The Mythologies of Wireless Communication

Tapan K. Sarkar

What is an Antenna ?

A device whose primary purpose is to *radiate* or *receive* electromagnetic energy

What is Radiation ?

Far Field (Fraunhofer region>$2L^2/\lambda$)

- the fields are transverse
- the shape of the field pattern is independent of the distance

What is the Near- Field (Fresnel region) ?

★The near field is in the region $D < 2\,L^2/\lambda$

★ Near Field: power is complex (need both *E* & *H*)

★Far Field – Real Power: need either *E* or *H*

PROPERTIES OF NEAR FIELD

For a Dipole →

$$E_z = -\,j30I_m[\exp(-\,jkR_1)/R_1 + \exp(-\,jkR_2)/R_2 - 2\cos(kH)\exp(-jk\,\rho)/\rho]$$

The near field can never be zero for a dipole!!!!

Only the far field has pattern nulls!!

What is the Far- Field?

$D > 2\,L^2/\lambda$: L – Antenna region

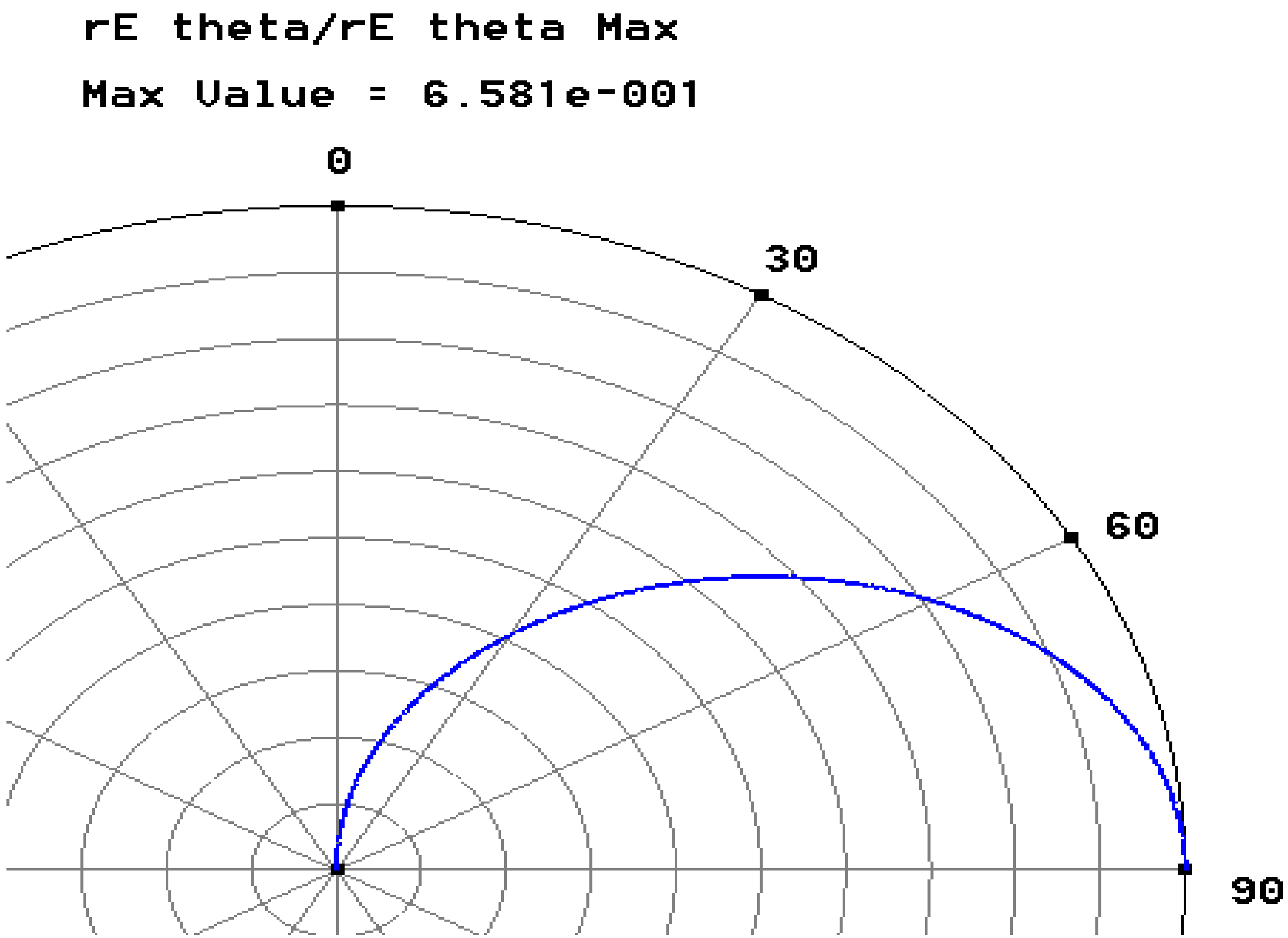
What is the far field of a half wave dipole for λ =0.3m (1GHz) ?

$\rightarrow 2\times 0,15 \times 0.15/0.3=0.15$m

What is the far field when the half wave dipole is 20 m above an infinite ground plane at λ =1m?

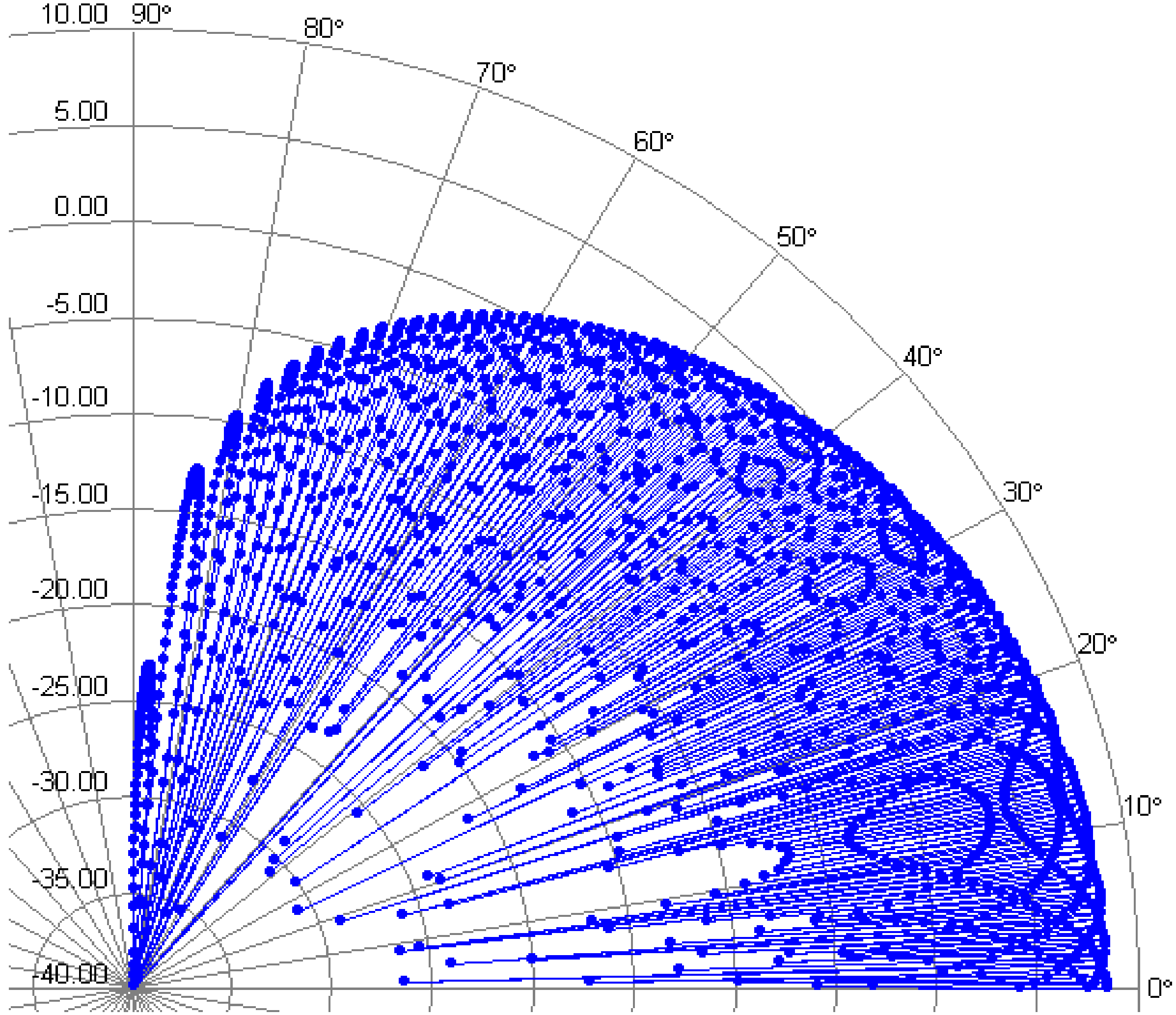
Equivalently if the dipole is on the top of a 20 m tower above a perfect ground plane?

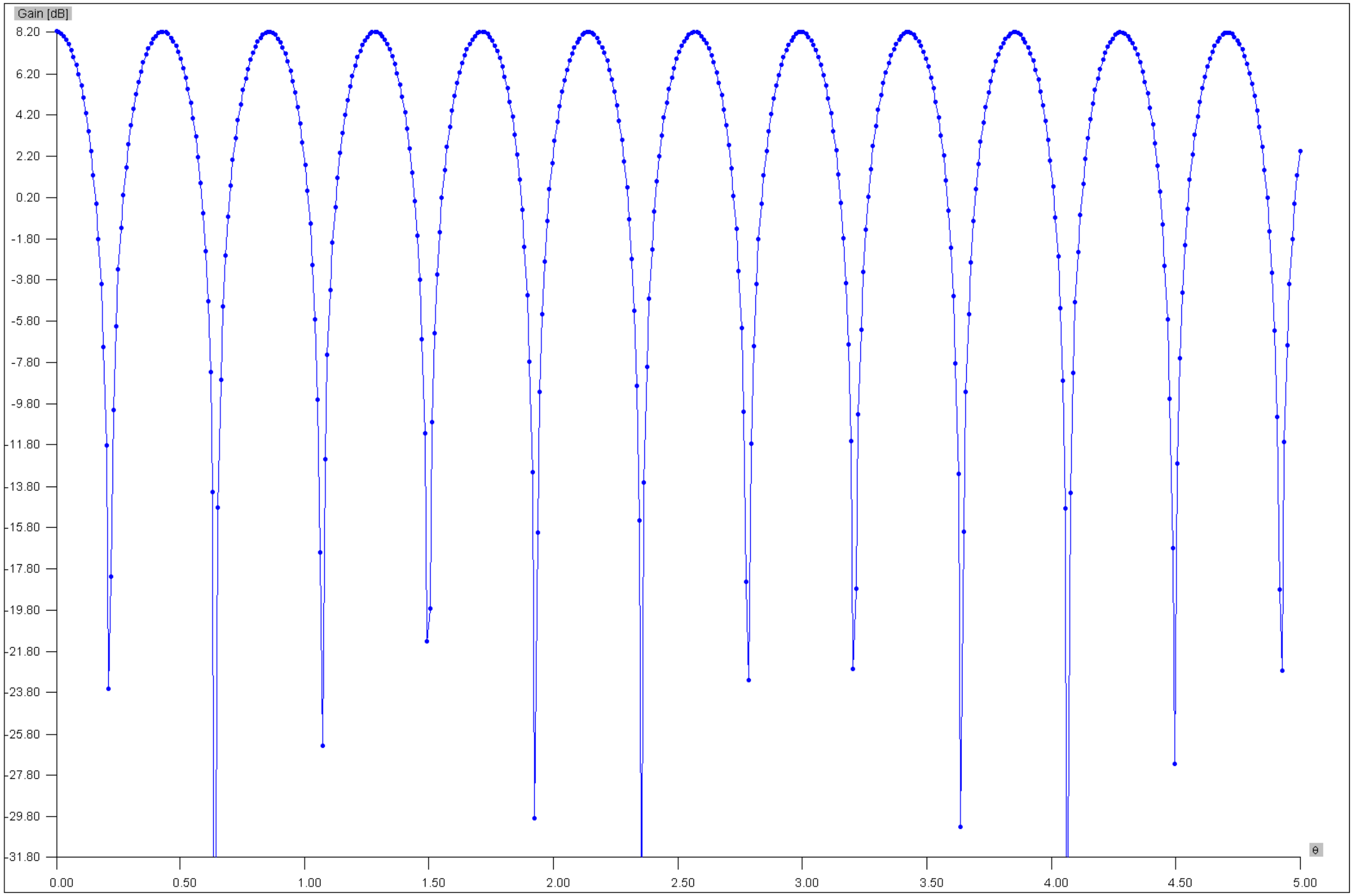
$\rightarrow 2\times 40\times 40/0.3=10,666 \approx 10.6$km



The radiation pattern of a half wave dipole in free space (only one fourth shown)

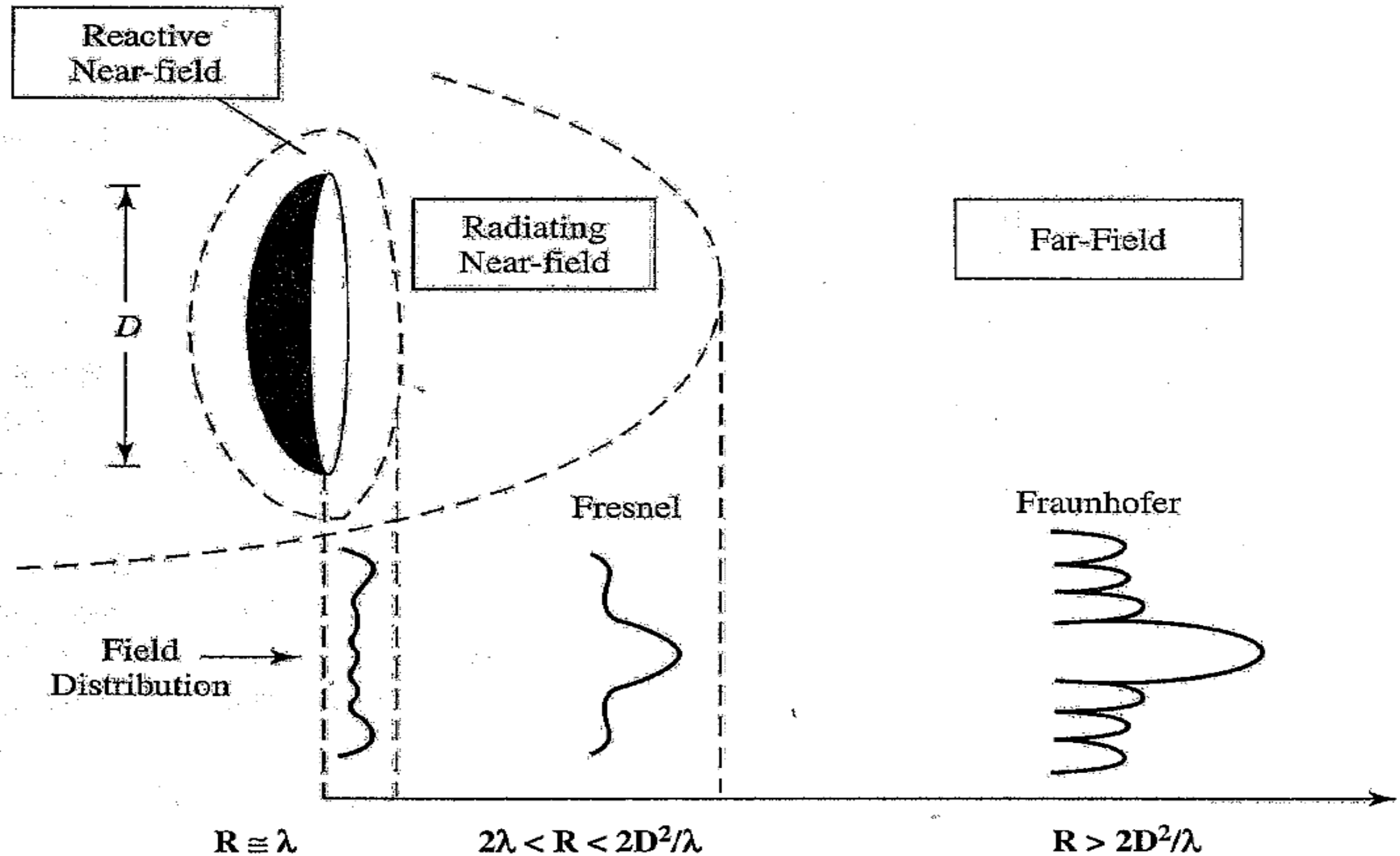
[redacted]


10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
-40.00
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°

