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

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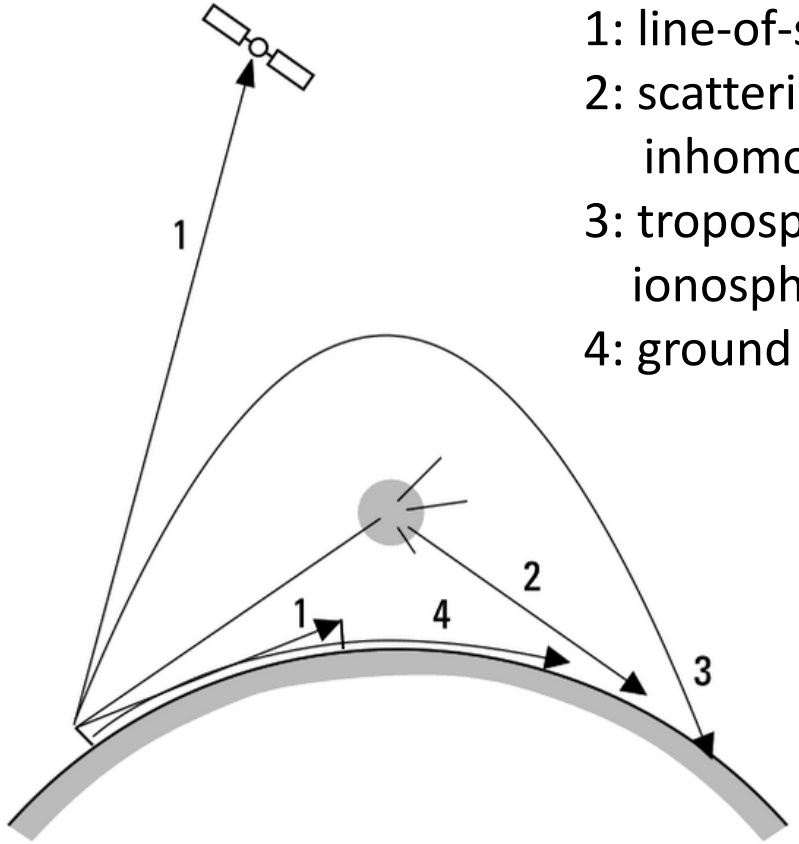
In this topic, we mainly cover Chapter 10 “Propagation of radio waves” in Radio Engineering for Wireless Communication and Sensor Applications by A. Raisanen and A. Lehto.
https://primo.aalto.fi/permalink/358AALTO_INST/1h25avu/cdi_askewsholts_vlebooks_9781580536691
(Aalto login required)

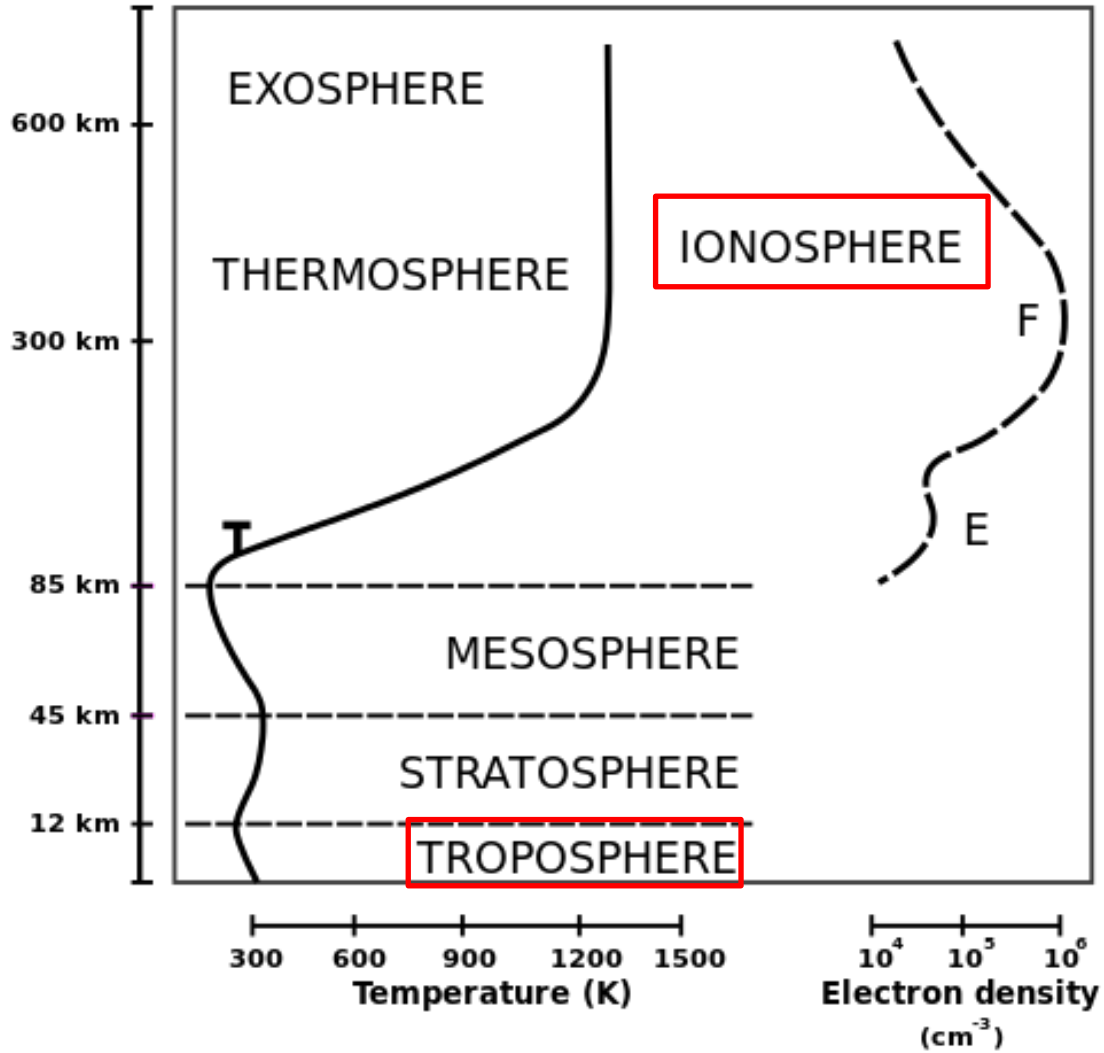
Wave propagation of long-range links



1: line-of-sight (LOS)
2: scattering from inhomogeneous atmosphere
3: tropospheric refraction or ionospheric reflection
4: ground (earth-surface) wave

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

Atmosphere around Earth's surface



https://en.wikipedia.org/wiki/Ionosphere

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*

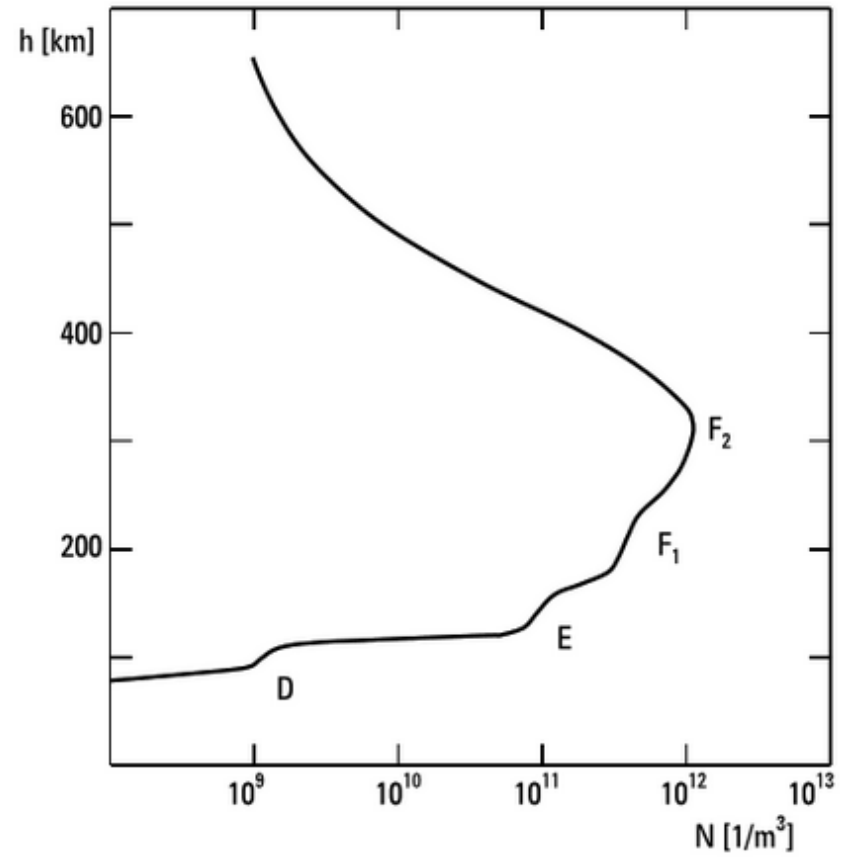


Figure 10.15 Electron density in the ionosphere versus altitude.

- 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.

