What's the Best Wireless Transport Option for Uncompressed HDTV Video?

Unlicensed, Wireless, Transport SMPTE292M, Video using V-Band MMW

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Millimeter Wave Products

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Forward

Once the exclusive realm of scientific research and military use, wireless systems operating in the upper millimeter wave (MMW) regions are now providing cost-effective solutions for high-capacity commercial data transport needs. While MMW technology is nothing new, the growing volume of commercial use with associated economies of scale has significantly reduced system costs, making MMW systems more attractive to the general consumer.

The unique attributes of MMW signal propagation, combined with the scarcity of RF spectrum at lower frequencies, assures that the proliferation of MMW systems and their effect on daily life will continue. This article examines the unique attributes of signal propagation in the MMW region. The goal of this analysis is to provide the reader with a general, working knowledge to make informed decisions when considering MMW solutions.

A dual channel SMPTE292M wireless transport system is used as a characteristic example of a commercial MMW application. This system demonstrates the capacity benefits of MMW techniques by providing roughly 3Gbps of raw HDTV production video throughput in an unlicensed band.

The Upper MMW Spectrum

The millimeter wave spectrum is defined as that region above microwave where the signal wavelength falls within the range of 1 to 0.1mm. Because of the direct relationship between signal frequency and signal wavelength, signal frequencies from 30-300GHz are defined as millimeter wave frequencies.

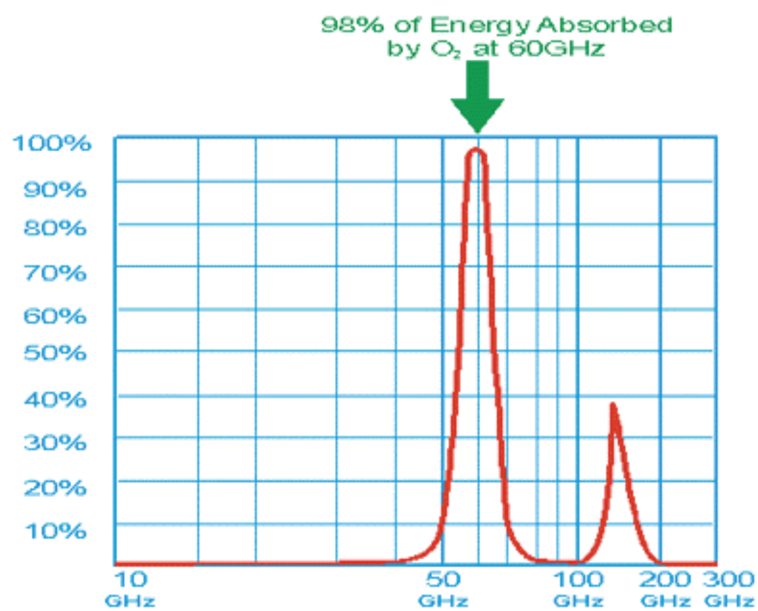
The millimeter wave spectrum is also identified by IEEE established letter designations. These “Band” designations relate to the band-specific size of transmission line waveguide used in MMW systems design. Waveguide is used at millimeter wave frequencies because of the excessive losses associated with coaxial transmission line at higher frequencies.

Band Designation	Frequency	Wave Guide
K_a Band	26.5 – 40GHz	WR-28
Q Band	30 – 50GHz	WR-22
U Band	40 – 60GHz	WR-19
V Band	50 – 75GHz	WR-15
E Band	60 – 90GHz	WR-12
W Band	75 – 110GHz	WR-10
F Band	90 – 140GHz	WR-8
D Band	110 – 170GHz	WR-6

Propagation Characteristics of Millimeter Wave Signals

As a general rule of thumb, as the frequency of RF signals increases, so do the transmission losses through free space (air). As a result, systems operating in the MMW regions have shorter operating ranges than those operating at lower frequencies.

The MMW region is also affected by specific elemental absorption related to the molecular resonance of atmospheric gases. The most prevalent of these occurs in the 60GHz region were atmospheric oxygen (O_2) attenuates RF radiation at a rate of 16dB/KM. 16dB means that roughly 98% of the transmitted signal is absorbed by atmospheric oxygen in the first kilometer of signal transmission.