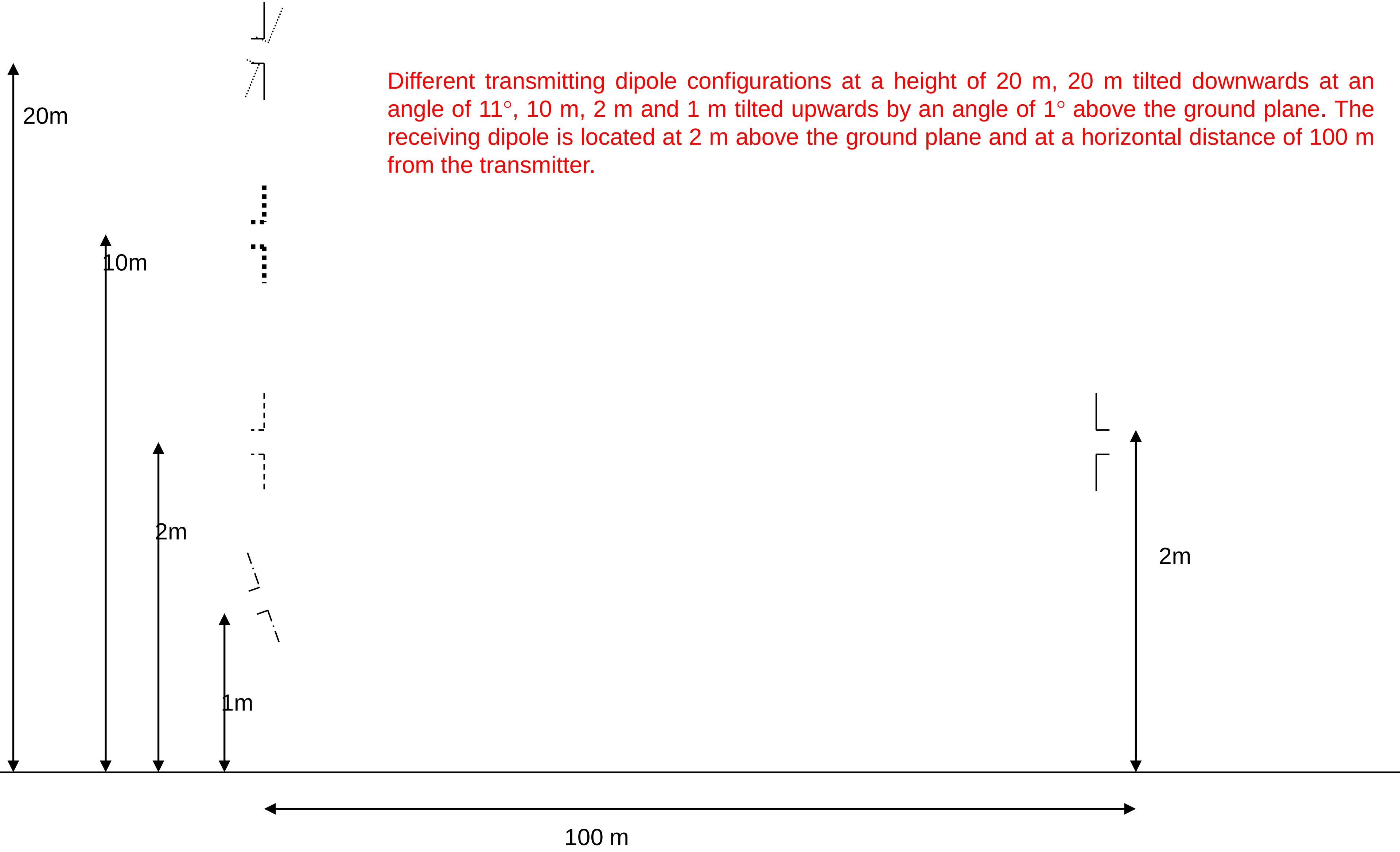


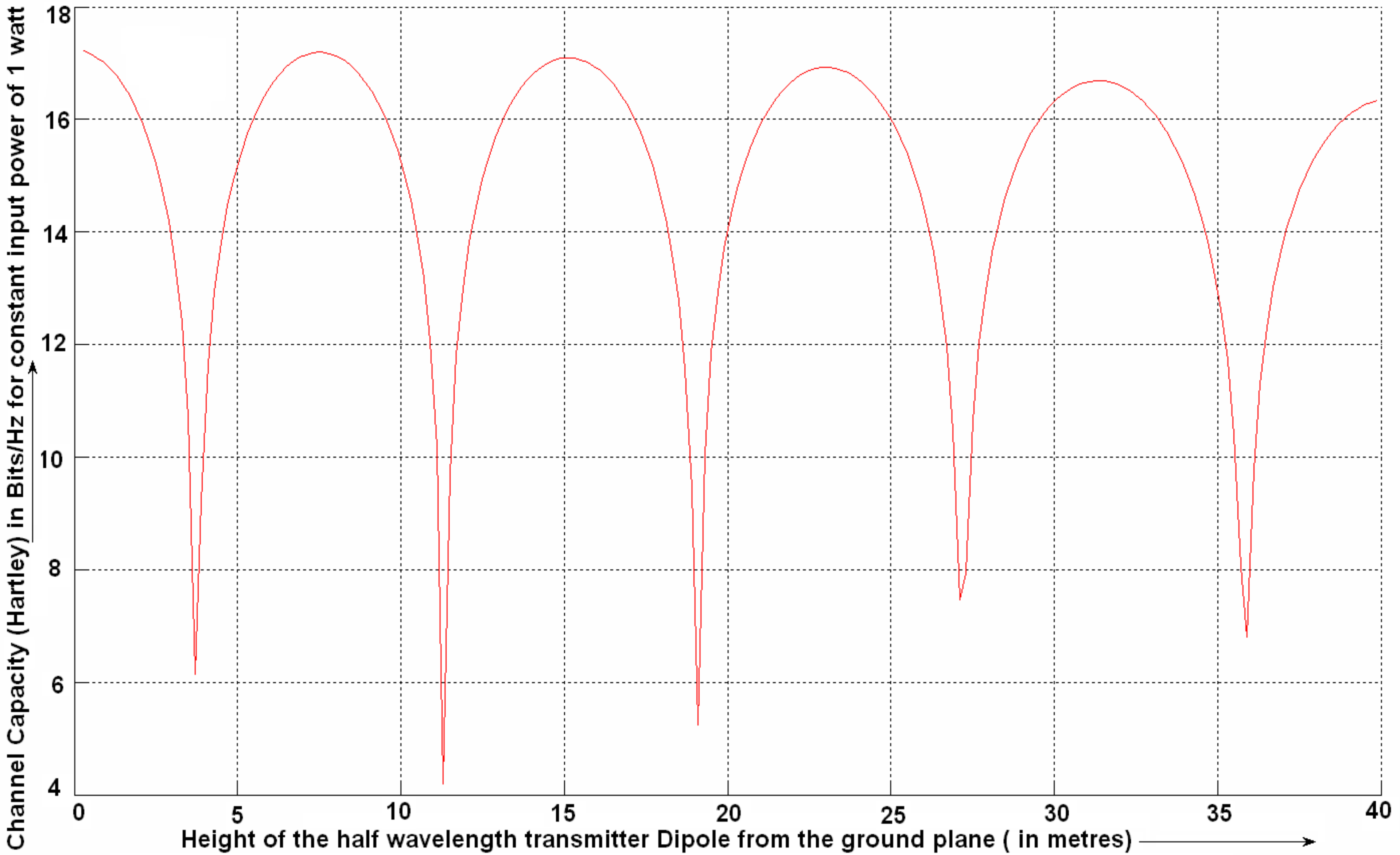
Antenna Pattern from 0 to 5 degree elevation

Field Regions Around An Antenna

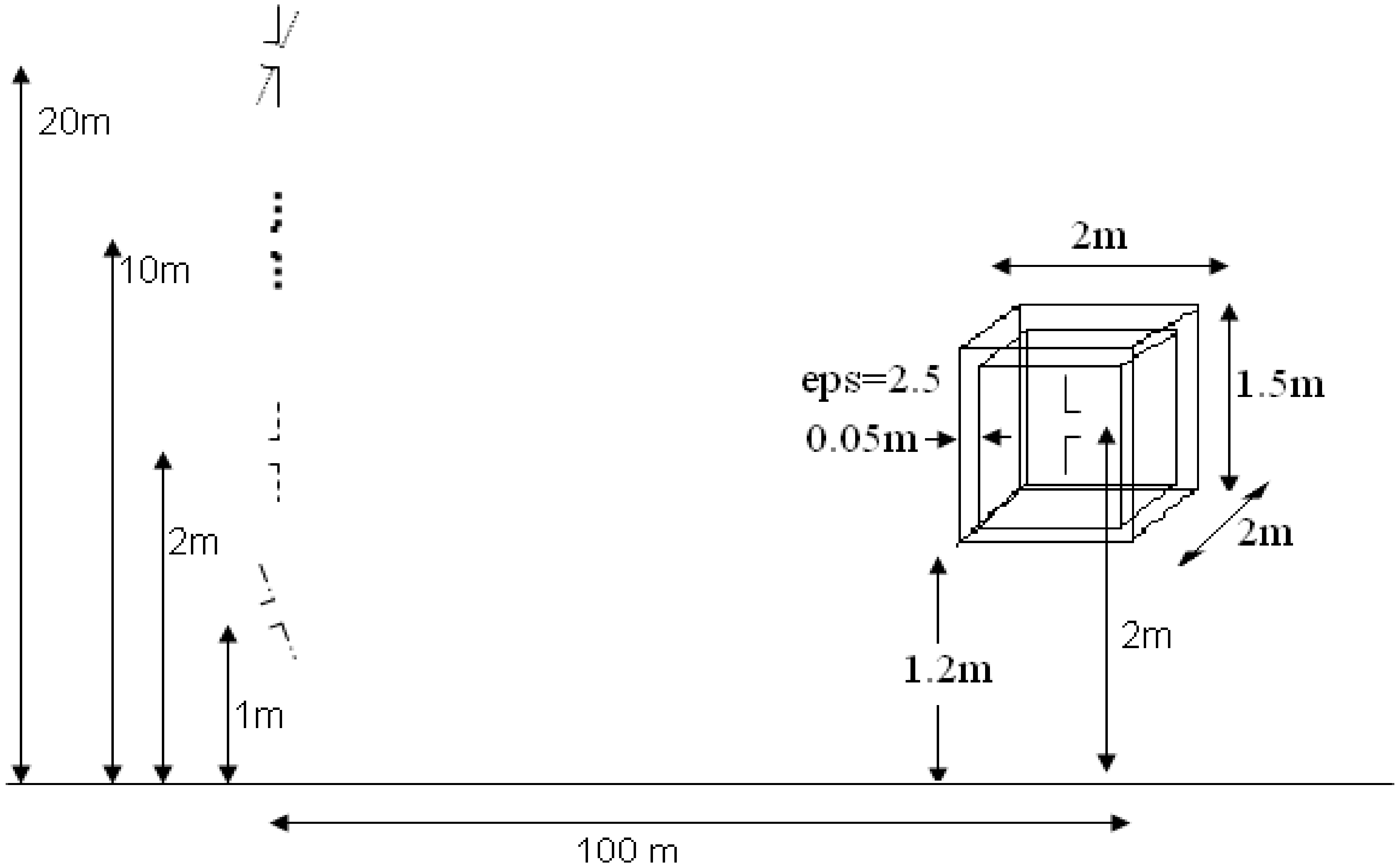


Different transmitting dipole configurations at a height of 20 m, 20 m tilted downwards at an angle of 11°, 10 m, 2 m and 1 m tilted upwards by an angle of 1° above the ground plane. The receiving dipole is located at 2 m above the ground plane and at a horizontal distance of 100 m from the transmitter.

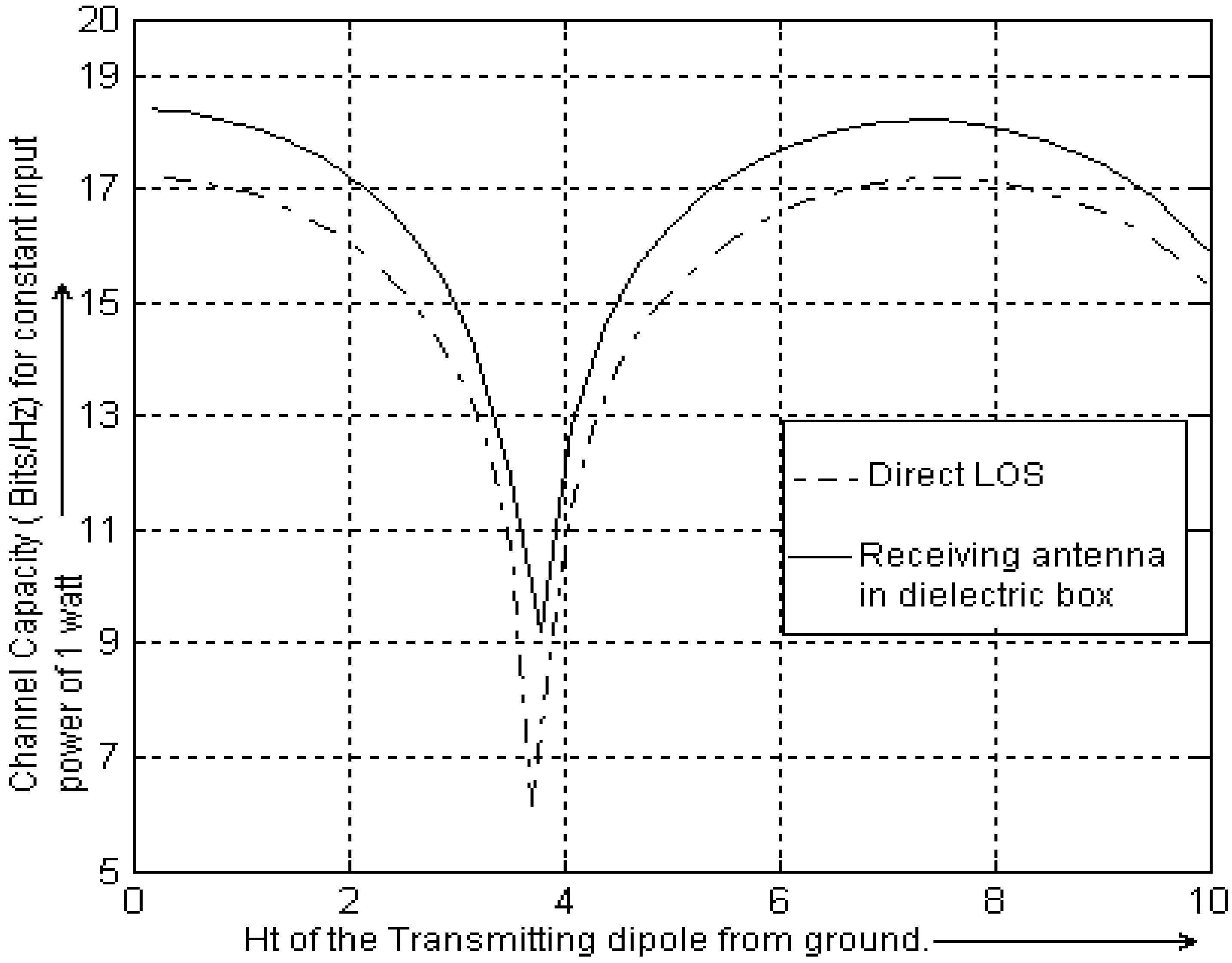




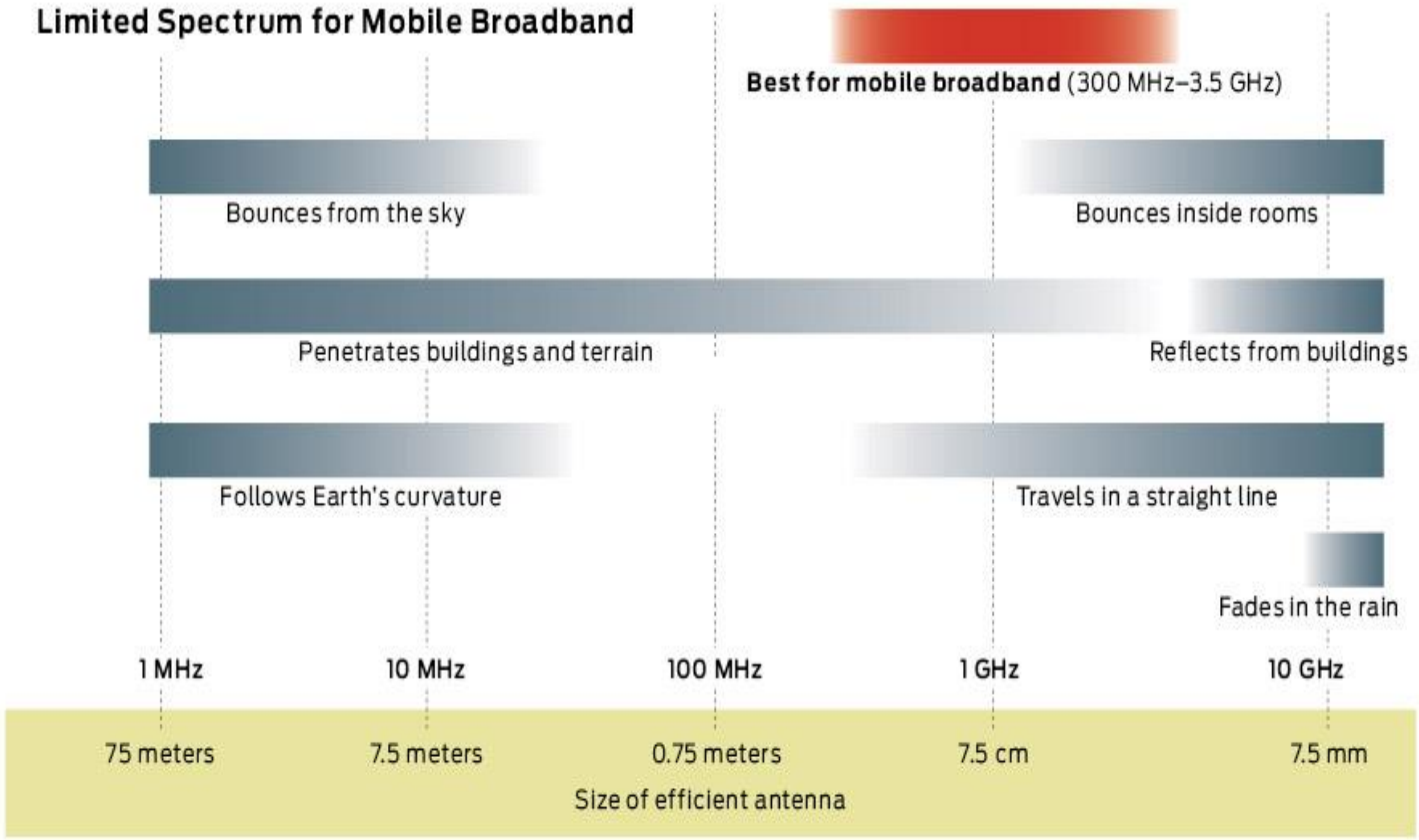
Plot of the variation of the channel capacity as a function of the height of the transmitting antenna above a perfectly conducting earth, for a fixed height of 2 m for the receiving antenna.



Different transmitting dipole configurations at a height of 20 m, 20 m tilted downwards at an angle of 11°, 10 m, 2 m and 1 m tilted upwards by an angle of 1° above the ground plane. The receiving dipole is located at 2 m above the ground plane and at a horizontal distance of 100 m from the transmitter. The receiving dipole is enclosed by a dielectric shell.

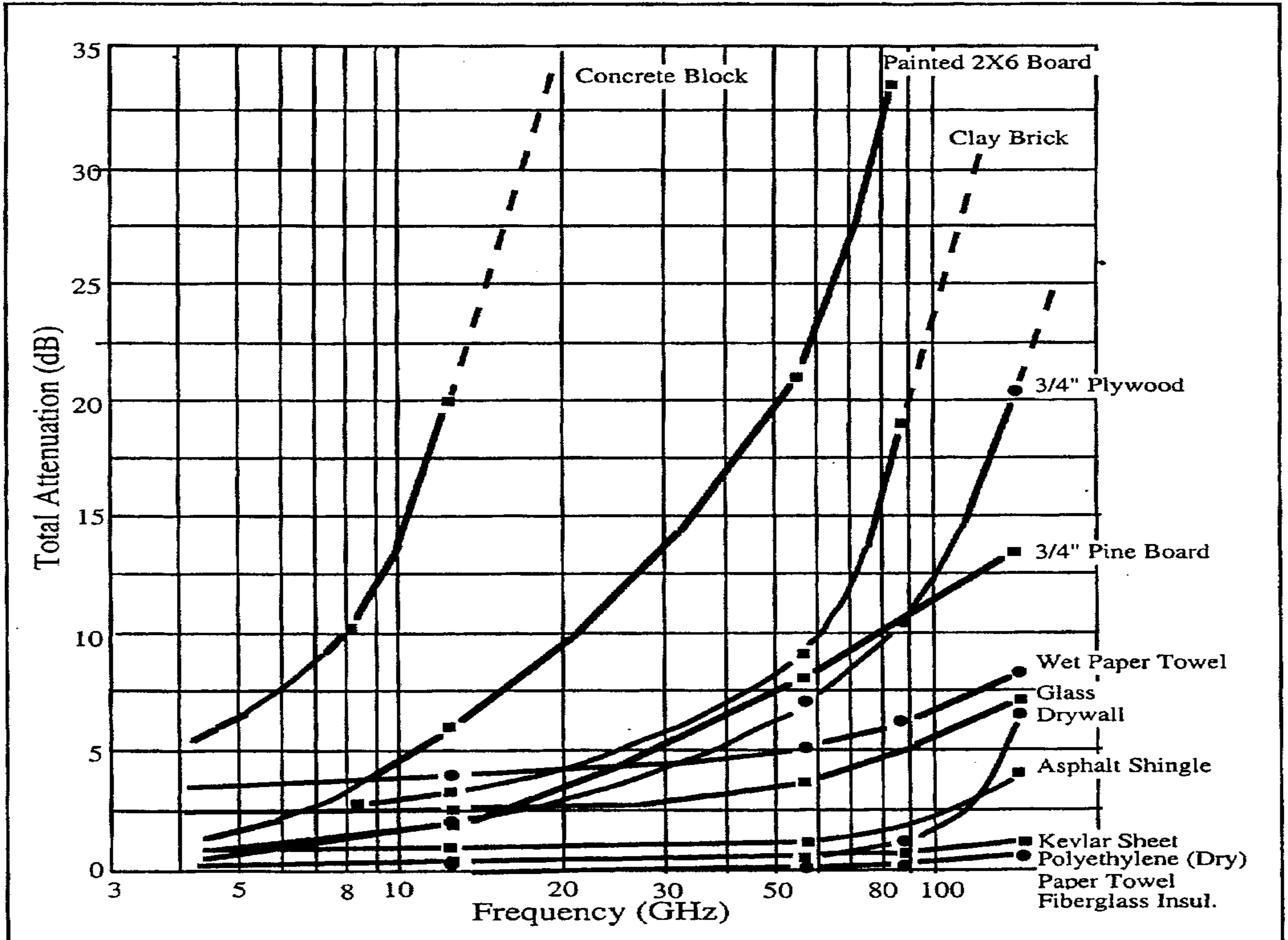


Comparison of the plots of the variation of the channel capacity as a function of the height of the transmitting antenna above a perfectly conducting earth, for a fixed height of 2 m for the receiving antenna. LOS stands for line-of-sight.

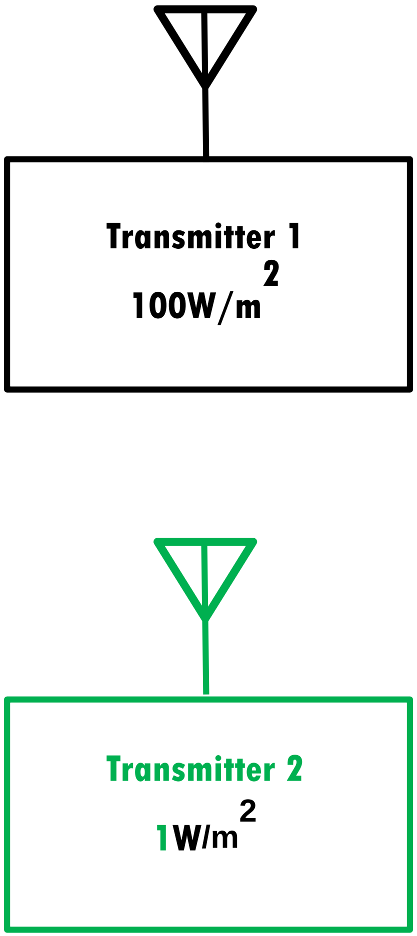


OPPORTUNITY WINDOW: The best frequencies for mobile broadband are high enough that the antenna can be made conveniently compact, yet not so high that signals will fail to penetrate buildings. This leaves a relatively narrow range of frequencies available for use [red band].

