Lecture no: 4

Channel models and antennas

Ove Edfors, Department of Electrical and Information Technology
Ove.Edfors@eit.lth.se

Contents

- Why do we need channel models?
- Narrowband models
  - Review of properties
  - Okumura's measurements
  - Okumura-Hata model
  - COST 231-Walfish-Ikegami model
- Wideband models
  - Review of properties
  - COST 207 model for GSM
  - ITU-R model for 3G
- Antennas
  - Efficiency and bandwidth
  - Mobile station antennas
  - Base station antennas
  - Dipole and parabolic antennas

WHY DO WE NEED CHANNEL MODELS?

Why do we need channel models?

During system design, testing and type approval:

Simple models reflecting the important properties of important channels (best, average, worst case)

Models used to make sure that the system design behaves well in typical situations.

During network design:

More detailed models appropriate for certain geographical areas

Models used to obtain an efficient network in terms of base station locations and other parameters

NARROWBAND MODELS

Narrowband models
Review of properties

Narrowband models contain ”only one” attenuation, which is modeled as a propagation loss, plus large- and small-scale fading.

Path loss: Often proportional to $1/d^n$, where n is the propagation exponent. (n may be different at different distances)

Large-scale fading: Log-normal distribution (normal distr. in dB scale)

Small-scale fading: Rayleig, Rice, Nakagami distributions ... (**not** in dB-scale)

NOTE: Several of these models are found in an on-line appendix of the textbook which can be downloaded from the publisher's website (see “Literature” on course web).

Printed copies of textbook appendices are allowed during Part B of the written exam.

Okumura's measurements
Background

Extensive measurement campaign in Japan in the 1960's.

Parameters varied during measurements:

Frequency	100 – 3000 MHz
Distance	1 – 100 km
Mobile station height	1 – 10 m
Base station height	20 – 1000 m
Environment	medium-size city, large city, etc.

Propagation loss is given as a **median** value (50% of the time and 50% of the area).

Results from these measurements are displayed in figures 7.12 – 7.14.

Okumura's measurements
How to calculate the prop. loss

1. We start by calculating the free-space attenuation
2. Apply a frequency and distance dependent correction
3. Apply a BS-height and distance dependent correction
4. Apply a MS-height, frequency and environment dependent correction

Free space attenuation → → → → L_{Oku}

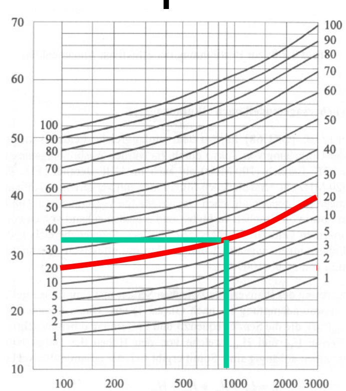


Fig. 7.12

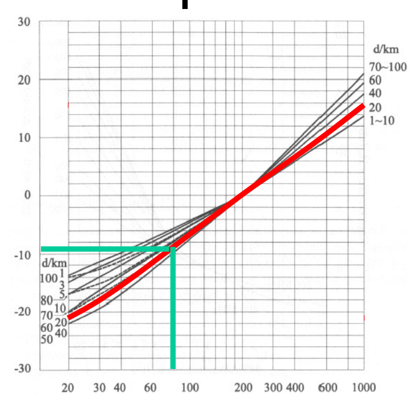


Fig. 7.13

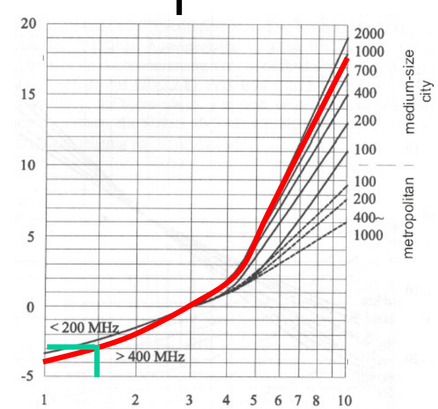


Fig. 7.14

Okumura's measurements
Example

Example

Propagation at 900 MHz in medium-size city with 40 m base station antenna height and 1.5 m mobile station antenna height.

Use Okumura's curves to calculate the propagation loss at a distance of 30 km between base station and mobile station.

Okumura's measurements
1. Calculate free-space loss

Example

Attenuation between two isotropic antennas in free space is (free-space loss):

$$L_{\mathrm{free}|\mathrm{dB}}(d) = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

The obtained value does not depend on antenna heights.

