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Radio Propagation Measurement and Modeling in Wireless Communication Environments

Soo Yong LIM (Grace)

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- Outline:
  - Introduction
  - Four distinct environments
    - Indoor Stairwell
    - Periodic Building Façade
    - Open-trench Drain
    - Cave
  - Conclusion

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- EM waves – the carrier of wireless information.
- Propagation prediction - for successful wireless communication systems design.

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What should we know about it?

- Large-scale path loss
- Small-scale multipath fading
- Angle of arrival/ departure (e.g. for MIMO systems)

Wireless Channel

What should we consider about it?

- Environment
  - Geometry
  - Materials
- Frequency
  - Bandwidth
- Antenna
  - Radiation pattern

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- In an indoor stairwell, the propagation environment is like a leaky waveguide with inhomogeneous fillings (stairs) inside.
- This unique propagation environment is different from multifloor and other indoor scenarios, hence, deserves careful studies.
- Reliable communication in indoor stairwell is crucial to law enforcement and firefighting safety.

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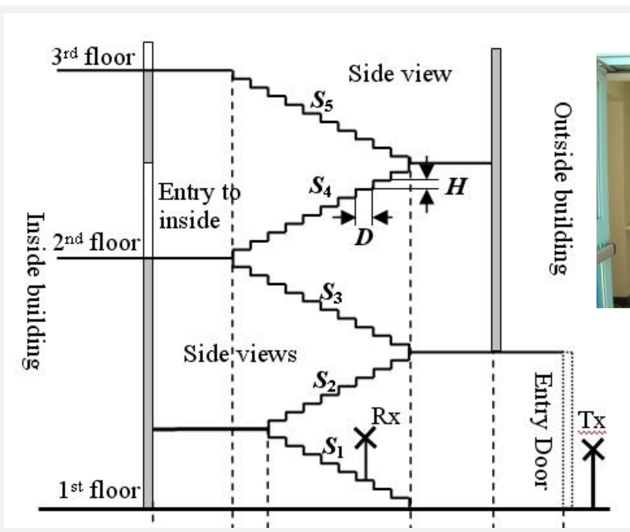

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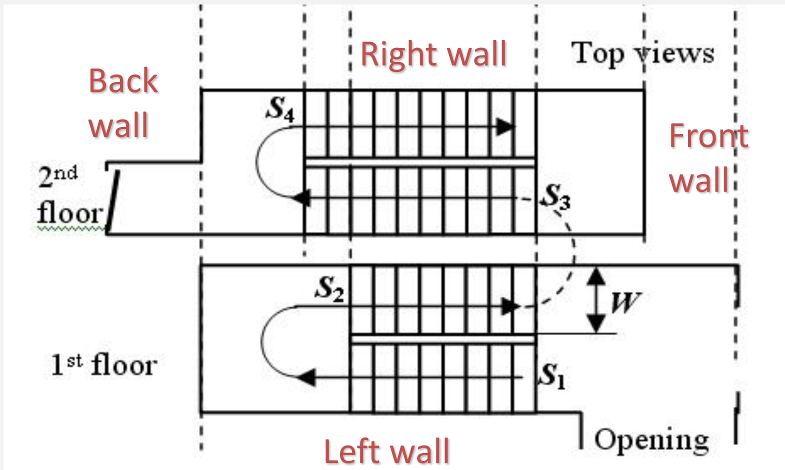

