Agilent Technologies

Antennas and Propagation Components

August 2005

Notice

The information contained in this document is subject to change without notice.

Agilent Technologies makes no warranty of any kind with regard to this material, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. Agilent Technologies shall not be liable for errors contained herein or for incidental or consequential damages in connection with the furnishing, performance, or use of this material.

Warranty

A copy of the specific warranty terms that apply to this software product is available upon request from your Agilent Technologies representative.

Restricted Rights Legend

Use, duplication or disclosure by the U. S. Government is subject to restrictions as set forth in subparagraph (c) (1) (ii) of the Rights in Technical Data and Computer Software clause at DFARS 252.227-7013 for DoD agencies, and subparagraphs (c) (1) and (c) (2) of the Commercial Computer Software Restricted Rights clause at FAR 52.227-19 for other agencies.

395 Page Mill Road, Palo Alto, CA 94304 U.S.A.

Acknowledgments

Mentor Graphics is a trademark of Mentor Graphics Corporation in the U.S. and other countries.

Microsoft®, Windows®, MS Windows®, Windows NT®, and MS-DOS® are U.S. registered trademarks of Microsoft Corporation.

Pentium® is a U.S. registered trademark of Intel Corporation.

PostScript® and Acrobat® are trademarks of Adobe Systems Incorporated.

UNIX® is a registered trademark of the Open Group.

Java™ is a U.S. trademark of Sun Microsystems, Inc.

SystemC® is a registered trademark of Open SystemC Initiative, Inc. in the United States and other countries and is used with permission.

Contents

1 Antennas and Propagation Components

Index

Chapter 1: Antennas and Propagation Components

Introduction

Antenna and propagation models simulate radio channel effects on the transmitted signal. These effects include signal fading and pathloss. Both antenna and propagation channel models are TSDF components with input and output timed signals.

Antenna models are identified by their coordinate and gain. For mobile antennas, the velocity vector is also included in the parameters. Multiple antenna inputs provide flexibility for adding contributions from various noise or fading channels. The propagation channel models are typically identified by the type of fading, the specification of power delay profile, and whether pathloss is to be activated.

The input as well as output impedance of antennas and channel models are left as infinite and zero, respectively. For the inclusion of antenna impedance, cosimulation with Circuit Envelope is recommended (for details, refer to "Introduction: Circuit Cosimulation Components). In this application, S-parameter block representing measurement (file), functions or impedance components can be placed on the circuit schematic page and co-simulated with signal processing designs. To access an example that demonstrates this, from the ADS Main window, choose *File* > *Example Project* > *Antennas-Prop* > *RadioChannel_prj*; from the Schematic window, choose *File* > *Open Design*, *ANTLOAD.dsn*.

The separate specification of antennas and (propagation) channel components is to provide a more intuitive and flexible use model. During the simulation, the effects of both antenna and channel models are merged and the combined antenna and propagation channel components are replaced with equivalent models in the pre-processing phase of the simulation.

Because of interdependency of antennas and channel models, certain restrictions in topology must be considered by the user: *there should be at least one propagation channel between a pair of transmit and receive antennas*. Examples of common antenna and propagation channel connections are shown in Figure 1-1 through Figure 1-4.

Figure 1-1 depicts the most common use model where a channel (PropGSM) is placed between a base station (AntBase) and mobile (AntMobile) antennas. (Note that the channel test port can be left unconnected. This port is supplied only if the user is interested in the behavior of the channel models.)

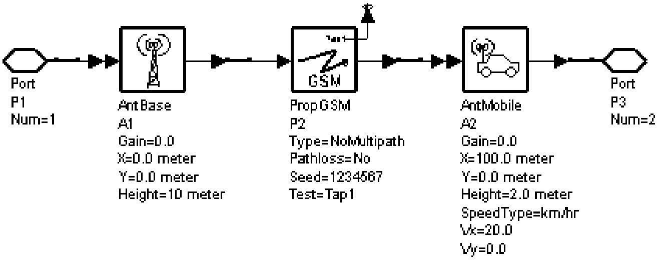


Figure 1-1. GSM Channel

Figure 1-2 shows a topology where two channels (PropNADCtdma) are placed in parallel between a base and mobile antennas. One of these channels could model a line-of-sight scenario (NoMultipath option) while the other one models a flat fading channel. The combined effect of these two channel types are simulated in this case. Antennas (AntMobile and AntBase) require a single carrier frequency for multiple input ports. If the channel outputs have different carrier frequencies, an RF converter (SummerRF) can be used as shown in this case. (Note that any number of parallel channels between two antennas are allowed.)

Figure 1-3 is a topology where a AWGN noise source is added to the input of the Rx antenna in addition to the fading channel (PropNADCcdma). The user can create and add any arbitrary channel between a pair of antennas.

Figure 1-4 shows a Tx antenna output entering two channels, each connected to an Rx antenna. This topology is used for simulation of antenna diversity or interference.

Figure 1-5 depicts the topologies that are not allowed; these include:

- channel model without Tx or Rx antenna
- channel model without Tx and Rx antenna
- channel model with more than one distinguishable Rx (or Tx) antenna.

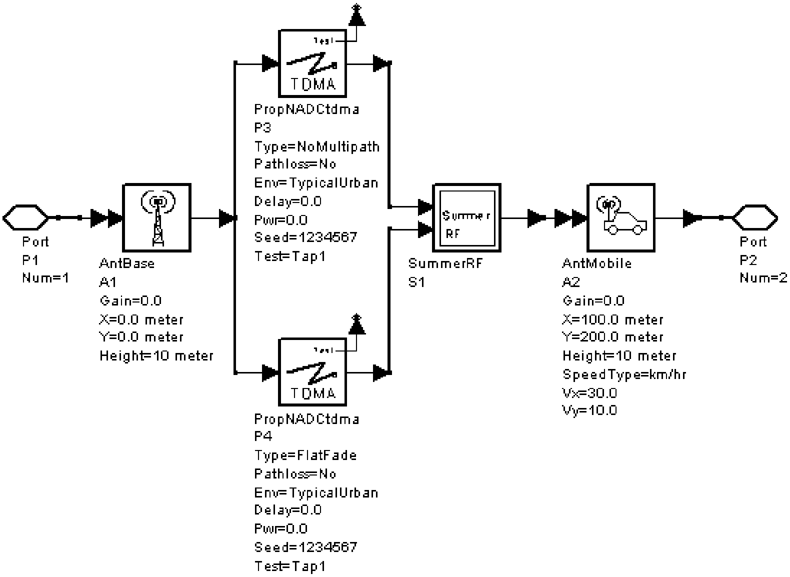


Figure 1-2. Two TDMA Channels

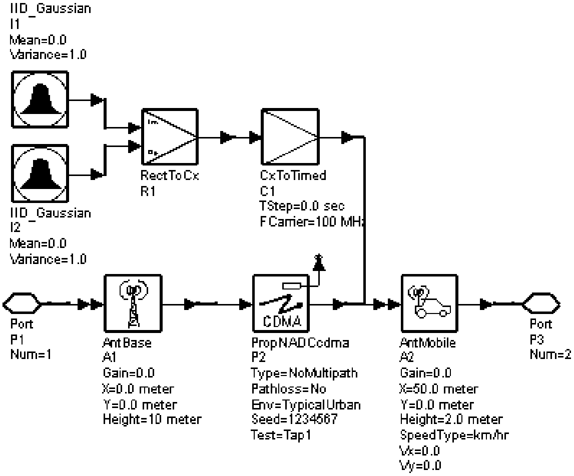


Figure 1-3. AWGN Noise Source

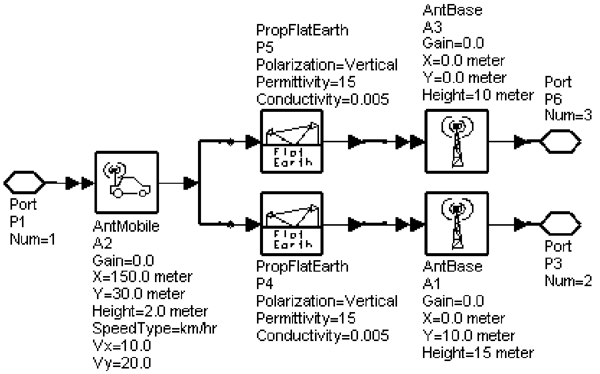


Figure 1-4. Tx Antenna Output

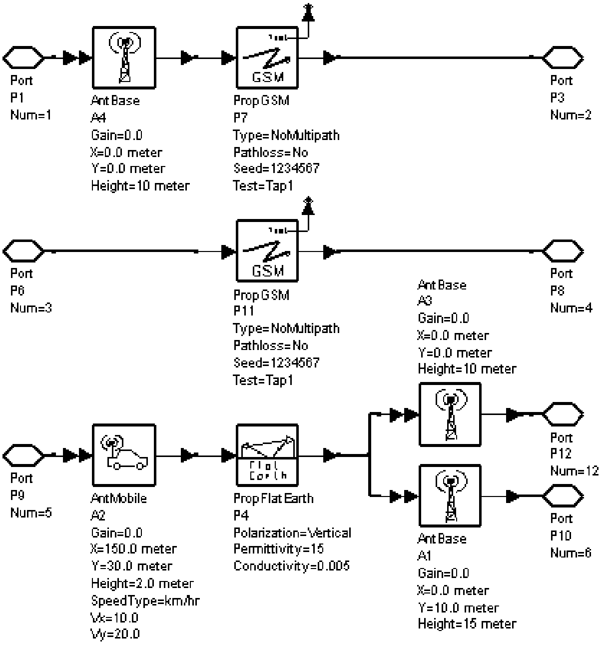


Figure 1-5. Disallowed Topologies

Multipath and Fading

This section defines terms and relations relevant to the multipath and fading in the propagation model types.

Definitions:

V = vehicle speed, in m/s
F_c = propagation (carrier) frequency, in Hz
ω_c = propagation (carrier) frequency, in radian/sec
ν = Doppler frequency, in Hz
ν_m = maximum Doppler frequency, in Hz
S(t) = transmitted (RF) signal
s(t) = complex envelope of transmitted signal
R(t) = received (RF) signal
r(t) = complex envelope of received signal
α_n= random amplitude of *n*th signal echo
γ_n = phase retardation of *n*th signal echo
τ_n = time-delay of *n*th signal echo
$G_t(\theta, \phi)$ = directive gain of transmitting antenna as a function of elevation and azimuth angles
$G_r(\theta, \phi)$ = directive gain of receiving antenna as a function of elevation and azimuth angles

Radio waves are received not only via direct path but often by scattering off numerous objects. Delay, attenuation and carrier phase shift are some of the alterations the transmitted signal experiences. This process can be modeled as a linear filter with randomly time-varying impulse response.

In a multipath environment, a transmitted RF signal

$$S(t) = \Re\left\{s(t)e^{jw_ct}\right\}$$

is received in the form

$$R(t)=\Re\left\{\sum_n \sqrt{G_t(\theta_n, \phi_n)G_r(\theta_n, \phi_n)}\alpha_n(t)s(t-\tau_n)e^{j[\omega_c[t-\tau_n]-\gamma_n]}\right\}$$

where n is the number of different echoes, each having a delay.

The received complex envelope is therefore

$$r(t)= \sum_n \sqrt{G_t(\theta_n, \phi_n)G_r(\theta_n, \phi_n)}\alpha_n(t)s(t-\tau_n)e^{-j[\omega_c\tau_n+\gamma_n]}$$

The (lowpass) impulse response of the discrete channel $h(\tau,t)$, is therefore characterized by several discrete paths—each having a specific delay and attenuation.

