RRC

Vehicular Communications – Part II
Radio Channel Characterisation

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Slides are provided as supporting tool, they are not a textbook!

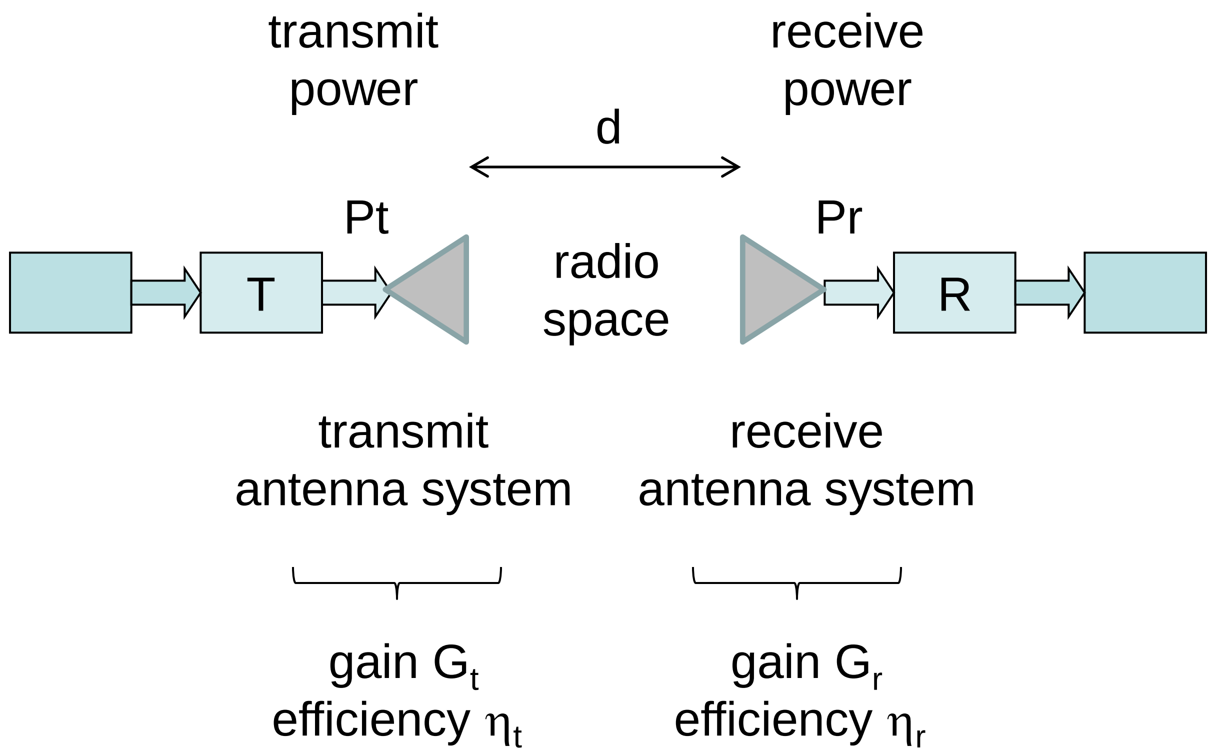
Outline

1. Fundamentals of Radio Propagation
2. Large Scale phenomena
3. Small Scale phenomena
   a) Wideband characterisation
   b) Narrowband characterisation
4. The Narrowband Mobile Radio Channel

**The scope of this lecture block is
to introduce the basics of radio channel characterisation
that will be useful to follow the link level analysis performed in this course.**

1. Fundamentals of Radio Propagation

Fundamentals of Radio Propagation



Fundamentals of Radio Propagation

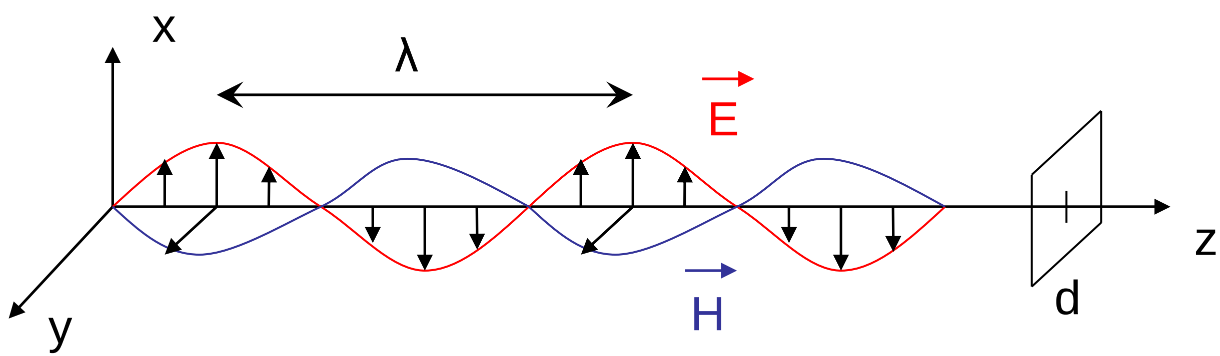
Radio → Waves

Fundamentals of Radio Propagation

Radio → Waves

Radio Communication is*

**the transmission, emission, reception
of signs, signals, writings, images, sounds or information
of whatever nature,
making use of *electromagnetic waves***



*** MIN. SV. EC – DIP. COM. IT. – Piano Naz. di ripartiz. delle frequenze – Glossario**

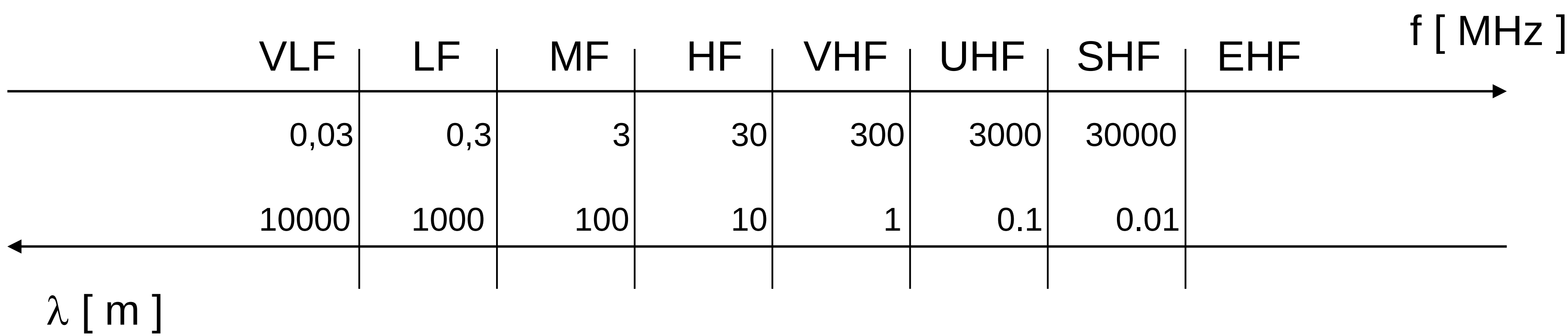
Fundamentals of Radio Propagation

Radio → Waves

Phase speed in clear sky
$c = 3\ 10^{8}\ m/s = f\ \lambda$

Power density in free space
$p(d) = 0.5\ E_m^{\ 2} / 377$
$= Pt\ Gt\ \eta_t / 4\ \pi\ d^2\ \ W/m^2$

Received power is
$Pr = p(d)\ Gr\ \ \eta_r / 4\ \pi / \lambda^2$ W



Inquiry Based Session

Is a GPRS link (Bc = 200 KHz, fc = 1800 MHz) affected by the presence of a vehicle?
Is it affected by rain drops?

How large should be the antenna system on a vehicle using 3G (fc = 2000 MHz)?
What about 5G, using 700 MHz, 3.6 GHz, 26 GHz bands?

Does the link between two vehicles suffer from the ground-reflected path?

Fundamentals of Radio Propagation

Radio → Waves

Phase speed in clear sky
$c = 3\ 10^{8}$ m/s = f λ

Power density in free space
$p(d) = 0.5\ E_m^{\ 2} / 377$
$= Pt\ Gt\ \eta_t / 4\ \pi\ d^2$ W/m²

Received power is
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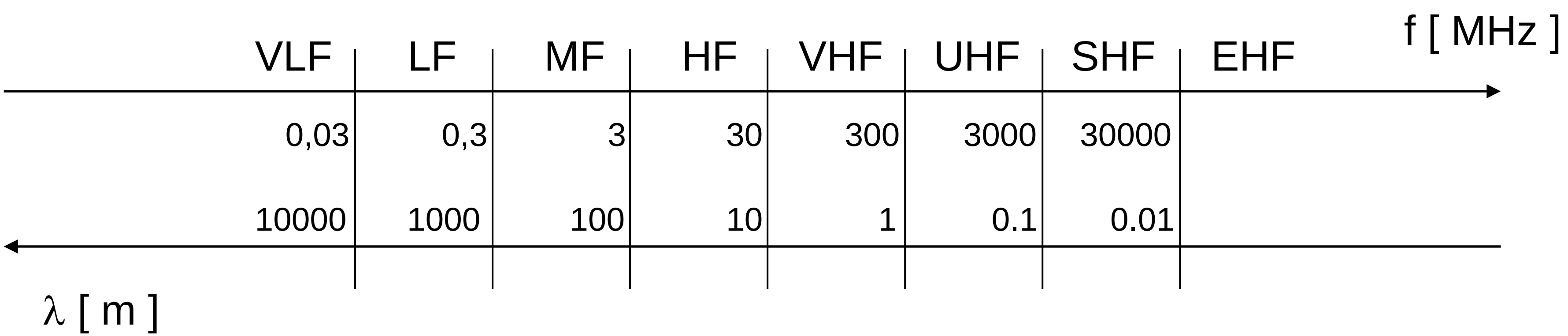
Waves tend to interact
with objects of size
equal to or larger than λ



Fundamentals of Radio Propagation

Radio → Waves

Phase speed in clear sky
$c = 3\ 10^{8}$ m/s = $f\ \lambda$

Power density in free space
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$= Pt\ Gt\ \ \eta_t / 4\ \pi\ d^2$ W/m^2

Received power is
$Pr = p(d)\ Gr\ \ \eta_r / 4\ \pi / \lambda^2$ W

Waves tend to interact
with objects of size
equal to or larger than λ

Efficient antennas have size
close to λ

	VLF		LF		MF		HF		VHF		UHF		SHF		EHF
f [MHz] →		0,03		0,3		3		30		300		3000		30000	
← λ [m]		10000		1000		100		10		1		0.1		0.01	

Fundamentals of Radio Propagation

Radio → Waves

Phase speed in clear sky
$c = 3\ 10^{8}$ m/s $= f\,\lambda$

Power density in free space
$p(d) = 0.5\ E_m^{\ 2} / 377$
$= Pt\ Gt\ \eta_t / 4\,\pi\,d^2$ W/m^2

Received power is
$Pr = p(d)\ Gr\ \eta_r / 4\,\pi / \lambda^2$ W

Waves tend to interact with objects of size equal to or larger than λ

Efficient antennas have size close to λ

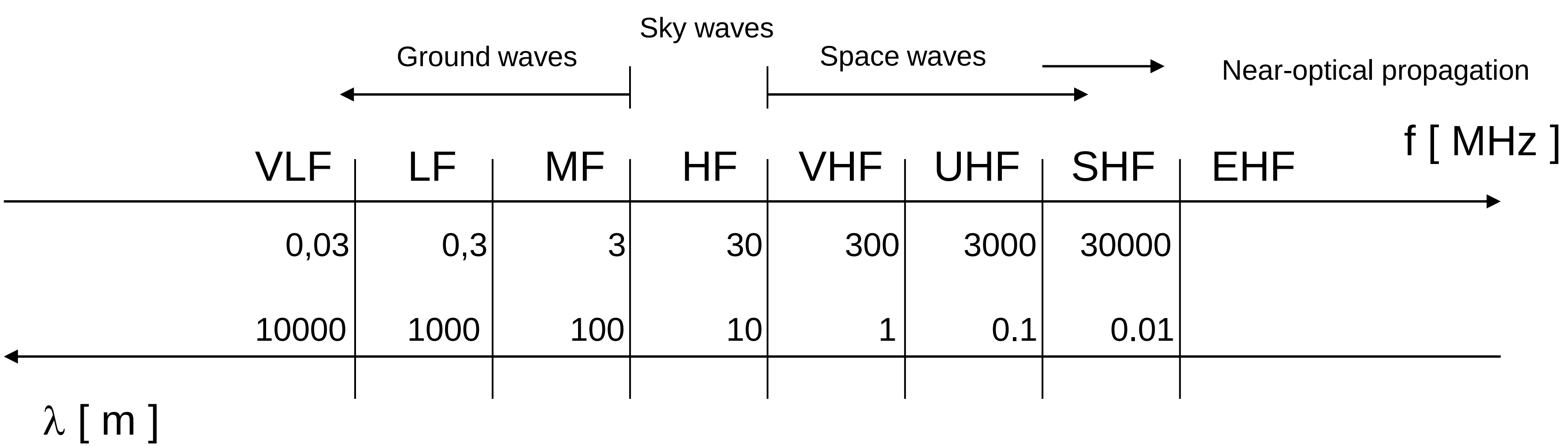
Propagation is almost free space if first Fresnel elipsoid is free from obstacles
($r = \mathrm{sqrt}(d\lambda/2)$)