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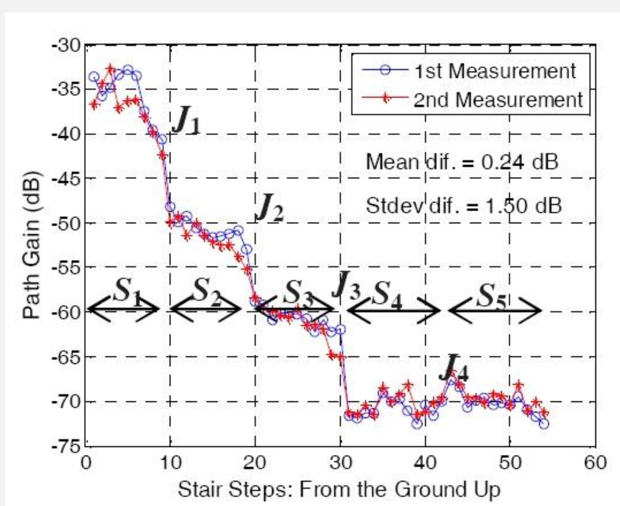
VV - Pol.

at 2.4 GHz



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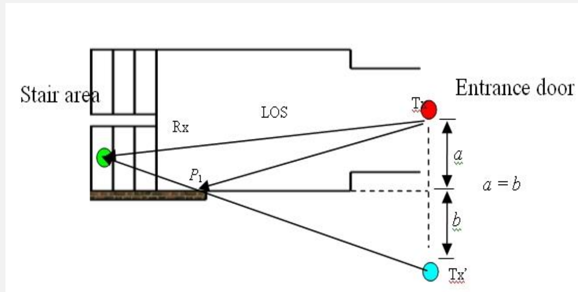
Ray Tracing



- To determine one-reflection ray, on the left-hand side of the wall from Tx to Rx, the image of Tx due to the wall is first determined as Tx'.
- Then connect Tx' and Rx; the intersection point on the left wall (P1) is the reflection point.

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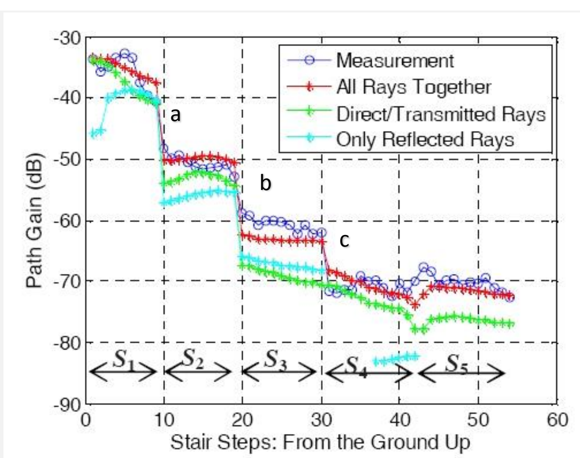
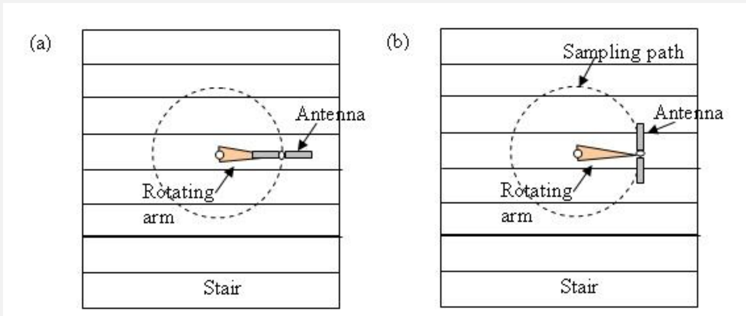


- The red line (all rays) include hybrid rays.
- Big drop in (a) , (b), and (c) are due to: -
  - a: LOS is lost.
  - b: Double transmission.
  - c: Blockage of Tx power by the front wall.

S. Y. Lim, Z. Yun, J. M. Baker, N. Celik, H. Youn, and M. F. Iskander, "Propagation modeling and measurement for a multifloor stairwell," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 583-586, 2009.



- When horizontal polarization is concerned, the receive antenna can assume two different orientations on the rotation arm when measurement is being done.
- Case (a) is when the main beam occurs.
- Case (b) is when the null occurs.

