Wireless Communications

EENG 5820

Lecture 4

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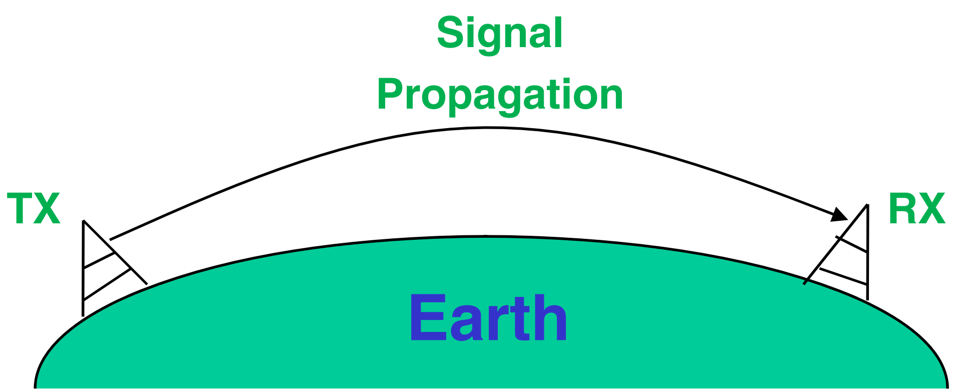
Today

- Introduction to radio wave propagation
- Large scale path loss
- Reflection

4.1 Introduction to Radio Wave Propagation

- Ground wave propagation
- Sky wave propagation
- Line-of-sight propagation

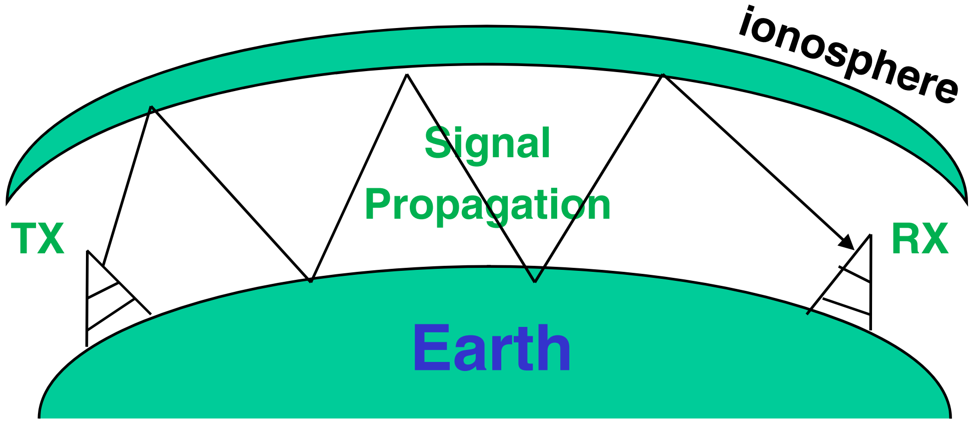


Ground wave propagation

- follows the contour of the earth
- scattered by the atmosphere (no penetration of upper atmosphere)
- < 2MHz, AM radio

4.1 Introduction to Radio Wave Propagation

- Ground wave propagation
- Sky wave propagation
- Line-of-sight propagation

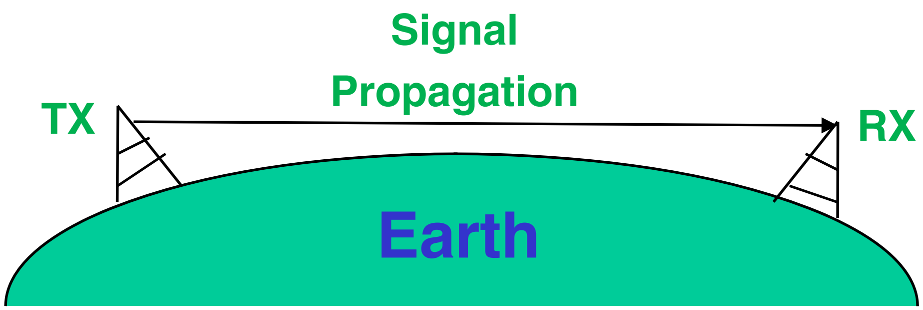


Sky wave propagation

- Bounced between ionosphere and earth
- Thousands of Kms
- 3 ~ 30MHz, international radio, BBC, VOA

