Wireless Communications

Dan Stancil

- Frequency Reuse: key to wireless networks
- HVAC Ducts: channels where you least expect them
- Time Reversal: more than science fiction!
- Wireless Megatrends: new paradigms

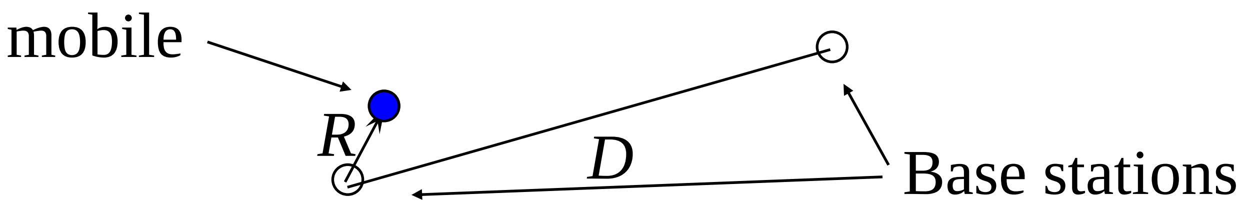
How Would You Make a Wireless System?

- How would you make a wireless system that could scale to serve everyone in the world?
- Could I give everyone a channel?
  - Say 10 kHz/person $\times$ 6 (10^9)people $=6(10^{13})$ Hz
  - Corresponds to an infrared wavelength of 5 μm!

What About Reusing Frequencies?

- If someone if so far away that I can’t hear them, I can use that frequency again!
- To build a strategy around this, we need to see how far away the other person needs to be
- To enable the mobiles to connect to the fixed infrastructure (I.e., wireline phone or internet), we need to strategically place *base stations* so that a mobile will always be in range of at least one
- We need to discuss *interference* that we might get from another base station reusing the frequency that our base station is using

Co-channel Interference



- Co-channel interference: neighboring base stations using the same channel set
- Interference is reduced by increasing the *co-channel reuse ratio Q=D/R*
- Small *Q* gives high capacity
- Large *Q* gives better signal quality (less interference)

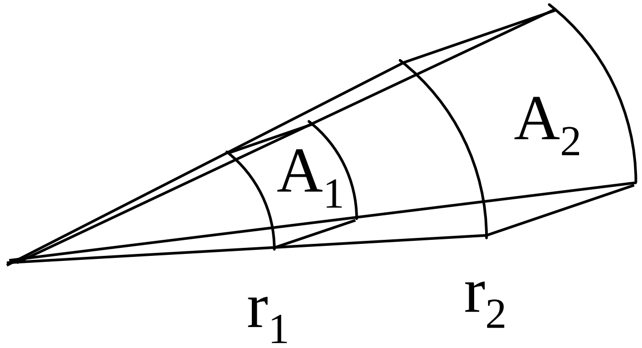
Signal-to-Interference Ratio

- For i_o co-channel interfering base stations:

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_o} I_i}$$

- where S=desired signal power, I_i = power from *ith* interfering base station
- For example, minimum S/I~5-7 dB

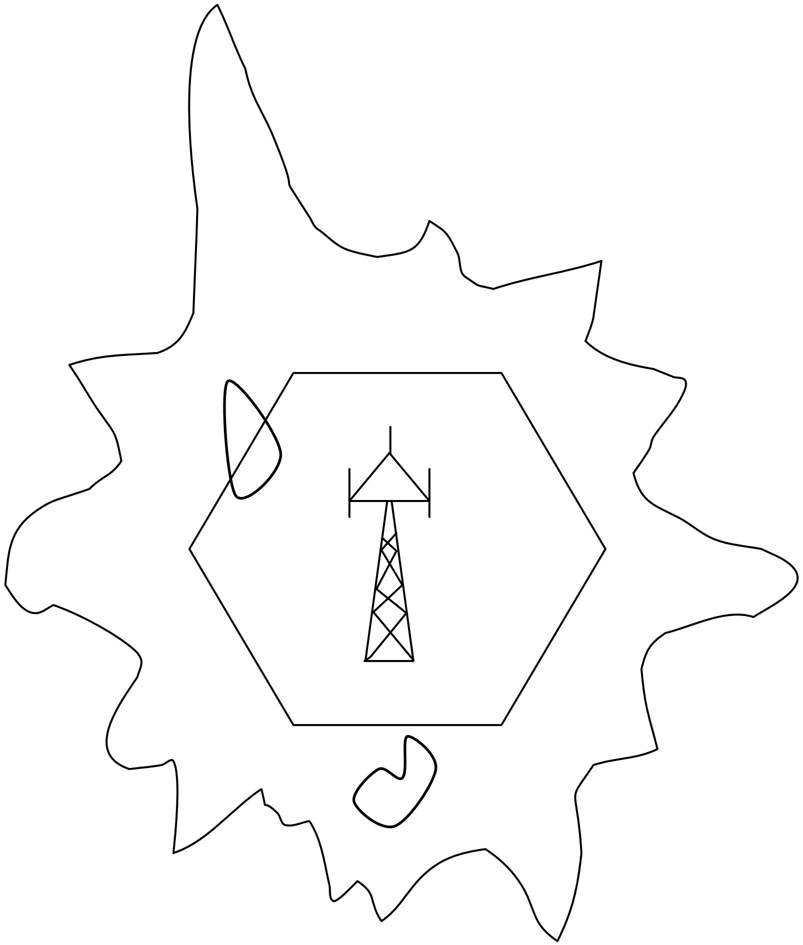
Carrier Power vs. Distance



$$\frac{A_2}{A_1} = \frac{r_2^2}{r_1^2}$$

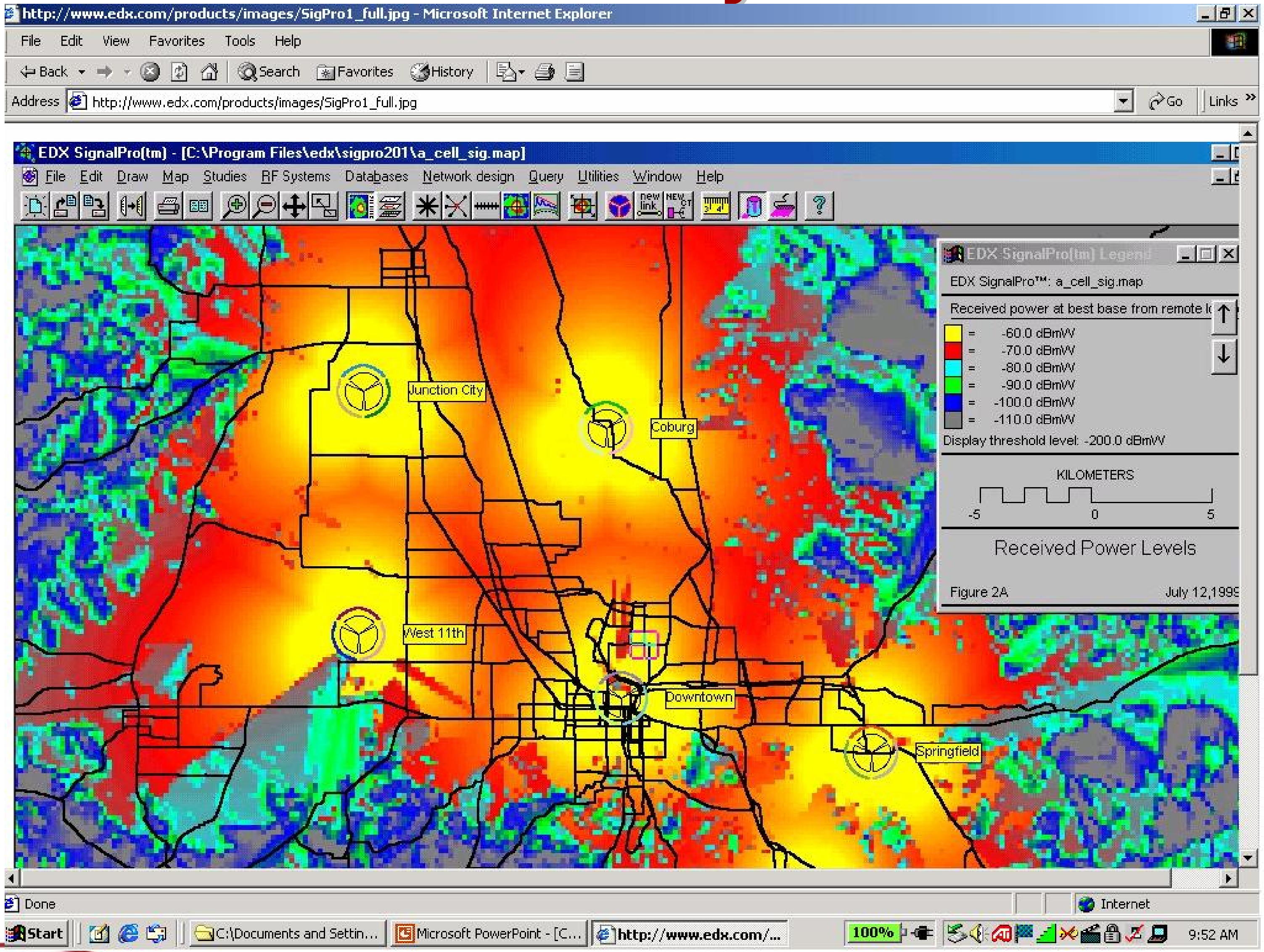
- For free space $P_r = P_0(r/r_0)^{-2}$
- In more cluttered environments $P_r = P_0(r/r_0)^{-n}$
- In many urban environments, $n \sim 4$