Oxygen absorption of 60GHz MMW signals *

**Source: "60GHz for Dummies" 1999, Harmonix Corp. S. Hakusui*

The FCC Part 15.255 60GHz Unlicensed Allocation

In 1999, the Federal Communications Commission allocated the spectrum from 59-64GHz for unlicensed use. In 2001, this allocation was expanded to provide 7GHz of un-channelized, unlicensed spectrum from 57-64GHz.

Since the release of the 57-64GHz unlicensed band, several thousand systems operating in the 60GHz band have been deployed providing point-to-point data connectivity primarily for local area network extensions at ranges of 1KM and less. As network interface protocols have increased in speed and throughput, 60GHz systems have kept pace. The majority of these systems now provide a native Gigabit Ethernet circuit with full data rate/full duplex operation.

“Bandwidth to Burn”

The main benefit of operation in the unlicensed Part 15.255 allocation is the large slice of un-channelized spectrum available. As shown in the table below, this allocation provides more than 50 times the raw frequency bandwidth of any other lower frequency, unlicensed spectrum. This unique attribute makes the 60GHz spectrum the ideal transport medium for high capacity services using simple, inexpensive and very robust modulation techniques.

Comparison of Unlicensed Bands and Channel Bandwidth

Operating Frequency	FCC Allocation Rule	Channel Bandwidth	Interference Mitigation Techniques
902.0 to 928.0 MHz	Part 15 (ISM)	25MHz	Spread spectrum
2.400 to 2.500 GHz	Part 15 (ISM)	124MHz	Spread spectrum
5.150 to 5.250 GHz	Part 15 U-NII Low	100MHz	Narrow band microwave
5.250 to 5.350 GHz	Part 15 U-NII Mid	100MHz	Narrow band microwave
5.725 to 5.825 GHz	Part 15 U-NII High	100MHz	Narrow band microwave
5.725 to 5.875 GHz	Part 15 (ISM)	124MHz	Spread spectrum
24.00 to 24.25 GHz	Part 15 (ISM)	124MHz	Spread spectrum
57.00 to 64.00 GHz	Part 15.255	7.0GHz	Propagation characteristics

Antenna Characteristics at MMW Frequencies

A direct relationship exists between antenna gain and its physical size relative to signal wavelength. As frequency increases the signal wavelength decreases, increasing antenna gain and narrowing the beamwidth of the radiated signal.

Antenna gain, expressed in dBi, increases proportionally to the area of the antenna reflector. Since the area of the reflector surface (πR^2) increases as a square of the radius, so does the gain of the antenna relative to the signal wavelength. Conversely, transmission beam-width shrinks as an inverse of antenna reflector or aperture diameter. Because of the relationship between signal wavelength and antenna size, a 3” diameter antenna used at 60GHz will exhibit the same performance characteristics as a 30” antenna operating at 6GHz.

The combination of high atmospheric attenuation levels and high gain, narrow beam width antenna systems virtually eliminates any cross talk or interference between same frequency systems operating in the 60GHz MMW spectrum.

Practical Range Limitations of 60GHz Systems

The same high atmospheric attenuation characteristics that minimize interference also reduce the range of reliable operation in the 60GHz unlicensed spectrum. In addition, transmit power is constrained both by Maximum Permissible Exposure (MPE) limits as well as the technical challenges of producing stable power at MMW frequencies.

Given the transmit power restrictions set by MPE limits and the high levels of atmospheric attenuation, antenna gain becomes the primary determinant of reliable operating range for MMW systems. However, because of the very narrow transmission beamwidths of high gain MMW antennas, the ability to achieve and maintain alignment accuracy is the real challenge to long-range operation at 60GHz.

Antenna Characteristic Comparison

Antenna Diameter	Antenna Gain	Beam Width	Alignment Accuracy (-3dB)	Maximum Range*
3" (7cm)	29dBi	7°	+/-3°	500M
1' (30cm)	43dBi	0.9°	+/-0.45°	1.2KM
2' (60cm)	48dBi	0.45°	+/-0.2°	1.7KM

* The table shown above details the maximum clear air range of a 60GHz point-to-point link based on a 1.485Gbps data throughput, an 8dB system noise figure, 10dBm (10mW) transmit power and a minimum S/N ratio of 15dB.