4.1 Introduction to Radio Wave Propagation

- Ground wave propagation
- Sky wave propagation
- Line-of-sight propagation



Line-of-sight (LOS) propagation

- > 30MHz

4.1 Introduction to Radio Wave Propagation

- **Large-scale** propagation model: predict the mean signal strength for an arbitrary T-R separation distance
- **Small-scale** propagation model (fading): characterize the rapid fluctuations of the received signal strength over short travel distance (~λ) or short time durations (~sec.)
- Fading tracks 5 λ ~ 40 λ. For 1GHz ~ 2GHz, measurements of 1m ~ 10 m

4.1 Introduction to Radio Wave Propagation

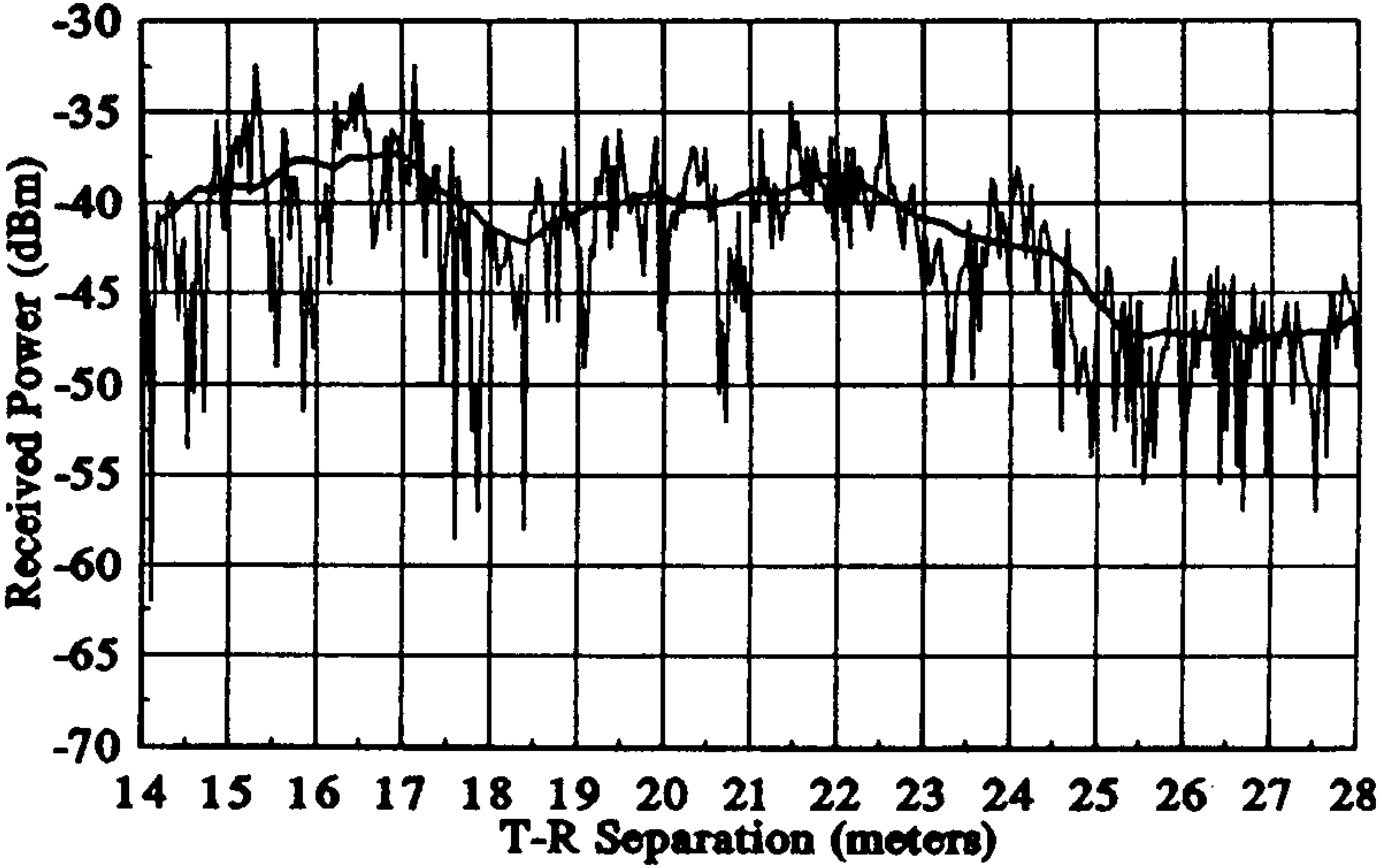


Figure 4.1 Small-scale and large-scale fading.

4.2 Free Space Propagation Model

- **Isotropic radiator**: radiates equally in all directions. Does not exist in practice, but is a good starting point
  - Transmitted power will radiate in a large sphere

$$P_r(d) = P_t\left(\frac{\lambda}{4\pi d}\right)^2$$

- **Antenna directivity**: if an antenna transmits more power in one direction than another, it is called directional.
- **Antenna efficiency**: Accounts for loss in the antenna itself, but does not include impedance mismatch of the antenna

