Sharif University of Technology

Tehran, Iran

Principles of Phased Array Systems

A graduate course in Electronics

Tutorial II

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Room 511

Phased Array Applications

Phased Array Applications

A system not an antenna

6 Decades of service

Military & civil applications

Surveillance

Target Tracking

Missile Guidance

Target Identification

Multi-function System

ECM, ECCM

Civil Applications:

Meteorology

Air Traffic Control

Mobile Satellite Systems

Radar and Imaging

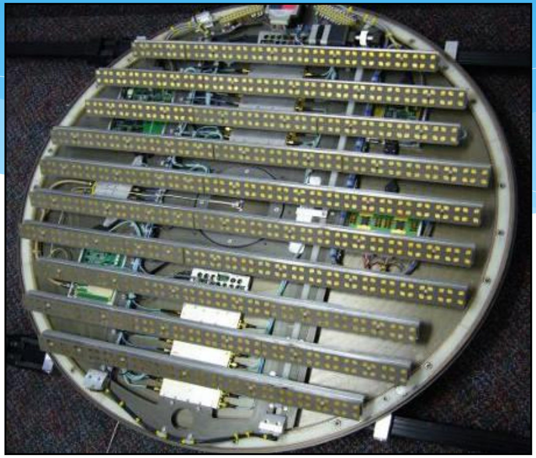
Radio Astronomy

Smart Antenna for WLAN or Cellular networks

Millimeter-wave wireless networks

Mobile Satellite Systems

- Conformal and Flexible
- Low Profile
- Signal Processing Power

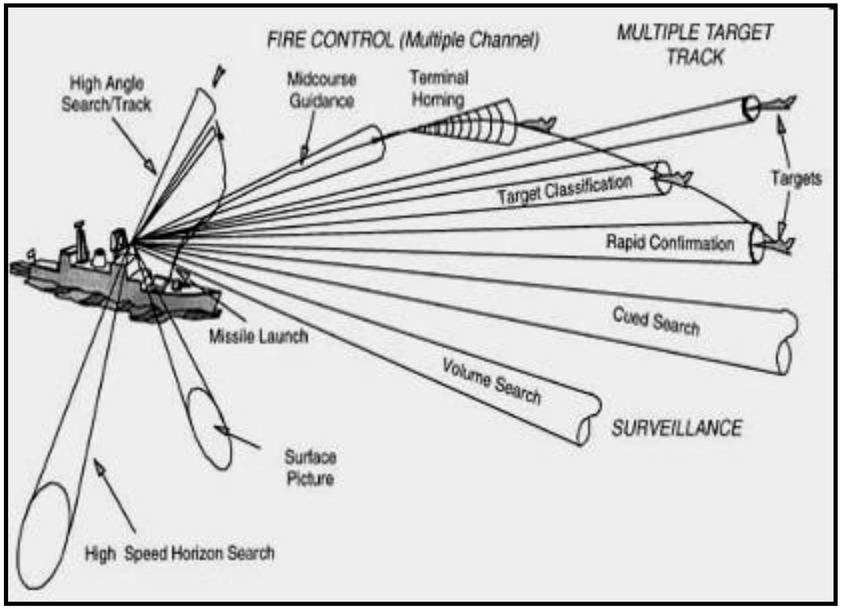


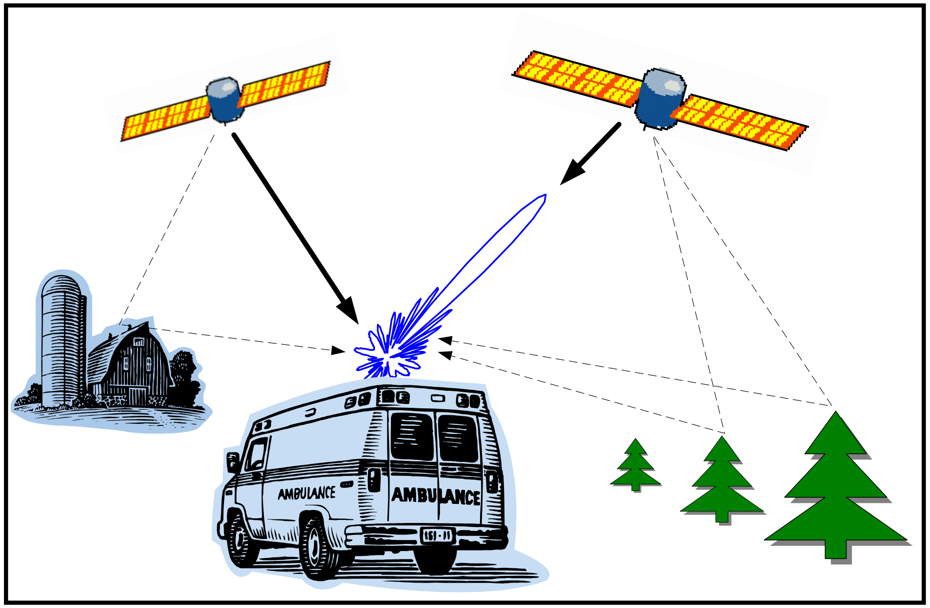
Mobile Ku-band Satellite Rx
Developed at Intelwaves Technologies
– University of Waterloo, Canada

Phased Array Applications (2)

Agile or Shaped Beam

Multifunction Radar   Interference Cancellation



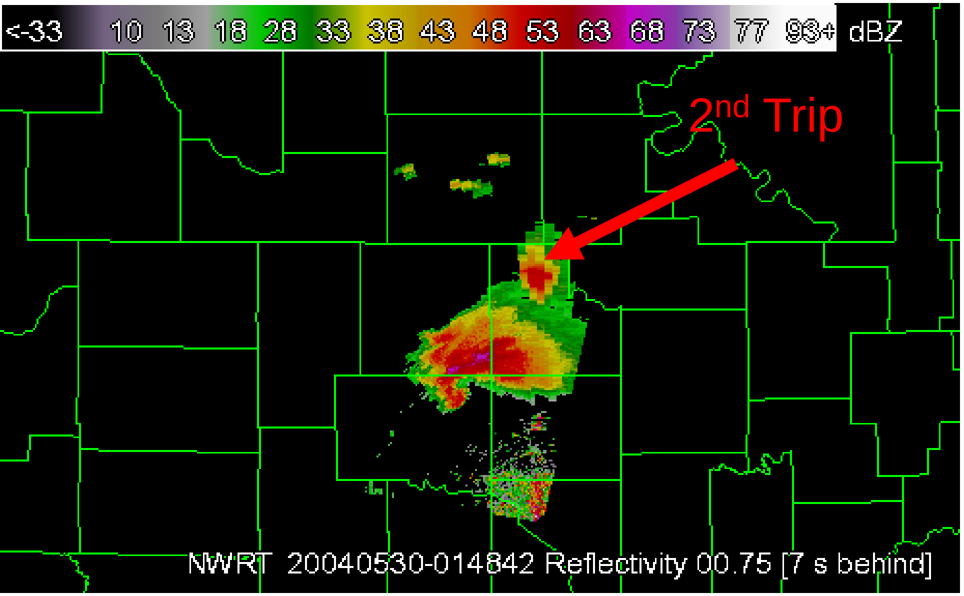


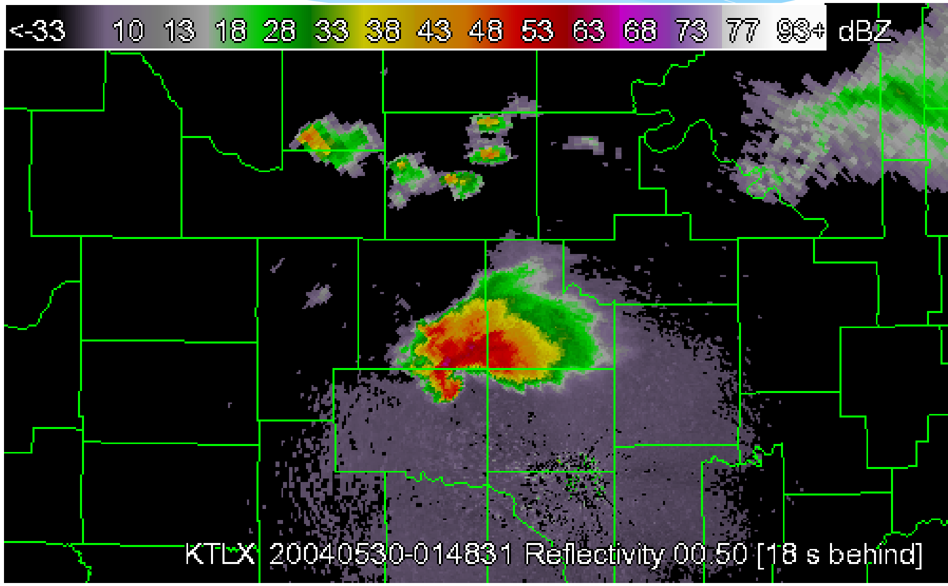
Phased array provides a high Effective Isotropic Radiated Power (EIRP)

NEXRAD-PAR Reflectivity Comparison

NWRT
Phased Array Radar

KTLX
WSR-88D

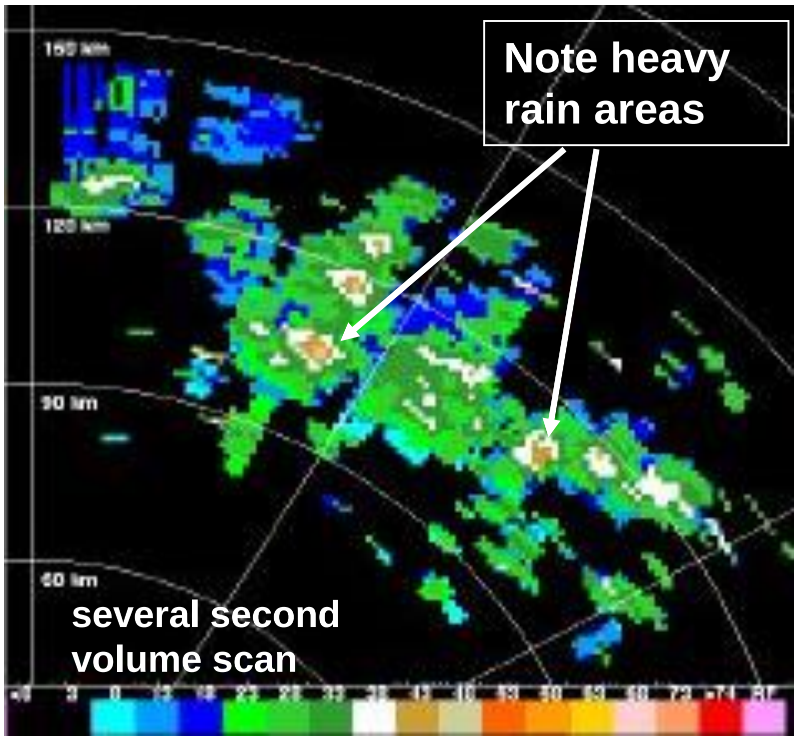




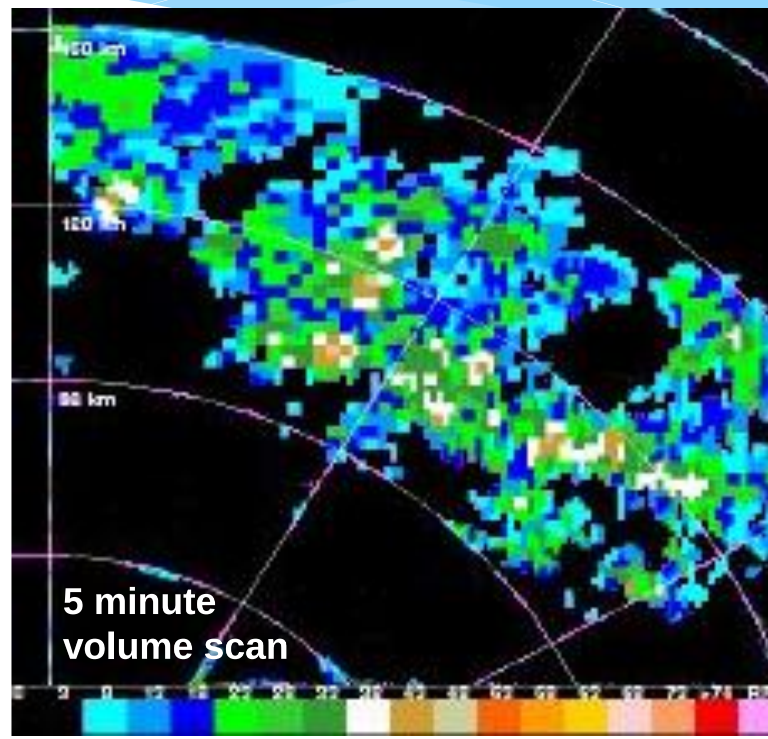
NWRT Volume Scan in less than 1 min.