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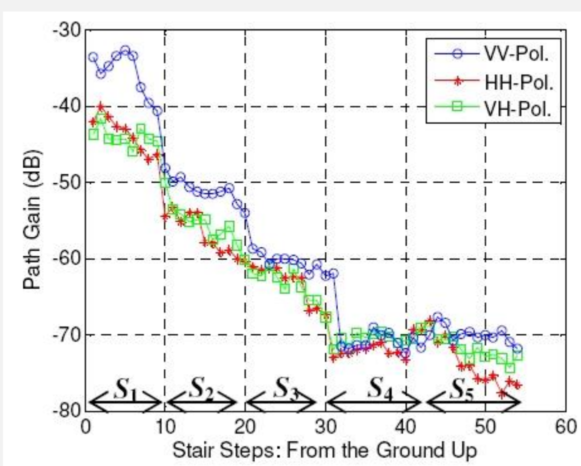

- For HH-Pol., the Tx antenna was oriented with the null of the radiation pattern facing the entry door.
- For VH-Pol.:
  - Tx antenna was placed vertically.
  - Rx antenna was placed horizontally.

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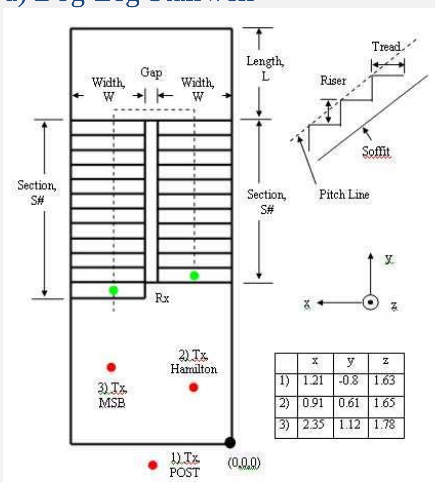
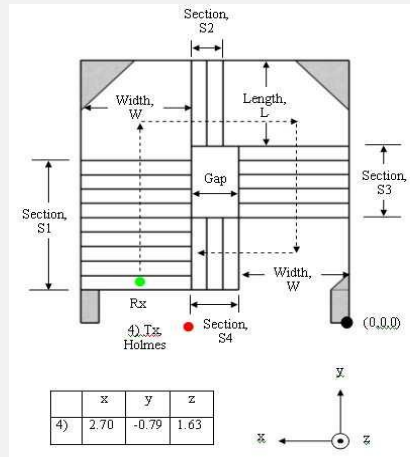
a) Dog-Leg Stairwell



	x	y	z
1)	1.21	-0.8	1.63
2)	0.91	0.61	1.65
3)	2.35	1.12	1.78

b) Stairwell Around a Square Well



	x	y	z
4)	2.70	-0.79	1.63

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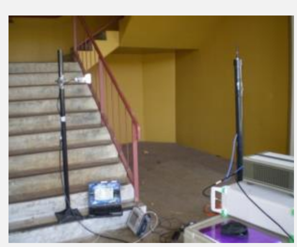
1) 

3) 

1) PO
2) HA
3) MS
4) HL

2) 

4) 

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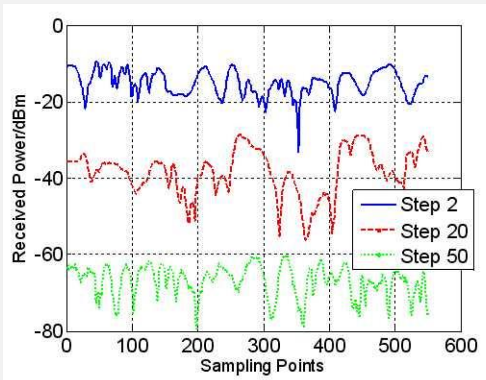
Small Scale Fading



- Typical received signals at different locations when the Rx antenna rotates a complete revolution.
- The sampling signals are recorded over a 30-second period when the Rx antenna is rotated around the post an entire revolution.
- These sampling signals are then averaged offline to yield the mean path gain at each stair step.

