# The challenges of moving to MIMO systems

Today's radio devices use a single-input, single-output (SISO) configuration with one transmitter and one receiver and information sent over a single data channel. However, a move is under way from single-carrier technologies that transmit one digital symbol at a time to new methods that can potentially transmit hundreds of symbols simultaneously. One such method is multiple-input multiple-output (MIMO). Now, multisignal transmission and reception adds more layers of complexity. This article gives an overview of SISO and MIMO systems and takes a deeper look at a typical MIMO radio setup and some of the design and testing challenges involved.

By Mark Elo

Today's radio devices use a single-input, single-output (SISO) configuration with one transmitter and one receiver and information sent over a single-channel. Multiple-input, multiple-output (MIMO) transmission transmits information over multiple radio channels, but only occupies the bandwidth of a single channel. MIMO presents one of the most significant changes to happen to radio architectures in recent history. This technology can now be used in a wide range of commercial communications devices including mobile phones, PDAs and laptops and is an integral part of the 802.11n and WiMAX Wave 2 standards.

Along with the benefits of increased bandwidth, multisignal transmission and reception adds more layers of complexity. For instance, the transmitters must be aligned in time and phase and must have a high degree of isolation from each other. Thus, moving from SISO to MIMO-based systems it presents a number of unique testing challenges that test engineers must consider.

## Going from SISO to MIMO

The SISO configuration (Figure 1) is used in almost all contemporary radio designs. Sometimes, there may be an extra antenna for spatial diversity that is constantly switched for the best signal path. However, this is still considered to be a SISO system because there is a single upconverter and a single downconverter, a single demodulator/modulator, and a single datastream in the higher levels of the product's communications stack.

Multipath effects can degrade a SISO transmission. For example, a Bluetooth signal with a symbol rate of 1M symbols per second must receive a symbol within a window of one microsecond. If multipath effect delays the signal by more than this, a significant symbol error will occur. MIMO systems, on the other hand, require multiple paths. If two signals are transmitted with known characteristics, for instance a header, at the receiver end, one can assume what the signal should look like and create a model of the channel effects. When the unknown signal comes, i.e. the data, subtracting the channel effects can solve for the transmitted symbols. The key to a MIMO system, and why it is different from SISO, is that the behavior of the channel is critical and must always be understood.

Three ways to transmit data using a MIMO configuration, include:

**1.** The spatial multiplexing technique transmits different data on each channel, thus increasing the throughput.

**2.** Spatial diversity transmits the same data on each channel. This redundancy in effect increases the robustness of the signal and improves the transmission coverage.

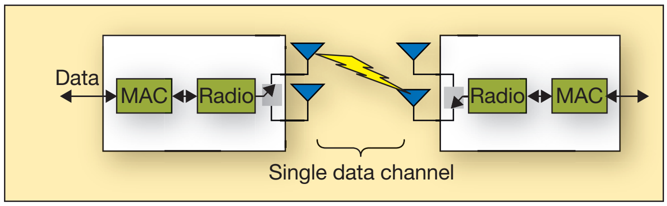


**Figure1. Typical single-input, single-output (SISO) radio configuration.**

**3.** Beam forming. This technique improves the throughput and coverage by controlling the directionality and the shape of the transmitted signal.

A typical MIMO configuration can range from a 2 x 2 system, containing two transmitters and two receivers, to a 4 x 4 system with four transmitters and four receivers (Figure 2). Many commercial wireless LAN (WLAN) devices today employ a 3 x 2 configuration of three transmitters and two receivers. In the future, beam-forming based systems could have up to 8 x 8 configurations.

## MIMO testing challenges

Perhaps the greatest testing challenge for MIMO systems involves synchronization with good channel isolation in the transmitter and the receiver. Transmission of multiple signals requires accurate synchronization of multiple channels in phase and sampling alignment. This means that RF test equipment such as signal analyzers and generators

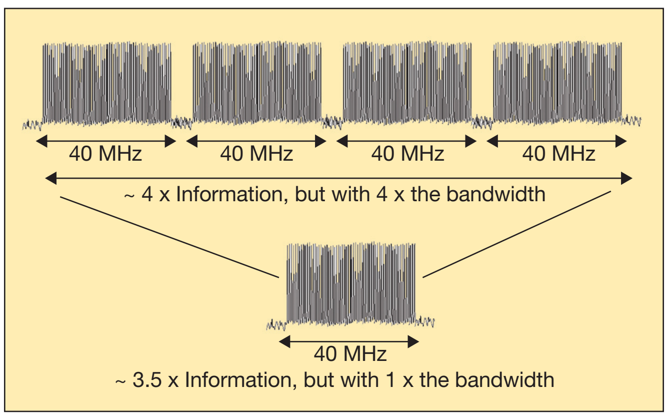


**Figure 2. A MIMO configuration shows how up to four times the amount of data can be transmitted with one-quarter the bandwidth.**

must have precise alignment and excellent isolation between channels in order to make accurate and repeatable measurements.