KTLX Volume Scan took 4.2 mins.

Composite Reflectivity: SPY-1 v. WSR-88D
Hurricane Fran Remnants



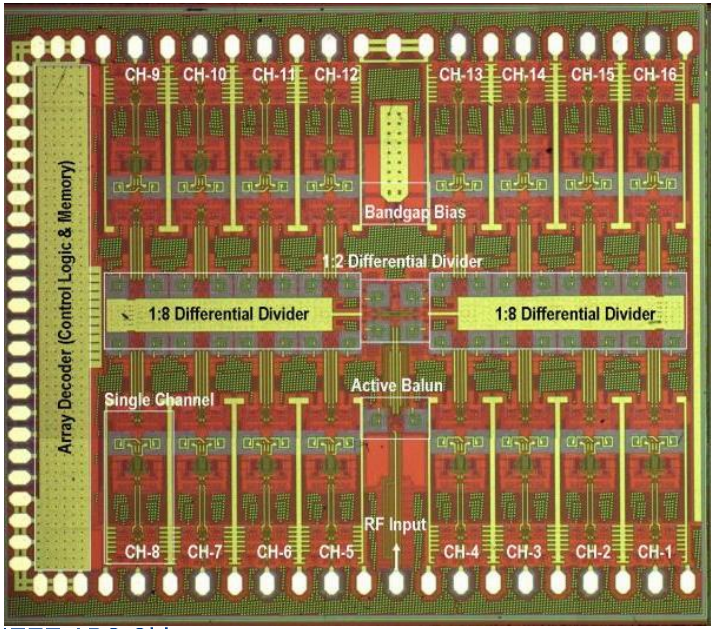
SPY-1



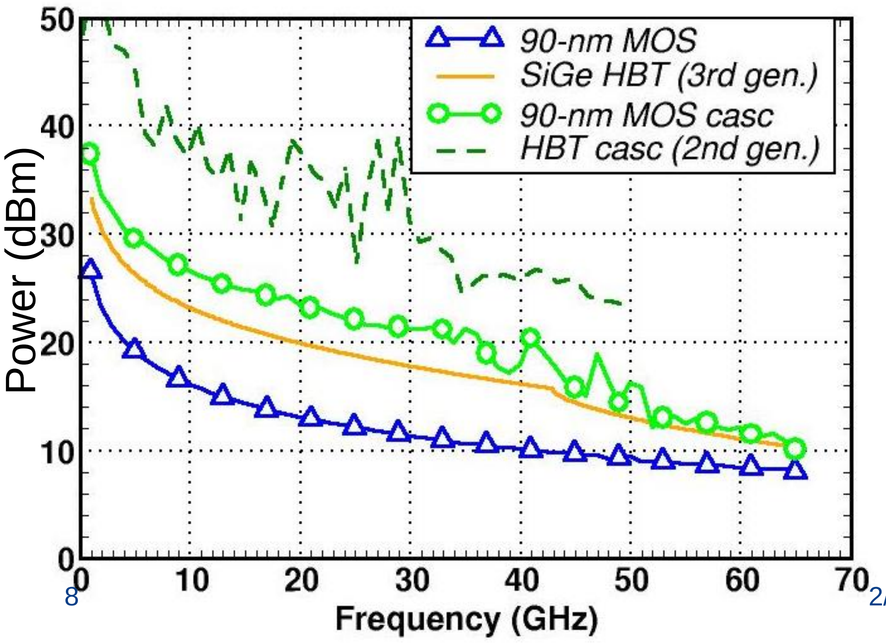
NEXRAD

Spatial Power Combination

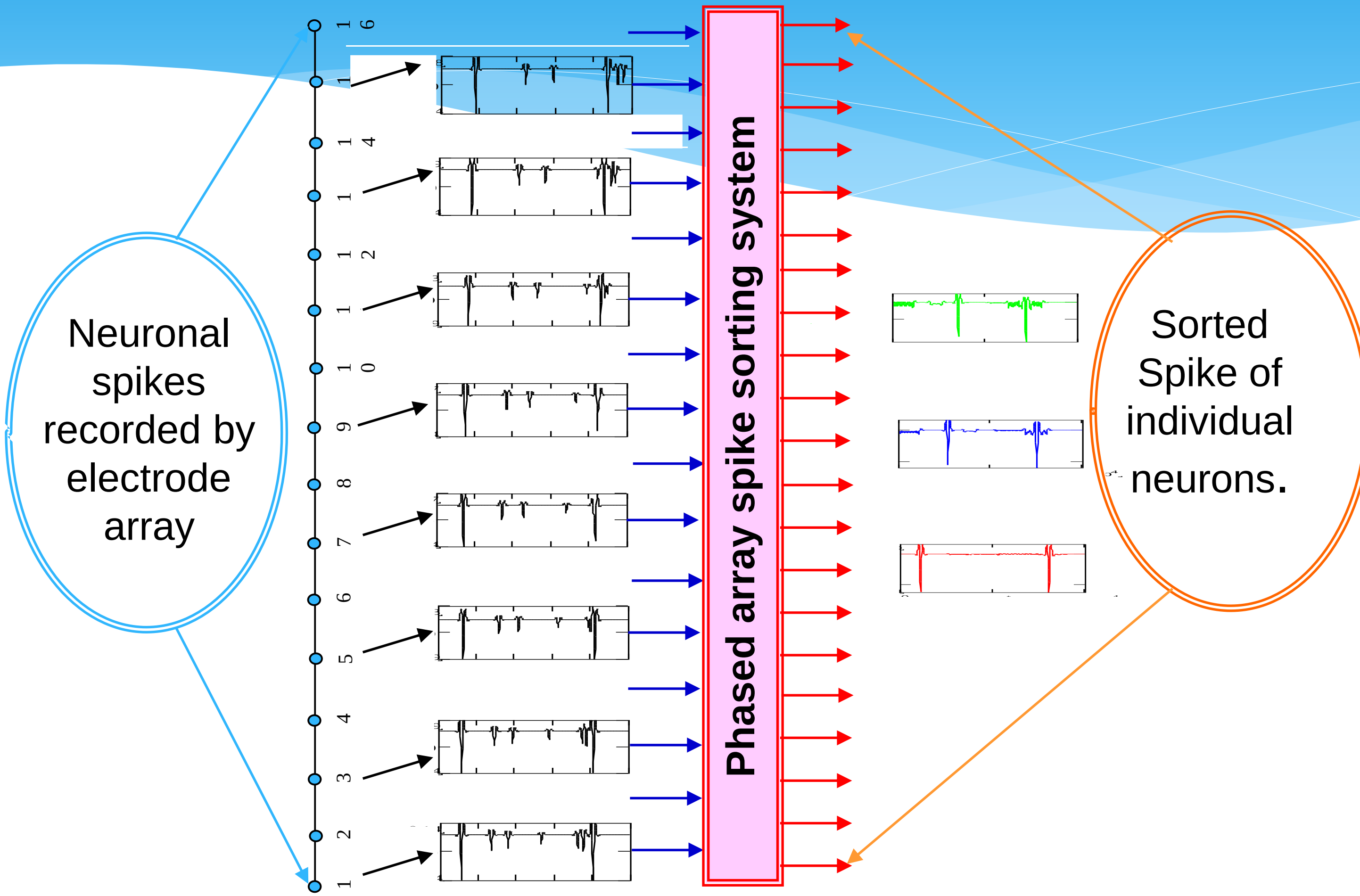
Spatial Power Combination → $20 \log_{10} (N)$
- CMOS/SiGe Technology
- At mm-wave $P_{out,PA}$<10dBm, G_{LNA}<14dB



