Reliable Wireless Video for First Responders

Today's public service professional has a large number of options to examine when deciding on the best solution for a wireless video transmission system for first responder applications.

System Requirements

The first step in designing a first responder communication system is to identify *who is going to use it and what are their specific requirements*. Factors to consider include the following:

Users

Will multiple agencies use this system? If so, could these various agencies potentially all be using the system at the same time? Priority of use, channel capacity and security must be evaluated.

Coverage Area

Where will the wireless system be used? What is the topography? Will the system be used in a clear line-of-sight open area or will it be used indoors, underground, or in dense urban settings? What kind of range is required? For example, should the system range cover just the incident scene and a short distance link to the command post or is a metropolitan-wide system required?

Type of Use

Will the link be a mobile or portable system that needs to be quickly deployed? What is more important to your application, rugged construction or weight and size? Will devices be used in an area where contamination is possible? If so, they will need to be waterproof in order to survive a decontamination wash-down.

What sources of power are available? If battery operation is required, what is the expected operation time between battery swaps? Will you need external antennas or built-in antennas? (It is likely that integrated antennas will result in reduced range.) Do you need to transmit audio and/or data in addition to video along the wireless link?

Knowing the answers to these questions will allow you to weigh the pros and cons of the wireless video technologies available, select the best technology for your application, and then select equipment utilizing the best features to fulfill your mission needs.

Regulatory Issues

In some cases you will need an FCC license. While some video equipment requires no license to operate, that type of gear will almost always give less than satisfactory results. Communication law regulates the frequency bands and how many channels within those bands you can use. Let's examine frequency spectrum allocation in more detail.

The frequency spectrum has been highly regulated since 1934 when Congress saw the need to organize this valuable resource to avoid ever increasing cases of interference. The frequency spectrum was divided into different bands according to type of service and user (commercial, military, amateur, research etc.). The FCC (Federal Communications Commission) was formed to enforce the rules and regulations on spectrum usage, to issue licenses and to evaluate changes to spectrum use as needs and technology changed. When using the term *service* we are referring to the *type of traffic* carried over the wireless link, video, audio etc.

It is helpful to view spectrum use in terms of the amount of information that needs to be transmitted per second. The higher the information rate, the greater the bandwidth needed to transmit it (Figure 1). Video and high-speed data are two services that require a substantial amount of bandwidth and therefore these services have to operate in the microwave frequency range. A low bandwidth service such a voice transmission can easily operate in the much lower VHF and UHF frequency bands. Unfortunately the price to be paid for more bandwidth is reduced range and less ability to penetrate solid objects such as buildings and foliage.

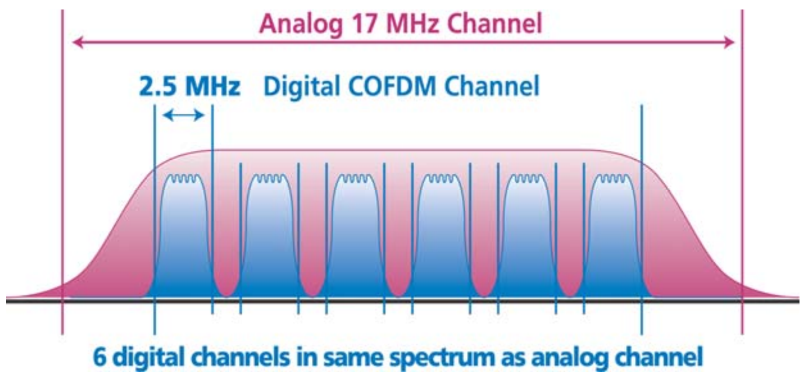

Figure 1 Bandwidth Comparison

Video Frequency Bands

For the public safety first responder, the two most popular frequency bands for reliable video transmission are the *2.4 GHz Public Service band* and the *4.9 GHz Public Safety band.* Wireless video equipment can be purchased in other frequency bands; however these other bands will have restrictions that make them unattractive for public safety use. Some of these other bands are restricted to federal government or DOD (Department of Defense) use only. Some bands are for commercial and broadcast use and require strict channel coordination and a purchased channel licenses. License-free equipment that operate in bands that are covered under Part 15 of the FCC rules and regulations are restricted to low radiated power levels and are good for only short-range transmission.

Provisions have been made under Part 90 of the FCC rules and regulations to allow relatively high-power wide-bandwidth transmissions in the 2.4 and 4.9 GHz band with an easy to obtain, no cost license, which is available only to law enforcement and public service agencies. The license can be obtained by going to the FCC web site and filling-out *FCC Form 601*.