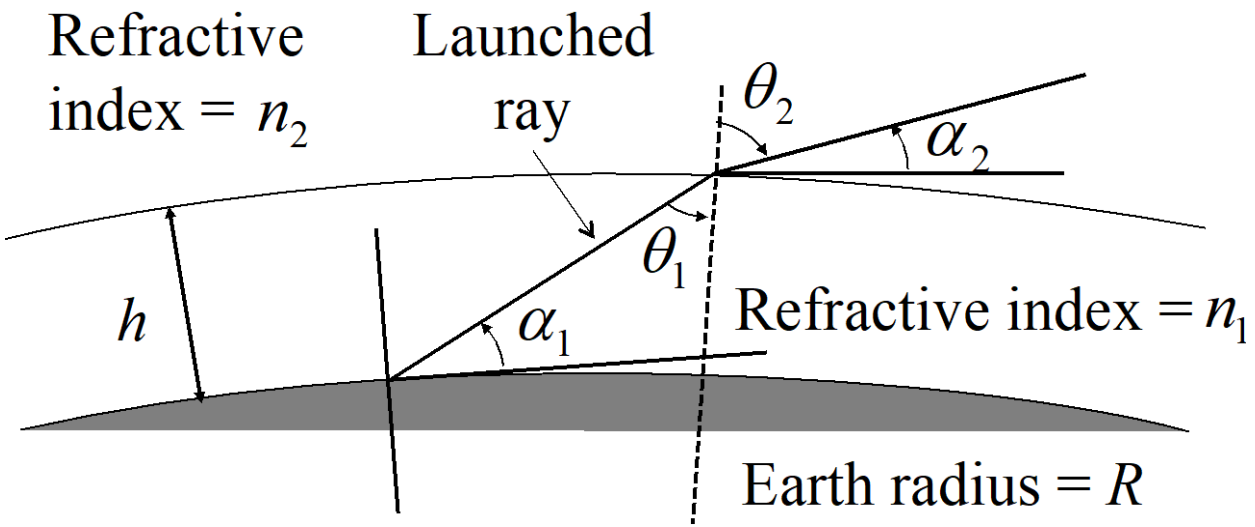
Tropospheric refraction

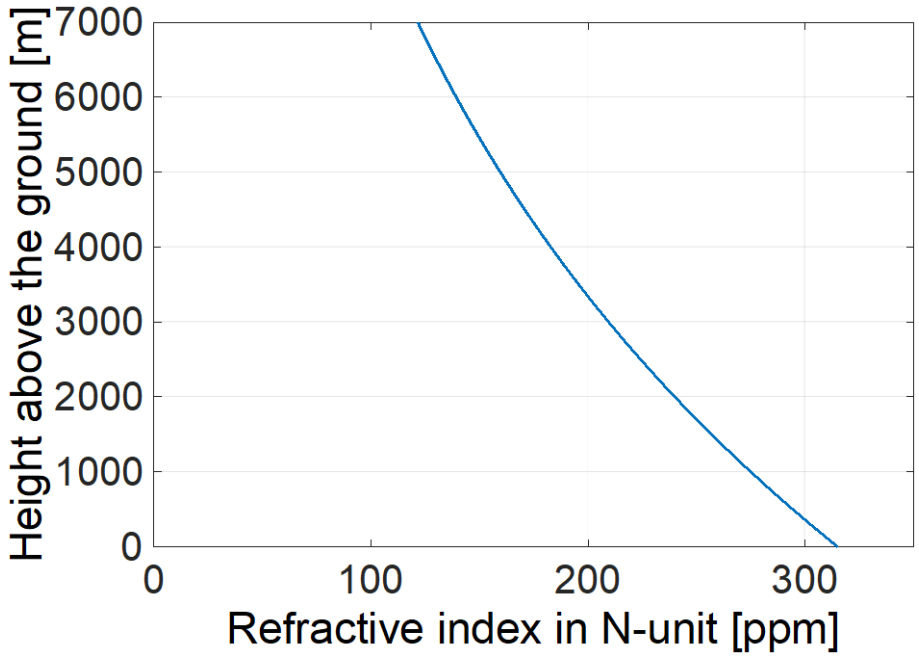
- Snell's law of refraction

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

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

- 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 λ

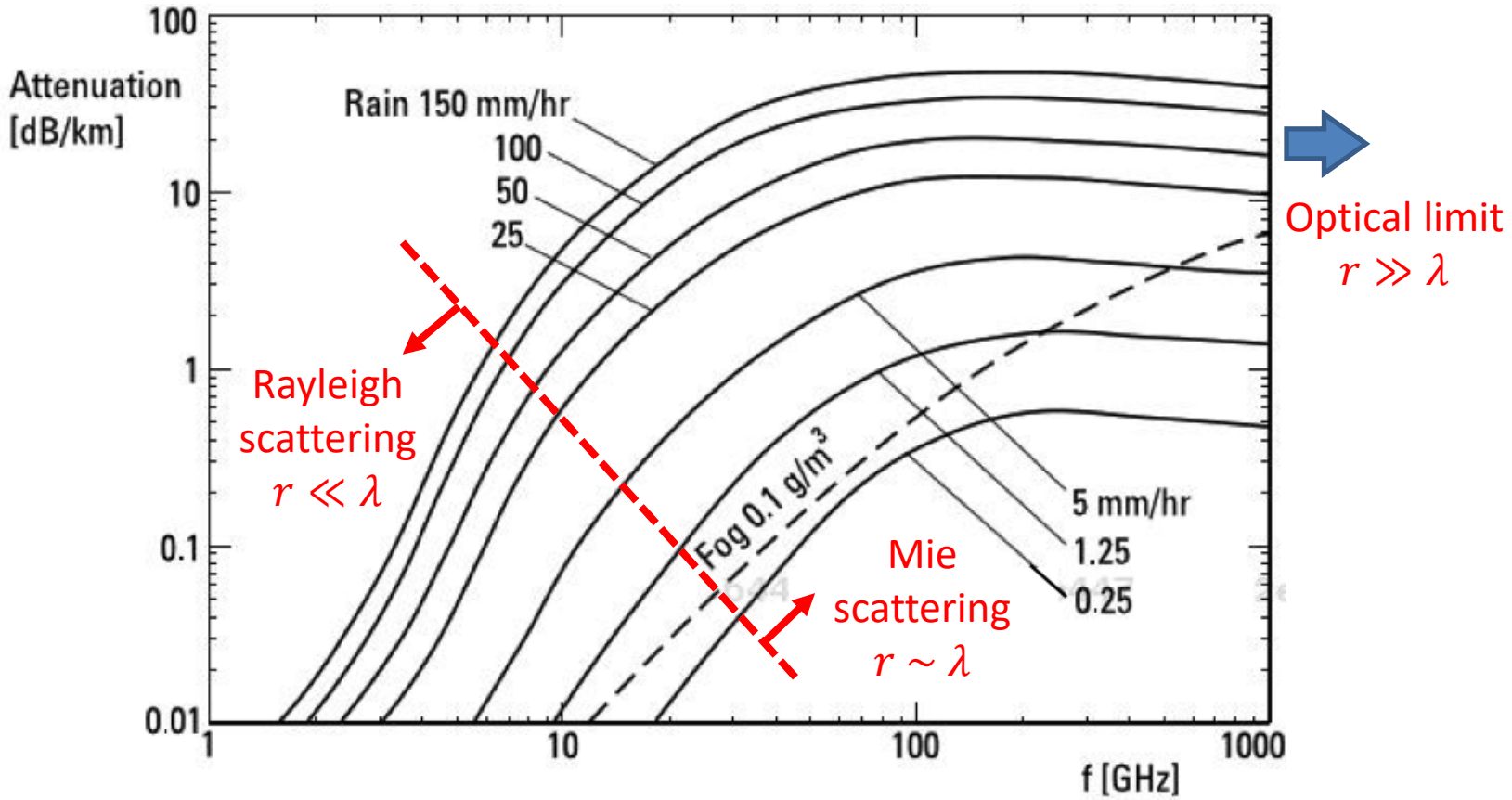


Figure 10.3 Attenuation due to rain and fog.

Ground waves

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

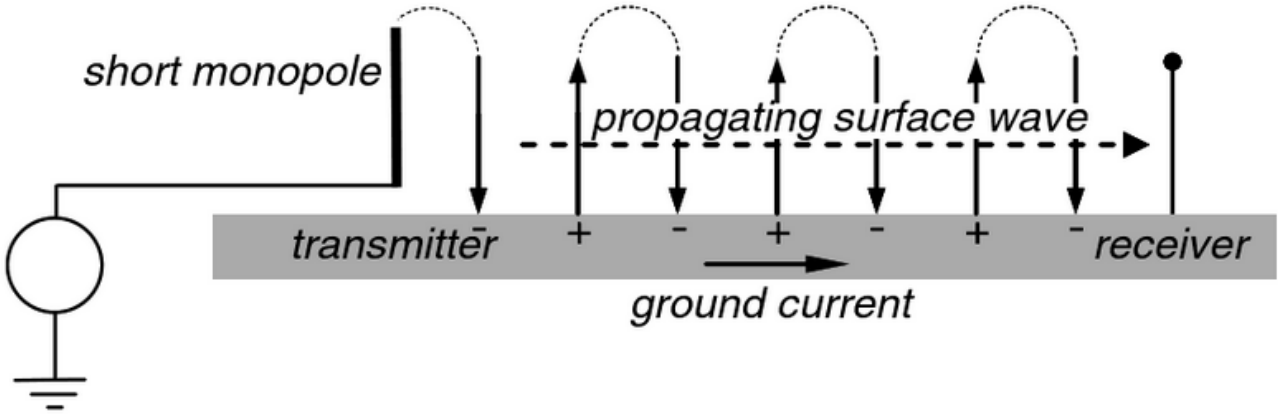
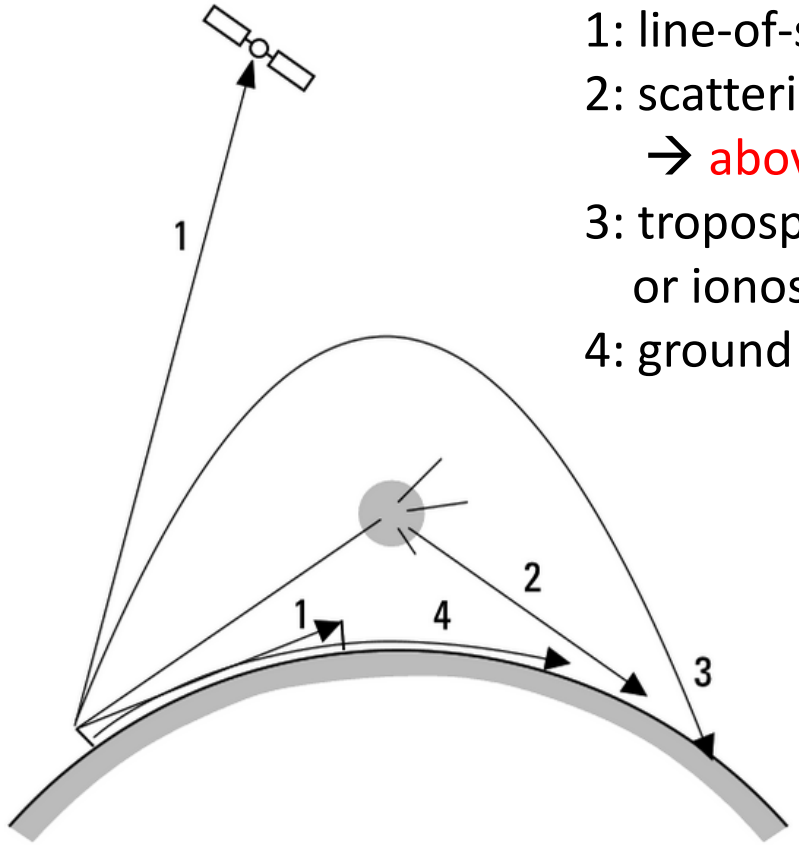


Fig. 2.1 Launch of the vertically polarised surface wave using a short vertical monopole

