Project: IEEE 802.11bb Task Group

Submission Title: IEEE 802.11bb Reference Channel Models for Indoor Environments

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Abstract: This contribution proposes LiFi reference channel models for indoor environments such as office, home and manufacturing cell.

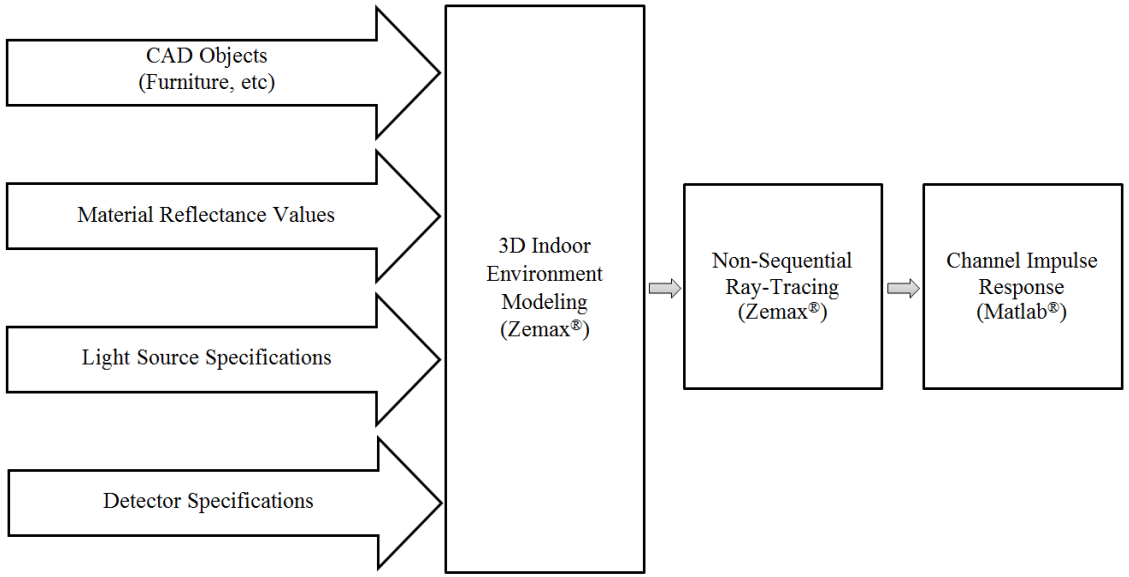
Purpose: To introduce reference channel models for the evaluation of different PHY proposals.

IEEE 802.11bb Reference Channel Models for Indoor Environments

Outline

- Introduction
  - Overview of Channel Modeling Methodology
- Indoor Scenarios under Consideration: Empty Room, Office, Home, Manufacturing Cell
  - Modeling of the Indoor Environment
  - Source Modeling
  - Illumination Level Requirements
  - Channel Impulse Responses (CIRs)
  - Effective Channel Responses
  - Channel Characteristics
- Conclusions

Overview of Channel Modeling Methodology



- A flexible and efficient method for realistic VLC channel modeling
  - Wavelength dependency
  - Realistic light sources
  - Effect of objects within the environment and types of surface (coating) materials

For additional details see

- IEEE 15-15-0352-01-007a, "Channel Modeling for Visible Light Communications"
- IEEE 15-15-0746-01-007a, "TG7r1 channel model document for high-rate PD communications"

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.

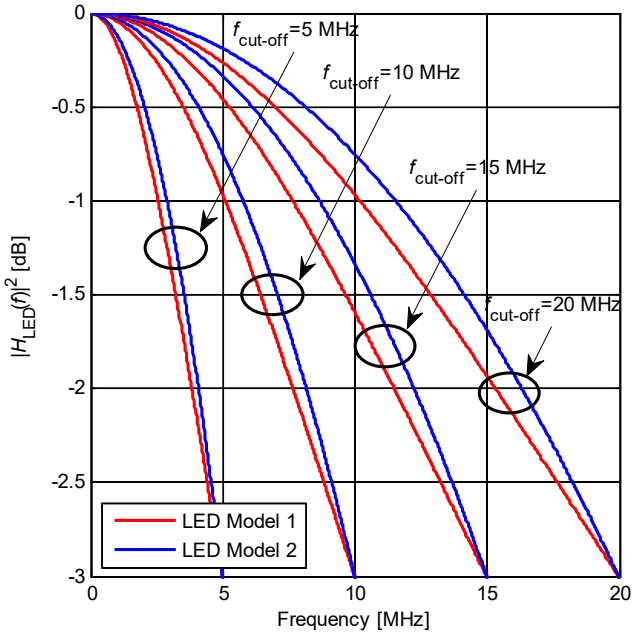
LED Model 1 [1]

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

LED Model 2 [2]

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

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

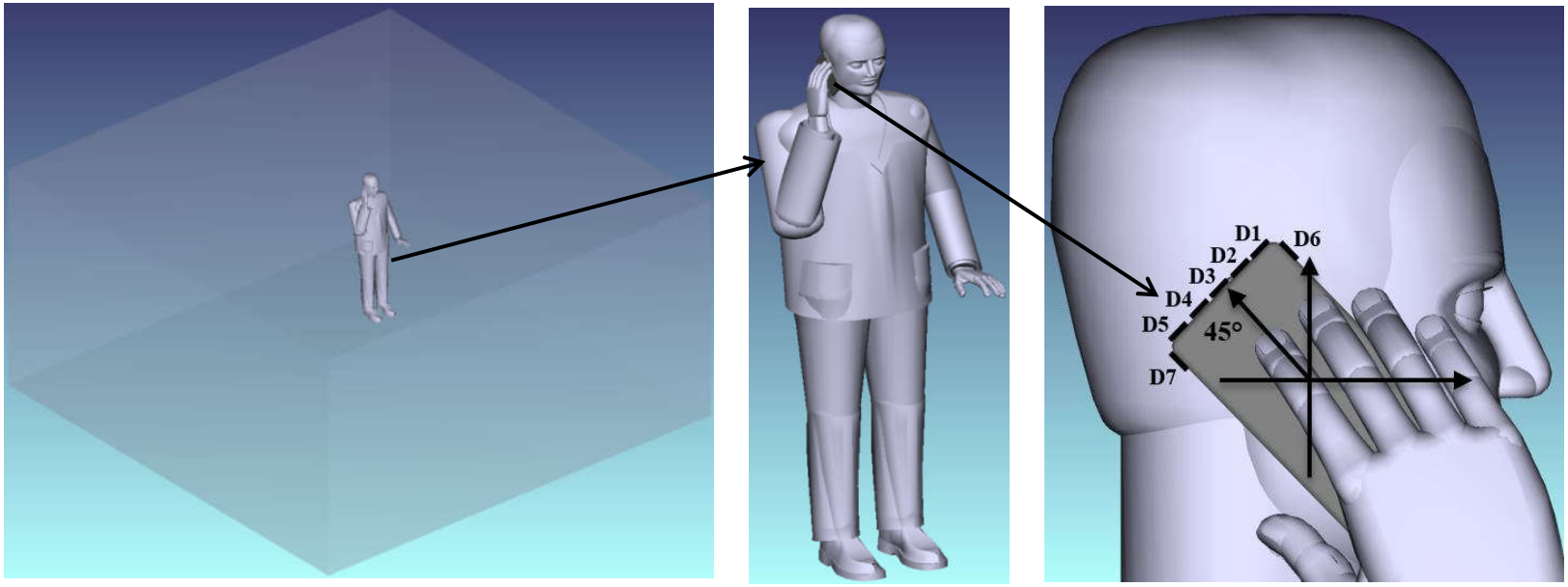


[1] L. Grobe, and K. D. Langer, "**Block-based PAM with frequency domain equalization in visible light communications**," In *IEEE Globecom Workshops (GC Wkshps)*, pp. 1070-1075, 2013.

[2] 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 0: Empty Room

- We consider an empty room with a size of 6 m × 6 m × 3 m with plaster ceiling/walls and pinewood floor.



Simulation Parameters

Room size	6 m × 6 m × 3 m
Materials	Walls: Plaster, Ceiling: Plaster, Floor: Pinewood
Objects specifications	Cell phone: Black gloss paint (5.5 cm × 10.5 cm × 0.5 cm) Human body: ▪ Shoes: Black gloss paint ▪ Head & Hands: Absorbing ▪ Clothes: Cotton
Luminary Specifications	Brand: CR6-800L Cree Inc. Half viewing angle: 40º
Number of luminaries	9
Number of PDs	7
Receiver area	1 cm^2

Light Source

- In simulation study, we use the LED luminary "CR6-800L" from Cree.

Cree.com / LED Lighting / Products / Indoor / CR Series – 4 & 6" Retrofit

CR Series – 4 & 6" Retrofit

Bringing LED Lighting to the masses.

The CR Series is an amazing combination of price and performance. Built upon technical innovations in optical, electronics, mechanical and thermal design, the CR Series provides amazing color accuracy and advanced dimming capabilities.

SUPERIOR QUALITY AND AFFORDABILITY
Developed with Cree TrueWhite® Technology, the CR4™ and CR6™ provide efficacy that is up to twice that of compact fluorescents, while achieving better color quality with a CRI of 90+. The CR Series is engineered with Cree LED technology and typically pays for itself in less than one year in many installations.

FAST INSTALL, UNRIVALED PERFORMANCE
Designed to easily install into existing IC or non-IC four-inch, six-inch and some five-inch housings. The CR LED Downlight Series provides higher efficacy and longer life than compact fluorescent lamps, with the beautiful light quality that you would expect from an incandescent. Dimmable down to 5% with widely available traditional dimmers and ENERGY STAR® qualified, this product is ideal for use in both residential and light-commercial new construction and retrofit applications.

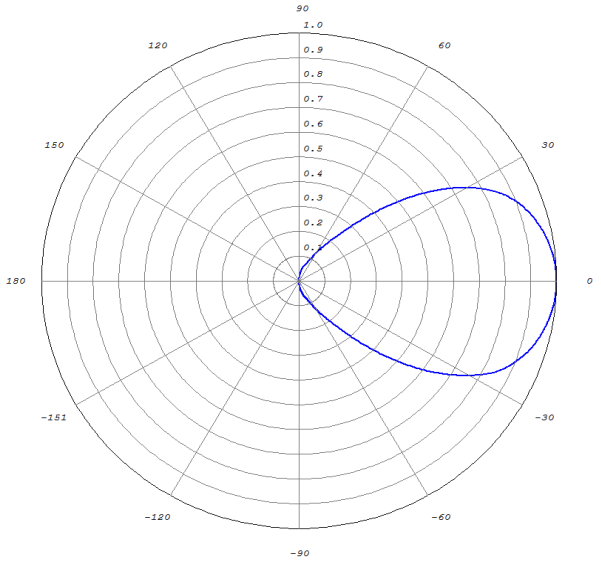
SPECIFICATIONS | VARIATIONS | DOCUMENTATION | MULTIMEDIA | ACCESSORIES

- Cree TrueWhite™ Technology
- Up to 67 lumens per watt
- Fits for most 6" and some 5" recessed housings (CR6)
- Fits most 4" recessed housings (CR4)
- Replaces either 65 watt or 90 watt incandescent (CR6)
- Replaces 50 watt incandescent (CR4)
- CCT: 2700K-4000K
- CRI: 90
- Dimmable to 5%, with most standard dimmers
- Designed to last up to 50,000 hours
- Energy Star® Qualified
- **Warranty:** Cree offers industry-leading limited product warranties. Visit our **warranty webpage** for more information on this product.

This product is available for:
QUICKSHIP™
Visit **cree.com/lighting/quickship** for eligible part numbers.

Applications

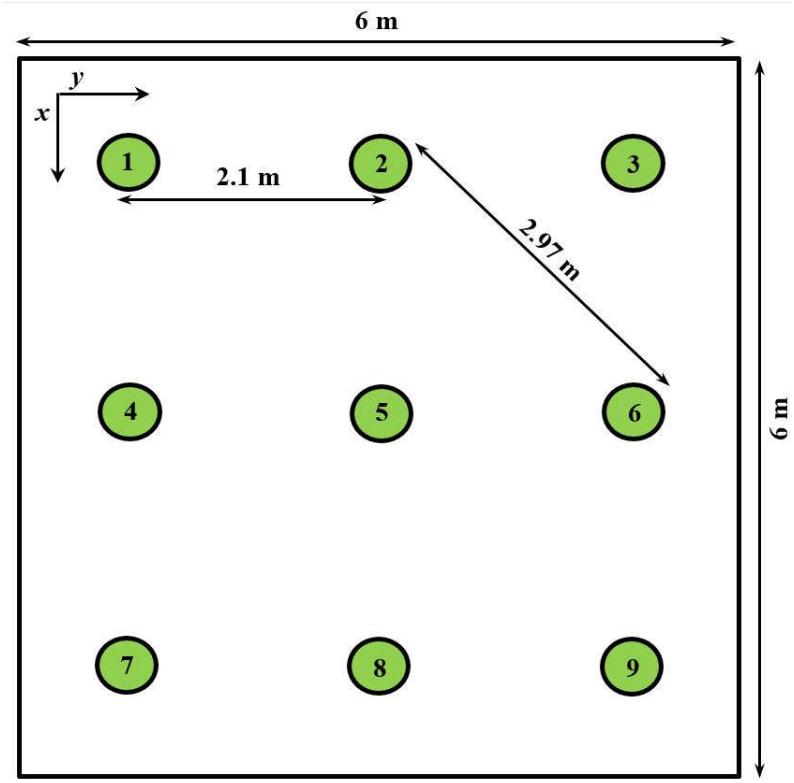
- Municipal Lighting
- Healthcare Facilities Lighting
- Residential Lighting
- Restaurant & Hotel Lighting
- Auto Dealership Lighting
- Education Facilities Lighting
- Retail & Grocery Lighting
- Petroleum & Convenience Lighting



Simulated emission pattern in Zemax®

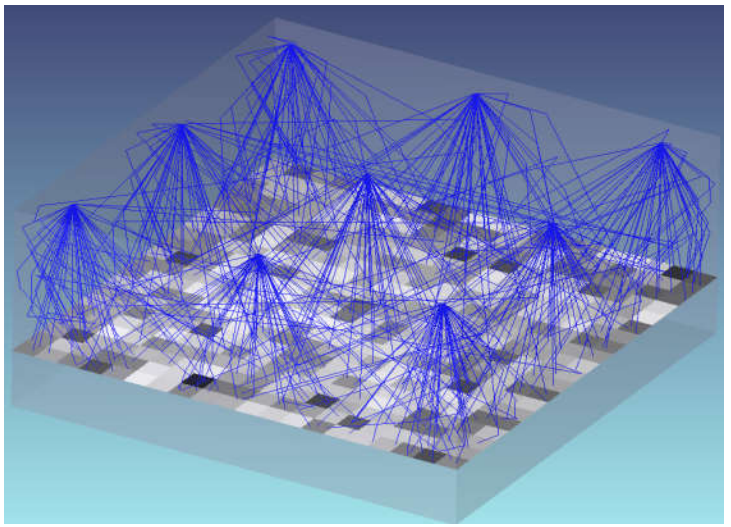
Illumination Levels

- Based on the properties of luminary, required illumination level (150 lx) and the size of room, we arrange the luminaries as follows:



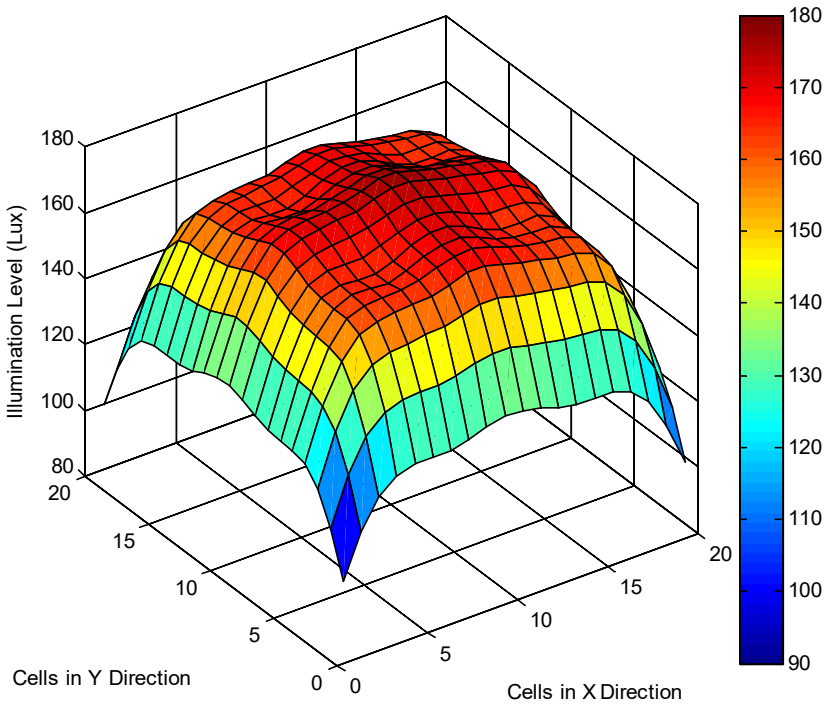
Arrangement of luminaries

Delivered light output from each luminary	737 lumens
Average of illumination level	153 lx
Uniformity of illumination	0.6422

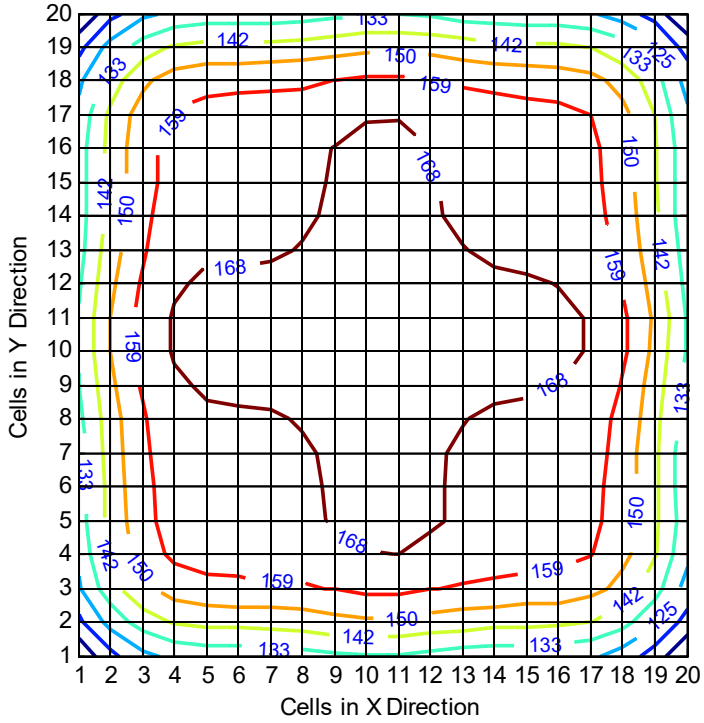


Evaluation of illumination level in Zemax®

Illumination Patterns



Simulated illumination levels in Zemax®

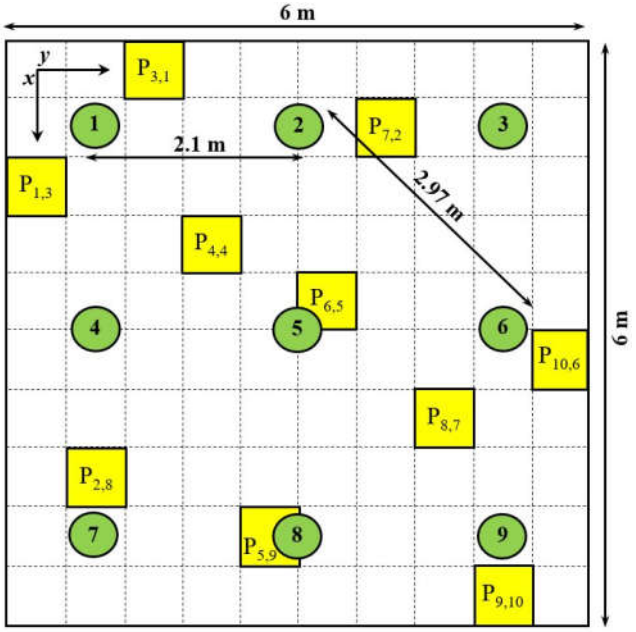


Illumination level contours in Matlab®

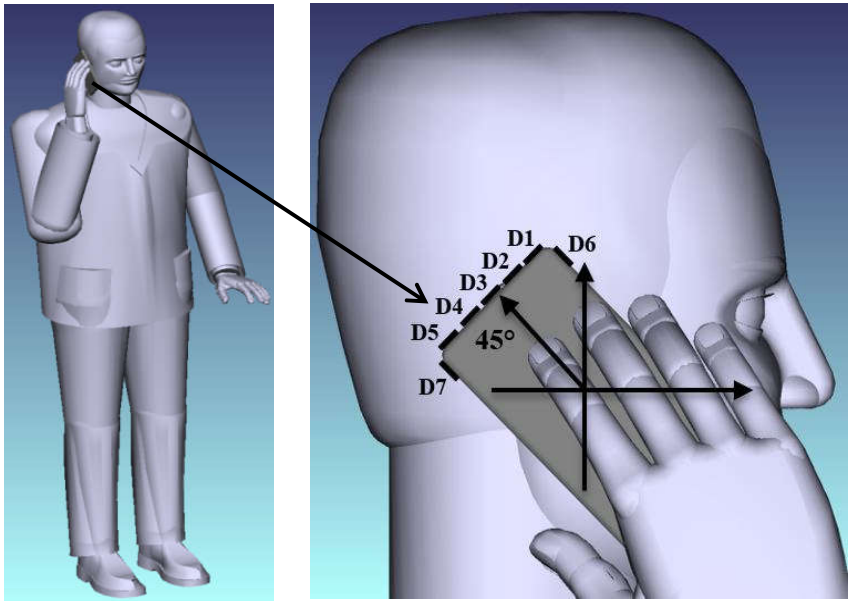
- The minimum and maximum values of illumination are 98.69 lx and 176.40 lx.

