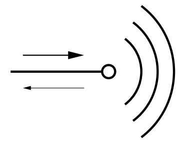

ELEC 411 – Antennas and Propagation

The Art and Science of Wireless Communications

Basic antenna concepts; antennas for low, medium and high frequencies; terrestrial and satellite propagation links; environmental effects on electromagnetic radiation. [3-0-0]

- During this lecture, the instructor will bring up many points and details not given on these slides. Accordingly, the student should annotate these notes during the lecture.
- The lecture only introduces the subject matter. Students must complete the reading assignments, review questions and problems if they are to master the material.

Course Objective

ELEC 411 - Antennas and Propagation focuses on the design and implementation of the airlink portion of wireless communications systems at both the systems and device levels.

The corresponding knowledge and skills apply directly to those:

- working in aerospace, defence, telecommunications, or broadcasting
- working for a wireless equipment manufacturer
- working for a wireless communications consulting firm
- working for a wireless service provider
- designing or testing wireless systems
- specifying or procuring antennas
- designing or testing antennas

Course Outline

Introduction

1. Wireless Test and Measurement
2. Electromagnetic Wave Propagation
3. RF Systems Engineering
4. Wireless Systems Engineering
5. Wire Antennas
6. Antenna Arrays

The course website

http://courses.ece.ubc.ca/elec411/

is your primary resource.

Course Grading

- 10% - five readiness assurance tests (RAT)
- 30% - six in-class quizzes (ICQ)
- 10% - course project report
- 50% - final exam (five problems)

- 100% - final course mark

- If you score at least 60% on the RAT and ICQ but score higher on the final exam, I will only count the final exam.

Industry Collaborators

Field Trips – Guest Lectures – Projects

UBC Radio Science Lab

CBC

TELUS®

KEYSIGHT TECHNOLOGIES

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HUAWEI

NIST National Institute of Standards and Technology U.S. Department of Commerce

5G Millimeter-Wave Channel Model Alliance

Objectives

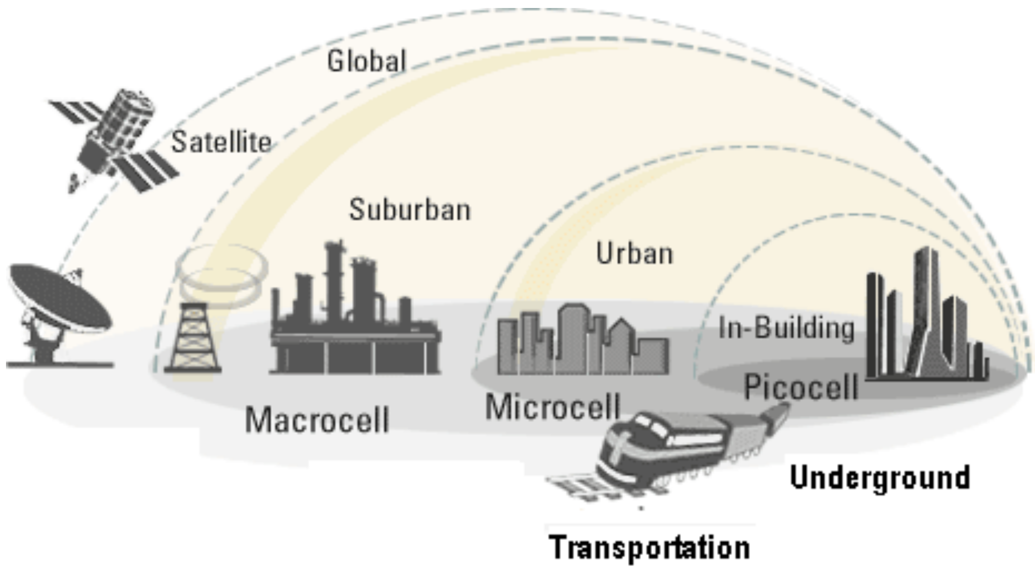
Upon completion of this lecture, the ELEC 411 student will be able:

1. to explain the key challenge of airlink design
2. to describe the key differences between wireless propagation at different frequencies
3. to explain the fundamental tasks of a wireless engineer
4. to formulate the performance of a wireless link
5. to derive the essential elements of the Friis Transmission Formula
6. to formulate a Link Budget
7. to apply the Rayleigh or Far-Field Criterion

