Università degli Studi di Napoli "Parthenope"
Dipartimento di Ingegneria
Corso di Laurea Magistrale in Ingegneria della Sicurezza dei Dati e delle Comunicazioni

Antennas and Propagation for Wireless Communication Systems

Propagation Models and Measurements to characterize Wireless channels

Ing. Simone Gargiulo

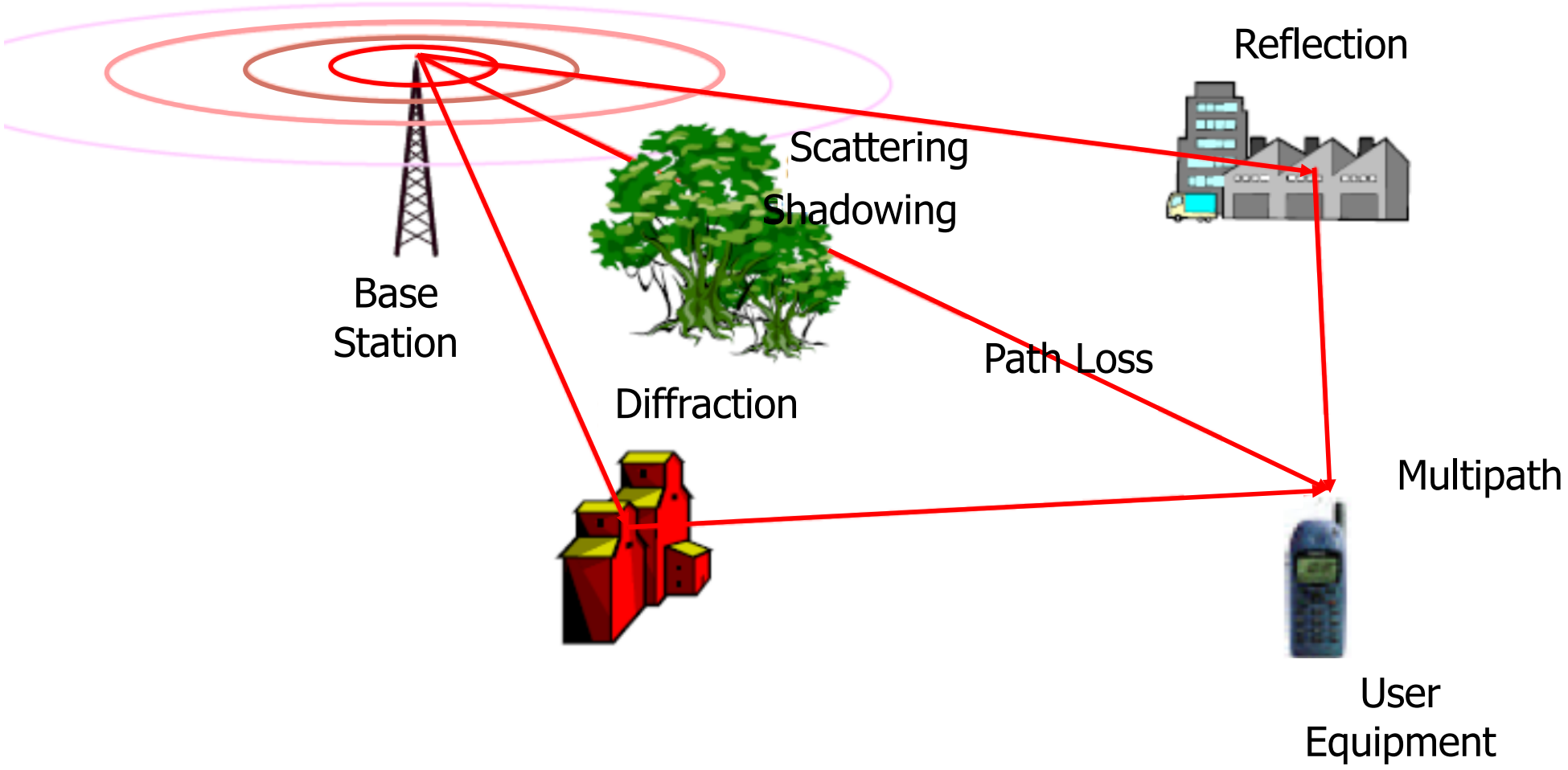
Wireless Radiomobile Channel is a LTV system: Linear and Time Variant

$$y(t) = x(t) \otimes h(t, \tau)$$

The received signal is affected by
FADING

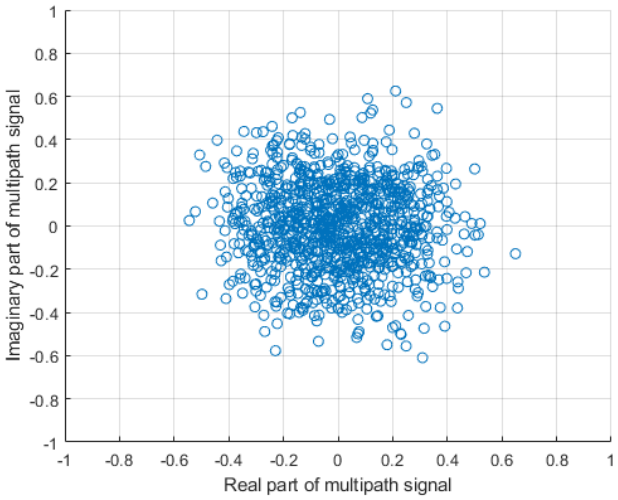
- Path Loss
- Shadowing
- Multipath Fading

Fading

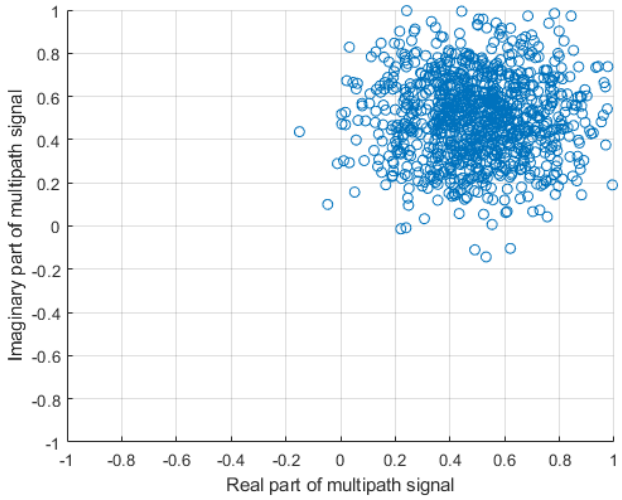

Reflection
Scattering
Shadowing
Base
Station
Path Loss
Diffraction
Multipath
User
Equipment

Multipath Fading

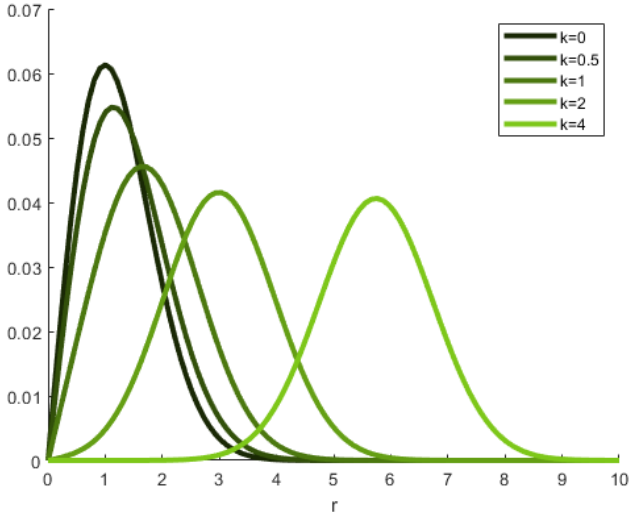
$$y(t)=\sum_i a_i e^{j(\omega\tau_i+\theta_i)}$$



Rayleigh



Rice



$$y(t) = x(t) \otimes h(t, \tau)$$

Propagation Models for the characterization of wireless channels 4/9

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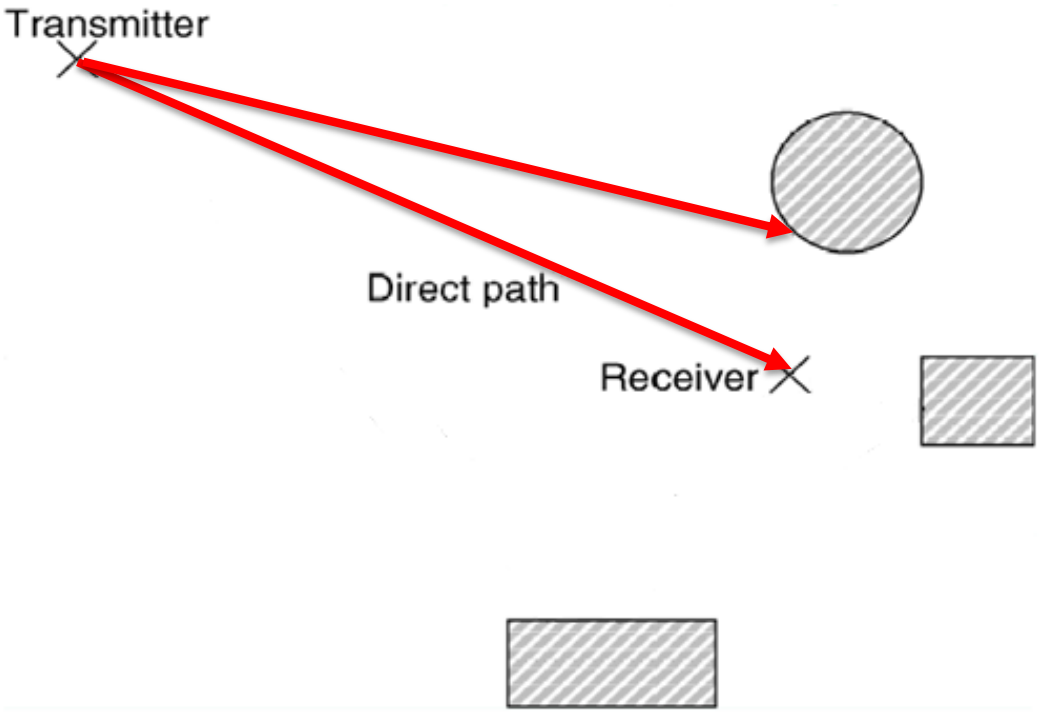

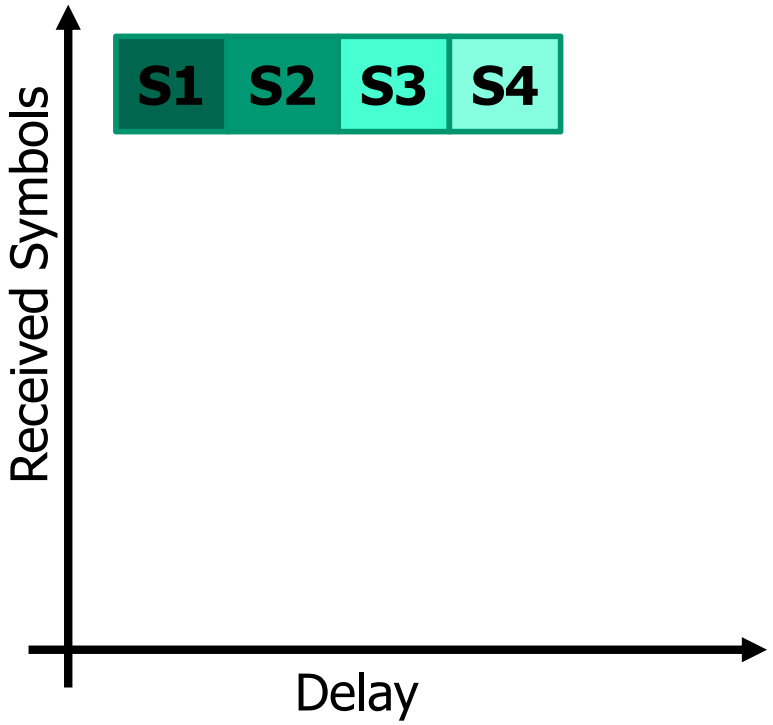

Propagation Models for the characterization of wireless channels 4/9

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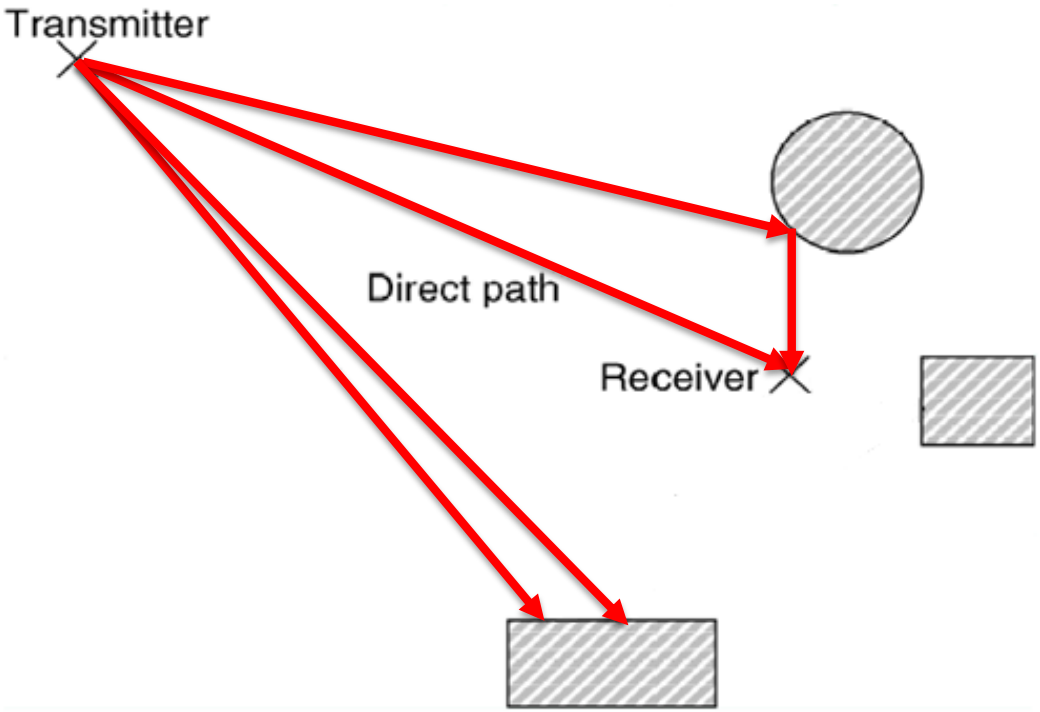

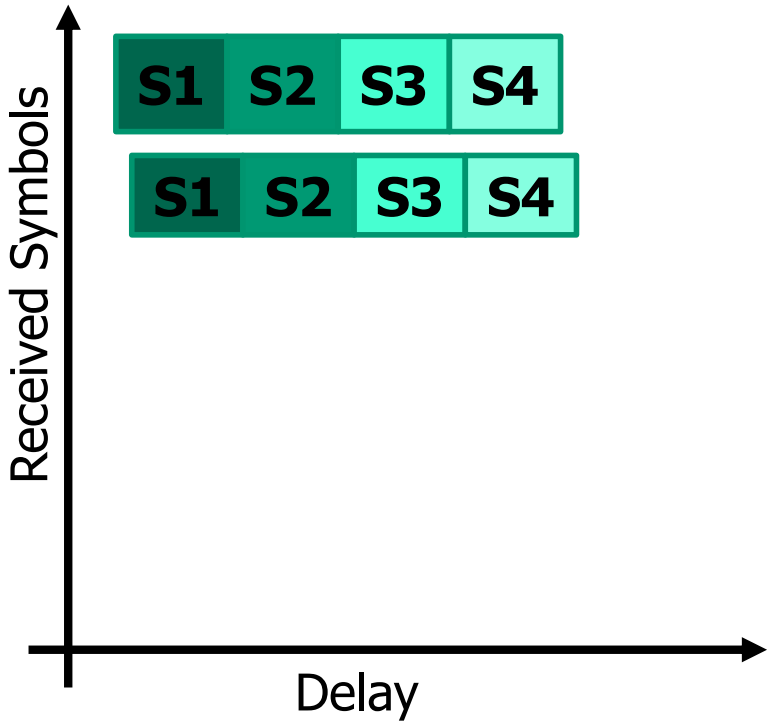

Propagation Models for the characterization of wireless channels 4/9

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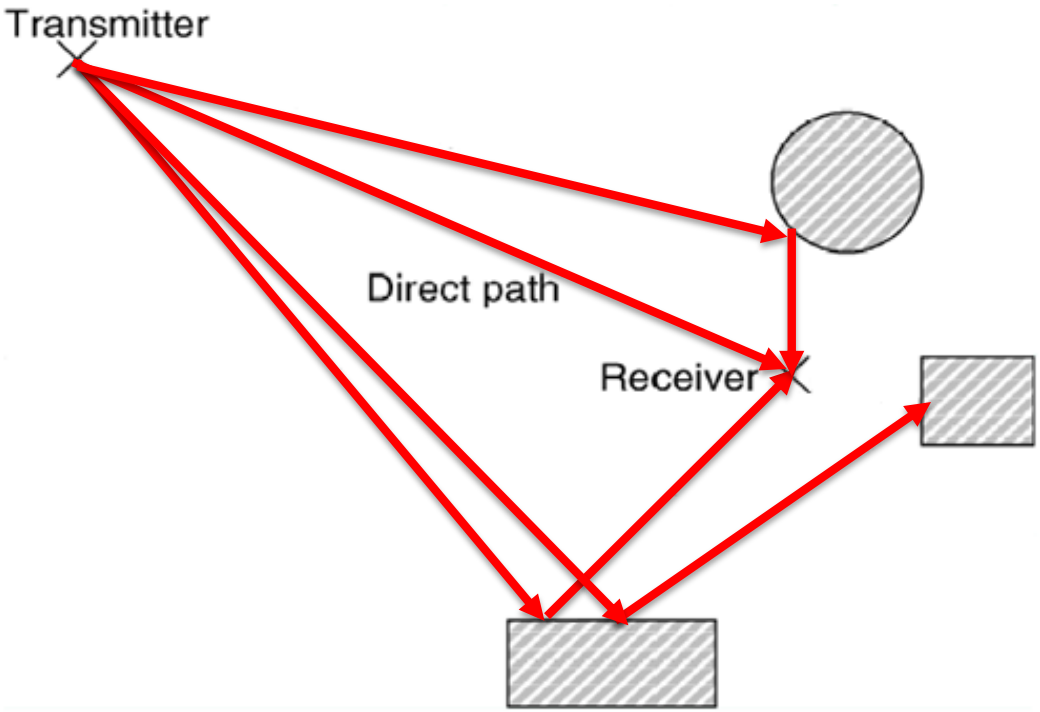

