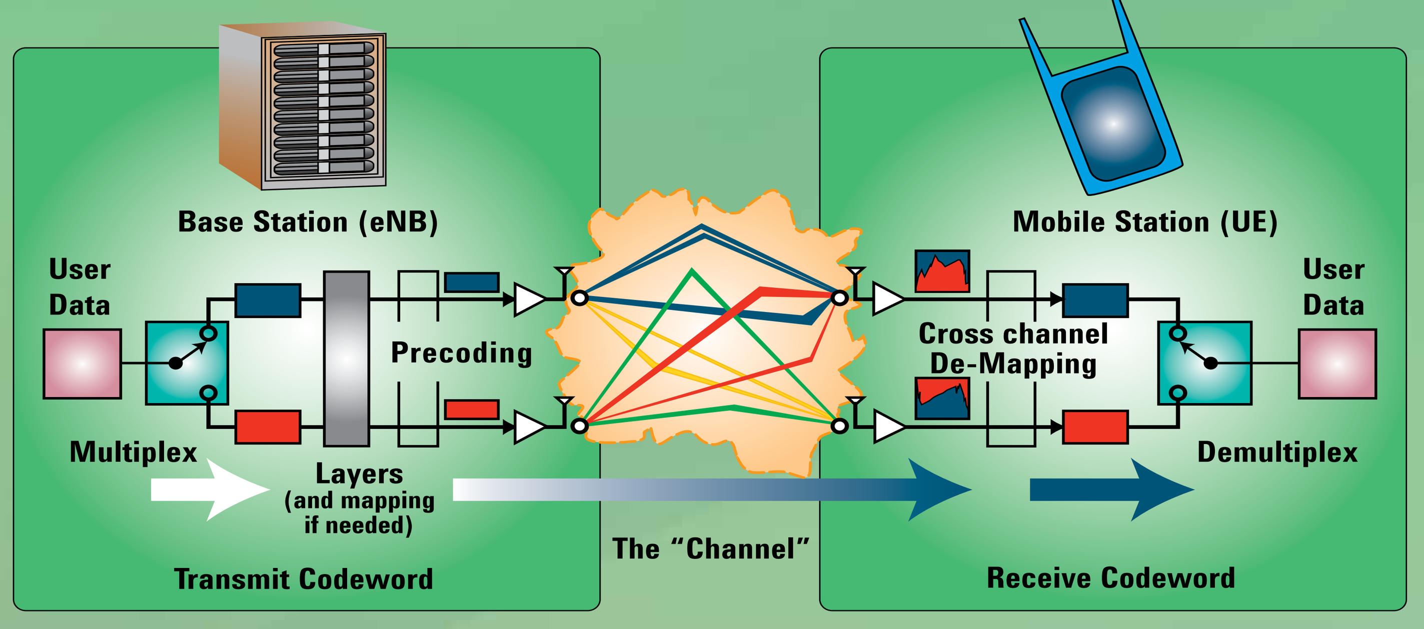
Ten Things You Should Know About MIMO

Agilent is committed to helping you understand MIMO technology so you can get your products to market fast. From R&D through integration and manufacturing, Agilent has test equipment to provide insight into these complex signals and allow you to meet your time to market goals. ***Agilent MIMO Design and Test Portfolio - Greater insight. Greater confidence.***

MIMO is used differently in the downlink and uplink of cellular systems

MIMO (Multiple Input Multiple Output) is the general term given to the transmission and reception of multiple data streams via multiple antennas. Spatial Multiplexing is the technique that increases the link capacity.

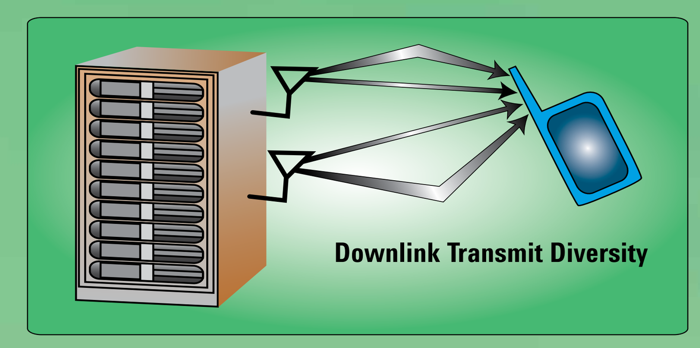
The difference between uplinks and downlinks suits typical asymmetric data throughput, and the performance may be directional due to different antenna configurations in the base and mobile stations.