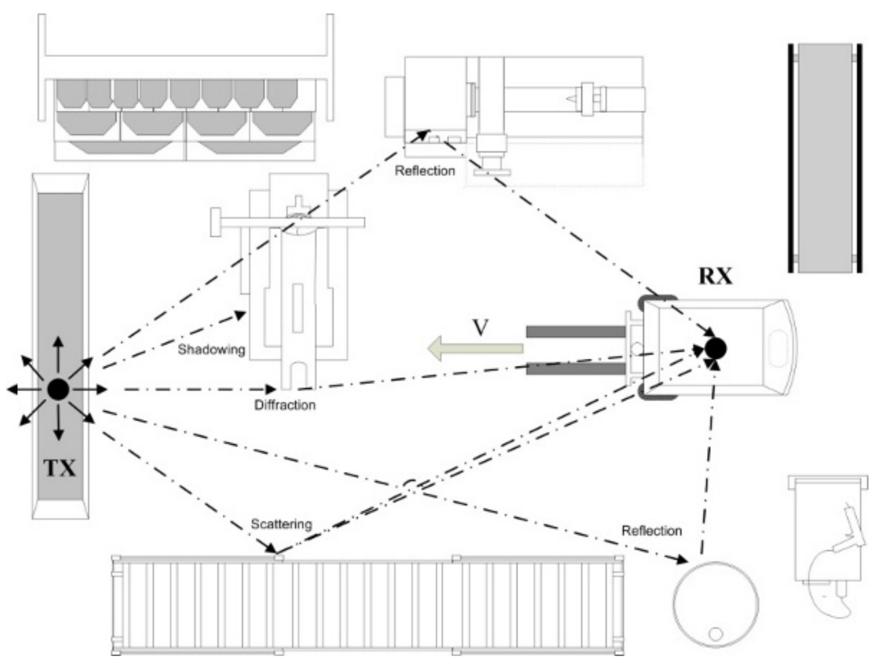
Outline

1. Wireless Networks are everywhere…
2. Introduction to Radiowave Propagation
3. What does a wireless engineer do?
4. A Typical Wireless Link
5. Friis Transmission Formula
6. Link Budget
7. Rayleigh or Far-Field Criterion

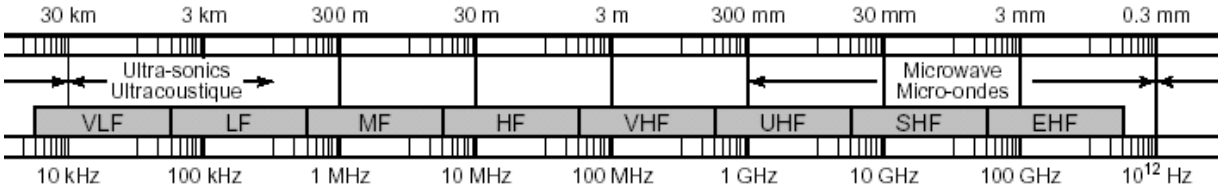
1. Wireless Networks are everywhere…



… but wireless networks are not always reliable



2. Introduction to Radiowave Propagation



- The RF Spectrum ranges from 9 kHz to 275 GHz.
- The physical mechanism by which electromagnetic waves propagate in the vicinity of the earth's surface is strongly determined by their wavelength and, to some extent, the height (expressed in wavelengths) of the transmitting and receiving antennas above the earth's surface.