Signal fading occurs due to destructive or constructive addition of a large number of phasors. If $h(\tau,t)$ is modeled as a zero mean Gaussian process, the envelope $|h(\tau, t)|$ at any time is Rayleigh-distributed. The transform of $h(\tau,\tau)$ with respect to time, gives the spectrum of time variation $S(\tau,\nu)$, generally referred to as delay-Doppler spread function [1]. The variable ν represents the Doppler frequency shift due to changes in the electrical path length as a result of mobile movement.

For two vertically polarized transmit and receive antennas and horizontal propagation of plane waves [2], the Doppler spectrum is

$$S(\nu) = \frac{1}{2\pi\nu_m\sqrt{1-\left(\frac{\nu}{\nu_m}\right)^2}} \qquad \nu \le |\nu_m|$$

$$= 0 \qquad \nu > \nu_m$$

where

$$\nu_m = \frac{V}{c} f_c$$

is the maximum Doppler shift due to vehicle speed. When a direct path exists the spectrum is Rician and is given by

$$S(\nu) = \frac{k_1}{2\pi\nu_m\sqrt{1-\left(\frac{\nu}{\nu_m}\right)^2}} + k_2\delta(\nu - k_3\nu_m) \qquad \nu \le |\nu_m|$$

with k_1, k_2, k_3 constants related to proportion of direct and scattered signal and the direct wave angle of arrival. Assuming the wide sense stationary uncorrelated scattering (WSSUS) [3], the average delay profiles and Doppler spectra information is needed for the simulation of radio channel. Delay profiles [4] $P(\tau)$ can be measured (or approximated) as

$$P(\tau) = \sum_n \sigma_n^2 \delta(\tau - \tau_n)$$

where

$$\sigma_n^2$$

is the power associated with each path.

Assuming a uniform distribution of independent scatterers in the horizontal plane, each with a Doppler shift relative to the velocity of the mobile, the delay-Doppler spread function $S(\tau, \nu)$ and the impulse response of the channel can be constructed. A wide-band, *frequency selective*, multipath fading model can therefore be constructed using a tapped-delay-line filter. The typical tapped-delay-line filter model for simulation is illustrated in Figure 1-6.

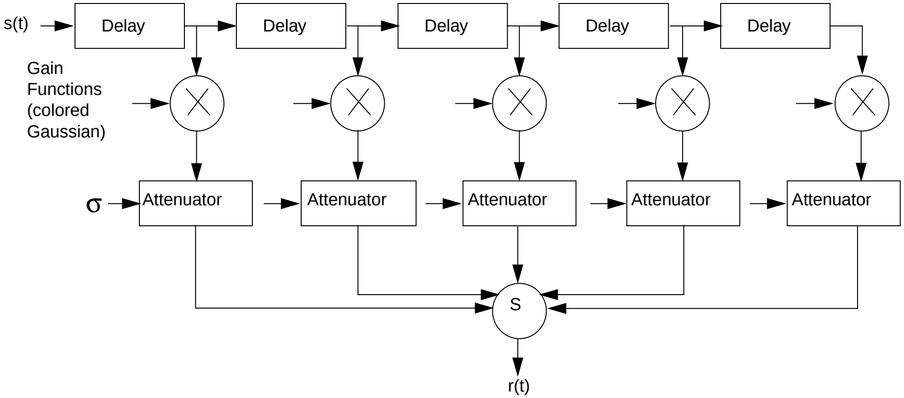


Figure 1-6. Tapped-Delay Line Model for a Wide-Band Channel

To generate a Rayleigh fading profile for each path, independent AWGN sources (in cascade with a filter representing the effects of Doppler spread) can be used; see Figure 1-7.

Jakes [5] proposes a more efficient alternative to Figure 1-7. In Jakes' model a number of low-frequency oscillators are used to generate signals that are added together. The amplitude and phases of these oscillators are chosen so that the pdf of the resultant phase approximates to a uniform distribution. The spectrum of the resulting complex function approximates the Doppler spectrum.

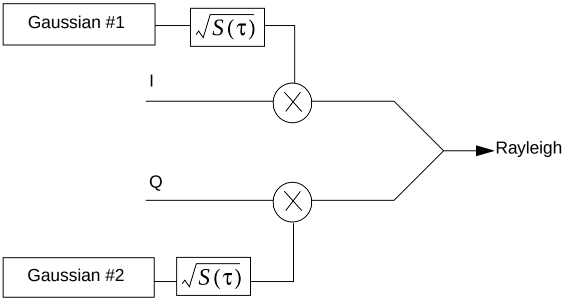


Figure 1-7. Generation of Rayleigh pdf with a Given PSD

Pathloss

This section defines terms and relations relevant to the pathloss in the propagation model types.

Definitions:

L_{FS} = pathloss in free-space environment, in dB
L_{RA} = pathloss in rural area environment, in dB
L_{HT} = pathloss in hilly terrain environment, in dB
L_{TU} = pathloss in typical urban environment, in dB
L_{TS} = pathloss in typical suburban environment, in dB
f_c = propagation (carrier) frequency, in MHz
λ_c = wavelength associated with propagation (carrier) frequency
D = major antenna dimension
H_{BS} = base station antenna height, in meters
H_{MS} = mobile station antenna height, in meters
R = distance between transmit and receive antenna, in km
a = correction factor, in dB

Free-space pathloss option provides the user with an optimistic model. This option is given (in dB) by

$$L_{FS} = + 20\log_{10}f_c + 20\log_{10}R + 32.4$$

There are a wide variety of pathloss models—the most widely used is Hata's. Hata's pathloss model [6] is based on an extensive data base derived by Okumura [7] from measurements in and around Tokyo. Hata's pathloss models cover urban, rural, and suburban environments and include the transmit and receive antenna heights.

The *typical urban Hata* model is given by

$$L_{TU} = 69.55 + 26.16\log_{10}f_c - 13.82\log_{10}H_{BS} - a\,(H_{MS}) \\ + (44.9 - 6.55\log_{10}H_{BS})\log_{10}R$$

The correction factor for small- to medium-size cities is given by

$$a = (1.1\log_{10} f_c - 0.7)H_{MS} - (1.56 \log_{10} f_c - 0.8)$$

Hata's urban model is equivalent to Type=TU in propagation components.

The *typical suburban Hata* model is given in terms of L_{TU} with a correction factor:

$$L_{TS} = L_{TU} - 2[\log_{10}(f_c/28)]^2 - 5.4$$

Similarly, the *rural Hata model* is a corrected form of L_{TU} as

$$L_{RA} = L_{TU} - 4.78(\log_{10}f_c)^2 + 18.33\log_{10}f_c - 40.94$$

Hata's rural model is equivalent to Type=RA in propagation components.

For GSM Hilly Terrain (HT) environment, adjustments prescribed in [5] are used.

All the pathloss formulas are valid—assuming that the receiving antenna is in the far field of the transmit antenna. The common criterion for antennas whose physical size is in the order of wavelength is that path length should exceed D^2/λ_c.

References

[1] J. D. Parsons, *The Mobile Radio Propagation Channel*, Halsted Press, 1992.

[2] R. H. Clarke, "A Statistical Theory of Mobile-Radio Reception," *The Bell System Technical Journal*, July-August 1968.

[3] Raymond Steele, *Mobile Radio Communications*, Pentech Press, 1992.

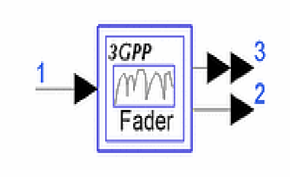
[4] GSM 05.05 Recommendation, *Radio Transmission and Reception*.

[5] W. C. Jakes (Editor), *Microwave Mobile Communications*, John Wiley & Sons, 1974.

[6] M. Hata, "Empirical Formula for Propagation Loss in Land Mobile Radio," *IEEE Trans*. VT-29, pp. 317-325, August 1980.

[7] Y. Okumura, “Field Strength and its Variability in VHF and UHF Land Mobile Service,” *Review of Electrical Communication Laboratory*, Vol 16, pp. 825-873, Sep-Oct. 1968.

3GPPFDD_Channel



Description **Fading channel model**
Library **Antennas & Propagation**

Parameters

Name	Description	Default	Unit	Type	Range
SpecVersion	version of specifications: Version_03_00, Version_12_00, Version_03_02	Version_12_00		enum	
Velocity	mobile velocity in km/hour	100km	km	real	(0, ∞)
GainArray	path gain in terms of decibel	0dB -10dB		real array	(-∞, ∞)†
DelayArray	path delay in terms of nanosecond	0ns 976ns		int array	[0, ∞)†
RicianFactor	ratio of specular power and the fading power	0.0		real	[0, ∞)
Algorithm	the algorithm used: SoS_Stochastic, SoS_Deterministic, Filter_AWGN_Noise	SoS_Stochastic		enum	
ChProfile	channel profile: UserDefined, Case1, Case2, Case3, Case4, Case5	UserDefined		enum	
† for each array element; number of elements in arrays GainArray and DelayArray must be the same					

Pin Inputs

Pin	Name	Description	Signal Type
1	in	input timed signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	out	output signal	timed
3	outChM	fading factor	multiple timed

Notes/Equations

1. This subnetwork model can be used to simulate the multipath fading channel:
   - according to 3GPP as defined in [1], when ChProfile is set to Case1, Case2, Case3, Case4, or Case5.
   - according to user-defined fading channel profile, when ChProfile is set to UserDefined.
2. This subnetwork is a hierarchical model that includes the Fader component, which is located in the Antennas & Propagation library; 3GPPFDD_Channel provides the interface to Fader. The schematic for this subnetwork is shown in Figure 1-8.

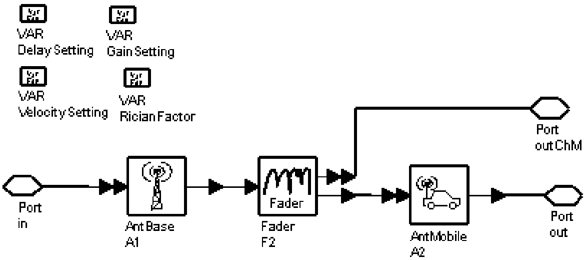


Figure 1-8. 3GPPFDD_Channel Schematic

3. When ChProfile=UserDefined, the fading channel profile (relative channel delay spread and average power) is determined by the external input from the GainArray and DelayArray parameters.

   When ChProfile is set to a pre-defined fading channel profile defined for 3GPP, the relative channel delay spread and average power are given in Table 1-1.

Table 1-1. Channel Profile Configurations

Case 1, 3km/h		**Case 2, 3 km/h**		**Case 3, 120 km/h**		**Case 4, 3 km/h**		**Case 5, 50 km/h**	
Relative Delay (nsec)	**Average Power (dB)**	**Relative Delay (nsec)**	**Average Power (dB)**	**Relative Delay (nsec)**	**Average Power (dB)**	**Relative Delay (nsec)**	**Average Power (dB)**	**Relative Delay (nsec)**	**Average Power (dB)**
0	0	0	0	0	0	0	0	0	0
976	-10	976	0	260	-3	976	0	976	-10
		20000	0	521	-6				
				781	-9				

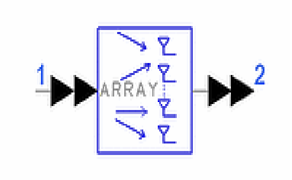
4. RicianFactor is the ratio of direct signal power and fading power; refer to Fader documentation for details.