4.2 Free Space Propagation Model

Antenna gain

- Gain = Directivity * Efficiency. For large antennas

$$G = \frac{4\pi A_e}{\lambda^2}$$

Received power considering antenna gains:

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

Path Loss: $$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi d)^2}\right]$$

Friis free space equation (L loss factor):

$$P_r(d) = P_t G_t G_r \frac{\lambda^2}{(4\pi)^2 d^2 L}$$

4.2 Free Space Propagation Model

Fraunhofer region

- d should be in the far-field of the transmitting antenna

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

$$d_f = \frac{2D^2}{\lambda}$$

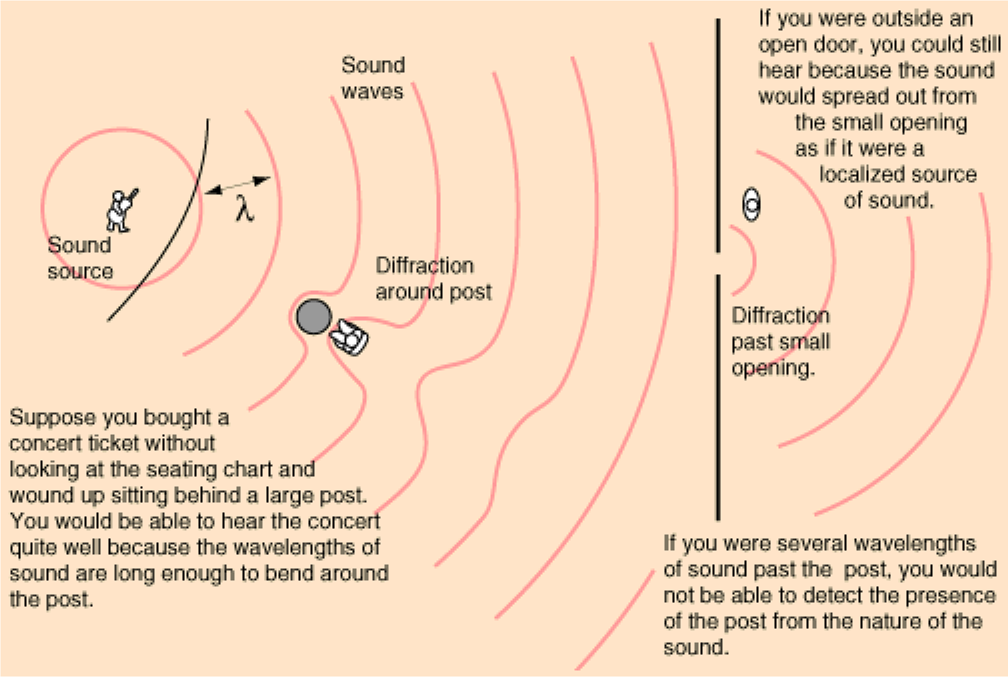
D: largest physical linear dimension of the antenna

$$d_f >> D \qquad d_f >> \lambda \qquad 5 \sim 40\lambda$$

Ex: D = 1m, f = 900MHz, find d_f

4.4 The Three Basic Propagation Mechanisms

- **Reflection: Bounced by large dimension objects (compared to wavelength, earth, wall)**
- **Diffraction: Obstructed by a surface that has sharp irregularities (edges)**
- **Scattering: Produced by objects with dimensions that are small (compared to wavelength, rough surface)**