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

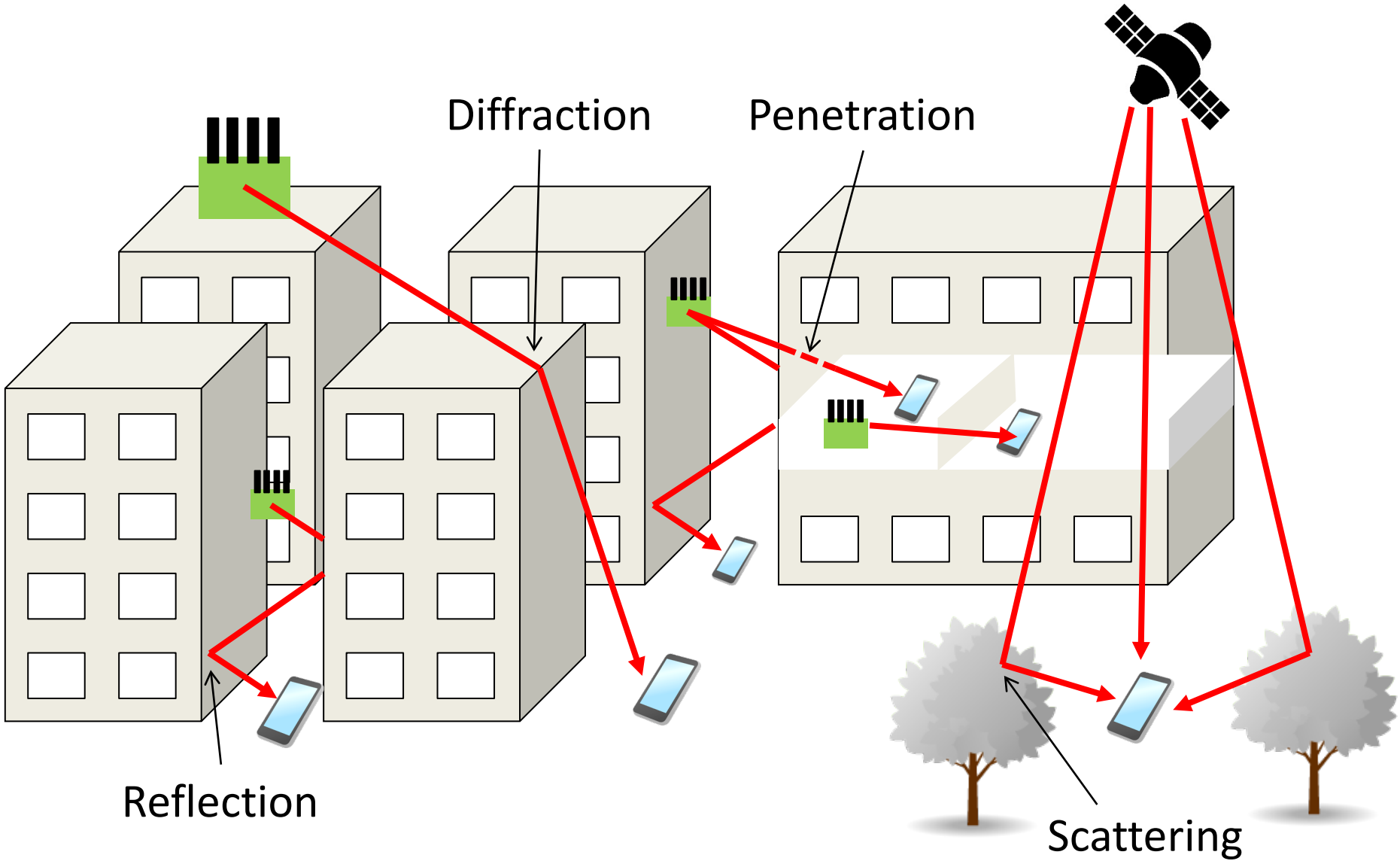
Summary: Wave propagation of long-range links



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).

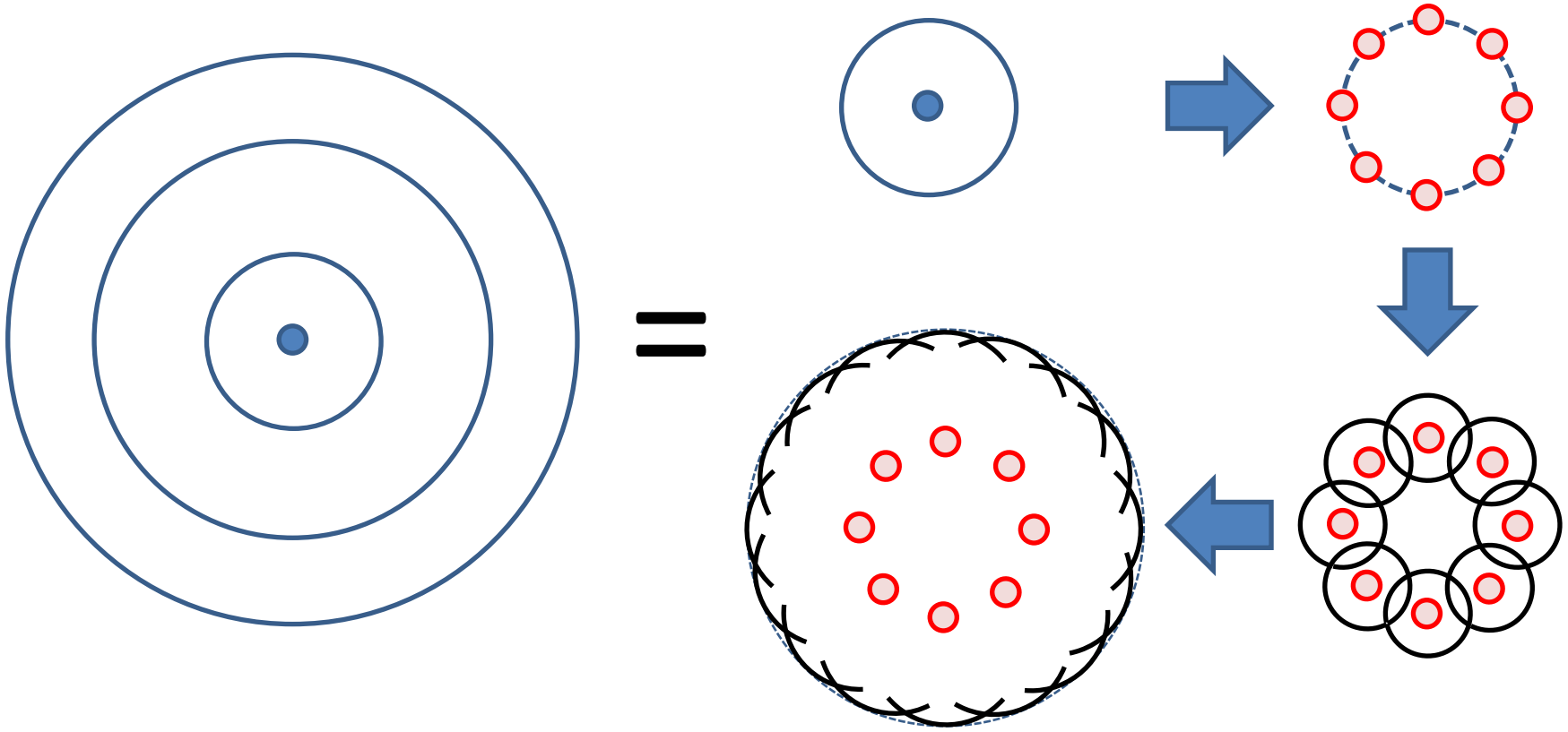
Cellular wireless environments



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.

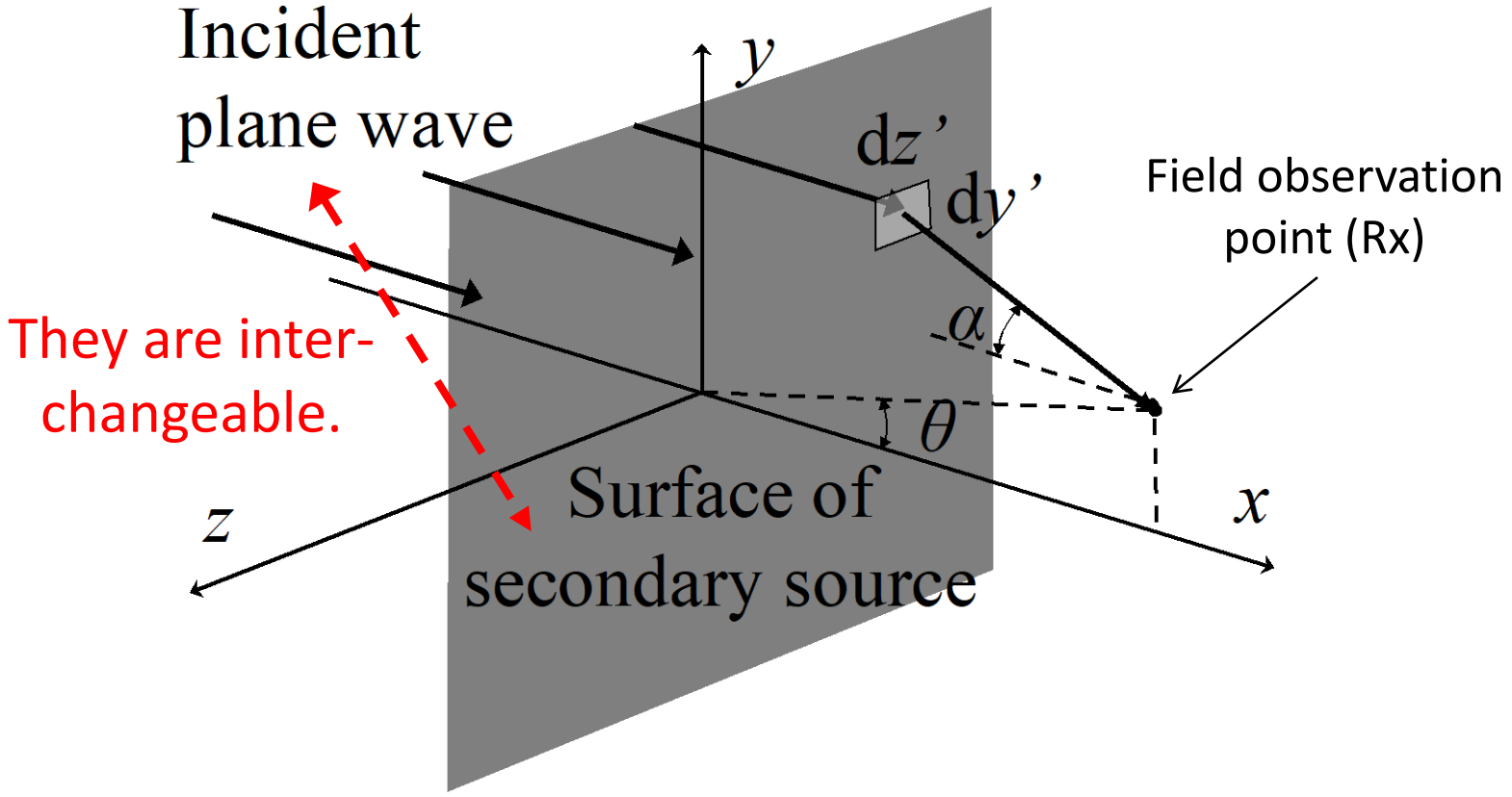
1. Snell’s law
2. Standing waves
3. Reciprocity of electromagnetic fields
4. Huygens’ principle
5. Secondary sources
6. I do not know.