Basic Cell



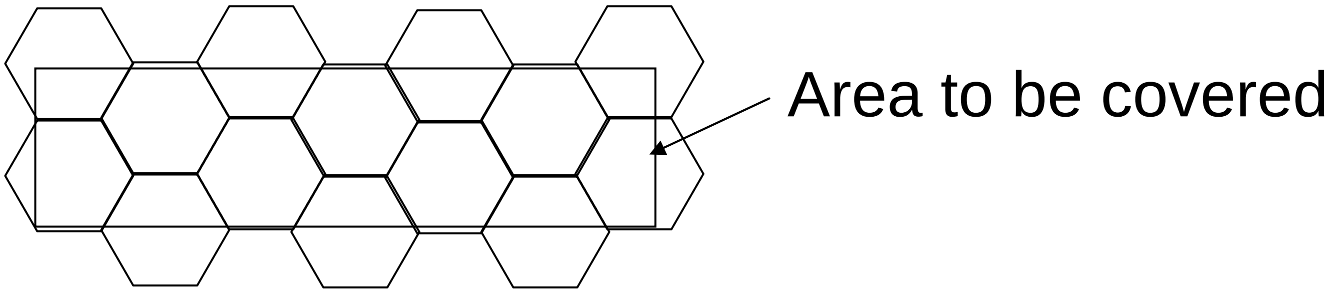
- Shape of actual coverage depends on terrain, buildings, etc.
- For simplicity, represent area of “guaranteed” coverage by hexagonal “cell” (geometry: you can tile these!)

This is What it Really Looks Like…..

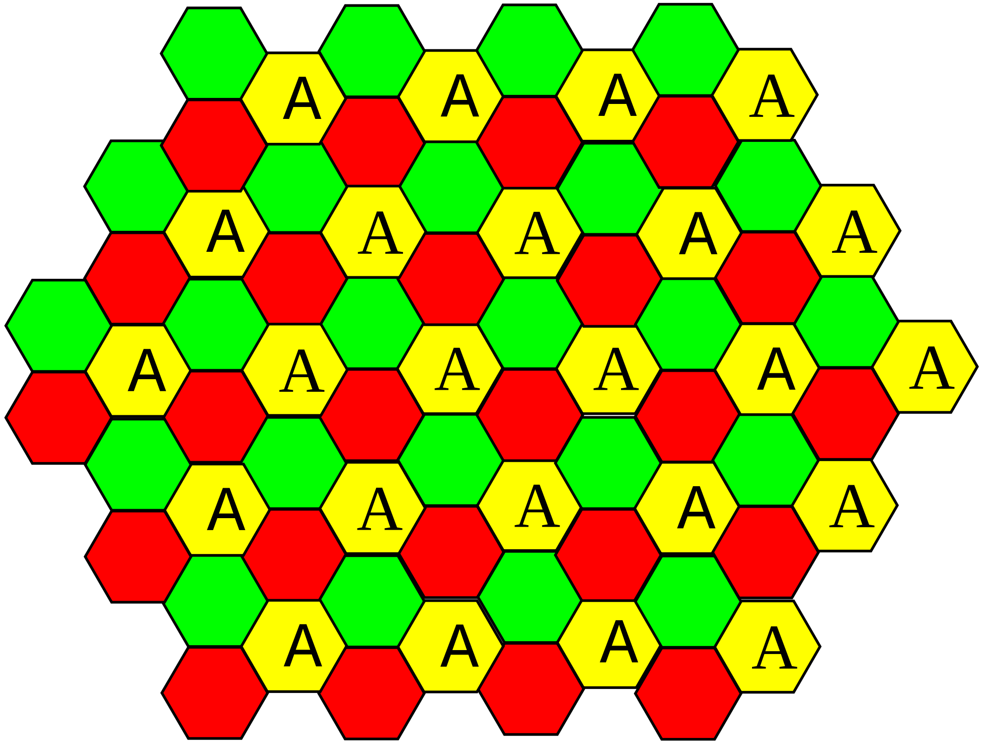


Coverage with Hexagonal "Tiles"

- Place separate base-station transmitter near the center of each cell
- cells that are sufficiently far away from each other can reuse the same frequencies!



Higher Tier Interferers



2nd tier for N=3

- There are 6n cells in the nth tier
- All co-channel cells contribute to the interference, but usually it is adequate to consider only the first tier

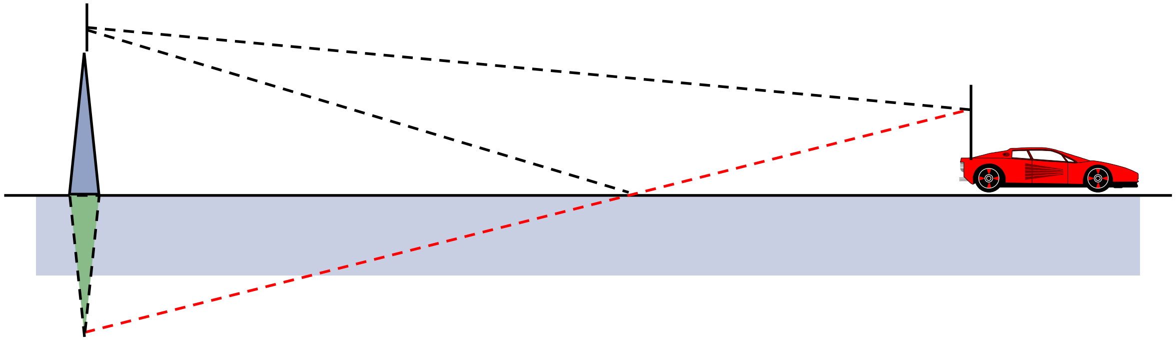
Diverging Interference?

- Distance to Nth tier is ~ND
- # of interferers at the Nth tier is 6N
- Total interference goes like

$$I_{tot} \sim \sum_{N=1}^{\infty} \frac{6N}{(ND)^2} = \frac{6}{D^2} \sum_{N=1}^{\infty} \frac{1}{N}$$