UCSD

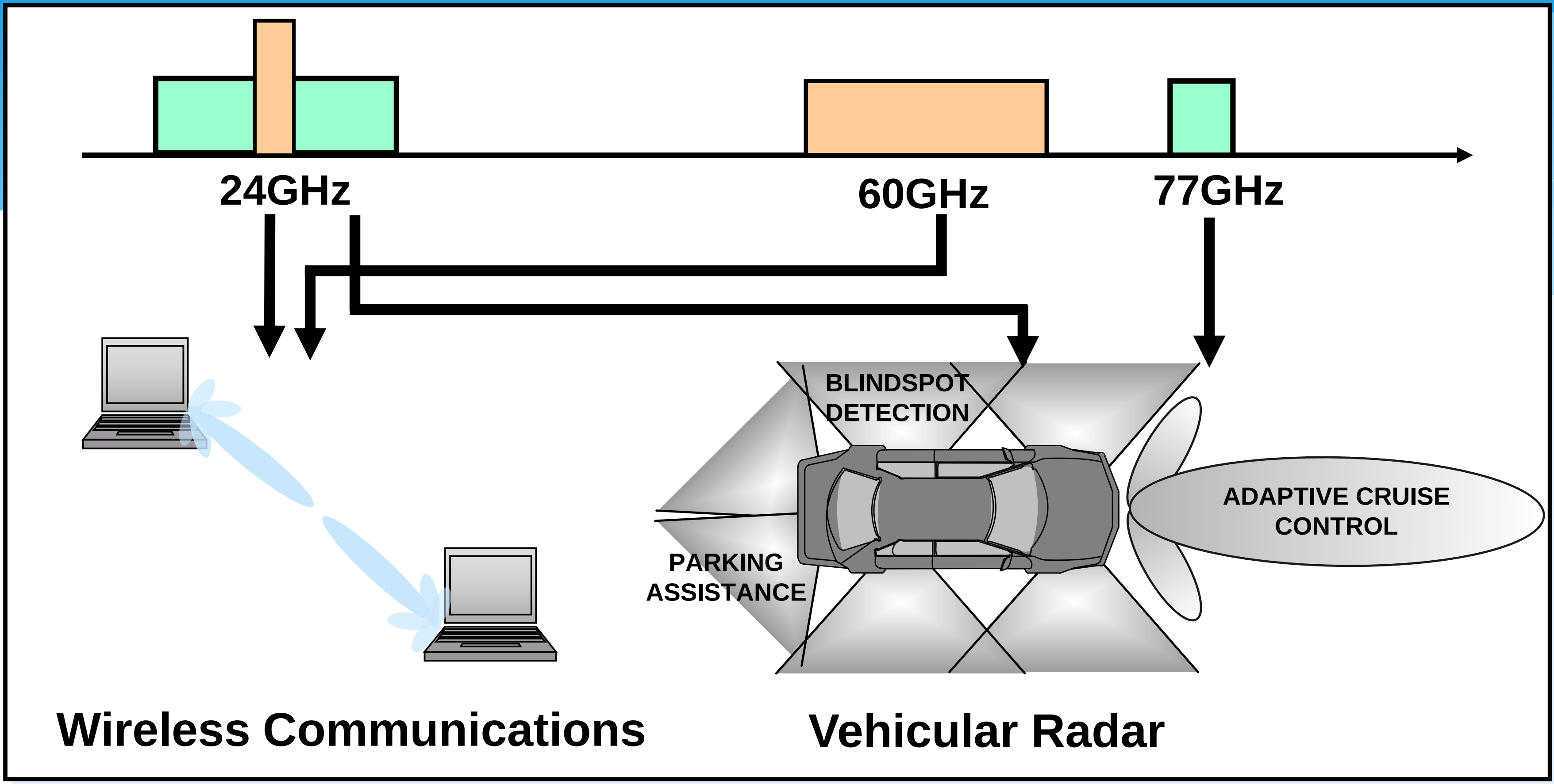


Phased array spike sorting



Center for Computational Biology, MSU

Automotive Radar

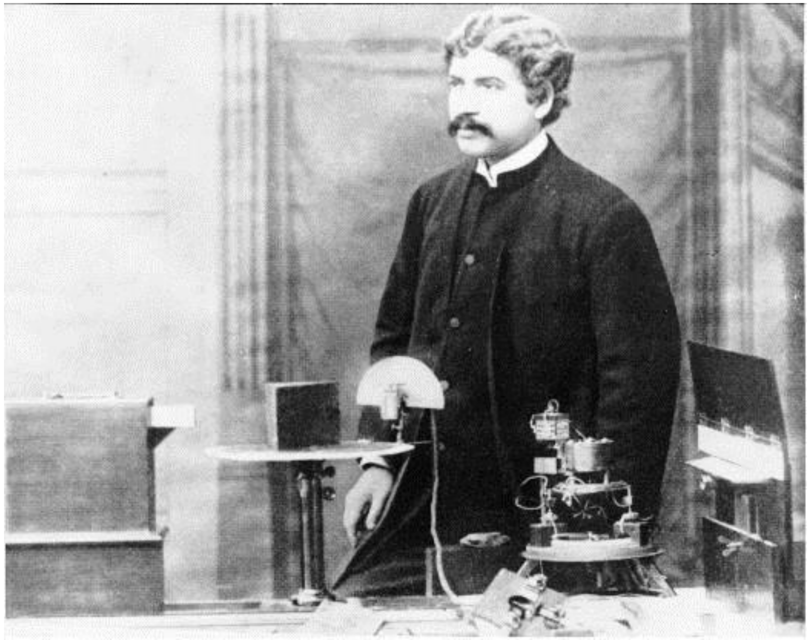


- Fully-integrated silicon-based multiple-antenna systems enable widespread commercial applications at high frequencies.
- Complex, novel architectures can be realized on silicon with greater reliability and lower cost.

Phased Array Drawbacks

* Cost and Complexity
* Bandwidth
* Calibration
* Beamforming

Bose before Marconi



* **THE WORK OF JAGADIS CHANDRA BOSE:**
* **100 YEARS OF MM-WAVE RESEARCH**

* (last revised February 1998)

* **D.T. Emerson**
* **National Radio Astronomy Observatory[1]**
* **949 N. Cherry Avenue**
* **Tucson, Arizona 85721**

* **E-mail: demerson@nrao.edu**

- Demonstration in London of setting off some explosives at almost a mile and ringing a bell using his 60 GHz communications apparatus

- First annoying cell phone ring tone and first remote controlled bomb!

- Why then is he not recognized as well as Marconi et al ?

- British class system at the time did not recognize non British born scientist, especially one without a peerage……..

- His next research caused him to loose any credibility he had…

Modern Times

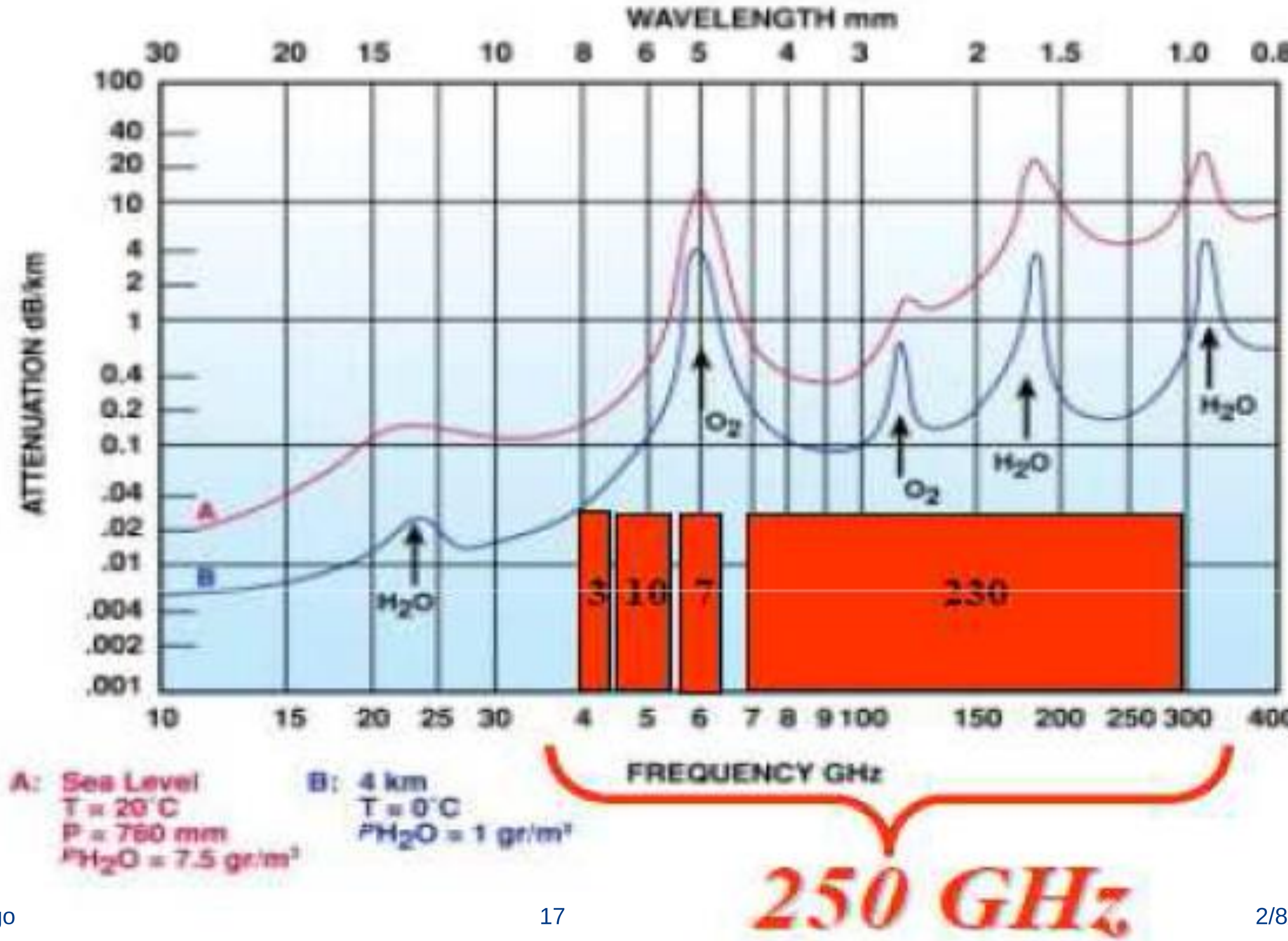
- 1950s; Bell Labs used buried MM Wave 300 GHz circular waveguide in advance of fiber optics
- 1960s; MM Wave Radio Astronomy developed high performance components and assemblies
- 1970s; Military radar, radiometer, smart missiles/munitions and communications programs enhanced the industrial base
- 1980s; US Government MMIC phase I and II developed commercial industrial base for MM Wave ICs
- 1990s; Broad emergence of commercial and government applications and programs
  - Auto radar at 24 and 77 GHz
  - Satcomm at 20, 30, 44, 60 GHz
  - Commercial products from 18 to 77 GHz

Modern Times……..

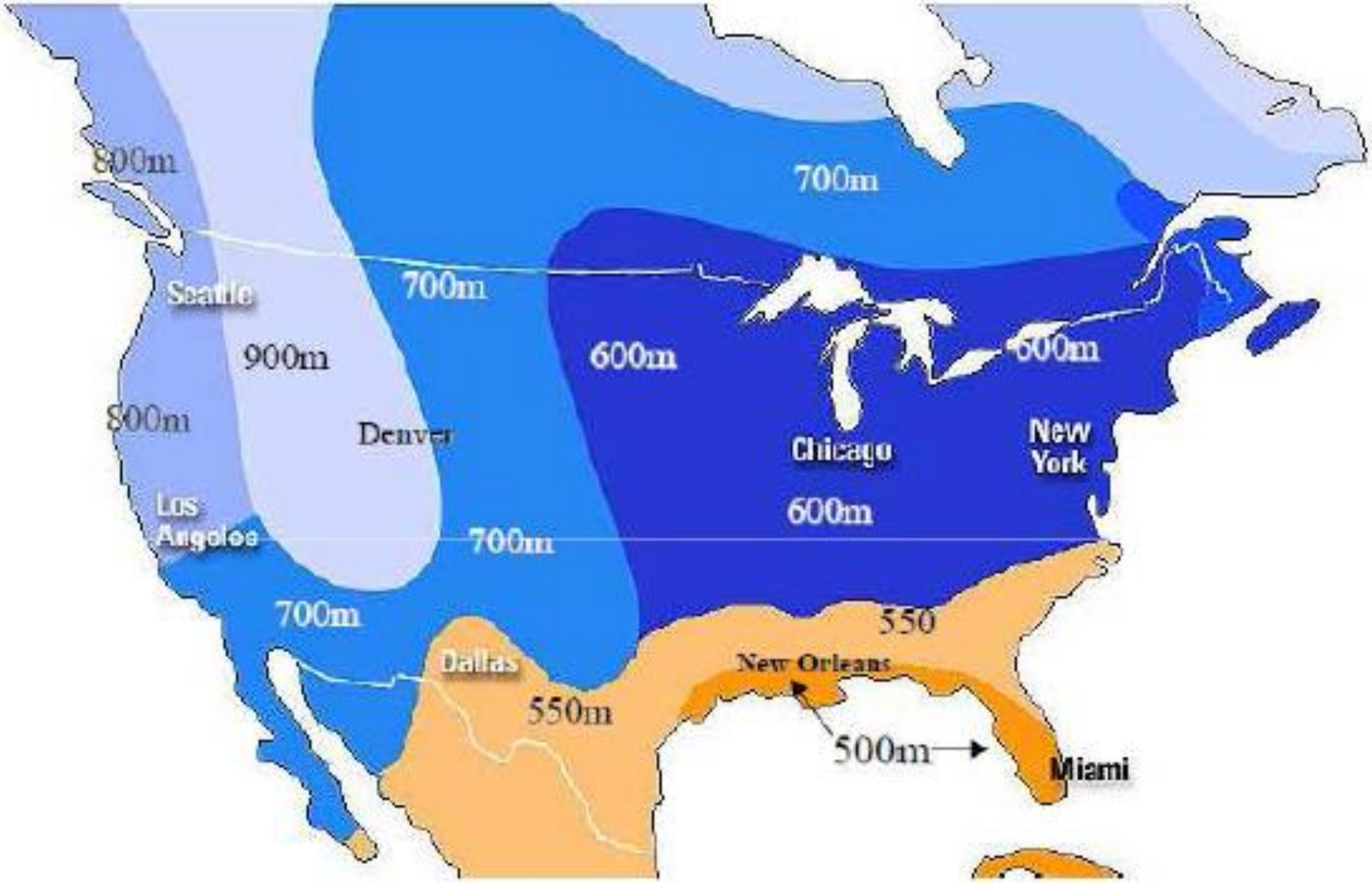
- 2000s; Finally the real mass market driver…..
- Consumer and industrial electronics
  - Auto collision avoidance technology 24 and 77 GHz