Huygens' principle and the secondary sources



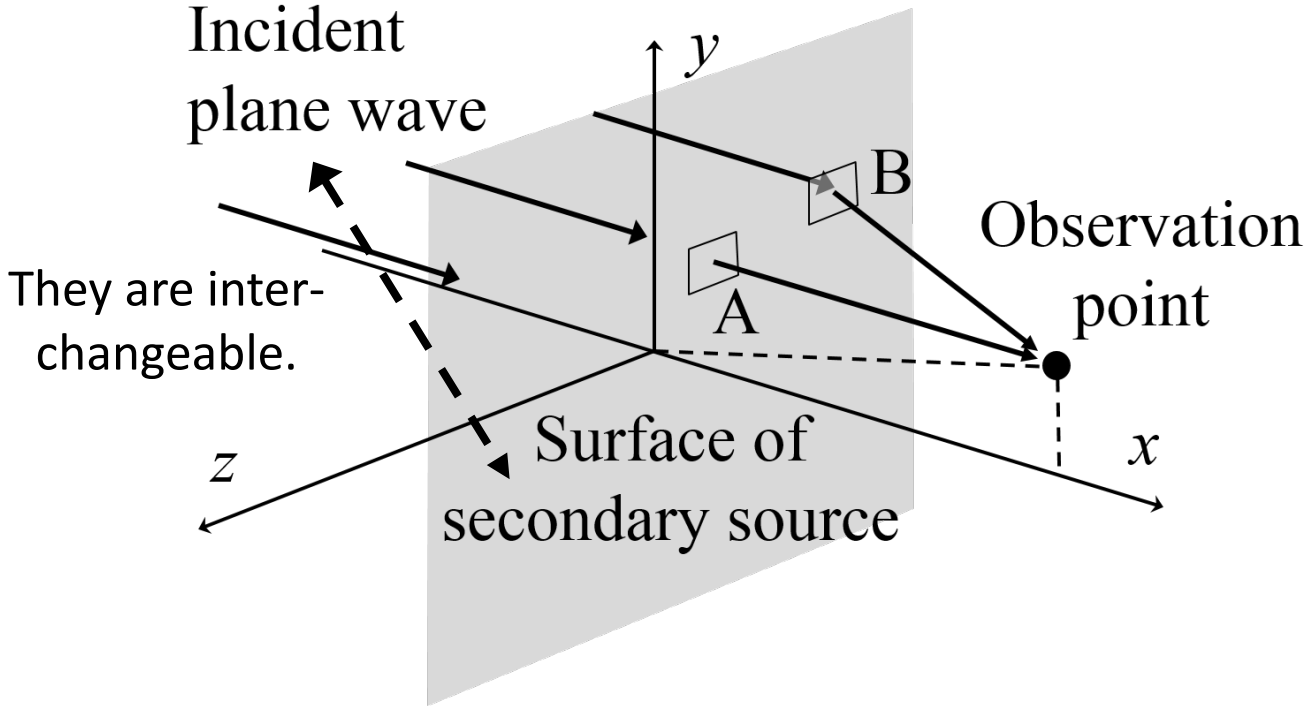
Huygens' principle and the secondary sources

- A single plane wave incidence

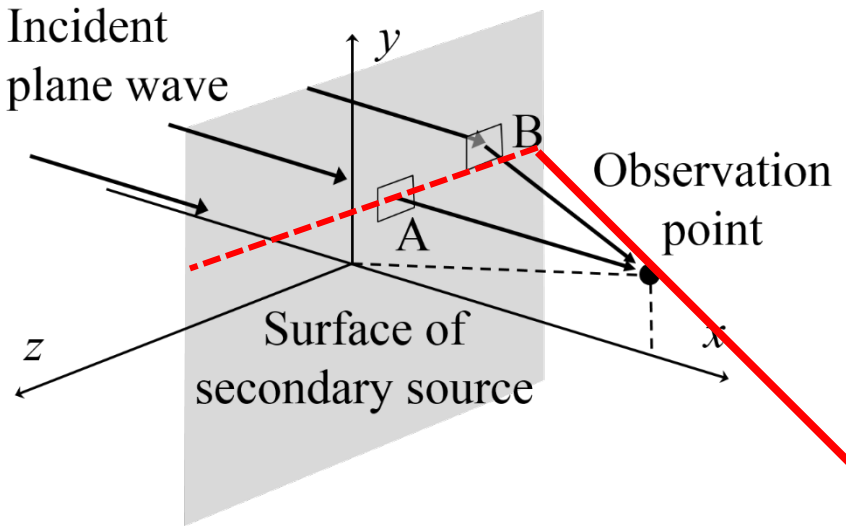


Q2: See the figure. At the observation point, we see field mainly from “A” point and not from “B” point because …

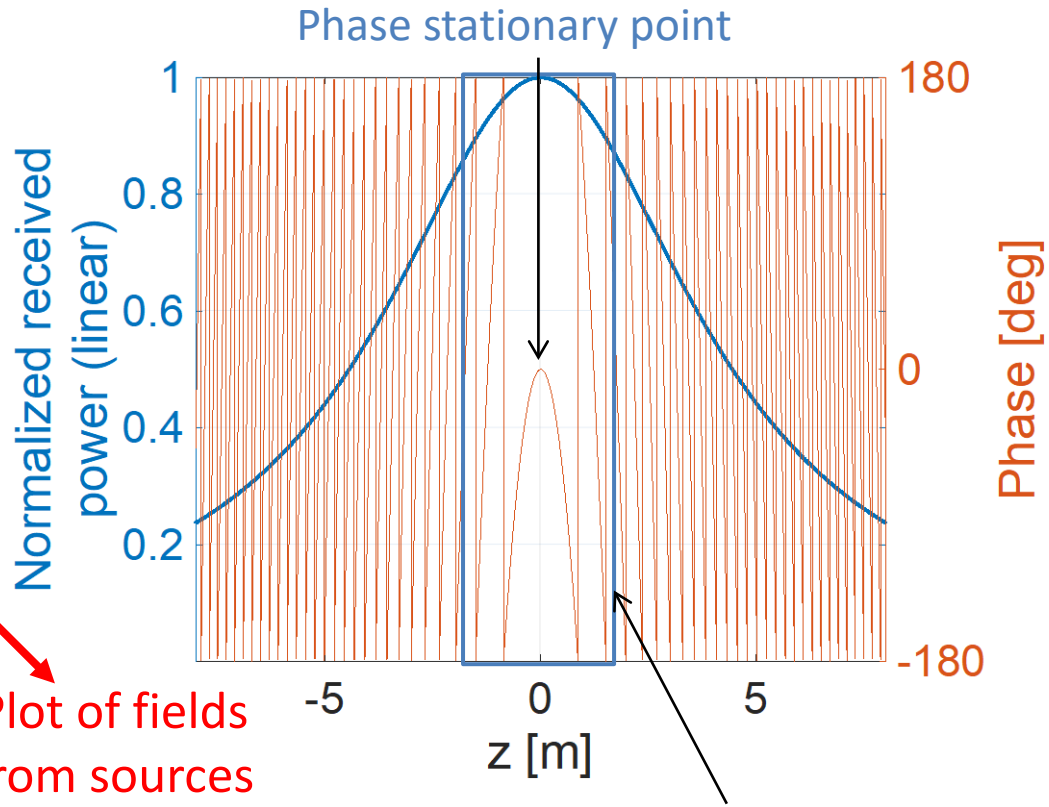
1. Field from B is cancelled by fields from other points.
2. Field from B is much weaker than field from A.
3. Field from B has opposite phase to field from A.
4. Field from B is cancelled by field from A.
5. I do not know.



Magnitude and phase of the observed fields from secondary sources



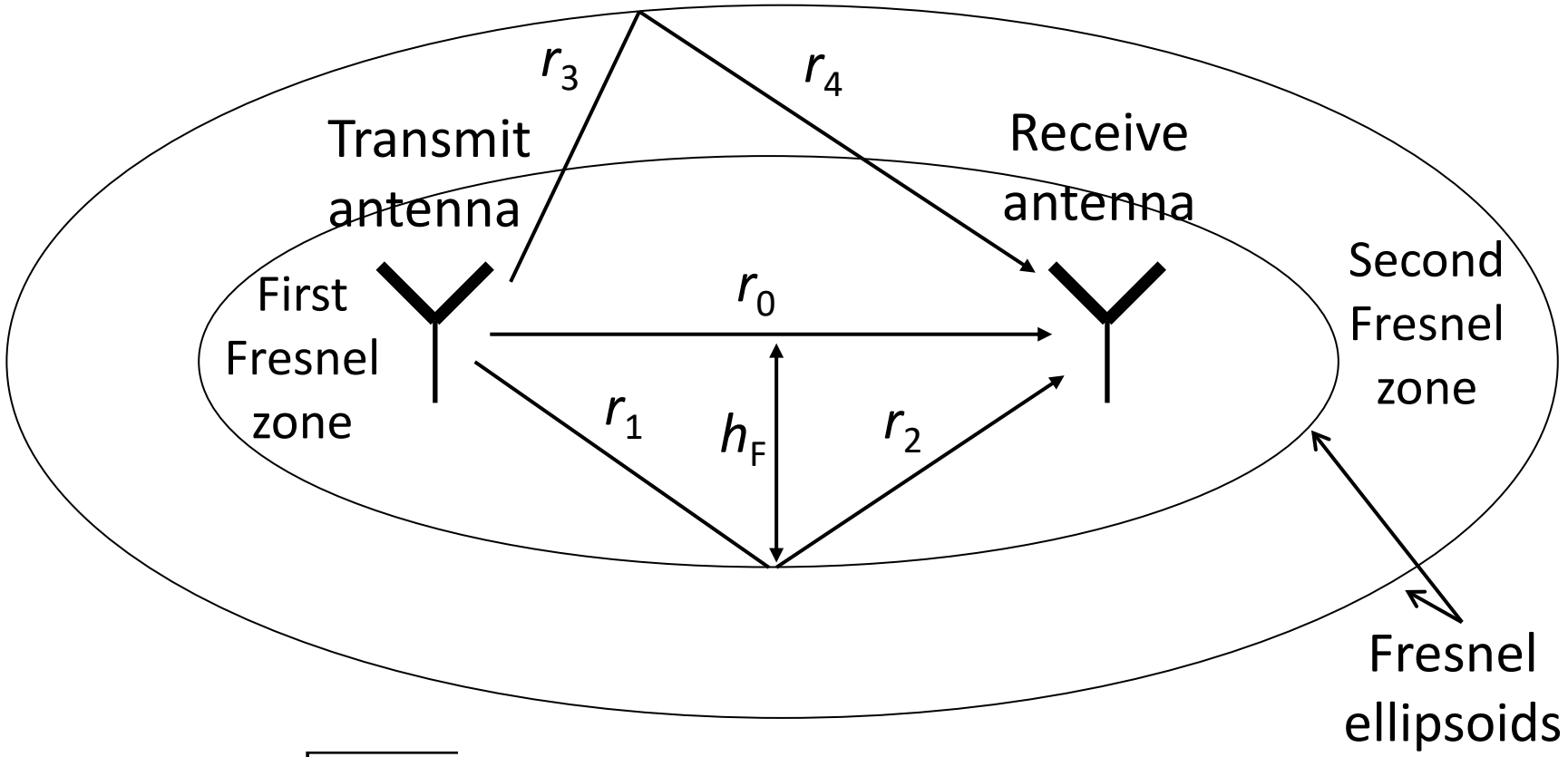
Observation point: x_2 = 4 m,
f = 900 MHz



