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Fading Simulation Made Easy

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presented by:

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All wireless devices, from WLAN to W-CDMA, have one thing in common – no wires. Signals passing through the air are distorted by atmospheric impairments including multipath and dispersion. This paper will briefly introduce several commonly used mathematical techniques for simulating real-world channel conditions in various fading and noise environments, provide a justification for why channel simulation is important to device designers, and discuss the traditional test methods used today. A new implementation of channel simulation will be introduced, promising to alleviate some of the toughest and most cost-intensive challenges of the traditional testing model through an innovative all-digital process that offers high bandwidth and automatically calibrated noise.

Agenda



What is fading?

What are the effects of fading?

How do I simulate the effects of fading?

How can Agilent help me verify my design?



The purpose of today's presentation is twofold: one is to provide education about channel simulation and two is to introduce a new product that Agilent is excited to bring to the market. First, I will offer an overview of fading theory. I will then discuss the various ways that fading influences wireless communications. The third section will cover some of the common fading profiles used to simulate an impaired channel. After talking about the challenges of fading simulation, I will introduce Agilent's new solution for baseband design verification. We will end by looking at some examples of how to use this solution to simulate fading for your device under test. The scope of this material is aimed at those engineers who have some very basic knowledge of fading, but technically we will stay fairly general. For those who work in the field and are knowledgeable about fading already, the second half of the presentation will probably be of more interest.

Agenda



What is fading?

What are the effects of fading?

How do I simulate the effects of fading?

How can Agilent help me verify my design?

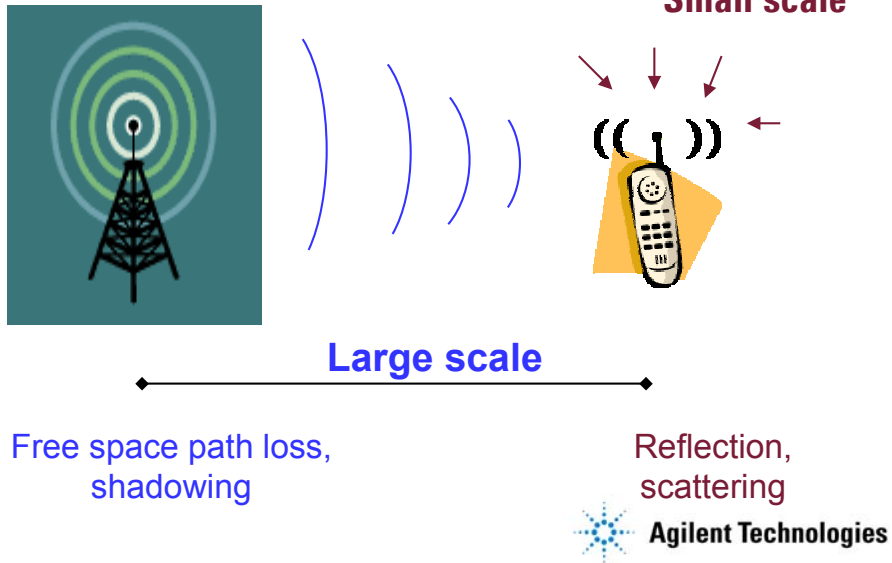


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In order to make sure we are all on the same track, let's first discuss what fading means. In the following section, I will give a brief overview of the physical phenomenon of fading, and how it can be viewed in terms of its effect over large distances and small distances. They are different in what causes them and also how they affect the transmitted signal.

What is fading?

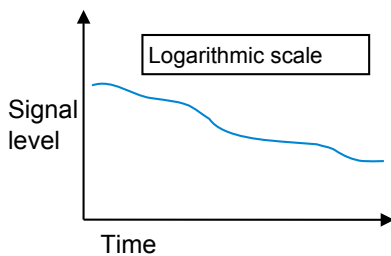
Overview



Communications quality between a base station transmitter and mobile (or stationary) receiver depends on a number of factors, including the general quality of the propagation channel through which the signal passes. In wireless applications, and especially cellular communications, the propagation path is terrestrial air with a myriad number of man-made and natural objects that get in the way. As the transmitted signal gets absorbed by the atmosphere and reflects off of buildings and trees, it experiences fluctuations in its amplitude and phase. This phenomenon is generally referred to as fading. The mechanism of fading is normally broken down into two different categories based on position of the receiver relative to the transmitter: large-scale fading for channel propagation over long distances, and small scale fading for effects that are found near to the receive antenna. Note that the small scale effects can be observed at the receive antenna of the base station as well as the mobile station.

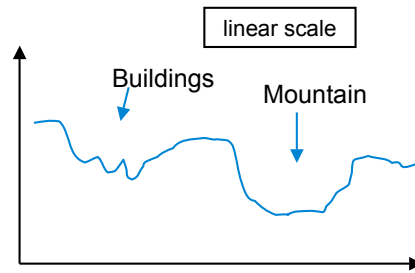
What is fading?

Overview - Large scale



**Free space path loss
(log-normal)**

average attenuation,
exponentially proportional
to distance



**Shadowing
(diffraction)**

secondary wavelets “wrap
around” large objects



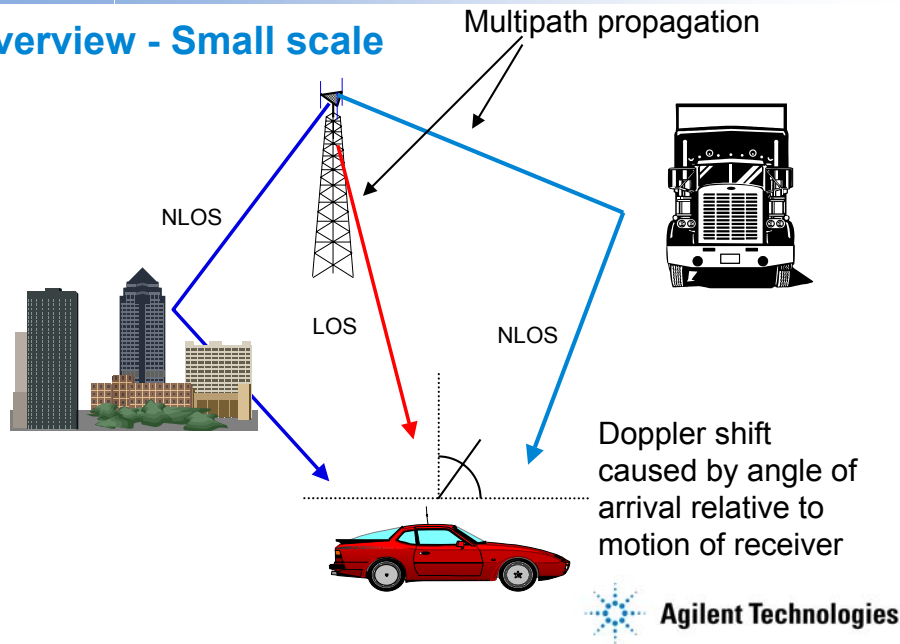
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Large scale fading essentially represents the average attenuation of a wireless signal as it travels a long distance (several hundred wavelengths or more). Degradation due to blockage by large objects is sometimes referred to as shadowing, because the fade area is very large and tends to blanket the area surrounding the antenna.

Mathematically, large scale fading is simulated by a log-normally distributed fluctuation superimposed on a mean path loss that is distance dependent. The distance dependence describes the average attenuation experienced as the signal travels through the atmosphere. An ideal signal traveling through free space would experience a path loss proportional to the distance squared. In the real world, a signal's energy is absorbed and reflected by the atmosphere, the curvature of the earth, and obstacles. Obstacles can be natural (trees, mountains, bodies of water) or man-made (buildings, billboards, streets). This usually causes the performance to degrade beyond the theoretical inverse-squared free space path loss law. The fluctuations on this average occur from shadowing effects, which are manifestations of the physical principle of diffraction. Diffraction allows signals to “wrap” themselves around corners and over edges of buildings, as secondary wavelets are produced at intersections of incident waves with boundaries.

What is fading?

Overview - Small scale



In addition to path loss over large distances, the receive antenna will also experience fluctuations in signal level that vary significantly over small distances (on the order of one to tens of wavelengths). The fluctuation is a result of two distinct processes: multipath propagation and Doppler shift.