References

[1] 3GPP Technical Specification TS 25.101 V3.10.0, UE Radio transmission and reception (FDD) March 2003, Release 1999.

http://www.3gpp.org/ftp/Specs/2002-03/R1999/25_series/25101-3a0.zip

AntArray



Description **Antenna Array**
Library **Antennas & Propagation**
Class **TSDFAntArray**
Derived From **antenna**

Parameters

Name	Description	Default	Sym	Unit	Type	Range
Gain	Gain of antenna, in dB	0.0	g		real	(-∞, ∞)
X	X-position coordinate of antenna	0.0		km	real	(-∞, ∞)
Y	Y-position coordinate of antenna	0.0		km	real	(-∞, ∞)
Height	base station height of antenna array, measured from average rooftop	15		km	real	(0, ∞)
AOA	angle of arrival array representing the multipath wavefront azimuth angles received by the array in the uplink operation mode	75.0 45.0 15.0 -15.0 -45.0 -75.0	φ		real array	(-∞, ∞)
OperationMode	operation mode of the array: UpLink, DownLink	UpLink			enum	
NumberOfElements	number of array elements	6	M		int	(1, ∞)
IntervalOfElements	interval between two antenna elements	0.075	d		real	(0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	inm	Antenna input signals from channel	multiple timed

Pin Outputs

Pin	Name	Description	Signal Type
2	outm	Output signals associated with array elements	multiple timed

Notes/Equations

1. This component simulates an antenna array using gain of antenna and the angle of arrival of each multipath echo specified by the AOA parameter.

   In the uplink mode, set by the OperationMode parameter, the model receives L input timed signals from a multipath channel, processes these signals and outputs M timed signal associated with an M-element array.

   In the downlink mode, it sums all received input timed signals and transmits M timed signals corresponding to the M-element array.

   At each firing, one timed token is consumed, and one token is produced.

2. Figure 1-9 shows the geometry of the array and a received multipath wavefront.

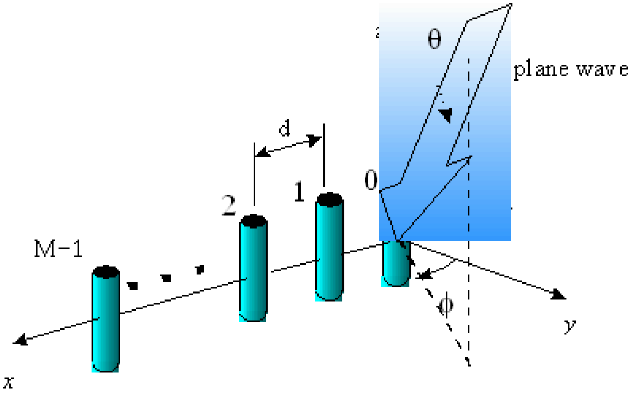


Figure 1-9.

As shown in Figure 1-9 the uniform array is placed along the X-axis with a separation *d*. The array response vector is described by the angle φ measured from the broadside direction perpendicular to the array in the azimuth plane. The array response vector for an array with M elements is given by

$$\alpha(\varphi_l) = \begin{bmatrix} 1 \\ \boldsymbol{exp}(-j\beta d\,\mathrm{sin}(\varphi_l)) \\ \boldsymbol{exp}(-j\beta 2d\,\mathrm{sin}(\varphi_l)) \\ \ldots \\ \boldsymbol{exp}(-j\beta(M-1)d\,\mathrm{sin}(\varphi_l)) \end{bmatrix}$$

where

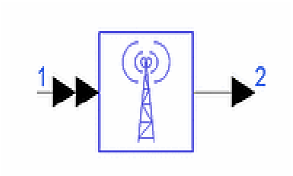
$\beta = 2\pi/\lambda$ is the wavenumber

The output of element k of the array can be expressed as

$$y_k = g\sum_{l=1}^{L}\alpha(\varphi_{kl})X_l$$

where X_l is the lth multipath echo received by the array.

AntBase



Description **Base Station Stationary Antenna Model**
Library **Antennas & Propagation**
Class **TSDFAntBase**
Derived From **antenna**

Parameters

Name	Description	Default	Sym	Unit	Type	Range
Gain	Gain of antenna, in dB	0.0	g		real	(-∞, ∞)
X	X-position coordinate	0.0		km	real	
Y	Y-position coordinate	0.0		km	real	
Height	antenna height above X-Y plane	10		km	real	(0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	input	Antenna input signal	multiple timed

Pin Outputs

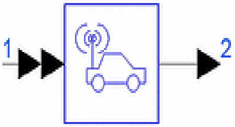
Pin	Name	Description	Signal Type
2	output	Antenna output signal	timed

Notes/Equations

1. Base (or fixed) station antennas are linearly polarized antennas used in mobile communication service at the base station of a radio relay link. The specification “EIA/TIA-329-B, Minimum Standards for Communication Antennas, Part I-Base Station Antennas” describes the standards for this class of antennas.

2. This component radiation has a dominant vertical component of the electric field (E_z).
3. The Gain unit is in dB and is defined with reference to an isotropic source (dBi). To comply with communication antenna standards, a dBd (gain with respect to a half-wave dipole) should be used, which is 2.15 dB over isotropic.
4. To accommodate for specification of input impedance versus frequency, circuit subnetworks can be created and co-simulated with the appropriate circuit simulator.
5. The antenna has a multi-input pin to receive multiple channels when at Rx mode. All inputs to AntBase must have the same carrier frequency.
6. For general information, refer to “Introduction” on page 1-1.

AntMobile



Description **Cellular Mobile Antenna**
Library **Antennas & Propagation**
Class **TSDFAntMobile**
Derived From **antenna**

Parameters

Name	Description	Default	Sym	Unit	Type	Range
Gain	Gain of antenna, in dB	0.0	g		real	(-∞, ∞)
X	X-position coordinate, in distance units	100.0		km	real	
Y	Y-position coordinate, in distance units	0.0		km	real	
Height	antenna height above X-Y plane, in length units	2.0		km	real	(0, ∞)
SpeedType	velocity unit: km/hr, miles/hr	km/hr			enum	
Vx	X component of velocity vector	0.0			real	
Vy	Y component of velocity vector	0.0			real	

Pin Inputs

Pin	Name	Description	Signal Type
1	input	Antenna input signal	multiple timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	Antenna output signal	timed

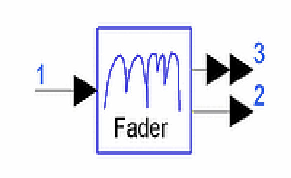
Notes/Equations

1. Mobile antennas are mounted on vehicles and used in the land-mobile communications services. The specification “EIA/TIA-329-B-1, Minimum Standards for Communication Antennas, Part II-Vehicular Antennas” describes the standards for this class of antennas.
2. This component radiation has a dominant vertical component of the electric field (E_z).
3. The Gain unit is in dB and is an isotropic source (dBi). To comply with standards for communication antennas, a dBd (gain with respect to a half-wave dipole) should be used, which is 2.15 dB over isotropic.
4. To accommodate for specification of input impedance versus frequency, circuit subnetworks can be created and co-simulated with the appropriate circuit simulator.
5. The antenna has a multi-input pin to receive multiple channels when at Rx mode. All inputs to AntMobile must have the same carrier frequency.
6. The mobile antenna position changes from initial location along a straight line during simulation. The new coordinates are

   $$X'(t) = X(t) + Vx \times t$$
   $$Y'(t) = Y(t) + Vy \times t$$

7. Propagation pathloss is updated based on changing distance between transmit and receive antennas.
8. For general information, refer to “Introduction” on page 1-1.

Fader



Description Fading channel model
Library Antennas & Propagation
Class TSDFFader
Derived From channel

Parameters

Name	Description	Default	Type	Range
GainArray	path gain in terms of decible	0dB -10dB	real array	(-∞, ∞)†
DelayArray	path delay in terms of ns	0ns 976ns	int array	[0, ∞)†
RicianFactor	ratio of specular power and the fading power	0.0	real	[0, ∞)
Algorithm	the algorithm used: SoS_Stochastic, SoS_Deterministic, Filter_AWGN_Noise	SoS_Stochastic	enum	
† for each element of the array				

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	output signal	timed
3	outChM	fading factor	multiple timed

Notes/Equations

1. This model is the fading channel emulator. The input signal is faded by multiplying the fading coefficients generated using the selected algorithm. If RicianFactor is 0.0, the fading probability density function is Rayleigh distributed; otherwise the fading probability density function is Rician distributed.
2. GainArray specifies the gain of each fading path in terms of decibel, while the delay of each path is specified by DelayArray in terms of nanosecond. The number of fading paths to be generated is equal to the size of GainArray and DelayArray. The generated multiple path fading coefficients are output from pin 3 for test purposes. Pin 2 is the output of the signal passing through a multipath fading channel.
3. The gain of this model has been normalized so that the output power is the same as the input power regardless of the channel configuration. RicianFactor is the ratio of direct signal power and fading power. Fading power is distributed to the multiple path signal according to the gain setting of each path. For example, if the input power is 1, RicianFactor is 2, and GainArray is “0dB -2dB”, then the direct signal power will be 2/(1+2)=2/3 and fading power will be 1/(1+2)=1/3. Fading power allocated to path 1 will be

   $$\frac{1}{3}\times10^{0.0/10}/(10^{0.0/10}+10^{-2/10})$$

   and power for path 2 will be

   $$\frac{1}{3}\times10^{-2/10}/(10^{0.0/10}+10^{-2/10}).$$

4. Three algorithms can be selected to generated the fading coefficient.
   - stochastic sum-of-sinusoid method in which the number of oscillators are selected as 64[1];
   - Jakes deterministic sum-of-sinusoid method [2];
   - to pass an AWGN noise through a shaping filter; this filter is identical with the one used in CDMA2K_ClassicSpec which is available in CDMA2K design library.

   If Filter_AWGN_Noise method is selected, it’s better to have the time step less than 1 μsec so that the fading coefficients will be more reasonable. In this case, a delay is shown because of noise filtering; the delay depends on time step and is equal to 16 times time step.

5. This model is used in conjunction with antennas. Either a base station antenna or a mobile antenna is connected with the input and output pins. This model reads velocity information from the antenna to calculate the Doppler frequency shift.

6. If the input time step is too large, interpolation will be performed to up-sample the signal so that the resulted time step will be less than 1 nsec. Simulation time in the case of a large interpolation rate would increase; in other cases when the delay for a path is larger, the signals to be buffered and interpolated would increase which would lead to increased simulation time.

7. The fading coefficients generated by SoS_Stochastic and Filter_AWGN_Noise methods are independent for different paths. However, caution must be given to proved [3] that the Jakes SoS Deterministic method doesn't have good correlation between different paths.

8. For general information, refer to "Introduction" on page 1-1.

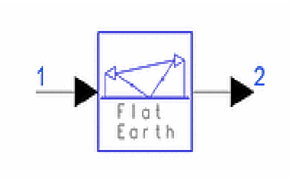
References

[1] Y. R. Zheng and C. Xiao, "Improved models for the generation of multiple un-correlated Rayleigh fading waveforms," IEEE Communications Letters, vol. 6, no. 6, pp. 256-258, June 2002.

[2] W. C. Jakes, Microwave Mobile Communications: Wiley, 1974. Reprinted by IEEE Press in 1994.