Single-User Downlink MIMO Operation

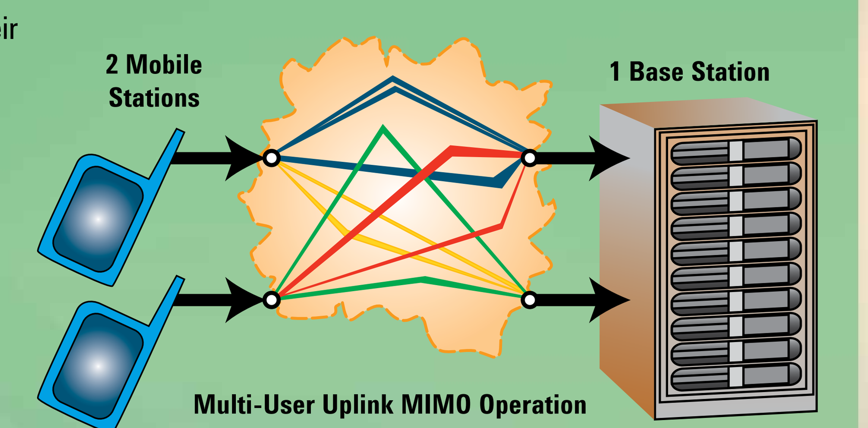
MIMO needs at least two transmitters and two receivers, and the receivers have to be in the same place

If not, the configuration is a diversity technique rather than MIMO. The receivers have to be in the same device, but the transmitters don't – hence the possibility of two mobile stations being used together for MIMO in the uplink.



The picture shows uplink 2x2 multi-user (collaborative) MIMO, where the data streams from two different mobile stations are controlled by the base station. Their transmissions are scheduled to occur at the same time, and occupy the same frequencies.

The key advantage of MU-MIMO is that the cell capacity is increased without the cost and battery drain of two transmitters in a single mobile station (UE).

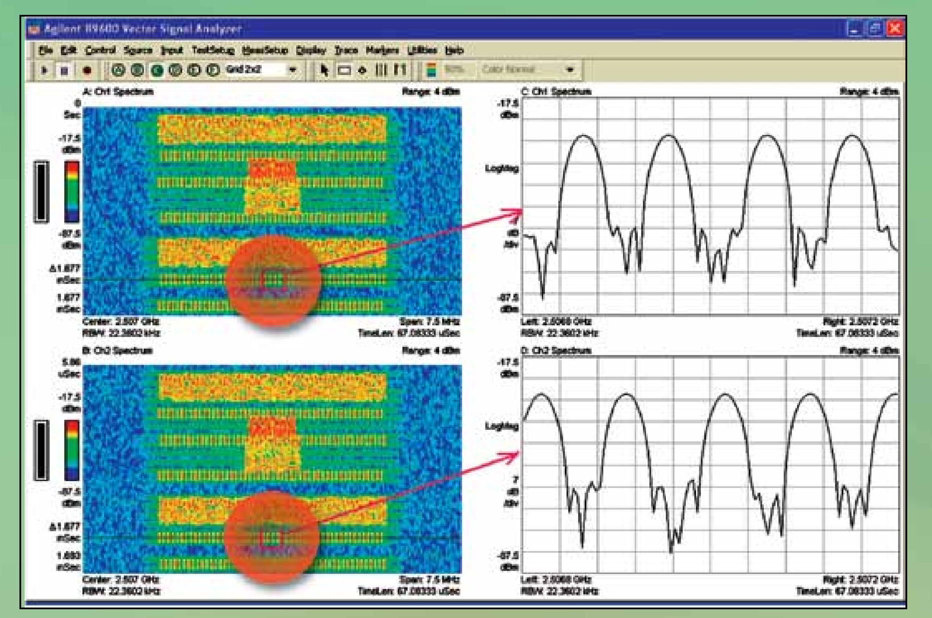


Multi-User Uplink MIMO Operation

MIMO signal recovery is a two-step process

1. Recover the channel coefficients
2. Separate the signals and demodulate

The plot shows the reference signals (pilots) in an LTE signal, used to recover the channel coefficients. The signal orthogonality, due to the difference in pilot frequencies, is shown in the time gated spectrum plot information. WiMAX uses a similar arrangement of non-overlapping pilots.



Channel Training Mechanisms

LTE

- Reference signals use different subcarriers for each transmitter.
- Reference signals are transmitted every 3rd or 4th symbol, mixed with data.

HSPA+

- HSPA+ uses code-based pilots to identify each transmitter.