	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
f [MHz] →	0,03	0,3	3	30	300	3000	30000	
← λ [m]	10000	1000	100	10	1	0.1	0.01	

Fundamentals of Radio Propagation

Radio → Waves

3 > f [MHz]	**λ [m] > 100**	**Ground Waves**
3 < f [MHz] < 30	**10 < λ [m] < 100**	**Sky Waves**
30 < f [MHz]	**10 > λ [m]**	**Space Waves**

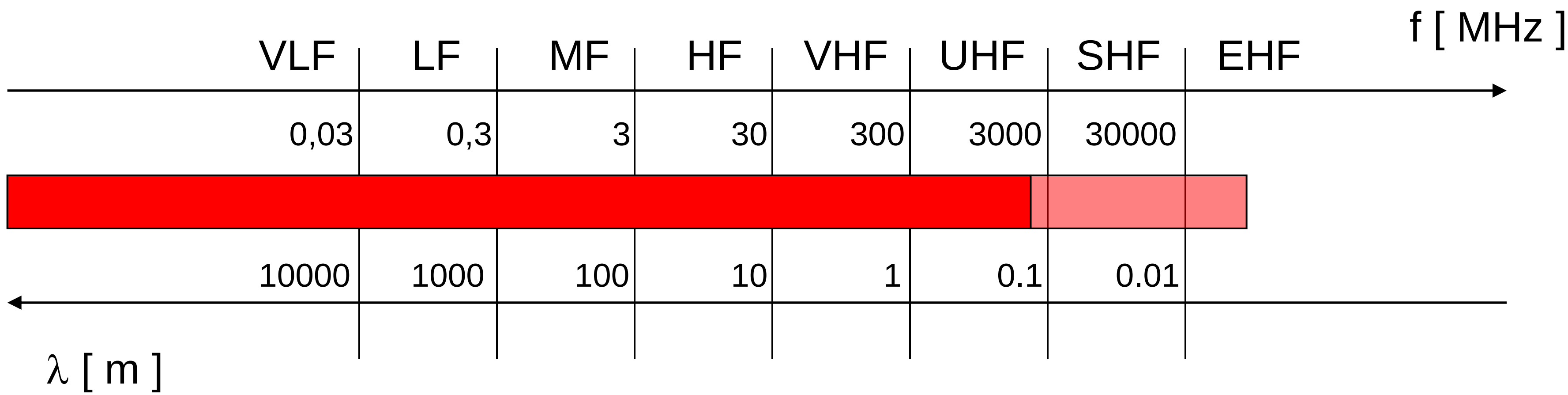


Fundamentals of Radio Propagation

Radio → Frequency Spectrum

Fundamentals of Radio Propagation

Radio → Frequency Spectrum



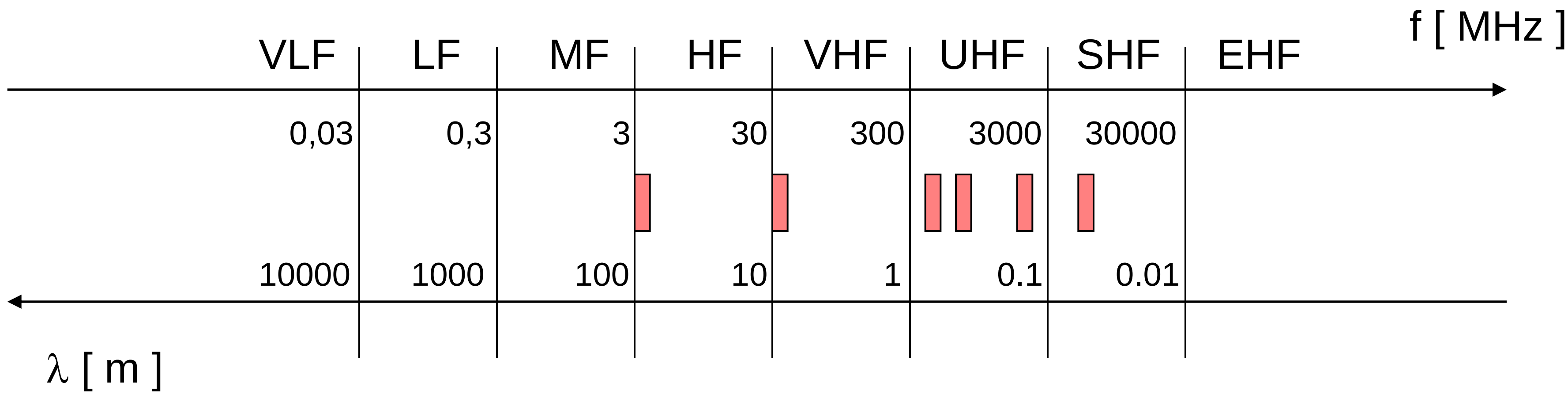
Frequency band assignments to services are:

1) Requested by industry alliances, standardisation bodies
2) Negotiated within and recommended by ITU-R
3) Regulated on a country basis by National Authorities
4) Released to operators / users

Fundamentals of Radio Propagation

Radio → Frequency Spectrum

ISM Bands: Licence - Exempt in Most Countries



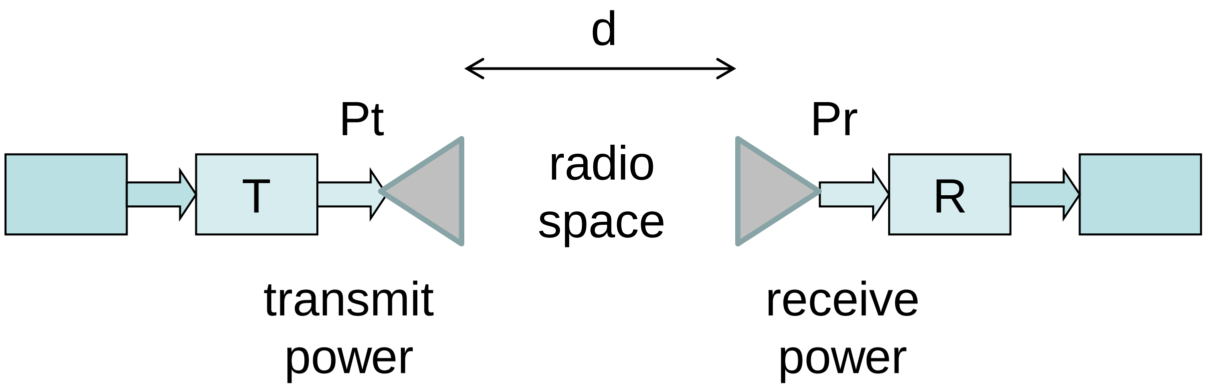
13.553 – 13.567 MHz	**RFid**
40.66 – 40.70 MHz	**RFid**
433 – 464 MHz	**Proprietary Radios**
867 – 868 MHz	**Proprietary Radios, LoRa, …**
2.4 – 2.48 GHz	**Proprietary Radios, Bluetooth, WiFi, Zigbee, …**
5.725 – 5.875 GHz	**WiFi, …**

Fundamentals of Radio Propagation

Radio → Unpredictable Channel

Fundamentals of Radio Propagation

Radio → Unpredictable Channel



If radio space is uniform, isotropic, perfect dielectric, without obstacles,

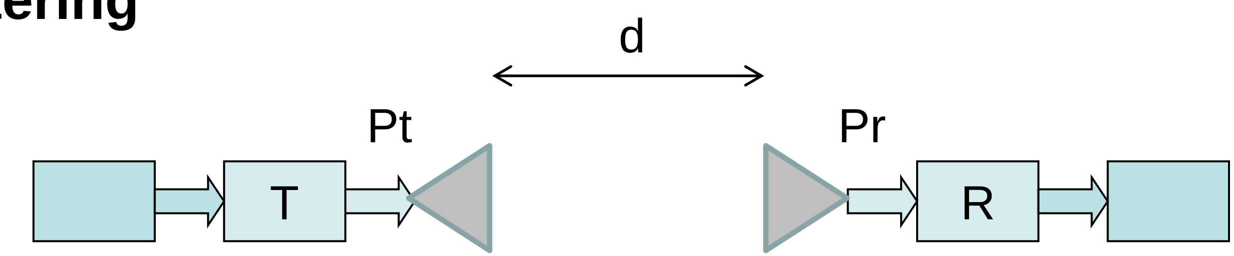
Pr = Pt Gt Gr / Aio **Aio = $(4 \pi d / \lambda)^2$** **[Friis, 1945]**

Otherwise Aio replaced by Aim = h * d^β * x where h is constant, x is r.v.