[3] P. Dent, G. E. Bottomley, and T. Croft, "Jakes fading model revisited," Electronics Letter, vol. 29, no. 13, pp. 1162-1163, June 1993.

PropFlatEarth



Description Direct and Reflected Ray Propagation Model
Library Antennas & Propagation
Class TSDFPropFlatEarth
Derived From channel

Parameters

Name	Description	Default	Type
Polarization	polarization type: Vertical, Horizontal	Vertical	enum
Permittivity	earth’s average relative permittivity	15	real
Conductivity	earth’s average conductivity	0.005	real

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output signal	timed

Notes/Equations

1. PropFlatEarth models the sum of a direct and reflected ray propagation channel model based on polarization and flat earth properties.
2. This component is based on the two-ray LOS model where the received signal is the sum of contributions from the direct and reflected rays. By summing the

contributions from each ray, the received signal at the Rx end for a pair of antennas can be expressed as

$$P_r = P_t\left(\frac{\lambda}{4\pi}\right)^2\left|\frac{1}{r_1}e^{-jkr_1} + \Gamma(\alpha)\frac{1}{r_2}e^{-jkr_2}\right|^2$$

where P_t is the transmitter power, r_1 is the direct distance from transmitter to receiver, r_2 is the distance through the reflection on the ground, and $\Gamma(\alpha)$ is the complex reflection coefficient as a function of incident angle α and complex permittivity of the ground e_r:

$$\Gamma(\alpha) = \frac{\cos\theta - q\sqrt{e_r - \sin^2\theta}}{\cos\theta + q\sqrt{e_r - \sin^2\theta}}$$

where $\theta = 90 - \alpha$ and $q=1$ or $(e_r)^{-1}$ for vertical or horizontal polarization, respectively.

3. The complex relative permittivity is related to medium’s average permittivity and conductivity:

   $e_r = \varepsilon_r\,(\text{average}) - j60\lambda\sigma$

   Typical values for permittivity and conductivity of various earth’s mediums are given in Table 1-2.

   Figure 1-10 shows the received power as a function of antenna separation using FlatEarth channel Reference [1].

Table 1-2. Typical Earth’s Constants

Type of Surface	**Average** ε_r	**Average** σ **(mho/meter)**
Fresh water (lakes and rivers)	81	0.001
Sea water	81	5.0
Good ground	25	0.02
Average ground	15	0.005
Poor ground	4	0.001
Mountains		0.00075

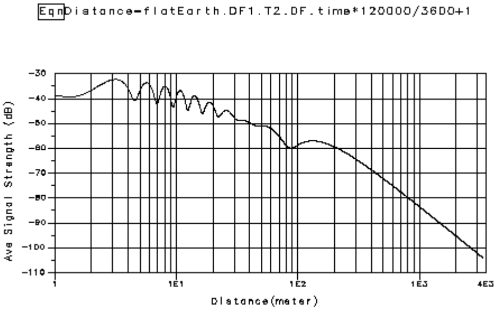


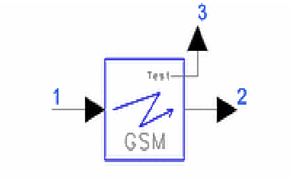
Figure 1-10. Received Power as a Function of Antenna Separation Using FlatEarth Channel

4. For general information, refer to “Introduction” on page 1-1.

References

[1] H. Xia, H. Bertoni, “Radio Propagation Characteristics for LOS Microcellular and Personal Communications,” *IEEE Trans*, APS, October 1993.

PropGSM



Description GSM Propagation Model
Library Antennas & Propagation
Class TSDFPropGSM
Derived From channel

Parameters

Name	Description	Default	Type
Type	GSM type: NoMultipath, RuralArea1, RuralArea2, HillyTerrain6Tap1, HillyTerrain6Tap2, HillyTerrain12Tap1, HillyTerrain12Tap2, UrbanArea6Tap1, UrbanArea6Tap2, UrbanArea12Tap1, UrbanArea12Tap2, EqualizationTest	NoMultipath	enum
Pathloss	inclusion of large-scale pathloss: No, Yes	No	enum
Seed	number to randomize channel output	1234567	int
Test	test port accessing single path random gain functions: Tap1, Tap2, Tap3, Tap4, Tap5, Tap6, Tap7, Tap8, Tap9, Tap10, Tap11, Tap12	Tap1	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output signal	timed
3	test	Test port	timed

Notes/Equations

1. PropGSM models a directional multipath channel based on GSM specifications. The model is a multi-tap filter, each tap having a delay and power. And, each tap is modulated by a colored noise source (gain function).

   Including the multipath fading and pathloss effects, the output of the channel can be described as

   $$r(t) = \left(\alpha \sum_{i=1}^{M} \beta_i s(t-\tau_i) e^{-j\tau_i\omega_c} g_i(t)\right)$$

   where

   α = pathloss attenuation, $\alpha \le 1$
   β_i = relative power of each echo, per specification
   τ_i = relative delay of each echo, plus the direct path delay τ_0
   $s(t)$ = complex envelope input signal
   gi = random gain function associated with each echo

   For the NoMultipath option, M=1, $\tau_1 = \tau_o$

   The gain function can be described as a sum of non-overlapping sinusoids of equal amplitudes and different frequency and phases.

   The pathloss attenuation factor α=1 when Pathloss=No. And, note that when Pathloss=No, the sum $r(t)$ may add up to be more than the input $s(t)$, implying that channel has a gain. For this reason, when Pathloss=No, the output is normalized to the linear sum of echo powers with each option.

   For more details, refer to “Introduction” on page 1-1.

2. Specification GSM 05.05, European Digital Cellular Telecommunications System (Phase 1) Radio Transmission and Reception, Annex 4 is the basis for the PropGSM model. With the exception of Type= NoMultipath, which is an addition, GSM system defines eleven different propagation profiles described by

the Type parameter: two for rural; four for hilly; four for urban; and one for equalizer test. Table 1-8 through Table 1-7 depict the GSM delay profiles associated with each Type.

Table 1-3. Hilly Terrain 6-Tap Types

	Relative Time (μsec)		**Average Relative Power (dB)**		
Tap Number	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Doppler Spectrum**
1	0.0	0.0	0.0	0.0	Classical
2	0.1	0.2	-1.5	-2.0	Classical
3	0.3	0.4	-4.5	-4.0	Classical
4	0.5	0.6	-7.5	-7.0	Classical
5	15.0	15.0	-8.0	-6.0	Classical
6	17.2	17.2	-17.7	-12.0	Classical

Table 1-4. Hilly Terrain 12-Tap Types

	Relative Time (μsec)		**Average Relative Power (dB)**		
Tap Number	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Doppler Spectrum**
1	0.0	0.0	-10.0	-10.0	Classical
2	0.1	0.2	-8.0	-8.0	Classical
3	0.3	0.4	-6.0	-6.0	Classical
4	0.5	0.6	-4.0	-4.0	Classical
5	0.7	0.8	0.0	0.0	Classical
6	1.0	2.0	0.0	0.0	Classical
7	1.3	2.4	-4.0	-4.0	Classical
8	15.0	15.0	-8.0	-8.0	Classical
9	15.2	15.2	-9.0	-9.0	Classical
10	15.7	15.8	-10.0	-10.0	Classical
11	17.2	17.2	-12.0	-12.0	Classical
12	20.0	20.0	-14.0	-14.0	Classical

Table 1-5. Urban Area 6-Tap Types

Tap Number	Relative Time (μsec)		Average Relative Power (dB)		Doppler Spectrum
	Option 1	Option 2	Option 1	Option 2	
1	0.0	0.0	-3.0	-3.0	Classical
2	0.2	0.2	0.0	0.0	Classical
3	0.5	0.6	-2.0	-2.0	Classical
4	1.6	1.6	-6.0	-6.0	Classical
5	2.3	2.4	-8.0	-8.0	Classical
6	5.0	5.0	-10.0	-10.0	Classical

Table 1-6. Urban Area 12-Tap Types

Tap Number	Relative Time (μsec)		Average Relative Power (dB)		Doppler Spectrum
	Option 1	Option 2	Option 1	Option 2	
1	0.0	0.0	-4.0	-4.0	Classical
2	0.1	0.2	-3.0	-3.0	Classical
3	0.3	0.4	0.0	0.0	Classical
4	0.5	0.6	-2.6	-2.0	Classical
5	0.8	0.8	-3.0	-3.0	Classical
6	1.1	1.2	-5.0	-5.0	Classical
7	1.3	1.4	-7.0	-7.0	Classical
8	1.7	1.8	-5.0	-5.0	Classical
9	2.3	2.4	-6.5	-6.0	Classical
10	3.1	3.0	-8.6	-9.0	Classical
11	3.2	3.2	-11.0	-11.0	Classical
12	5.0	5.0	-10.0	-10.0	Classical

Table 1-7. EqualizationTest Types

Tap Number	Relative Time (μsec)	Average Relative Power (dB)	Doppler Spectrum
1	0.0	0.0	Classical
2	3.2	0.0	Classical
3	6.4	0.0	Classical
4	9.6	0.0	Classical

Table 1-7. EqualizationTest Types

Tap Number	Relative Time (μsec)	Average Relative Power (dB)	Doppler Spectrum
5	12.8	0.0	Classical
6	16.0	0.0	Classical

Table 1-8. Rural Types

	Relative Time (μsec)		Average Relative Power (dB)		
Tap Number	Option 1	Option 2	Option 1	Option 2	Doppler Spectrum
1	0.1	0.0	0.0	0.0	Rician
2	0.2	0.2	-4.0	-2.0	Classical
3	0.3	0.4	-8.0	-10.0	Classical
4	0.4	0.6	-12.0	-20.0	Classical
5	0.5		-16.0		Classical
6	0.6		-20.0		Classical

3. Type= NoMultipath simulates a single line-of-sight (LOS) path with the free-space pathloss.
4. Each Type option contains a unique set of parameters: the environment (rural, hilly, or urban), number of taps, and two options for 6- and 12-tap settings. And, a model (Type=EqualizationTest) is artificially created to test the equalizer.
5. As an example, the average delay profile of each Type is depicted in Figure 1-11. As shown in this figure, the rural environment is the least hostile (roughly a one-path non-dispersive model), while hilly and urban environments are examples of more dispersive channels.
6. Type options include a reference delay of

$$\tau_0 = \frac{R}{c}$$

   where R is the initial distance between two antennas and c is the free space speed of light. If there is more than one path in a propagation model, the relative delay of each path is with respect to τ_0.

7. For each Type option (except Type= NoMultipath and Type=RuralArea) the paths are assumed to have a Rayleigh envelope distribution with a (classical) Doppler spectrum. For Type=NoMultipath a simple Doppler shift is assumed.

For Type=RuralArea, the first tap has a Rician envelope distribution implying a direct LOS in addition to Rayleigh fading.

