



# Understanding the Basics of MIMO Communication Technology

A General Education White Paper for Business Professionals and Technical Staff



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Radio systems utilizing MIMO (multiple-in, multiple-out) technology have become increasingly common over the past several decades, with notable examples being Wi-Fi networks and cellular 3G / 4G LTE & massive MIMO system that make up a large part of our modern communication infrastructure.

More recently, MIMO has been finding its way into rapidly growing markets such as professional broadcast video, law enforcement, and government sectors thanks to newer generations of smaller, better performing radio solutions and antenna designs that support MIMO technology. With the bandwidth requirements that today's video, audio, and data systems demand, MIMO is often an ideal solution for communication especially urban environments where clear line-of-site is harder to achieve and the abundance RF / microwave systems that can pose interference issues.

There are many types of MIMO systems currently in use, with different MIMO radio manufacturers offering their own versions of the technology with unique features and advantages. The new generation of small, high-performance tactical MIMO radios allows for the benefits of MIMO to be utilize by smaller groups as well as large organizations. Ad-hoc and mesh networking capabilities of many radio systems allows for dynamic deployment and quick response to changing situations without network outages.

This white paper will touch upon topics related to the basics of understanding MIMO communication that can be understood by readers of all levels of technical levels, particularly those that are new to the RF market or have no previous working experience with MIMO technology.

## Introduction to MIMO

An acronym for **M**ultiple-**I**n, **M**ultiple-**O**ut, MIMO communication sends the same data as several signals simultaneously through multiple antennas, while still utilizing a single radio channel. This is a form of antenna diversity, which uses multiple antennas to improve signal quality and strength of an RF link. The data is split into multiple data streams at the transmission point and recombined on the receive side by another MIMO radio configured with the same number of antennas. The receiver is designed to take into account the slight time difference between receptions of each signal, any additional noise or interference, and even lost signals.

By transmitting the same data on multiple streams, the MIMO radios introduce redundancy into data transmission that classic single antenna setups (SISO: **S**ingle **I**n, **S**ingle **O**ut) can't provide. This gives MIMO systems several advantages over typical SISO configurations:

1. MIMO radios can utilize the bounced and reflected RF transmissions (known as multipath propagation) to actually improve signal strength even without clear line-of-site, since MIMO radios receive and combine multiple streams of the same data that are received at slightly different time intervals. This is particularly useful in urban environments, where signal degradation between single antennas without clear line-of-site is a major issue. Urban environments provide plenty of reflection paths for MIMO signals to take between the transmit and receive radios.
2. Overall throughput can be improved, allowing for greater quality and quantity of video or other data to be sent over the network.
3. By utilizing multiple data streams, issues such as fading caused lost or dropped data packets can be reduced, resulting in better video or audio quality.

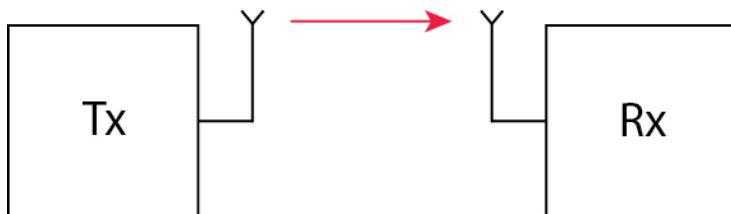


Figure 1: Example of SISO system, where one antenna is used on each side of the RF link.

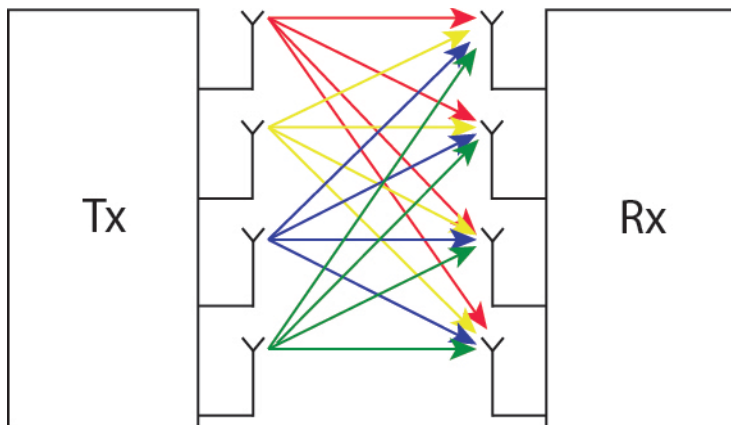


Figure 2: Example of a 4x4 MIMO system, where four antennas from the transmit radio communicate with four antennas on the receive radio to improve link connection strength and bandwidth.