2.4 GHz ISM Band

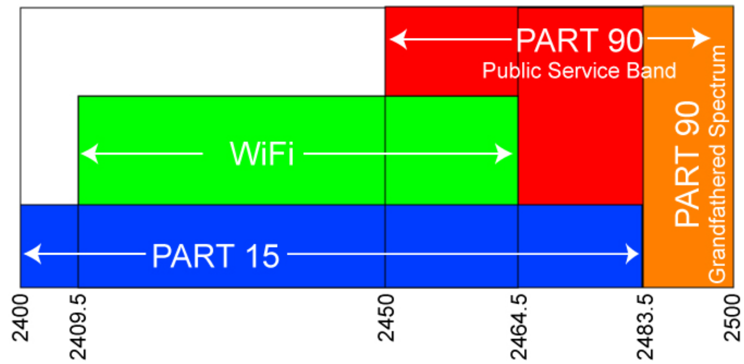

Figure 2 2400 to 2500 MHz Band

Governed under FCC Part 90 rules for Public Service use, this is the most commonly used frequency band for the transmission of video. The 2.4 GHz (2400 to 2500MHz) band (Figure 2) is also used for the license-free ISM (Industrial, Scientific, Medical) service; video can be transmitted in this band *without a license* but *at very low power levels*. Part 90 licenses are not difficult to get and there is no charge for them, once a license is obtained, the Public Service agency can operate from 2450 to 2483.5 MHz at power levels of up to 5 Watts with no restrictions in antenna gain or signal bandwidth.

When evaluating the 2.4 GHz and the 4.9 GHz band the one most likely to provide the greatest range is the 2.4 GHz band. However, due to its popularity and shared spectrum with the license-free ISM and Part 15 (WiFi, cordless phones, etc) users, this band is full of interference. That should be given careful consideration before purchasing equipment.

Center Freq. (MHz)	Channel No.	Channel Bandwidth
4940.5	1	1 MHz
4941.5	2	1 MHz
4942.5	3	1 MHz
4943.5	4	1 MHz
4944.5	5	1 MHz
4947.5	6	5 MHz
4952.5	7	5 MHz
4957.5	8	5 MHz
4962.5	9	5 MHz
4967.5	10	5 MHz
4972.5	11	5 MHz
4977.5	12	5 MHz
4982.5	13	5 MHz
4985.5	14	1 MHz
4986.5	15	1 MHz
4987.5	16	1 MHz
4988.5	17	1 MHz
4989.5	18	1 MHz

Figure 3 4.9 GHz Channel Allocation Table

4.9 GHz Public Safety Band

In the aftermath of 911, the Federal Government recognized the need for dedicated bandwidth for public safety and homeland security. In 2002 they mandated that a new frequency band from 4940 to 4990 MHz be created that would allow power levels of up to 2 Watts and bandwidths of up to 20 MHz. Licensees would be assigned the use of the entire band on a geographic basis. However, channel coordination amongst different users in the same area was expected to be by mutual agreement. Due to the restricted use of this band, the possibility of interference from multiple users on the same channel is low.

Different agencies in the same geographic area can arrange for a *Central Channel Coordinator* to reduce the possibility of interference.

Output power is determined by the bandwidth of the signal being transmitted. For example, the widest signal allowed, 20MHz, can use the most power, 2 Watts. Output power then decreases by one half for every halving of the bandwidth. Channels are assigned by bandwidths of either 1MHz or 5MHz however channels can be combined for higher bandwidth services up to 20MHz (Figure 3).

Omni or directional antennas with a gain of up to 9dBi may be employed. If a directional antenna with greater than 9dBi gain is used, an output power reduction equal to the excess antenna gain must be employed. Primary use of this band is for point to multi-point base/portable/mobile deployment or portable point to point links. Secondary use is for fixed point to point links. A point-to-point link that has been deployed for greater than one year is considered to be fixed and must protect primary users from interference.

Video Transmission Technology

We will consider the three most common methods of transmitting wireless video. Each technology has its strong and weak points which will be reviewed in turn.

Analog Video

Analog video transmission frequency-modulates the video signal (usually from a camera) onto a microwave radio carrier. Audio channels (if used) are provided on additional FM sub-carriers. This form of transmission is one of the oldest and most prevalent mainly due to its low cost. Analog video systems are reliable due to their simplicity. Analog is very power efficient, particularly in higher RF output power systems. This may be an important consideration when battery or solar-powered systems are necessary.