Plot of fields
from sources
on this line

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

Fresnel zones

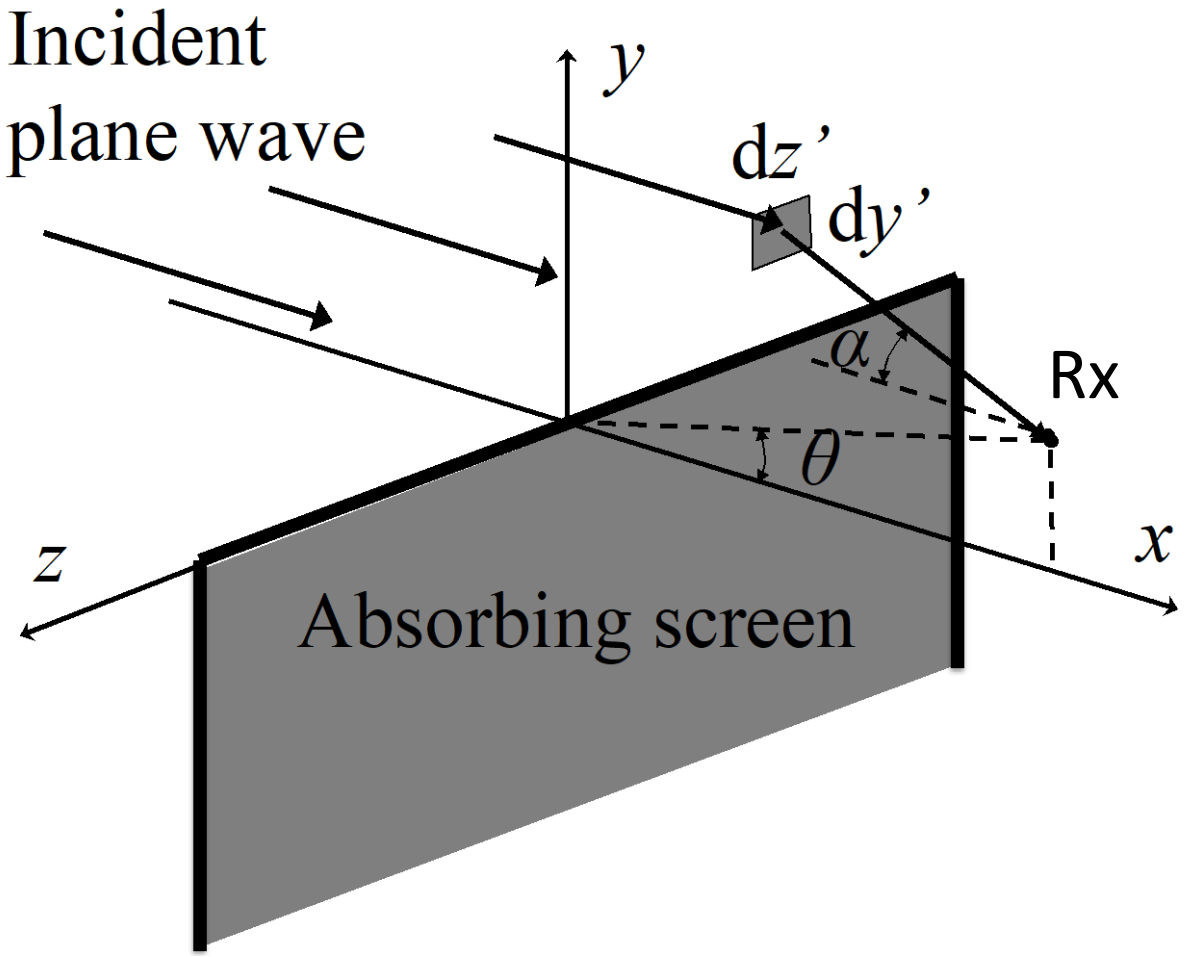


$$h_F \approx \sqrt{\frac{\lambda r_1 r_2}{r_1 + r_2}}$$

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

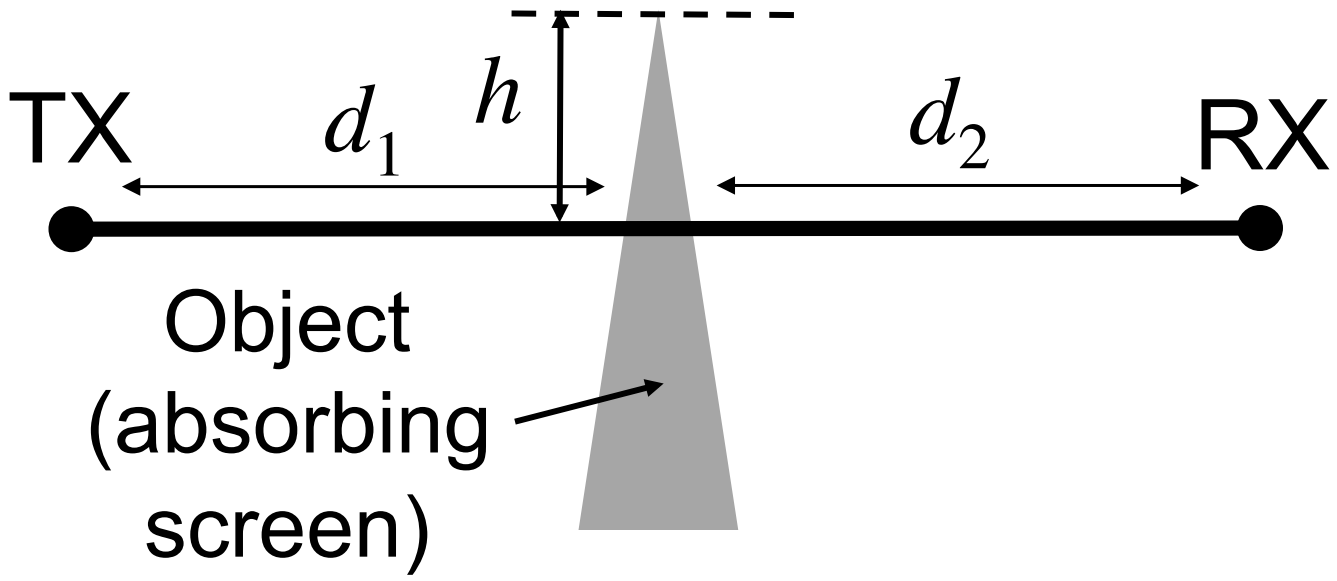
$r_3 + r_4 = r_0 + \lambda$: Second Fresnel ellipsoid

Diffraction due to a half-plane absorbing screen

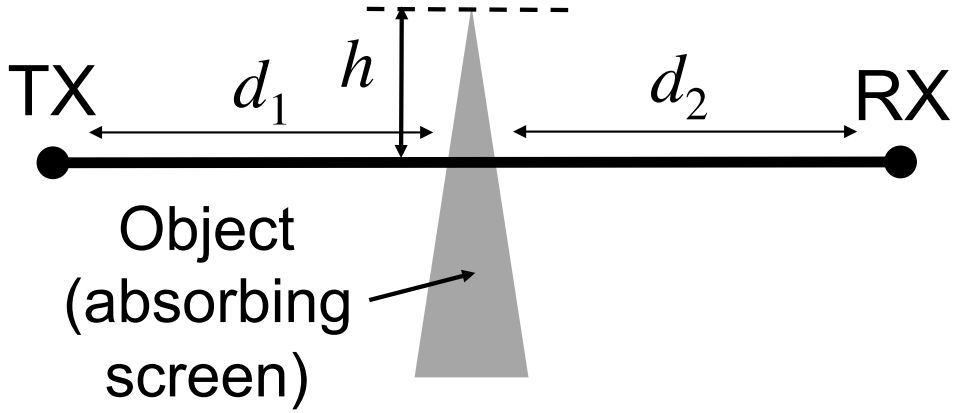


Q3: A tip of the absorbing screen is just the heights of the transmit and receive antennas, i.e., $h = 0$. What is the loss of the link, compared to an unobstructed link?

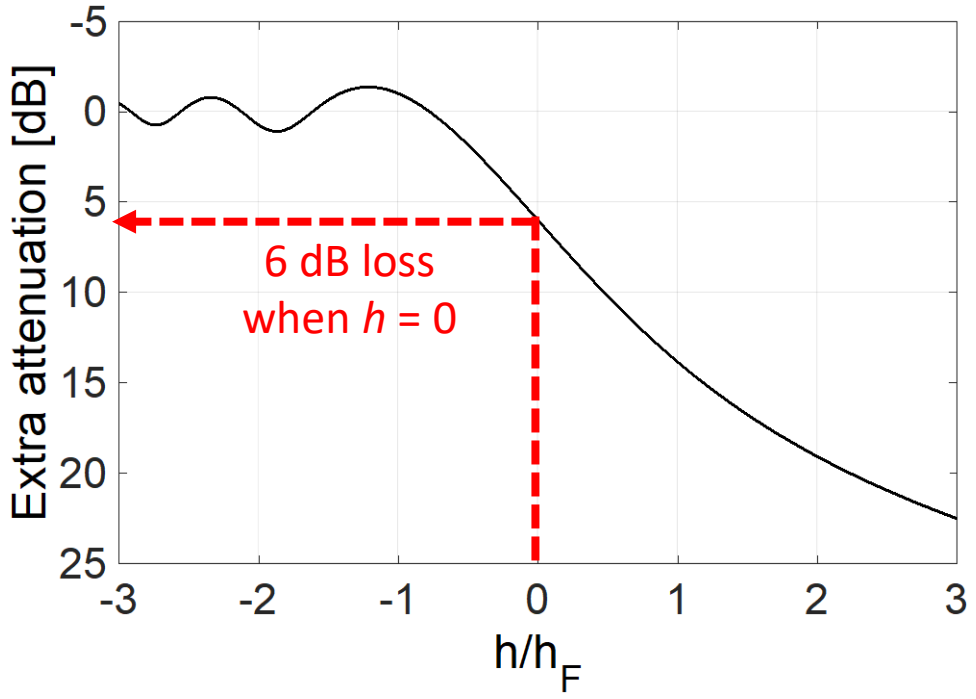
1. 0 dB.
2. 3 dB.
3. 6 dB.
4. 10 dB.
5. I do not know.