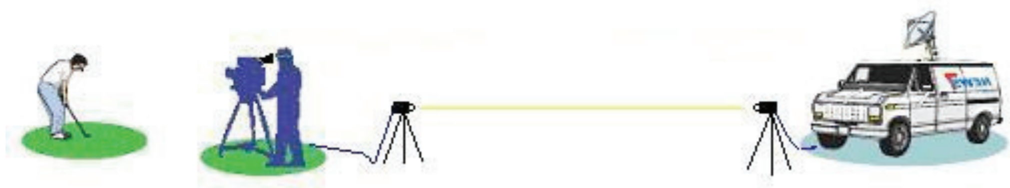
While 60GHz systems using omnidirectional antennas have been demonstrated for personal area network (PAN) applications, the maximum range of operation for these systems is limited to tens of meters vs. hundreds of meters for outdoor point-to-point links. For the purposes of this article, we will restrict our analysis to the more common point-to-point applications.

60GHz Band Attribute Summary

- Low transmit power for low exposure levels
- 7GHz of unchannelized, unlicensed spectrum 57-64GHz
- Small antennas with high gain and narrow transmission beam width
- High atmospheric attenuation
- Compact terminal format
- Diminishing range improvements from larger antennae due to alignment difficulties.
- Interference free due to oxygen absorption
- Commercially successful as point-to-point LAN extension

Dual Channel, SMPTE292M Transport

Having provided a baseline explanation of the 60GHz spectrum and its unique properties, an even greater understanding is possible by examining the operation of a representative system. A system transporting (2) 1.485Gbps, channels of uncompressed HDTV video is a perfect example of such a system.



The SMPTE292M Standard

The Society of Motion Pictures and Television Engineers has established the SMPTE292M digital standard for HDTV production for display formats of 1080p. In its uncompressed form, the SMPTE292M signal is a serial stream of one and zero bit states at a rate of 1.485 billion bits per second. Unlike other digital standards like Ethernet, the SMPTE292M protocol has no limit on repetitive same data states, making detection and recovery difficult.

The SMPTE292M standard supports both optical and electrical interfaces. Typically, optical interfaces are used to support longer transmission distances, with coaxial interfaces used to provide transport at ranges of 100 meters or less. Belden type 1694A, 75Ω coaxial cable using high quality BNC connectors is the accepted standard transmission line for SMPTE292M transport.

To comply with the SMPTE292M coaxial interface standard, equipment must operate over a wide dynamic range of signal level, equalize frequency drift and re-clock the signal to preserve error-free operation. As is common practice in the broadcasting industry, video test patterns are used to measure system performance with the difficult SDI Matrix pattern considered the “acid test” for SMPTE 292M performance.

The HD-Link transmitter uses application-specific interface circuitry to equalize, boost and re-clock the arriving SMPTE292M signal. A proprietary direct digital modulation technique is then applied to convert the SMPTE292M serial bit stream of high and low bit states into an electrical square wave.

This square wave is then used to directly modulate a 60GHz RF signal through up-conversion with the unwanted sideband suppressed through a band pass filter. By applying a pseudo-single sideband up-conversion, a higher bit per cycle efficiency can be achieved that provides adequate frequency separation (FDD isolation) between the two independent 1.485Gbps channels while retaining the robust OOK modulation characteristics.

At the HDTV link receiver terminal a reverse of the same technique is applied to down-convert and faithfully recover the SMPTE292M bit stream in its original bit timing and sequence. Throughout transmission and reception, both SMPTE signals are processed through independent circuits eliminating any cross channel interaction. They are received by the transmitter on two physically separate interfaces and transported back onto the coaxial medium through two physically separate interfaces at the receiver terminal.