Some MIMO radio systems also offer Ad-Hoc networking capability, where individual user nodes (such as a person with hand-held radio or vehicle with on-board MIMO radio and antennas installed) can enter or leave the MIMO network at any time, and automatically forward data from other node users through the network, creating a self-forming, self-healing mesh network that doesn't rely on a central architecture to operate. This is similar to how scalable MANET radio systems work.

The ability to take advantage of this type of networking opens up MIMO radio systems to new groups of users who need reliable, scalable network coverage. These systems are more practical than ever as MIMO radio systems continue to decrease in size and can be packaged into familiar hand-held radio form factors. Base stations and network repeaters can also be quickly deployed for short-term events that need a larger coverage area, without the hassle of permanent installation.

A few example of users groups who are taking advantage of MIMO systems:

- First responders who often operate in chaotic, changing situations and can't rely on cellular networks or other existing fixed infrastructure to be operational when needed due to natural disasters, power outages, overloaded networks, or other issues.
- Broadcast television production, such as live sports or news broadcasts, where the story may change during broadcast and video transmission locations have to move without notice, or where the shoot might involve multiple, simultaneous areas of interest. Eliminating long, expensive cable runs is another major advantage for this market.
- Law enforcement or military users who need to operate their own separate communication networks on dedicated radio bands. This includes intra-team communication among small groups, as well as larger networks that include ground vehicles, UAV / UGV systems, and more.



Figure 3: Example of a Silvus MIMO radio with two gooseneck antennas being used to transmit HD video at the Indianapolis 500.

## Standard MIMO Configurations

MIMO radio systems utilize multiple antennas in order to send and receive multiple data streams at once. The number of antennas needed is defined by the radio manufacturer based on what they determine will work for optimal transmission and reception with their particular hardware and software.

Typical configurations are:

- 2X2 MIMO (two transmit antennas, two receive antennas)
- 3X3 MIMO (three transmit antennas, three receive antennas)
- 4X4 MIMO (four transmit antennas, four receive antennas)
- 8X8 MIMO (eight transmit antennas, eight receive antennas)

Generally speaking, the more antennas a system has the more simultaneous data streams can be transmitted at once, improving the radio link. However individual system setups, current physical and RF environmental conditions, and advances in radio technology means that more antennas doesn't always equal better system performance.

## Antenna Choices for MIMO Radios

There are many antenna choices for MIMO radios, depending on how the user wishes to configure their radio system based on the unique needs of their application.

Broadly speaking, antennas for MIMO use can be broken down the following categories:

1. Traditional vertically polarized dipole antennas. These are the same antennas used on SISO systems, the only difference being that the MIMO system will utilize two or more of the same antenna. In practice almost any [omni-directional antenna](#) can be used as long as it meets the frequency band requirements, gain, RF power handling, and other parameters for the system being specified.



Figure 4: Examples of two vertically polarized [omni-directional antennas](#) that can be utilized in matched pairs on MIMO systems.

2. [Multi-antenna products](#) contained within a single radome. These antennas contain two or more RF connectors, which each connect to a different antenna within the radome. These are often designed with a slant left and slant right polarization, with each element offset 90 degrees (orthogonally) from the other, providing additional antenna polarization diversity for busy RF environments without increasing system installation complexity for the end user.



Figure 5: Examples of [multi-antenna products](#) designed specifically for MIMO use. Each product features multiple RF connectors, each connected to a discrete antenna within the product's radome. These are often cross-polarized for additional polarization and spatial diversity.

Just as with SISO systems, MIMO systems can utilize omni-directional antennas or directional panels and sector antennas for different communication scenarios and coverage needs.

## Antenna Polarization Choices

MIMO radio systems can take advantage of multiple types of antenna polarization schemes to improve diversity, which is one of the key ways MIMO systems are able to provide robust connectivity even challenging environments that would prove difficult for single antenna radio systems.