IEEE SPECTRUM Magazine, October 2010, pp. 29

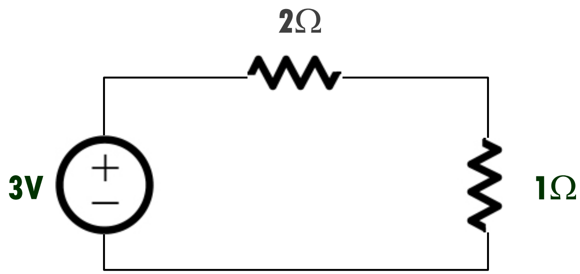


Total Attenuation (dB)
35
30
25
20
15
10
5
0
3
5
8
10
20
30
50
80
100
Frequency (GHz)
Concrete Block
Painted 2X6 Board
Clay Brick
3/4" Plywood
3/4" Pine Board
Wet Paper Towel
Glass
Drywall
Asphalt Shingle
Kevlar Sheet
Polyethylene (Dry)
Paper Towel
Fiberglass Insul.



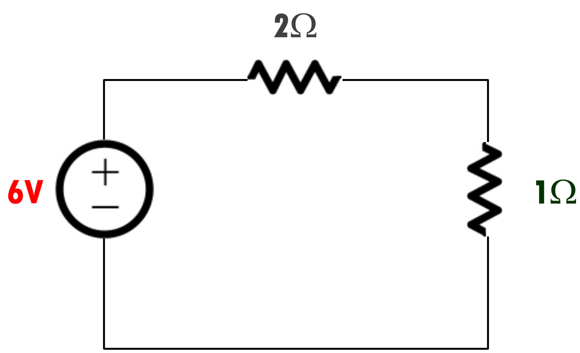
There will be constructive and destructive interference. So what will be the variation of power?

$$(100 \pm 1)\ \mathrm{W/m^2}\ ??$$



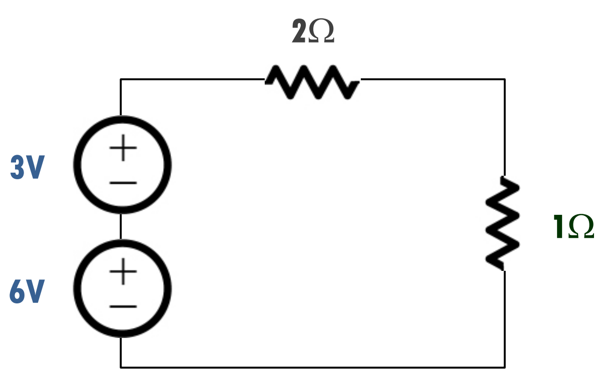
Power Dissipated in 1Ω

$= I^2 R = 1$



Power Dissipated in 1Ω

$= I^2 R = 2^2 \cdot 1 = 4$

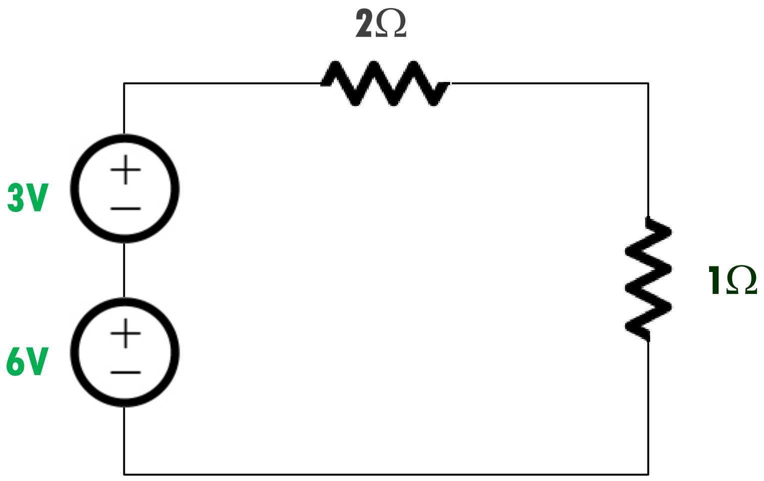


Applied Superposition

Power Dissipated in 1Ω

$= I^2 R = 3^2 \cdot 1 = 9$

Power Superposition does not work in electrical engineering!



Applied Superposition

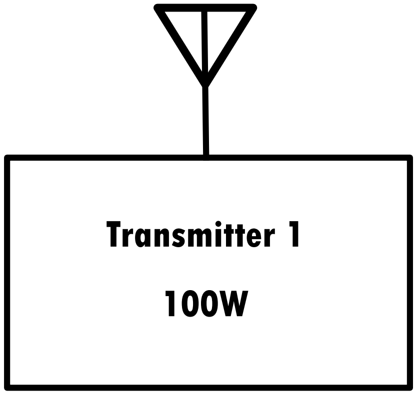
Power Dissipated in 1Ω

$= I^2 R = 3^2 \cdot 1 = 9$

Power Superposition does not work in electrical engineering! Only Superposition of the VOLTAGES and the CURRENTS are allowed!!

In electrical engineering, unlike mechanical engineering, it is vector in nature!

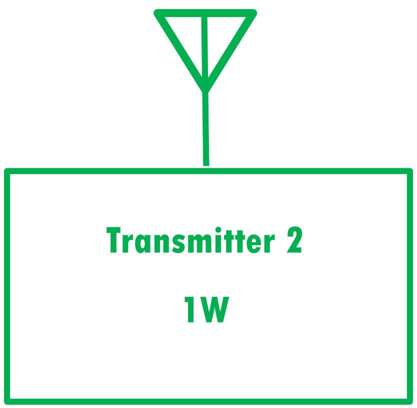
ONLY VOLTAGES AND CURRENTS CAN BE SUPERIMPOSED AND NOT POWER! THAT IS WHY WE CALL EE FIELD THEORY. The field quantities expressed by the electric and magnetic fields are related to voltage and current, respectively. The fields add up not power.



Field

$$100 = \frac{E_1^2}{2\eta}$$

$$E_1 = 10\sqrt{2\eta}$$



$$1 = \frac{E_2^2}{2\eta}$$

$$E_2 = 1\sqrt{2\eta}$$

Interference occur between the fields *E1* and *E2* . So the variation in field is

$$\sqrt{2\eta} \cdot (10 \pm 1)$$

Therefore the variation in the power due to interference is

121W ↔ 81W !!

Shannon's Capacity for a Single Channel

$$C = B\log_2\left(1 + P/N\right)$$

Extension of Shannon Channel Capacity to multichannel system (like MIMO)

$$C_M = M \cdot B\log_2\left(1 + \frac{P}{M \cdot N}\right)$$

This equation is often used to claim that a MIMO is better than a SISO! Does it make sense?

Power superposition is not applicable in electrical engineering!!!

Dennis Gabor wrote:[1952, IEEE Trans on Information Theory, First Issue]

The wireless communication systems are due to the generation, reception and transmission of electro-magnetic signals. Therefore all wireless systems are subject to the general laws of radiation.

Communication theory has up to now been developed mainly along mathematical lines, taking for granted the physical significance of the quantities which are fundamental in its formalism.

But communication is the transmission of physical effects from one system to another. Hence communication theory should be considered as a branch of physics.

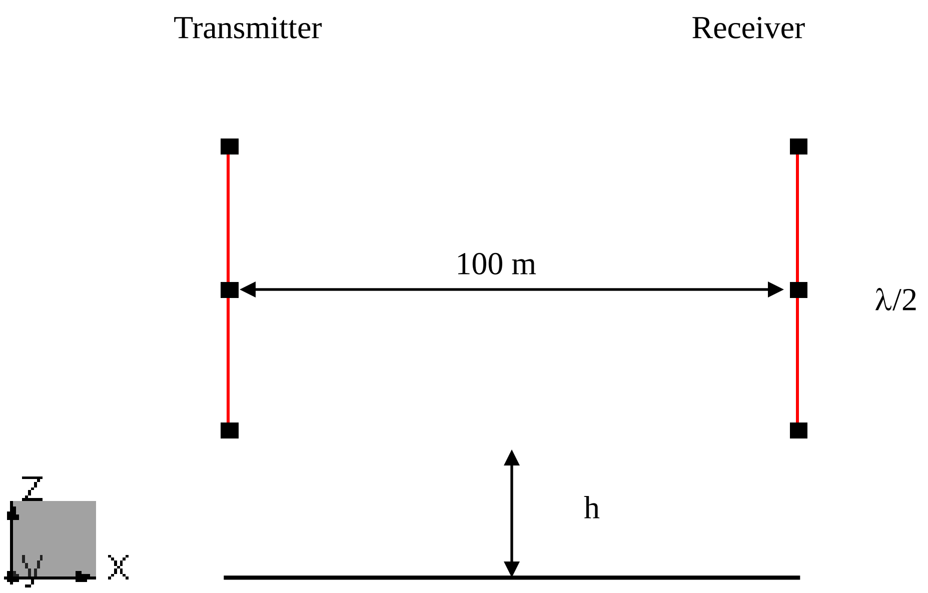
Channel Capacity

Shannon Formula

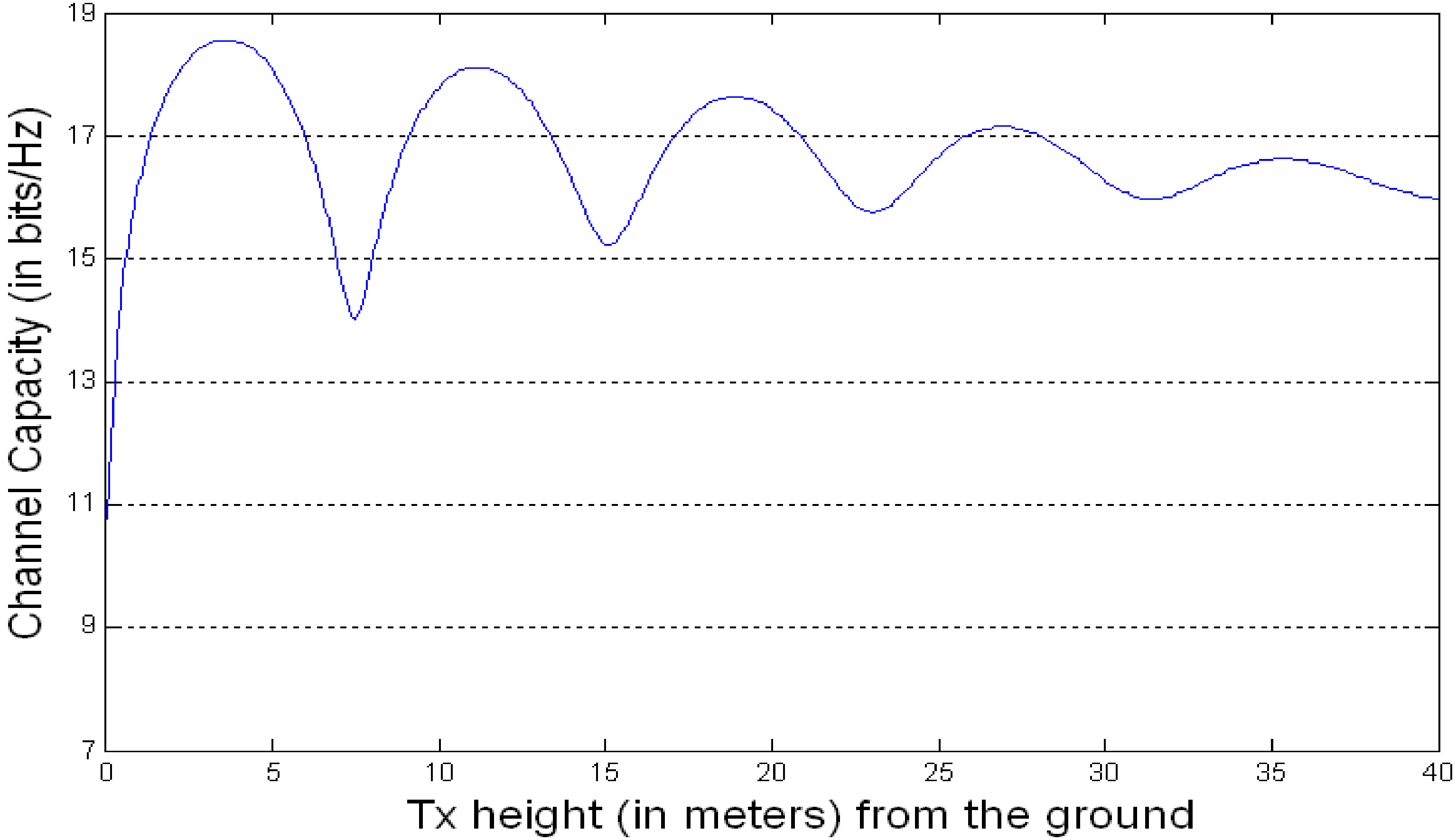
$$C_S = B\log_2\left(1+\frac{P_S}{P_N}\right)$$

- **Use signal power and noise power**
- **Does not represent near-field behavior of the signals**
- **Under the constraint that the average radiated power is constant**

freq= 1GHz
λ = 30 cm
Radius of wire=0.0001λ



Variation of Channel Capacity with the height of the Tx antenna



Load on the received antenna (Rx Ant HT =2M)

Tx Ant Ht	Case 1: 50 Ω	Case 2: Matched
Free Space	50	97.6 – j 45.4
h = 15 cm	50	97.6 – j 45.4
h = 1 m	50	97.6 – j 45.4
h= 10 m	50	97.6 – j 45.4
h= 20 m	50	97.6 – j 45.4

Magnitude of the Received Power

Capacity defined by **log2(Ratio)**

$$C_0^U = C_0^M - 0.28B$$

	Case 1 [μW]		Case 2 [μW]	
Free space	**0.064**	**$C_0^U = C_0^M - 0.28B$**	**0.078**	**C_0^M**

For S/N ≈ 128 or 21.2 dB

$\log_2 (S/N) \approx \log_2 (2^7) \approx$ **7**

Compare 7B to 0.28B for the capacity. CONCLUSION:

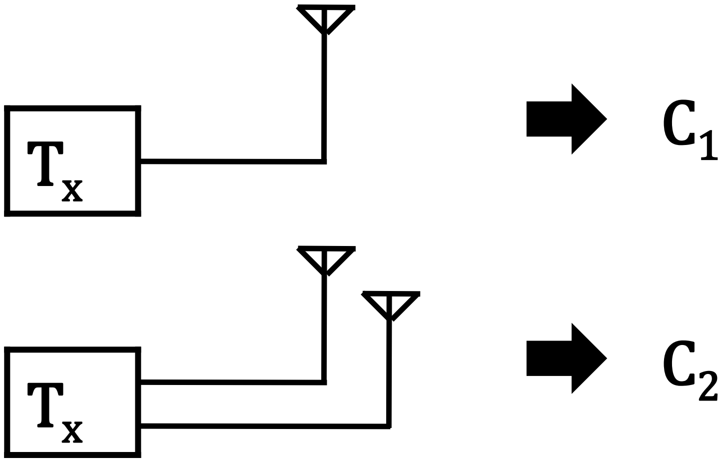
ELECTROMAGNETIC PRINCIPLES of MATCHING DEVICES THEREFORE ARE IRRELEVANT!!!

MIMO:
A
STAISTICAL
ABERRATION ?!?

METHODOLOGIES

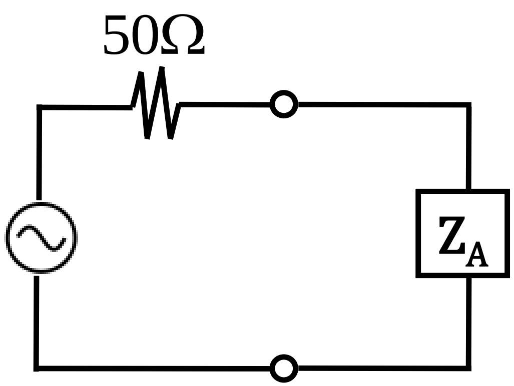
- Using a Simplistic Thinking
- Using a Signal Processing Terminology
- Using Maxwell-Poynting Theory

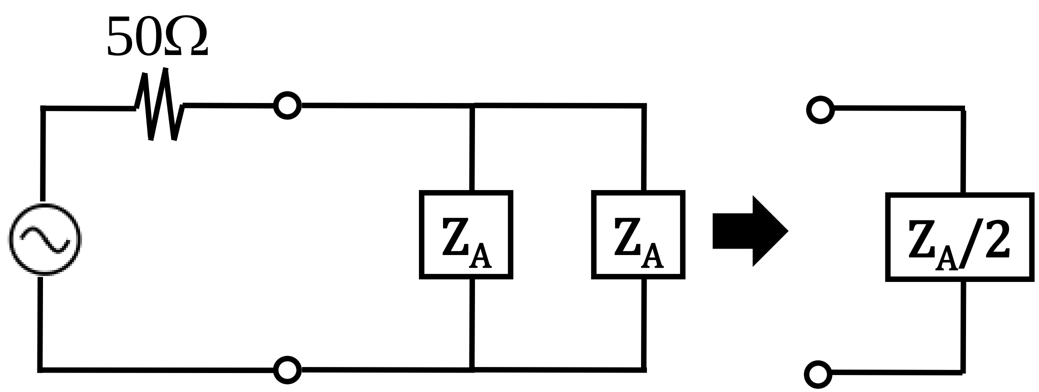
Using a Simplistic Thinking



$$C_2 > C_1$$

$$Z_A = 93\Omega$$





Using a Signal Processing Terminology

$M - T_x$

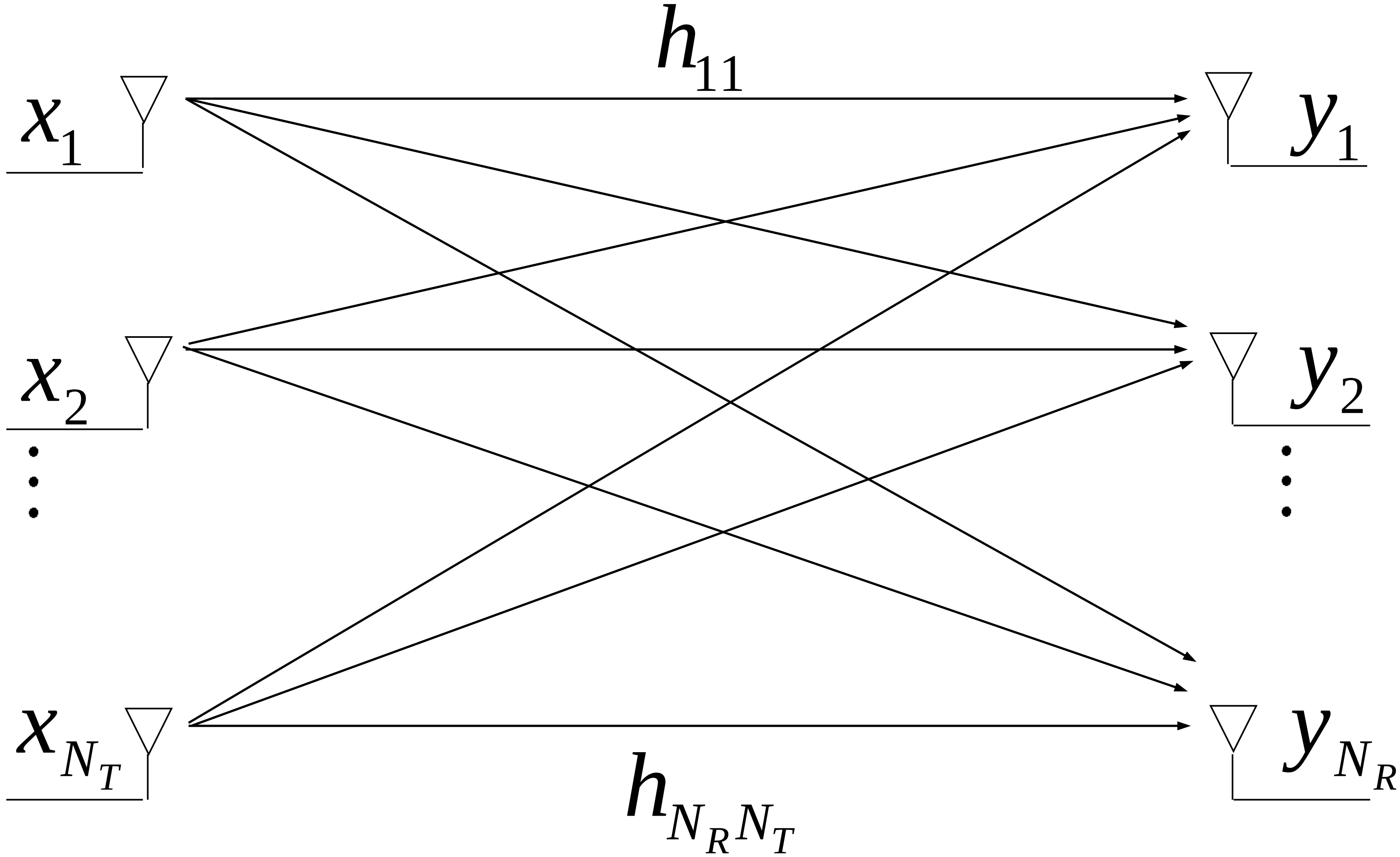
$X \to$ Input

$N - R_x$

$Y \to$ Output

$$[Y]_{N\times 1} = [H]_{N\times M}\,[X]_{M\times 1}$$

$[H] \Longrightarrow$ Transfer function matrix



A MIMO System

Using a Signal Processing Terminology

In general

$$[H]=[U][\Sigma][V]^H \quad with \quad [U][U]^H=[I] \; and \; [V][V]^H=[I]$$

$$[\Sigma] \; is \; a \; DIAGONAL \quad MATRIX$$

$$[Y]=[U][\Sigma][V]^H[X]$$

$$[Y]'=[U]^H[Y]=[\Sigma][X]'=[\Sigma][V]^H[X]$$

$$[X]'=[V]^H[X]\Rightarrow[X]=[V][X]'$$

$$[Y]'=[U]^H[Y]\Rightarrow[Y]=[U][Y]'$$

$$[Y]'=[\Sigma][X]' \qquad [V]^H[X]=[X]'\Rightarrow[\Sigma]\Rightarrow[Y]'=[U]^H[Y]$$