WiMAX

- Pilot positions are constant from frame to frame, but vary symbol by symbol within a subframe zone.
- Subcarrier coverage builds over several symbols, allowing interpolation.
- Details depend on the zone type.

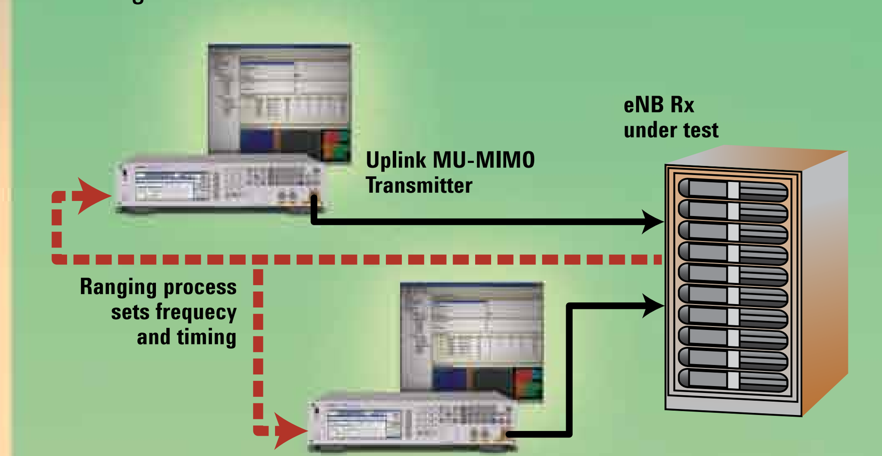
Wireless LAN

- A preamble is used for training. The same subcarriers are used for all transmitters. Signals are separated with a CDMA code.
- Four orthogonal pilots are used (6 for 40 MHz), using common subcarriers. They are never transmitted without data.

Transmit and receive phase differences don't affect open loop MIMO

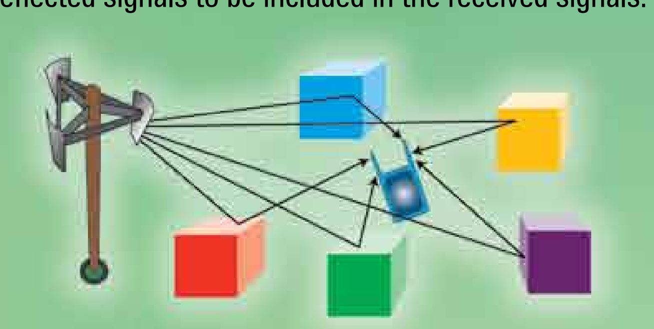
Phase and small frequency differences and time offsets are removed by the tracking processes in the demodulator.

This setup shows how to simulate two mobile stations collaborating for an uplink MIMO base station receiver test using the Agilent MXG with Signal Studio Software.



The combination of BS and MS antenna configuration has a major impact on channel path correlation

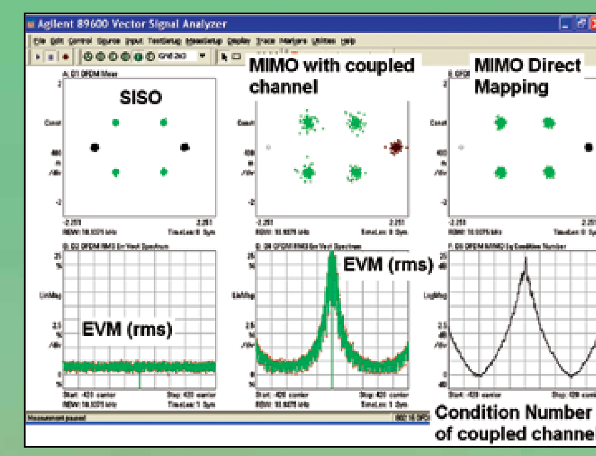
The angle of departure from the BS antenna towards an individual user is relatively narrow, while the angle of arrival at the MS is wide, allowing a range of reflected signals to be included in the received signals.



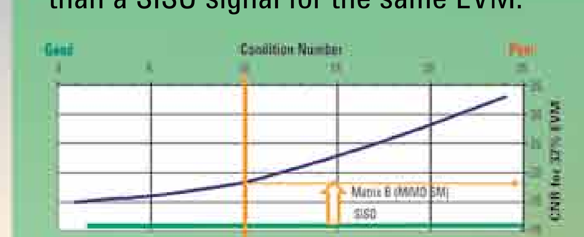
Correlation is a statistical measurement of the channel

MIMO needs a better carrier-to-noise ratio than SISO

Errors due to noise, interference or channel tracking make it difficult to recover the constellation. MIMO is more difficult to recover than SISO because any signal coupling that is not completely removed will make one data stream look like interference to the other.