Location of Test Points (Receivers)

- We consider 100 cells with equidistant spacing of 0.6 m in *x* and *y* directions.
- We consider a user with a height of 1.8 m who holds the phone in his hand next to his ear with 45° rotation upward the ceiling and at a height of 1.65 m. The cell phone is equipped with a single photodetector. We consider seven possible locations for the photodetectors.

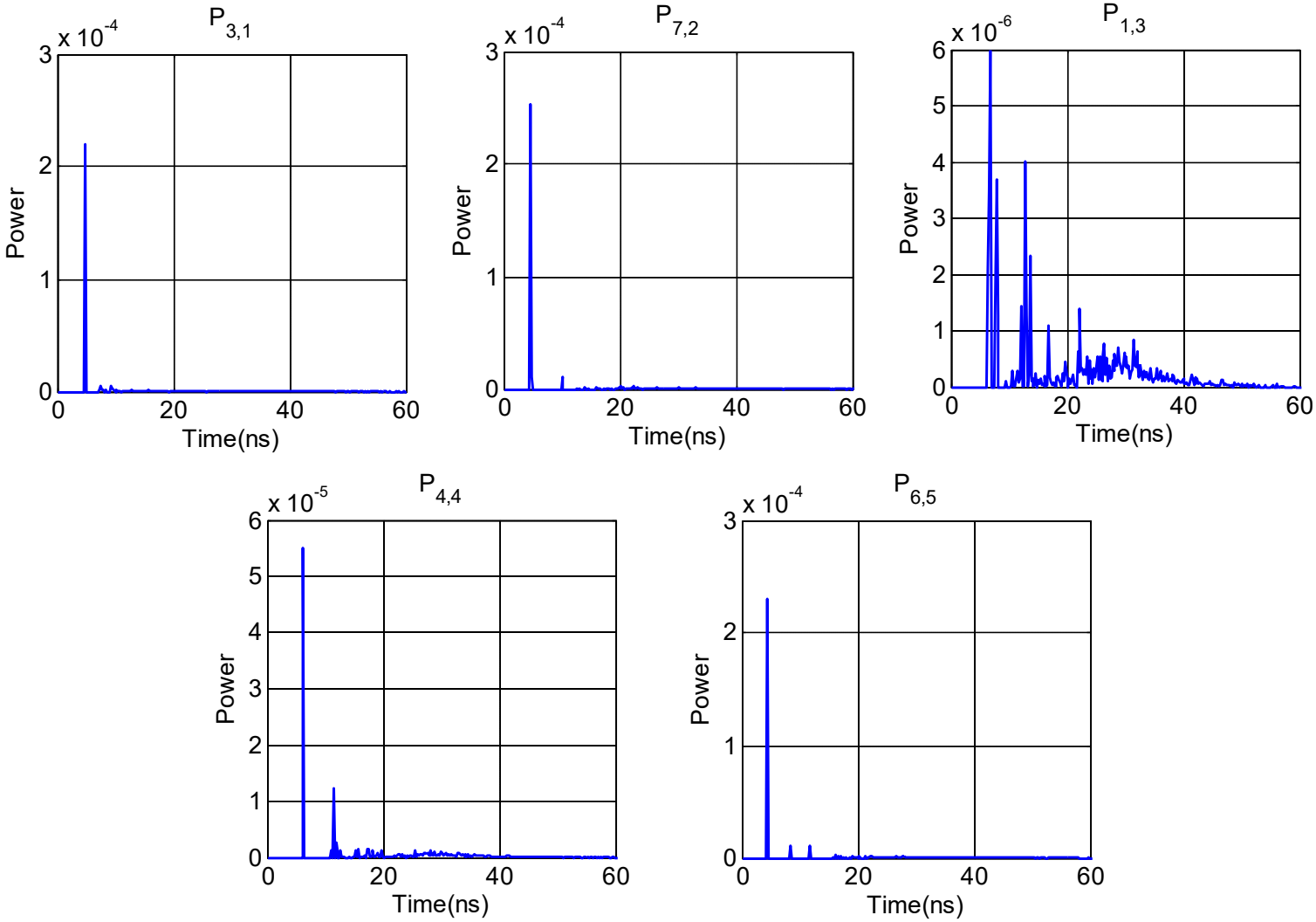


Room under consideration
with green circles denoting luminaires

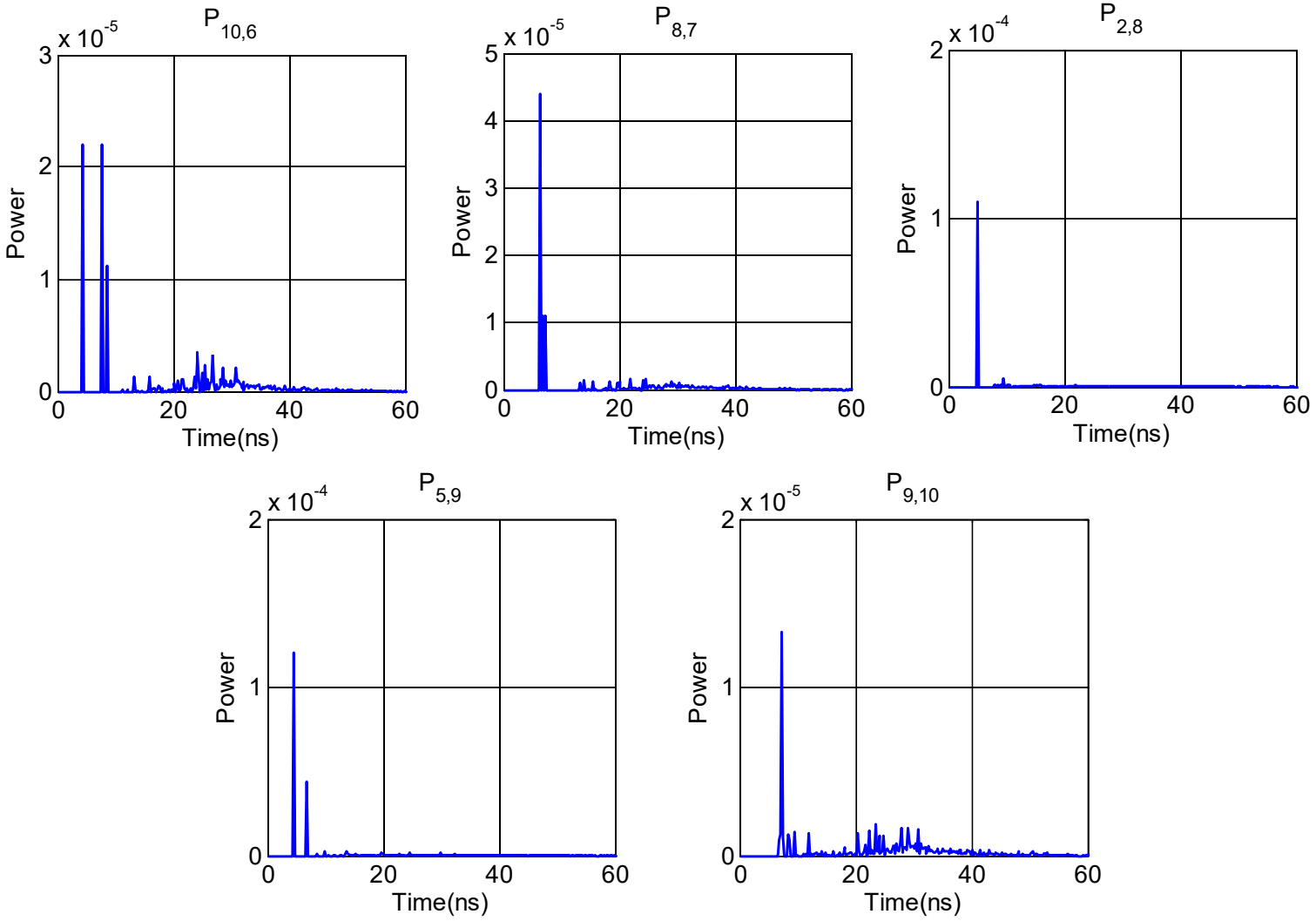


Location and rotation of test points

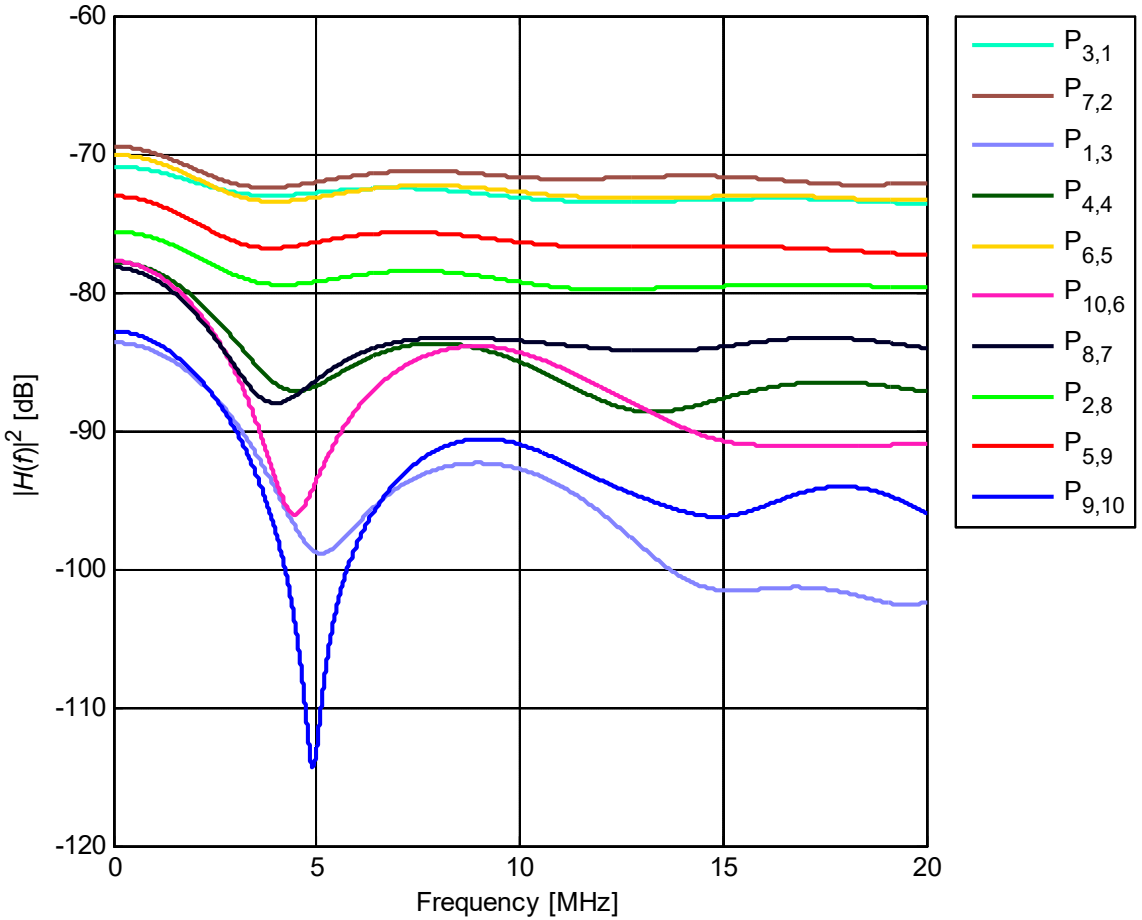
Sample CIR Results for D5 (1/2)



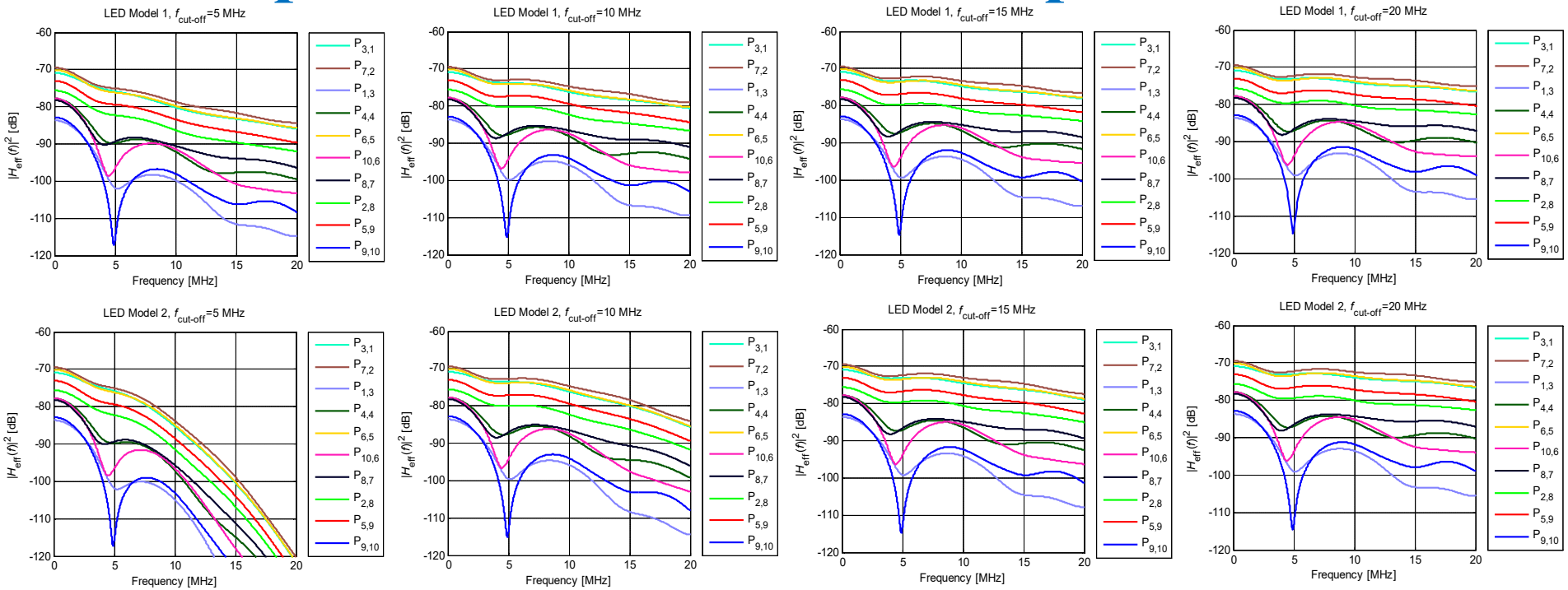
Sample CIR Results for D5 (2/2)



Sample Optical Channel Responses for D5

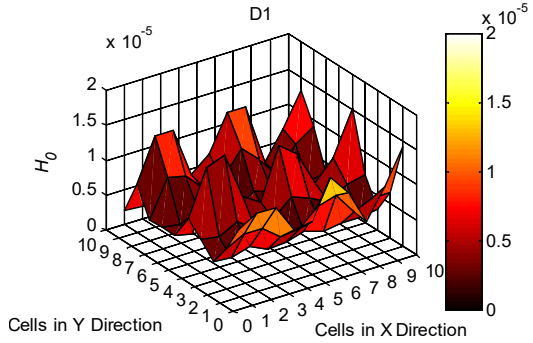


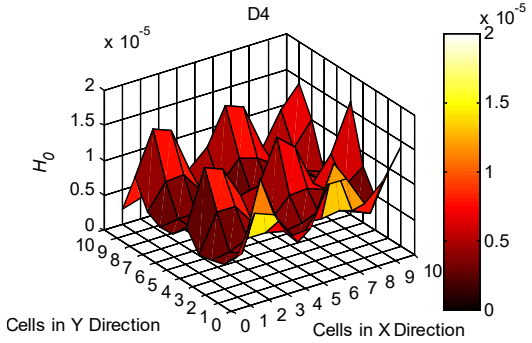
Sample Effective Channel Responses for D5

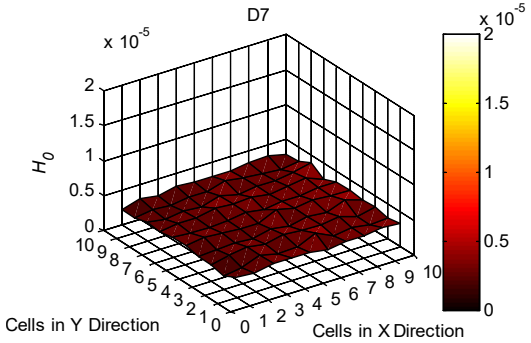


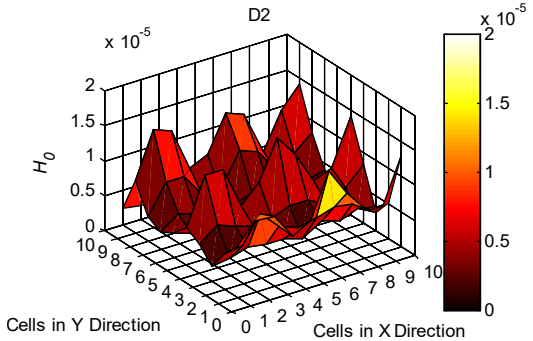
- In the effective channel responses of $P_{1,3}$, $P_{10,6}$ and $P_{9,10}$, frequency selectivity are more pronounced. It is a result of the fact that these locations are close to the walls (see p. 12) and therefore more reflected rays are received (see corresponding CIRs in p. 13 and p. 14).
- In the rest of this presentation, the "LED Model 1" with cut-off frequency of 20 MHz is considered.