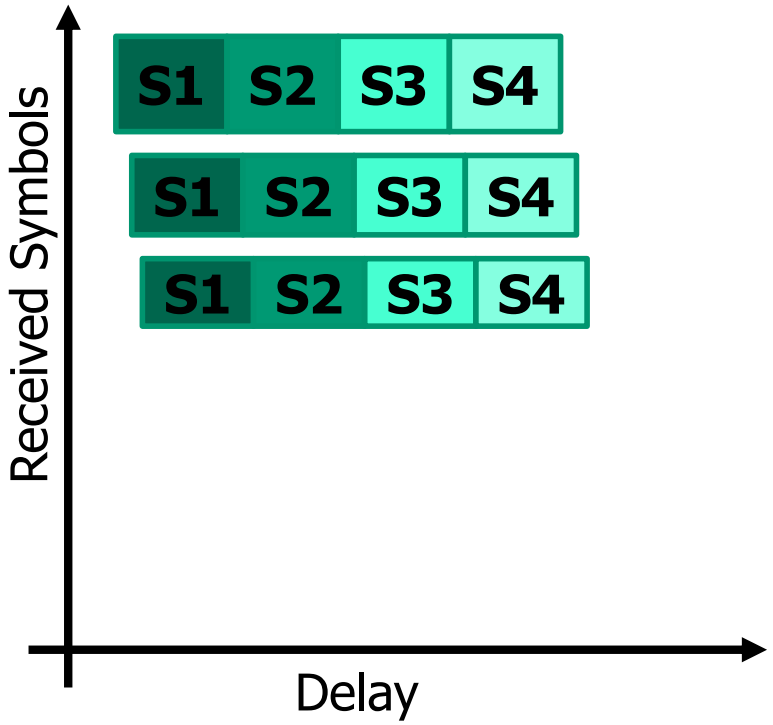

Propagation Models for the characterization of wireless channels 4/9

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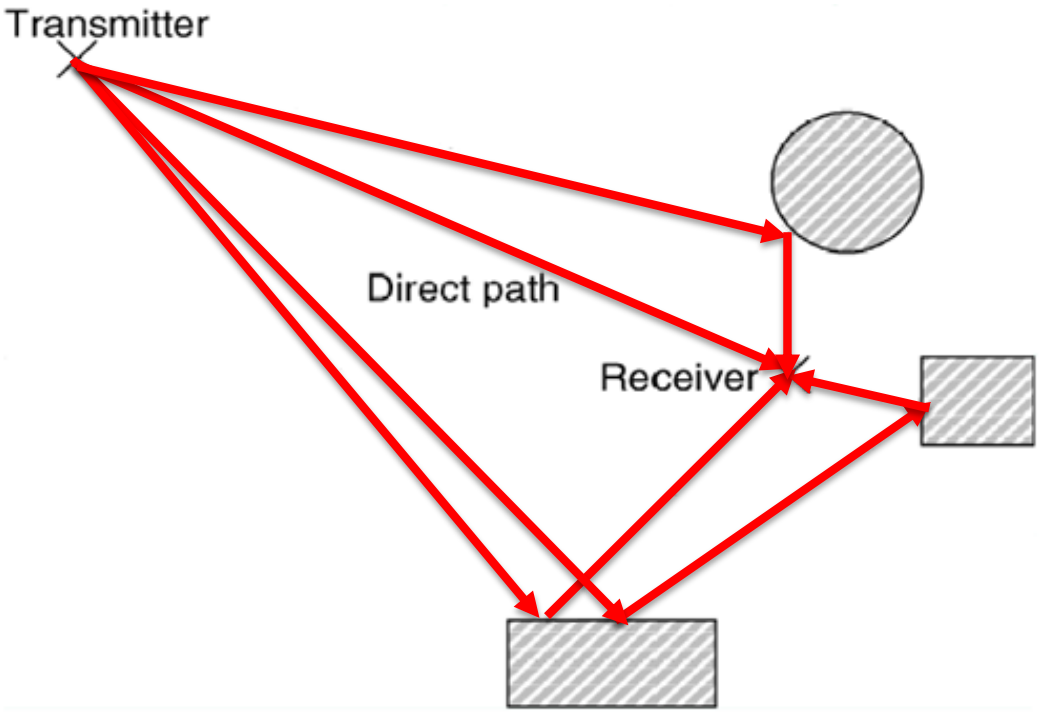

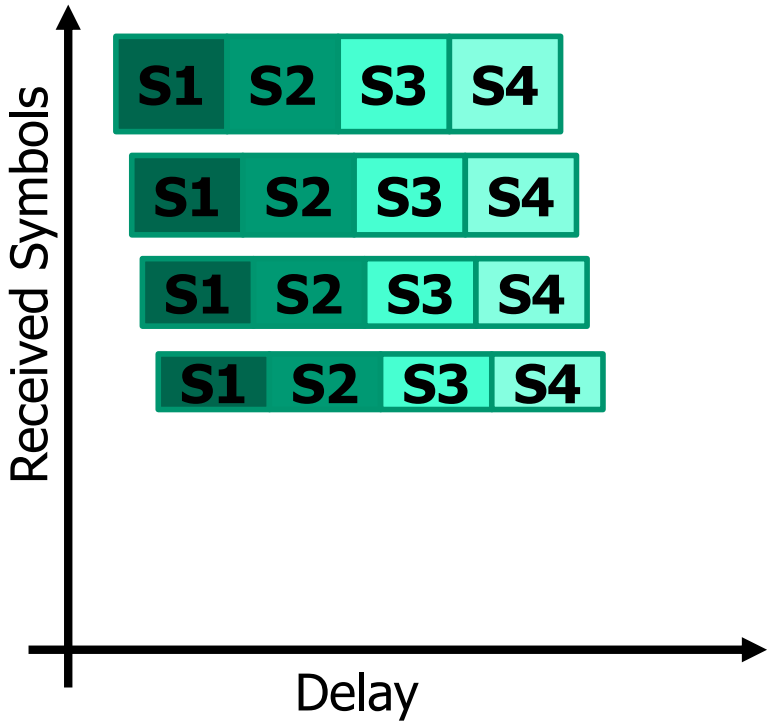

Propagation Models for the characterization of wireless channels 4/9

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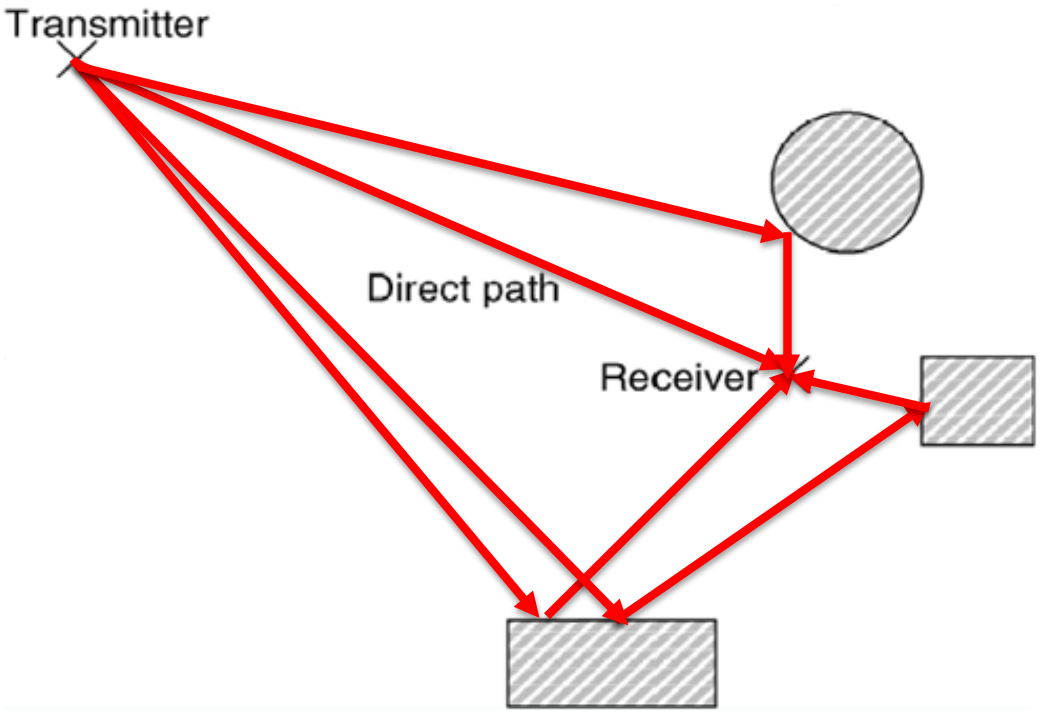

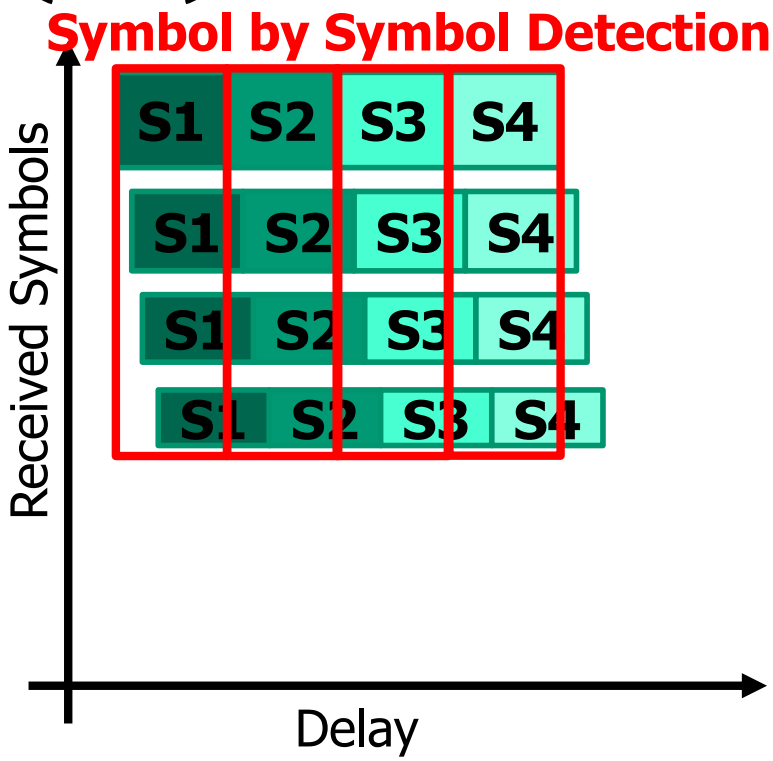

Propagation Models for the characterization of wireless channels 4/9

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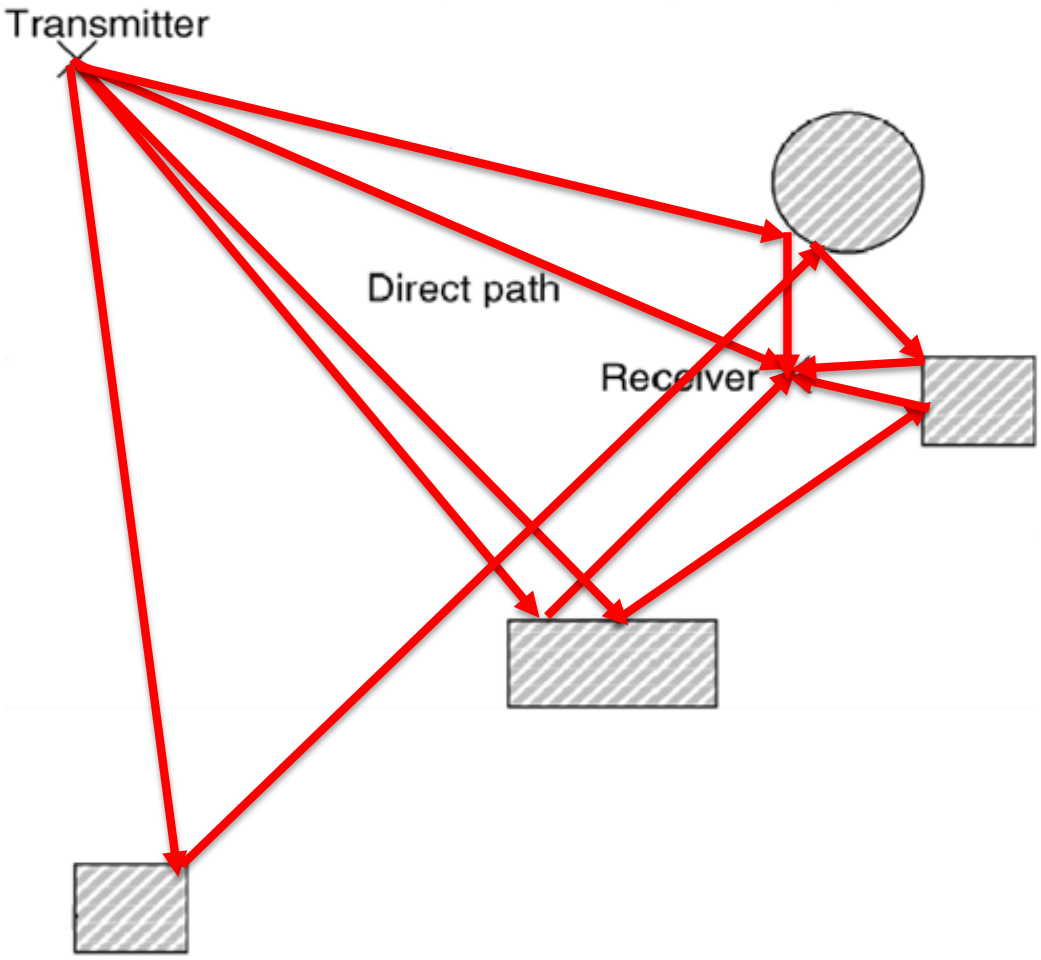

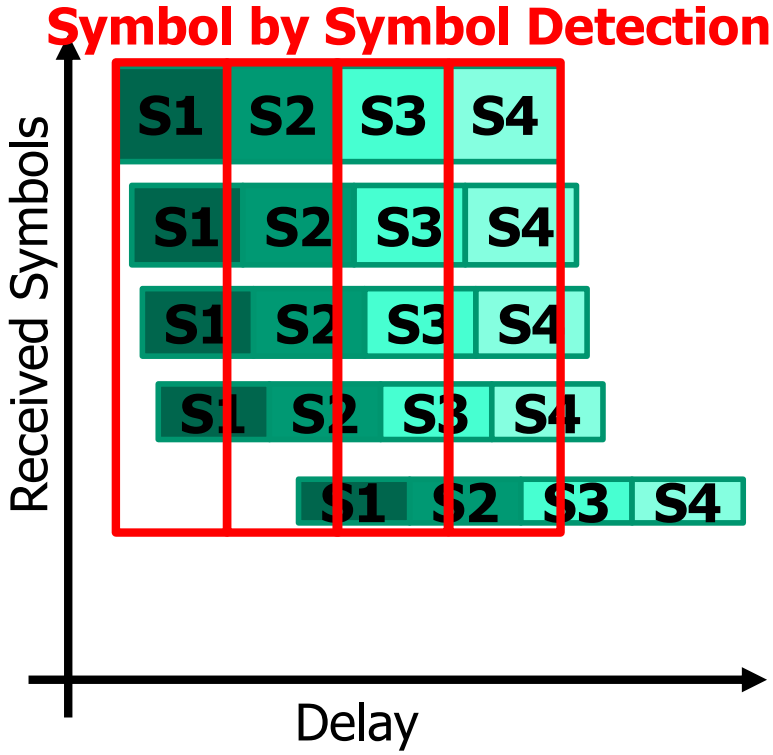

Propagation Models for the characterization of wireless channels 5/9

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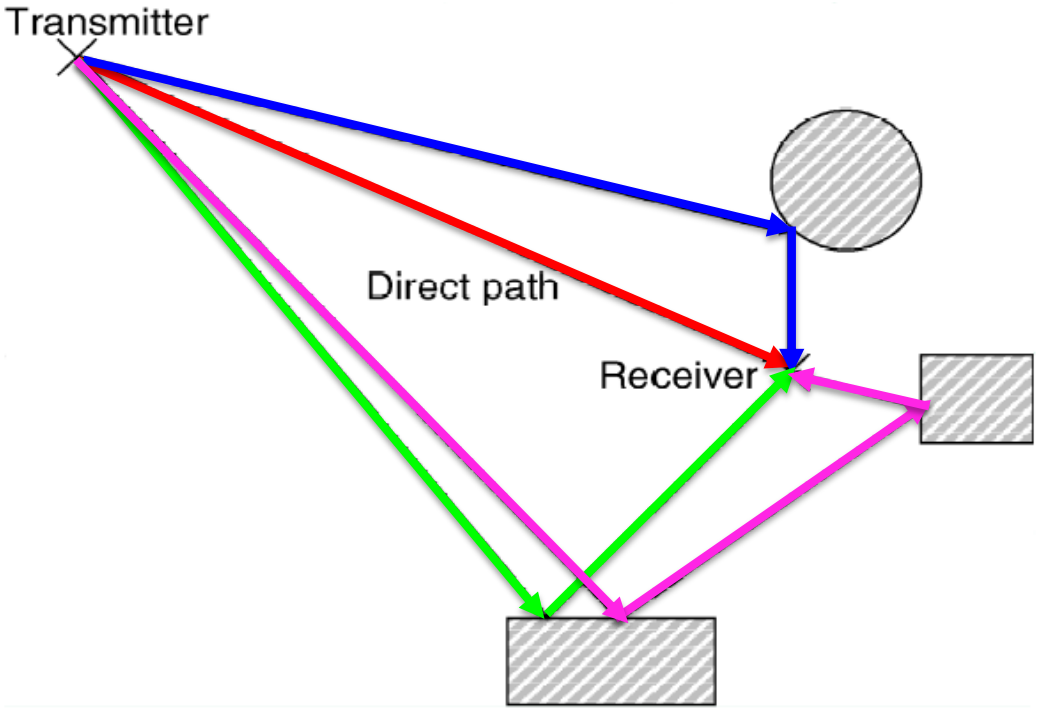