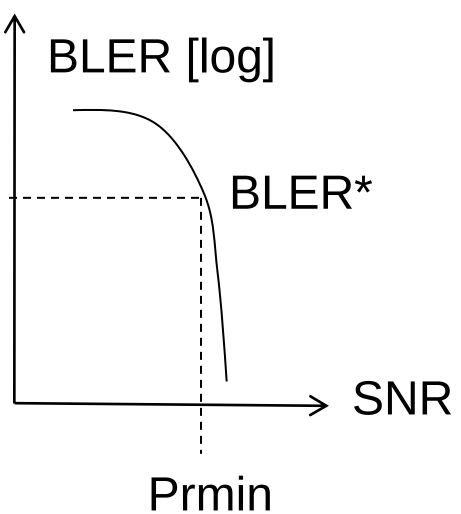
Fundamentals of Radio Propagation

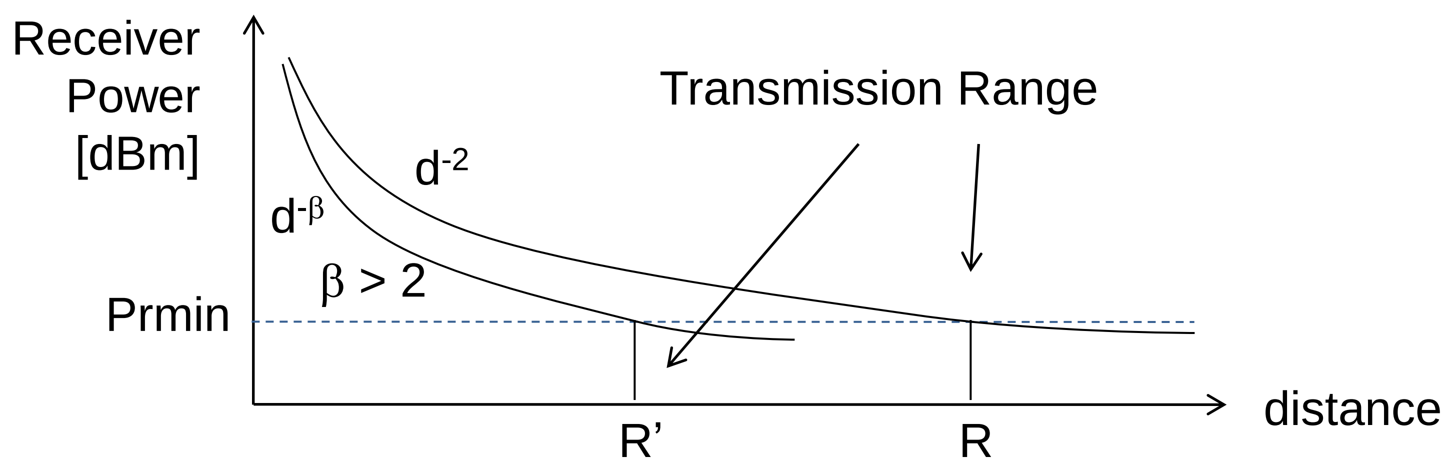
Radio → Unpredictable Channel

Channel Filtering



Pr = Pt Gt Gr / Aim

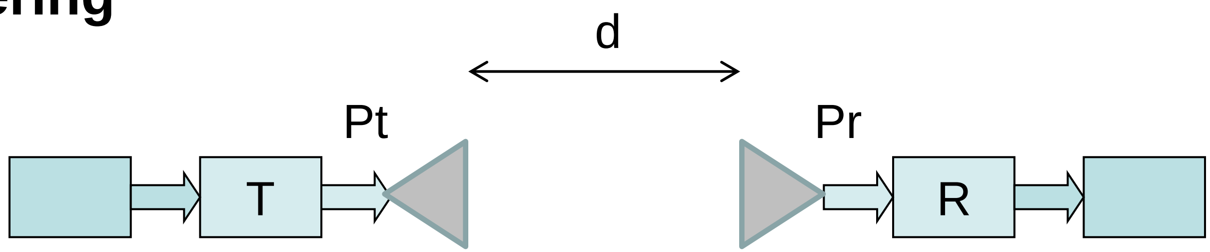


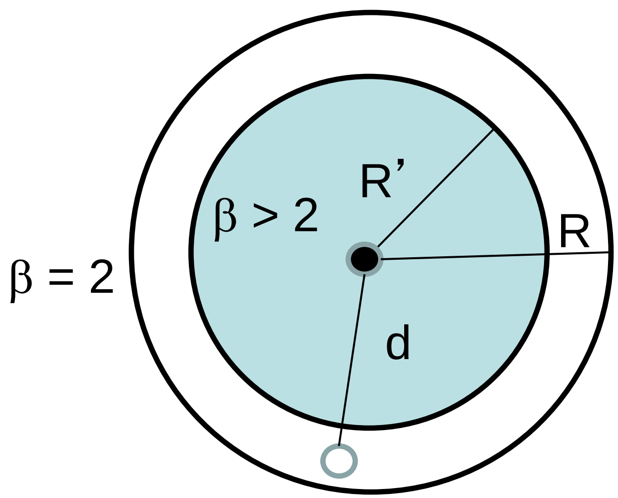


Fundamentals of Radio Propagation

Radio → Unpredictable Channel

Channel Filtering

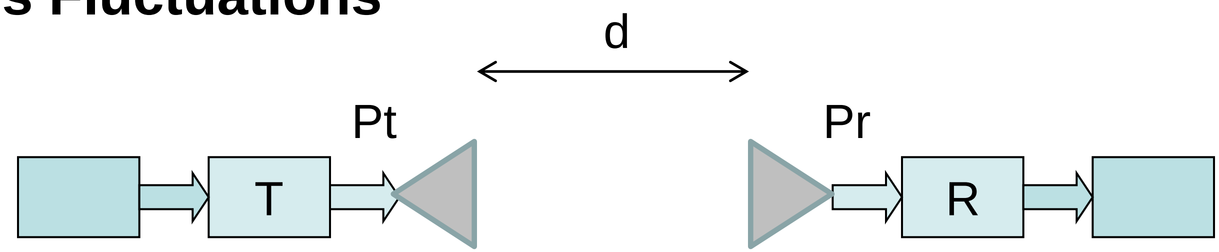


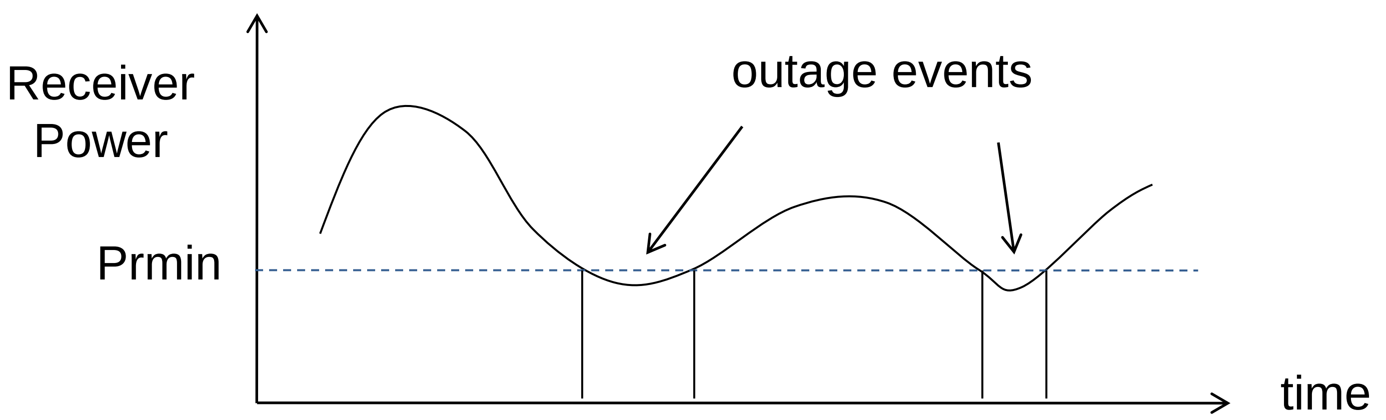


Fundamentals of Radio Propagation

Radio → Unpredictable Channel

Channel Loss Fluctuations

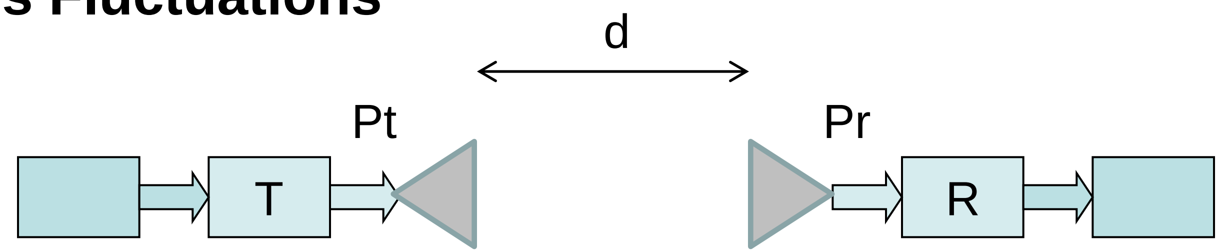


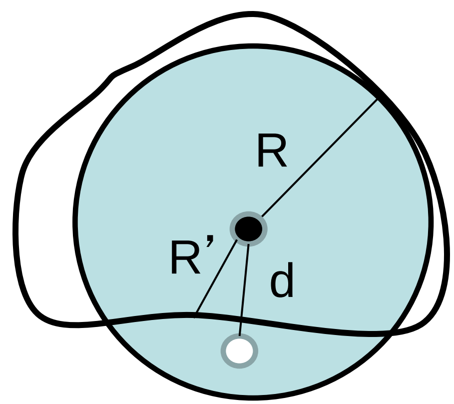


Fundamentals of Radio Propagation

Radio → Unpredictable Channel

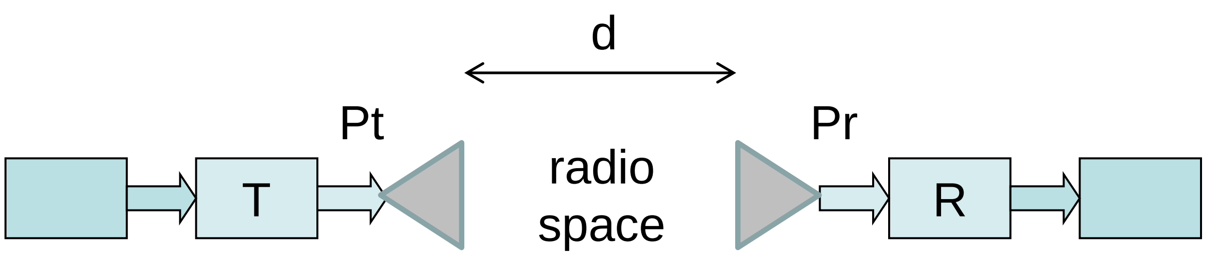
Channel Loss Fluctuations





Fundamentals of Radio Propagation

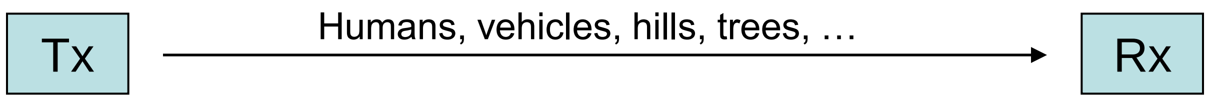
Radio → Unpredictable Channel



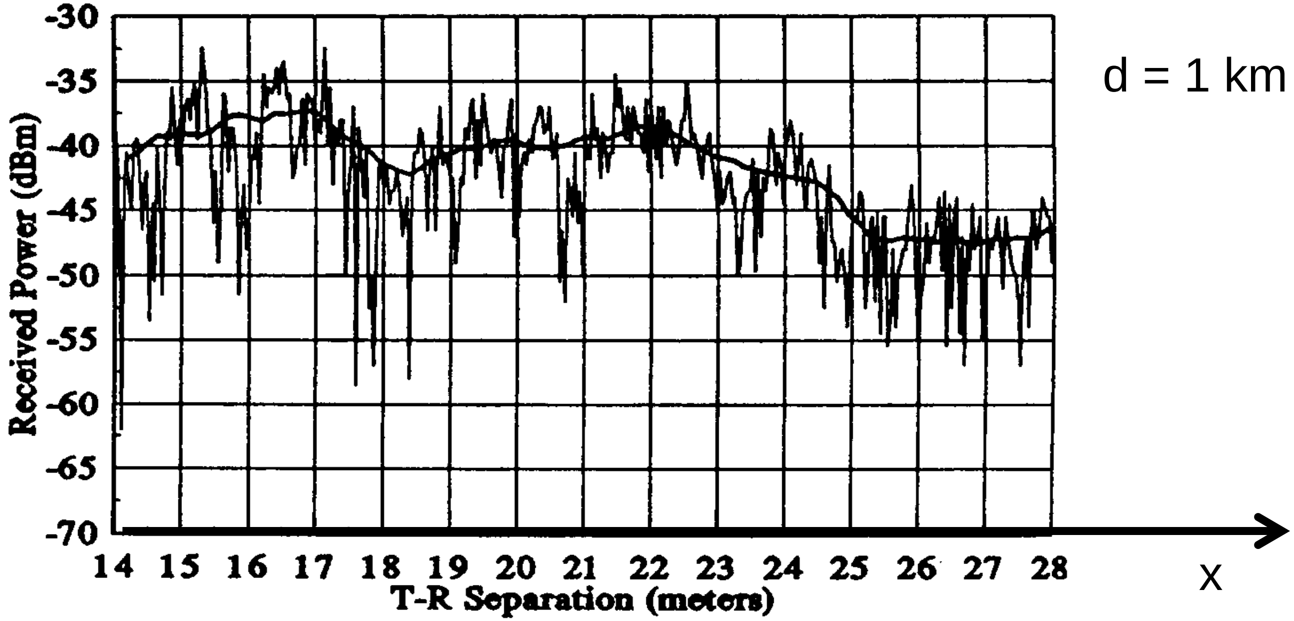
$$Pr = k\, d^{-\beta}\, \xi$$

2. Large Scale Phenomena

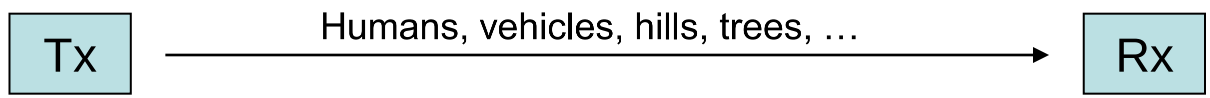
Large Scale: Shadowing



Narrowband characterisation



Large Scale



Shadowing effect: isotropic attenuation is the product of several terms:

Aim = A1 A2 … An

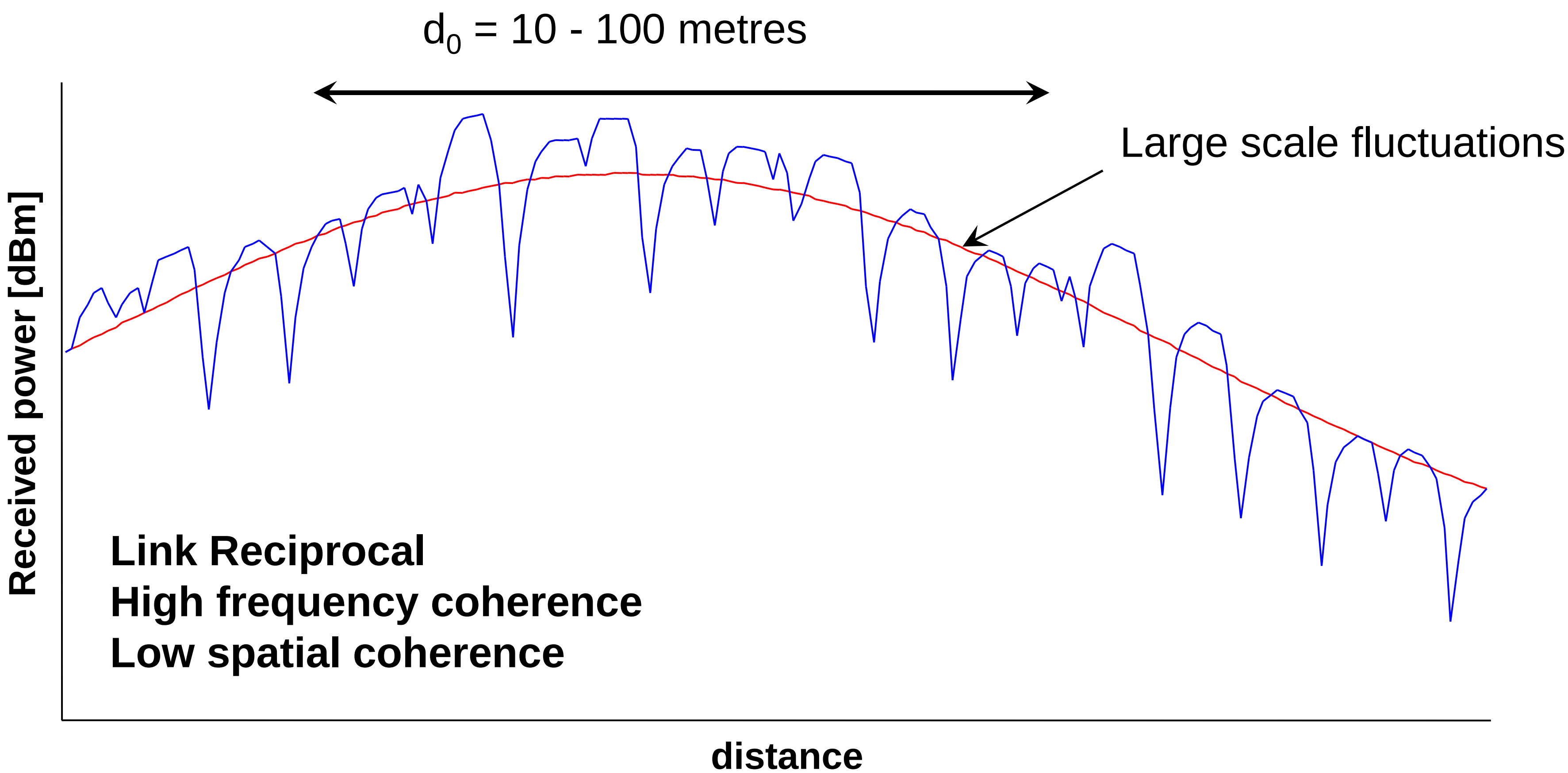
Aim [dB] = A1 [dB] + A2 [dB] + … + An [dB]