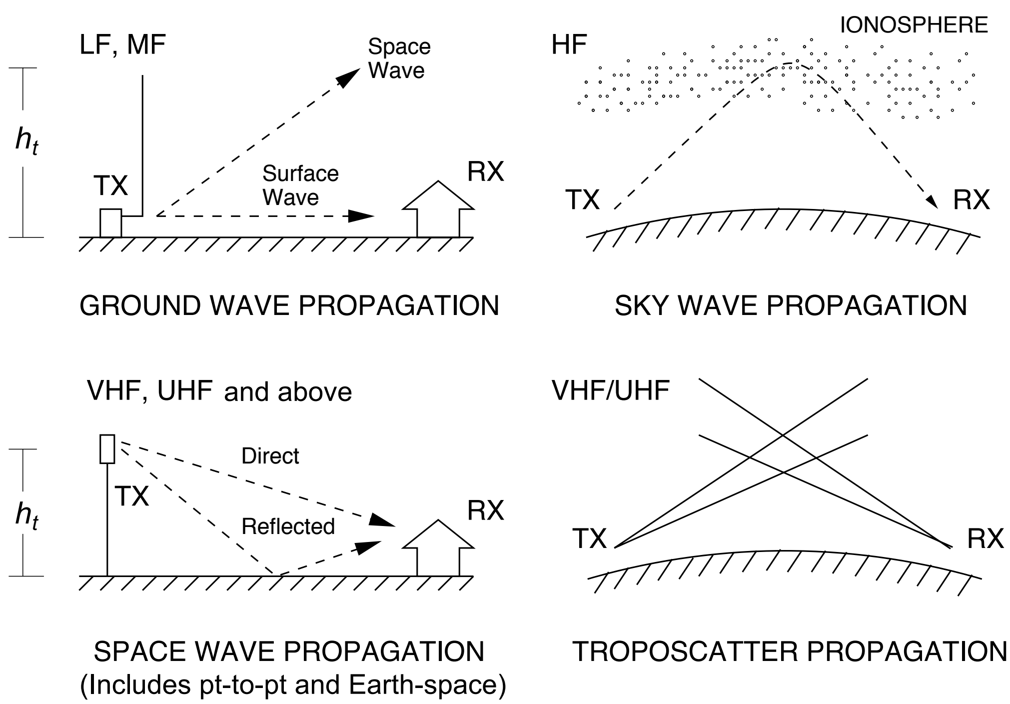
Ground and Ionospheric Propagation

- At frequencies below 3 MHz, , i.e., wavelengths of greater than 100 m, *ground wave propagation* predominates. Here, the propagating wave is bound to the interface between free space and the earth's surface.
- At frequencies between 3 and 30 MHz, , i.e., wavelengths between 10 and 100 m), long distance communication depends upon refraction by the ionosphere or *sky wave propagation*. Because the characteristics of the ionosphere vary with time of day and over time, so does the quality and reliability of long distance shortwave communications.

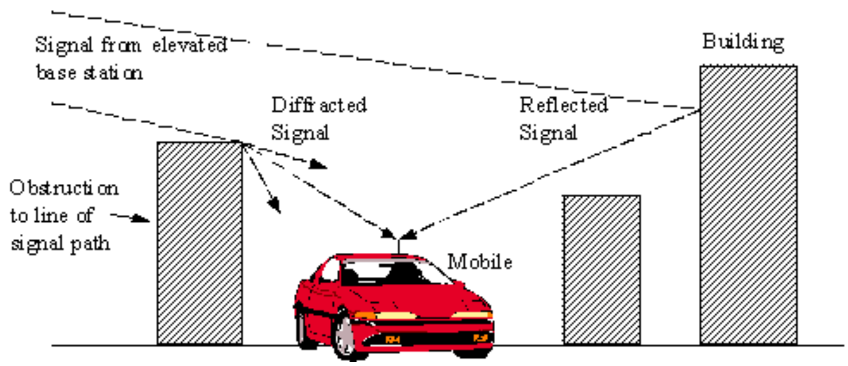
Space Wave and Troposcatter Propagation

- At frequencies above 30 MHz, i.e., wavelengths of less than 10 m, communications is often by a direct space wave. Obstruction by intervening obstacles (including the atmosphere) and reflected waves can play an important role in determining the characteristics of the channel.
- At frequencies between 30 and 3000 MHz, long distance communications can be achieved through scattering of the signal by mechanisms such as propagation by means of random reflections and scattering from irregularities in the dielectric gradient density of the troposphere, smooth-Earth diffraction, and diffraction over isolated obstacles. This mode is commonly referred to as tropospheric scatter or troposcatter.