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- Path loss is an indication of power loss in the channel: $P(d) = 10\log_{10}\left(\frac{P_t}{P_r}\right)$
- The mean power predicted above is a random variable, which can be characterized by adding an extra term, a log-normal distribution for both outdoor and indoor propagation environments:

$$P(d)[dB] = \bar{P}(d)[dB] + X_\sigma[dB]$$

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Freq.	Stairwell/ Pol.	n-Values		σ_m (dB)	
		S. Dist.	W. Dist.	S. Dist.	W. Dist.
2.4 GHz	HL/VV	8.93	5.75	7.23	3.94
	HL/HH	7.48	4.83	6.39	3.71
	PO/VV	9.64	5.79	7.62	3.22
	PO/HH	8.57	4.97	5.83	2.20
	PO/VH	7.77	4.62	5.82	2.28
	HA/VV	8.76	5.73	5.16	4.21
	HA/HH	7.62	5.01	5.77	4.80
	MS/VV	8.17	6.53	5.06	3.25
	MS/HH	7.33	5.82	4.37	3.20
	PO/HH (II)	8.75	4.83	5.66	2.13
	Average	8.30	5.39	5.89	3.29
5.8 GHz	HL/VV	10.12	6.36	6.28	2.72
	HL/HH	7.49	4.89	6.64	3.66
	PO/VV	12.94	7.45	9.59	2.84
	PO/HH	8.74	5.06	6.63	2.08
	MS/VV	10.96	8.58	7.72	1.77
	MS/HH	8.16	6.16	5.88	4.11
	Average	9.74	6.42	7.12	2.86

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Freq. (GHz)	Pol.	n		σ (dB)	
		S. Dist.	W. Dist.	S. Dist.	W. Dist.
2.4	VV	8.88	5.95	5.72	3.89
	HH	7.95	5.15	4.67	3.25
	Average	8.30	5.39	5.20	3.57
5.8	VV	11.34	7.46	6.23	2.11
	HH	8.13	5.37	2.53	1.64
	Average	9.74	6.42	4.38	1.88

The σ value shows how severe the variation of path loss is about the mean of a normal distribution. A low value of σ will indicate less variation and the path loss model can predict more accurately.

S. Y. Lim, Z. Yun, and M. F. Iskander, "Propagation measurement and modeling for indoor stairwells at 2.4 and 5.8 GHz," *IEEE Transactions on Antennas and Propagation*, accepted.

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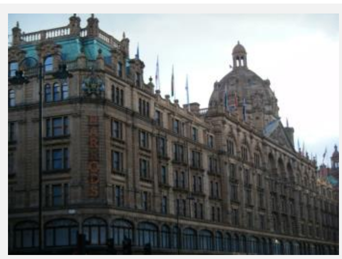

London, 2012.

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To investigate by means of measurement and simulation how much accuracy would be compromised in a ray tracing simulation when the complex building façade is approximated by a simpler structure.

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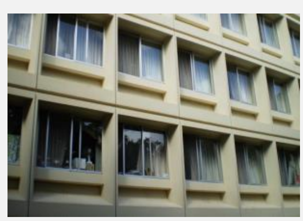
1) 

3) 

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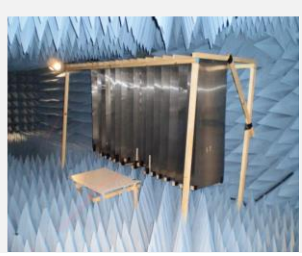
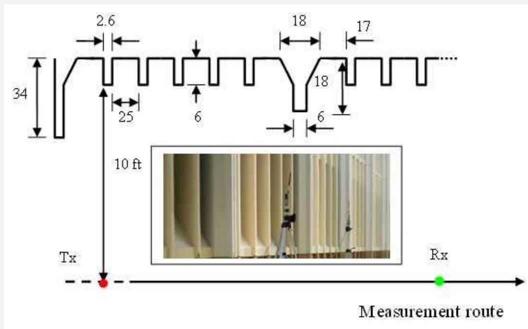
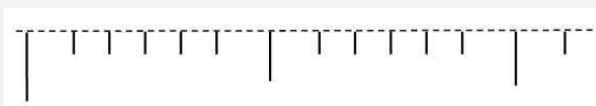
4) 

