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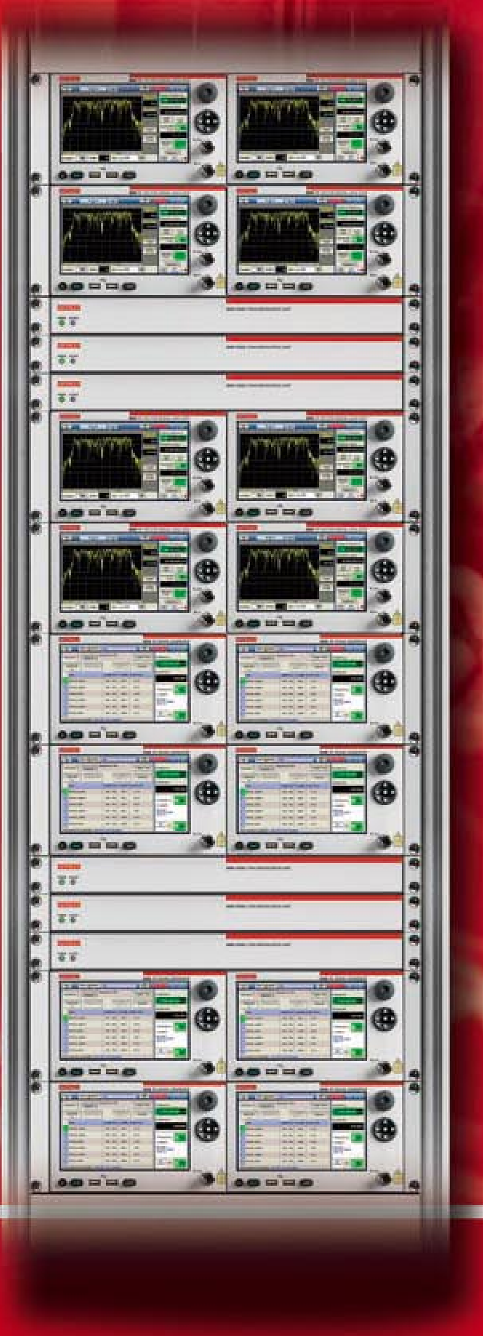
新一代移动通信射频测试技术研讨会



RF Test & Measurement Revolution
OFDM Plus MIMO

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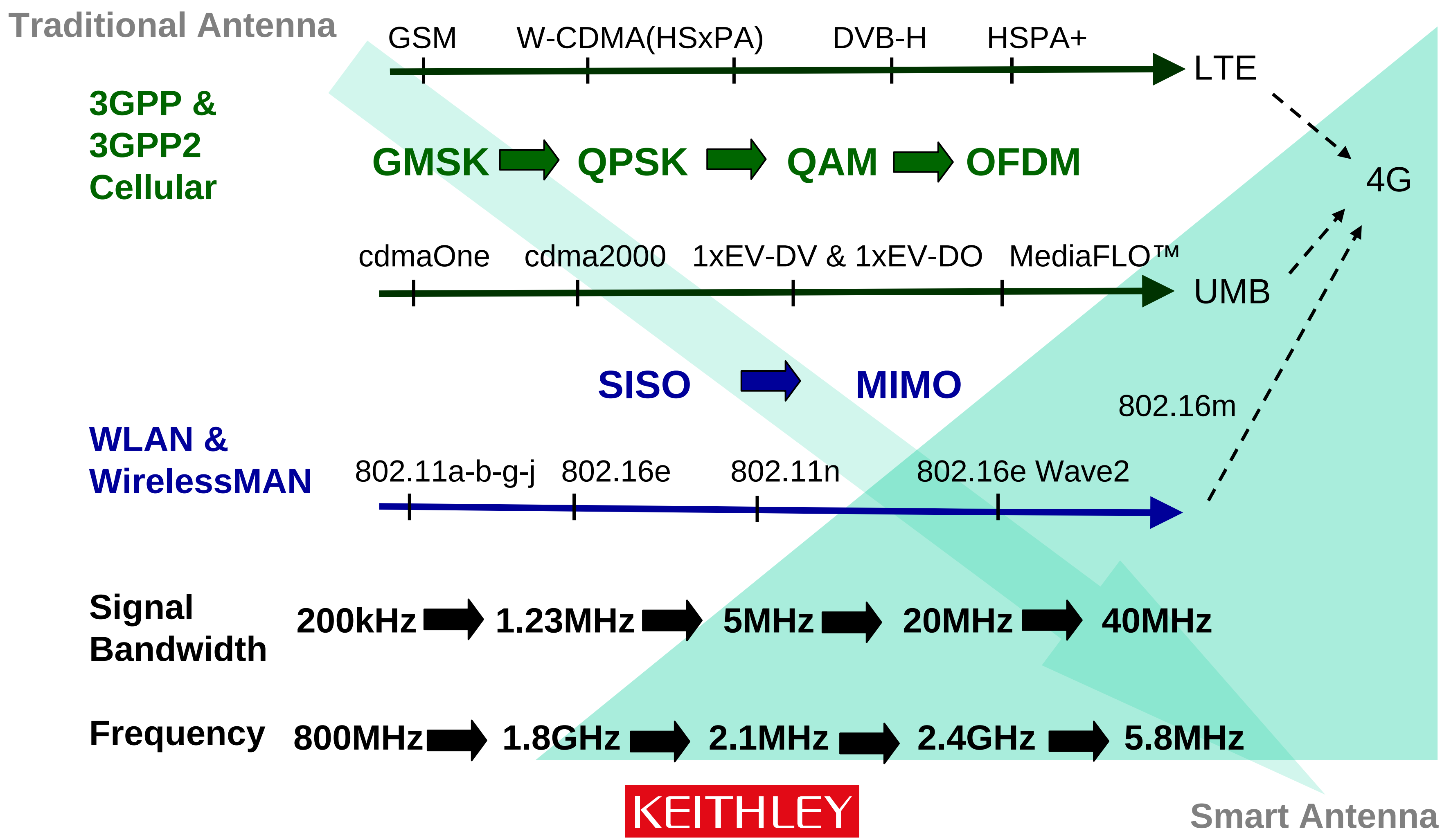
Agenda

- **The evolution of communications and an introduction to the test tools**
- **Part One – OFDM and SISO radio configurations**
  - The case for OFDM
  - OFDM Signal Structure, generic and WLAN.
  - Measurements
  - OFDM and OFDMA
  - Peak to average ratio considerations
  - WiMAX and LTE
- **Part Two – OFDM and MIMO radio configurations**
  - MIMO – Multiple Input Multiple Output Radio Topology
  - How it works.
  - Measurements
  - Channel Considerations
  - Smart Antenna Systems and Beam Forming Conclusion
- **Technology Overview and Test Equipment Summary**

The Evolution of RF Technology



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Test tools we will use today

2800 VSA and 2900 VSG
SISO
Spectrum Analyzer, Signal Generator
GSM
CDMA
WLAN
WiMAX
LTE

2800 VSA, 2900 VSG + 2895
MIMO
WLAN
WiMAX
LTE

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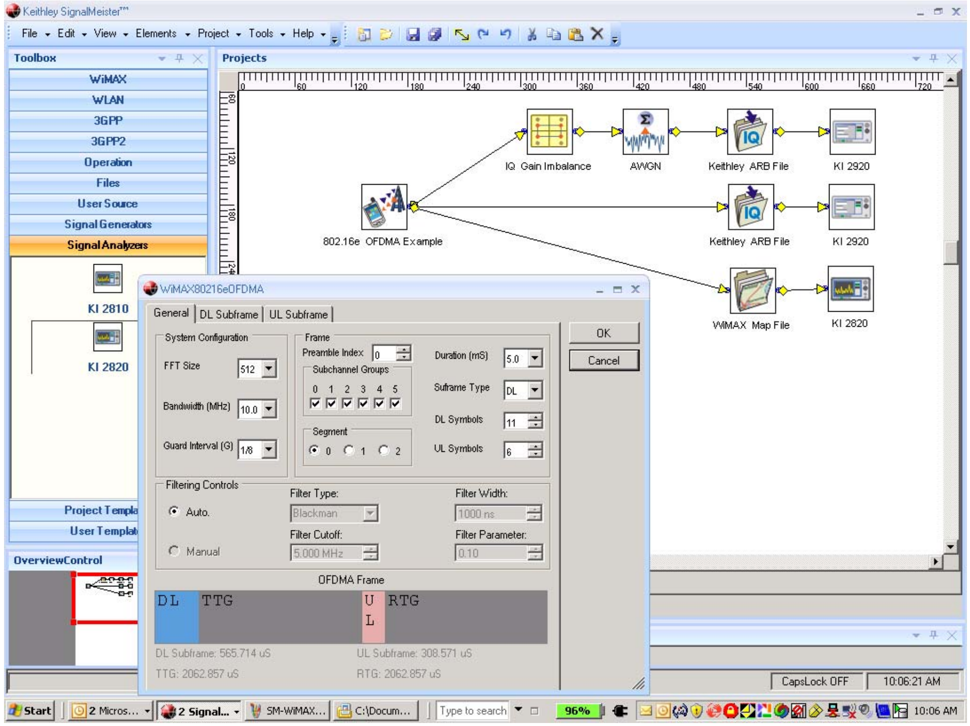
Keithley Simplifies Signal Creation and Analysis

- **Introducing the industries only graphically based signal creation and analysis software – Signal Meister.**
- **Simplifies signal creation allowing users to create signals then optionally add distortion parameters quickly and easily**
- **Includes signal creation and analysis for 3GPP, 3GPP2, WiMAX, WLAN with MIMO configurations and channel distortion.**
- **Interfaces to the 2900/2800 series of Keithely vector signal generators and analyzers.**



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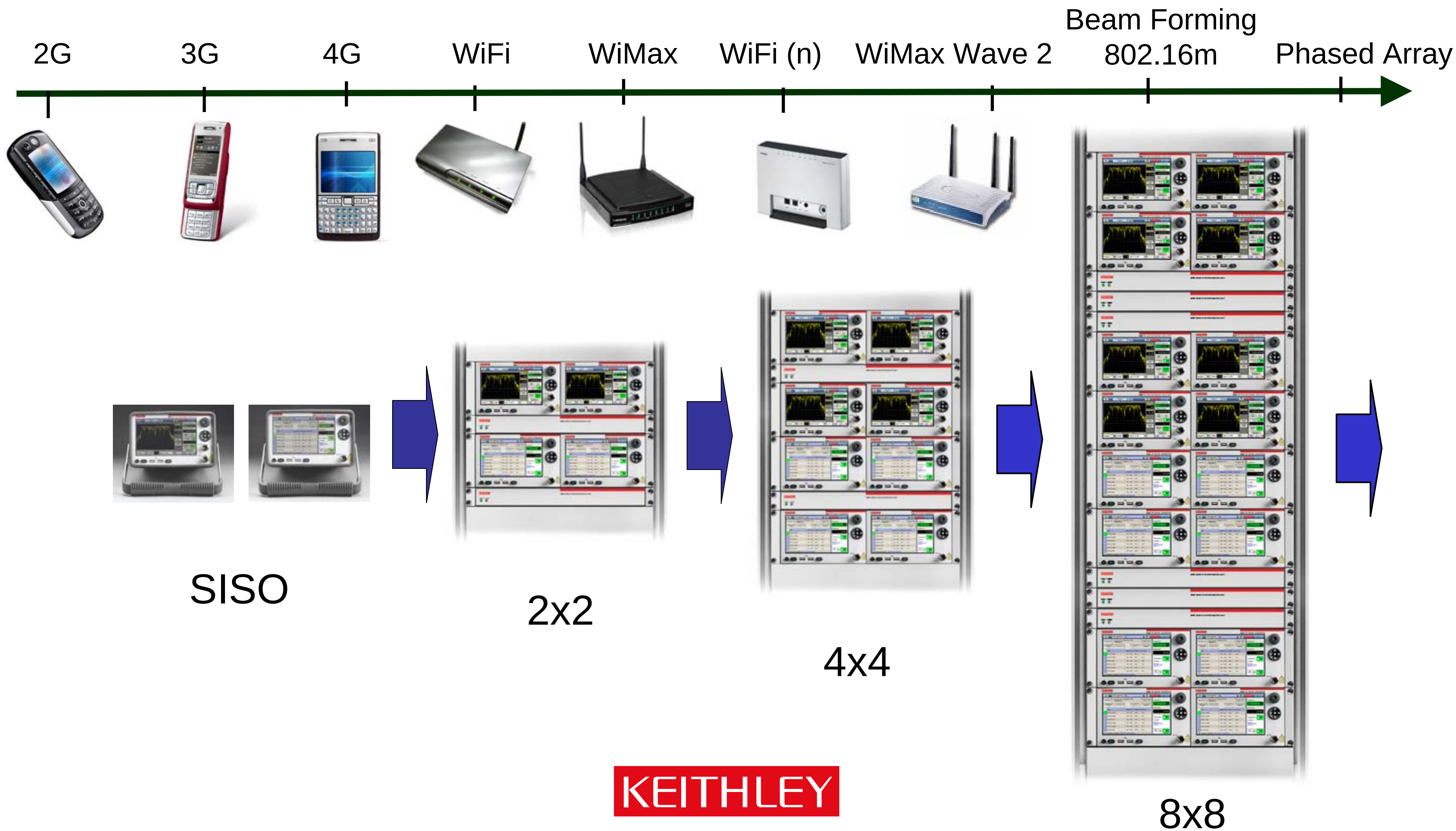
Technology Evolution



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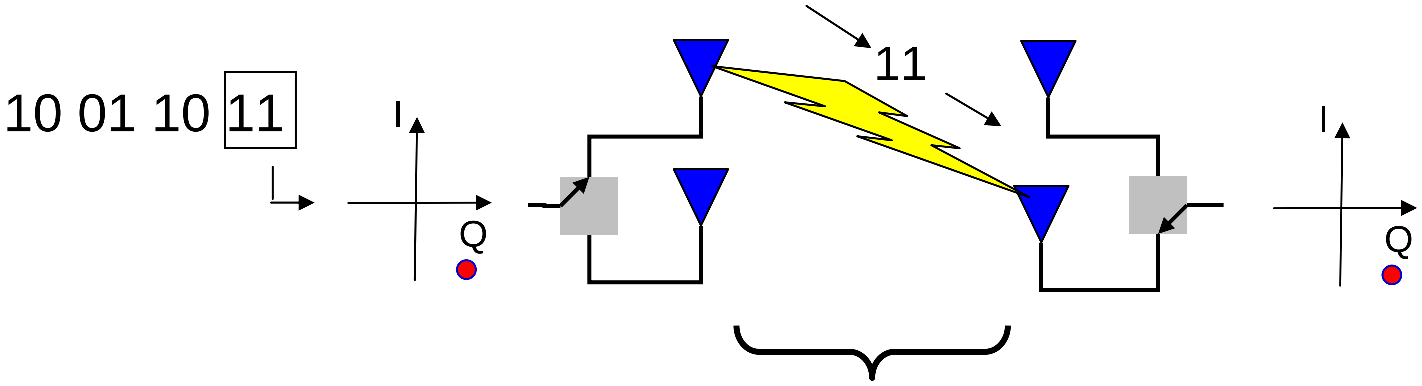
Traditional Serial Transmission using a SISO radio

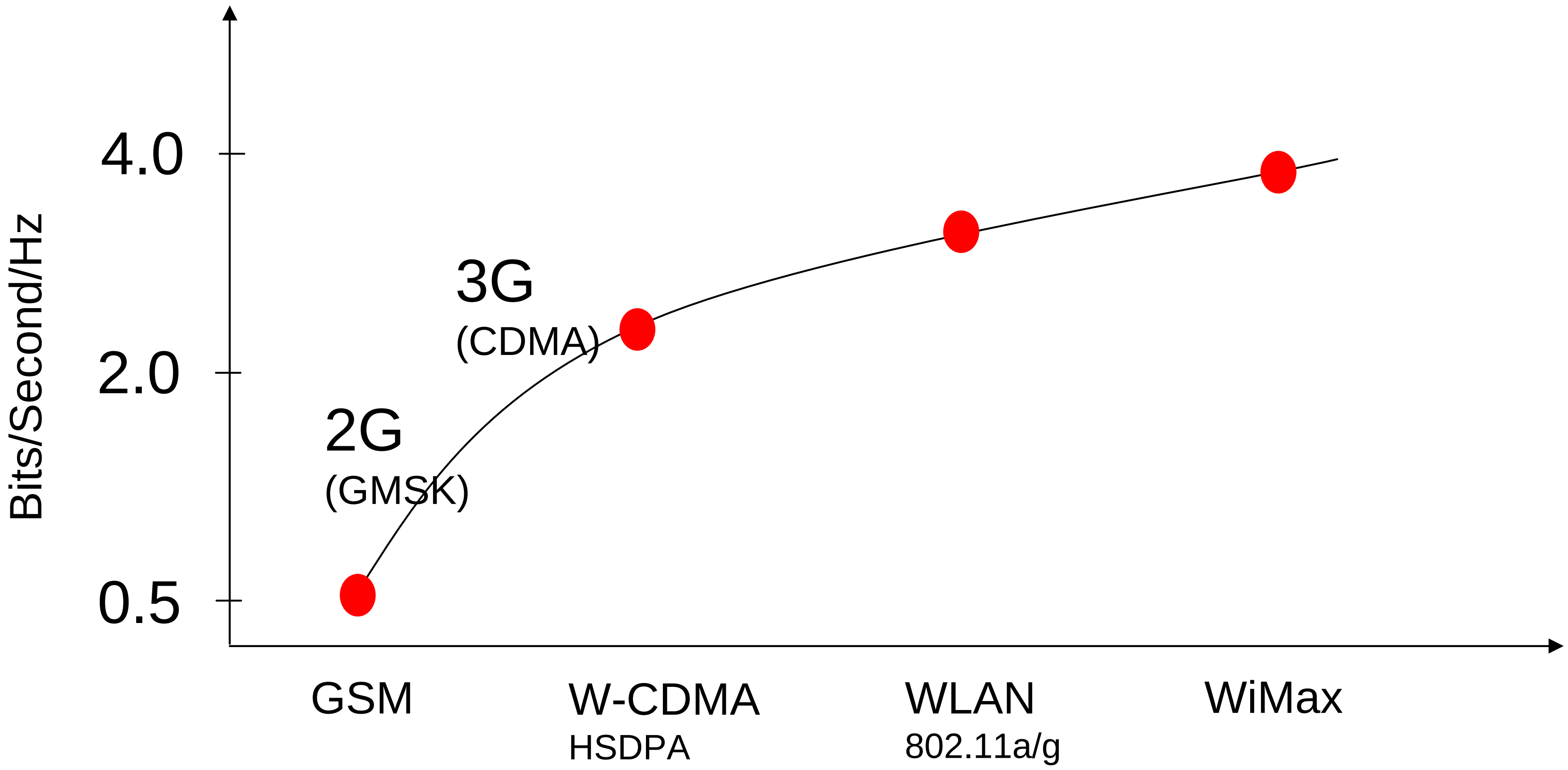


- Only one symbol is transmitted at a time
- One radio, only one antenna used at a time (e.g., 1 x 1)
- Antennas constantly switched for best signal path

Why use Orthogonal Frequency Division Multiplex?

- High spectral efficiency – provides more data services.
- Resiliency to RF interference – good performance in unregulated and regulated frequency bands
- Lower multi-path distortion – works in complex indoor environments as well as at speed in vehicles.

High Spectrally Efficiency – OFDM



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Why OFDM?

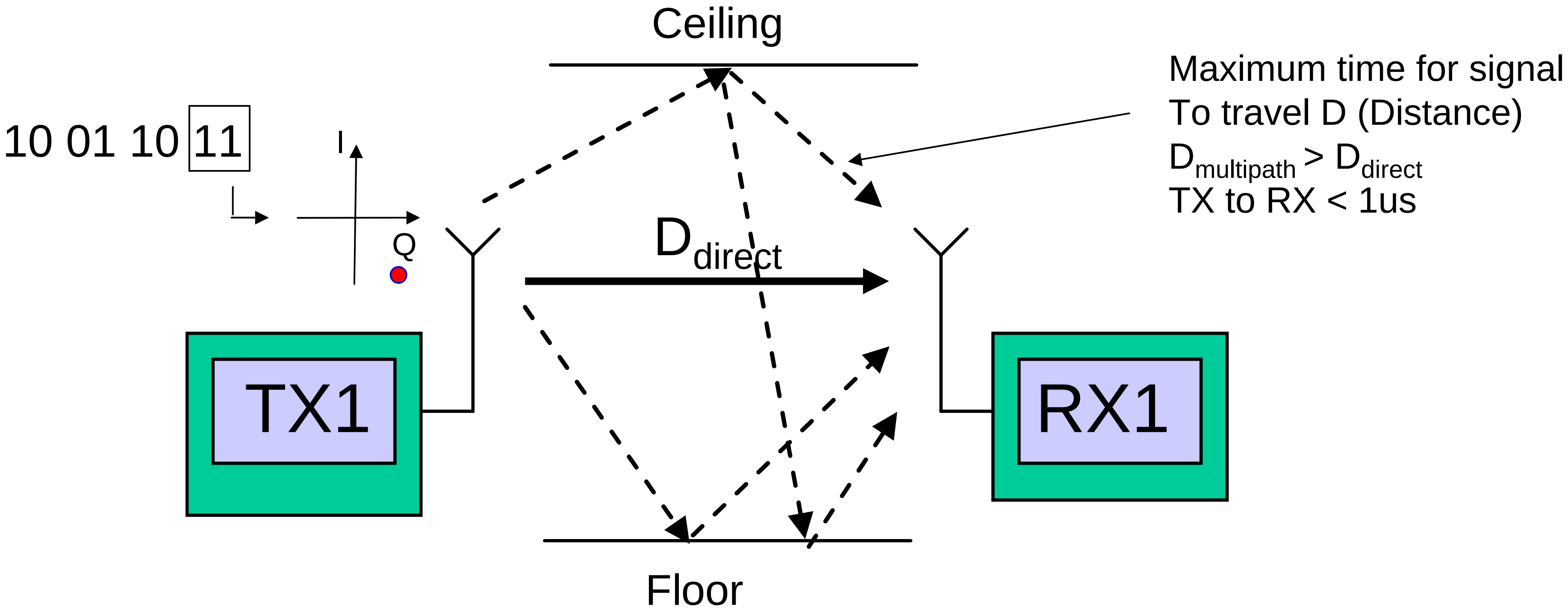
…Resiliency to RF interference.

- **The ISM Band (Industrial Scientific and Medical) is a set of frequency ranges that are unregulated.**
- **Most popular consumer bands**
  - 915MHz Band (BW 26MHz)
  - 2.45GHz Band (BW 100MHz)
  - 5.8GHz Band (BW 100MHz)
- **Typical RF transmitters in the ISM band include…**
  - Analog Cordless Phones (900MHz)
  - Microwave Ovens (2.45 GHz)
  - Bluetooth Devices (2.45GHz)
  - Digital Cordless Phones (2.45GHz or 5.8GHz)
  - Wireless Lan (2.45GHz or 5.8GHz).

The Multi-Path Problem
Example: Bluetooth Transmitter & Receiver

Symbol Rate = 1MSymbols/s
Symbol Duration = 1/1E6 = 1us

Maximum Symbol Delay < 1us



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Single Carrier – Single Symbol

- **Bluetooth, GSM, CDMA and other communications standards use a single carrier to transmit a single symbol at a time.**
- **Data throughput is achieved by using a very fast symbol rate.**

W-CDMA - 3.84 Msymbols/sec
Bluetooth – 1 Msymbols/sec

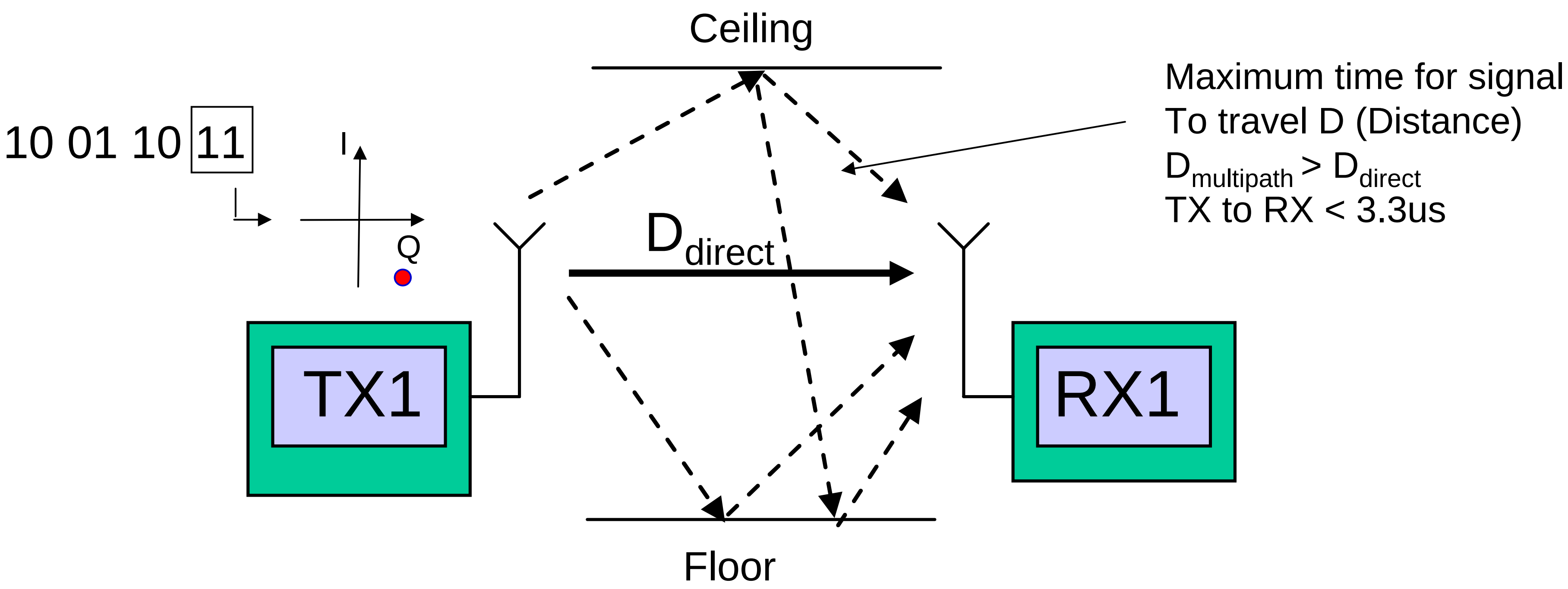
- **A primary disadvantage is that fast symbol rates are more susceptible to Multi-path distortion.**

Slow the symbol rate

Reduce the previous examples symbol rate by a third

Symbol Rate = 300kSymbols/s
Symbol Duration = 1/300 = 3.3us

Maximum Symbol Delay < 3.3us



But the data throughput is reduced!

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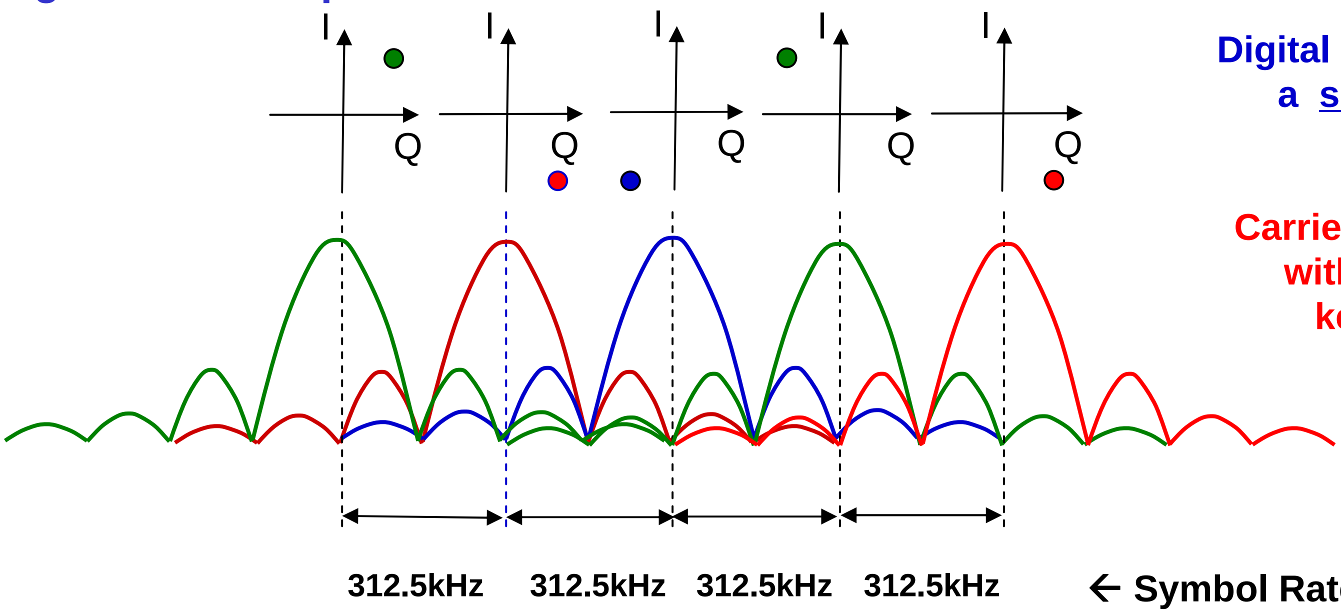
Improve the throughput -
use more than one carrier!

802.11a-g WLAN example



Digital filtering creates a $\frac{\sin x}{x}$ spectra

Carrier spacing aligned with spectra nulls keeps carriers orthogonal

← Symbol Rate α Carrier Spacing

Low symbol rate per carrier * multiple carriers = high data rate

250 kbps symbol rate * 48 sub-carriers * 6 coded bits /sub-carrier * ¾ coding rate = 54 Mbps

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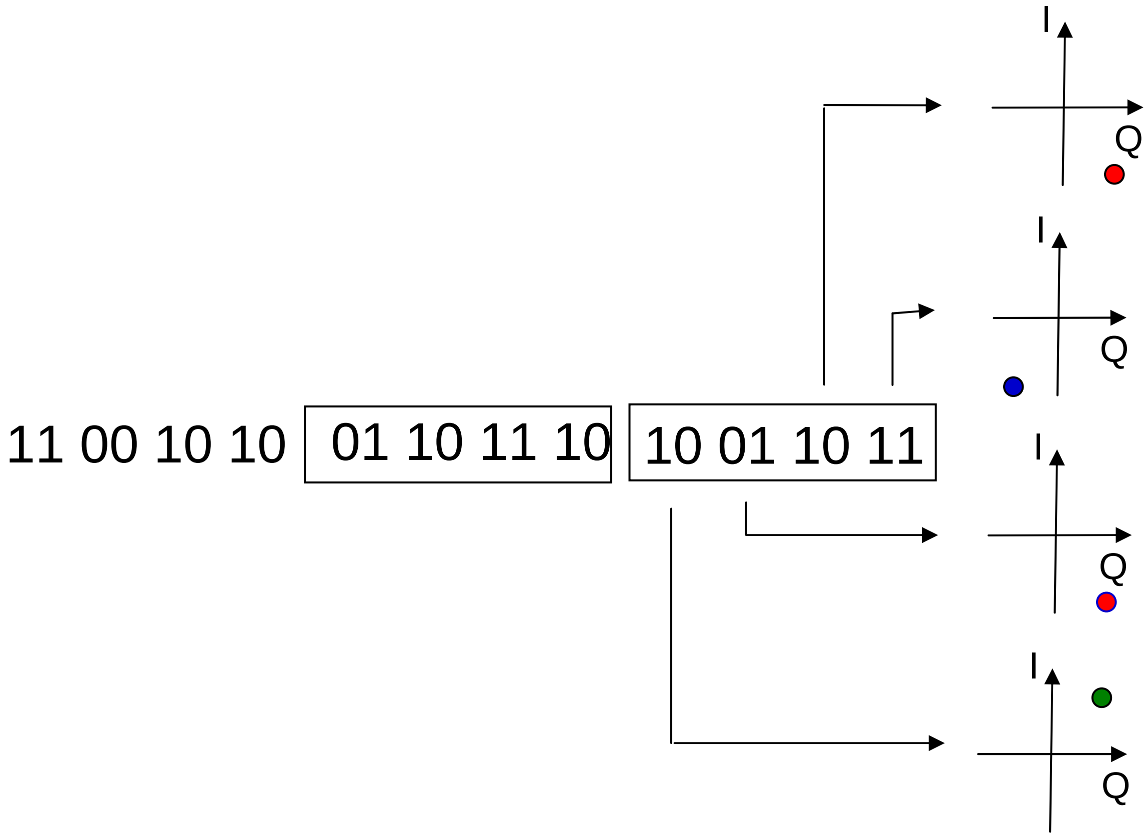
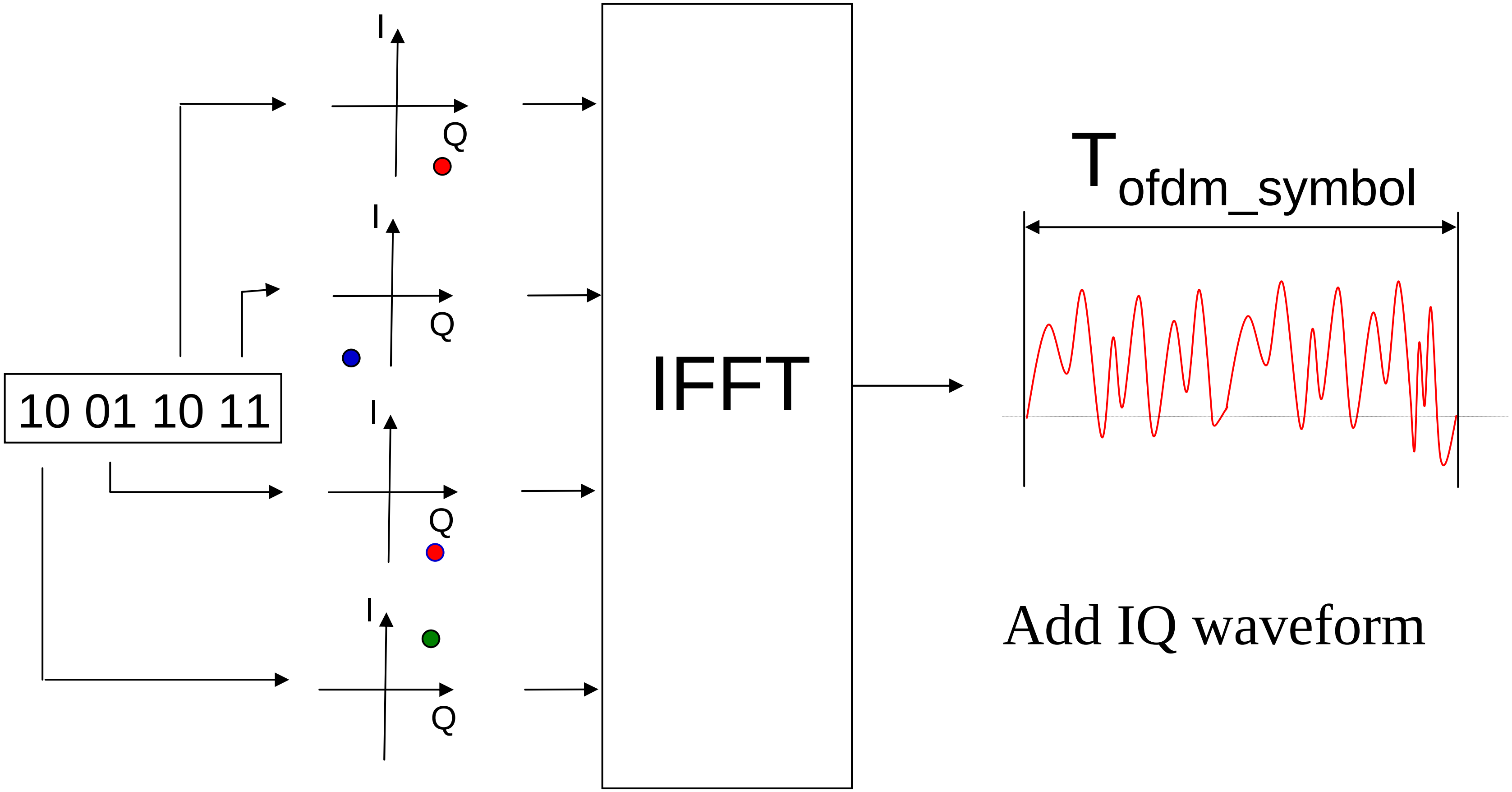
Parallel Symbols



Parallel Symbols



Add IQ waveform

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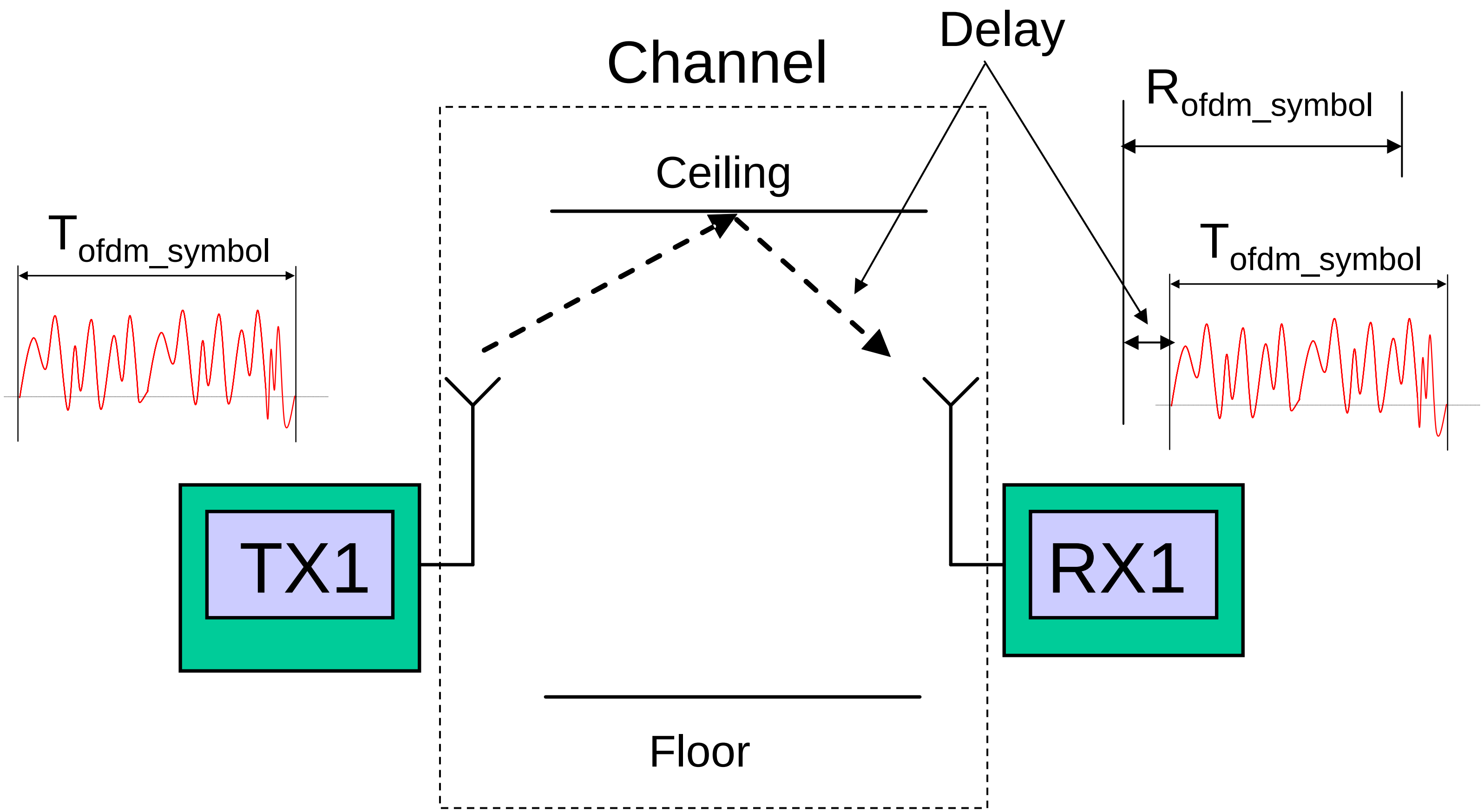
Delays in the channel