For most test engineers, a major challenge is the ability to transition smoothly from single-channel to multichannel testing and, therefore, choosing instruments that provide a clear and easy upgrade path to MIMO. For example, moving from WiMAX SISO to the MIMO versions based on Matrix A, B and even C, the highest 4 x 4 configuration, can significantly lower test costs. Test engineers should also consider whether there is a clear upgrade path beyond the 4 x 4 Matrix C configuration.

Another major concern is keeping the cost of test per channel low while maintaining good performance, especially with respect to maintaining excellent channel isolation. This is important because measuring the channel characteristics is fundamental to verifying any MIMO device. The test equipment should ideally have independent transmitters and receivers for the best channel isolation and at least 14-bit or better amplitude resolution for good dynamic range.

Bandwidth is another important consideration. For mobile WiMAX, the subcarrier spacing is fixed at 10.94 kHz. The standard allows for FFT sizes from 128 to 2048, which means that the maximum signal bandwidth will be in excess of 20 MHz—so test equipment needs to have at least 20 MHz of bandwidth. If working with WLAN, then 40 MHz of bandwidth is even better for the 802.11n MIMO standard.

Instrument usability, or its user friendliness, is an often overlooked but equally important consideration. Intuitive displays are essential for debugging complex radio systems, especially when dealing with multiple signals. Going beyond the constellation diagram, users need to see how modulation quality behaves over time and over subcarriers.

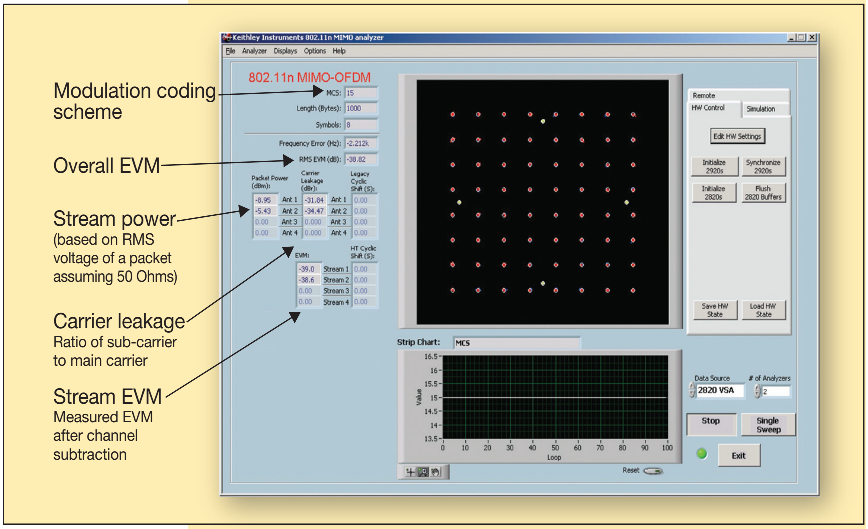


**Figure 3. Some key measurements involved with MIMO systems.**

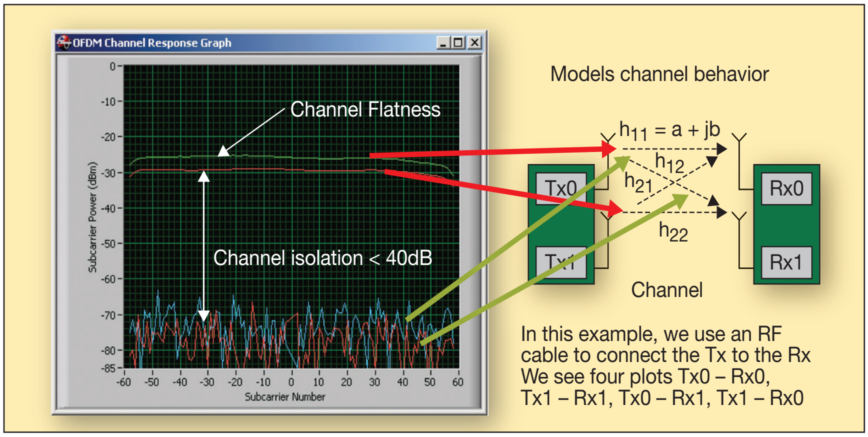


**Figure 4. Modeling channel behavior for a 2 x 2 MIMO configuration.**

The measurements for SISO are similar to MIMO. For example, EVM is a key metric for establishing the quality of any digital signal. In a MIMO system, it is still important to understand the EVM performance of the system, i.e., the composite EVM. However, as part of the design process, it is also important to be able to understand the EVM performance of each channel, while it is in the presence of all the other channels. Here lies a significant challenge. For instance, if one of the transmitters is generating an in-band spurious signal, then the composite EVM would be degraded. The next step is to check the EVM of each channel or stream. In so doing, the engineer would notice that one of the streams has a degradation in EVM. This performance could be attributed to either time domain or frequency domain effects. By then observing the EVM of each OFDM carrier over the frequency, it will quickly become apparent that some in-channel distortion is causing the radios performance to be degraded (Figure 3).