1) Moore Hall
2) Sakamaki Hall
3) Hale Kuahine
4) Idealized façade



Simplified Version of Moore Hall



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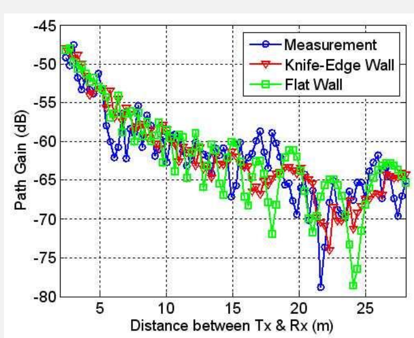
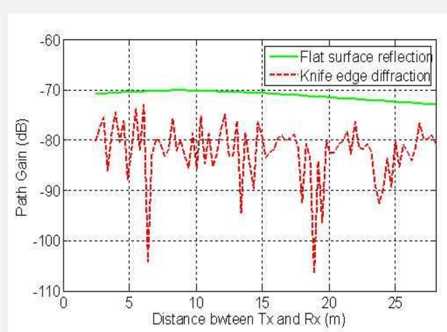
Façade: ε_r = 2.0; σ = 0.0001 S/m; **Ground**: ε_r = 7.0; σ = 0.0001 S/m
***stdv*:**
Flat surface = 4.4 dB; **Knife-edge** = 3.3 dB





S. Y. Lim, Z. Yun, and M. F. Iskander, "Modeling scattered EM field from a periodic building facade," *IEEE International Symposium on Antennas and Propagation (AP-S)*, July 11-17, 2010, Toronto, Ontario, Canada.

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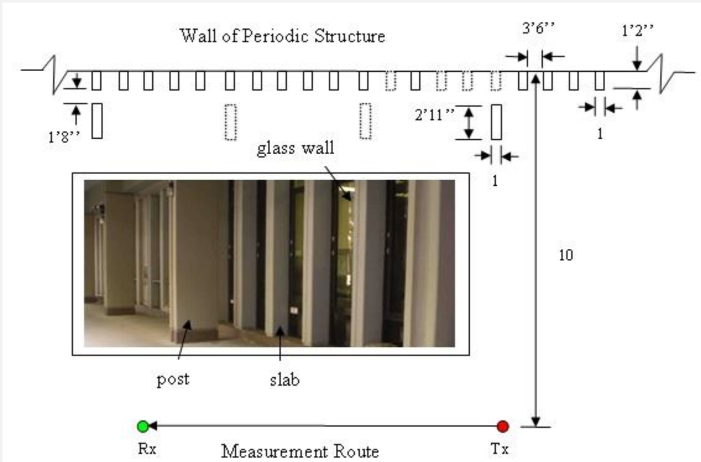
Sakamaki Hall (2.4 & 5.8 GHz)



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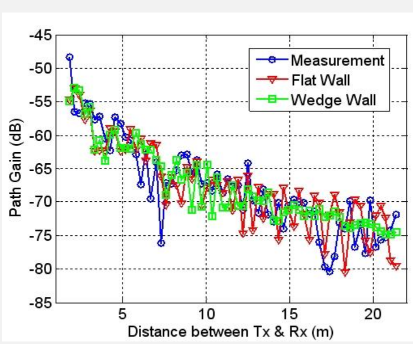
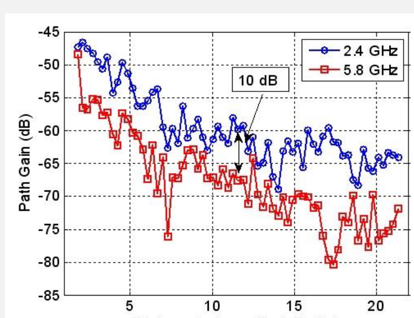
Façade: $\varepsilon_r = 2.0$; σ = 0.0001 S/m; **Ground**: $\varepsilon_r = 15.0$; σ = 0.0001 S/m
***stdv*:**
Flat surface = 4.32 dB; **Wedge surface** = 3.57 dB