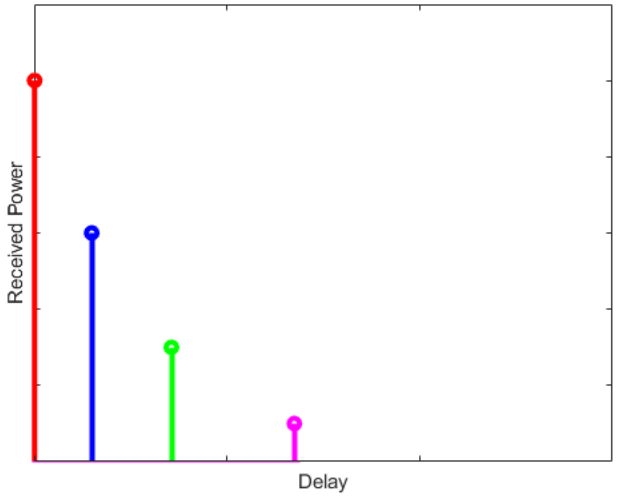

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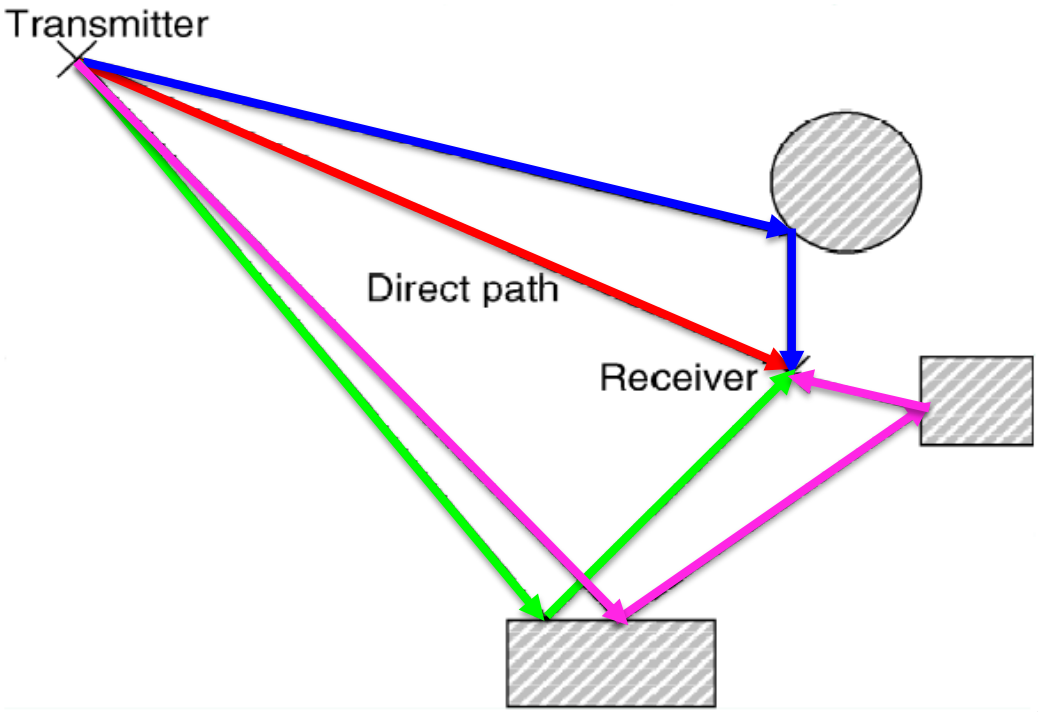
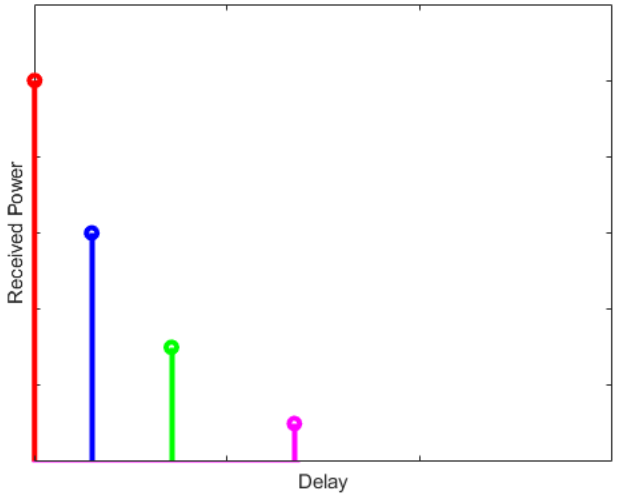
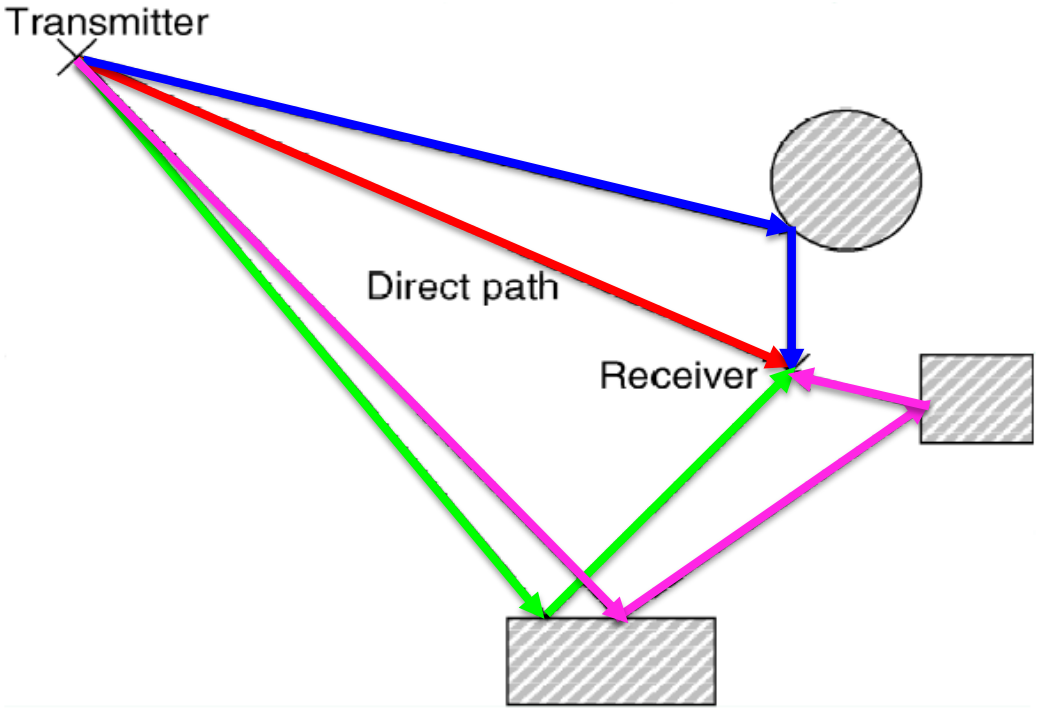


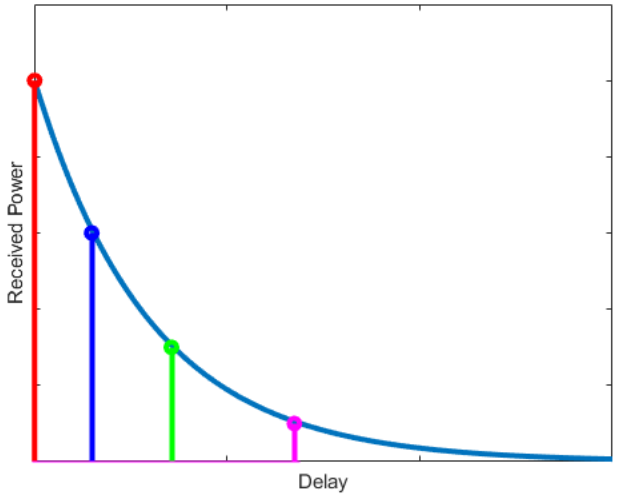


Power Delay Profile (PDP)

$$PDP(\tau) = E[|h(t, \tau)|^2]$$

$$y(t) = x(t) \otimes h(t, \tau)$$



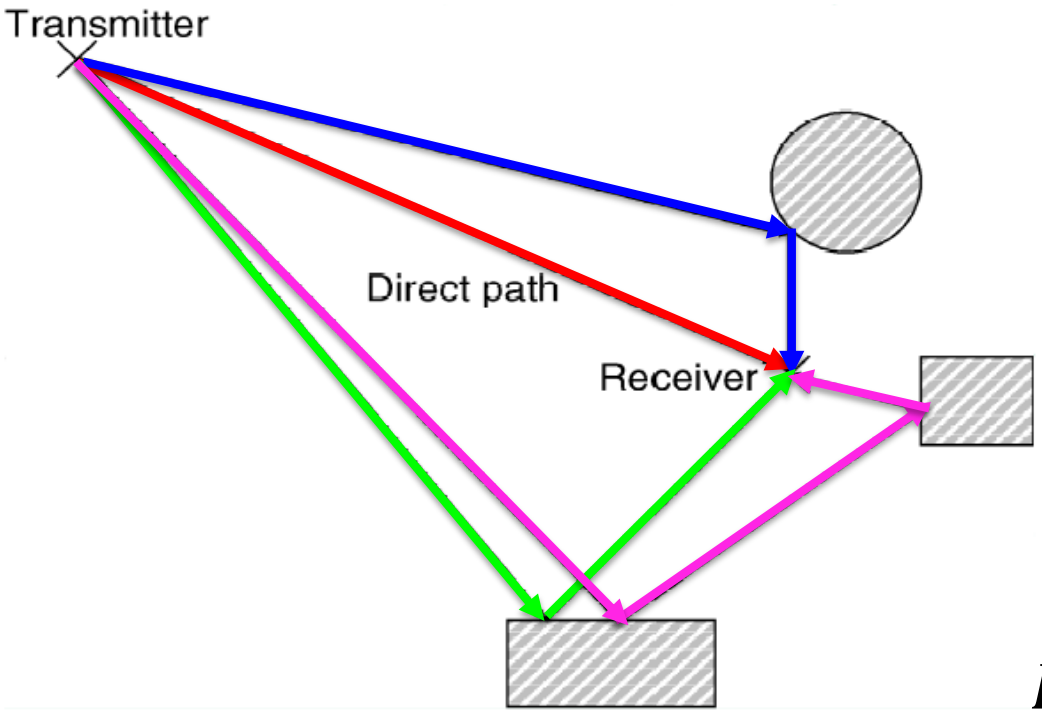


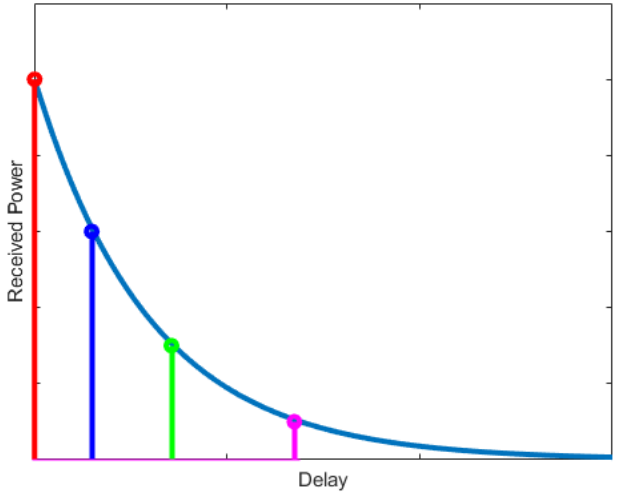
Power Delay Profile (PDP)

$$PDP(\tau) = E[|h(t,\tau)|^2] = \frac{1}{\tau_{RMS}} e^{\frac{-\tau}{\tau_{RMS}}}$$

Propagation Models for the characterization of wireless channels 5/9

$$y(t) = x(t) \otimes h(t, \tau)$$





Power Delay Profile (PDP)

$$PDP(\tau) = E\left[|h(t,\tau)|^2\right] = \frac{1}{\tau_{RMS}} e^{\frac{-\tau}{\tau_{RMS}}}$$

Root Mean Square Delay

$$\tau_{RMS} = \sqrt{\frac{1}{P_T}\sum_{i=1}^{n} P_i {\tau_i}^2 - {\tau_0}^2}$$

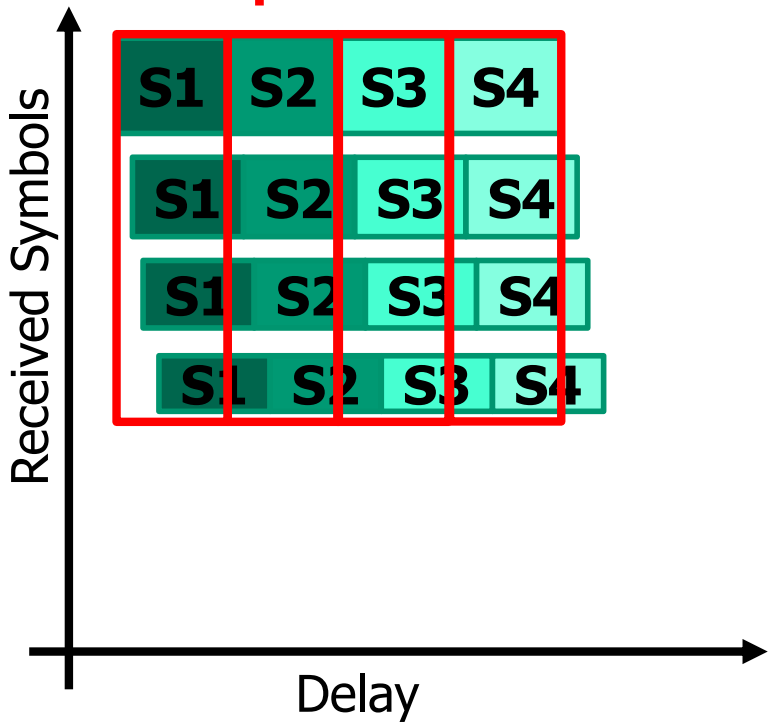
Mean Delay

$$\tau_0 = \frac{1}{P_T}\sum_{i=1}^{n} P_i \tau_i$$

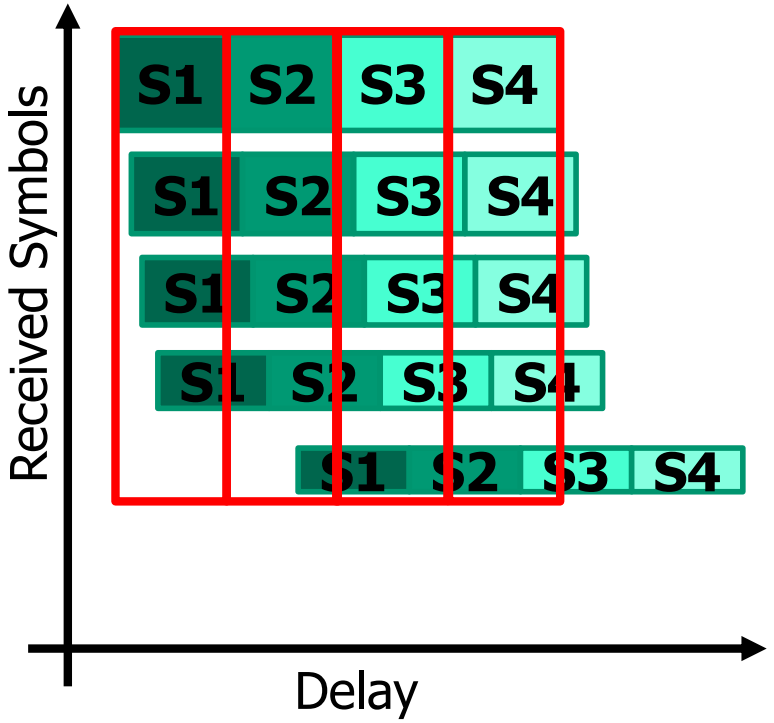
Propagation Models for the characterization of wireless channels 5/9

$$y(t) = x(t) \otimes h(t, \tau)$$

Non Dispersive Channel



Dispersive Channel



Power Delay Profile (PDP)

$$PDP(\tau) = E\left[|h(t,\tau)|^2\right] = \frac{1}{\tau_{RMS}} e^{\frac{-\tau}{\tau_{RMS}}}$$

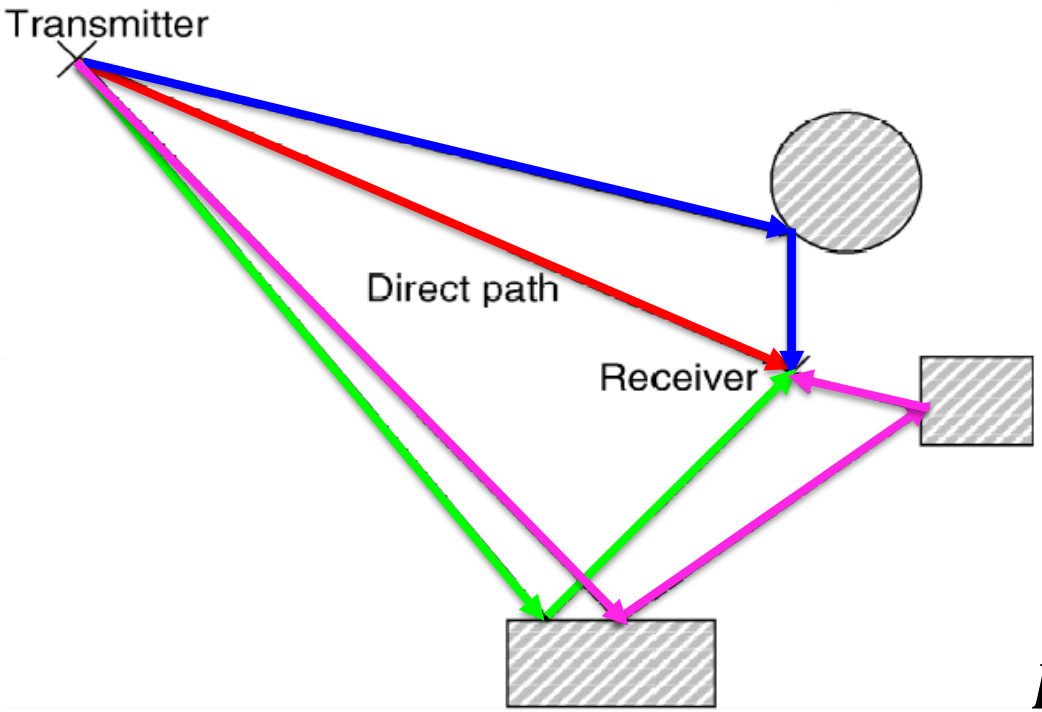
If:

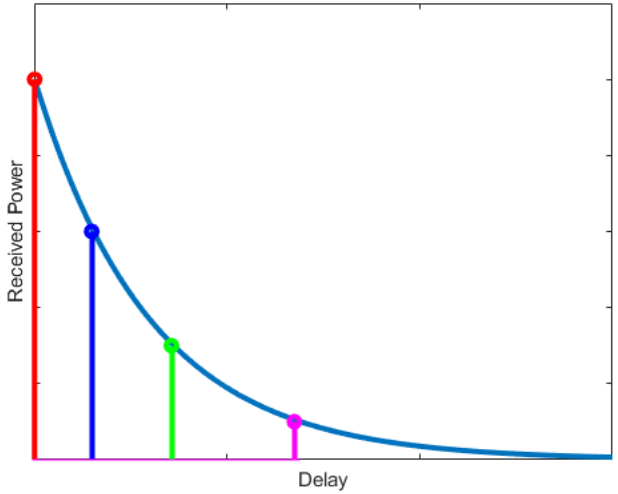
$T_{sym} \geq 10\tau_{RMS}$: *Non Dispersive channel in the time domain*

$T_{sym} < 10\tau_{RMS}$: *Dispersive channel in the time domain*

Propagation Models for the characterization of wireless channels 5/9

$$y(t) = x(t) \otimes h(t, \tau)$$





Power Delay Profile (PDP)

$$PDP(\tau) = E[|h(t,\tau)|^2] = \frac{1}{\tau_{RMS}} e^{\frac{-\tau}{\tau_{RMS}}}$$

Root Mean Square Delay

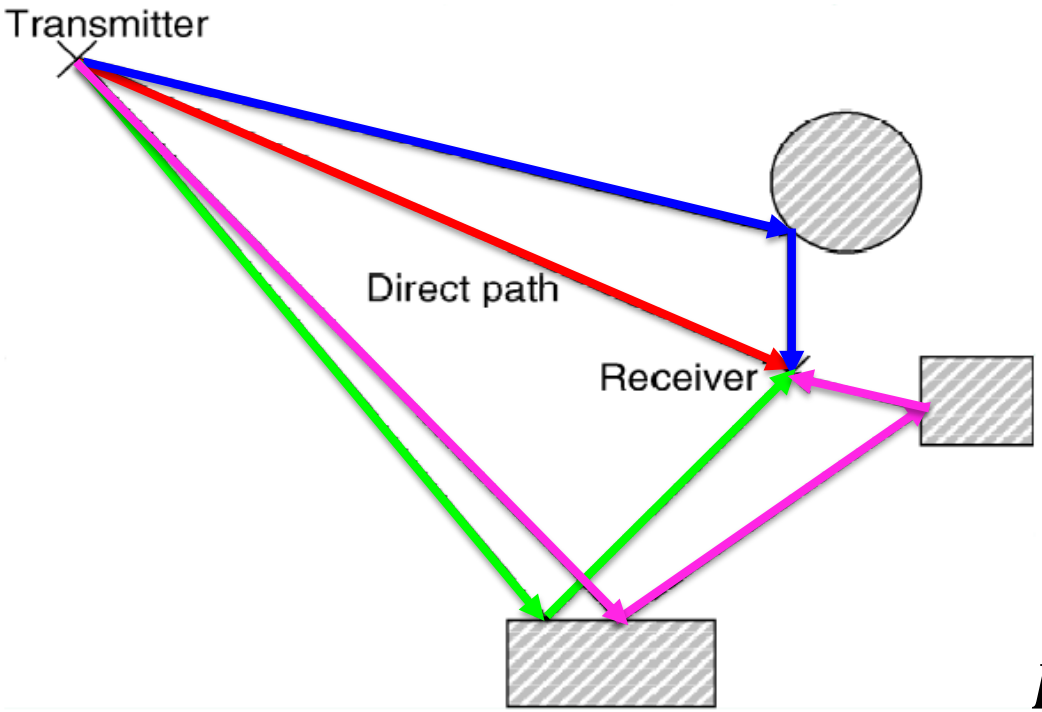
$$\tau_{RMS} = \sqrt{\frac{1}{P_T} \sum_{i=1}^{n} P_i {\tau_i}^2 - {\tau_0}^2}$$

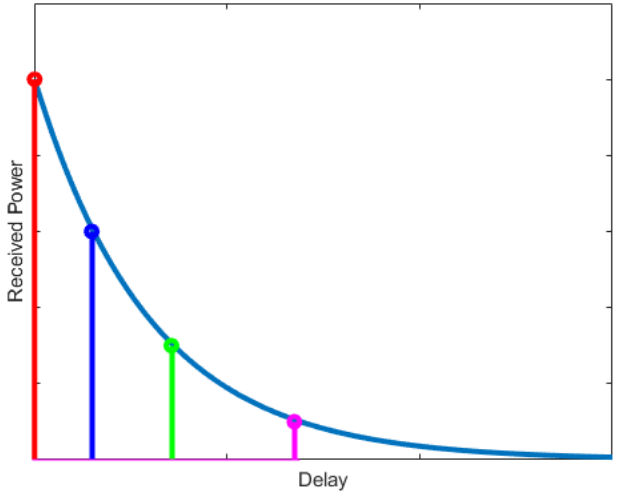
$$T_{sym} = N_{bit} * T_{bit}$$

$$BER = \left(\frac{\tau_{RMS}}{T_{bit}}\right)^2$$

Propagation Models for the characterization of wireless channels 5/9

$$y(t) = x(t) \otimes h(t, \tau)$$





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Root Mean Square Delay

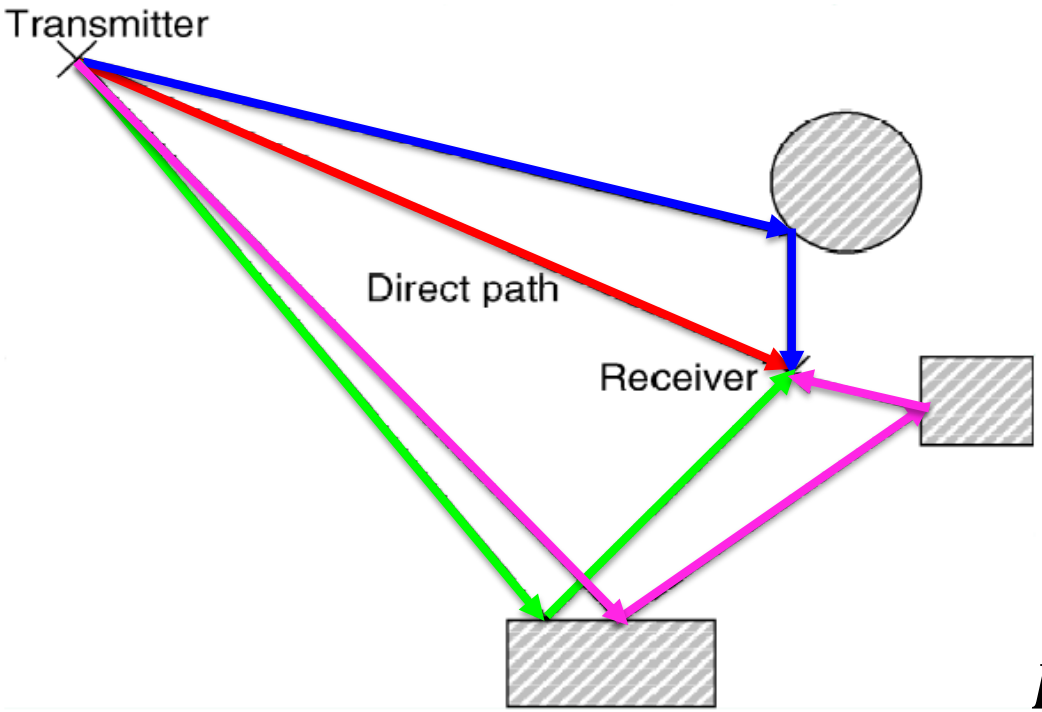
$$\tau_{RMS} = \sqrt{\frac{1}{P_T}\sum_{i=1}^{n} P_i {\tau_i}^2 - {\tau_0}^2}$$

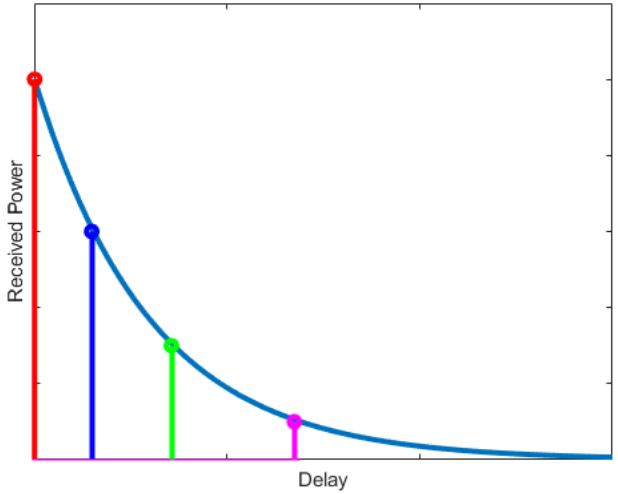
Coherence Bandwidth

$$B_c \propto \frac{1}{\tau_{RMS}}$$

Propagation Models for the characterization of wireless channels 5/9

$$y(t) = x(t) \otimes h(t, \tau)$$





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Coherence Bandwidth

$$B_c \propto \frac{1}{\tau_{RMS}}$$

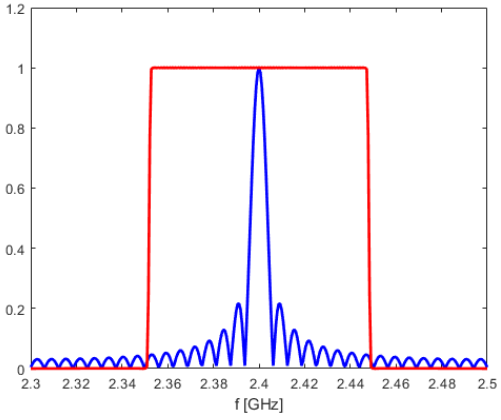
$$\rho(\Delta f) = \frac{E[T(f,t), T^*(f+\Delta f, t)]}{E[T(f,t), T^*(f,t)]}$$

$$T(f,t) = \int e^{-j*2*\pi*f*\tau} * h(t.\tau) d\tau$$

Propagation Models for the characterization of wireless channels 6/9

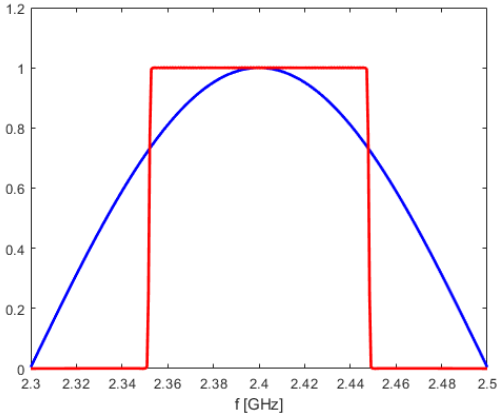
$$y(t) = x(t) \otimes h(t, \tau)$$

	Time Domain	**Frequency Domain**
$T_{sym} \geq 10\tau_{RMS}$ e W>B_c	Non Dispersive Channel	Selective Channel
$T_{sym} \geq 10\tau_{RMS}$ e W<B_c	Non Dispersive Channel	Non Selective Channel
$T_{sym} < 10\tau_{RMS}$ e W>B_c	Dispersive Channel	Selective Channel
$T_{sym} < 10\tau_{RMS}$ e W<B_c	Dispersive Channel	Non Selective Channel



$|H_{ch}(f)|$

$|\mathrm{X}(f)|$



$$y(t) = x(t) \otimes h(t, \tau)$$

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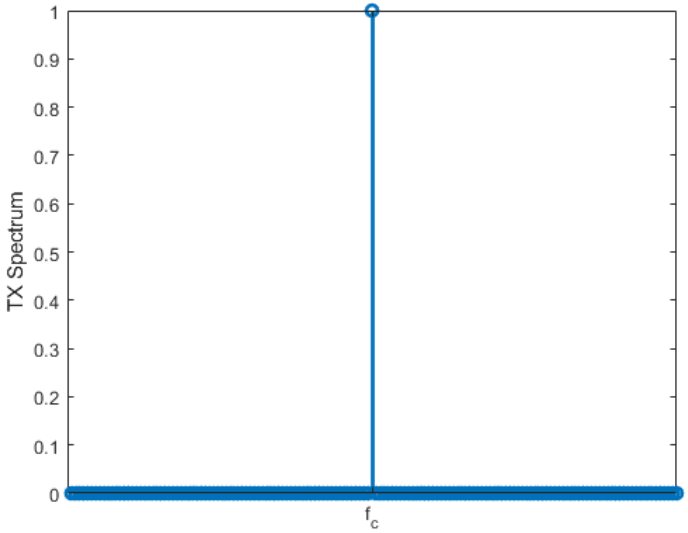
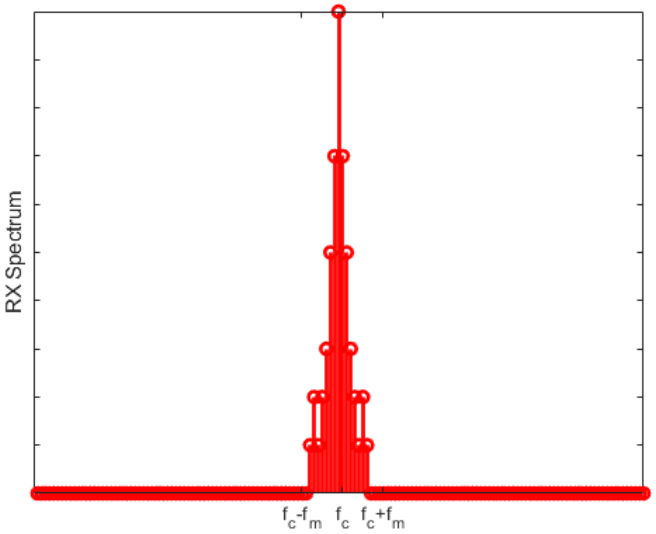
Doppler Spread





$$f_D = f_c \frac{c}{v} \cos\theta$$

$$f_m = f_c \frac{c}{v}$$

$$B_D = 2 f_m$$

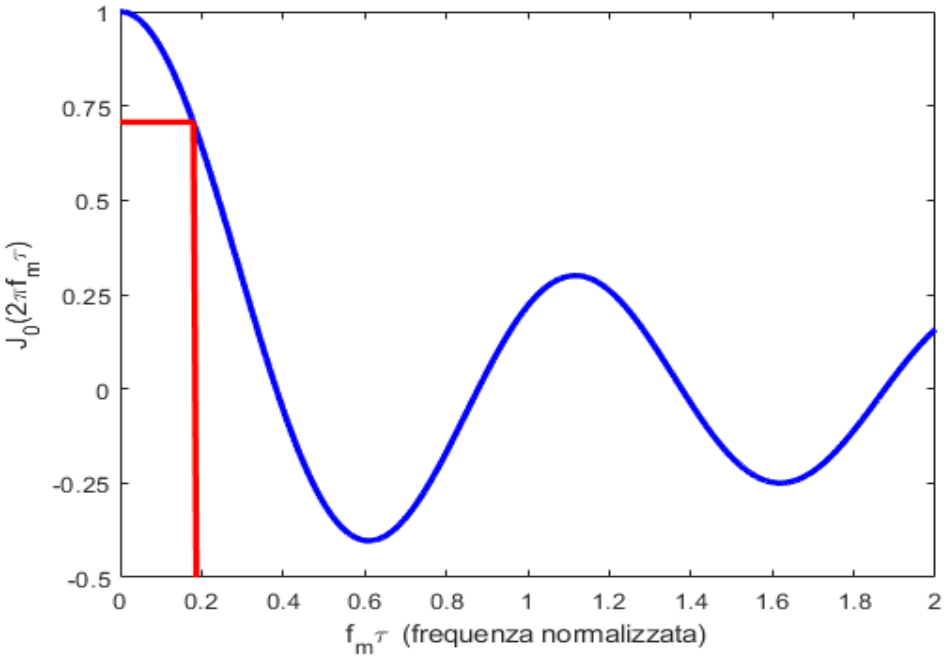
Doppler Bandwidth

$$B_D \propto \frac{1}{T_c}$$

$$y(t) = x(t) \otimes h(t, \tau)$$

Autocorrelation Function (ACF)

$$A(\tau) = \frac{E[y(t)y^*(t+\tau)]}{E[|y(t)|^2]} = J_0(2\pi f_m \tau)$$



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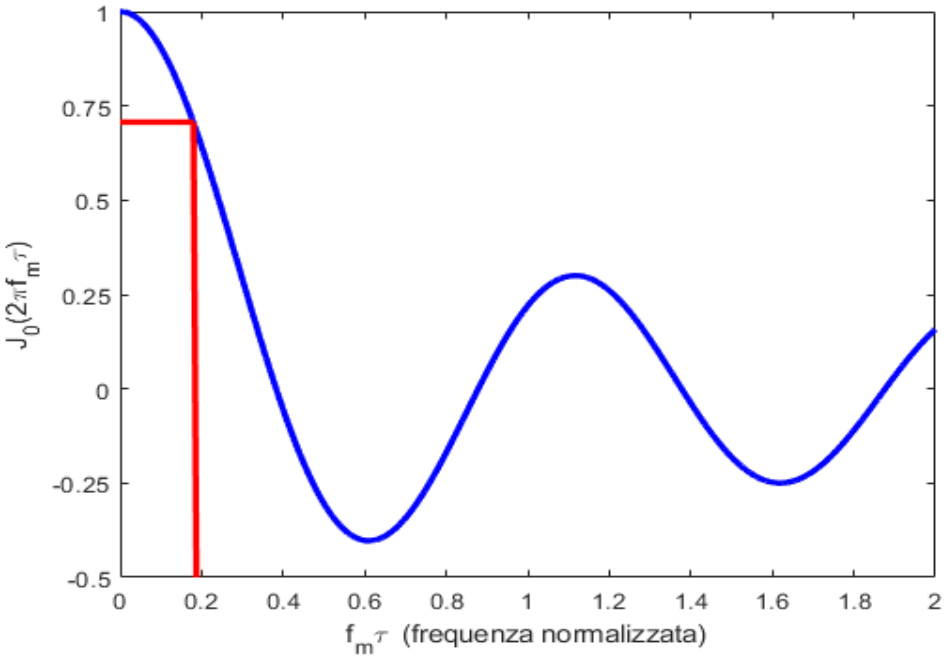

