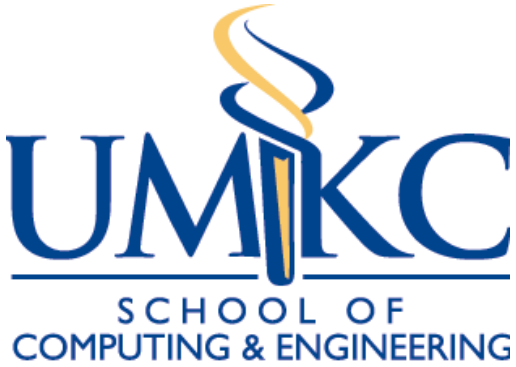


MILITARY APPLICATIONS OF RADIO FREQUENCY PROPAGATION

Dr. Deb Chatterjee,
Associate Professor,
CSEE Department

Outline

UMKC SCHOOL OF COMPUTING & ENGINEERING

- **Subject**
- **Purpose**
- **Scope**
- **Methods**
- **Results**
- **References**

Military Needs

- Unmanned Aerial Vehicles (UAVs)
- Tactical Missiles (Patriot MIM 104)
- Airforce/Navy - SensorCraft
- US Army – Thru' Wall Imaging

UAVs: SensorCraft (AFRL)

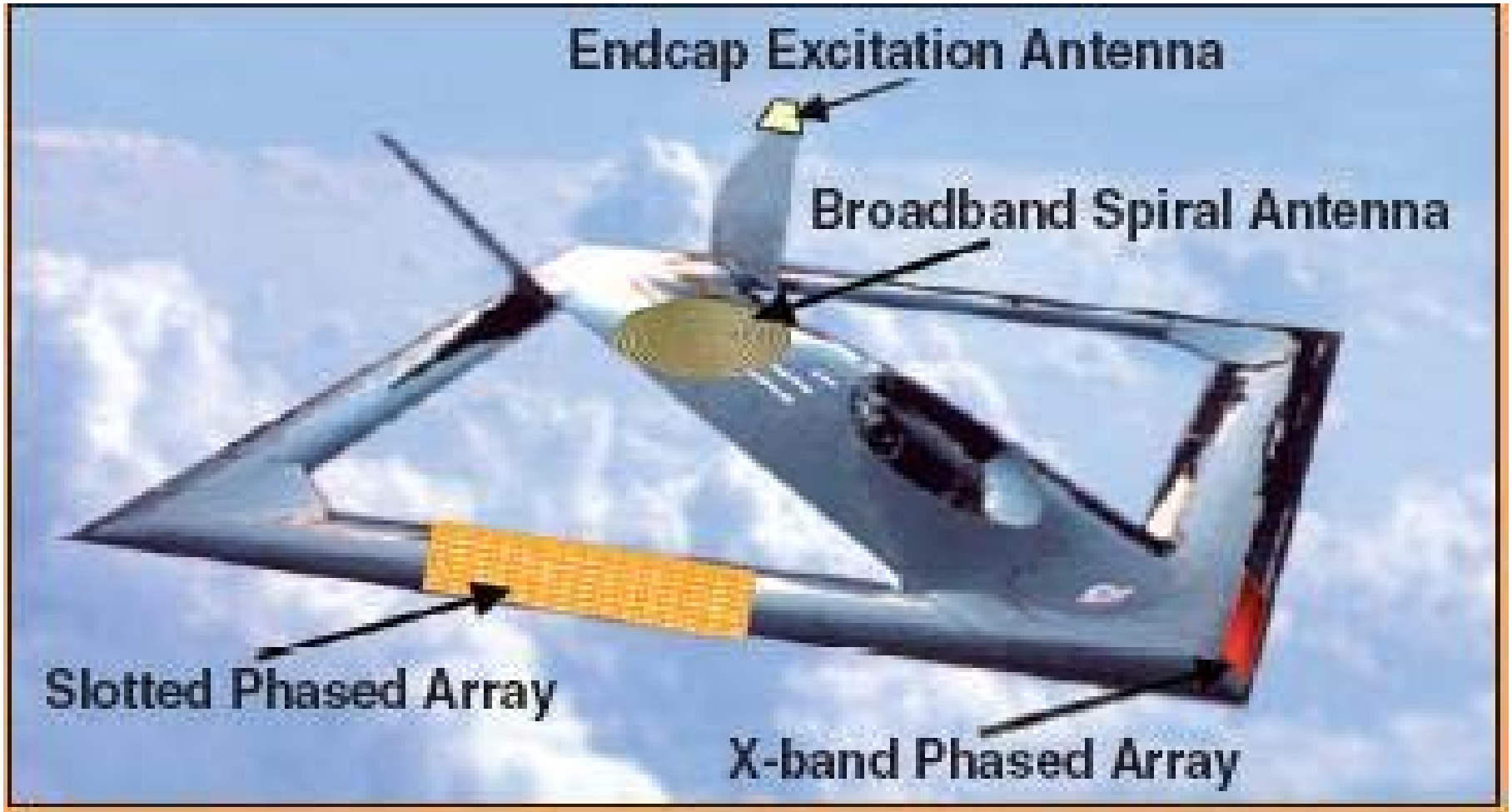


Figure 5. SensorCraft's advanced structurally embedded arrays

Tactical Missiles: Patriot MIM 104

February 2, 2009

RF Sensors on UAVs (SensorCraft)
Conformal Microstrip Phased Array

UMKC SCHOOL OF COMPUTING & ENGINEERING

February 2, 2009

Advanced Functions: UAVs

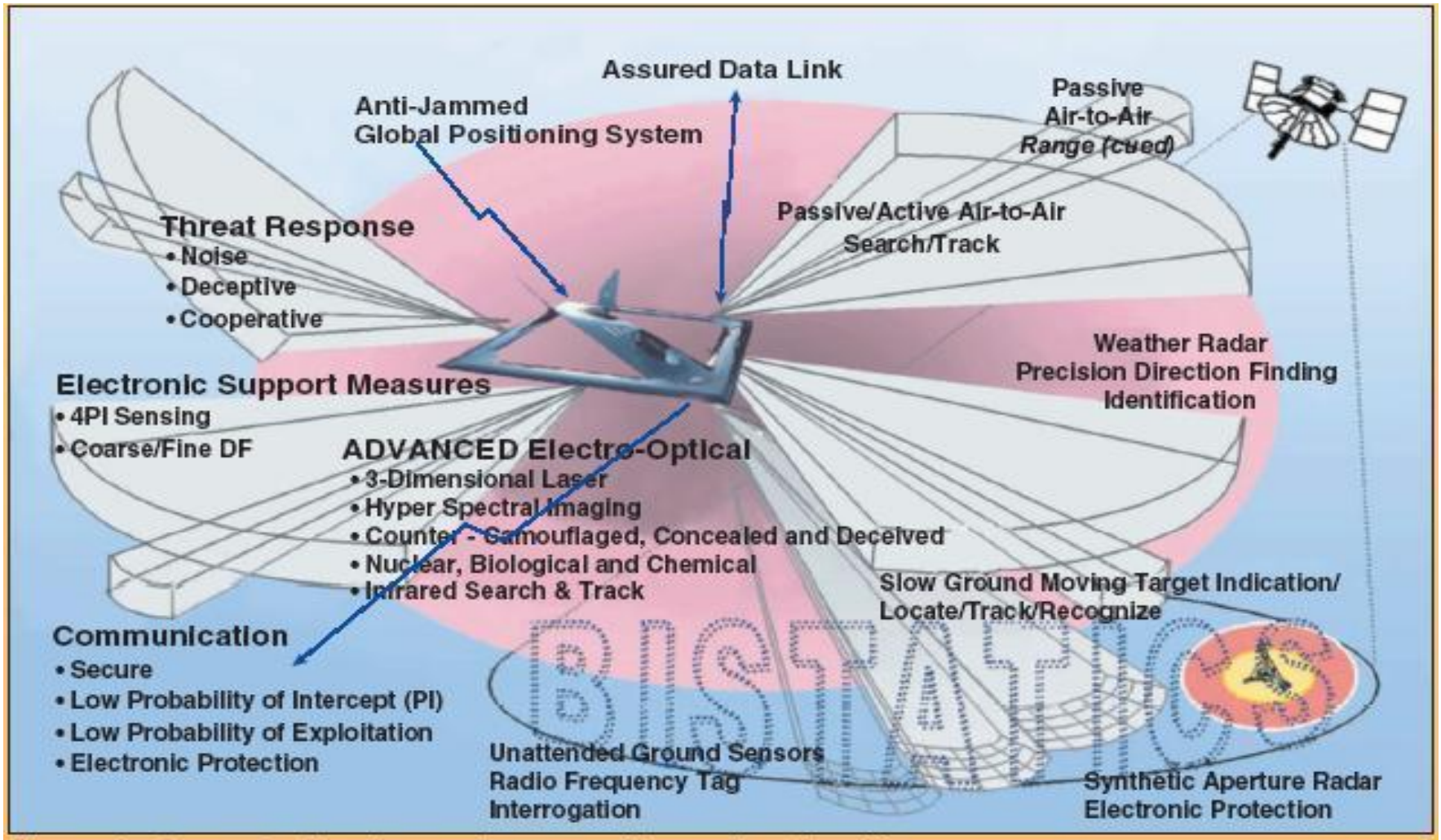


Figure 4. SensorCraft's advanced sensors diverse functionality

UMKC SCHOOL OF COMPUTING & ENGINEERING

Features of Advanced RF Sensors

- Flush-Mounted / Conformal
- Low Probability of Intercept – LPI
- Constant (all weather) Survelliance
- Multichannel / Multifunction
- Secure Communications