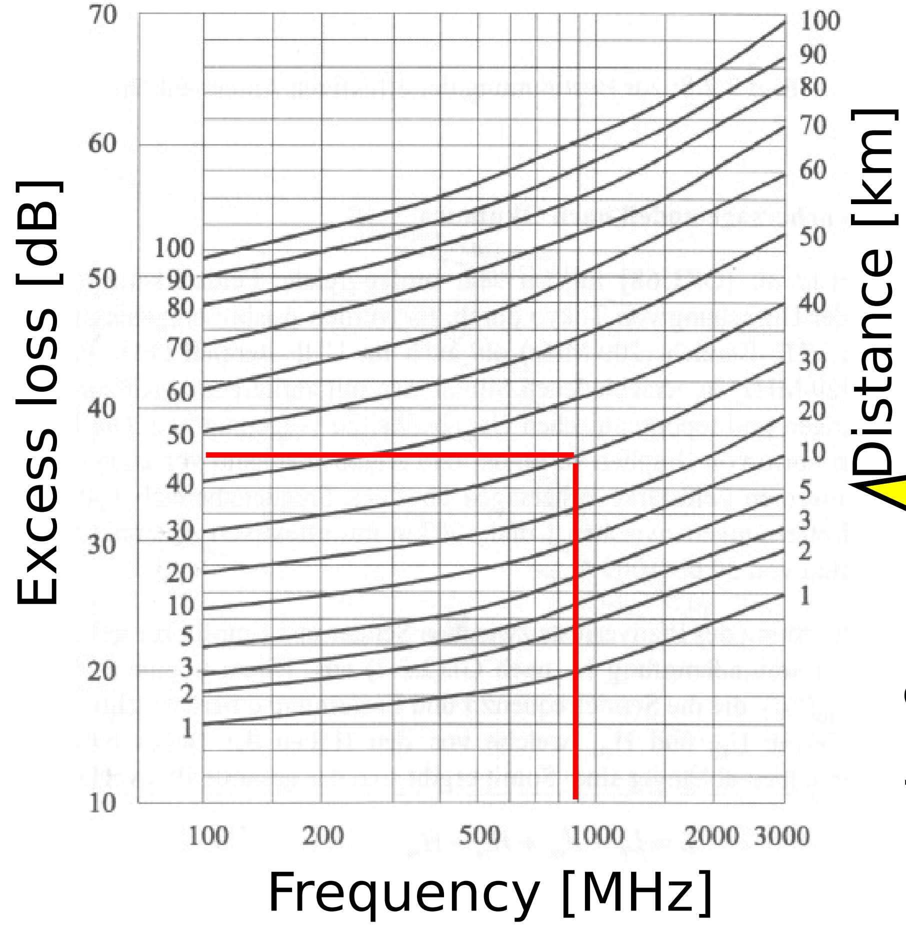
900 MHz and
30 km distance

=> **121 dB**

Okumura's measurements
2. Apply correction for excess loss

Example

FIGURE 7.12



These curves are only for h_b=200 m and h_m=3 m

900 MHz and
30 km distance

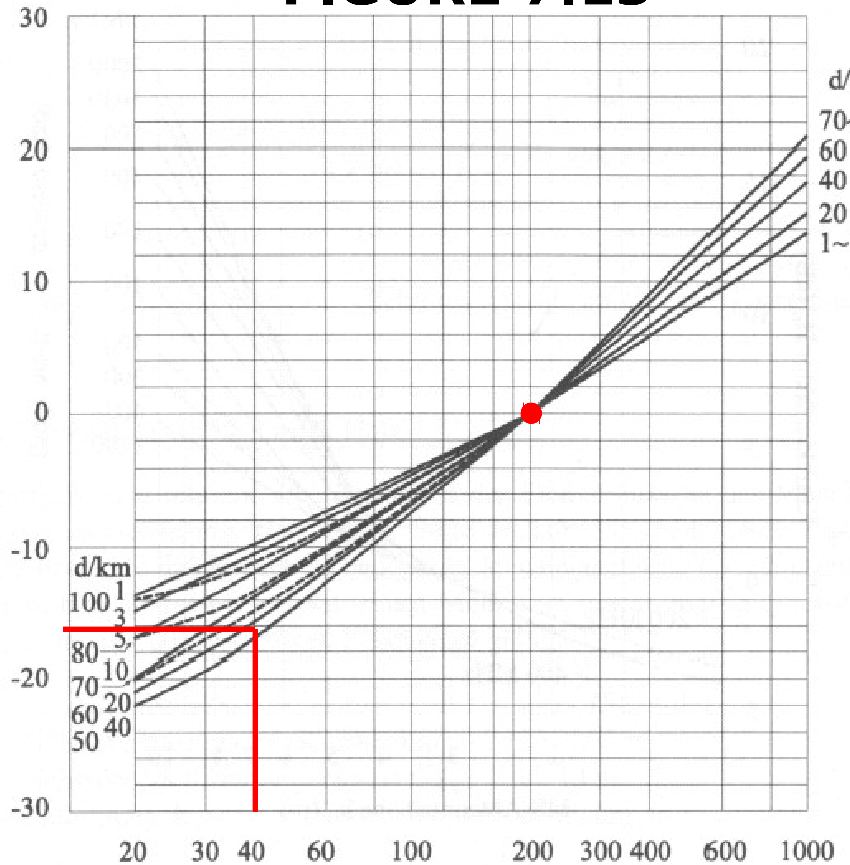
=> **36.5 dB**

Okumura’s measurements
3. Apply correction of BS height

Example

FIGURE 7.13

Correction factor [dB]



Distance [km]

BS height [m]

Note: Lower base station means INCREASING attenuation => **subtract** this number.

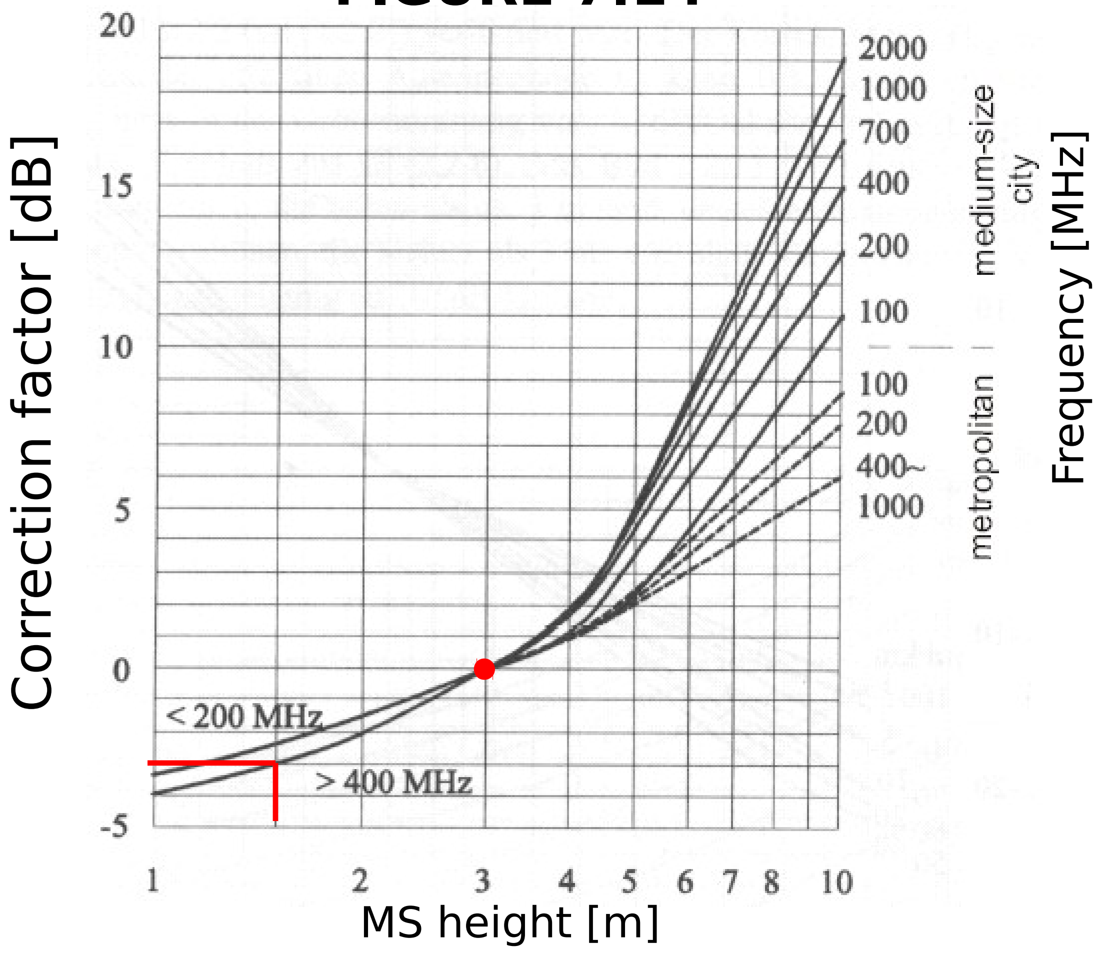
40 m BS and
30 km distance

=> -**16 dB**

Okumura's measurements
4. Apply correction of MS height

Example

FIGURE 7.14



Note: Lower mobile station means INCREASING attenuation => **subtract** this number.