Coherence Time

$$T_c \simeq \frac{9}{16\pi f_m}$$

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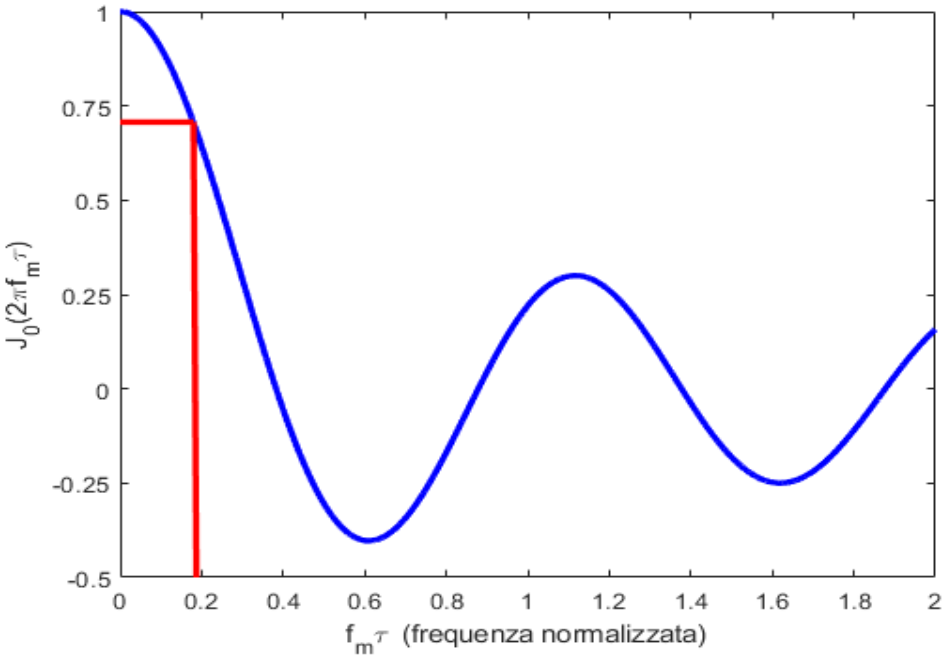


Coherence Time

$$T_c \simeq \frac{9}{16\pi f_m}$$

If:

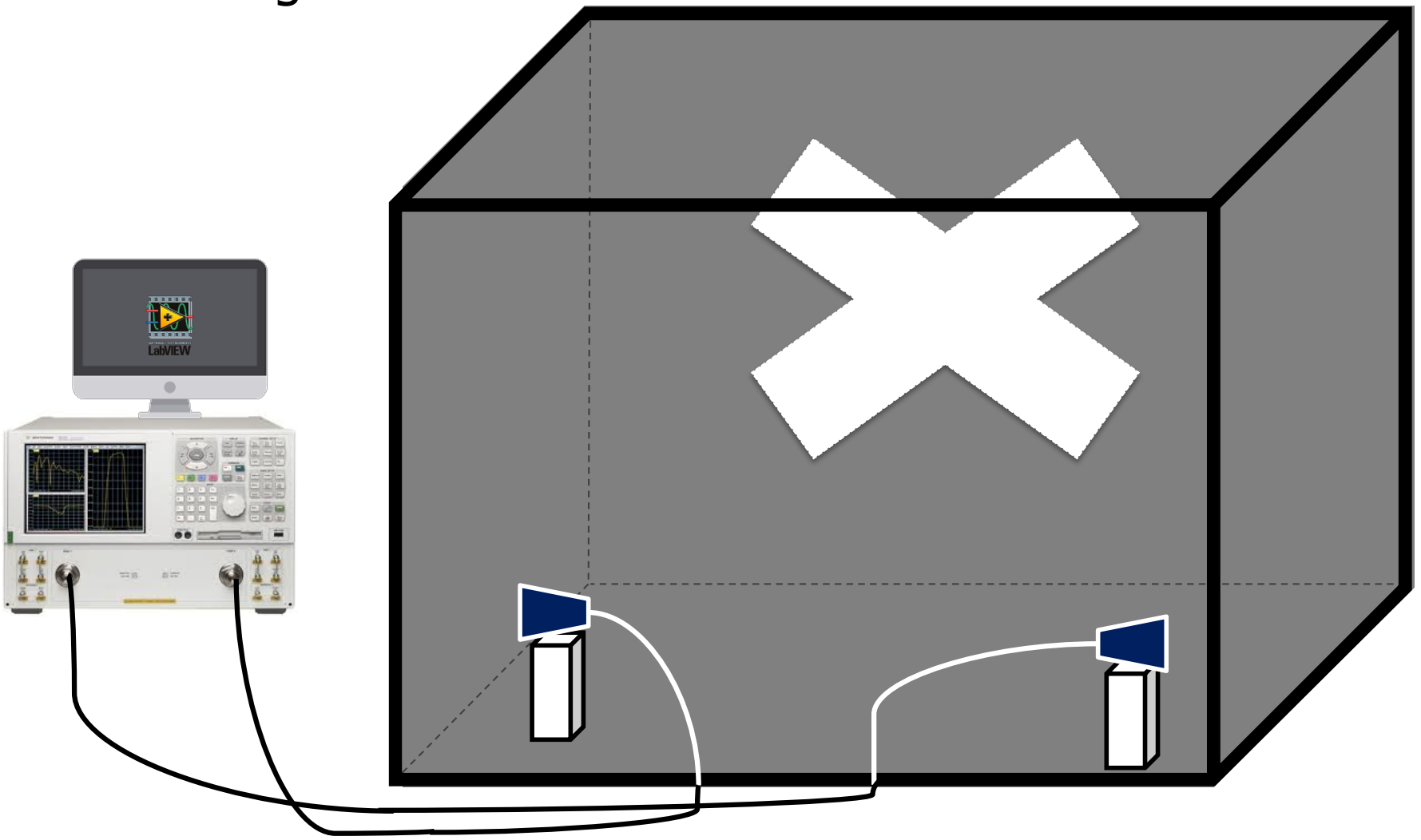
$T_c \gg T_{sym}$: *Non Selective channel in the time domain*

$T_c \ll T_{sym}$: *Selective channel in the time domain*

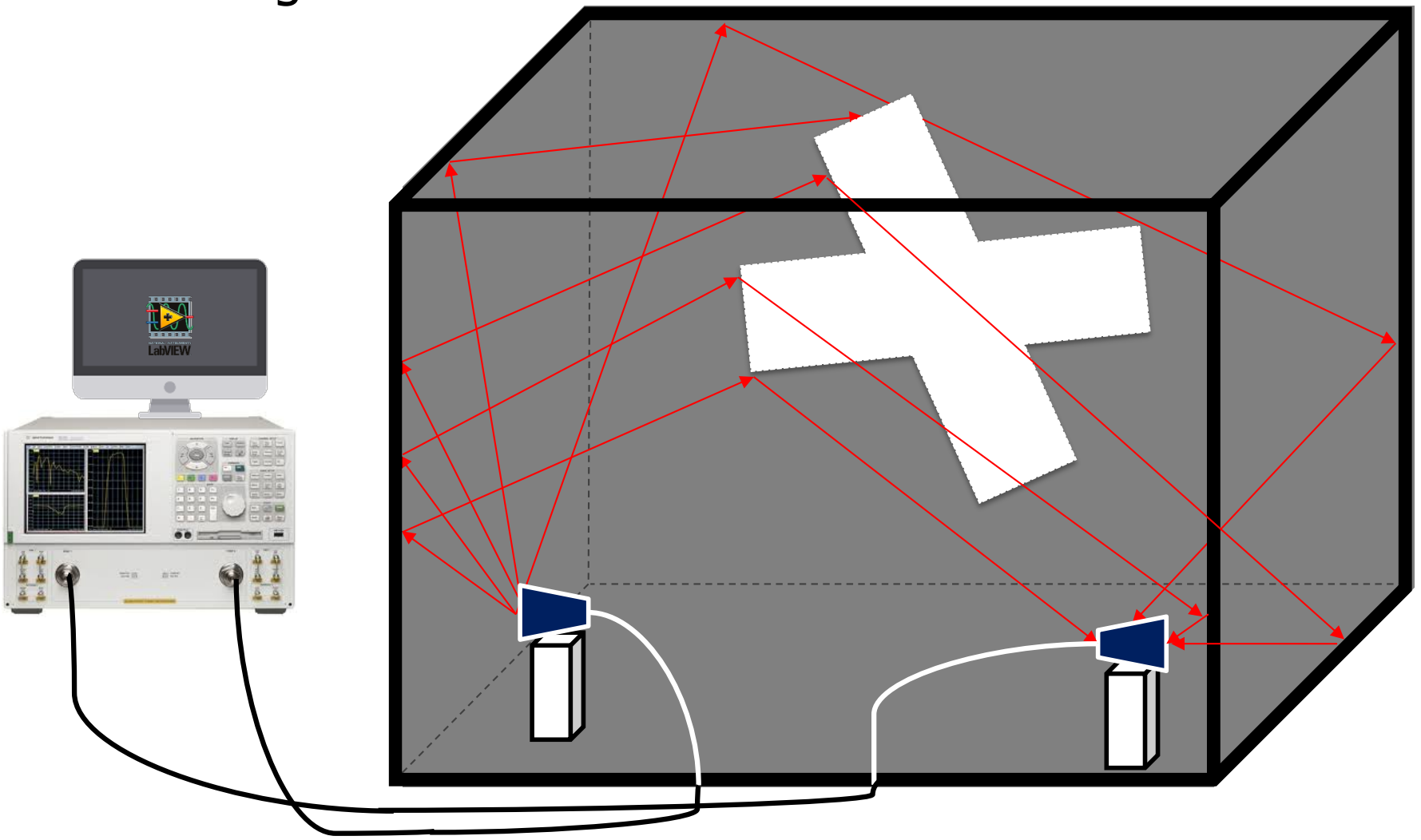
Wireless Channels Classification

	τ_{RMS}: $High$	τ_{RMS}: Low
T_c: $High$	**Easy Equalization**	**Best Case**
T_c: Low	**Worst Case**	**FEC**

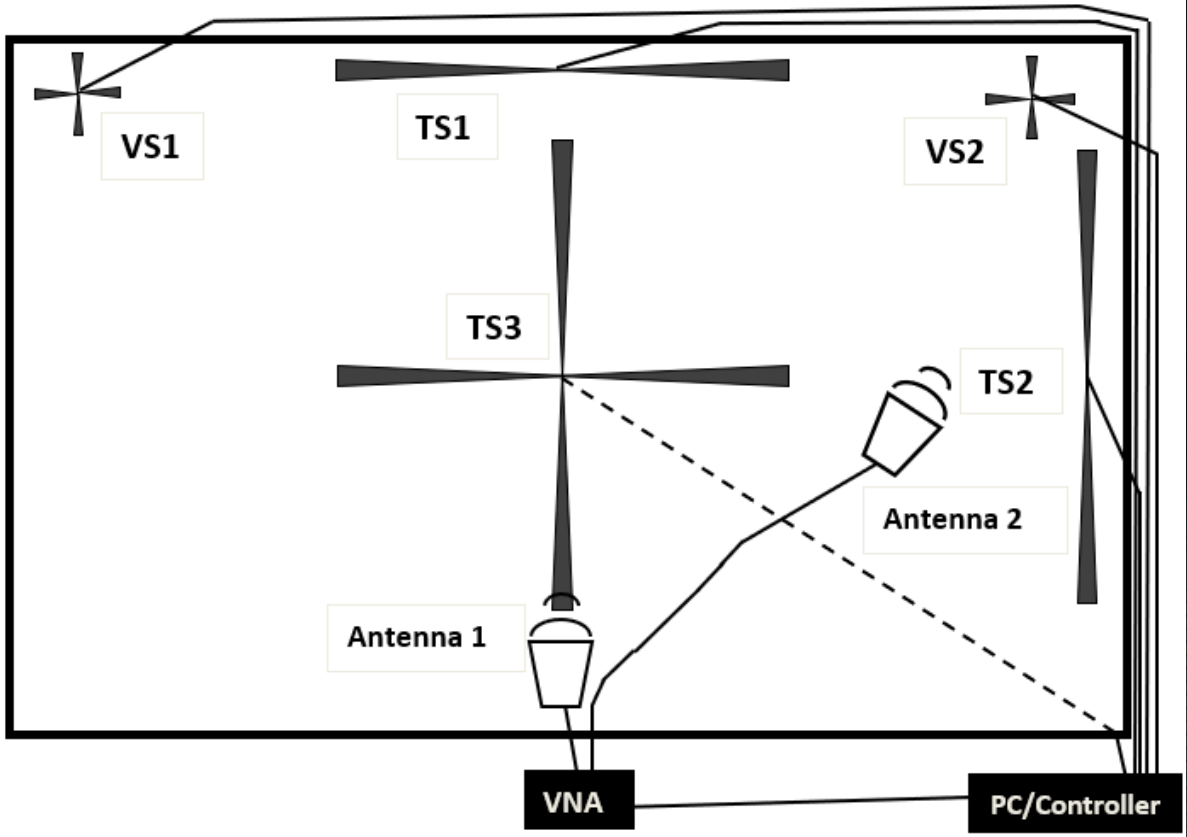
Reverberating Chamber



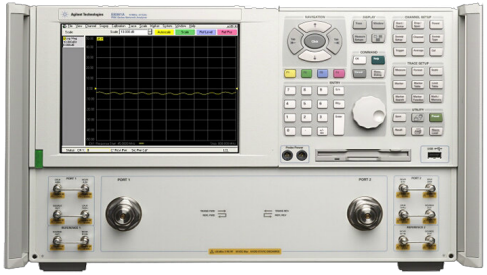
Reverberating Chamber

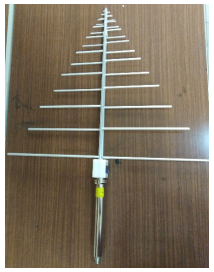
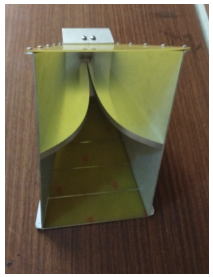


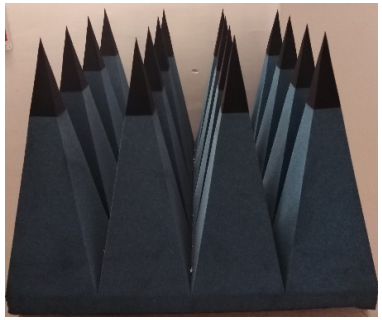
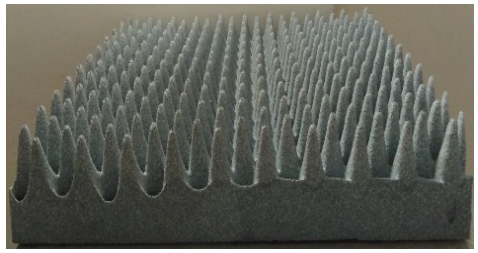
Reverberating Chamber



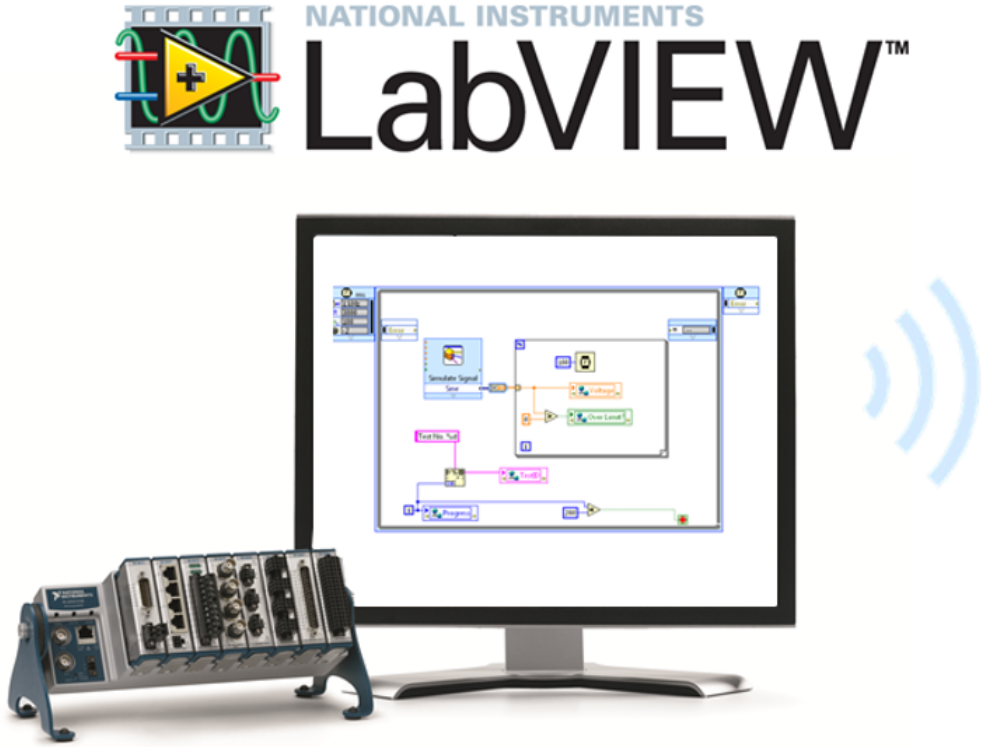
Vector Network Analyzer:
Agilent Technologies E8363B