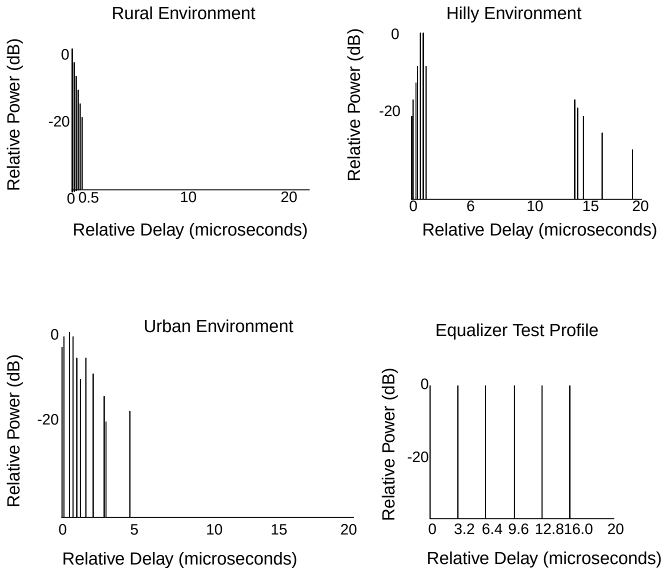


Figure 1-11. Typical Average Delay Profile of GSM Propagation Channels

8. The pathloss computation is *dynamic*, which means, during simulation due to mobile travel the distance between the transmit and receive antennas is changing and pathloss is adjusted accordingly.
9. The parameter Seed randomizes the output of the propagation model. A fixed Seed results in the same output from simulation to simulation and among models in a multi-channel design.
10. The test port is the output of a (user-selected) single path without pathloss or delay effects. The output is the *gain function*, which is described in the introductory part of this chapter.
11. Typical short-term fading signal (Rayleigh) envelope and RF Doppler spectrum are depicted in Figures 1-12 and 1-13.

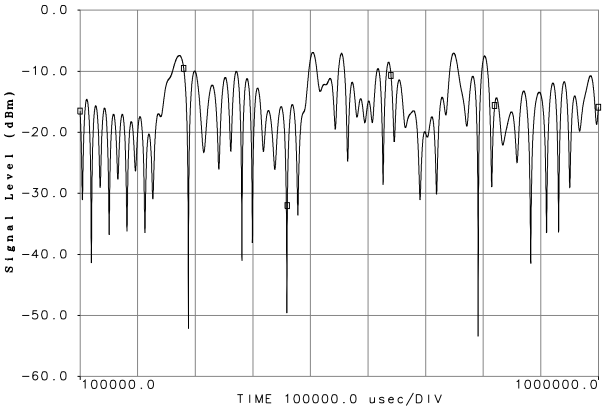


Figure 1-12. Typical Fading Envelope of PropGSM

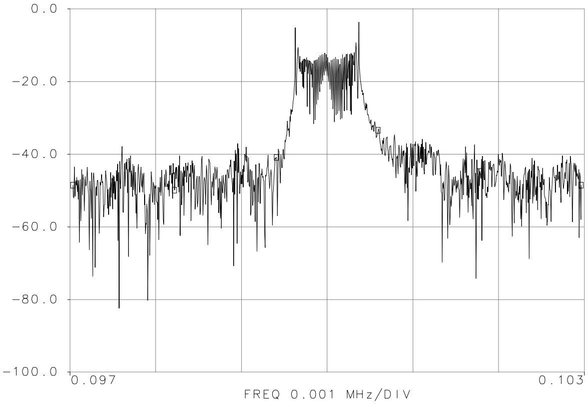
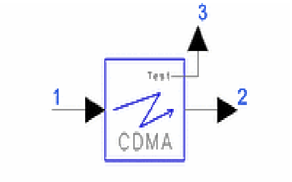


Figure 1-13. Typical Doppler Spectrum of PropGSM

12. For general information, refer to “Introduction” on page 1-1.

PropNADCcdma



Description **Propagation Channel (CDMA) Model**
Library **Antennas & Propagation**
Class **TSDFPropNADCcdma**
Derived From **channel**

Parameters

Name	Description	Default	Type
Type	propagation type: NoMultipath, OnePath, TwoPath, ThreePath	NoMultipath	enum
Pathloss	inclusion of large scale pathloss: No, Yes	No	enum
Env	Environment Type Options: TypicalUrban, TypicalSuburban, RuralArea, FreeSpace	TypicalUrban	enum
Seed	number to randomize channel output	1234567	int
Test	test port for single path random function: Tap1, Tap2, Tap3	Tap1	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output signal	timed
3	test	Test port	timed

Notes/Equations

1. PropNADCcdma models a multipath channel based on IS-97 specifications. The model is a multi-tap filter, each tap having a delay and power. And, each tap is modulated by a colored noise source.

   Including the multipath fading and pathloss effects, the output of the channel can be described as

   $$r(t) = \left(\alpha \sum_{i=1}^{M} \beta_i s(t-\tau_i) e^{-j\tau_i\omega_c} g_i(t)\right)$$

   where

   α = pathloss attenuation, $\alpha \leq 1$
   β_i = relative power of each echo, per specification
   τ_i = relative delay of each echo, plus the direct path delay τ_0
   s(t) = complex envelope input signal
   gi = random gain function associated with each echo

   For the NoMultipath option, M=1, $\tau_1 = \tau_o$

   The gain function can be described as a sum of non-overlapping sinusoids of equal amplitudes and different frequency and phases.

   The pathloss attenuation factor α=1 when Pathloss=No. And, note that when Pathloss=No, the sum *r(t)* may add up to be more than the input *s(t)*, implying that channel has a gain. For this reason, when Pathloss=No, the output is normalized to the linear sum of echo powers with each option.

   For more details, refer to the “Introduction” on page 1-1.

2. This component is based on the North American Dual Model Cellular (NADC) IS-97 specification.

3. Except for Type=NoMultipath, where free space pathloss and a pure Doppler shift is assumed, other Type options have a Rayleigh envelope distribution with a (classical) Doppler spectrum and pathloss defined by the Env parameter.

4. Figure 1-14 depicts two- and three-path power delay profiles used in PropNADCcdma.

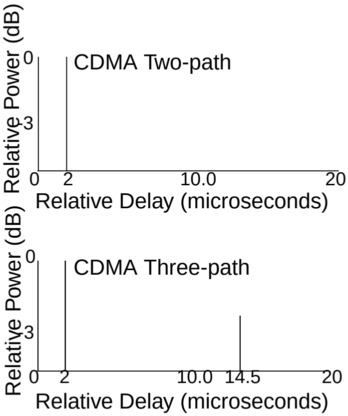


Figure 1-14. Average Delay Profiles of CDMA Propagation Channels

5. Type options include a reference delay of

$$\tau_o = \frac{R}{c}$$

   where R is the initial distance between two antennas and c is the free space speed of light. If there is more than one path in a propagation model, the relative delay of each path is with respect to τ_0.

6. The two- and three-path models have a Rayleigh envelope distribution with a (classical) Doppler spectrum.

7. The parameter Seed randomizes the output of the propagation model. A fixed Seed results in the same output from simulation to simulation and among models in a multi-channel design.

8. The test port is the output of a (user-selected) single path without pathloss or delay effects. The output is the *gain function* described in the introductory part of this chapter.

9. Sufficient simulation time is required for accurate pdf and cpdf. For evaluation of envelope statistics, it is preferable to have independent samples (that is, samples at a low rate, which implies TStep is large). The duration of the simulation (Stop parameter of the data collecting sink) should be large enough to cover 100 or more wavelengths of mobile travel.

   This translates to simulation time that is greater than

$$\frac{100}{|\upsilon|}$$

where

$$\upsilon = \frac{V}{\lambda}$$

is the maximum doppler frequency.

10. Typical probability density function (pdf) and cumulative probability density function (cpdf) of the signal envelope are depicted in Figures 1-15 and 1-16. Sufficient simulation time is required for accurate pdf and cpdf.

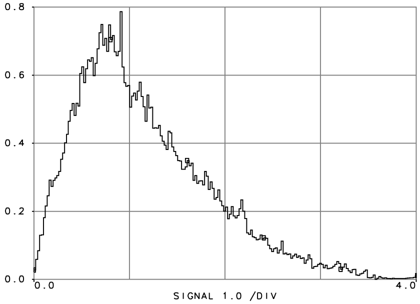


Figure 1-15. Typical pdf of Signal Envelope

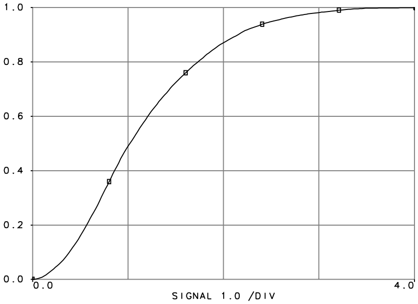
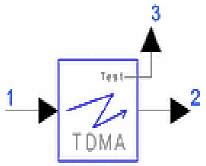


Figure 1-16. Typical cpdf of Signal Envelope

PropNADCtdma



Description **NADC Propagation (TDMA) Model, Directional**
Library **Antennas & Propagation**
Class **TSDFPropNADCtdma**
Derived From **channel**

Parameters

Name	Description	Default	Type
Type	propagation type: NoMultipath, FlatFade, TwoPath	NoMultipath	enum
Pathloss	inclusion of large scale pathloss: No, Yes	No	enum
Env	Environment Type Options: TypicalUrban, TypicalSuburban, RuralArea, FreeSpace	TypicalUrban	enum
Delay	relative delay (Type=TwoPath) with respect to first path, in microseconds	0.0	real
Pwr	relative power (Type=TwoPath) with respect to first path, in dB	0.0	real
Seed	integer number to randomize channel output	1234567	int
Test	test port for single path: Tap1, Tap2	Tap1	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output signal	timed
3	test	Test port	timed

Notes/Equations

1. PropNADCtdma models a unidirectional multipath channel based on IS-55 and IS-56 propagation specifications. The model is a multi-tap filter, each tap having a delay and power. And, each tap is modulated by a colored noise source *gain function* described in the introductory part of this chapter.

   Including the multipath fading and pathloss effects, the output of the channel can be described as

   $$r(t) = \left(\alpha \sum_{i=1}^{M} \beta_i s(t-\tau_i) e^{-j\tau_i\omega_c} g_i(t)\right)$$

   where

   α = pathloss attenuation, $\alpha \le 1$
   β_i = relative power of each echo, per specification
   τ_i = relative delay of each echo, plus the direct path delay τ_0
   $s(t)$ = complex envelope input signal
   gi = random gain function associated with each echo

   For the NoMultipath option, M=1, $\tau_1 = \tau_0$.

   The gain function can be described as a sum of non-overlapping sinusoids of equal amplitudes and different frequency and phases.

   The pathloss attenuation factor α=1 when Pathloss=No. And, note that when Pathloss=No, the sum *r(t)* may add up to be more than the input *s(t)*, implying that channel has a gain. For this reason, when Pathloss=No, the output is normalized to the linear sum of echo powers with each option.

   For more details, refer to the “Introduction” on page 1-1.

2. This component is based on the North American Dual Model Cellular (NADC).

3. Flat fade is assumed to be the non-frequency-selective fading.

4. Except for Type=NoMultipath where free space pathloss and a pure Doppler shift is assumed, all other Type options have a Rayleigh envelope distribution with a (classical) Doppler spectrum and pathloss defined by the Env parameter.
5. Type options include a reference delay of

   $$\tau_o = \frac{R}{c}$$

   where R is the initial distance between two antennas and c is the free space speed of light.

   Delay in the two-ray model is the delay of the second ray with respect to the first ray, which is assumed to be τ_0.

   Pwr in the two-ray model is the power of the second ray below the power of the first ray.
6. The parameter Seed randomizes the output of the propagation model. A fixed Seed results in the same output from simulation to simulation and among models in a multi-channel design.
7. The test port is the output of a (user-selected) single path without pathloss or delay effects. The output is the *gain function* described in the introductory part of this chapter.
8. Typical envelope and envelope square spectrum of PropNADCtdma is shown in Figure 1-17. Also, pathloss profiles (no multipath) for different environments and different sets of transmit and receive antenna heights are shown in Figure 1-18.