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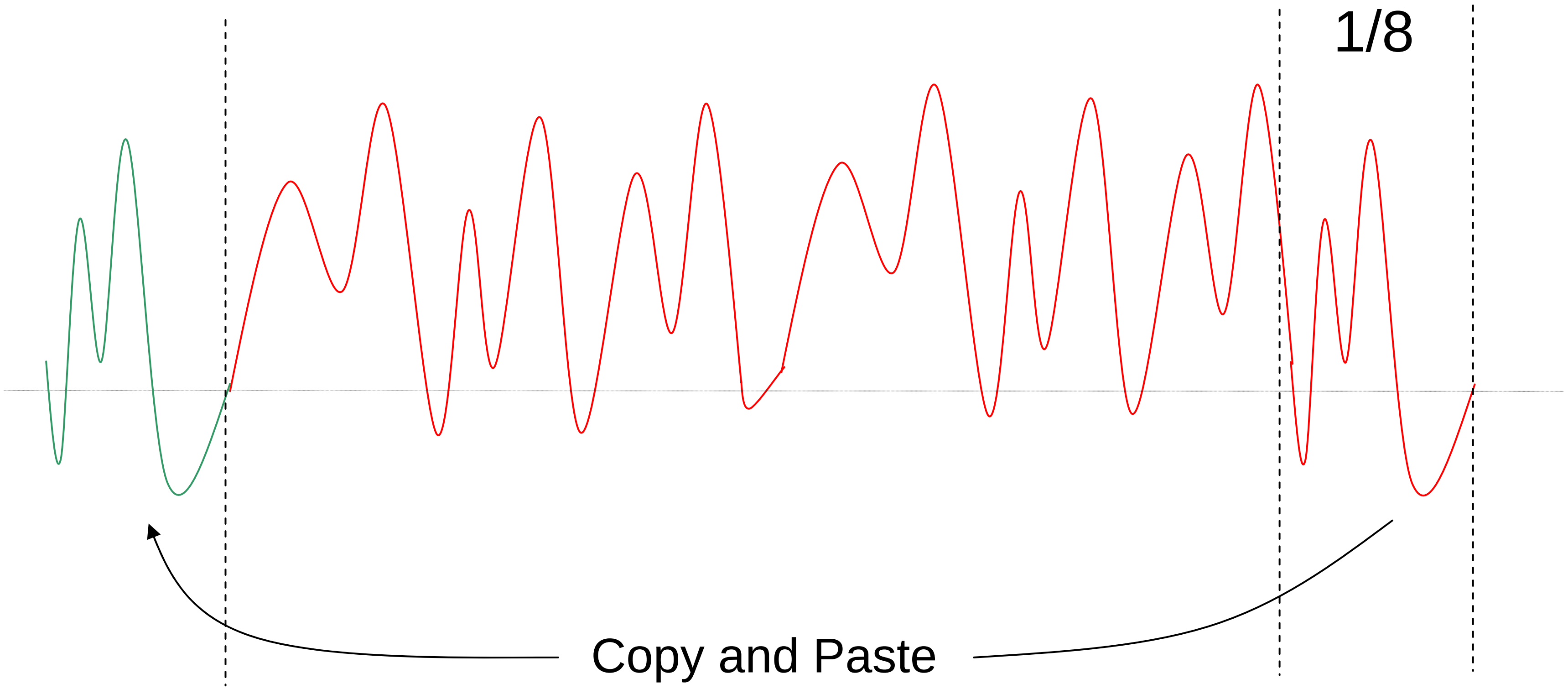
The guard interval and cyclic prefix

Lengthen without discontinuity



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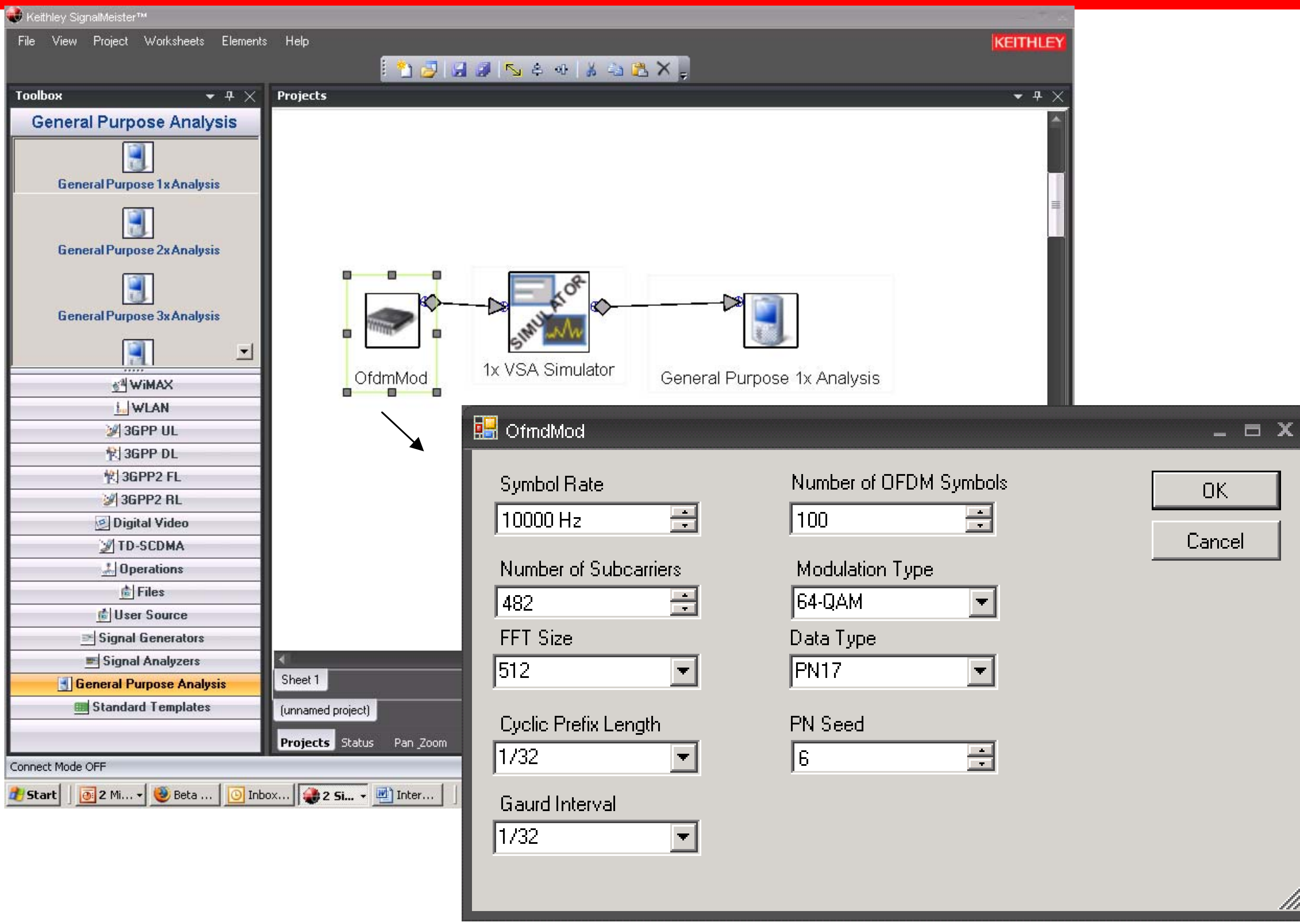
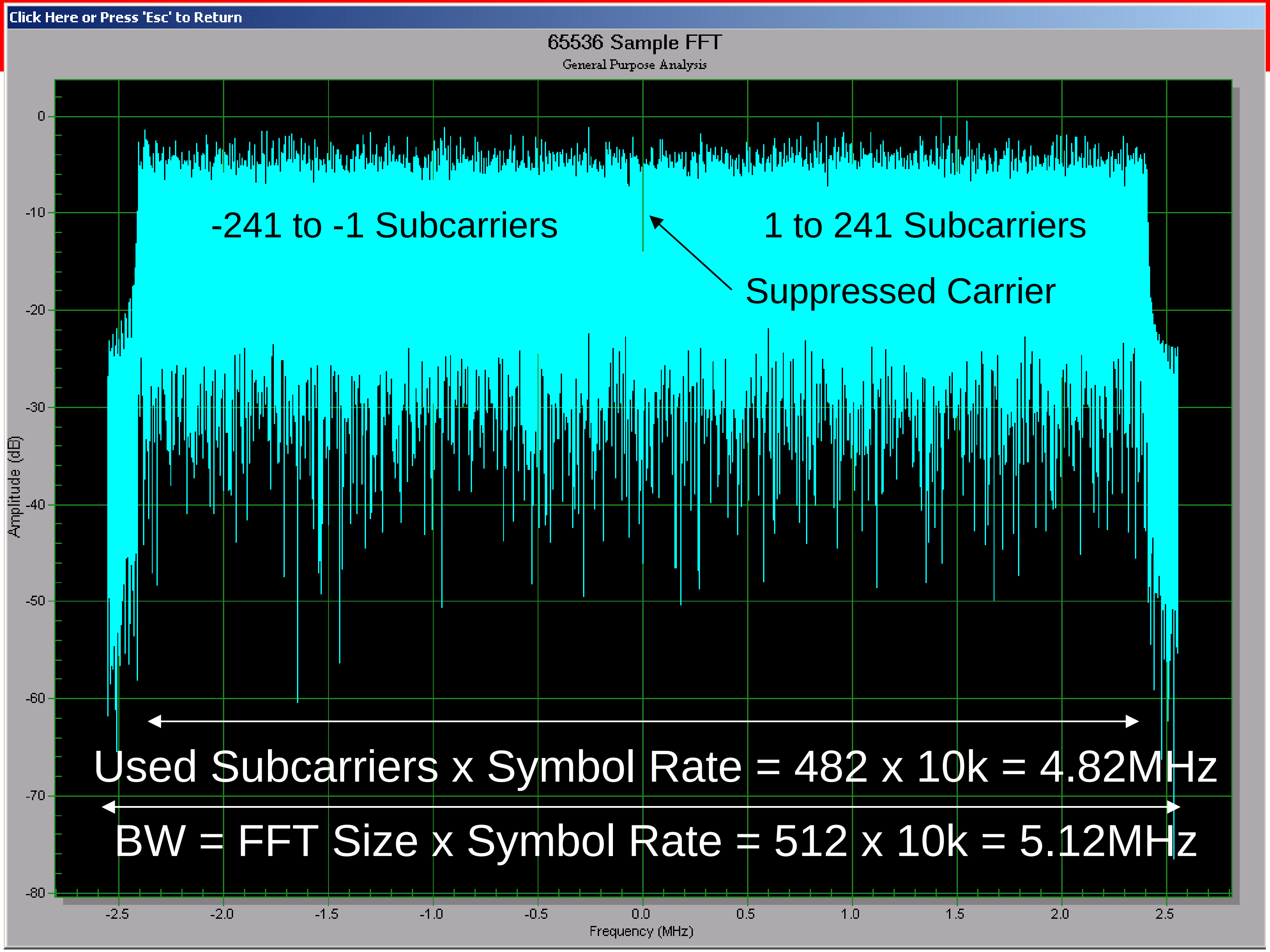
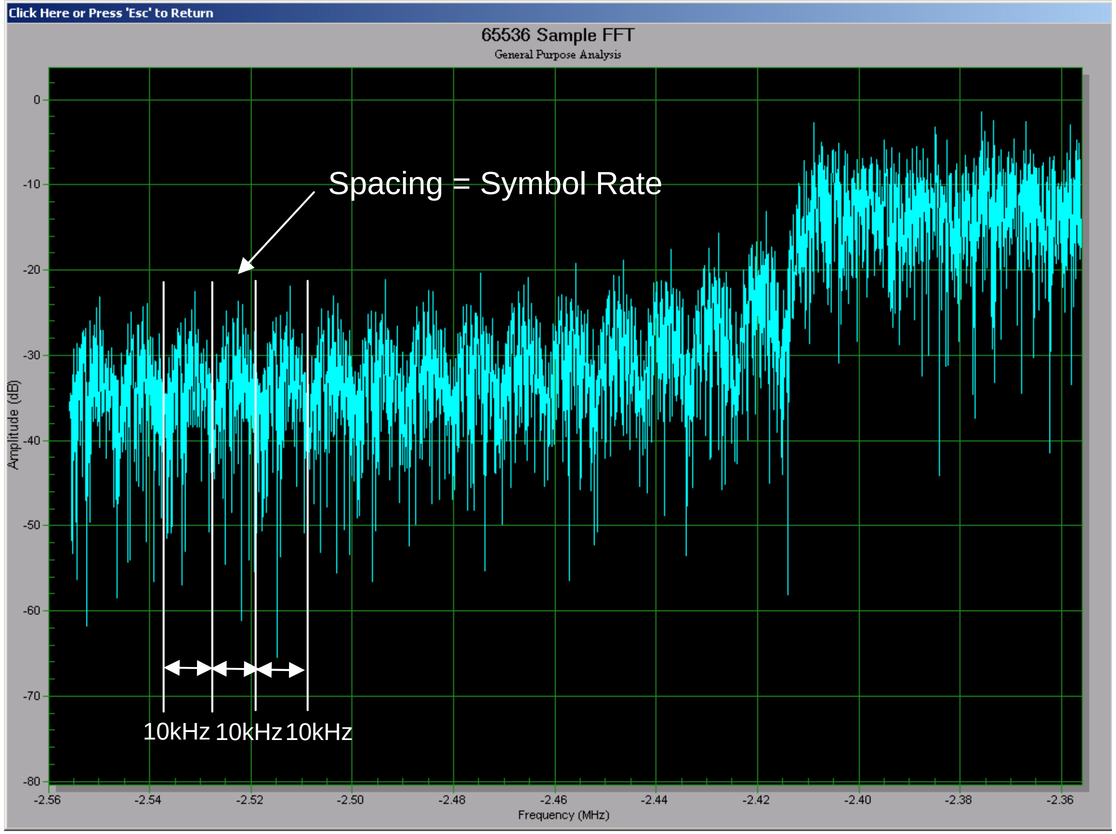
Building a simple OFDM signal



Examine the Signal in the Frequency Domain



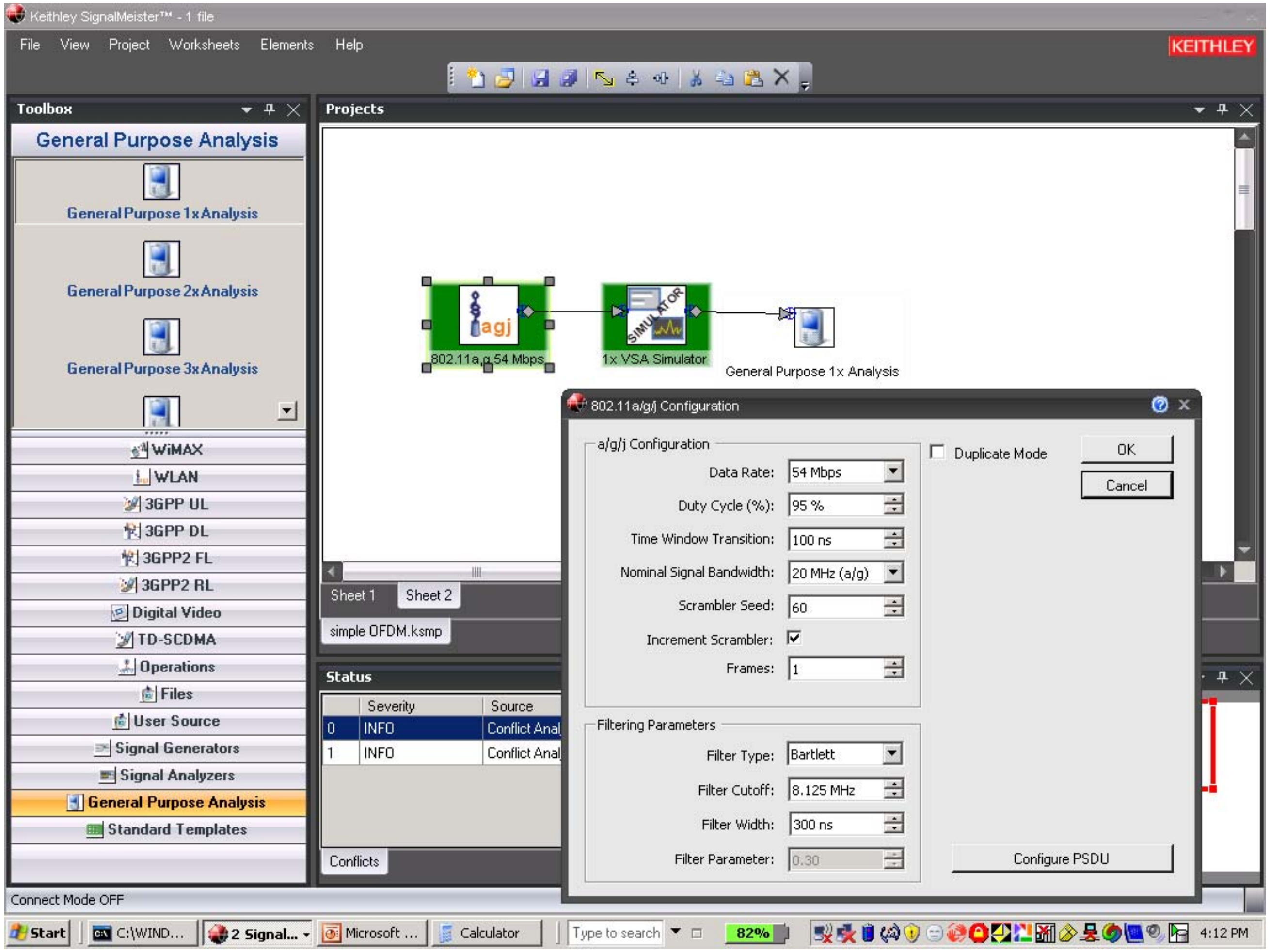
Examine the Signal in the Frequency Domain



Example: WLAN (802.11a/g)

- Modulation Technique OFDM
- Bandwidth 16.25MHz
- Number of sub-carriers 52
- Sub-carrier numbering -26 to + 26
- Pilot sub-carriers -21, -7, +7 and +21 (BPSK)
- Sub-carrier BW 312.5kHz
- Packet Structure – Preamble – Header – Data Block
- SUB Carrier Modulation Types - BPSK, QPSK, 16-QAM or 64-QAM

WLAN Signal Generation



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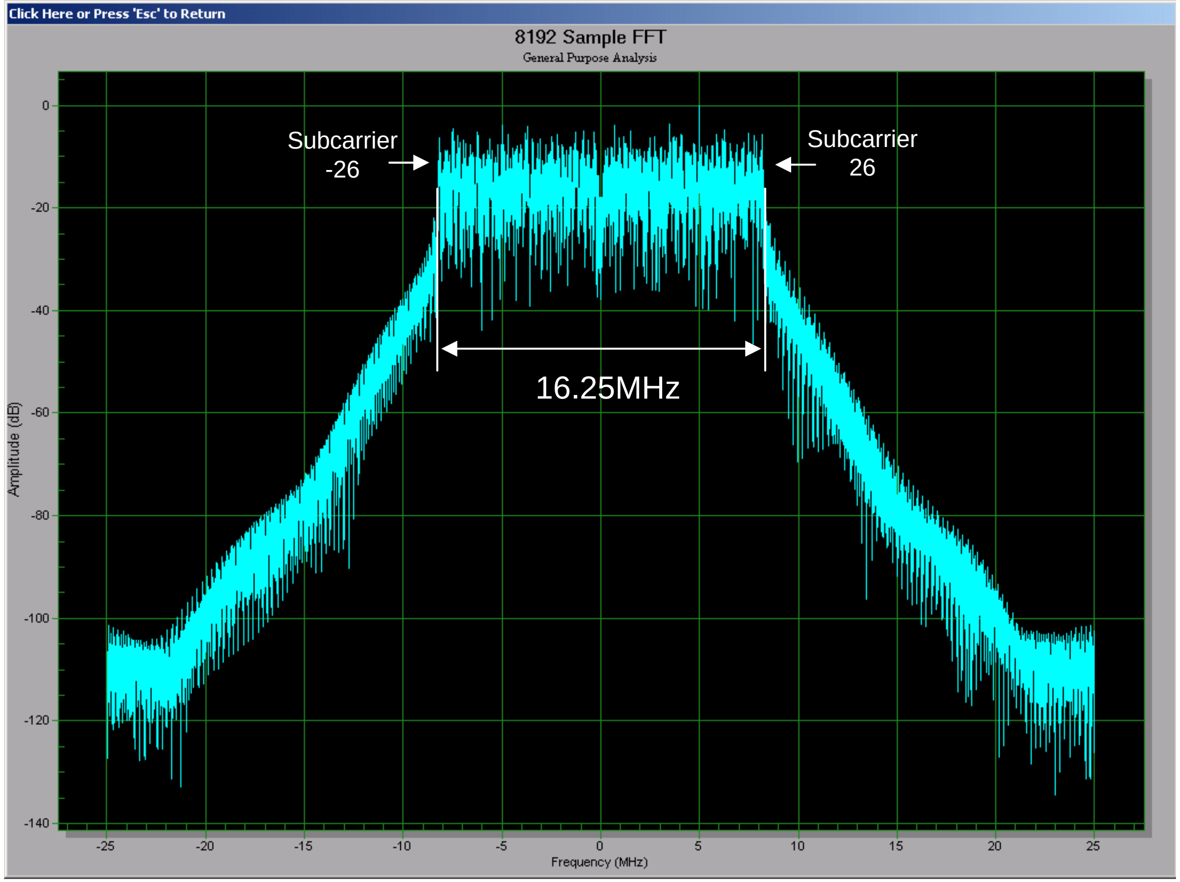
Frequency Domain 802.11g



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Key OFDM Measurements

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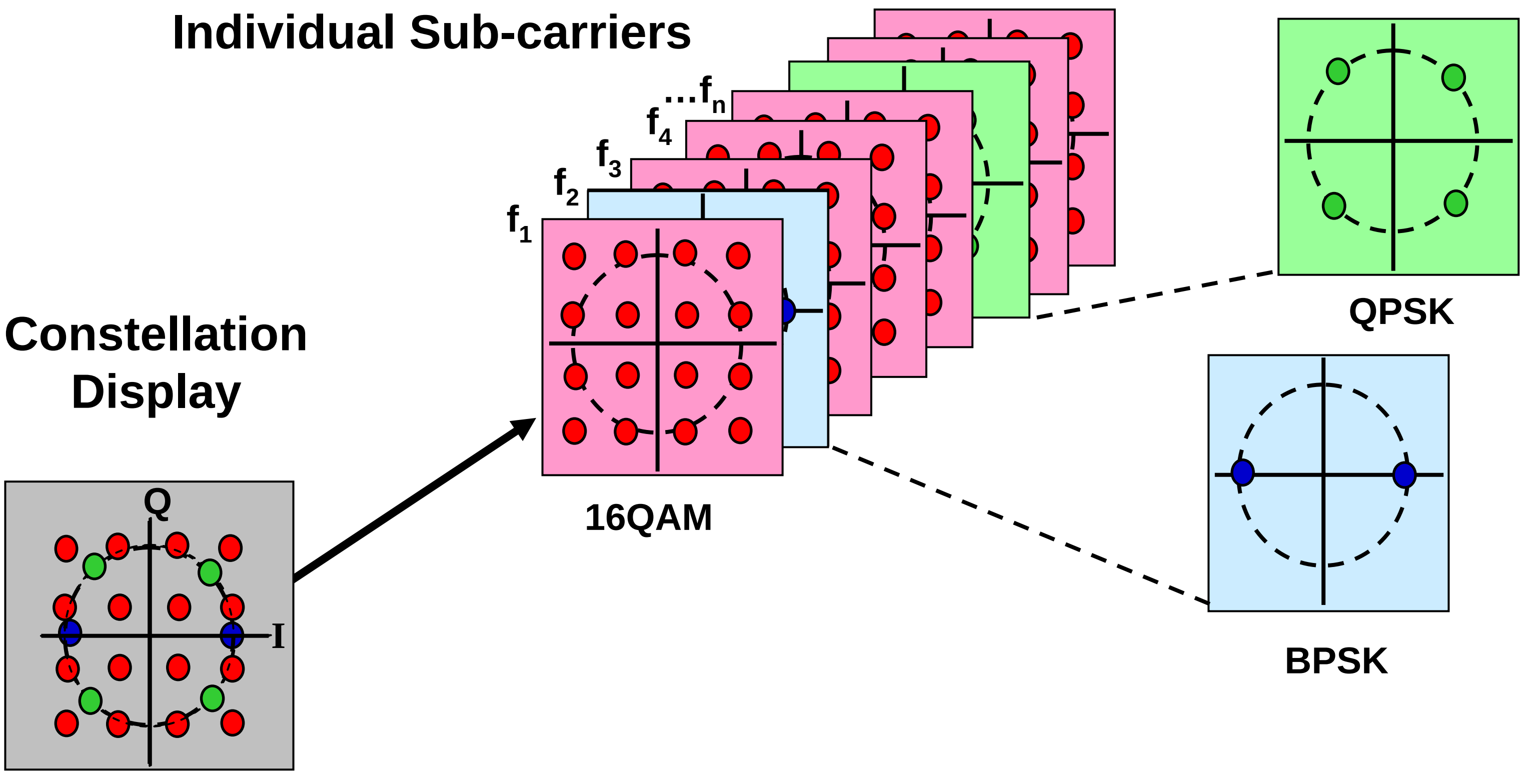
EVM - Constellation Display Is a Composite of all OFDM Sub-carriers



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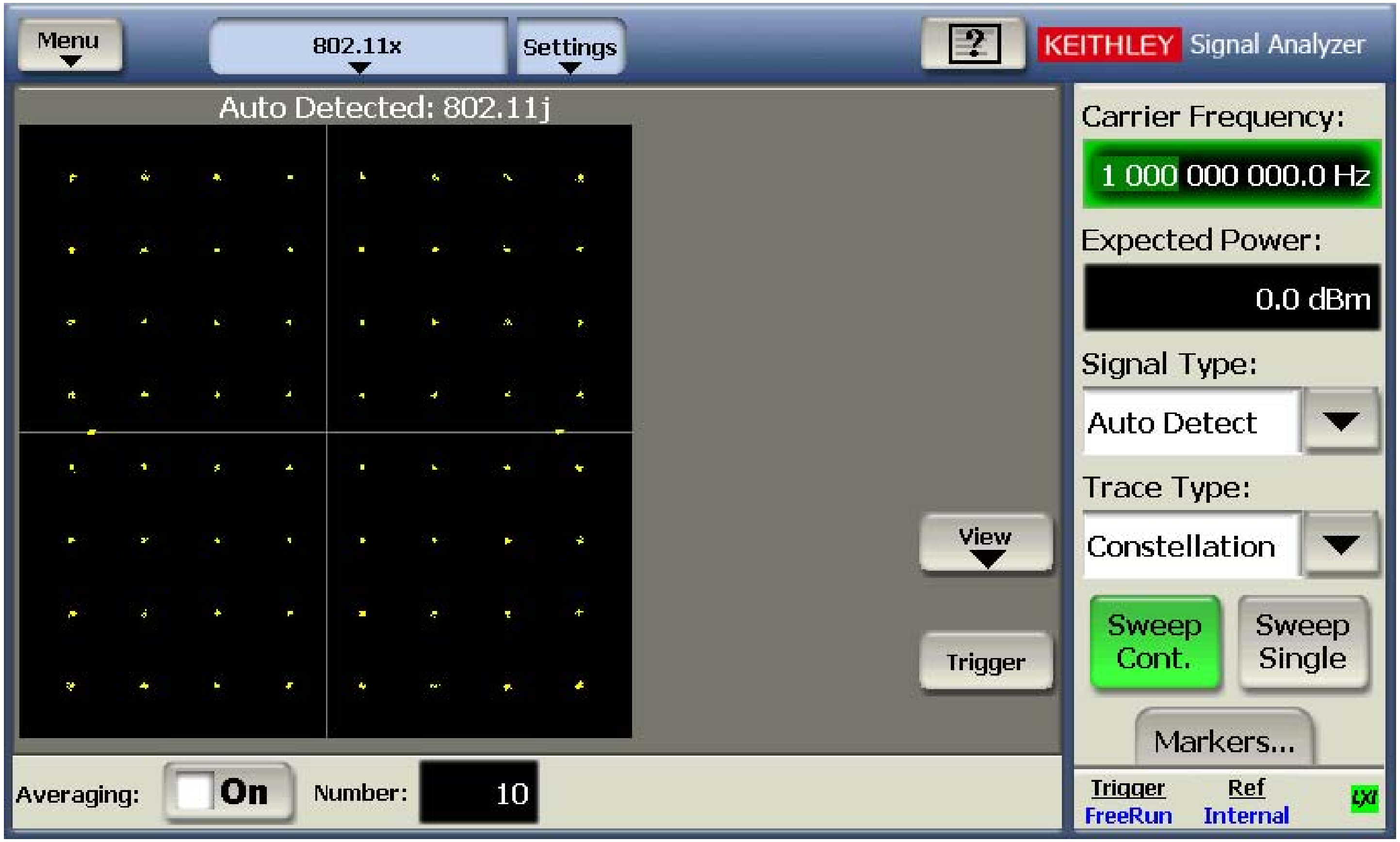
EVM
Error Vector Magnitude



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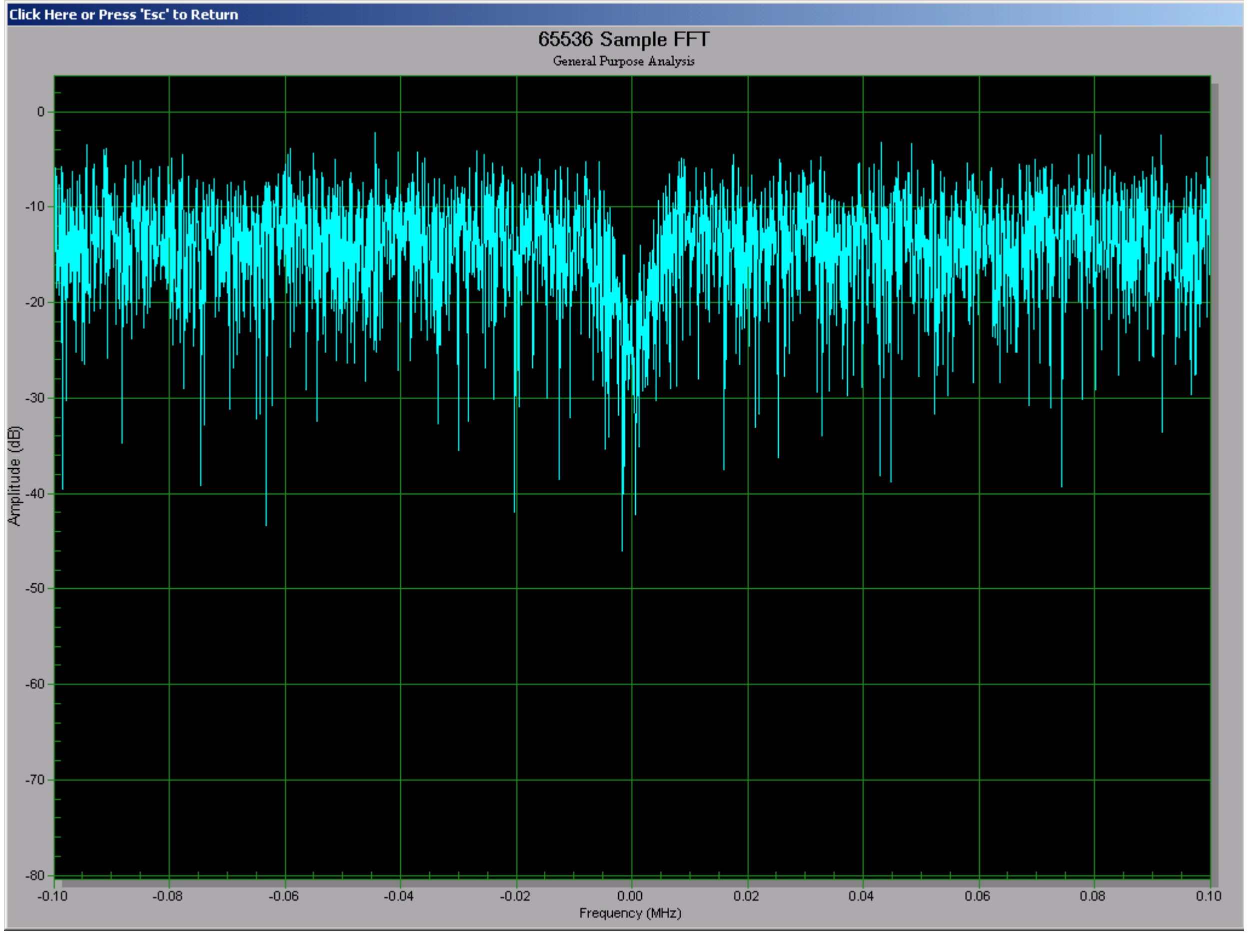
Carrier Feed Through



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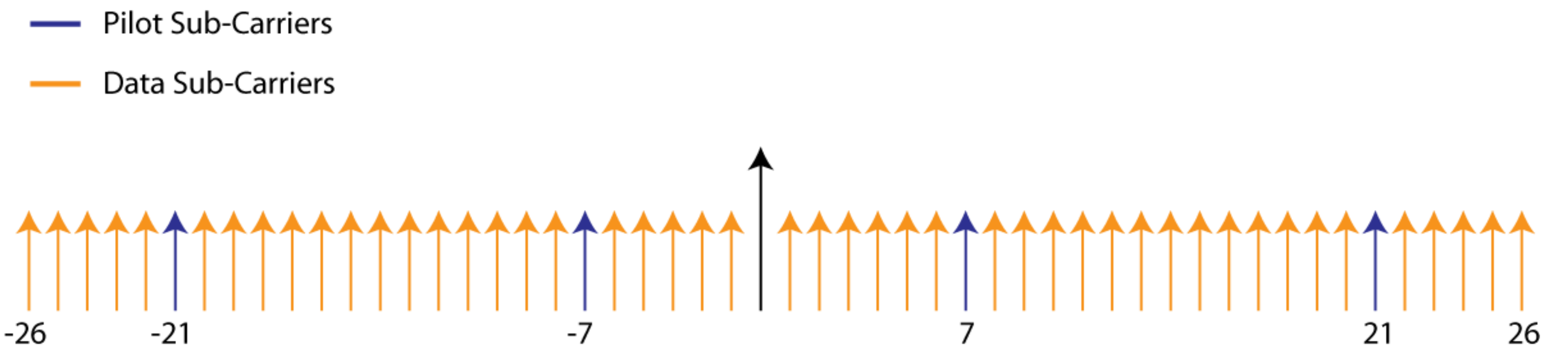
Pilot Carriers

- Not all of the sub-carriers are used to transmit data.
- Pilot sub-carriers are used to transmit training symbols throughout the duration of the packet.
- The receiver uses this information to correct for impairments such as phase variation, clock differences between transmitter and receiver, amplitude variation, and even assist in channel estimation.
- Pilots are transmitted using BPSK modulation.



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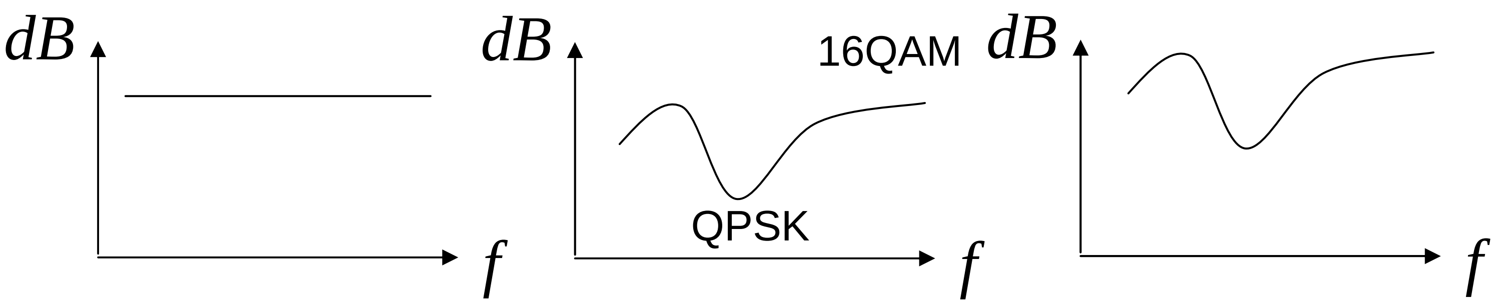
Channel Flatness



RX can equalize or
in a closed loop system
Send information back to TX.

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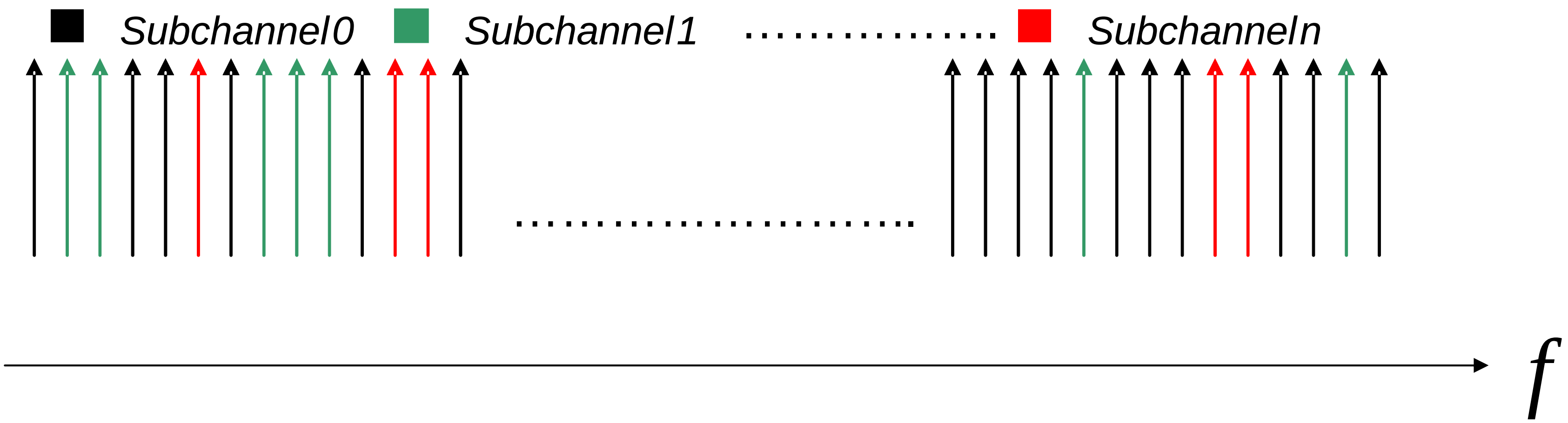
OFDM to OFDMA

- **OFDM** used by WLAN and WiMAX Fixed (802.16d) as a modulation technique is not multi user – all sub-carriers in a channel are used to facilitate a single link.

- **OFDMA** used by WiMAX mobile (802.16e) and LTE (3GPP Release 8) assigning different number of sub-carriers to different users.