– Contraband detection

Lots of Spectrum, 7 GHz at 60 GHz and 10 GHz at 70/80 GHz



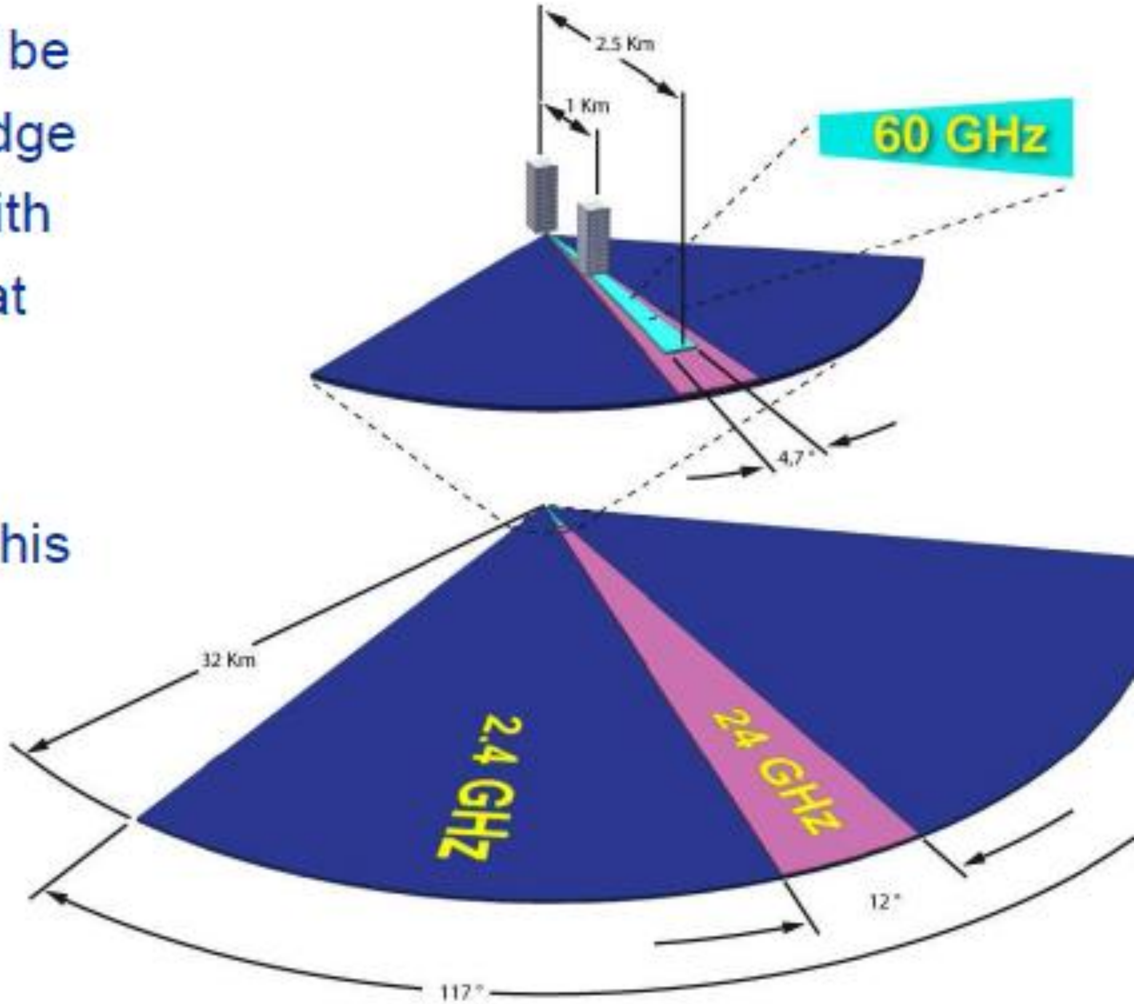
Typical Range Presentation for 5 9s Availability, LT 5 minutes year outage due to rain! Note 60 GHz, 70/80 GHz 2X to 3X



Antenna Aperture Provides Security aka Spatial

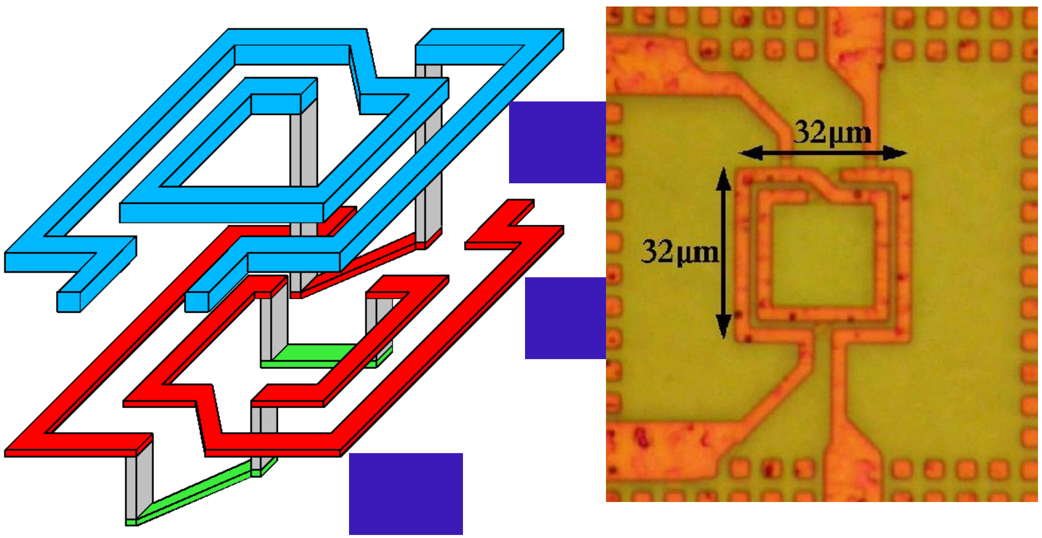
- A 60 GHz signal can only be intercepted in the tiny wedge – and will only interfere with another 60 GHz link in that very wedge.

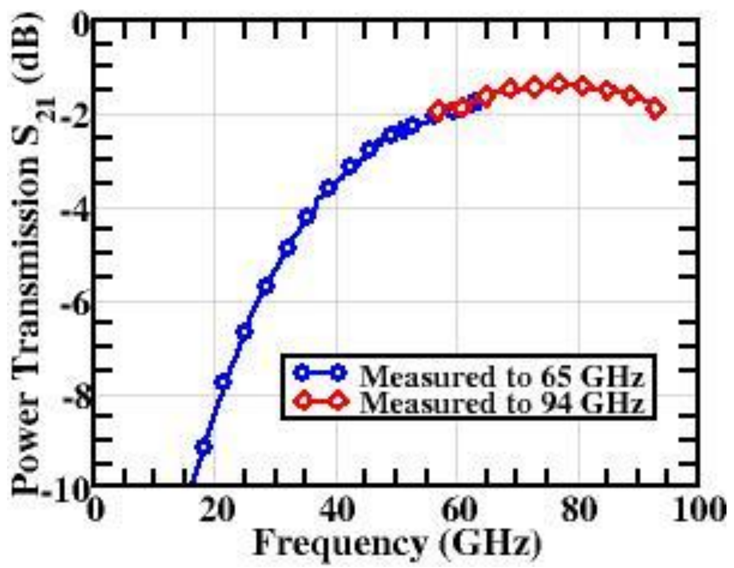
- With 2.4 GHz or 24 GHz this is quite a different story!



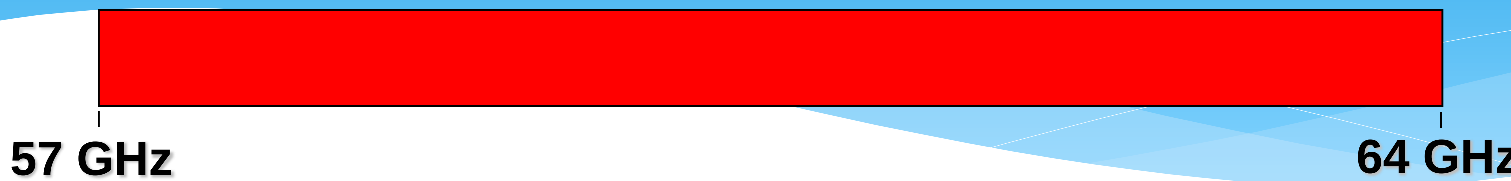
Key Enabler: Lumped mm-Wave Inductors and Transformers

- Reduced form factor of on-chip passives at mm-waves
- Spiral inductors preferred over CPW or μ-strip T-lines
- Vertically stacked, Xfmr measured up to 94GHz



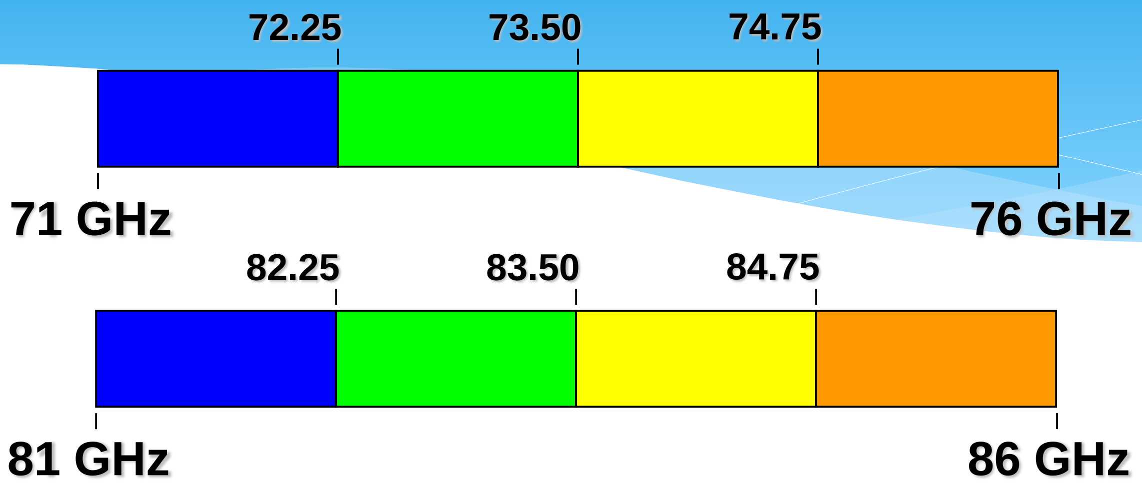


60 GHz Band



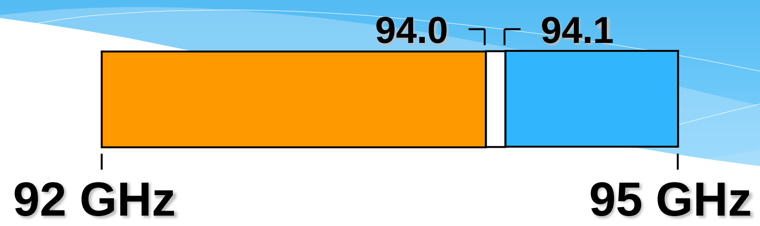
- **Unlicensed band governed by Part 15.225**
- **15 dB/Km of O_2 absorption**
- **Robust PHY layer security**
- **High frequency reuse**
- **Connectivity up to 10 Gbps**
- **Currently used in MAN and campus networks**
- **New commercial applications: mmwLAN and PAN**

70 & 80 GHz Allocation



- FCC opened these bands for commercial use in October 2003
- Divided into 4 unpaired segments per band
- Segments may be aggregated
- Cross band aggregation permitted with some restriction
- “Pencil-beam” applications
- License based on interference protection on a link-by-link basis

90 GHz Allocation



- FCC opened these bands for commercial use in October 2003
- Divided into 2 unpaired segments
- 94 GHz to 94.1 GHz allocated for exclusive Federal use
- Segments may be aggregated
- License based on interference protection on a link-by-link basis for outdoor use
- No license required for indoor use

Going Completely Wireless

* Opportunities
  * Low maintenance : no wires
  * Low power: no large switches
  * Low cost: all of the above

  * Fault tolerant: multiple network paths
  * High performance: multiple network paths

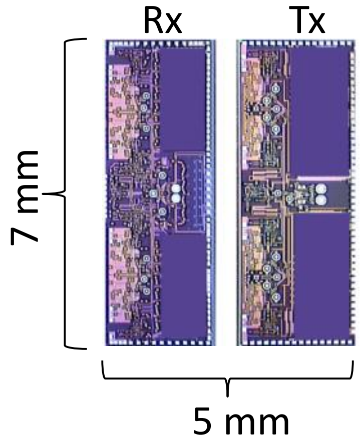
Which wireless technology?

60GHz Wireless Technology

- Short range
  - Attenuated by oxygen molecules
- Directional
  - Narrow beam
- High bandwidth
  - Several to over 10Gbps
- License free
  - Has been available for many years

Why now?