The signal being transmitted from the base station can take different paths to the receiver, due to reflection, diffraction, and local scattering. (Hence the name 'multipath' fading.) Direct paths are also known as line of sight (LOS) paths, while reflected rays are called non line of sight (NLOS.) Different paths have different lengths associated with them, which causes the receiver to see multiple copies of the signal at different times of arrival. Also, the signal can shift in phase as it is reflected and scattered off of local objects. All of these signals at different power levels and phase converge on the receive antenna with constructive or destructive interference. As the antenna moves through space, it will experience peaks and valleys of signal strength as these interfering wavelets add and subtract at the receiver.

Another artifact of motion is Doppler shift. As the receive antenna moves in relation to a fixed transmitter, the incoming signal will modulate in frequency according to the direction of movement. Copies of the signal that arrive via paths directly in front of the moving receiver will seem to have a higher frequency, while copies of the signal arriving via paths behind the moving receiver will seem to have a lower frequency.

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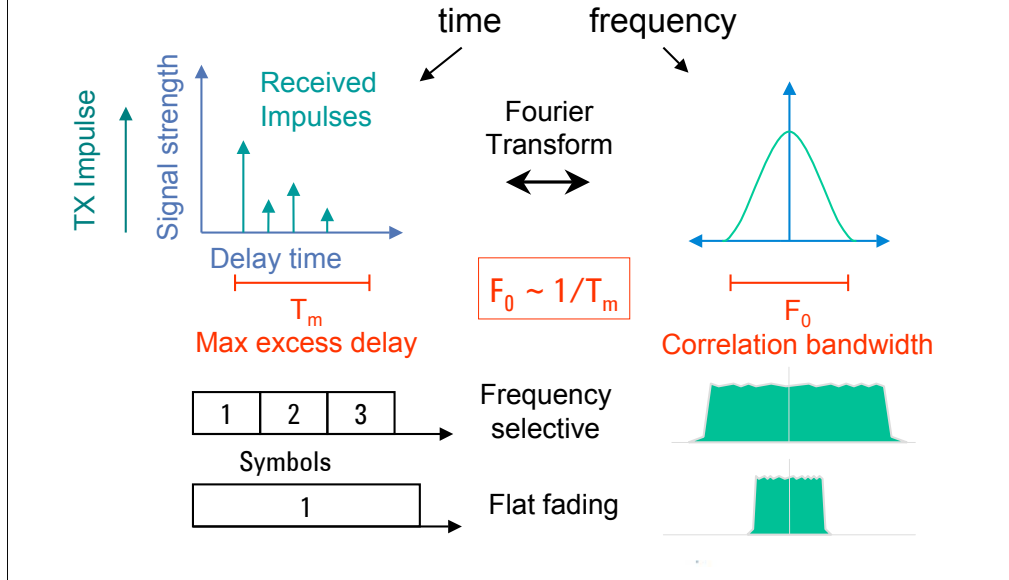


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Now that we have a general idea of what causes fading, let's talk about the effects of fading. Because small-scale fading is less predictable and more potentially destructive than large-scale fading, most of the presentation will focus on small-scale effects. In the next series of slides, I will show how multipath reflection and Doppler shift alter the transmitted signal and how that makes it more difficult for the receiver to accurately detect the altered signal. The last slide in this section will introduce some common design techniques utilized to mitigate the effects of fading in a wireless link.

How does fading affect my signal?

Time spreading



One effect of multipath propagation is to spread the signal in time, so that there is some finite delay between when the antenna receives the first copy of the signal on the shortest path and when it receives the last copy of the same signal on the longest path. The maximum excess delay time is represented by T_m . (The RMS value of delay spread is more commonly used in practice than the maximum delay time, but is a bit more mathematically complex.) The delay spread answers the question, “If I send an impulse, how does my received power change as a function of the delay time *after* I receive the first part of the signal?” This tells us how the channel disperses the signal in time.

When observed in the frequency domain, the delay spread manifests itself as a sort of frequency notch filter. The coherence bandwidth, which is represented by f_0 , is the range of frequencies within which the signal impairments of the channel don't vary significantly. In other words, if two signals are sent that are more than f_0 apart from each other in frequency, they will experience different channel conditions. F_0 is inversely proportional to T_m .

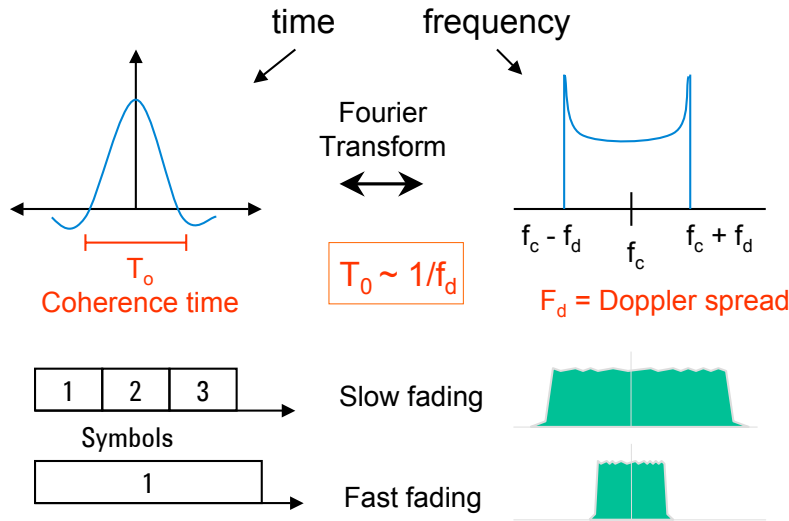
If the time taken to transmit one symbol is longer than the maximum delay spread ($T_s > T_m$), the path is said to exhibit flat fading, which means that all the multipath components of the transmitted symbol are received within one symbol period. Since signaling rate is inversely proportional to symbol period, this is equivalent to the case where the symbol bandwidth is less than the coherence bandwidth. ($B < f_0$).

On the other hand, frequency selective fading occurs when $T_s < T_m$ or when $B > f_0$. In this case, different spectral components of the signal will be altered by the channel in different ways. As a result, a wideband signal could see a large variation in received power over its bandwidth.

Typical RMS delay spread in an urban environment is $\sim 2\mu\text{s}$. For perspective, a cdma2000 signal with a chip rate of 1.28MHz will send a symbol in 78 μs and a W-

How does fading affect my signal?

Time variance



The multipath effects seen on the previous slide can affect a receiver that is stationary, since a transmitted signal will always experience reflection when encountering objects. For receivers that change their location relative to the transmitter, there are other factors in addition to multipath reflection that affect the signal's amplitude and phase. To distinguish from the time spreading discussed earlier, these effects can be described as time variance or spatial variance. Now we are asking, "If I send an impulse at time t_1 , then I send the same impulse at time t_2 , how much different are they as a result of the varying channel?". This tells us not about the fading conditions, but *how rapid the fading conditions are changing*. Remember that if we assume an antenna moves with a constant velocity, sending impulses separated in time is identical to sending impulses separated in space.

One important thing to know when sending a signal through a varying channel is how long you have before the conditions change. This is called the coherence time, T_0 . In more technical terms, T_0 is the time period over which the channel's impulse response is highly correlated.

If we look at time variance in the frequency domain, we see that a receiver antenna in constant motion will experience shifts in frequency that are dependent on the angle of arrival of the incoming signal and on the speed of motion. Instead of the signal being spread in time, now we see it being spread in frequency. This Doppler spread, which is represented by f_d , is reciprocally related to the coherence time T_0 .

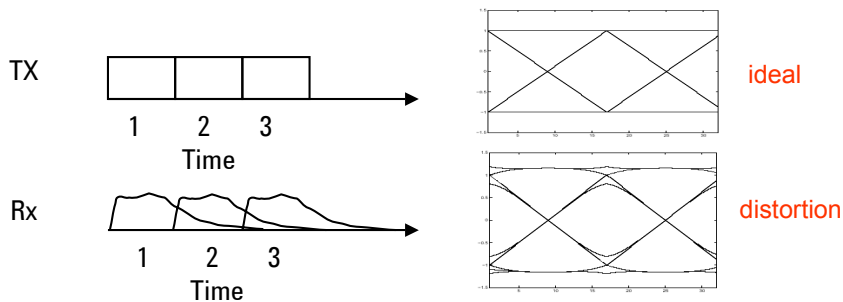
If the symbol period is longer than the coherence time ($T_s > T_0$), the channel exhibits fast fading, because the fading conditions are coming and going faster than the symbols are being transmitted. This is the same thing as saying that the user bandwidth is smaller than the Doppler spread, or $B < f_d$.