If n is large, and central limit theorem assumptions hold, then

Aim [dB] is Gaussian distributed.
Standard deviation from 4 to 12 depending on environment

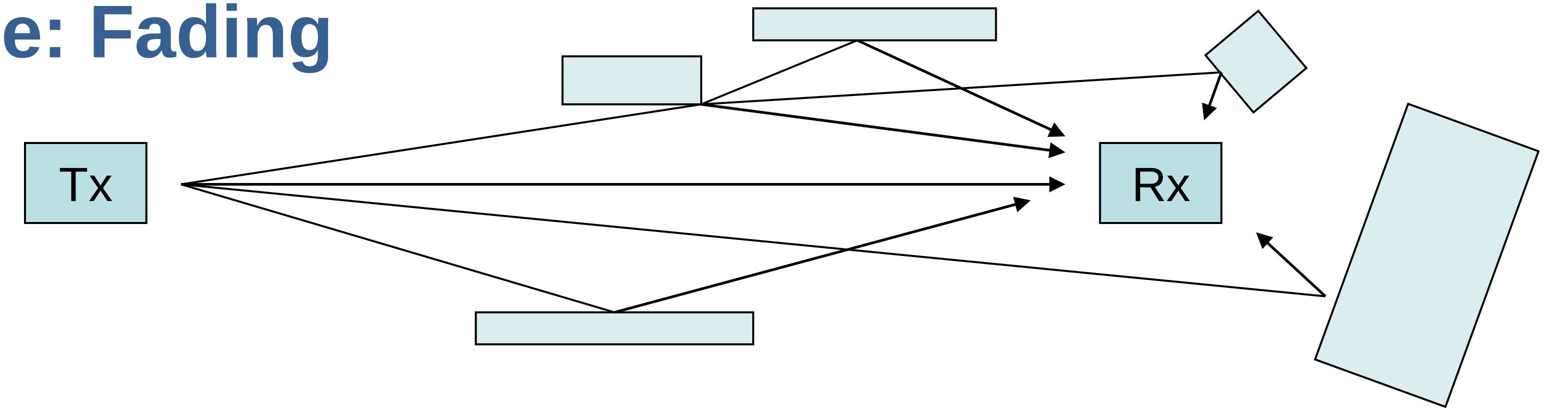
Large Scale

Shadowing is usually log-normally distributed, for both mobile/stationary applications
Autocorrelation function is $R(d) = R_0 \exp[-d/d_0]$ **[Gudmunson's Model]**

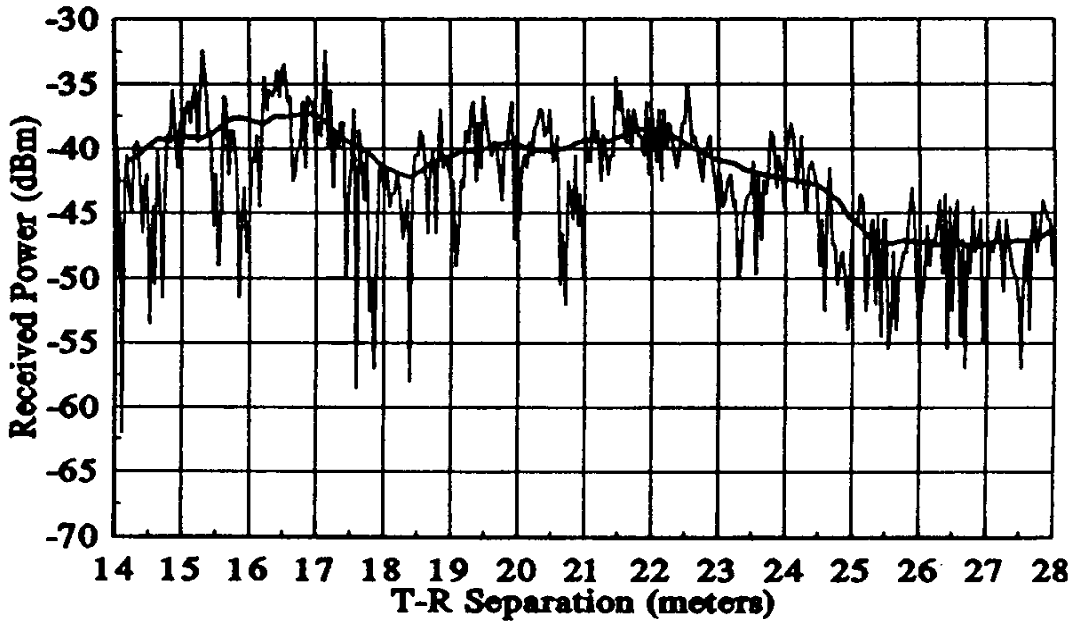


3. Small Scale Phenomena

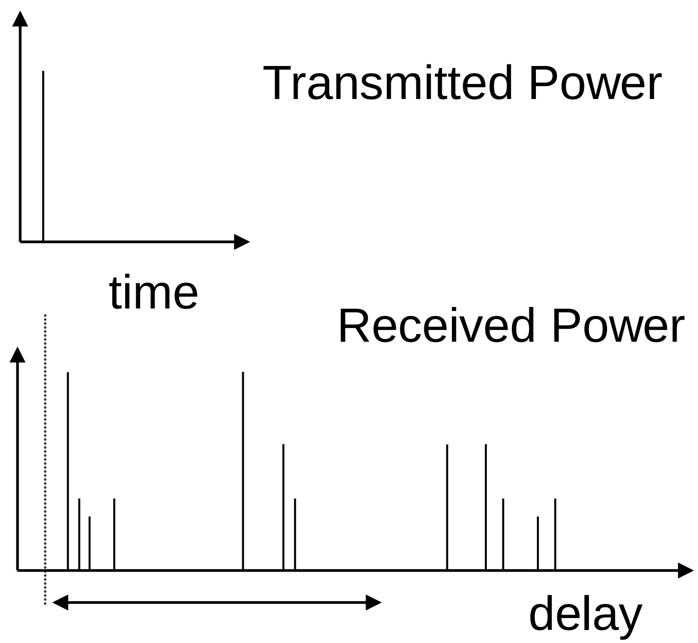
Small Scale: Fading



Narrowband characterisation



Wideband characterisation



Small Scale: Wideband Characterisation

Power Delay Profile:

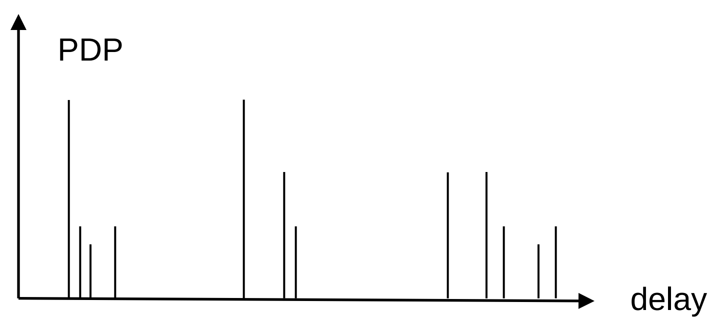
$P_h(\tau) = \text{Int} [|h(t, \tau)|^2]$

Mean Delay:

$T_m = \text{Int} [\tau P_h(\tau)] / P_r$

Root Mean Square Delay Spread:

$\sigma_\tau = \sqrt{[((\text{Int}\ \tau^2 P_h(\tau)) / P_r) - T_m^2]}$



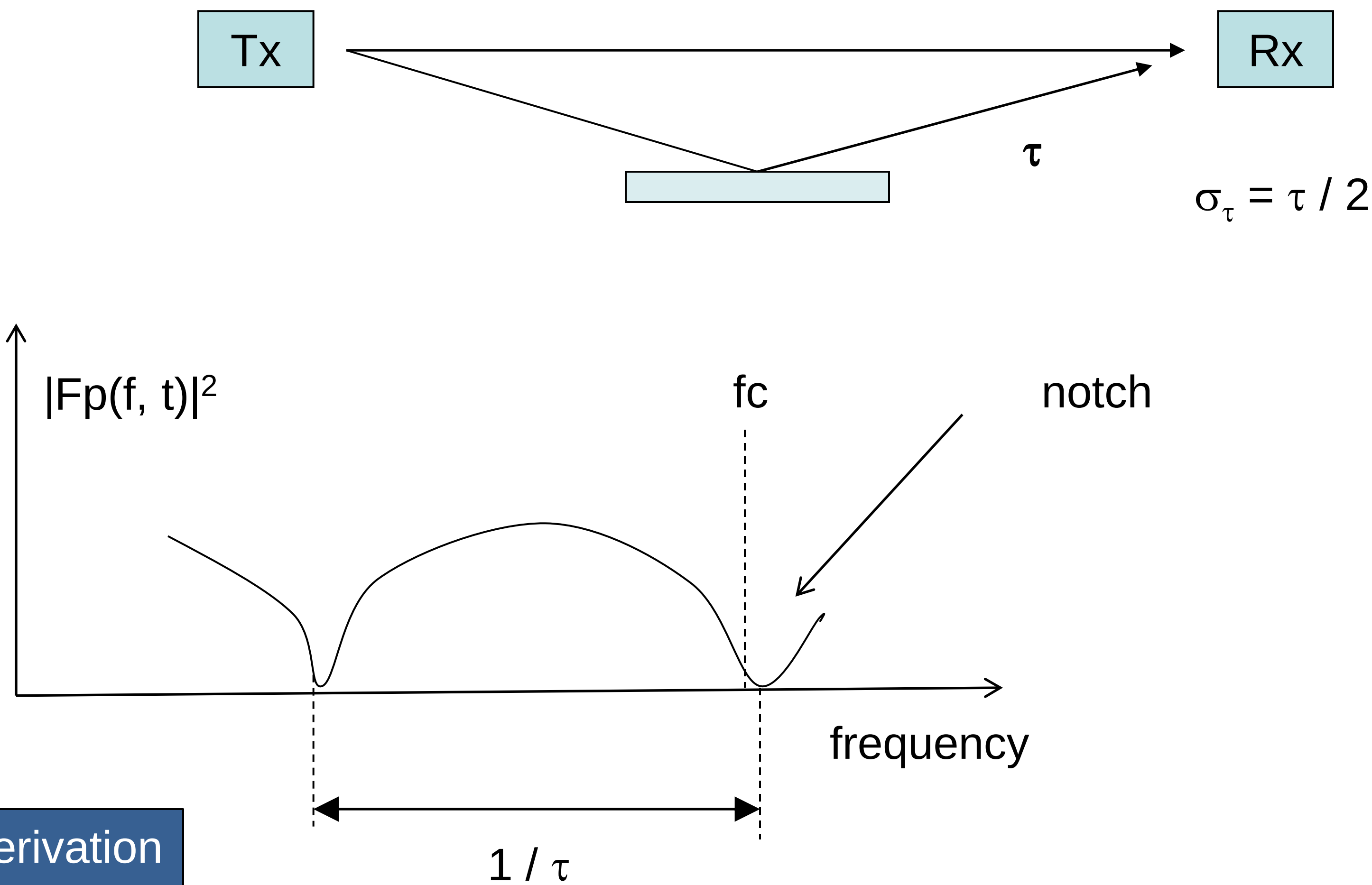
Small Scale: Wideband Characterisation

Table 5.1 Typical Measured Values of RMS Delay Spread

Environment	Frequency (MHz)	RMS Delay Spread (σ_τ)	Notes	Reference
Urban	910	1300 ns avg. 600 ns st. dev. 3500 ns max.	New York City	[Cox75]
Urban	892	10–25 μs	Worst case San Francisco	[Rap90]
Suburban	910	200–310 ns	Averaged typical case	[Cox72]
Suburban	910	1960–2110 ns	Averaged extreme case	[Cox72]
Indoor	1500	10–50 ns 25 ns median	Office building	[Sal87]
Indoor	850	270 ns max.	Office building	[Dev90a]
Indoor	1900	70–94 ns avg.	Three San Francisco buildings	[Sei92a]