- GPS Capability
- ECM / ECCM

RF Sensor: Phased Array

Flush Mounted	Sensor Platform Effects
High Directive Gain	Narrow 3-dB Beams
Low Sidelobes	Low Mutual Coupling
Null-Steering	Low Mutual Coupling
Wide Angle Scanning	Adaptive Matching Network
Multichannel / Ultrawideband	Broadband Array Elements
Scan Angle Limitation	Tolerance on Boresight Gain

Survelliance, Multi-channel / Function and Secure Communications

UMKC SCHOOL OF COMPUTING & ENGINEERING

Survelliance → **Phased Arrays, or Electronic Scan**

Multi-channel → **Ultrawideband**

Security & ECM → **Null-Steering**

February 2, 2009

What is Involved ???

- **Electromagnetics – Radio Waves**
- **Modeling – Mathematics**
- **Simulation – Environment Effects**
- **Go for it !!! ☺**

What is Computational Electromagnetics (CEM) ?

UMKC SCHOOL OF COMPUTING & ENGINEERING

- Maxwell's Equations
- Boundary Value Problem
- Numerical Solutions
- Validation

LPI – RF Invisiblity (Basic Equation)

UMKC SCHOOL OF COMPUTING & ENGINEERING

$$\sigma_{ant} \equiv \frac{\lambda^2}{4\pi} G_t G_r p_t p_r \left|\Gamma\right|^2$$

LPI – RF Invisibility (contd.)