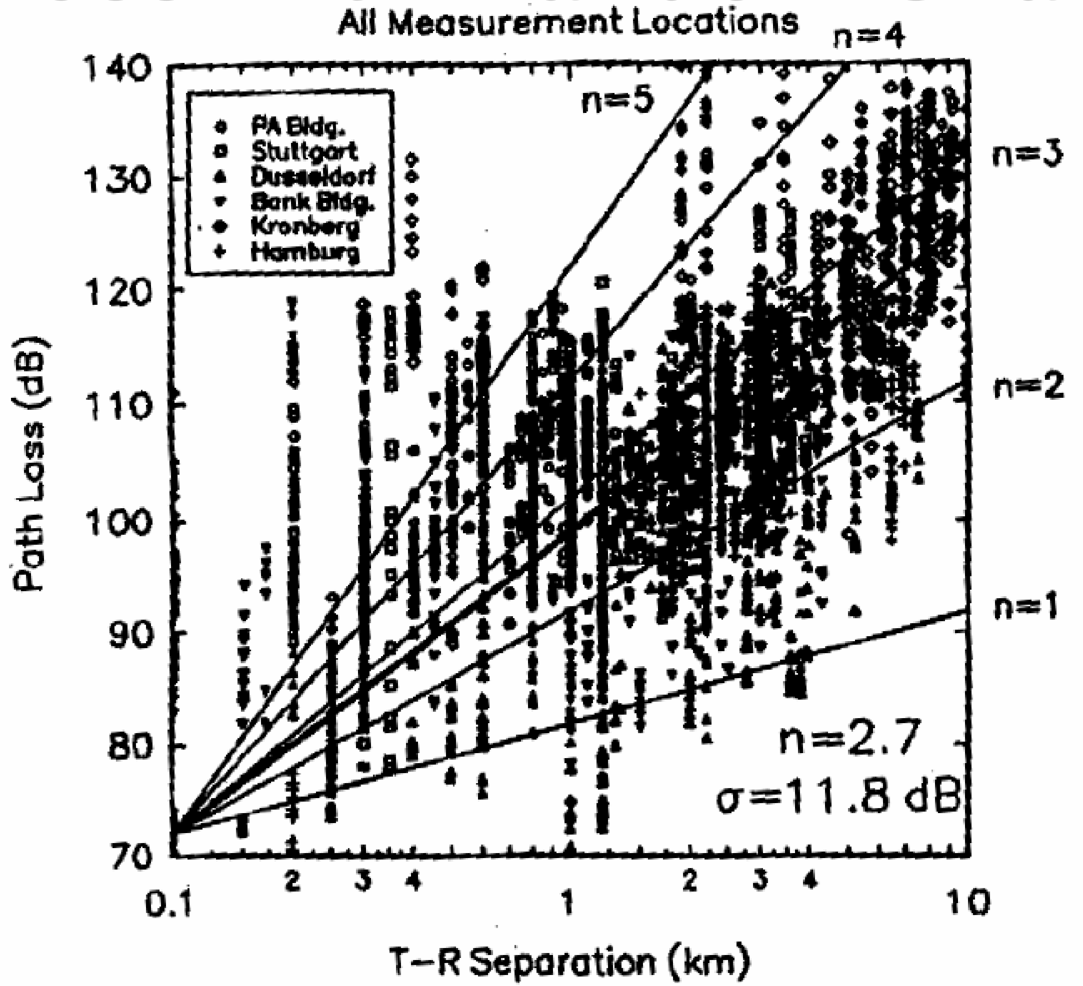
- This series diverges!
- Frequency reuse would not be possible if signal always dropped off as $1/r^2$!

2-Ray Ground Reflection Model



- Ground reflection tends to cancel direct path
- At large distances signal power goes like $1/r^4$

Path Loss with Random Shadowing



Seidel et al, 1991

- Modern cellular communications would not be possible if the path loss exponent was not typically more than 2!

Wireless Building Communications: A New Approach

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Building Communication Systems & Challenges

- Cellular/PCS Voice
  - Interior coverage of large buildings is often challenging
- Wireless LANs
  - Difficult to design for coverage because of distinct properties of each building
- Typically these are all distinct systems with their own infrastructure:
  - Wireline voice
  - Cordless phones
  - Wired broadband internet access
  - Building controls
  - Building alarms

Proposal: Use Building HVAC as Integrated Communication System Backbone

- Every building has a built-in RF distribution system-- HVAC ducts
- These hollow metal ducts act as RF waveguides
  - Low loss
  - Time invariant (independent of motion in building)
  - High capacity
- *Proposal: Develop a co-design procedure and "Radio-Friendly" ducts so that HVAC and all communication needs can be satisfied by the same infrastructure!*