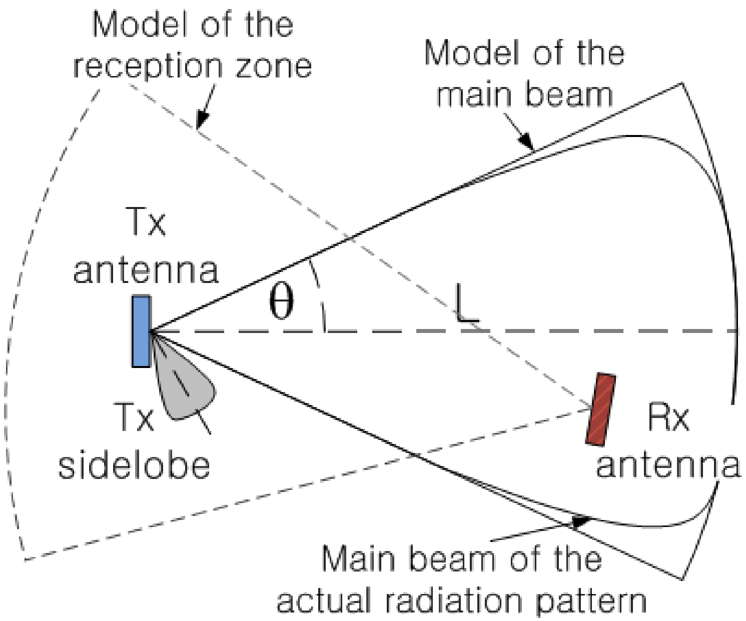
- CMOS Integration
  - Size < dime
  - Manufacturing cost < $1



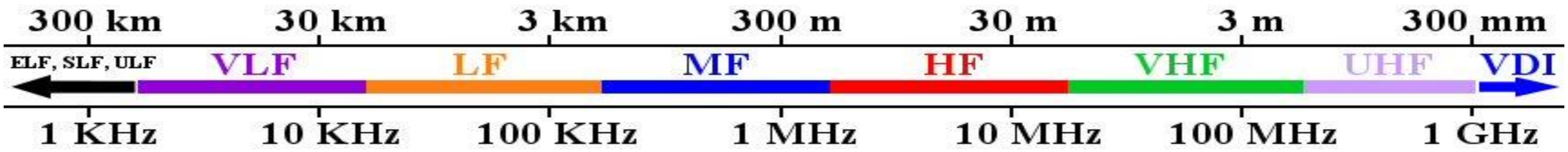
[Pinel '09]

60 GHz Antenna Model

- One directional
  - *Signal angle between 25° and 45°*
  - *Maximum range < 10 m*
  - No beam steering
- Bandwidth < 15Gbps
  - TDMA (TDD)
  - FDMA (FDD)
- Power at 0.1 – 0.3W



How to integrate to datacenters?



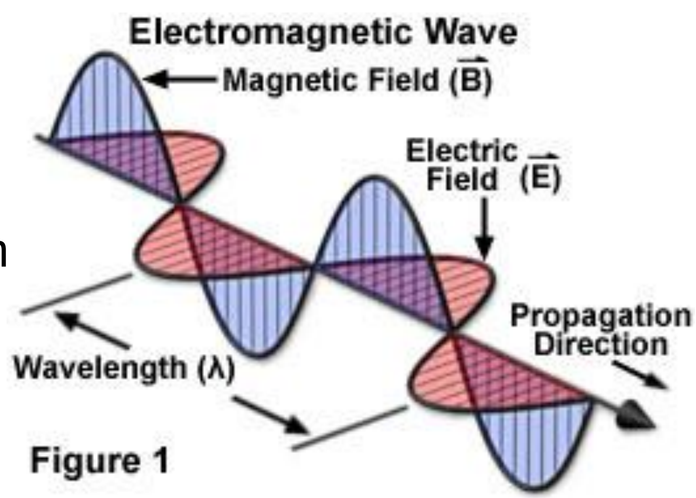
Relationship Between Wavelength and Frequency

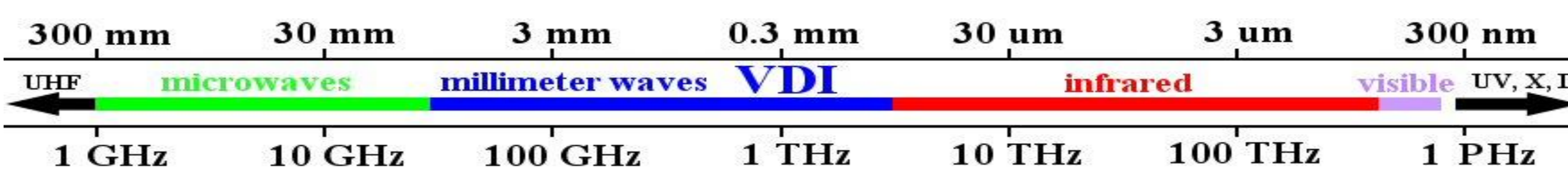
Speed of light: 3e8 m/s

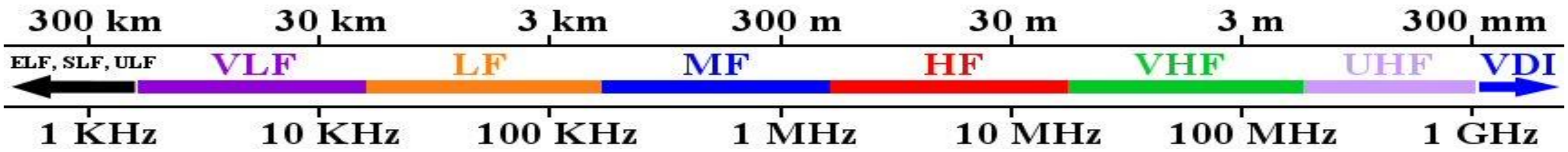
(Speed of light) = (Wavelength) x (Frequency)

$$c = \lambda \nu$$

1 GHz → 30 cm
30 GHz → 10 mm
60 GHz → 5 mm
300 GHz → 1mm

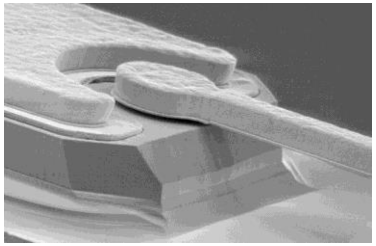


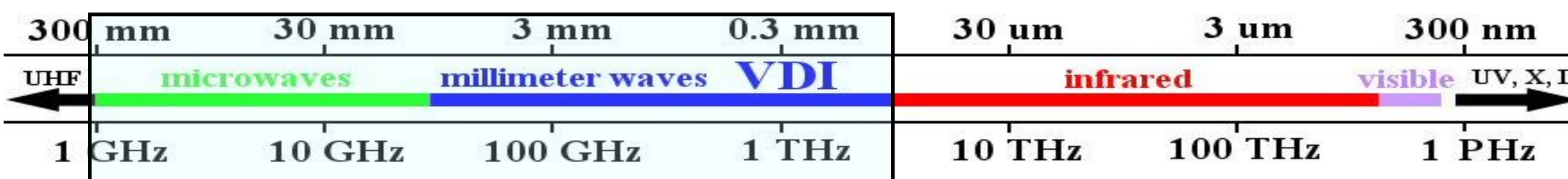




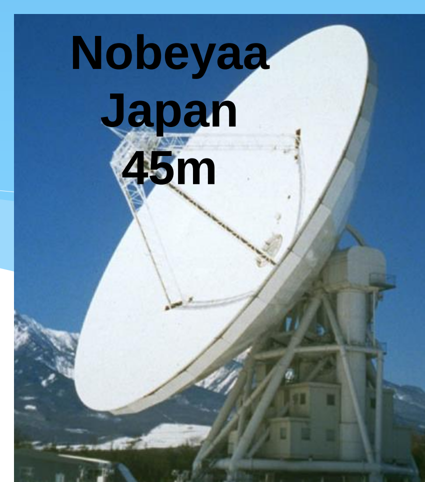
Microwave and mm-Wave Band Designations

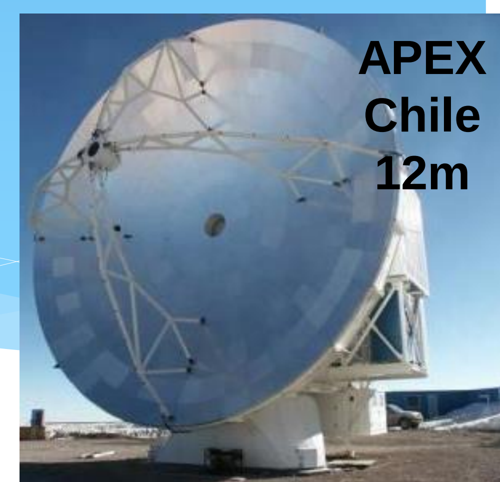
Band	WR-	(GHz)
L	650	1.1-1.7
R	430	1.7-2.6
S	284	2.6-3.95
H (G)	187	3.95-5.85
C	137	5.85-8.2
W (H)	112	7.05-10
X	90	8.2-12.4
K_u	62	12.4-18
K	42	18-26.5
K_a	28	26.5-40
Q	22	33-50
U	19	40-60
V	15	50-75
E	12	60-90
W	10	75-110
F	8	90-140
D	6.5	110-170
G	5.1	140-220
	4.3	170-260
	3.4	220-325





Millimeter Telescopes





The Effect of Human Body on Indoor Radio Wave Propagation at 57-64 GHz

M. Fakharzadeh, J. Ahmadi-Shokouh, B. Biglarbegian,M.R. Nezhad-Ahmad, and S. Safavi-Naeini

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Outline

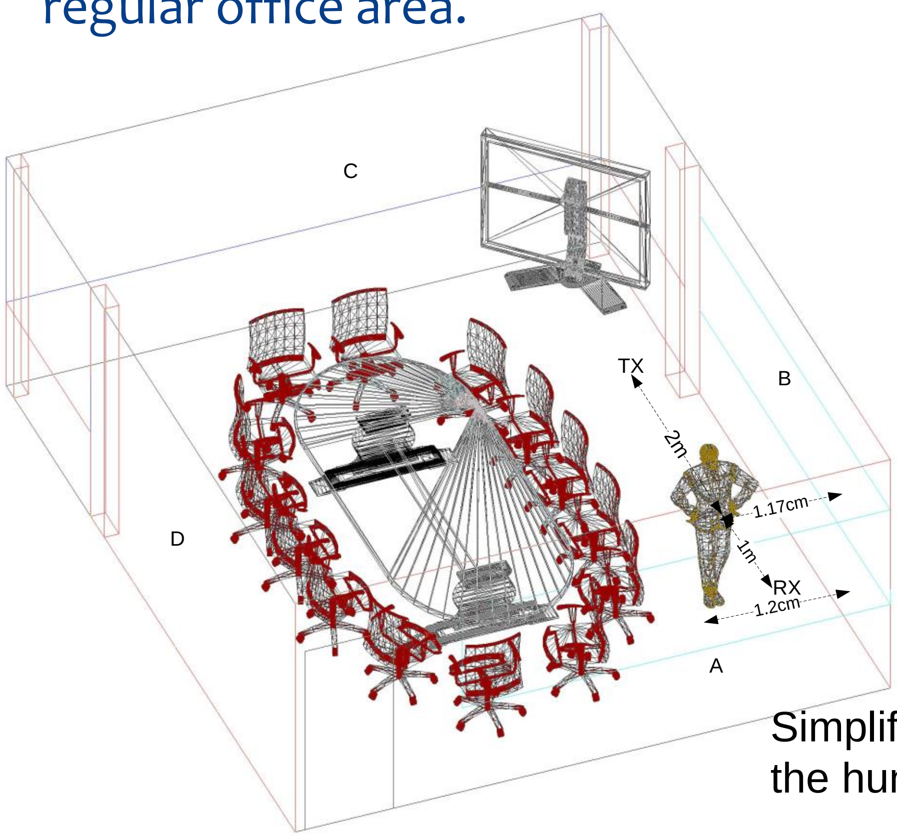
* **Introduction**
* **Ray-tracing Analysis**
* **Experimental Results**
* **Conclusion**