Another factor to consider is latency, which is the time between when the camera sends a frame of video and when the monitor at the receiver end displays that frame of video. Analog systems have, by far, the lowest latency of any video technology and this may be very important if wireless video is being used for remote control applications such as robotics.

Analog video has three major deficiencies. It is susceptible to multipath interference. It gets noisy when the signal strength weakens. And, it requires a large amount of bandwidth.

Multipath is caused by reflected signals arriving at the receiver antenna at slightly different times due to delays incurred through reflections (Figure 4). When the direct-path signal and the non-direct-path (reflected) signal combine together at the receiver antenna a cancellation will occur that will cause the video to become noisy and distorted. These cancellations will occur regardless of the distance between the transmitter and receiver and are particularly prevalent in indoor situations and in dense urban settings where there are many surfaces for the microwave signal to reflect off of.

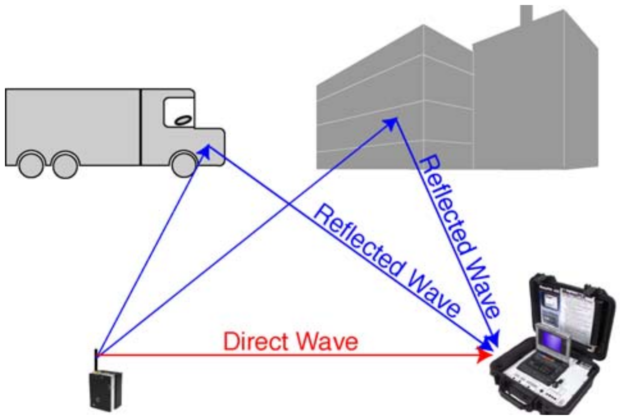

Figure 4. Multipath

There are ways to minimize multipath such as by using diversity receivers and circularly-polarized antennas. But, there is no way to eliminate multipath or to make an analog system immune to its effects. Because of the very nature of an analog video system, as the signal weakens, the receiver will begin to pick up noise mixed-in with the desired video signal. This is an unfortunate but tolerable shortcoming. Analog video channels are typically 15 to 20MHz wide, depending on whether audio and/or data sub-carriers are being transmitted along with the video.

A wide bandwidth is undesirable in today's era of increasing demand for valuable microwave frequency spectrum--a finite resource. Newer digital video technologies are *much* more bandwidth-efficient; a narrow bandwidth also translates into better range.

COFDM Digital Video

COFDM (Coded Orthogonal Frequency Division Multiplexing) represents a huge advance in wireless technology. Through advances in digital signal processing, large scale integration, and video compression, portable high-quality wireless video systems that are noise and multipath immune are now commonplace.

Conventional wireless data transmission is done by modulating a single microwave carrier with a high data rate stream. COFDM is a way of wirelessly sending data by dividing the high data rate stream up into *many lower data rate streams* and modulating *many carriers* with these low data rate streams. The carriers are all closely spaced to each other in an orthogonal (90 degree) relationship so there is no cross-talk interference between adjacent carriers (Figure 5).

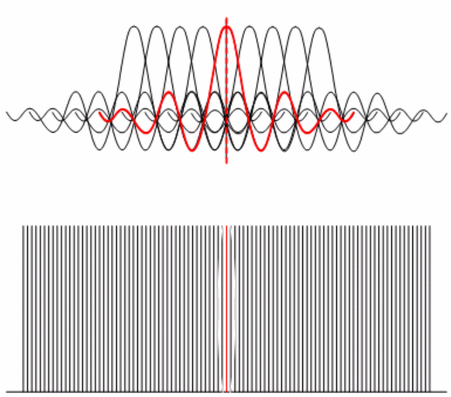

Figure 5. COFDM Carriers

By utilizing this technique of putting small amounts of data on many closely-spaced carriers versus putting a large amount of data on a signal carrier, multipath effects are virtually eliminated. This is because a low-data-rate carrier is much more tolerant of signals that are delayed (due to reflections) than a high-data-rate-carrier would be. In fact, COFDM actually takes advantage of signals that arrive by non-direct paths. Because of this, they can work well in non-line-of-sight high multi-path environments such as urban locations.

If some of the carriers are lost due to multipath cancellation another technique is employed called FEC (or Forward Error Correction) which can recover lost data by *coding* data before it is sent. As you may have already guessed a COFDM video system has to have a means to digitize the video and then transmit it as data. The video is sampled and then compressed and converted into a digital data stream. One big advantage of transmitting video as a data stream is that noise is no longer going to show up in the video. There will be a perfect picture until the digital errors caused by noise are so great that the FEC can no longer effectively correct them. At this point, the link will start to drop frames, frames will freeze, and then the link will go away completely without warning (sometimes called the cliff effect).