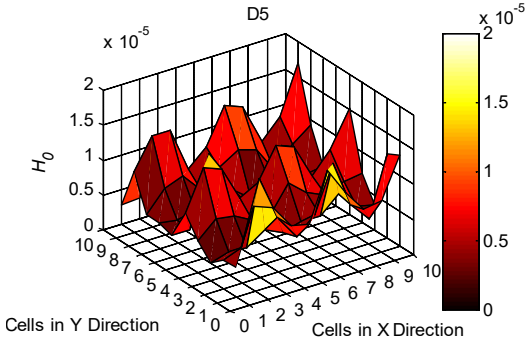
Spatial Distribution of DC Gains & Channel Characteristics (1/2)

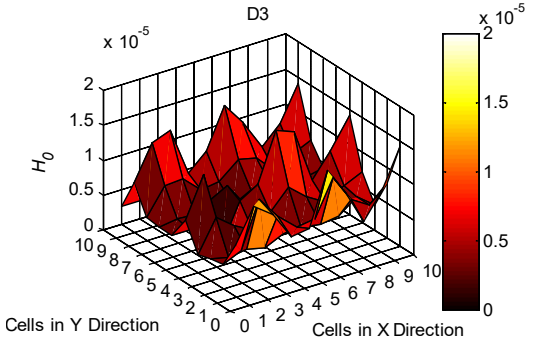


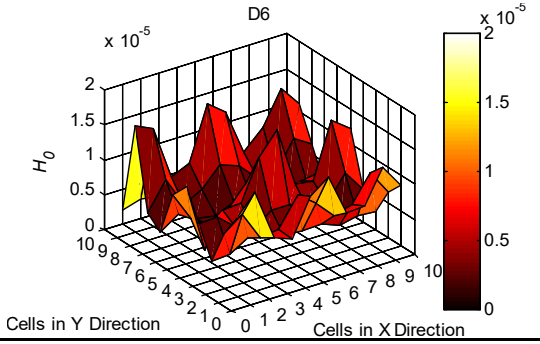






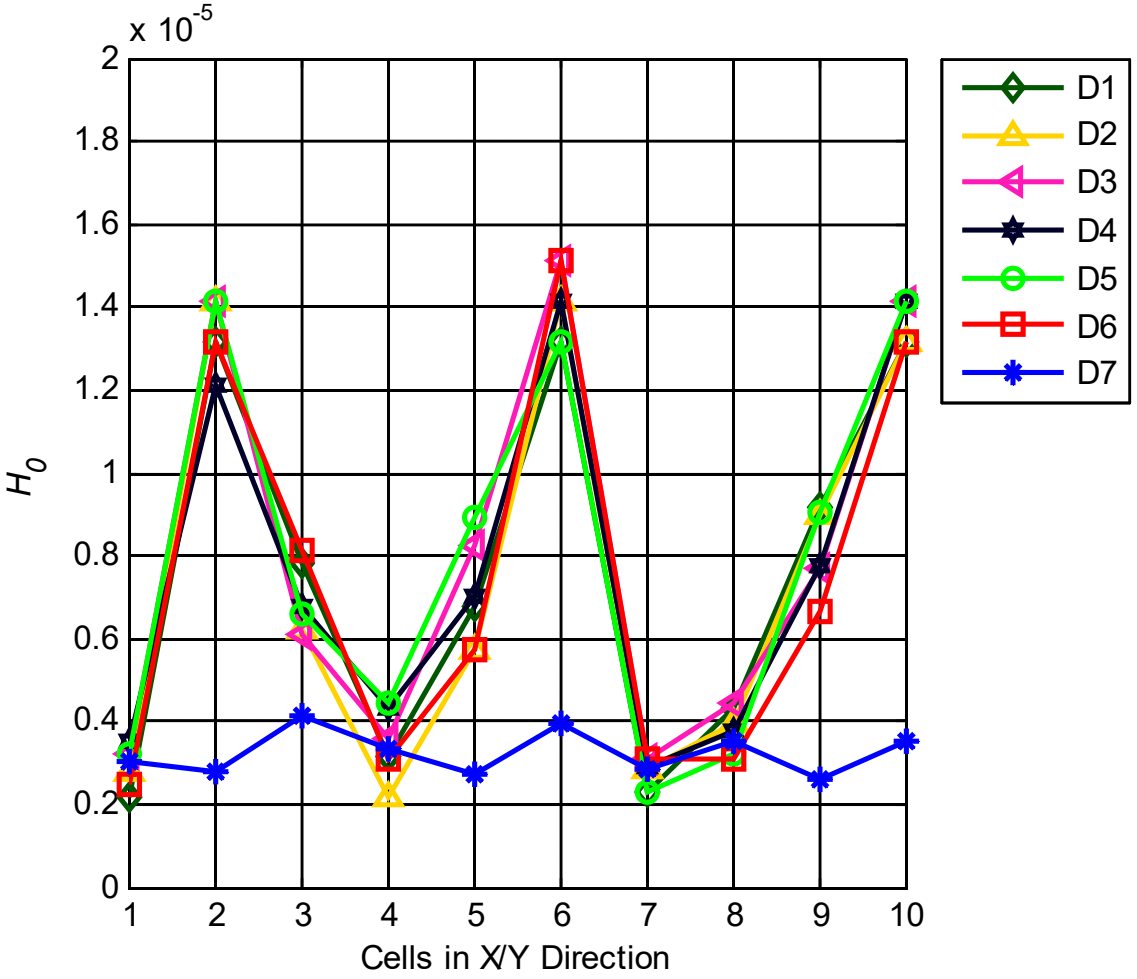




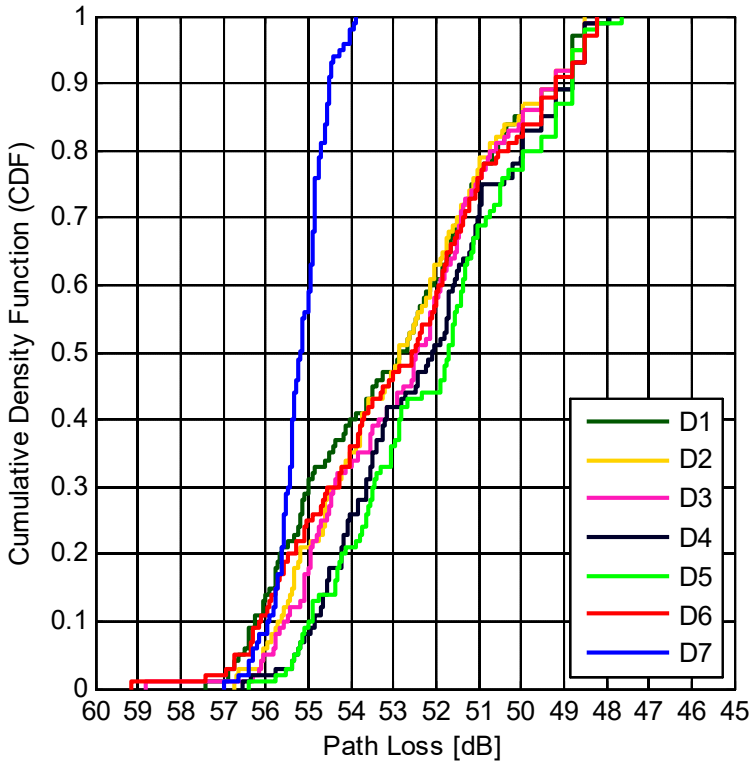


	Average over 100 Cells	
	τ_{RMS} (ns)	H_0
D1	13.92	6.00×10^{-6}
D2	14.10	6.08×10^{-6}
D3	14.07	6.33×10^{-6}
D4	14.09	6.89×10^{-6}
D5	14.10	7.19×10^{-6}
D6	14.06	6.25×10^{-6}
D7	13.22	3.05×10^{-6}

Spatial Distribution of DC Gains & Channel Characteristics (2/2)



Cumulative Distribution Function (CDF) of Path Loss

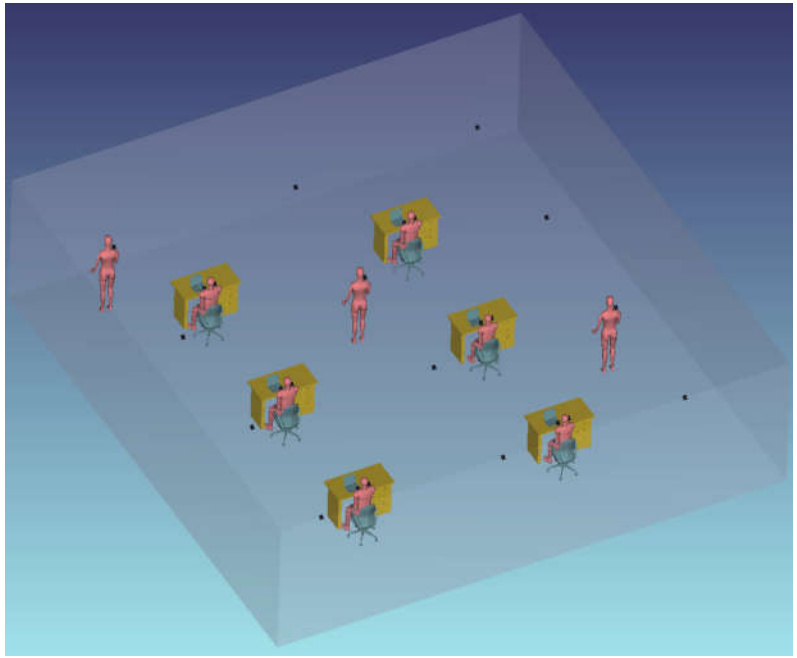


- It can be noted that D1, D2, D3, D4, D5 and D6 have similar path loss values in the range of 51.95 dB-52.94 dB. In comparison to them, D7 has about 2.2 dB-3.2 dB more path loss on average since there is no LOS component.

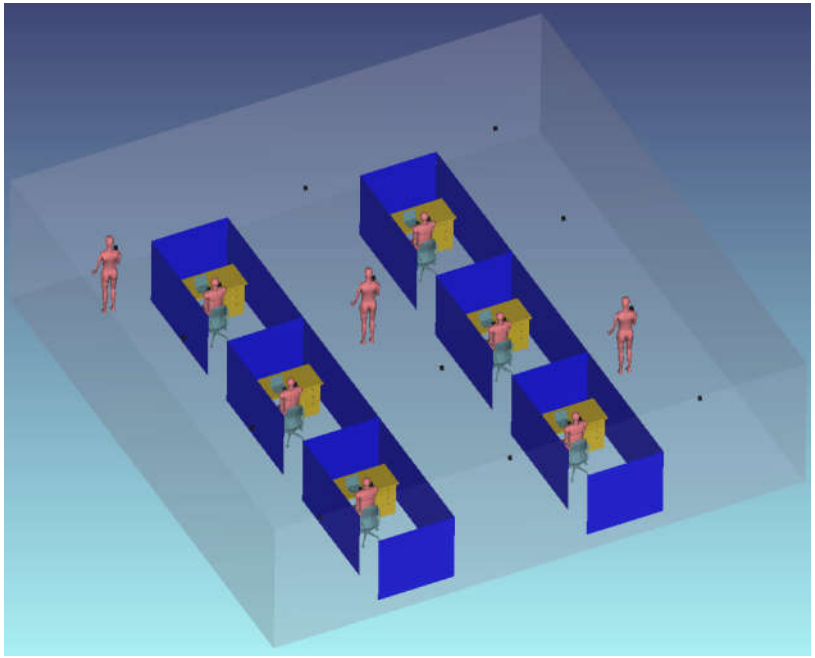
Simulation Scenario 1: Office

- Typical office places include furniture (e.g., desk, chairs, cubicles etc), various equipments (e.g., computers, printers etc) and personnel.

Open Office



Office With Cubicles



Simulation Parameters

Room size	14 m × 14 m × 3 m
Materials	Walls: Plaster, Ceiling: Plaster, Floor: Pinewood
Objects	6 desks and a chair paired with each desk 6 laptops on each desk 6 cubicles (optional) 9 human bodies
Objects specifications	Cubicles: Plaster Desk: Pinewood (Typical height of 0.85 m) Chair: Pinewood Laptop: Black gloss paint Human body: ▪ Shoes: Black gloss paint ▪ Head & Hands: Absorbing ▪ Clothes: Cotton
Luminary Specifications	Brand: LR24-38SKA35 Cree Inc. Half viewing angle: 40º
Number of luminaries	32
Receiver area	1 cm^2

Light Source (Transmitter)

- In simulation study, we use the LED luminary “LR24-38SKA35” from Cree.

Cree.com / LED Lighting / Products / Indoor / LR Series

LR Series

LED Architectural Troffer

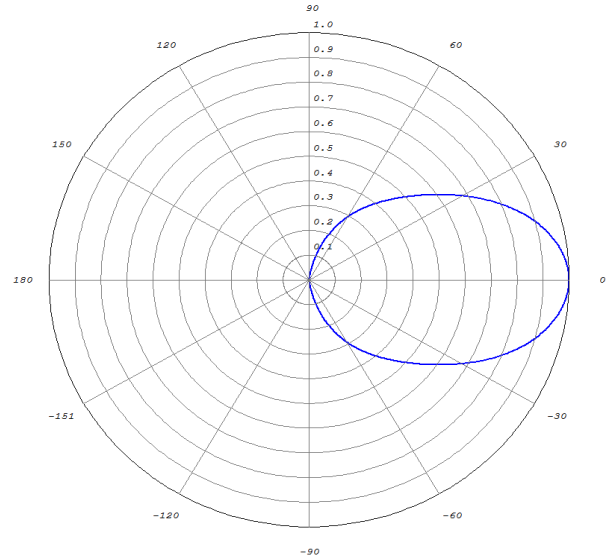
The architecturally designed recessed flat panel of the LR22™ LED troffer blends seamlessly into any ceiling and offers soft, smooth, fully-luminous light, creating a quiet ceiling that keeps spaces bright and vibrant. The innovatively thin 3.6" depth of the LR22 LED troffer easily accommodates narrow plenums and is ideal for both retrofit and new construction. The LR22 LED troffer delivers 3400 lumens of exceptional 90 CRI light while achieving an efficacious 100 lumens per watt. This breakthrough performance is achieved by combining the high efficacy and high-quality light of Cree TrueWhite® Technology. Delivering 0-10V continuous dimming on every luminaire allows for further energy savings when utilized for even faster payback.

SPECIFICATIONS | VARIATIONS | DOCUMENTATION | MULTIMEDIA

- Cree TrueWhite® Technology
- Efficacy: 100 LPW
- Delivered Light Output: 3400 lumens
- Input Power: 34 watts
- CRI: 90
- CCT: 3500K or 4000K
- Lifetime: Designed to last for 75,000 hours L70 @ 25°C
- DLC Qualified
- Controls: Continuous dimming to 5% with 0-10V controls
- Limited Warranty: 10 Years
- Mounting: Recessed

Applications

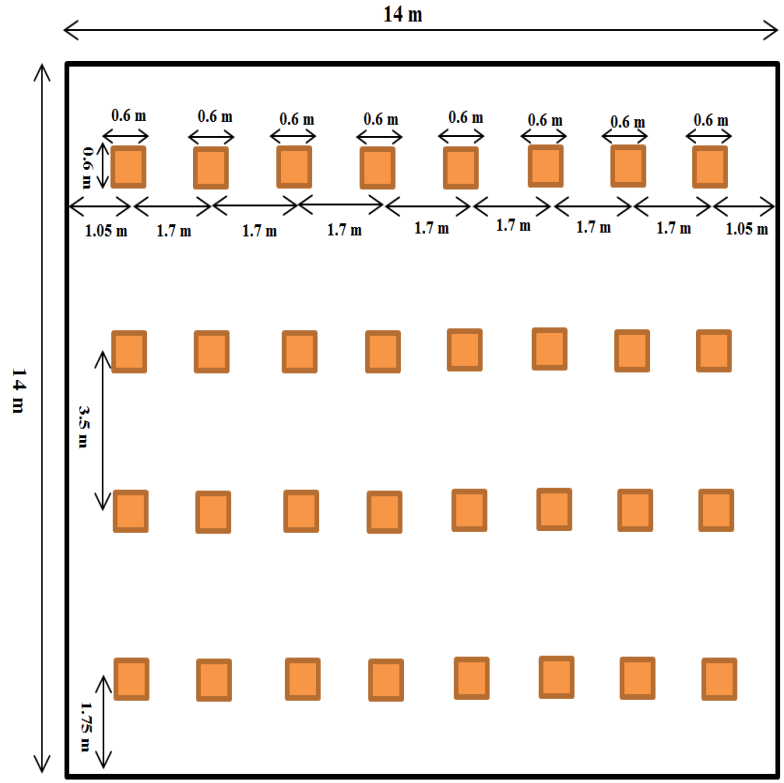
- Government Facilities Lighting
- Corporate Campus Lighting
- Healthcare Facilities Lighting
- Restaurant & Hotel Lighting
- Retail & Grocery Lighting



Simulated emission pattern in Zemax®

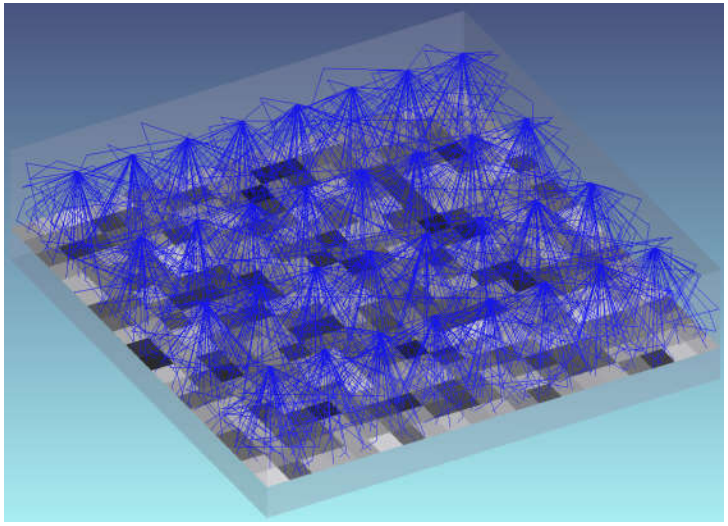
Illumination Levels

- Based on the properties of employed luminary, required illumination level (500 lx) and the size of office place, we arrange the luminaries as follows:



