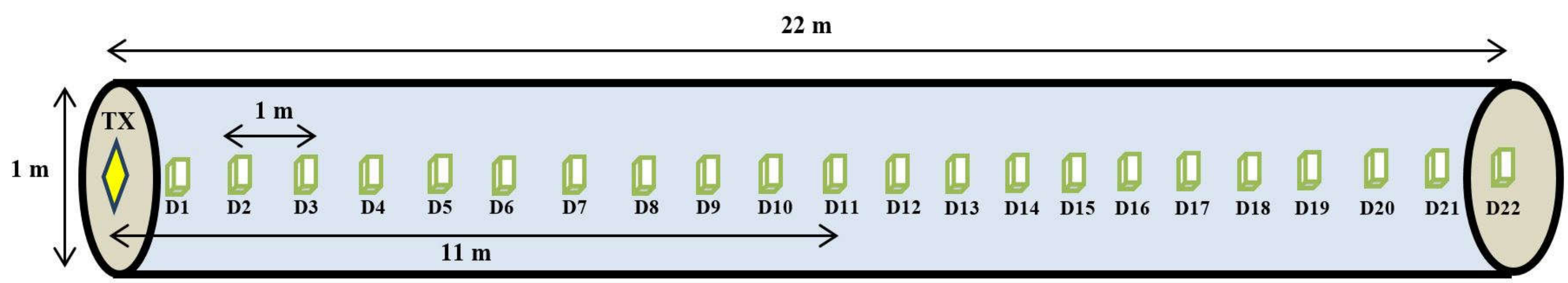


[6] L. Grobe, and K. D. Langer, "**Block-based PAM with frequency domain equalization in visible light communications**," In *IEEE Globecom Workshops (GC Wkshps)*, pp. 1070-1075, 2013.

[7] M. Wolf, S. A. Cheema, M. Haardt, and L. Grobe, "**On the performance of block transmission schemes in optical channels with a Gaussian profile**," *In 16th International Conference on Transparent Optical Networks (ICTON)*, pp. 1-8, 2014.

Simulation Scenario

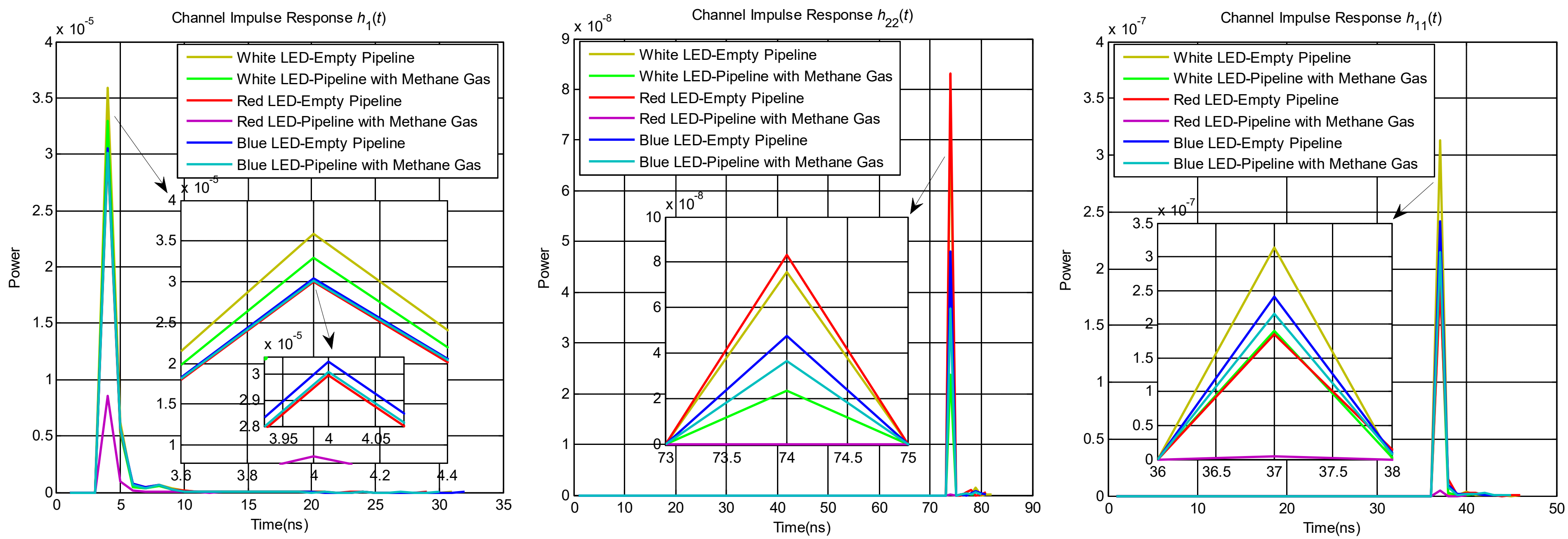
- The pipeline under consideration is used for transport of Liquefied Natural Gas (LNG) and has a cylindrical shape with a length of 22 meters and a diameter of 1 meter (see figure below).
- As a wireless transmitter, an LED (i.e., denoted as TX) is located at the head of the pipeline.
- Receiver test points with 1 meter apart from each other are assumed within the pipeline.



