

# Pre-assignment of Topic 5

Answer the following questions. You can consult with Wikipedia, for example, for some intuitive explanations of Huygens' principle. You can use drawings of your own and try not to copy any figure drawn by others (for your learning). Watching <https://youtu.be/vqa4L0DuWbM> may be of help.

1. Explain, what is the Huygens' principle.
2. Explain propagation of a plane wave, e.g., incident from  $-z$  direction toward  $+z$  direction ( $f(z) = e^{-jkz}$ ), using the Huygens' principle.
3. Explain using the Huygens' principle. Why we can receive radio signals behind a corner, even though we do not see the other side of a radio transmitter?

# Interactive lecture of Topic 5: Radio wave propagation and radiation safety

March 10, 2022

Katsuyuki Haneda

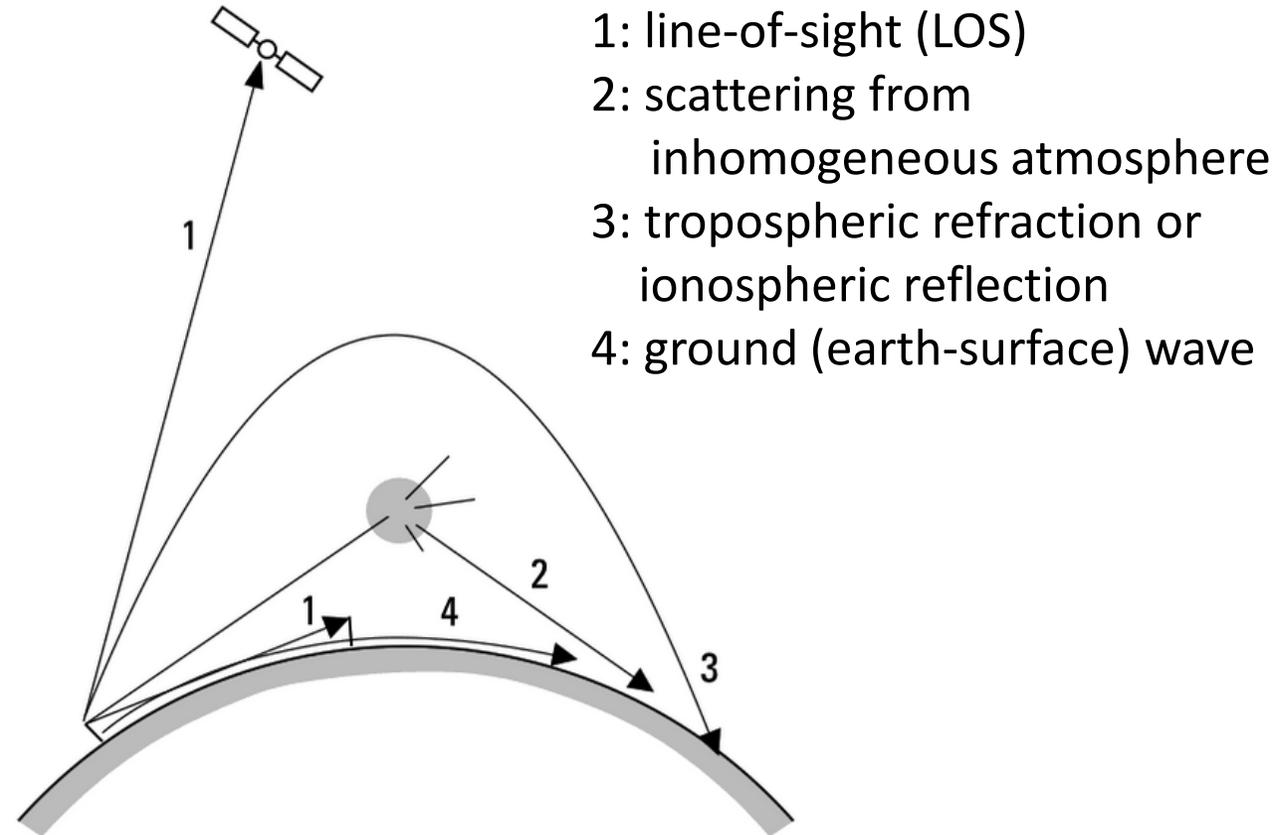
Department of Electronics and Nanoengineering

In this topic, we mainly cover Chapter 10 “Propagation of radio waves” in Radio Engineering for Wireless Communication and Sensor Applications by A. Raisanen and A. Lehto.

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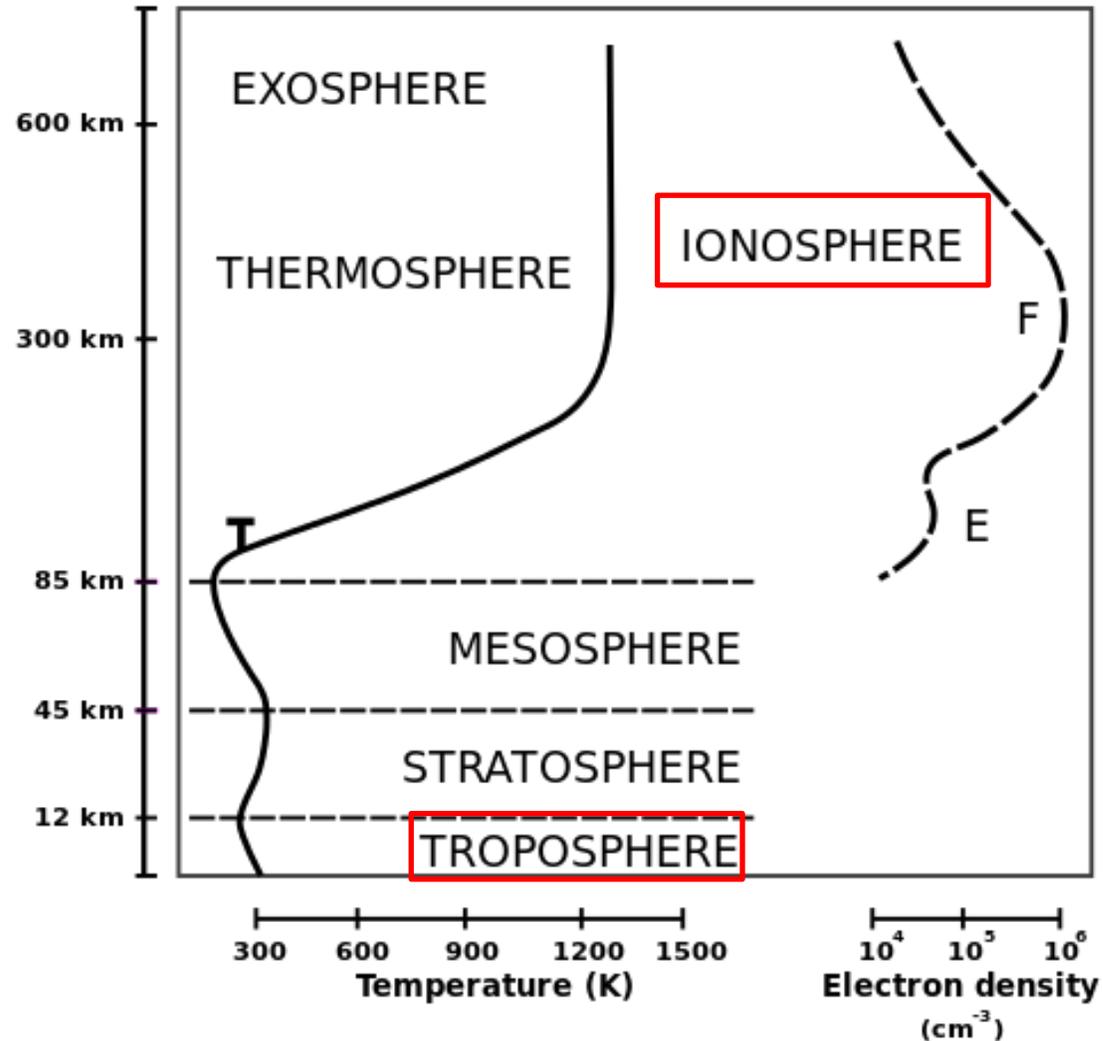
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# Wave propagation of long-range links



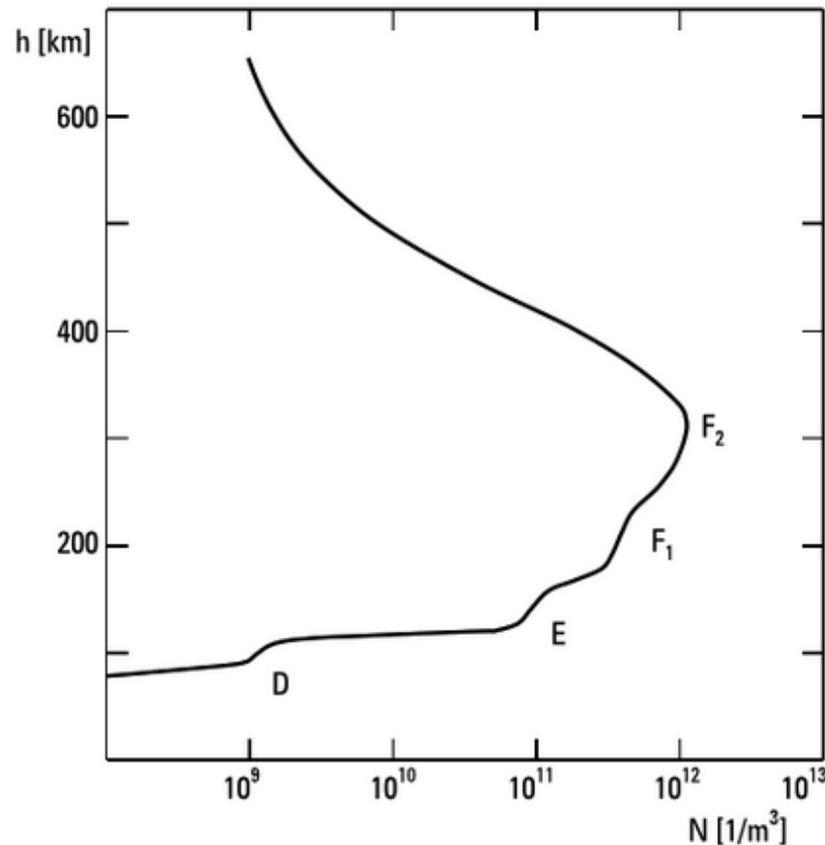
**Figure 10.1** Propagation mechanisms of radio waves (numbers refer to different mechanisms described in text).

# Atmosphere around Earth's surface



# Ionosphere effects on radio propagation

- Ionization and recombination of gas atoms and molecules due to e.g. ultraviolet (UV) radiation from the sun → free electron
- Key parameter: electron concentration per cubic meter  $N$



- The electron concentration influences the refractive index:

$$n_0^2 = 1 - \left( \frac{f_c}{f} \right)^2$$

$$f_c = 8.9788 \sqrt{N} \text{ [Hz]}$$

: Critical frequency **around MHz**

- Refractive index becomes imaginary below  $f_c$  and electromagnetic field bounces back to ground.

Figure 10.15 Electron density in the ionosphere versus altitude.