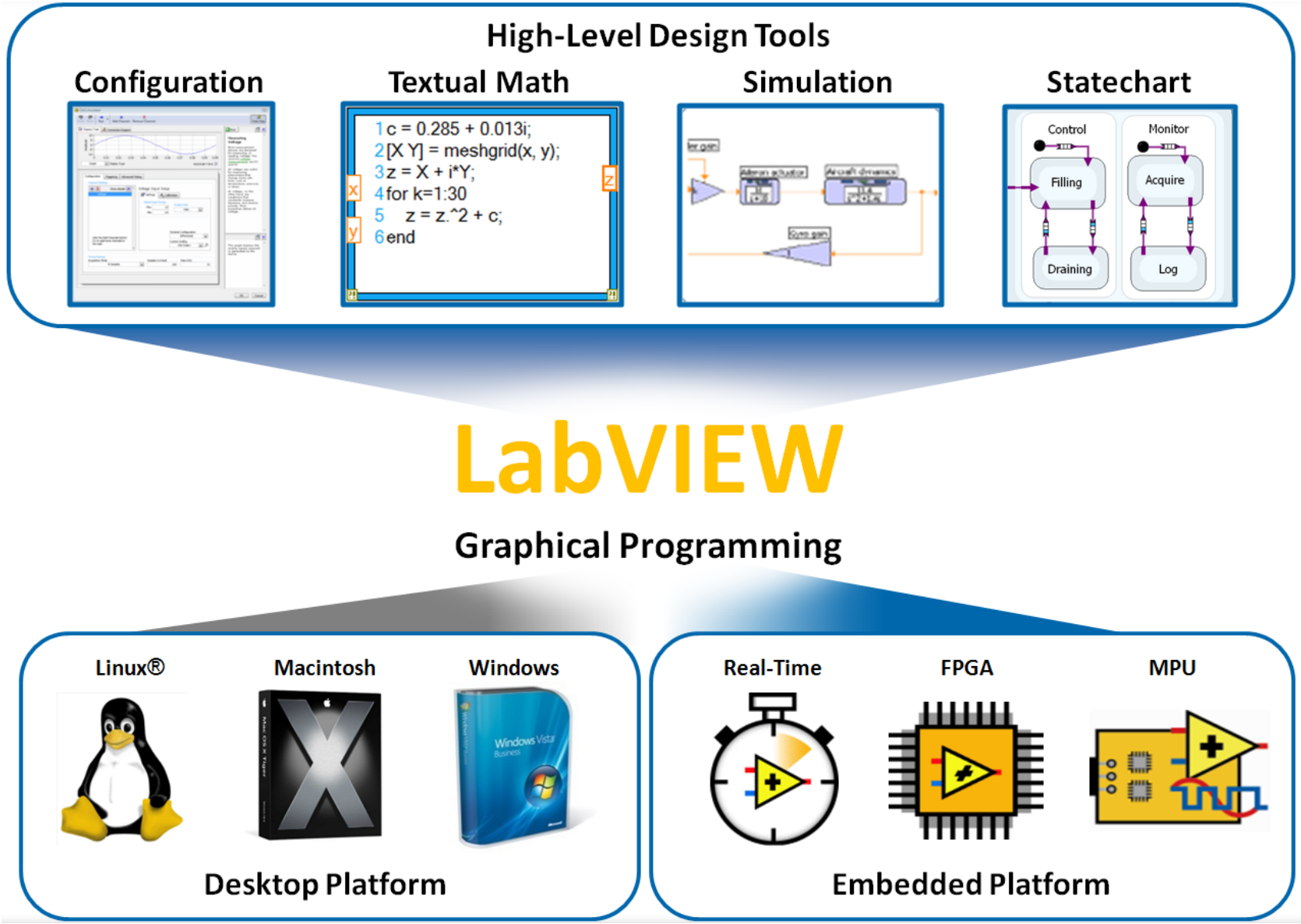


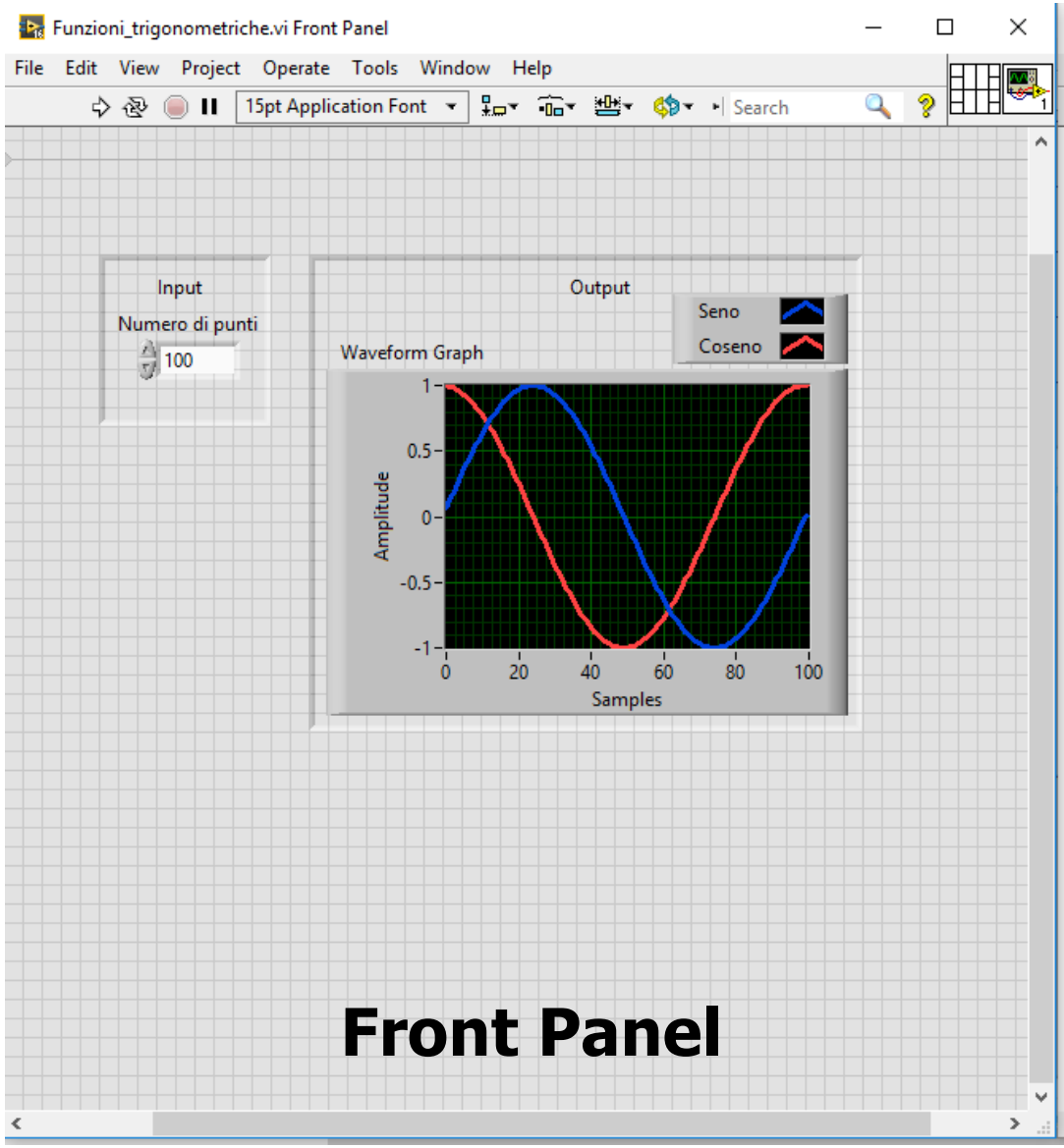
Antennas Types:	
Log-periodic: Schwarzbeck USLP 9143	
180 MHz - 8 GHz	
Horn: ETS-Lindgren 3115	
1 GHz – 18 GHz	
Horn: Schwarzbeck BBHA 9170	
15 GHz- 40 GHz	

Absorbers Types:	
Pure Graphite	
Pyramidal: Emerson & Cuming Microwave ECCOSORB VHP-18	
Conical: Cuming Microwave Corporation C RAM FAC 6	
Multilayer: Emerson & Cuming Microwave ECCOSORB AN-W-79	

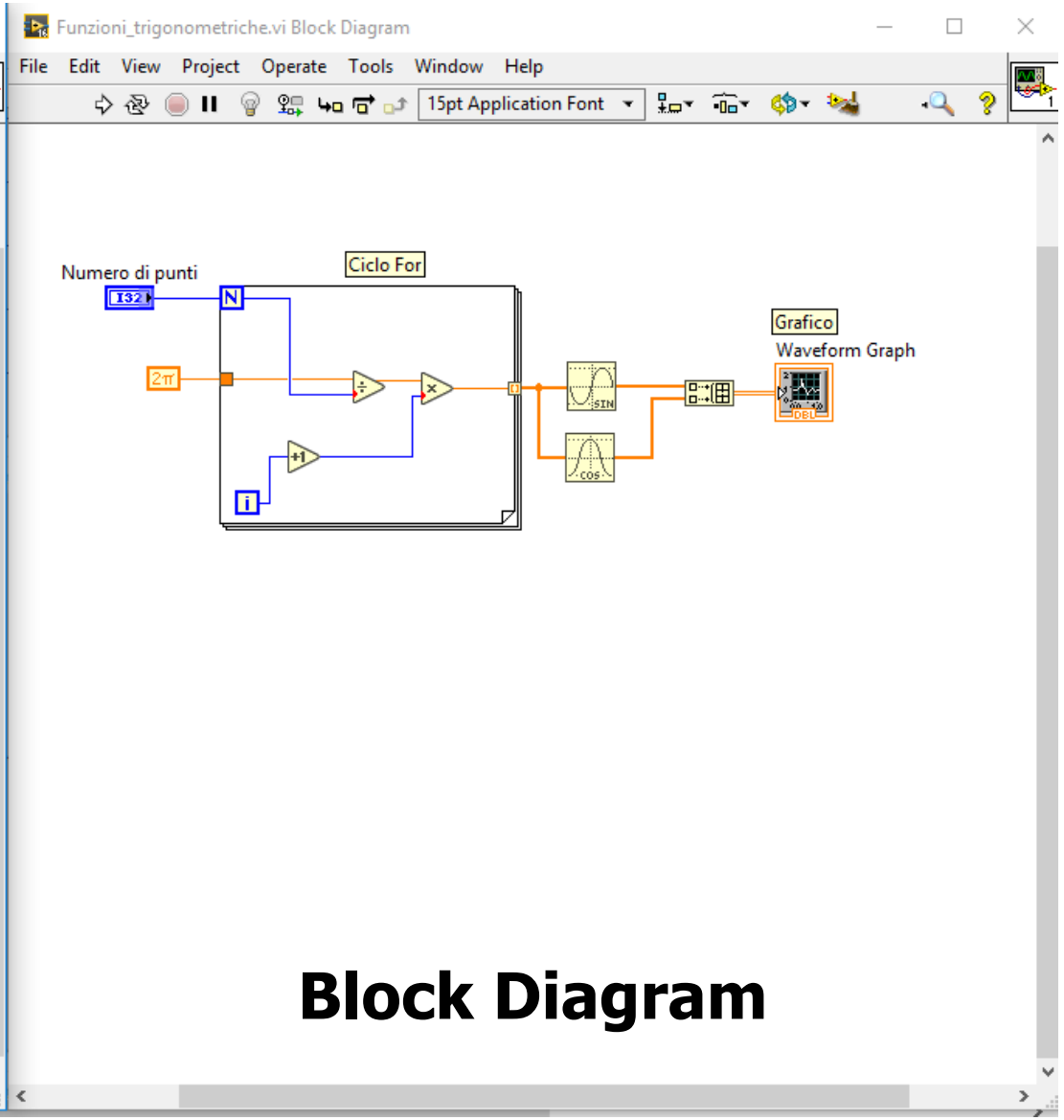
The graphical programming language: **LabVIEW**




High-Level Design Tools
Configuration
Textual Math
1 c = 0.285 + 0.013i;
2 [X Y] = meshgrid(x, y);
3 z = X + i*Y;
4 for k=1:30
5 z = z.^2 + c;
6 end
Simulation
Statechart
Control
Monitor
Filling
Acquire
Draining
Log
LabVIEW
Graphical Programming
Linux®
Macintosh
Windows
Desktop Platform
Real-Time
FPGA
MPU
Embedded Platform



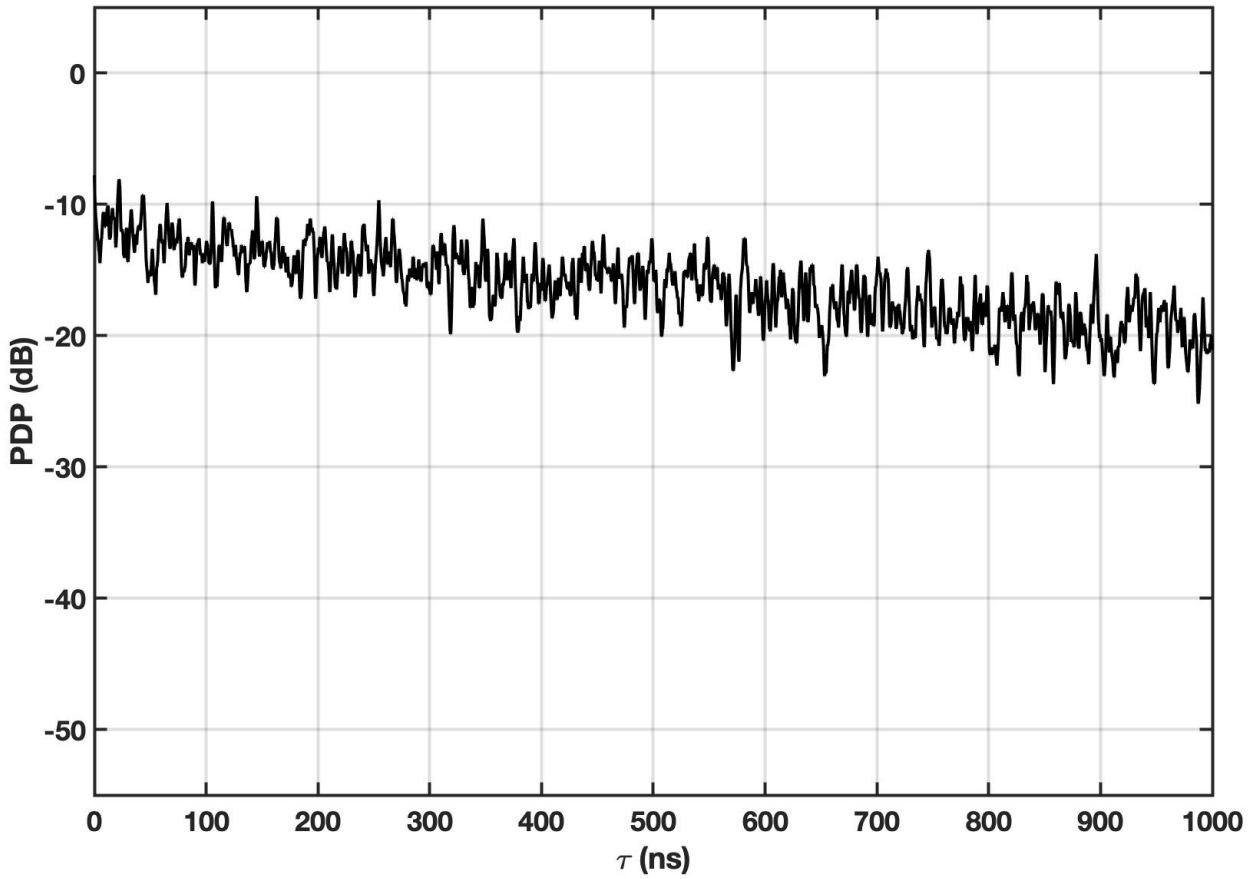
Front Panel



Block Diagram

Measurements	Reverberating Chamber	Indoor Scenario
Power Delay Profile	✓	✓
Autocorrelation Function	✓	✓

Power Delay Profile – Unloaded scenario

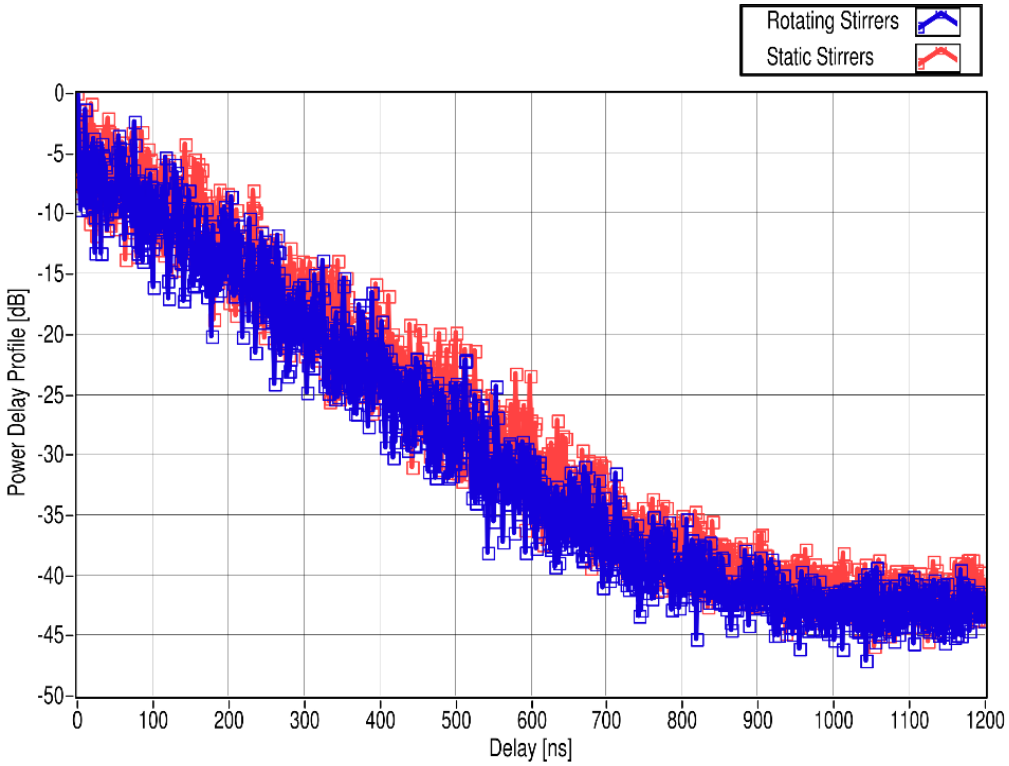


In the unloaded case, the PDP decayes very slowly for increasing time

The loaded case must be considered

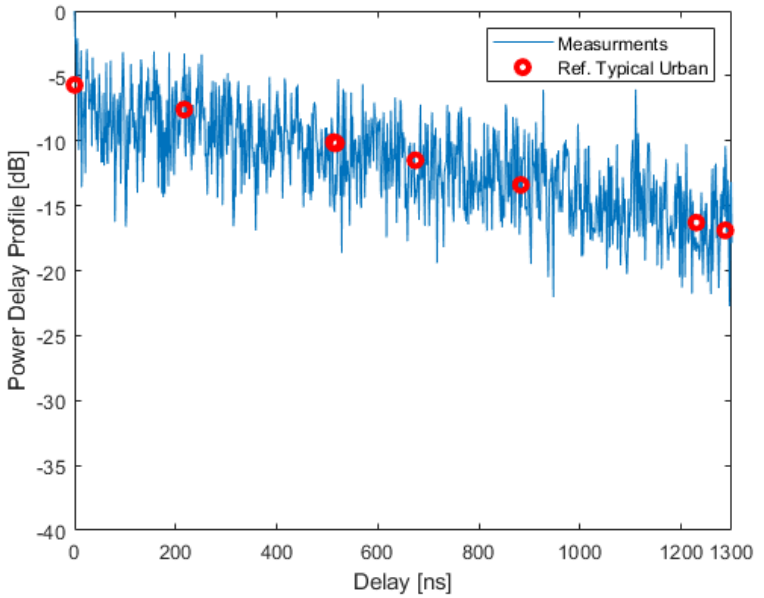
Power Delay Profile - stirring

Degrees of freedom	PDP
Antennas placement	✓
Absorbers number	✓
Absorbers placement	✓
Stirrers velocity	✗