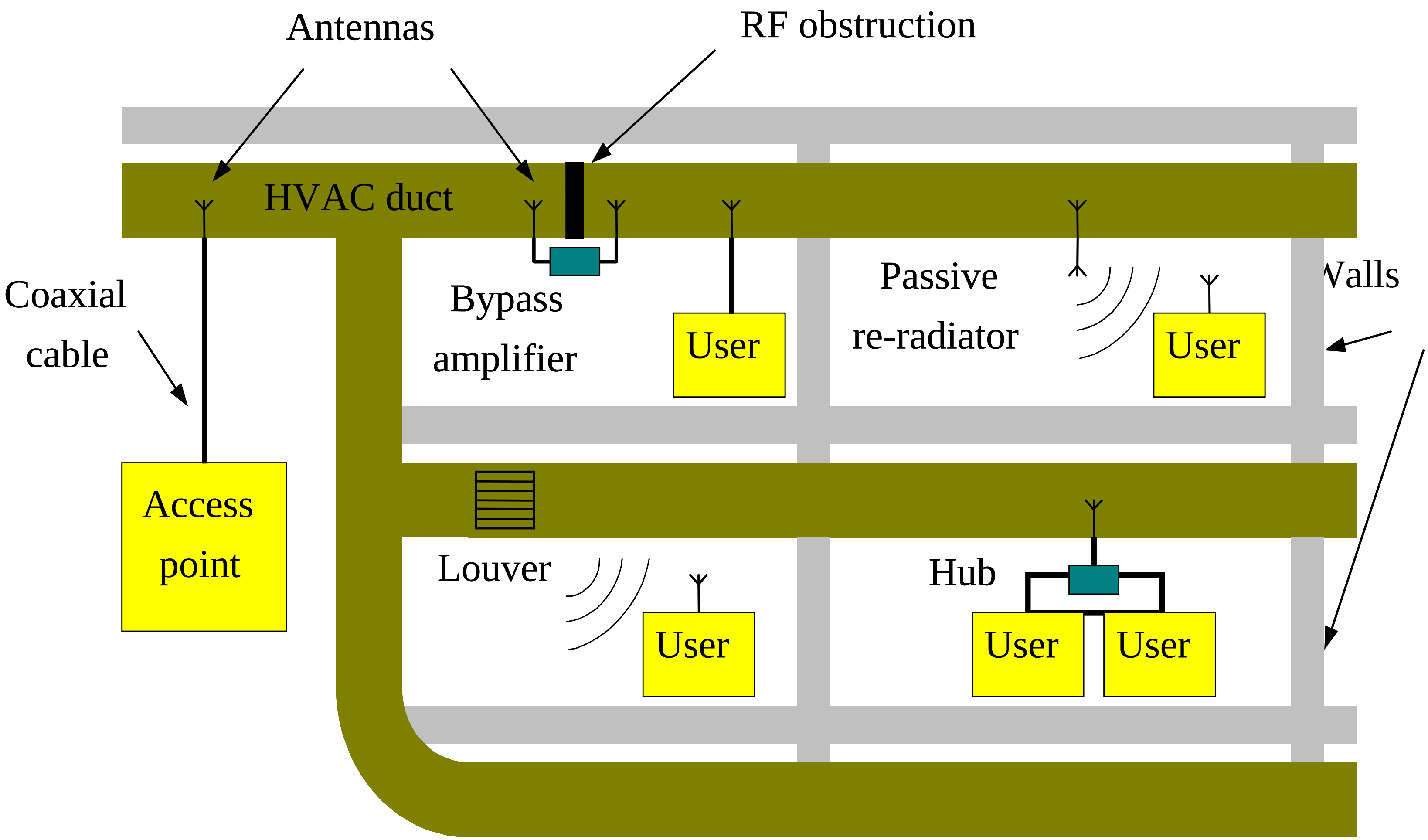
Channel Loss Comparisons

Attenuation in dB for a distance of 100 m

Center Frequency	12" duct	Belden 9913	RG 6A/U	Free Space
2.45 GHz	16*	29.5	69	80

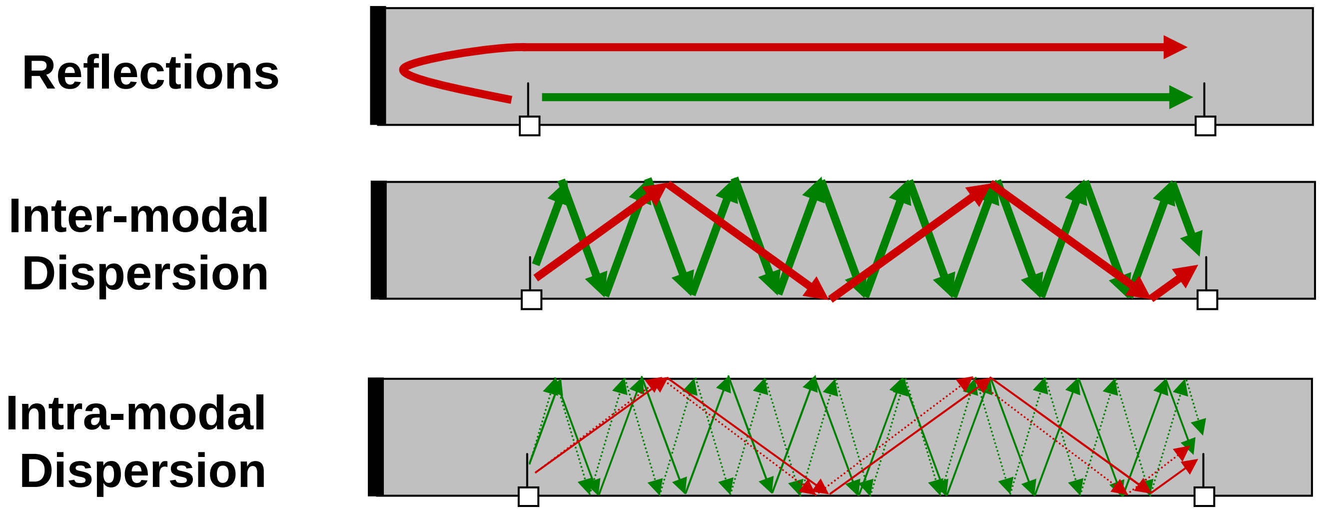
- *Depends on particular mode mix

HVAC Communication System



Signal Distortion in Ventilation Ducts

- Multiple echoes of a signal cause distortion

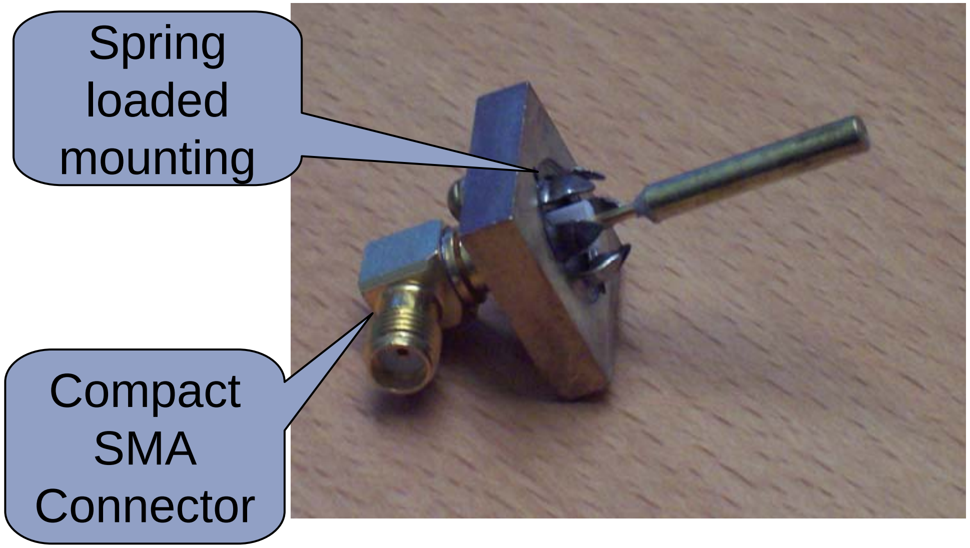


- Reducing dispersion:
  - Reflections: add absorber at endcaps
  - Inter-modal: minimize propagating mode count
  - Intra-modal: use lowest order modes possible

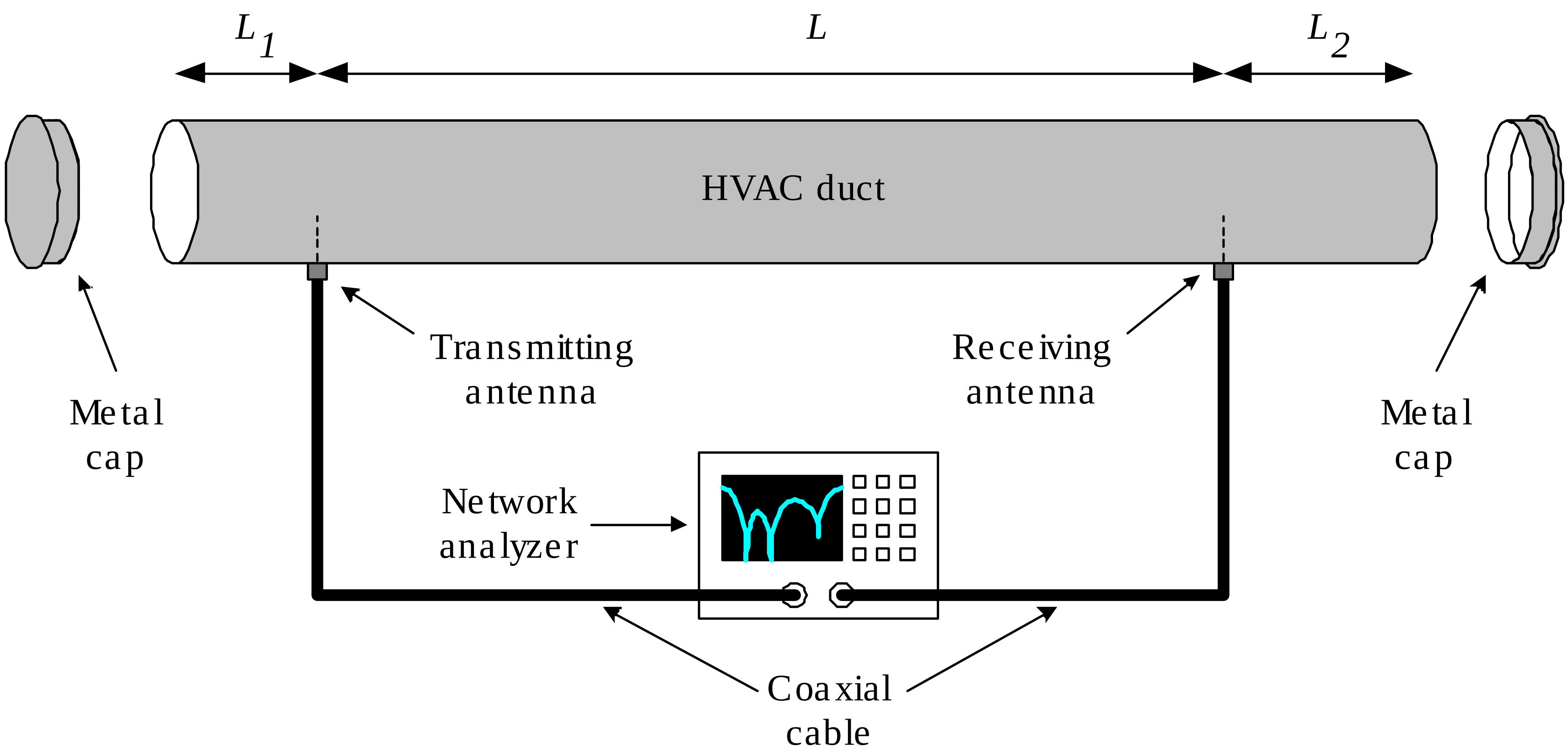
Antenna

- Antenna provides coupling in and out of HVAC ducts
- Simplest antenna is a coaxial-fed monopole probe