Signal propagation is weaker at 5.8 GHz than that at 2.4 GHz by approximately 10 dB.

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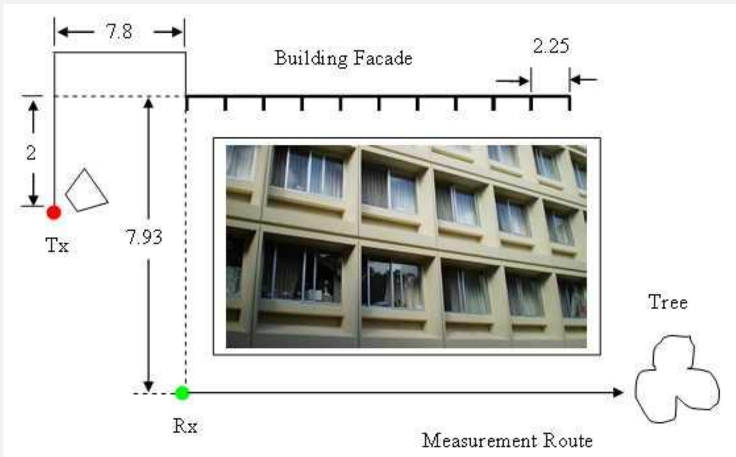
Hale Kuahine (2.4 GHz)



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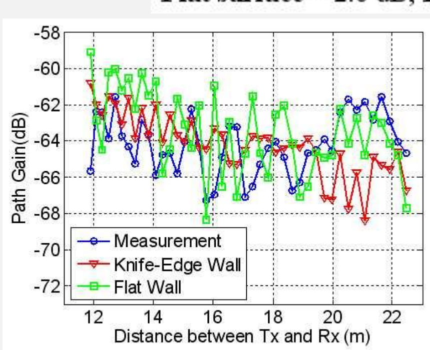
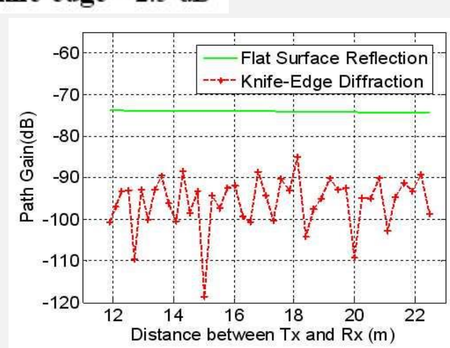
Façade: $\varepsilon_r = 3.3317$; σ = 0.0001 S/m
***stdv*:**
Flat surface = 2.6 dB; **Knife-edge** = 2.5 dB





The reflection from the flat surface is stronger (~15dB) than the diffraction from the knife edges.

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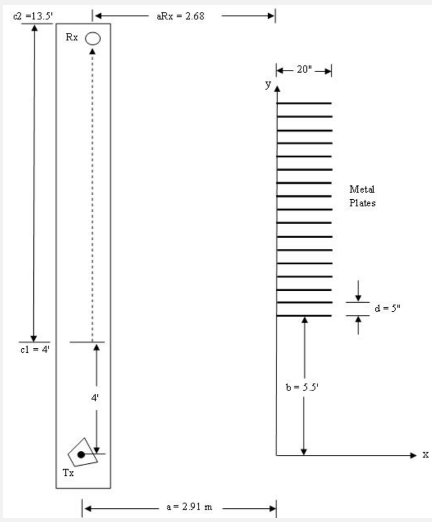
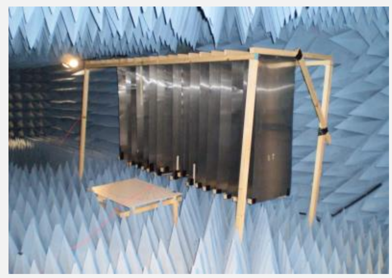