All antennas have a specific polarization direction, which is determined by their design and represents the oscillation direction of the electromagnetic radio waves as they propagate from the antenna's radiating element. The 'electric' portion of the electromagnetic wave is only half of the transmitted signal, with a magnetic wave that oscillates at a 90 degree angle at the opposite timing of the electrical wave. As the electrical wave rises the magnetic wave falls, and vice-versa for each cycle.

Polarization types can be broken down into two key types: "linear polarization" and "circular polarization":

- Linear polarization occurs in a straight line, and can be vertical, horizontal, or at any angle such as 45 degrees. The electrical wave of the antenna's signal oscillates up and down along the axis of this straight line.

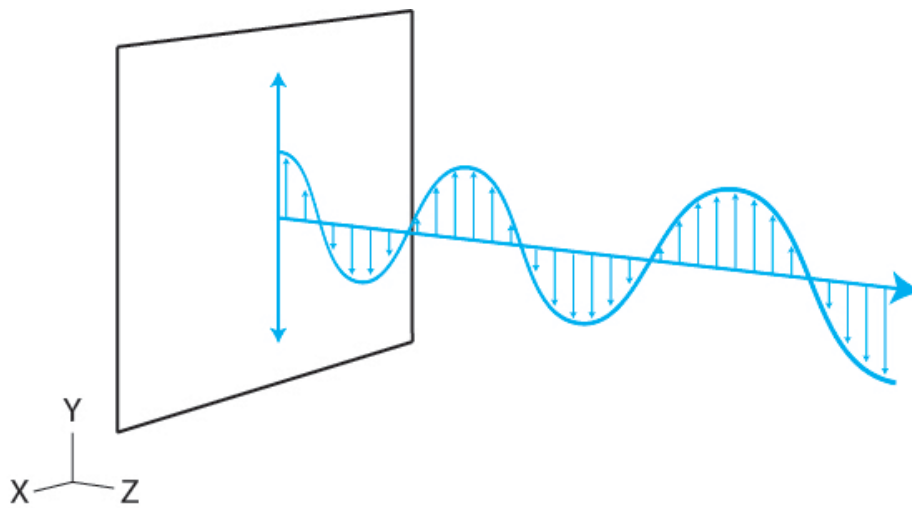


Figure 6: Example of linear polarization, with the radio wave's electrical field oscillating on a single plane, in this case vertically.

- Circular polarization, instead of occurring on a single plane, rotates as it leaves the antenna. Imagine a spiral corkscrew radiating out of the antenna. Circular polarization can either rotate left (counter-clockwise) or right (clockwise). One revolution is completed for each wavelength of the transmission. Antennas that are circularly polarized are often better suited for operating in inclement weather conditions, as they can more easily pass through rain and other atmospheric disturbances compared to linear polarized antennas.



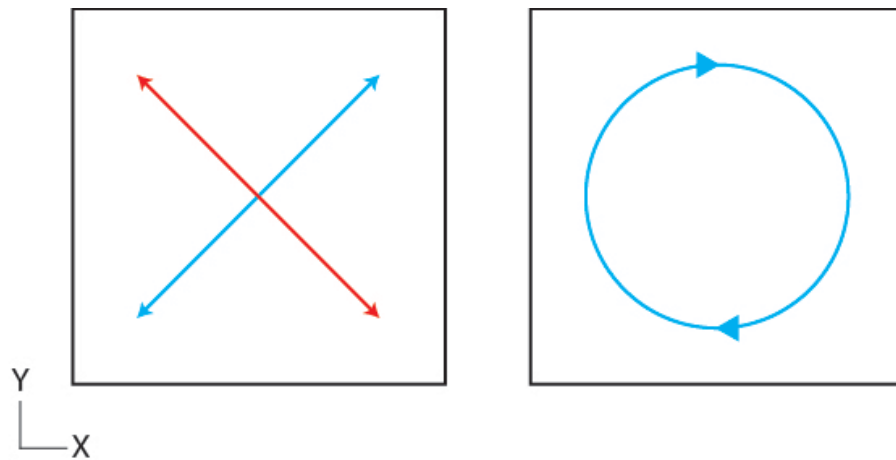


Figure 7: Examples of linear cross polarization (left) and circular polarization (right)

The choice of antenna polarization is important because transmit and receive antennas need to be paired by matched polarization type. A vertically polarized antenna works best with another vertically polarized antenna, and circularly polarized antennas will work best with other circularly polarized antennas. If a polarization mismatch occurs, a loss of gain will be introduced reducing communication distance and impacting the quality of video or data transmission.