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

Received power, normalized by line-of-sight power

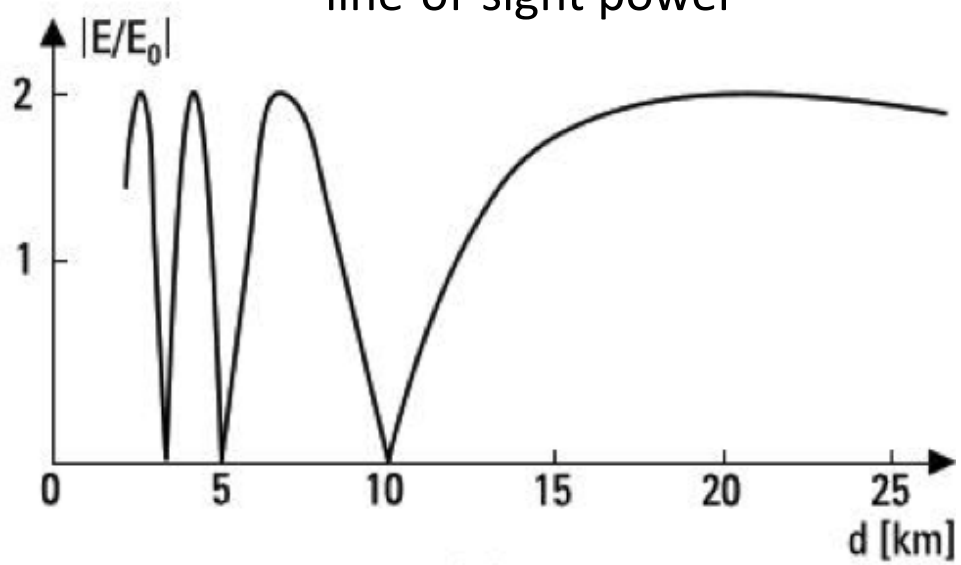
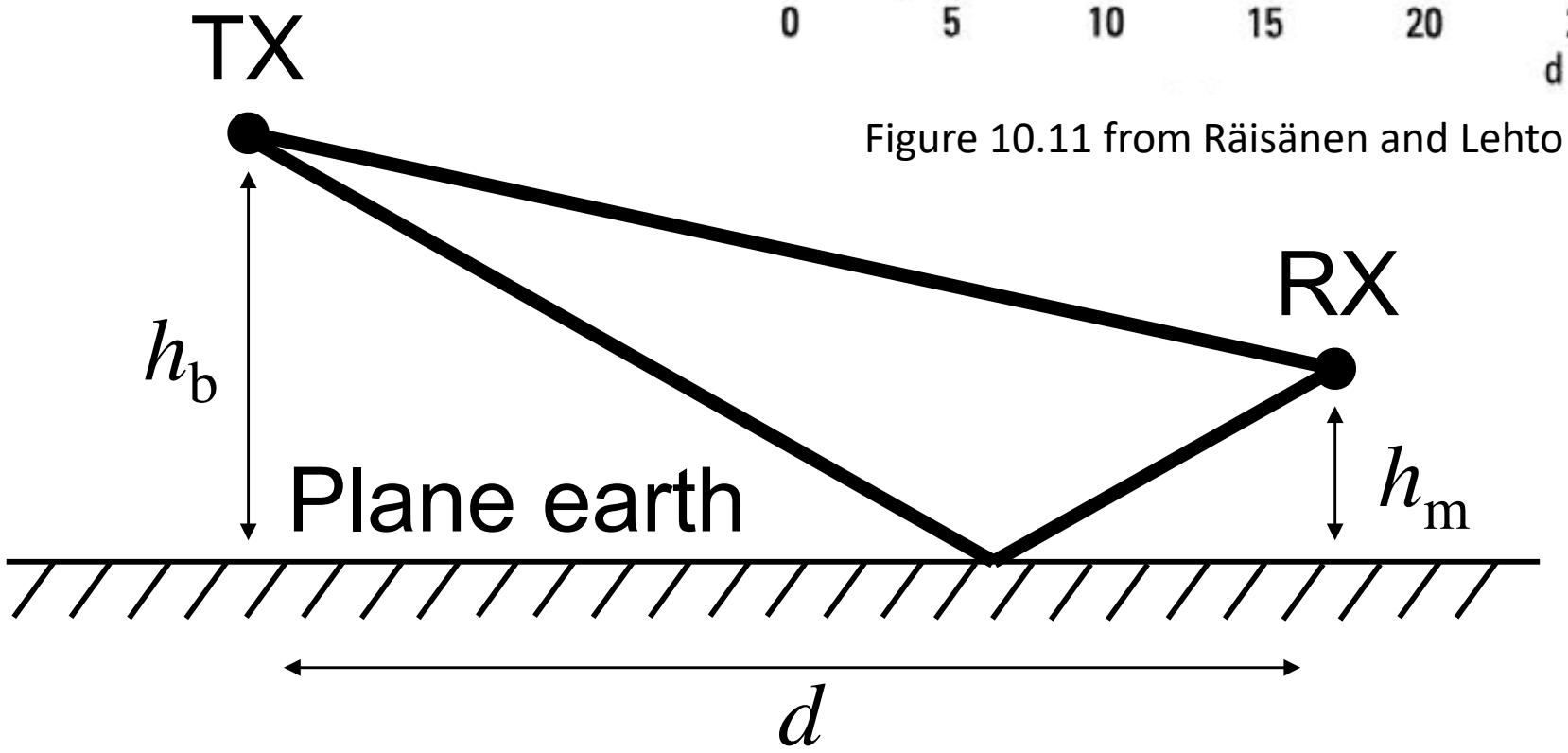


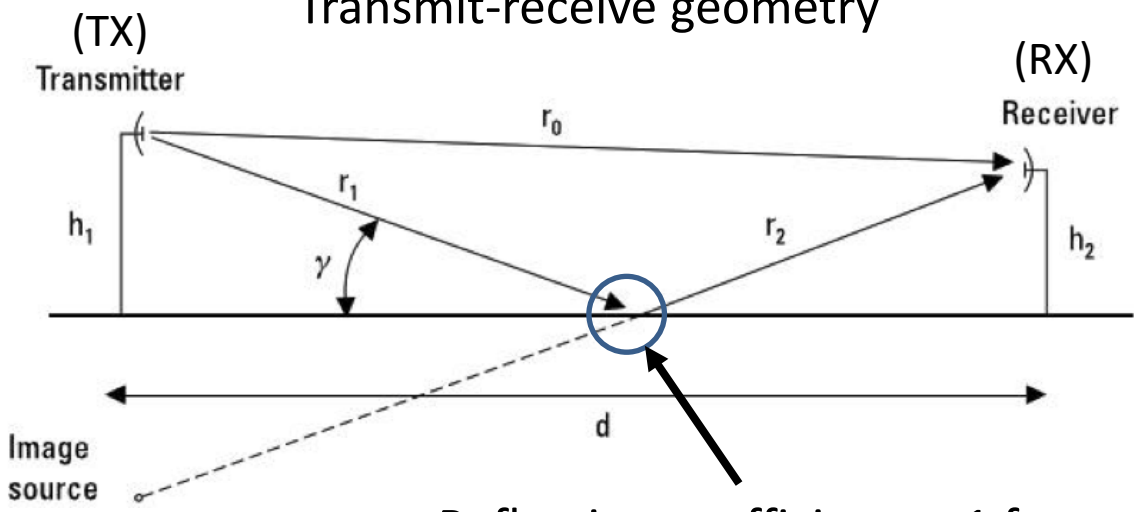
Figure 10.11 from Räisänen and Lehto



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?

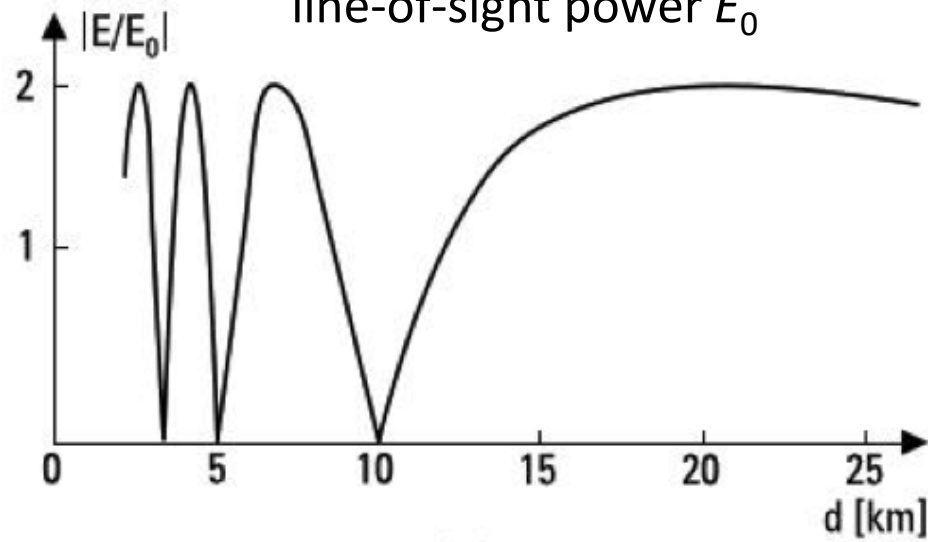
1. At TX-RX distance of 7.5 km, the signal receives very well.
2. Data communication may suffer from outage at some TX-RX distances.
3. Having very high transmit power ensures good data communication across all TX-RX distances.
4. Signal outage is due to destructive interference of the two waves.
5.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

Transmit-receive geometry



Reflection coefficient ≈ -1 for horizontal polarized fields

Received power, normalized by line-of-sight power E_0

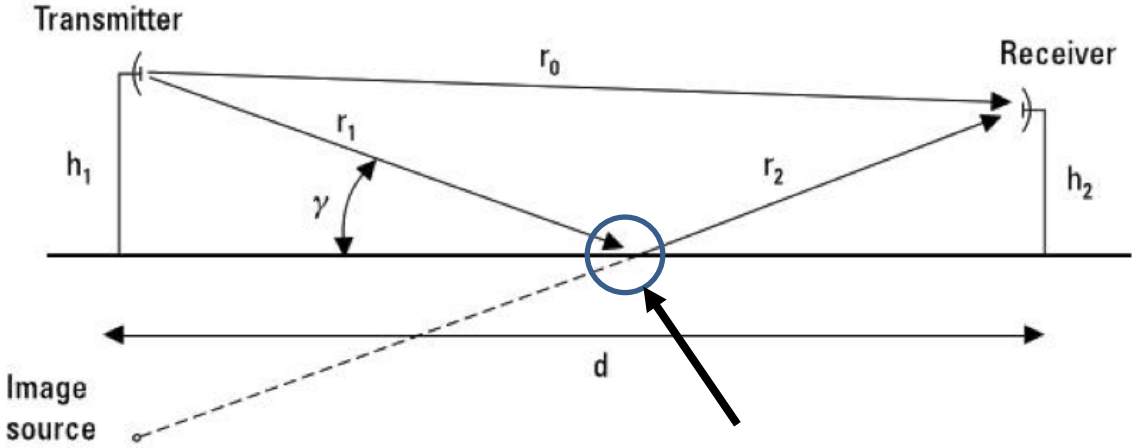


Figures 10.10 and 10.11 from Räisänen and Lehto

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?

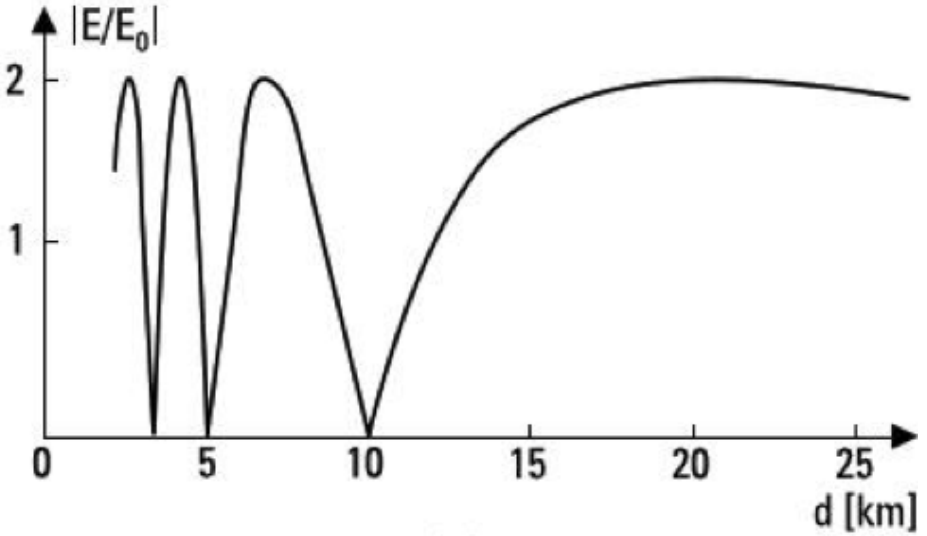
1. $r_1 + r_2 - r_0 = \lambda/4$.
2. $r_1 + r_2 - r_0 = \lambda/2$.
3. $r_1 + r_2 - r_0 = \lambda$.
4. $r_1 + r_2 - r_0 = 28.5\lambda$.
5. I do not know.