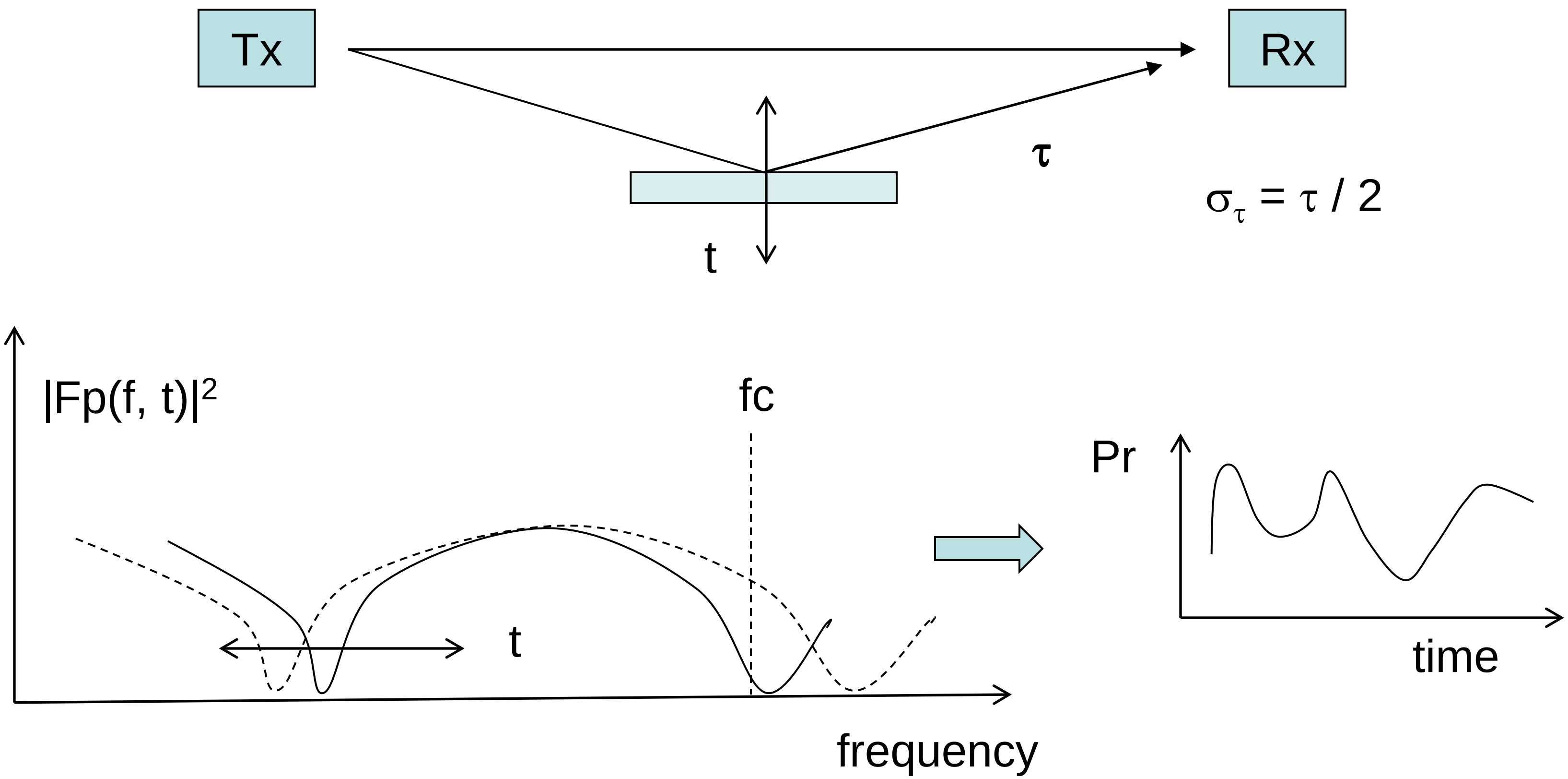
To be compared to symbol time.

Small Scale: Two Path Model

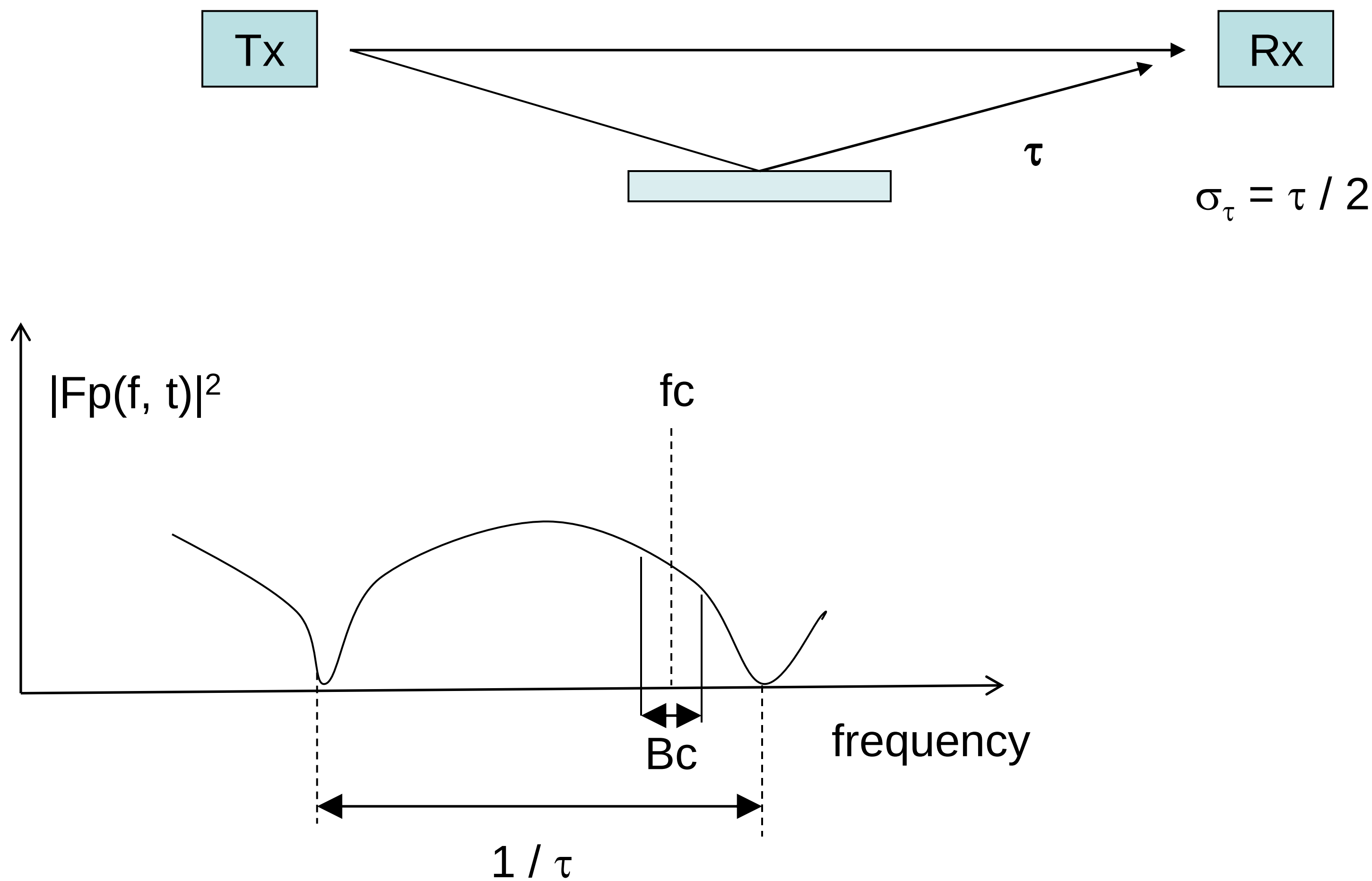


Math. derivation

Small Scale: Two Path Model



Small Scale: Two Path Model



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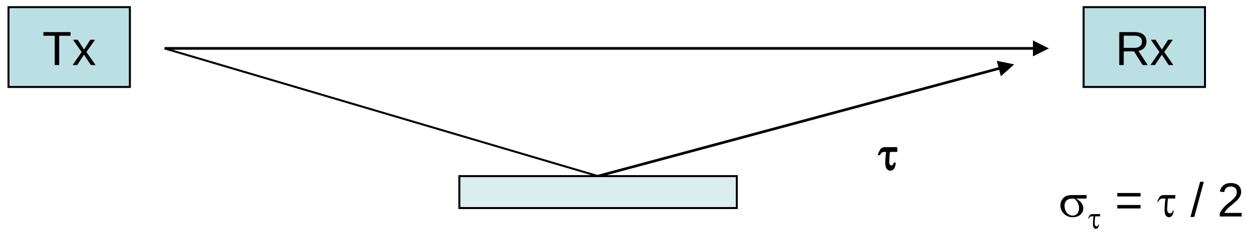
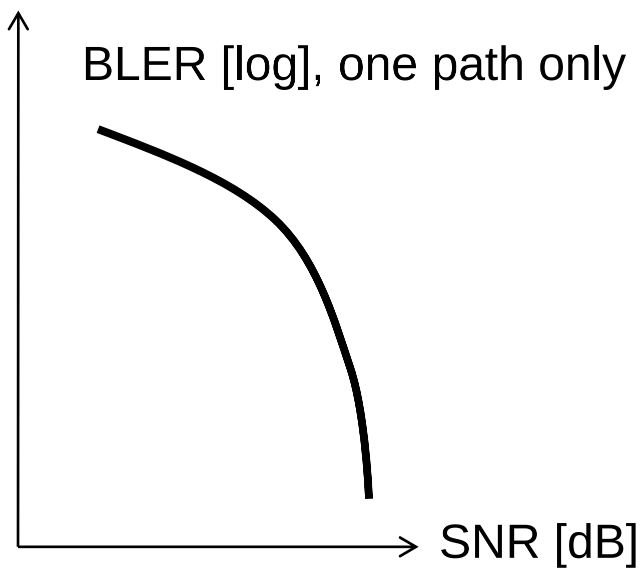
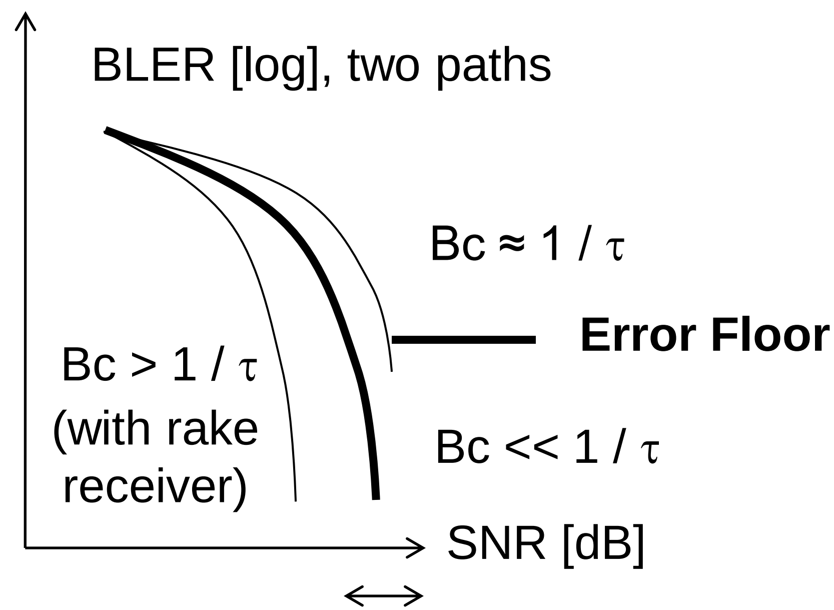






Small Scale: Wideband Characterisation

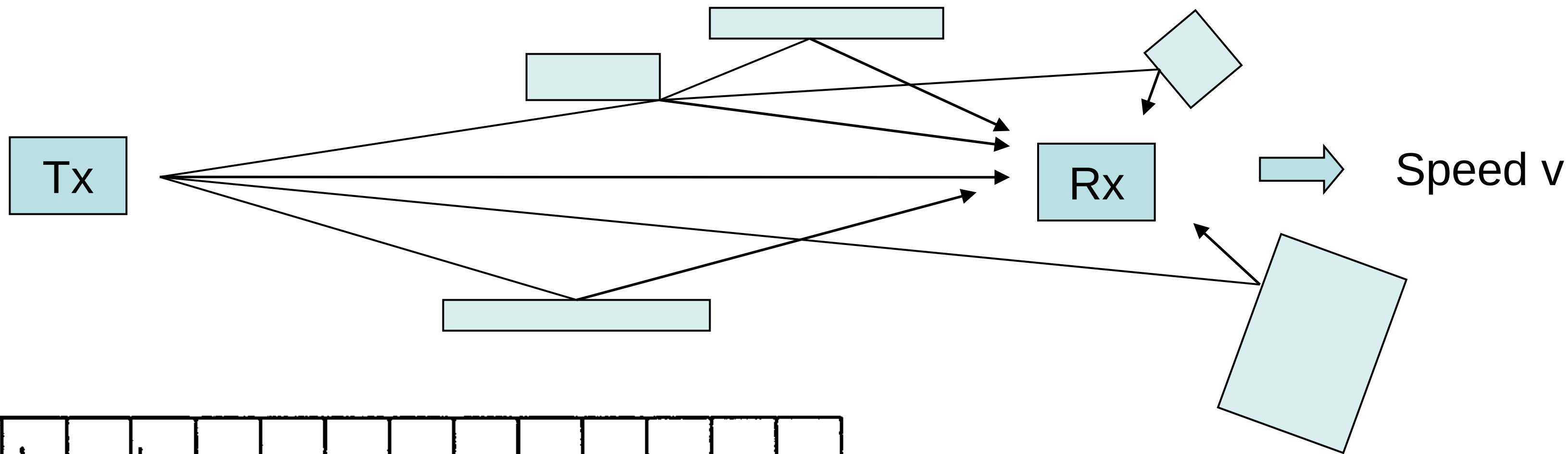
Small-Scale Fading
(Based on multipath time delay spread)