While polarization matching on both sides of the RF link is still important with MIMO systems, since there are two or more sets of antennas used with every radio users can configure opposite polarizations with each set of antennas on the radio to introduce cross polarized isolation between the multiple data streams being transmitted by the radio, increasing diversity and improving transmission quality.

For example, a 2X2 MIMO system can be configured to use two antennas with slant 45 degree polarizations. Setting two antennas at opposite 45 degree angles gives a 90 degree orthogonal polarization between the two transmit antennas, giving each antenna 30 dB of isolation from one another, in addition to isolating those streams from other vertically polarized broadcasts in the area that may interfere with the transmission despite not sharing the same frequency band.

On the receive side, the antennas are configured to match the same 45 degree polarization in order to receive the signal without issue. By isolating each data stream, fading and other quality problems can be mitigated.



*Figure 8: Example of two antennas set at opposite cross-polarized 45 degree angles, offering good polarization diversity.*

## Antenna Selection for MIMO Systems

Every MIMO system will be configured differently based on the particular needs of the users operating the system, what type of data needs to be transmitted, and what environment the system will be operated in. However some generalized suggestions for different operating scenarios are outlined below:



## 1. Hand-Held or Bodyworn Tactical MIMO Radio Systems

For users who will be wearing the radio in a pouch or vest, or carrying the radio along with other equipment (such as a television camera), light weight omni-directional antennas are an ideal choice. The 360 degree coverage of the antenna allows for a network connection no matter which direction the user is facing, and these antennas are generally small and help keep the overall weight of the entire kit to a reasonable level. Antennas with [built-in spring bases](#) or [integrated RF coaxial goosenecks](#) are popular choices for bodyworn radio systems.

Another choice that can be utilized are [body worn antennas](#). These often focus the antenna's beam in a particular direction, giving enhanced directional coverage and an increase in gain over omni-directional antennas. These are often circularly polarized and worn in a MOLLE pouch on tactical vests by users on both the front and back of the body, giving complete coverage around the user.

## 2. Vehicle Mounted MIMO Radios

For mobile systems installed into vehicles both omni-directional and directional antennas easily be utilized depending on the needs of the system, and can be mounted internally or externally at the discretion of the user. Many [omni-directional antennas](#) are made to be directly installed onto the roof of the vehicle, creating a permanent system. Temporary installations can also be easily created by using [magnetic mounting kits](#), allowing for vehicles to be quickly outfitted for specific needs without the hassle of permanent installation. A strong magnet holds the antenna in place while the vehicle is in motion.

For UAVs, airplanes, and helicopters, antennas with special mounting systems are available, such as flight-rated STC mounts that are secured to the airframe. Blade-shaped antennas and even internally-mounted antennas are options as well.

## 3. Directional and Sector Infrastructure Antennas

For MIMO coverage of specific areas, [panel and sector antennas](#) are often used. The tight beamwidth and high gain allows for more precise directional network coverage of specific areas. These can be utilized as base stations or repeaters for large coverage areas, being fed by individual MIMO radio nodes within the network. Installation can be permanent for long-term use or done as a quick deployment for specific events.

## Conclusion

MIMO radio systems are becoming an increasingly popular communication solution due to their advantages over traditional single-antenna systems in many situations. This paper introduced basic concepts around the fundamentals of MIMO radio systems, covering the radio and antenna technology used in these systems.



### **About Southwest Antennas**

Southwest Antennas specializes in the design and manufacture of rugged, high-performance RF and Microwave antennas, accessory products, and customized antenna solutions built for today's demanding communication environments. Founded in 2005 and headquartered in San Diego, California, Southwest Antennas manufactures over 1,200 antenna products and accessories and offers a full range of technical services for broadcast video, military / defense, law enforcement, homeland security, surveillance, aerospace, oil and gas, and M2M/IoT markets. For more about Southwest Antennas, visit their website at <http://www.southwestantennas.com>.