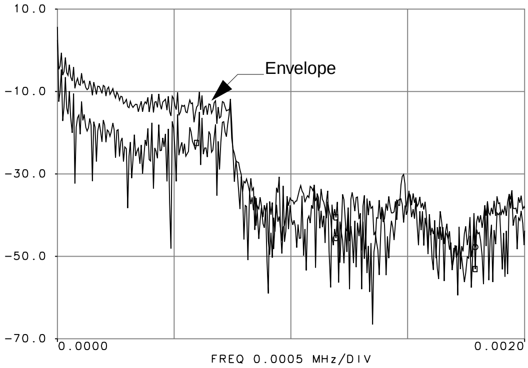


Figure 1-17. Typical Envelope and Envelope Square Spectrum of PropNADCtdma

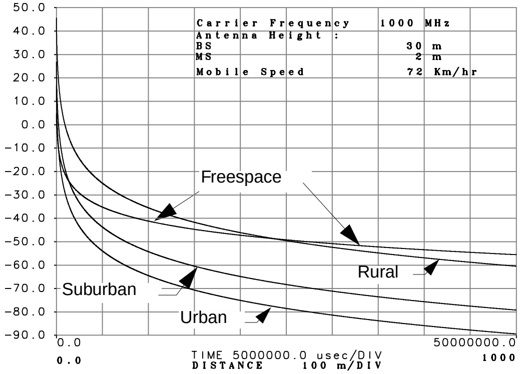
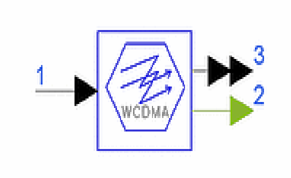


Figure 1-18. Pathloss Profiles for Different Environments

PropWCDMA



Description **WCDMA Propagation Channel**
Library **Antennas & Propagation**
Class **TSDFPropWCDMA**
Derived From **channel**

Parameters

Name	Description	Default	Sym	Type	Range
ChannelType	Indicate the test environment (Delay, Power, and Doppler Spectrum of each path).: NoMultipath, Indoor A, Indoor B, Pedestrian A, Pedestrian B, Vehicular A, Vehicular B	Vehicular B		enum	
Pathloss	option for inclusion of large-scale pathloss: No, Yes	No		enum	
Environment	IMT2000 environment for pathloss computation: Indoor, Pedestrian, Vehicular, FreeSpace	FreeSpace		enum	
NumberOfFloors	number of floors for indoor pathloss	4		int	(0, ∞)
N	2N+1 is the number of sine waves used in Jakes model	10	N	int	(0, ∞)
Seed	integer number to randomize the channel output (Jakes model)	1234567		int	(0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	testOut	complex gain of the channel	complex
3	mout	Antenna input signal	multiple timed

Notes/Equations

1. This component models a fading channel based on the IMT2000 standard specification. The specification includes the delay spread, doppler spread and pathloss for various environments. A line of sight (LOS) option called NoMultipath is also available where the doppler shift due to mobility and the LOS delay are modeled. Results are available at channel output pin mout.
2. For doppler spread, Jakes model [2] is used that provides the doppler spectrum as well as the statistics of the fading channel. An additional output pin testOut is provided that conveys the complex gain multipliers of Jakes model.
3. The delay spread is modeled via a tap delay line where the number of taps is based on IMT2000 specifications for a given environment. There are 6 options (A and B for indoor, pedestrian, and vehicular environments) that are depicted in Table 1-9 through Table 1-11. In each case the input signal is delayed and the carrier phase due to the delay signal is incorporated. However, in the narrowband case (FLAT option in the indoor office test environment) only the carrier phase change associated with the multipath delay is included.

   The delay profile for the various channel types result in the frequency selective fading.

   The modeling process depicted in Figure 1-19 indicates that the output of complex multipliers (multipath echoes) are not summed. PropWCDMA channel is typically followed by a Bus component (see WCDMAVectorChannel). The connected Bus allows each multipath (echo) to be intact when connecting to an AntArray component or any multiple timed input port. If PropWCDMA is directly connected to an antenna (either simple or array), only the first path (echo) will be passed to the antenna.
4. Unless stated otherwise, the use model is consistent with the guidelines described in the “Introduction” on page 1-1.

Table 1-9. Indoor Office Test Environment Tapped-Delay-Line Parameters

Tap	Channel A		Channel B		Doppler Spectrum
	Relative Delay (nSec)	Avg. Power (dB)	Relative Delay (nSec)	Avg. Power (dB)	
1	0	0	0	0	FLAT
2	50	-3.0	100	-3.6	FLAT
3	110	-10.0	200	-7.2	FLAT
4	170	-18.0	300	-10.8	FLAT
5	290	-26.0	500	-18.0	FLAT
6	310	-32.0	700	-25.2	FLAT

Table 1-10. Outdoor to Indoor and Pedestrian Test Environment Tapped-Delay-Line Parameters

Tap	Channel A		Channel B		Doppler Spectrum
	Relative Delay (nSec)	Avg. Power (dB)	Relative Delay (nSec)	Avg. Power (dB)	
1	0	0	0	0	CLASSIC
2	110	-9.7	200	-0.9	CLASSIC
3	190	-19.2	800	-4.9	CLASSIC
4	410	-22.8	1200	-8.0	CLASSIC
5			2300	-7.8	CLASSIC
6			3700	-23.9	CLASSIC

Table 1-11. Vehicular Test Environment, High Antenna, Tapped-Delay-Line Parameters

Tap	Channel A		Channel B		Doppler Spectrum
	Relative Delay (nSec)	Avg. Power (dB)	Relative Delay (nSec)	Avg. Power (dB)	
1	0	0	0	-2.5	CLASSIC
2	310	-1.0	300	0	CLASSIC
3	710	-9.0	8900	-12.8	CLASSIC
4	1090	-10.0	12900	-10.0	CLASSIC
5	1730	-15.0	17100	-25.2	CLASSIC
6	2510	-20.0	20000	-16.0	CLASSIC

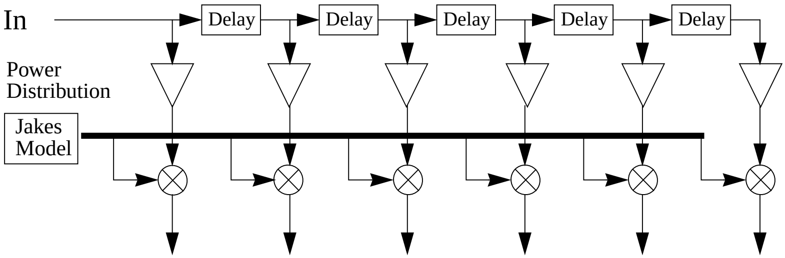


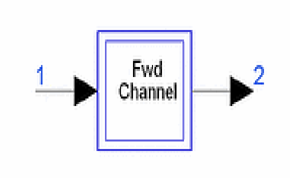
Figure 1-19. Delay and Doppler Spread and Carrier Phase Shift

References

[1] Draft New Recommendation ITU-R M.[FPLMT.REVAL], Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000/FPLMTS (Question ITU-R 39/8).

[2] W. C. Jakes, *Microwave Mobile Communications*, IEEE Press, 1994.

TDSCDMA_FwdChannel



Description **Multipath fading channel for forward link**
Library **Antennas & Propagation**

Parameters

Name	Description	Default	Type
Case	propagation conditions for multipath fading environments: case_1, case_2, case_3	case_1	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	input data	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	data after fading channel	timed

Notes/Equations

1. This subnetwork is used to simulate propagation conditions for multipath fading environments.

   The schematic for this subnetwork is shown in Figure 1-20.

   Each firing, 1 Output token is produced when 1 Input is consumed.

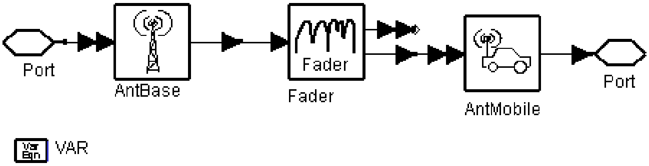
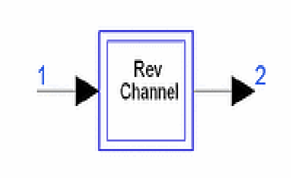


Figure 1-20. TDSCDMA_FwdChannel Schematic

Reference

[1] 3GPP TS 25.142, *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Base station conformance testing (TDD) (Release 4)*, version 4.5.0, Jun., 2002.

TDSCDMA_RevChannel



Description **Multipath fading channel for reverse link**
Library **Antennas & Propagation**

Parameters

Name	Description	Default	Type
Case	propagation conditions for multipath fading environments: case_1, case_2, case_3	case_1	enum

Pin Inputs

Pin	Name	Description	Signal Type
1	Input	input data	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	Output	data after fading channel	timed

Notes/Equations

1. This subnetwork is used to simulate propagation conditions for multipath fading environments.

   The schematic for this subnetwork is shown in Figure 1-21.

   Each firing, 1 Output token is produced when 1 Input is consumed.

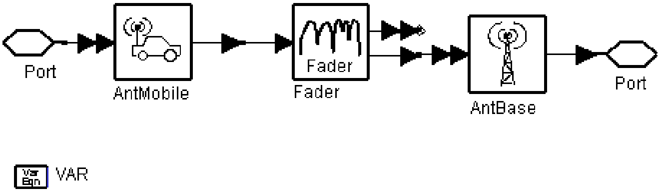
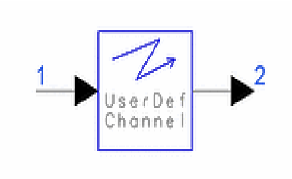


Figure 1-21. Schematic of TDSCDMA_RevChannel

References

[1] 3GPP TS 25.142, *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Base station conformance testing (TDD) (Release 4)*, version 4.5.0, June 2002.

UserDefChannel



Description **User-Defined Channel**
Library **Antennas & Propagation**
Class **TSDFUserDefChannel**
Derived From **channel**

Parameters

Name	Description	Default	Sym	Type	Range
PathNumber	number of multipath echos	2	L	int	(0, ∞)
AmpArray	amplitude weight of path array	1.0 0.5		real array	(-∞, ∞)
DelayArray	delays associated with path array, in microseconds	0.1 0.2		real array	(-∞, ∞)
Seed	integer number to randomize channel output (Jakes model)	1234567		int	(0, ∞)
N	2N+1 is number of sine waves used in Jakes model	10	N	int	(0, ∞)
Pathloss	option for inclusion of large-scale pathloss: No, Yes	No		enum	
Env	environment for pathloss computation: TypicalUrban, TypicalSuburban, RuralArea, FreeSpace	TypicalUrban		enum	

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output signal	timed

Notes/Equations

1. This component models a fading channel based on user-specified multipath delay profile via the DelayArray and AmpArray parameters. The results are available at the channel output port.
2. For doppler spread, Jakes model [1] is used, which provides the doppler spectrum as well as the statistics of the fading channel.
3. The delay spread is modeled via a tap delay line where the number of taps is based on the size of DelayArray and AmpArray. In each case the input signal is delayed and the carrier phase due to the delay signal is incorporated.