Test engineers also need to see how the radio responds to changes in the channel, especially with different multipath models (Figure 4). Channel response shows how all the radio transmissions interact with each other in the channel. In a 2 x 2 system the interaction is between Tx1 and Rx1, Tx2 and Rx2, Tx1 and Rx2 and Tx2 and Rx2. As the channel or stream count increases, the number of channel interactions also increases. For example, in a 4 x 4 system, the measurement needs to process 16 streams or channel responses to determine how each channel interacts with the other.

Beam forming also presents many test challenges. Beam forming is a technique that helps increase receiver sensitivity to the desired signal and decreases the sensitivity to interference and noise. This is accomplished by creating a series of beams and nulls in the transmitted signal. Test equipment for beam forming should be capable of finite phase and amplitude adjustment to be able to effectively create and receive specific patterns of radiation from each antenna.

## Solutions to testing

Keithley's slate of next-generation RF test instruments, including the new 4 x 4 MIMO RF test system, are designed to meet the challenges faced by designers and manufacturers of today's wireless technologies. They have the flexibility to test multiple signals and can be used in test configurations for SISO and 4 x 4 MIMO testing. They also provide the measurement accuracy required for product development, combined with high test speeds and repeatability for production test.

Furthermore, MIMO synchronization unit (2895) can synchronize up to four vector signal generators (VSGs) and vector signal analyzers (VSAs). The test system offers flexible capability for MIMO configurations from 2 x 2 to the most challenging 4 x 4 40 MHz applications, combined with support for a number of commercial standards including cellular (GSM/EDGE/W-CDMA/cdma2000), WiMAX, and SISO WLAN (802.11a/b/g/j).

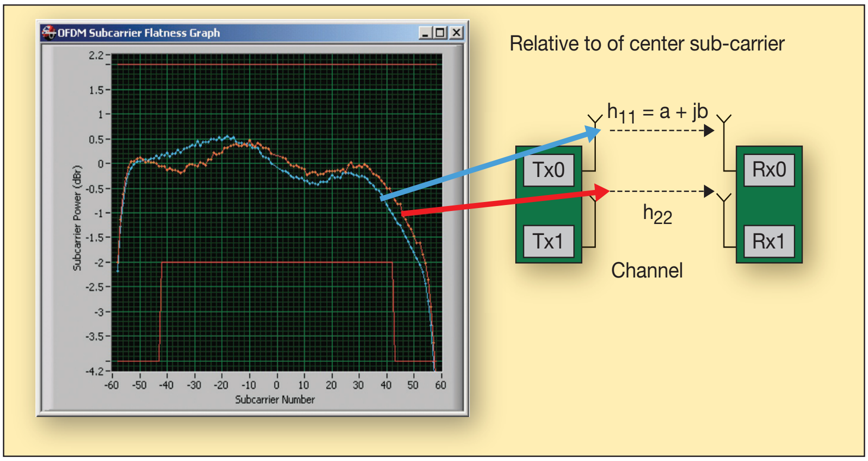


**Figure 5. Modeling subcarrier flatness in a 2 x 2 MIMO configuration.**

When faced with one of the industry's most demanding signals—the 40 MHz-wide OFDM WLAN signal defined by the 802.11n standard—2820 VSA can measure a characteristic EVM of – 40 dB. It also features ±1 nanosecond (ns) signal sampler synchronization, less then one ns peak-to-peak signal sampler jitter, and less than one degree of peak-to-peak RF-carrier phase jitter when using the MIMO synchronization unit.

The 4 x 4 MIMO RF test solution uses a DSP-based software-defined radio (SDR) architecture that adapts to the quickly changing test requirements of the dynamic wireless market, giving the instrument added longevity by making it easily upgradable. It can generate or demodulate virtually any signal with up to 40 MHz of modulation bandwidth, important for many of today's devices and for tomorrow's new signal standards such as 3G long-term evolution (LTE) and ultramobile broadband (UMB) with only a simple software upgrade.

In addition, WLAN 802.11n MIMO signal analysis software (280111) is a PC-based analysis tool for either single-channel or multichannel analysis of 802.11x signals. It is equipped with an extensive measurement suite for analyzing all 802.11x signals and is also capable of supporting 4 x 4 MIMO channel configurations. The software user interface is easy to set up and comes with a SCPI command set to quickly and easily interface with test systems.

Thus, these models are MIMO-ready with the hardware and software required to configure them into a MIMO test system. Besides performing as stand-alone bench or rack units, with standard spectrum analysis and signal-generation capability, they can also be easily configured as a MIMO test system. Also, the initial configuration of a 2 x 2 system can be upgraded to three or four channels by adding standard 2820 or 2920 instruments without the need for extra calibration. This flexibility is useful for users who do not want to dedicate a large investment to a MIMO system, yet want the capability to do so when necessary.


## ABOUT THE AUTHOR

**Mark Elo** is marketing director for Keithley Instruments. He joined the company in 2006 after working for Agilent Technologies in R&D and marketing positions. Elo holds a bachelor's degree in engineering with honors from the University of Salford, Lancashire, England, and an MBA from Herriot Watt University in Edinburgh,Scotland.