Transmit-receive geometry



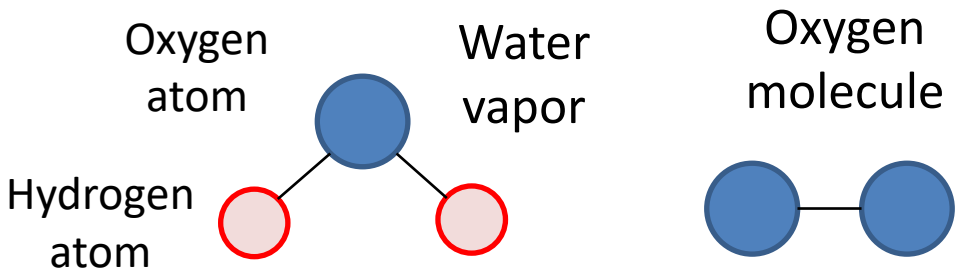
Reflection coefficient ≈ -1 for horizontal polarized fields

Received power, normalized by line-of-sight power E_0



Figures 10.10 and 10.11 from Räisänen 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.

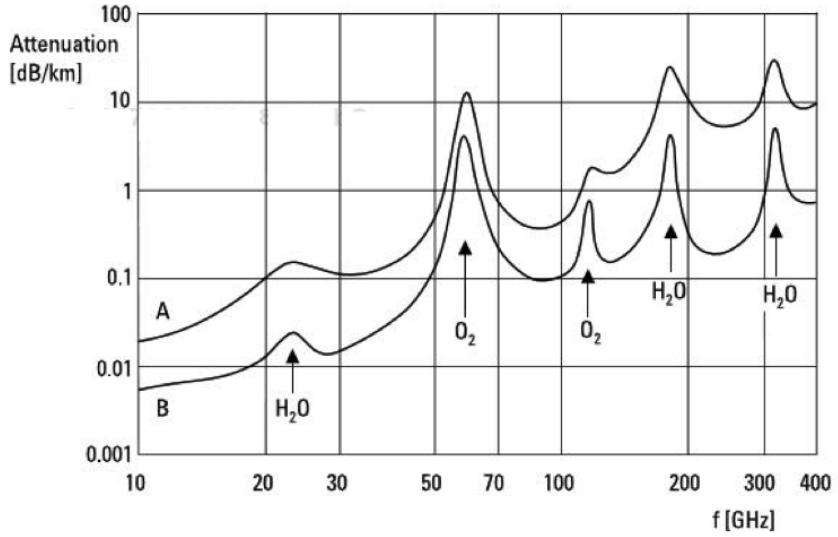


Figure 10.2 Attenuation in clear atmosphere versus frequency. Curve A: at sea level (T = 20°C, water vapor density 7.5 g/m^3). Curve B: at altitude of 4 km (T = 0°C, water vapor density 1 g/m^3).

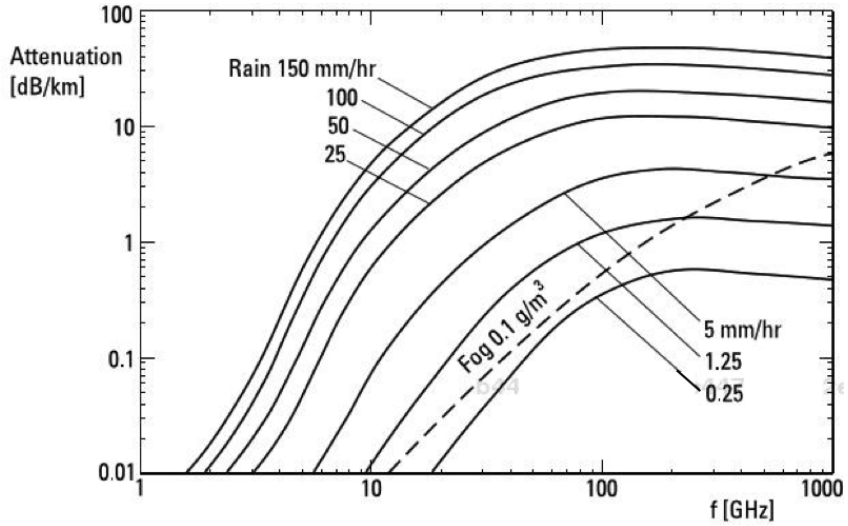
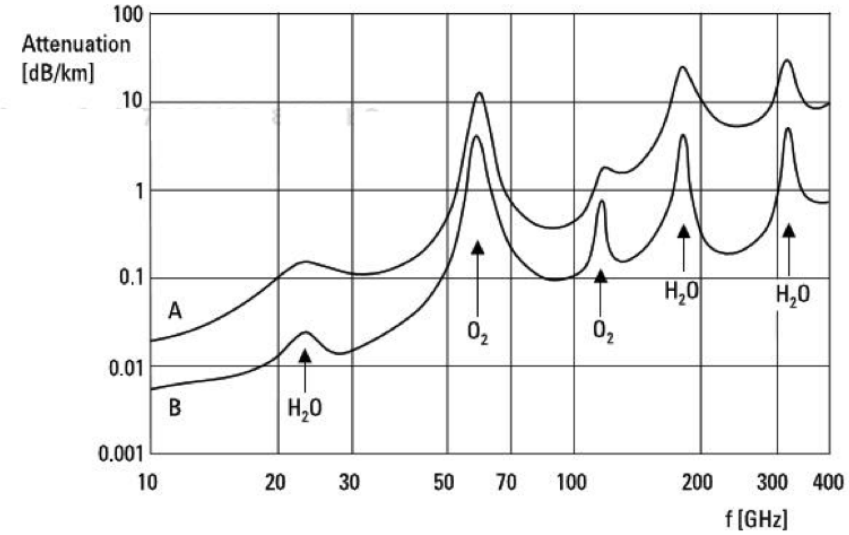


Figure 10.3 Attenuation due to rain and fog.

Figures from Räisänen and Lehto, Ch. 10.

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.



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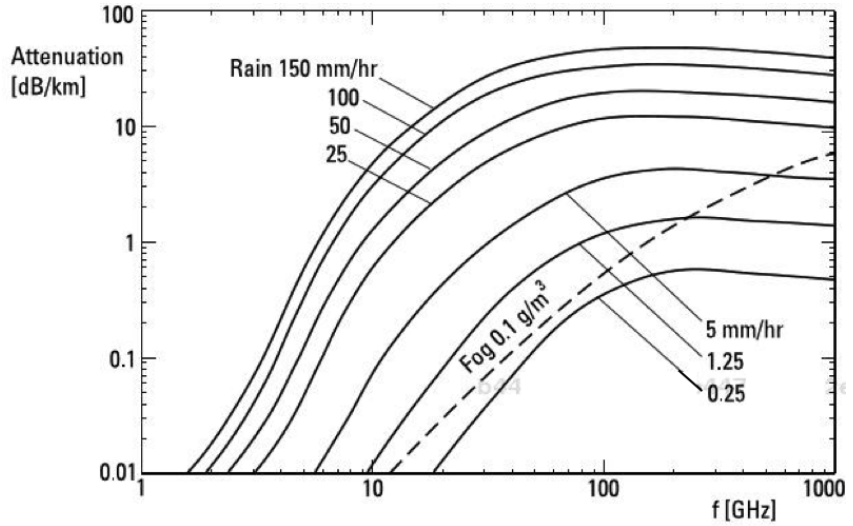
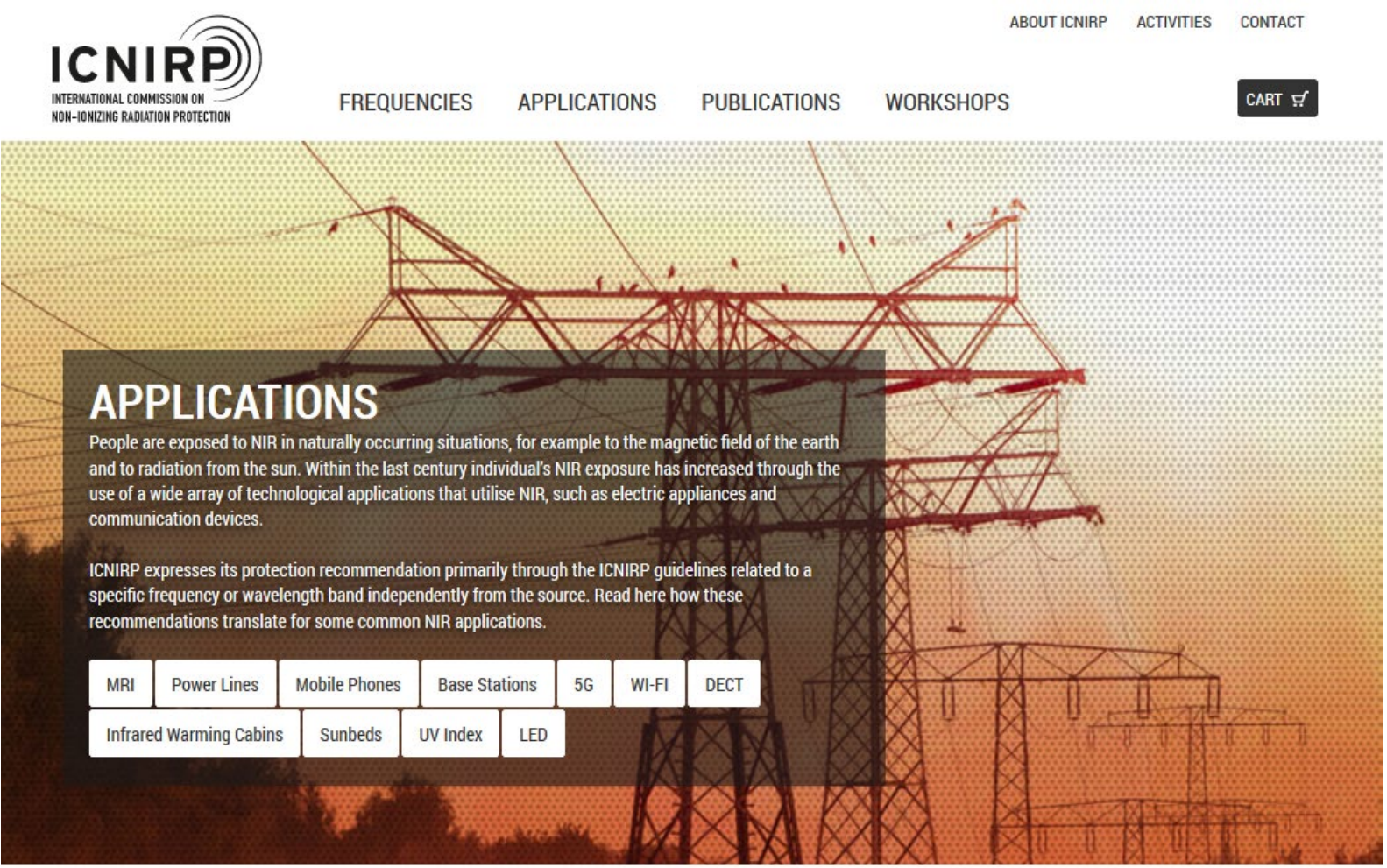
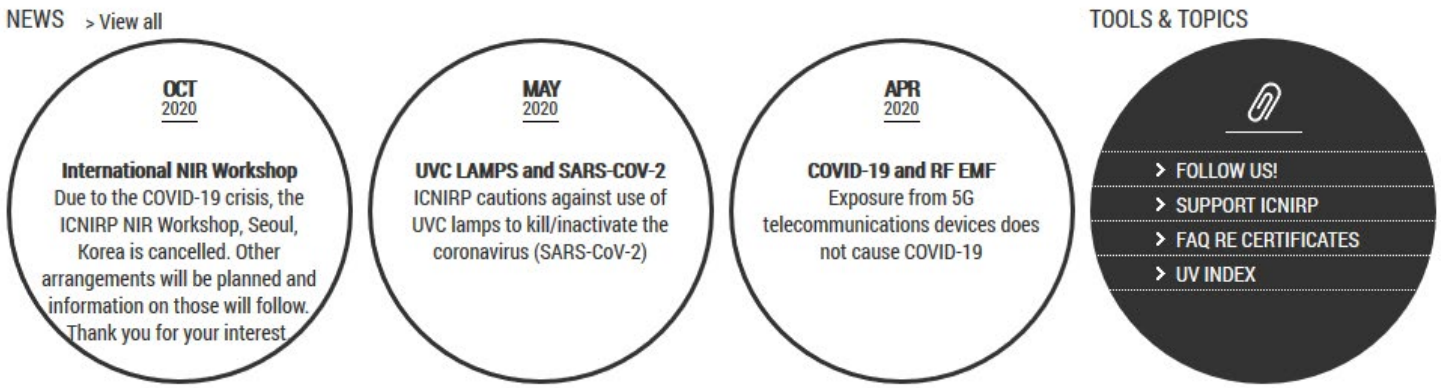