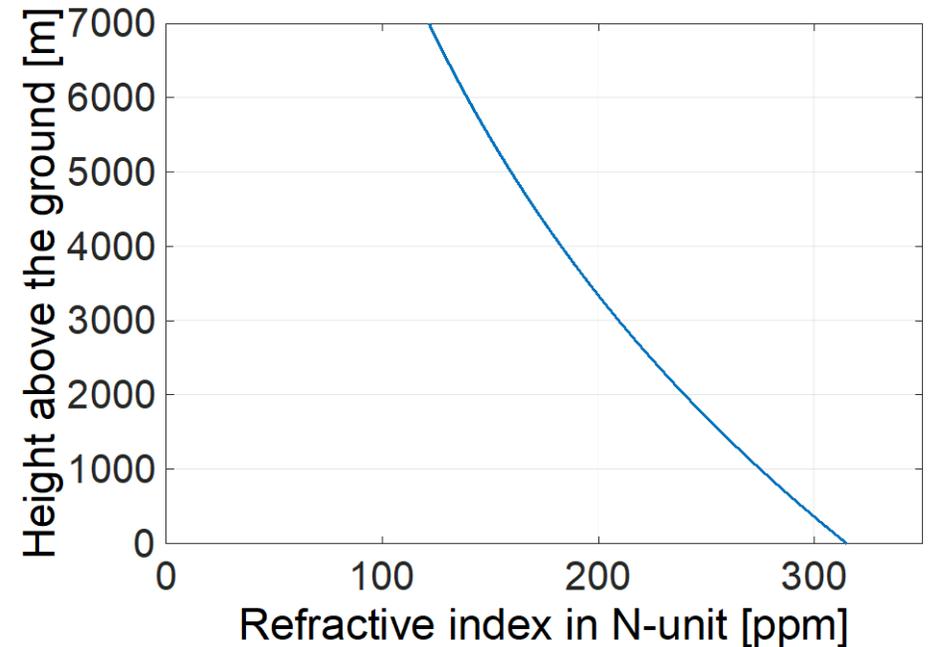
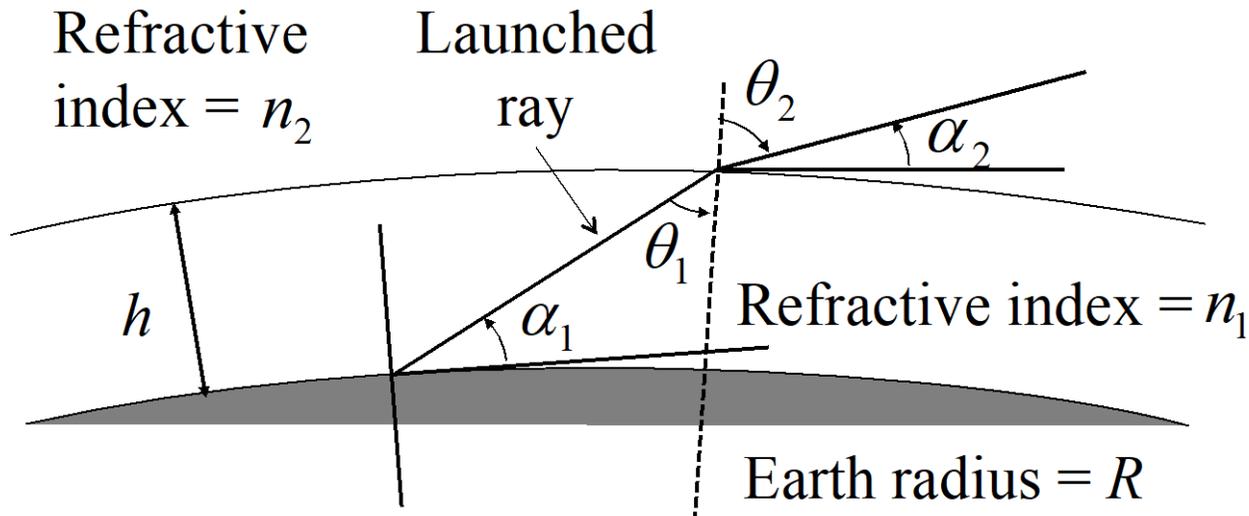
# Tropospheric refraction

- Snell's law of refraction

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_i = c_0 \sqrt{\epsilon_i \mu}$$

- Refractive index changes due to pressure and temperature.
- Waves launched to lower elevation angle may refract back to the ground → Long range link in any radio frequency.



# Atmospheric effects

- ... can be analyzed through a relationship between the radius of, e.g., rain drop  $r$  and wavelength  $\lambda$

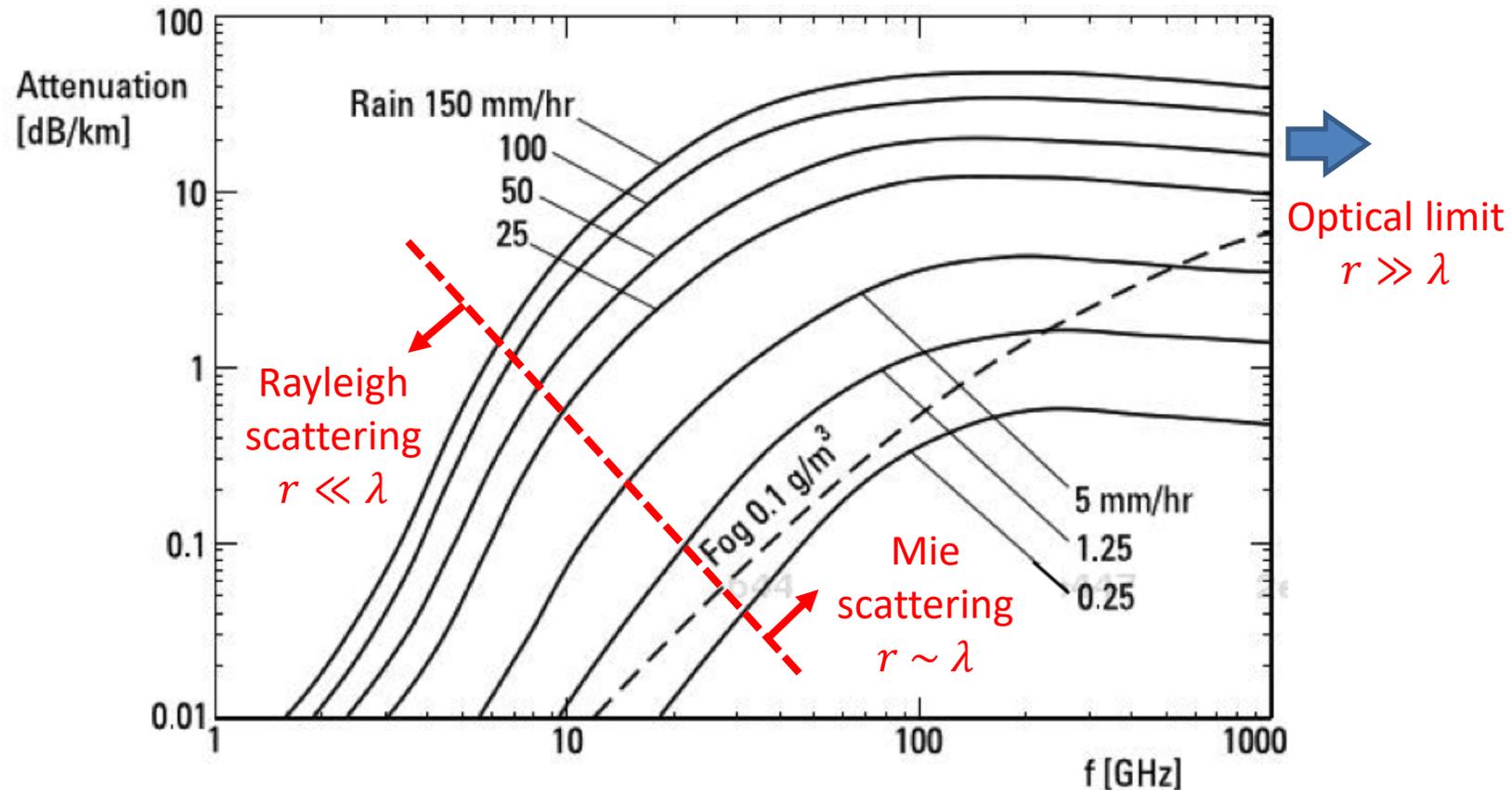
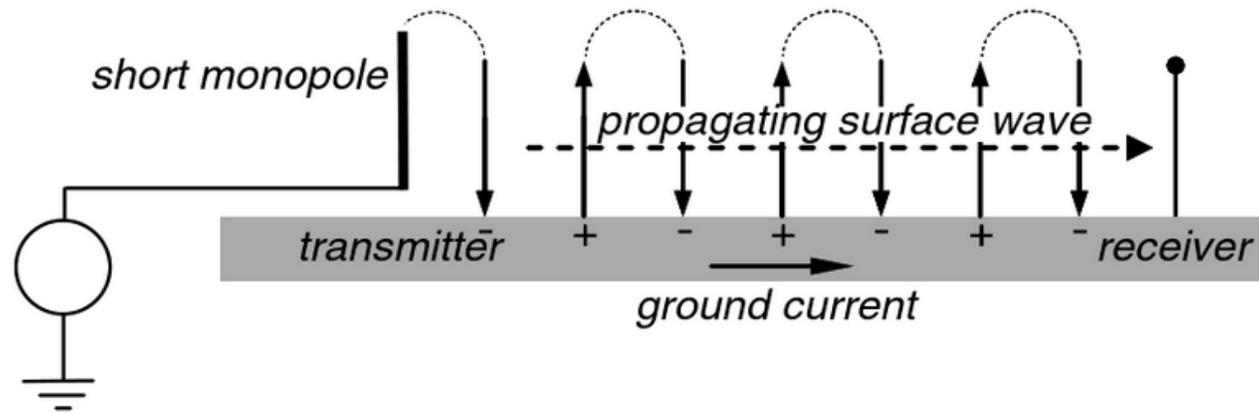


Figure 10.3 Attenuation due to rain and fog.

# Ground waves

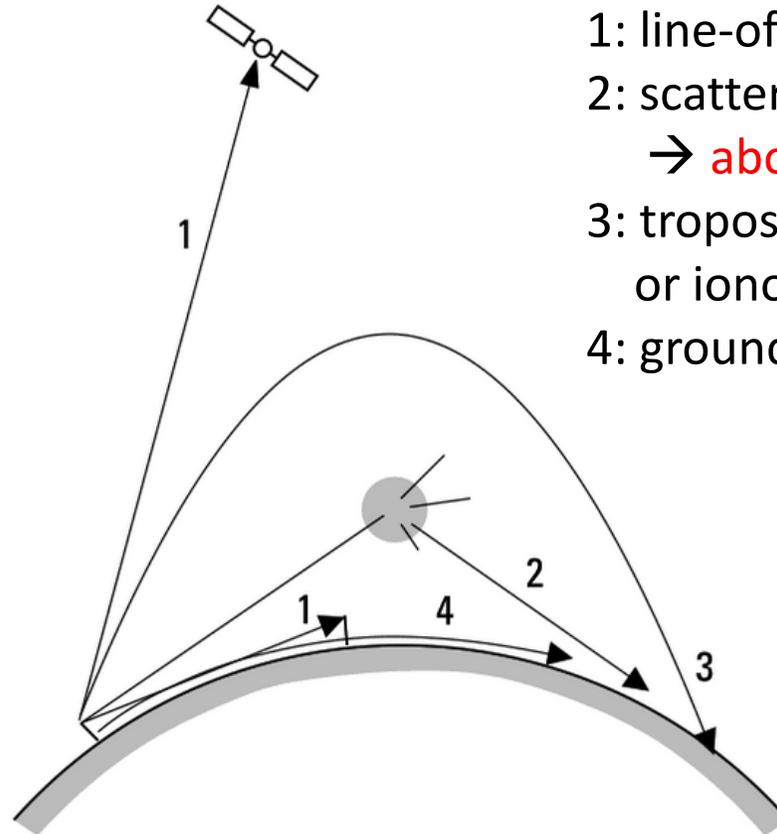
- ... are thought of diffraction of electric fields across earth terrain
- ... do not attenuate over conducting terrain, e.g., ocean
  - Analogy to  $\lambda/4$  dipole with a ground plane
- ... are observed **below a few MHz RF**  $\rightarrow$  wavelength of longer than 100 m



**Fig. 2.1** Launch of the vertically polarised surface wave using a short vertical monopole

Figure from J. A. Richards, "Radio wave propagation: an introduction for the non-specialist", Springer (e-book available in Aalto library).