1.5 m MS and 900 MHz in medium-size city => **-3 dB**

Okumura’s measurements
Summary of example

Example

Propagation loss (between isotropic antennas) using Okumura’s measurements:

$$L_{Oku|dB} = 121 + 36.5 - (-16) - (-3) = \boxed{176.5 \text{ dB}}$$

Calc. step: 1 2 3 4

The Okumura-Hata model Background

In 1980 Hata published a parameterized model, based on Okumura's measurements.

The parameterized model has a *smaller range of validity* than the measurements by Okumura:

Frequency	150 – 1500 MHz
Distance	1 – 20 km
Mobile station height	1 – 10 m
Base station height	30 – 200 m

The Okumura-Hata model
How to calculate prop. loss

$$L_{O-H} = A + B\log\left(d_{|km}\right) + C$$

$$A = 69.55 + 26.16\log\left(f_{0|MHz}\right) - 13.82\log\left(h_b\right) - a\left(h_m\right)$$

$$B = 44.9 - 6.55\log\left(h_b\right)$$

h_b and h_m in meter

<table>
<tr><th></th><th>$a\left(h_m\right) =$</th><th>$C =$</th></tr>
<tr><td>Metropolitan areas</td><td>$8.29\left(\log\left(1.54\,h_\mathrm{m}\right)\right)^2 - 1.1 \quad \text{for } f_0 \leqslant 200\,\mathrm{MHz}$
$3.2\left(\log\left(11.75\,h_\mathrm{m}\right)\right)^2 - 4.97 \quad \text{for } f_0 \geqslant 400\,\mathrm{MHz}$</td><td>$0$</td></tr>
<tr><td>Small/medium-size cities</td><td rowspan="3">$\left(1.1\log\left(f_{0|MHz}\right) - 0.7\right)h_m -$
$\left(1.56\log\left(f_{0|MHz}\right) - 0.8\right)$</td><td>$0$</td></tr>
<tr><td>Suburban environments</td><td>$-2\left(\log\left(f_{0|\mathrm{MHz}}/28\right)\right)^2 - 5.4$</td></tr>
<tr><td>Rural areas</td><td>$-4.78\left(\log\left(f_{0|\mathrm{MHz}}\right)\right)^2 + 18.33\log\left(f_{0|\mathrm{MHz}}\right) - 40.94$</td></tr>
</table>

COST 231-Walfish-Ikegami model
Background

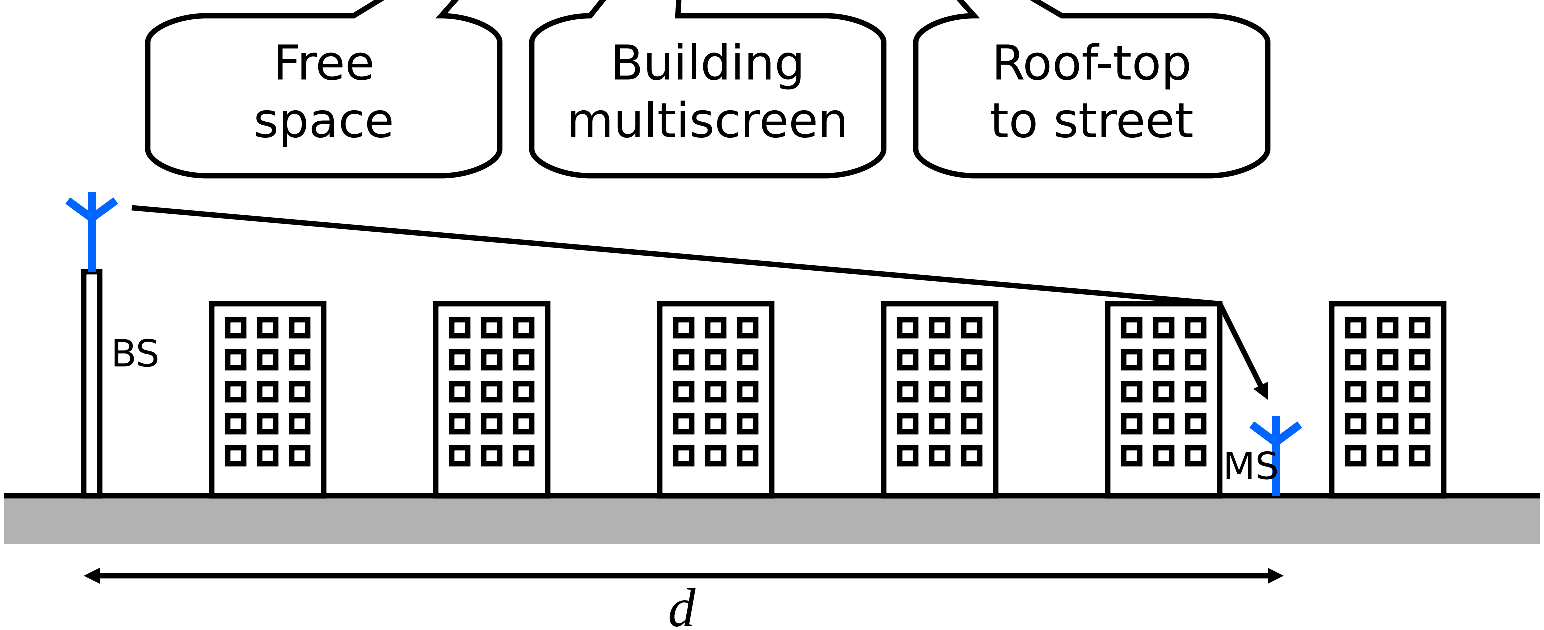
The Okumura-Hata model is not suitable for micro cells or small macro cells, due to its restrictions on distance ($d > 1$ km).

The COST 231-Walfish-Ikegami model covers much smaller distances and is better suited for calculations on small cells.

Frequency	800 – 2000 MHz
Distance	0.02 – 5 km
Mobile station height	1 – 3 m
Base station height	4 – 50 m

COST 231-Walfish-Ikegami model
How to calculate prop. loss

$$L = L_0 + L_{msd} + L_{rts}$$



Details about calculations can be found in Appendix 7.B.

WIDEBAND MODELS

Wideband models
Review of properties

Let’s assume the tapped delay-line model

$$h(t,\tau)=\sum_{i=1}^{N}\alpha_i(t)\exp\left(j\theta_i(t)\right)\delta\left(\tau-\tau_i\right)$$

The **power-delay profile** tells us how much energy the channel has at a certain delay τ (essentially the rms values of the $\alpha_i(t)$’s).

The **Doppler spectrum** tells us how fast the channel changes in time (essentially how fast the $\alpha_i(t)$’s and $\theta_i(t)$’s change). There can be one Doppler spectrum for each delay.