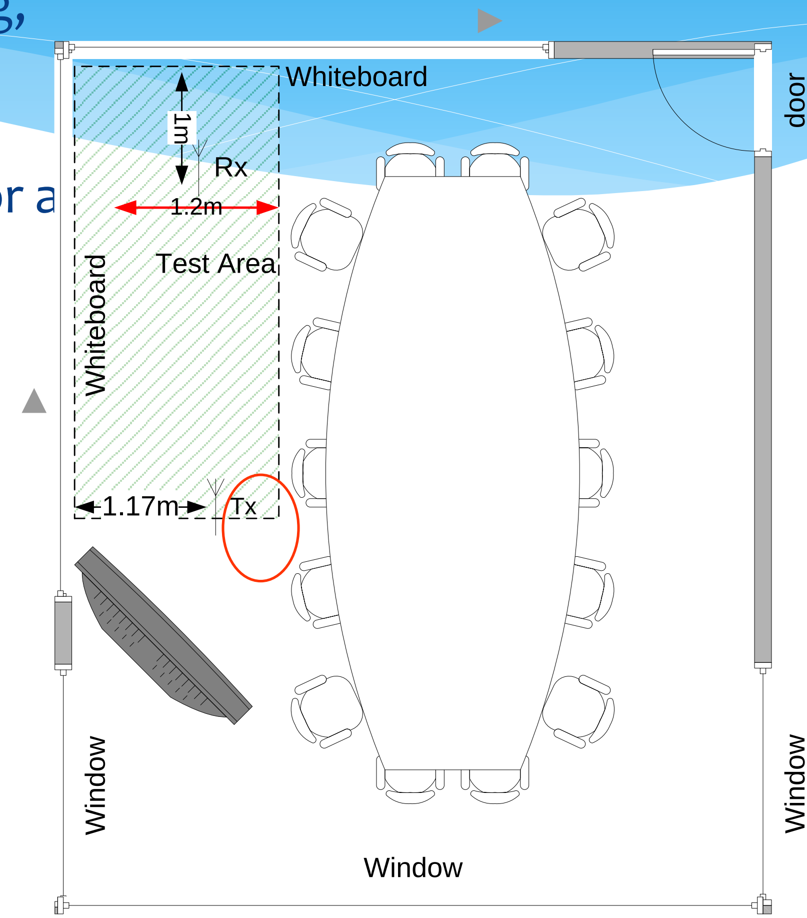
Motivation

* Seven GHz bandwidth around 60 GHz frequencies has been released to develop high-rate short-range wireless data communication.
* A regular propagation phenomenon is the shadowing of the Line-of-Sight (LOS) link caused by moving people.
* One research shows this phenomenon disconnects the LOS link for 2% of the time [1].
* It must be determined that how much attenuation is caused by a human body obscuring the LOS path.

Ray-tracing analysis

In this work, a 3-D ray-tracing modeling, Geometrical Optics plus diffraction, is employed to evaluate the signal coverage at 60GHz frequency range for a regular office area.



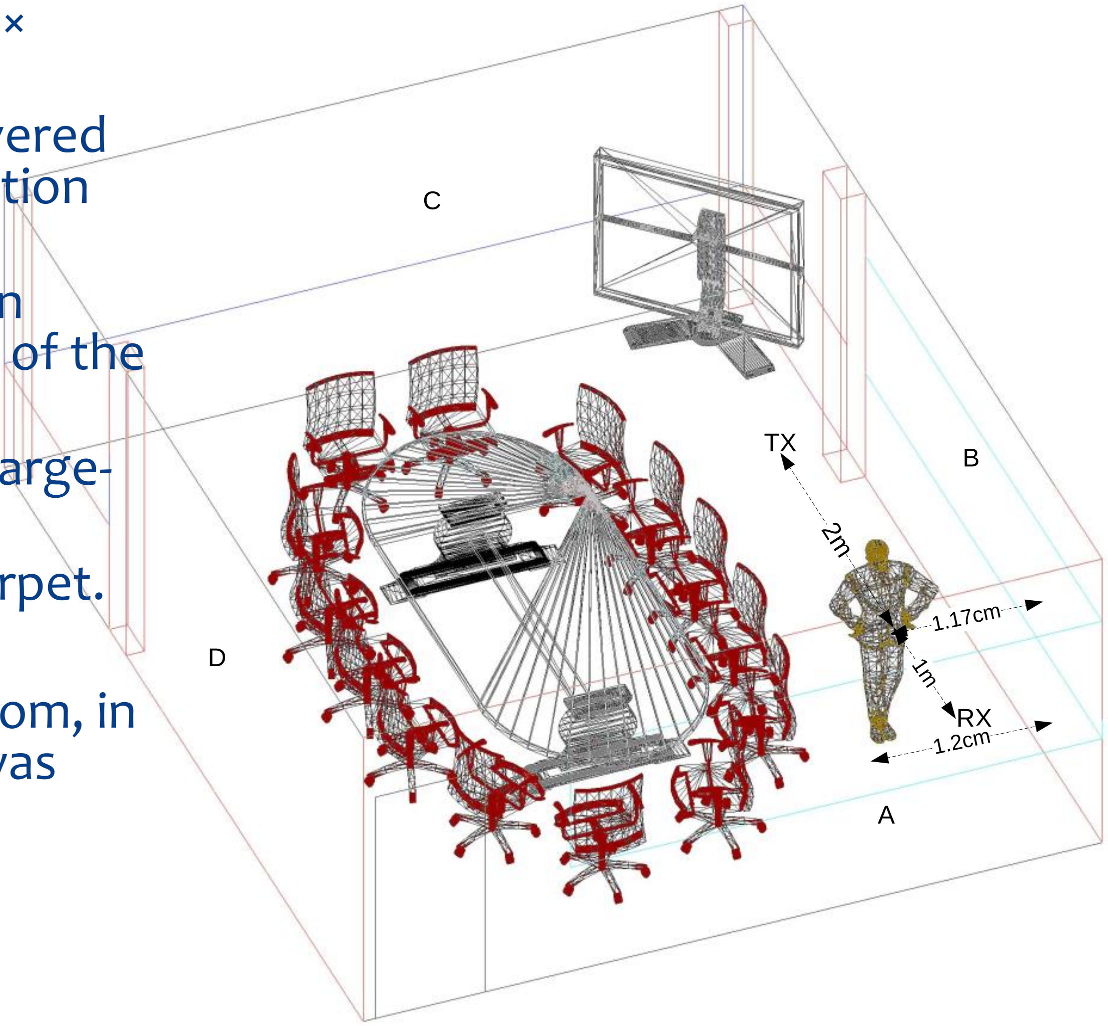


Simplified map of a seminar room used to study the human body effects on wave propagation.

Simulation Environments

* Size of the room was 7.42m × 6.25m × 2.73 (l×w×h).
* A and B in were partially covered by whiteboards (high reflection coefficient)
* Two layer windows had been installed on wall C and parts of the wall B and D.
* A big conference table and large-screen TV .
* The floor was covered by carpet.

* The top left corner of the room, in proximity to whiteboards, was designated to the test area.



Ray-Tracing Modeling

* The empirical data reported in [2] and [3] was used to calculate the reflection coefficients of the material in the room.
* Measured permittivity data for biological tissues in [4] was used.
* Two horn antennas with 24dB gain at 60GHz and roughly 10° beamwidth were used as the transmitter and receiver antennas.
* Such directive antennas are used
  * To provide the radiation gain required to combat high path loss at mm-wave range
  * To attenuate the multipath components from Non-Line-Of-Sight (NLOS) directions.

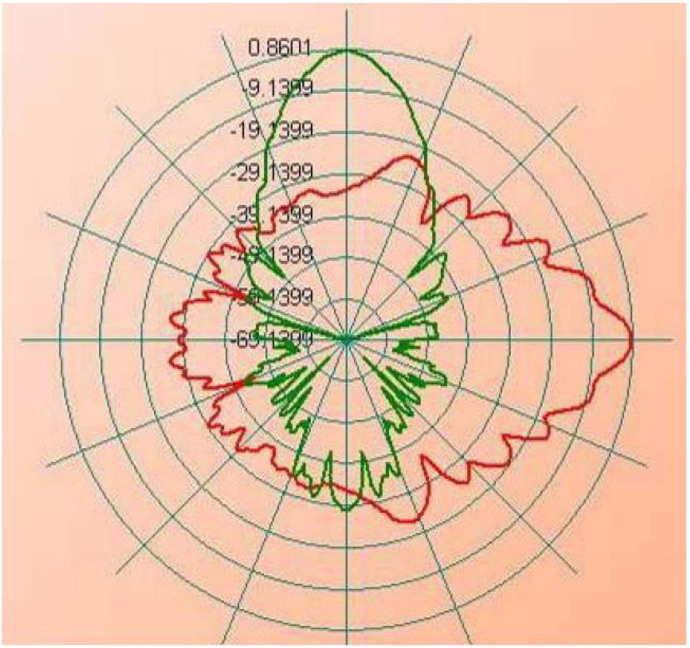
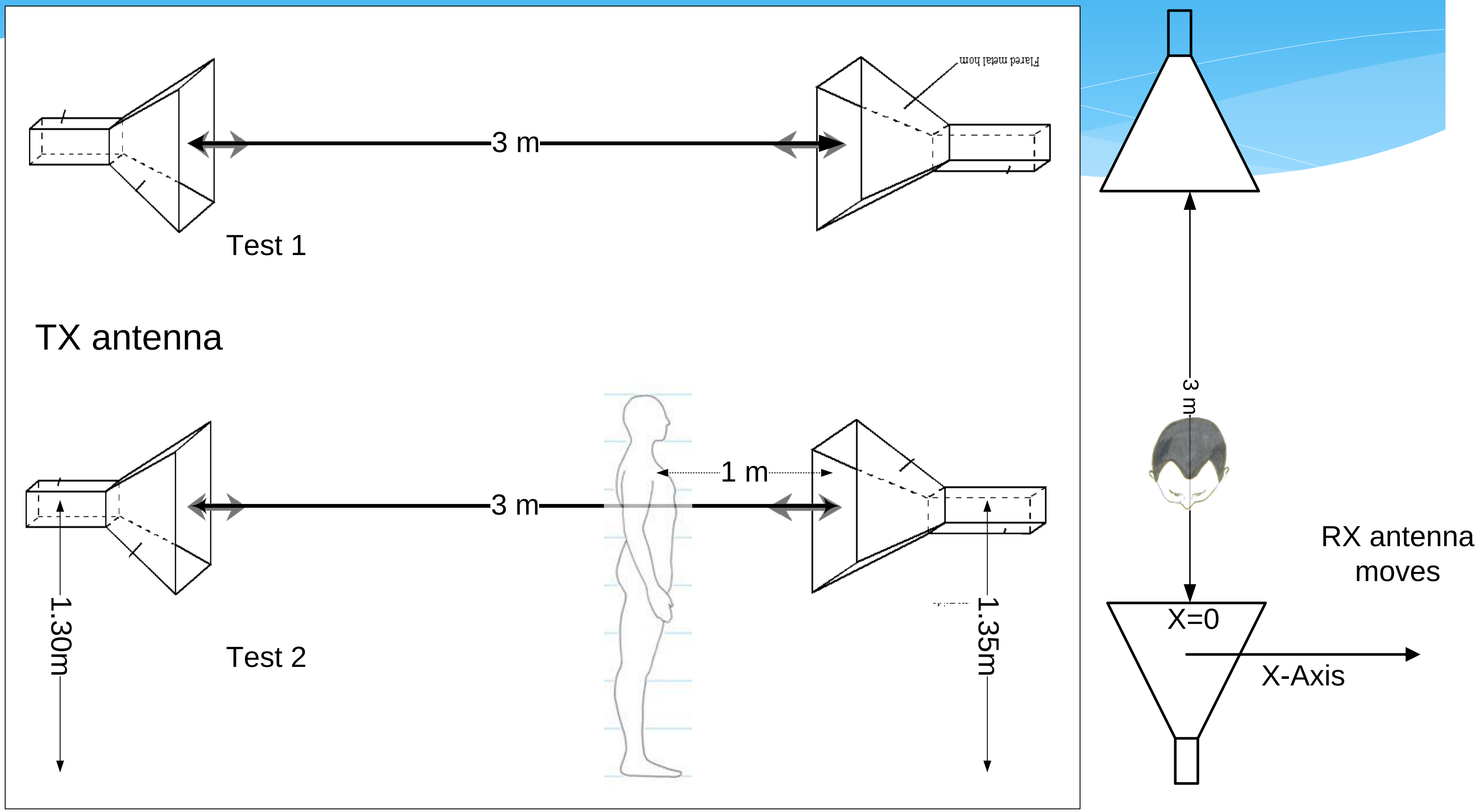