Simulation Parameters

Pipeline specifications	Length: 22 m Diameter: 1 m Internal material: Carbon steel
Fluid specifications	Methane gas
LED specifications	Cree MC-E Xlamp® White LED Cree XP-C Xlamp® Blue LED Cree XP-C Xlamp® Red LED Half viewing angle: 60º Input power: 1 W
Detector specifications	Area: 1 cm^2 FOV: 85º

CIR Results (1/3)

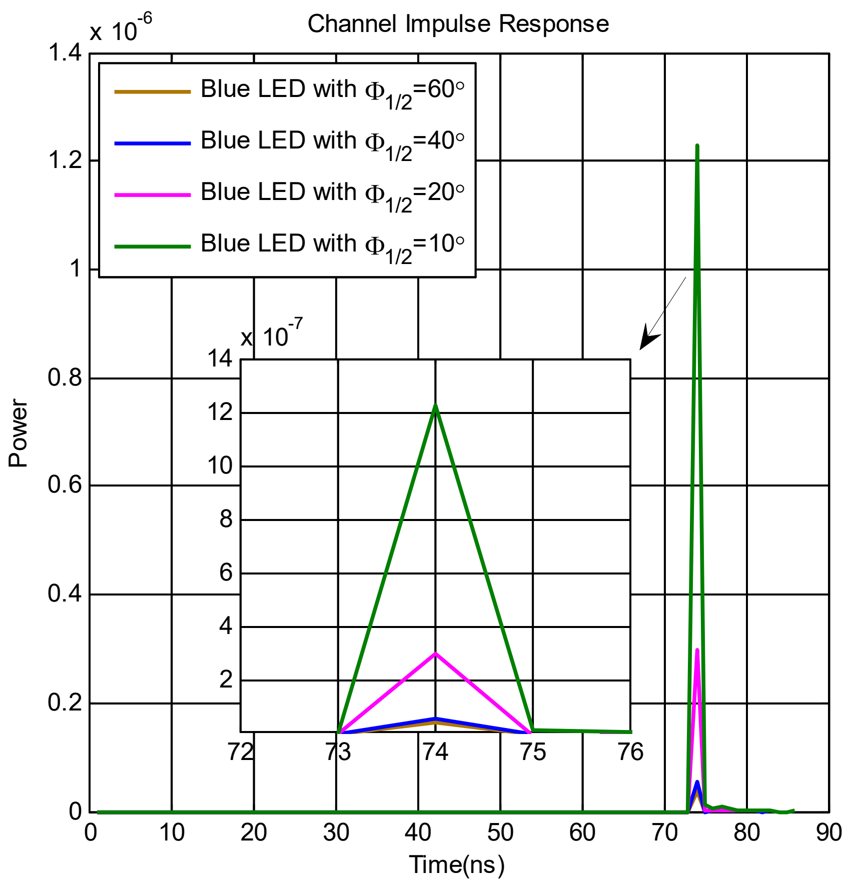


CIR Results (2/3)

LED	Configuration	H_0		
		D1	D11	D22
White LED	Empty Pipeline	4.41×10^{-5}	3.19×10^{-7}	7.77×10^{-8}
Red LED	Empty Pipeline	3.78×10^{-5}	2.06×10^{-7}	8.51×10^{-8}
Blue LED	Empty Pipeline	3.84×10^{-5}	2.57×10^{-7}	4.97×10^{-8}
White LED	Pipeline with Methane Gas	3.99×10^{-5}	1.94×10^{-7}	2.41×10^{-8}
Red LED	Pipeline with Methane Gas	9.70×10^{-6}	4.07×10^{-9}	2.08×10^{-11}
Blue LED	Pipeline with Methane Gas	3.80×10^{-5}	2.28×10^{-7}	3.80×10^{-8}

- It is observed that the channel gains obtained with red LED are smaller than those ones obtained with blue and white LEDs. This is as a result of the fact that the minimum transmittance of methane gas is in the red band i.e., 617 nm-631 nm (see p. 8).
- It is also revealed that the channel gains obtained with white LED are more or less same as those obtained with the blue LED. Since the illumination purposes are not of concern in telemetry application under consideration, we choose blue LED with larger bandwidth as the transmitter in the rest of this study.