WiMAX (Mobile) sub-channels Frequency Domain



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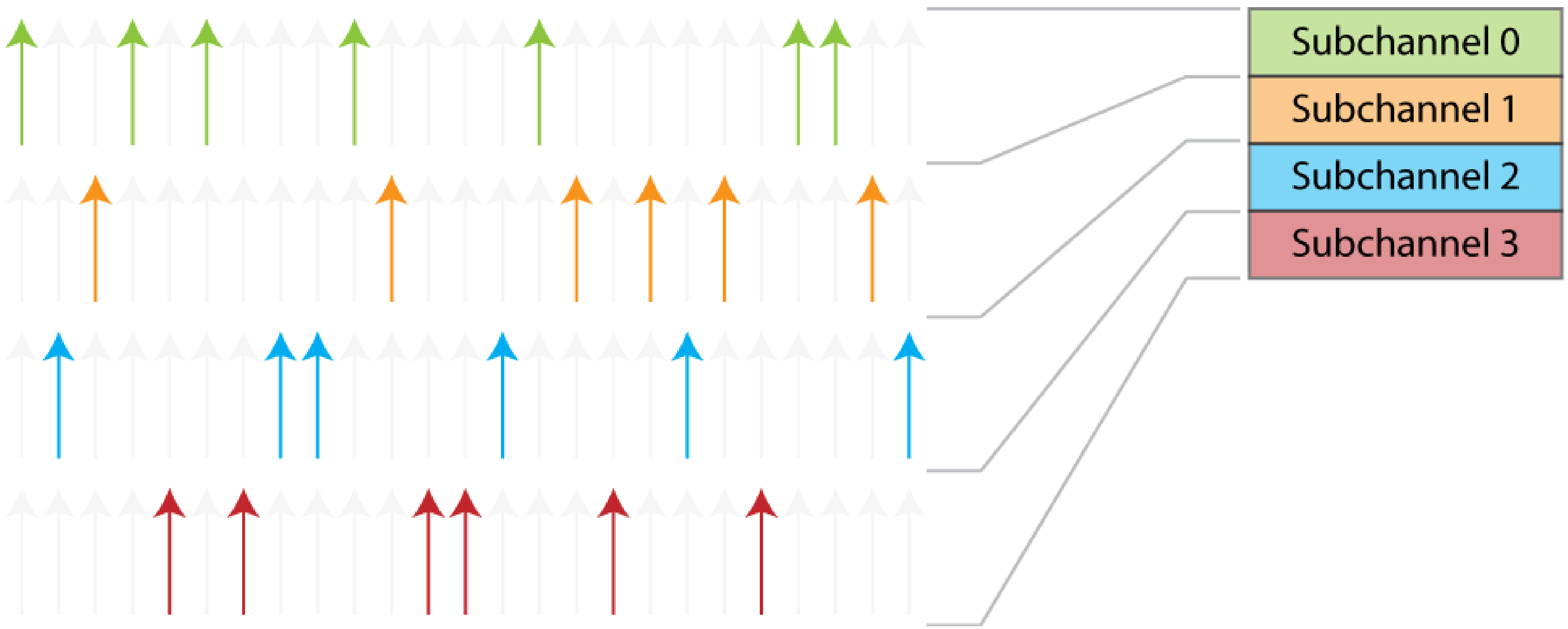
The Physical Channels are Different from the Logical Channels



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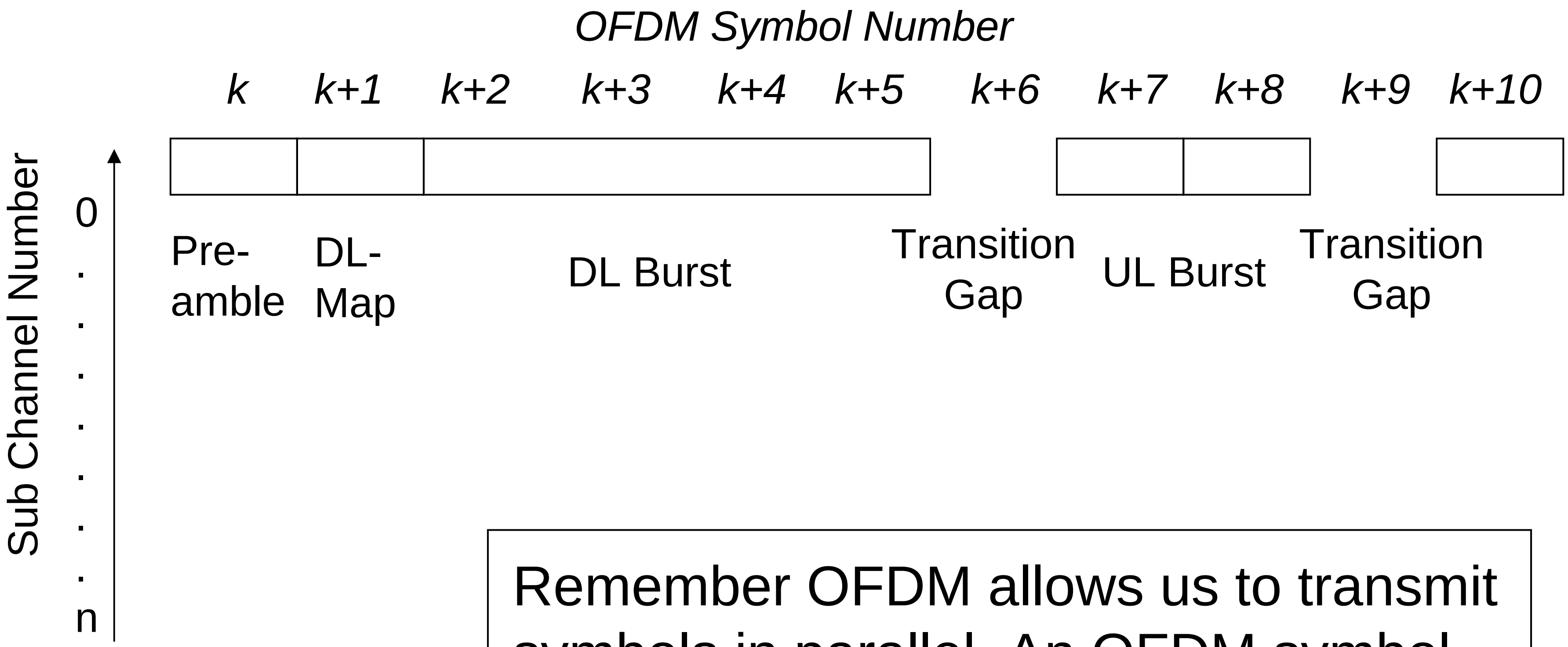
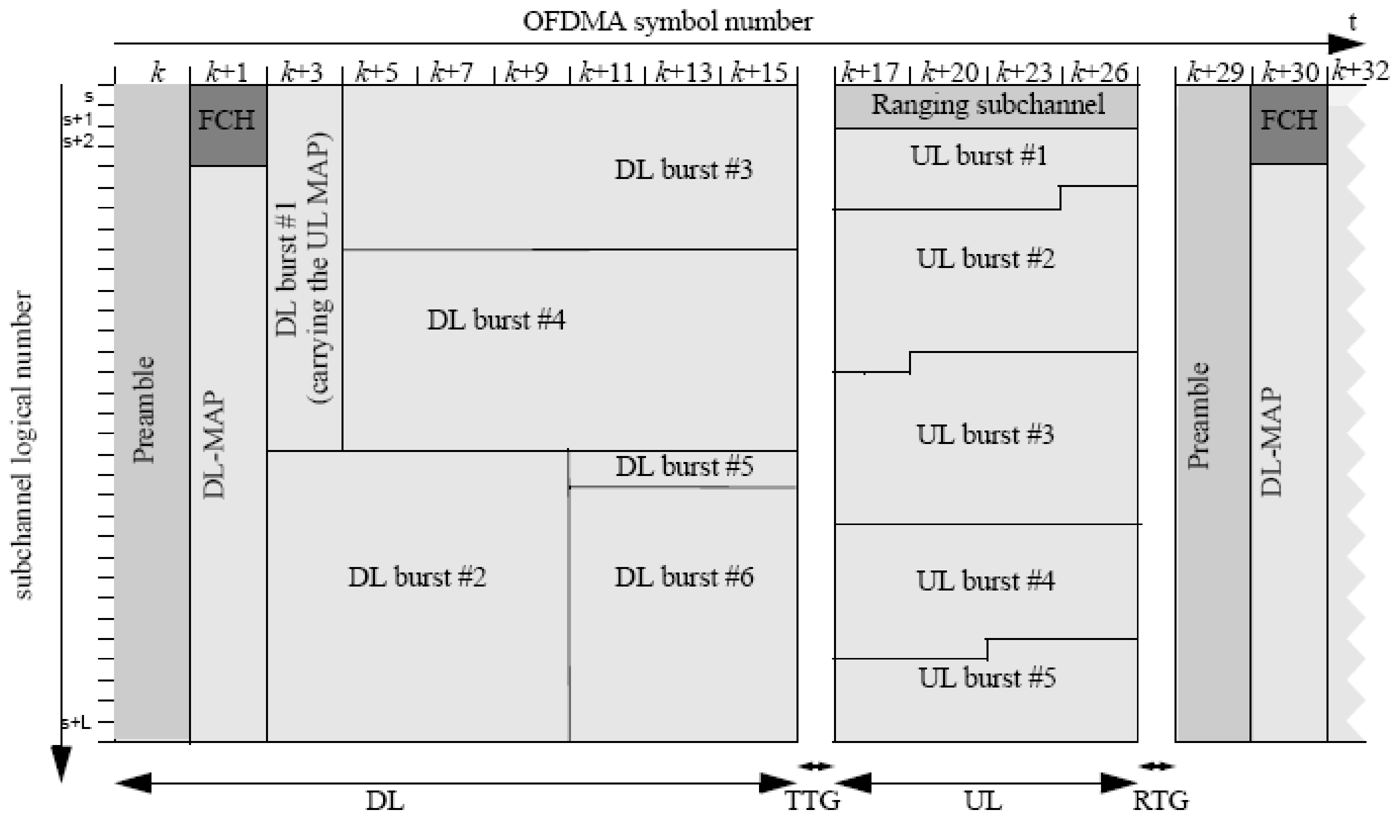
Symbol Transmission verses Time



Remember OFDM allows us to transmit symbols in parallel. An OFDM symbol period is a group of parallel symbols.

The WiMAX Symbol Map



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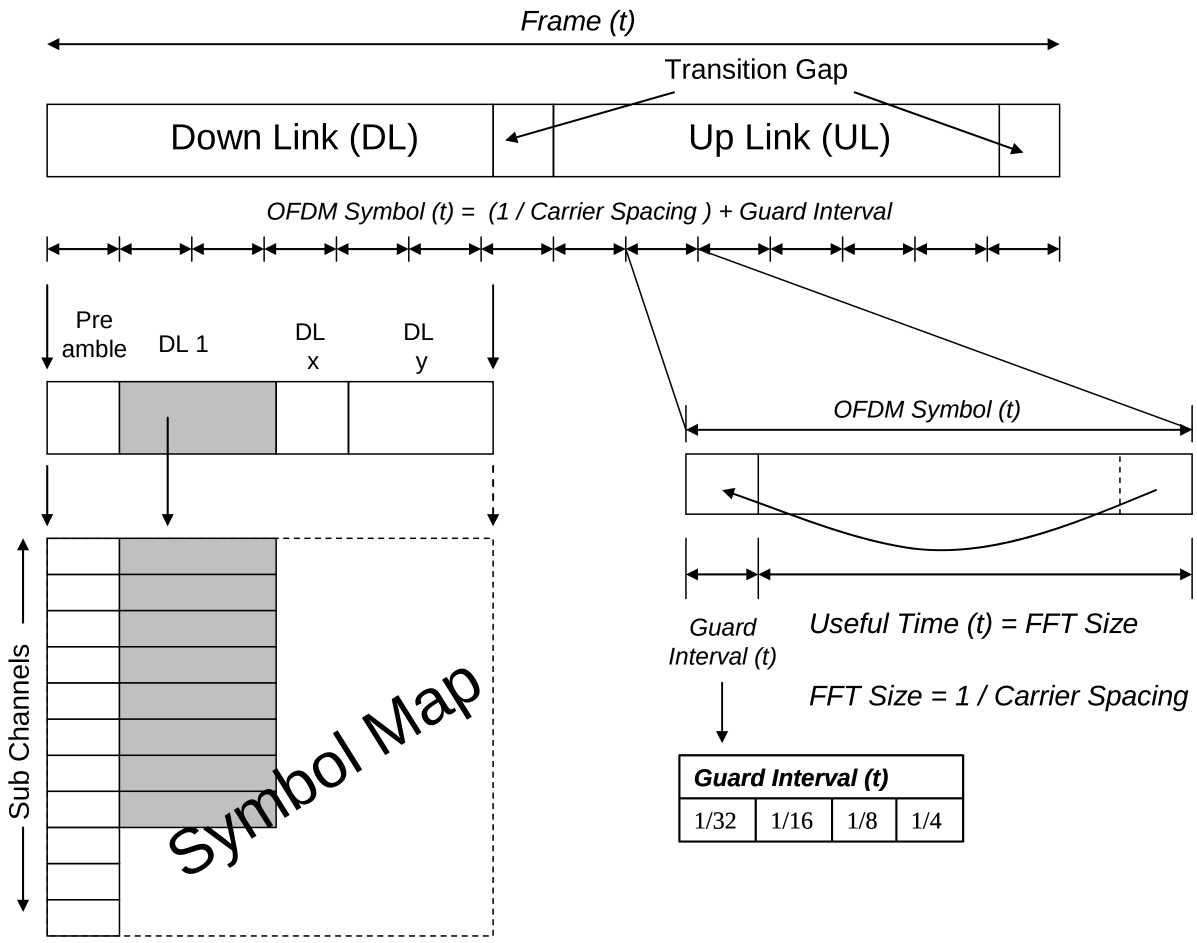
WiMAX putting it all together



Guard Interval (t)			
1/32	1/16	1/8	1/4

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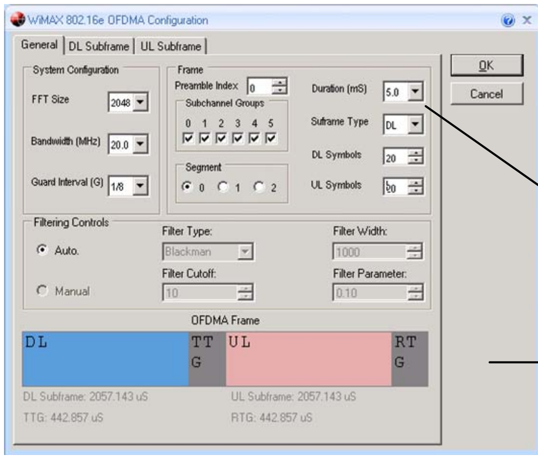
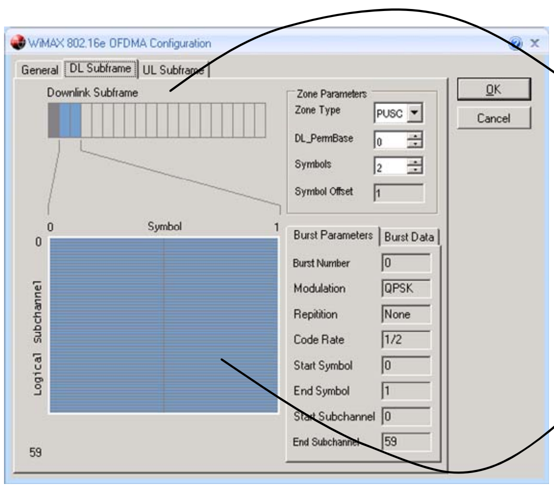
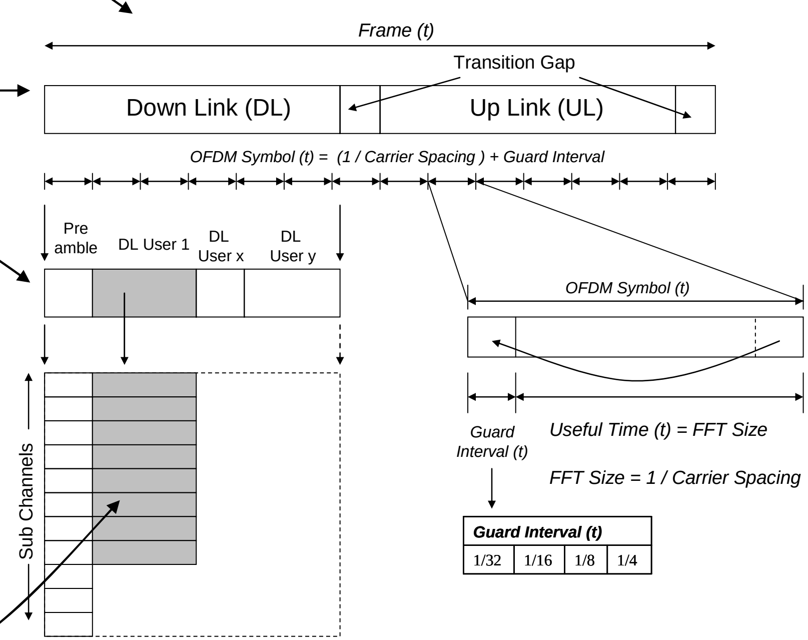
Creating a Signal







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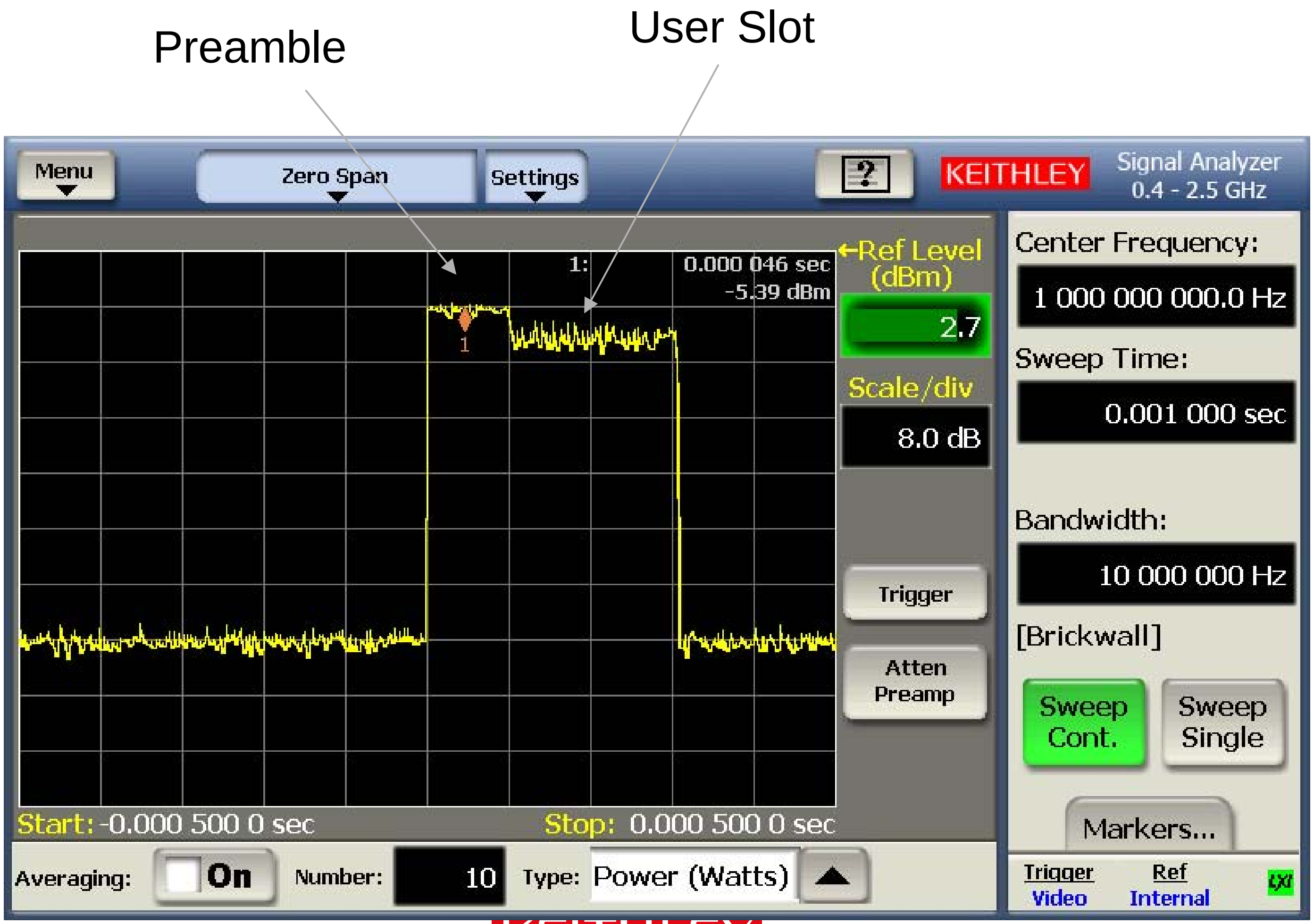
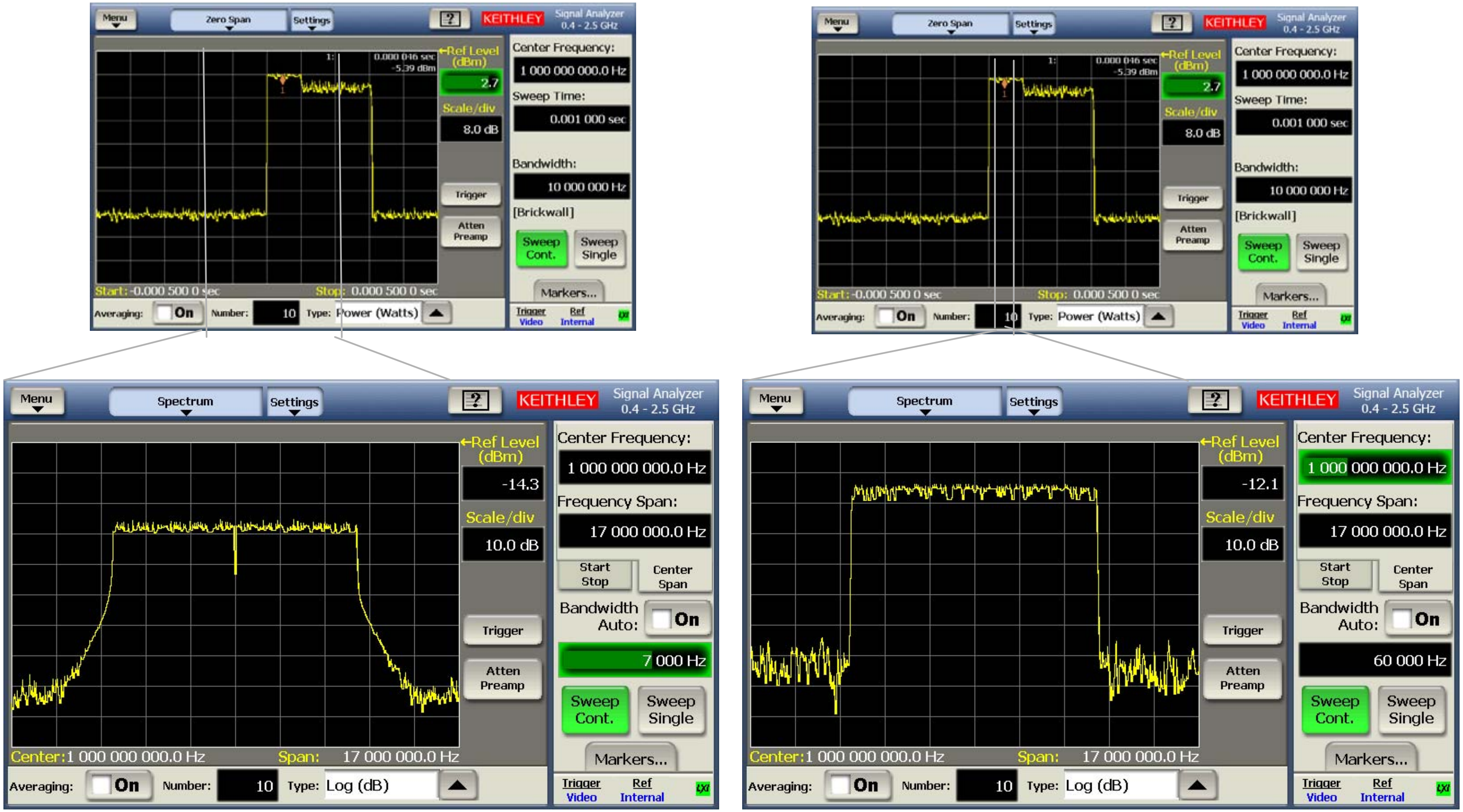
Time Domain Measurement



Frequency Domain Transient Effects



With Transients KEITHLEY Gated on Slot

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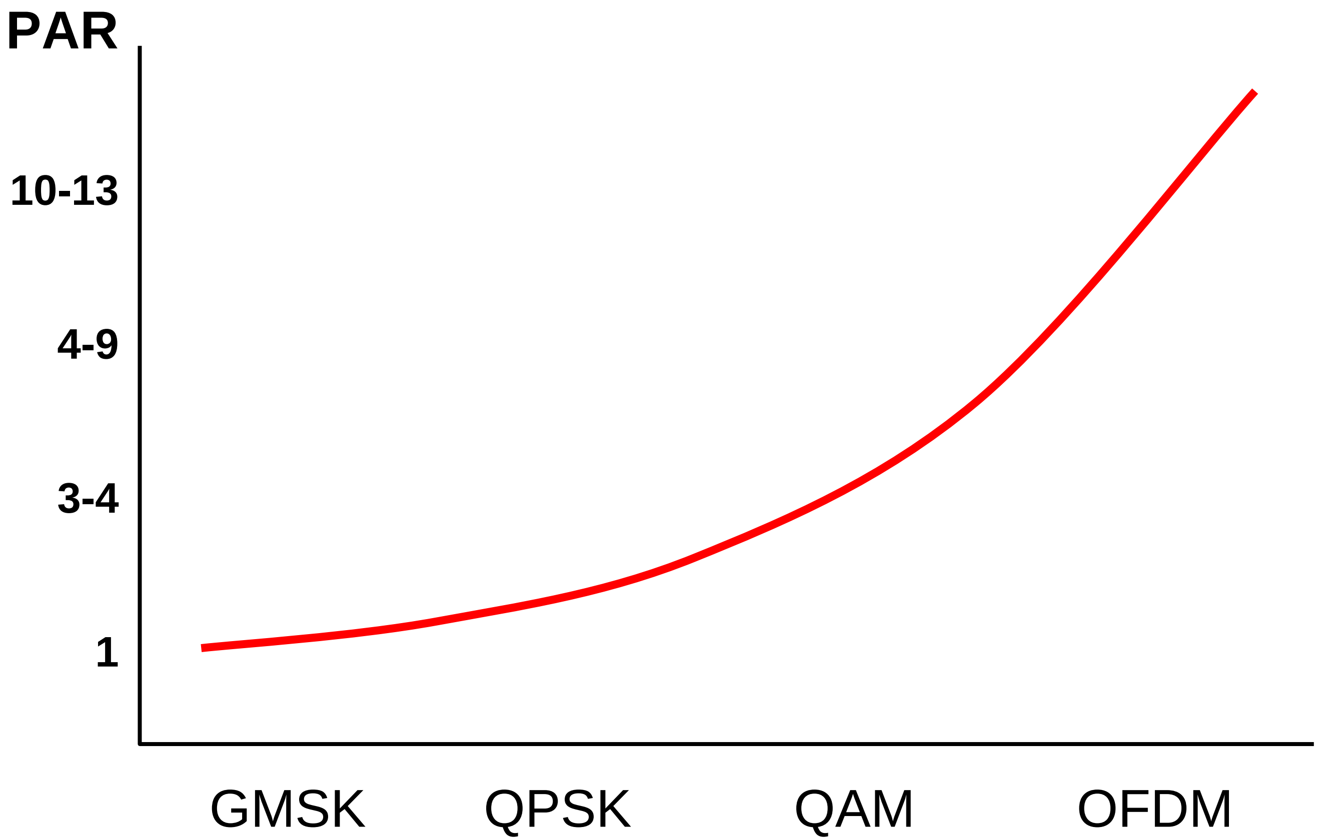
Peak to Average Ratio for WiMAX and WLAN



Gain Compression Issues

- **Gain compression is illustrated graphically in figure 1.**

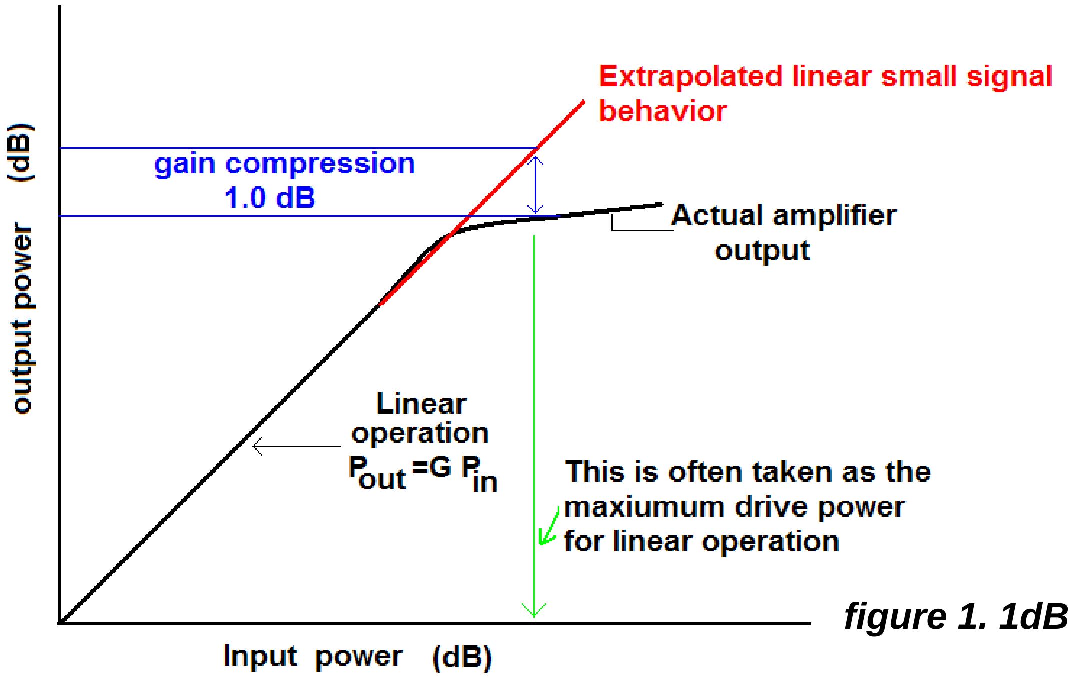
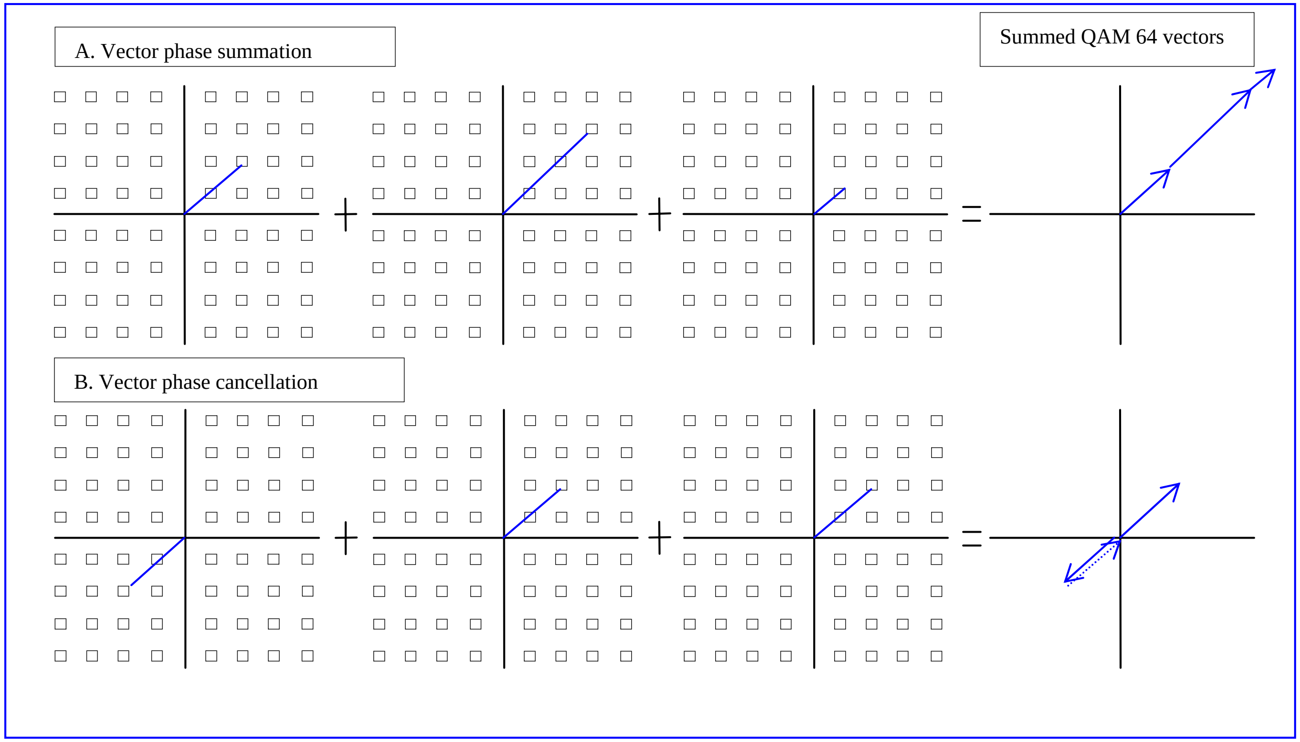


figure 1. 1dB Gain Compression

•The 1dB Gain Compression point is the input power level that causes the actual amplifier output level to be 1dB less than the extrapolated linear small signal behavior.

Random Phase Addition of Multi-carrier QAM 64 Waveforms

- Since each sub-carrier transmits their symbols in the same channel the instantaneous signal power due to random phases can add up constructively or they can cancel out.
- This means that the range of signal powers that the RF amplifier has to generate is widely varying and very dynamic. This is what creates the high peak to average ratio (PAR)



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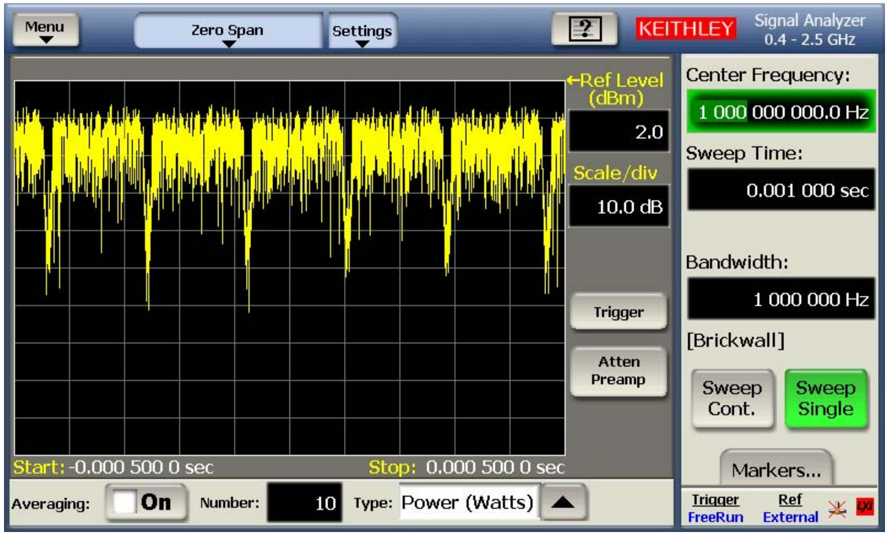
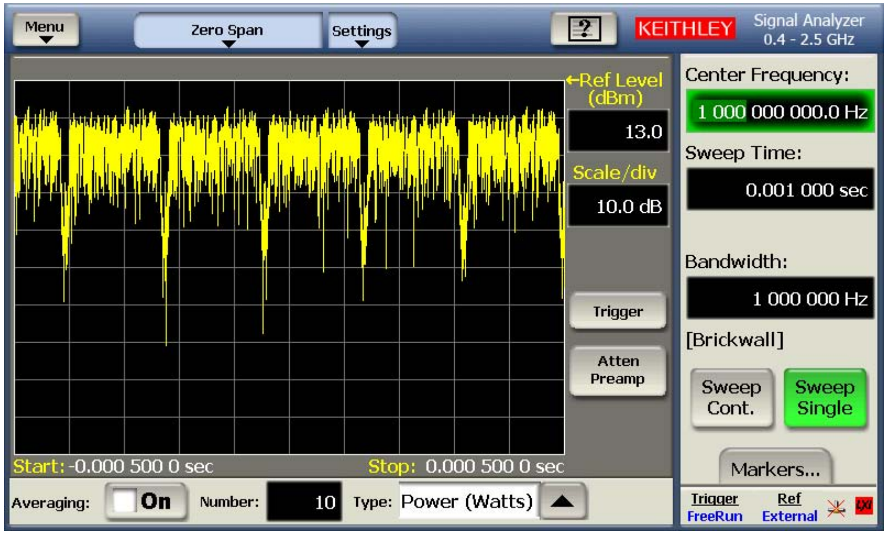
Effects of Gain Compression in OFDM Signals

- Waveforms having a large PAR can severely stress an RF amplifier causing it to distort during peaks.
- The issue for measurement instrumentation is that it is not always easy to tell whether an amplifier is being stressed into compression because the signals are so noise like.



802.11A 64QAM signal with 0% compression in zero span



802.11A 64QAM signal with 20% compression in zero span

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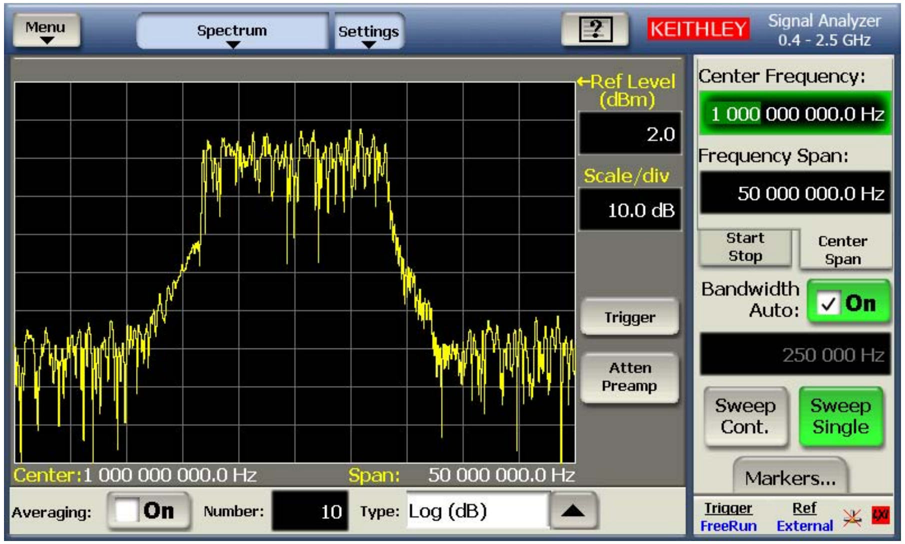
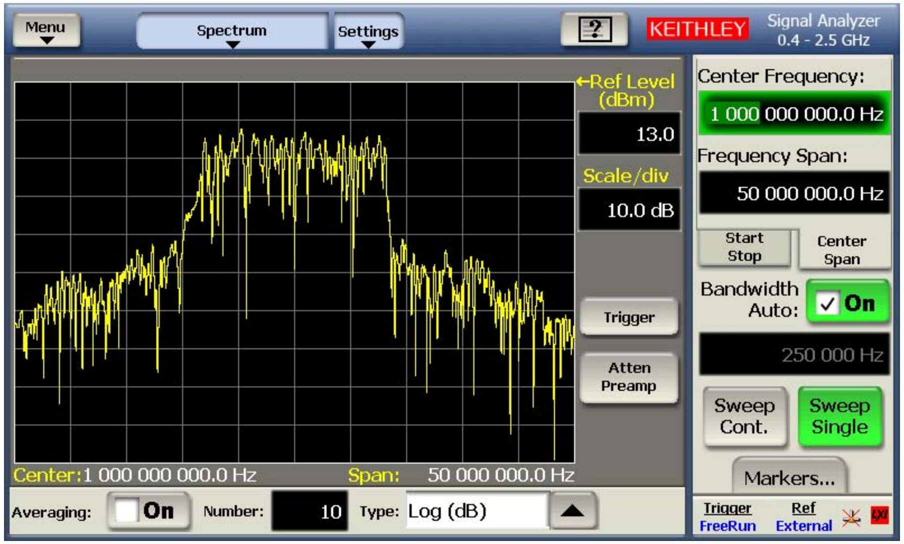
Effects of Gain Compression in OFDM Signals

- There are obvious degradations to the signal as viewed in the frequency domain as distortion increases, but it is difficult to derive a quantitive measure that would provide the designer feedback to optimize the circuit.



802.11A 64QAM signal with 0% compression



802.11A 64QAM signal with 20% compression

Quantifying Gain Compression for OFDM Signals

•The noise like nature of OFDM signals means that in order to extract useful information from the signal a statistical description of the waveform's power levels is required.

•For these types of signals a complimentary cumulative distribution function (CCDF) is required.

•CCDF curves can specify completely the power characteristics of the signals that are transmitted in a communications channel.

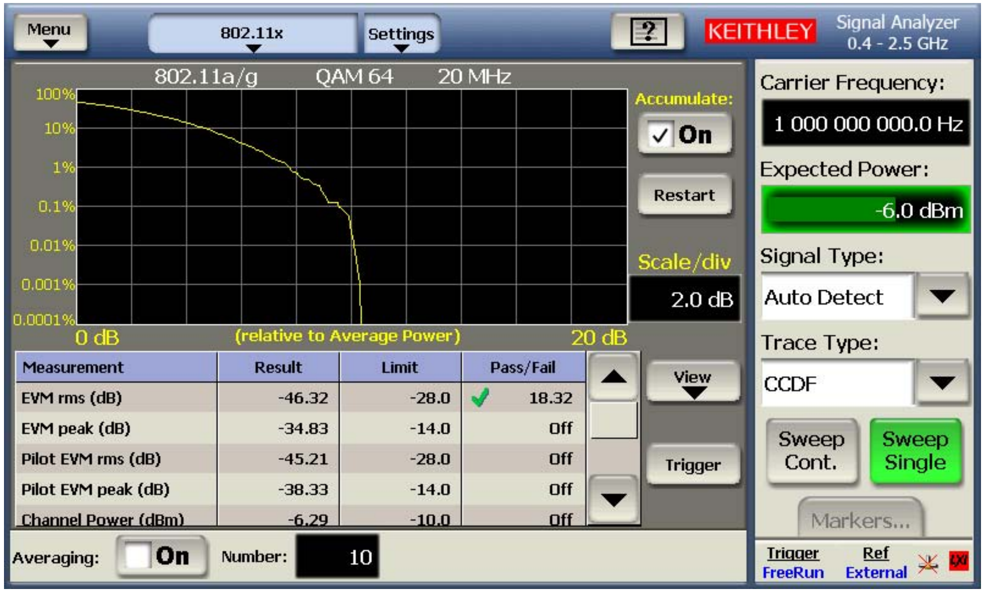


Figure 2. CCDF curve of 802.11A 64QAM signal - No Compression.