Wideband models
COST 207 model for GSM

The COST 207 model specifies:

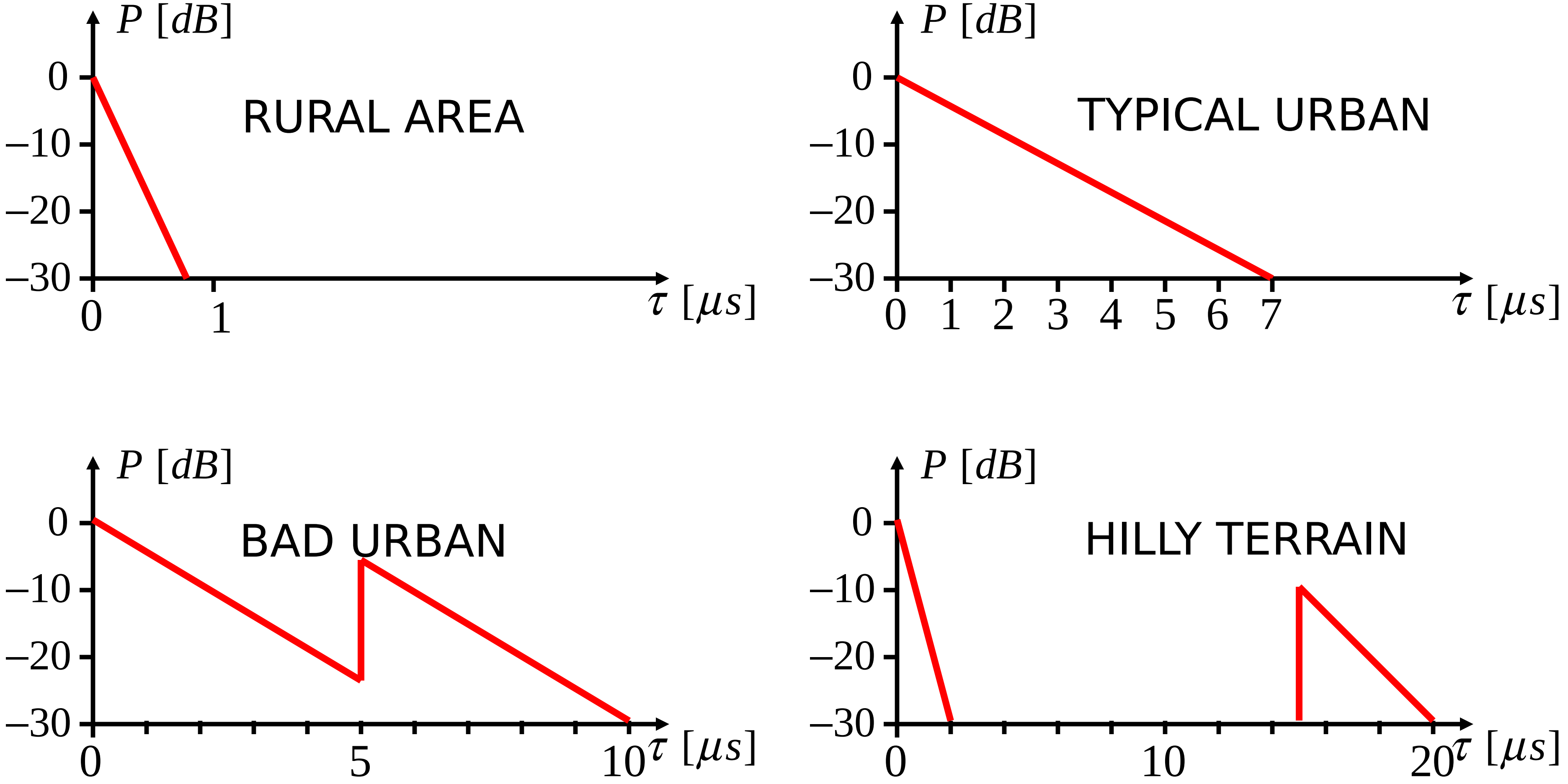
FOUR power-delay profiles for different environments.

FOUR Doppler spectra used for different delays.

IT **DOES NOT** SPECIFY PROAGATION LOSSES FOR THE DIFFERENT ENVIRONMENTS!