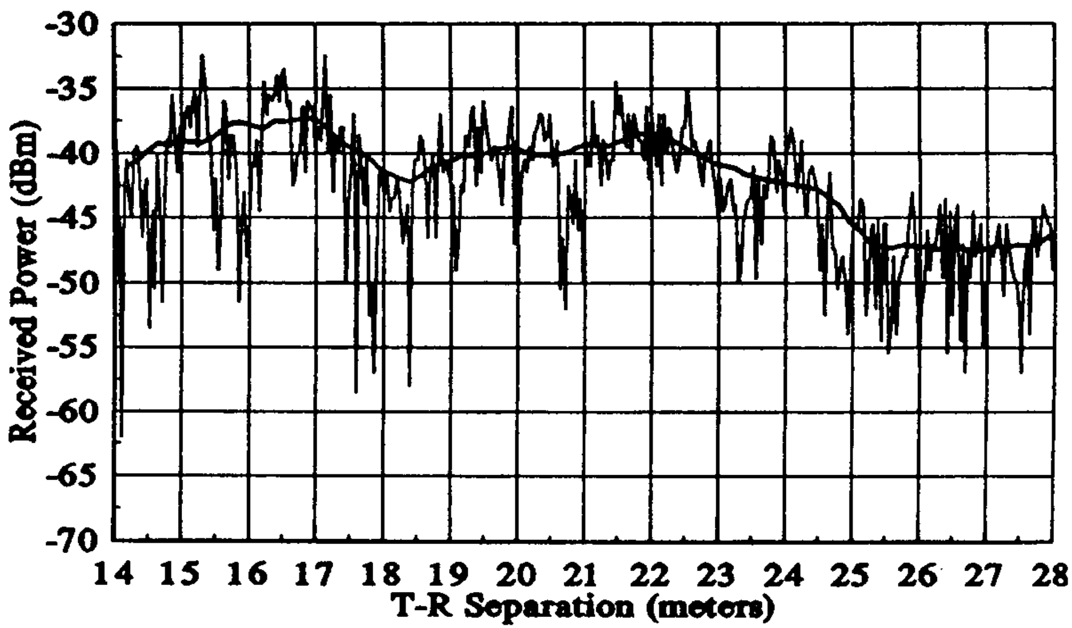
Flat Fading	Frequency Selective Fading
1. BW of signal < BW of channel	1. BW of signal > BW of channel
2. Delay spread < Symbol period	2. Delay spread > Symbol period

Rs τ << 1	**Rs τ ~ 1 or larger**
Signal strength (random) attenuation	**signal distortion**

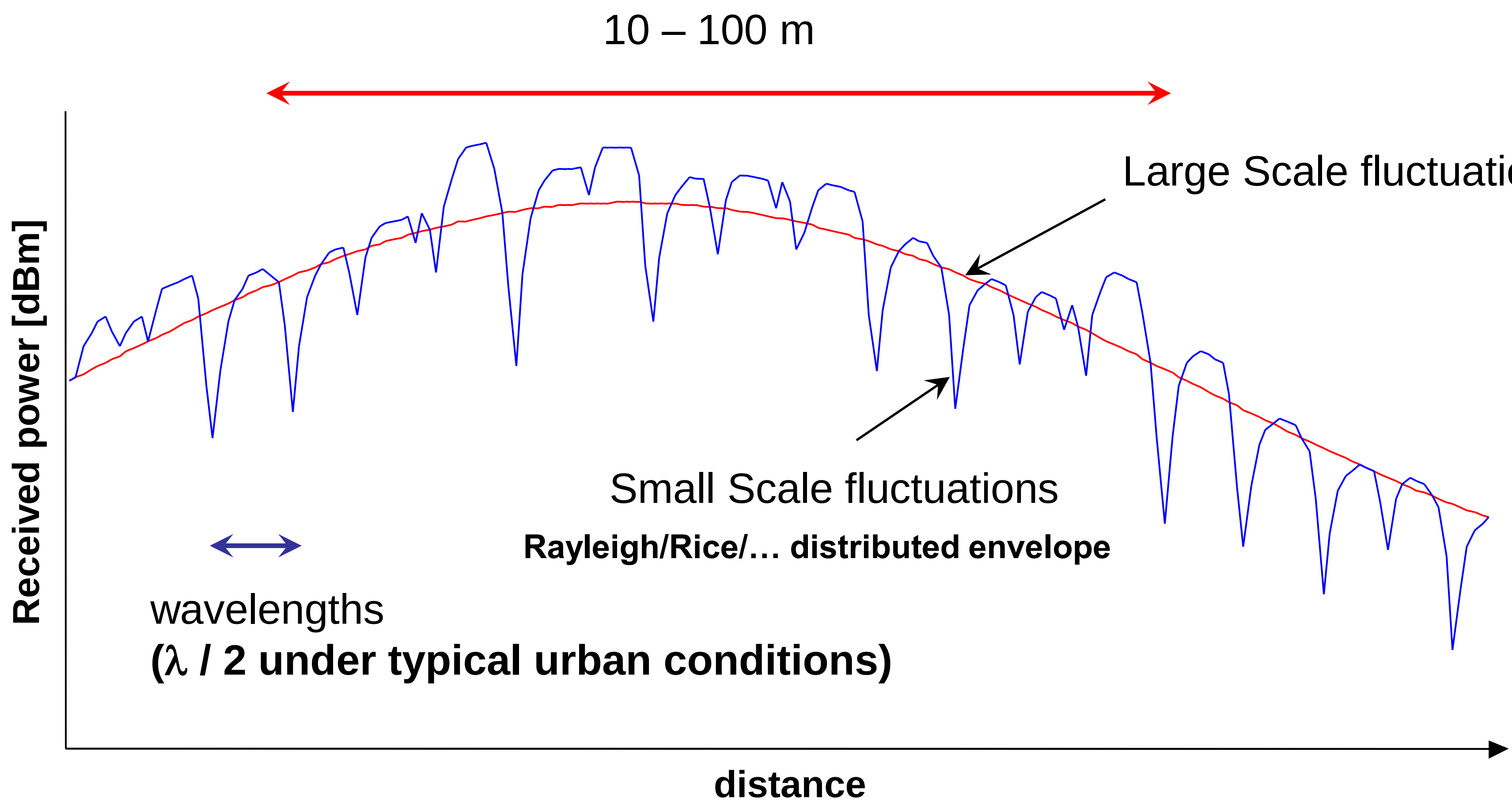
τ represents delay spread of the channel impulse response

Small Scale: Narrowband (Mobile) Characterisation





Small Scale: Narrowband (Mobile) Characterisation



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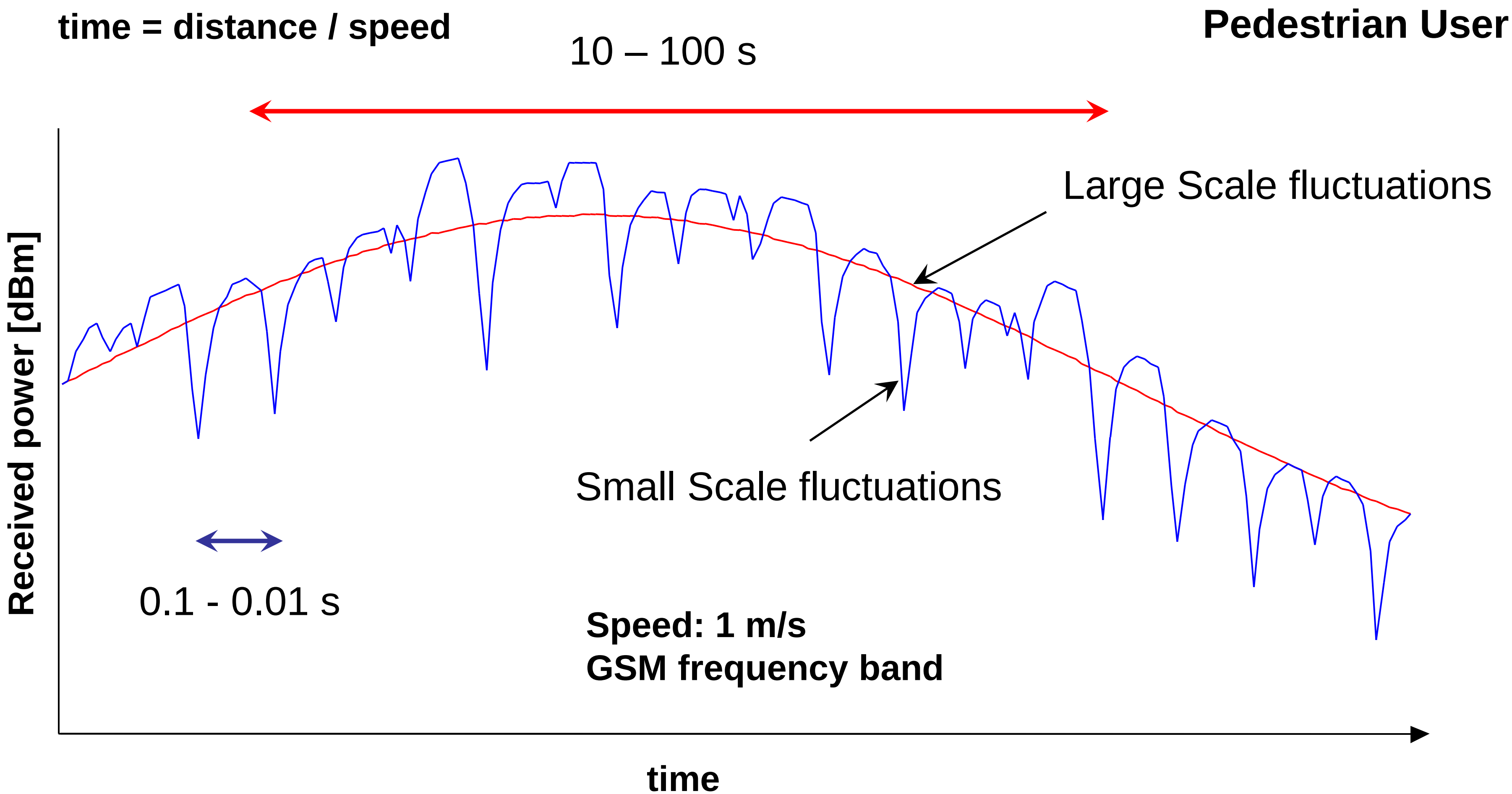

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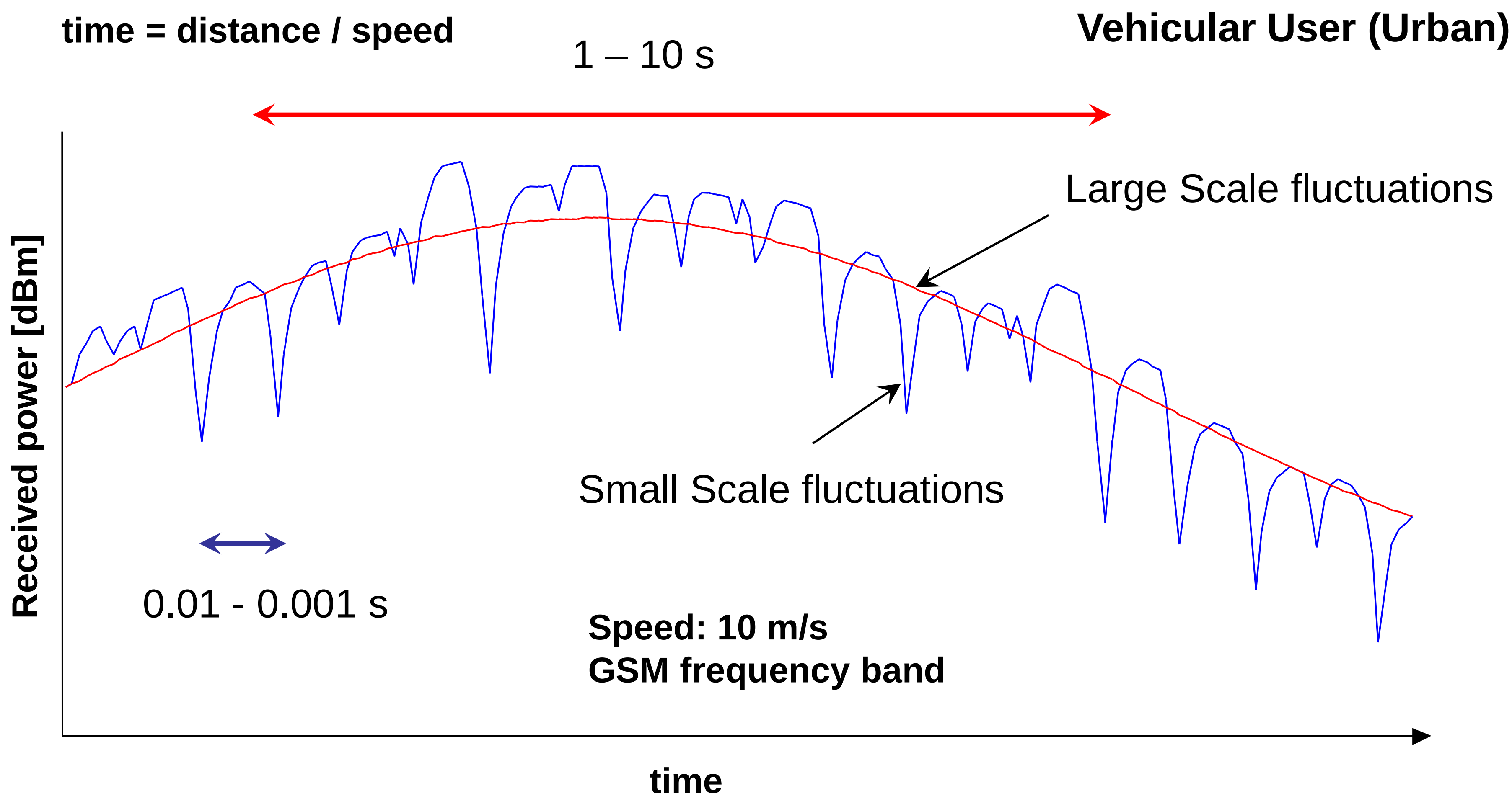