If $T_s < T_0$ (or $B > f_d$), the channel exhibits slow fading, meaning that the channel conditions are stable and predictable during the time that the symbol is transmitted. Note that for most cellular applications, the user bandwidth is generally orders of magnitude greater than the frequency spread, so we usually see slow fading effects.

One word of warning: since symbol frequency is inversely related to symbol period, changing the

How does fading affect my device?

- **Reduced signal to noise ratio (SNR)**
- **Intersymbol interference**
- **Must account for total fading margin in link budget analysis**



Intersymbol interference on BPSK modulated signal



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Large-scale direct path fading results mostly in attenuation of the overall signal level. Path loss is heavily dependant on distance. The effect on the device is to reduce SNR by lowering received signal power.

Shadowing and large scale reflection can be represented as deviations from the mean path loss described above. These variations, when measured on a log scale, tend to have a normal (or Gaussian) distribution. It will typically degrade the signal 6-10dB in addition to the direct path attenuation described above.

Small-scale fading by multipath and Doppler is the most potentially destructive and can be observed at the receive antenna in a number of ways. Frequency selective fading causes intersymbol interference (ISI), where adjacent symbols on the transmit side seem to melt together on the receive side, making accurate detection more difficult. This is illustrated above for a BPSK signal. Flat fading degrades SNR because reflections cause phasor components to cancel each other out. Fast fading distorts the transmitted baseband pulse, which can cause synchronization problems in phase locked loops. Like flat fading, slow fading will also reduce SNR. Worst case scenario for NLOS small scale fading will degrade the signal 20-30dB in the deepest fades when multipath components come in directly out of phase..

What this means for a device designer is that sufficient “fading margin” must be built into the link budget. The signal power must be strong enough, or the receiver sensitive enough, to withstand a fading condition in excess of 40-50dB of loss.

What can I do to reduce fade effects?

- ⊕ **Signal conditioning**
 - limits on bandwidth and bit rate
- ⊕ **Error correction**
 - interleaving and coding
- ⊕ **Device design**
 - Rake receiver – CDMA
 - Adaptive equalizer – GSM
- ⊕ **Modulation format**
 - OFDM, UWB



The best performance of a wireless link will only be realized in the absence of any type of channel impairment. The presence of Gaussian noise prevents the wireless channel from being completely clear, but there are a myriad of techniques that can be employed in the design of wireless devices to reduce the effects of fading. These techniques reduce the error probability from the worst-case Rayleigh curve and bring it closer to the best case AWGN curve. As we have seen in earlier slides, fading can take a number of different forms. Frequency selective fading or fast fading affects the bit error rate probability significantly, while flat fading and slow fading affect it less significantly. When designing a wireless link to withstand fading degradation, it is important first to determine what kind of fading is evident in the channel. When this is known, the bit rate used can be chosen to reduce the avoidable errors.

Equalization is a commonly used technique to fight ISI caused by frequency selective fading. The process invokes a filter that has an impulse response opposite of that of the propagating channel. Thus the combination of the transmission path plus the receive filter yields a flat, linear response. GSM uses adaptive equalization to mitigate distortion.

CDMA technologies use a Rake Receiver to mitigate ISI. It involves using special filters (called fingers) that sniff out the spread out signal components, collect them, and add them coherently by delaying the earlier arriving paths longer than the later arriving paths.

Interleaving and coding can be used to reduce the E_b/N_0 required for accurate detection. Coding provides redundancy by sending multiple copies of the signal on orthogonal symbol paths. Interleaving provides robustness to the link by spreading errors out in time, avoiding large amounts of contiguous data loss that would cut a wireless link.

Then there are transmission technologies whose signaling properties avoid the most common effects of fading. Ultra wideband transmits pulses of such short duration that they are not affected by delay spread in a channel. Orthogonal Frequency Division Multiplexing avoids frequency selective fading by breaking the carrier signal into subcarriers with lower bit rates and thereby longer symbol durations.

Agenda



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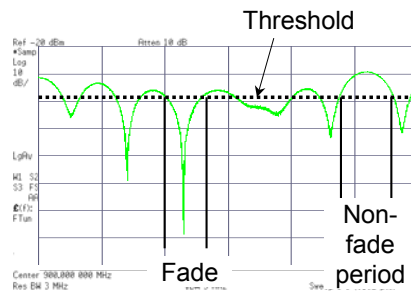
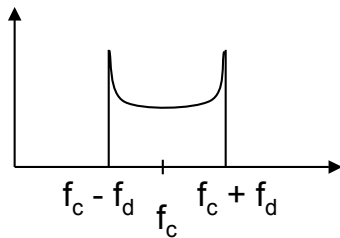
We all agree that a signal propagating through a wireless channel is necessarily impeded by fading. In order to design devices that can withstand this impairment, it is important to have tools that can represent the phenomenon in a laboratory setting. These tools recreate the real-world effects by mathematically generating conditions that mimic large-scale and small-scale fading. The mathematical representations are based on models that use statistics to predict how electromagnetic energy behaves during propagation. In this section of the presentation, I will describe a few of the classical models of fading and give some examples of fading tests that are required in the major cellular communications standards documents.

Common fading profiles

Rayleigh

$$S(f) \propto \left\{ \frac{1}{f_d \sqrt{1 - \left(\frac{f - f_c}{f_d} \right)^2}} \right\} |f - f_c| < f_d$$

f_c = carrier freq, f_d = Doppler spread



- No line of sight
- Deep fades separated by half-wavelength on average
- Worst-case scenario



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The Rayleigh distribution is a good model for channel propagation when there is no strong line of sight path from transmitter to receiver. This can be used to represent the channel conditions seen on a busy street in a city, where the base station is hidden behind a building several blocks away and the arriving signal is bouncing off many scattering objects in the local area. In the time domain, Rayleigh fading looks like periodic peaks of 10dB or less interspersed between deep troughs of 40dB or more. (see the illustration in upper right) These deep fades (nulls in signal power) will typically occur at separations of a half-wavelength.

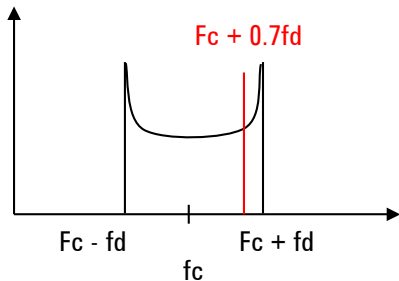
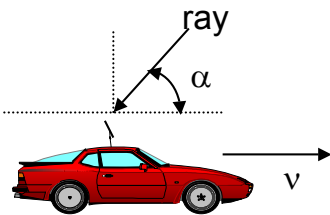
In the frequency domain, the effect is the U-shaped curve seen in the bottom left of the illustration. The dense scatterer model, which explains cellular communications propagation, states that the amplitude of multipath rays will follow a Rayleigh distribution, while the angle of arrival (multipath phase) follows a uniform distribution.

The Doppler shift of each incident ray is given by the following formula: $\Delta f = (v/\lambda)\cos\alpha$, where v is the speed of the receiver, λ is the wavelength of the signal, and α is the angle of arrival relative to the direction of motion.

The max spread f_d is determined by the speed of the vehicle and is only experienced by the spectral components arriving on paths directly in front of (max positive) or directly behind (max negative) the motion of the receiver. No shift is seen at 90 and 270 degrees relative to the motion. This is why we see the most spectral density at the edges of the Doppler spread, which correlate to the rays that are coming in directly in front of and directly behind the motion of the antenna. In theory, these edges are infinitely high, but for wireless design verification purposes, the cutoff is typically 6dB between power at F_c and power at $F_c \pm F_d$.