   Figure 1-22 illustrates this modeling process when connected to a simple antenna.
4. Unless stated otherwise, the use model is consistent with the guidelines described in the "Introduction" on page 1-1. The delay profile specified by the user determines the frequency selective nature of the channel.

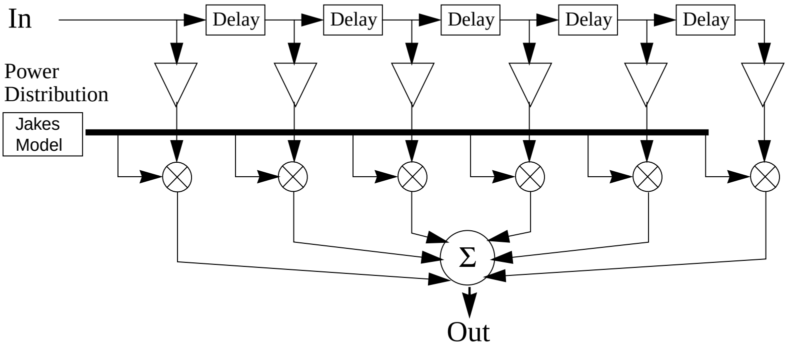
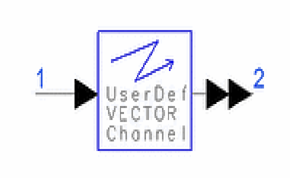


Figure 1-22. Delay and Doppler Spread and Carrier Phase Shift

References

[1] W. C. Jakes, *Microwave Mobile Communications*, IEEE Press, 1994.

UserDefVectorChannel



Description **User-Defined Vector Channel**
Library **Antennas & Propagation**
Class **TSDFUserDefVectorChannel**
Derived From **channel**

Parameters

Name	Description	Default	Sym	Type	Range
PathNumber	number of multipath echos	2	L	int	(0, ∞)
AmpArray	amplitude weight of path array	1.0 0.5		real array	(-∞, ∞)
DelayArray	delays associated with path array, in microseconds	0.1 0.2		real array	(-∞, ∞)
Seed	integer number to randomize the channel output (Jakes model)	1234567		int	(0, ∞)
N	2N+1 is the number of sine waves used in Jakes model	10	N	int	(0, ∞)
Pathloss	option for inclusion of large-scale pathloss: No, Yes	No		enum	
Env	environment for pathloss computation: TypicalUrban, TypicalSuburban, RuralArea, FreeSpace	TypicalUrban		enum	

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	mout	multiport channel output	multiple timed

Notes/Equations

1. UserDefVectorChannel is identical to UserDefChannel, except the output of this model keeps the multipaths (echos) intact thus allowing a vector channel simulation when an AntArray component or any multiple timed input port is connected.
2. Figure 1-23 illustrates the user-defined vector channel model when its output is connected to an array antenna.

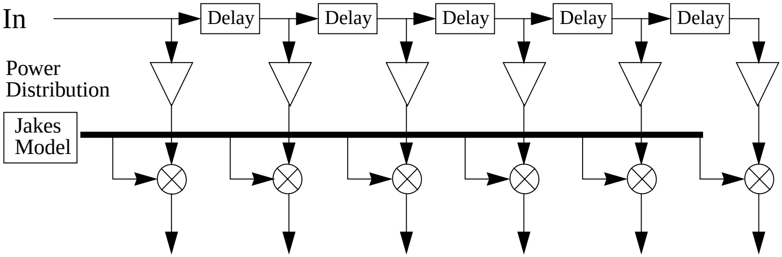
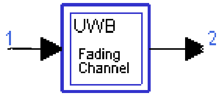


Figure 1-23. User-Defined Vector Channel Model when Connected to an Array Antenna

UWB_Channel



Description UWB channel model
Library Antennas & Propagation

Parameters

Name	Description	Default	Unit	Type	Range
ChannelModel	channel model type: CM1, CM2, CM3, CM4	CM1		enum	
ChannelNumber	channel realization number	1		int	[1, 100]
TimeStep	time step	1.894 nsec	sec	real	
Fmin	-10dB lower edge frequency of the UWB signal	3169 MHz	Hz	real	(0, ∞)
Fmax	-10dB upper edge frequency of the UWB signal	4751 MHz	Hz	real	(0, ∞)
BlockLength	input signal block length in samples for fast convolution	165		int	[1, +∞]

Pin Inputs

Pin	Name	Description	Signal Type
1	RF_In	input RF singal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	RF_Out	output RF singal	timed

Notes/Equations

1. This subnetwork is used to simulate multipath channels for UWB system. The schematic for this subnetwork is shown in Figure 1-24.

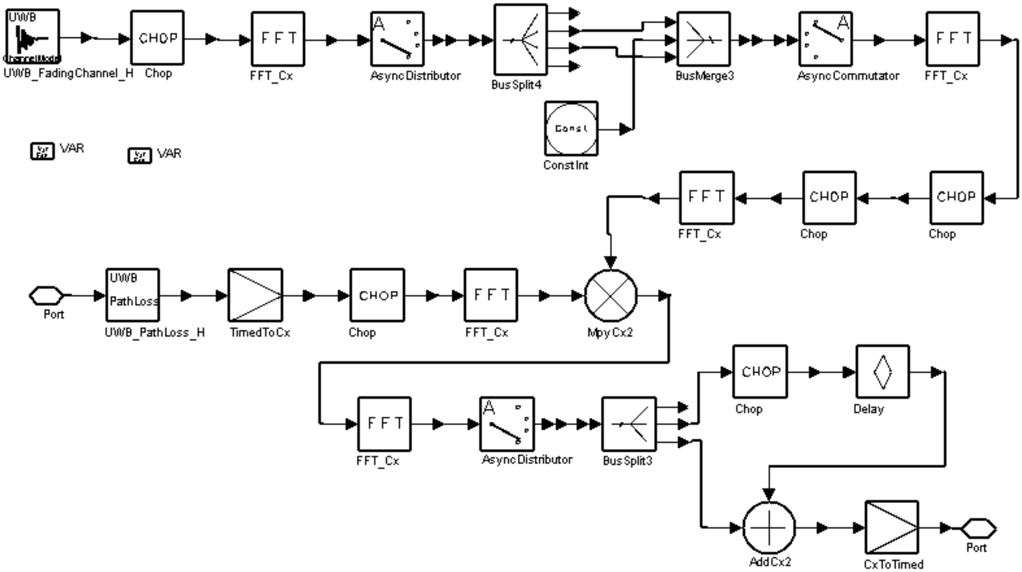


Figure 1-24. UWB_Channel Schematic

2. UWB channel model is derived from a modified Saleh-Valenzuela model, which consists of the following discrete time impulse response:

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{K} a^i_{k,l} \delta(t - T^i_l - \tau^i_{k,l})$$

where

$a^i_{k,l}$ are the multipath gain coefficients

T^i_l is the delay of the lth cluster,

$\tau^i_{k,l}$ is the delay of the kth multipath component relative to the lth cluster arrival time

X_i represents the log-normal shadowing

i refers to the ith realization.

3. Four multipath channel models are specified in Reference [1] that represent different multipath scenarios:

- CM1 is based on LOS (0-4m) channel measurements reported in Reference [2].
- CM2 is based on NLOS (0-4m) channel measurements reported in Reference [2].
- CM3 is based on NLOS (4-10m) channel measurements reported in Reference [2], and NLOS measurements reported in Reference [3].
- CM4 was generated to fit a 25nsec RMS delay spread to represent an extreme NLOS multipath channel.

One hundred actual realizations for each channel model are derived from the models and provided in Channel Modeling Sub-committee Final Report to help evaluate the UWB proposals.

4. To accommodate various sample times, the continuous-time model's (time,value) pair is quantized to ts/N where ts is the desired resolution and N is a suitably large integer. If multiple (time,value) pairs are quantized into the same time bin, their values are added. Then, in normal discrete-time processing, perform a band-pass with complex frequency down-conversion and decimate down by N. When choosing N, ensure that $N \times fs = N/ts$ is at least 100 GHz and that N=1. Thus, N=max(1, ceil($ts \times$ 100 GHz)).

5. Path loss is also calculated in this subnetwork based on the link analysis table in Reference [1], where path loss at 1 meter is

$$L_1 = 20\log 10\left(\frac{4\pi f'_c}{c}\right)$$

and pass loss at d m is

$$L_2 = 20\log 10(d)$$

and

$$f'_c = \sqrt{f_{min} f_{max}}$$

is the geometric center frequency of waveform; f_{min} and f_{max} are the -10dB edges of the waveform spectrum.

6. Fast convolution with FFT is used in this subnetwork to improve efficiency. The BlockLength parameter is the length of each input block segmentation; BlockLength must be larger than channel dispersion; BlockLength is a multiple

of samples in one OFDM symbol and is divided by the number of samples in one frame.

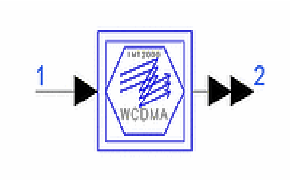
References

[1] IEEE P802.15-02/490r1-SG3a, Channel Modeling Sub-committee Report Final, February 2003.

[2] IEEE P802.15-02/240-SG3a, Empirically Based Statistical Ultra-Wideband Channel Model.

[3] IEEE P802.15-02/279-SG3a, UWB Channel Modeling Contribution from Intel.

WCDMAVectorChannel



Description **WCDMA Vector Channel**
Library **Antennas & Propagation**

Parameters

Name	Description	Default	Sym	Type	Range
ChannelType	type of Channel: NoMultipath, Indoor A, Indoor B, Pedestrian A, Pedestrian B, Vehicular A, Vehicular B	Vehicular B		enum	
Echos	number of multipath echos	6	L	int	(0, ∞)
Pathloss	option for inclusion of large-scale pathloss: No, Yes	No		enum	
Environment	IMT2000 environment for pathloss computation: Indoor, Pedestrian, Vehicular, FreeSpace	FreeSpace		enum	
NumberOfFloors	number of floors for indoor option	4		int	(0, ∞)
N	2N+1 is the number of sine waves used in Jakes model	10	N	int	(0, ∞)
Seed	integer number to randomize the channel output(Jakes model)	1234567		int	(0, ∞)

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input	complex

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output	multiple complex

Notes/Equations

1. WCDMAVectorChannel is a subcircuit design consisting of PropWCDMA and Bus components. The size of Bus must equal the number of multipath (echos) in the channel; otherwise, WCDMAVectorChannel acts identical to PropWCDMA. The connecting Bus allows each multipath (echo) to be intact when it is connected to an AntArray component or any multiple timed input port.
2. Figure 1-25 illustrates the WCDMA vector channel model output when connected to an array antenna.