Radiowave Propagation - 4



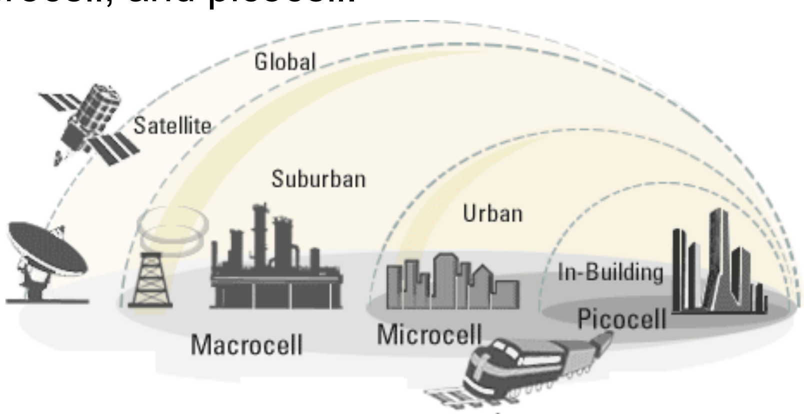
Radiowave Propagation - 5



- Signal propagation in macrocell environments:
  - Base station above local rooftop level
  - Mobile terminal below local rooftop level

ITU-R Propagation Zones

- The ITU-R has described four basic classes of radiowave propagation environments based upon range of coverage and the nature of the intervening obstructions: satellite (megacell), macrocell, microcell, and picocell.



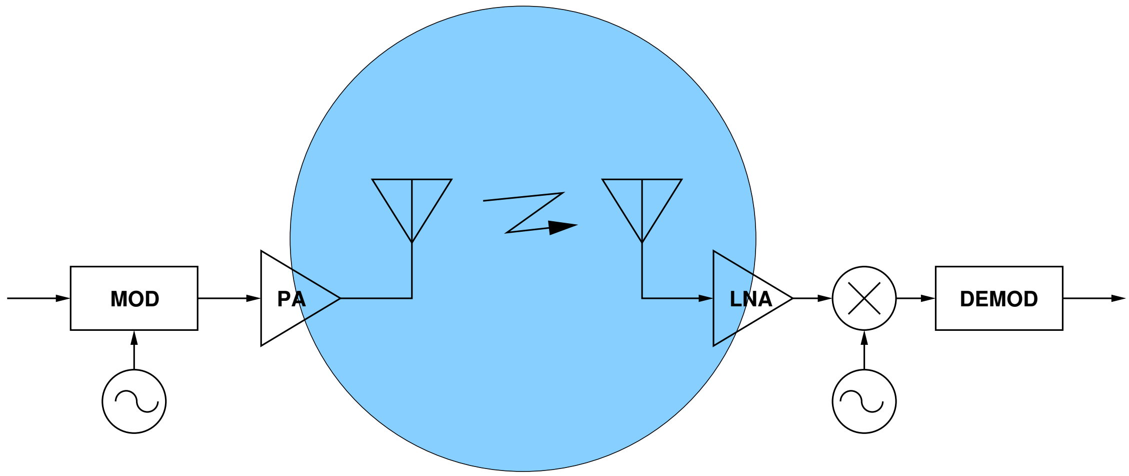
3. What Does a Wireless Engineer Do?

- Given a communications scenario, a wireless engineer proposes an equipment configuration that will permit voice, data or other information to be transmitted with the required throughput, reliability and cost.
- Account must be taken of:
  - Table of frequency allocations (carrier frequency or frequency band)
  - Radio regulations (power, bandwidth, modulation)
  - RF coverage (path loss)
  - Link reliability (noise, fading)
  - Interference (to or from others)