Common fading profiles

Rician



$$S(f) \propto \left\{ \frac{P_{Ry}}{\pi f_d \sqrt{1 - \left(\frac{f - f_c}{f_d}\right)^2}} + P_{Rc} \delta[(f - f_c) - \theta_{Rc} f_d] \right\}$$

if $|f - f_c| < f_d$, where

P_{Ry} = coefficient of power of Rayleigh component

P_{Rc} = coefficient of power of Rician component

θ_{Rc} = angle of arrival of Rician direct path

- Rayleigh + direct path
- Good for rural areas
- K factor ratio between direct path and NLOS paths



Let me repeat the Doppler shift theory explained on the previous page. The Doppler shift of each incident ray is given by the following formula: $\Delta f = (v/\lambda)\cos\alpha$,

where v is the speed of the receiver, λ is the wavelength of the signal, and α is the angle of arrival relative to the direction of motion.

The max spread f_d is determined by the speed of the vehicle and is only experienced by the spectral components arriving on paths directly in front of (max positive) or directly behind (max negative) the motion of the receiver. (Because this is where the cosine of the angle of arrival is 1. At any other angle the cosine is less than 1.) No shift is seen at 90 and 270 degrees relative to the motion. This is why we see the most spectral density at the edges of the Doppler spread, which correlate to the rays that are coming in directly in front of and directly behind the motion of the antenna. In theory, these edges are infinitely high, but for wireless design verification purposes, the cutoff is typically 6dB between power at F_c and power at $F_c \pm F_d$.

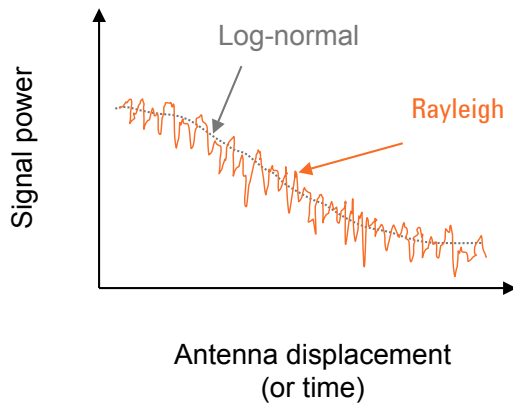
Rayleigh fading is considered a worst case scenario. In rural environments, where the multipath profile includes a few reflected paths combined with a strong line of sight path, the spectral power follows a Rician distribution. The angle of arrival of the direct ray, as well as the ratio of the power between the direct ray and the multipath rays, determine how much effect the energy from the direct path has on the normal Rayleigh model. Observing this effect in the frequency domain, what you see is a spike in power corresponding to the frequency shift attributed to the direct ray.

As an example, in the GSM specifications, the angle of arrival of the direct path is set to 45 degrees. We take the cosine of the angle to see how much statistical weight we give to that particular path. In this case it is 0.7. Thus we have a spike in received signal power at 0.7 times the max frequency shift. The Rician model also allows for setting the ratio of power between the direct path and the Rayleigh paths. This ratio is called the K factor.

Note: I have used a basic CW tone to illustrate the concept of the Doppler Spread. If you were to look at a typical 5MHz W-CDMA modulated signal in a spectrum analyzer, you would not see this power spike, as a Doppler shift of several hundred Hz would be virtually undetectable over the signal bandwidth.

Common fading profiles

Suzuki



- Log-normal + Rayleigh fading
- Rayleigh represents small scale fading
- Log-normal represents large-scale fading



Suzuki fading superimposes small scale fading (or fast fading) from multipath onto large scale fading (or slow fading) from reflection and diffraction. The large scale follows a log-normal distribution and the small scale follows a Rayleigh distribution.

What do the standards say about fading?

Channel	Section	Test
W-CDMA UE Receiver Tests (from 3GPP TS 34.121 V3.12.0, 2003-03)		
DCH	7.3	Demodulation in multi-path fading
	7.4	Demodulation in moving propagation
	7.5	Demodulation in birth/death propagation
	7.6	Demodulation of DCH in downlink transmit diversity
cdma2000 BTS Receiver Tests (from 3GPP2 C.S0010-B V1, 2002-12)		
Common Control Channel	3.3.2	Demodulation performance in multipath fading with closed loop power control
Reverse Traffic Channel	3.4.2	Demodulation performance in multipath fading without closed loop power control
	3.4.3	Demodulation performance in multipath fading with closed loop power control



Most of the major cellular communications standards currently accepted suggest guidelines for testing a wireless device under fading conditions. Here is a small example of some of the tests required by the 3GPP and 3GPP2 specifications. There are also tests either required or suggested by the following standards:

GSM/EDGE

WLAN (802.11)

1xEV-DO

COST 259

TS-SCDMA

CdmaOne


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 **How can Agilent help me verify my design?**



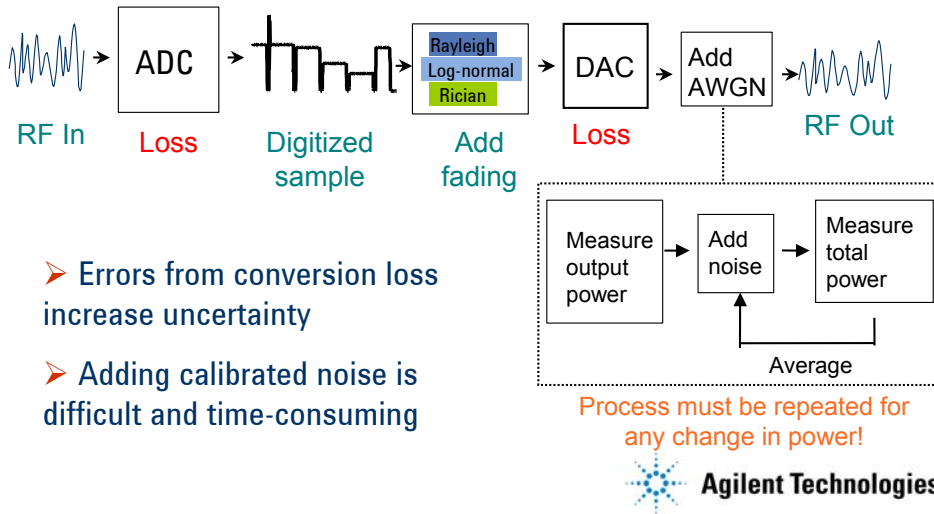
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In the next section I would like to introduce a new fading simulation tool from Agilent called Baseband Studio for Fading. It is one part of an exciting new suite of design verification tools now being offered by Agilent. Baseband Studio is a set of products providing baseband signal processing functions. Integrated with Agilent signal creation software and RF or microwave generation hardware, they simplify verification and testing at any device plane. A PC equipped with a Baseband Studio PCI card can now run two new software applications: N5110A Baseband Studio for Streaming and N5115A Baseband Studio for Fading. (Note: at this time the two software packages are not compatible with each other.) Baseband Studio for Streaming enables unique baseband waveform data of virtually unlimited length to be streamed from a PC hard drive into an ESG or PSG for RF or microwave signal simulation. Baseband Studio for Fading provides digitally integrated fading of ESG baseband signals along with calibrated noise in a single easy-to-setup solution. The N5102A Baseband Studio Digital Signal Interface Module delivers the ESG and PSG baseband signals in the form of digital I/Q and digital IF data for testing your cellular, wireless networking and aerospace/defense devices and subsystems.

To set the stage for why Agilent has developed this new fading simulation instrument, I will give a brief overview of a couple of the challenges associated with the current method of channel simulation.

What are the challenges?