3.1 cm probe in 30.5 cm duct



Experimental Setup



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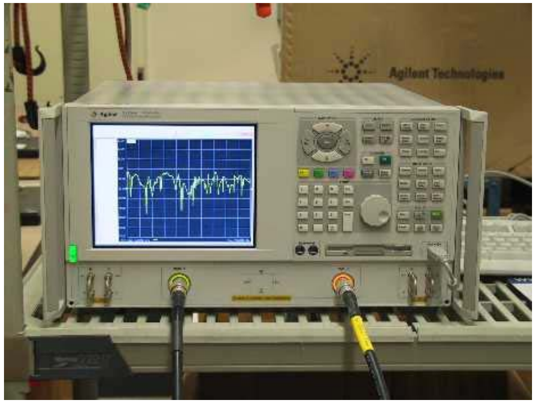
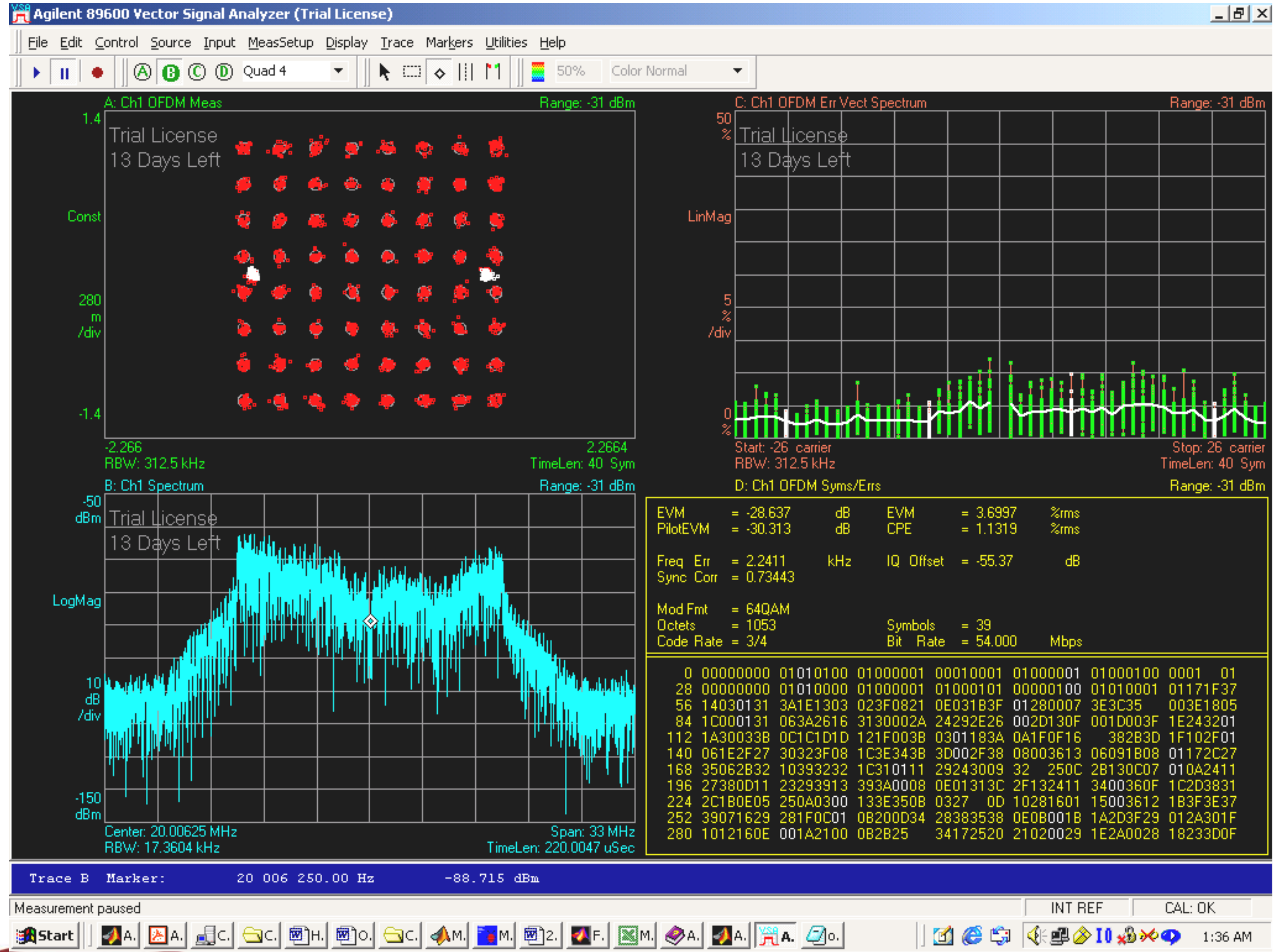


Fun with Ducts

802.11g Transmission through network in Roberts Hall

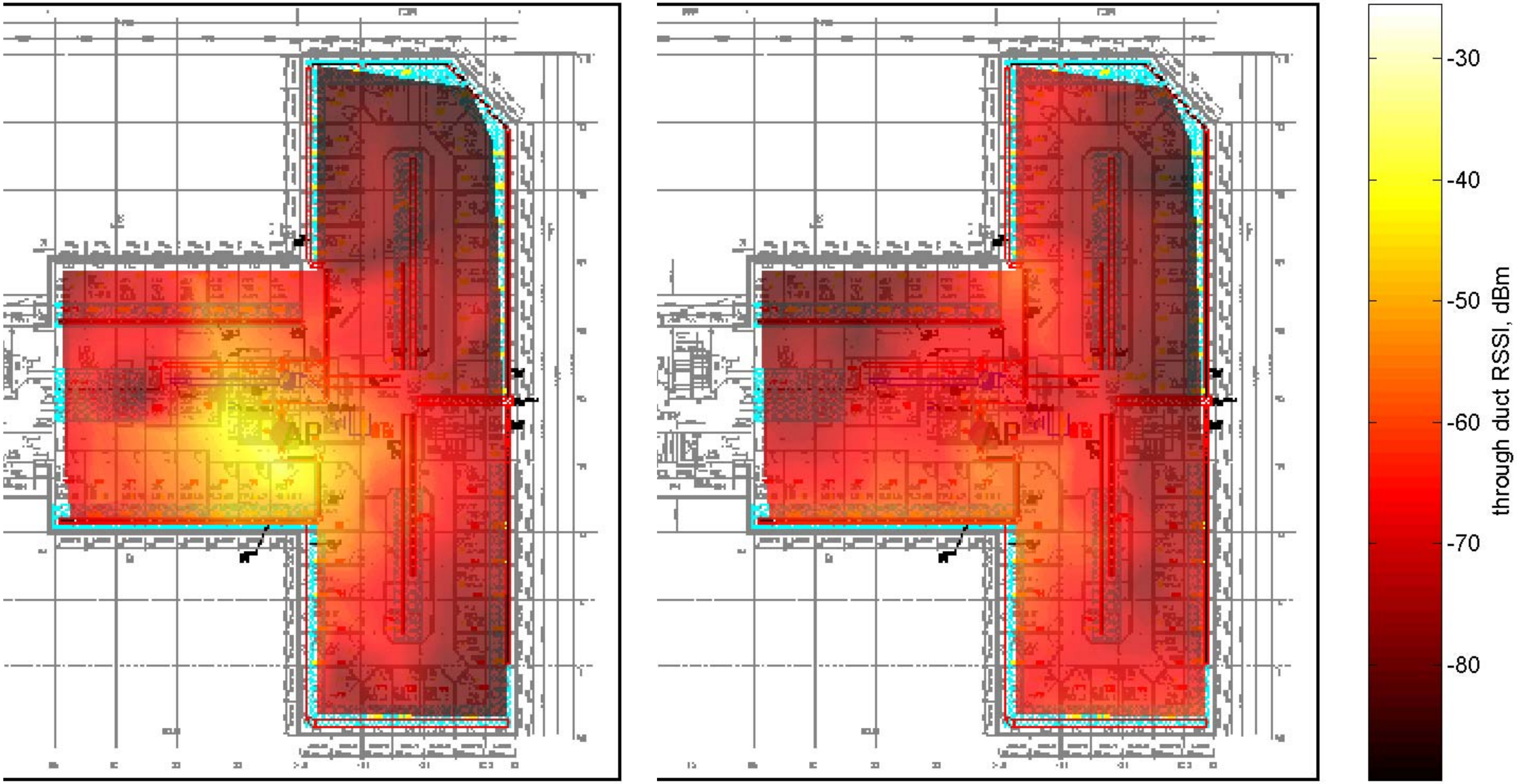


36 Mbps throughput

Measured RSSI: Conventional and Duct Stavanger, Norway

Conventional Coverage

Duct Coverage



Duct provides more even coverage, unaffected by building structure

Super-resolution Focusing and Nulling in Rich Multipath Environments using Time-Reversal Techniques