The stirrers velocity does not play a key role

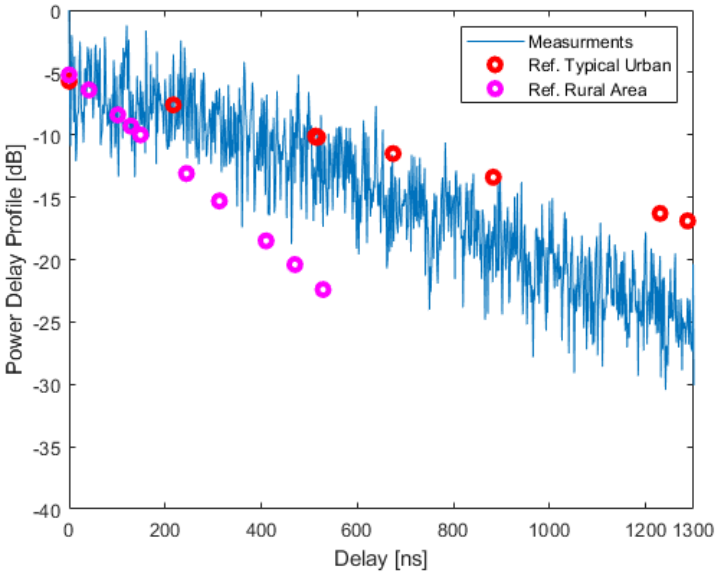
Power Delay Profile



Typical Urban	
(dB)	Time (ns)
-5.7	0
-7.6	217
-10.1	512
-10.2	514
-10.2	517
-11.5	674
-13.4	882
-16.3	1230
-16.9	1287

3GPP Technical Report 25.943 V10.0.0

Power Delay Profile

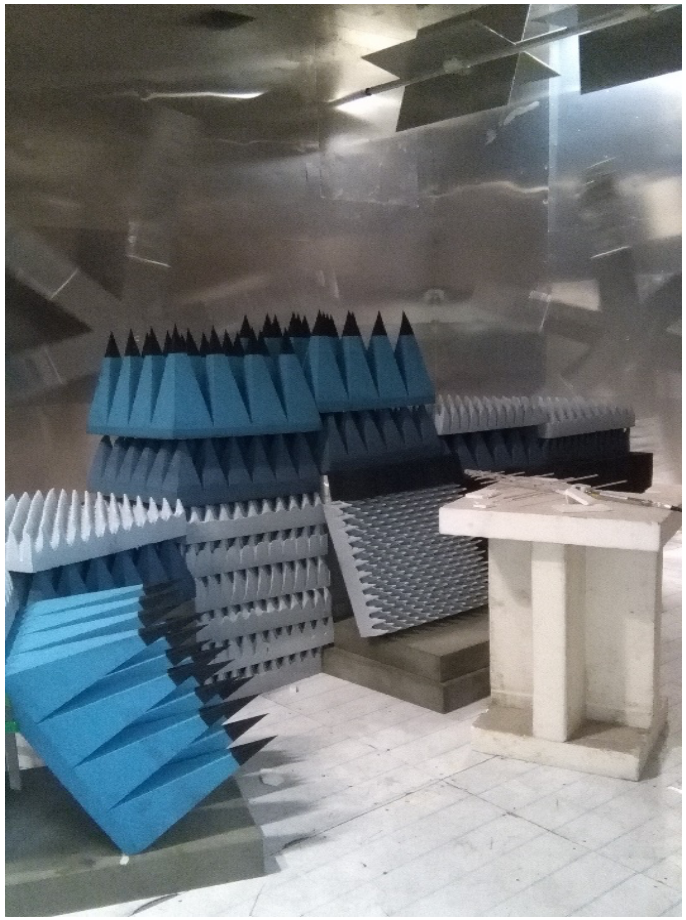


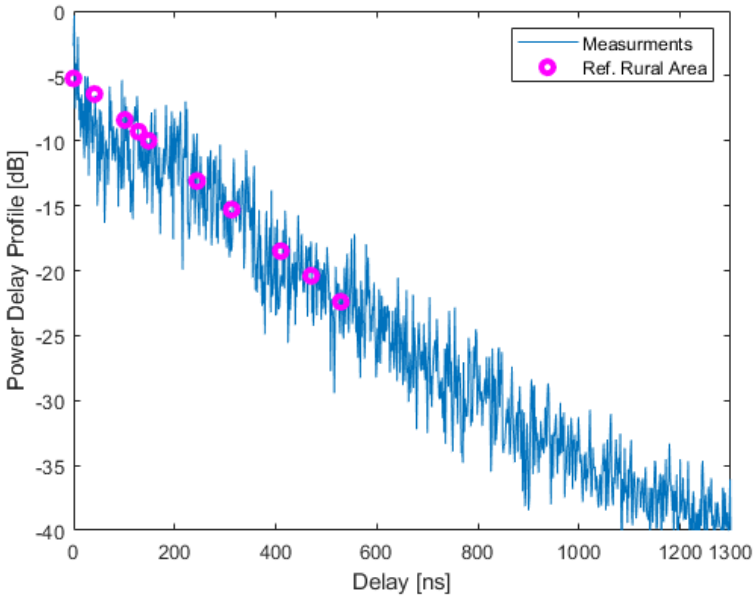
Rural Area		Typical Urban	
(dB)	Time (ns)	(dB)	Time (ns)
-5.2	0	-5.7	0
-6.4	42	-7.6	217
-8.4	101	-10.1	512
-9.3	129	-10.2	514
-10	149	-10.2	517
-13.1	245	-11.5	674
-15.3	312	-13.4	882
-18.5	410	-16.3	1230
-20.4	469	-16.9	1287
-22.4	528		

3GPP Technical Report 25.943 V10.0.0

Antennas Placement	✗	Absorbers Number	✓	Absorbers Placement	✓

Power Delay Profile



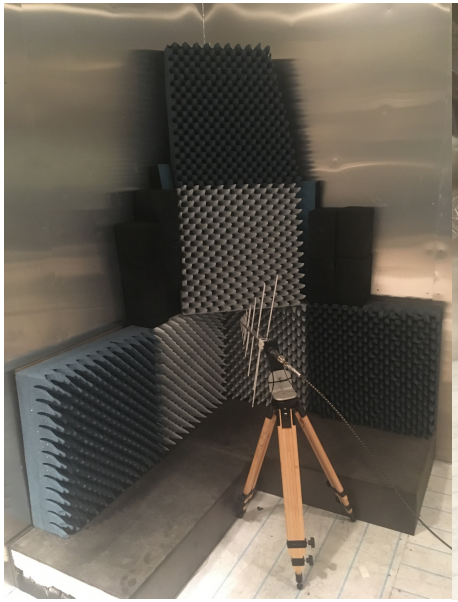


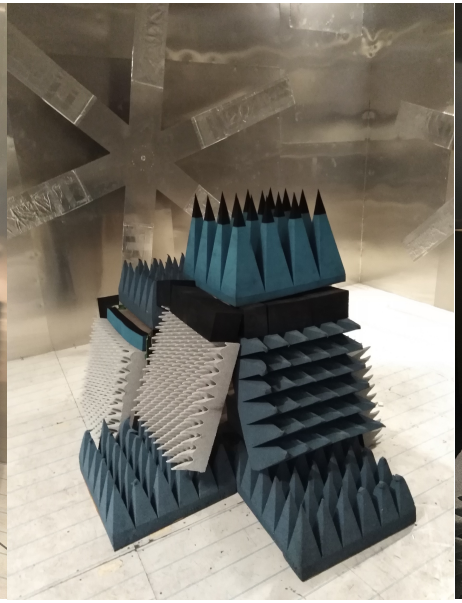
Rural Area	
(dB)	Time (ns)
-5.2	0
-6.4	42
-8.4	101
-9.3	129
-10	149
-13.1	245
-15.3	312
-18.5	410
-20.4	469
-22.4	528

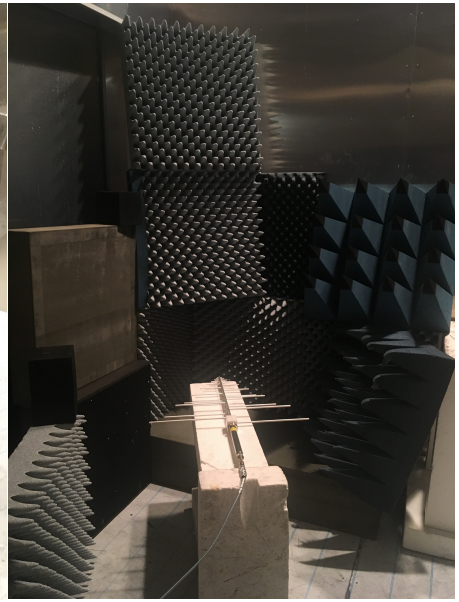
3GPP Technical Report 25.943 V10.0.0

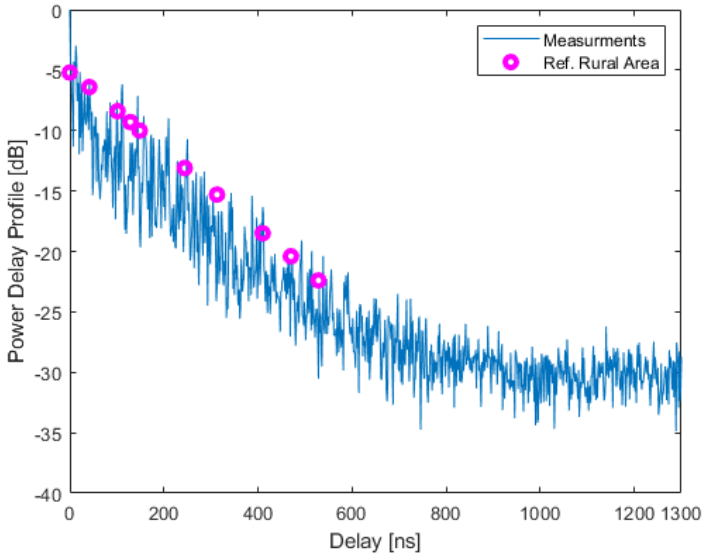
Antennas Placement	✗	Absorbers Number	✓	Absorbers Placement	✓

Power Delay Profile



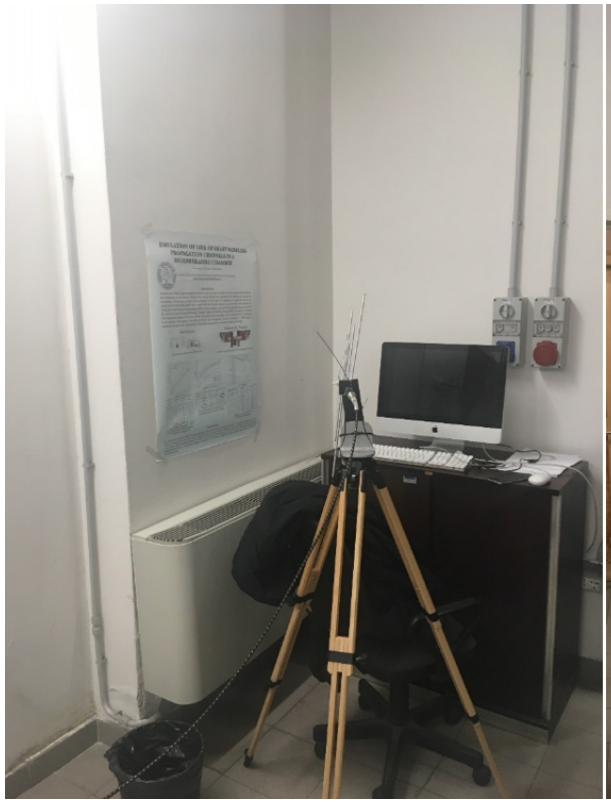


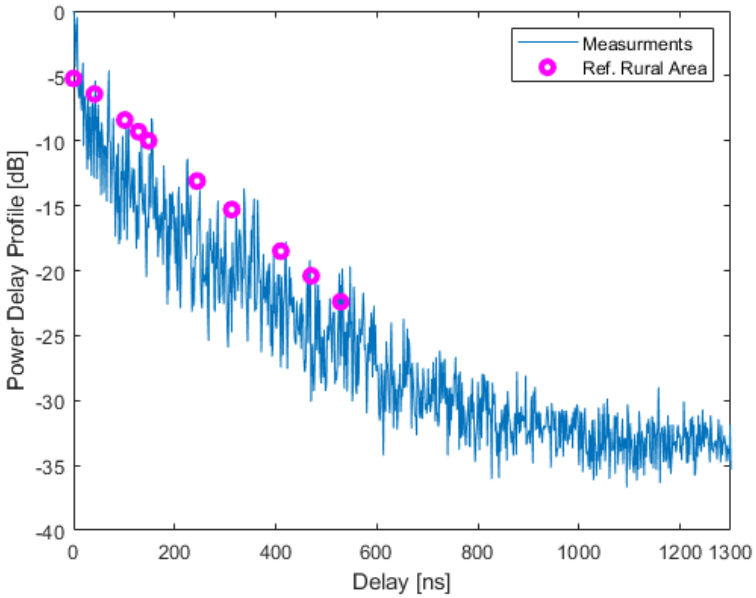




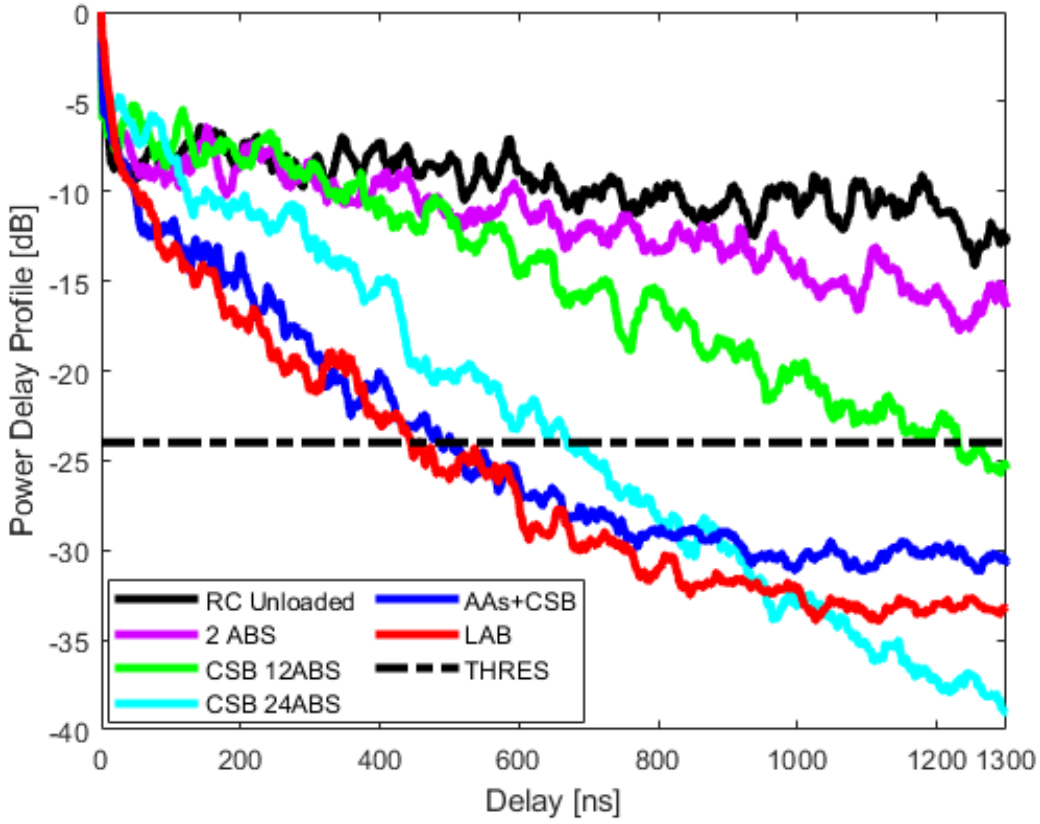
Antennas Placement	✓	Absorbers Number	✓	Absorbers Placement	✓