CIR Results (3/3)

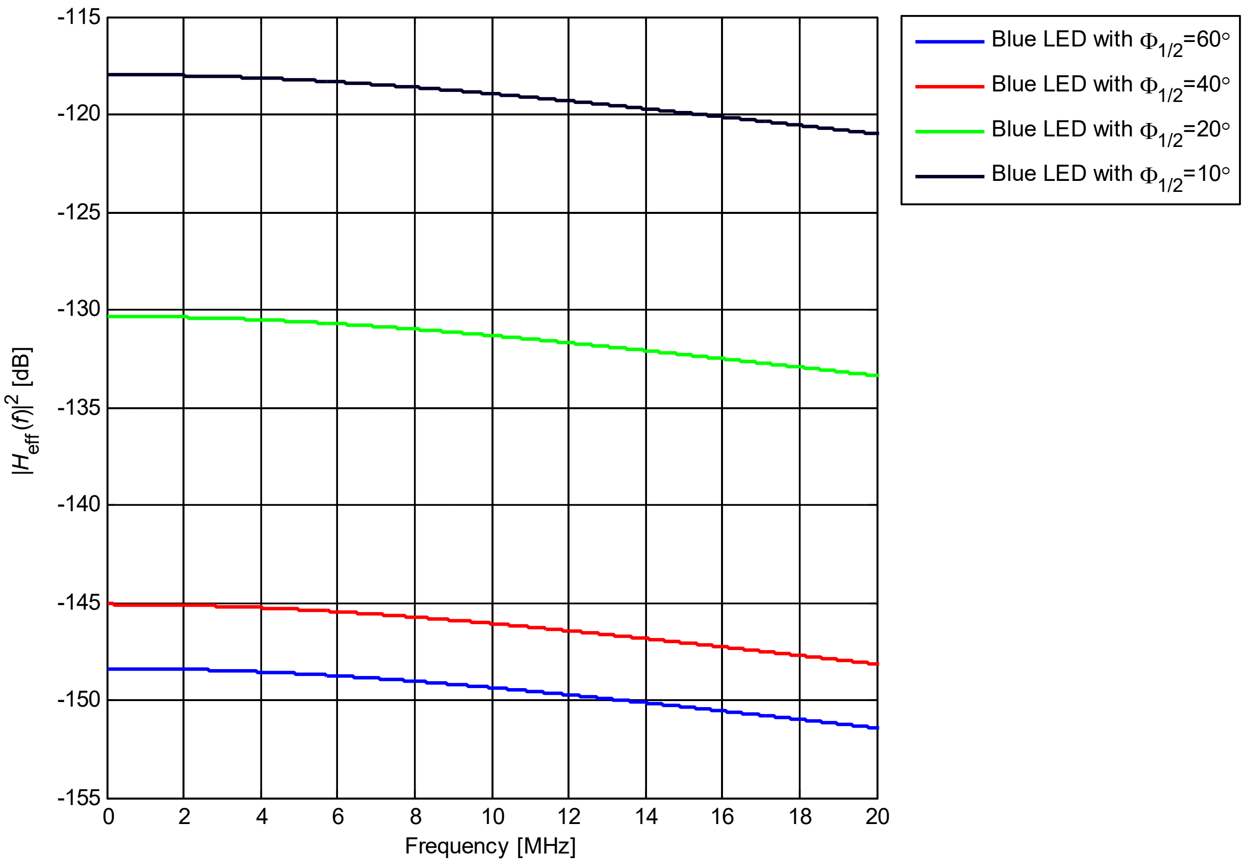


Configuration	H_0
Blue LED with $\Phi_{1/2}=60^\circ$	3.80×10^{-8}
Blue LED with $\Phi_{1/2}=40^\circ$	5.56×10^{-8}
Blue LED with $\Phi_{1/2}=20^\circ$	3.03×10^{-7}
Blue LED with $\Phi_{1/2}=10^\circ$	1.26×10^{-6}

- It is observed that as half viewing angle decreases, the number of reflected rays decreases and LOS channel gain increases. Particularly, channel DC gain is equal to 3.80×10^{-8} for 60º while it increases to 1.26×10^{-6} for 10º.