Notice the Y-axis is in percent and the x-axis is in dB relative to the average power.

This signal spends almost 1% of it's time at 8dB above the average power.

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Quantifying Gain Compression for OFDM Signals

- **The addition of Gain Compression in this amplifier has affected the CCDF curve but not in any way that you could reliably indicate the level of gain compression.**

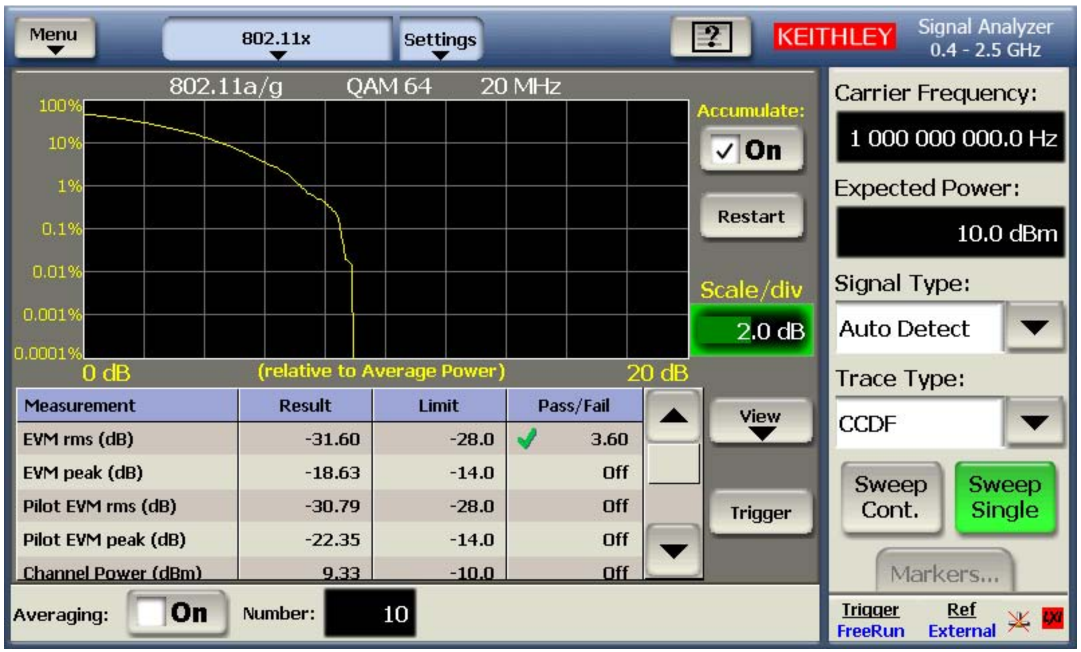

Figure 3. CCDF curve of 802.11A 64QAM signal – with 10% compression.

The compressed signal is noticeable on the CCDF curve but there can be no way to make a measurement of compression levels.

This signal spends almost 1% of it's time at 7.25dB above the average power.

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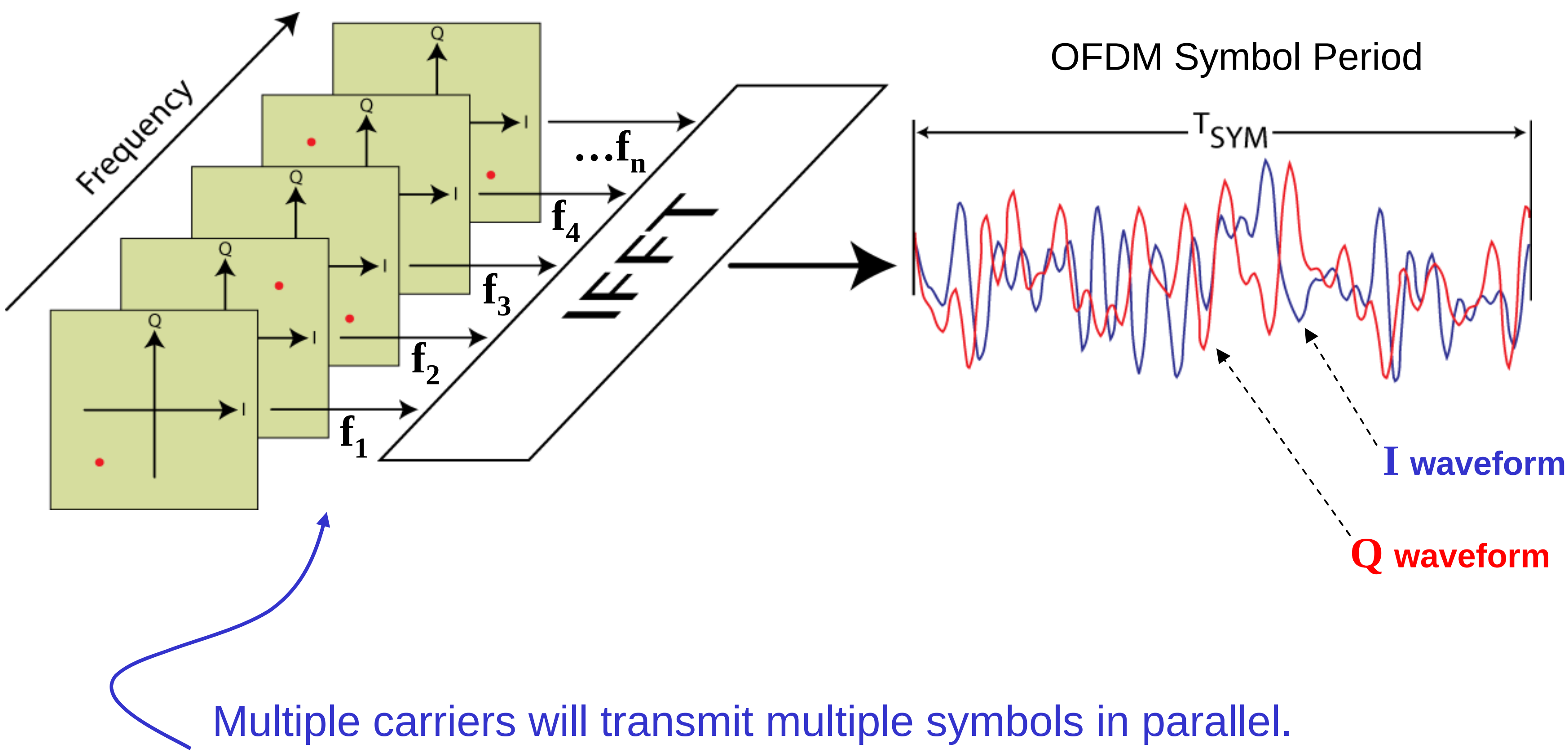
Symbol to Waveform

OFDM – Parallel Symbol Transmissions

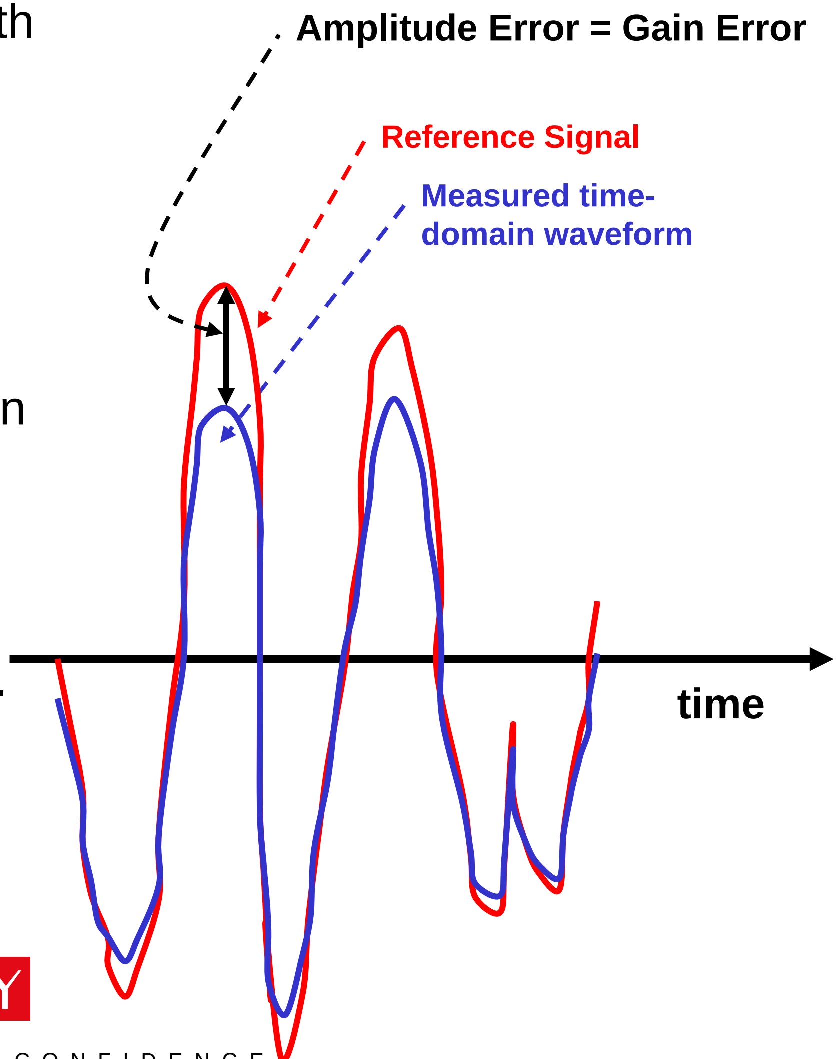


Multiple carriers will transmit multiple symbols in parallel.
Carriers may have different modulations – BPSK, QPSK… 64QAM.

Quantifying Gain Compression for OFDM Signals

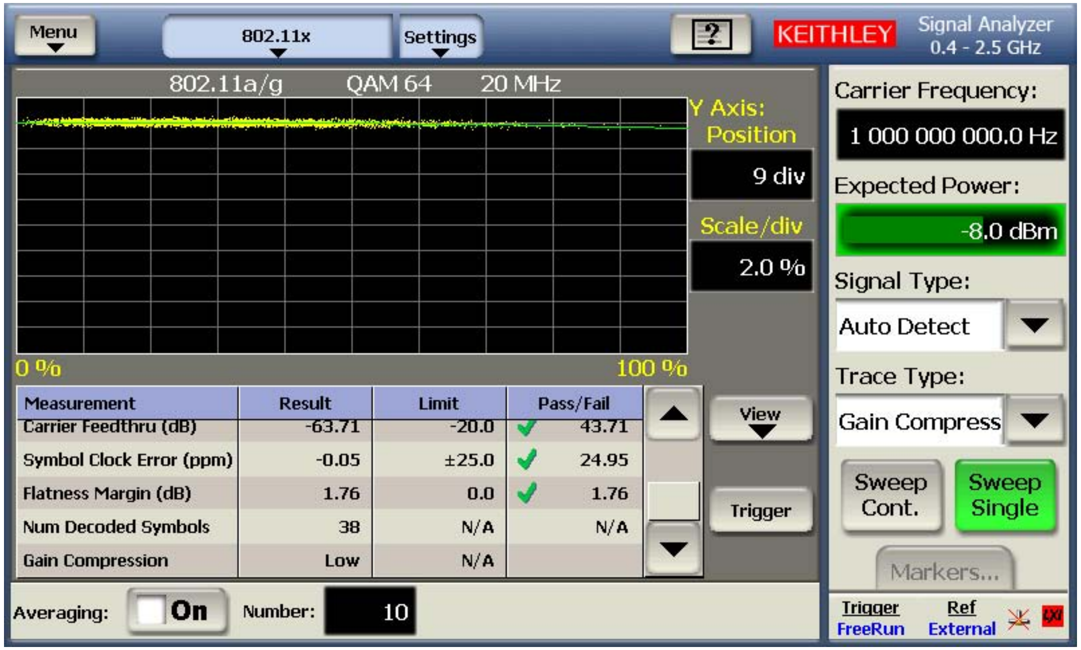
- Compare the measured time-domain signal with a reference signal and plot the difference as a function of input magnitude.
- The reference signal is an ideal time-domain waveform, constructed from the demodulated symbol targets using an IFFT.
- Time domain errors are measured as a function of input magnitude.
- The linear gain error equates to the gain compression.
- Linear gain error is plotted relative to full scale. This gives % magnitude error as a function of input magnitude.

$$\frac{\textbf{Measured Magnitude} - \textbf{Reference Magnitude}}{\textbf{Full Scale Magnitude}}$$



Quantifying Gain Compression for OFDM Signals

- **Keithley has developed a measurement technique that can easily and reliably discern the level of gain compression in RF amplifier DUT's employing OFDM signaling.**



Axis are *Error in observed power level vs expected power level.*

Figure 4. Keithley Gain Compression Measurement algorithm – No deliberate compression.

The Y-axis scale shows the level of amplitude error in percent %.
The X-axis scale shows the full scale input power range in percent %

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Quantifying Gain Compression for OFDM Signals

- As the RF amplifiers input power is increased the OFDM signal begins to cause compression in the amplifiers output.

•*Optional example 2. Measuring Gain Compression on an RF amplifier transmitting OFDM signals*.

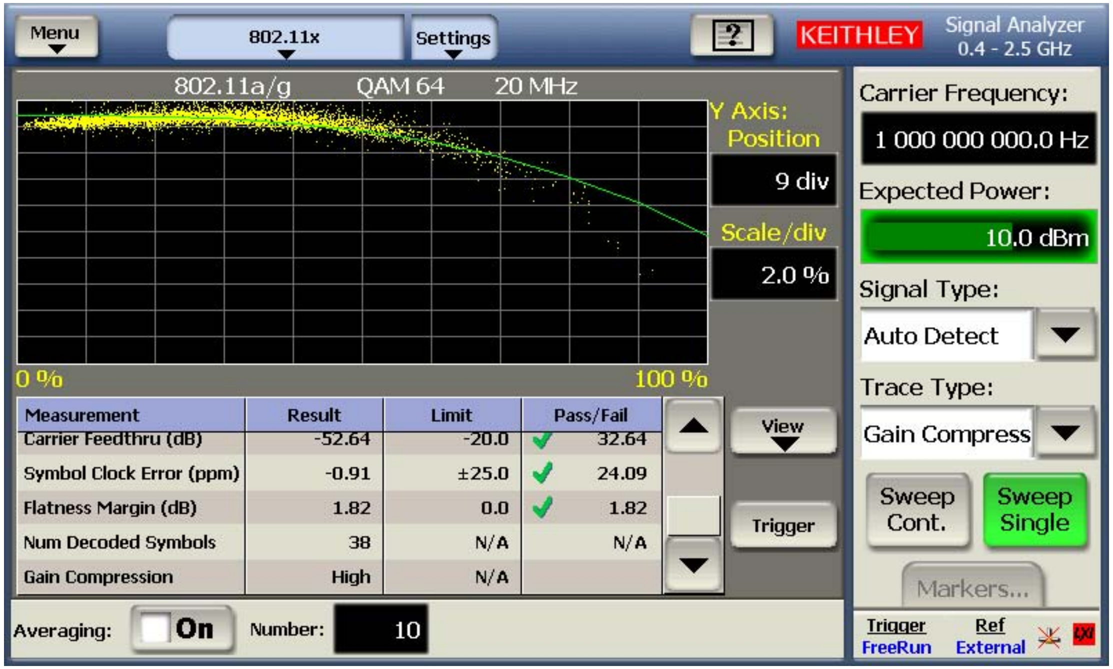

Figure 5. Keithley Gain Compression Measurement algorithm.

The Y-axis scale shows the level of linear gain error in percent %. The X-axis scale shows the full scale input power range in percent %

Notice that with 10% compression present there are larger errors in the measured values near the high power end of the response.

Axis are *Error in observed power level vs expected power level.*

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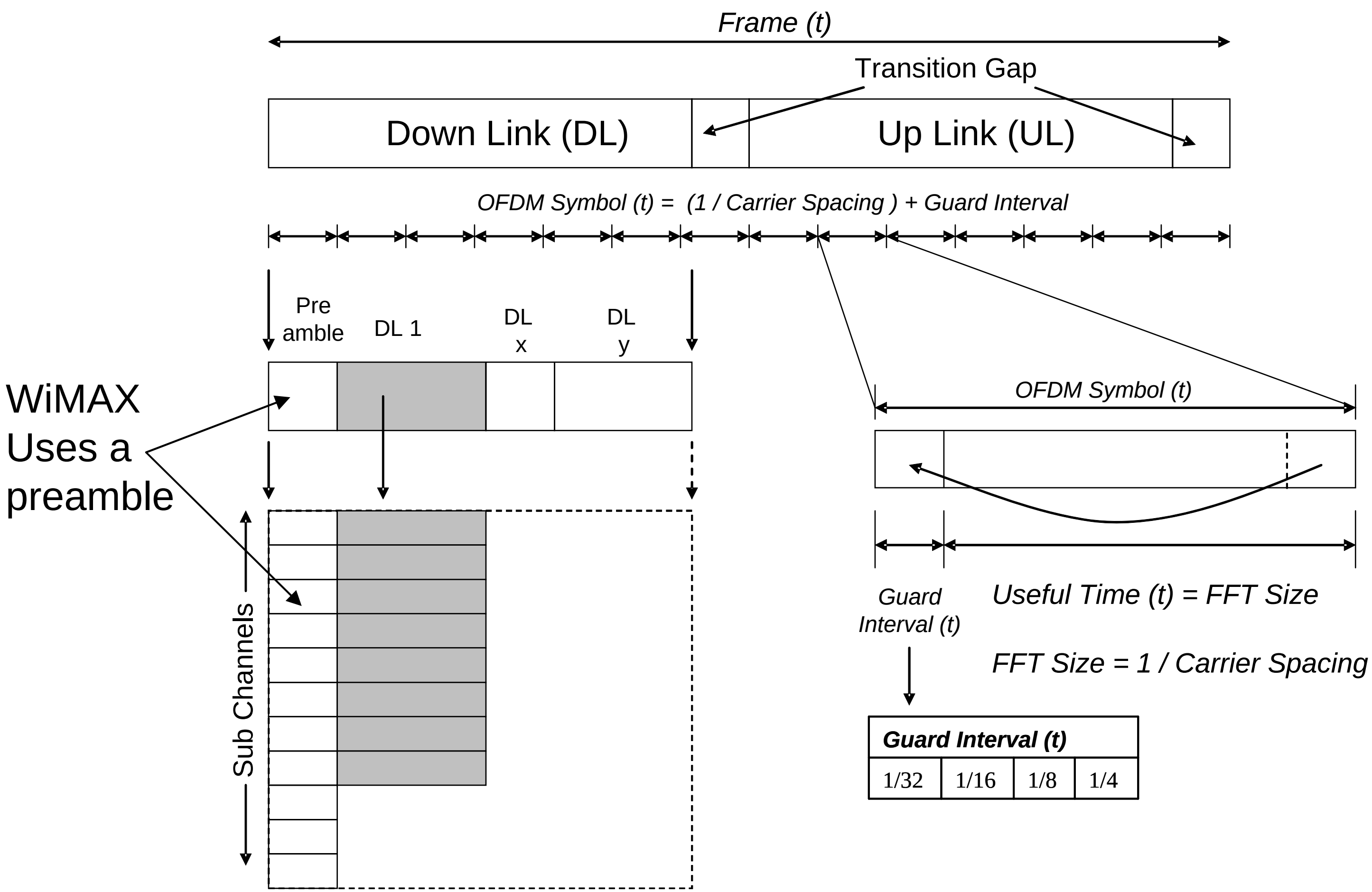
WiMAX and LTE

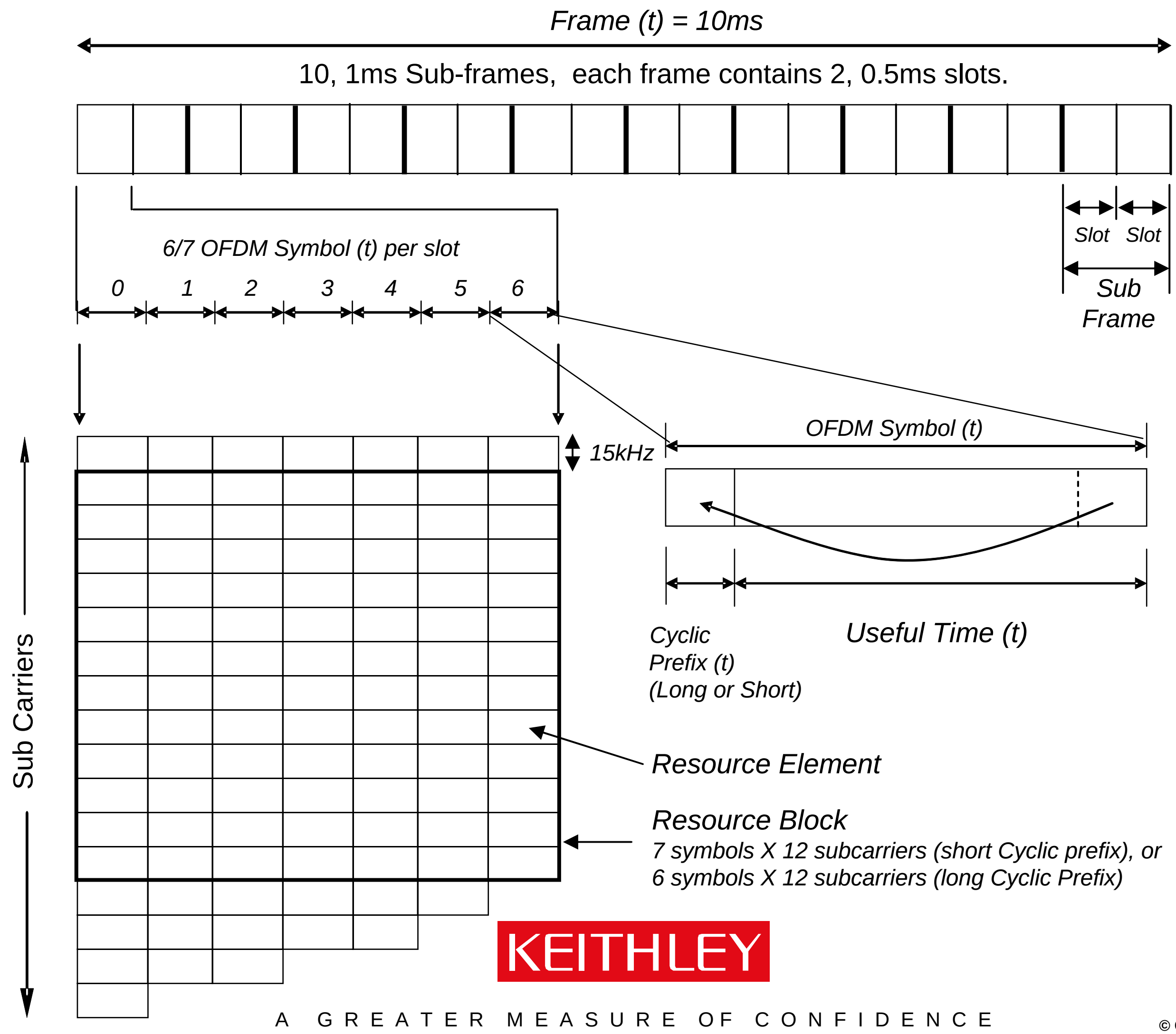
	WiMAX (802.16e)	LTE (Down Link)	LTE (Up Link)
Bandwidth	**Up to 20MHz**	**Up to 20MHz**	**Up to 20MHz**
Access scheme	**OFDMA**	**OFDMA**	**SC-FDMA**
Sub-carrier spacing	**10.94KHz**	**15kHz**	**60kHz (4x15khz)**
Modulation	**QPSK, 16QAM, 64QAM**	**QPSK, 16QAM, 64QAM**	**QPSK, 16QAM, 64QAM**
Duplex	**TDD/**FDD	**TDD/**FDD	**TDD/**FDD
MIMO	Up to 4	Up to 4	SISO

WiMAX TDD Frame Structure



Guard Interval (t)			
1/32	1/16	1/8	1/4

LTE FDD Frame Structure



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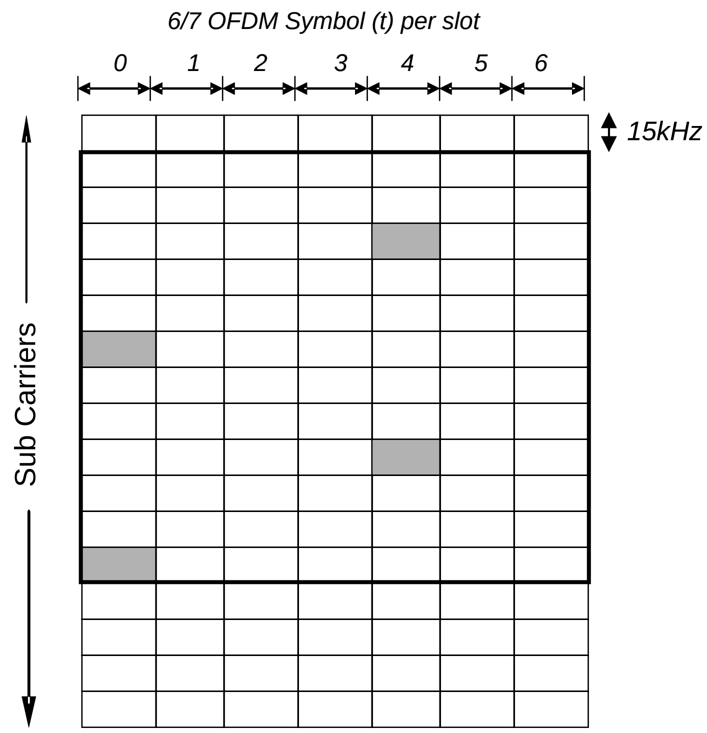
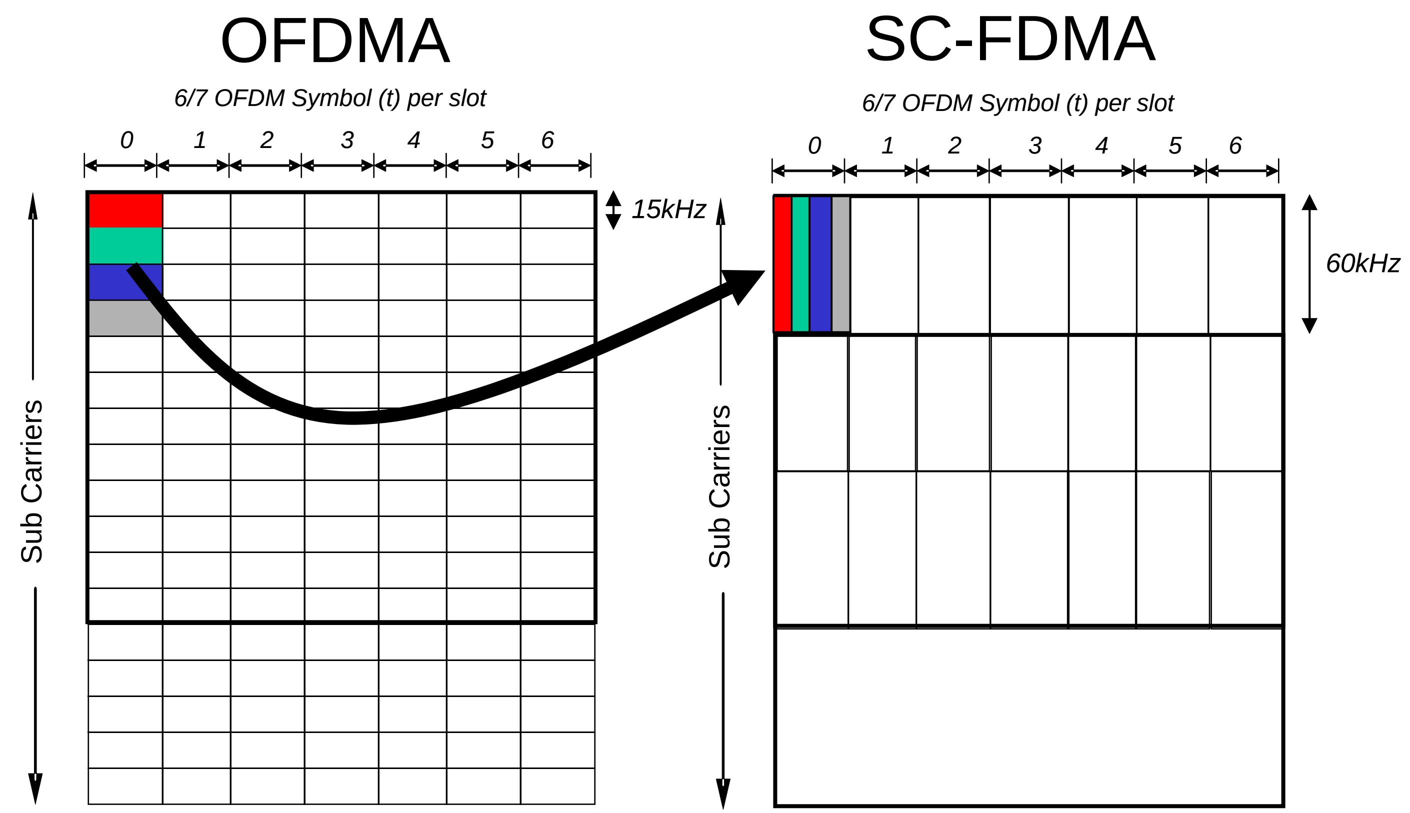
LTE, is not packet based



LTE is not a packet-oriented network, therefore does not employ preamble for carrier offset, channel estimation and timing synchronization. It uses reference signals transmitted during the first and fifth OFDM symbols of each slot when the short Cyclic prefix is used and during the first and fourth OFDM symbols when the long Cyclic Prefix is used.

LTE Up Link SC-FDMA

Single Carrier – Frequency Domain Multiple Access



In the baseband section SC-FDMA combines four subcarriers worth of symbols, then transmit them in a single symbol period using a carrier has four times the bandwidth.

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WiMAX Up Link vs. LTE Up Link

- **Proponents of LTE state that SC-FDMA with a lower peak to average ratio can use a lower cost power amplifier, thus saving in cost and battery life.**

- **Proponents of WiMAX state that the increased baseband processing requirements for SC-FDMA requires a more expensive FPGA or ASIC that uses more power thus reducing battery life.**

Summary

- **Advantages**
  – Improved spectral efficiency
  – Good multipath performance
  – Resilient to interference
  – Complementary to MIMO transmission. (Part 2)
- **Disadvantages**
  – Increased baseband processing requirements.
  – High peak to average ratio.

Agenda

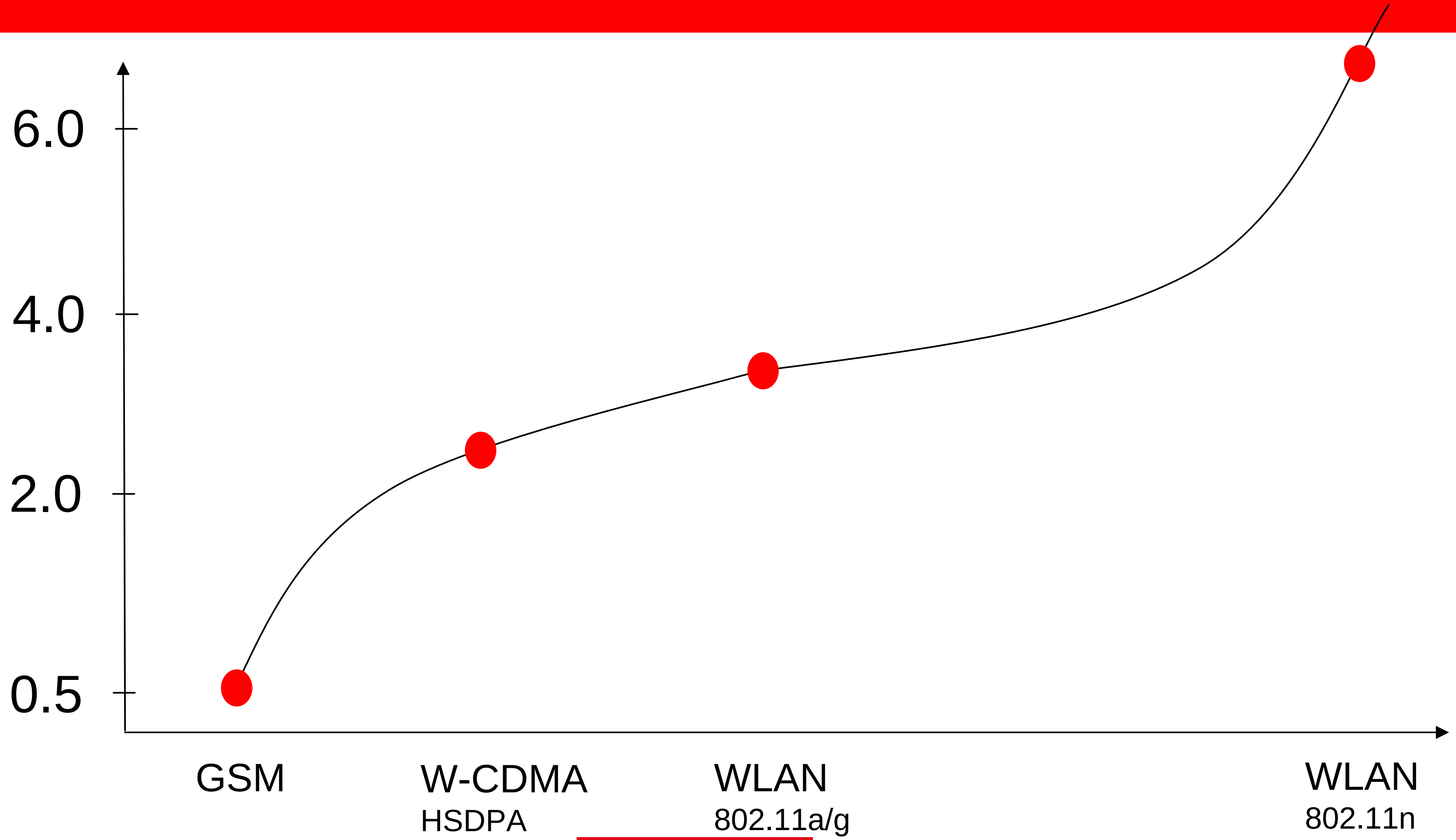
- The evolution of communications and an introduction to the test tools
- Part One – OFDM and SISO radio configurations
  - The case for OFDM
  - OFDM Signal Structure, generic and WLAN.
  - Measurements
  - OFDM and OFDMA
  - Peak to average ratio considerations
  - WiMAX and LTE
- **Part Two – OFDM and MIMO radio configurations**
  - MIMO – Multiple Input Multiple Output Radio Topology
  - How it works.
  - Measurements
  - Channel Considerations
  - Smart Antenna Systems and Beam Forming Considerations
- Technology Overview and Test Equipment Summary

OFDM/A to MIMO

- MIMO based systems use multiple transmitters and receivers that are modulated with OFDM/A.
- WLAN (802.11n), WiMAX (802.16e) and LTE (3GPP Rel 8) all have MIMO configurations.

Spectrally Efficiency – SISO - MIMO

Bits/Second/Hz



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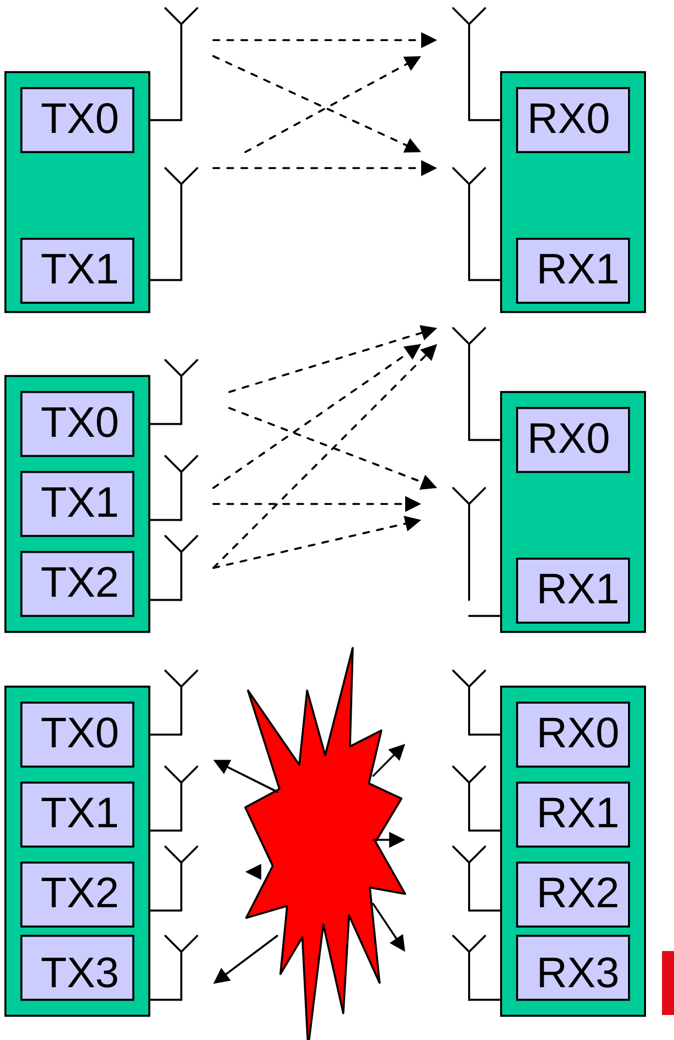
MIMO Configurations
Spatial Diversity, Spatial Multiplexing and Beam Forming

- Multiple replicas of the radio signal from different directions in space give rise to spatial *diversity*, which increases the reliability of the fading radio link.
- MIMO channels can support parallel data streams by transmitting and receiving on orthogonal spatial filters ("*spatial multiplexing*").
- *Beamforming*, the transmit and receive antenna patterns can be focused into a specific angular direction by the appropriate choice of complex baseband antenna weights. The more *correlated* the *antenna signals*, the better for beamforming.

MIMO Radio Configuration



2X2

3X2

4X4

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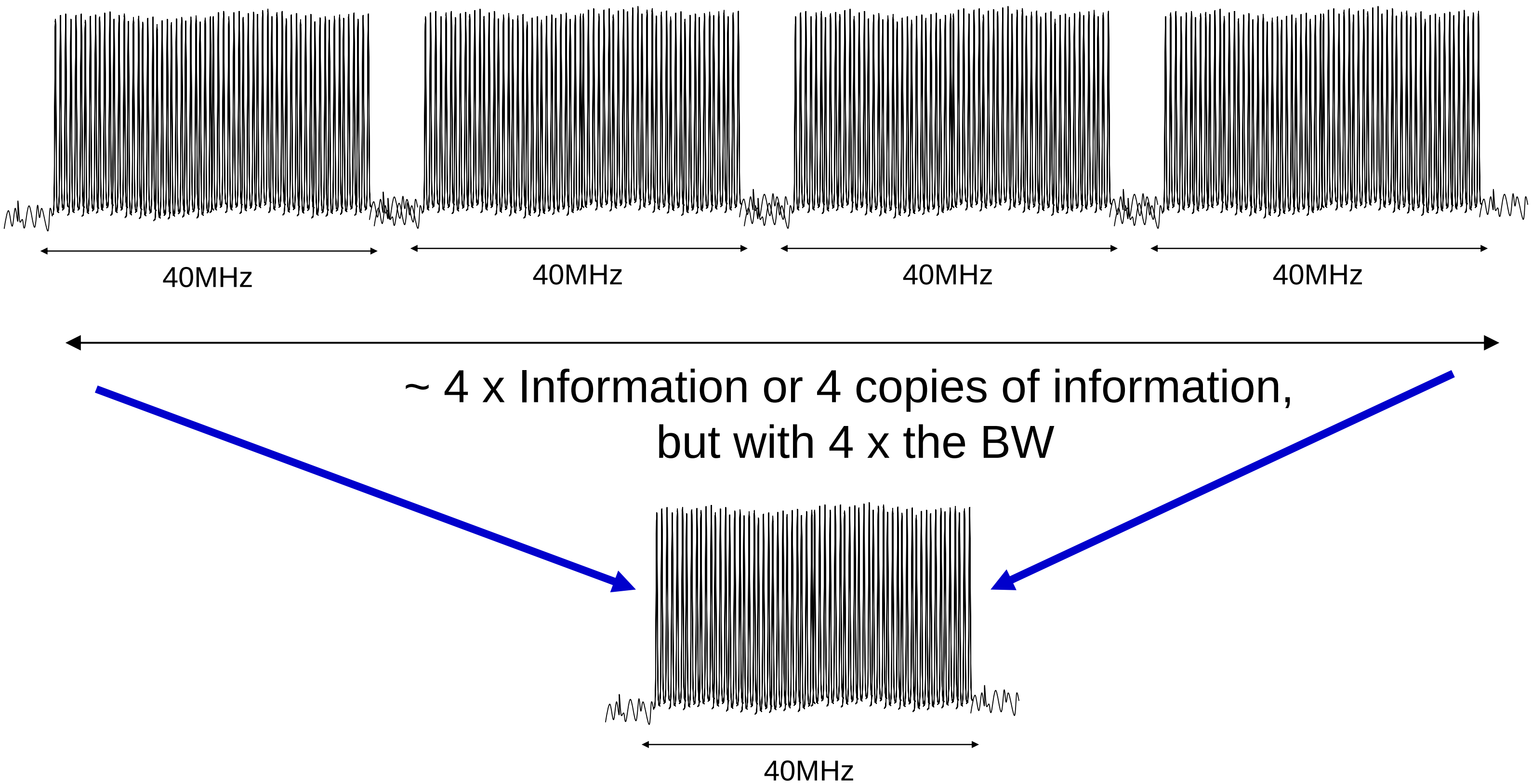
Why is MIMO different from standard OFDM?