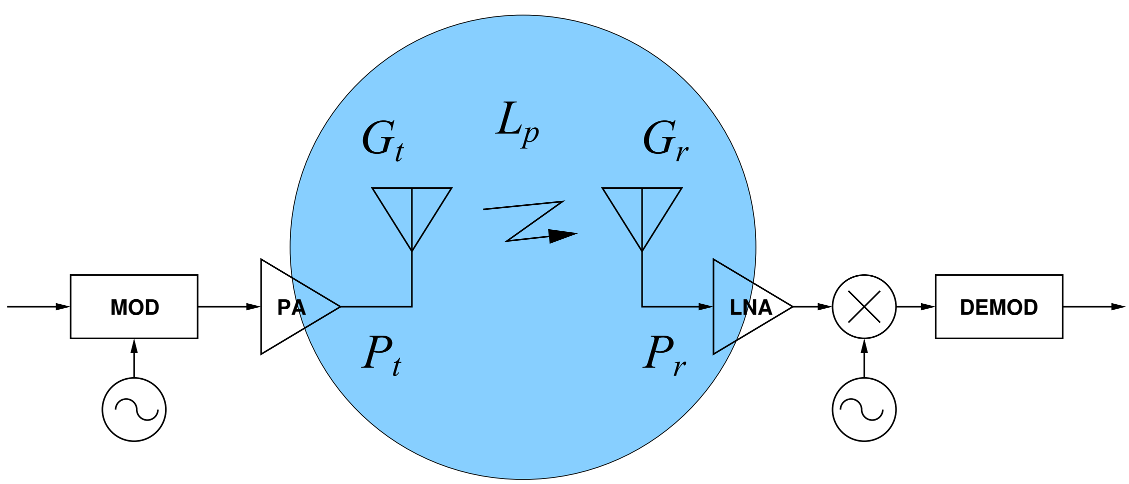
The Problem

- A transmitting antenna is used to launch a propagating wave which is intercepted by a receiving antenna located some distance away.
- How much power will appear at the output port of the receiving antenna?
- For free space or line-of-sight (LOS) propagation with no reflections, the calculation is very straightforward.
- If the path is obstructed (non-line-of-sight or NLOS), there are multiple propagation paths, or time-varying factors such as weather or moving objects (people, vehicles) affect transmission along the path, the calculation is much more involved.

4. A Typical Wireless Link



Analyzing a Typical Wireless Link



5. Friis Transmission Formula

- For the special case of transmission through free space,

$$P_r = P_t \cdot G_t \cdot G_r \cdot \left(\frac{\lambda}{4\pi r} \right)^2 .$$

- Where does this equation come from?
- What is the physical significance of each factor?
- What is meant by “derive on demand”?

Analyzing the Friis Transmission Formula

- Isotropic Radiated Power Density

$$P_d = P_t \cdot \frac{1}{4\pi r^2}$$

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Analyzing the Friis Transmission Formula

- Effective Isotropic Radiated Power Density (in a particular direction)

$$P_d = P_t \cdot G_t \cdot \frac{1}{4\pi r^2}$$

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Analyzing the Friis Transmission Formula

- Received Power

$$P_r = P_d \cdot A_{eff}$$

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Analyzing the Friis Transmission Formula

- Effective Area of a Receiving Antenna

$$A_{eff} = \frac{\lambda^2}{4\pi} \cdot G_r$$

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Analyzing the Friis Transmission Formula

- Received Power

$$P_r = P_d \cdot \frac{\lambda^2}{4\pi} \cdot G_r$$

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Analyzing the Friis Transmission Formula

- Received Power

Effective Area of the receiving antenna

$$P_r = P_t \cdot G_t \cdot \frac{1}{4\pi r^2} \cdot \frac{\lambda^2}{4\pi} \cdot G_r$$

EIRP

Power Density at distance r

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Analyzing the Friis Transmission Formula

- Received Power

$$P_r = P_t \cdot G_t \cdot \frac{1}{4\pi r^2} \cdot \frac{\lambda^2}{4\pi} \cdot G_r$$

Path Gain (free space)

$$G_p = \frac{1}{L_p} = \left(\frac{\lambda}{4\pi r} \right)^2$$

- Exercise: Define each parameter in the equation, explain its physical significance and give its SI unit.

Friis Transmission Formula

- QED - For the special case of transmission through free space, i.e., no reflections or obstructions,

$$P_r = P_t \cdot G_t \cdot G_r \cdot \left(\frac{\lambda}{4\pi r} \right)^2 .$$

- However, the parameters are expressed in linear units.
- Would it make sense to express them in decibels?
- Later, we will show how to: 1) account for reflections and obstacles and 2) extend to radar systems.

Friis Transmission Formula (in dB)

$$P_r = P_t + G_t + G_r + \boxed{20\log\lambda - 20\log r - 21.98}$$

Path Gain
(free space)

- Exercise: Give the above expression in terms of frequency in MHz rather than wavelength in metres.

6. Link Budget

- It is useful to summarize the factors that reduce the power applied to the transmitting antenna to the power observed at the receiver in the form of a spreadsheet.
- This allows us to assess the effect of trading of different design parameters on system performance and compare the received power P_r to the receiver sensitivity P_{sens}.
- Simple link budgets compare the received power P_r to the receiver sensitivity P_{sens}.
- More complicated link budgets will compare the received power P_r to the noise power at the receiver input in order to estimate the input signal-to-noise ratio.