4.5 Reflection

■ Reflection from dielectrics

- Review of basic EM

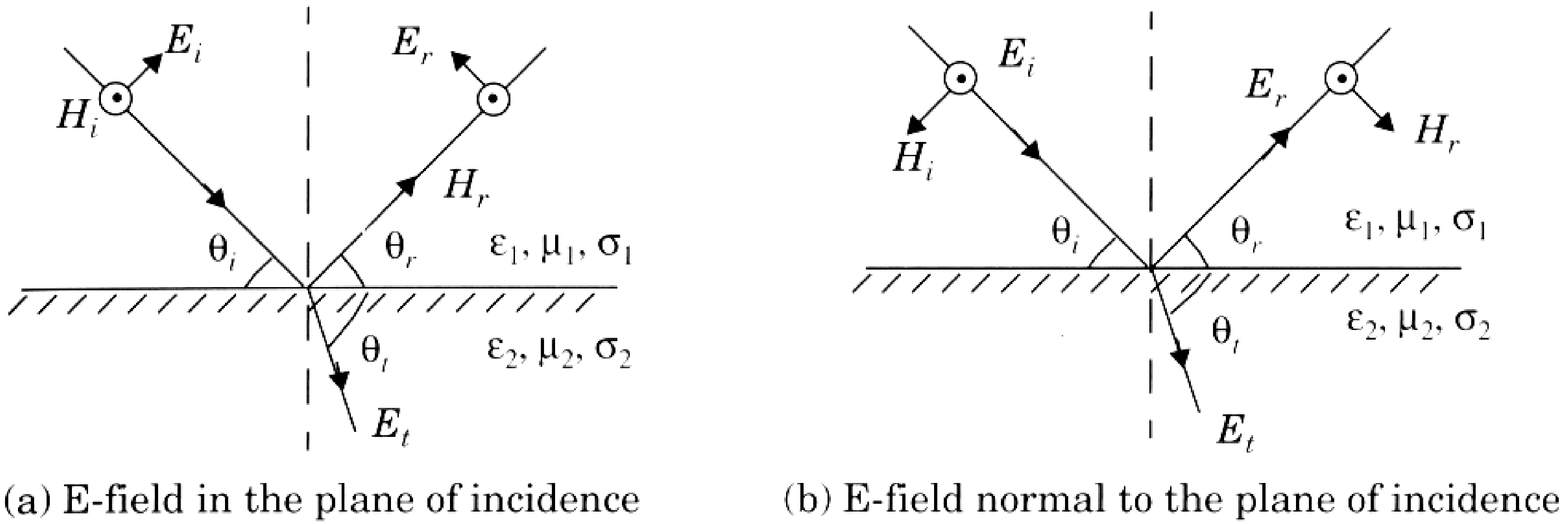


Figure 4.4 Geometry for calculating the reflection coefficients between two dielectrics.

ε: permittivity, μ: permeability, σ: conductance

4.5 Reflection

■ Dielectric properties of materials

Table 4.1 Material Parameters at Various Frequencies

Material	Relative Permittivity ε_r	Conductivity σ (s/m)	Frequency (MHz)
Poor Ground	4	0.001	100
Typical Ground	15	0.005	100
Good Ground	25	0.02	100
Sea Water	81	5.0	100
Fresh Water	81	0.001	100
Brick	4.44	0.001	4000
Limestone	7.51	0.028	4000
Glass, Corning 707	4	0.00000018	1
Glass, Corning 707	4	0.000027	100
Glass, Corning 707	4	0.005	10000

4.5 Reflection

Reflection coefficients

$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_2 \sin\theta_t + \eta_1 \sin\theta_i} \quad \text{(E - field in plane of incidence)}$$

$$\Gamma_{\perp} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_2 \sin\theta_i + \eta_1 \sin\theta_t} \quad \text{(E - field normal to the plane of incidence)}$$