~ 3.5 x Information, but with 1 x the BW

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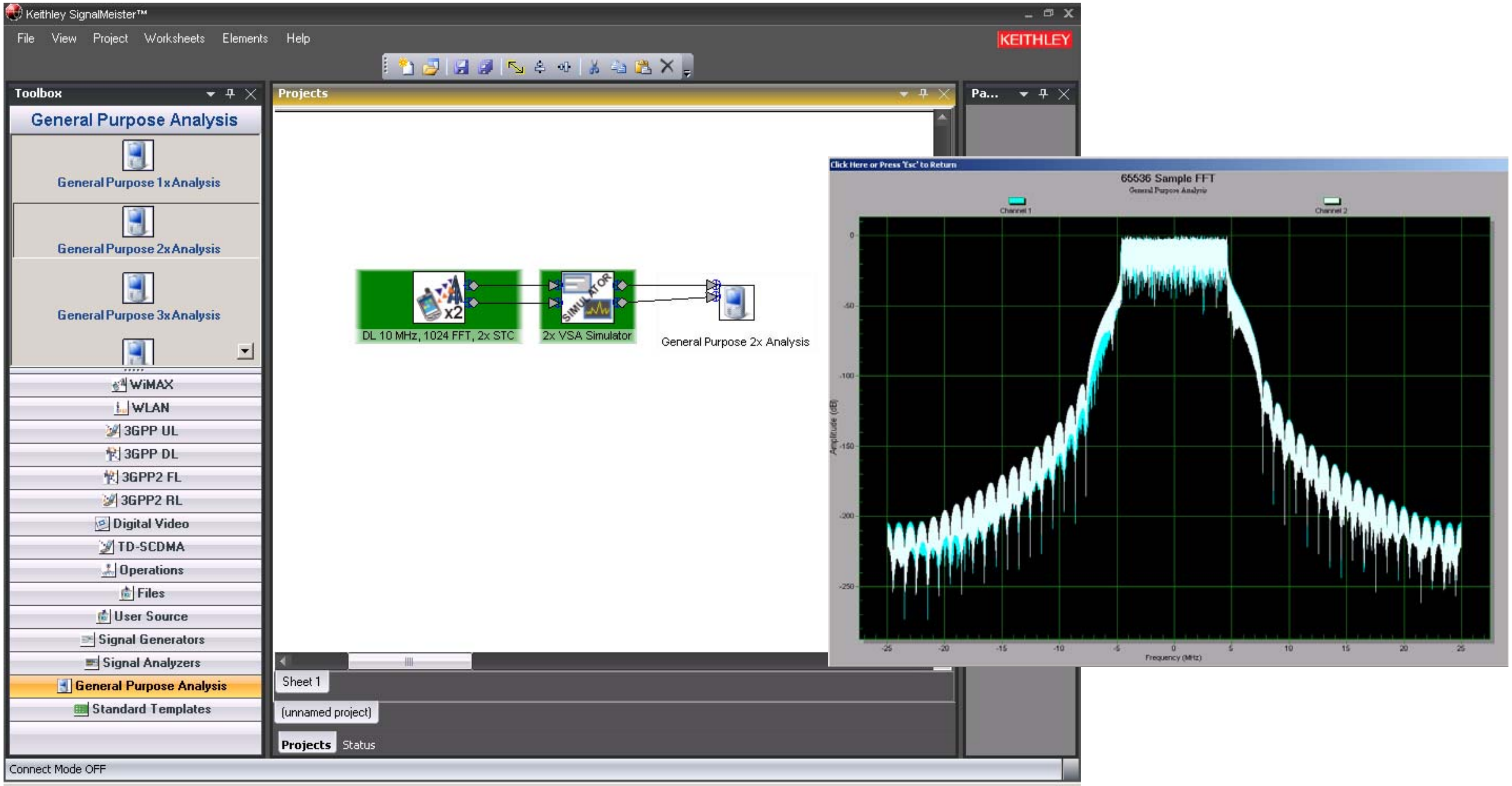
Generate a 2x2 MIMO signal.

WiMAX Matrix A Space Time Coding



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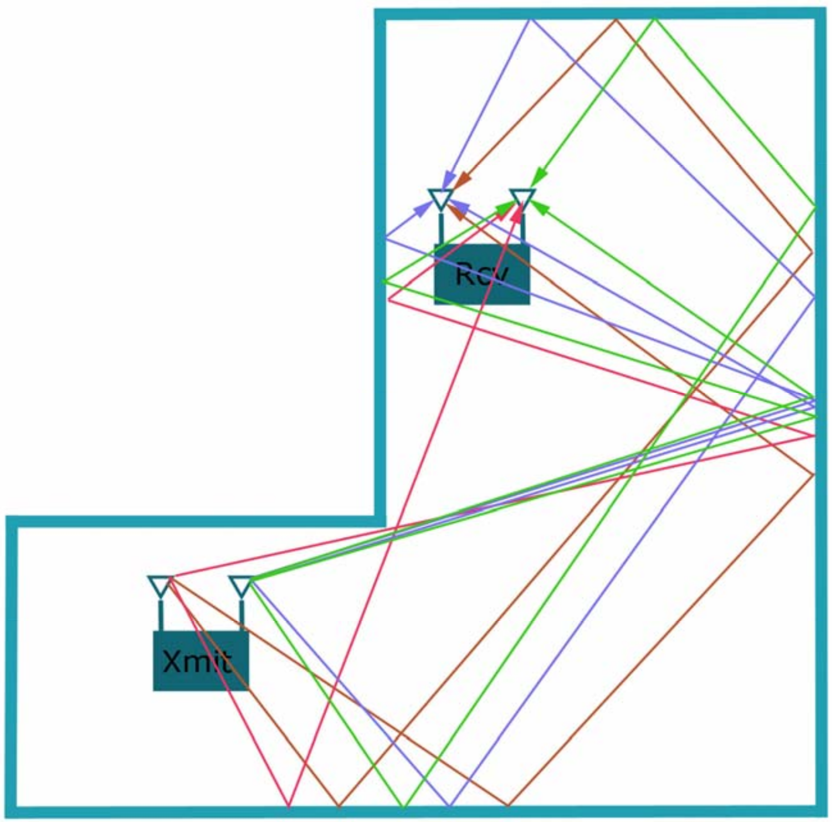
Solving for original stream symbols MIMO requires lots of paths!



If you have two unknown transmitted signals and two measurements at the receivers. If the two measurements are sufficiently independent, you can solve for the transmitted symbols!

Mathematically
Model the Channel

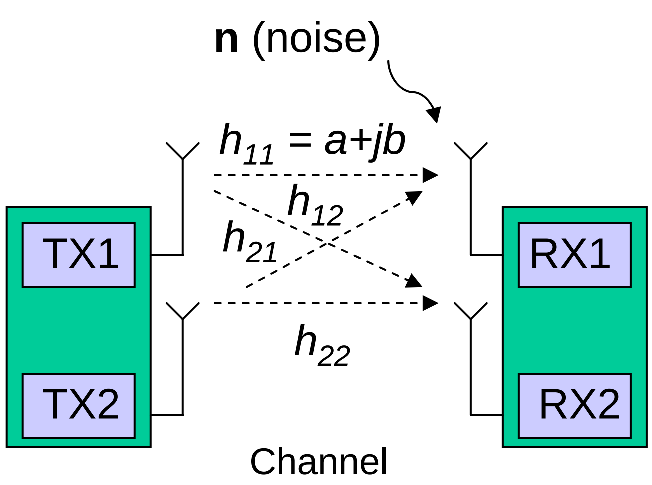
$$y = Hx + n$$

y = Receive Vector

x = Transmit Vector

H = Channel Matrix

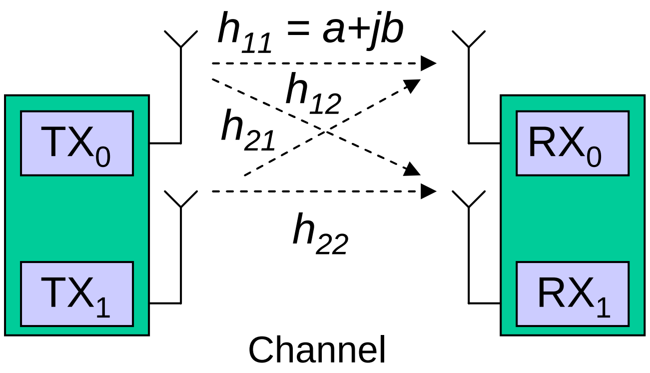
n = Noise Vector



$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

Correct for channel effects

$$RX = H * TX + n$$



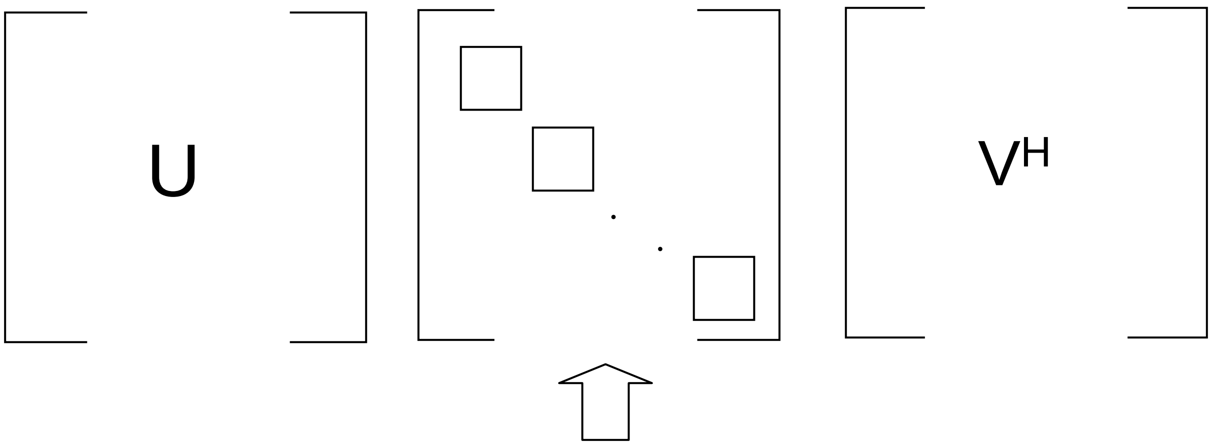
$$\begin{bmatrix} TX_0 \\ TX_1 \end{bmatrix}_{\text{Data}} = \frac{\begin{bmatrix} RX_0 \\ RX_1 \end{bmatrix}_{\text{Data}} - n}{\begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}_{\text{Header}}}$$

Note this has the disadvantage of possible noise enhancement if |H| is small.

A Different Channel Model

$H=UDV^H$

Three matrices can represent the channel



D. Scaling matrix,
or singular values

The Details

•We could also express **H** as:

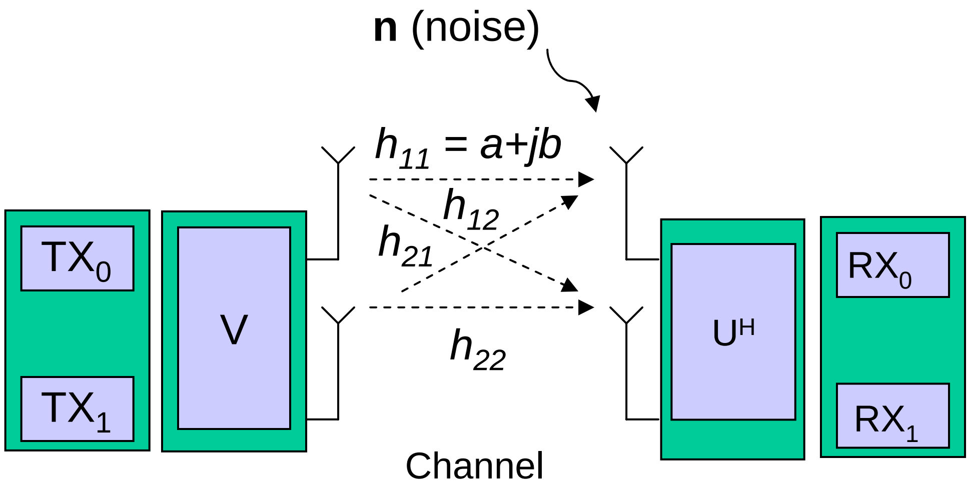
$$\mathbf{H} = \mathbf{U} \bullet \mathbf{D} \bullet \mathbf{V}^H = \begin{bmatrix} u_0 & u_1 & \dots & u_{N-1} \end{bmatrix} \begin{bmatrix} \sigma_0 & 0 & 0 & 0 \\ 0 & \sigma_0 & 0 & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & \sigma_{M-1} \end{bmatrix} \begin{bmatrix} \mathbf{V}_0^H \\ \mathbf{V}_1^H \\ \dots \\ \mathbf{V}_{N-1}^H \end{bmatrix}$$

•We represent the **U** and **V** matrices as column vectors of their singular values for convenience.

•The factor **D,** is composed of the singular values of **H**

A more Complete Channel Model

$$H=U.D.V^H$$



$RX = U.D.V^H.TX + n$

→"Do the math" and

→$RX=D.TX+U^H.n$

D elements are singular values of H.

Also, |U| is unitary, so there is no noise enhancement.

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WLAN Example

Number of Stream and Modulation type is determined by the MCS

Selecting Modulation Coding Schemes (MCS)

- The table at right contains the specification of some of the 802.11n defined MCS
- This information is automatically encoded in the packet header of the 802.11n waveform, and automatically decoded by the WLAN analyzer program

MCS Index	Modulation	Code rate	Spatial Streams	FEC coders	PHY rate 20 MHz	PHY rate 40 MHz
0	BPSK	½	1	1	6.5	13.5
1	QPSK	½	1	1	13	27
7	64-QAM	5/6	1	1	65	135
8	BPSK	½	2	1	13	27
14	64-QAM	¾	2	1	117	243
21	64-QAM	2/3	2	2	156	324
28	16-QAM	¾	4	2	156	324
31	64-QAM	5/6	4	2	260	540

For example a 2x2 BPSK can be analyzed by setting the MCS index to 8

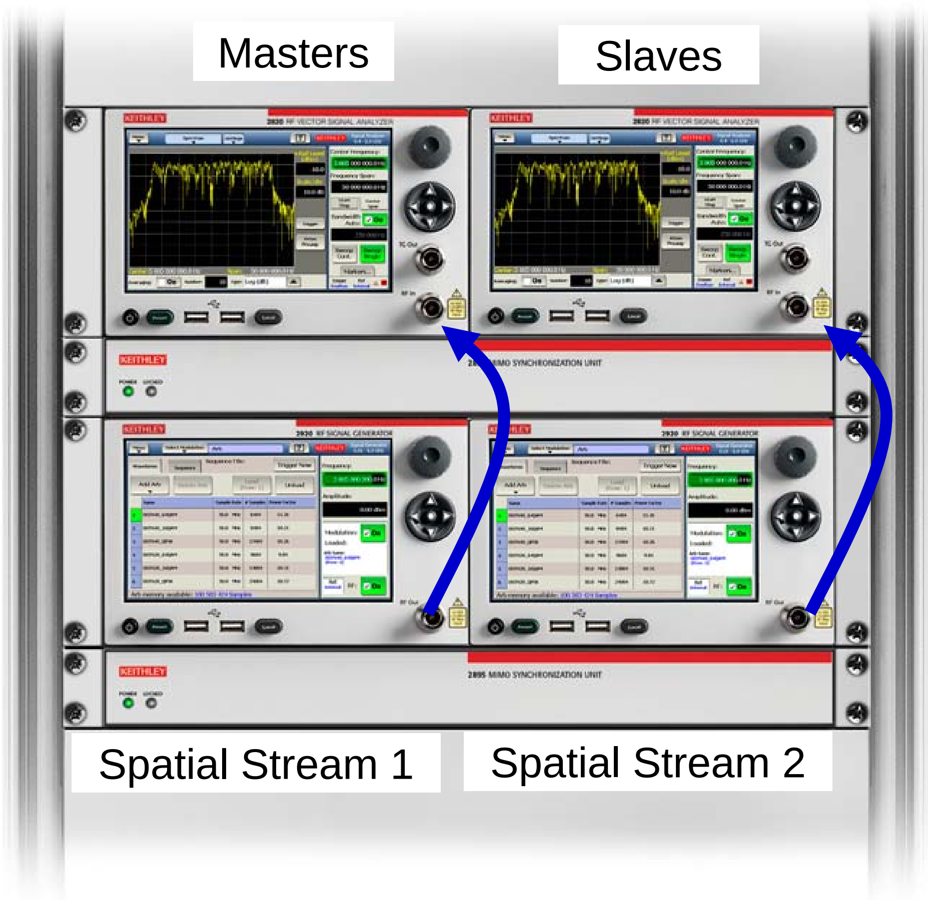
2x2 MIMO Configuration

Analyzers →

VSA MIMO Sync Unit →

Generators →

VSG MIMO Sync Unit →



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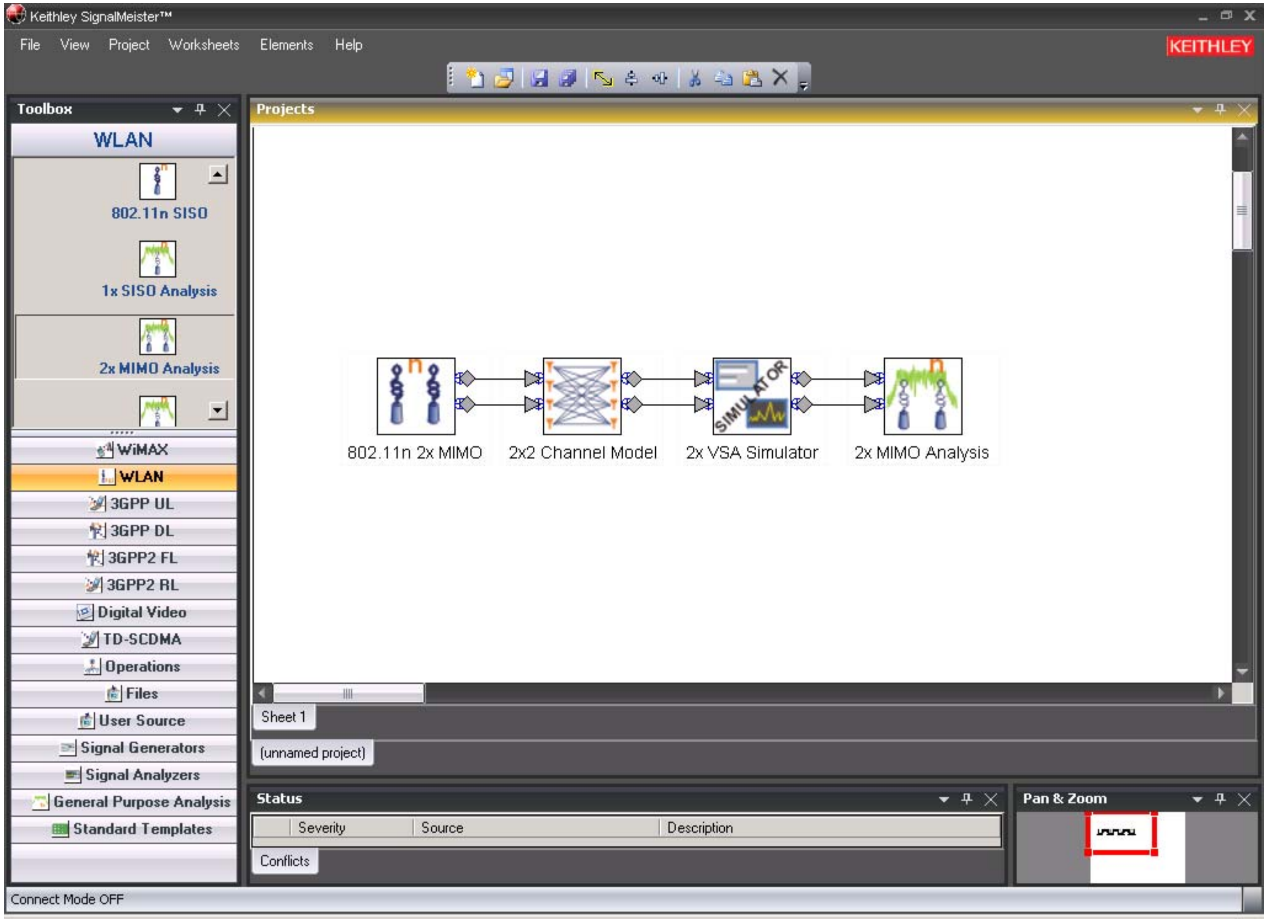
Generate a Signal



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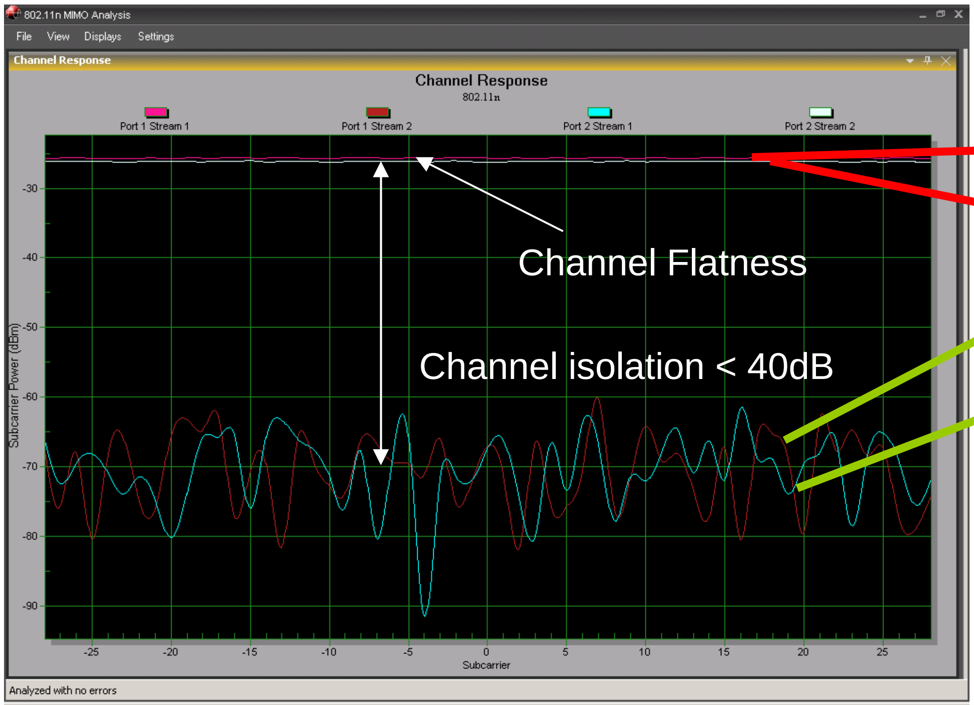
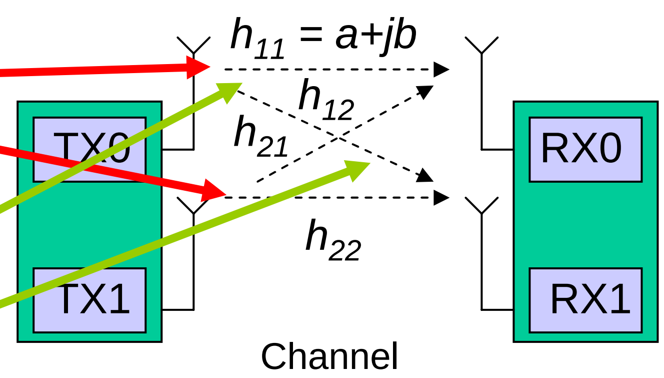
Test conditions require different channel conditions



Models Channel Behavior



In this example we use an RF cable to connect the TX to the RX. We see four plots TX0-RX0, TX1-RX1, TX0-RX1 and TX1-RX0

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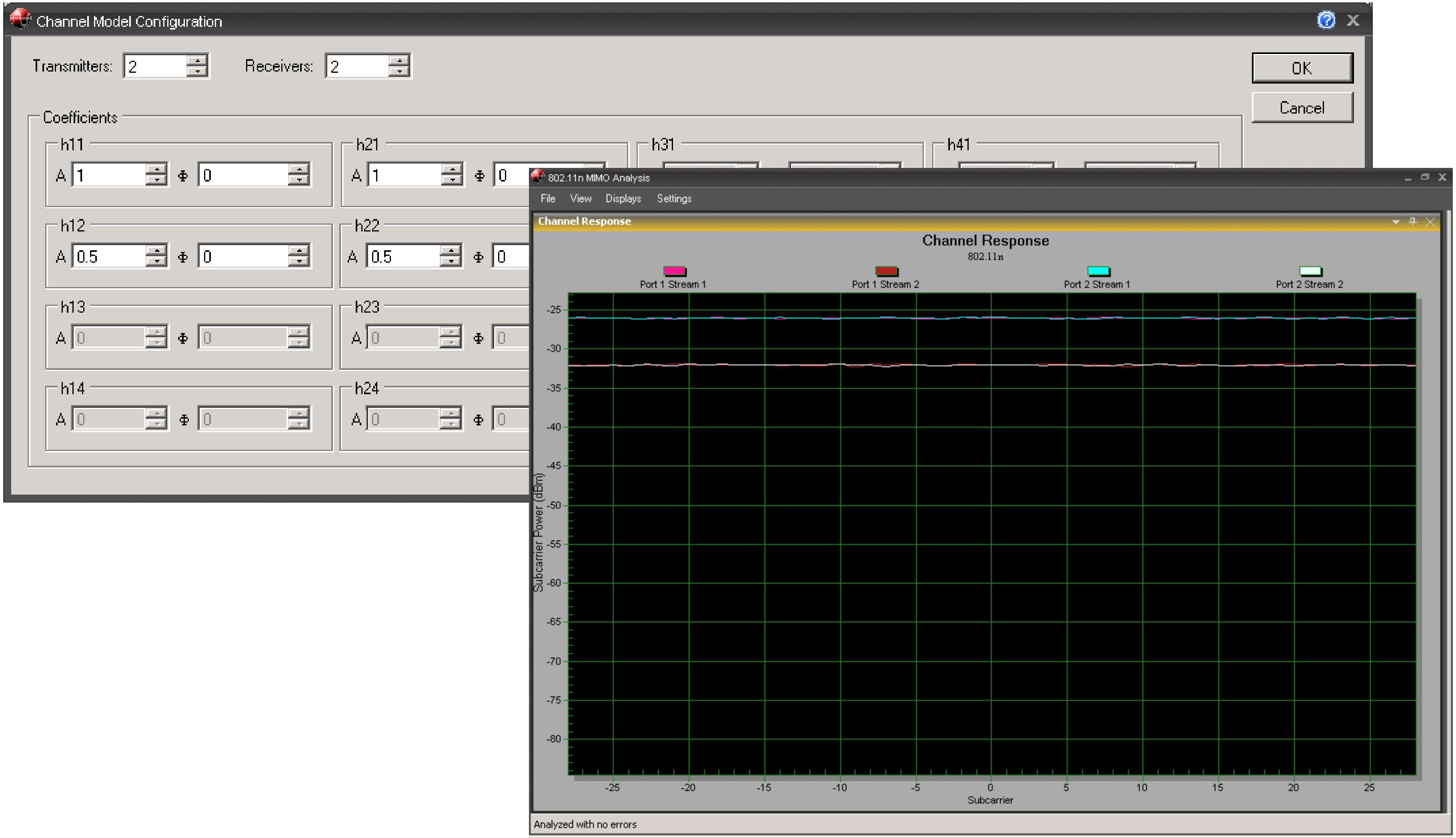
Examine different channel conditions
Magnitude only increase in cross components



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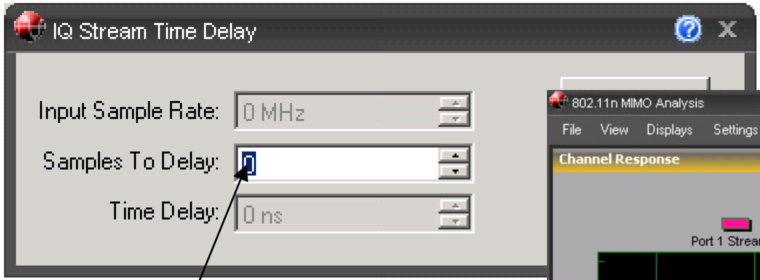
Add delay to the equation



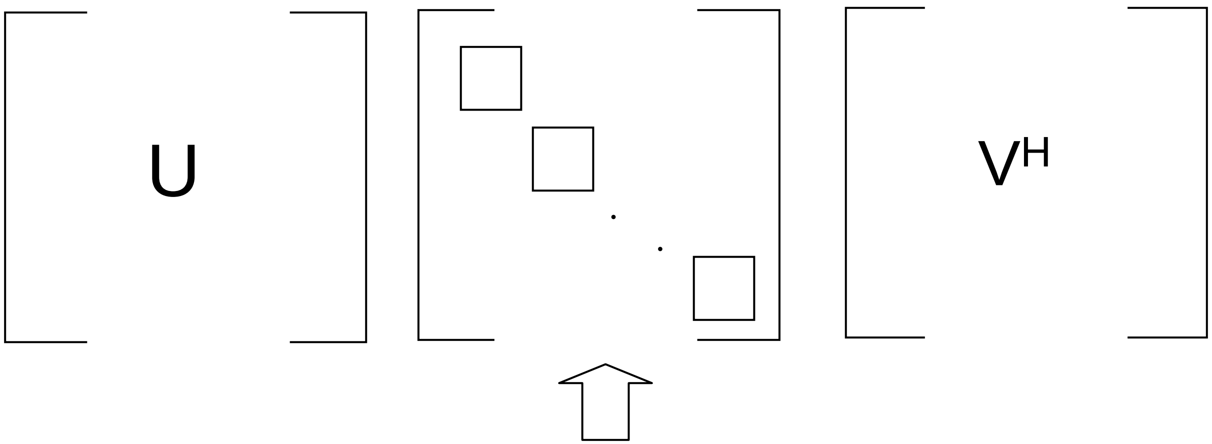
40 Sample Delay

Deep fade
In channel now
apparent.

Key Measurements
2: Channel Metrics - Singular Value Decomposition
SVD

$$H = UDV^H$$

Three matrices can represent the channel

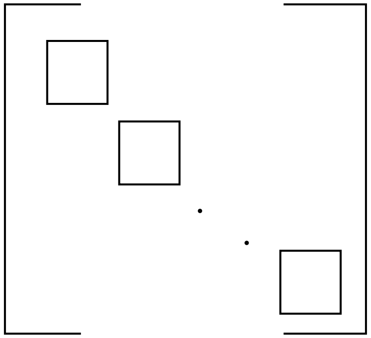


D. Scaling matrix,
or singular values

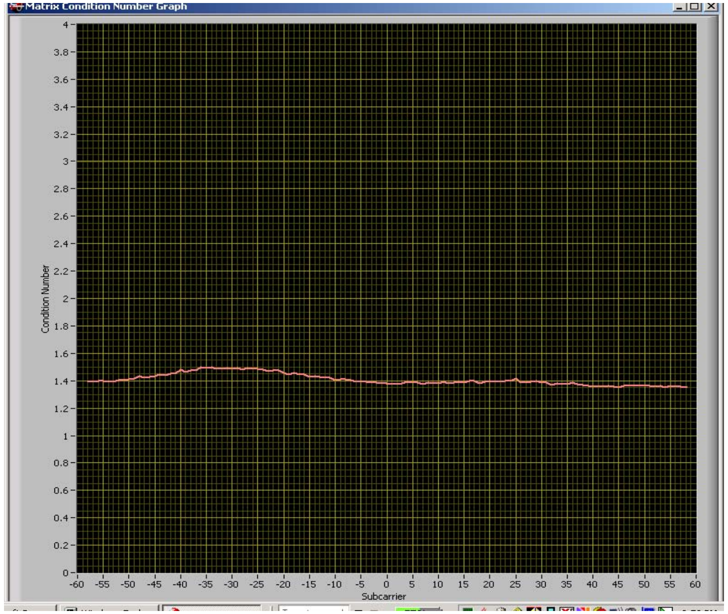
Key Measurements
2: Channel Metrics - Matrix Condition

The ratio of the highest singular value to the lowest is called the matrix condition.

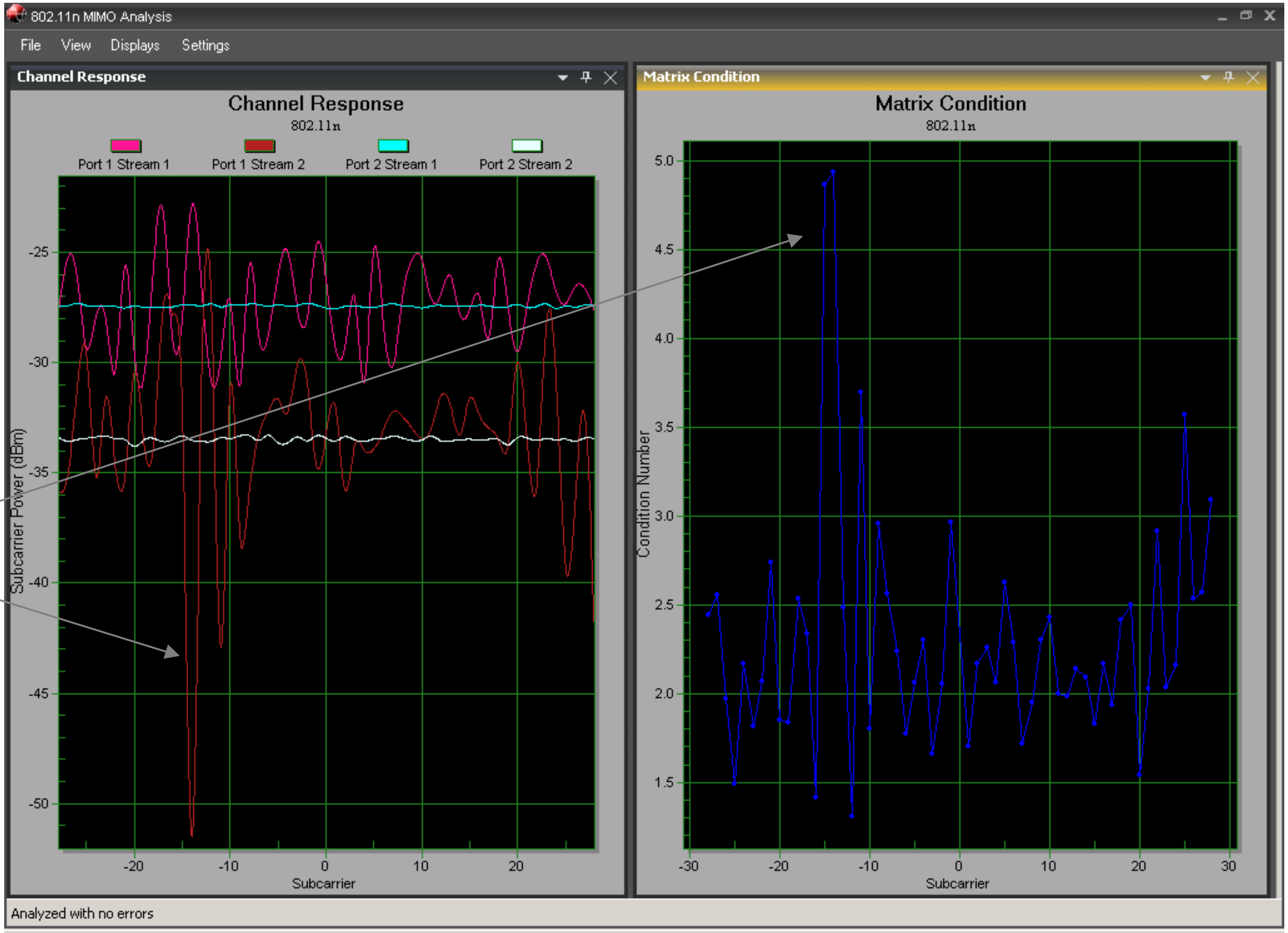
If the received path was received with equal signal to noise, then the matrix condition would be unity. If the signal to noise ratio is very low on one of the paths, then the matrix condition would be high.



Scaling matrix,
or singular values

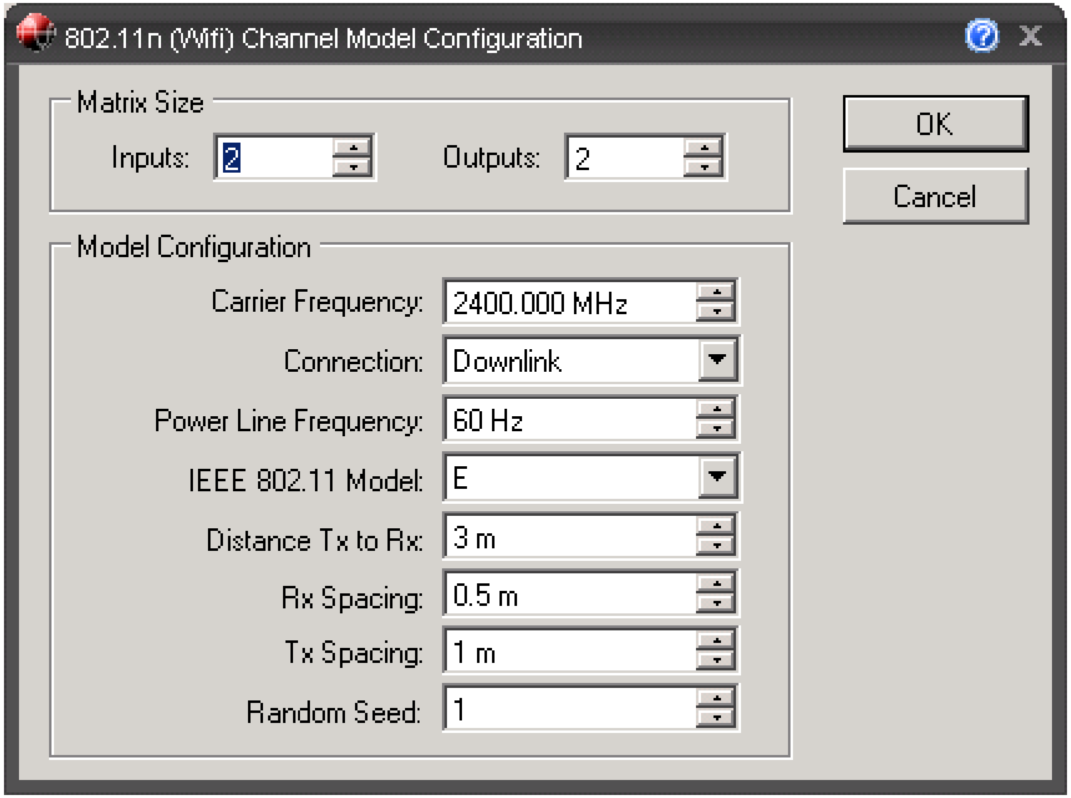


Matrix Condition



Note: Deep Fade Causes Low Signal to Noise, Creating a high matrix condition number.