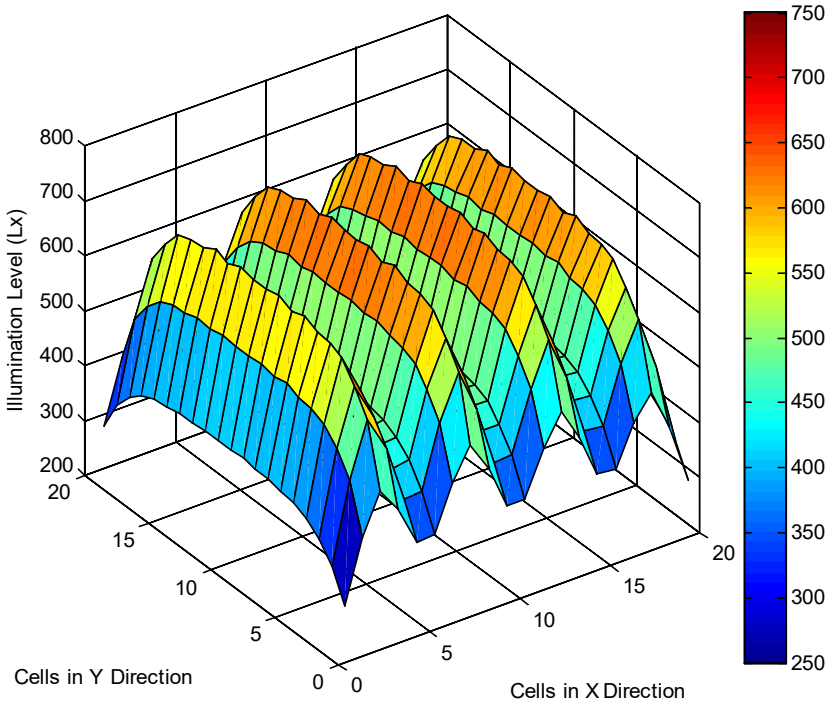
Arrangement of luminaries

Delivered light output from each luminary	3504 lumens
Average of illumination level	533 lx
Uniformity of illumination	0.5211

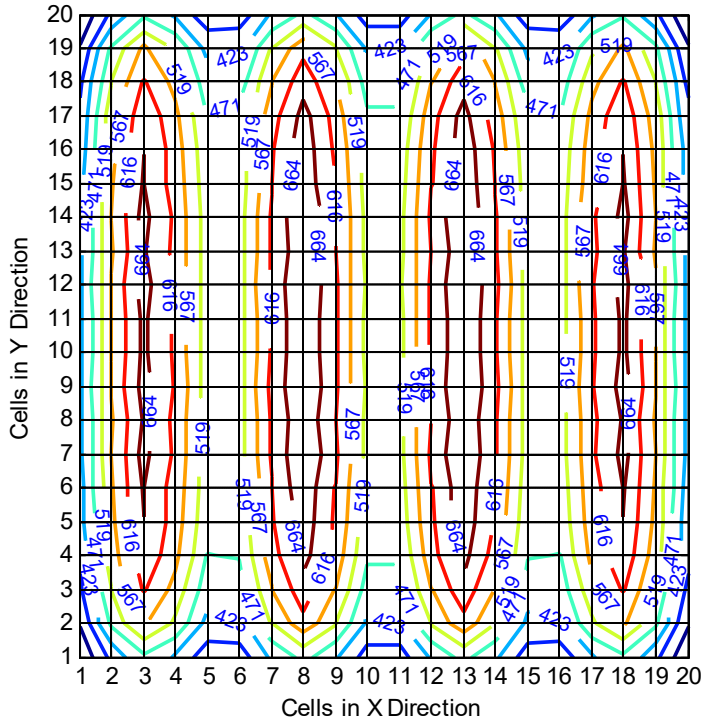


Evaluation of illumination levels in Zemax®

Illumination Patterns



Simulated illumination levels in Zemax®



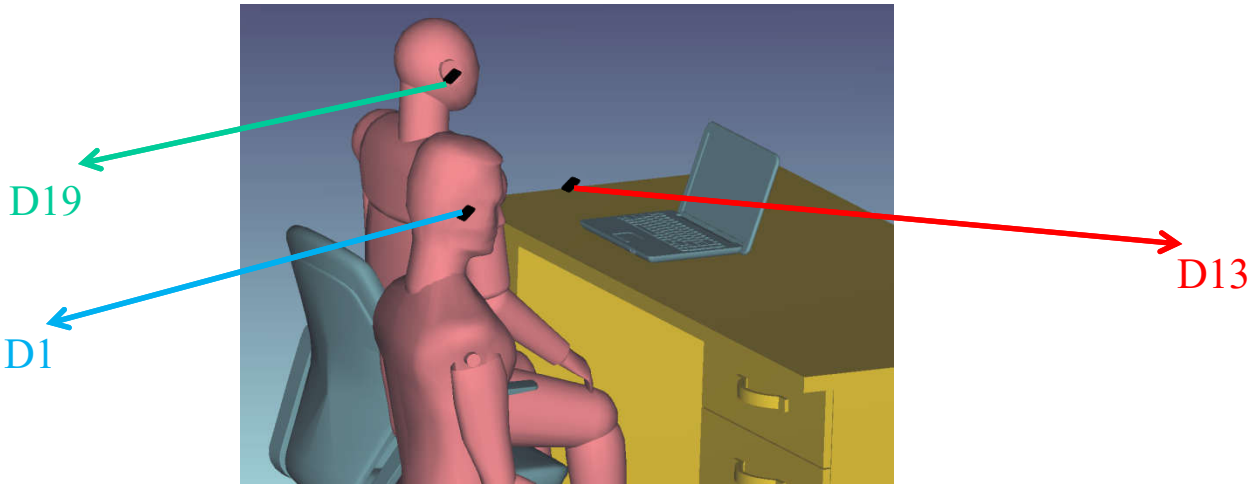
Illumination level contours in Matlab®

- Different colors show different values of illumination (lx) at the height of desk in office place. Red indicates the highest illumination level.
- The minimum and maximum values of illumination are 278 lx and 712 lx respectively.

Location of Test Points (Receivers)

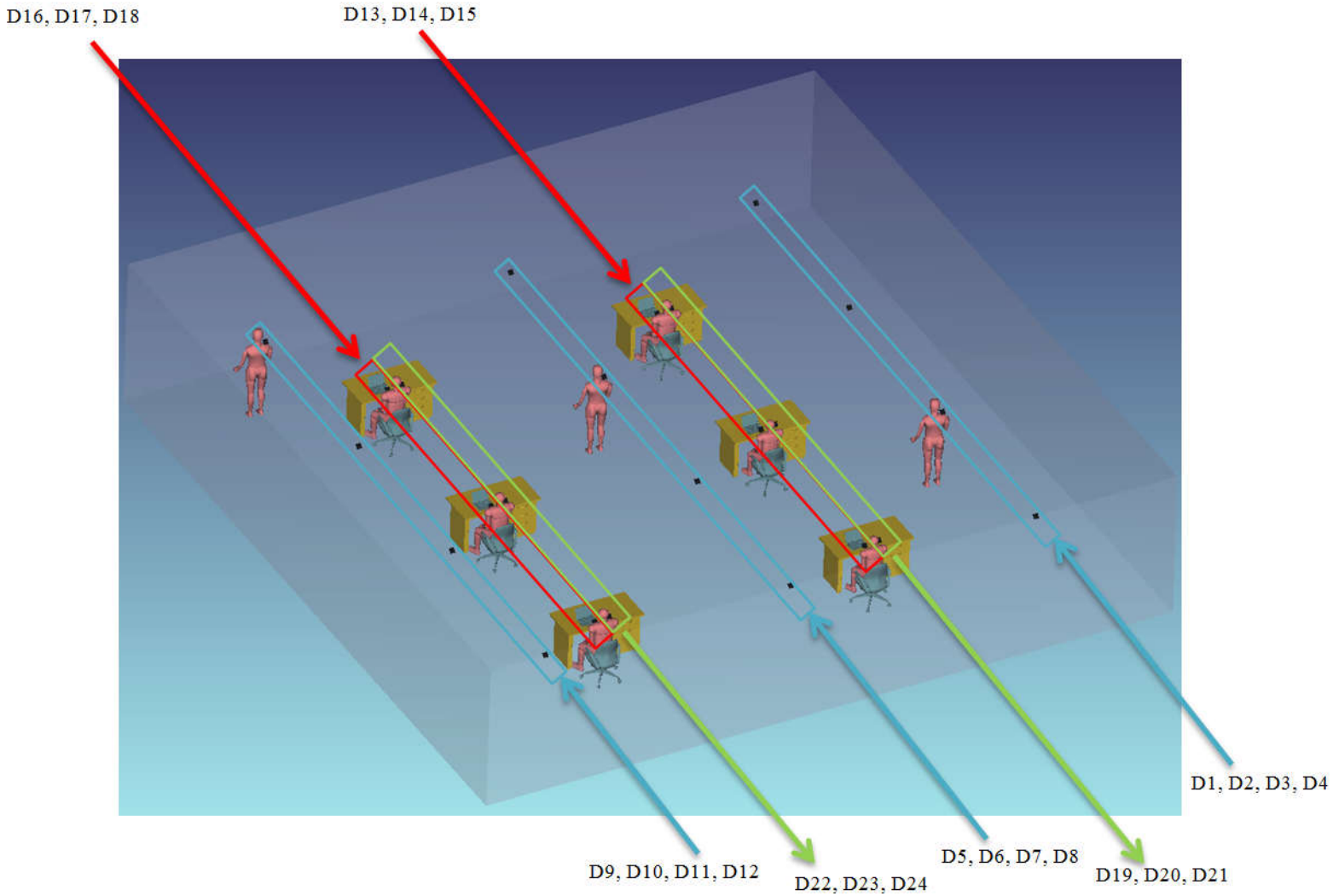
- 24 test points are chosen which are categorized into three groups:

In the corridors at a height of 1.7 m with 45º rotation (e.g., people who stand with a cell phone in hand)	D1-D12
On the top of chairs at a height of 0.95 m with 45º rotation (i.e., people with a cell phone in hand)	D13-D18
On the top of chairs at a height of 1.1 m with 45º rotation (e.g., people who sit with a cell phone in hand to his/her ear)	D19-D24

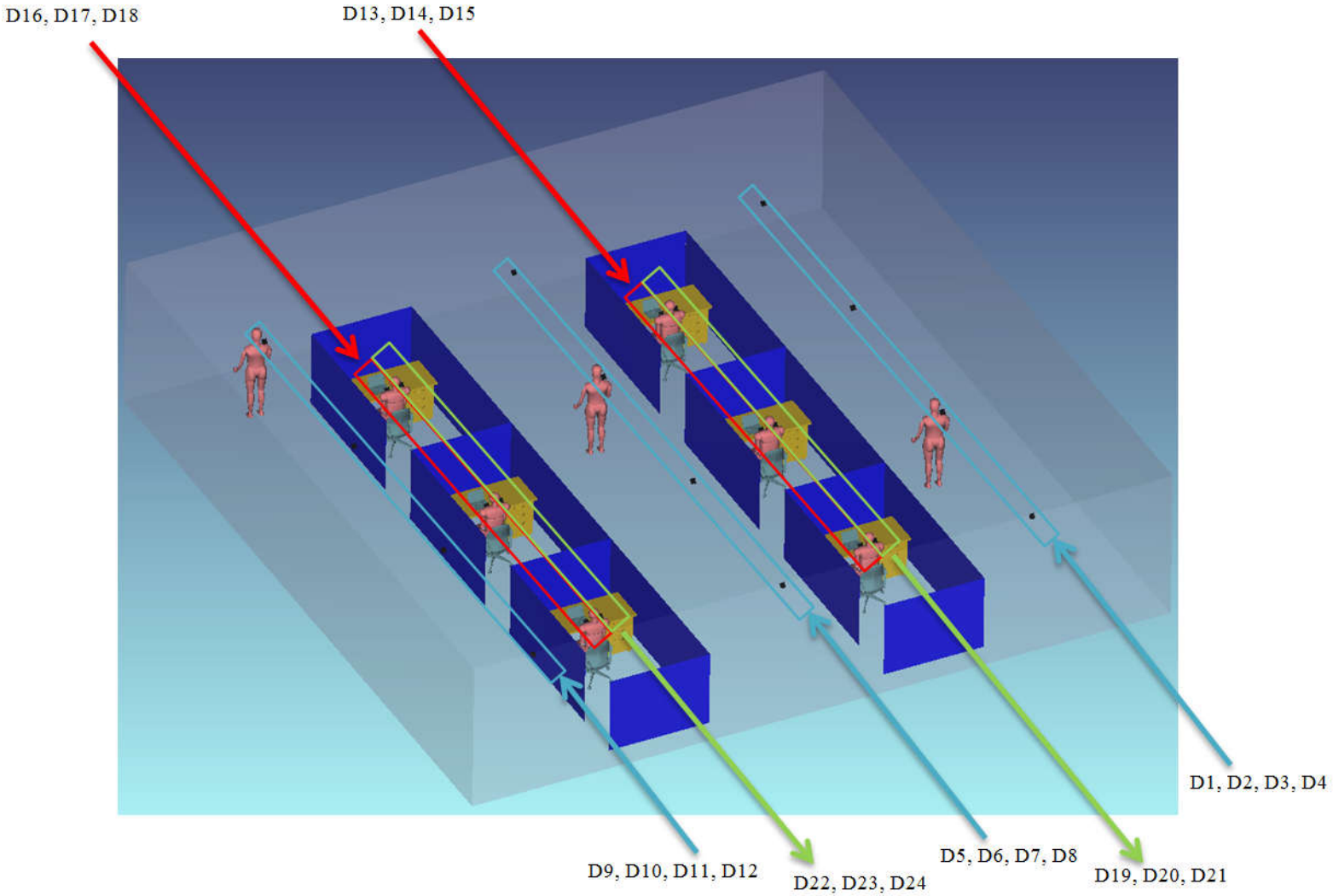


Location and rotation of test points

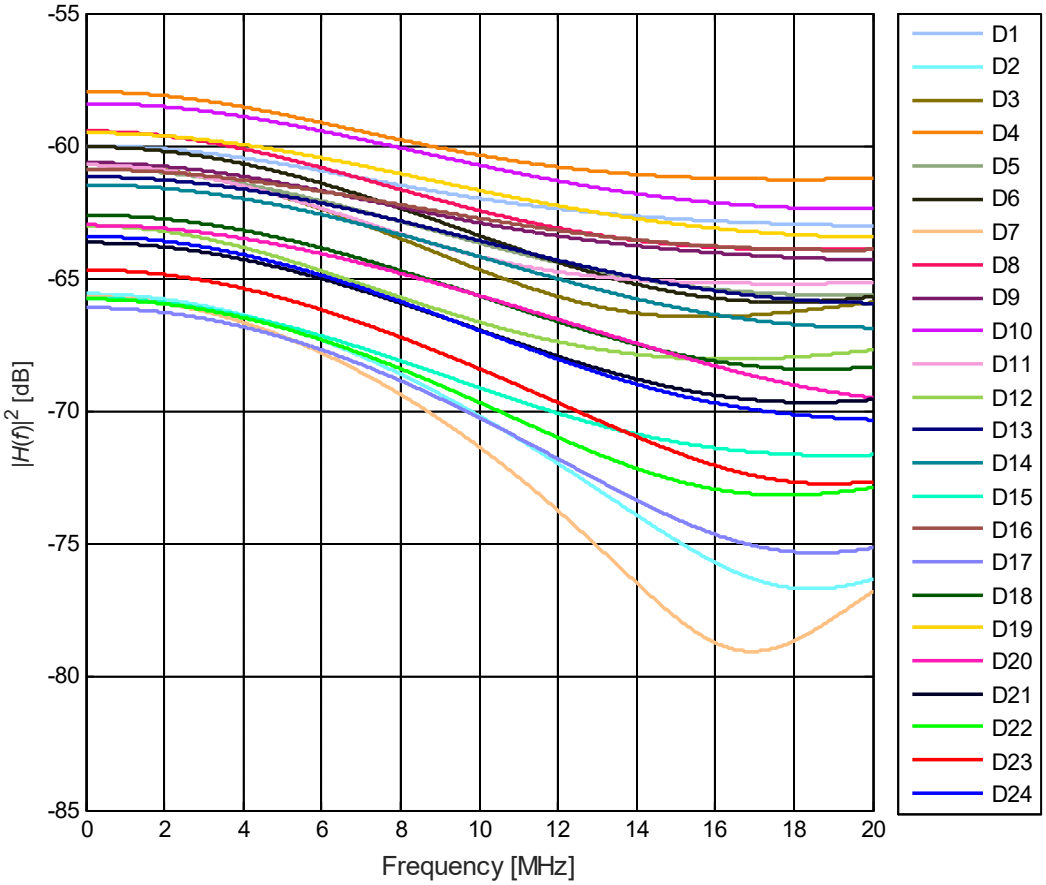
Test Points (Open Office)



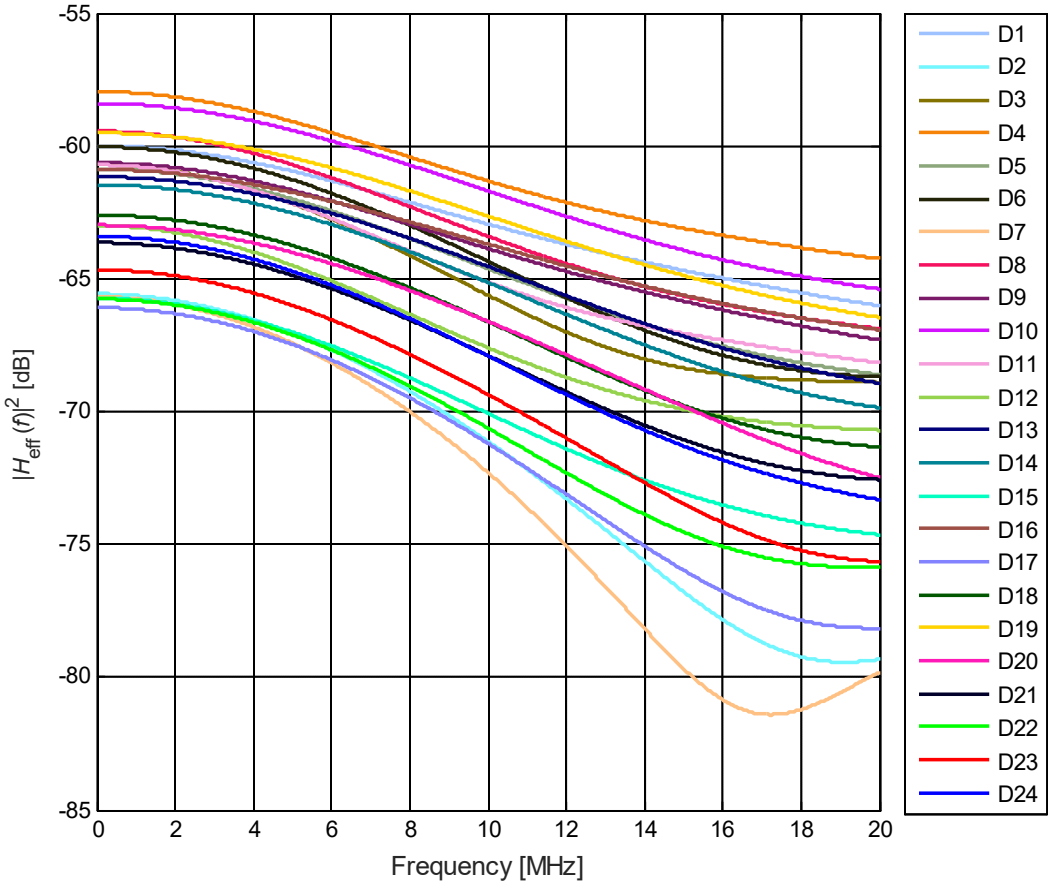
Test Points (Office with Cubicles)