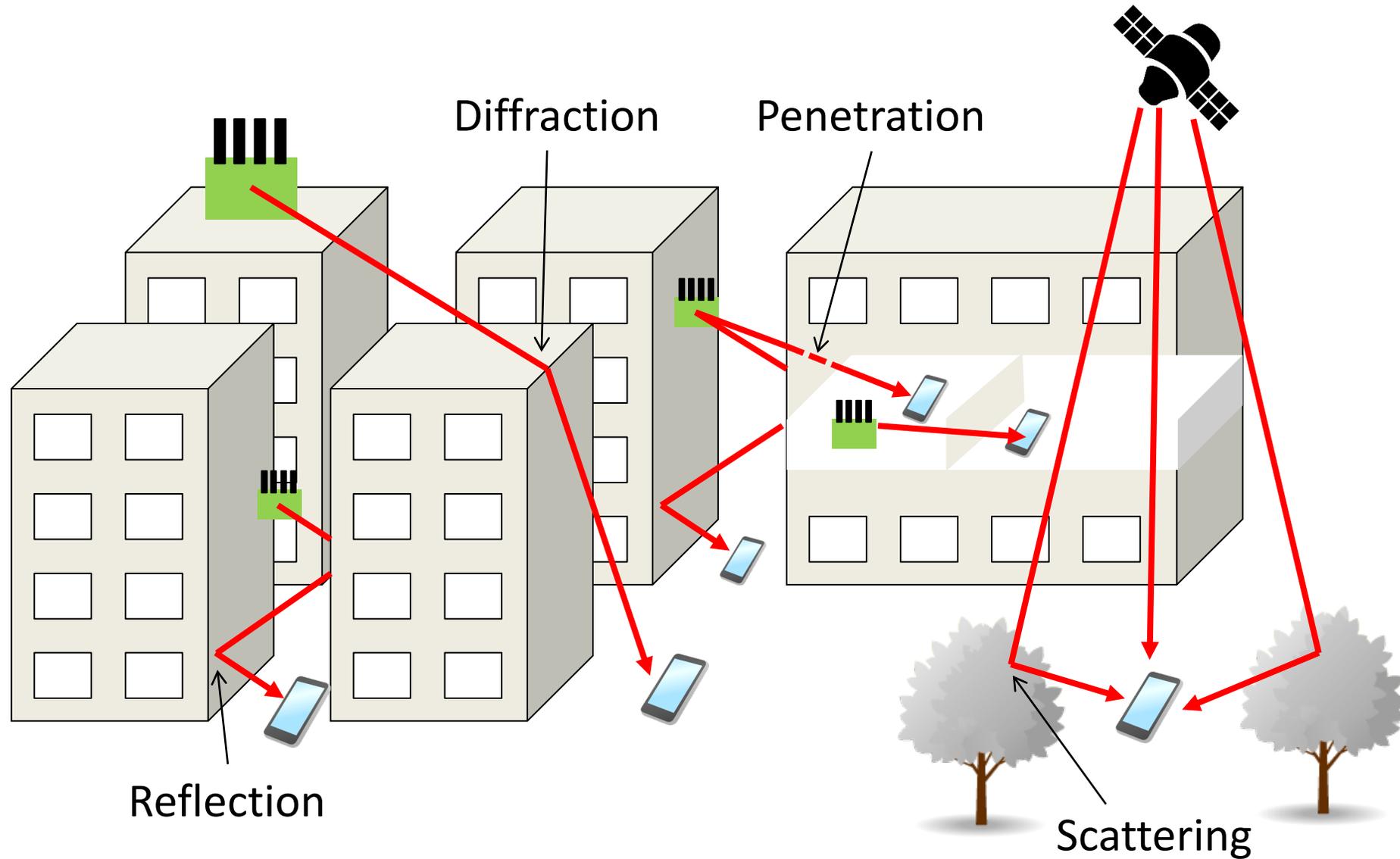
# Summary: Wave propagation of long-range links



- 1: line-of-sight (LOS) → all frequencies
- 2: scattering from inhomogeneous atmosphere → above 300 MHz
- 3: tropospheric refraction → all frequencies  
or ionospheric reflection → below 30 MHz
- 4: ground (earth-surface) wave → below a few MHz

**Figure 10.1** Propagation mechanisms of radio waves (numbers refer to different mechanisms described in text).

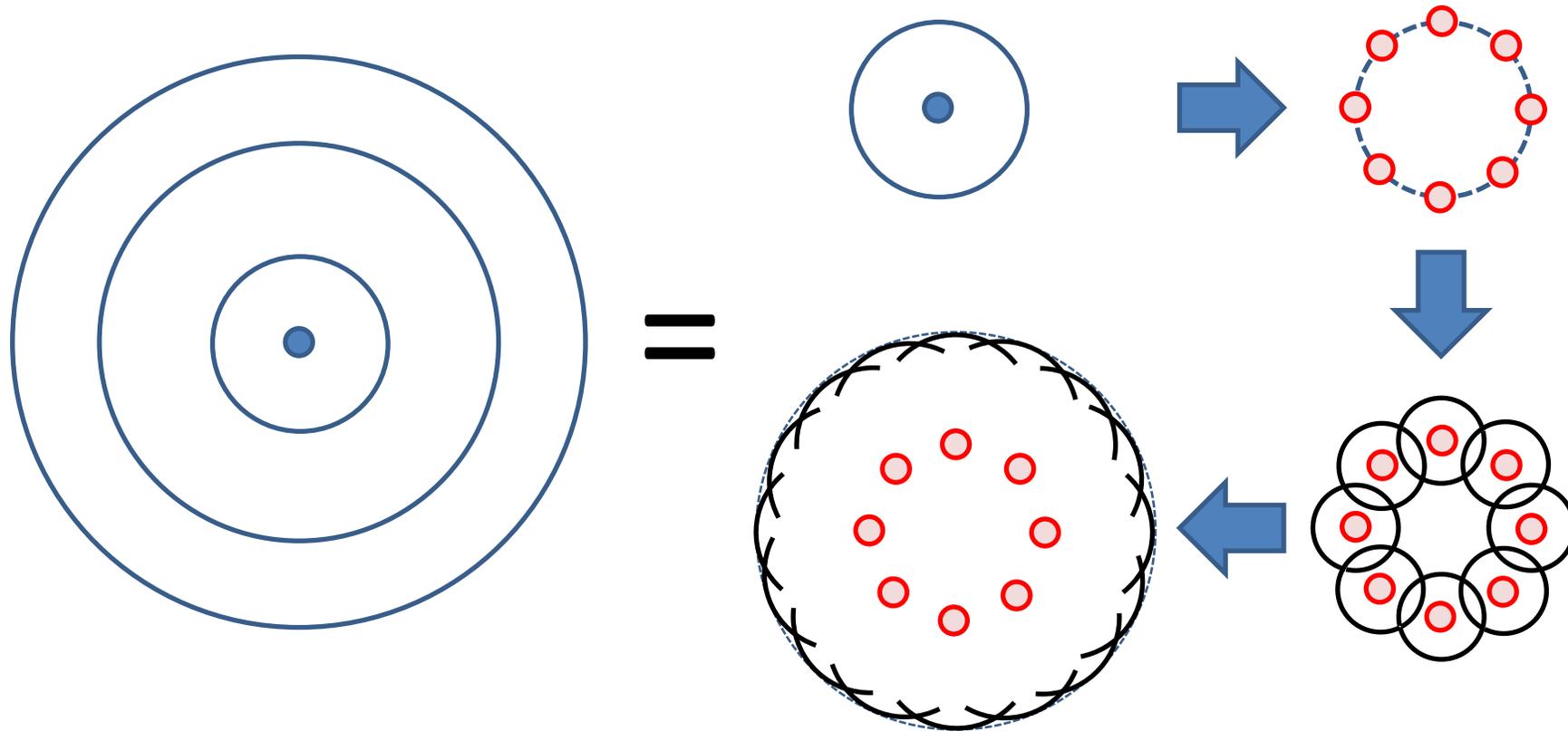
# Cellular wireless environments



Q1: Which of the following tells us that electromagnetic waves can go behind a corner? Choose 6. when you do not know which one to choose.

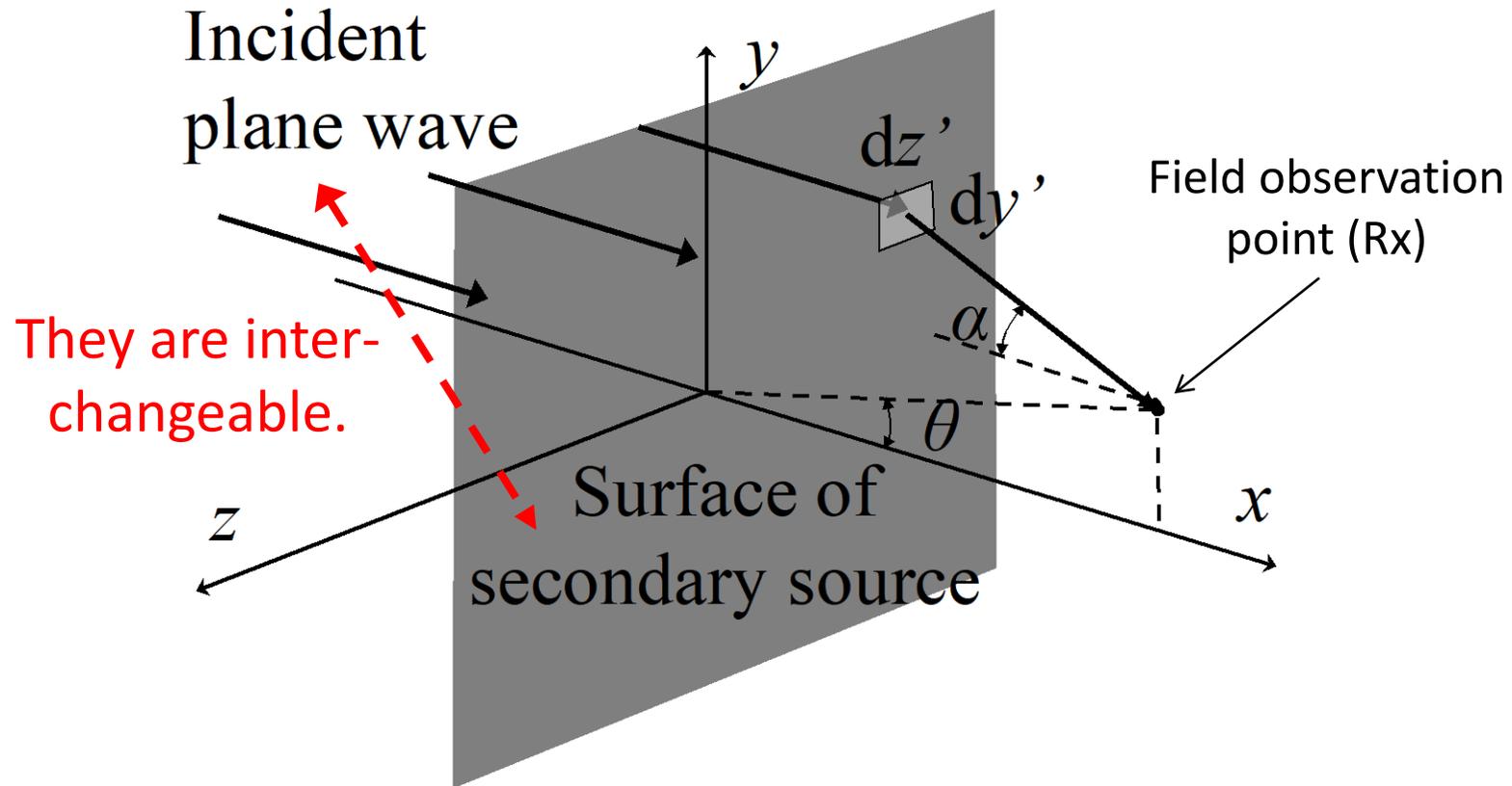
1. Snell's law
2. Standing waves
3. Reciprocity of electromagnetic fields
4. Huygens' principle
5. Secondary sources
6. I do not know.