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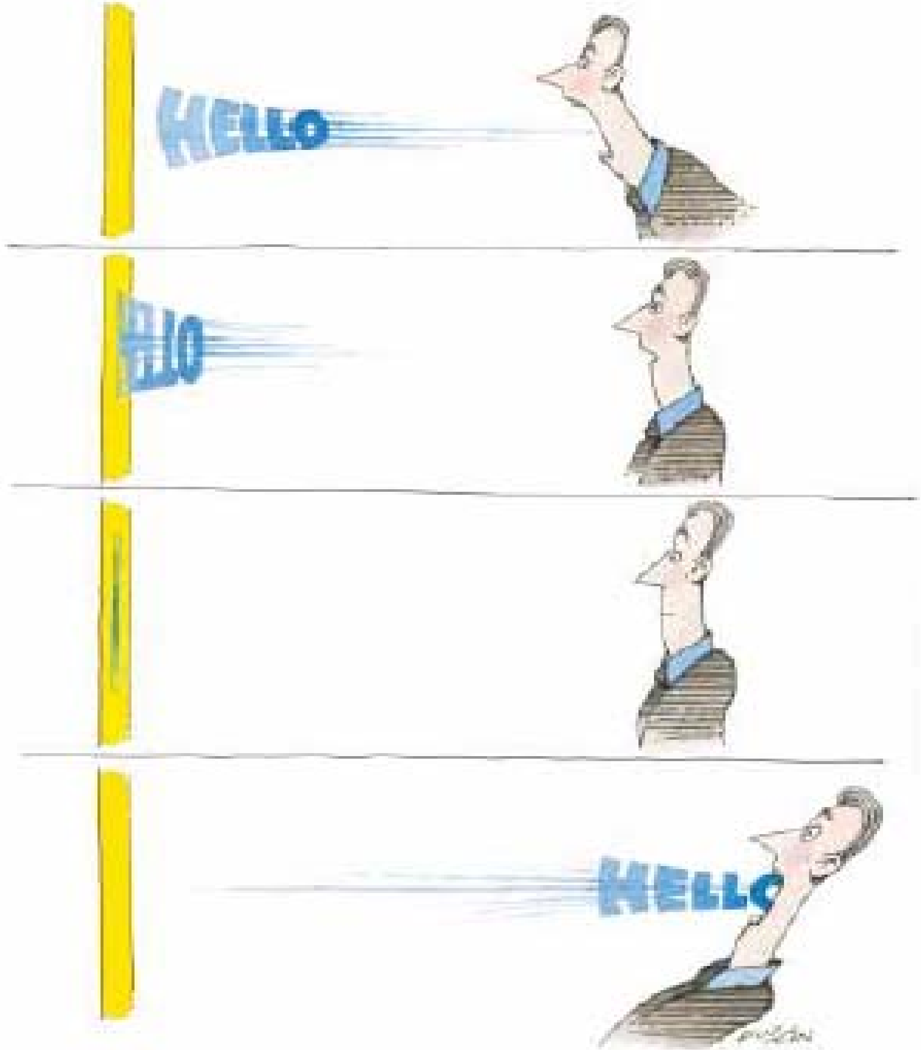
ICEAA '05

Time-Reversal Made Simple



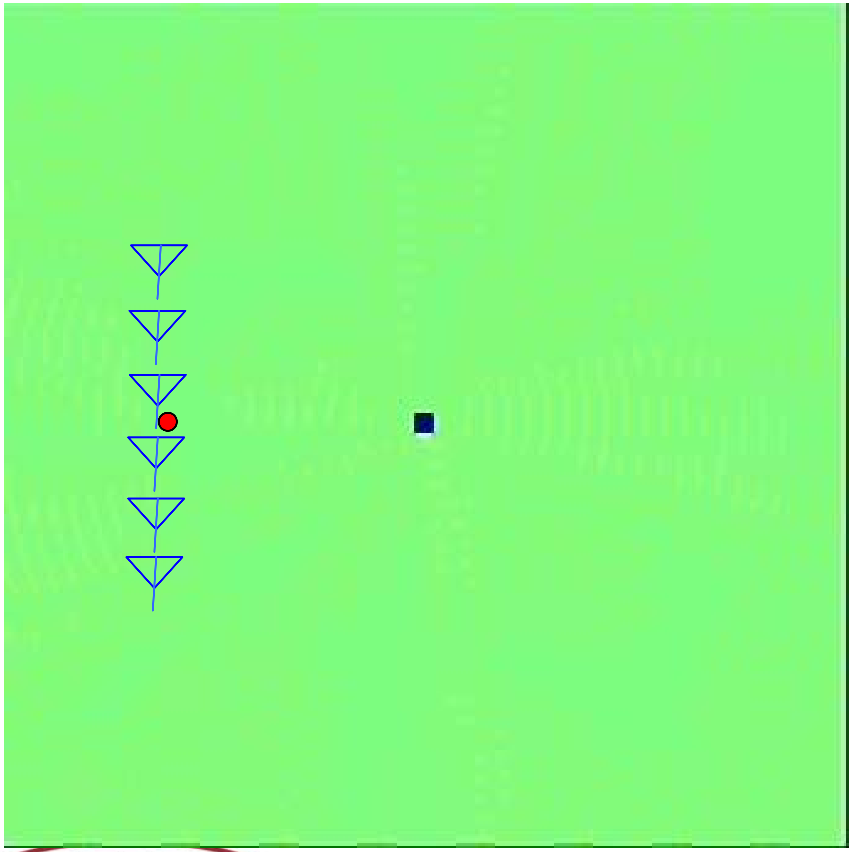
*M. Fink, "Time-reversed Acoustics", Scientific American, November 1999

FDTD Time Reversal Illustration

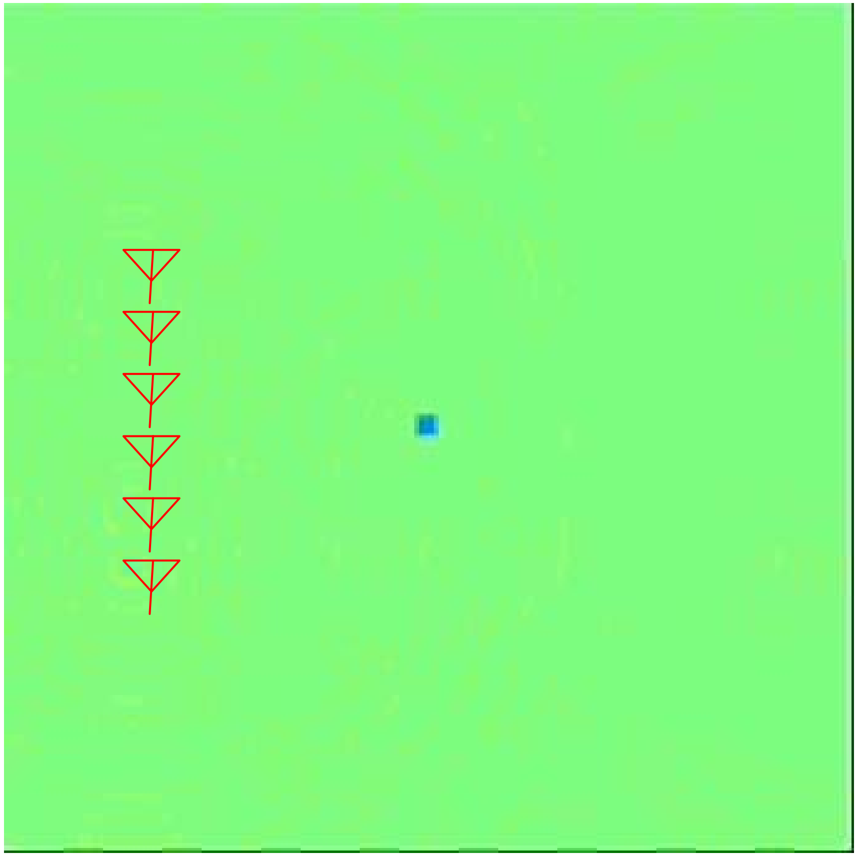
Transmitting a 1 ns pulse, carrier frequency 2.5 GHz (λ = 12 cm).

6 antenna, each separated by 2λ, Region 3.6mX3.6m .

Scatterer illumination



Broadcast time reversed signal



Y. Jiang, J. Zhu

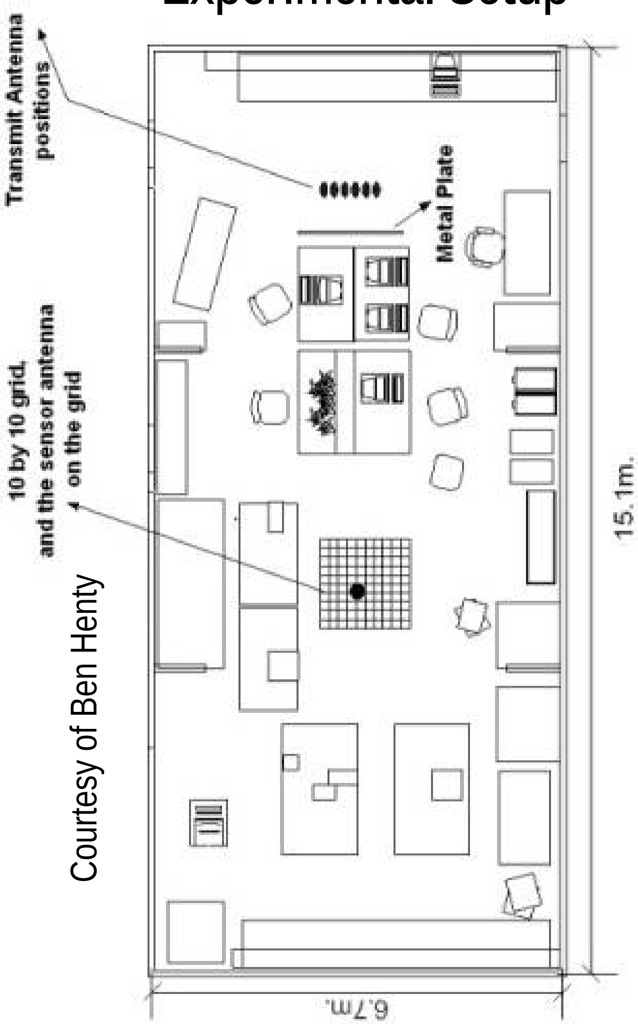
A1

1. Prepared to answer the question why you choose 2.5 GHz carrier frequency? What is the difference by using different carrier frequency? This question may related to radar carrier frequency.
2. If 2.5 GHz is your carrier frequency what is your baseband signal? What is your baseband signal bandwidth?
3. Why you seperate antenna by 2 lumda?
4. It is better to put dimensions on your simulation, size of the space, size of the scatter,etc.