Optical Channel Responses (Open Office)



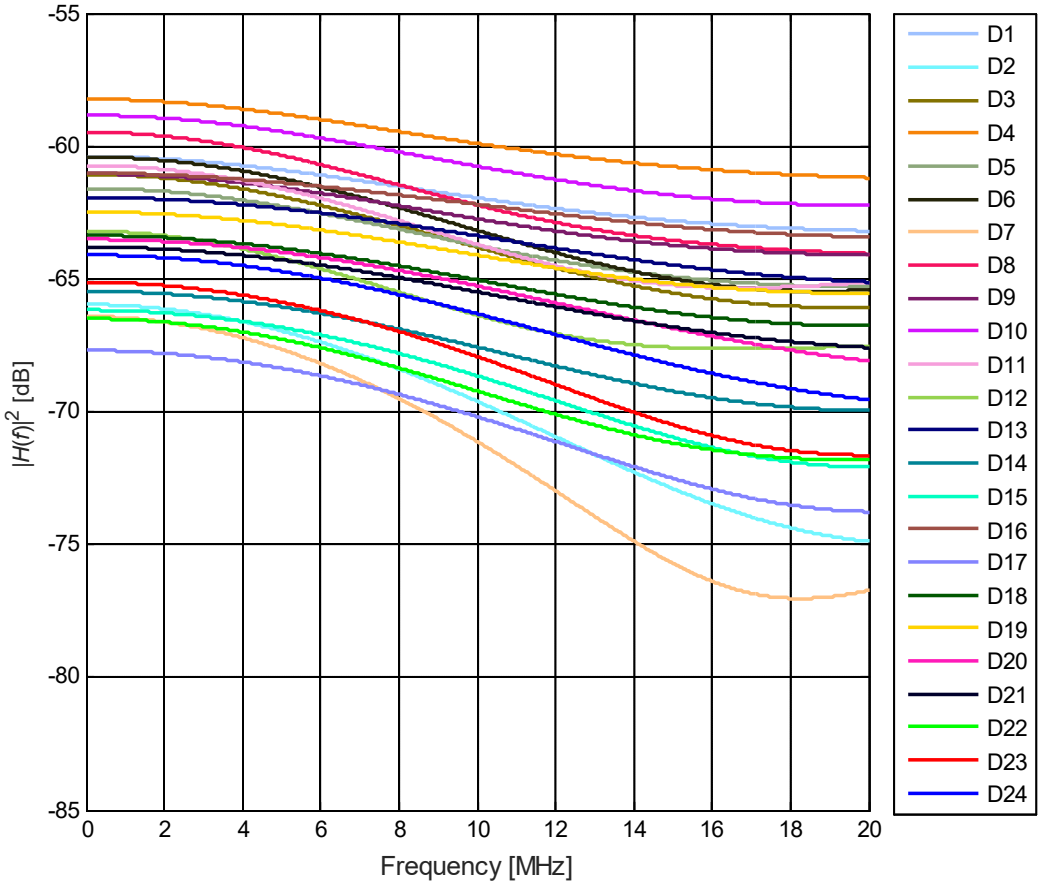
Effective Channel Responses (Open Office)



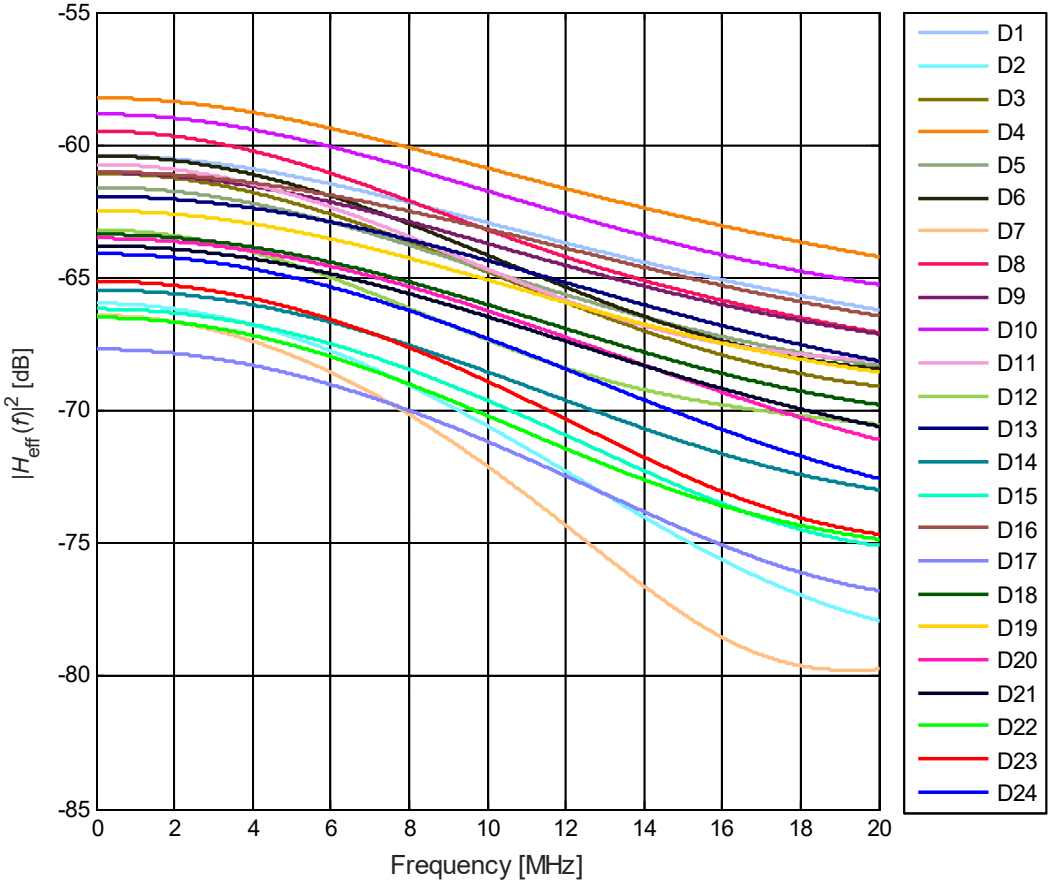
Channel Characteristics

	τ_{RMS} (ns)	H_0
D1	15.51	2.60×10^{-6}
D2	18.84	1.36×10^{-6}
D3	18.92	2.40×10^{-6}
D4	16.97	3.32×10^{-6}
D5	16.75	2.34×10^{-6}
D6	17.33	2.60×10^{-6}
D7	20.44	1.36×10^{-6}
D8	17.83	2.79×10^{-6}
D9	16.11	2.40×10^{-6}
D10	15.97	3.12×10^{-6}
D11	18.99	2.40×10^{-6}
D12	19.57	1.82×10^{-6}
D13	15.37	2.27×10^{-6}
D14	16.09	2.21×10^{-6}
D15	17.70	1.36×10^{-6}
D16	14.74	2.34×10^{-6}
D17	18.10	1.30×10^{-6}
D18	16.67	1.95×10^{-6}
D19	15.25	2.73×10^{-6}
D20	15.81	1.82×10^{-6}
D21	17.36	1.69×10^{-6}
D22	18.02	1.36×10^{-6}
D23	17.99	1.49×10^{-6}
D24	17.85	1.75×10^{-6}

Optical Channel Responses (Office with Cubicles)



Effective Channel Responses (Office with Cubicles)

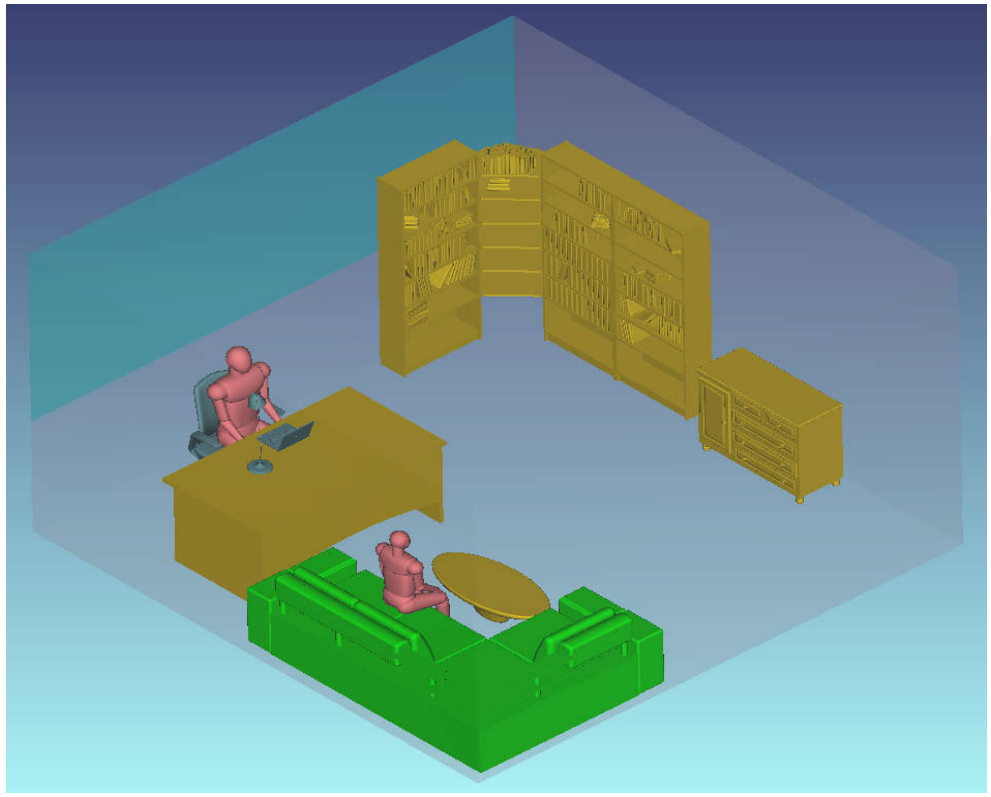


Channel Characteristics

	τ_{RMS} (ns)	H_0
D1	13.80	2.48×10^{-6}
D2	17.33	1.30×10^{-6}
D3	16.47	2.30×10^{-6}
D4	14.39	3.18×10^{-6}
D5	15.17	2.16×10^{-6}
D6	16.14	2.48×10^{-6}
D7	18.87	1.24×10^{-6}
D8	16.77	2.76×10^{-6}
D9	13.91	2.30×10^{-6}
D10	14.80	2.97×10^{-6}
D11	16.64	2.39×10^{-6}
D12	17.80	1.79×10^{-6}
D13	12.80	2.08×10^{-6}
D14	14.31	1.38×10^{-6}
D15	14.74	1.27×10^{-6}
D16	12.36	2.31×10^{-6}
D17	14.92	1.07×10^{-6}
D18	13.35	1.76×10^{-6}
D19	13.49	1.95×10^{-6}
D20	13.36	1.73×10^{-6}
D21	13.38	1.67×10^{-6}
D22	15.79	1.23×10^{-6}
D23	15.45	1.44×10^{-6}
D24	14.54	1.62×10^{-6}

Simulation Scenario 2: Office with Secondary Light

- In this office environment, there are two light sources; one of them is the main light source at the ceiling and the other one is mounted on the desk to provide task lighting.



Simulation Parameters

Room size	5 m × 5 m × 3 m
Materials	Walls: Plaster, Ceiling: Plaster, Floor: Pinewood
Objects	1 desk and a chair paired with desk 1 laptop on the desk, 1 desk light on the desk, 1 library 1 couch, 1 coffee table, window, 2 human bodies
Objects specifications	Desk: Pinewood (Typical height of 0.88 m) Chair: Black gloss paint, Laptop: Black gloss paint Desk light: Black gloss paint, Library: Pinewood, Window: Glass Couch: Cotton, Coffee table: Pinewood Human body: ▪ Shoes: Black gloss paint ▪ Head & Hands: Absorbing ▪ Clothes: Cotton
Luminary Specifications	Brand: LR24-38SKA35 Cree Inc. Half viewing angle: 40º
Number of luminaries	1 on the ceiling 1 for the desk light
Receiver area	1 cm^2

Light Source (Transmitter)

- In simulation study, we use the LED luminary “LR24-38SKA35” from Cree.

Cree.com / LED Lighting / Products / Indoor / LR Series

LR Series

LED Architectural Troffer

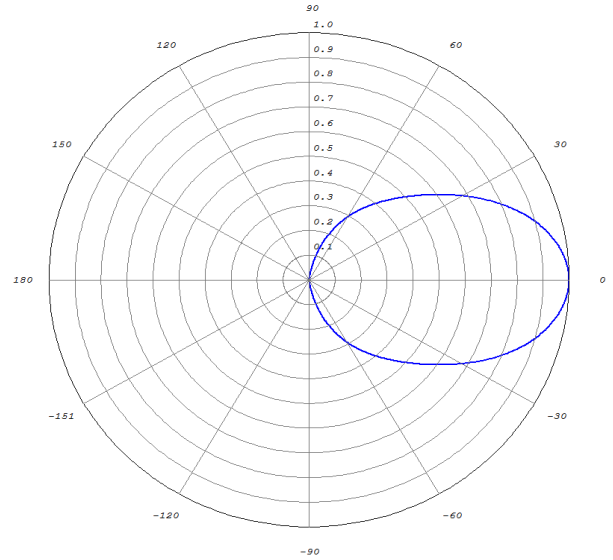
The architecturally designed recessed flat panel of the LR22™ LED troffer blends seamlessly into any ceiling and offers soft, smooth, fully-luminous light, creating a quiet ceiling that keeps spaces bright and vibrant. The innovatively thin 3.6" depth of the LR22 LED troffer easily accommodates narrow plenums and is ideal for both retrofit and new construction. The LR22 LED troffer delivers 3400 lumens of exceptional 90 CRI light while achieving an efficacious 100 lumens per watt. This breakthrough performance is achieved by combining the high efficacy and high-quality light of Cree TrueWhite® Technology. Delivering 0-10V continuous dimming on every luminaire allows for further energy savings when utilized for even faster payback.

SPECIFICATIONS | VARIATIONS | DOCUMENTATION | MULTIMEDIA

- Cree TrueWhite® Technology
- Efficacy: 100 LPW
- Delivered Light Output: 3400 lumens
- Input Power: 34 watts
- CRI: 90
- CCT: 3500K or 4000K
- Lifetime: Designed to last for 75,000 hours L70 @ 25°C
- DLC Qualified
- Controls: Continuous dimming to 5% with 0-10V controls
- Limited Warranty: 10 Years
- Mounting: Recessed

Applications

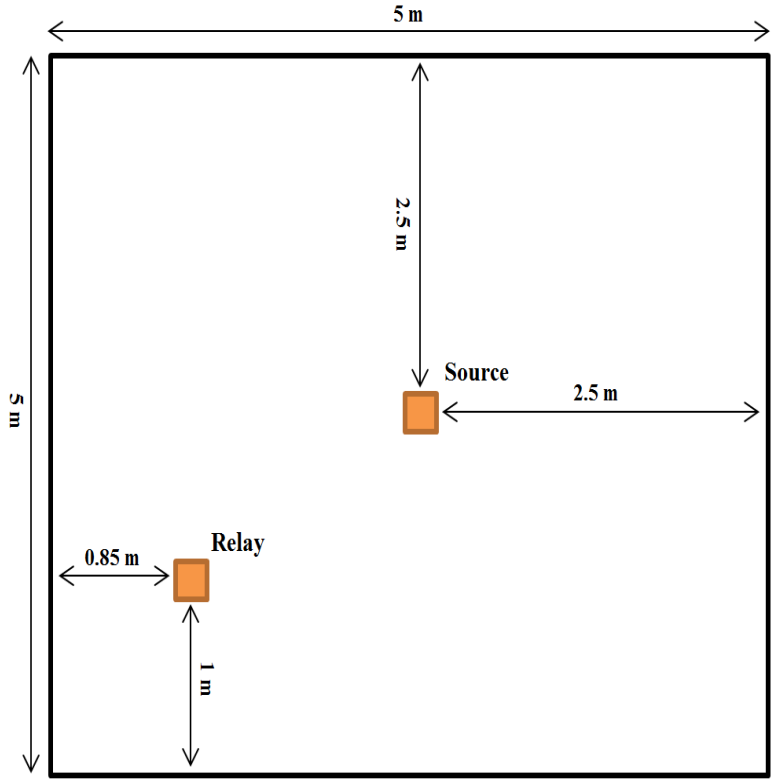
- Government Facilities Lighting
- Corporate Campus Lighting
- Healthcare Facilities Lighting
- Restaurant & Hotel Lighting
- Retail & Grocery Lighting



Simulated emission pattern in Zemax®

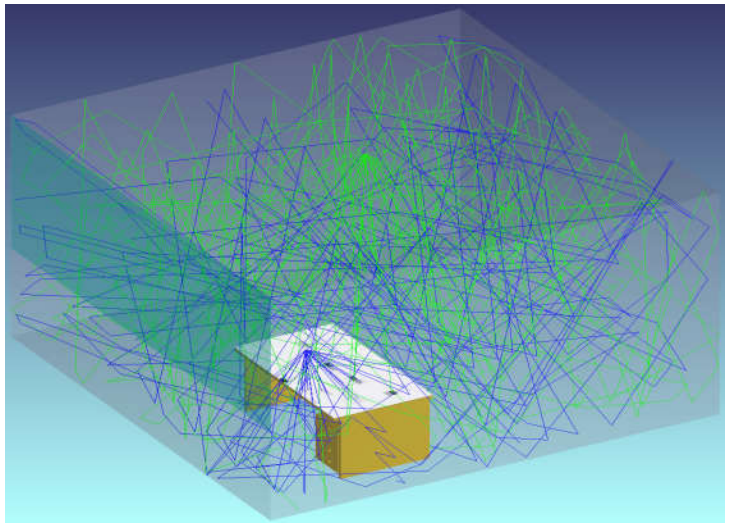
Illumination Levels

- Based on the properties of employed luminary, required illumination level (500 lx) and the size of office place, we arrange the luminaries as follows:



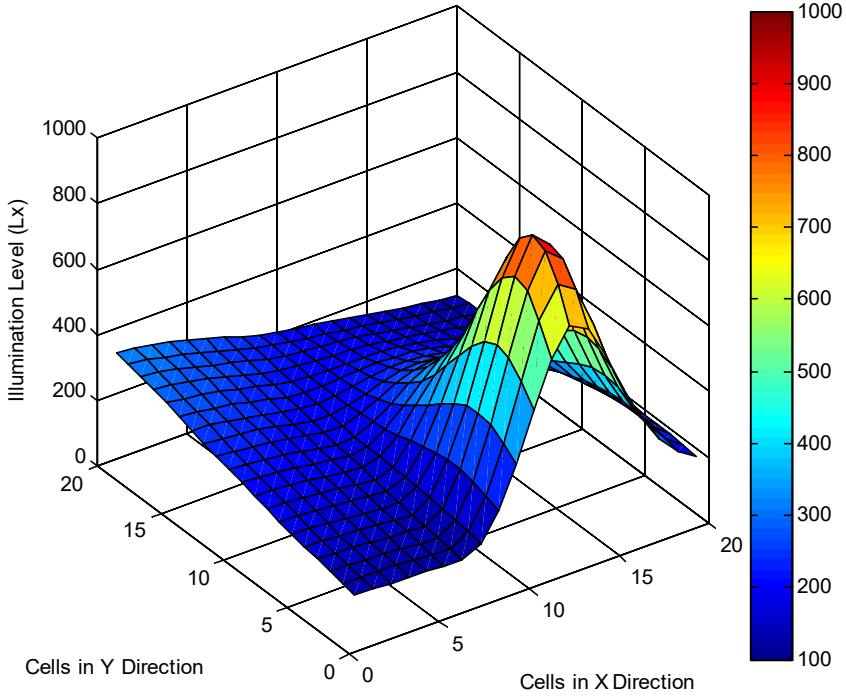
Arrangement of luminaries

Delivered light output from each luminary	3796 lumens
Average of illumination level	270 lx
Uniformity of illumination	0.4409