Fig. 3 Radiation pattern of the horn Antenna

TX-RX Antenna Distance

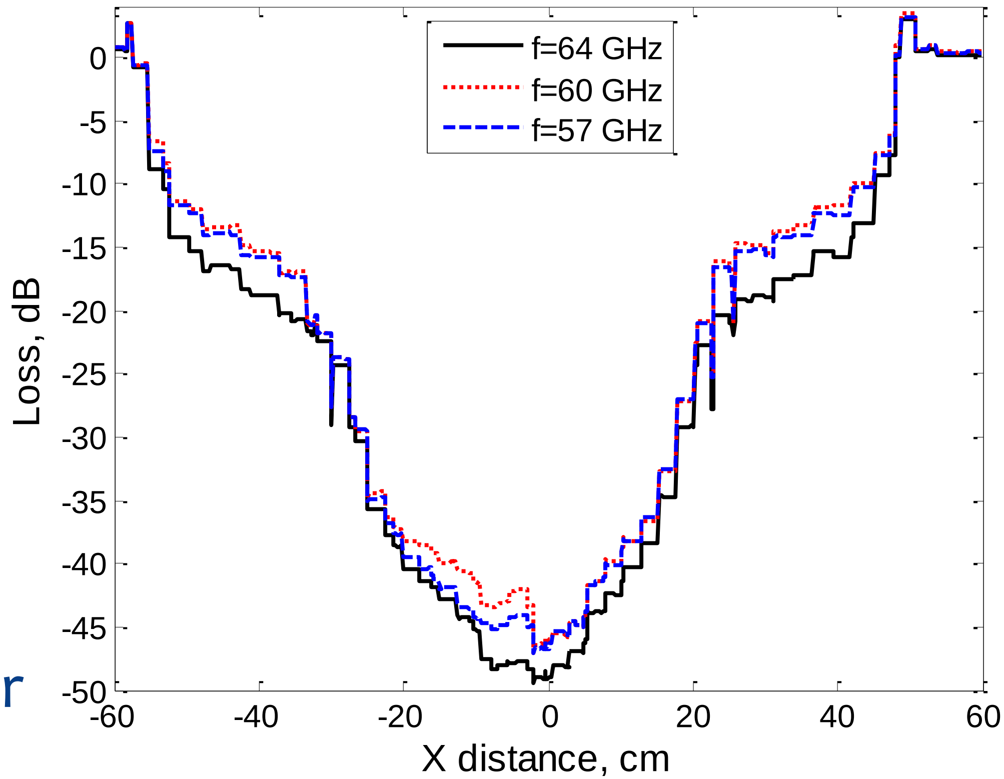


Ray-Tracing Scenario

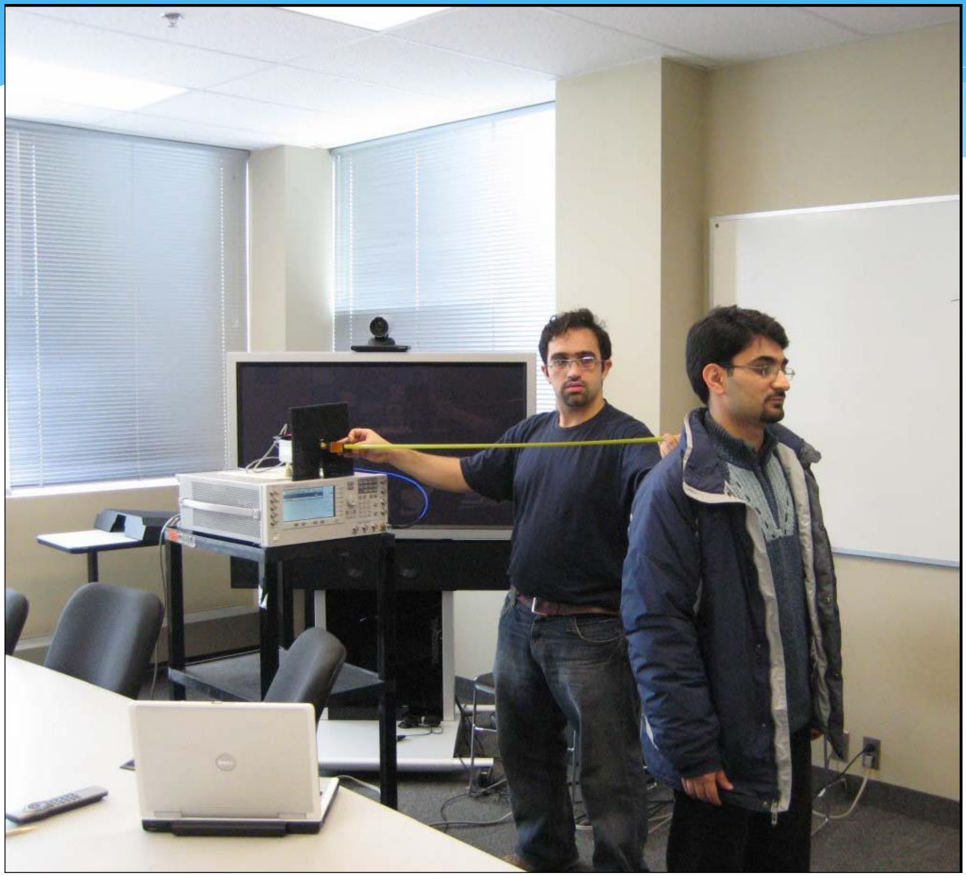
* The RX antenna was moved along a horizontal line, in steps of 1mm, to cover a distance of ±60cm around the initial position.
* The total received power of all rays was calculated at each RX antenna position.
* This procedure was repeated at three frequencies, 57, 60 and 64GHz, with and without human body to find the shadowing loss.

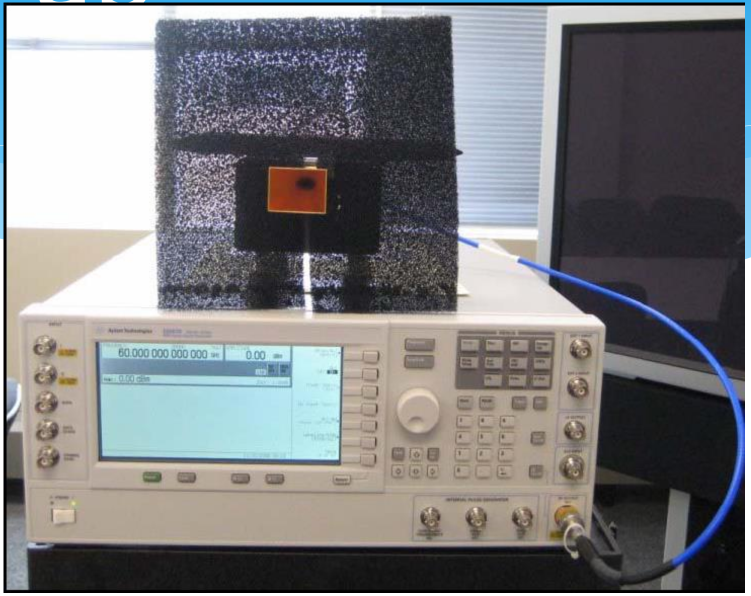
Ray-tracing Results

- Maximum attenuation occurs around x=0cm (> 40dB).
- The attenuation is larger for higher frequencies.
- Received power is almost symmetrical around x=0.
- Maximum attenuation varies from 45 to 50 dB for different frequencies.



Test Set-up





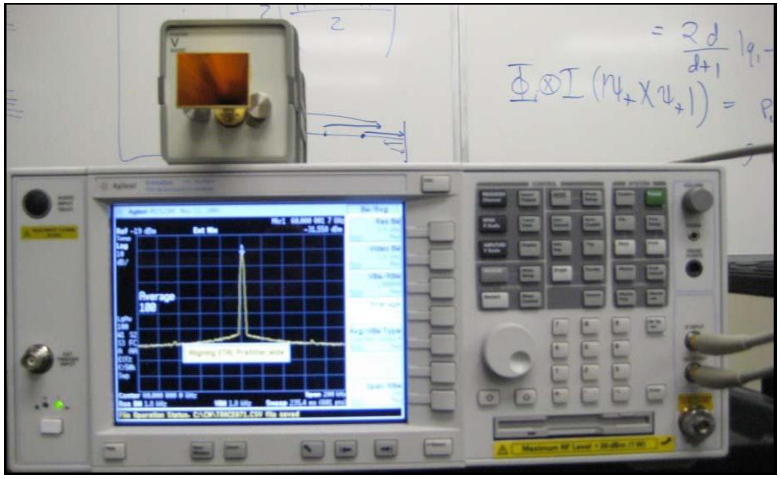
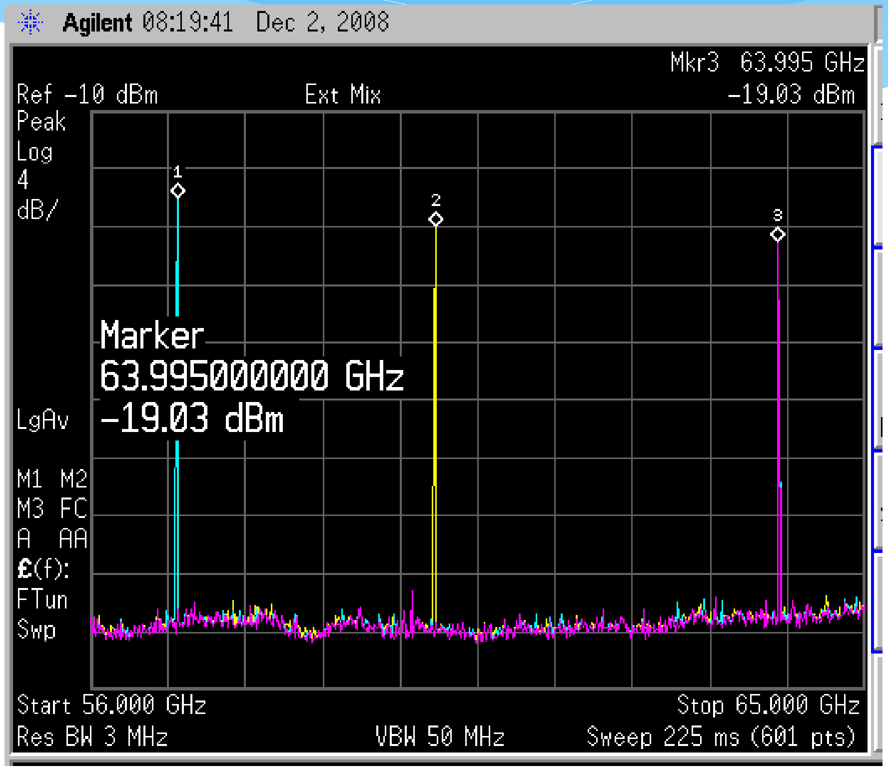


Fig. 5 Left: Test set-up. Top-Right: Source and transmitter antenna. Bottom-Right: Receiver antenna and spectrum analyzer.

Measured Spectrum (LOS)

To measure the shadowing loss of the human body, the RX antenna was moved in steps of 5cm.