A Simple Link Budget

It is useful to summarize the factors that reduce the power applied to the transmitting antenna to the power observed at the receiver in the form of a spreadsheet.

P_t	Transmitted Power	20 dBm
L_t	Cable Loss	3 dB
G_t	Transmitting Antenna Gain	5 dBi
L_p	Path Loss	95 dB
G_r	Receiving Antenna Gain	0 dBi
L_r	Cable Loss	3 dB
P_r	Received Power	-76 dBm
P_{min}	Receiver Sensitivity	-85 dBm
	System Margin	9 dB

- Add gains (in dB) and subtract losses (in dB) to yield the received power
- The system margin is the difference between the received power and receiver sensitivity

Notes on a Simple Link Budget

- Cable losses are typically between 1 and 10 dB.
- Typical antenna gains include:

  0 dBi normal mode helix

  2.2 dBi half-wave dipole

  15 dBi directional antenna

  24 dBi parabolic reflector
- Receiver sensitivity may range from -70 to -120 dBm.
- A reliable link generally requires a margin of at least 10 dB.
- EIRP = Effective Isotropic Radiated Power = $P_t G_t$

Notes on a Simple Link Budget - 2

- A well-considered link budget lies at the heart of any successful wireless systems design.
- In a large organization, a senior member of the systems engineering design team is typically designated as the keeper of the link budget.
- Designers must keep track of the evidence and assumptions that underlie each entry in the link budget.
- More complicated link budgets will also account for noise, interference and performance parameters such as bit error rate (BER)

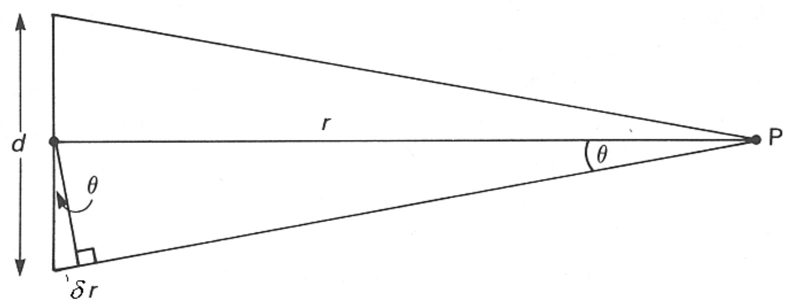
Notes on a Simple Link Budget - 3

- Many problems in ELEC 411 and in real life will involve formulation and solution of a link budget.
- Some parameters will be given, others must be determined by measurement or calculation.
- In most cases, the objective is to determine:
  – which design parameters are fixed,
  – which design parameters be adjusted, and
  – what values for the adjustable design parameters will allow one to achieve the desired performance goals

7. Rayleigh or Far-Field Criterion

- The Friis transmission formula assumes that the wave incident upon the receiving antenna is a plane wave.
- In practice, the wave radiated by an antenna is a spherical wave.
- If r (both the separation between the antennas and the radius of curvature of the spherical wavefront) is sufficiently large, the wave is *effectively* plane.
- How large is sufficient? It depends upon:
  – the size or extent of the receiving antenna, and,
  – the variation in phase across the antenna aperture that we can tolerate.

Rayleigh or Far-Field Criterion - 2



- If the angle θ is small, $\theta \approx \dfrac{d}{2r}$ and $\delta r \approx \dfrac{d}{2}\theta.$
- Thus, the additional phase shift $\delta\phi$ encountered at the edge of the aperture is

$$\delta\phi = \delta r \frac{2\pi}{\lambda} = \frac{\pi d}{\lambda} \cdot \frac{d}{2r}$$

Rayleigh or Far-Field Criterion - 3

- The Rayleigh criterion for the transition from a spherical wave to an "effectively plane wave" allows a phase variation across the aperture of the receiving antenna of 45° or ±22.5° .
- This occurs when $r = 2d^2 / \lambda.$
- In the worst case, if both antennas are of significant extent with maximum aperture dimensions d_1 and d_2, respectively, the far-field criterion becomes

$$r = 2(d_1^2 + d_2^2) / \lambda.$$

- Exercise: Prove this.

Summary

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