The graph shows that a MIMO signal in a channel with condition number =10 dB requires a CNR approximately 7 dB better than a SISO signal for the same EVM.



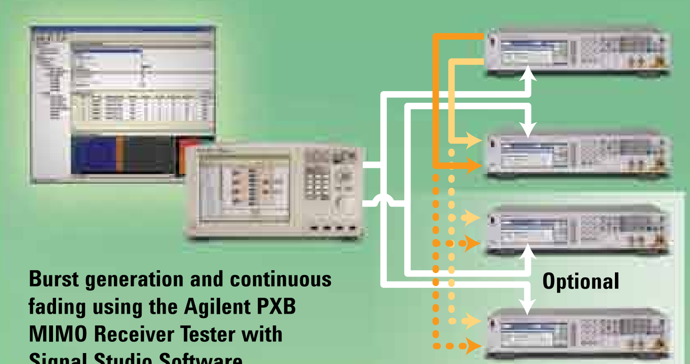
Overall system performance is improved since MIMO can potentially double the data capacity.

This example shows channels intentionally coupled to degrade the condition number. The channel is causing the central subcarriers to suffer further degradation relative to the SISO case, and need higher carrier-to-noise ratio for the same BER.

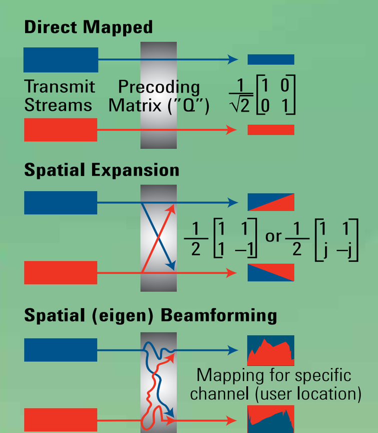
Precoding and eigenbeamforming couple the transmit signals to suit the channel

They are both forms of closed loop MIMO, where the transmitted signals are cross coupled to suit the current channel conditions. Precoding isn't needed to make MIMO work, but it can improve performance if the channel doesn't change too fast. LTE has a simple 1-of-3 precoding choice. Some WLAN devices apply LTE codebook index 1 all the time, and call it spatial expansion.

Downlink 2x2 (optional 4x4) Precoded MIMO Transmitter



Burst generation and continuous fading using the Agilent PXB MIMO Receiver Tester with Signal Studio Software.

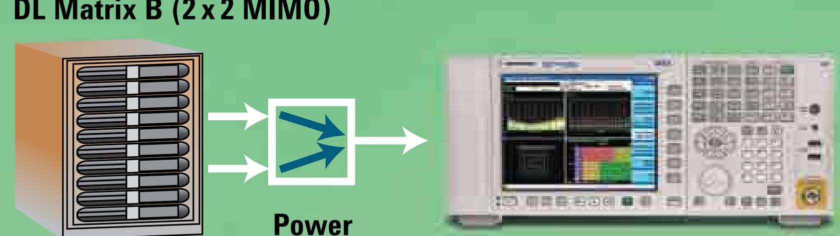


Eigenbeamforming (an enhanced form of precoding) modifies the transmit signals to give the best CINR at the output of the channel. 802.11n refers to eigenbeamforming simply as "beamforming".

Cross-channel measurements can be made with a single-input analyzer, using the reference signals (pilots)

Pilots in LTE and WiMAX are unique (orthogonal) to each transmitter. They are not subject to precoding. WLAN uses too few pilots to allow the same measurements.

DL Matrix A (2 x 1 STC) *or* DL Matrix B (2 x 2 MIMO)

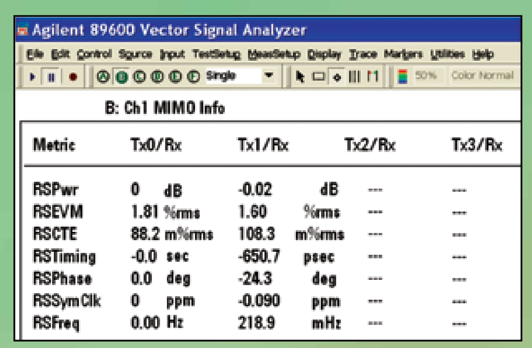


Individual measurements:

- Modulation analysis
- Isolation

Measurements with combiner:

- Relative timing
- RF Phase



Agilent 89600 Vector Signal Analyzer

B: Ch1 MIMO Info

Metric	Tx0/Rx	Tx1/Rx	Tx2/Rx	Tx3/Rx
RSPwr	0 dB	-0.02 dB	---	---
RSEVM	1.81 %rms	1.60 %rms	---	---
RSCTE	88.2 m%rms	108.3 m%rms	---	---
RSTiming	-0.0 sec	-650.7 psec	---	---
RSPhase	0.0 deg	-24.3 deg	---	---
RSSymClk	0 ppm	-0.090 ppm	---	---
RSFreq	0.00 Hz	218.9 mHz	---	---

Condition number measures short-term MIMO channel performance

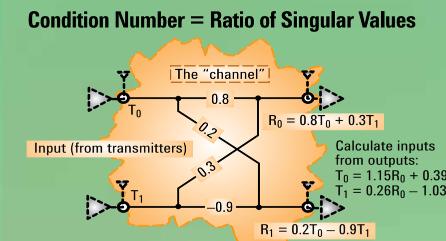
The expression relating MIMO channel capacity to condition number is:

$$C = \sum_{i=1 \text{ to } N} B.\log_2\left(1 + \frac{\rho}{N}\sigma_1^2(H)\right)$$

N = the number of independent transmitter-receiver pairs

$\sigma_1^2(H)$ = the singular values of the radio channel matrix, H

Condition Number = Ratio of Singular Values



Channel Matrix H

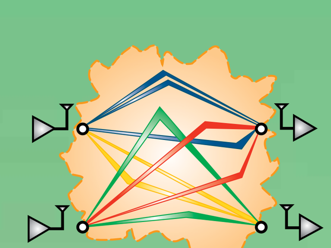
$$\begin{bmatrix} 0.8 & 0.3 \\ 0.2 & -0.9 \end{bmatrix}$$

Transpose Matrix H^T → **H^TH**

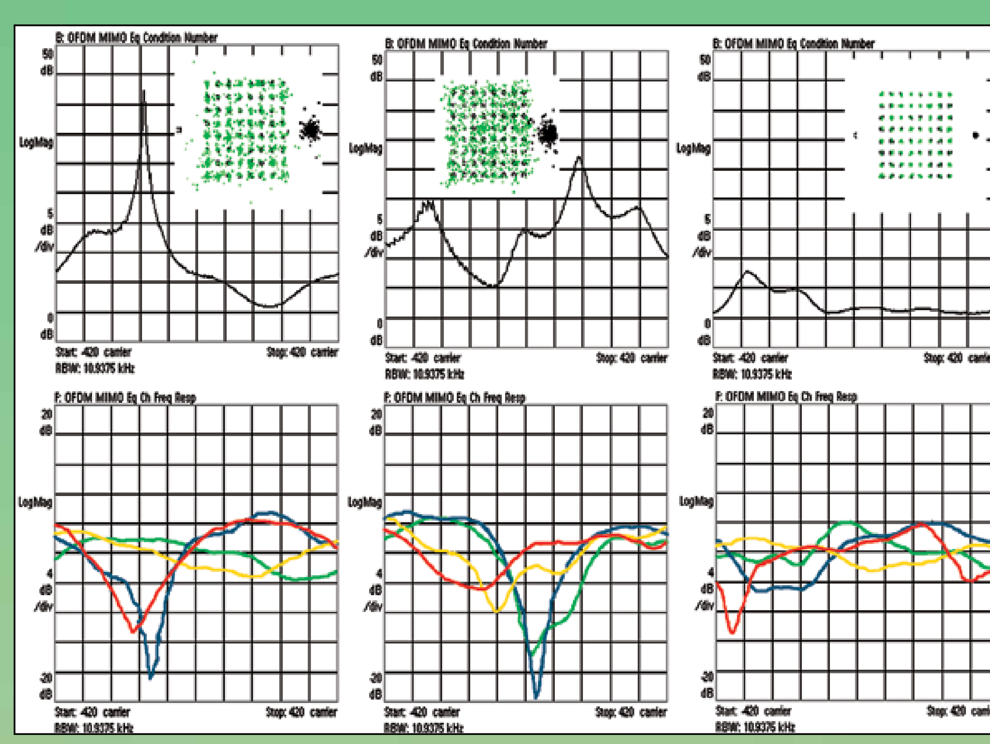
$$\begin{bmatrix} 0.8 & 0.2 \\ 0.3 & -0.9 \end{bmatrix} \rightarrow \begin{bmatrix} 0.73 & -0.11 \\ -0.11 & 0.85 \end{bmatrix}$$