Author, 11/2/2004

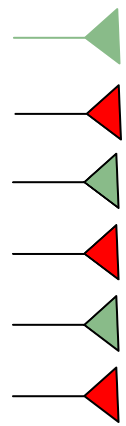
Multiple-Antenna Time-Reversal

Experimental Setup

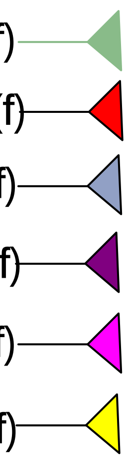


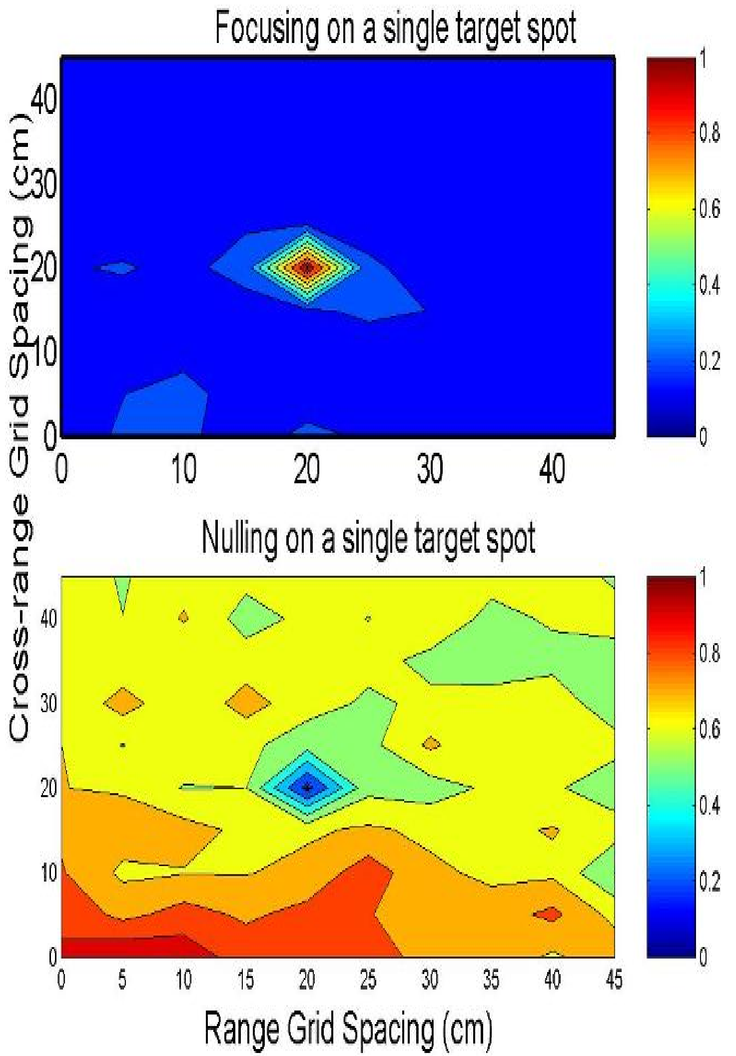
Courtesy of Ben Henty

TR Focusing



TR Nulling

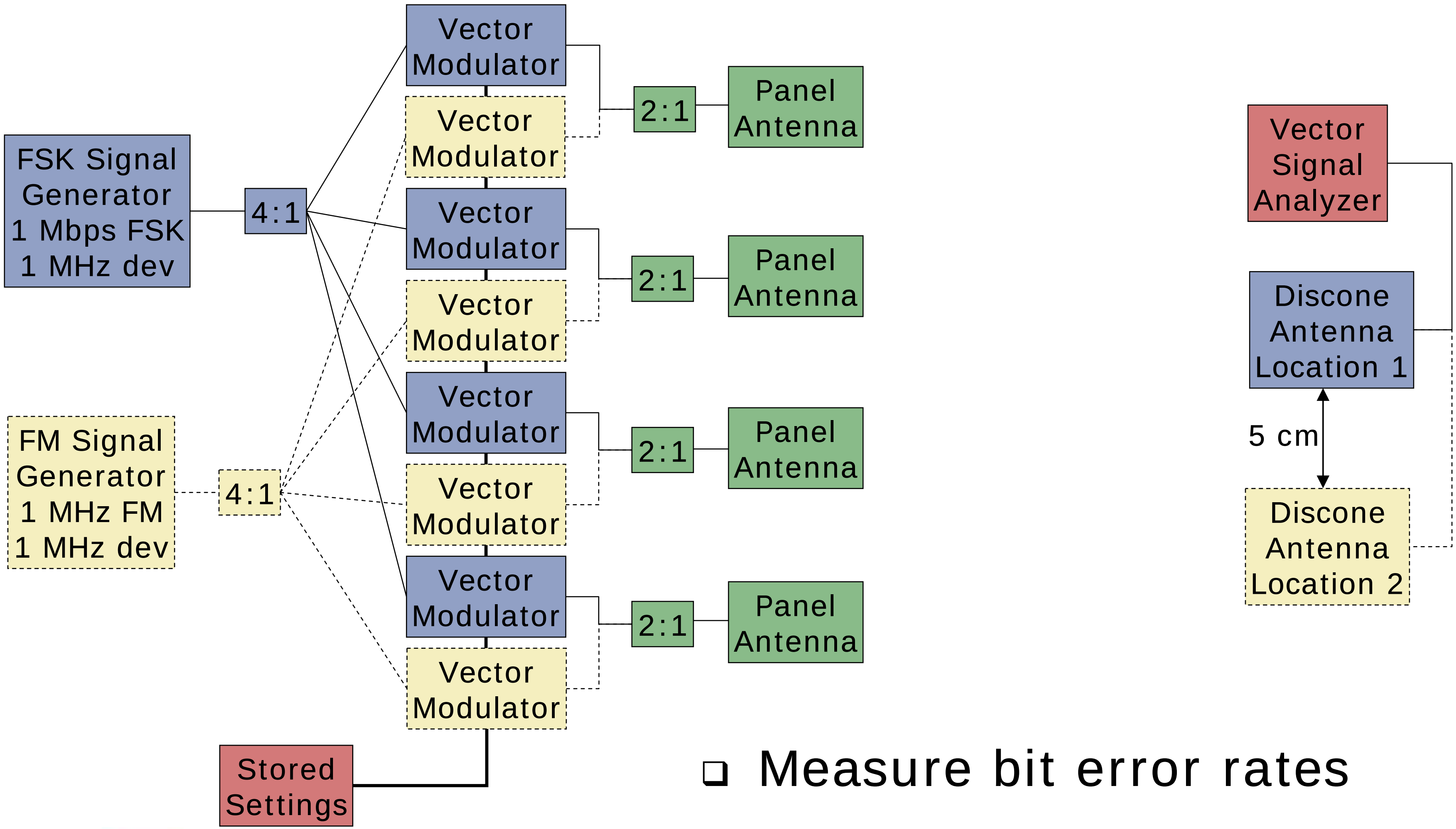




6 antenna array

Signals combined using MATLAB

Communication Applications



- Measure bit error rates

Bit Error Rate Measurements

Open Lab LOS		Cluttered Lab no LOS	
SIR (dB)	BER (%)	SIR (dB)	BER (%)
1.9	4.5	15.5	0.1
0.2	-	11.2	2.2