Idealized Façade (2.4 & 5.8 GHz)



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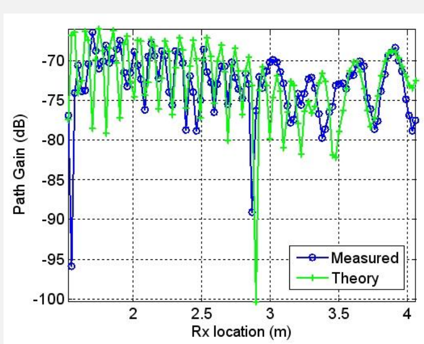
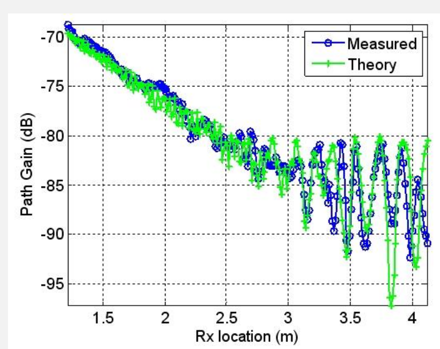
2.4 GHz



5.8 GHz



S. Y. Lim, Z. Yun, and M. F. Iskander, "Modeling scattered EM field from a façade-like structure for wireless communications," *IEEE International Symposium on Antennas and Propagation (AP-S) and URSI*, July 3-9, 2011, Spokane, Washington.

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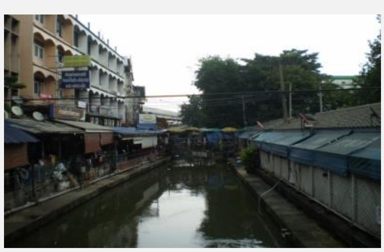
Bangkok, 2013



Palembang, 2012

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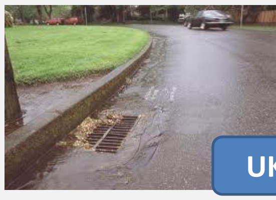
UK


USA


Jakarta


Taipei


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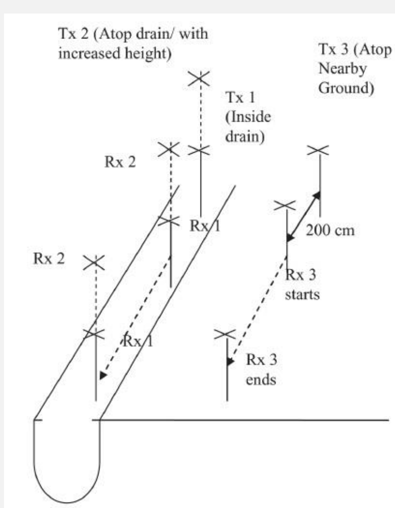

To investigate how differently EM waves would propagate inside the open-trench drain, compared to where the drains were covered.

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Scenarios/ Frequency Bands	Inside Drain	Atop Drain/ Inside Drain with Increased Height	Atop Nearby Ground
900 MHz	Strong Signal Strength	Weak Signal Strength	Strong Signal Strength
2.4 GHz	Strongest Signal Strength	Medium Signal Strength	Weakest Signal Strength
5.8 GHz	Weakest Signal Strength	Medium Signal Strength	Medium Signal Strength

S. Y. Lim, and C. C. Pu, "Measurement of a tunnel-like structure for wireless communications," *IEEE Antennas and Propagation Magazine*, vol. 54, no. 3, pp. 148-156, June 2012.