- σ_{ant} ***to be reduced over wide angular range***

DESIRED

1. $G_{t,r}$ ***must be highly directive & low sidelobes***

2. $\Gamma \approx 0$ ***over a wide range of frequencies***

3. $p_{t,r} \approx 0$ ***for wide frequency range***

Major Research Activity

UMKC SCHOOL OF COMPUTING & ENGINEERING

- **(Ultra)Wideband Microstrip Antennas**

- **Conformal Array Antennas for Tactical Applications**

What is Ultrawideband

UMKC SCHOOL OF COMPUTING & ENGINEERING

$$\eta \equiv \frac{f_u - f_l}{f_u + f_l}$$

$$0.25 \leq \eta \leq 1.0$$

What is Ultrawideband

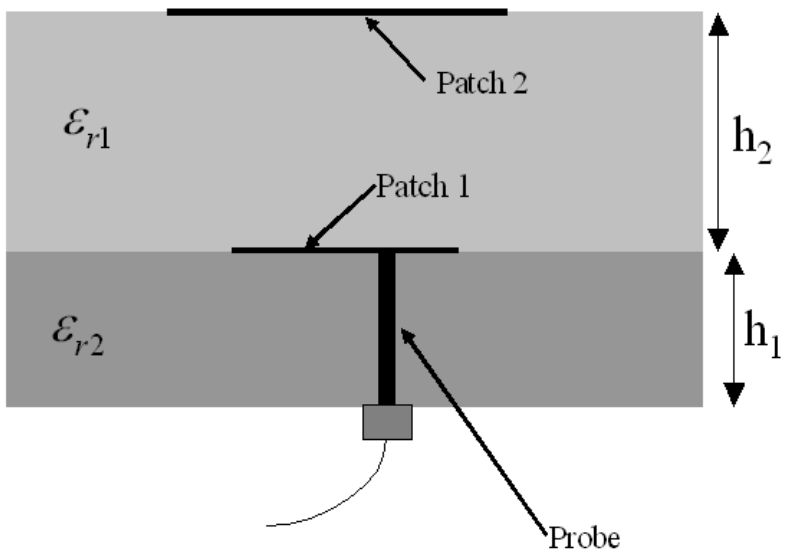
UMKC SCHOOL OF COMPUTING & ENGINEERING