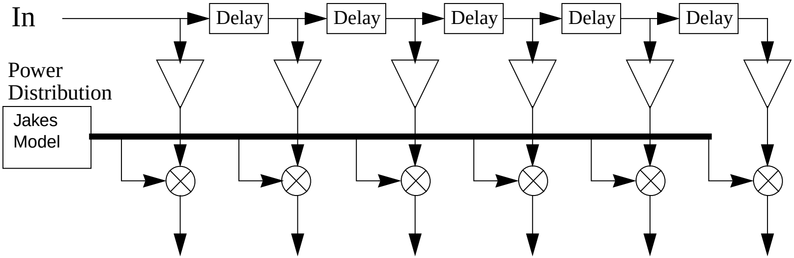
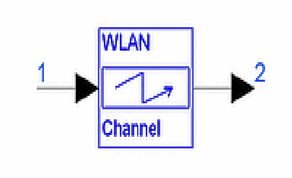


Figure 1-25. WCDMA Vector Channel Model when Connected to an Array Antenna

WLAN_ChannelModel



Description **channel model**
Library **Antennas & Propagation**
Class **TSDFWLAN_ChannelModel**
Derived From **channel**

Parameters

Name	Description	Default	Type	Range
Algorithm	fading algorithm: Jakes, NoiseFilter	NoiseFilter	enum	
ModelType	fading model: NoMultipath, A, B, C, D, E, UserDefined	A	enum	
PathNumber	number of multipath echoes, effective only when ModelType is set as UserDefined	4	int	[1, 150]
PowerArray	average relative power of path array, in dB, effective only when ModelType is set as UserDefined	0.0 -14 -18 -20	real array	(-∞, ∞)
DelayArray	delays associated with path array, in nsec, effective only when ModelType is set as UserDefined	0.0 56 106 185	real array	[0, ∞)
FadingType	fading type of first path, effective only when ModelType is set as UserDefined: Rayleigh, Ricean	Rayleigh	enum	
RiceanFactor	Ricean factor, effective only when ModelType is set as UserDefined and FadingType is set as Ricean	10	int	[1, ∞)
Seed	integer number to randomize channel output(Jakes model)	1234567	int	(-∞, ∞)

Name	Description	Default	Type	Range
N	number of oscillators in Jakes model	80	int	(PathNumber, ∞)
Pathloss	option for inclusion of large-scale pathloss: No, Yes	No	enum	
Env	environment type options: TypicalUrban, TypicalSuburban, RuralArea, FreeSpace	TypicalUrban	enum	

Pin Inputs

Pin	Name	Description	Signal Type
1	input	channel input signal	timed

Pin Outputs

Pin	Name	Description	Signal Type
2	output	channel output signal	timed

Notes/Equations

1. This component is used to simulate a multi-path fading channel based on a tapped-delay line model. Each firing, one token is consumed at the input pin, and one token is produced at the output pin.
2. The multipath delay profile determines the frequency selective nature of the channel. Delay profile is specified by the user via the ModelType, DelayArray, and PowerArray parameters.
3. The fading type of the first path can be Rayleigh or Ricean; if FadingType = Ricean, RiceanFactor determines the power ratio of the direct signal to all other indirect signals.
4. If ModelType = A, B, C, D or E, the PathNumber, DelayArray, FadingType, and RiceanFactor parameters are automatically set according to [2].

   If ModelType = UserDefined, the user determines channel characteristics by setting these parameters.

   If ModelType = NoMultipath, only Doppler frequency shift is incorporated.

5. The delay spread is modeled via a tapped delay line where the number of taps is based on the size of DelayArray and PowerArray. In each case the input signal is delayed and the carrier phase due to the delay signal is incorporated.

   Figure 1-26 illustrates this modeling process when connected to a simple antenna.

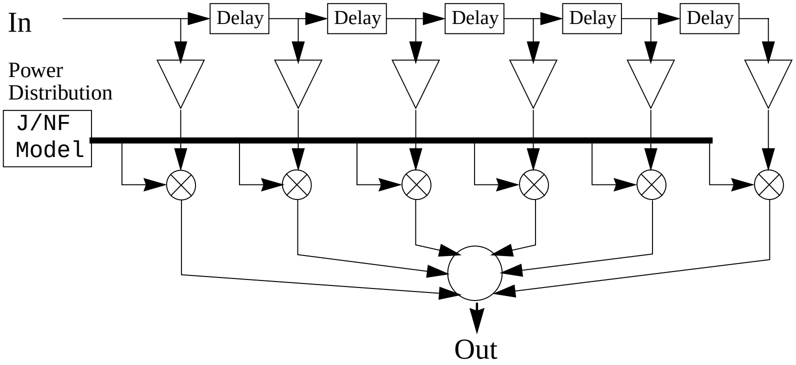


Figure 1-26. Delay and Doppler Spread and Carrier Phase Shift

6. If DelayArray values are not the time as Tstep, the interpolation is made to gain this point of signal and a delay of 64 tokens is introduced.
7. For each tap, Jakes model or noise filter model provides Doppler spectrum as well as the fading channel specifications.
   - Jakes model uses N_0 low-frequency oscillators to generate a fading waveform.

$$T(t) = \sum_{n=1}^{N_0} [\cos(\beta_n) + i\sin(\beta_n)]\cos(\omega_n t + \theta_n)$$

where

$$\omega_n = \omega_m \cos(2\pi n / N)$$
$$N = 2 \times (2 \times N_0 + 1).$$

The maximum Doppler frequency offset $\omega_m = 2\pi V/\lambda$, λ denotes wave-length of carrier. β_n is set as $\beta_n = 2\pi/N_0$. Original phase shifts θ_n are randomized and uniformly distributed over $[0, 2\pi]$. $N_0 = 80$ is used in the component.

Details about Jakes model can be found in reference [1].

- Noise filter model feeds white Gaussian noise to a digital filter matched to the respective fading spectrum, i.e., the filter frequency response must be a good approximation to the square root of the (normalized) tap power spectral density. An interpolator with rate conversion factor follows. Changing tap Doppler spreads is done by simply changing the interpolation factor.

  This implementation is illustrated in Figure 1-27. The AWGN, filter, and interpolator outputs are complex. The filter and AWGN operate at the signal sampling rate. An 8th-order IIR filter is used for classic and flat spectrums whose normalized fading frequencies are 0.05686. A simple linear interpolator often suffices for changing Doppler spreads.

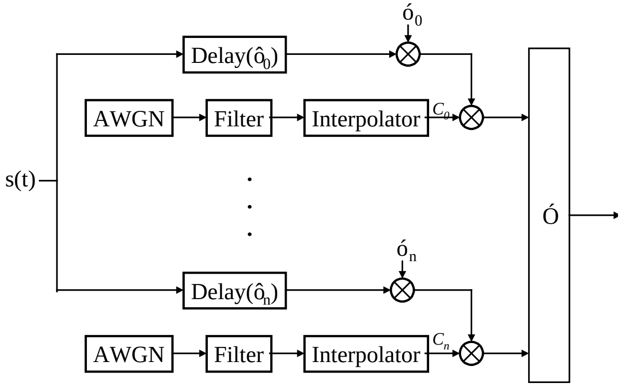


Figure 1-27. Noise Filter Model Implementation

8. If speed is zero, the channel is not a time-variant. However, multipath still exists so a static channel is applied and each tap is a complex constant value.The complex constant value is randomly generated and can be changed by changing the Seed parameter.
9. Five model types have been designed based on reference [2]:
   - Model A corresponds to a typical office environment.
   - Model B corresponds to a typical large open-space environment with NLOS conditions or an office environment with a large delay spread.
   - Models C and E correspond to typical large open-space indoor and outdoor environments, respectively, with a large delay spread.

- Model D corresponds to LOS conditions in a large open-space indoor or outdoor environment.

Characteristics of these models are listed in Table 1-12 through Table 1-16.

Table 1-12. Model A: Typical Office Environment with NLOS Conditions and 50ns Average rms Delay Spread

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
1	0	0.0	0	Class
2	10	-0.9	0	Class
3	20	-1.7	0	Class
4	30	-2.6	0	Class
5	40	-3.5	0	Class
6	50	-4.3	0	Class
7	60	-5.2	0	Class
8	70	-6.1	0	Class
9	80	-6.9	0	Class
10	90	-7.8	0	Class
11	110	-4.7	0	Class
12	140	-7.3	0	Class
13	170	-9.9	0	Class
14	200	-12.5	0	Class
15	240	-13.7	0	Class
16	290	-18.0	0	Class
17	340	-22.4	0	Class
18	390	-26.7	0	Class

Table 1-13. Model B: Typical Large Open-Space and Office Environments with NLOS Conditions and 100ns Average rms Delay Spread

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
1	0	-2.6	0	Class
2	10	-3.0	0	Class
3	20	-3.5	0	Class
4	30	-3.9	0	Class
5	50	0.0	0	Class
6	80	-1.3	0	Class
7	110	-2.6	0	Class

Table 1-13. Model B: Typical Large Open-Space and Office Environments with NLOS Conditions and 100ns Average rms Delay Spread (continued)

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
8	140	-3.9	0	Class
9	180	-3.4	0	Class
10	230	-5.6	0	Class
11	280	-7.7	0	Class
12	330	-9.9	0	Class
13	380	-12.1	0	Class
14	430	-14.3	0	Class
15	490	-15.4	0	Class
16	560	-18.4	0	Class
17	640	-20.7	0	Class
18	730	-24.6	0	Class

Table 1-14. Model C: Typical Large Open Space Environment with NLOS Conditions and 150ns Average rms Delay Spread

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
1	0	-3.3	0	Class
2	10	-3.6	0	Class
3	20	-3.9	0	Class
4	30	-4.2	0	Class
5	50	0.0	0	Class
6	80	-0.9	0	Class
7	110	-1.7	0	Class
8	140	-2.6	0	Class
9	180	-1.5	0	Class
10	230	-3.0	0	Class
11	280	-4.4	0	Class
12	330	-5.9	0	Class
13	400	-5.3	0	Class
14	490	-7.9	0	Class
15	600	-9.4	0	Class
16	730	-13.2	0	Class
17	880	-16.3	0	Class
18	1050	-21.2	0	Class

Table 1-15. Model D: Typical Large Open Space Environment with LOS Conditions and 150ns Average rms Delay Spread; a 10 dB spike at zero delay has been added resulting in an rms delay spread of approximately 140ns

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
1	0	0.0	10	Class+spike
2	10	-10.0	0	Class
3	20	-10.3	0	Class
4	30	-10.6	0	Class
5	50	-6.4	0	Class
6	80	-7.2	0	Class
7	110	-8.1	0	Class
8	140	-9.0	0	Class
9	180	-7.9	0	Class
10	230	-9.4	0	Class
11	280	-10.8	0	Class
12	330	-12.3	0	Class
13	400	-11.7	0	Class
14	490	-14.3	0	Class
15	600	-15.8	0	Class
16	730	-19.6	0	Class
17	880	-22.7	0	Class
18	1050	-27.6	0	Class

Table 1-16. Model E: Typical Large Open Space Environment with NLOS Conditions and 250ns Average rms Delay Spread

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
1	0	-4.9	0	Class
2	10	-5.1	0	Class
3	20	-5.2	0	Class
4	40	-0.8	0	Class
5	70	-1.3	0	Class
6	100	-1.9	0	Class
7	140	-0.3	0	Class
8	190	-1.2	0	Class
9	240	-2.1	0	Class

Table 1-16. Model E: Typical Large Open Space Environment with NLOS Conditions and 250ns Average rms Delay Spread (continued)

Tap Number	Delay(ns)	Average Relative Power	Ricean K	Doppler Spectrum
10	320	0.0	0	Class
11	430	-1.9	0	Class
12	560	-2.8	0	Class
13	710	-5.4	0	Class
14	880	-7.3	0	Class
15	1070	-10.6	0	Class
16	1280	-13.4	0	Class
17	1510	-17.4	0	Class
18	1760	-20.9	0	Class

References

[1] W. C. Jakes, *Microwave Mobile Communications*, IEEE Press, 1994.

[2] Channel Models for HIPERLAN/2 in Different Indoor Scenarios, ETSI EP BRAN 3ER1085B 30 March 1998.

Index