Two-spot time-reversal focusing

Megatrends in Wireless

Way we use Spectrum is not working

- Spectral allocations for cellular communications and unlicensed wireless LANs not adequate for projected demands
- Various monitoring projects have shown that significant segments of licensed spectrum are under-used
- New technologies such as ultrawideband require the use of spectrum in ways not previously considered
- Developments in Software Defined Radio and Cognitive Radio promise a degree of flexibility and agility not previously possible
- **Conclusion: New paradigms are needed for how spectrum is used for communications**

Examples of New Paradigms for Spectrum Use

- Allow license holders greater freedom in how to use their spectrum
- Use of dynamic spectrum managers

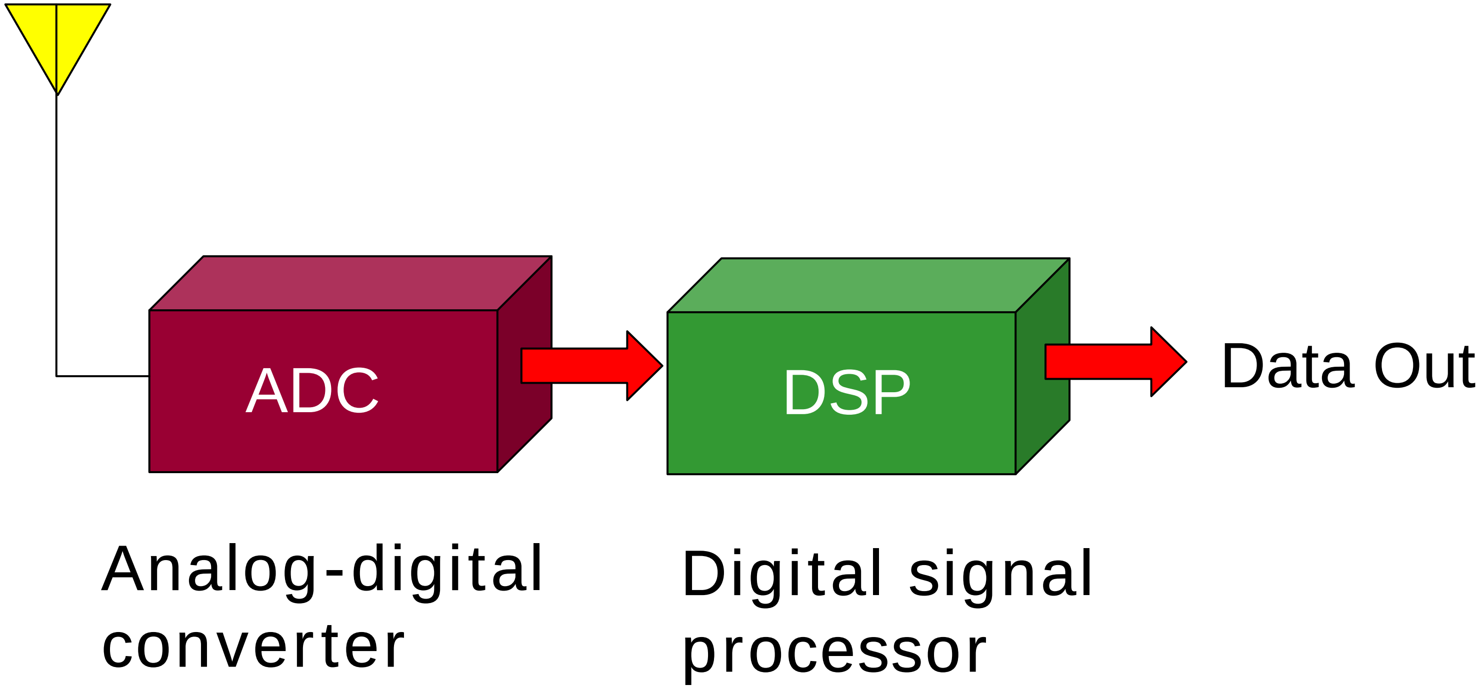
- Allowing secondary access for a fee
- Cooperative mesh networks

- Allowing opportunistic (unpaid) use of spectrum by choosing Power levels, frequencies, times, and antenna directivity to prevent significant interference

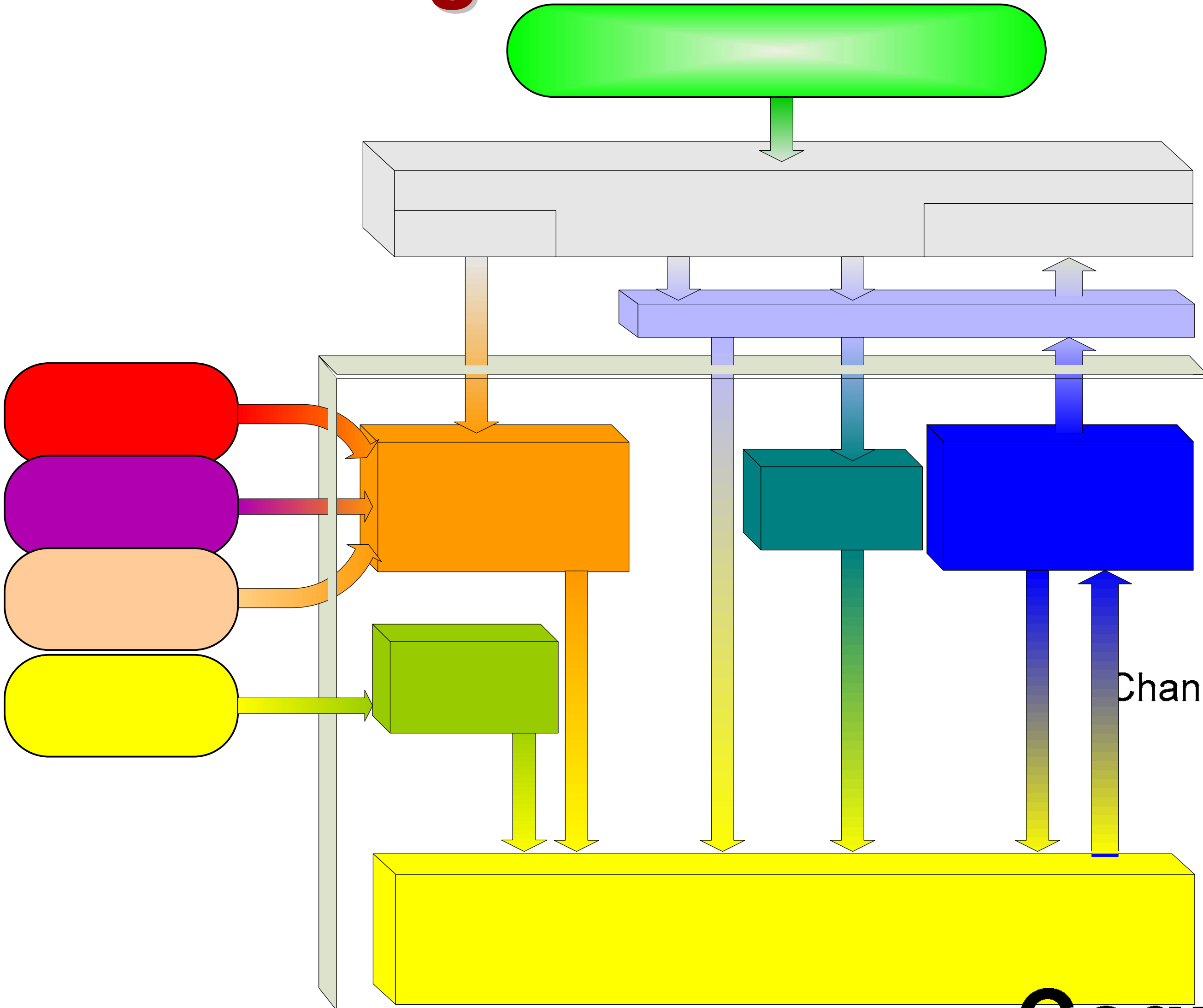
New Paradigms Require New Technologies

- Protocols for negotiating dynamic spectrum use
- Protocol and coding schemes for ensuring QoS requirements, security and enforcement
- Agile and intelligent radios to select and use whatever spectrum resource may be available
- Ways of recognizing interference
- Use of signal processing and smart antennas such as adaptive arrays to increase capacity and reduce interference
- *Software defined radios and Cognitive Radios will be needed to achieve these capabilities*

Simplified Ideal Software Defined Radio Block Diagram



Cognitive Radio



- Va Tech Cognitive Radio

That's All Folks!