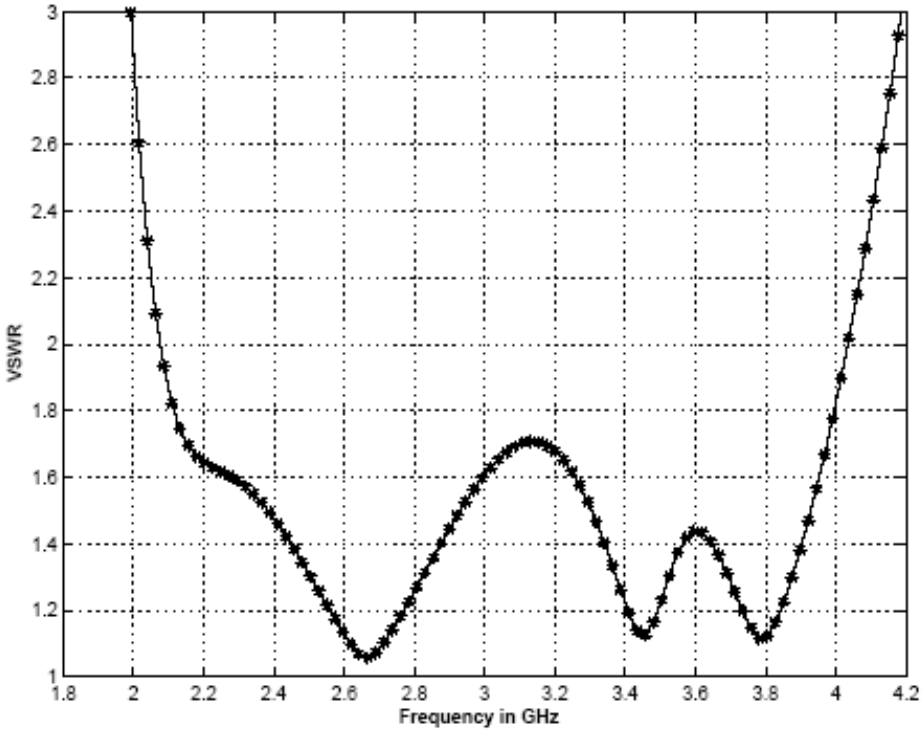
Bandwidth (%) = 200 *η

Ultrawideband: $0.25 \leq \eta \leq 1.0$

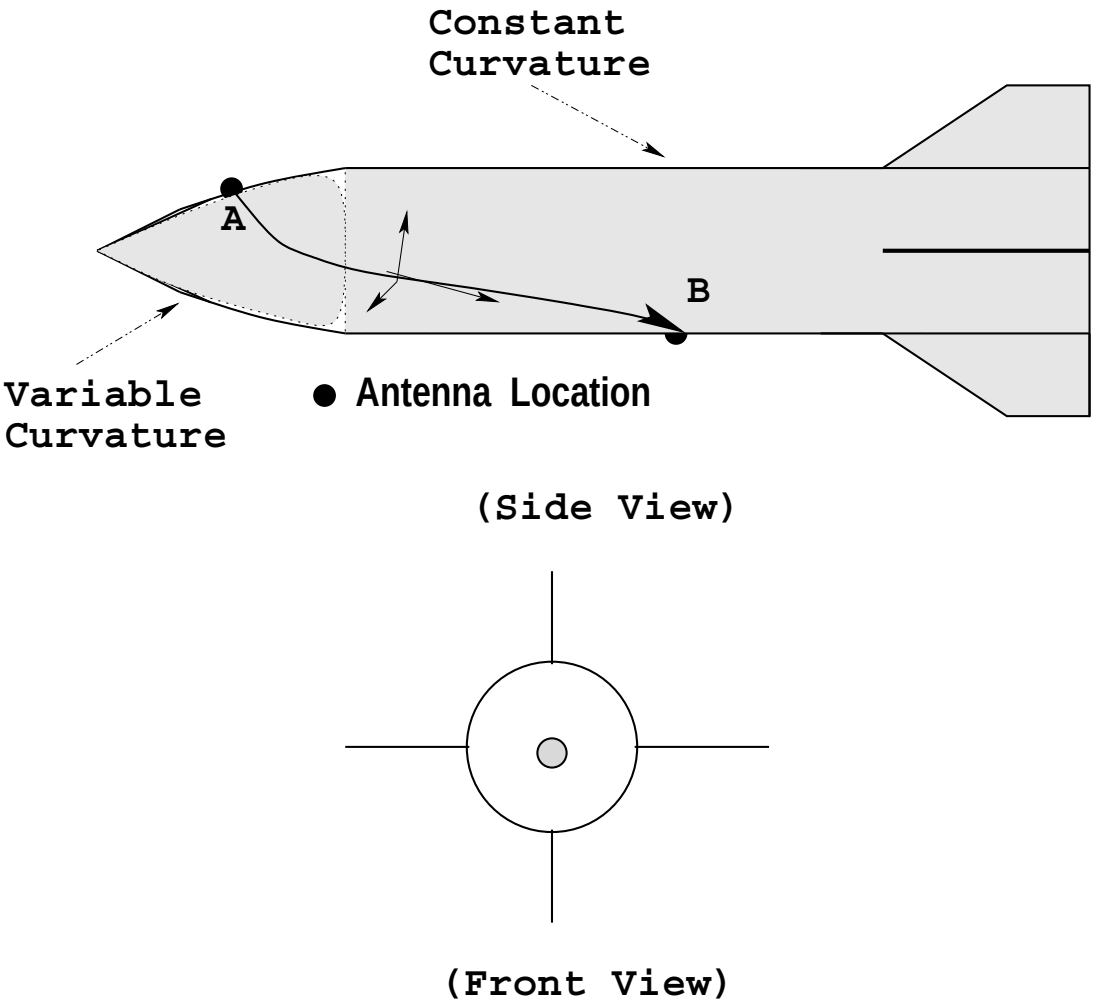
Wideband: $0.01 \leq \eta \leq 0.25$

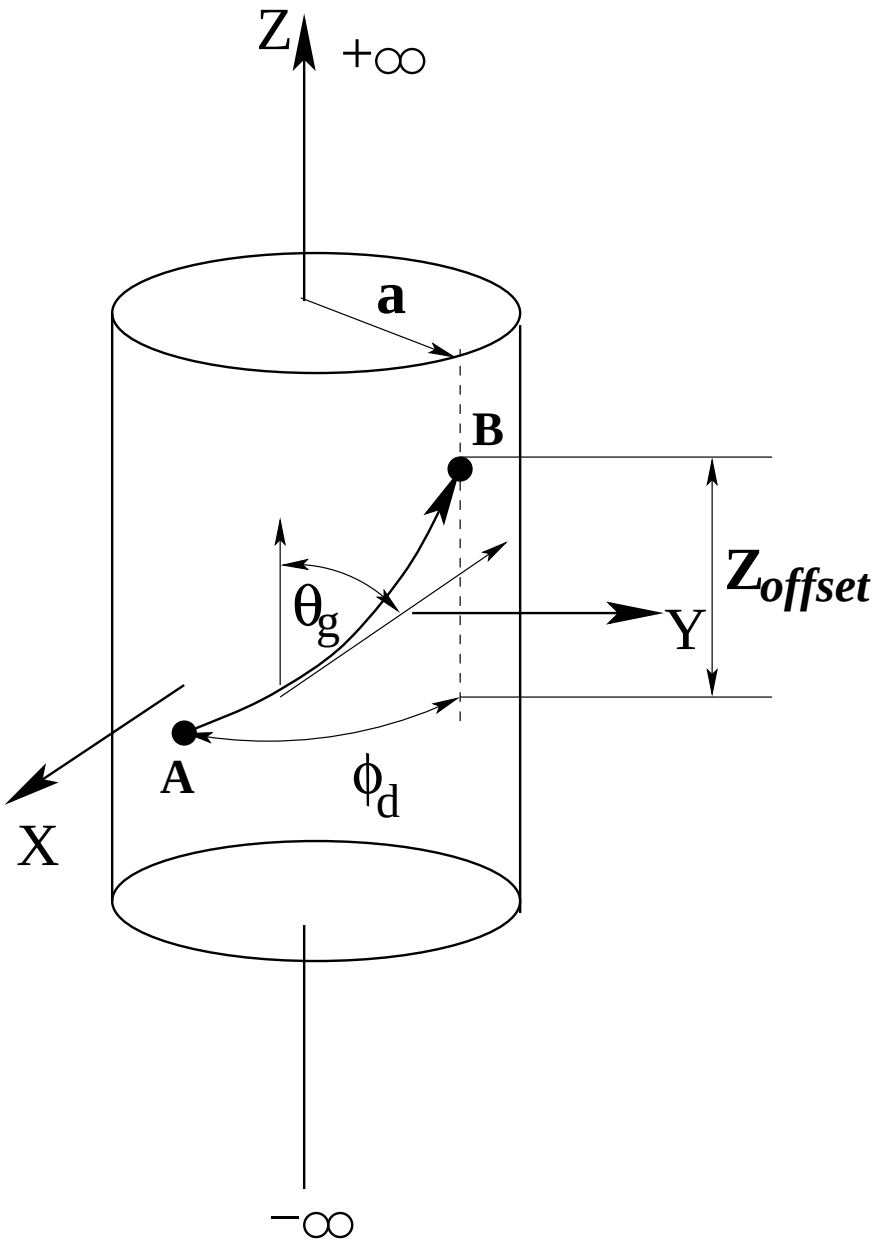
Example: Dual U-Slot



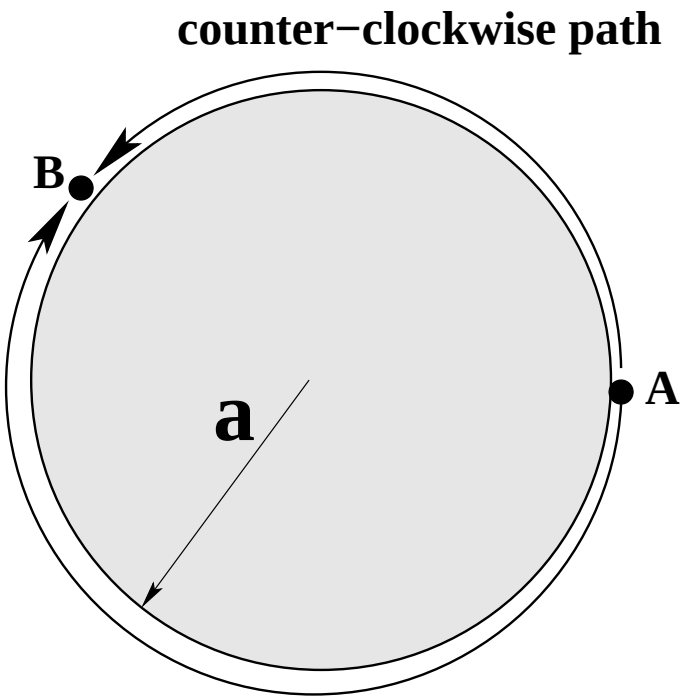


Raytheon MIM 104 Missile (PATRIOT)




Z
+∞
a
B
θg
Y
Zoffset
A
ϕd
X
−∞

(a)


counter−clockwise path
B
a
A
clockwise path

(b)

Subject/Topics

UMKC SCHOOL OF COMPUTING & ENGINEERING

- Channel Capacity, BER
- RF Propagation Path Loss
- Urban Environments

Purpose

UMKC SCHOOL OF COMPUTING & ENGINEERING

- Effects of Urban Topology
- Multipath and Scattering
- How to model ?