# Huygens' principle and the secondary sources



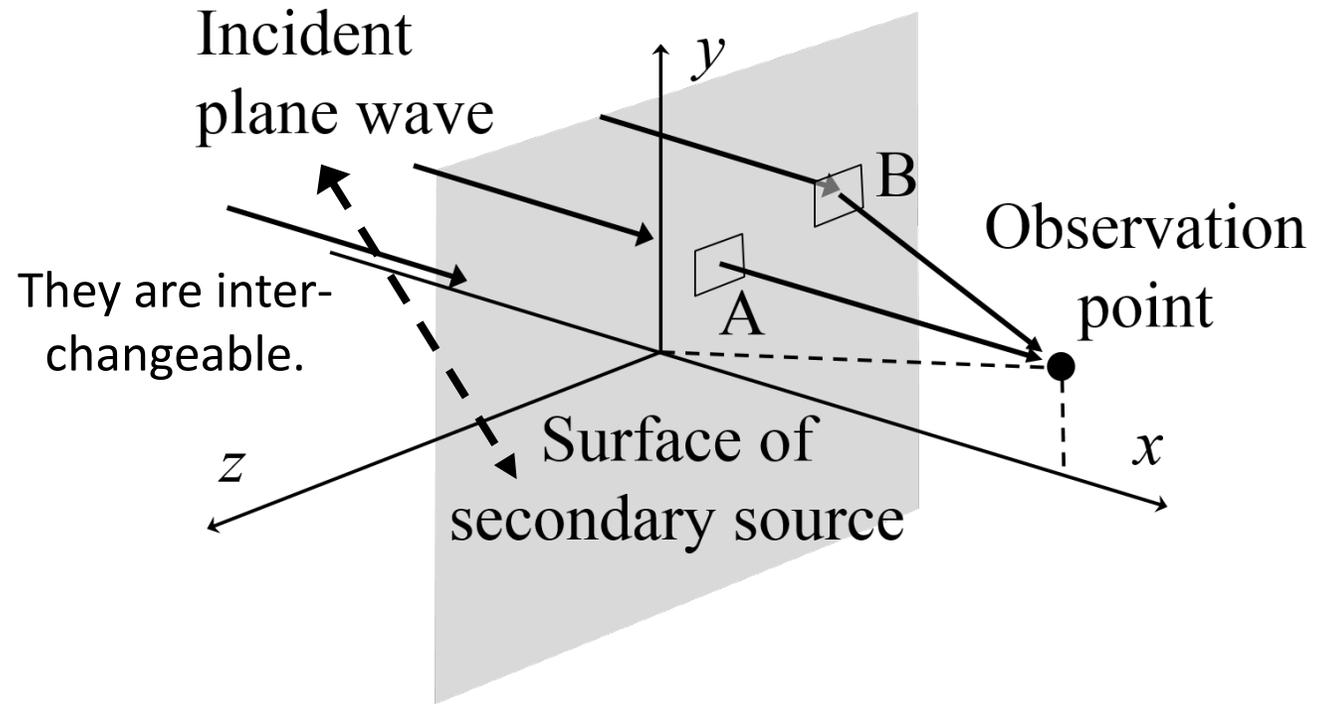
# Huygens' principle and the secondary sources

- A single plane wave incidence

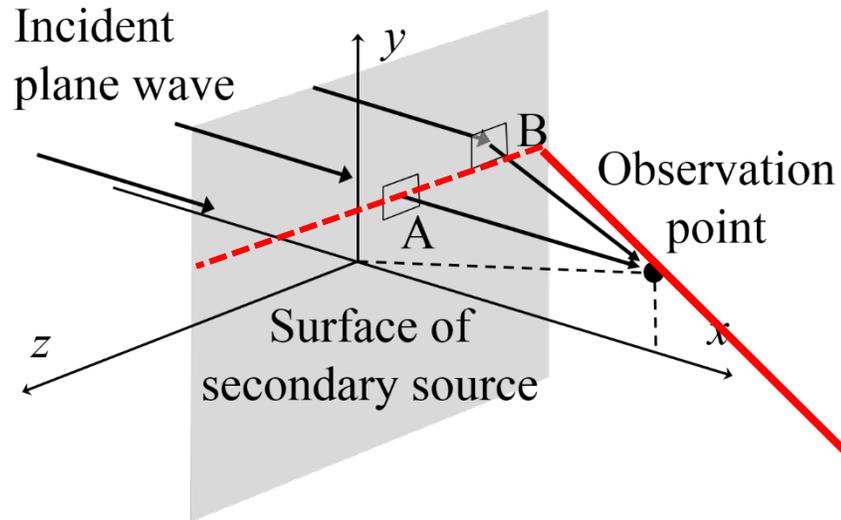


Q2: See the figure. At the observation point, we see field mainly from “A” point and not from “B” point because ...

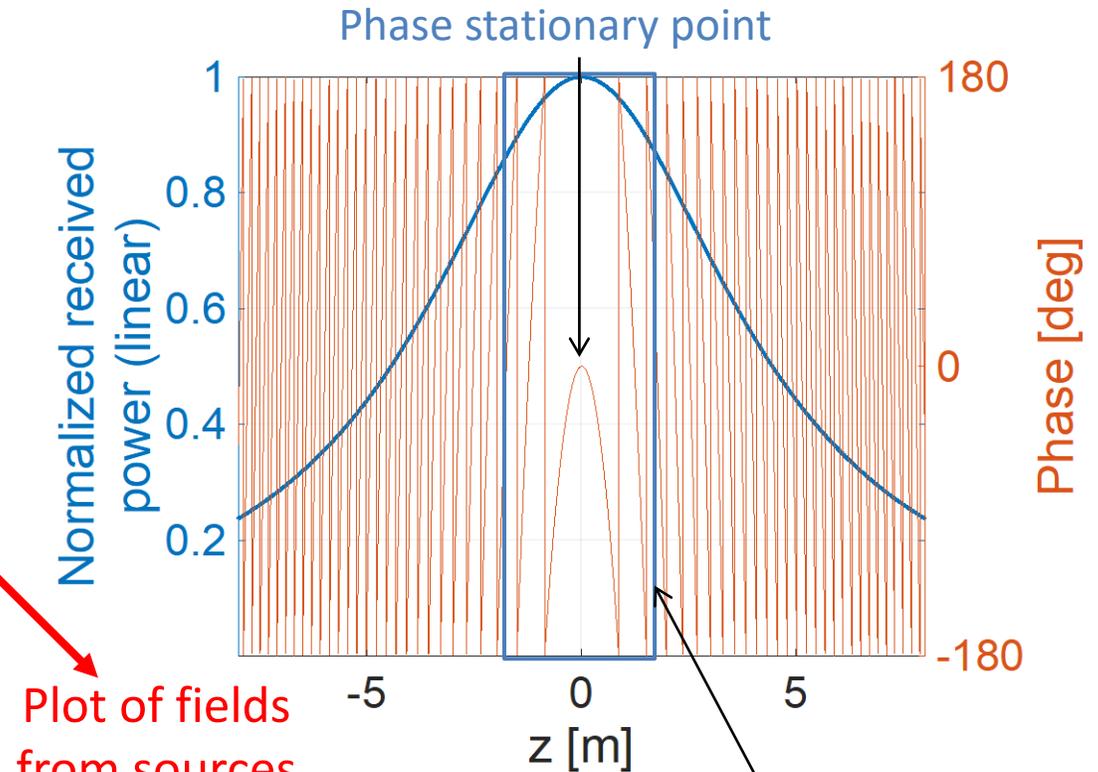
1. Field from B is cancelled by fields from other points.
2. Field from B is much weaker than field from A.
3. Field from B has opposite phase to field from A.
4. Field from B is cancelled by field from A.
5. I do not know.



# Magnitude and phase of the observed fields from secondary sources



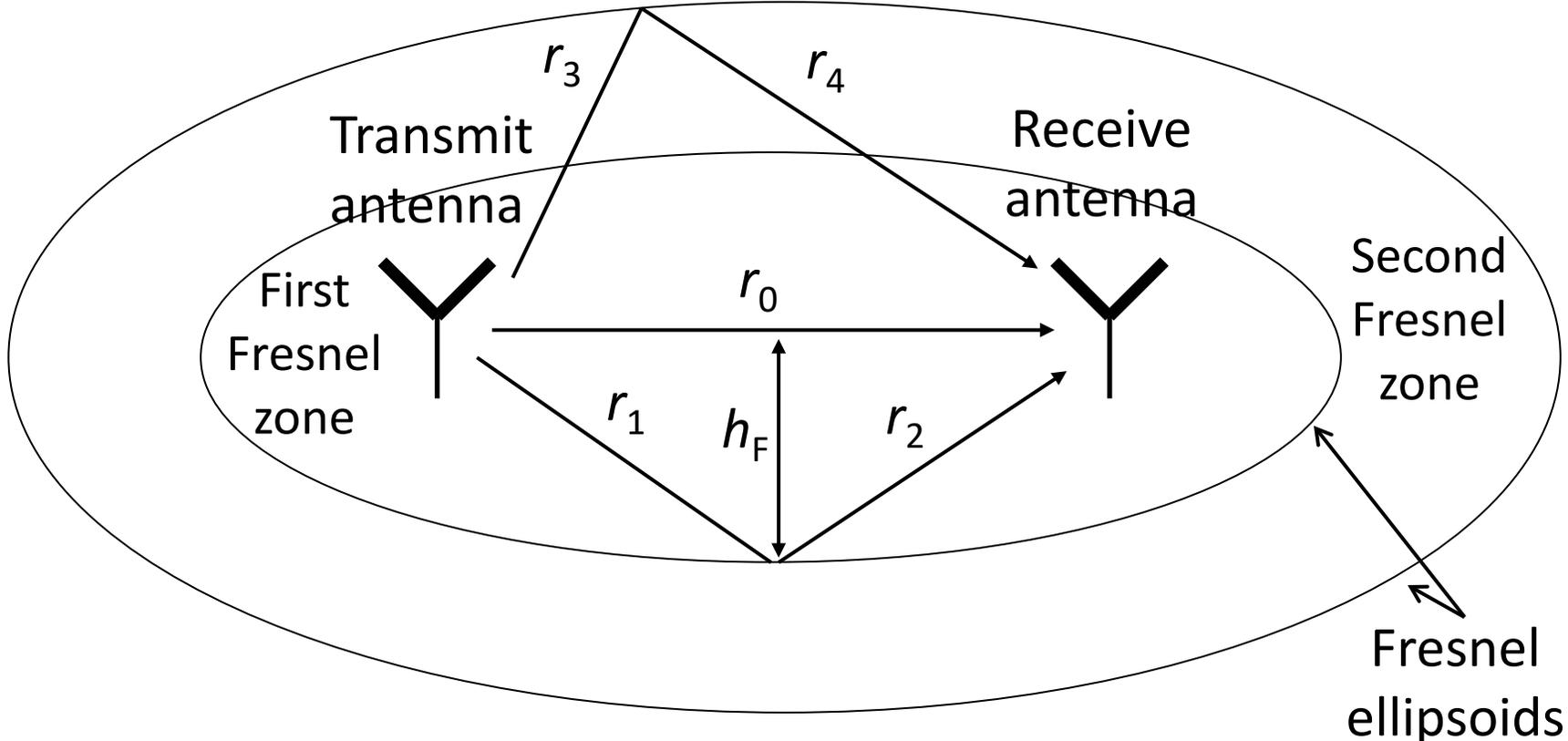
Observation point:  $x_2 = 4$  m,  
 $f = 900$  MHz