Where intrinsic impedance $\eta_i = \sqrt{\mu_i / \varepsilon_i}$

Snell's law $\sqrt{\mu_1 \varepsilon_1} \sin(90 - \theta_i) = \sqrt{\mu_2 \varepsilon_2} \sin(90 - \theta_t)$

$$\theta_i = \theta_r \qquad E_r = \Gamma E_i \qquad E_t = (1 + \Gamma) E_i$$

4.6 Ground Reflection (Two-Ray) Model

- One direct path is inaccurate
- In mobile systems, T-R distance is a few tens of Kms → earth is assumed to be flat

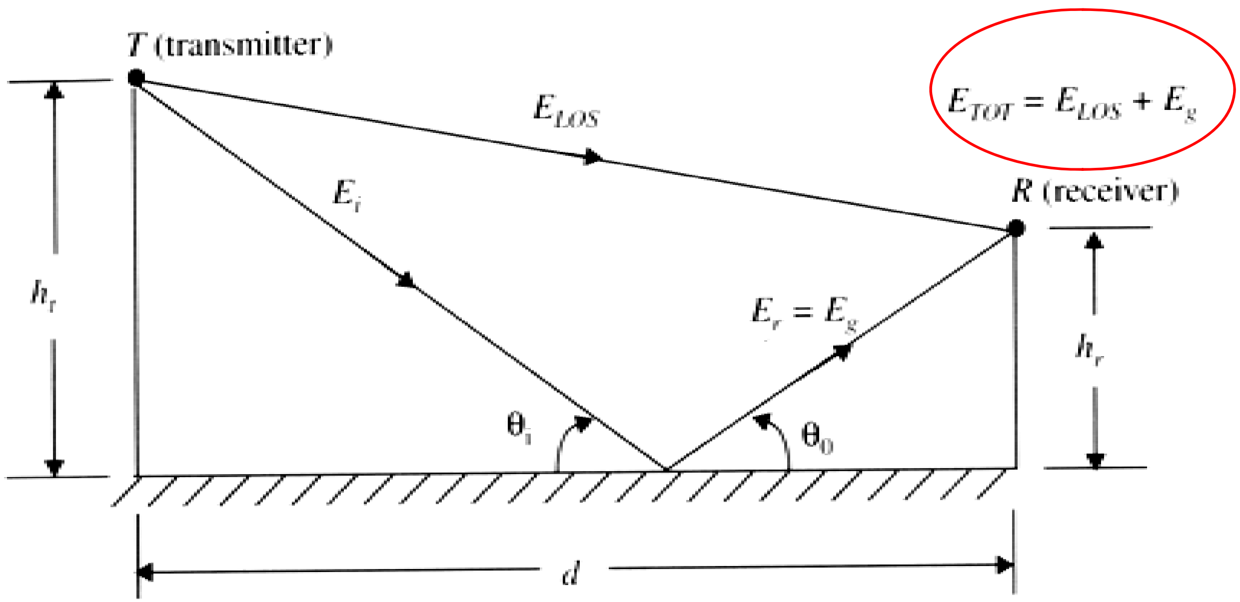


Figure 4.7 Two-ray ground reflection model.

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4.6 Ground Reflection (Two-Ray) Model