Channel Models



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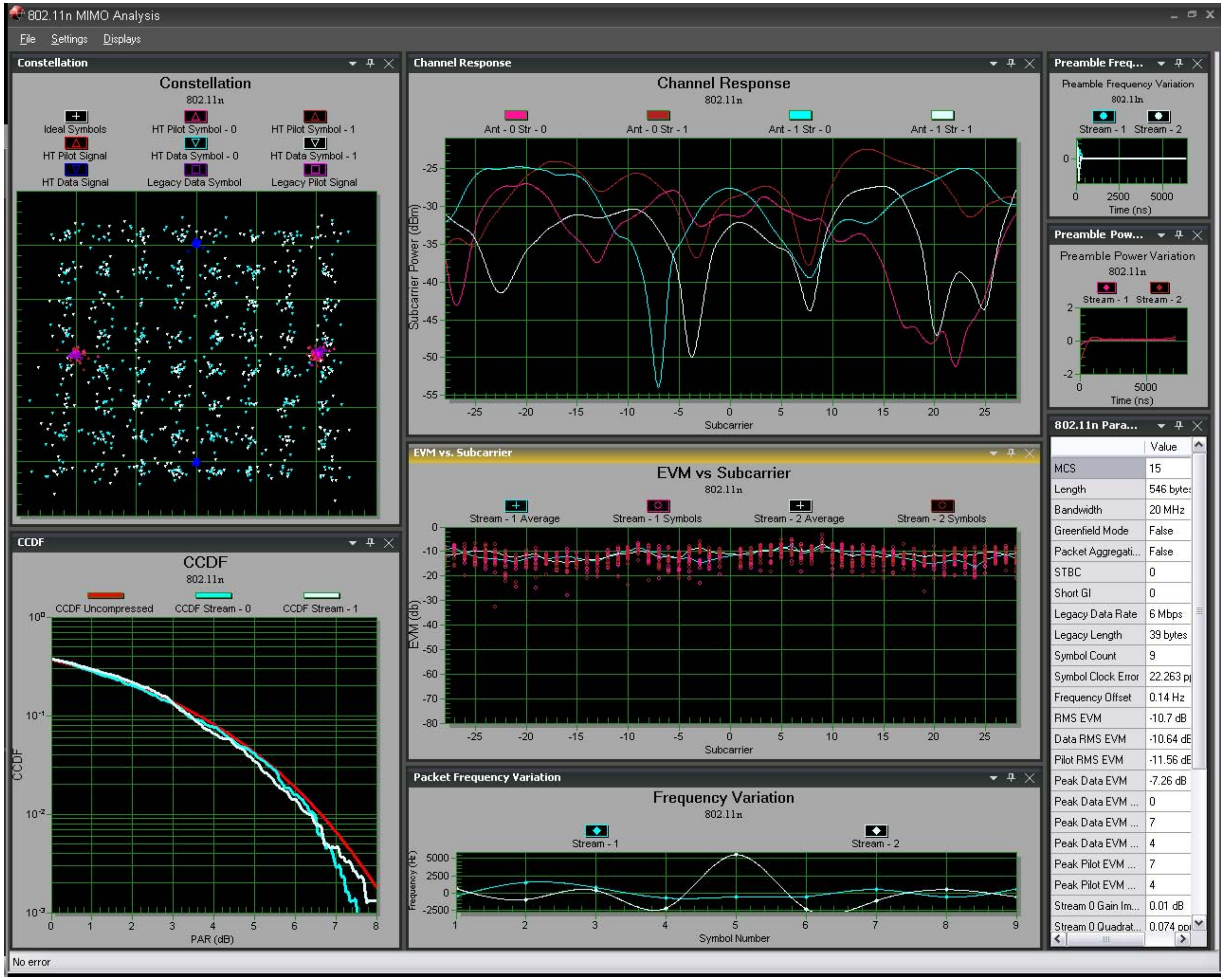
802.11n Analysis Display
2x2 MIMO Example with Channel Model E



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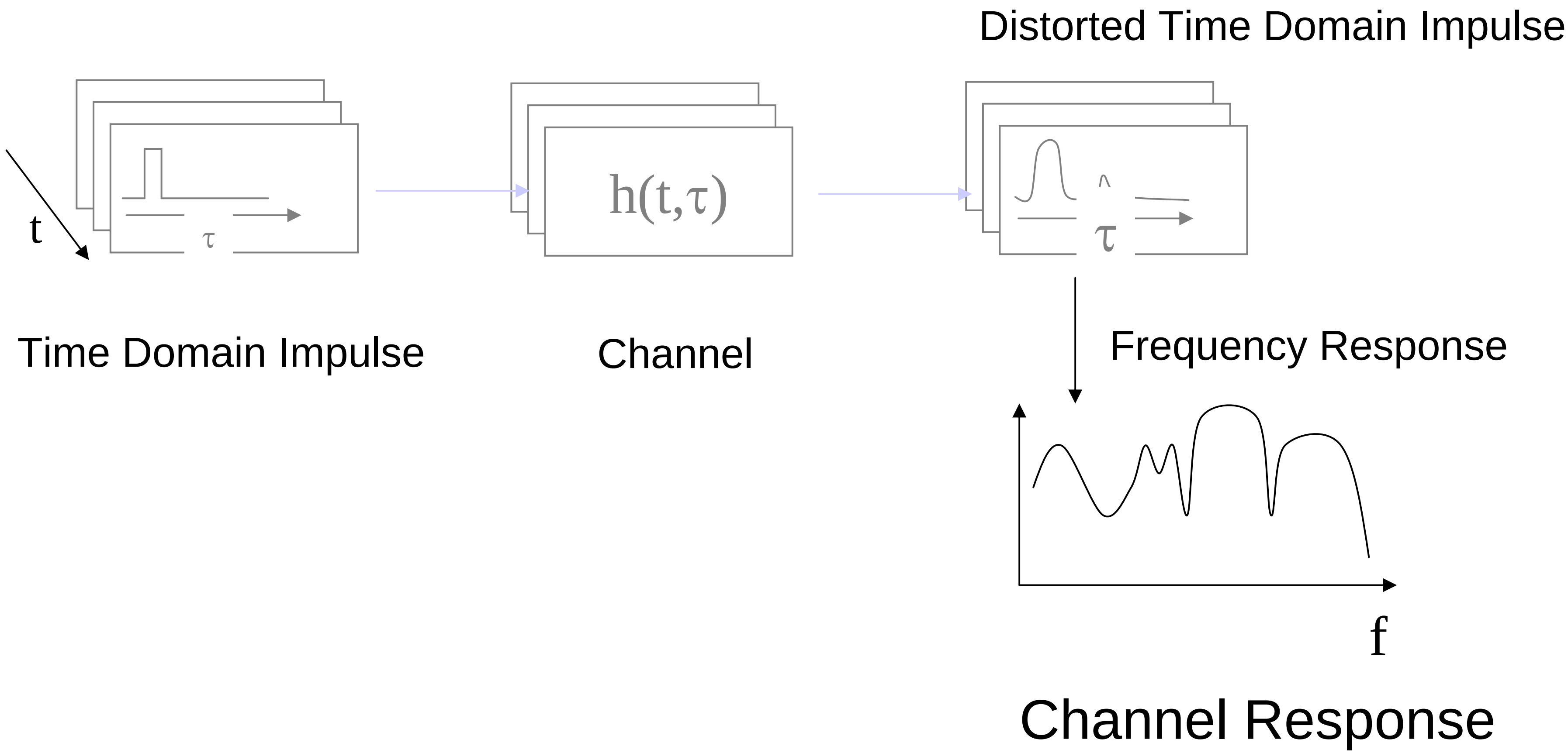
Understanding and Modeling the Channel
Sound the channel



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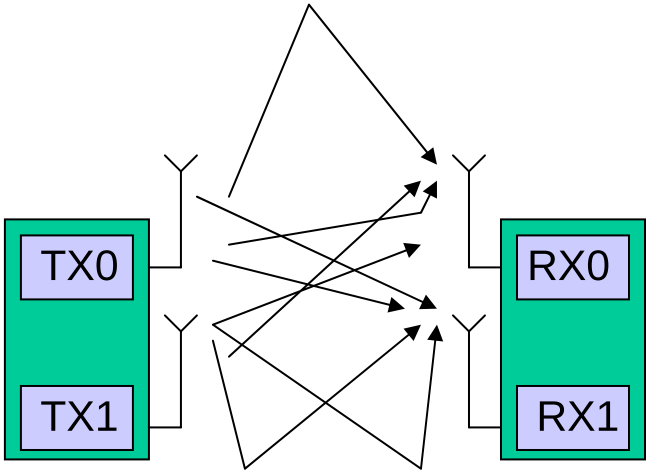
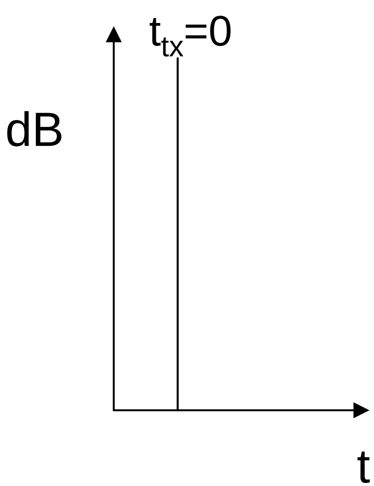
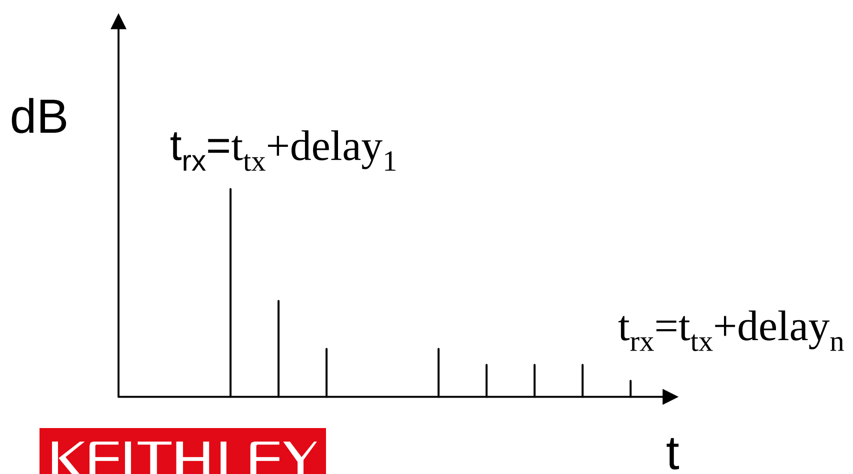
Model The Channel – Multi-path Represented by a Power Delay Profile



Because of multiple path reflections, the channel impulse response of a wireless channel looks likes a series of pulses. In practice the number of pulses that can be distinguished is very large, and depends on the time resolution of the communication or measurement system.





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Static Channel Model Only

- **Sounding the channel with an impulse models the channel at single point in time does not account for mobility or environmental changes.**
- **A real time emulator such as the Azimuth Emulator would be used for this.**

Example of a channel emulator:
Azimuth Systems ACE 400WB
4x4 bidirectional unit
www.azimuthsystems.com

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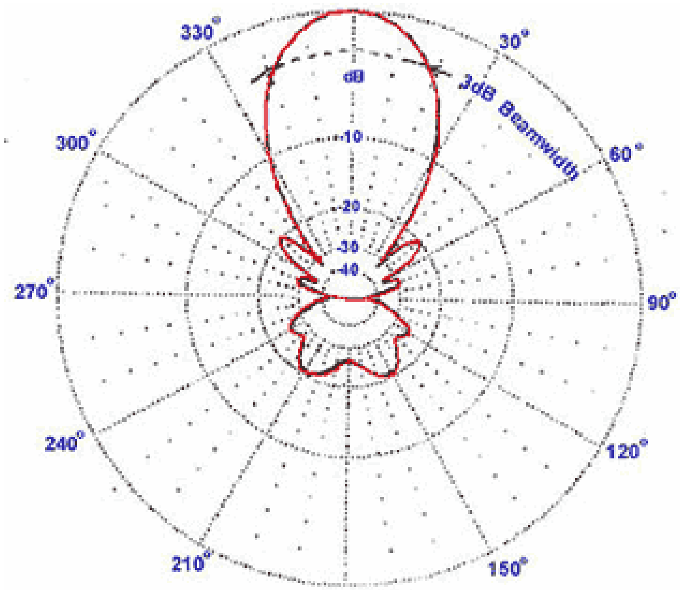
Smart Antenna Systems and Beam Forming



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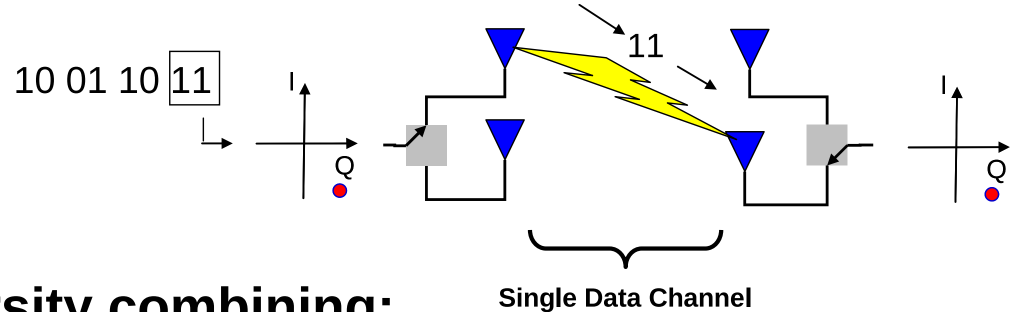
Antenna Systems

- **Diversity – most commonly used antenna system**
- **Sectorized – used by base stations**
- **Smart – Form a radiated RF beam, *beam forming*.**
  - Fixed
  - Adaptive

Diversity Systems (Time)

– **Switched/Selection diversity:**
  - The system continually switches between antennas so as always to use the element with the largest output.
  - No gain increase since only one antenna is used at a time.



– **Diversity combining:**
  - **This approach constructively sums the signals by correcting the phase error in two multi path signals effectively combining the power of both signals to produce gain.**

Diversity System (Space) MIMO based.

A single data stream is replicated and transmitted over multiple antennas.

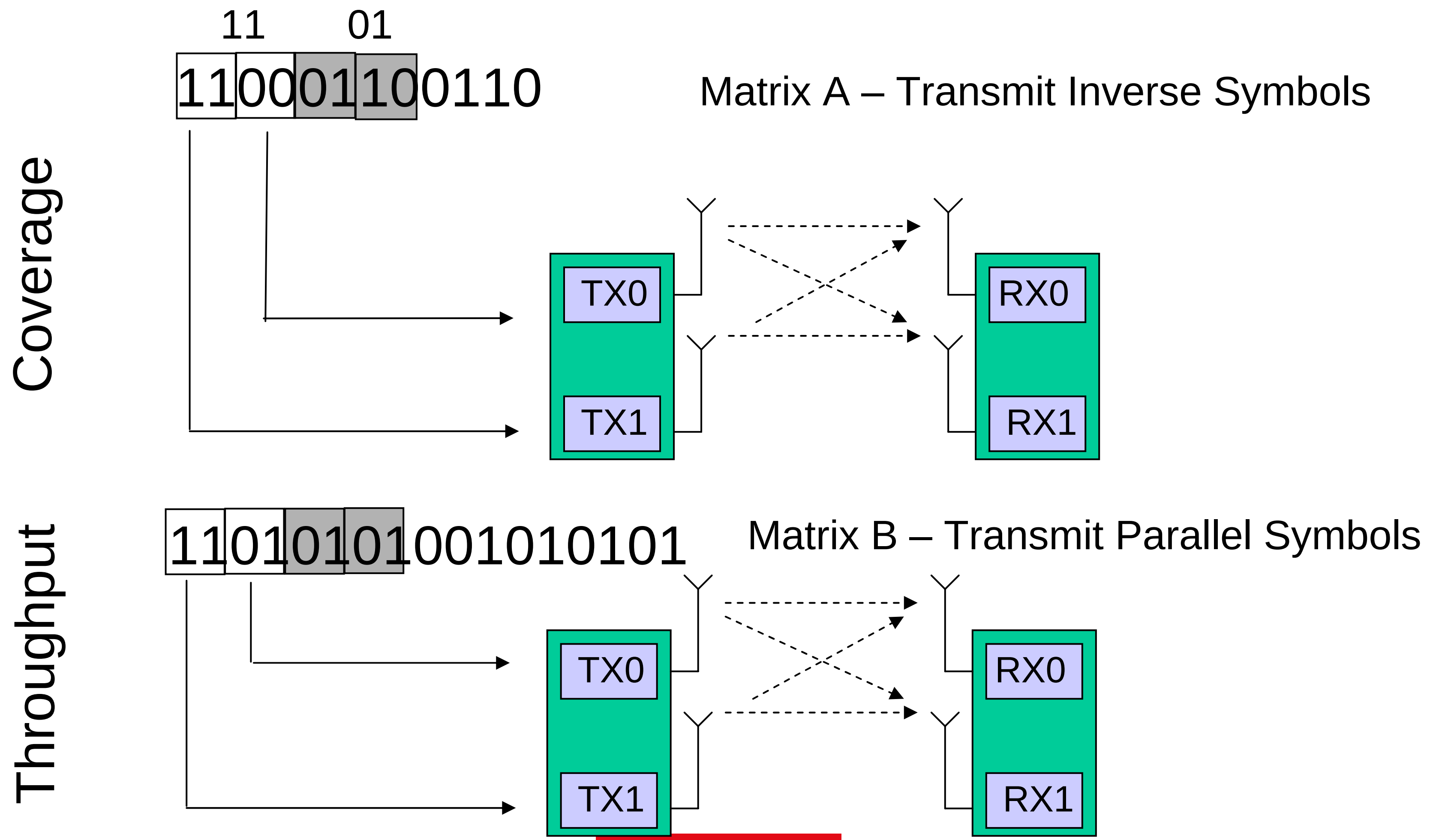
The redundant data streams are each encoded using a mathematical algorithm known as Space Time Block Codes.

Each transmitted signal is orthogonal to the rest reducing self-interference and improving the capability of the receiver to distinguish between the multiple signals.

With the multiple transmissions of the coded data stream, there is increased opportunity for the receiver to identify a strong signal that is less adversely affected by the physical path.

The receiver additionally can use a diversity combining technique to combine the multiple signals for more robust reception.

Spatial Diversity
WiMAX Matrix A STC vs Matrix B SMX



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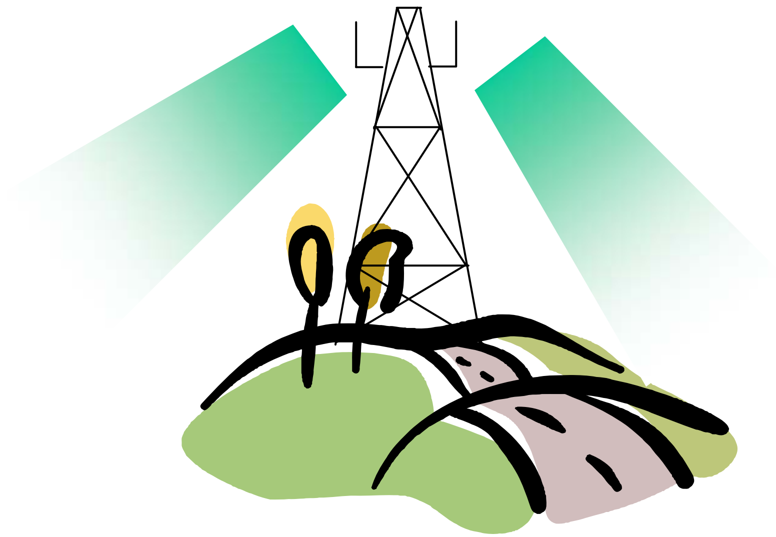
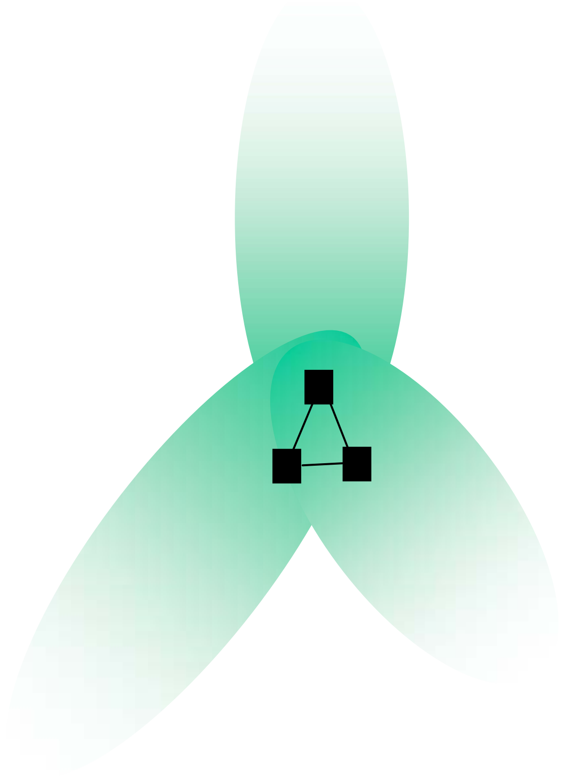
Sectorized antenna systems
Radiation Pattern



Side View



Top View

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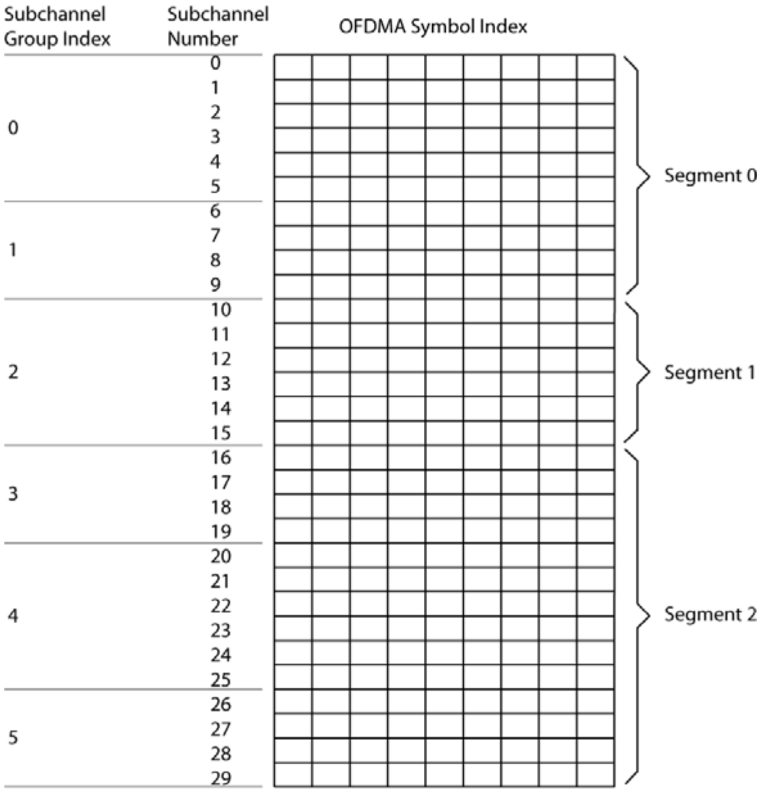
WiMAX and sectorized transmission.

- **The Base Station may have multiple BS MACs.**
- **Each BS MAC may have a portion of the subchannel groups referred to as a segment.**
- **The functionality supports sectorized transmission.**



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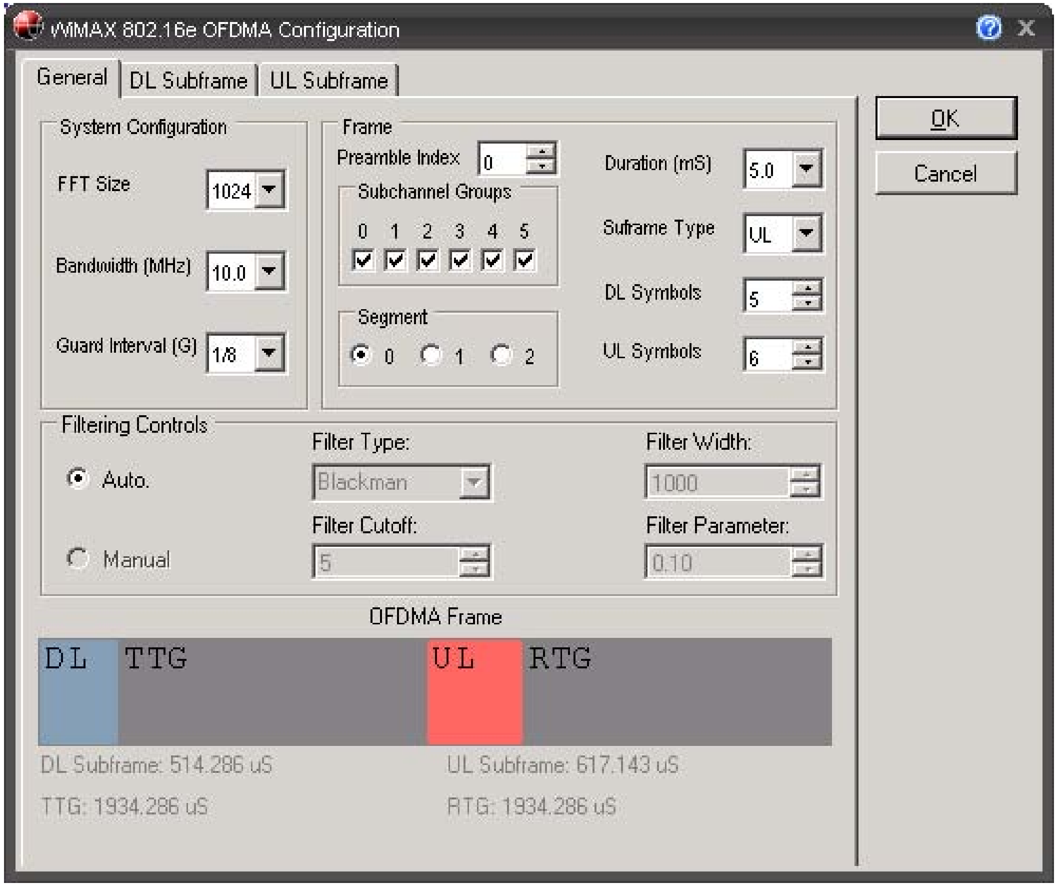
Configuring a Segment/Sector



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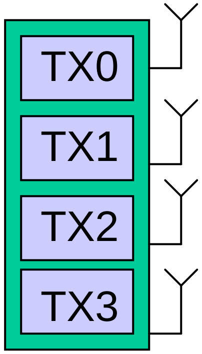
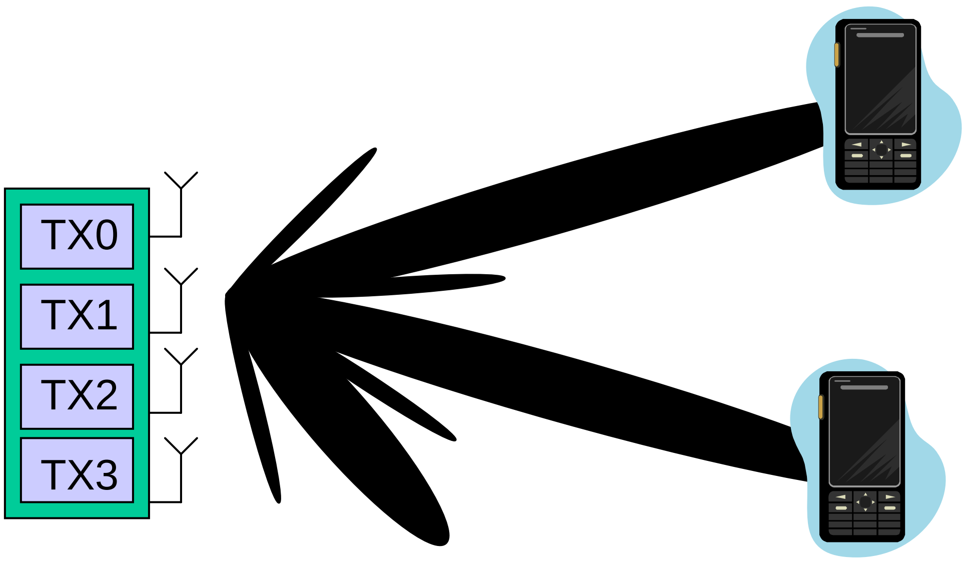
Smart Antenna Technology

- **How can an antenna be made more intelligent?**
  - Instead of having one transmitter you require multiple, the more the better!
  - The antenna becomes an antenna system that can be designed to shift signals before transmission at each of the successive elements so that the antenna has a composite effect.
  - When transmitting, a beam former controls the **phase** and relative **amplitude** of the signal at each transmitter, in order to create a pattern of constructive and destructive interference in the wave front. When receiving, information from different sensors is combined in such a way that the expected pattern of radiation is preferentially observed.



Beam Forming Benefits



By controlling the directionality and shape of the radiated pattern increased range, capacity and the throughput of the transmission is achieved.

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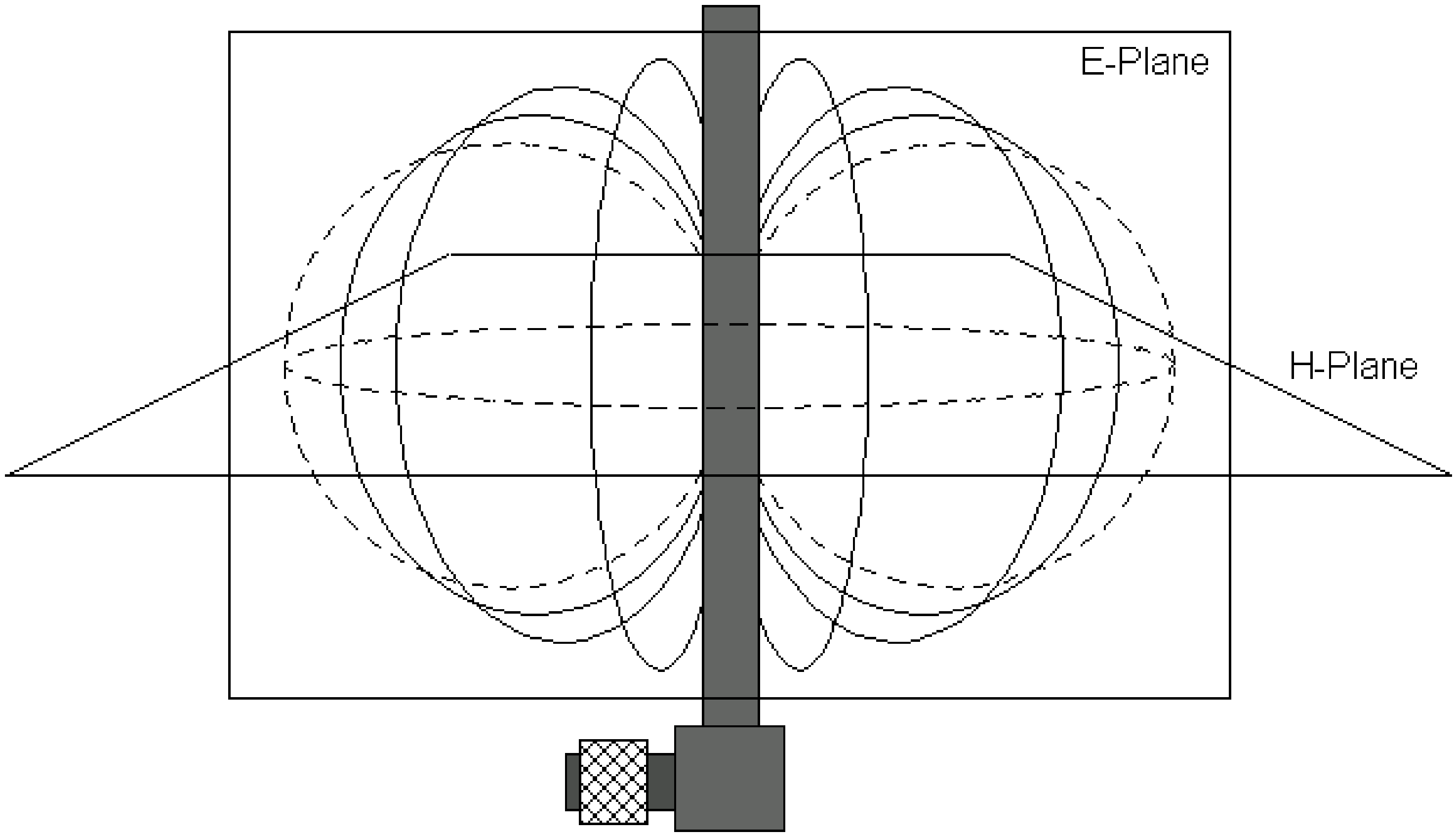
Antenna Radiation Pattern



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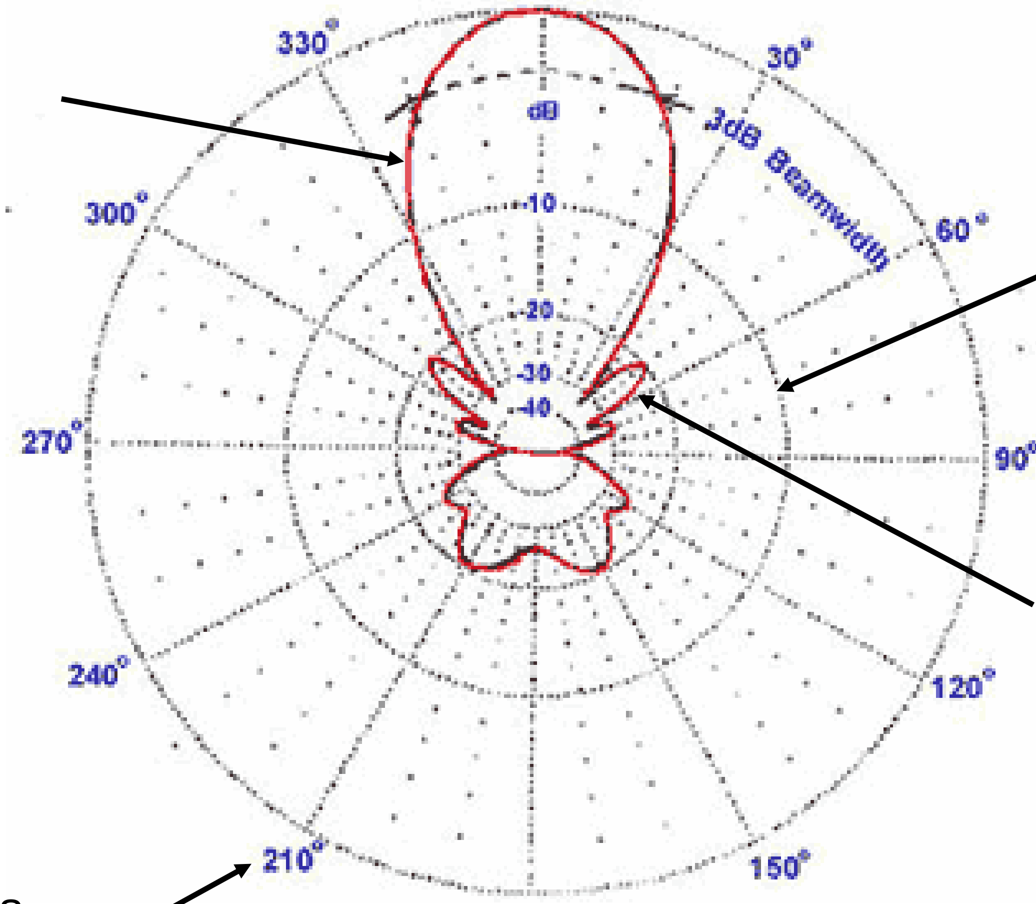
Log Plot of Radiation Pattern
Azimuth ("E" plane)

Main Lobe

dB from
Maximum gain

Side Lobe
(20dB down)

Degrees from
Main Lobe axis



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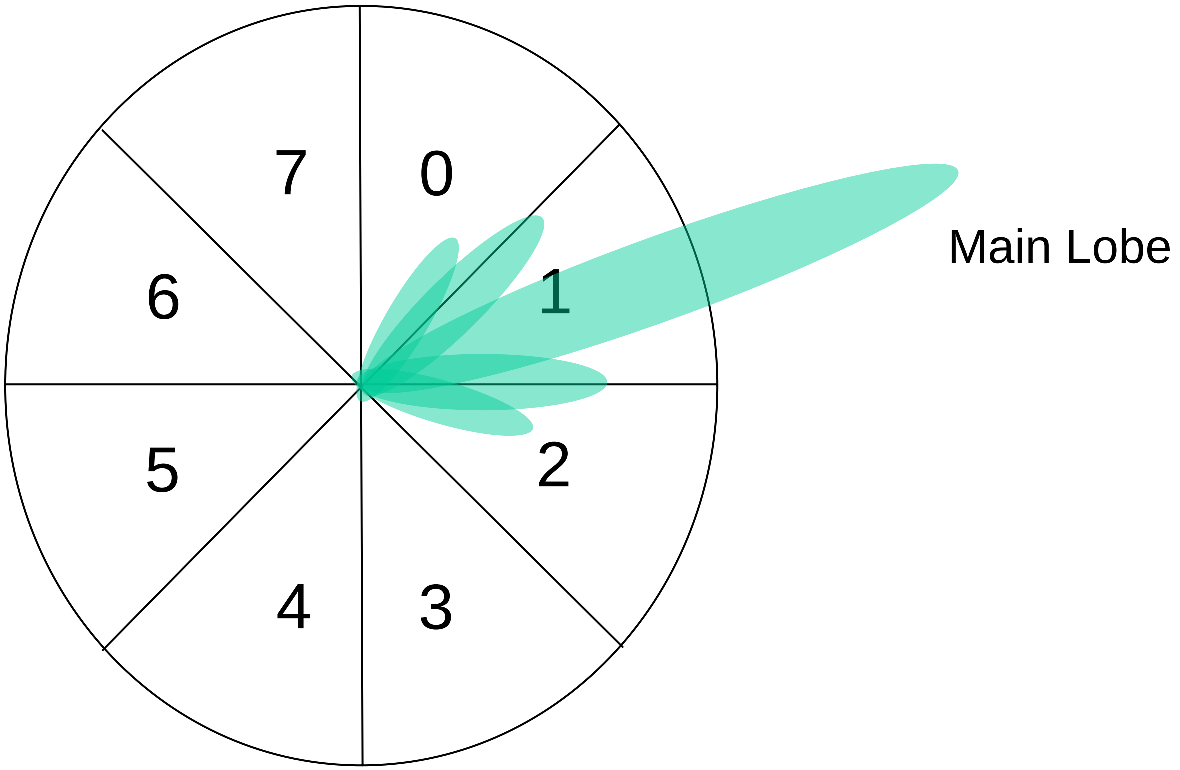
Fixed Beam Forming



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The Adaptive Beam Forming Process
LTE Example - Closed Loop

Look up table approach

Antenna Correlation
High and Low

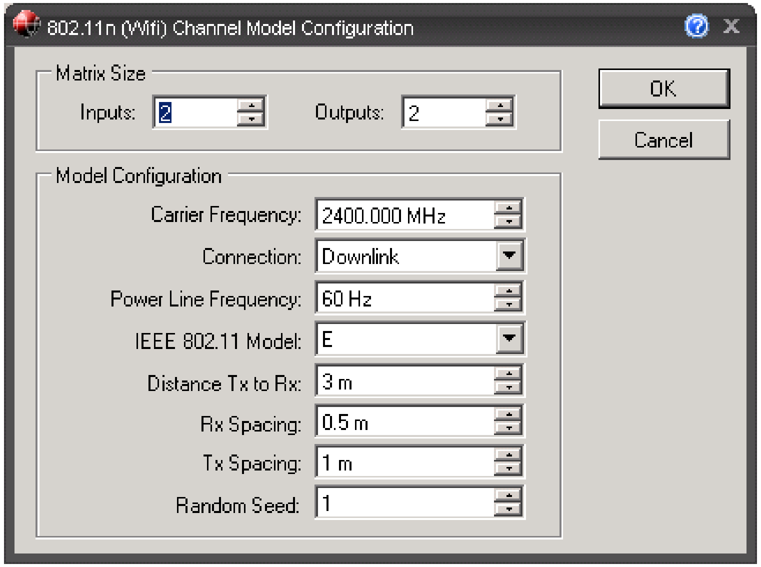
High - The distance between antennas is small (less than one wavelength).

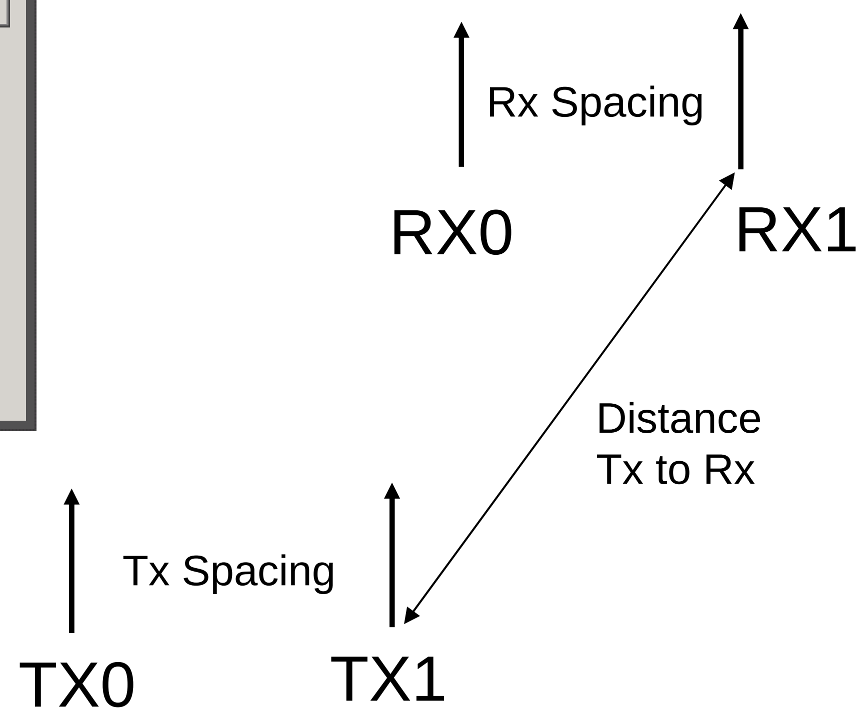
- Assume the same fade for each antenna (channel).
- The beam can be steered by phase shifts alone
- The beam tends to be wide

Low – The distance between antennas large (typically several wavelengths), or change polarization H vs. E.