Plot of fields from sources on this line

Zones where secondary sources are not totally cancelled = **low-order Fresnel zones**

# Fresnel zones

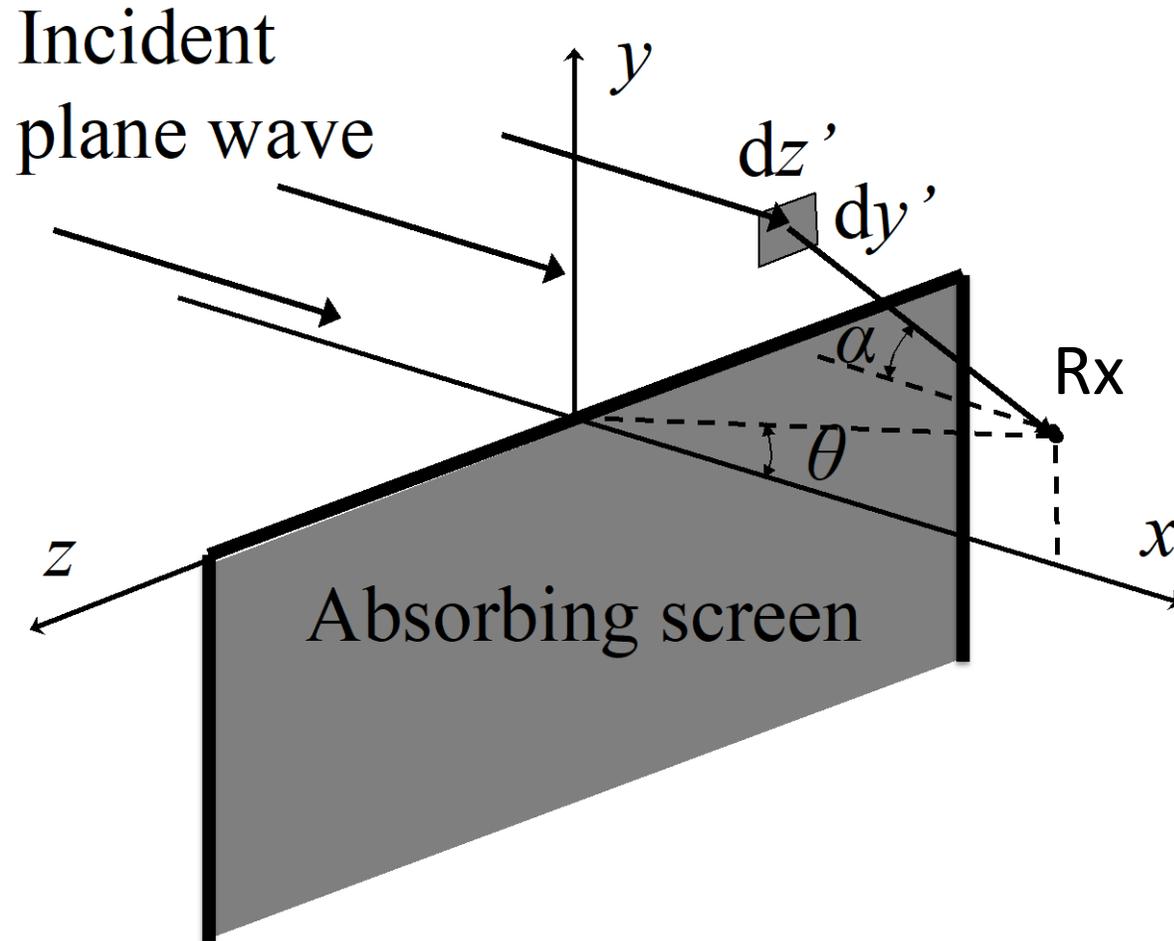


$$h_F \approx \sqrt{\frac{\lambda r_1 r_2}{r_1 + r_2}}$$

$r_1 + r_2 = r_0 + \lambda/2$ : First Fresnel ellipsoid

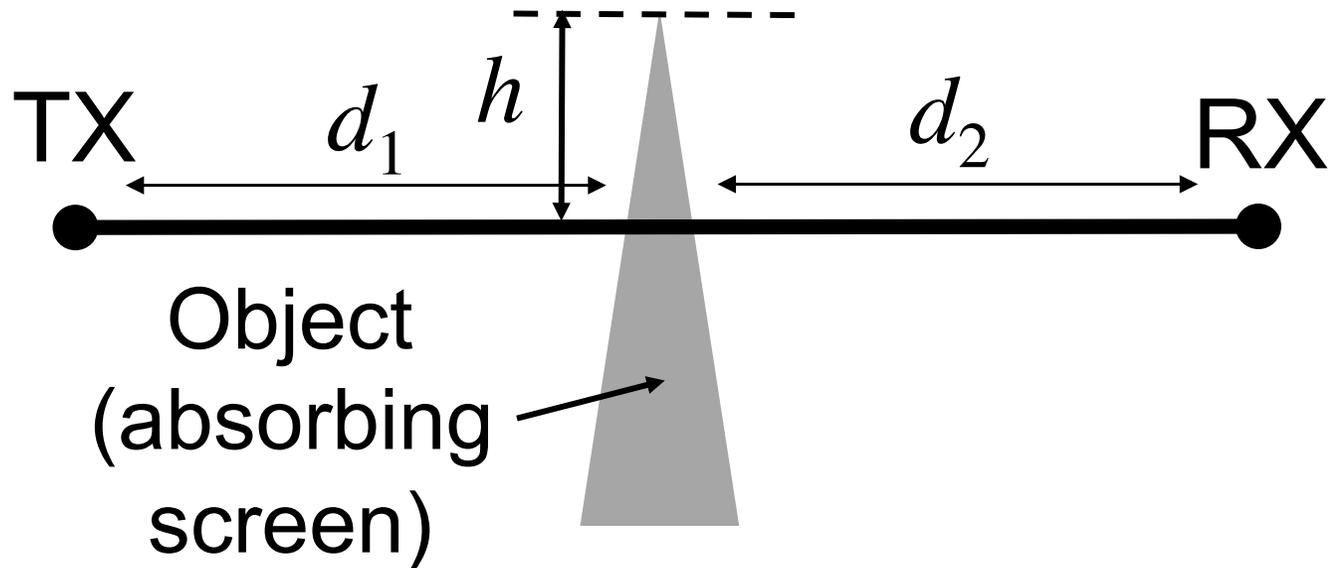
$r_3 + r_4 = r_0 + \lambda$ : Second Fresnel ellipsoid

# Diffraction due to a half-plane absorbing screen

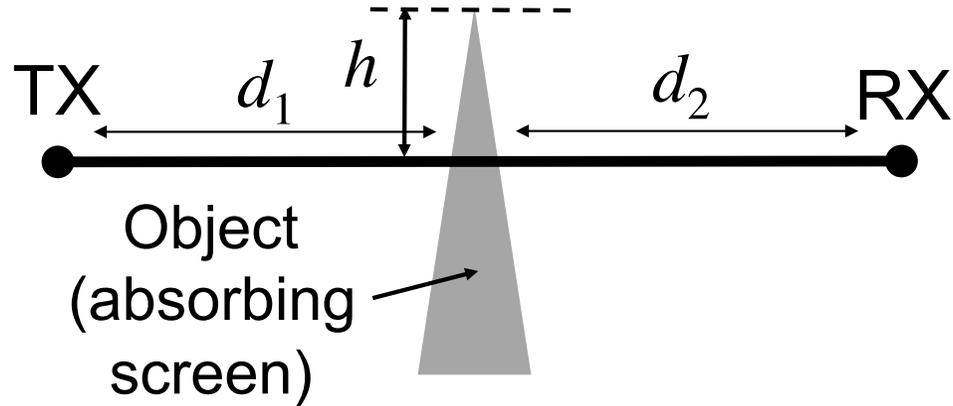


Q3: A tip of the absorbing screen is just the heights of the transmit and receive antennas, i.e.,  $h = 0$ . What is the loss of the link, compared to an unobstructed link?

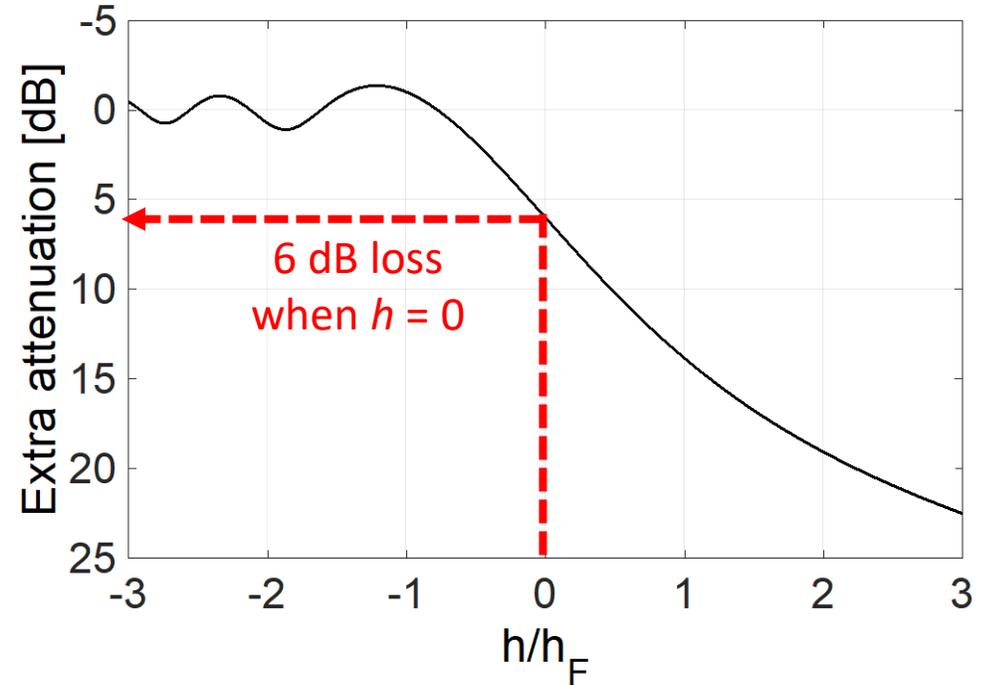
1. 0 dB.
2. 3 dB.
3. 6 dB.
4. 10 dB.
5. I do not know.