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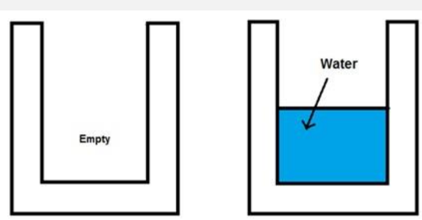
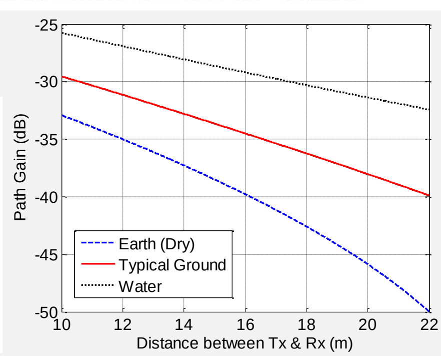
To tackle a practically important problem because in reality the open-trench drain environment is not always dry and empty.



Open-trench drain with and without water flow.

Dry earth, $\varepsilon_r = 7$; Typical ground, $\varepsilon_r = 15$; Water, $\varepsilon_r = 81$.

Permeability, $\mu_r = 1$; conductivity, $\sigma = 0.001$ S/m.



S. Y. Lim, Y. H. Liew, and K. P. Seng, "Propagation modeling of an open-trench drain," *IEEE International Conference on Wireless Information Technology and Systems (ICWITS)*, November 11-16, 2012, Maui, Hawaii.

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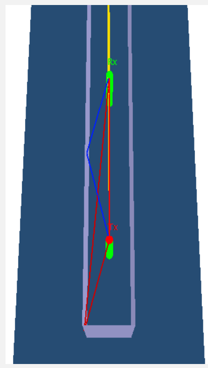
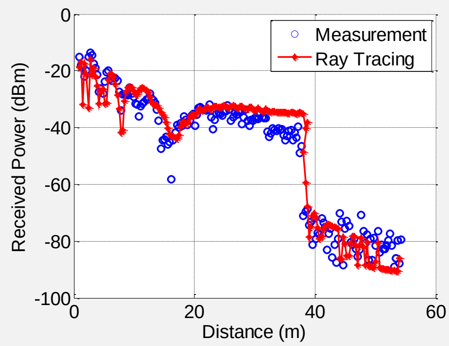
To utilize an interactive full 3D ray tracing software package for running simulation in an open-trench drain.





S. Y. Lim, A. K. Awelemdy, Z. Yun, and M. F. Iskander, "Utilizing an interactive full 3D ray tracing software package for radio propagation in drain," *International Conference on Electromagnetics in Advanced Applications & IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications*, August 3-9, 2014, Palm Beach, Aruba. **[Invited talk in the special session on "Propagation modeling for communications and directional aware networking"]**.

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To integrate research into teaching (an intervention to teach EM as an appetizer course for CS and IT undergraduates).

S. Y. Lim, "Education for electromagnetics: Introducing electromagnetics as an appetizer course for computer science and IT undergraduates," *IEEE Antennas and Propagation Magazine*, accepted.

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Mulu National Park, Sarawak, Malaysian Borneo, March 2012.
A UNESCO World Heritage Site that encompasses caves and karst formation in a mountainous equatorial rainforest setting.

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- Outline:
  - Introduction
  - Four distinct environments
    - Indoor Stairwell
    - Periodic Building Façade
    - Open-trench Drain
    - Cave
  - Conclusion

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- Fundamental propagation mechanisms in the following environments have been investigated at several frequencies, e.g. 900 MHz, 2.4 and 5.8 GHz:-
  - Indoor stairwell
  - Periodic building facade
  - Idealized periodic structure
  - Open-trench drain
- Future work: cave environment

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THANK YOU!