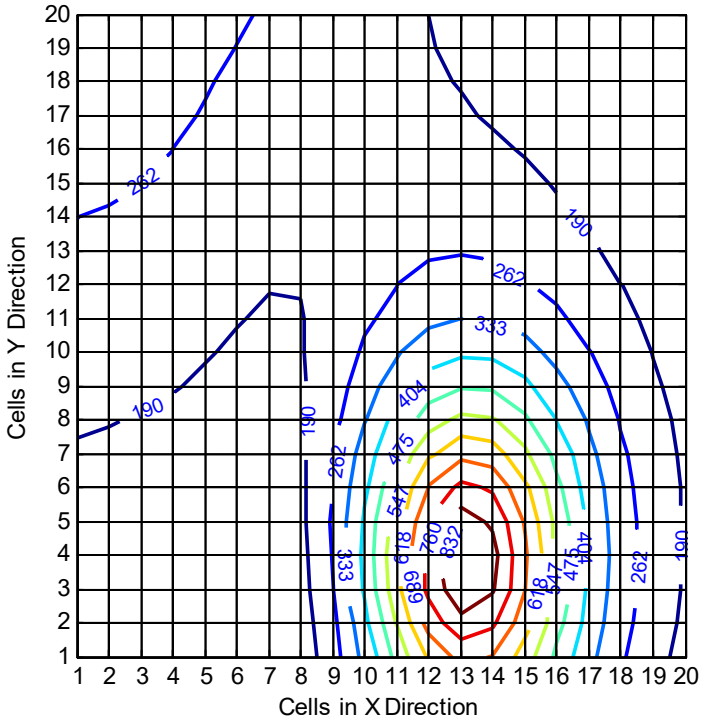


Evaluation of illumination levels in Zemax®

Illumination Patterns



Simulated illumination levels in Zemax®



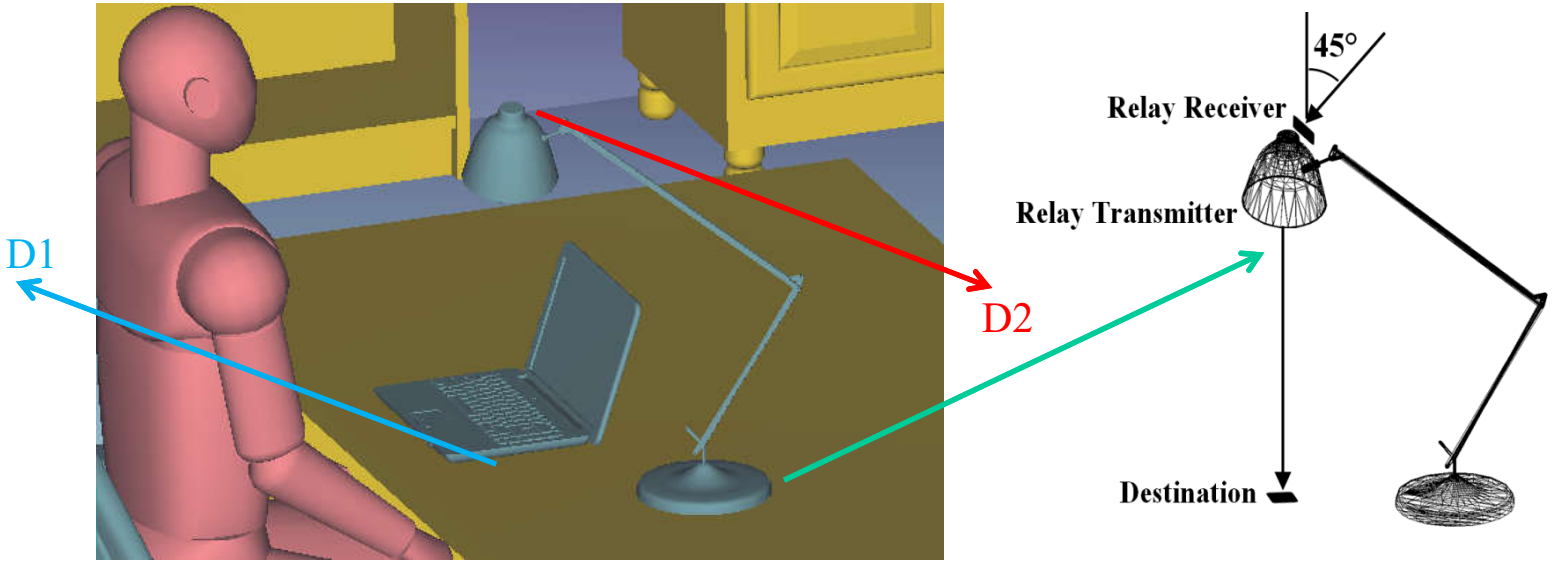
Illumination level contours in Matlab®

- The minimum and maximum values of illumination are 119 lx and 902 lx respectively.

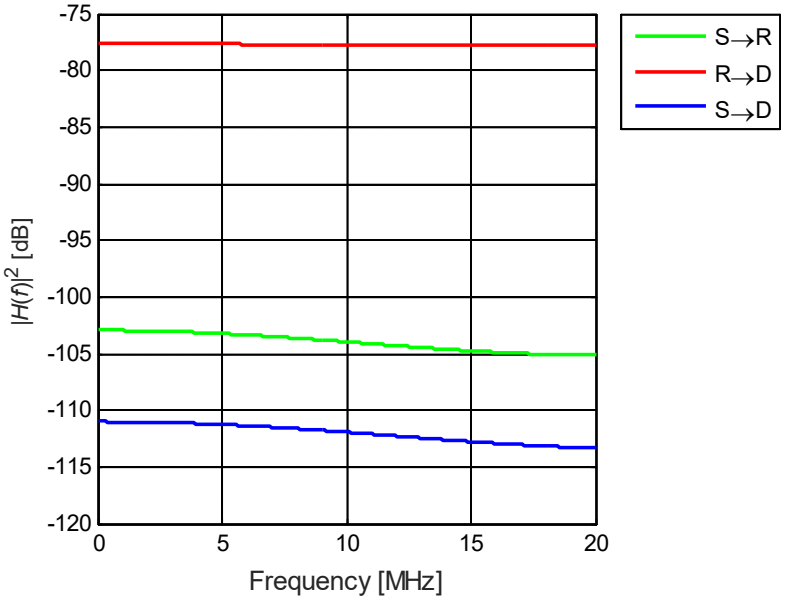
Location of Test Points (Receivers)

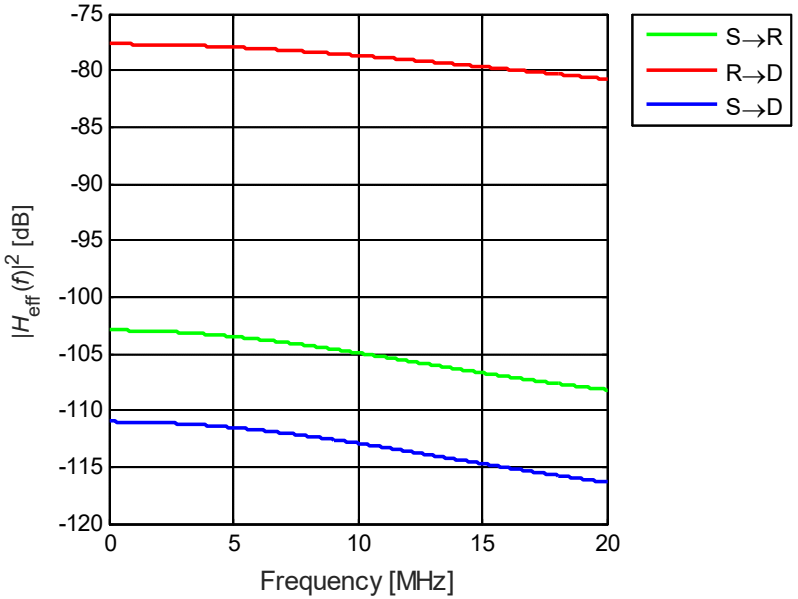
- 2 test points are chosen:

On the desk next to the laptop at a height of 0.88 m (e.g., a USB-type device connected to laptop)	D1
On the top of desk light at a height of 1.5 m with 45º rotation toward the source on the ceiling	D2



Optical and Effective Channel Responses & Channel Characteristics

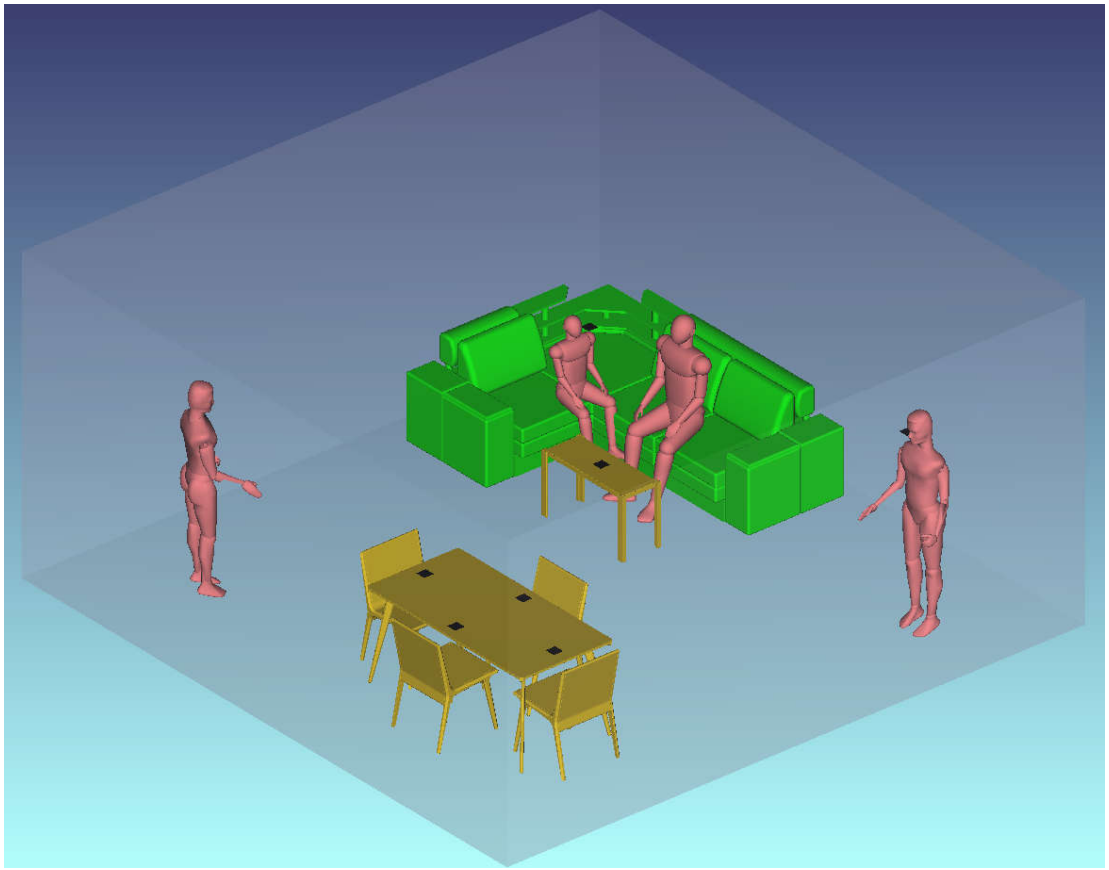




	τ_{RMS} (ns)	H_0
S→R	11.52	2.84×10^{-5}
R→D	8.07	5.21×10^{-4}
S→D	11.11	1.12×10^{-5}

Simulation Scenario 3: Home

- We consider a living room with table, chairs, couch, coffee table and human bodies.



Simulation Parameters

Room size	6 m × 6 m × 3 m
Materials	Walls: Plaster, Ceiling: Plaster, Floor: Pinewood
Objects	Table with 4 chairs Couch Coffee table 4 human bodies
Object Specifications	Tables: Wooden with size of 2 m × 1 m × 0.9 m Chairs: Wooden matched with table Couch: Cotton Coffee table: Glass Human body: ▪ Shoes: Black gloss paint ▪ Head & Hands: Absorbing ▪ Clothes: Cotton
Luminary Specifications	Brand: CR6-800L Cree Inc. Half viewing angle: 40º
Number of luminaries	9
Receiver area	1 cm^2

Light Source

- In simulation study, we use the LED luminary “CR6-800L” from Cree.

Cree.com / LED Lighting / Products / Indoor / CR Series – 4 & 6" Retrofit

CR Series – 4 & 6" Retrofit

Bringing LED Lighting to the masses.

The CR Series is an amazing combination of price and performance. Built upon technical innovations in optical, electronics, mechanical and thermal design, the CR Series provides amazing color accuracy and advanced dimming capabilities.

SUPERIOR QUALITY AND AFFORDABILITY
Developed with Cree TrueWhite® Technology, the CR4™ and CR6™ provide efficacy that is up to twice that of compact fluorescents, while achieving better color quality with a CRI of 90+. The CR Series is engineered with Cree LED technology and typically pays for itself in less than one year in many installations.

FAST INSTALL, UNRIVALED PERFORMANCE
Designed to easily install into existing IC or non-IC four-inch, six-inch and some five-inch housings. The CR LED Downlight Series provides higher efficacy and longer life than compact fluorescent lamps, with the beautiful light quality that you would expect from an incandescent. Dimmable down to 5% with widely available traditional dimmers and ENERGY STAR® qualified, this product is ideal for use in both residential and light-commercial new construction and retrofit applications.

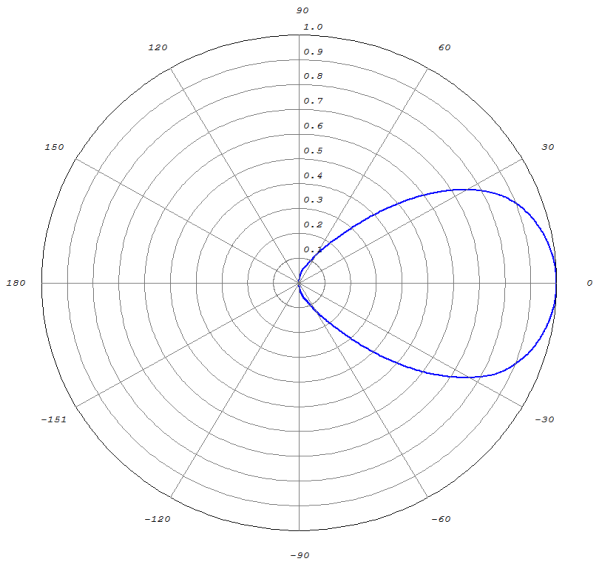
SPECIFICATIONS | VARIATIONS | DOCUMENTATION | MULTIMEDIA | ACCESSORIES

- Cree TrueWhite™ Technology
- Up to 67 lumens per watt
- Fits for most 6" and some 5" recessed housings (CR6)
- Fits most 4" recessed housings (CR4)
- Replaces either 65 watt or 90 watt incandescent (CR6)
- Replaces 50 watt incandescent (CR4)
- CCT: 2700K-4000K
- CRI: 90
- Dimmable to 5%, with most standard dimmers
- Designed to last up to 50,000 hours
- Energy Star® Qualified
- **Warranty:** Cree offers industry-leading limited product warranties. Visit our **warranty webpage** for more information on this product.

This product is available for:
QUICKSHIP™
Visit **cree.com/lighting/quickship** for eligible part numbers.

Applications

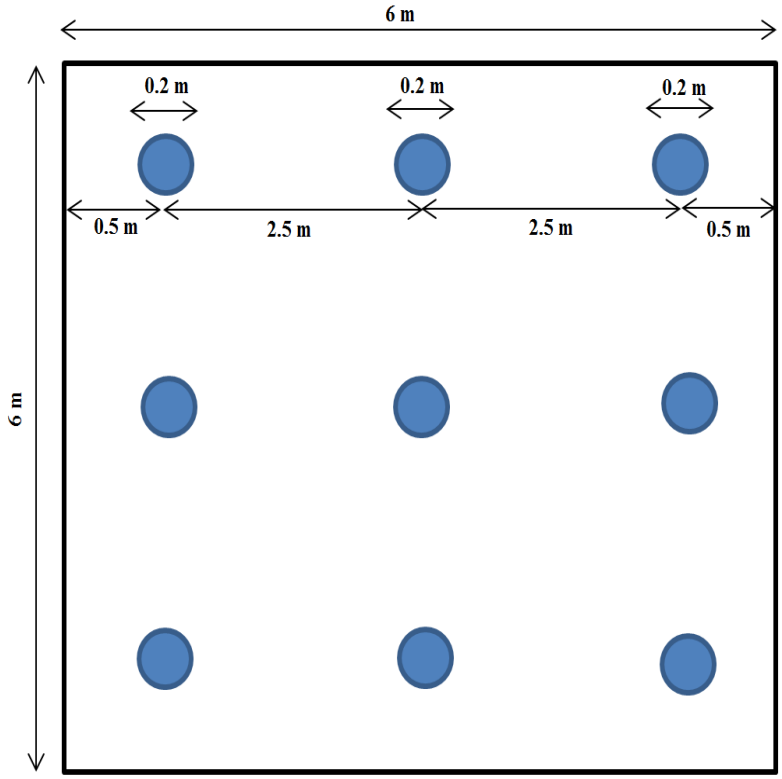
- Municipal Lighting
- Healthcare Facilities Lighting
- Residential Lighting
- Restaurant & Hotel Lighting
- Auto Dealership Lighting
- Education Facilities Lighting
- Retail & Grocery Lighting
- Petroleum & Convenience Lighting



Simulated emission pattern in Zemax®

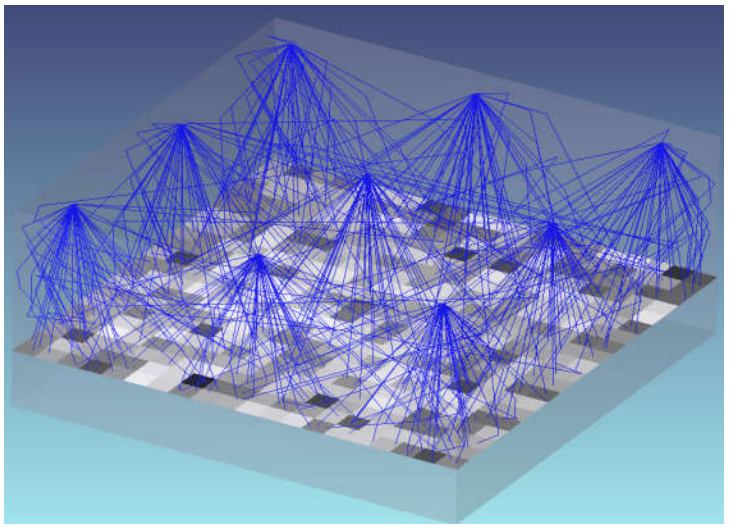
Illumination Levels

- Based on the properties of luminary, required illumination level (150 lx) and the size of room, we arrange the luminaries as follows:



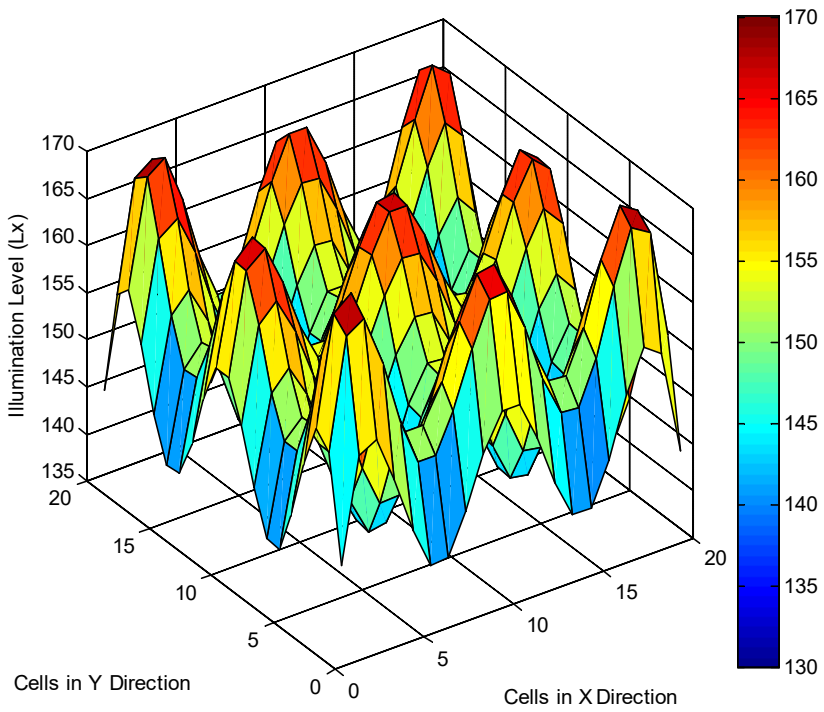
Arrangement of luminaries

Delivered light output from each luminary	804 lumens
Average of illumination level	153 lx
Uniformity of illumination	0.9068

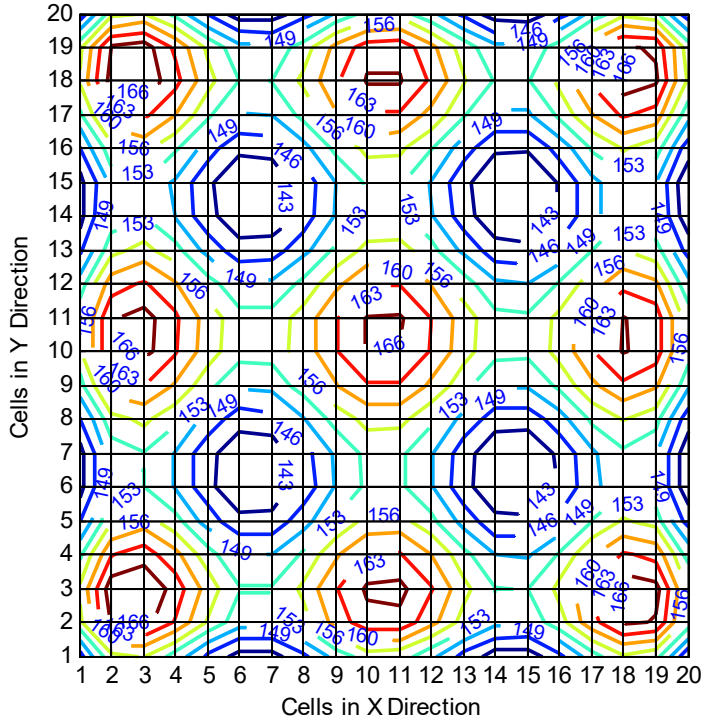


Evaluation of illumination level in Zemax®

Illumination Patterns



Simulated illumination levels in Zemax®

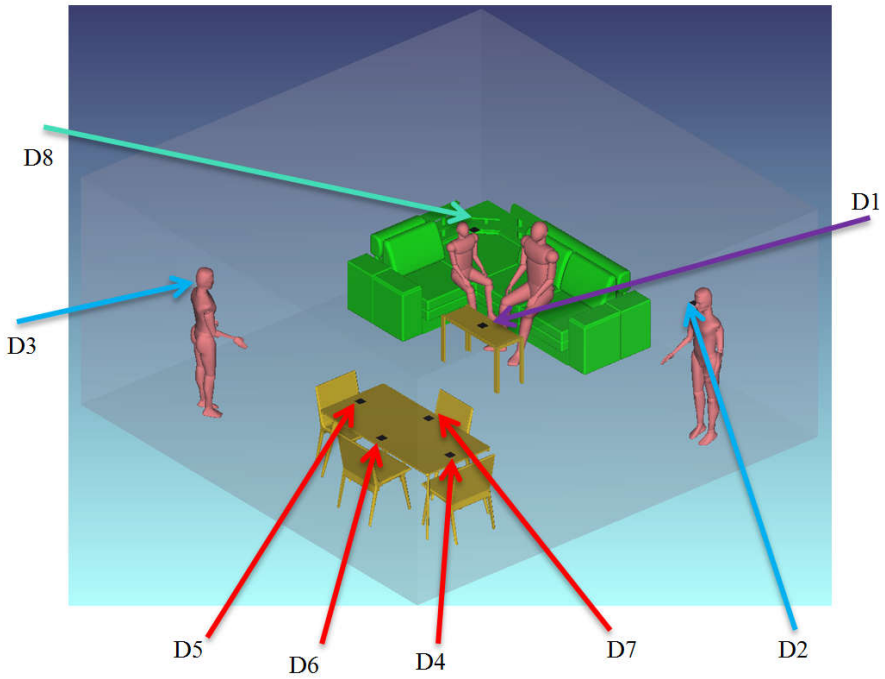


Illumination level contours in Matlab®

- The minimum and maximum values of illumination are 139 lx and 169 lx.

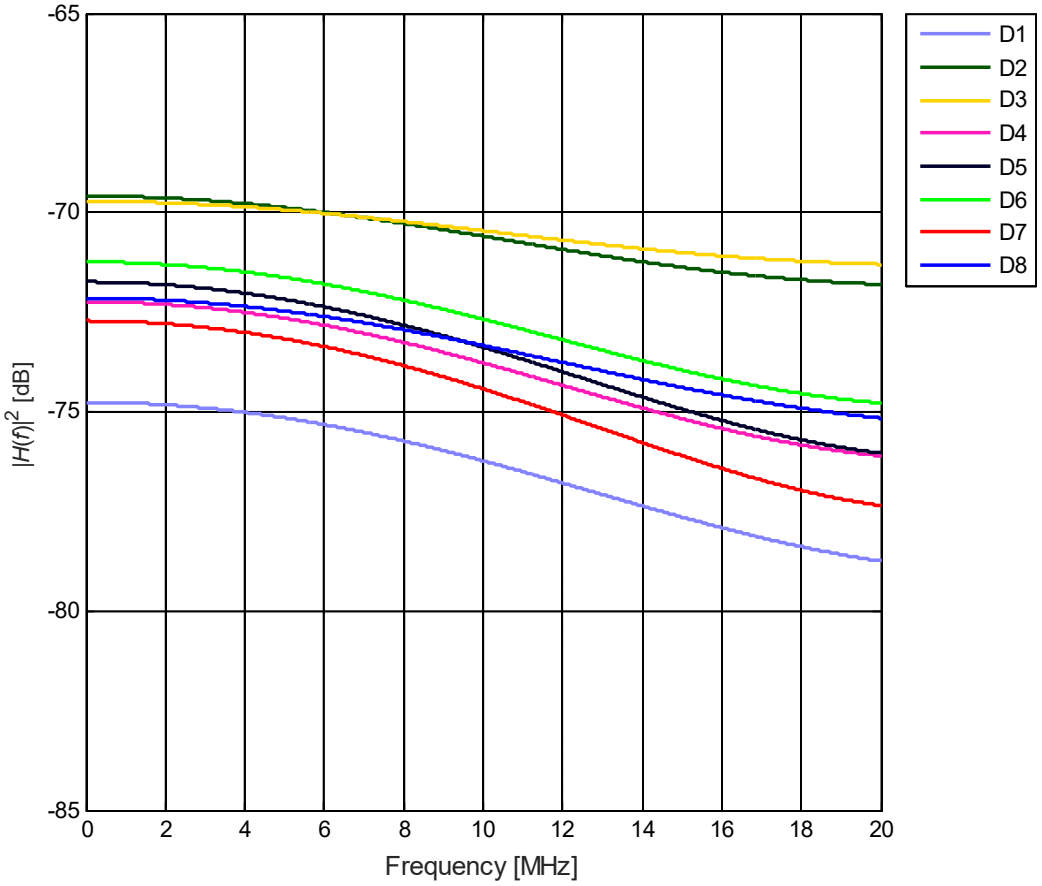
Location of Test Points (Receivers)

- 8 test points are chosen which are categorized into four groups:

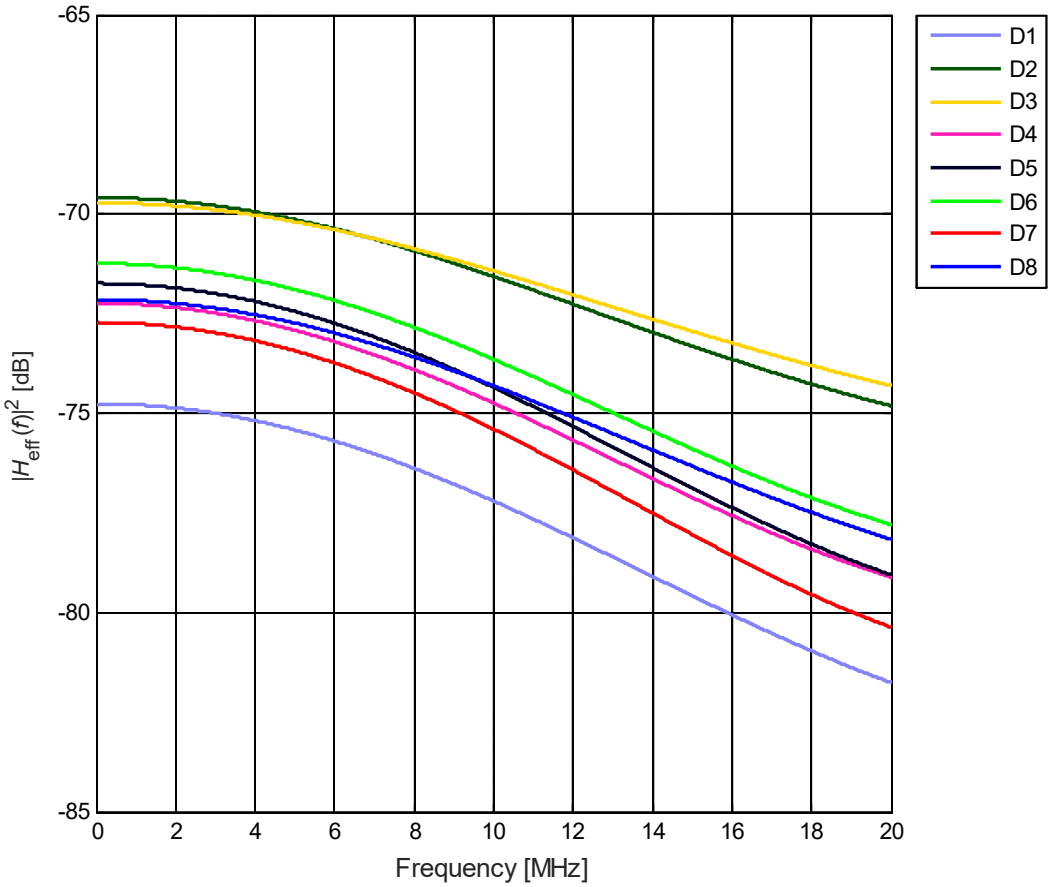


On the coffee table at a height of 0.6 m with 45º rotation	D1
Next to the wall at a height of 1.7 m (e.g., standing people) with 45º rotation	D2-D3
On the table at a height of 0.9 m	D4-D7
On the top of couch at height of 1.1 m (e.g., sitting people) with 45º rotation	D8

Optical Channel Responses



Effective Channel Responses

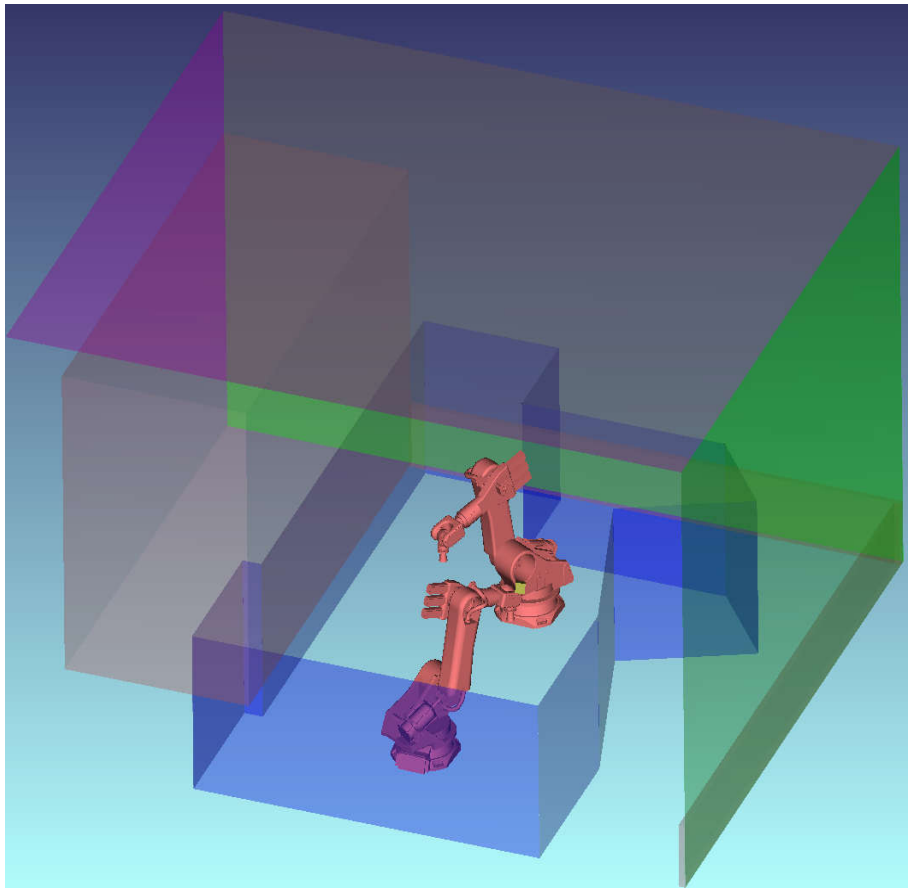


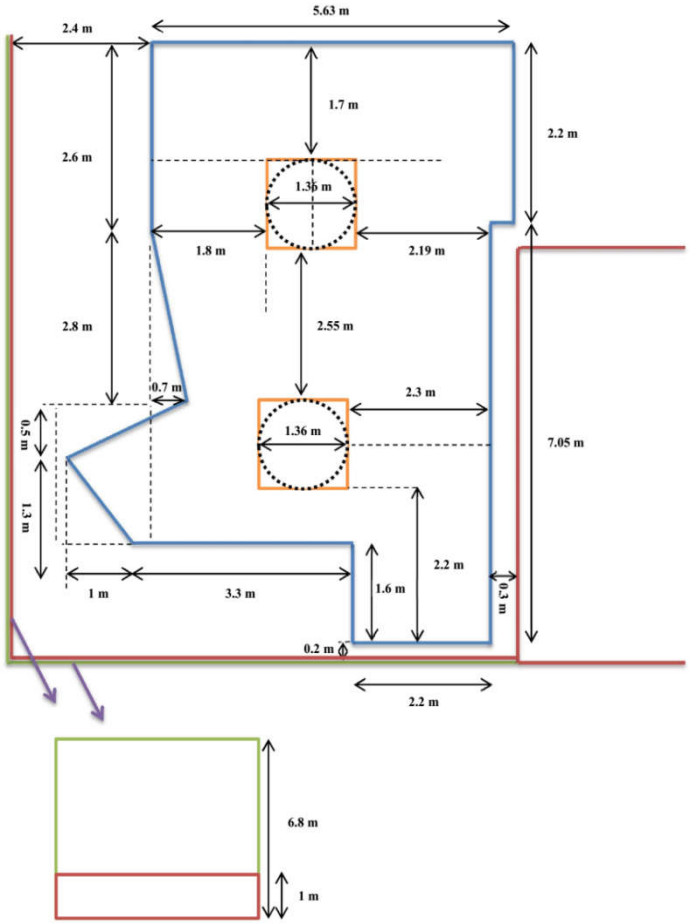
Channel Characteristics

	τ_{RMS} (ns)	H_0
D1	12.49	6.75×10^{-6}
D2	11.50	1.22×10^{-5}
D3	10.72	1.20×10^{-5}
D4	12.70	9.03×10^{-6}
D5	12.90	9.56×10^{-6}
D6	12.48	1.01×10^{-5}
D7	13.01	8.55×10^{-6}
D8	11.88	9.13×10^{-6}

Simulation Scenario 4: Manufacturing Cell

- We consider a manufacturing cell with two robots.





Simulation Parameters

Room size	8.03 m × 9.45 m × 6.8 m (See p.48 for exact layout)
Materials	Red Walls: Concrete Green Walls: Aluminum metal Blue Walls: Plexiglas (PMMA) Ceiling: Aluminum metal Floor: Concrete
Objects	Two robots
Object Specifications	Robot: Galvanized steel metal Height of Robot: 2.7 m Height of Plexiglas boundary: 2.5 m
LED Specifications	Brand: MC-E Cree Xlamp Inc. Half viewing angle: 60º
Number of LEDs	6
Receiver area	1 cm^2

Light Source (Transmitter)

- In simulation study, we use the LED "Xlamp MC-E" from Cree.

Cree.com / LED Components / Products / XLamp LEDs / MC-E

XLamp MC-E

High-Lumen Output in a Small Form Factor

The XLamp MC-E LED is a lighting-class, multi-chip LED that provides high lumen output, color consistency and multi-color packaging flexibility in a small-footprint package. The XLamp MC-E LED is available with EasyWhite™ 2-step and 4-step bins, which improve LED-to-LED color consistency and reduce manufacturing complexity. Compared to discrete LEDs, XLamp MC-E LEDs reduce the distance between LED die, creating a small optical source for excellent optical control and efficient color mixing.