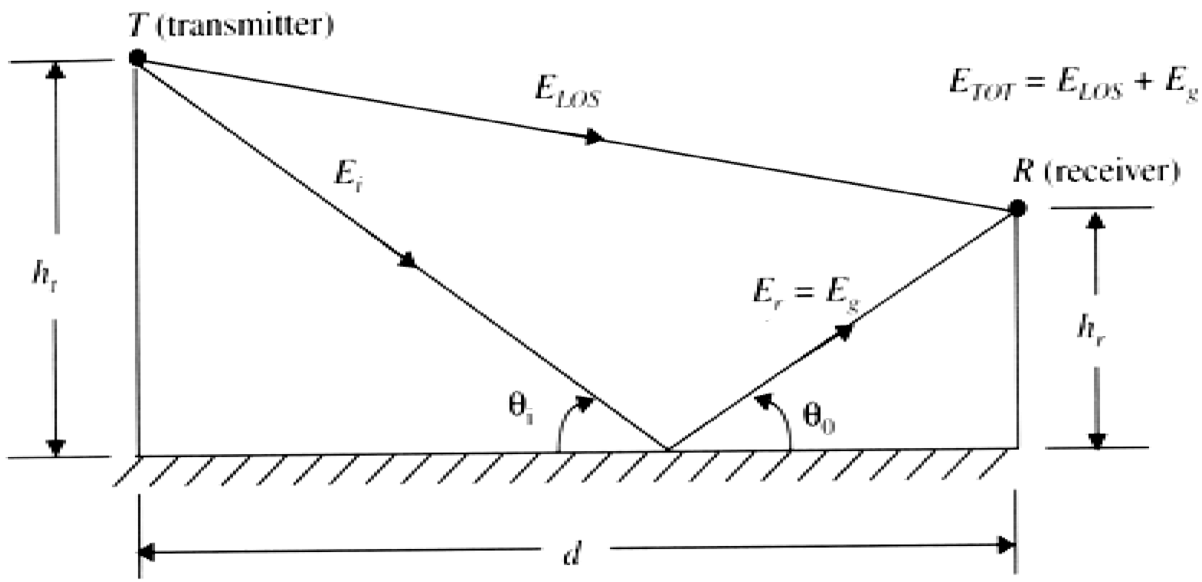

Figure 4.7 Two-ray ground reflection model.

$$E(d,t) = \frac{E_0 d_0}{d}\cos\left(\omega_c\left(t - \frac{d}{c}\right)\right), \quad d > d_0$$

E_0 : electric field (V/m)

d_0 : some small distrance from the TX that is in the far field

4.6 Ground Reflection (Two-Ray) Model

$$E(d,t)=\frac{E_0 d_0}{d}\cos\left(\omega_c\left(t-\frac{d}{c}\right)\right),\quad d>d_0$$

Due to LOS:

$$E_{LOS}(d',t)=\frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t-\frac{d'}{c}\right)\right)$$

Due to reflection:

$$E_g(d'',t)=\Gamma\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t-\frac{d''}{c}\right)\right)$$

Total:

$$\left|E_{TOT}(d,t)\right|=\left|E_{LOS}+E_g\right|$$

$$E_{TOT}(d,t)=\frac{E_0 d_0}{d'}\cos\left(\omega_c\left(t-\frac{d'}{c}\right)\right)+(-1)\frac{E_0 d_0}{d''}\cos\left(\omega_c\left(t-\frac{d''}{c}\right)\right)$$