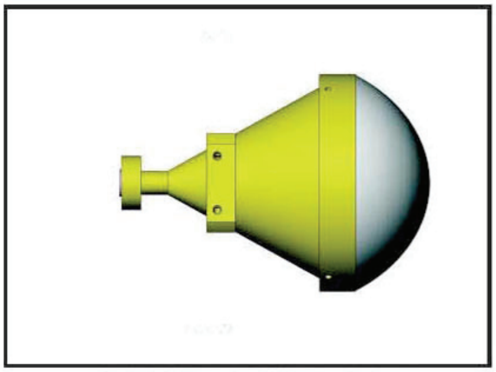
Because the direct modulation technique is applied instantly to the uncompressed video signal, there is no signal processing latency associated with the modulation or demodulation. Also because RF energy propagates through free space at essentially the speed of light, the transport latency associated with this transmission is 30% less than using coaxial or fiber optic transport media.

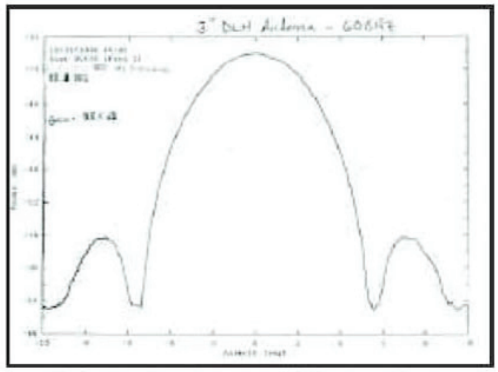
The interface and transport characteristics of the dual channel HDTV link make it the ideal solution for wireless transport of 3D HDTV production video from stereo camera systems or as a protected configuration for single channel real-time HDTV production.

Balancing Range with Ease of Alignment for Portability

The Dual Channel SMPTE292M system compromises range for ease of alignment by using a 3” diameter antenna producing 29dBi of gain with a manageable 7° radiated beam width.

Extensive field tests have demonstrated that operators simply aligning the transmitter and receiver “by eye” can consistently achieve the necessary alignment accuracy for ranges of up to 500 meters in clear air conditions.


3.0" Dielectric Horn Antenna


3.0" Horn antenna radiation pattern

Simplified Controls and Rugged Construction for Field Operation

To survive the punishing environment of portable video production, both transmitter and receiver terminals are assembled within a machined aluminum housing. All mating surfaces are sealed, electrically to reduce radiated emissions and environmentally to prevent the intrusion of moisture regardless of the conditions of use. The internal construction of both terminals is based on proven military packaging technique and designed for harsh environments.

Single LED indicators located above each channel interface turn on to show the presence of a signal at that interface. 12VDC Power can be provided via XLR4 power feed or by an on-board v-mount battery capable of providing uninterrupted operation for up to 8 hours. The HDTV receiver module includes an intuitive 10- segment, LED bar graph to indicate signal strength and confirm alignment.

For quicker and more precise terminal alignment, both the transmitter and receiver modules are fitted with a standard Picantinny rail mount so any gun sight can be affixed to aid aiming.

HDTV-Link System Specifications

Video/Audio Formats	Two Channels, SMPTE 292M
Video Inputs/Outputs	Dual HD-SDI, BNC x 2
Aggregate Throughput	2.97Gbps, HD-SDI x 2
Bit Error Rate	$<1\times10^{-12}$
Transport Latency	<2ns (30% less than fiber)
Transmitter Power	+10dBm (10mW)
Antenna Gain/Beam-width	30dBi / 7°
Operating range (clear to moderate rain)	20 – 500 meters
Power Service	10.5-17VDC, 15W via XLR4 or V-Mount Battery
Regulatory Approvals	FCC Part 15.255 FCCID#O2700002-30-30 MPT (59-66GHz) Unlicensed
Environmental	0 to +65°C, IPC65 rated enclosure
Size (transmitter or receiver)	9.5"L x 9.5"W x 4.75"H (240mm x 240mm x 120mm)
Weight (transmitter or receiver)	11 lbs. (5Kg)

About the Author:
Mr. Russell is a respected Industry pioneer and currently employed by HXI as Product Line Manger for MMW Radio Systems. He has held similar positions at Proxim Corp., Terabeam Corporation and Harmonix Corporation and has been a MMW proponent for many years. Mr. Russell has chaired several related technical sessions, and is a graduate of the University of Lowell.