Multiple Decoupled Spatial Channels

Operating at the same FFREQUENCY

Using a Signal Processing Terminology

The principle of MIMO

$$[Y]' = [\Sigma][X]'$$

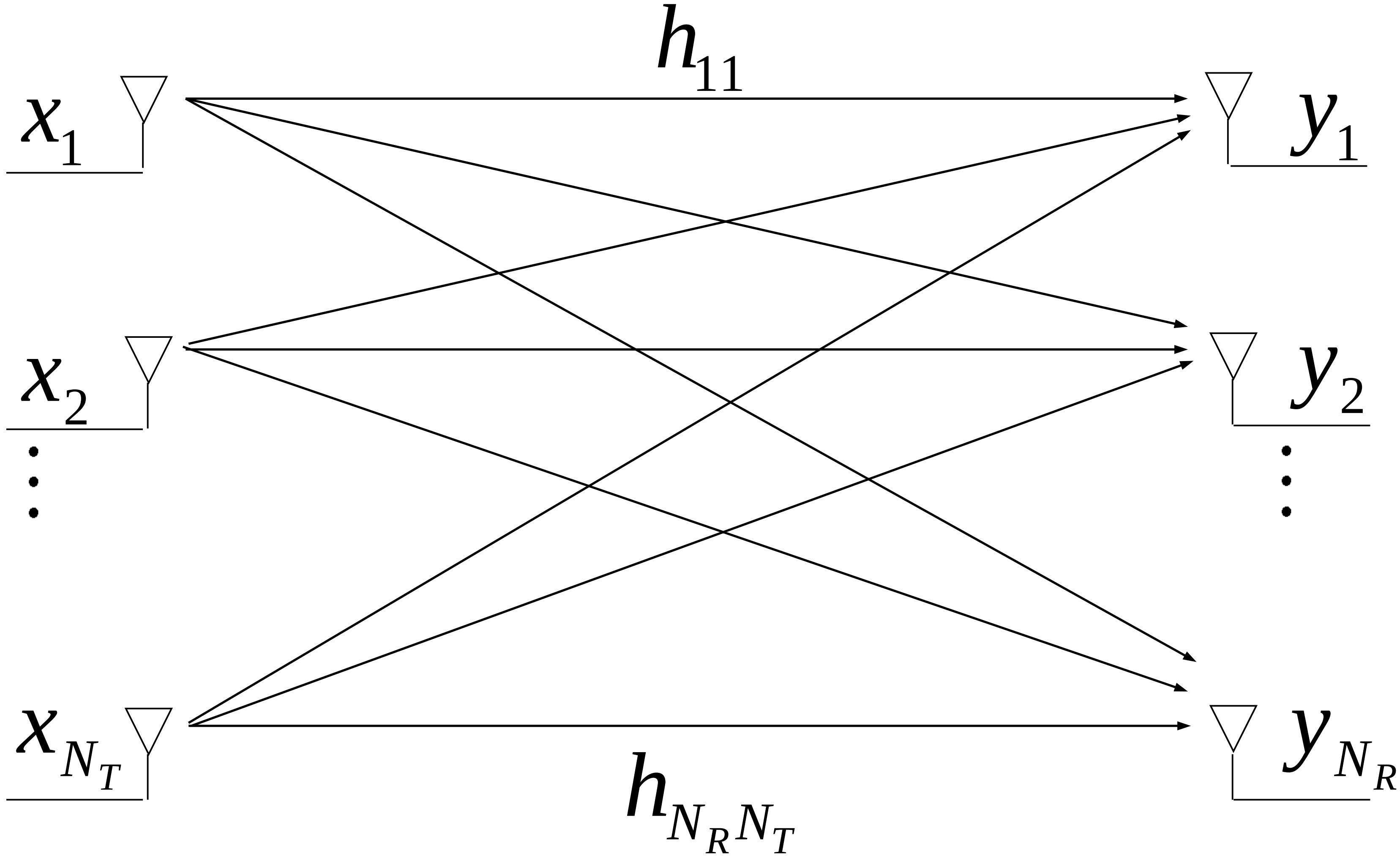
$$\begin{bmatrix} y_1' \\ y_2' \\ \vdots \end{bmatrix} = \begin{bmatrix} \sigma_1^2 & 0 & \\ 0 & \sigma_2^2 & \\ & & \ddots \end{bmatrix} \begin{bmatrix} x_1' \\ x_2' \\ \vdots \end{bmatrix}$$

There are multiple separate decoupled channels

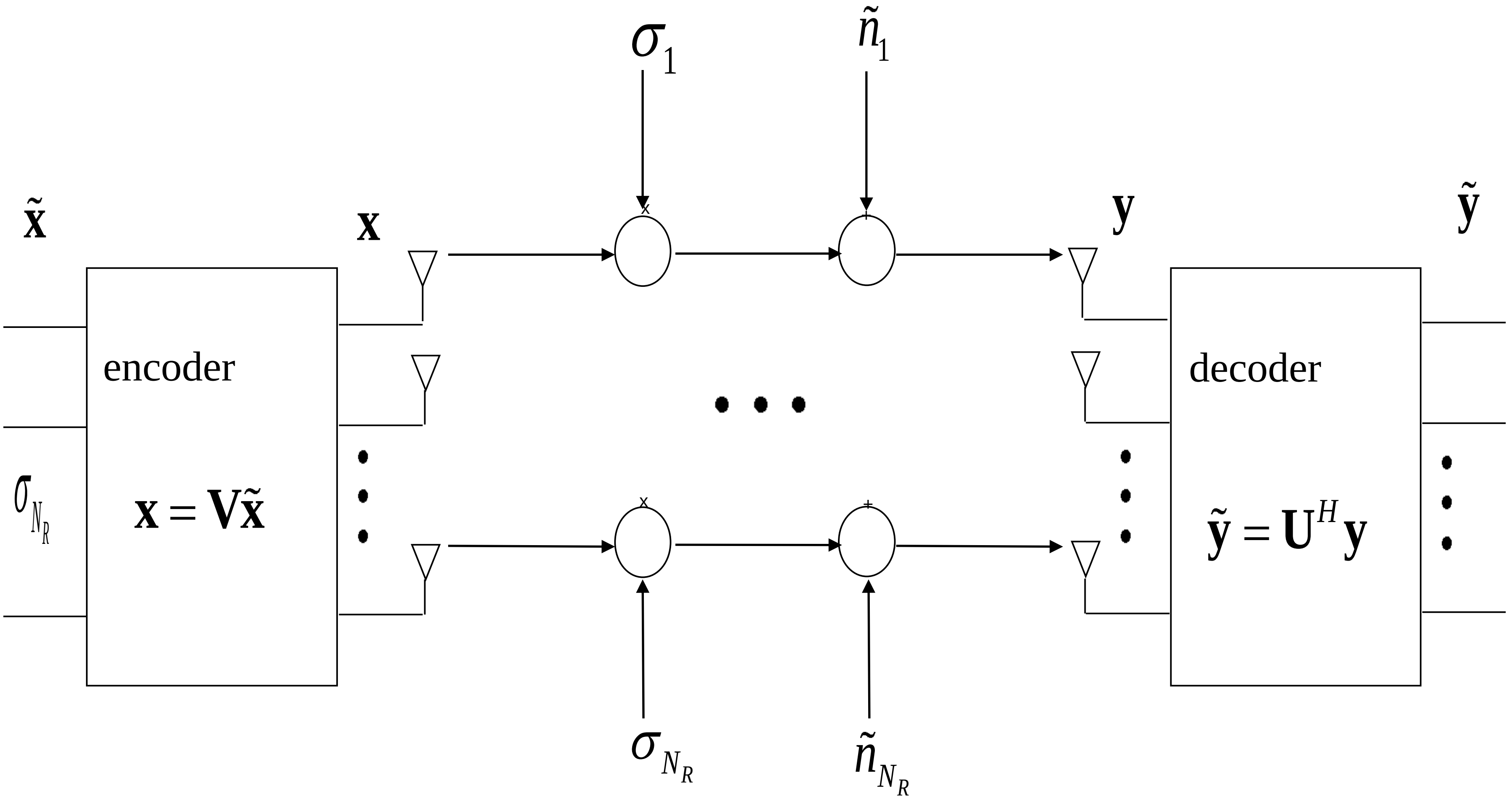
$$y_1' = \sigma_1^2 x_1'$$
$$y_2' = \sigma_2^2 x_2'$$
$$\vdots$$

Hence the conjecture simultaneous multiple transmission can be made

$$[X] \rightarrow \boxed{[V]^H} \rightarrow \underbrace{[X]' \rightarrow [\Sigma] \rightarrow [Y]'}_{\text{WIRELESS COMES IN}} \rightarrow \boxed{[U]} \rightarrow [Y]$$



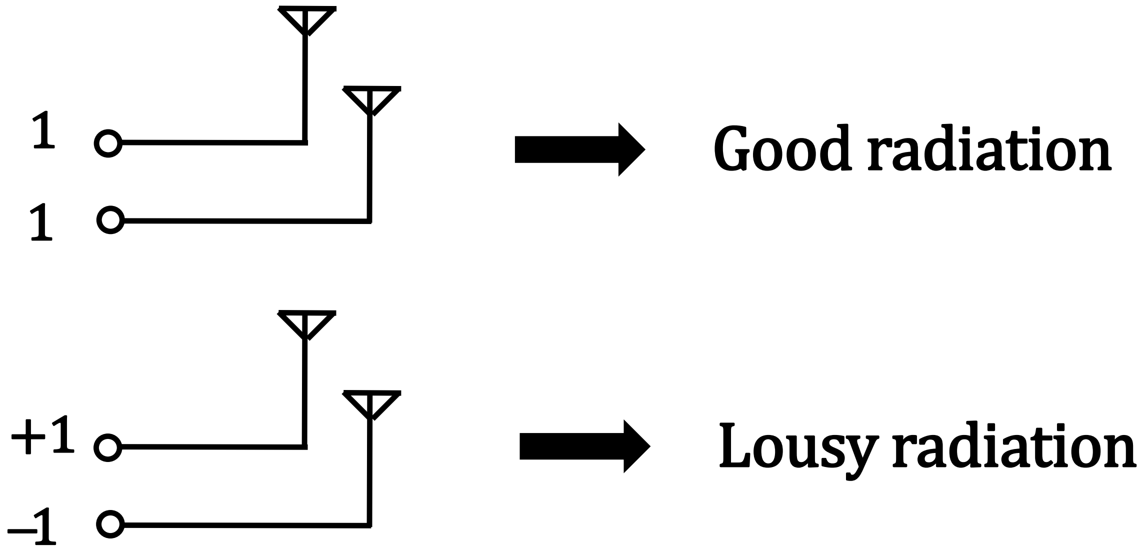
A MIMO System



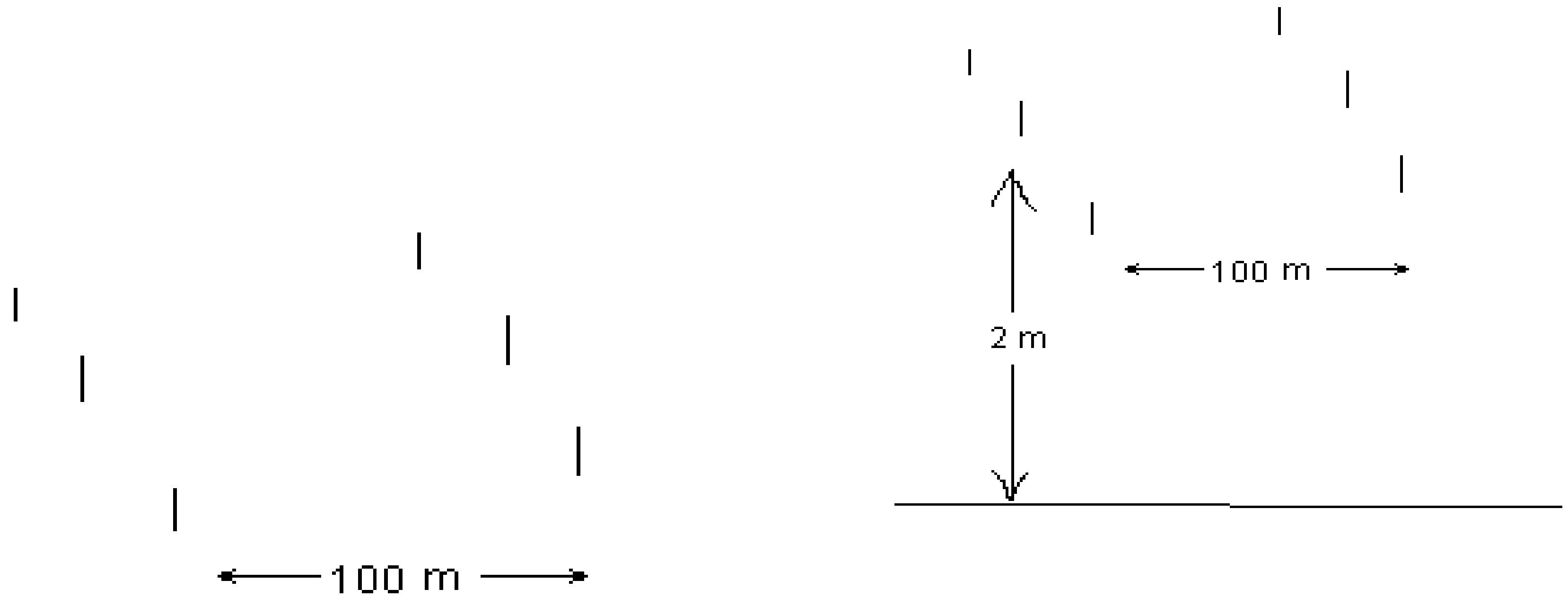
$$\tilde{\mathbf{y}} = \mathbf{U}^H\mathbf{y} = \mathbf{U}^H\mathbf{H}\mathbf{x} = \mathbf{U}^H(\mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^H)\mathbf{x} + \mathbf{U}^H\mathbf{n}$$

$$\tilde{\mathbf{y}} = \boldsymbol{\Sigma}\mathbf{V}^H\mathbf{x} + \mathbf{U}^H\mathbf{n} \qquad \tilde{\mathbf{y}} = \boldsymbol{\Sigma}\tilde{\mathbf{x}} + \tilde{\mathbf{n}}$$

Using a Maxwell-Poynting Theory



Hence, even though simultaneous multiple channels are possible, only one is practical and the others are not very useful from a systems perspective



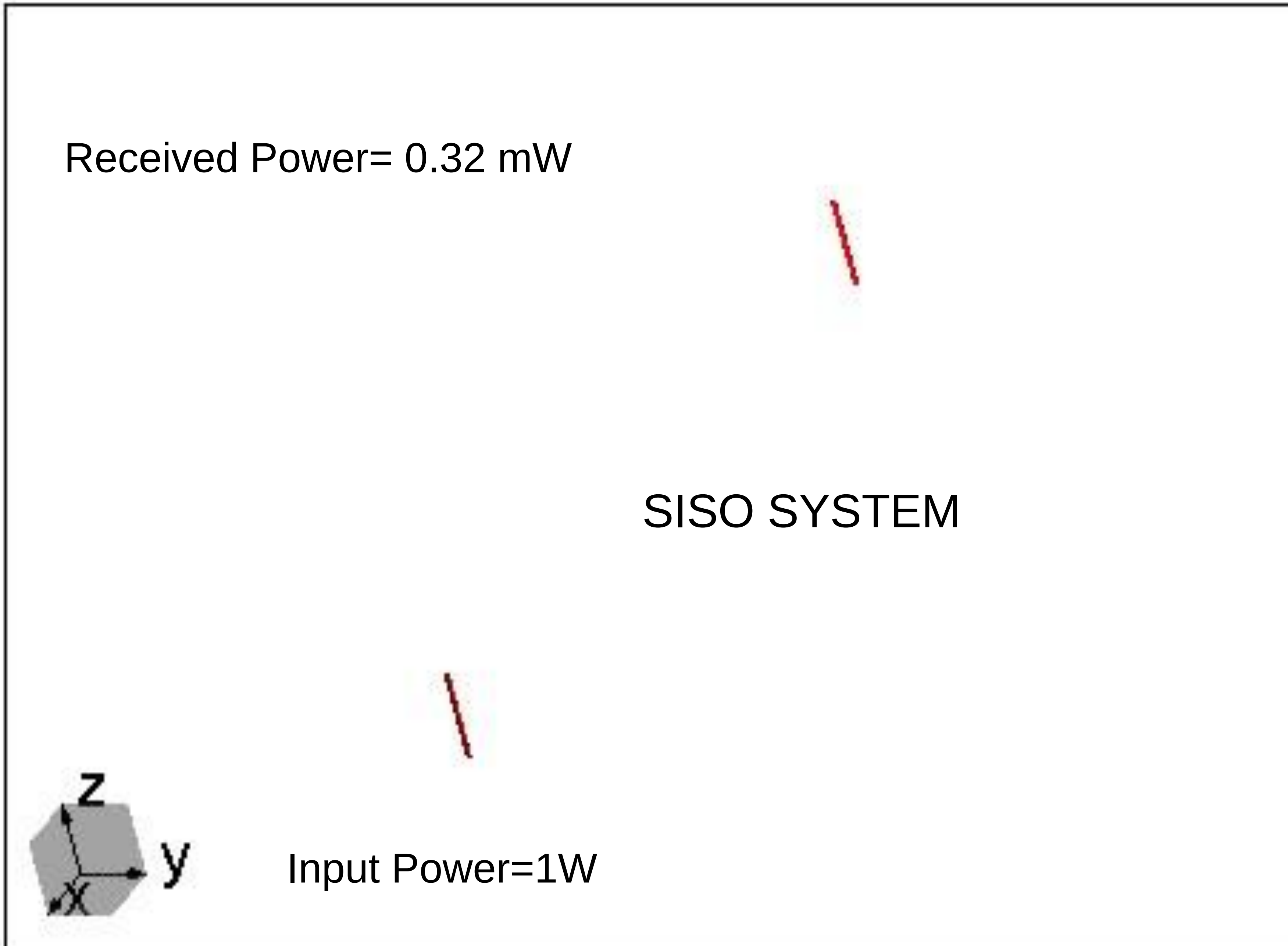
A typical 3 × 3 MIMO system consisting of half wave dipoles, half wavelength spaced and separated by 100 m.