Wideband models
COST 207 model for GSM

Four specified power-delay profiles

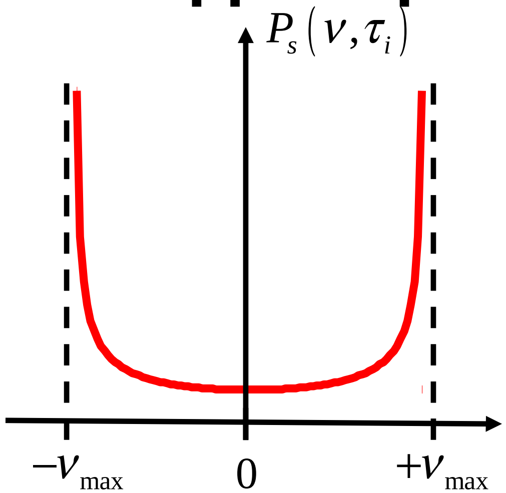


Wideband models
COST 207 model for GSM

Four specified Doppler spectra

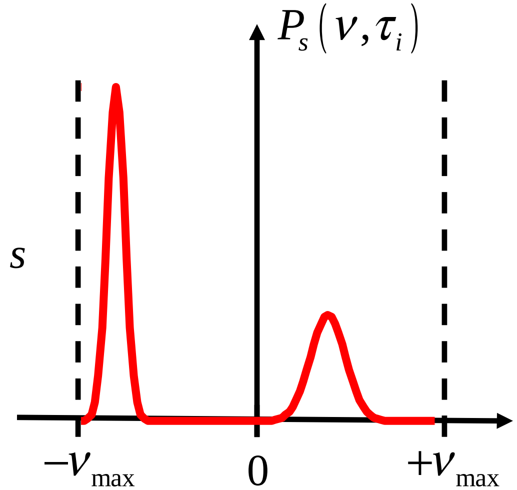
CLASS

$\tau_i \le 0.5 \mu s$



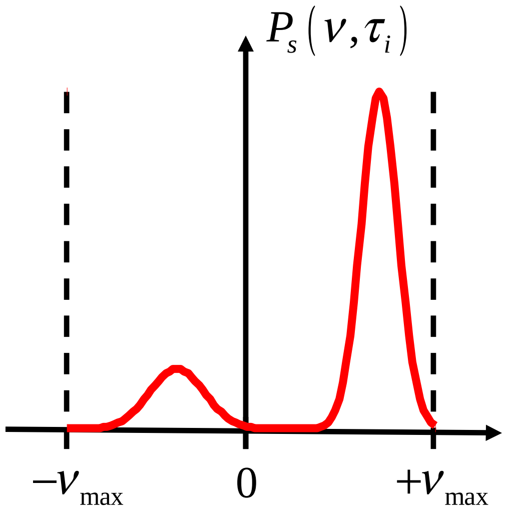
GAUS1

$0.5 \mu s < \tau_i \le 2 \mu s$



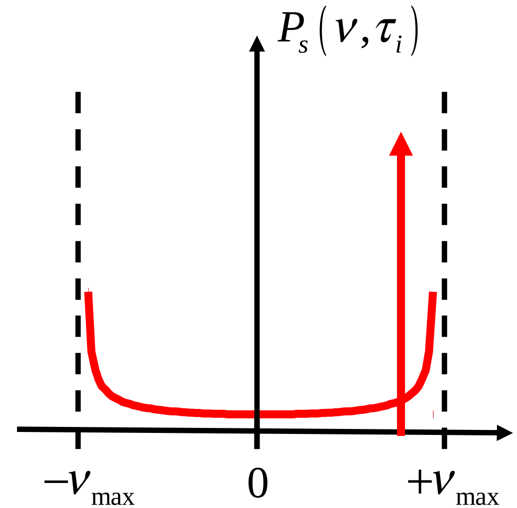
GAUS2

$\tau_i > 2 \mu s$

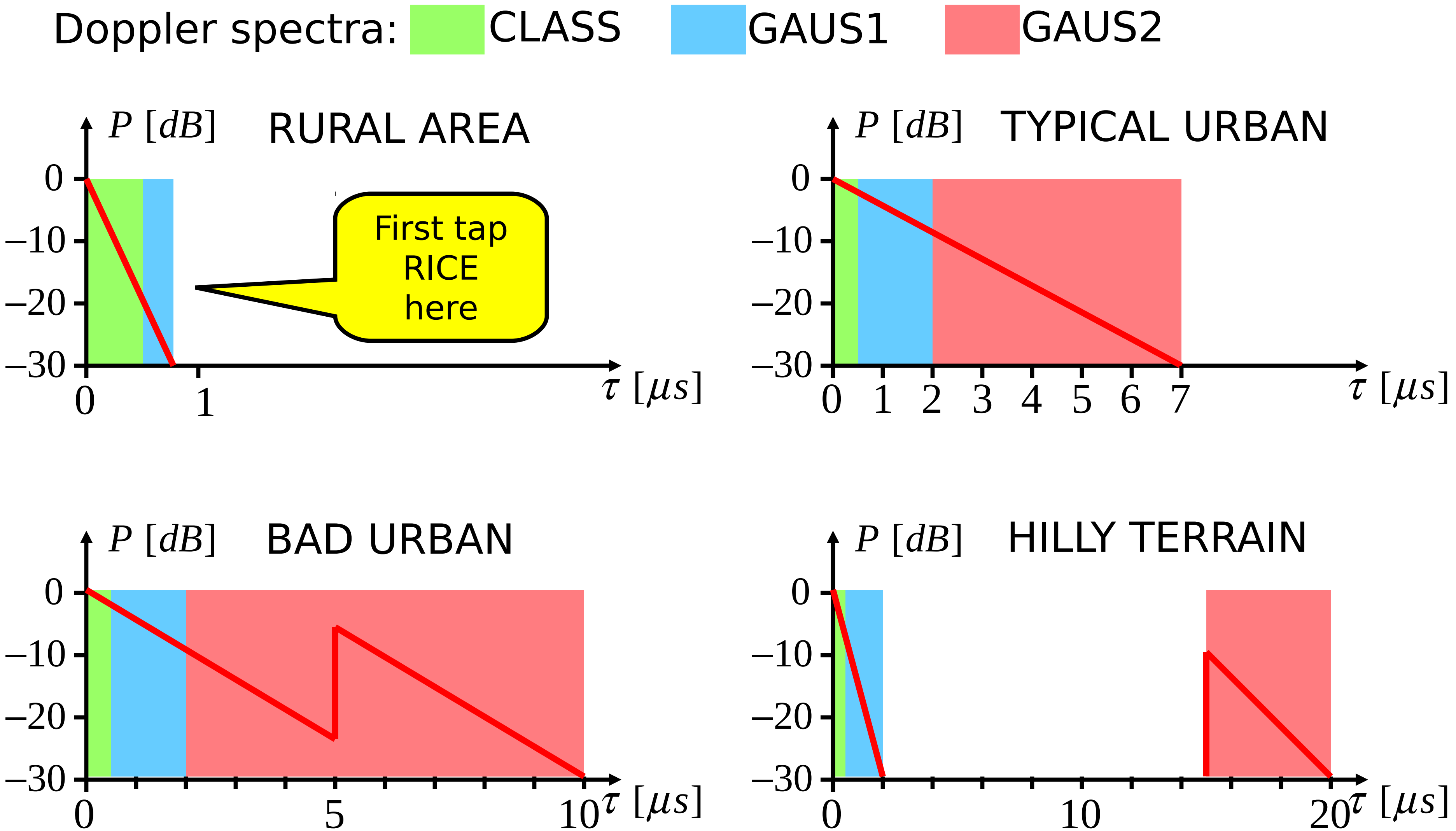


RICE

Shortest path in rural areas



Wideband models
COST 207 model for GSM



Wideband models
COST 207 model for GSM

There are also suggested tapped delay-line implementations, with six Rayleigh-fading taps per channel. See Appendix 7.C (on-line).

QUICK QUIZ: The system bit-rate of GSM is 271 kbit/s.

How long is one bit in time?

How long are the different COST 207 channels, measured in bit-times?

Wideband models
ITU-R model for 3G

The ITU-R model specifies:

- SIX different tapped delay-line channels for three different scenarios (indoor, pedestrian, vehicular).
- TWO channels per scenario (one short and one long delay spread).
- TWO different Doppler spectra (uniform & classical), depending on scenario.
- THREE different models for propagation loss (one for each scenario).
- The standard deviation of the log-normal shadow fading is specified for each scenario.
- The autocorrelation of the log-normal shadow fading is specified for the vehicular scenario.

Wideband models
ITU-R model for 3G

Tap No.	delay/ns	power/dB	delay/ns	power/dB
INDOOR	**CHANNEL A** (50%)		**CHANNEL B** (45%)	
1	0	0	0	0
2	50	-3	100	-3.6
3	110	-10	200	-7.2
4	170	-18	300	-10.8
5	290	-26	500	-18.0
6	310	-32	700	-25.2
PEDESTRIAN	**CHANNEL A** (40%)		**CHANNEL B** (55%)	
1	0	0	0	0
2	110	-9.7	200	-0.9
3	190	-19.2	800	-4.9
4	410	-22.8	1200	-8.0
5			2300	-7.8
6			3700	-23.9
VEHICULAR	**CHANNEL A** (40%)		**CHANNEL B** (55%)	
1	0	0	0	-2.5
2	310	-1	300	0
3	710	-9	8900	-12.8
4	1090	-10	12900	-10.0
5	1730	-15	17100	-25.2
6	2510	-20	20000	-16.0

ANTENNAS

Antennas
Efficiency

The antenna efficiency measures “how efficiently” an antenna converts the input power into radiation. This translates directly into power consumption and battery life.