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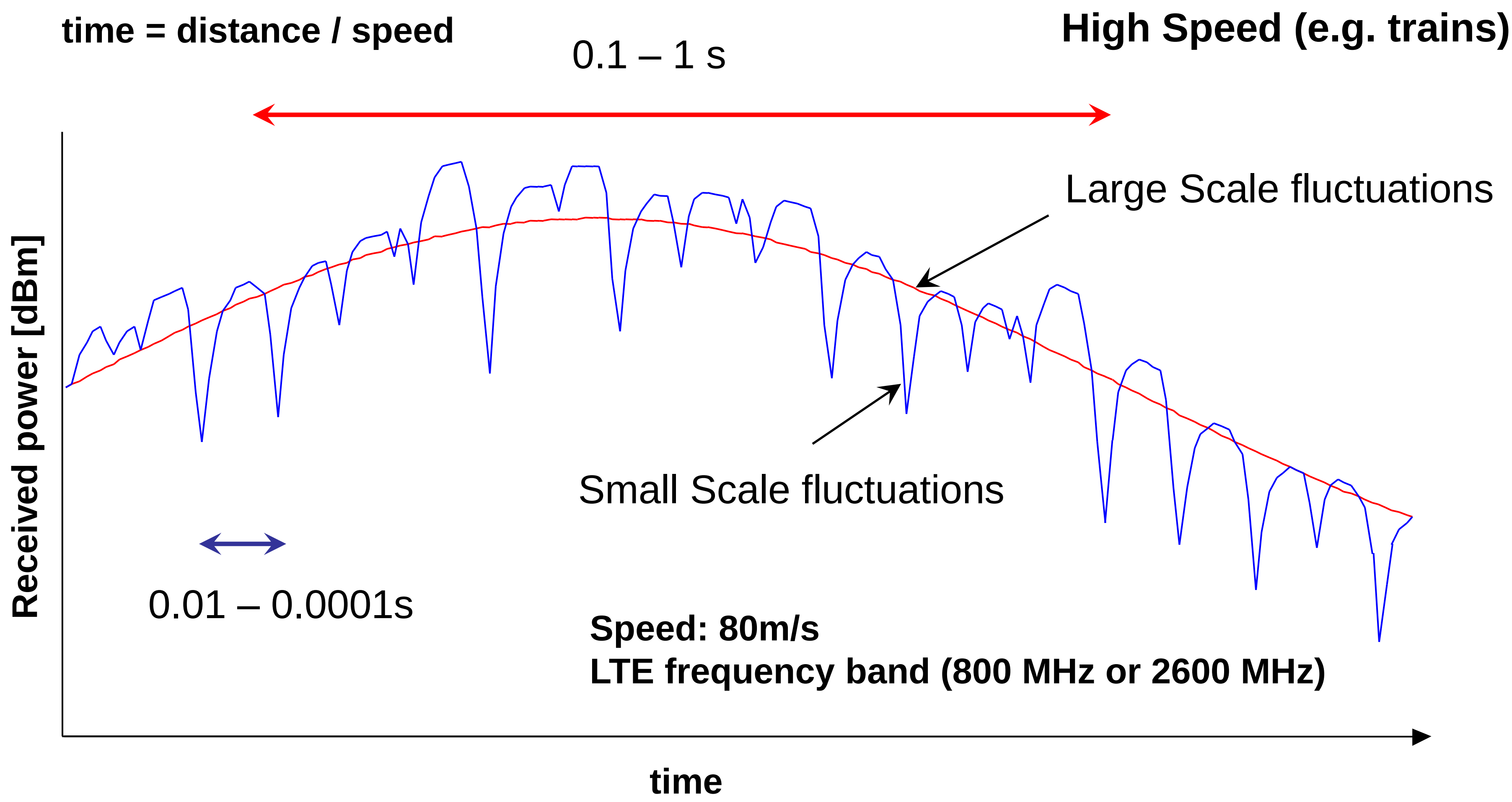
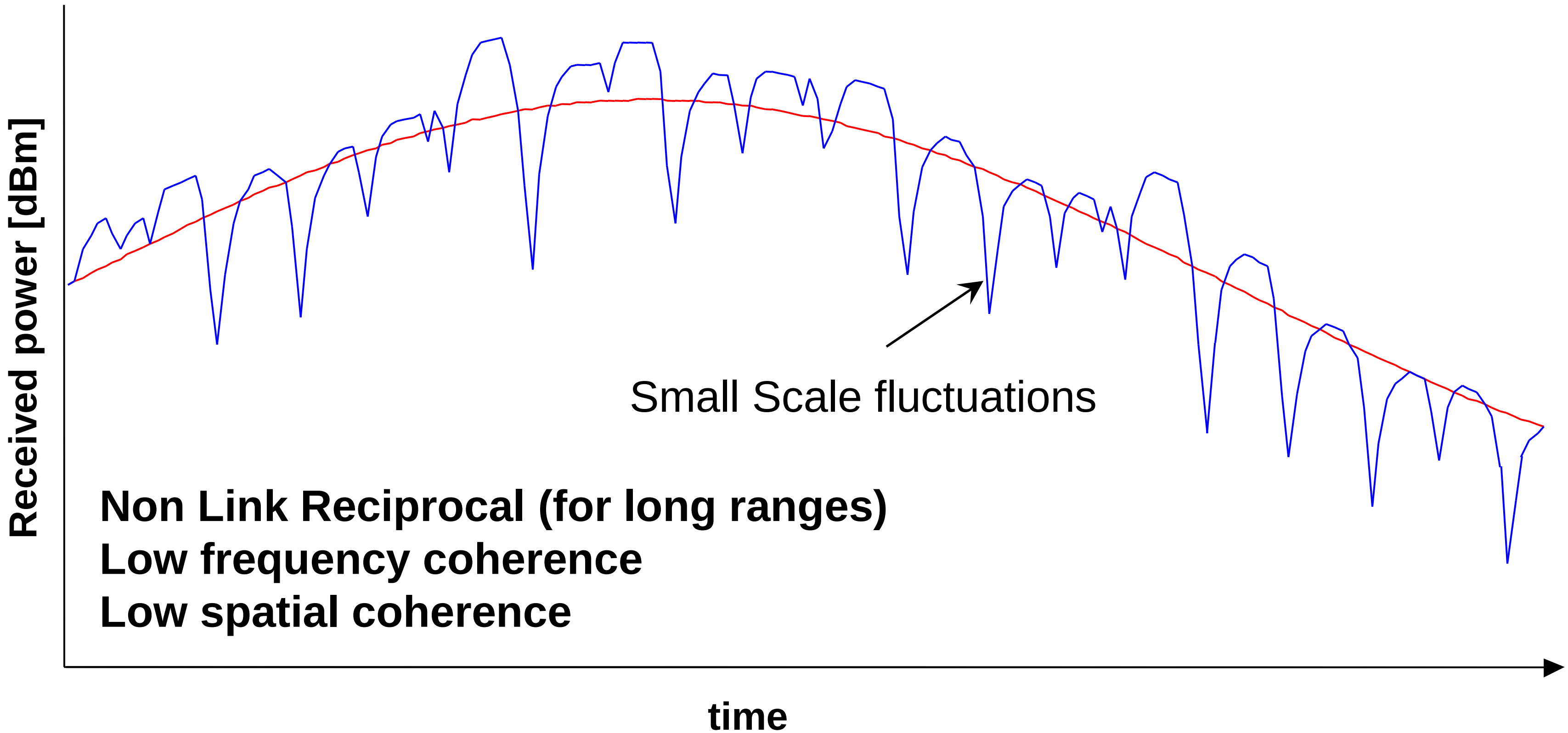
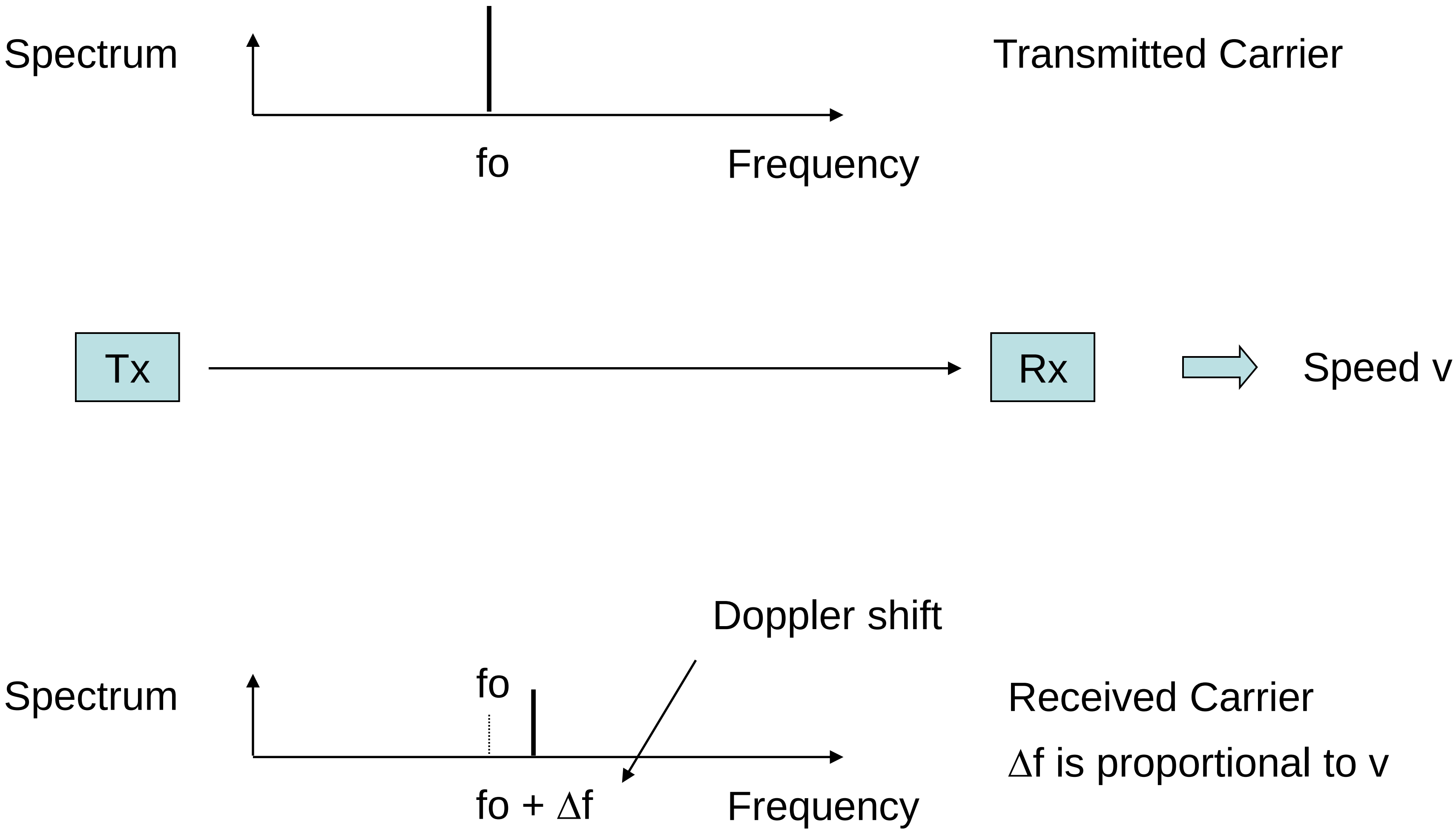