Power Delay Profile



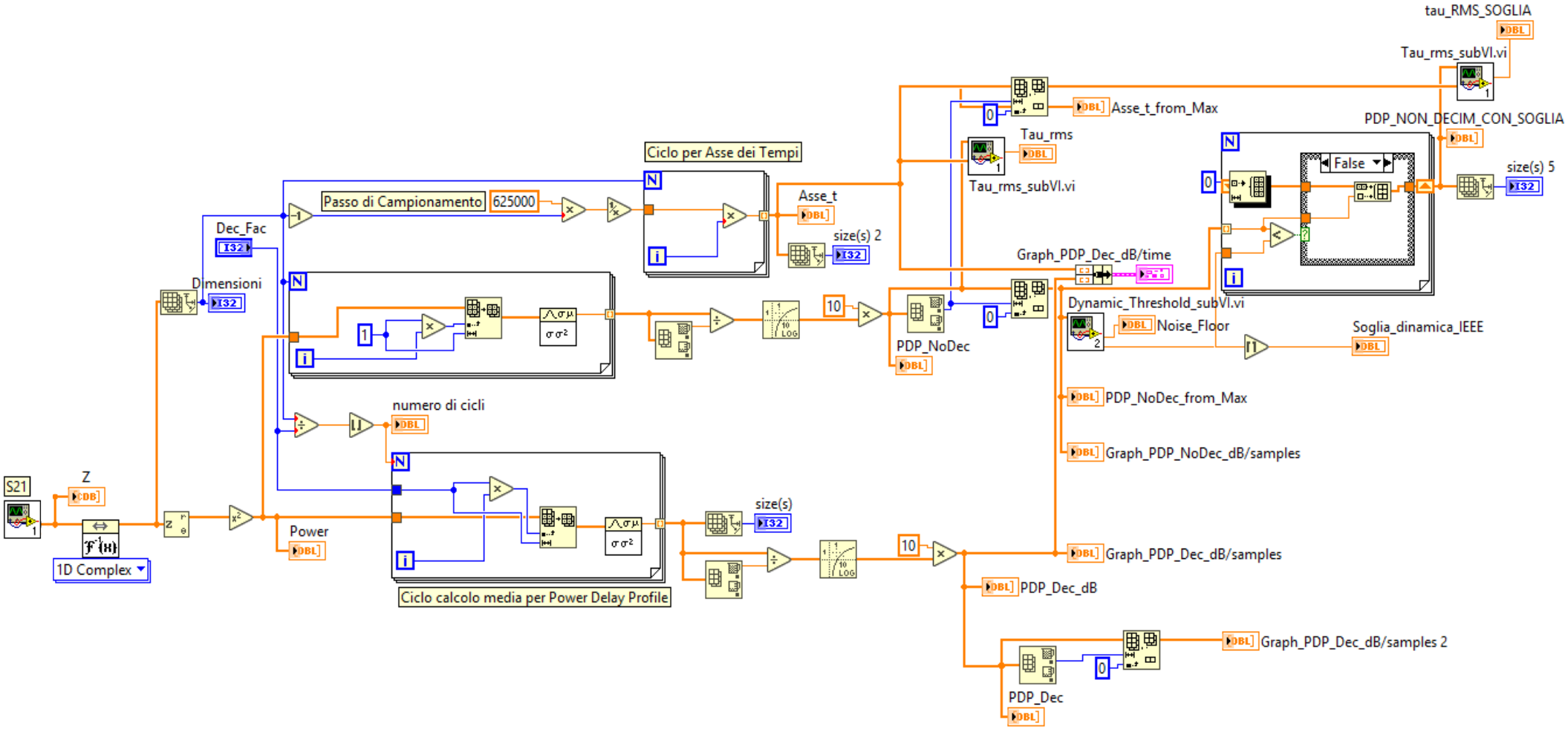


Power Delay Profile

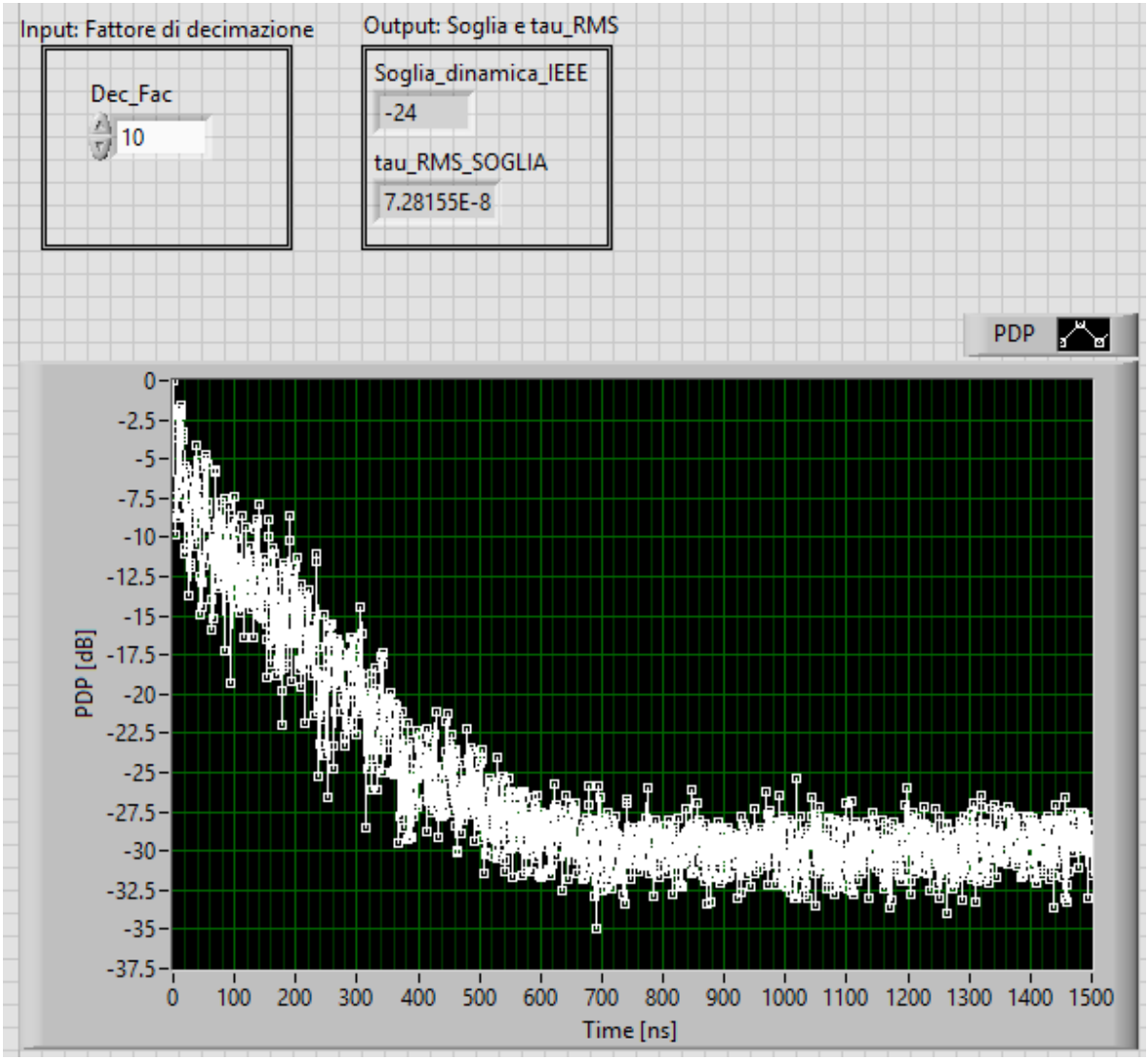


Measurements	τ_{RMS}
2 Absorbers	315 [ns]
Central Shielding Barrier (12 Absorbers)	172 [ns]
Central Shielding Barrier (24 Absorbers)	124 [ns]
Anechoic Angles + Central Shielding Barrier	57 [ns]
Laboratory	50 [ns]

Block Diagram

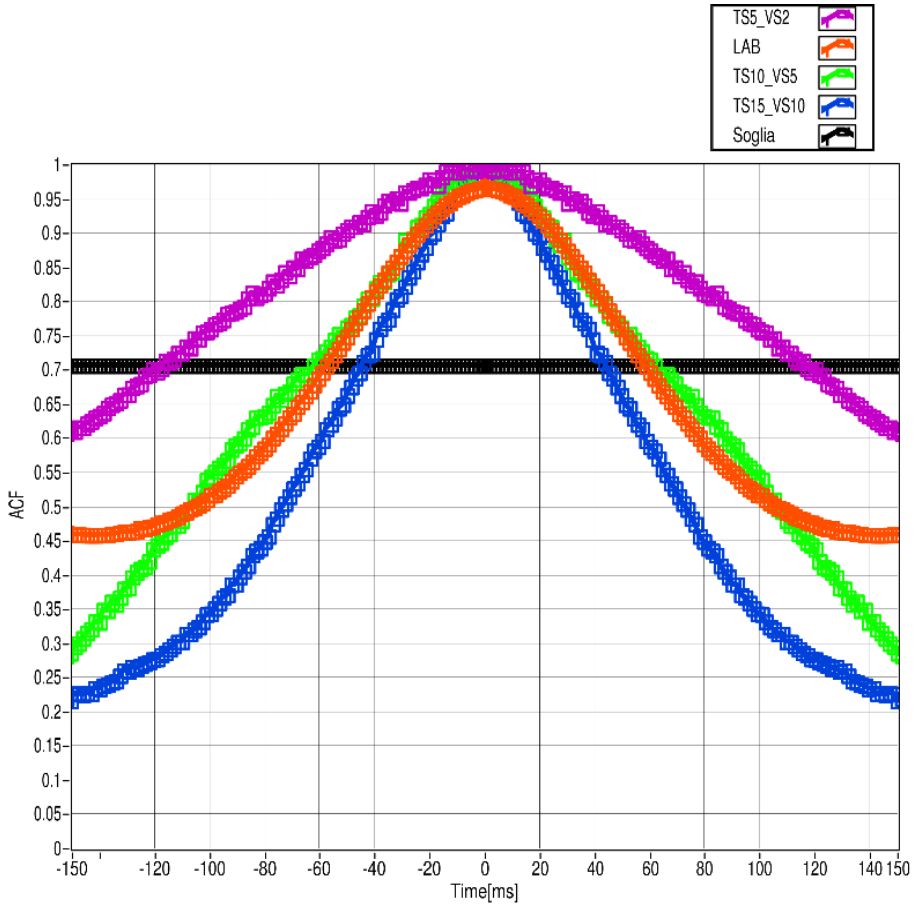


Front Panel

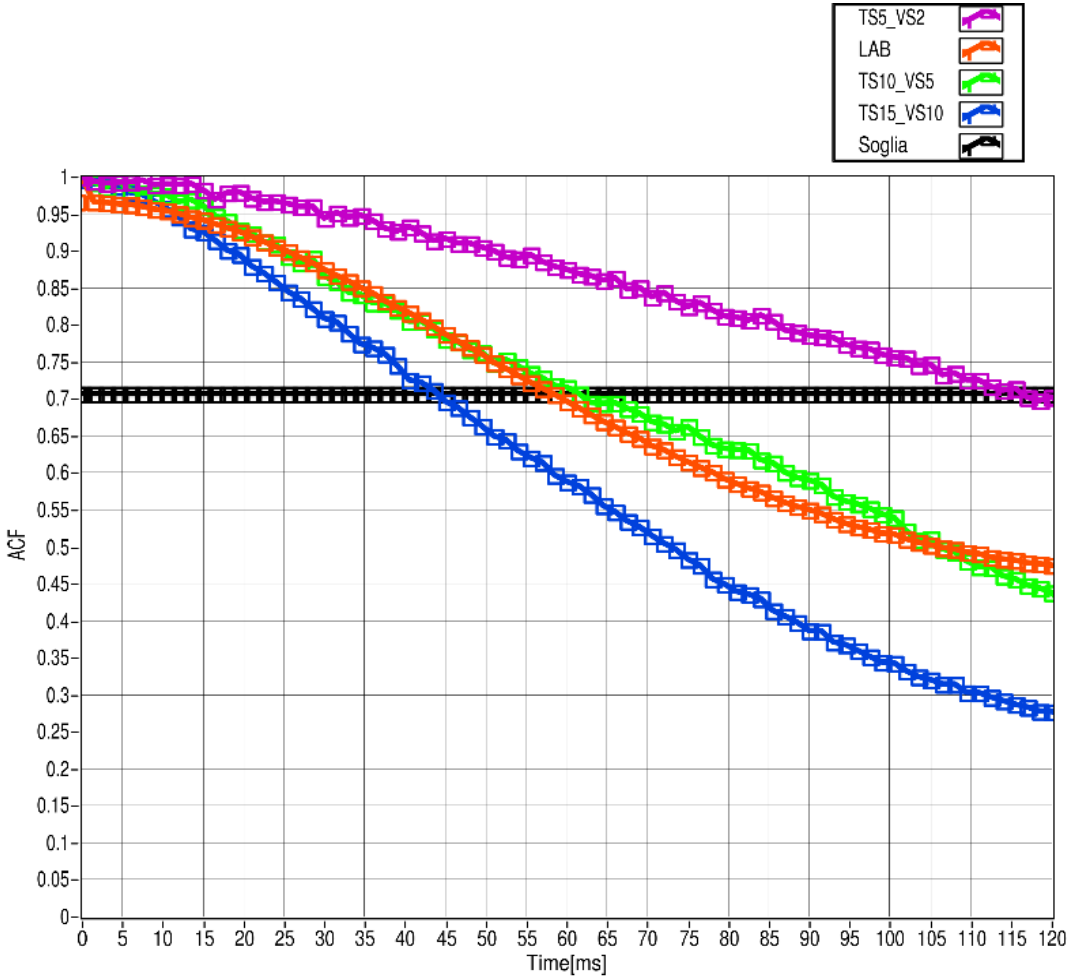

Input: Fattore di decimazione
Dec_Fac
10
Output: Soglia e tau_RMS
Soglia_dinamica_IEEE
-24
tau_RMS_SOGLIA
7.28155E-8
PDP
PDP [dB]
0
-2.5
-5
-7.5
-10
-12.5
-15
-17.5
-20
-22.5
-25
-27.5
-30
-32.5
-35
-37.5
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
Time [ns]

Autocorrelation Function

Degrees of freedom	PDP
Antennas placement	✗
Absorbers number	✗
Absorbers placement	✗
Stirrers velocity	✓

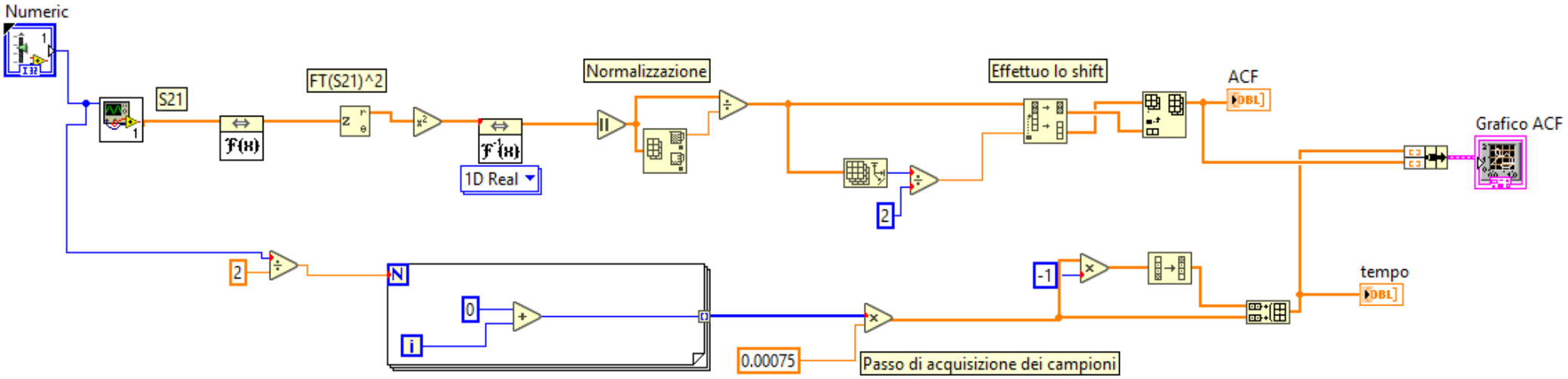


Autocorrelation Function



Measurements	T_c
TS=5 RPM, VS=2 RPM	112 [ms]
TS=10 RPM, VS=5 RPM	57 [ms]
TS=15 RPM, VS=10 RPM	41 [ms]
Laboratory	55 [ms]

Block Diagram



Front Panel

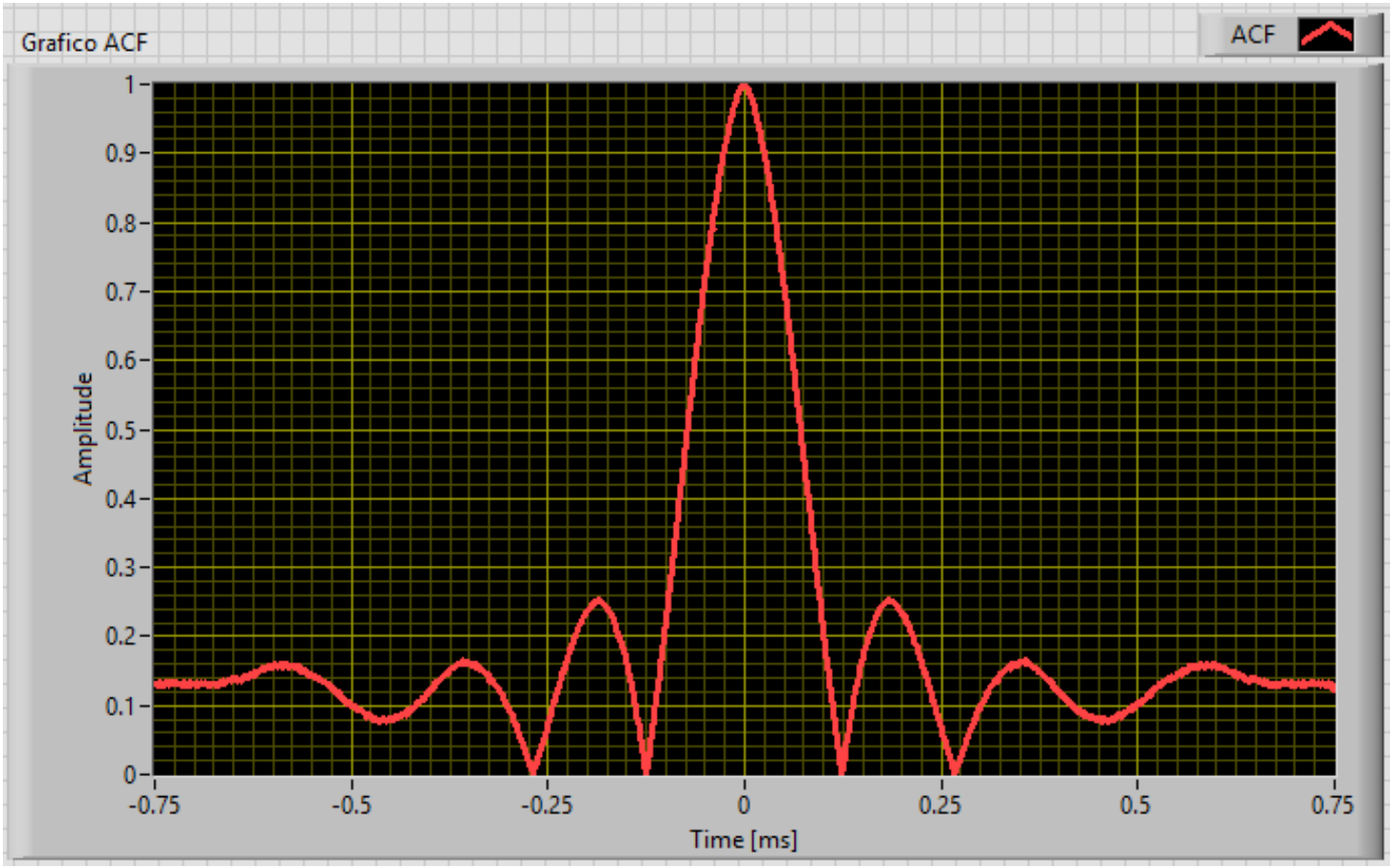


Grafico ACF
ACF
Amplitude
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
Time [ms]

Conclusions

- Radiomobile Channel Characterization
- The reverberating chamber is an effective controlled environment for an accurate emulation of different propagation scenarios
- Modeling and quantitative analysis of the millimeter waves propagation