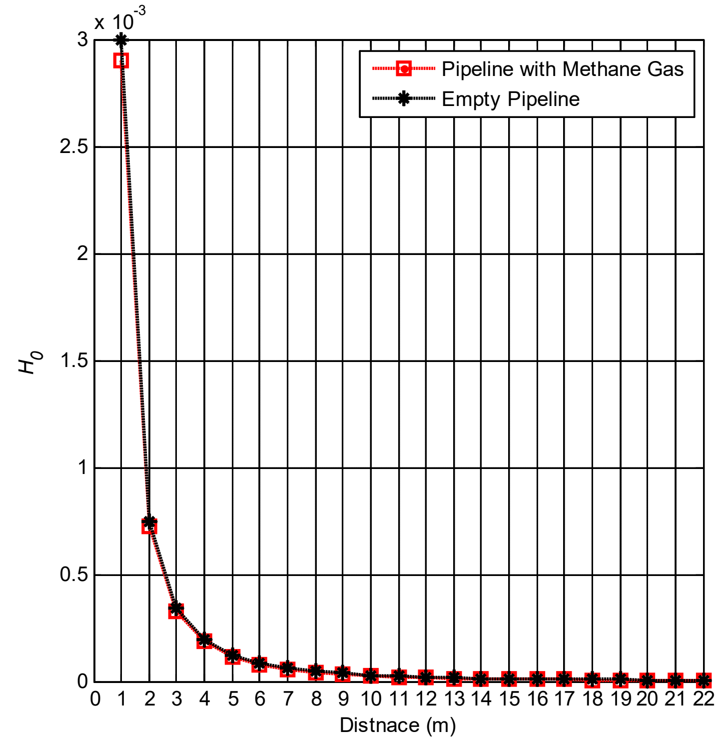
Effective Channel Responses

- For the effective channel responses, the “LED Model 1” with cut-off frequency of 20 MHz is considered.



Channel Characteristics

Receivers	Blue LED with $\Phi_{1/2} = 10^{\circ}$			
	Pipeline with Methane Gas		Empty Pipeline	
	τ_{RMS} (ns)	H_0	τ_{RMS} (ns)	H_0
D1	7.9535	2.90×10^{-3}	7.9536	3.00×10^{-3}
D2	7.9596	7.27×10^{-4}	7.9595	7.47×10^{-4}
D3	7.9671	3.27×10^{-4}	7.9675	3.41×10^{-4}
D4	7.9635	1.84×10^{-4}	7.9646	1.93×10^{-4}
D5	7.9650	1.13×10^{-4}	7.9656	1.21×10^{-4}
D6	7.9658	7.88×10^{-5}	7.9670	8.52×10^{-5}
D7	7.9613	5.70×10^{-5}	7.9614	6.23×10^{-5}
D8	7.9631	4.13×10^{-5}	7.9623	4.62×10^{-5}
D9	7.9630	3.36×10^{-5}	7.9628	3.78×10^{-5}
D10	7.9617	2.56×10^{-5}	7.9593	2.91×10^{-5}
D11	7.9617	2.14×10^{-5}	7.9603	2.45×10^{-5}
D12	7.9673	1.81×10^{-5}	7.9614	2.08×10^{-5}
D13	7.9593	1.41×10^{-5}	7.9574	1.65×10^{-5}
D14	7.9587	1.20×10^{-5}	7.9586	1.41×10^{-5}
D15	7.9604	1.00×10^{-5}	7.9622	1.21×10^{-5}
D16	7.9559	9.26×10^{-6}	7.9575	1.12×10^{-5}
D17	7.9586	7.93×10^{-6}	7.9634	9.69×10^{-6}
D18	7.9644	7.13×10^{-6}	7.9643	8.91×10^{-6}
D19	7.9581	6.28×10^{-6}	7.9590	8.03×10^{-6}
D20	7.9619	5.65×10^{-6}	7.9718	7.29×10^{-6}
D21	7.9703	4.93×10^{-6}	7.9691	6.44×10^{-6}
D22	7.9719	5.04×10^{-6}	7.9715	6.59×10^{-6}



Conclusions

- This contribution proposes LiFi reference channel models for gas pipelines to assist the IEEE 802.11bb.

Acknowledgement

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