SISO 1×1	MIMO 2×2	MIMO 3×3	MIMO 4×4	MIMO 5×5
1.0	5.21	11.95	22.18	**34.85**
	3.73×10^{-6}	9.67×10^{-5}	6.26×10^{-4}	$\mathbf{2.75 \times 10^{-3}}$
		2.85×10^{-11}	$1.88 \times 10^{--9}$	$\mathbf{2.40 \times 10^{-8}}$
			4.28×10^{-16}	$\mathbf{5.42 \times 10^{-14}}$
				$\mathbf{9.15 \times 10^{-21}}$

Ratio of the Square of the Singular Values for the Various Spatial MIMO Modes with Respect to the SISO Case (Broadside Orientation).

SISO 1×1	MIMO 2×2	MIMO 3×3	MIMO 4×4	MIMO 5×5
1.0	4.46	10.58	19.45	31.05
	7.96×10^{-5}	1.38×10^{-3}	9.13×10^{-3}	3.79×10^{-2}
		1.22×10^{-8}	4.68×10^{-7}	6.00×10^{-6}
			3.47×10^{-12}	2.33×10^{-10}
				1.60×10^{-15}

Ratio of the Square of the Singular Values for Various Spatial MIMO Modes with Respect to the SISO Case (Collinear Array Over a Ground Plane).


Received Power= 0.32 mW
SISO SYSTEM
Input Power=1W
z
y
x

2×2 MIMO SYSTEM

2 orthogonal spatial modes

Mode 1: Excitation 1V; 1V

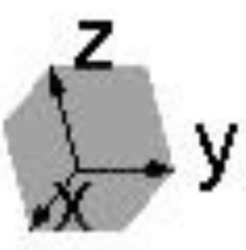
Mode 2: Excitation 1V; –1V

Received Power
for each mode

Mode 1: 1.4 mW

Mode 2: 6.6 μW

How does one get a feed
to extract the two signals
For the two orthogonal
spatial modes ?



Input Power=1W; for
each spatial mode

$$C_{SISO} = B\log_2\left(1 + \frac{0.00034}{P_N}\right)$$

$$C_{MIMO} = B\log_2\left(1 + \frac{0.0014}{2 \times P_N}\right) + B\log_2\left(1 + \frac{0.0000066}{2 \times P_N}\right)$$

Observations:

1. **The phased-array mode is the efficient one as expected over a SISO**
2. **One of the MIMO modes is a lousy radiator, that is why antenna engineers use only a single spatial mode**
3. **Channel has a linear increase; whereas power has a logarithmic increase**

SUPERPOSITION OF POWER!!!

$$C_s = B\left[\log_2\left\{1+\frac{P_{S_1}}{P_N}\right\}+\log_2\left\{1+\frac{P_{S_2}}{P_N}\right\}\right]$$

Even if P_{S_2} is not suitable for a physical channel, dividing by P_N might provide an useful theoretical number!!

Then comes the MYTHOLOGY!!!

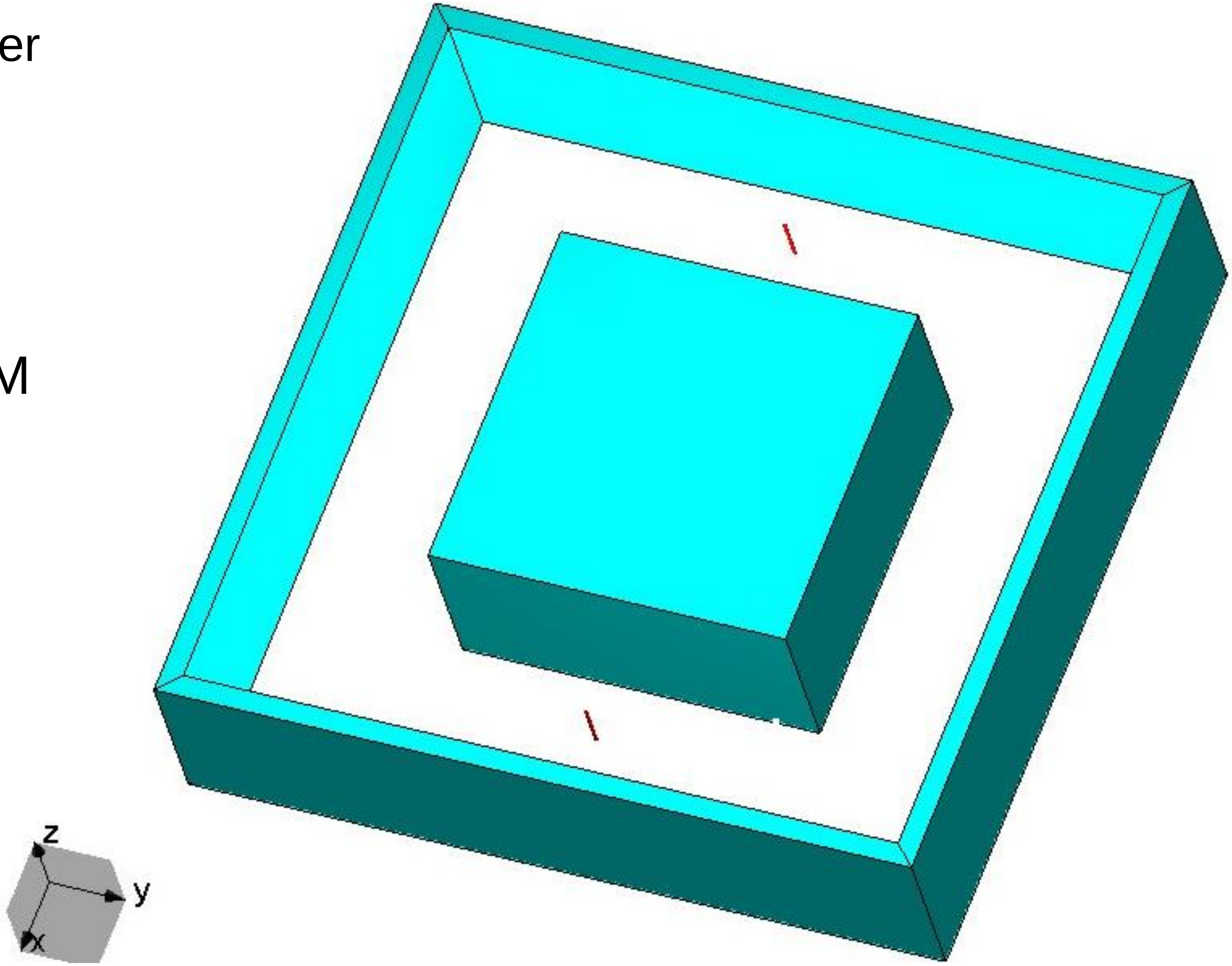
NEED A RICH MULTIPATH ENVIRONMENT FOR MIMO TO WORK!

(*What does this silly concept mean??*)

THIS CAN NEVER HAPPEN AS IT DOES NOT EXIST!!!!

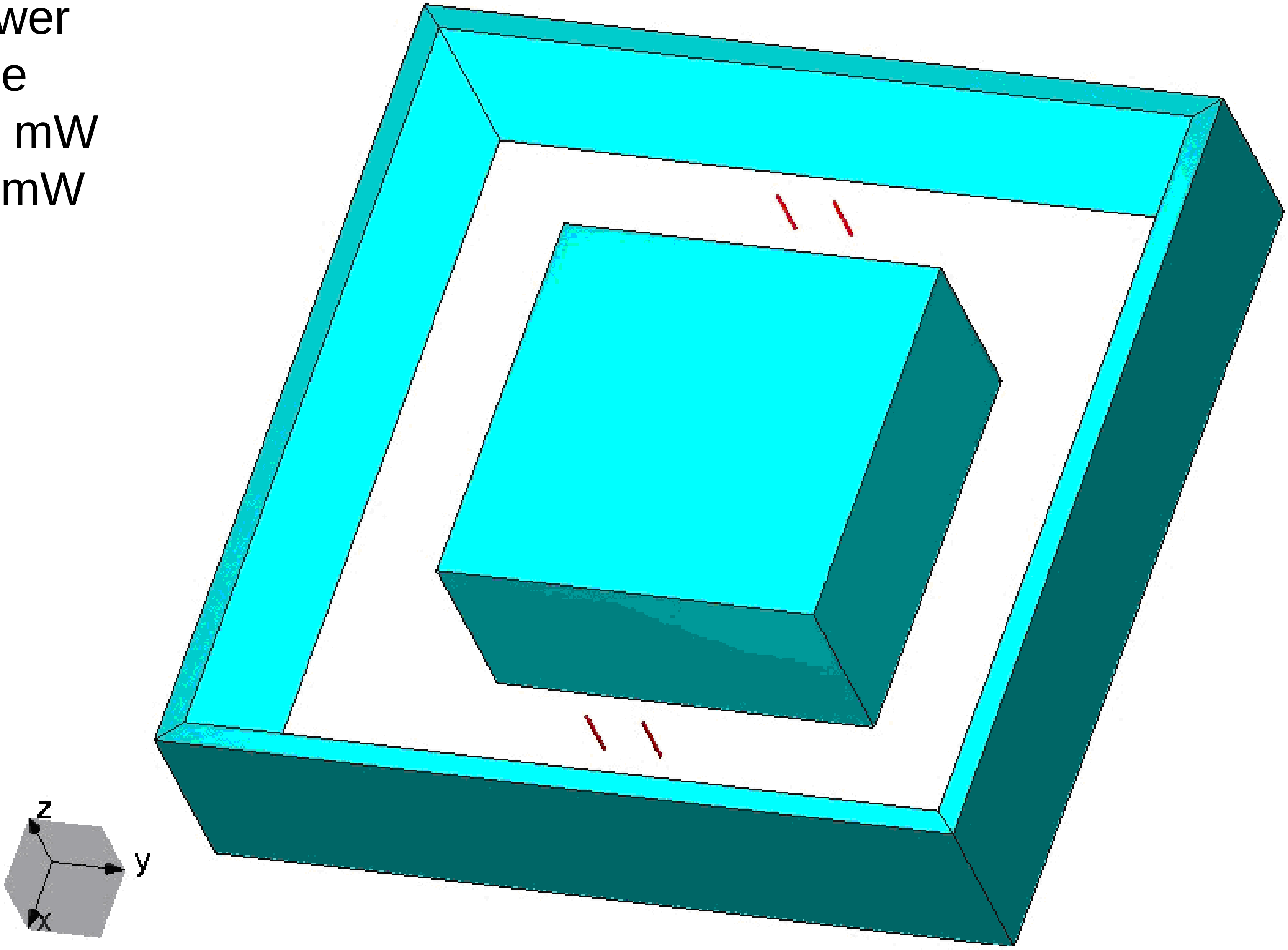
Received Power
= 18.2 mW

SISO SYSTEM



Input Power=1W

Received Power
for each mode
Mode 1: 13.1 mW
Mode 2: 3.4 mW



Input Power=1W; for each spatial mode

$$C_{SISO} = B\log_2\left(1+\frac{0.0182}{P_N}\right) = 43.05\ B$$

3 times less

10 times less

$$C_{MIMO} = B\log_2\left(1+\frac{0.0131}{2\times P_N}\right) + B\log_2\left(1+\frac{0.0034}{2\times P_N}\right)$$

$$= B ? 41.57 \quad B ? 39.63 \quad B \times 81.2$$

Observations:

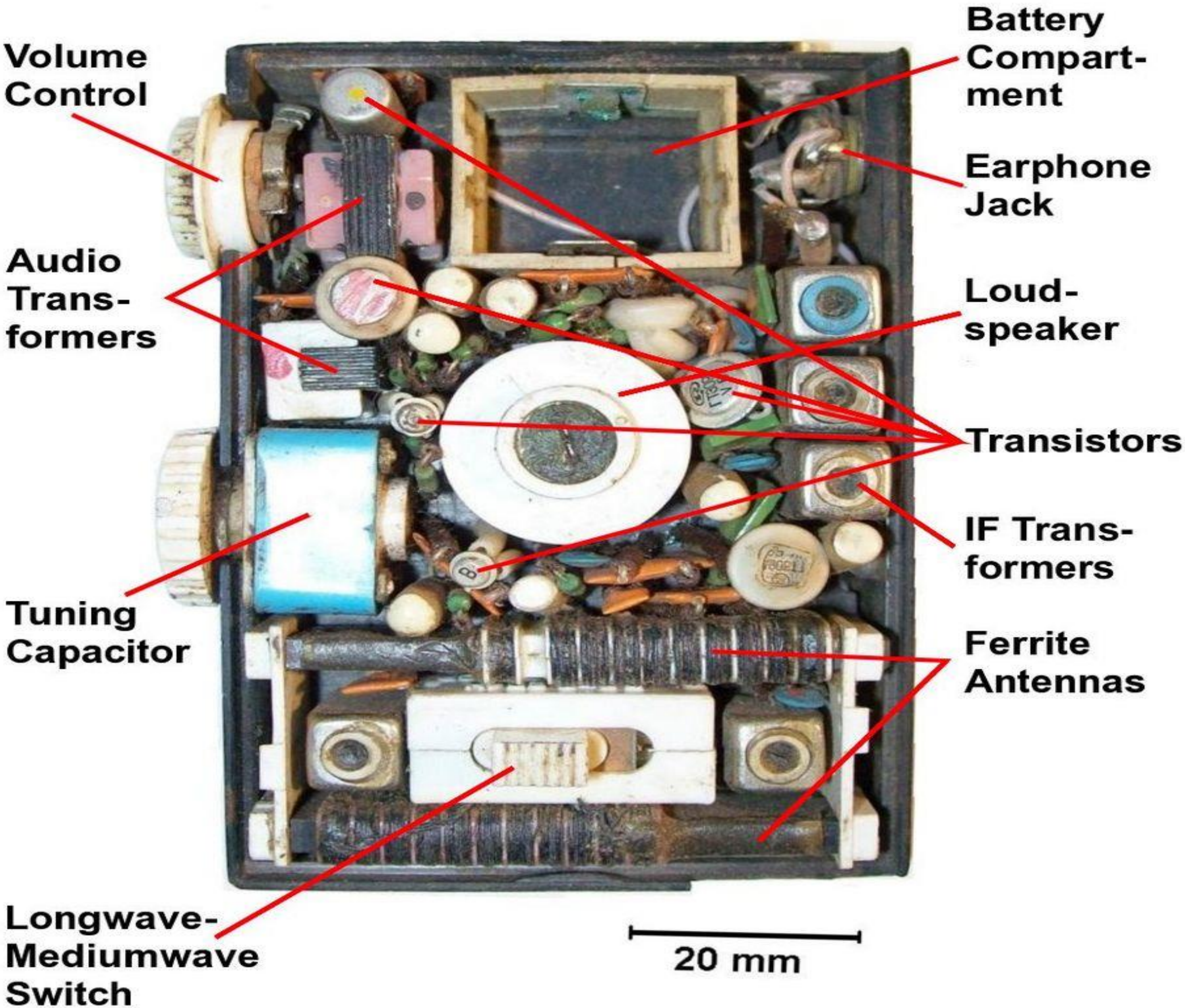
1. **Two inefficient radiating modes; yet the capacity is higher than a SISO**
2. **Two SISO is always better than a 2×2 MIMO under this non-physical metric**
3. **There is a threshold effect as a function of Signal-to-noise ratio**

SUMMARY:

→No Plane waves

→ It is a Near Field Environment

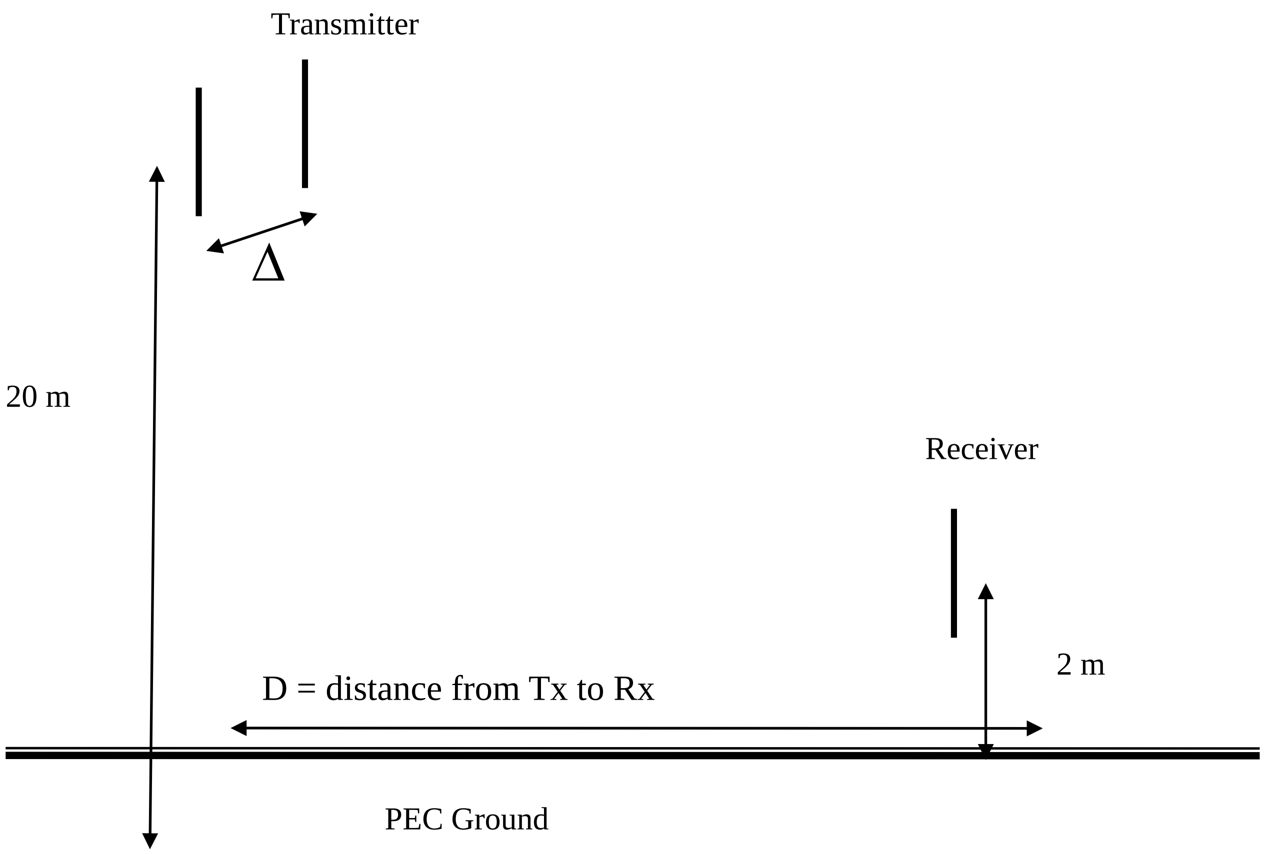
→ Can one define a multipath without a plane wave?