COFDM video has been used extensively in television terrestrial and satellite broadcasting. In terrestrial broadcasting of HDTV (High Definition Television), it is known as the DVB-T standard (Digital Video Broadcast Terrestrial) and has been in use for over a decade. Portable DVB-T transmitters for broadcast ENG (Electronic News Gathering) and security/law enforcement purposes are available from a number of manufacturers.

COFDM video systems are the most bandwidth-efficient of the three technologies being reviewed. Bandwidths range from 1MHz to 8MHz, depending on the desired video quality and other information such as the audio being transmitted. COFDM, due to its narrow bandwidth and digital signal processing has a very good range for a given amount of output power. This is in the order of two to three times the range of an analog system of equivalent output power. COFDM has the additional benefits of *no video noise* and *multipath immunity* which allows for non-line-of-sight operation.

The downside of COFDM video systems are higher price than analog, higher DC power consumption (more heat), higher latency (50mS or more typical) and larger size. Technology is rapidly advancing COFDM video products though, and cost, size and power consumption are dropping each year.

Video over wireless IP

Another method of digitally transmitting video is to convert the video to a digital IP (Internet Protocol) data stream and then send it over a wireless IP router (Figure 6). (An IP router has a transmitter and receiver built-in.) The wireless IP router is typically compliant, at least at the physical layer, with the WiFi (IEEE 802.11) standard. WiFi has *some* of the advantages of COFDM but is a very different implementation of the OFDM technology.

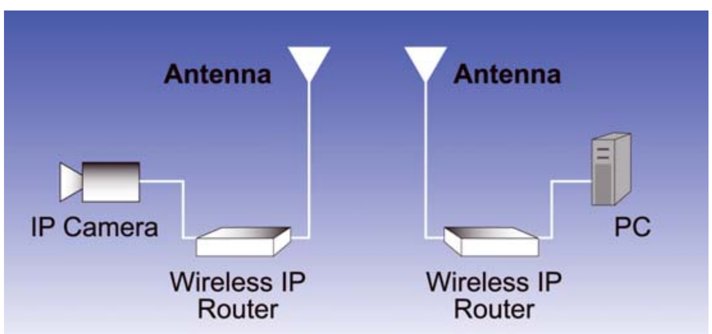

Figure 6 IP Video System Elements

WiFi uses only 64 carriers versus 2000 used in DVB-T COFDM systems. This translates into a much shorter operating distance in which multipath immunity is guaranteed. WiFi was never intended for long distance use. WiFi has a much wider bandwidth than COFDM; it uses 20MHz wide channels. WiFi systems operate in frequency bands governed by FCC part 15 rules and are subjected to the power and antenna limitations dictated by those rules.

There are some manufacturers who are upgrading their WiFi based IP routers to take advantage of the higher output power and antenna gain allowed under a Part 90 license. But, this still does not overcome the multipath and bandwidth issues previously raised. IP-based systems still require a good quality IP camera (which is expensive) to get comparable video quality to a COFDM video transmitter.

There are newer IP-based wireless transmission standards such as WiMax (IEEE 802.16) which promises to provide the advantages of IP-based wireless routers and also be effective over long distances. The transmission equipment is in early commercial deployment and is more expensive than COFDM systems but those prices could change rapidly.

IP systems support two way data on a single channel, which is very useful in some applications. IP based video systems have the obvious advantage of being capable of distribution on an IP network. Many see this as being the key to sending video thru ad-hoc wireless Mesh networks that can be extended to fulfill distance requirements by simply adding more mesh nodes.

There are two problems with this approach. The first is latency through the network, which can be considerable depending on network traffic. The second issue is if the wireless router works on a CSMA-CA (Carrier Sense Multiple Access Collision Avoidance) media access protocol, as the WiFi routers do, then the wireless nodes will have to have multiple transceivers in them operating at different channels to keep from interfering with adjacent nodes. The problem compounds itself as more nodes are added, especially if they are located within a close distance of each other.

Video over IP has a bright future as long is it is based on WiMax or some other means that can robustly transmit data over long distances and has an intelligent means of scheduling access and bandwidth on the network. Both digital video technologies, COFDM and video over IP, lend themselves to better security. More sophisticated types of encryption can be used to code and decode the signals making them nearly impossible to intercept by uninvited third-parties.