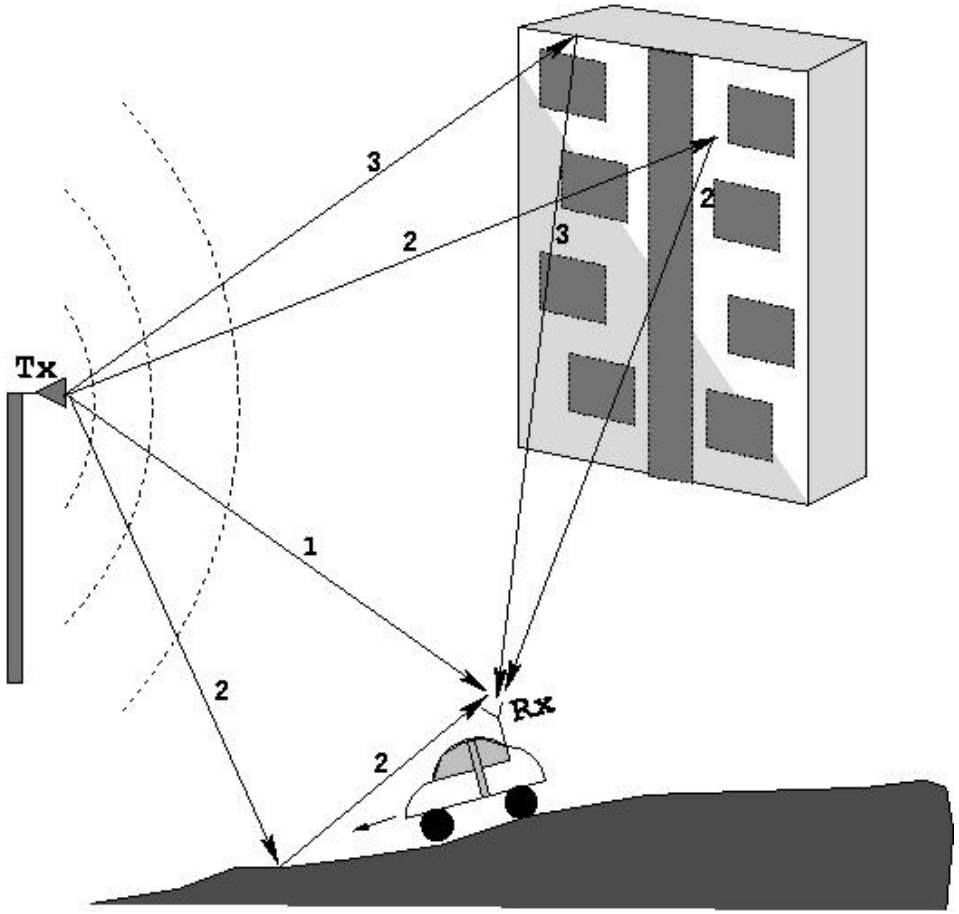
SCOPE

UMKC SCHOOL OF COMPUTING & ENGINEERING

- **Nature of specific Modeling Techniques – generality of the solutions**

- **Computational burden – multi-ray tracing in complex environments**

Electrically Large Problems



Channel Capacity

UMKC SCHOOL OF COMPUTING & ENGINEERING

$$C_{shannon} = B \log_2 \left(1 + \frac{P_S}{P_N} \right)$$

Important !!!

1. Channel Capacity is a REAL number

2. P_S and P_{max} MUST be REAL

3. Can apply only in Far-Field (real powers)

$$R_{ff} \geq \frac{2D^2}{\lambda}$$

Friis Formula (Reaction)

$$C = \frac{\left| I_R V_{oc} \right|^2}{16 P_{rr} P_{rt}}$$

V_{oc} via ***Ray*** Techniques

(Geometrical Theory of Diffraction: GTD)