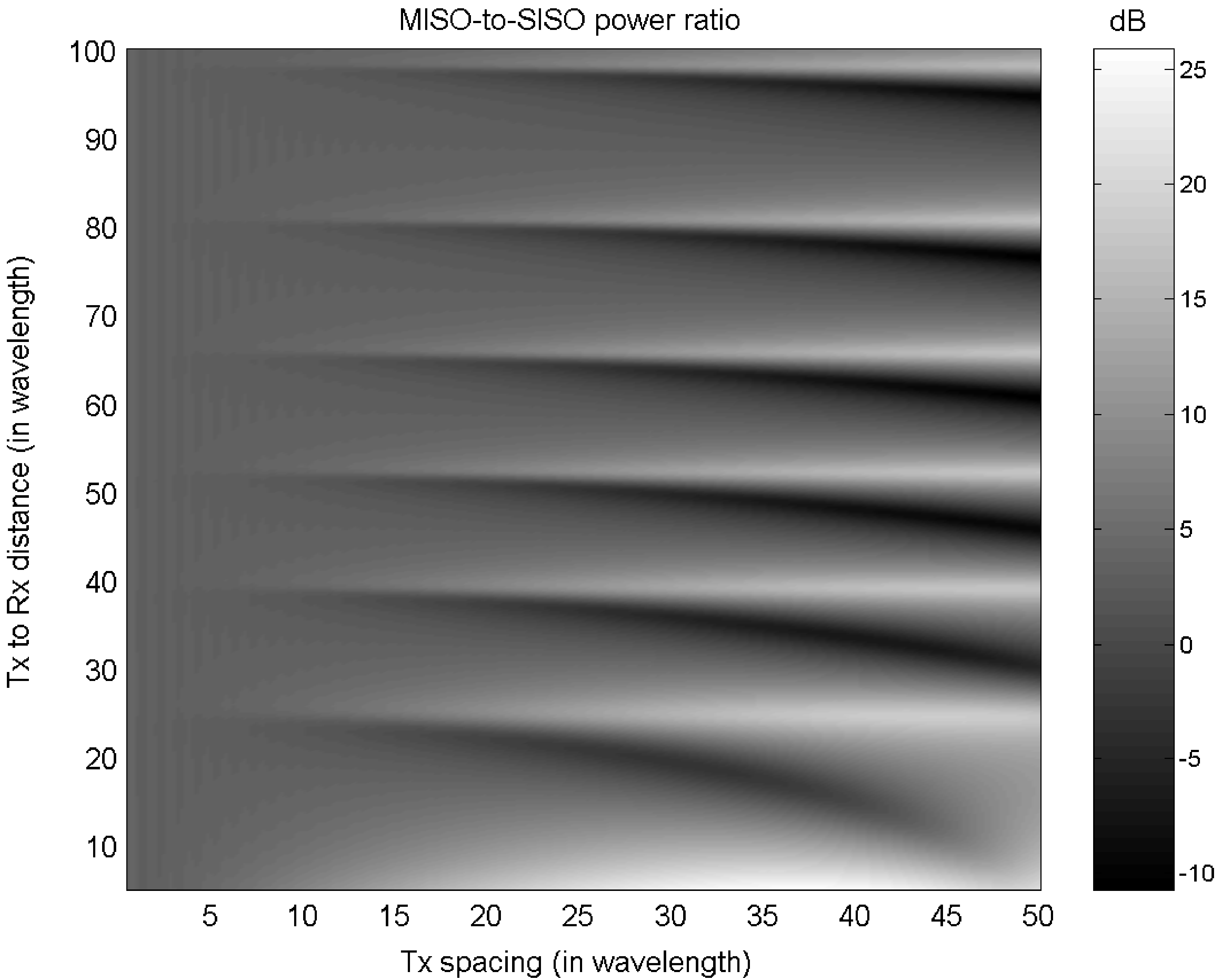
Volume Control
Audio Trans- formers
Tuning Capacitor
Longwave- Mediumwave Switch
Battery Compart- ment
Earphone Jack
Loud- speaker
Transistors
IF Trans- formers
Ferrite Antennas
20 mm

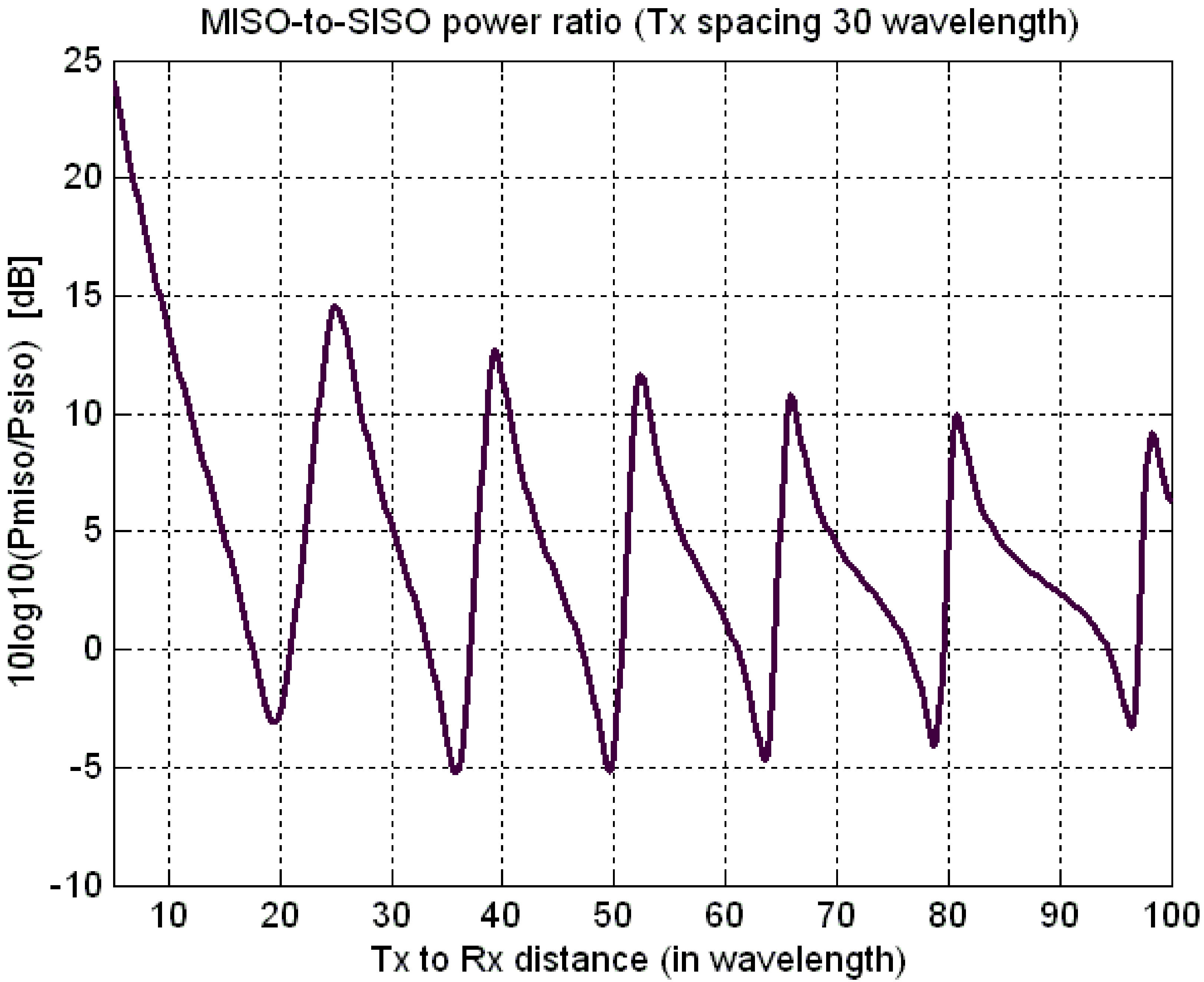

SONY
WALKMAN
AM
FM
160
130
100
70
53
x10
kHz
108
102
96
92
88
MHz
MEGA BASS
FM STEREO


Energizer
9 VOLTS
2006
PILE ALCALINE
P-200
0.1W8Ω
SAMMI
.02µF



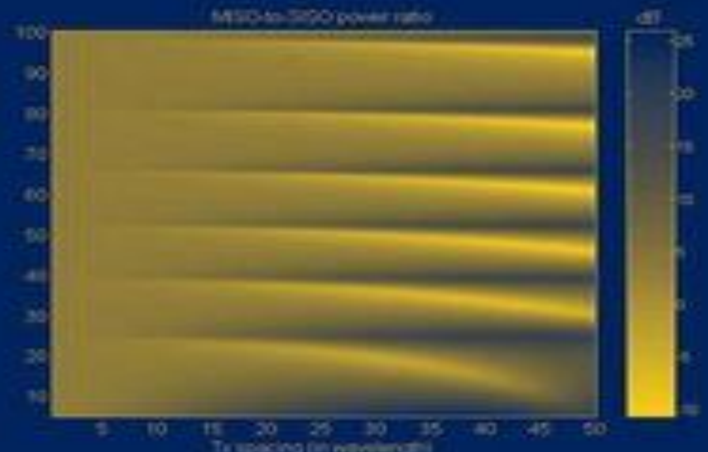
MISO system setup; Transmitter is 20 m. above ground; Rx is 2 m. above ground; = transmitting antenna spacing; D = distance between the transmitter and the receiver. (For the SISO case, the transmitting antenna is placed at the center of the MISO transmitter.)


MISO-to-SISO power ratio
dB
25
20
15
10
5
0
-5
-10
Tx to Rx distance (in wavelength)
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
50
Tx spacing (in wavelength)


MISO-to-SISO power ratio (Tx spacing 30 wavelength)
10log10(Pmiso/Psiso) [dB]
25
20
15
10
5
0
-5
-10
10
20
30
40
50
60
70
80
90
100
Tx to Rx distance (in wavelength)

WILEY

Physics of Multiantenna Systems and Broadband Processing



TAPAN K. SARKAR
MAGDALENA SALAZAR-PALMA
ERIC L. MOKOLE

Wiley Series in Microwave and Optical Engineering • Kai Chang, Series Editor

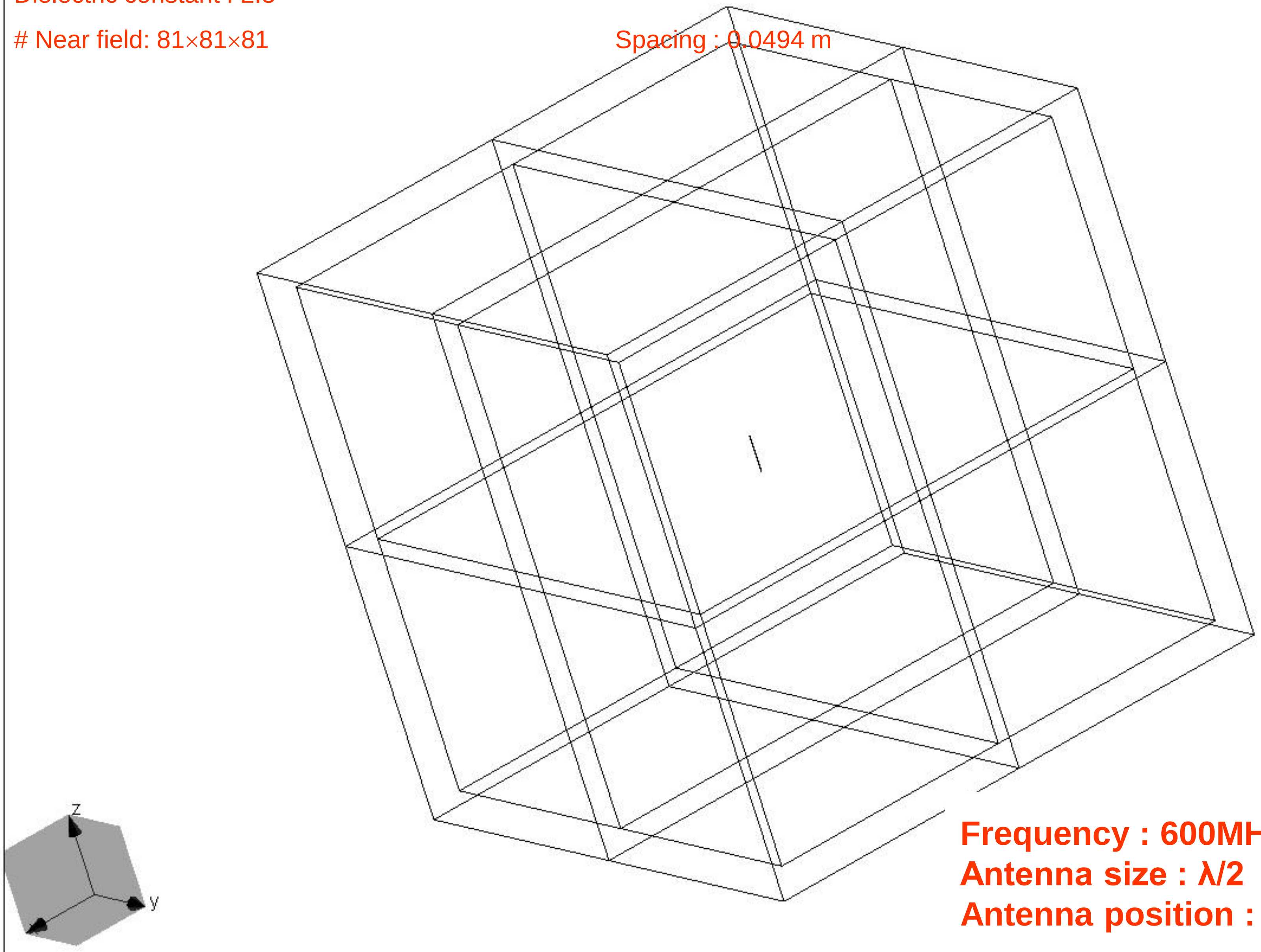
Inner dielectric: 3.5m×3.5m×3.5m; Outer dielectric: 3.8m×3.8m× 3.8m

Dielectric thickness: 0.15m

Dielectric constant : 2.5

Near field: 81×81×81

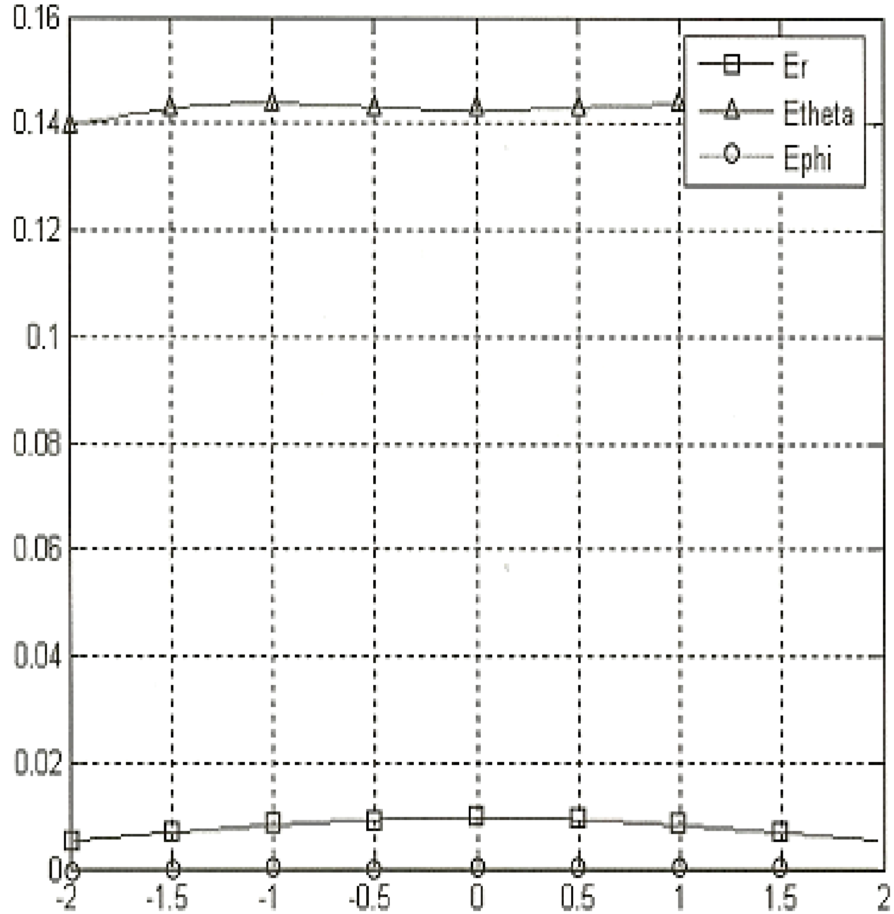
Spacing : 0.0494 m



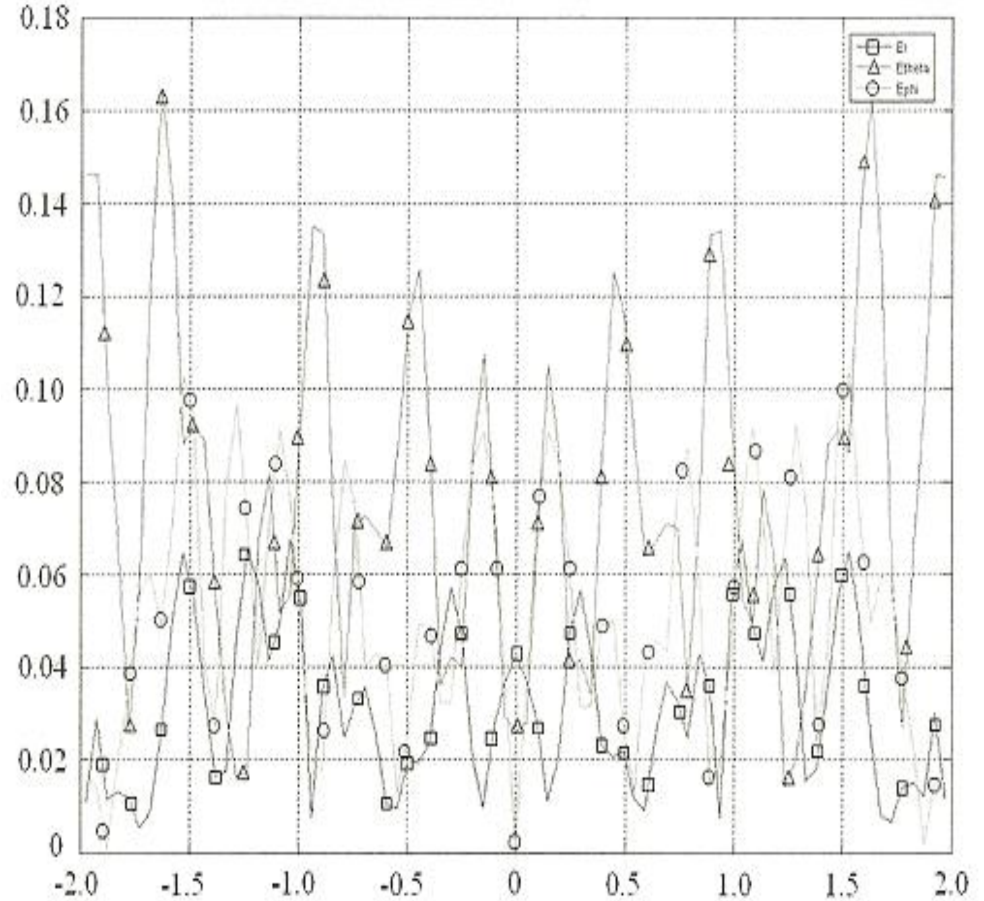
Frequency : 600MHz;

Antenna size : λ/2 (0.25m)

Antenna position : (0,0,0)

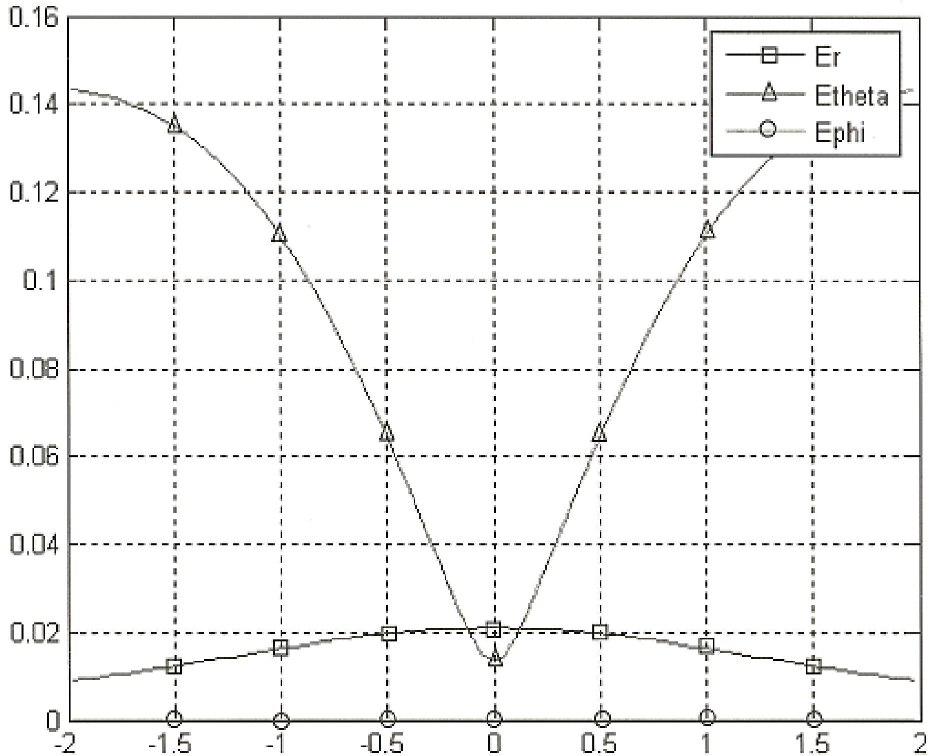


Free Space



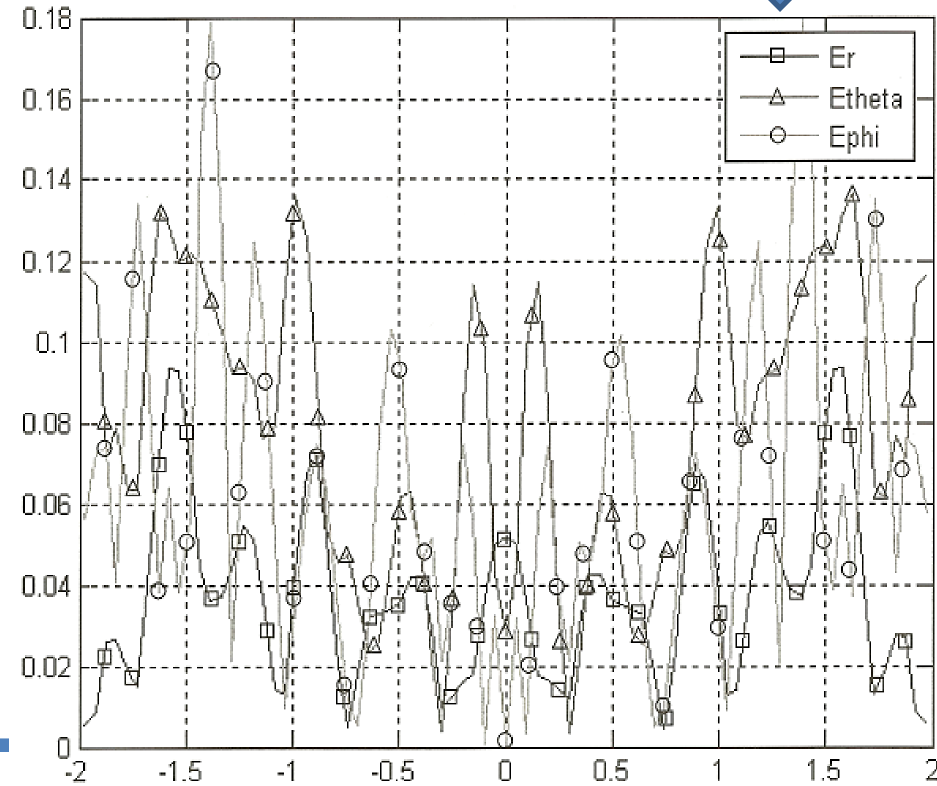
Inside a Dielectric Room

The three components of the fields *Er, Eθ, Eφ* inside the room at x = –3.75λ, z = –3.75λ , as a function of y