Antenna efficiency of mobiles has **decreased** mainly due to cosmetic restrictions.

What cosmetic restrictions?

Antennas
Bandwidth

We can say that the bandwidth of an antenna is the width of the frequency range over which it fulfills some specification.

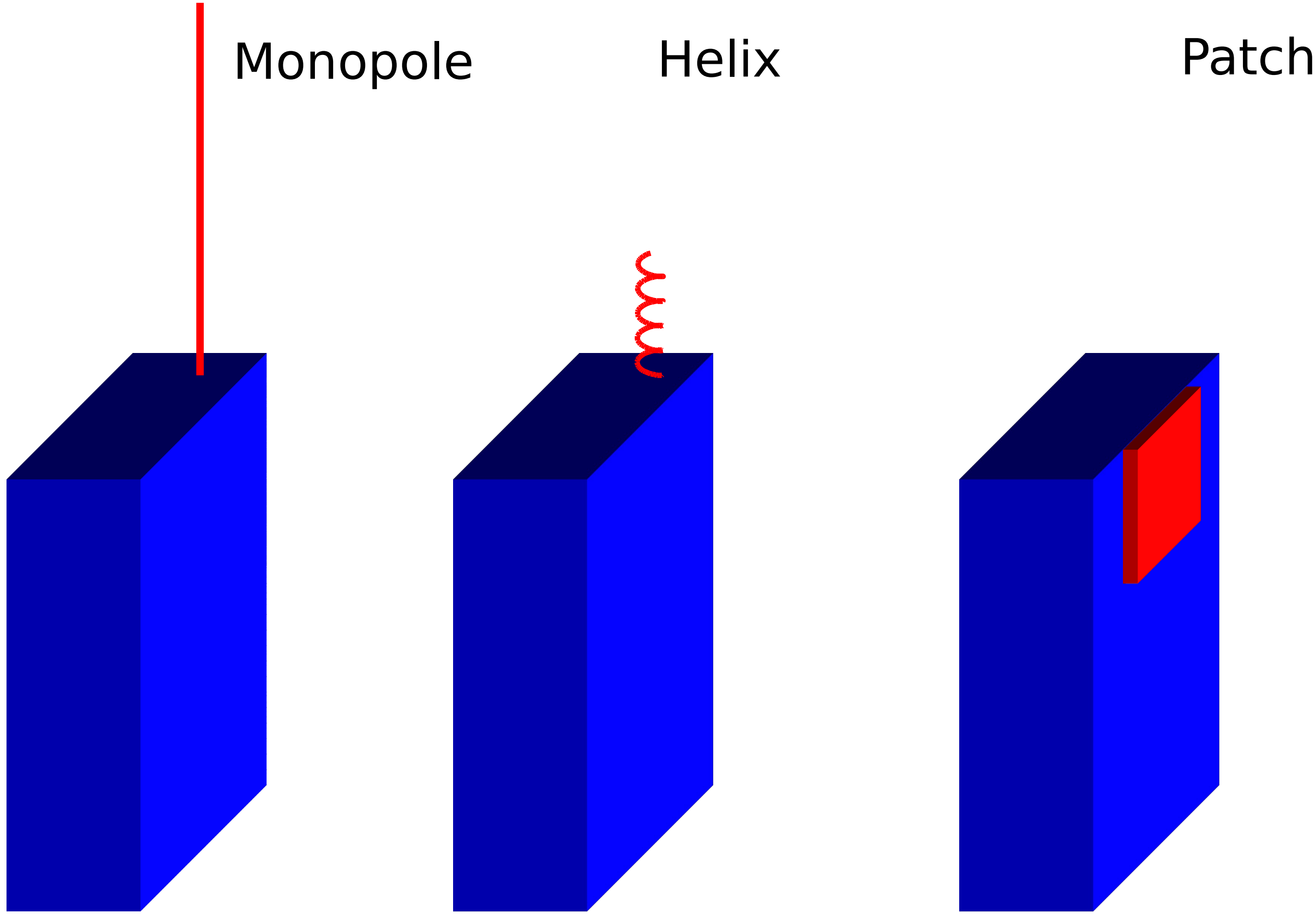
Most cellular systems have a bandwidth requirement in the range of 10% of the carrier frequency.

Example: 900 MHz GSM needs an antenna that can transmit/receive well in a total bandwidth of about 100 MHz.

It is difficult to make small and efficient broadband antennas!

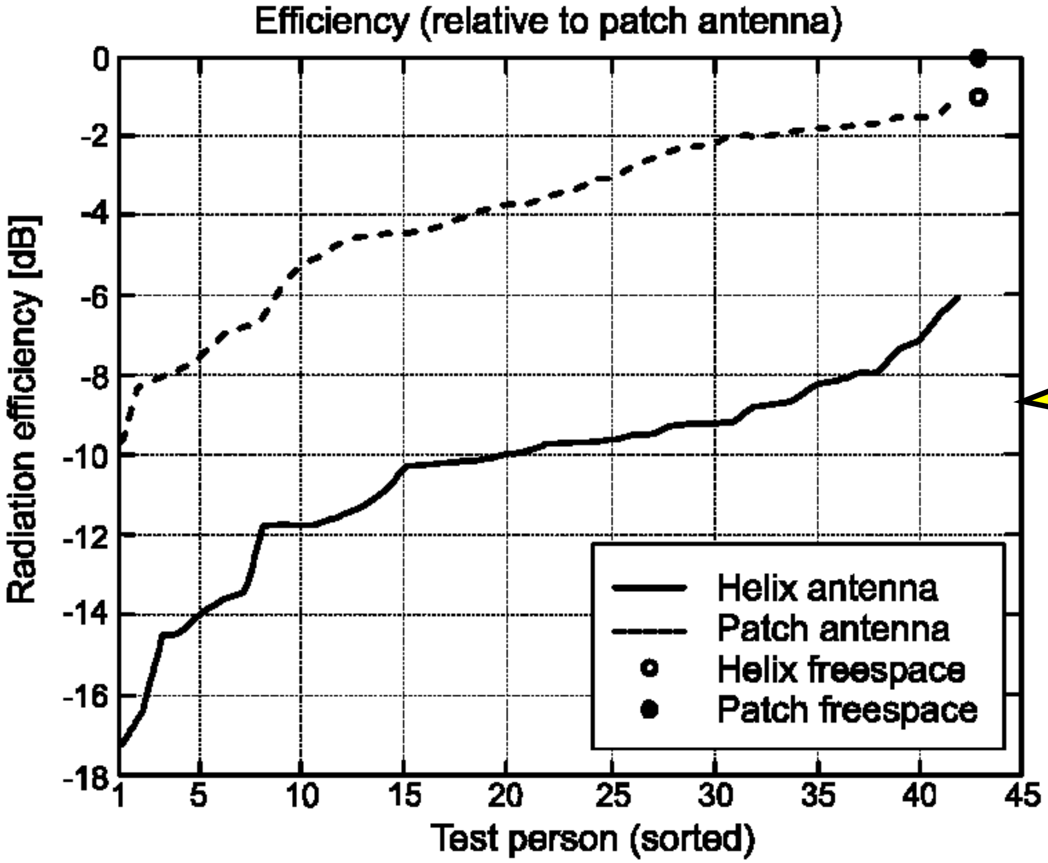
What happens when we have dual- (900/1800) or triple-band (900/1800/1900) GSM phones ... or phones with 3G and Bluetooth (2.4 GHz) as well?