Computational Algorithm

- **Total Ray Field & Received Power:**

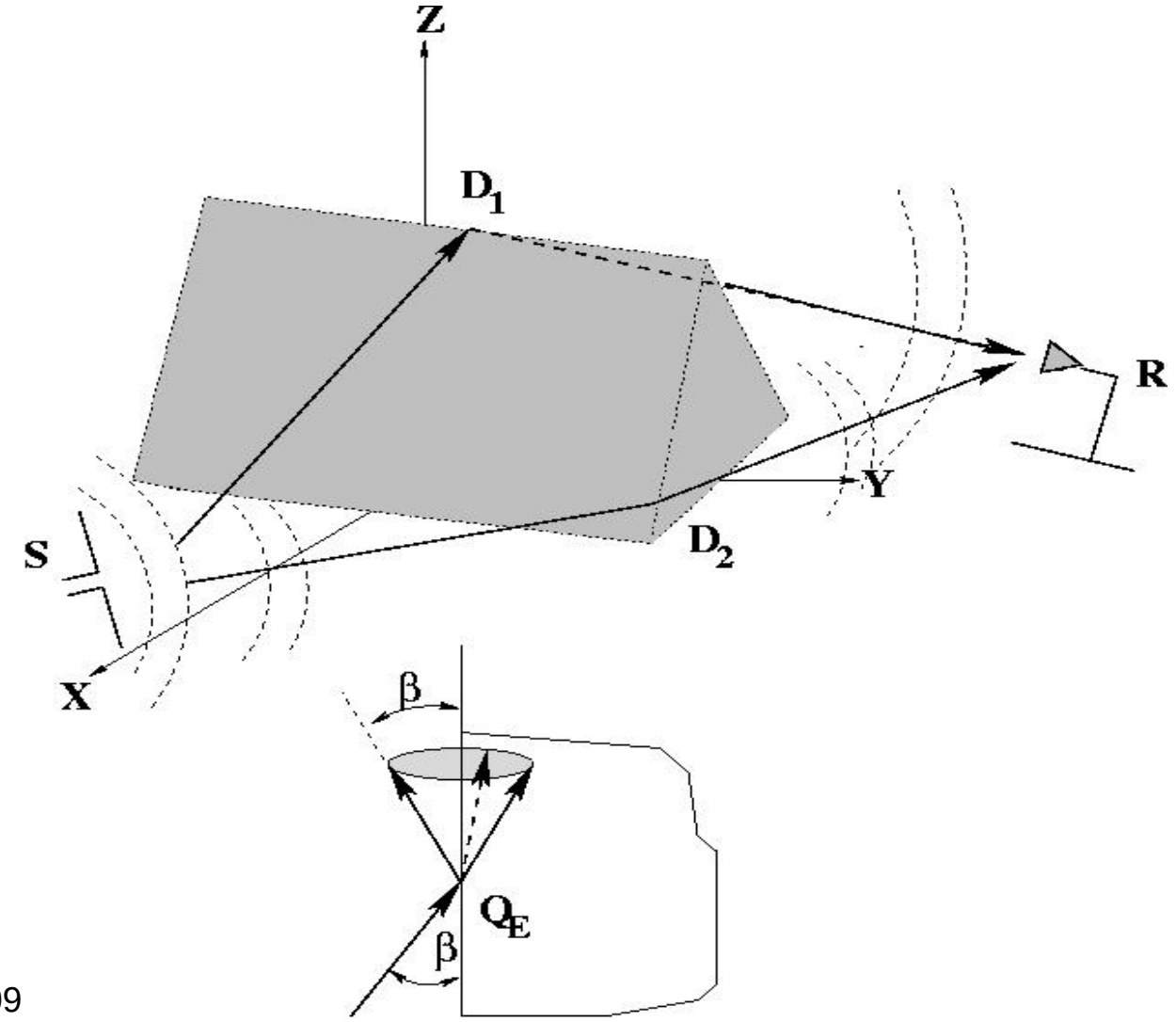
$$\vec{E}_T = \vec{E}_{inc} + \vec{E}_{ref} + \vec{E}_{diff} + \vec{E}_{trans} + \vec{E}_{ref/diff} + \vec{E}_{diff./ref.} + \ldots$$

$$\vec{E}_T = \sum_{p=1}^{N_{rays}} \vec{E}_p .$$

$$V_{oc} = \vec{h}_{eff} \bullet \vec{E}_T = \sum_{p=1}^{N_{rays}} \vec{h}_{eff} \bullet \vec{E}_p . = \sum_{p=1}^{N_{rays}} V_{oc}^{p}$$