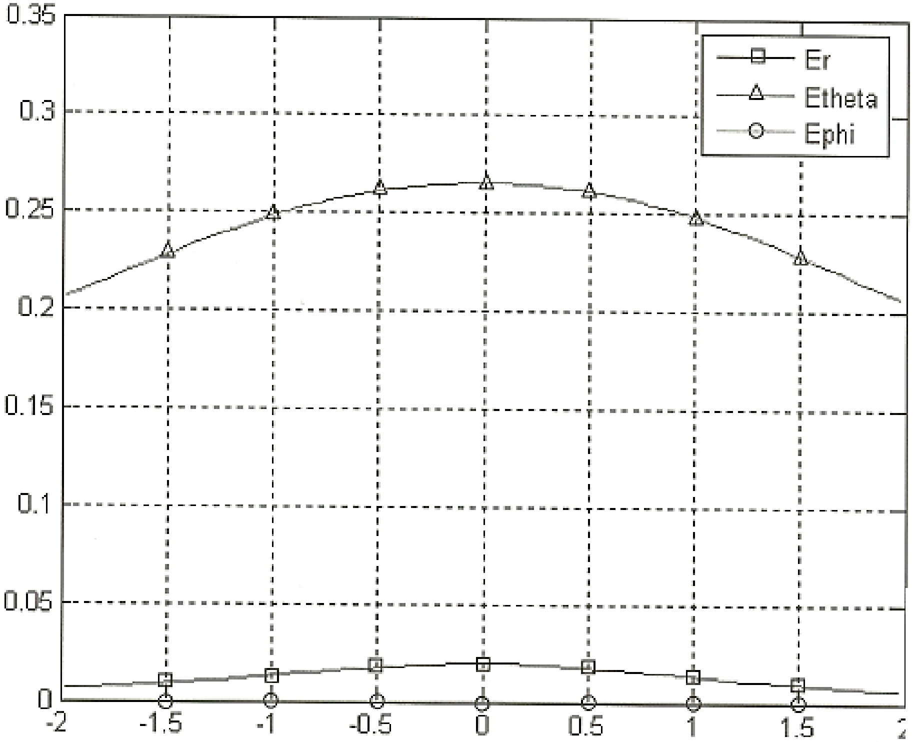


FREE SPACE

DIELECTRIC ROOM

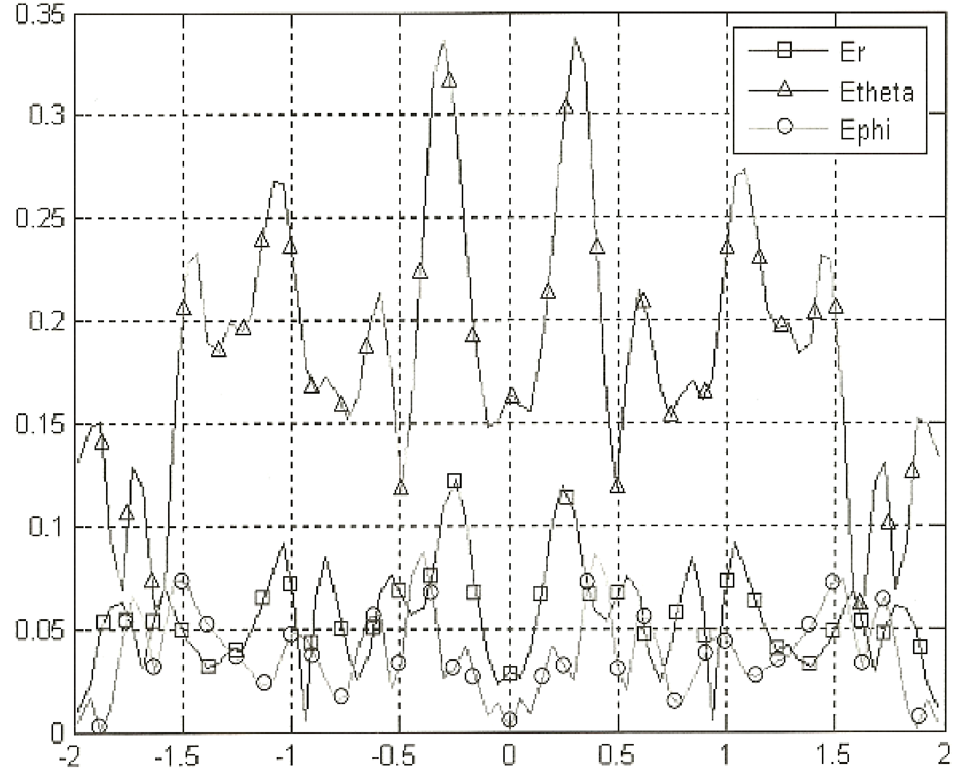


The three components of the fields *Er, Eθ, Eφ* inside the room at x = –0.0198λ, z = –3.75λ , as a function of y



FREE SPACE

DIELECTRIC ROOM



The three components of the fields *Er, Eθ, Eφ* inside the room at x = –3.75λ, z = –0.198λ asa function of y.


10

Objective

- To illustrate that an electromagnetic macro modeling can properly predict the path loss exponent in a mobile cellular wireless communication system.
- **Path loss exponent in a cellular wireless communication system is 3, preceded by a slow fading region, and followed by the fringe region where the path loss exponent is 4.**
- **Theoretical analysis: Radiation from a vertical dipole over a horizontal imperfect ground plane: Schelkunoff formulation.**
- **Experiments: Okumura et al. and more extensive experimental data from different base stations.**

Point Source: Field decays as 1/R^2
: Power decays ar 1/R^4 - 10 Log10(P)
- 40 dB/decade

Line Source: Field decays as 1/R
: Power decays ar 1/R^2
- 20 dB/decade

Planar source:: Field decays as

What type of a source has: Field decays as 1/R^1.5
: Power decays ar 1/R^3
- 30 dB/decade

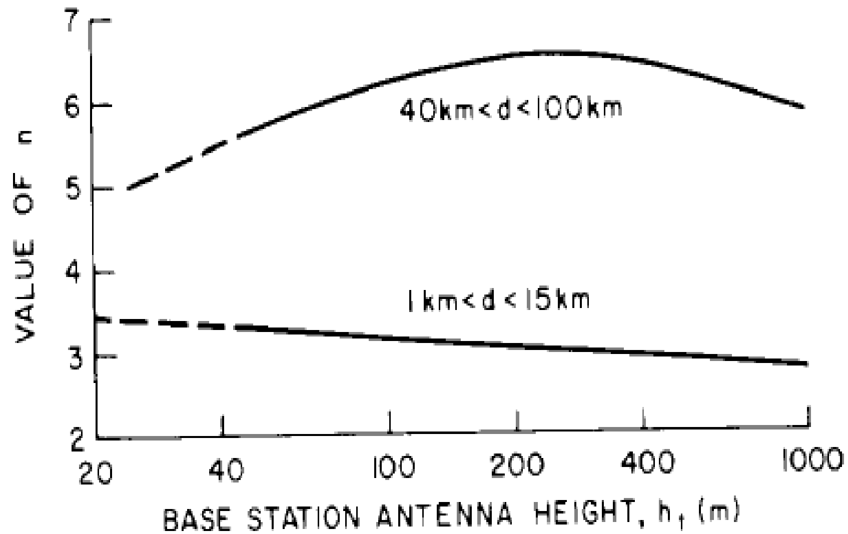
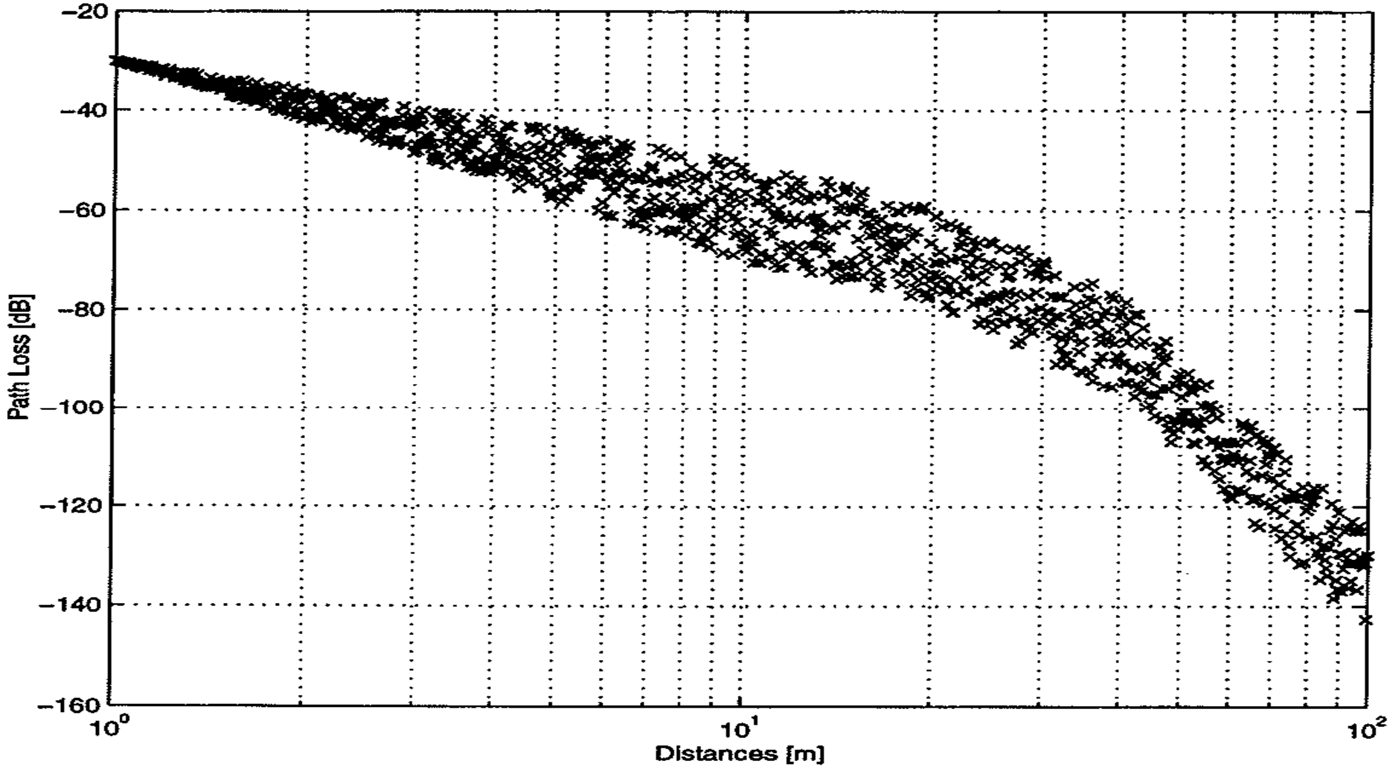
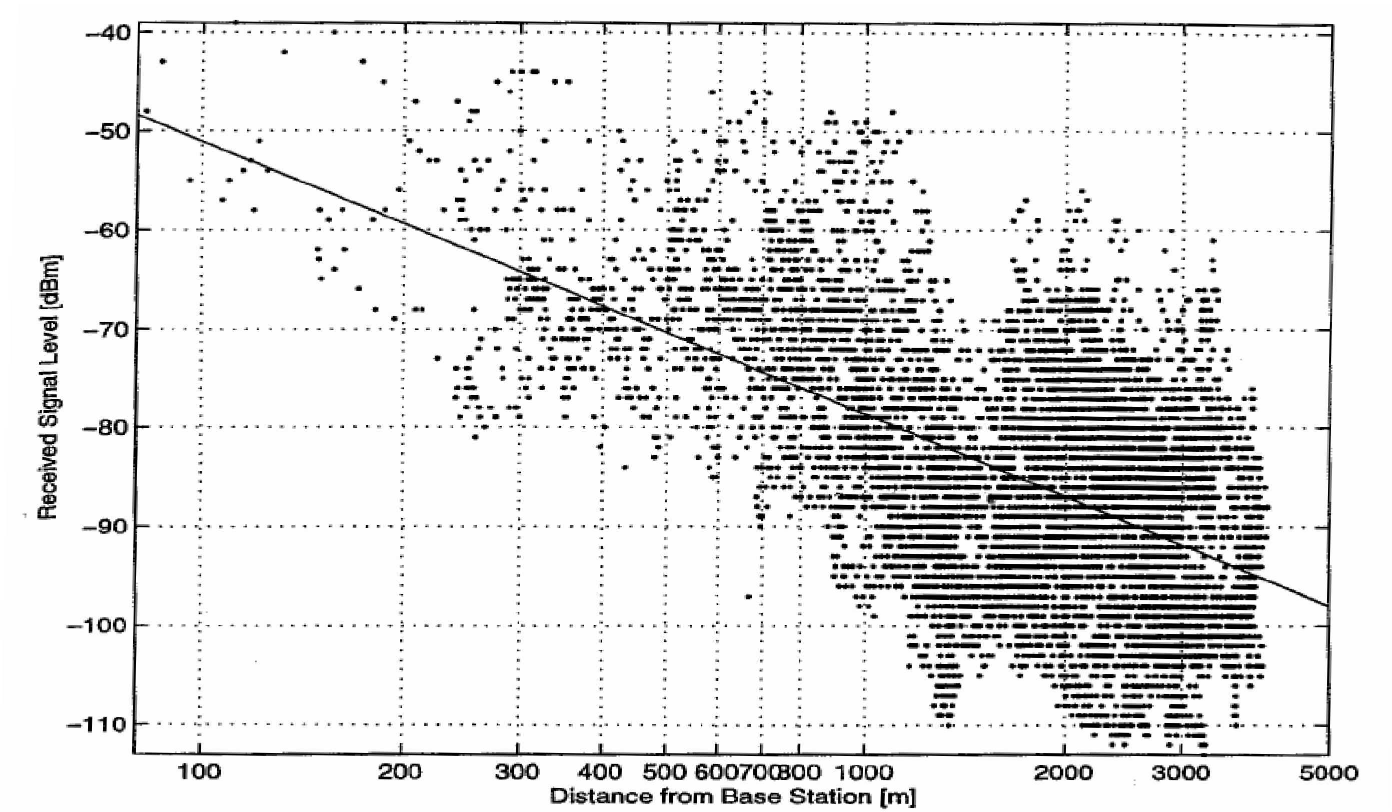


Figure 2.2-14 Distance dependence of median field strength in an urban area $P_r \alpha d^{-n}$).



Prediction from Ericsson in-building path loss model. Reproduced by permission from Simon R. Saunders, Advances in mobile propagation prediction methods, Chapter 3 of *Mobile Antenna Systems Handbook,* Edited by: Kyohei Fujimoto, Artech House, 2008.



Empirical model of macrocell propagation at 900 MHz, the dots are measurements taken in suburban area, where as the solid line represents a best fit empirical model. Reproduced by permission from Simon R. Saunders, Advances in mobile propagation prediction methods, Chapter 3 of *Mobile Antenna Systems Handbook, Third edition*, Edited by: Kyohei Fujimoto, 2008, Artech House, Inc.

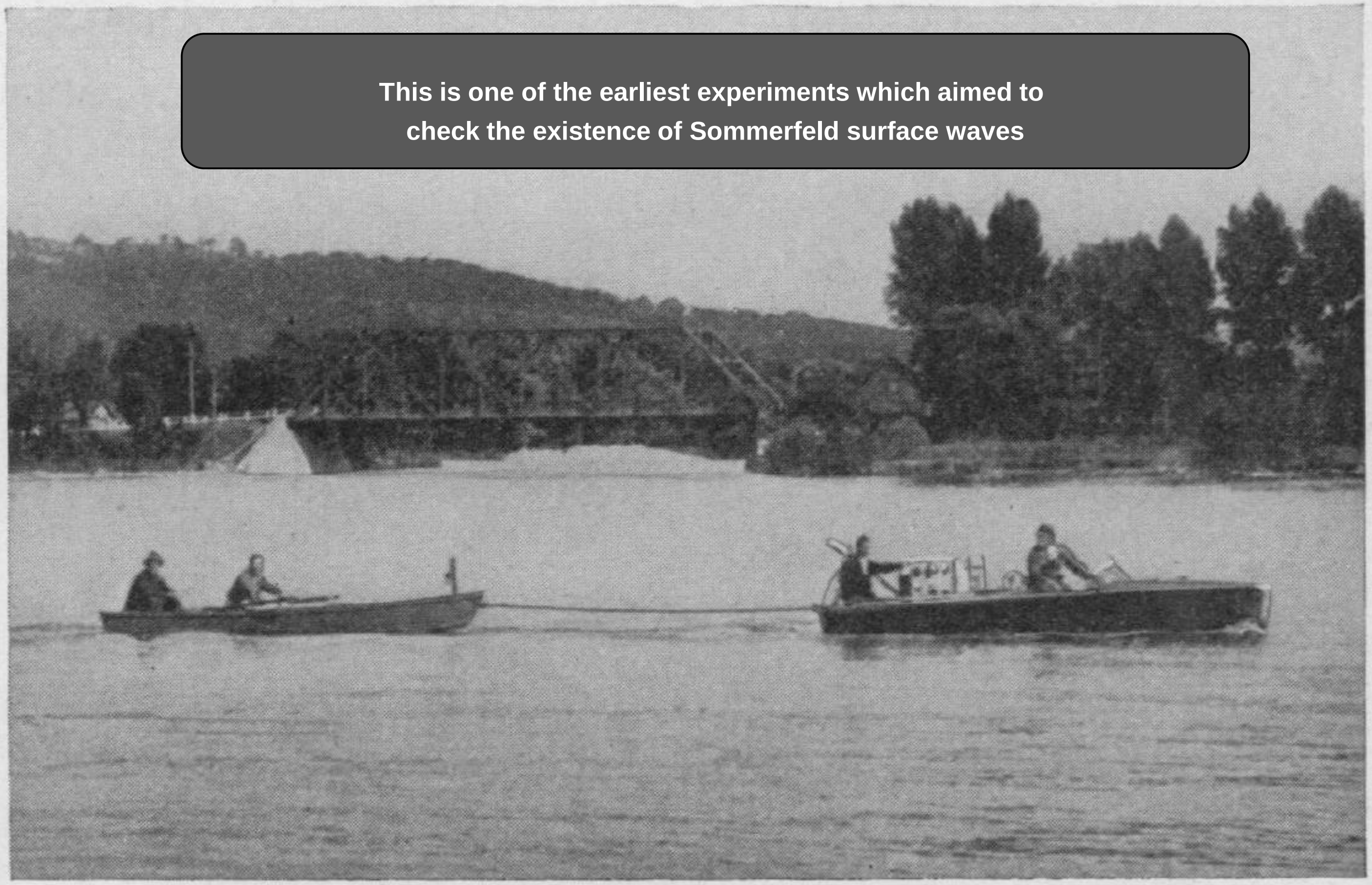
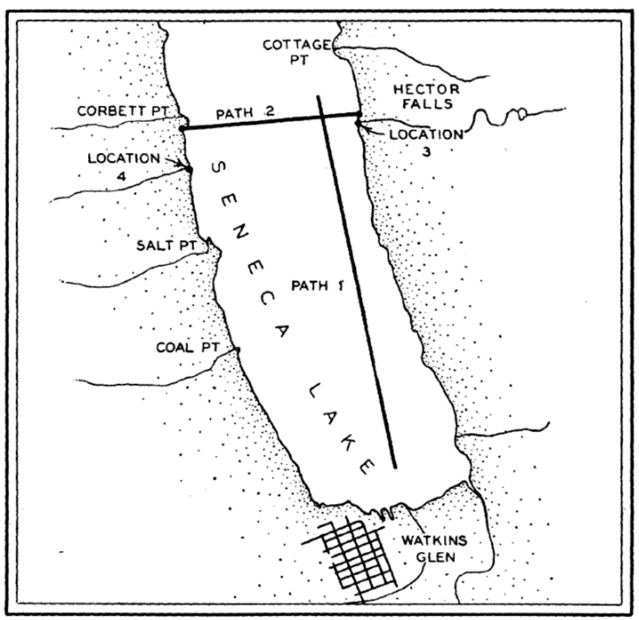