Equipment Considerations

Equipment options can be considered in two broad categories, portable and fixed. There are a wide variety of wireless video transmission systems available in each of these categories.

Portable

If equipment is going to be used for portable applications the following requirements need to be considered. The power source to run the equipment, the transmitter in particular, has to be evaluated.

If the transmitter has to be small, lightweight and battery-powered, then consider that as range is increased by increasing the transmitter output power, battery life will decrease. Also consider that if *digital* video technology is used, battery life will be shorter than analog--although COFDM systems have a better range than analog systems of equivalent output power and far better video quality.

Figure 7. Battery Powered Transmitter

Larger batteries will extend operational life but at the expense of greater weight and size. Mobile (vehicular-mounted) equipment rarely has to be concerned about battery life and this is where higher power systems that have greater range tend to be located. A typical scenario would be to use low power body-worn video transmitters for close-in work. Then these signals would be received at a nearby mobile command post and relayed over a greater distance using a high power transmitter (repeater) powered off a generator or vehicular power. Almost all portable video equipment runs off a nominal 12VDC power source.

Packaging for portable equipment comes in all forms but tends to be very compact, especially on the transmitter end. Battery packs may be built into the equipment (Figure 7) or they can sometimes be external.

The equipment will often have a number of preprogrammed channels that can be changed by the user to suit the needs of the particular mission. Typically there will be either two monaural or one stereo audio channel.

Figure 8. Waterproof TX

Unique packaging to fulfill a nitch application may be available from certain vendors. Examples of this include transmitters that have built-in cameras sealed in a waterproof housing (Figure 8) and transmitters that have a built in camera on a PTZ (Pan Tilt Zoom) mount, which will allow remote camera control from the video receiver (Figure 9).

Fixed

Fixed video links are becoming more popular with Public Service and Homeland Security. The fixed systems are usually permanently mounted in a building or shelter. Fixed systems are generally long-distance or wide-area links. Power consumption and size are not a top concern.

Figure 9. PTZ Camera TX

Also fixed systems usually have high-gain high-efficiency antenna systems. Two common configurations of a fixed system will be considered (Figure 10), point-to-point and point-to-multi-point. The point-to-point configuration would typically be used for relay/repeater applications where a short-range video transmission from a portable system is received and then repeated over a fixed link to another remote receive location such as fire or police headquarters.

The point-to-multipoint wide-area system can be viewed as operating much like a cellular telephone system (only for video rather than audio). A central receiver is located at the center of the desired coverage area with the antenna system being located high enough to provide the necessary coverage and be free of obstructions that would block the antenna. Typically a central receiver is located within a tall building and the antennas for the receiver are mounted on the rooftop. The central receiver uses diversity antenna combining, which allows multiple antennas to be connected to a single receiver.

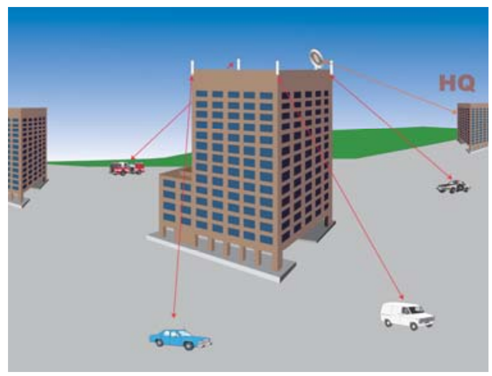

Figure 10. Point to Multipoint

A typical system would have a quad-diversity receiver with four antennas connected to it. Each antenna would be mounted to a corner of the building and have 90 degrees, or more, of beamwidth so that the total coverage would be 360 degrees.

The central receiver would also be expandable to allow more than one channel of video coverage. With a city-wide central receive system in place, video signals could be picked up from portable or mobile transmitters located anywhere in the antenna coverage area and then either monitored at the central receiver site or relayed through a fixed point-to-point link (or other means such as fiber optic cable) to another location. A central receiver system eliminates the need to set up a portable relay station at the incident site. It is also great for relaying mobile video transmissions back to a fixed location.

Antennas

No discussion of wireless equipment is complete without looking at antennas. Antennas can be categorized by whether they are directional or omni directional (360 degree coverage). They are also categorized by their polarization: linear or circular.

Omni directional antennas have a pattern that radiates equally in all directions in the horizontal plane (azimuth) and have a peak in the vertical plane (elevation). The radiation pattern can be viewed as being donut shaped. The higher the gain of the omni antenna, the more pronounced the peak in the elevation which can be viewed as a donut that is being flattened.