Antennas
Mobile station antennas



Antennas
Mobile station antennas

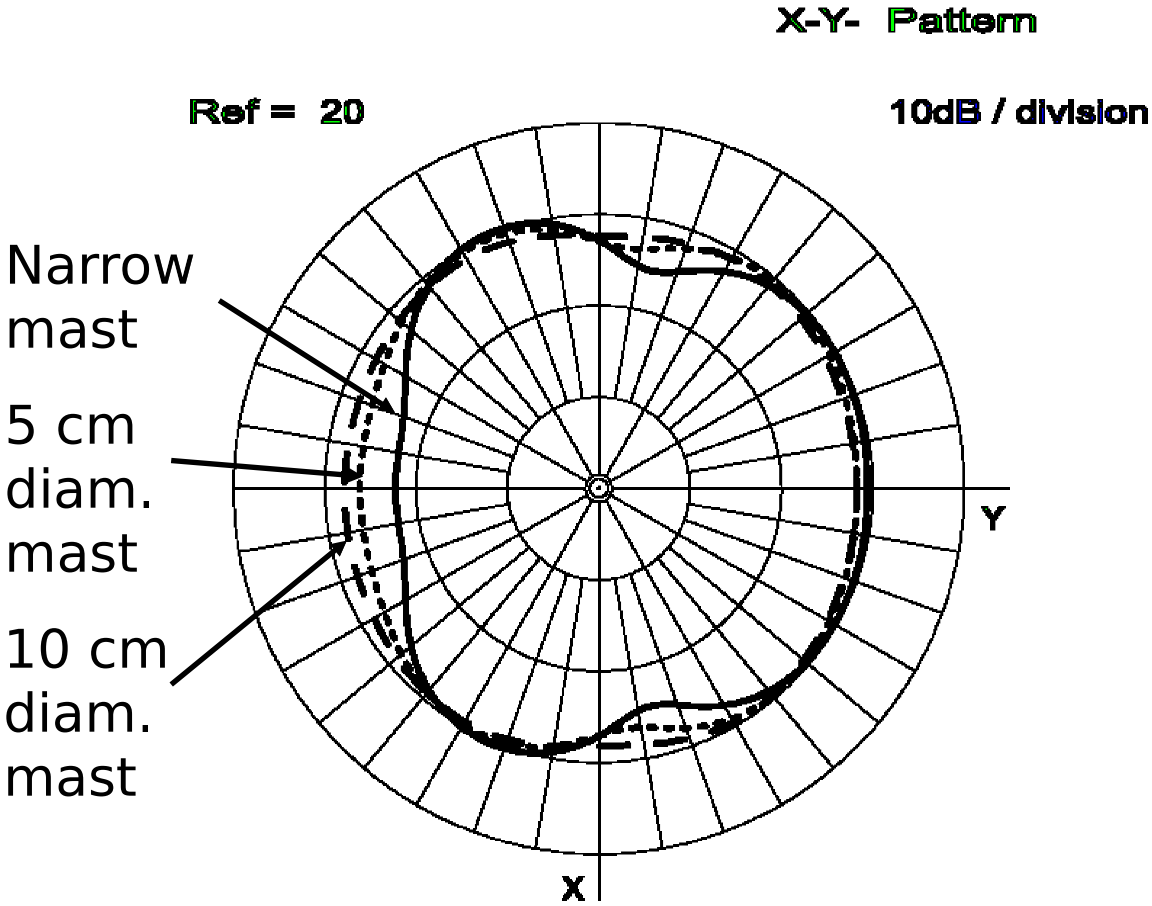
The efficiency depends on many parameters, but a very important one is its environment. Below you can see differences in antenna efficiency for 42 test persons holding the mobile.



Up to around 10 dB difference, depending on person.

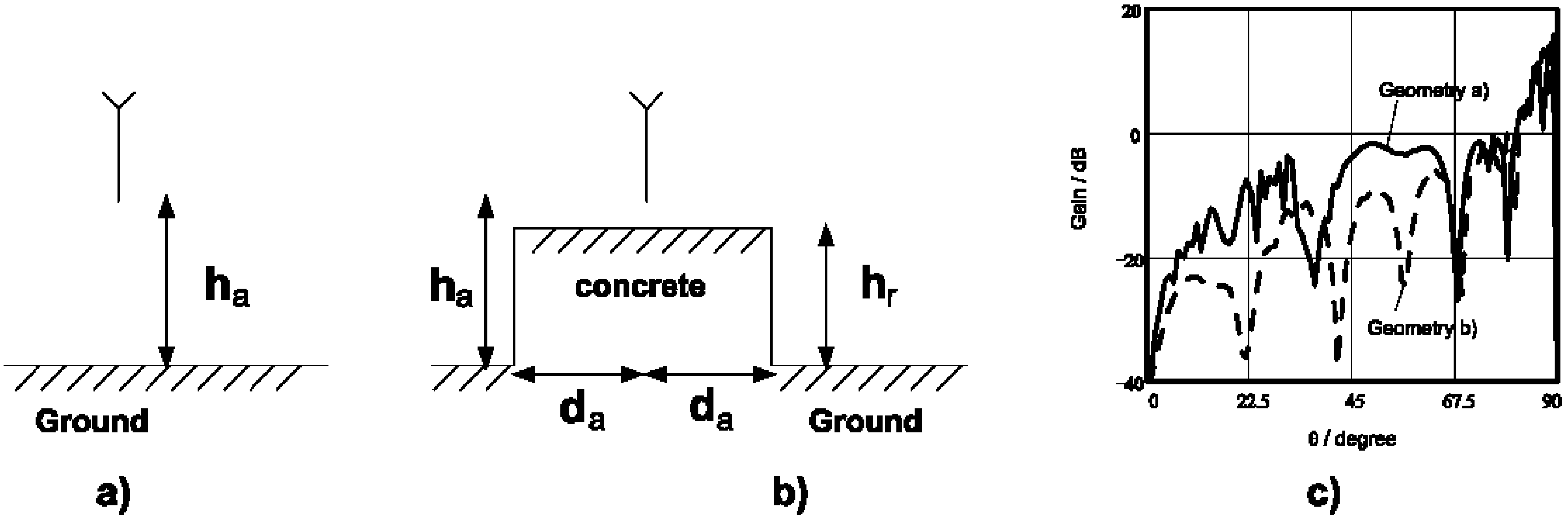
Antennas
Base station antennas

Base station antenna pattern affected by the mast (30 cm from antenna).