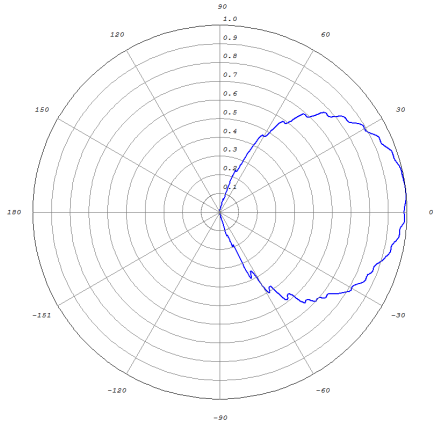
SPECIFICATIONS | VARIATIONS | DOCUMENTATION | MULTIMEDIA

Data Sheet (pdf)

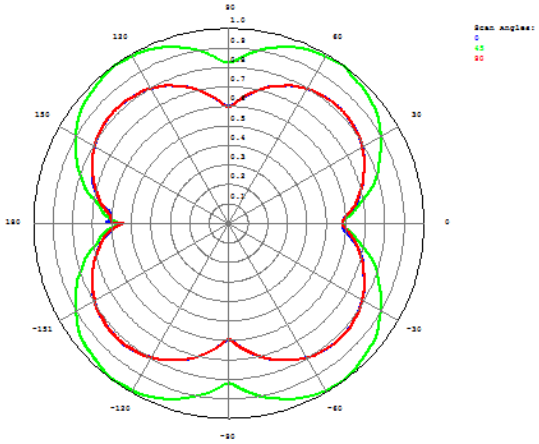
Size	7 x 9 mm
Product Options	White EasyWhite® Dynamic White Color (RGBW)
Maximum Drive Current	0.7 A per LED die
Maximum Power	9.5 W
Maximum Light Output	751 lm
Maximum Efficacy at Binning Conditions	99 lm/W
Typical Forward Voltage	3.1 V per LED die White @ 350 mA 2.1 V per LED die Red @ 350 mA 3.4 V per LED die Green @ 350 mA 3.2 V per LED die Blue @ 350 mA
Maximum Reverse Voltage	5 V
Viewing Angle	110 ° White 115 ° Color
Maximum Junction Temperature	150 °C
Binning	2- and 4-Step EasyWhite®
Maximum ESD Withstand Voltage	8000 V (HBM per Mil-Std-883D)
Reflow Solderable	Yes - JEDEC J-STD-020C-compatible
REACH-Compliant	Yes
RoHS-Compliant	Yes
UL-Recognized	Yes - Level 1 Enclosure Consideration

Applications

- Directional
- Entertainment
- Vehicle



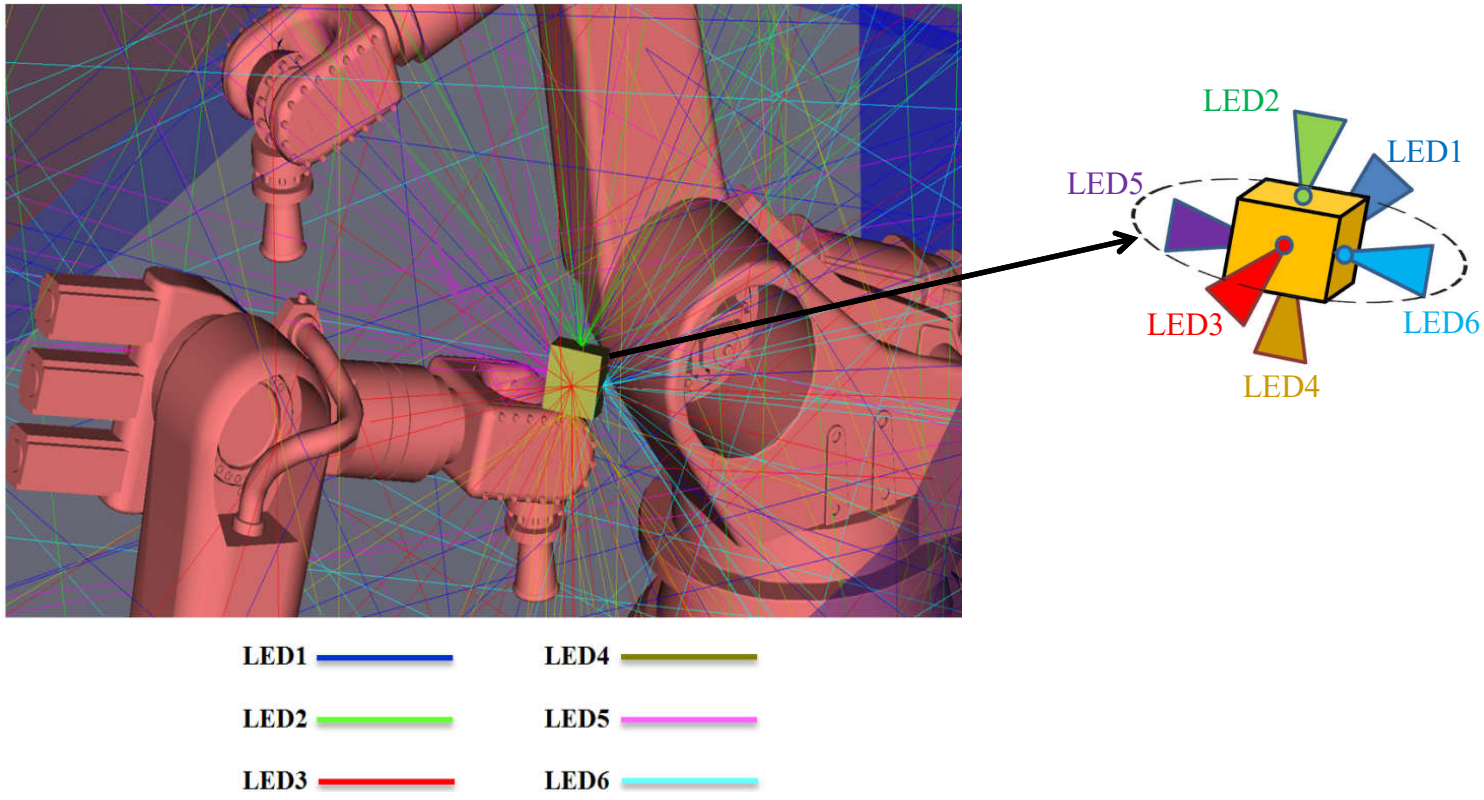
Simulated emission pattern in Zemax®



Emission pattern of six LEDs which cover 360º

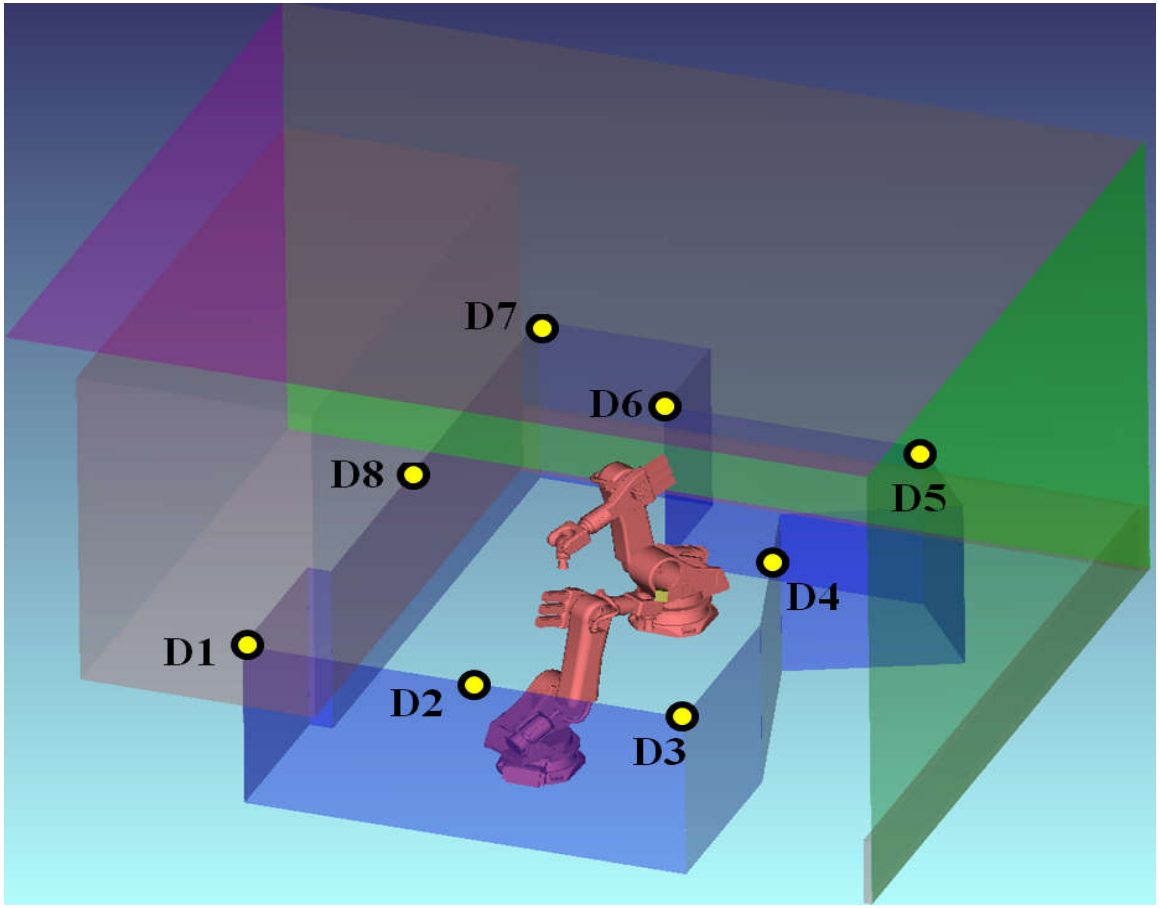
Location of Luminaries (Transmitters)

- 6 transmitters are located at the head of the robot, arranged on the six sides of a cube to cover 360º.

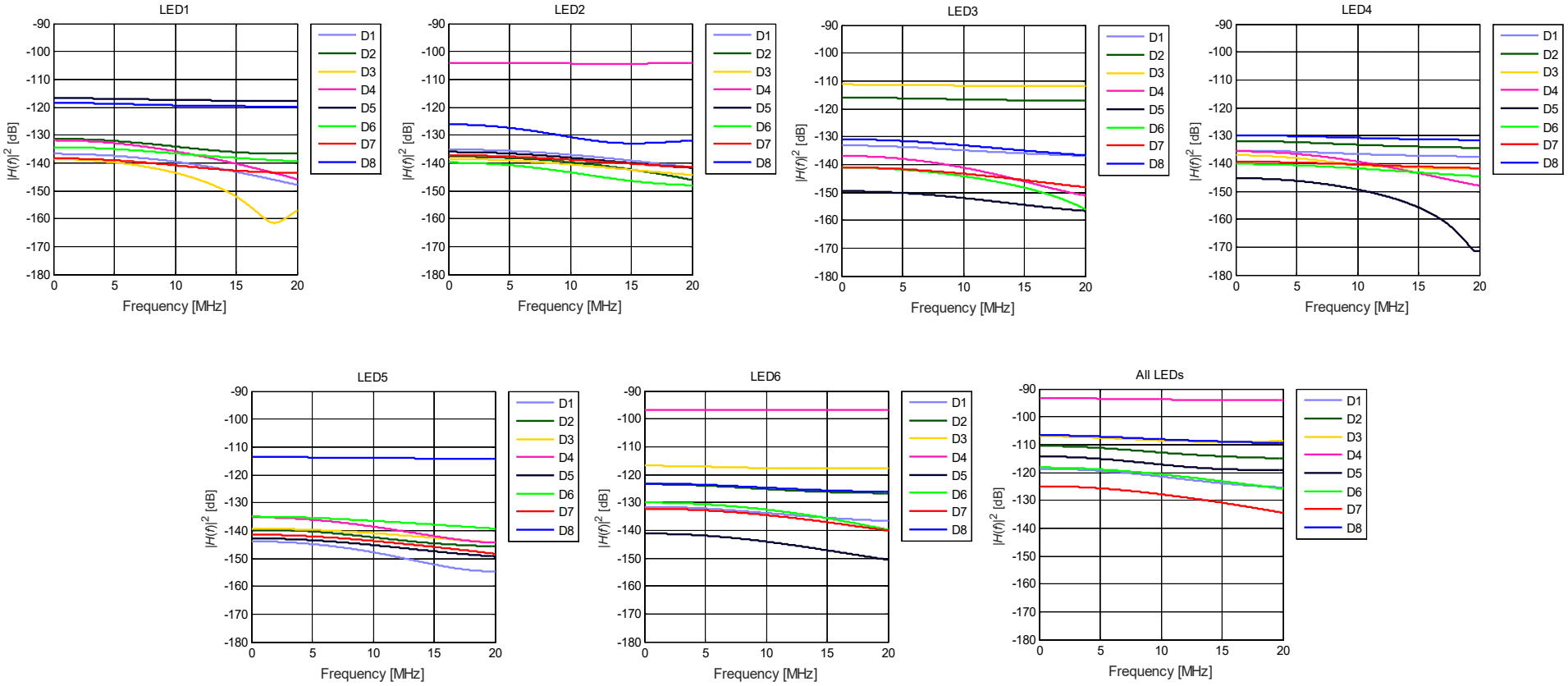


Location of Test Points (Receivers)

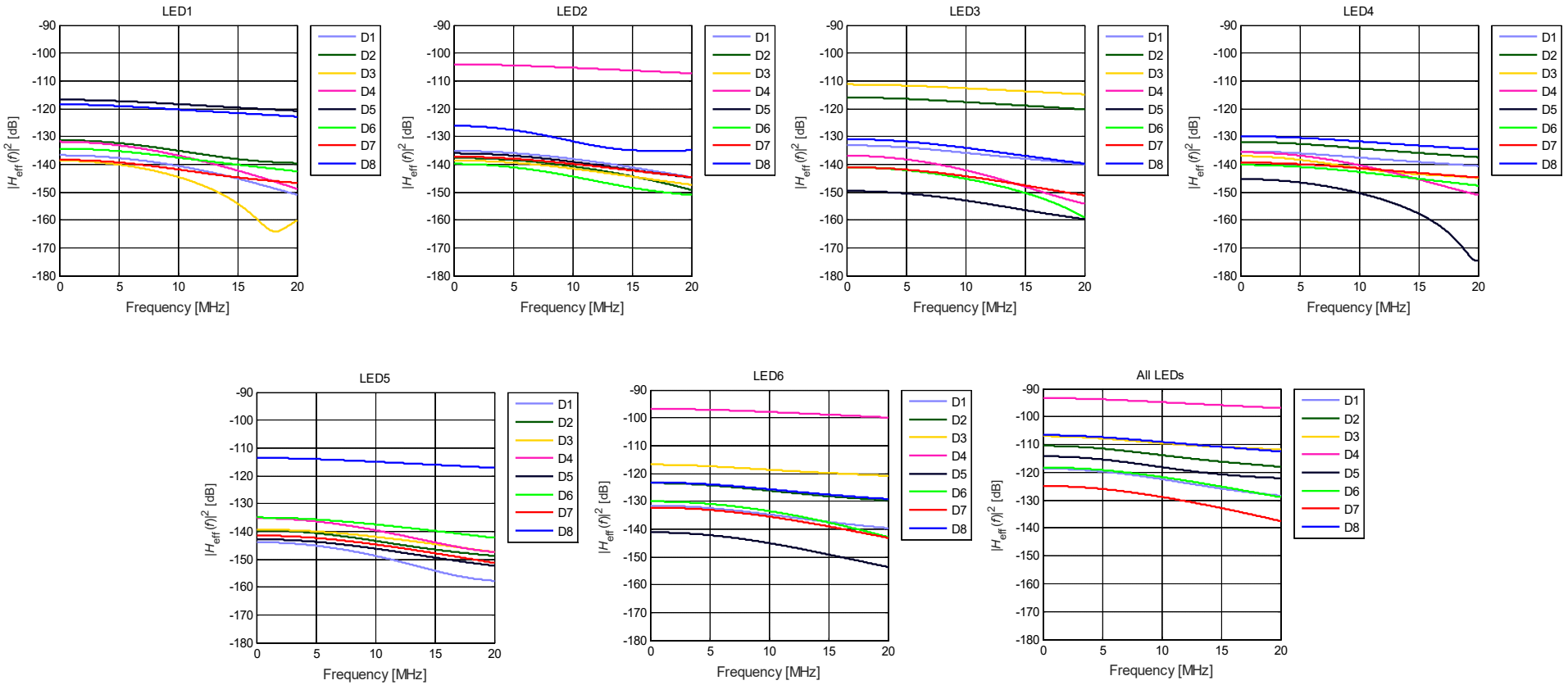
- Test points are considered on the top of the Plexiglas boundary which are looking in the direction of the robots.



Optical Channel Responses



Effective Channel Responses



Channel Characteristics

TX-RX		τ_{RMS} (ns)	H_0
LED1	D1	15.20	5.81×10^{-7}
	D2	15.68	1.08×10^{-6}
	D3	17.84	4.64×10^{-7}
	D4	17.53	1.01×10^{-6}
	D5	10.96	5.79×10^{-6}
	D6	15.13	7.67×10^{-7}
	D7	15.03	4.82×10^{-7}
	D8	12.11	4.77×10^{-6}
LED2	D1	13.29	6.94×10^{-7}
	D2	13.51	5.21×10^{-7}
	D3	13.66	4.68×10^{-7}
	D4	9.64	2.50×10^{-5}
	D5	14.03	6.30×10^{-7}
	D6	16.79	4.05×10^{-7}
	D7	13.00	5.47×10^{-7}
	D8	18.82	1.96×10^{-6}
LED3	D1	13.93	8.78×10^{-7}
	D2	11.16	6.35×10^{-6}
	D3	10.09	1.09×10^{-5}
	D4	17.59	5.70×10^{-7}
	D5	14.66	1.32×10^{-7}
	D6	15.94	3.55×10^{-7}
	D7	14.29	3.53×10^{-7}
	D8	14.24	1.13×10^{-6}

TX-RX		τ_{RMS} (ns)	H_0
LED4	D1	12.71	6.79×10^{-7}
	D2	13.23	1.01×10^{-6}
	D3	17.82	5.61×10^{-7}
	D4	16.81	6.60×10^{-7}
	D5	16.81	2.17×10^{-7}
	D6	12.92	3.90×10^{-7}
	D7	11.66	4.29×10^{-7}
	D8	11.48	1.27×10^{-6}
LED5	D1	16.99	2.55×10^{-7}
	D2	15.89	4.21×10^{-7}
	D3	12.96	4.32×10^{-7}
	D4	16.52	6.92×10^{-7}
	D5	14.77	2.88×10^{-7}
	D6	13.00	7.10×10^{-7}
	D7	14.48	3.37×10^{-7}
	D8	10.08	8.34×10^{-6}
LED6	D1	14.81	1.05×10^{-6}
	D2	13.98	2.68×10^{-6}
	D3	12.19	5.75×10^{-6}
	D4	8.84	5.78×10^{-5}
	D5	15.39	3.48×10^{-7}
	D6	14.40	1.25×10^{-6}
	D7	14.24	9.74×10^{-7}
	D8	13.19	2.75×10^{-6}

TX-RX		τ_{RMS} (ns)	H_0
All LEDs	D1	15.66	7.78×10^{-7}
	D2	15.52	1.99×10^{-6}
	D3	14.13	2.96×10^{-6}
	D4	10.45	1.43×10^{-5}
	D5	16.42	1.29×10^{-6}
	D6	14.85	8.15×10^{-7}
	D7	15.83	3.78×10^{-7}
	D8	13.58	3.10×10^{-6}

Conclusions

- This contribution proposes LiFi reference channel models for indoor environments to assist the IEEE 802.11bb.
- Our results are extended versions of the previous contribution in 802.15.7r1 where the effect of LED response is further considered.

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