- Assume different fading characteristics for each antenna (channel).
- Beam must be steered by phase shifts and magnitude changes via the beam steering vector.

Antenna Correlation High and Low





Single layer Beam Forming

- **To maximize the signal at the receiver:**
  - Select a beam forming vector **V** such that

$$v_i = h_i^* / \mathrm{sqrt}(\Sigma_{k=1}^{Nt} |h_k|^2)$$

  - This normalizes the signal to the complex conjugate of the channel so that total transmit power is unchanged.

- **Observations:**
  - This technique phase rotates the transmit signals so received signals are time aligned.
  - In general, more power is allocated to antennas with good channel conditions. This maximizes capacity.
  - Overall transmit power is constant.

Single layer Beam Forming

- **High correlation vs. Low Correlation beam forming observations:**
  - More knowledge of channel is needed for low correlation beam forming.
  - The beam forming vector must take the channel into account.
  - For FDD (Frequency Division Duplex), only the receiver knows the channel, so it must feedback channel information to the transmitter.
  - For TDD (Time Division Duplex) the up and down links share frequencies so the channel is known without feedback.

  - The above assumes channel gain is constant vs. frequency. If it's not then no single set of **B** coefficients are possible.
    - This can be resolved by using OFDM precoding weight based on each sub-carrier characteristic.

The Beam Forming Process
WiMAX Example - Closed Loop

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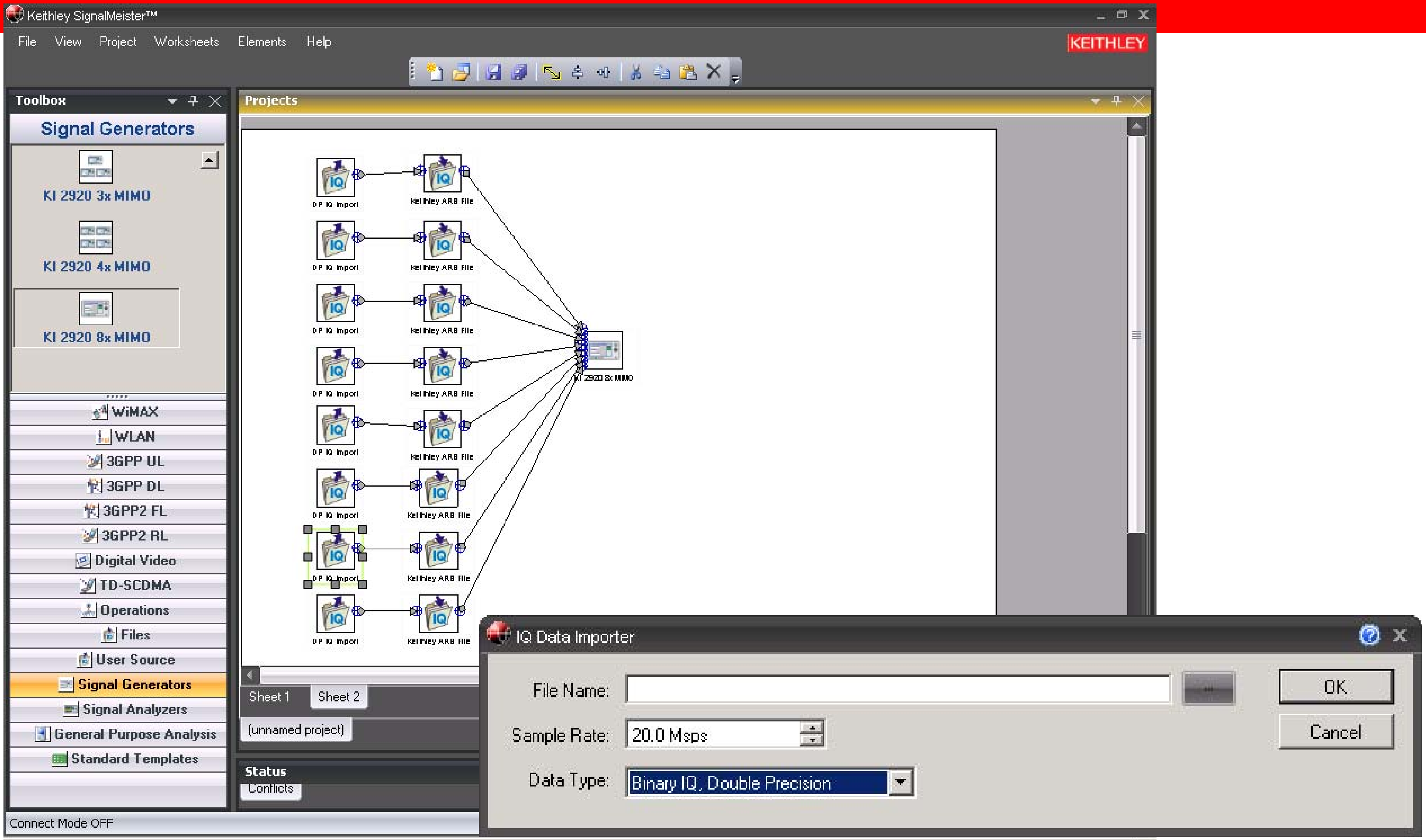
Creating a Signal



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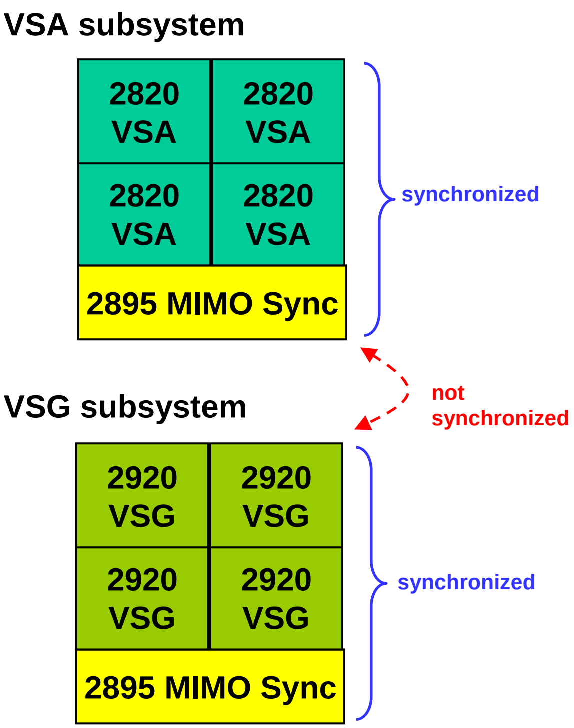
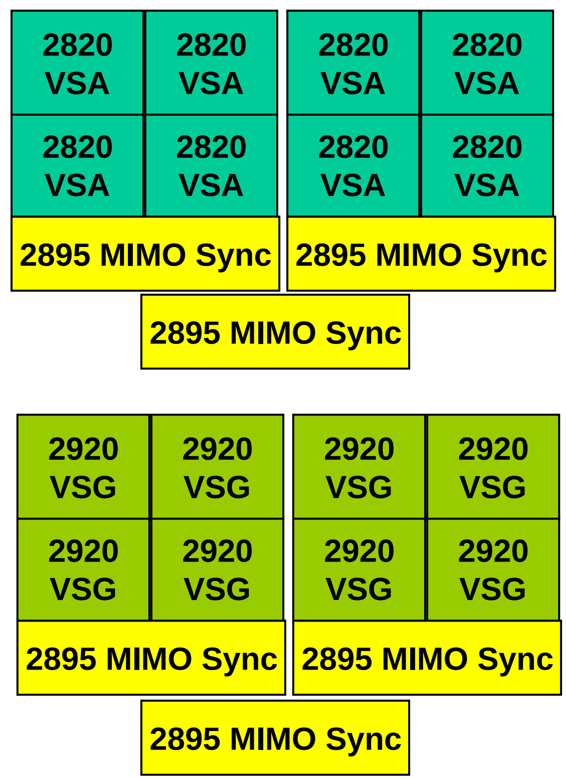
VSA and VSG Subsystem Configuration Groups…
…that are Synchronized Analyzers and Generators[1]

4x4 MIMO system
(or 2x2, 3x3, etc.)



8x8 MIMO system



1. Each VSA and VSG subsystem group is synchronized and cannot be separated. The VSA and VSG subsystems are separate and asynchronous from each other.

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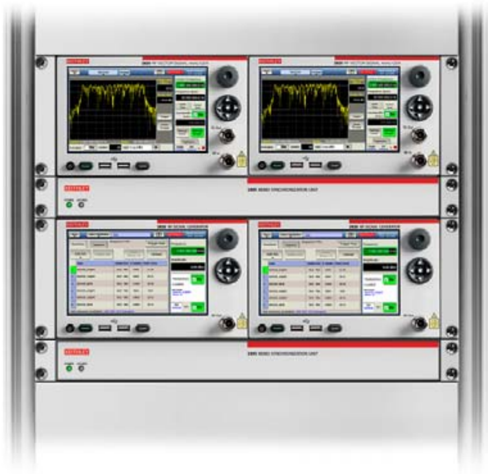
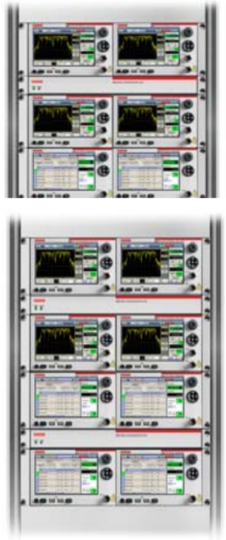
Scalable Solutions

SISO	2x2 – 4x4 MIMO	8x8 MIMO
		
GSM, W-CDMA, WLAN, WiMAX	WLAN, LTE, WiMAX	Advanced Antenna Research

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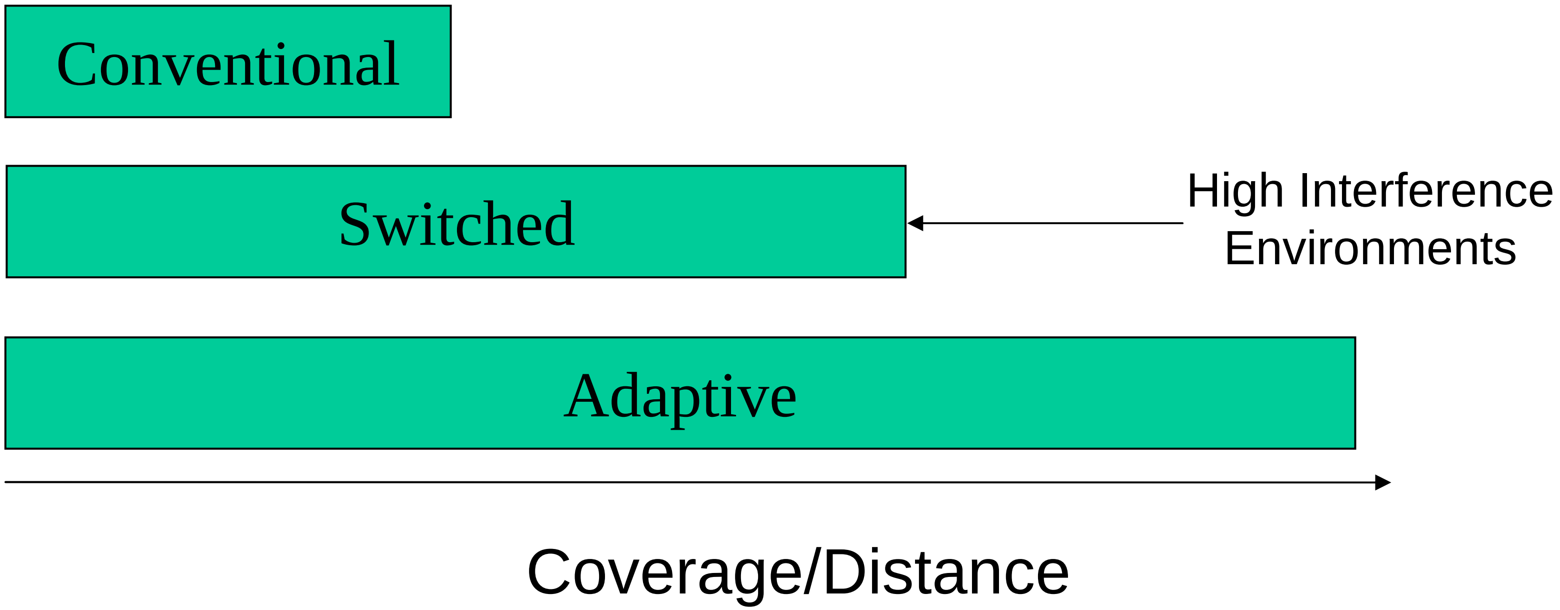
Beam Forming Summary



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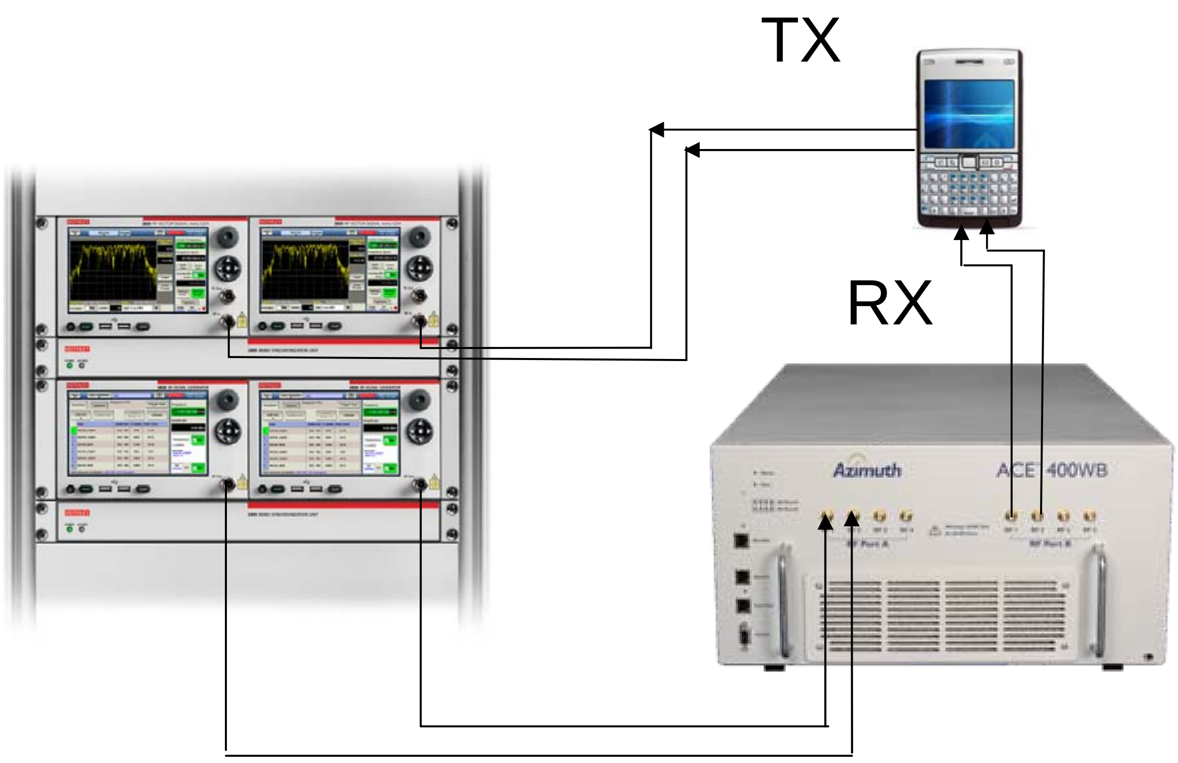
MIMO Conclusion

- **Allows for better throughput and coverage**
  - STC, Space Time Coding
  - SMX, Spatial Multiplexing
  - Beam forming
- **Requires knowledge of channel**
- **Requires higher levels of baseband processing**

Typical Test Setup 2x2



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Throughput, Flexibility, and Ease of Use
Delivered in new wireless connectivity test capabilities

2800 VSA and 2900 VSG
SISO
GSM
CDMA
WLAN
WiMAX

2800 VSA, 2900 VSG + 2895
MIMO
WLAN
WiMAX
LTE

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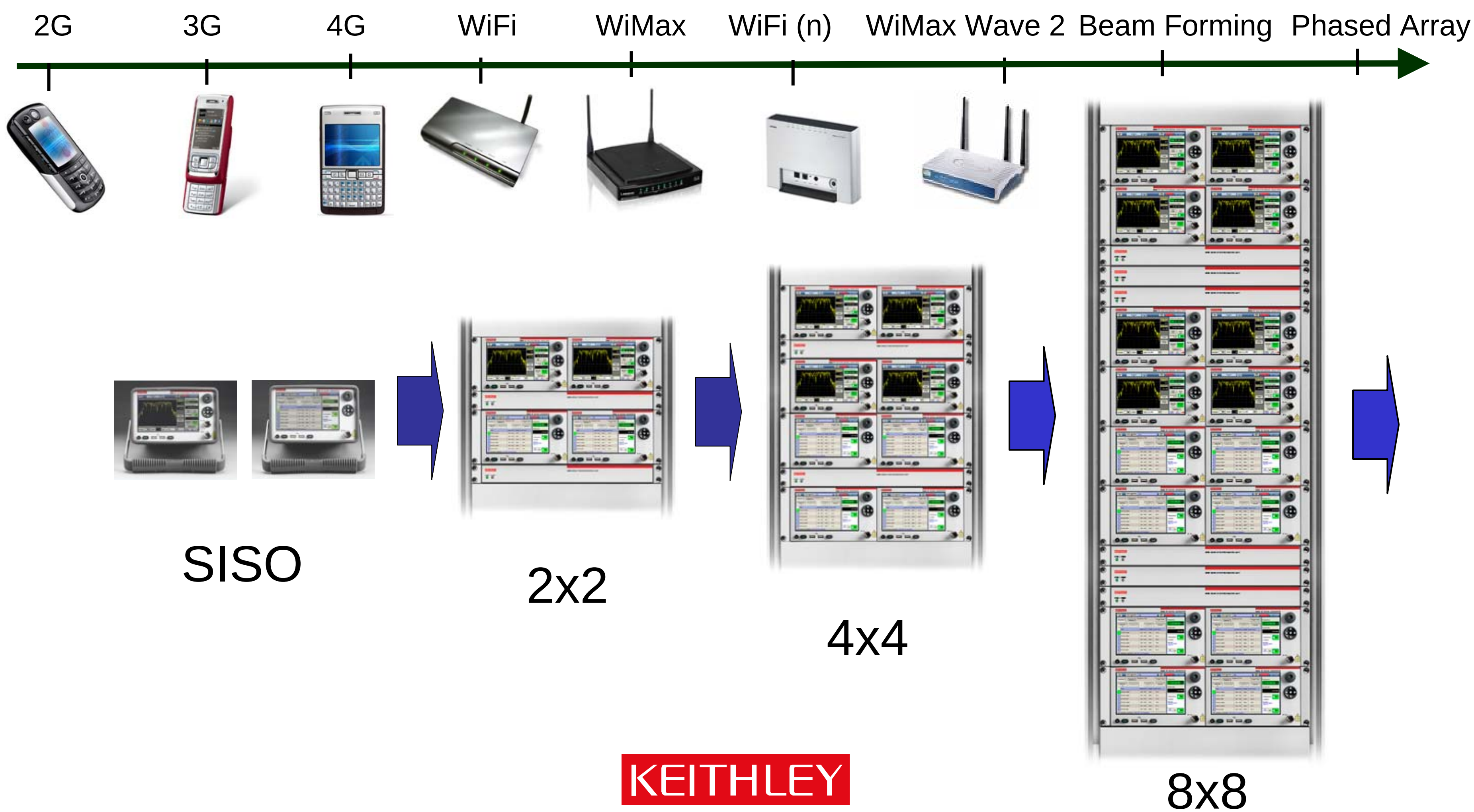
Technology Evolution



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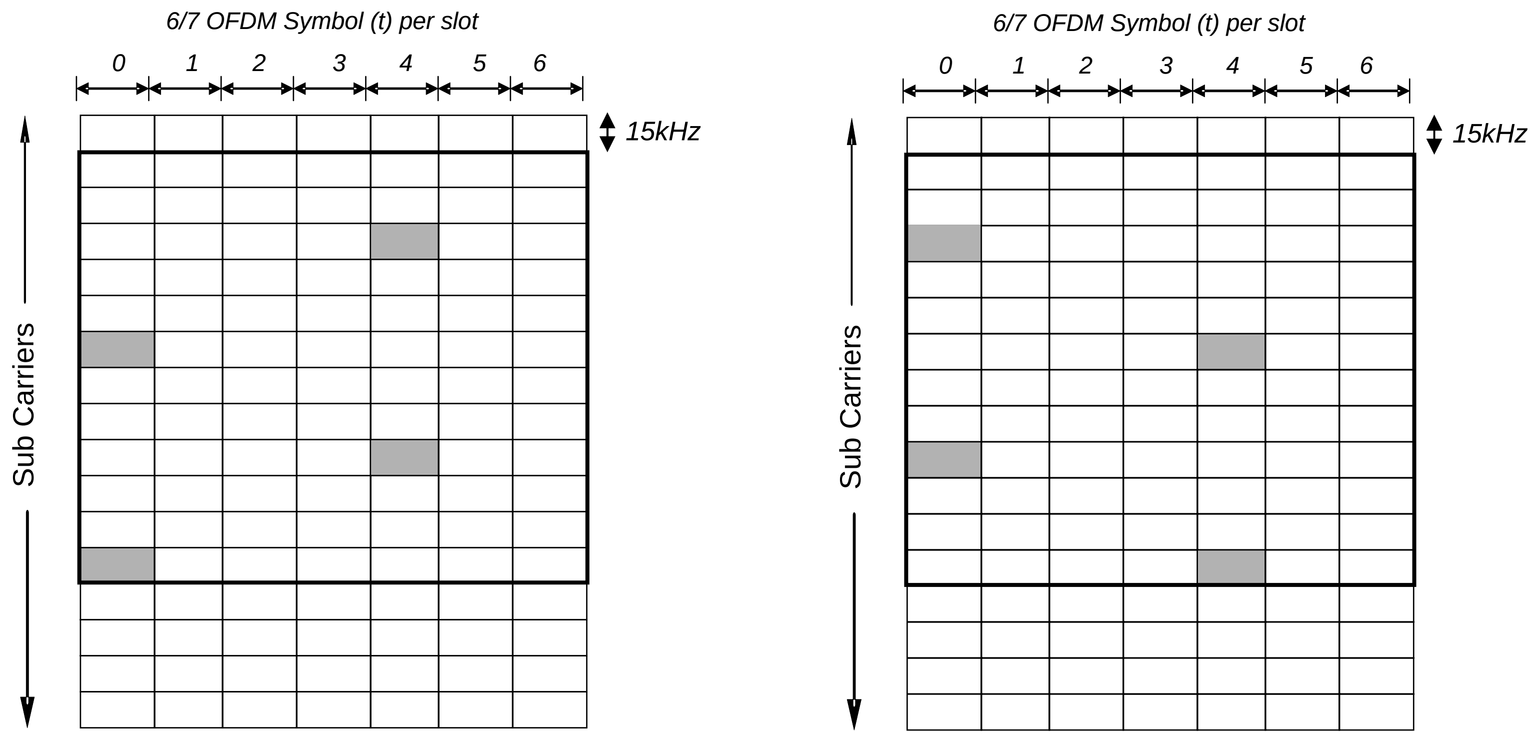
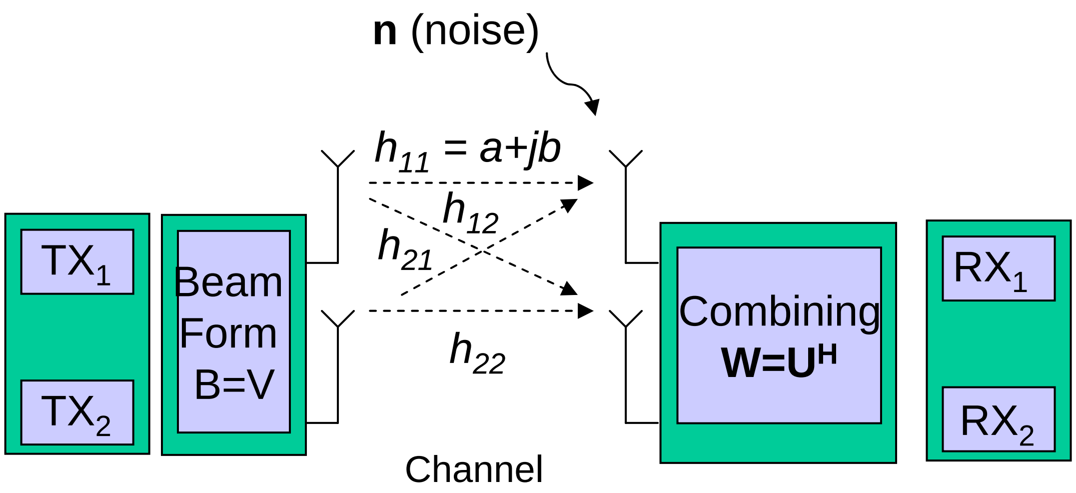
Time alignment LTE 2x2



A more Complete Channel Model
- leading to a more general solution



Beam form
B=V

Combining vector
$W=U^H$

- **The prior diagram suggests we should modify both the transmit and receive ends to maximize signal**
- **As shown with the diagram on the left, this is done with a beam forming matrix, B on the transmit side and a combining matrix W, on the receiver.**
- **Note:**
  - **If we only add W, we get noise enhancement.**
  - **If we only add B, the transmit power can be very high.**

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A bit more detail on "Do the math"

- Since we defined **H**=**U.D.V**^{H} Lets talk a bit more about that factorization.
  - We define **U**$_{MxM}$ and **V**$_{NxN}$ to be square, unitary matrices
  - In other words: **U**^{H}**.U** = **V**^{H}**.V** = **I**. Where **I** is the identity matrix.
  - This also means, **U**^{H} = **U**$^{-1}$ and **V**^{H} = **V**$^{-1}$
  - **D** is the singular values matrix of size MxN whose elements appear in increasing order.
  - **V**^{H} denotes Hermitian (transpose complex conjugate) ex;

$$a_{i,j} = \overline{a_{j,i}}$$

$$\mathbf{H} = \begin{bmatrix} 3 & 2-\mathrm{i} \\ 2+\mathrm{j} & 1 \end{bmatrix}$$

- The result, if **H** is complex, there is always a singular value decomposition with positive singular values.

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A bit more detail on “Do the math”

- Recall the decoded signal RX is what we want.

- Since we also defined $H=UDV^H$ we can rewrite the decoded signal equation as:
    - $\mathbf{RX} = \mathbf{U}^H(\mathbf{H}.\mathbf{V}.\mathbf{Tx}+\mathbf{n}) = \mathbf{U}^H(\mathbf{U}.\mathbf{D}.\mathbf{V}^H)\mathbf{V}.\mathbf{Tx}+\mathbf{U}^H.\mathbf{n}$
- Recall, $\mathbf{U}^H.\mathbf{U} = \mathbf{V}^H.\mathbf{V} = \mathbf{I}$. **I** is the identity matrix. So now,

    - $\mathbf{RX} = \mathbf{D}.\mathbf{TX} + \mathbf{U}^H.\mathbf{n}$

- Result: no noise enhancement $|\mathbf{U}^H|=1$ and since **D** is diagonal, decoded signal is decoupled. In other words, we have orthogonality.

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Dedicate Keithley RF Application Example

2920 VSG DFS Radar Profile Generator Personality

October 2008

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DFS Application Agenda

- **In general, what is DFS, and what does the 2920 DFS Radar Profile Generator (abbreviated as DFS RPG) Personality do?**
- **What Radar Profiles are currently supported?**
- **How are the ARB Files Generated?**
- **Details of PC-based ARB file generation software**
- **Customer use and troubleshooting techniques**

What is DFS?

- **DFS = Dynamic Frequency Selection**
  - DFS is a communications technique where transmitters actively 'listen' to the RF environment and *dynamically* choose transmit channels based on the environment characteristics.
  - The goal for transmitters employing DFS is to transmit on the 'best' channel, where the 'best' channel is typically the channel with the lowest level of detectable RF energy.
- **Keithley's usage of the term 'DFS' refers to government agencies' *requirement* for wireless transmitters operating in the U-NII radio band to implement DFS algorithms to avoid interfering with radar (for example, military and weather radar).**
  - U-NII radio band = Unlicensed National Information Infrastructure radio band, 5.15GHz – 5.825GHz
  - The 'government agencies' include the USA's FCC (Federal Communications Commission), Europe's ETSI (European Telecommunications Standards Institute), and Japan's TELEC (TELecom Engineering Center).
- **802.11a WLAN Access Points (APs) represent the largest portion of commercial transmitters required to implement DFS algorithms**
  - In the US, the 802.11a operating band has 24 20MHz channels, with center frequencies from 5.180 – 5.320GHz, 5.500 – 5.700GHz, and 5.745 – 5.825GHz

What Does the 2920 DFS RPG Personality Do?

- **Generates 2920 ARB files to simulate a wide range of *Radar Profiles***
  - A *Radar Profile* describes the **RF and Time Domain characteristics** of a given radar signal type, where the types are defined by the various government communications agencies.
  - Time Domain characteristics:
    - Radar Pulse Width (seconds) and Pulse Repetition Frequency (PRF, Hz) or Pulse Repetition Interval (PRI, seconds). Note that radar signals are typically **Constant-Envelope Bursted** signals:
      - **Constant-Envelope** implies that they have no amplitude variation
      - **Bursted** implies that the signal is present for some time (turned 'on' during the pulse width), and then disappears for some time (turned 'off'). The sum of the 'on' and 'off' times is the PRI (PRF = 1 / PRI).
    - Number of *radar pulses* per *radar burst*
      - A *radar burst* will typically have multiple *radar pulses.*
    - Number of *radar bursts*
      - Some *radar profiles* have multiple *radar bursts.*
  - Frequency domain characteristics:
    - Burst Center Frequency (Hz)
      - For single-burst profiles, this is always fixed. For multi-burst *frequency hopping* profiles, this will change from burst-to-burst.
    - Chirp Bandwidth (Hz)
      - Chirp Bandwidth describes the change in **instantaneous frequency** of a pulse versus time. For most profiles, the Chirp Bandwidth is **zero**, implying that the pulse is just a Continuous Wave (CW) signal at the current center frequency.

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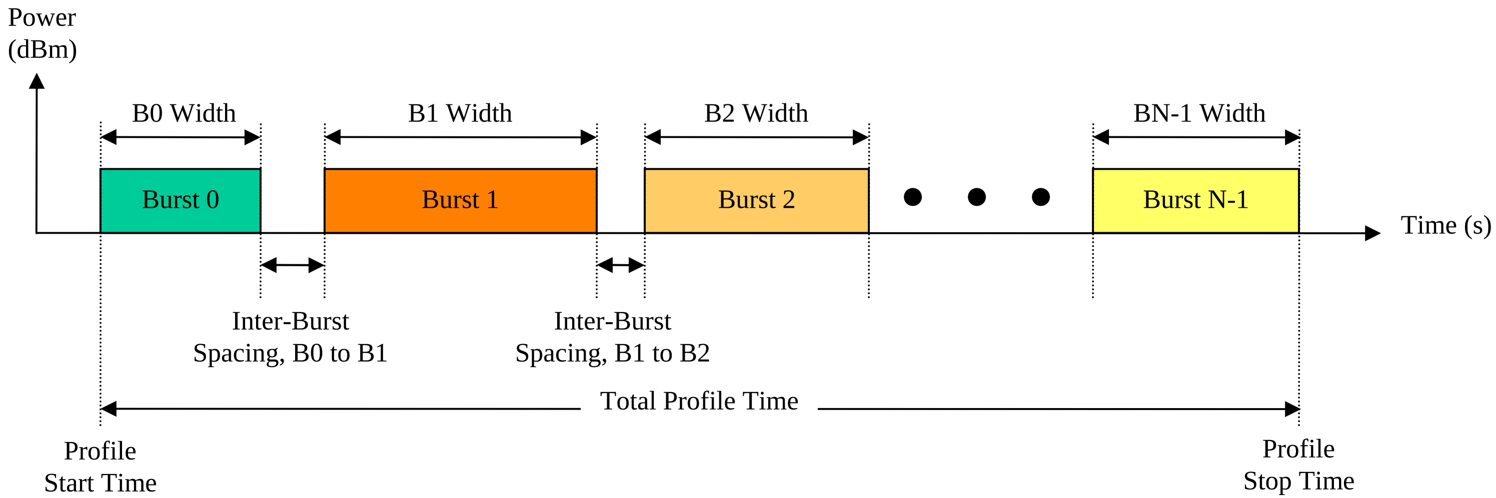
Time Domain View of a Radar Profile at the PROFILE Level



- **Notes:**
  - Each profile is made up of one or more bursts. Most profiles only have a **single** burst.

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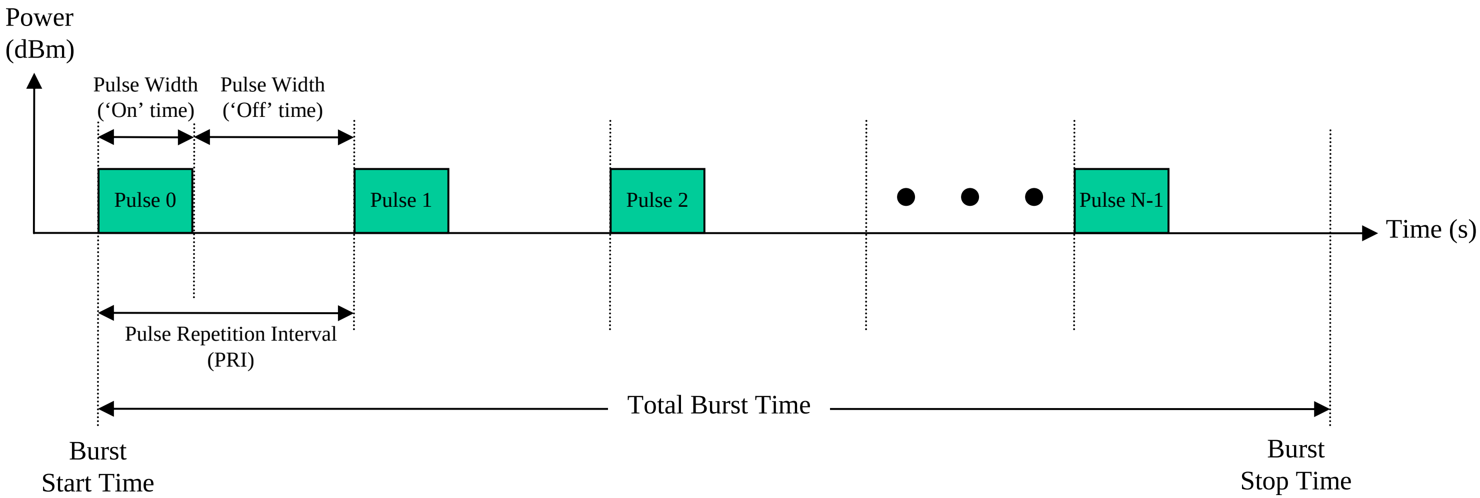
Time Domain View of a Radar Profile at the BURST Level



- **Notes:**
  - For both single and multi-burst profiles, all pulses have a fixed amplitude (constant-envelope).
  - Within a single burst of a multi-burst profile, all pulses have a fixed pulse width and a fixed chirp bandwidth (might be zero – see next slide). For the other bursts, both pulse width and chirp bandwidth can change.

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What Profiles Are Currently Supported in KI DFS RPG?

- **FCC Profiles (taken from FCC doc FCC-06-06A1):**
  - Short Pulse Radar Test Waveforms – KI DFS RPG software refers to these profiles as "USA 'Bin 1'" through USA 'Bin 4'"

Table 5 – Short Pulse Radar Test Waveforms

Radar Type	Pulse Width (μsec)	PRI (μsec)	Number of Pulses	Minimum Percentage of Successful Detection	Minimum Number of Trials
1	1	1428	18	60%	30
2	1-5	150-230	23-29	60%	30
3	6-10	200-500	16-18	60%	30
4	11-20	200-500	12-16	60%	30
Aggregate (Radar Types 1-4)				80%	120

** 'Randomness' of these parameters is handled automatically by software.

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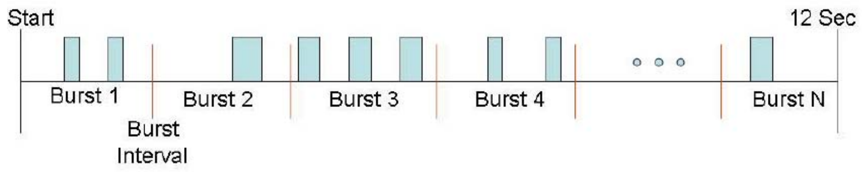
What Profiles Are Currently Supported in KI DFS RPG?

- **FCC Profiles continued:**
  - Long Pulse Radar Test Waveform – KI DFS RPG software refers to this profile as "USA 'Bin 5'"

Table 6 – Long Pulse Radar Test Waveform

Radar Type	Pulse Width (µsec)	Chirp Width (MHz)	PRI (µsec)	Number of Pulses per *Burst*	Number of *Bursts*	Minimum Percentage of Successful Detection	Minimum Number of Trials
5	50-100	5-20	1000-2000	1-3	8-20	80%	30

- Most complex of all profiles, since every parameter is random, either from burst-to-burst or within a given burst:
  - Number of bursts is random, but profile is **always 12 secs long**.



  - Pulse width, Chirp BW, and Number of Pulses are random from burst-to-burst
  - PRI is random **within** a given burst, implying that pulses are not evenly spaced within a burst

What Profiles Are Currently Supported in KI DFS RPG?

- **FCC Profiles continued:**
  - Frequency Hopping Profile – KI DFS RPG software refers to this profile as "USA 'Bin 6'"

Table 7 – Frequency Hopping Radar Test Waveform

Radar Type	Pulse Width (µsec)	PRI (µsec)	Pulses per Hop	Hopping Rate (kHz)	Hopping Sequence Length (msec)	Minimum Percentage of Successful Detection	Minimum Number of Trials
6	1	333	9	0.333	300	70%	30

- Multi-burst profile, where the only change from burst-to-burst is the center frequency:
  - Overall hop frequency range is from 5.250 – 2.724GHz, with 1MHz channel spacing (or, equivalently, 475 center frequencies). From this overall range, 100 frequencies are randomly selected (100 hops * 3msec / hop = 300msec total profile time)

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What Profiles Are Currently Supported in KI DFS RPG?

- **Japan Profiles (TELEC document titled "Characteristic test method for 5GHz Band Low Power Data Communication System (5.6GHz Band") – KI DFS RPG software refers to these as "Japan 'Fixed pulse 1'" through "Japan 'Fixed pulse 3' and Japan 'Variable pulse 4'" through "Japan 'Variable pulse 6'".**

Fixed pulse radar wave test signals

Test signal	Pulse width (μs)	Repeat frequency (Hz)	Number of successive pulses	Repeat cycle (s)
Fixed pulse 1	0.5	720	18	15.0
Fixed pulse 2	1.0	700	18	15.0
Fixed pulse 3	2.0	250	18	15.0

- Very similar to FCC Bins 1 – 4, only major difference is that minimum pulse width is decreased to 500ns.

Variable pulse radar wave test signals

Test signal	Pulse width (μs)	Repeat frequency (Hz)	Number of successive pulses	Repeat cycle (s)
Variable pulse 4	within 1 to 5μs range and add whole number multiple of 1μs	any frequency between 4,347 and 6,667Hz	whole number between 23 and 29	15.0
Variable pulse 5	within 6 to 10μs range and add whole number multiple of 1μs	any frequency between 2,000 and 5,000Hz	whole number between 16 and 18	15.0
Variable pulse 6	within 11 to 20μs range and add whole number multiple of 1μs	any frequency between 2,000 and 5,000Hz	whole number between 12 and 16	15.0

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What Profiles Are Currently Supported in KI DFS RPG?