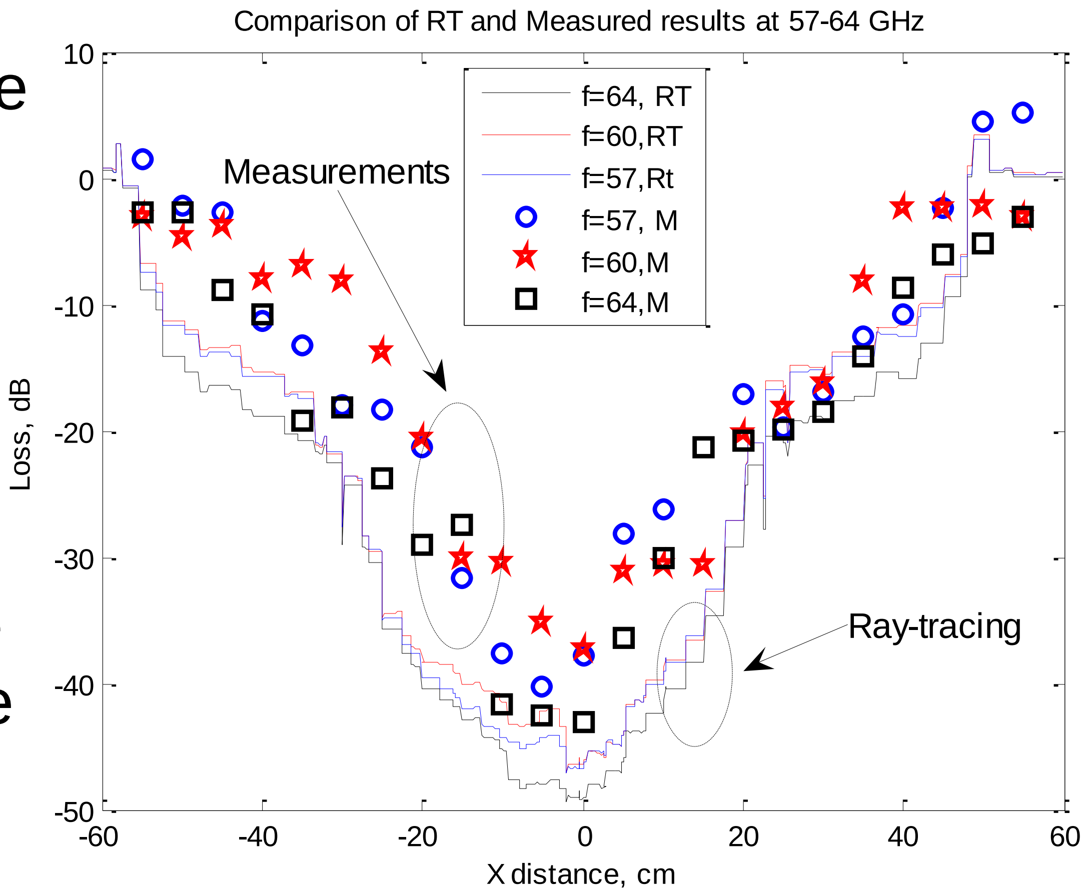
At each point the received power spectrum was measured at 57, 60 and 64GHz.



Experimental Results

There is a good agreement between the simulation and measurement results from x=-10 to x=60cm.

Maximum measured loss is around 40dB which occurs when the human body blocks the LOS path completely.



Conclusion

* In conclusion, it was shown that the shadowing loss of the human body at 57-64GHz can exceed 40dB.
* Ray-tracing analysis provides good approximation of the wave propagation at this frequency range.
* These results are of crucial importance for link budget design of 60 GHz indoor wireless networks.

Multi-Gigabit/sec Data Transmission

WiFi on Steroids: 802.11ac and 802.11ad

Lochan Verma and Mohammad Fakharzadeh, Peraso Technologies, Inc.
Sunghyun Choi, Seoul National University

IEEE Wireless Communications • December 2013

Article of month Feb 2014

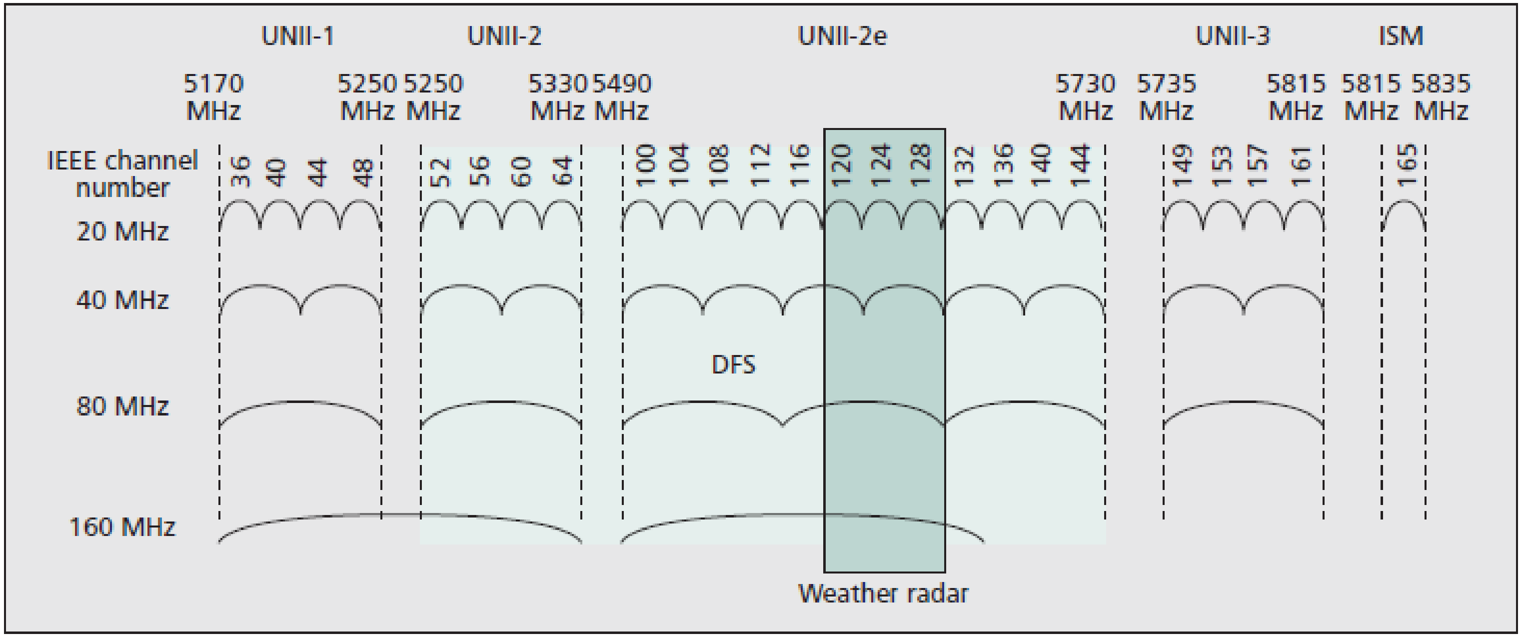


Figure 1. *The 5 GHz spectrum available for Wi-Fi usage with DFS and TDWR restrictions.*

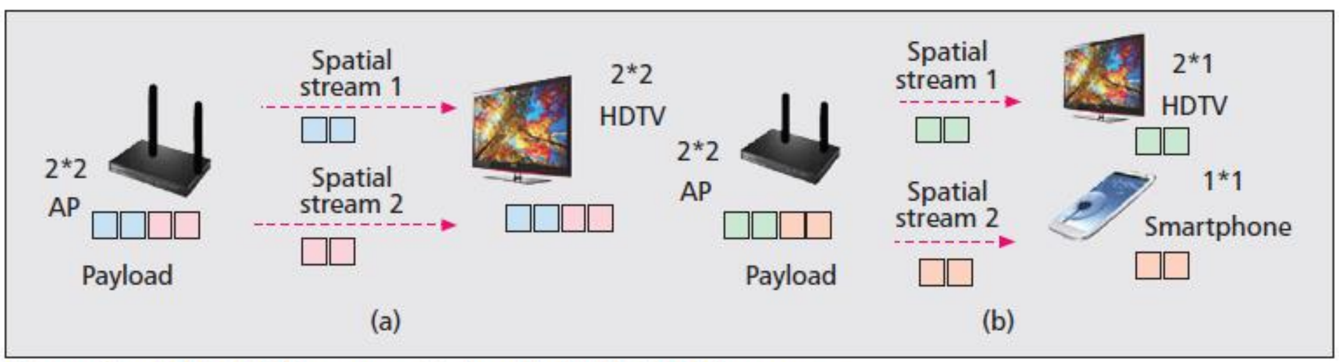


Figure 2. *a) SU-MIMO concept; b) downlink MU-MIMO concept.*

802.11AD

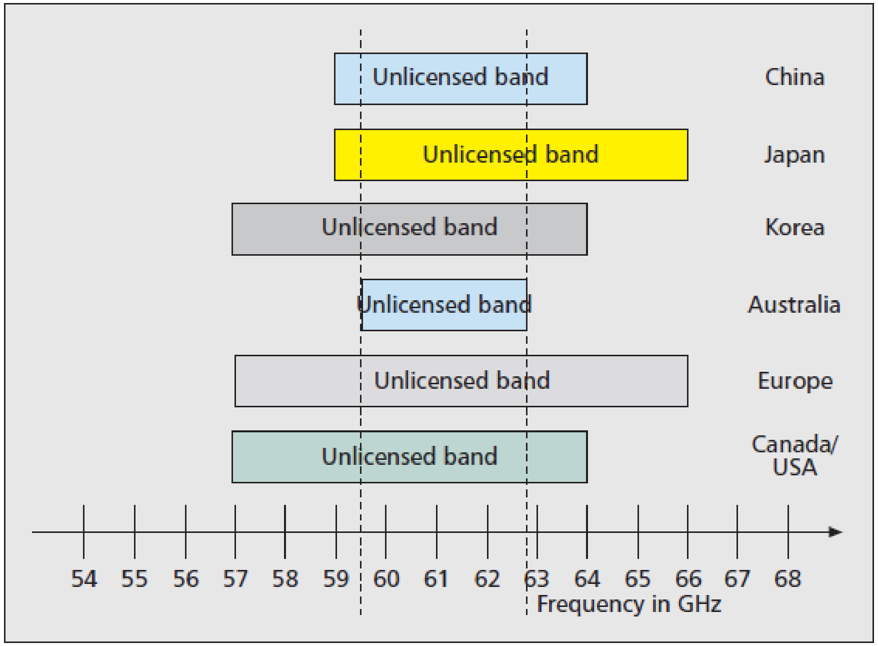


Figure 3. *Worldwide frequency allocation for unlicensed operation at 60 GHz band.*

Modulation	Code rate	PHY data rate (Mb/s)					Spatial streams	Standard
		20 MHz channel	40 MHz channel	80 MHz channel	160 MHz channel	2.16 GHz channel		
BPSK	1/2	6.5	13.5	—	—	—	1	802.11n[2]
QPSK	3/4	19.5	40.5	—	—	—	1	802.11n
16-QAM	3/4	26	81	—	—	—	1	802.11n
64-QAM	5/6	65	135	—	—	—	1	802.11n
64-QAM	5/6	260	540	—	—	—	4	802.11n
BPSK	1/2	6.5	13.5	29.3	58.5	—	1	802.11ac[2]
QPSK	3/4	19.5	40.5	87.8	175.5	—	1	802.11ac
16-QAM	3/4	39	81	175.5	351	—	1	802.11ac
64-QAM	5/6	65	135	292.5	585	—	1	802.11ac
256-QAM	5/6[1]	78	180	390	780	—	1	802.11ac
256-QAM	5/6[1]	312	720	1560	3120	—	4	802.11ac
256-QAM	5/6[1]	624	1440	3120	6240	—	8	802.11ac
p/2-BPSK	1/2	—	—	—	—	385	1	802.11ad
p/2-BPSK	3/4	—	—	—	—	1155	1	802.11ad
p/2-QPSK	3/4	—	—	—	—	2310	1	802.11ad
p/2 16-QAM	3/4	—	—	—	—	4620	1	802.11ad
64-QAM	13/16	—	—	—	—	6756.75	1	802.11ad

[1] Code rate of 3/4 for 20 MHz channel width.
[2] Guard interval = 800 ns.

Table 1. *Modulation and coding schemes for 802.11n, 802.11ac, and 802.11ad.*