Singular Values → **Condition Number**

$$\begin{bmatrix} 0.975 \\ 0.815 \end{bmatrix} \rightarrow 0.957/0.815 = 1.17$$

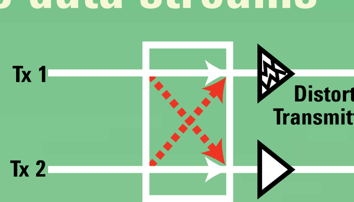


This two-input measurement is designed to show errors in the RF and analog hardware. The plots show condition number and frequency response vs. subcarrier number in a WiMAX signal, and the resulting constellation.

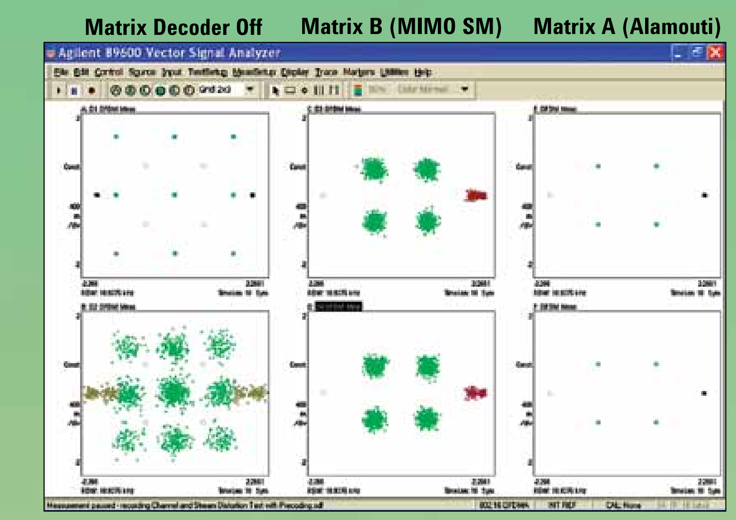


Distortion in one component can degrade all the data streams

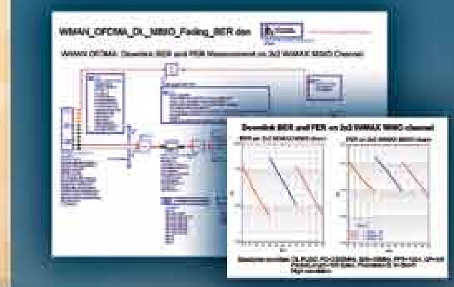
The example is of a transmitter with one amplifier clipping. With matrix decoding off, only one channel is distorted. With matrix B (MIMO SM), both streams are affected. Matrix A (Alamouti) or Tx diversity is unaffected.



Multi-input signal acquisition hardware



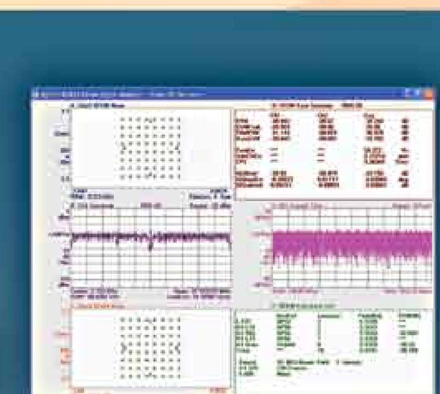
Agilent's MIMO Design and Test Solutions



Wireless Design Library

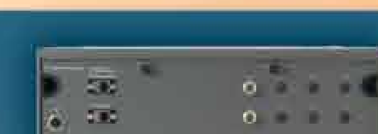
PXB Baseband Generator and Channel Emulator

Choice of signal generator with Signal Studio Software



Vector signal analysis software

Choice of signal analyzer with measurement applications

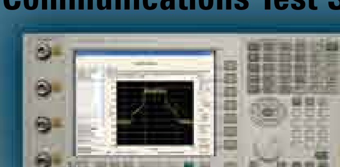


Multi-channel Signal Analysis System

Agilent 90000 X-series Infiniium scopes

Logic Analysis for DigRF v3 & v4

PXT Wireless Communications Test Set



Wireless Networking Test Set

Wireless Connectivity Test Set

Mobile WiMAX Test Set

"WiMAX" is a trademark of the WiMAX Forum.

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