# Radio waves can go beyond a corner: Diffraction



$h$  is a depth of line-of-sight below the knife edge.



$h_F$  is a width of the first Fresnel ellipsoid.

$$h_F \approx \sqrt{\frac{\lambda r_1 r_2}{r_1 + r_2}}$$

# Two-ray model of radio wave propagation

- E.g., long-range point-to-point or cellular links in rural area

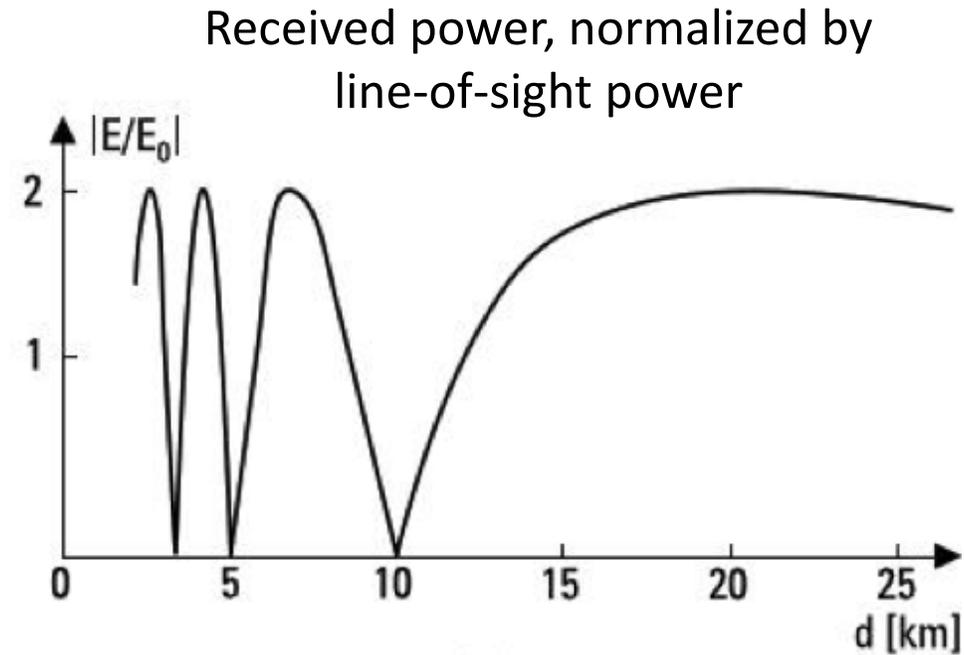
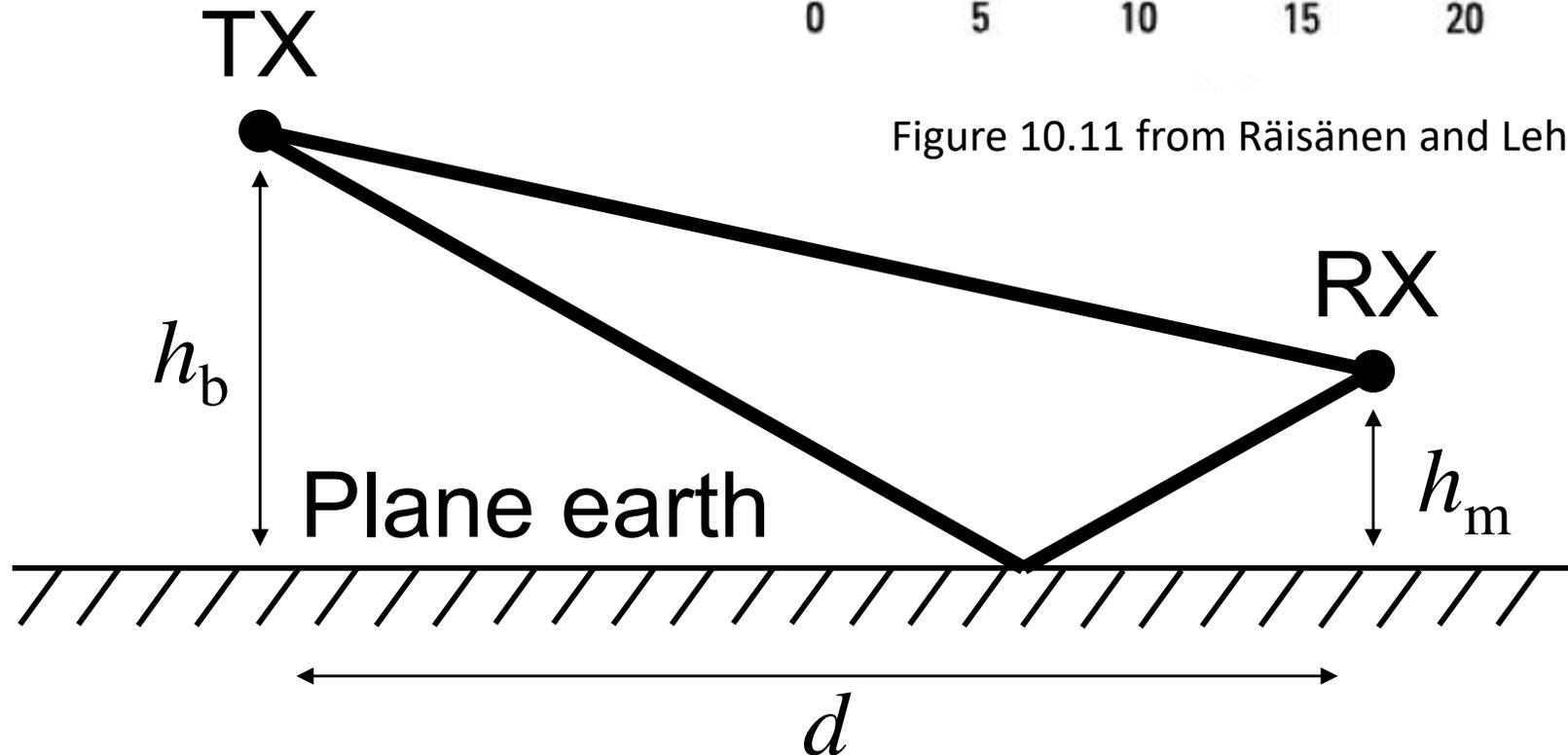
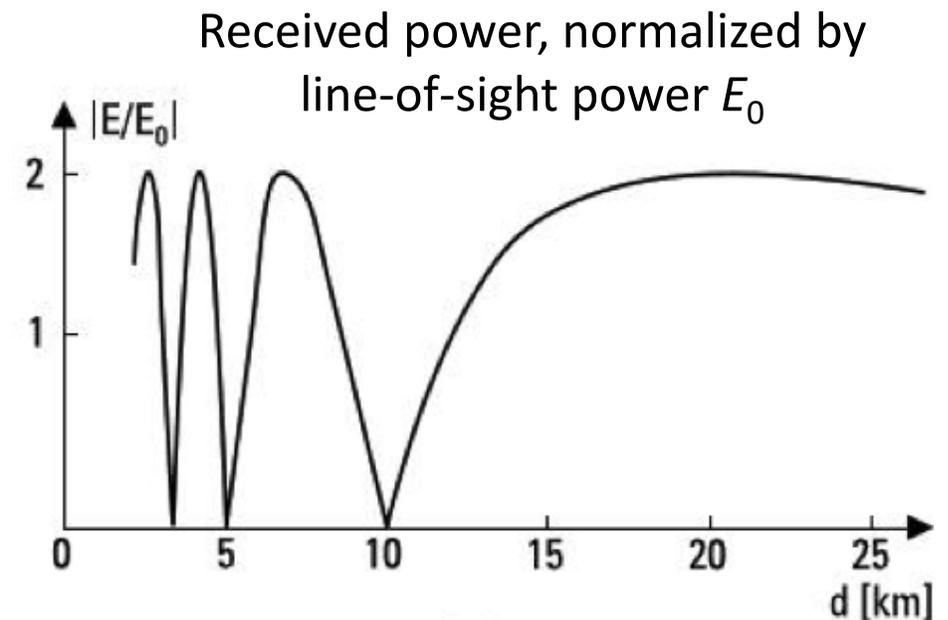
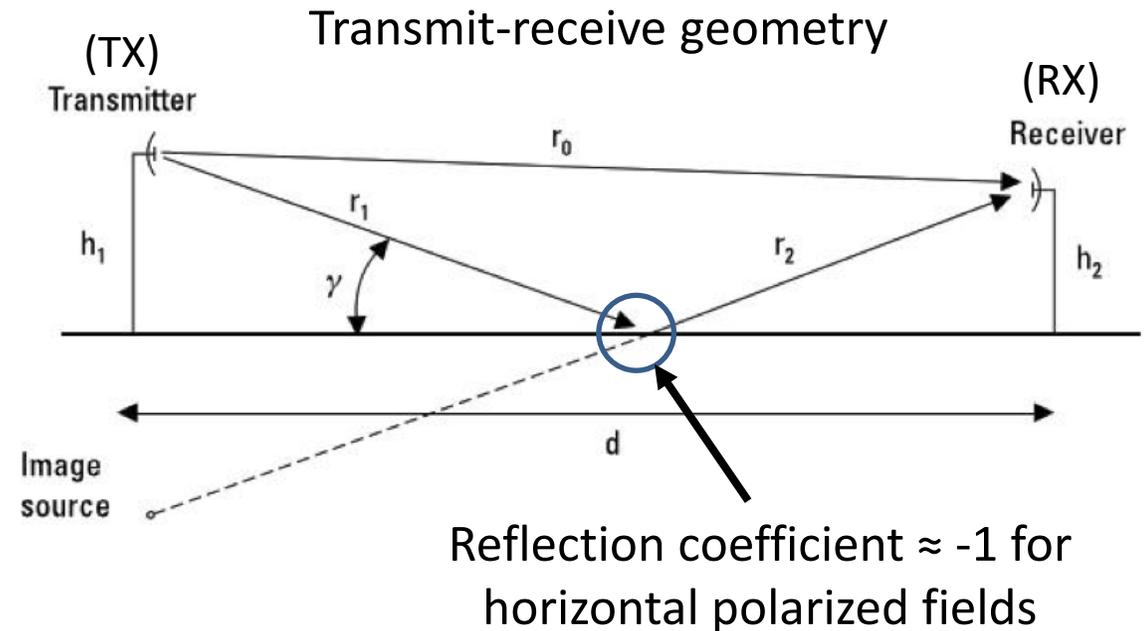


Figure 10.11 from Räsänen and Lehto

Q4: There are line-of-sight and ground-reflected waves, with a reflection coefficient of the ground  $-1$ . Which of the following is **incorrect** explanation?