Conversion Loss and Noise Calibration



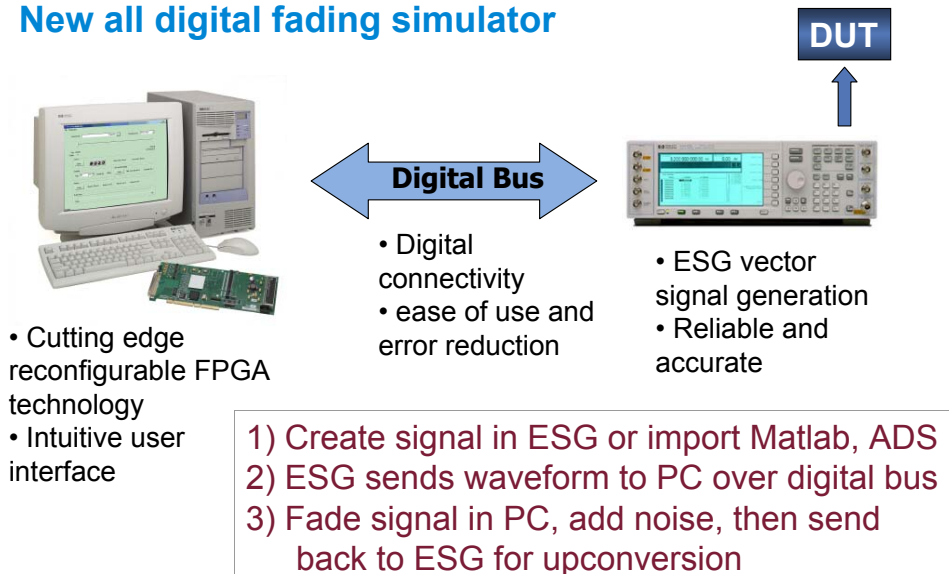
Current methods of channel simulation operate on an RF in, RF out basis. In this process, the signal to be faded is downconverted and digitized. The fading profile is added to the digital signal and the result is upconverted back to RF. Then the noise is added in. Noise must be kept separate from the fading profile because AWGN is independent of any multipath channel response. There are two major inefficiencies in this process: conversion loss and noise calibration.

Conversion loss occurs every time a signal is sampled from analog or reconstructed to analog. This adds errors to the system that are caused by the test equipment, not the channel or device under test. The more you can reduce these errors the more accurate simulation you will achieve.

When adding AWGN to the signal, it is crucial to add it at the right level. It must be inserted after fading so that the background noise doesn't get attenuated. But adding noise changes the total power level as well as the carrier to noise ratio. (C/N) In order to calibrate the noise level to the incoming signal power, it is necessary to determine the carrier power after fading. This can be a time-consuming process, since many measurements must be taken at several output power levels to get a statistically correct pdf. Towards the end of a device's design cycle, this extra time can be very expensive.

What does Agilent have to offer?

New all digital fading simulator

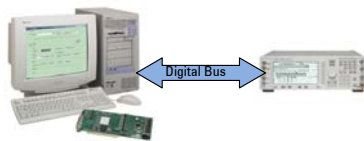
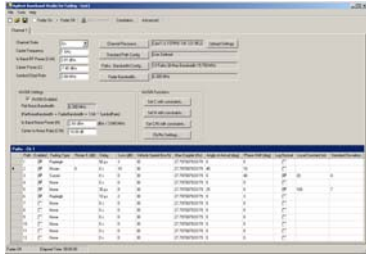


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For R&D engineers working on digital design in wireless devices, Agilent has developed a new channel simulation technique that will reduce design verification time through faster and more accurate channel simulation. The new method enhances the capabilities of the industry leading ESG vector signal generation platform by offering an intuitive software interface packaged with state of the art baseband generation hardware. The ESG creates digital baseband IQ signals using its own internal waveforms, Signal Studio applications, or custom waveforms created by mathematical modeling tools such as Agilent Eesof's Advanced Design System (ADS) or Matlab. These digital baseband signals are streamed to a PC containing the Baseband Studio PCI Card and Baseband Studio for Fading software, where the channel simulation parameters are configured through the easy to use software interface. The baseband signal is faded digitally in the Baseband Studio PCI Card and then sent back to the ESG for conversion to analog I/Q or RF.

Baseband Studio for Fading

Feature Overview



- Simple and easy AWGN
 - Digital accuracy in C/N
- Optimize paths and bandwidth
 - Choose up to 48 paths or 30 MHz bandwidth
- One or two channel fading
 - Up to two channels for testing with antenna diversity or interfering signals
- A variety of fading profiles
 - Rayleigh, Rician, Suzuki, or pure Doppler
- Preconfigured setups for wireless formats
 - WLAN, W-CDMA, GSM, 1xEV-DO and others
- Programmable control with .NET API
 - Automate the channel simulation process



Value Proposition

For design engineers in the cellular communications, WLAN and A/D industries **who** create and verify component, transceiver or subsystem designs, **our** Baseband Studio for Fading product **provides** a signal stimulus that emulates real-world signal conditions to reduce design iterations. This solution saves you time and money by enabling test efficiencies that have not previously been possible, including digitally integrated fading and calibrated noise in one easy-to-set up solution. Some highlights:

Optimize paths or bandwidth

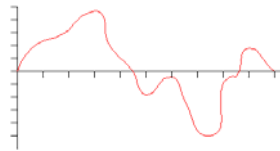
Baseband Studio for fading offers two bandwidth options, 17 MHz or 30 MHz, so you can choose the level of performance you need, whether you need to fade signals for cellular radio formats or WLAN applications. The exact bandwidth of the faded channel depends on the sample rate of the signal delivered to Baseband Studio for fading. Signals that are sampled at a higher rate will have a greater fading bandwidth available. The E4438C ESG signal creation applications automatically optimize the sample rate for the highest possible fading bandwidth.

Baseband Studio for fading supports a minimum of 15 paths for a 17 MHz bandwidth and 9 paths for a 30 MHz bandwidth to meet your most demanding fading needs. A unique processing algorithm in the Baseband Studio PCI Card enables more paths to be available if the maximum fading bandwidth is not required for a particular application. Up to 48 paths can be realized for narrow bandwidth applications.

One- or two-channel fading

What's the big deal?

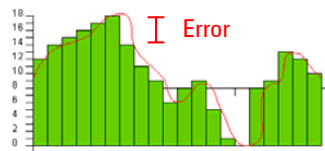
All digital – no added quantization errors



1



2



3

1. Original analog signal
2. Low resolution sample
3. High resolution sample



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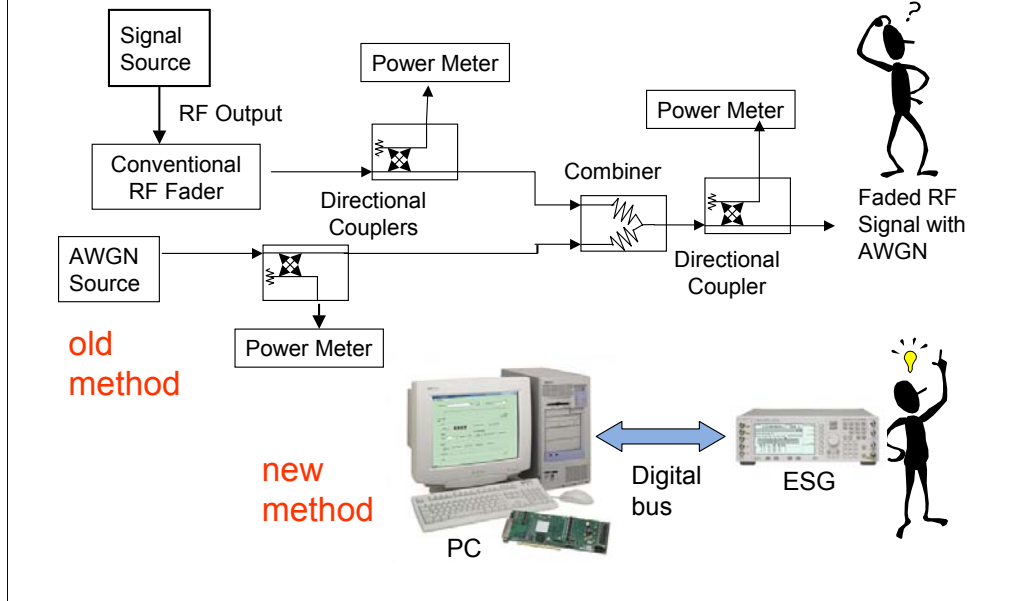
As was mentioned before, the traditional process of digitizing an incoming RF signal, then fading it, then upconverting it back to RF adds a lot of unnecessary uncertainty to the process. This uncertainty is caused by non-linear distortion in the DAC, quantization error, clipping, sampling misinterpretation, carrier feedthrough, and others. All this extra error margin must be taken into account when testing a new wireless device.