Figure 10.3 Attenuation due to rain and fog.

Radio exposure and safety





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."

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 (≥ 6-minutes).[a]

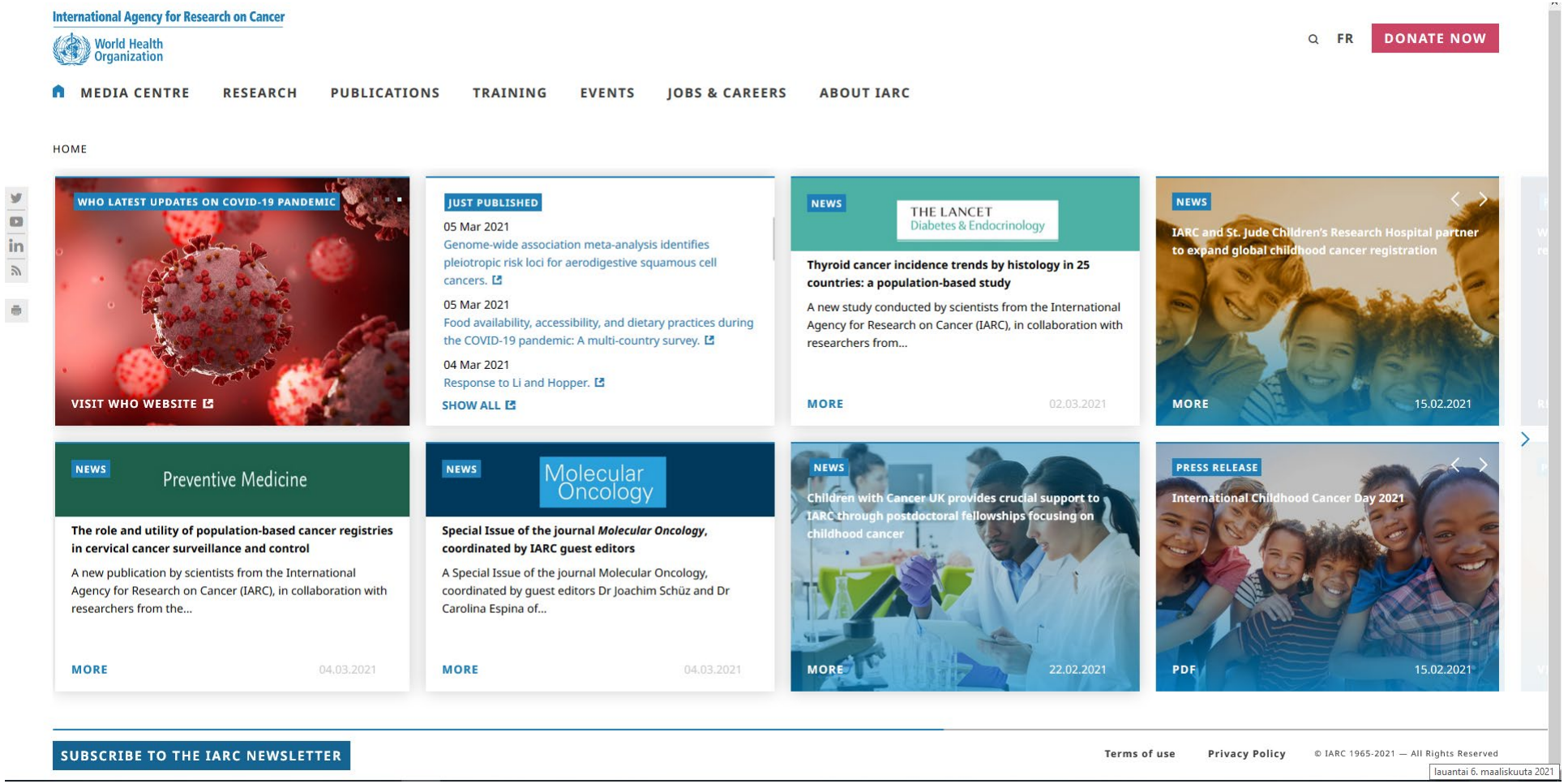
Exposure Scenario	Frequency Range	Whole body average SAR ($W\ kg^{-1}$)	Local head/torso SAR ($W\ kg^{-1}$)	Local limb SAR ($W\ kg^{-1}$)	Local S_{tr} ($W\ m^{-2}$)
Occupational	100 kHz – 6 GHz	0.4	10	20	---
	>6 GHz – 300 GHz	0.4	---	---	100
General Public	100 kHz – 6 GHz	0.08	2	4	---
	>6 GHz – 300 GHz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

[a] 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 cm^2 (>6-30 GHz), or 1 cm^2 (>30 GHz).

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

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

IARC: International Agency for Research on Cancer



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, Magnetic Fields (ELF), Radiofrequency electromagnetic fields
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), Electric fields, extremely low-frequency, Electric fields, static, Magnetic fields, static
Group 4	Probably not carcinogenic to humans	1	Caprolactam

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

30-year trend in brain cancer

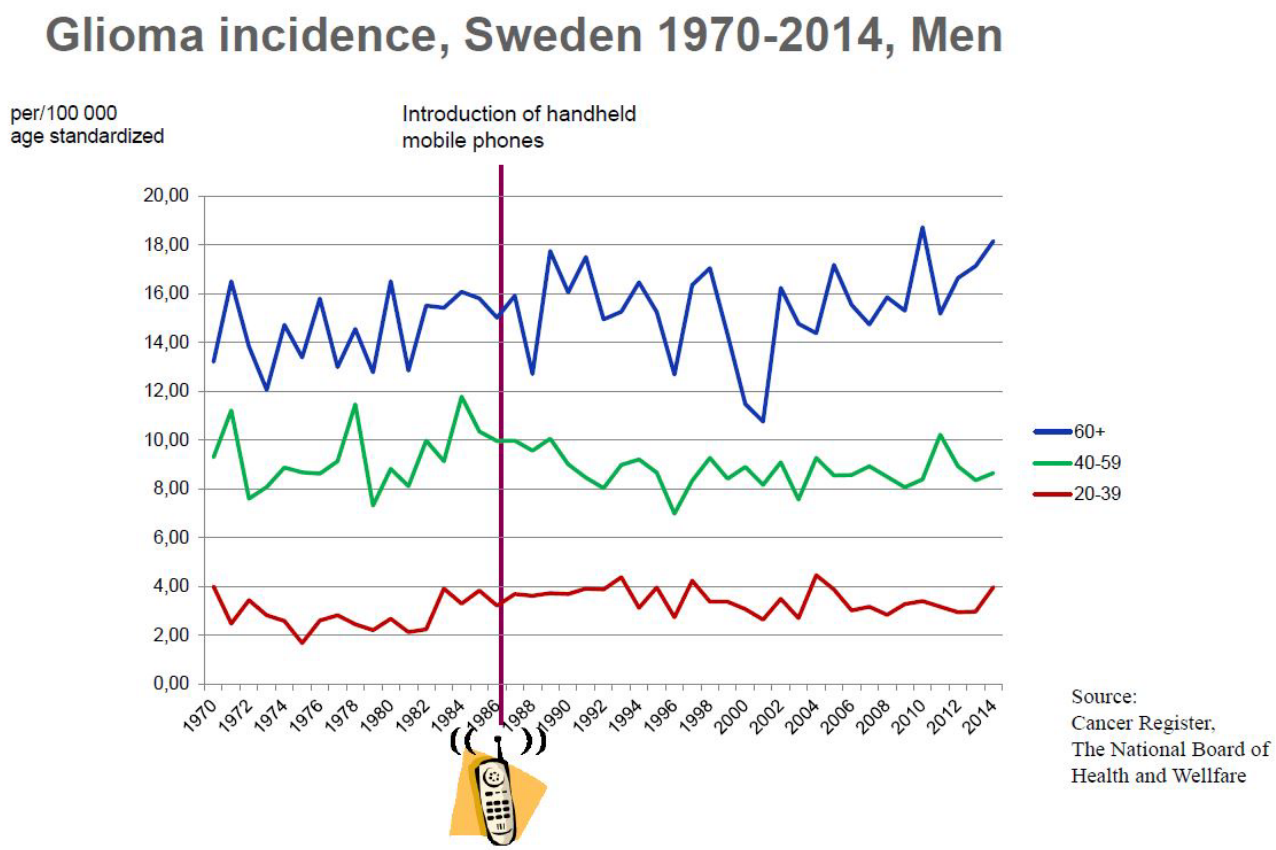
during which the cellular radios are in use

- **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)

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

Glioma incidence in Sweden

Glioma = a type of tumor in brain cells



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

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

Radiation and Nuclear Safety Authority in Finland (STUK)