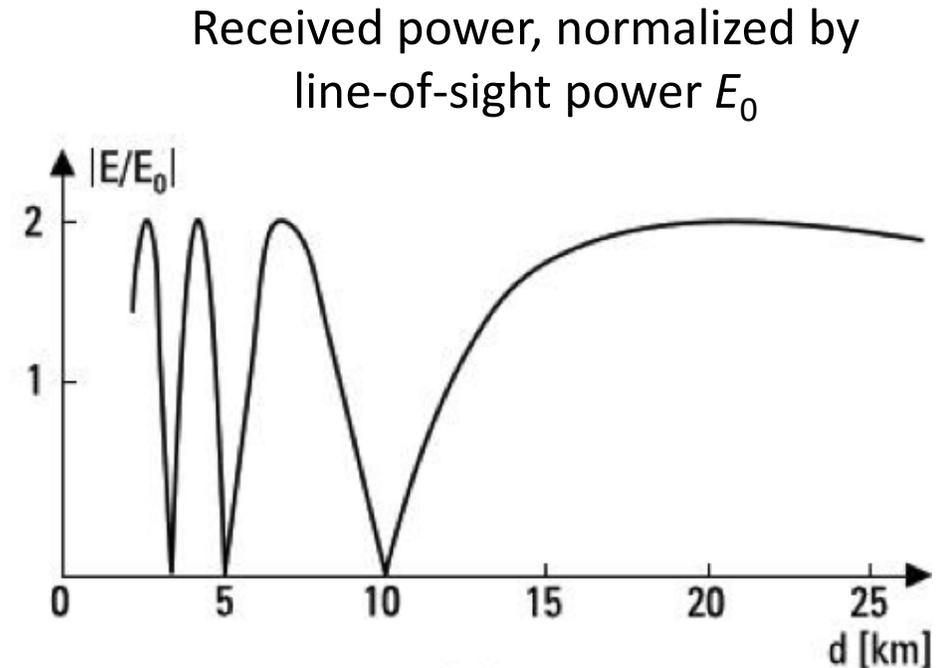
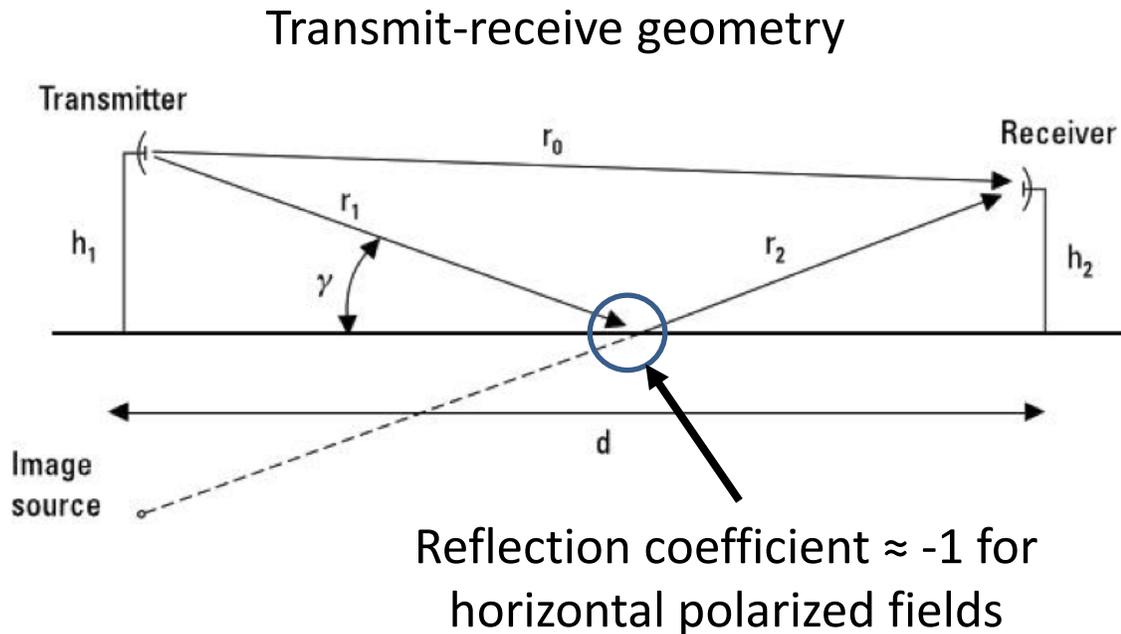
1. At TX-RX distance of 7.5 km, the signal receives very well.
2. Data communication may suffer from outage at some TX-RX distances.
3. Having very high transmit power ensures good data communication across all TX-RX distances.
4. Signal outage is due to destructive interference of the two waves.
5. I do not know.



Figures 10.10 and 10.11 from Räsänen and Lehto

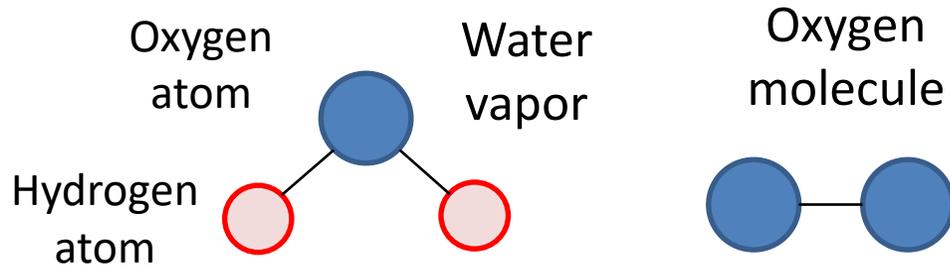
Q5: There are line-of-sight and ground-reflected waves, with a reflection coefficient of the ground -1. Which of the following leads to very small power at the receiver?

1.  $r_1 + r_2 - r_0 = \lambda/4$ .
2.  $r_1 + r_2 - r_0 = \lambda/2$ .
3.  $r_1 + r_2 - r_0 = \lambda$ .
4.  $r_1 + r_2 - r_0 = 28.5\lambda$ .
5. I do not know.

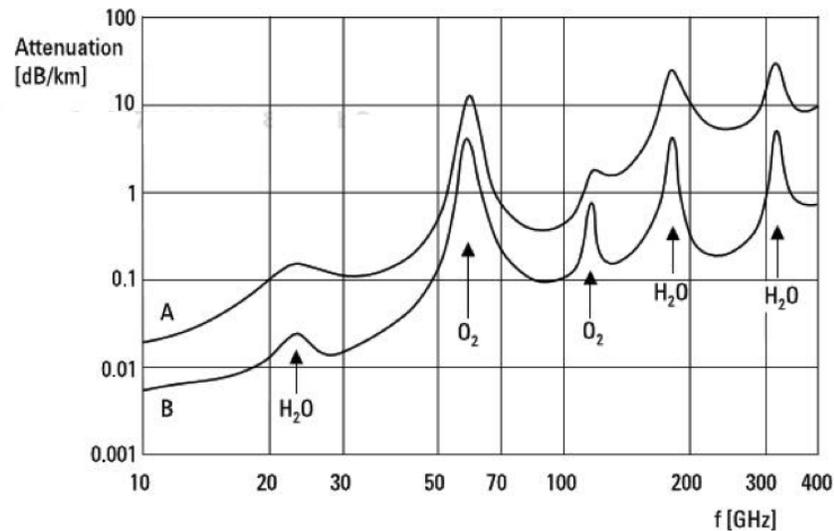


Figures 10.10 and 10.11 from Räsänen and Lehto

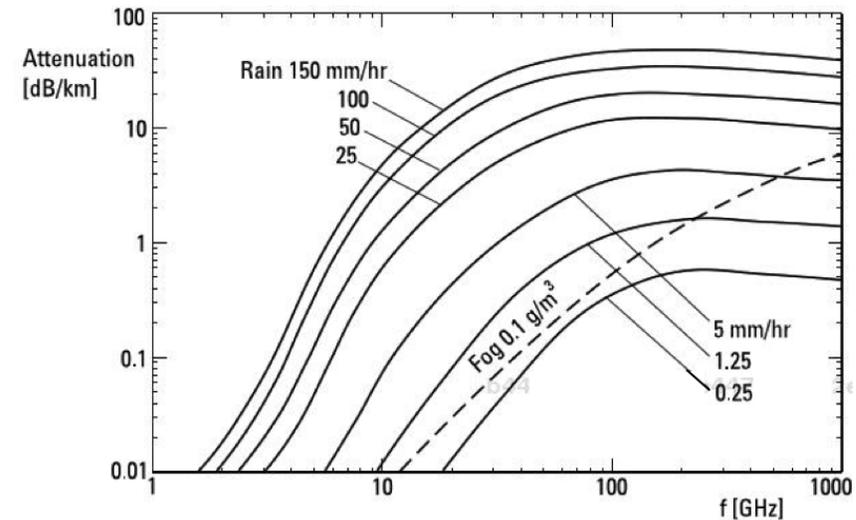
# Atmospheric attenuation



Oxygen molecules have quantized rotational energy state (resonances). They have energy corresponding to energy quantum with wavelength of approximately 5 mm.



**Figure 10.2** Attenuation in clear atmosphere versus frequency. Curve A: at sea level ( $T = 20^\circ\text{C}$ , water vapor density  $7.5 \text{ g/m}^3$ ). Curve B: at altitude of 4 km ( $T = 0^\circ\text{C}$ , water vapor density  $1 \text{ g/m}^3$ ).



**Figure 10.3** Attenuation due to rain and fog.

Q6: Which one is **incorrect** explanation according to the two figures?

1. Atmospheric attenuation at 60 GHz band is so large that we cannot use them for cellular communications.
2. Higher frequency radio propagation is more prone to atmospheric or meteorological phenomena.
3. Presently deployed wifi and cellular wireless networks work robustly regardless of the weather condition.
4. Satellite links must have sufficient link margin to combat atmospheric and meteorological attenuation.
5. I do not know which one is incorrect.

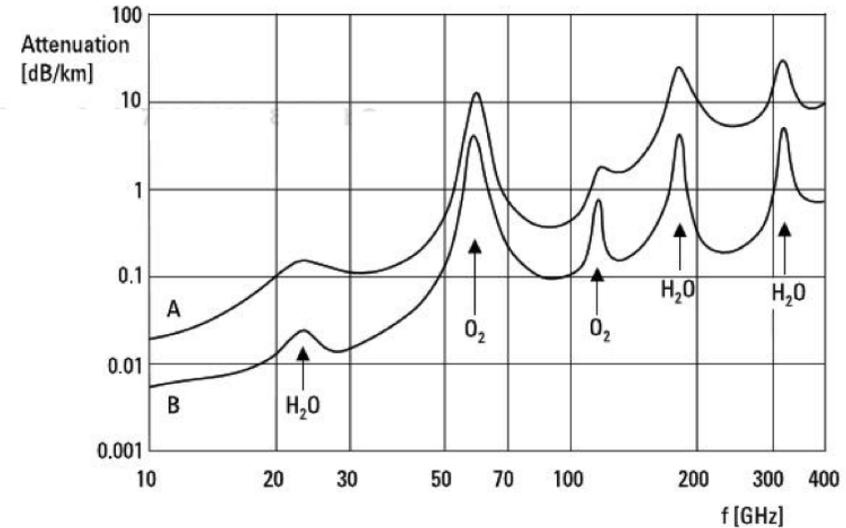


Figure 10.2 Attenuation in clear atmosphere versus frequency. Curve A: at sea level ( $T = 20^{\circ}\text{C}$ , water vapor density  $7.5 \text{ g/m}^3$ ). Curve B: at altitude of 4 km ( $T = 0^{\circ}\text{C}$ , water vapor density  $1 \text{ g/m}^3$ ).