Directional antennas come in all sizes and shapes as well as gains and coverage patterns. Gain comes from narrowing the coverage pattern either in the azimuth plane or the elevation plane (Figure 11). The desired coverage pattern is usually a factor of how much antenna gain is required, the distance between transmitter and receiver, and the antenna height.

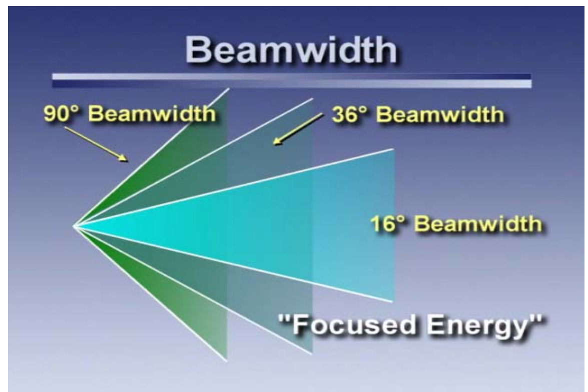

Figure 11. Antenna Beamwidth vs. Gain

These requirements should be discussed with the antenna supplier before deciding what is needed. Generally speaking portable and mobile transmitters usually use omni antennas since their location is always changing in relation to the receiver. The receiver may use either omni directional or directional antennas. When using a directional receive antenna one must be careful to insure the transmitter is always within the coverage pattern of the receive antenna(s).

Antenna gain is measured in decibels (dBi). The important thing to remember is that every 3dBi of antenna gain is equivalent to doubling the transmitter output power. Or, put another way, 6dBi gain will theoretically double the range of the link. The price to be paid for antenna gain is a reduced antenna coverage pattern and larger antenna size.

Antenna polarization describes the manner in which the radio signal is launched into space. Linear polarization means the radio signal is oriented either vertically or horizontally. For an omni directional antenna, vertical will be when the antenna is oriented in a vertical position. For a directional antenna the proper orientation will be marked on the antenna. A circularly polarized antenna launches the radio signal in a cork screw manner and can be either in a right hand or left hand circular direction. Circularly polarized antennas are used almost exclusively with analog video system because a circularly polarized antenna will help to reject multipath reflections (a weakness of analog systems) (Figure 12). Remember that in all cases the transmitter and receiver antenna polarizations must match each other.

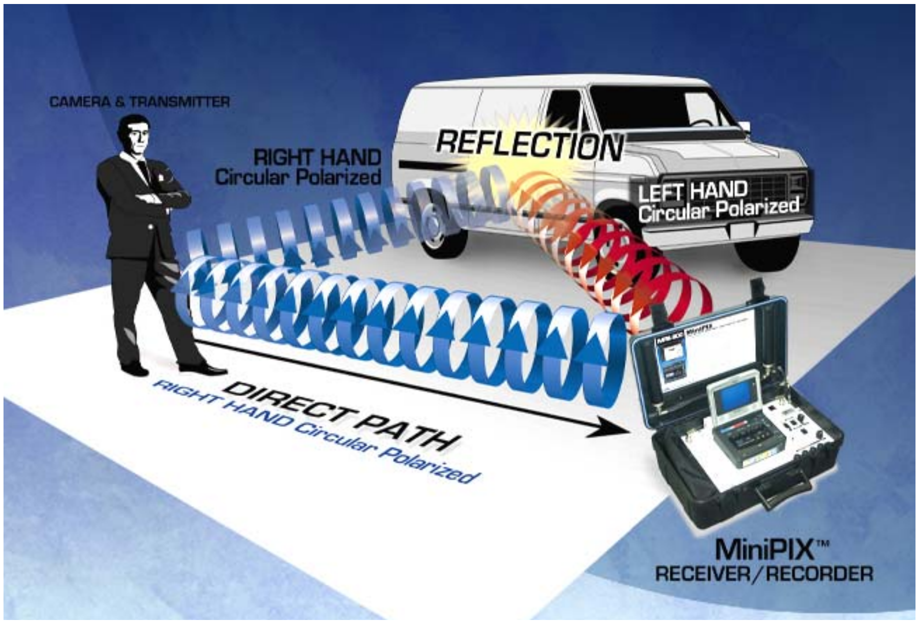

Figure 12. Circular Polarization

Conclusion

This review should provide insight into what wireless video technologies are currently available to the public service professional, what the trade-offs are between competing technologies, and what equipment configurations and licensing requirements need to be considered.