One way is to increase the resolution of the digitizer, using a higher data rate to better approximate the original analog signal. The best solution is to not convert at all! These errors could be eased significantly if the entire process was completed digitally using the original digital I/Q output from a signal generator. There are no extra errors added in downconversion, because there is no digitization process. The signal is generated in the ESG's baseband memory, then sent to the fader as a digital signal. The amplitude accuracy of a signal in fading is just as good as in the signal generator itself! Like a CD records music with much less error than a vinyl record, fading the signal in an all digital process reduces errors in normal analog to digital and digital to analog conversion.

Note: obviously for some applications, such as conformance test, there is no way around the downconversion. But for accurate design verification in the early stages of product development, keeping the waveform data in its digital form is the best way to reduce instrument-added errors.

What's the big deal?

All digital – calibrated and integrated noise



Adding AWGN to a faded signal has often created problems in setting the desired carrier-to-noise ratio or E_b/N_o . Traditional faders typically do not include a built-in AWGN generator, resulting in the need to combine two different RF signals to achieve the overall ratio. This often involves a lengthy calibration cycle requiring power meters and determining overall system uncertainties. Baseband Studio for Fading seamlessly integrates with the E4438C ESG, eliminating calibration issues associated with traditional fading simulators. The baseband signal from the ESG is sent to Baseband Studio for Fading as a 16-bit digital signal. Baseband Studio adds the multipath fading and AWGN to the original baseband data, all in the digital domain. In fact, the entire channel simulation process remains digital right up to the point where it is upconverted to RF. This results in an exceptional C/N ratio accuracy because the uncertainties associated with adding analog signals has been eliminated.

What's the big deal?

Software interface makes configuration a snap

Channel
setup

Noise
settings

Path
profiles

The screenshot displays the Agilent Baseband Studio for Fading software interface. The window title is "Agilent Baseband Studio for Fading - cdma2000 example". The interface is divided into several sections:

- Channel Setup:** Includes fields for Channel State (On), Channel Resource (Card 1 & TCPPO:141.121.95.02), Carrier Frequency (1 GHz), In-Band RFP Power (C+N) (3.01 dBm), Carrier Power (C) (7.40 dBm), Symbol (Chp) Rate (1.238 MHz), Standard Path Config (CDMA2000/1xEv-Rev2/4), Paths - Bandwidth Config (12 Paths @ Max Bandwidth 15.750 MHz), and Fader Bandwidth (6.300 MHz).
- Noise Settings:** Includes AWGN Enabled (checked), Flat Noise Bandwidth (6.300 MHz), In-Band Noise Power (N) (2.60 dBm), and Carrier to Noise Ratio (C/N) (10.00 dB).
- AWGN Functions:** Includes buttons for "Set C with constraints", "Set N with constraints", "Set C/N with constraints", and "Eb/No Settings...".
- Paths - Ch 1:** A table listing 12 paths with columns for Path, Enabled, Fading Type, Delay, Loss (dB), Vehicle Speed (km/h), Max Doppler (Hz), Angle of Arrival (deg), Phase Shift (deg), Log Normal, Local Constant (In), and Standard Deviation.

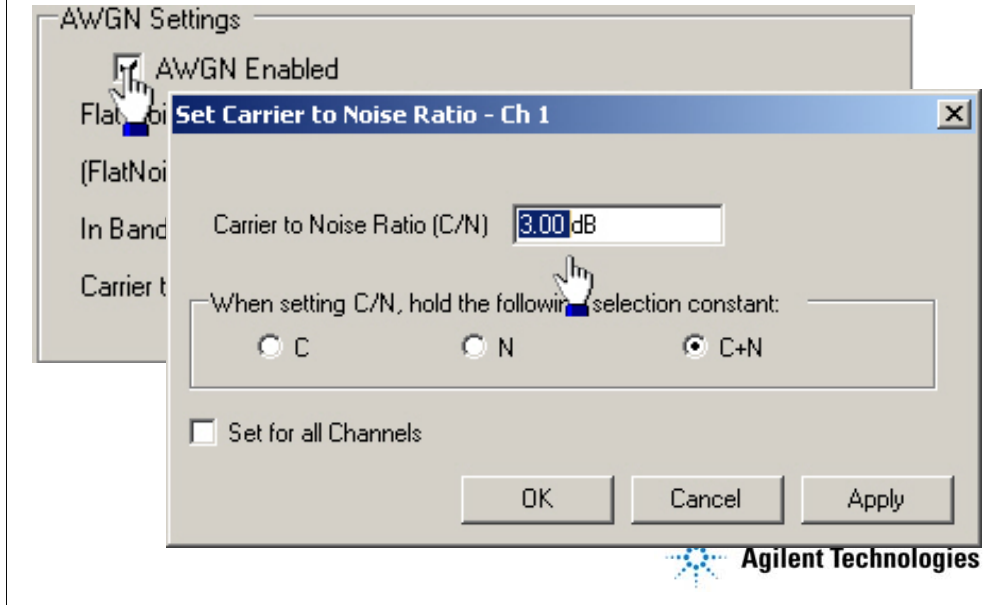
Path	Enabled	Fading Type	Delay	Loss (dB)	Vehicle Speed (km/h)	Max Doppler (Hz)	Angle of Arrival (deg)	Phase Shift (deg)	Log Normal	Local Constant (In)	Standard Deviation
1	<input checked="" type="checkbox"/>	Rayleigh	0 s	0	0	0	0	0	<input type="checkbox"/>		
2	<input checked="" type="checkbox"/>	Rayleigh	0 s	0	0	0	0	0	<input type="checkbox"/>		
3	<input checked="" type="checkbox"/>	Rayleigh	0 s	0	0	0	0	0	<input type="checkbox"/>		
4	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		
5	<input type="checkbox"/>	None	30 μs	9	30	22.797007933179	25	0	<input checked="" type="checkbox"/>	100	7
6	<input type="checkbox"/>	Rayleigh	10 μs	2	30	22.797007933179	0	3	<input type="checkbox"/>		
7	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		
8	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		
9	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		
10	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		
11	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		
12	<input type="checkbox"/>	None	0 s	0	30	22.797007933179	0	0	<input type="checkbox"/>		



The user interface provides quick access to fading profiles and noise settings through pull-down menus and dialog boxes. This screen shot shows the overall layout of the settable parameters.

Baseband Studio for Fading Software

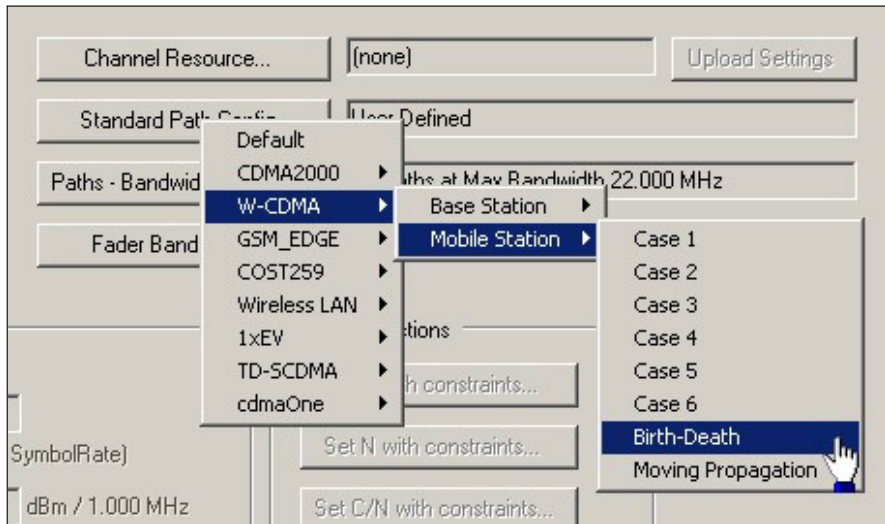
Add noise with a mouse click



Adjusting the value of the AWGN is as simple as entering the C/N or Eb/No value in the user interface. The software automatically queries the ESG for the current power levels and data rates for the various channels. When setting the level of AWGN you can specify to hold C, N, C/N, or C+N constant, making receiver testing extremely simple. For example, fix the C/N ratio as the carrier power changes, or fix the total received power as the C/N ratio varies. This holds the receiver front-end gain fixed, which is important for evaluating receiver performance under known conditions. Eb/No enables AWGN to be added by setting the ratio of energy transmitted on a specific channel to the overall noise power spectral density. This is useful for testing the robustness of a particular channel for a given coding scheme. C/N and Eb/No can quickly be changed enabling the characterization of receiver performance over a continuum of AWGN levels without having to readjust separate carrier and noise powers. This simplified approach to adding AWGN helps reduce your test time from hours to minutes. Complicated noise summing is reduced to a few mouse clicks. The flat noise bandwidth of the added AWGN is automatically set to exceed the modulated carrier bandwidth simplifying AWGN setup