Small Scale: Narrowband (Mobile) Characterisation

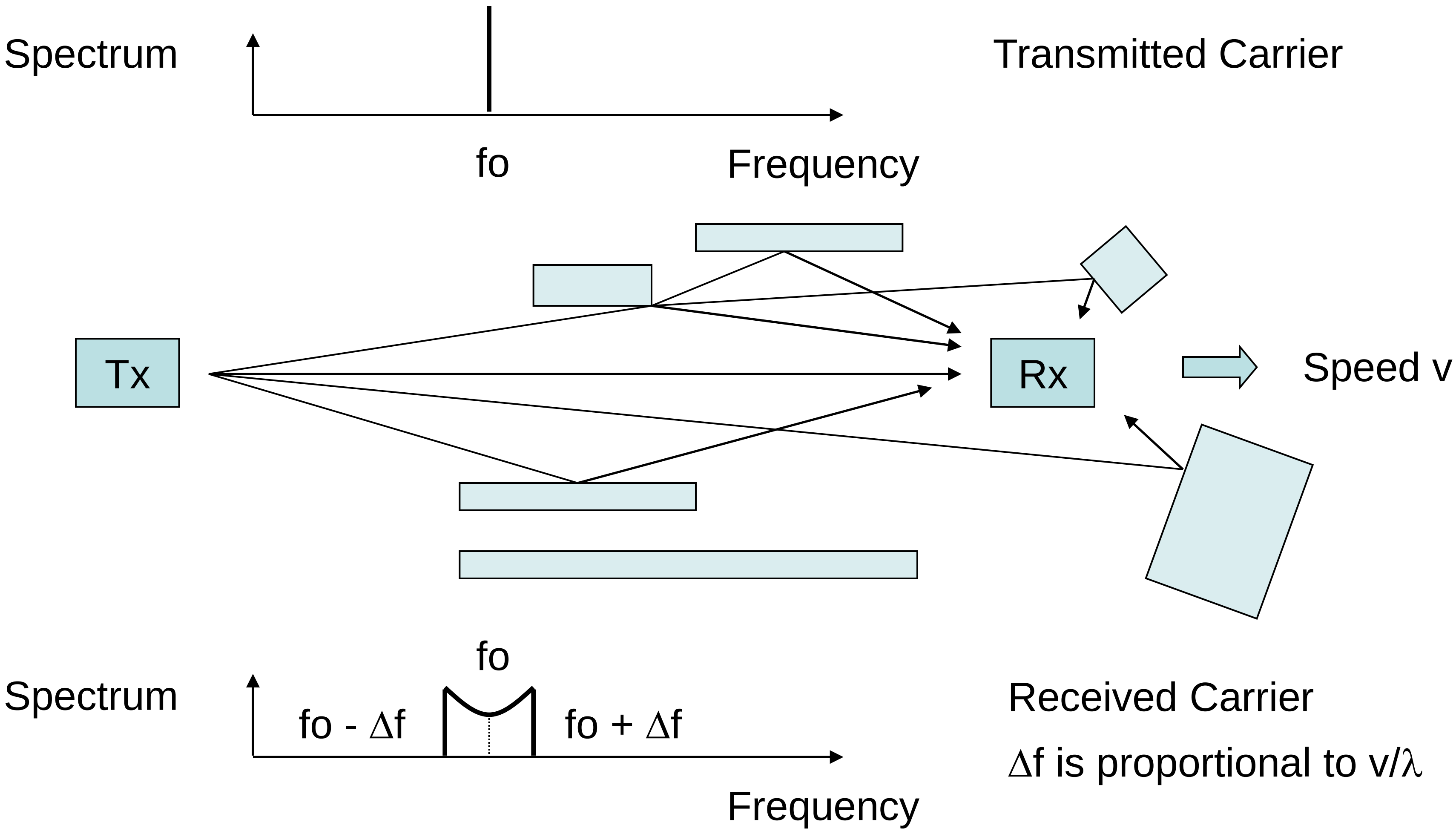


Non Link Reciprocal (for long ranges)
Low frequency coherence
Low spatial coherence

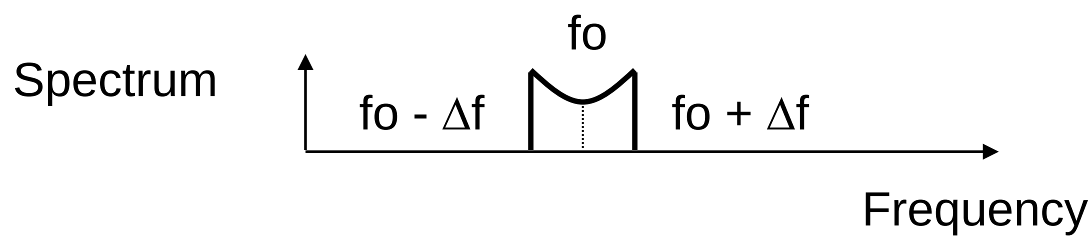
Small Scale: Doppler Effect

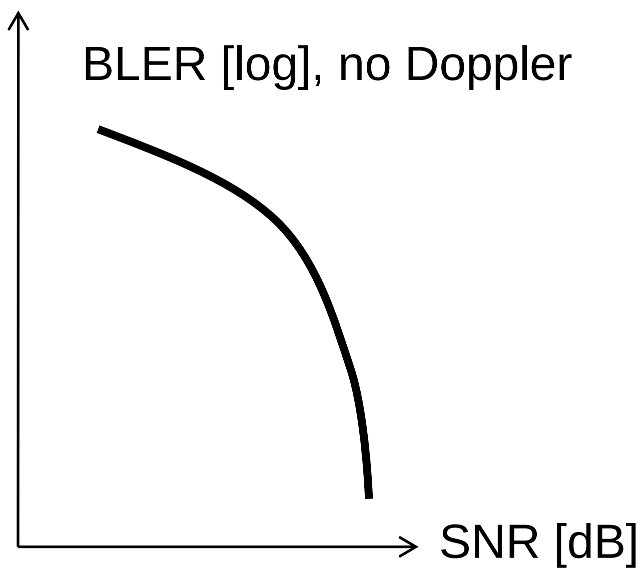


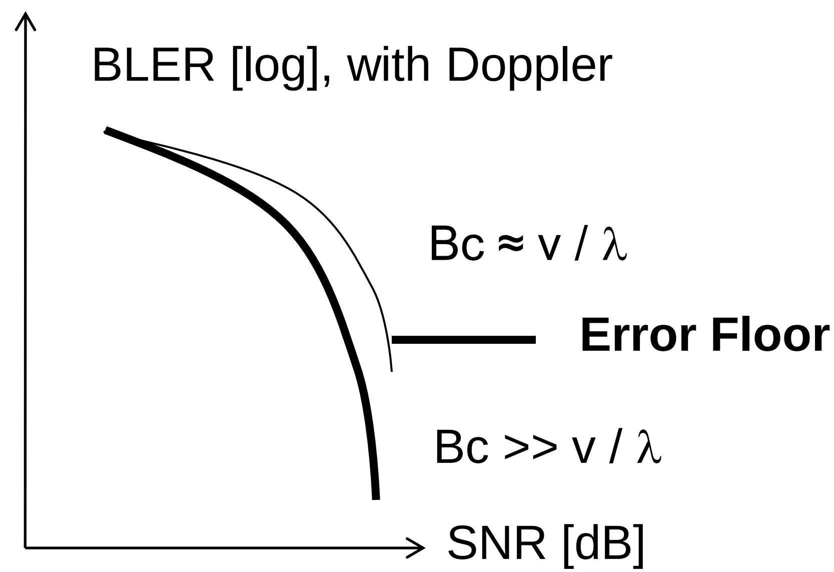
Small Scale: Doppler Spectrum



Small Scale: Doppler Spectrum







Small Scale: Narrowband (Stationary) Characterisation

Do not use previous model for v tending to zero; the speed of obstacles has to be considered

The Doppler spectrum might change (typically bell-shaped)

The fluctuation rate depends on speed of scatterers

The statistics of channel fluctuations might change

Small Scale: Narrowband Characterisation

Channel fluctuations are fast or slow depending on the user speed.

In any case, one has to define what “Fast” or “Slow” means with respect to the figures considered

e.g. The quality of human oriented communications:

**it is known that human perception is not sensitive
to fluctuations faster than a few Hertz,
Hence, link quality has to be averaged over fast fluctuations
where “fast” means “with a frequency larger than a few Hertz”
(for instance, fading for pedestrian or vehicular speeds
in the GSM frequency band)**

Radio Channel Characterisation in a nutshell

The main phenomena characterising the mobile channel can be categorised as:

Large Scale	**shadowing due to <u>obstruction</u> along the entire path**
Small Scale	**fading due to <u>multipath</u> caused by reflections, diffractions, over objects in the vicinity of receiver (scatterers)**

Channel characterisation can be

Narrowband	**Single carrier is transmitted: link budget is the issue flat or time selective fading (small scale) shadowing (large scale)**
Wideband	**Short pulse is transmitted: multipath delay is the issue frequency selective fading (small scale)**

We focus mainly on link budget related issues (i.e. narrowband characterisation)

Radio Channel Characterisation in a nutshell

Frequency bands from 400 MHz to 4 GHz

		Fading	Shadowing
Coherence Time	T_{coh}	0.1 – 100 ms	1 – 10 s
Coherence Band	B_{coh}	0.1 – 10 MHz	10 – 100 MHz
Coherence Space	S_{coh}	0.1 – 10 m	10 – 100 m

Inquiry Based Session

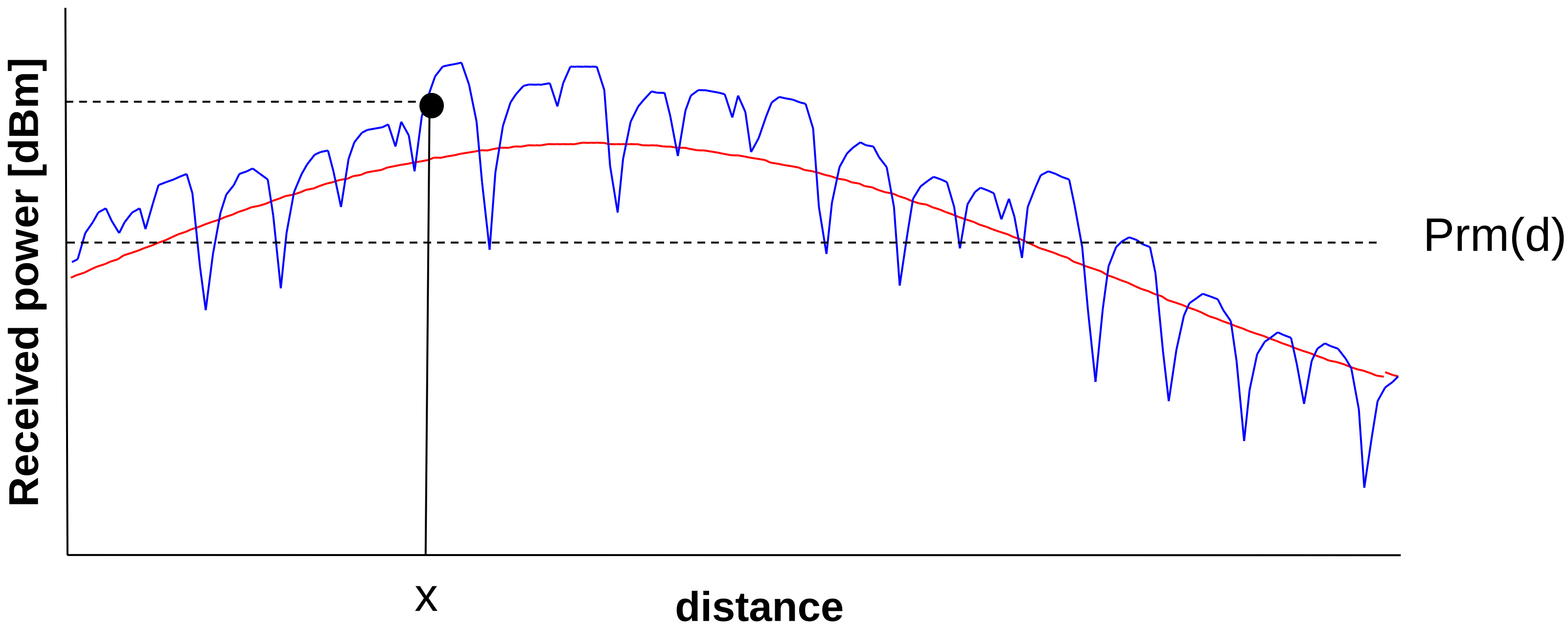
Does GPRS (Bc = 200 KHz, fc = 1800 MHz) suffer from frequency selective fading?

Does WiFi (Bc = 22 MHz, fc = 2.4 GHz) suffer from frequency selective fading?

Does GPRS (Bc = 200 KHz, fc = 1800 MHz) suffer from time selective fading?

4. The Narrowband Mobile Radio Channel

The Narrowband Mobile Radio Channel



Pr(x) = Prm(d) m²(x) r²(x) = Pra(x) r²(x)

Pr(x)	short term average power	(over few carrier cycles)
Pra(x) = Prm(d) m^2(x)	long term average power	(over fading: few wavelenghts)
Prm(d)	median power	(distance dependent component)

The Narrowband Mobile Radio Channel

$Pr(x) = Prm(d)\ m^2(x)\ r^2(x)$

Model Assumptions

Shadowing:

$m^2(x)$ is assumed to be log-normal distributed:

Pra(x) [dBm] =
Prm(d) [dBm] + s(x) [dB]

s(x) is Gaussian, zero mean, std dev. σ

Fading:

r(x) is assumed to be Rayleigh distributed (worst case), i.e.

$f(x) = r^2(x)$ is negative exponentially distributed:

$pdf(f) = [1 / X] \exp(- f / X)\ u(f)$ $X = E[r(x)^2] = 1$

u(f) step function

Median Power:

$Prm(d) = k\ d^{-\beta}$