$$P_S = C \times P_{in}$$

METHODOLOGY AND EXAMPLE FOR RAY TRACING IN COMPLEX ENVIRONMENTS



February 2, 2009

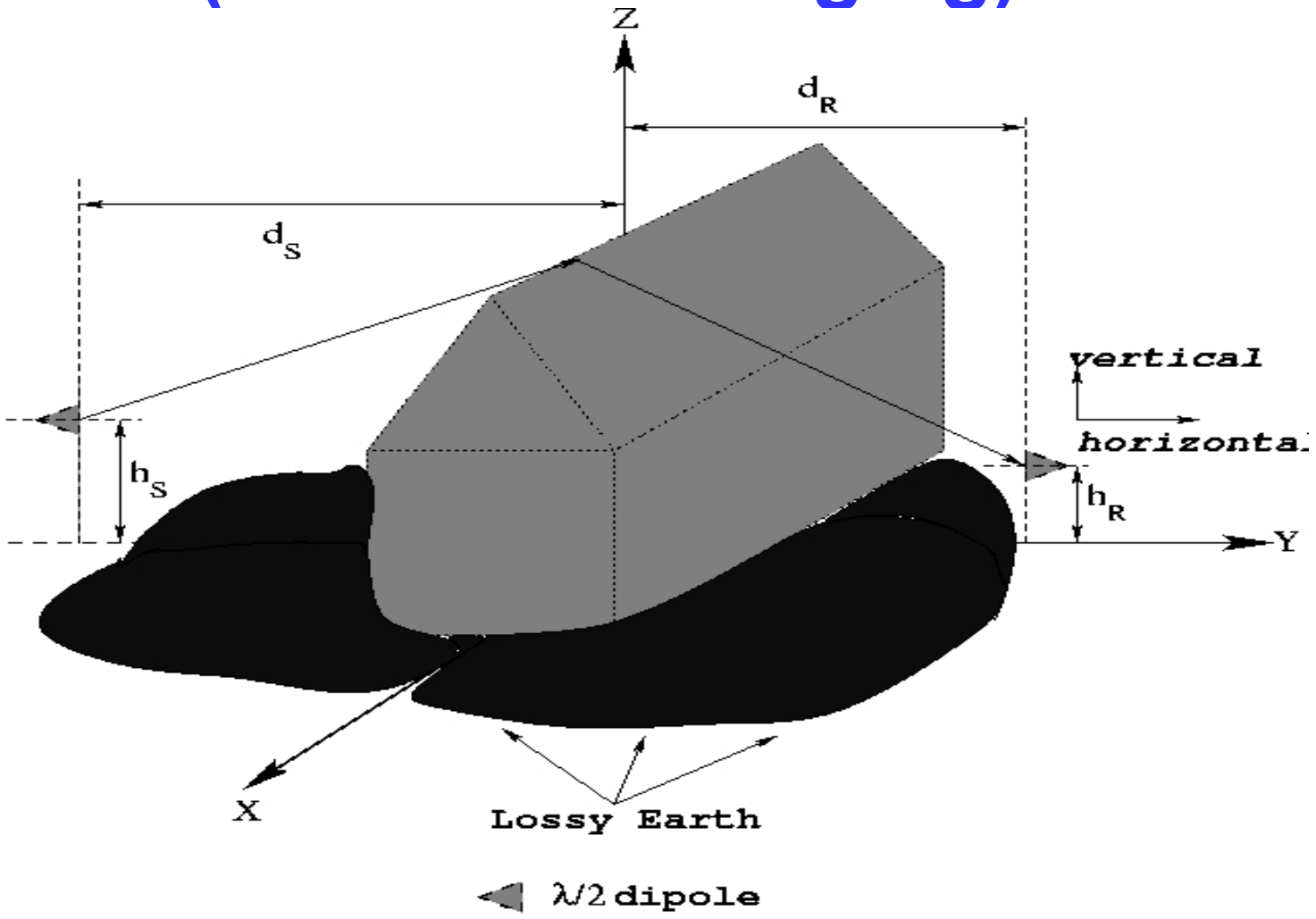
Computational Strategy

UMKC SCHOOL OF COMPUTING & ENGINEERING

- **Determine Ray Paths – Fermat Principle**

- **Superpose and Calculate the Fields on Ray Paths**
  (*GEOMETRICAL THEORY OF DIFFRACTION***: GTD)**

Typical Example (Thru' Wall Imaging)

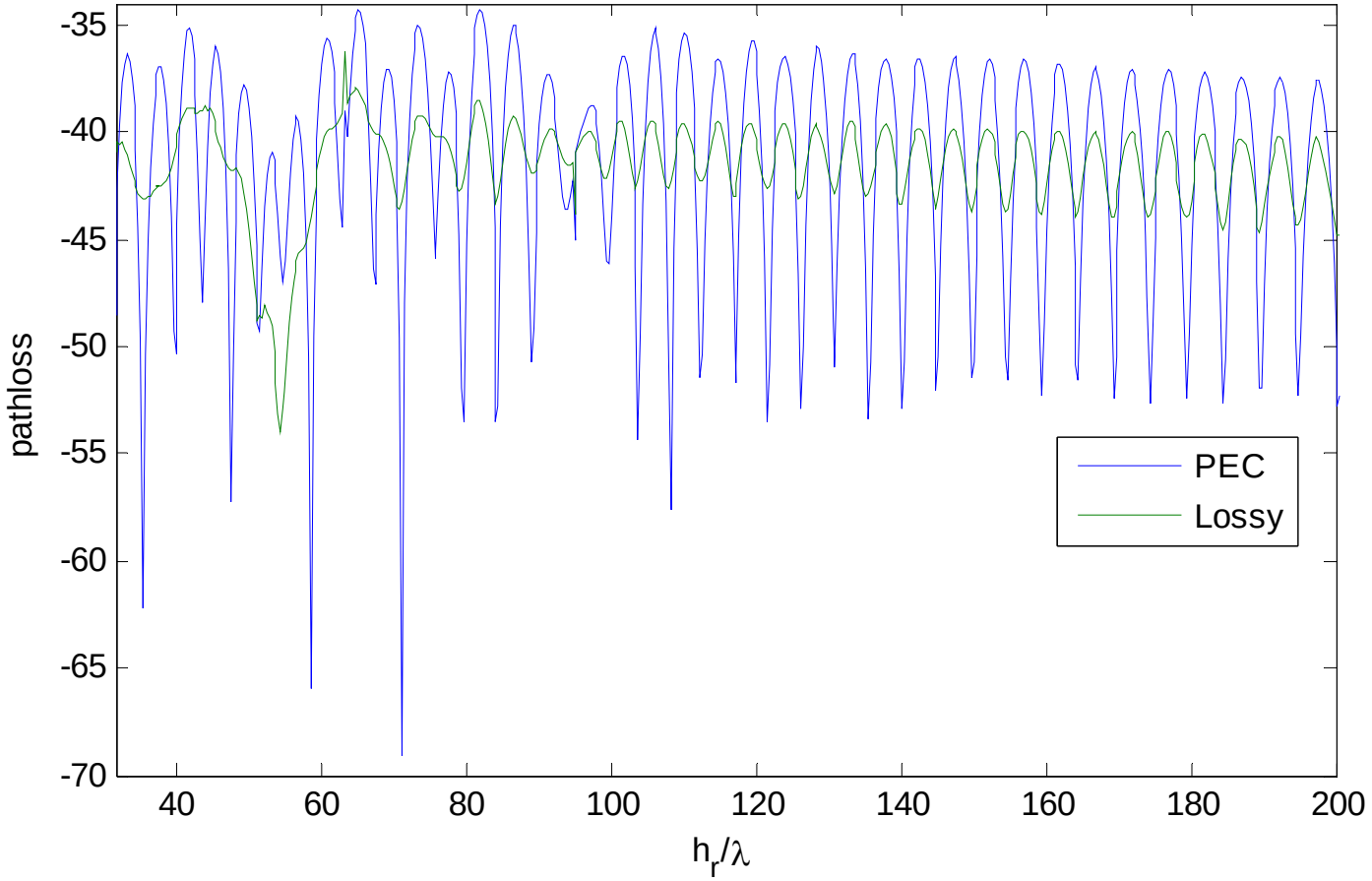


RF Propagation: NECBSC

- Brickwall Building with 10 cm thick bricks
- Half-wave dipoles
- Lossy and PEC ground