Baseband Studio for Fading Software

Preconfigured setups for major cell standards



The ability to simulate different fading profiles is essential for evaluating receiver performance in a variety of environments. Baseband Studio for fading can simulate both small scale and large scale fading models or combinations of the two. This enables the simulation of rapid signal fluctuations, due to small movements of the receiver, and slow changes in average power, caused by shadowing effects of distant objects. The PC-based user interface makes configuring simulation quick and easy. The supported fading profiles include

- Rayleigh – small-scale multipath scattering
- Rician – Rayleigh with a direct path
- log normal – large scale free space path loss
- Suzuki – Rayleigh with log normal
- pure Doppler – frequency shift due to motion

Also available are predefined setups for common cellular formats that simplify test preparation. These profiles can be modified to provide custom configurations for simulating specific environments. The unique 3GPP W-CDMA moving propagation and birth-death fading profiles are included as predefined setups.

Baseband Studio for Fading Software

Customize each path

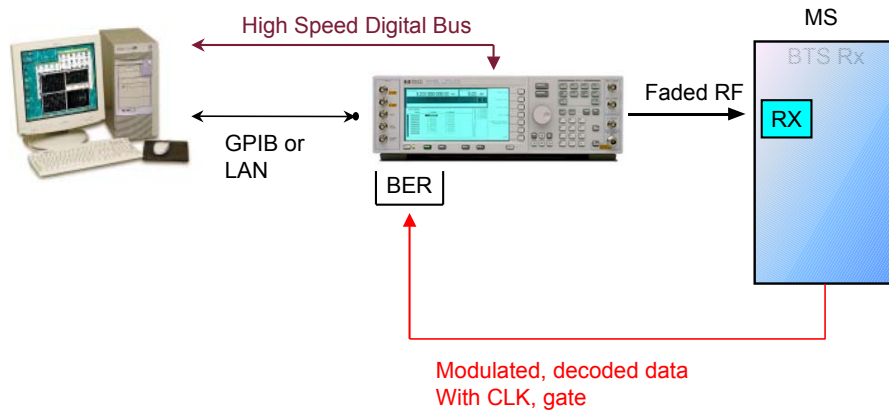
Paths - Ch 1							
	Path	Enabled	Fading Type	Rician K (dB)	Delay	Rel Loss (dB)	Vehicle Speed
	1	<input checked="" type="checkbox"/>	R	All Rayleigh	0 s	0	0.00
	2	<input type="checkbox"/>	R	All Rician	0 s	0	0.00
▶	3	<input checked="" type="checkbox"/>	R	All PureDoppler	0 s	0	0.00
	4	<input type="checkbox"/>	R	All Suzuki	0 s	0	0.00
	5	<input type="checkbox"/>	Rayleigh		0 s	0	0.00
	6	<input type="checkbox"/>	Rayleigh		0 s	0	0.00
	7	<input type="checkbox"/>	Rayleigh		0 s	0	0.00
	8	<input type="checkbox"/>	Rayleigh		0 s	0	0.00
	9	<input type="checkbox"/>	Rayleigh		0 s	0	0.00
	10	<input type="checkbox"/>	Rayleigh		0 s	0	0.00



You can also customize your channel conditions on a path by path basis. By simply clicking on the dialog box within each enabled path, you can set the fading type, K factor, delay, relative path loss, vehicle speed, max Doppler shift, angle of arrival, phase shift, and several other parameters.

Baseband Studio for Fading

Single Channel - UE/MS, WLAN receiver testing



You can use baseband studio for Fading as a single channel instrument for the following tests:

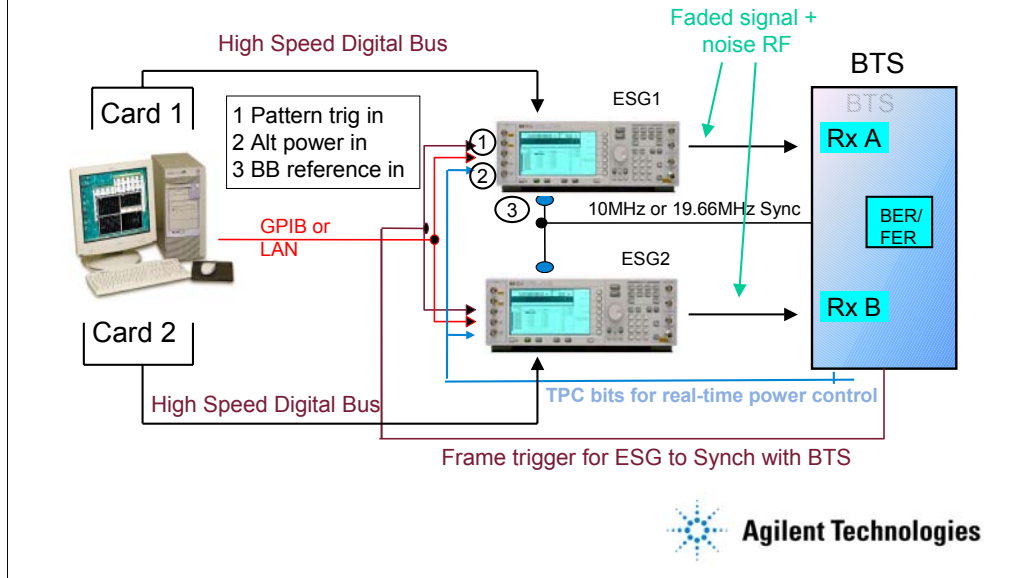
MS Receiver Testing, WLAN Receiver Testing

- with AWGN
- with multi-path fading
- with Signal Studio signals

The high speed digital bus transmits the waveform information back and forth between the ESG and PCI fader card. The GPIB/LAN connection detects the number of cards that are in use and handles licensing information.

Baseband Studio for Fading

Dual Channel - BTS Receiver Testing with Diversity



You can use baseband studio for Fading as a dual channel instrument for the following tests:

W-CDMA UL BTS Receiver Test with diversity receiving

- with AWGN
- with multi-path fading
- with close-loop power control
- with DPCH, PRACH, compress frame

cdma2000 RL BTS Receiver Test with diversity receiving

- with AWGN
- with multi-path fading
- with Reverse Traffic Channel, R-CCCH (Reverse Common Control Channel)

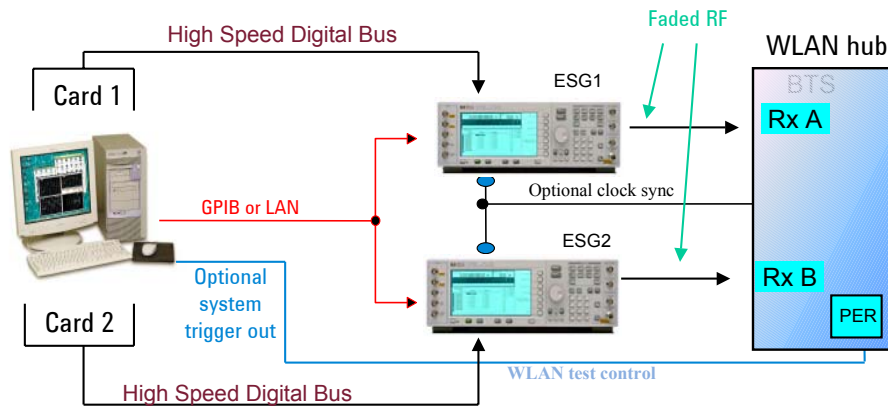
Co-channel interference rejection

- both signal and interference (CW or modulated signal) need to be faded
- with multi-path fading
- with specific format and channels

Card one and card 2 need to be synchronized with a 3 line SMA cable. The triggering between the cards and the ESG is achieved on a pin in the digital bus. The digital bus transmits the waveform information back and forth between the ESG and fader card. The GPIB/LAN connection detects the number of cards that are in use and handles licensing information. The reference clock is set to 10MHz for W-CDMA and to 19.66MHz (GPS) for cdma2000.