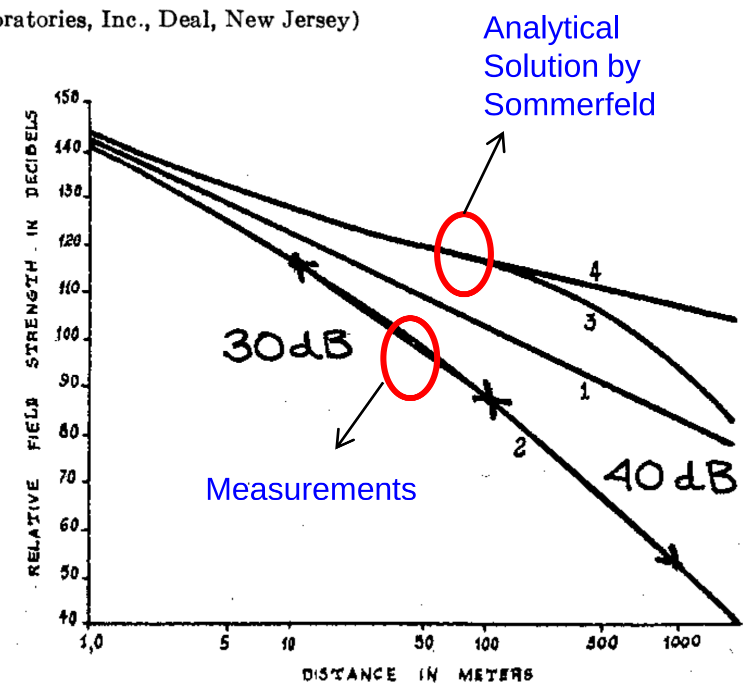
Fig. 1—Experimental arrangement for determining the variation of the received field strength with distance.

Proceedings of the Institute of Radio Engineers
Volume 25, Number 2 *February, 1937*

THE SURFACE WAVE IN RADIO PROPAGATION OVER PLANE EARTH*

By
Charles R. Burrows
(Bell Telephone Laboratories, Inc., Deal, New Jersey)

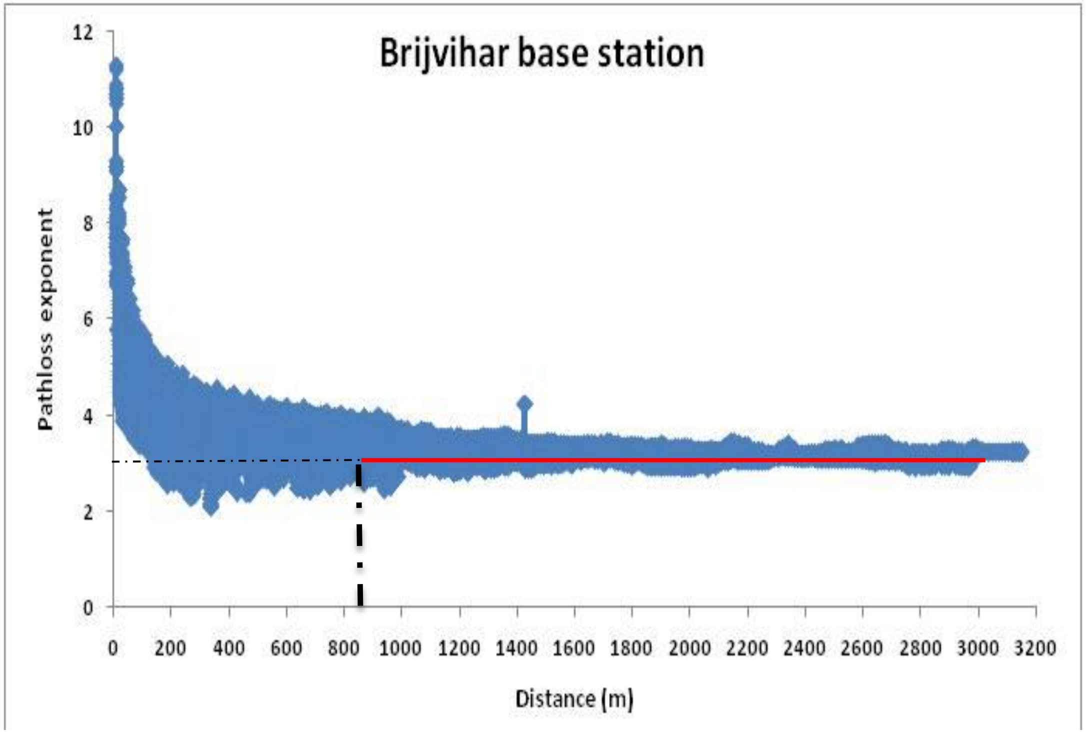




Experimental Data

Photograph of a Delhi typical urban environment in this study.

Experimental Data



Variation of path loss exponent with distance for BJV base station (1800 MHz). Base station height: 24 m. Beginning of smooth region: 864 m.

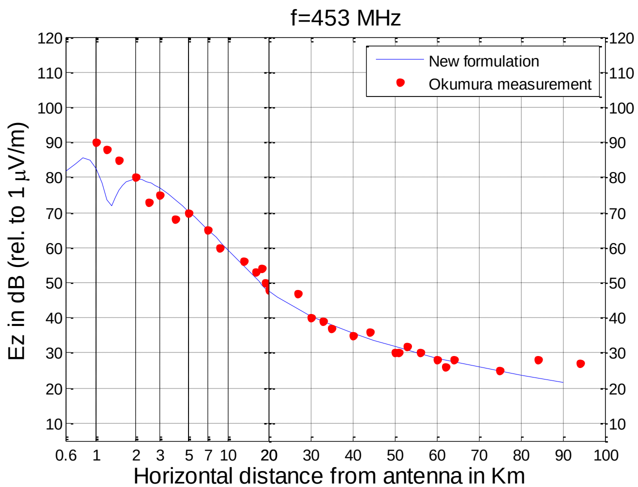
Theory – Field Near the Interface

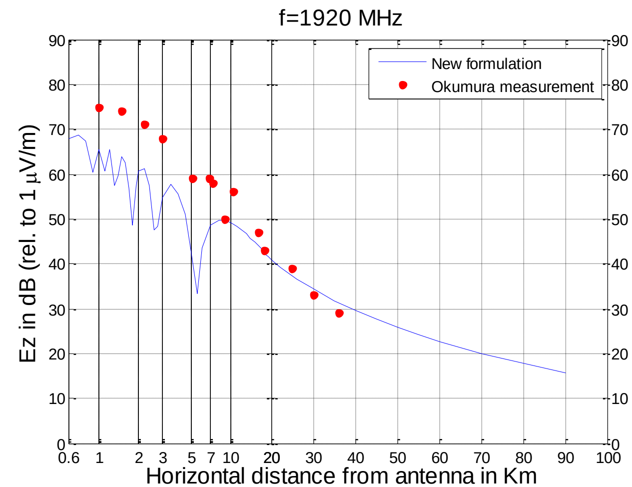
- In summary, the expressions for the total Hertz potential near the interface for $|\varepsilon| \to \infty$ and $\theta \approx \pi/2$ are:

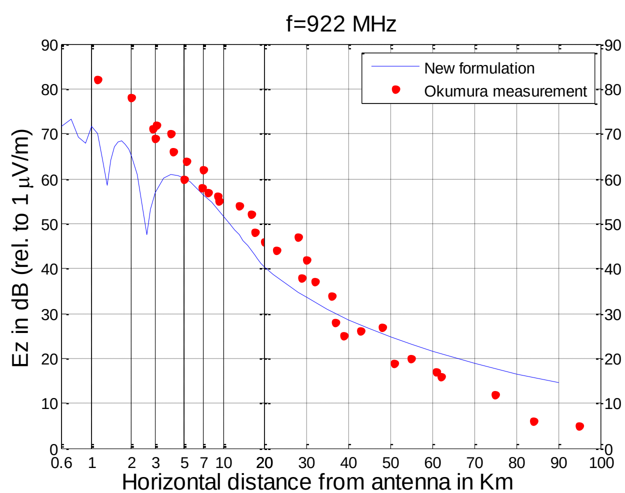
$$\Pi_{1z} \approx \begin{cases} P\left[\dfrac{\exp(-jk_1R_1)}{R_1} - \dfrac{\exp(-jk_1R_2)}{R_2} - \sqrt{j2\pi k_1}(z+z')\dfrac{\exp(-jk_1R_2)}{R_2^{\,1.5}}\right] & , W<1 \\ P\left[\dfrac{\exp(-jk_1R_1)}{R_1} - \dfrac{\exp(-jk_1R_2)}{R_2} + 2\sqrt{\varepsilon}(z+z')\dfrac{\exp(-jk_1R_2)}{R_2^{\,2}}\left[1-\dfrac{\varepsilon}{jk_1R_2}\right]\right] & , W>1 \end{cases}$$

where we can recognize **two distinct regions**:

- the first one, closer to the dipole, with a path loss exponent of 3, height gain, and no dependence with the ground parameters;
- the second one, further away from the dipole, with a path loss exponent of 4, height gain and dependence with the ground parameters.

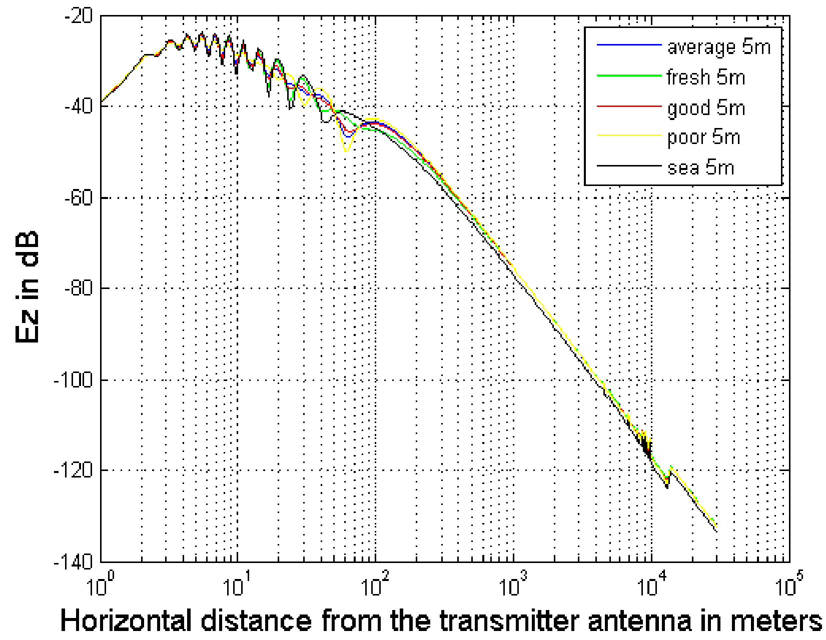






Comparison between Okumura's drive test measurements and the numerical analysis done using Schelkunoff Integrals

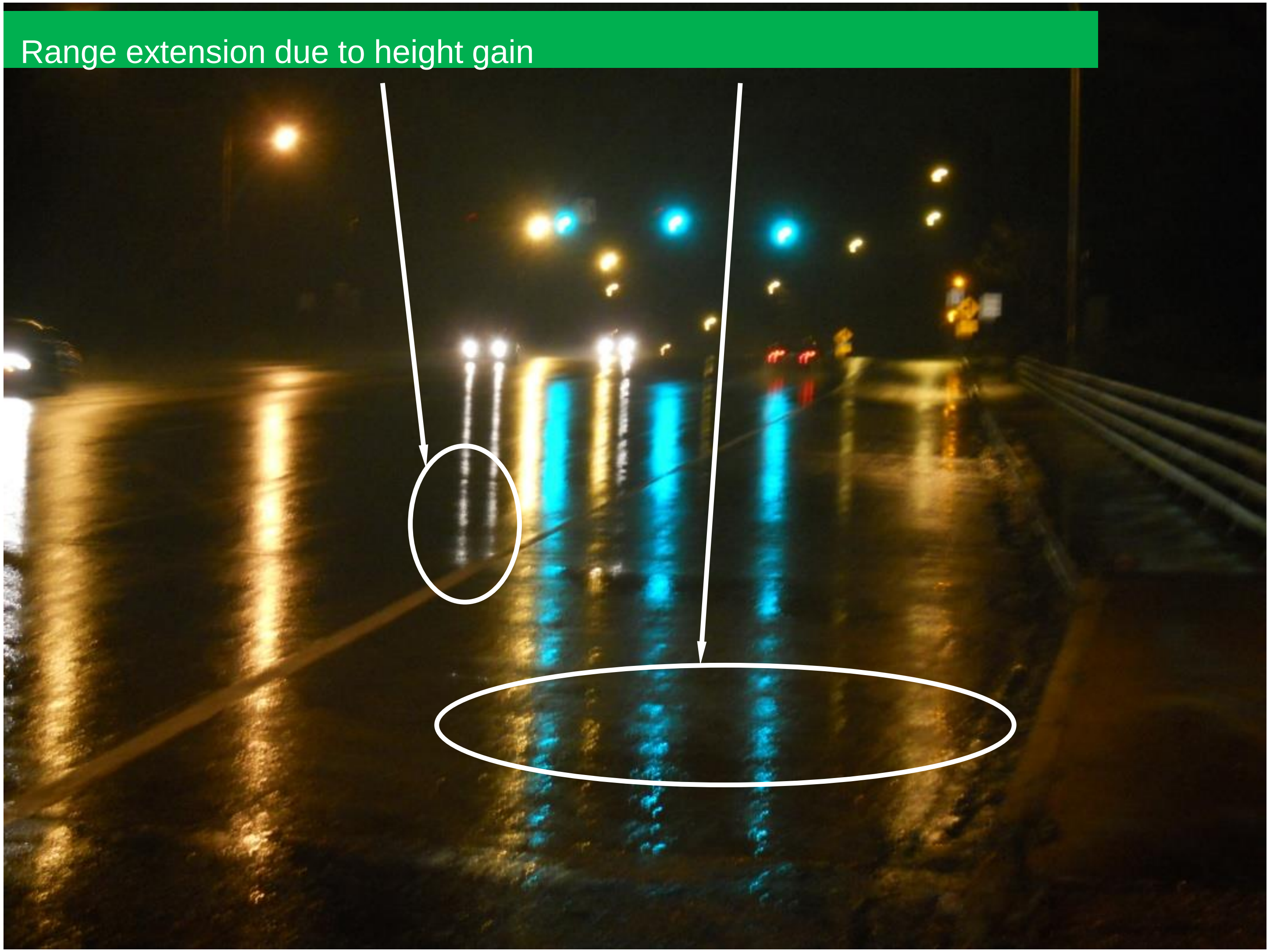
Numerical Analysis – Field Near an Earth-Air Interface

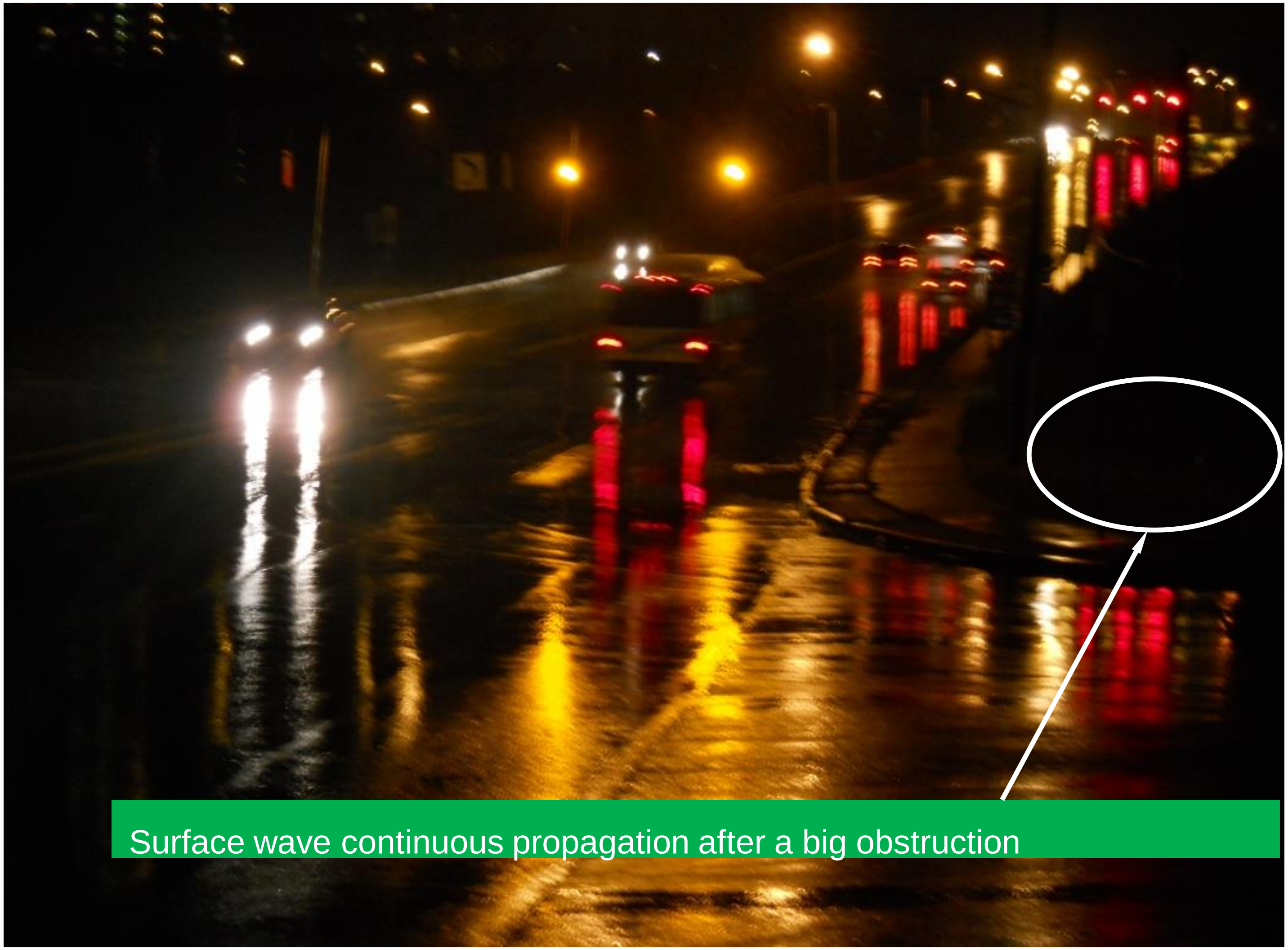


Variation of magnitude of Ez from a half-wavelength dipole as a function of distance, at an operating frequency of 900 MHz. The height of the observation point was 2 m. Five different types of ground have been used, with different parameters.

What Type of Wave Is It?

- An optical analog situation:


Range extension due to height gain


Surface wave continuous propagation after a big obstruction


10