- **Japan Profiles Continued:**
  - Chirped Profile – KI DFS RPG software refers to this profile as Japan 'Chirp 1'":

Test signal	Pulse width (μs)	Repeat frequency (Hz)	Number of successive pulses	Repeat cycle (s)
Chirp 1	within 50 to 100μs range and add whole number multiple of 1μs	any frequency between 500 and 1,000Hz	whole number between 1 and 3	12.0

    - Exactly the same as FCC "USA 'Bin 5'"

- Frequency Hopping Profile – KI DFS RPG software refers to this profile as "Japan 'Hopping 1'":

Frequency hopping radar wave test signals

Test signal	Pulse width (μs)	Repeat frequency (Hz)	Number of successive pulses	Repeat cycle (s)
Hopping 1	1.0	3,000	9	10.0

    - Exactly the same as FCC "USA 'Bin 6'"

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What Profiles Are Currently Supported in KI DFS RPG?

- **European Profiles (ETSI EN 301 893 V1.4.1 (2007-07)) – KI DFS RPG software refers to these as "ETSI V1.4.1, '1 – Fixed'", and "ETSI V1.4.1, '2 – Variable'" through "ETSI V1.4.1, '6 – Variable Mod":**

Table D.4: Parameters of DFS test signals

Radar test signal	Pulse width W [µs] (see note 5)	Pulse repetition frequency PRF [pps]	Pulses per burst [PPB] (see note 1)	Detection probability with 30 % channel load
1 - Fixed	1	750	15	P_d > 60 %
2 - Variable	1, 2, 5	200, 300, 500, 800, 1 000	10	P_d > 60 %
3 - Variable	10, 15	200, 300, 500, 800, 1 000	15	P_d > 60 %
4 - Variable	1, 2, 5, 10, 15	1 200, 1 500, 1 600	15	P_d > 60 %
5 - Variable	1, 2, 5, 10, 15	2 300, 3 000, 3 500, 4 000	25	P_d > 60 %
6 - Variable modulated (see note 6)	20, 30	2 000, 3 000, 4 000	20	P_d > 60 %

- All profiles are single burst, hence there is no frequency hopping profile.
- Random variables are now 'quantized' versus being a continuous range as they are in the FCC and TELEC profiles:
  - Example: the pulse widths for the '2 – Variable' profile are now a discrete set: 1, 2, and 5 µs.
- Profile '6 – Variable modulated' has a fixed chirp BW of 5MHz.

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What Profiles Are Currently Supported in KI DFS RPG?

- **New European Profiles (ETSI EN 301 893 V1.5.1 (2008-08)) – KI DFS RPG software refers to these profiles as "ETSI V1.5.1, '1 – CPRF'" through "ETSI V1.5.1, '4 – CPRF'" (the 'C' stands for 'Constant'), and "ETSI V1.5.1, '5 – SPRF'" and "ETSI V1.5.1, '6 – SPRF'" (the 'S' stands for 'Staggered').**
  - Note that ETSI EN 301 893 V1.4.1 (2007-07) is considered to be the current standard, although ETSI EN 301 893 V1.5.1 (2008-08) has been approved. Regardless, KI DFS RPG supports both.

Table D.4: Parameters of radar test signals

Radar test signal # (see notes 1 to 3)	Pulse width W [μs]		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
1	0,8	5	200	1 000	1	10 (see note 6)
2	0,8	15	200	1 600	1	15 (see note 6)
3	0,8	15	2 300	4 000	1	25
4	20	30	2 000	4 000	1	20
5	0,8	2	300	400	2/3	10 (see note 6)
6	0,8	2	400	1 200	2/3	15 (see note 6)

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What Profiles Are Currently Supported in KI DFS RPG?

- **ETSI EN 301 893 V1.5.1 (2008-08) continued:**
  - Radar profiles 5 and 6 are reffered to as 'Staggered PRF' profiles:
    - Example: Profile 5 has 2 or 3 different PRFs in the burst, each ranging from 300 to 400Hz

Radar test signal # (see notes 1 to 3)	Pulse width W [µs]		Pulse repetition frequency PRF (PPS)		Number of different PRFs	Pulses per burst for each PRF (PPB) (see note 5)
	Min	Max	Min	Max		
5	0,8	2	300	400	2/3	10 (see note 6)

    - In the time domain, the burst would look as shown below, where the different PRFs alternate. If, for example, the software randomly selected 2 PRFs (versus 3), the first pulse in the burst would have PRF_0 and the second would have PRF_1. The sequence would then repeat as PRF_0 PRF_1 PRF_0 PRF_1 ...

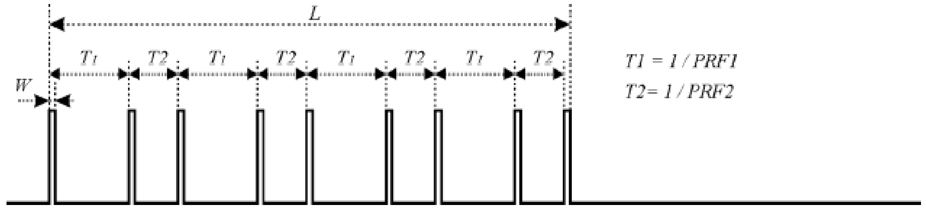


Figure D.3: General structure of a single burst / single pulse based staggered PRF radar test signal

How Are The ARB Files Generated?

- **Basic Profiles: single burst, fixed pulse width, fixed PRI/PRF, fixed number of pulses, no chirping, no frequency hopping:**
  - If the selected profile has 'random' parameters, the software automatically selects the random value(s) from the allowable set.
  - A single ARB file is generated – this represents a single pulse *plus* the off-time
    - All I samples are +1, are Q samples are 0
    - ARB file is encrypted, required license string is currently 'Pre-Release ARB Files'. Note that this will change once KI DFS RPG software is released as a real product. Note that all ARB files created, regardless of profile type, are encrypted.
  - An ARB sequence file is generated:
    - Single entry that specifies that the ARB file is to be played back N times, where N is the number of pulses.

How Are The ARB Files Generated?

- **Frequency Hopped Profiles: multiple burst, fixed pulse width, fixed PRI/PRF, fixed number of pulses per burst, no chirping:**
  - – Overall hop frequency range is from 5.250 – 5.724GHz, with 1MHz channel spacing (or, equivalently, 475 center frequencies)
  - – From this overall range, 100 frequencies are randomly selected (100 hops * 3msec / hop = 300msec total profile time)
  - – Multiple ARB files are generated, one for every burst 'seen':
    - A burst is 'seen' if it its center frequency falls between sig gen's center frequency +/- 0.4 * sample rate (either 50MHz or 100MHz – note that the DFS RPG software *will not* work unless the sig gen is optioned for either 50MHz or 100MHz)
      - – For 100MHz, the burst's center frequency must fall within Fsig_gen – 40MHz ≤ Fburst ≤ Fsig_gen + 40MHz, where Fsig_gen is where the signal generator is tuned to during the signal generation.
      - – For 50MHz, the burst's center frequency must fall within Fsig_gen – 20MHz ≤ Fburst ≤ Fsig_gen + 20MHz
    - Note that Fsig_gen *does not* change during a frequency hopped test – the signal is shifted in the spectrum mathematically when the ARB samples are generated.
  - – One additional 'blanked' file is generated (blanked means that all I and Q samples are zero) to account for all bursts that *are not* seen (this file has the sample number of samples as the 'real' ARB files).
  - – A 100 entry sequence file is generated, where each line in the sequence file is either one of the 'real' burst files or the 'blanked' file.

How Are The ARB Files Generated?

- **Frequency Hopping Profile generation question: Why doesn't the software just generate a single file (single burst), then generate a 100 entry sequence file where this single file is played back at a different center frequency?**
  – This won't work because the frequency switching time of the VSG is non-deterministic, implying that the precise timing requirements for the hopped signal would be unachievable
- **Is it valid to only generate bursts that fall within the sig gen's center frequency +/-0.4 * the ARB sample rate?**
  – **YES.** Why?
    - A customer's DUT will be tuned to the same center frequency as the VSG, and because he has a bandpass filter on the receiver's front end (~20 MHz bandwidth), he wouldn't see bursts outside of the this range anyway.

How Are The ARB Files Generated?

- **Simple Chirped Profiles: single burst, fixed pulse width, fixed PRI/PRF, fixed number of pulses per burst, no frequency hopping:**
  - A single ARB file is generated – this represents a single pulse *plus* the off-time
    - All I samples and Q samples are generated such that they implement a 'linear FM chirp', with the specified chirp bandwidth (chirp BW) (see next slide).
  - A single entry ARB sequence file is generated that specifies that the ARB file is to be played back N times, where N is the number of pulses.

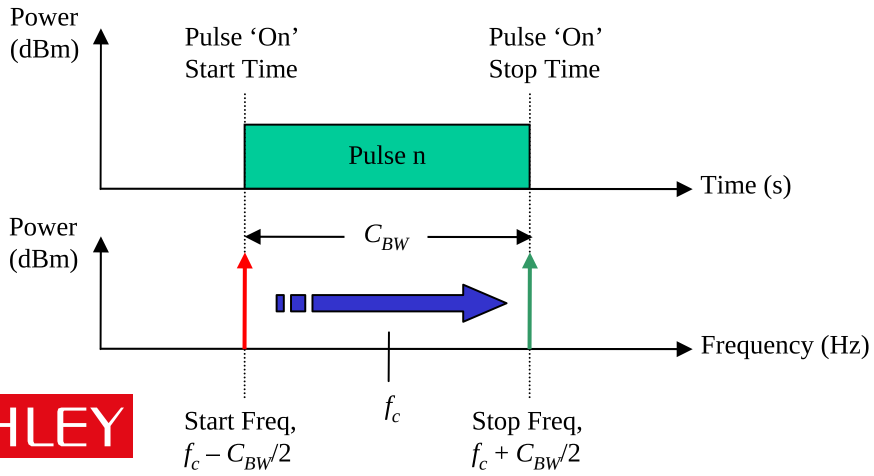
How Are The ARB Files Generated?

- **Question: What is meant by 'linear FM chirp' and 'chirp BW'?**
  - For chirped profiles, the pulses are not transmitted at a single CW center frequency. Instead, the instantaneous frequency of the pulse varies with time – in radar terminology, this is referred to as a 'chirped' pulse.
- **In the DFS RPG software, all chirped pulses implement a *linear FM chirp*, where the instantaneous frequency *f(t)* of the pulse varies linearly with time:**

$$f(t) = \left(f_c - \frac{C_{BW}}{2} \right) + kt \Big|_{t=0}^{t=T_P}$$

, where f_c is the center frequency (the frequency that the VSG is tuned to), C_{BW} is the chirp bandwidth, T_P is the pulse width, and k is a constant, $k = \frac{C_{BW}}{T_P}$.

- The above equation simply states that the pulse starts at a frequency C_{BW} / 2 below f_c, and ends at a frequency C_{BW} / 2 above f_c. Again the VSG stays fixed at a specific center frequency – the instantaneous frequency is moved via the ARB file samples.



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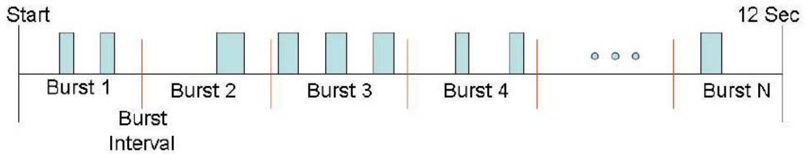
How Are The ARB Files Generated?

- **Complex Chirped Profiles (specifically USA 'Bin 5' and Japan 'Chirped 1'): multiple burst, fixed pulse width, variable PRI/PRF, variable number of pulses per burst, no frequency hopping:**
  - Recall that the number of bursts is random, but the profile is always 12 seconds long:



- An ARB file is generated for each burst:
  - All ARB files generate will be the same length – this is required for 'seamless playback' of the sequence in the 29xx VSG series ('seamless playback' means that the there are no additional clock cycles required for switching to the next ARB waveform in the sequence)
  - Each ARB file will have the following 'segments'
    - The 'active' part of the burst, i.e. the portion that contains the pulses
    - A variable 'blanked' time – this is used as a 'length adjuster' to make sure that each burst file is ultimately the same length (in the KI DFS RPG software, this is referred to as 'Last Pulse Trail Off Time').
- An additional 'blanked' burst file is generated, again having the same length as a 'real' burst file

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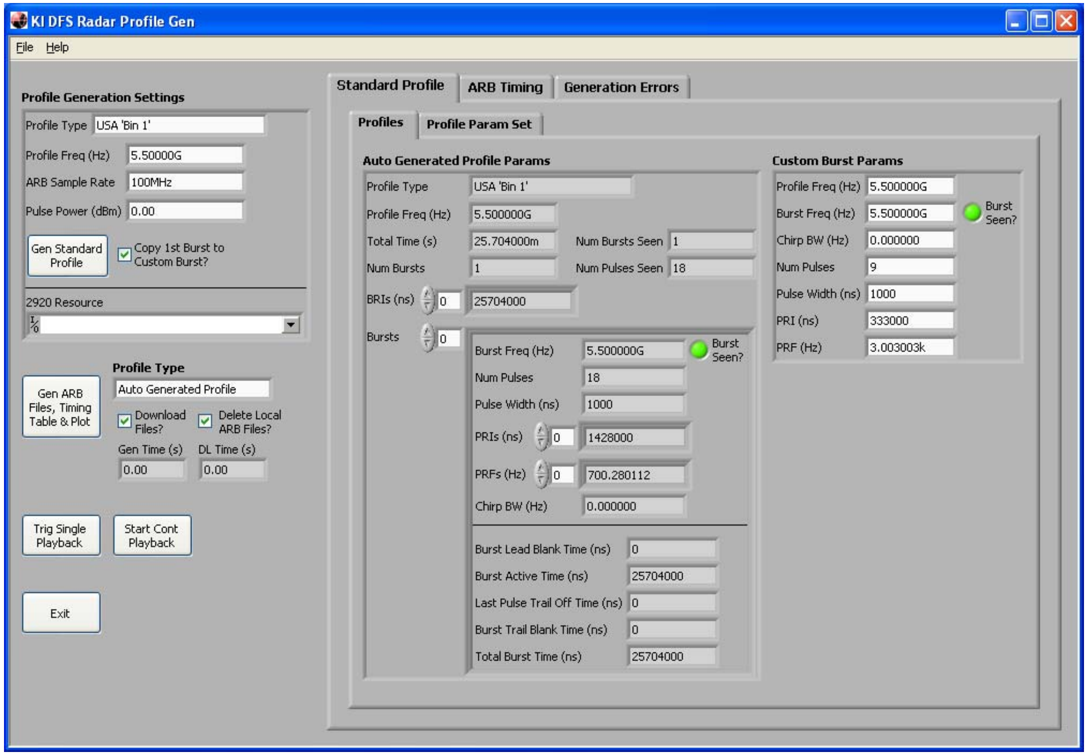
How Are The ARB Files Generated?

- **Complex Chirped Profiles continued:**
  - A sequence file is generated according the following algorithm:
    - The total time length of the sequence (12 seconds) is divided by N, where N is the number of bursts in the profile (number of bursts can vary from 8 – 20).
    - N 'segments' are formed, where each of these segments is made up of three components:
      - A random leading blank time, which is just a random number of repetitions of the blanked file (referred to in the software as 'Burst Lead Blank Time').
      - One of the N burst files
      - A trailing blank time, again just a random number of repetitions of the blanked file (referred to in the software as 'Burst Trail Blank Time').
      - The sum of the time of the above three elements will be such that it will be as close to the segment time as possible.
    - The total time length off all the segments will be as close to 12 seconds as possible (always slightly less than 12 seconds).

  - As an example, assume that there are 12 bursts:
    - Each segment will be approximately 1 second long (12 seconds / 12 = 1 second per segment).
    - The sequence file will be constructed according to the following playback sequence:
      - Segment 1:
        - » Repeat blanked file X1 times (leading blank time for burst 1)
        - » Play burst 1
        - » Repeat blanked file Y1 times (trailing blank time for burst 1)
      - Segment 2:
        - » Repeat blanked file X2 times (leading blank time for burst 2)
        - » Play burst 2
        - » Repeat blanked file Y2 times (trailing blank time for burst 2)
      - Segments 3 – 11 …
      - Segment 12:
        - » Repeat blanked file X12 times (leading blank time for burst 12)
        - » Play burst 12
        - » Repeat blanked file Y12 times (trailing blank time for burst 12)

KI DFS RPG Software Details

- **Highlights:**
  - Written in LabVIEW
  - Generates FCC, Japan, and ETSI Current / Future profiles
  - Capability to define a single burst custom signal
  - Software is free, but requires 'Pre-Release ARB Files' license in 29xx VSG
  - Bob Green has been tasked with turning this into an official product



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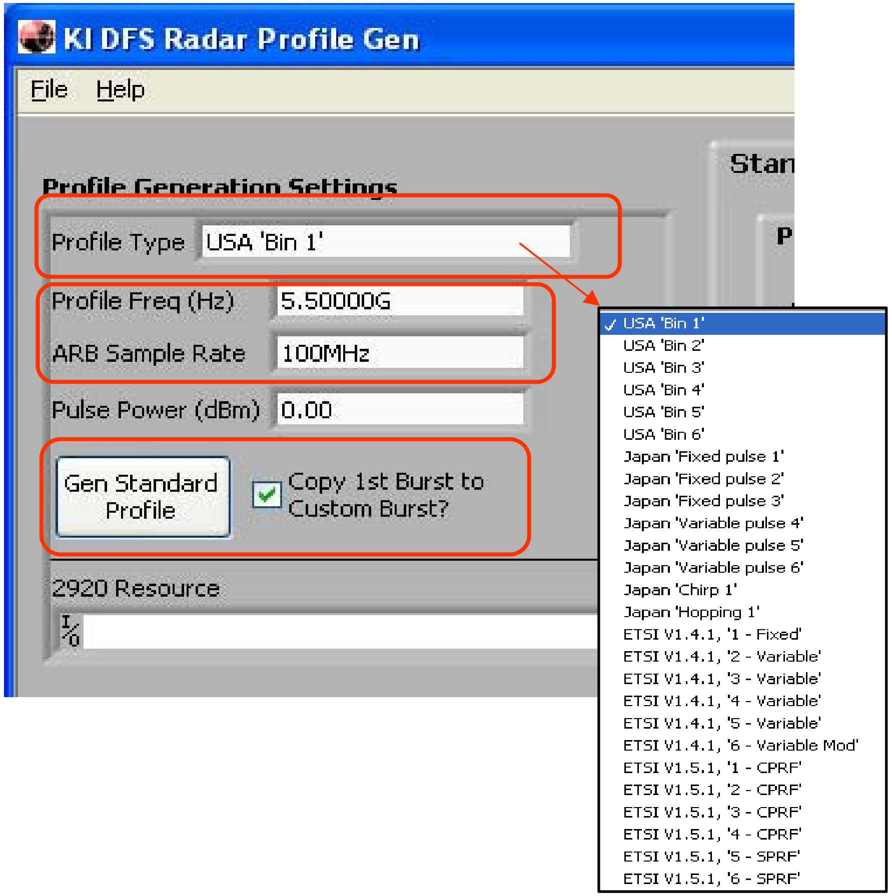
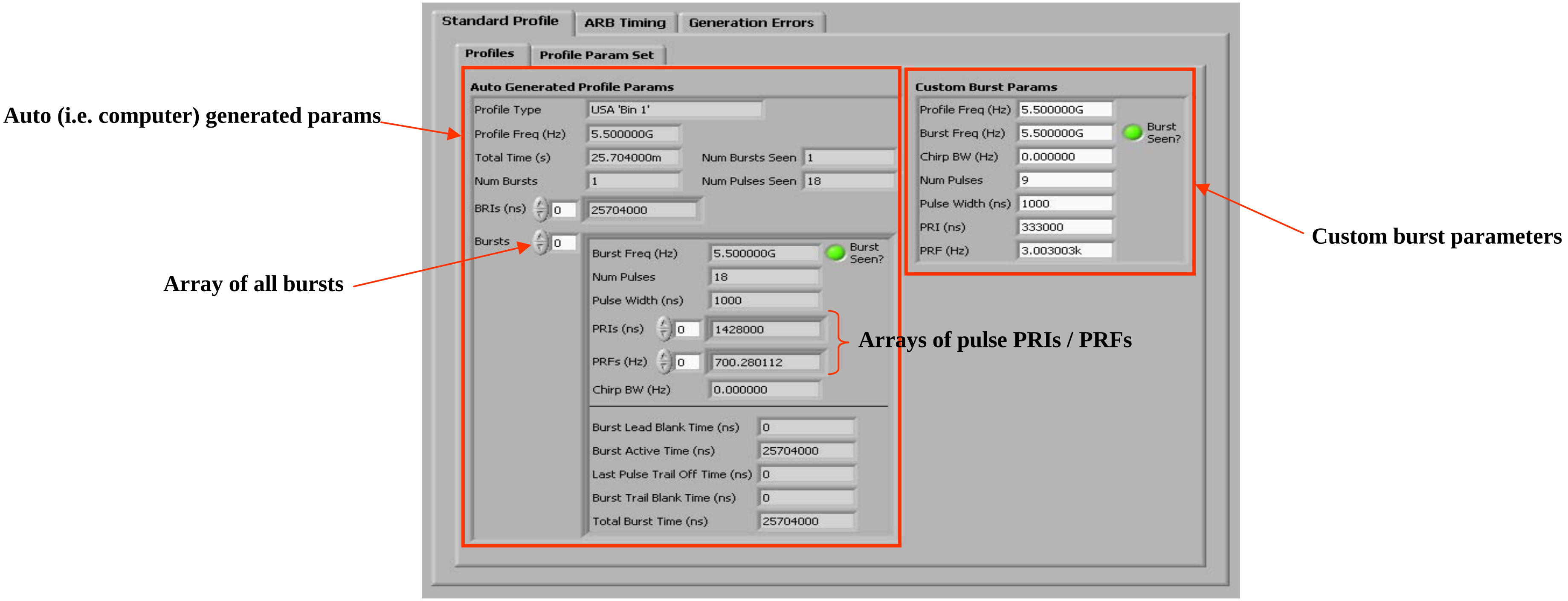
KI DFS RPG Software Details
Profile Generation Steps

1. **Choose the profile you want to generate.**
2. **Set the profile center frequency and ARB Sample Rate – note that these are particularly important for frequency hopped profiles.**
3. **Optionally check the 'Copy 1st Burst to Custom Burst?' checkbox to provide a starting parameter set for a custom profile definition.**
4. **Press the 'Gen Standard Profile' button.**



KI DFS RPG Software Details
Profile Generation Steps

- At this point, no ARB Files have been generated, but the software has chosen all necessary random parameters, and optionally copied the 1st burst to the Custom Burst Params input.



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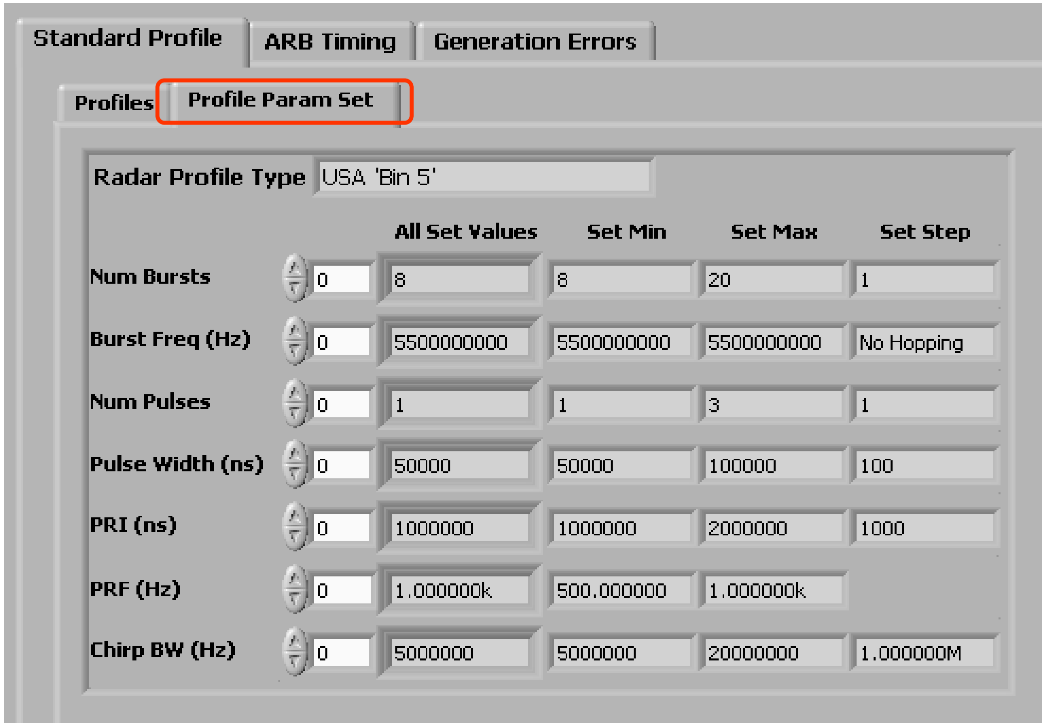
KI DFS RPG Software Details
Profile Generation Steps

- **If you want to know what set of parameters were used for a given profile generation, look at the ‘Profile Param Set’ tab:**
  - This tab shows the ‘boundary conditions’ for profile generation (e.g., the max and min number of pulses in a profile that supports a random number of pulses).



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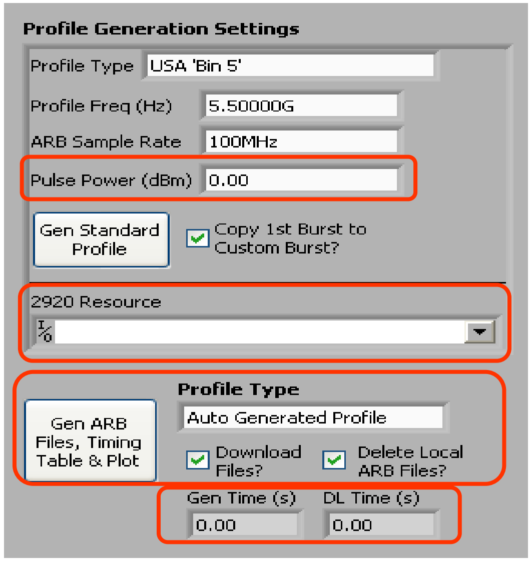
KI DFS RPG Software Details
Profile Generation Steps

- **Once you are satisfied with either the auto-generated profile or your custom settings, you can now generate the actual ARB files (note that this is done as a separate step since generating the actual ARB files generation will take longer than setting up the profile):**
  1. If you plan on downloading the files to a 29xx instrument:
     a. Set the VSG VISA Resource and the Pulse Power.
     b. Check the 'Download Files?' checkbox, and *optionally* check the 'Delete Local ARB Files?' checkbox to delete the files from your local PC after download.
  2. Choose the profile to generate ARB files for, either auto-generated or custom.
  3. Choose the profile type to generate, either auto-generated or custom.
  4. Press the 'Gen ARB Files, Timing Table & Plot'
     - A file dialog will open asking you what folder you want to put the generated files in. It is highly suggested that you use a separate folder for each profile you generate.
     - After the generation is complete, both the generation time and the download time will be reported in 'Gen Time (s)' and 'DL Time (s)' respectively.



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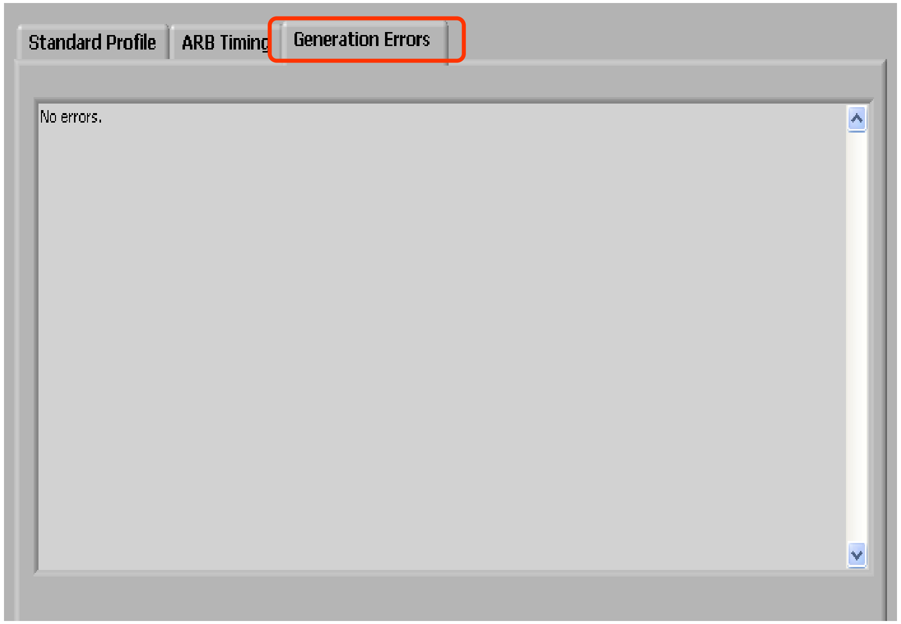
KI DFS RPG Software Details
Profile Generation Steps

- **After the ARB files are generated, the software will do a check on the ARB files to make sure they are valid. If there were any generation errors, these will be reported on the 'Generation Errors Tab':**
  - If there are errors, this tab will automatically open. Although there has been significant testing of the code, there hasn't been an official audit, so it's possible that there are bugs. If you find any errors, report the text in the 'Generation Errors' text box to Steve Murray.



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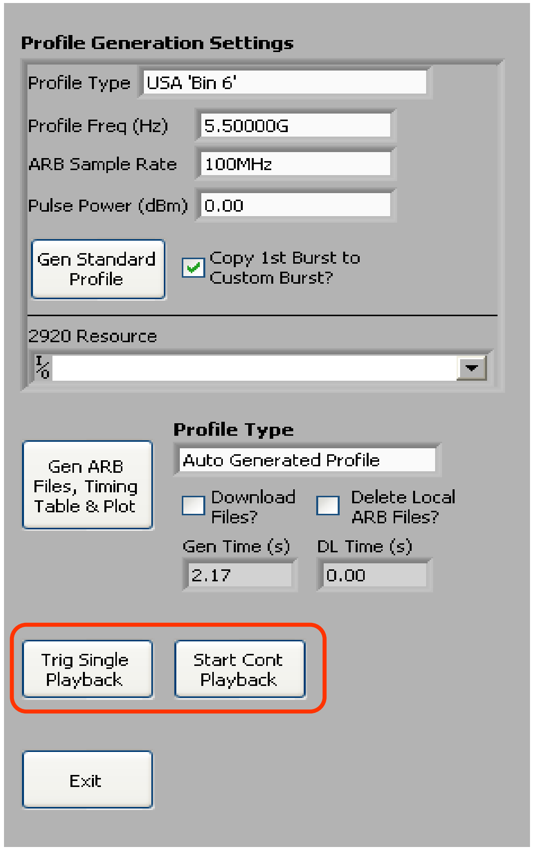
Customer Use And Troubleshooting Techniques

- **In general, customers will want the capability to both play back a sequence a single time or let the sequence loop over-and-over again:**
  - Press ‘Trig Single Playback’ to playback the sequence one time.
  - Press ‘Start Cont Playback’ to loop the sequence over-and-over.



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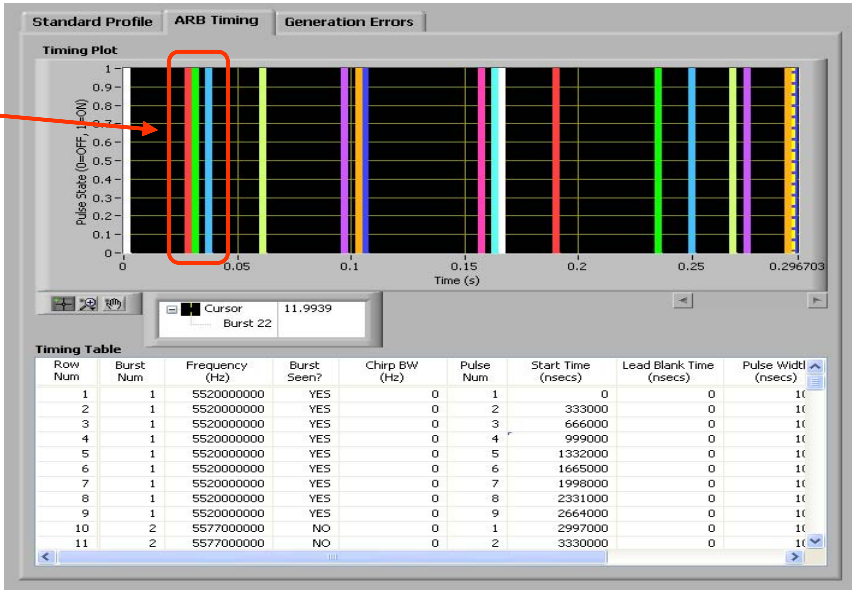
Customer Use And Troubleshooting Techniques

- **To help customers with troubleshooting, both a timing plot and a timing table will be displayed immediately after the ARB files are generated:**
  - The ‘Timing Plot’ is a graphical representation of what the signal would look like if you looked at a playback on a spectrum analyzer in zero span.
  - The ‘Timing Table’ lists in *great detail* the entire sequence:
    - When bursts start, when pulses in bursts start, how wide the pulses are, etc.

Bursts 2, 3, 4 of a Frequency Hopped profile



Row Num	Burst Num	Frequency (Hz)	Burst Seen?	Chirp BW (Hz)	Pulse Num	Start Time (nsecs)	Lead Blank Time (nsecs)	Pulse Widtl (nsecs)
1	1	5520000000	YES	0	1	0	0	1(
2	1	5520000000	YES	0	2	333000	0	1(
3	1	5520000000	YES	0	3	666000	0	1(
4	1	5520000000	YES	0	4	999000	0	1(
5	1	5520000000	YES	0	5	1332000	0	1(
6	1	5520000000	YES	0	6	1665000	0	1(
7	1	5520000000	YES	0	7	1998000	0	1(
8	1	5520000000	YES	0	8	2331000	0	1(
9	1	5520000000	YES	0	9	2664000	0	1(
10	2	5577000000	NO	0	1	2997000	0	1(
11	2	5577000000	NO	0	2	3330000	0	1(

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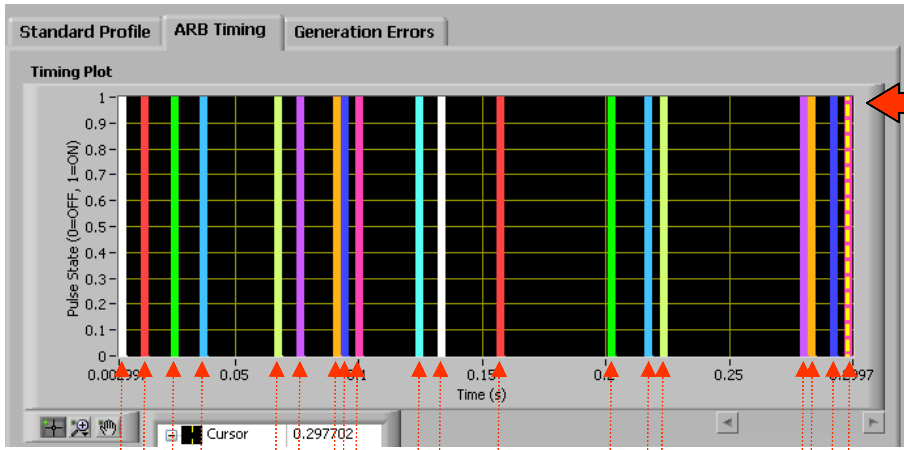
Customer Use and Troubleshooting Techniques

- **The best debugging tool is a 28xx signal analyzer – you can prove to the customer that the signal generator is generating the signals it claims to be generating:**
  - Connect ‘Sync Out’ on 29xx to ‘Trig In’ on 28xx.
  - Set 28xx to ‘Zero Span’, max bandwidth (40MHz), and Single Sweep.
  - Set 29xx to output a Sync pulse on ‘At beginning of sweep/list/sequence’.
  - Press the ‘Trig Single Playback’ button, and adjust the sweep time / trigger delay on the 28xx until the 28xx display matches the ARB Timing Plot.

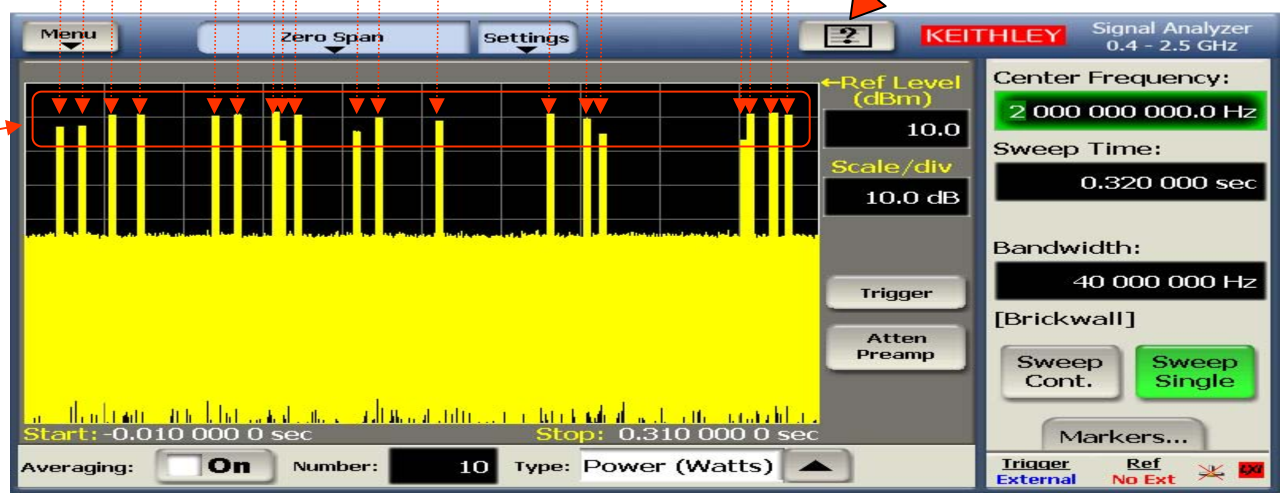
Customer Use and Troubleshooting Techniques

- Example:
  - USA 'Bin 6' Generation (Frequency Hopping)



Software ARB Timing Plot

2810 Zero-Span Capture



** Difference in burst levels is due to the fact that some bursts have center frequencies that are closer to one edge of the 2810 capture filter.

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Customer Use and Troubleshooting Techniques

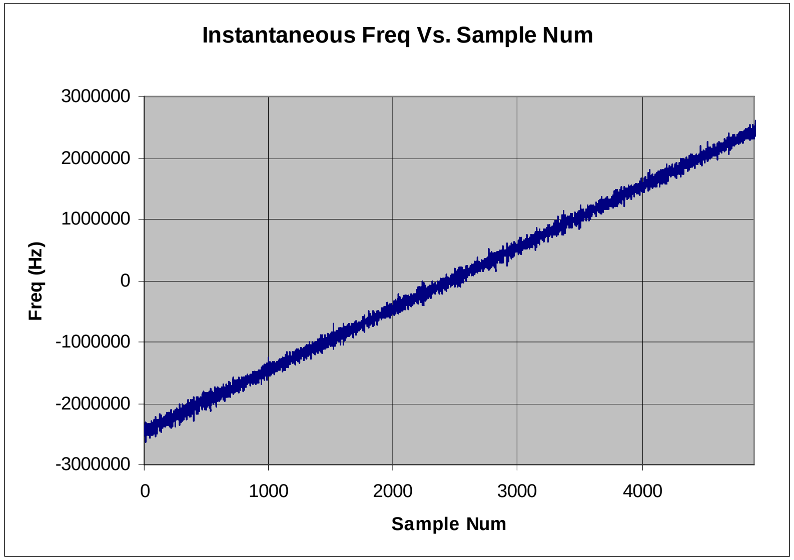
- **How do you verify a chirped signal?**
  - ‘Simple’ way:
    - Put 28xx in ‘Spectrum’ mode, set ‘Trace Hold’ to ‘Max Hold’.
    - Display will eventually show a spectrum that looks ‘spread’ but it’s tough to tell that’s it’s a chirped signal, and exactly what the chirp BW is.

Chirped signal with 5MHz bandwidth

Customer Use and Troubleshooting Techniques

- **How do you verify a chirped signal?**
  - ‘Better’ way:
    - Put 28xx in ‘Zero Span’ mode, maximum bandwidth, capture a single pulse with :MEAS:IQ? SCPI command.
    - Import into Excel, find the instantaneous frequency at each sample point (Finstantaneous = dPhase / dTime), and plot this versus time.

Signal starts 2.5MHz below the center frequency, and ends 2.5MHz above. Thus the chirp BW is 5MHz.



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