Baseband Studio for Fading

Dual Channel - WLAN Hub Receiver testing



You can use baseband studio for Fading as a dual channel instrument for the following tests:

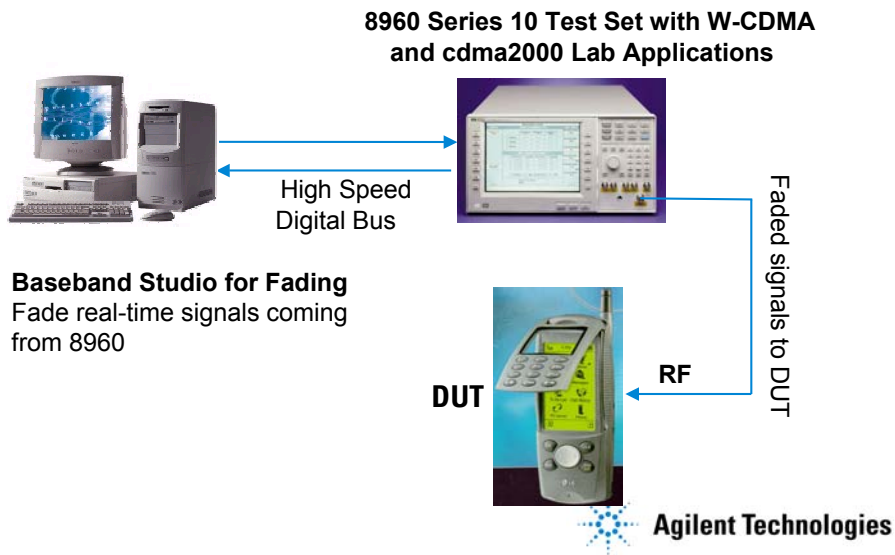
WLAN receiver performance with dual antenna receiving diversity

Card one and card 2 need to be synchronized with a 3 line SMA cable. The triggering between the cards and the ESG is achieved on a pin in the digital bus. The digital bus transmits the waveform information back and forth between the ESG and fader card. The GPIB/LAN connection detects the number of cards that are in use and handles licensing information.

Note: PER measurements are not a specific feature implemented in the baseband studio software. This requires extra chipset specific software, such as a test mode setup.

Coming Soon

Fading with call processing



For those who need to test their handsets under fading conditions within a call framework, Agilent will introduce Baseband Studio for Fading on its One Box Tester platform in the spring of 2004.

- At first release, W-CDMA and cdma2000 Lab Applications will be supported.
- It will require a hardware upgrade for existing E5515C mainframes. This upgrade will most likely happen at a service center.
- It is targeted for mobile station qualification and verification.

Baseband Studio for Fading

Available Fading Configurations

Model/option number	Description	Notes	1-ch	2-ch
N5101A	Baseband Studio PCI card	Required	1	2
N5115A	Baseband Studio for fading	Required	1	2
N5115A-160	One fading channel with up to 17 MHz RFBW	Required	1	2
N5115A-161	Extend one fading channel from 17 up to 30 MHz RFBW	Optional	1	2
N5115A-168	Add AWGN to one fading channel	Optional	1	2
N5115A-170	ESG signal generator connectivity for one fading channel	Required	1	2
E4438C-601	Internal baseband generator with 8 Msa and digital bus	Required	1	2
E4438C-602	Internal baseband generator with 64 Msa and digital bus	Optional	1	2

•Minimum configuration in red

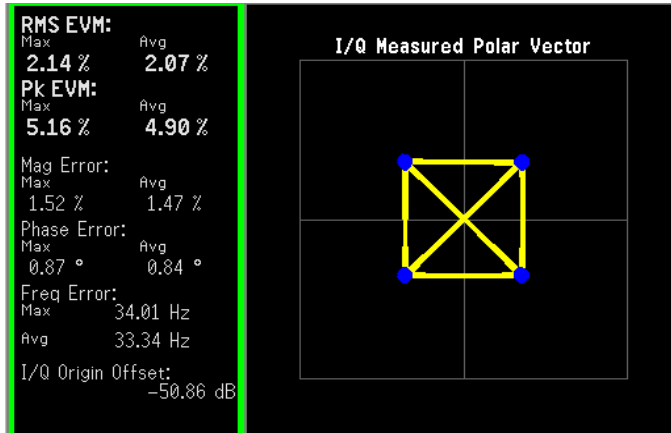


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We have tried to streamline the ordering process for this new solution. Shown in red is the minimum configuration needed to run the Baseband Studio for Fading, assuming you already have an ESG and a compatible PC. Also shown are the various available options. To make a dual channel setup, no complicated configurations are needed, simply purchase two of everything.

Example Simulation

QPSK Signal in Rayleigh Deep Fade



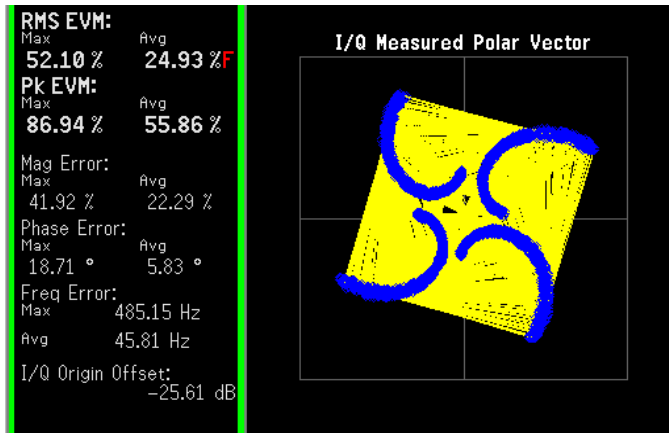
QPSK Pilot Signal with no fade



The following two slides serve as an example of channel impairment simulation using the Agilent Baseband Studio for Fading. It shows what can happen to a signal under worst case Rayleigh fading. The screen shot shown above is an ideal, unfaded CDMA pilot QPSK symbol at 1GHz. The next screen shot is the same input signal under Rayleigh fading conditions with Doppler spread set to 400MHz.

Example Simulation

QPSK Signal in Rayleigh Deep Fade



QPSK Pilot Signal with deep Rayleigh fade



This screen shot is the same input signal under Rayleigh fading conditions with Doppler spread set to 400MHz. Notice how the constellation is affected two ways: the trajectory is coming closer to the origin, illustrating attenuation of symbol power, and the trajectory is also rotated, illustrating variance of received phase from multipath effects. The important question to ask is: Can your receiver demodulate this signal?

References

- Bernard Sklar; Rayleigh Fading Channels in Mobile Digital Communication Systems Part I: Characterization; IEEE Communications Magazine; July 1997

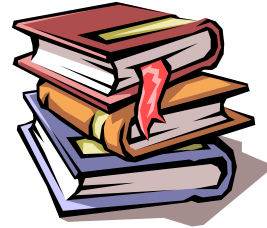
- Bernard Sklar; Rayleigh Fading Channels in Mobile Digital Communication Systems Part II: Mitigation; IEEE Communications Magazine; July 1997

- Wally Rasmussen; Simulating the Complex Multipath Signal Conditions of the Mobile Radio Environment; Hewlett-Packard Wireless Communications Symposium; 1993

- Victor Shtrom, Jose Tellado, A. Paulraj; Designing MIMO systems for reliable coverage in non-LOS wireless links; RF Design; October 2002

- Theodore Rappaport; Wireless Communications: Principles and Practices; Prentice Hall PTR; 1996

- www.howstuffworks.com



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The sources above were all used in the research for the material presented today.

For more information, please visit
www.agilent.com/find/basebandstudio



Q&A