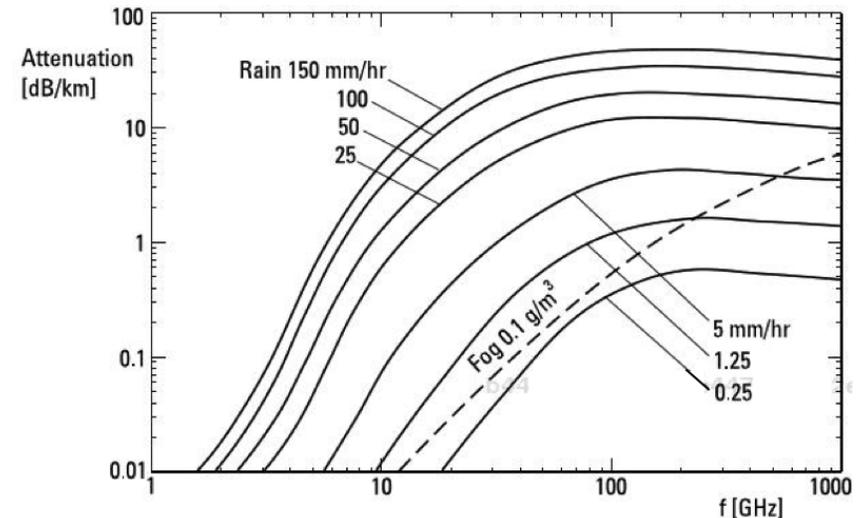


Figure 10.3 Attenuation due to rain and fog.

# Radio exposure and safety

## APPLICATIONS

People are exposed to NIR in naturally occurring situations, for example to the magnetic field of the earth and to radiation from the sun. Within the last century individual's NIR exposure has increased through the use of a wide array of technological applications that utilise NIR, such as electric appliances and communication devices.

ICNIRP expresses its protection recommendation primarily through the ICNIRP guidelines related to a specific frequency or wavelength band independently from the source. Read here how these recommendations translate for some common NIR applications.

- |                         |             |               |               |    |       |      |
|-------------------------|-------------|---------------|---------------|----|-------|------|
| MRI                     | Power Lines | Mobile Phones | Base Stations | 5G | WI-FI | DECT |
| Infrared Warming Cabins | Sunbeds     | UV Index      | LED           |    |       |      |

ICNIRP: International commission on non-ionizing radiation protection

<https://www.icnirp.org/>

“... provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR) to protect people and the environment from detrimental NIR exposure.

NIR refers to electromagnetic radiation such as ultraviolet, light, infrared, and radiowaves, and mechanical waves such as infra- and ultrasound.”

### NEWS > View all

**OCT**  
2020

**International NIR Workshop**  
Due to the COVID-19 crisis, the ICNIRP NIR Workshop, Seoul, Korea is cancelled. Other arrangements will be planned and information on those will follow.  
Thank you for your interest.

**MAY**  
2020

**UVC LAMPS and SARS-COV-2**  
ICNIRP cautions against use of UVC lamps to kill/inactivate the coronavirus (SARS-CoV-2)

**APR**  
2020

**COVID-19 and RF EMF**  
Exposure from 5G telecommunications devices does not cause COVID-19

### TOOLS & TOPICS



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# Radio exposure limits by ICNIRP, 1998

- Radio exposure safety is ensured by limiting
  - Specific absorption rate (SAR) in human tissues
  - Local power density of electromagnetic fields to human body

## Basic Restrictions Summary

Table 2. Basic restrictions for electric, magnetic and electromagnetic field exposure ( $\geq 6$ -minutes).<sup>a</sup>

Exposure Scenario	Frequency Range	Whole body average SAR ( $\text{W kg}^{-1}$ )	Local head/torso SAR ( $\text{W kg}^{-1}$ )	Local limb SAR ( $\text{W kg}^{-1}$ )	Local $S_{tr}$ ( $\text{W m}^{-2}$ )
Occupational	100 kHz – 6 GHz	0.4	10	20	---
	>6 GHz – 300 GHz	0.4	---	---	100
General Public	100 kHz – 6 GHz	0.08	2	4	---
	>6 GHz – 300 GHz	0.08	---	---	20

Five-time more protective measure for general public than occupational exposure.



<sup>a</sup> Note:

1. Whole body average SAR is to be averaged over 30-minutes.
2. Local SAR and  $S_{tr}$  exposures are to be averaged over 6-minutes.
3. Local SAR is to be averaged over a 10-g cubic mass.
4. Local  $S_{tr}$  is to be averaged over 4  $\text{cm}^2$  (>6-30 GHz), or 1  $\text{cm}^2$  (>30 GHz).

# IARC: International Agency for Research on Cancer

International Agency for Research on Cancer

World Health Organization

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lauantai 6. maaliskuuta 2021

<https://www.iarc.who.int/>

# Evaluation of carcinogenic risk to humans: IARC classification

ELF magnetic fields (power lines) /  
RF electromagnetic fields



ELF electric fields / static  
electric and magnetic fields



<http://monographs.iarc.fr/ENG/Classification/index.php>

Class		Agents	
Group 1	Carcinogenic to humans	120	Alcoholic Beverages, Asbestos (all forms), Arsenic, Benzene, Formaldehyde, Ionizing Radiation (all types), Sunlight (solar radiation), Tobacco smoking, smoke and smokeless.....
Group 2A	Probably carcinogenic to humans	82	Petroleum refining (occupational exposure), Biomass fuel (primarily wood), indoor emissions from household combustion of, DDT, red meat (consumption of), very hot beverages at above 65 ° C (drinking)
Group 2B	Possibly carcinogenic to humans	311	Diesel fuel, marine, Dry cleaning (occupational exposure), Chloroform, Pickled vegetables, Styrene, Aloe vera, whole leaf extract, Welding fumes, Gasoline, <u>Magnetic Fields (ELF)</u> , <u>Radiofrequency electromagnetic fields</u>
Group 3	Not classifiable as to its carcinogenicity to humans	500	Coffee, drinking, caffeine, Acrylic acid, Chlorinated drinking water, Fluorescent lighting, Hair colouring Products (personal use of), <u>Electric fields, extremely low-frequency, Electric fields, static, Magnetic fields, static</u>
Group 4	Probably not carcinogenic to humans	1	Caprolactam

# 30-year trend in brain cancer

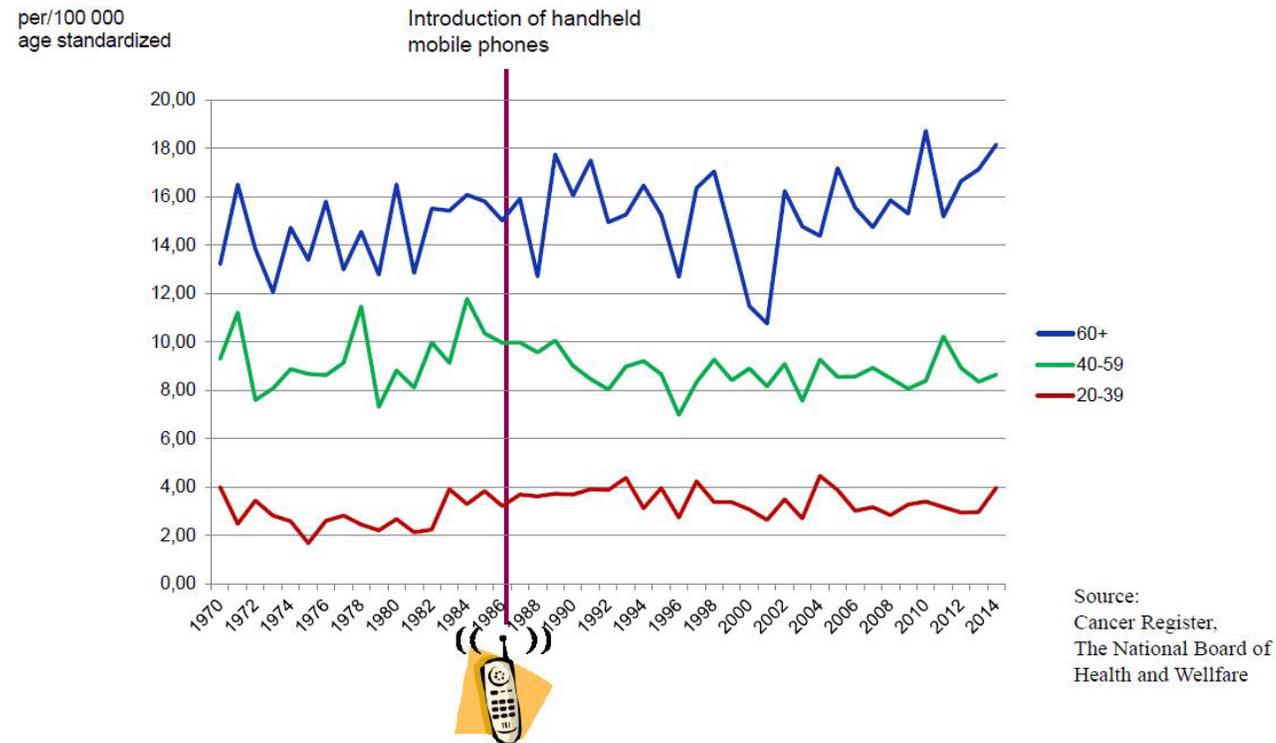
during which the cellular radios are in use

- **New Zealand:** *“..there has been no consistent increase in incidence rates of primary brain cancers.”* during 1995-2010 (2015).
- **Taiwan:** *“we do not detect any correlation between the morbidity/mortality of malignant brain tumors and cell phone use in Taiwan.”*(2013)
- **UK:** Examined time trends in brain cancer incidence rates in England from 1998 to 2007, *“Increases in incidence should have begun to appear in cancer registry data if mobile phone use had an important impact on the cancer risk.”* (2011)
- **United States:** *“these incidence data do not provide support to the view that cellular phone use causes brain cancer”* (2010)
- **Scandinavia:** *“...No change in incidence trends were observed from 1998 to 2003, the time when possible associations between mobile phone use and cancer risk would be informative about an induction period of 5-10 years.”* (2009)
- **Switzerland:** *“...after the introduction of mobile phone...brain tumour mortality rates remained stable in all age groups.”* (2007)

# Glioma incidence in Sweden

Glioma = a type of tumor in brain cells

## Glioma incidence, Sweden 1970-2014, Men



Feychting, ICNIRP 8th Int. NIR Workshop, May 2016.

Slide: courtesy of Dr. Barbioli, University of Bologna, Italy

# Radiation and Nuclear Safety Authority in Finland (STUK)

The screenshot shows the homepage of the Radiation and Nuclear Safety Authority (STUK) in Finland. The browser address bar displays 'stuk.fi' and the URL 'https://www.stuk.fi/web/en'. The page features a blue header with the STUK logo, a search bar, and navigation links for 'Contact Information', 'FI', 'SV', and 'EN'. The main content area has a blue background with a repeating pattern of small white icons. The title 'Radiation and Nuclear Safety Authority' is prominently displayed. A vertical menu on the right lists various sections: 'What's new', 'Topics', 'STUK supervises', 'Services', 'Regulations', 'Publications', and 'About us'. Below the main content, there are two columns of links under the headings 'TOPICS' and 'FOR PROFESSIONALS'. The 'TOPICS' column includes links for Radon, UV-radiation, health care, mobile telephones, electricity, beauty care, and Lasers. The 'FOR PROFESSIONALS' column includes links for safety in radiation practices, starting the use of radiation, regulation of operations, abnormal incidents, training, radiation measurements, forms, and transport of radioactive substances.

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- Transmission of electricity and power lines >
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