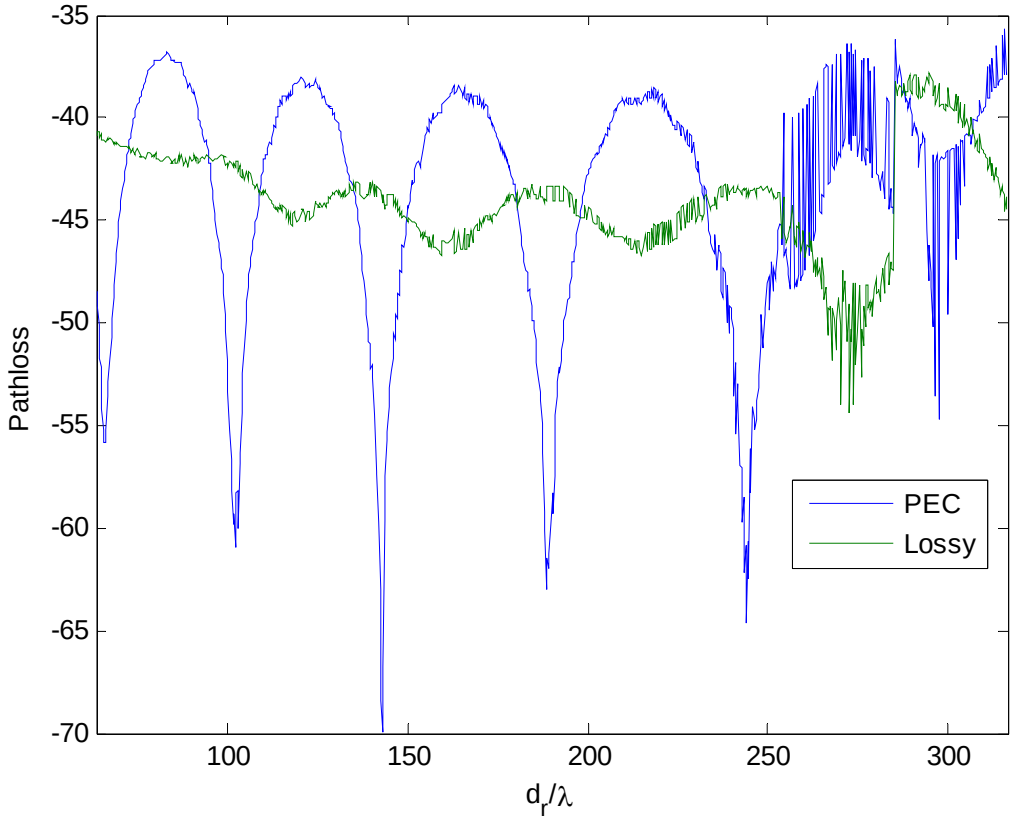
- F=950 MHz
- ε_r=4, tanδ=0.05 (brickwall)
- h_S=20 m ; h_R=10 m
- ε_r=15, tanδ=0.29368 (lossy ground)
- d_S=-120 m; d_R=20 m

RF Propagation Path Loss Results NECBSC Code



February 2, 2009

RF Propagation Path Loss Results NECBSC Code



February 2, 2009

CEM Research @ UMKC

SCHOOL OF COMPUTING & ENGINEERING

Research Topics

- Miniature, Ultrawideband antennas
- Conformal Arrays

Resources

- RF-CAD Softwares: FEKO, WIPL-D, IE3D, NECBSC, NEWAIR
- Graduate Students

Summary

- Sensors - Effects of Tactical Platforms
- RF Stealth (LPI/LOT) – scattering
- Thru' Wall Imaging – RF Propagation

REFERENCES

1. R. Vaughan and J. B. Andersen, ***Channels, Propagation and Antennas for Mobile Communications.*** **(ISBN: 0-85296-084-0)**

2. N. Blaunstein and J. B. Andersen, ***Multipath Phenomena in Cellular Networks.*** **(ISBN: 1-58053-185-7)**

3. H. L. Bertoni, ***Radio Propagation for Modern Wireless Systems.*** **(ISBN: 0-13-023673-7)**

REFERENCES (contd.)

4. K. Fujimoto (ed.), ***Mobile Antenna Systems Handbook***. **ISBN: 978-1596931268**

5. M. I. Skolnik (ed.), ***Radar Handbook***. **ISBN: 978-0071485470**

6. L. Josefsson & P. Persson, ***Conformal Array Antenna Theory & Design***. **ISBN: 978-0471465843**

Recent Publications

1. R. Hofer, D. E. Oliver and D. Chatterjee, *"Analysis of U-Slot Microstrip Phased Array Radiator Elements on Electrically Thick Substrates,"* Proc. IEEE Ant. Prop. Symp.,Honolulu, HI, June 2007. (published)

2. S. D. Walker and D. Chatterjee, *"Surface Curvature Effects on Element Characteristics in Large, Finite, Conformal Cylindrical Dipole Arrays,"* Proc. IEEE Ant. Prop. Symp.,San Diego, July 2008. (published)

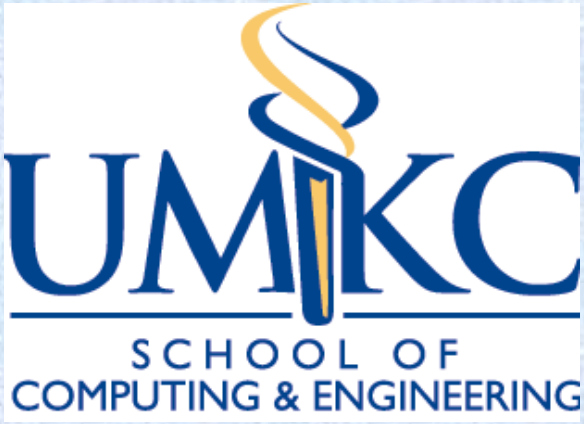
3. D. Ketharnath, S. D. Walker and D. Chatterjee, *"Full-Wave Analysis of PEC- Embedded U-Slot Microstrip Patch Elements,"* ANTEM 2009, Banff, Calgary, Feb. 2009. (accepted).

4. S. D. Walker and D. Chatterjee, *"Study of Exact and High Frequency Code Solvers for Applications to a Conformal Cylindrical Dipole Array,"* ACES Conference, Monterey, CA, March 2009. (accepted).

5. S. D. Walker and D. Chatterjee, *"Creeping Wave Radiation Analysis from an Infinite Conformal Cylindrical Dipole Array,"* Proc. IEEE Ant. Prop. Symp.,Clemson, SC, June 2009. *(submitted, under review)*

6. D. Chatterjee, *"An Improved Analysis for Design of Single-Layer, Probe-Fed, U-Slot Microstrip Patch Antenna,"* Proc. IEEE Ant. Prop. Symp.,Clemson, SC, June 2009. *(submitted, under review)*

February 2, 2009



Thank You !

February 2, 2009