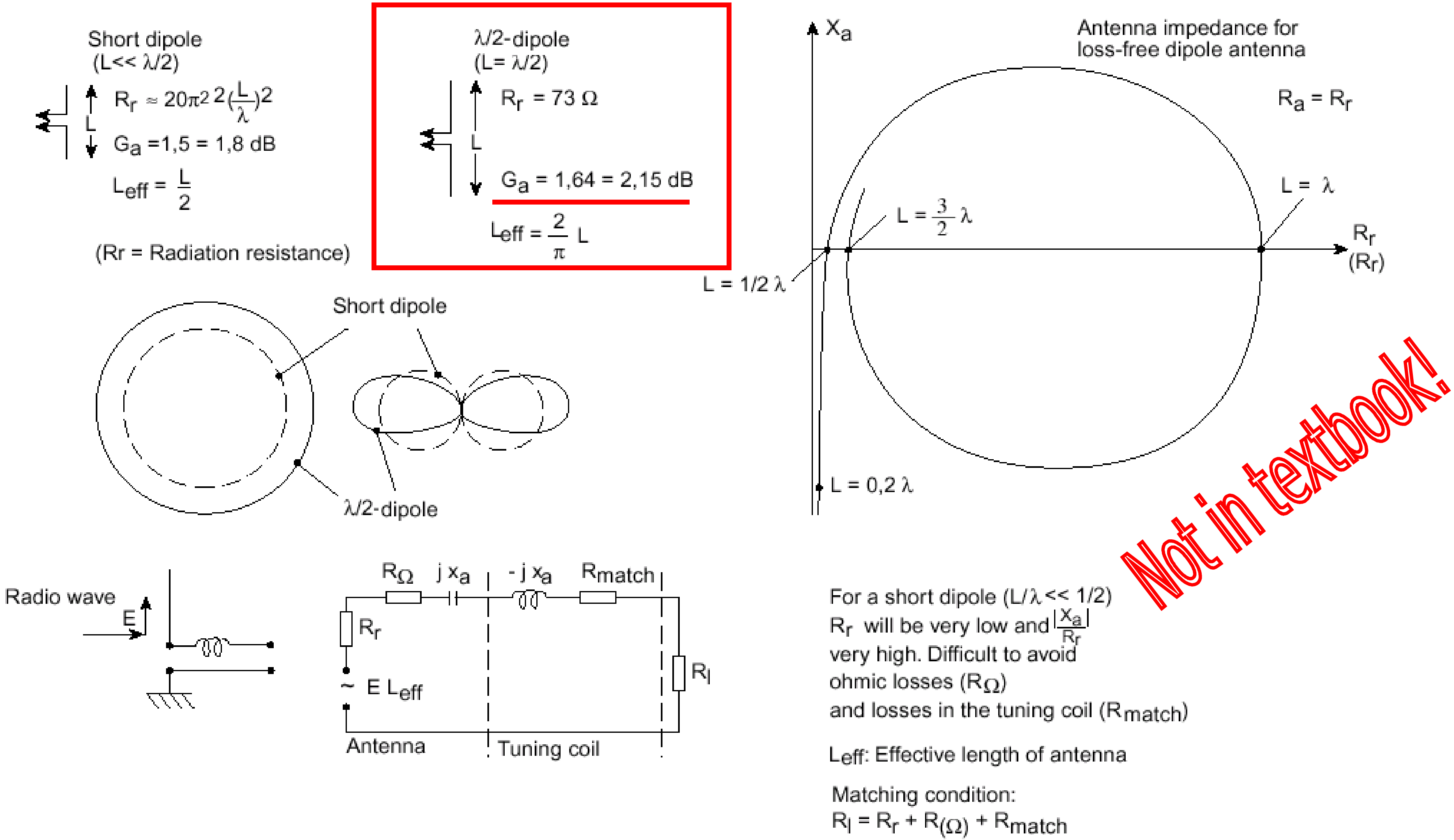


Antennas
Base station antennas

Base station antenna pattern affected by a concrete foundation.

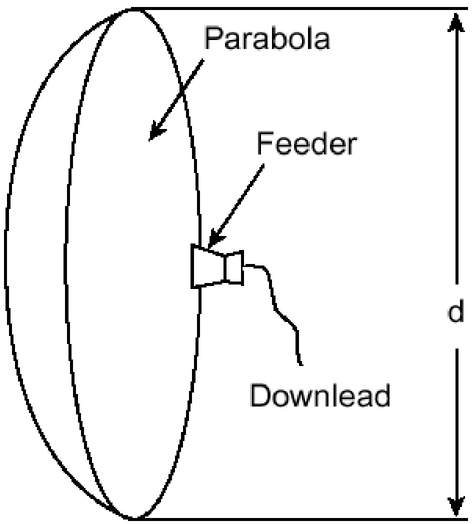


Antennas
The dipole antenna



[Figure from Ericsson Radio School documentation]

Antennas
The parabolic antenna

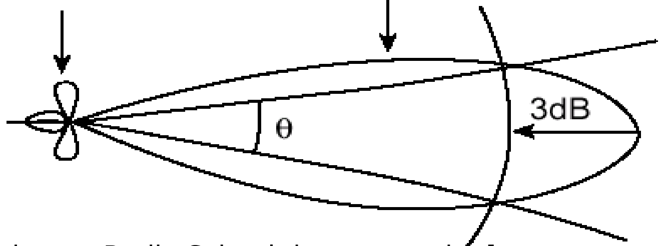


Opening area: $A = \frac{\pi d^2}{4}$

Effective area: $A_{eff} \approx 0.55 A$

Antenna gain: $G_a = \frac{4\pi}{\lambda^2} A_{eff} \approx 0.55 \frac{\pi^2 d^2}{\lambda^2}$

Not in textbook!



3dB beamwidth: $\theta \approx \frac{200}{\sqrt{G_a}} [\text{degrees}] \, (\theta < 25^o)$

[Figure from Ericsson Radio School documentation]

Summary

- Narrowband models: **Okumura´s measurements**, **Okumura-Hata**, **COST 231-Ikegami-Walfish**. Mainly models for **propagation** loss. Fading has to be added.
- Wideband models: **COST 207 for GSM** & **ITU-R for 3G**. Mainly specification of **power-delay profile** and **doppler spectrum** (IRT-R also gives e.g. path loss).
- Antennas: **Efficiency** has decreased for mobile antennas. Antenna **environment** changes their properties. Some specific properties for **dipole** and **parabolic** antennas.