4.6 Ground Reflection (Two-Ray) Model

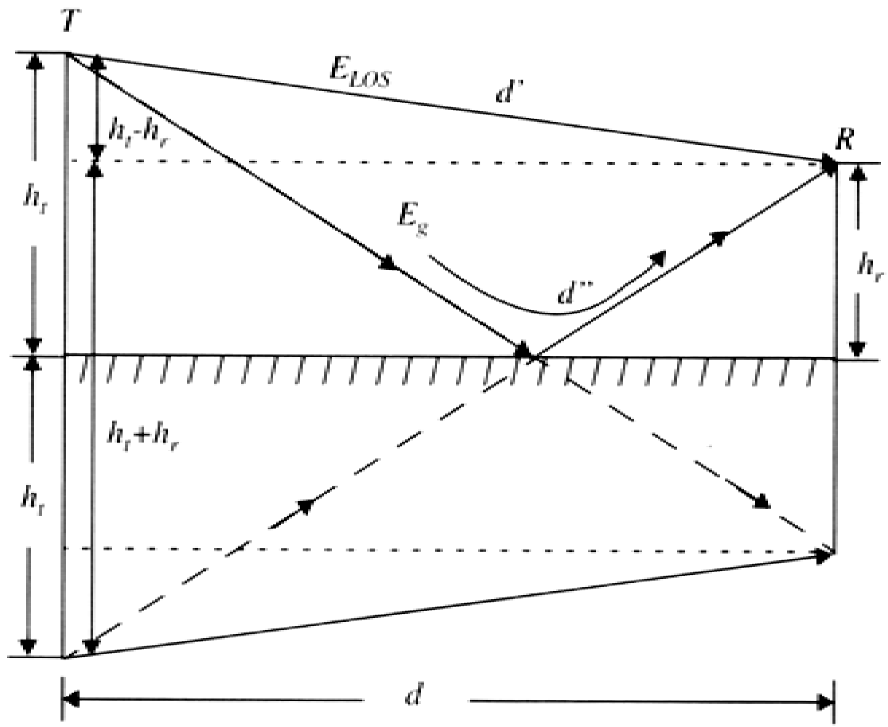

Figure 4.8 The method of images is used to find the path difference between the line-of-sight and the ground reflected paths.

$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

$$d >> h_t + h_r \quad \longrightarrow \quad \Delta = d'' - d' \cong \frac{2h_t h_r}{d}$$

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4.6 Ground Reflection (Two-Ray) Model

Phase: $$\theta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\omega_c \Delta}{c}$$

Time delay: $$\tau_d = \frac{\Delta}{c} = \frac{\theta_\Delta}{2\pi f_c}$$

For large distance: $$\left|\frac{E_0 d_0}{d}\right| \cong \left|\frac{E_0 d_0}{d'}\right| = \left|\frac{E_0 d_0}{d''}\right|$$

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) = \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(\frac{d''}{c} - \frac{d'}{c}\right)\right) - \frac{E_0 d_0}{d''} \cos 0$$

4.6 Ground Reflection (Two-Ray) Model

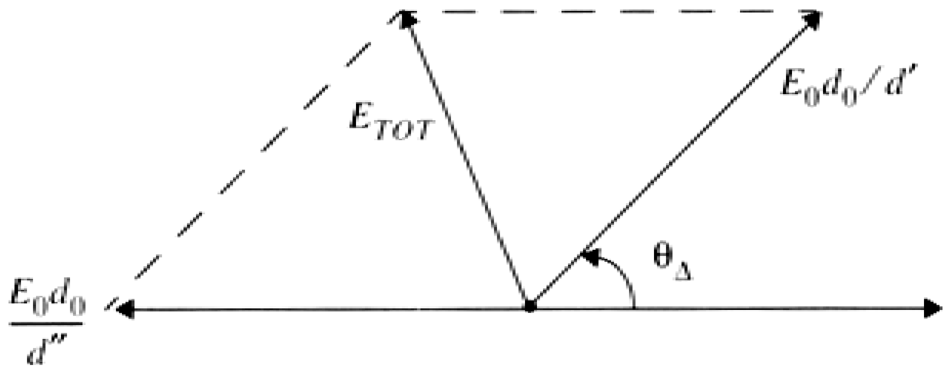

Figure 4.9 Phasor diagram showing the electric field components of the line-of-sight, ground reflected, and total received E-fields, derived from Equation (4.45).

$$\left|E_{TOT}(d)\right| = \sqrt{\left(\frac{E_0 d_0}{d}\right)^2 (\cos\theta_\Delta - 1)^2 + \left(\frac{E_0 d_0}{d}\right)^2 \sin^2\theta_\Delta}$$

$$\left|E_{TOT}(d)\right| = \frac{E_0 d_0}{d}\sqrt{2 - 2\cos\theta_\Delta} = 2\frac{E_0 d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right)$$

4.6 Ground Reflection (Two-Ray) Model

$$\left|E_{TOT}(d)\right| = \frac{E_0 d_0}{d}\sqrt{2-2\cos\theta_\Delta} = 2\frac{E_0 d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right)$$

$$\frac{\theta_\Delta}{2} \cong \frac{2\pi h_t h_r}{\pi d} < 0.3\text{rad}$$

$$\sin\frac{\theta_\Delta}{2} \cong \frac{\theta_\Delta}{2}$$

$$\left|E_{TOT}(d)\right| = \frac{2E_0 d_0}{d}\frac{2\pi h_t h_r}{\lambda d} \quad \longrightarrow \quad P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

The power for a 2-ray model is falling off as d^4 which is faster than the free space value of d^2