How to Transmit 4K Video and 10 Gbps using 60 GHz Wireless

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Abstract

The FCC recently modified its Part 15 rules governing unlicensed communication equipment in the 57GHz-64GHz band (known as the 60GHz band) opening the way for enhanced use of the unlicensed spectrum. With its 7GHz of bandwidth, this band now promises to provide wireless broadband network connectivity over distances of up to one kilometer at data rates up to 10 Gb/s. This enables low cost, point-to-point wireless contribution of uncompressed 4K video and high bandwidth IP data. The "First Mile" and "Last Mile" of any broadband network is the most difficult and the most expensive to connect. Broadcasters, sports leagues, news bureaus, government agencies and the military will have a short-range, back-haul wireless link connecting uncompressed 4K video and up to 10Gb/s data to the broadband video and IP networks. The technology is ideal for sporting events, newsgathering, permanent building-to-building links, and stealthy military applications and more. This paper will discuss the theoretical and commercial implementation challenges and advantages of 60GHz systems vs. 2-5GHz/70/80/90GHz systems. We will discuss and compare quadrature amplitude modulation (QAM) and phase shift keying (PSK) as applied to 60GHz transmission. We will compare horn antennas and parabolic dish antennas for different applications. We will outline a practical implementation of a custom-built 60GHz wireless camera system for the NHL, discussing the technical and implementation challenges over traditional cable, fiber optic and wireless systems. We will present an application for the NFL where a 60GHz wireless link transported uncompressed video 700 meters from a sports arena to a studio several blocks away. Lastly, we will show how the absorption of 60GHz RF by oxygen molecules makes 60GHz ideal for stealthy military applications.

Introduction

In this presentation we are going to look at some of the different challenges that 4K presents. If you are a broadcaster, you might be looking for a higher resolution. If you are a sports league, you might want a higher frame rate for instant replay. We will touch on some of these subjects, and we'll share with you some of our future developments in the area of 4K wireless video transmission.

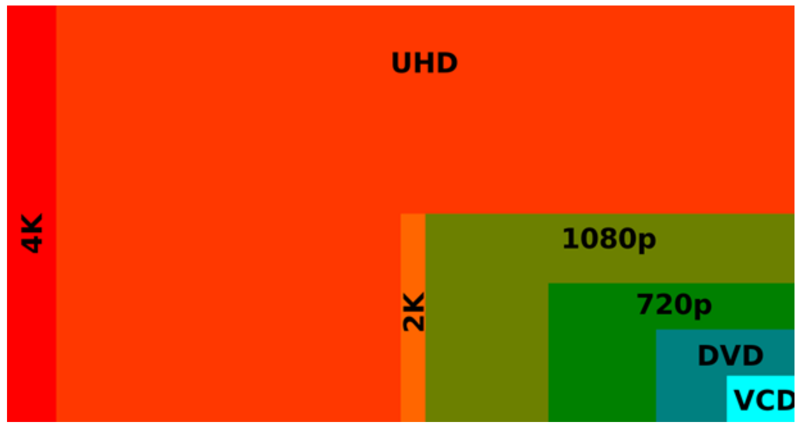


Figure 14K UHD

What is the problem we are dealing with? Well, we have this higher resolution video that's been thrown at us. Actually, there is not so much higher resolution video yet being produced, but there are many 4K displays out there. The manufacturers of these displays have been doing well with their marketing, pushing 4K, getting people to buy a 4K display at their local Costco, but there is not a lot of 4K content out there yet. Usually we see this the other way around, or the content lags behind the displays just a small amount. In this case, the consumer side is strongly leading the technology.

There is also a divergence in the way the video is described. High definition in the past was described in terms of resolution, by the number of lines, 720p, 1080, and such. 4K now is describing the number of pixels horizontally instead of the number of lines vertically. I think the marketing people at some of these display manufacturers have taken hold of that, and the terminology has now changed.

4K is not the whole picture, some of these scan rates are above 4,000 pixels horizontally, some are a little less. We have different aspects ratios, some are for television, others are for cinema. 1080p is a quarter of the size of a UHD or a 4K image, so we have to deal with 4 times the number of pixels, 4 times the bandwidth, and 4 times the throughput. This adds to the challenges we face, whether it is through a coaxial distribution, fiber optics distribution, or wireless distribution.

Format	Resolution	Display aspect ratio	Pixels
Ultra High Definition Television	3840 × 2160	1.78:1 (16:9)	8,294,400
Ultra Wide Television	5120 × 2160	2.33:1 (21:9)	11,059,200
WHXGA	5120 × 3200	1.60:1 (16:10)	16,384,000
DCI 4K (native resolution)	4096 × 2160	1.90:1 (256:135)	8,847,360
DCI 4K (CinemaScope cropped)	4096 × 1716	2.39:1	7,028,736
DCI 4K (flat cropped)	3996 × 2160	1.85:1	8,631,360

Figure 2, 4K Video

What we are going to concentrate on is the wireless challenges with the distribution of 4K. In the future, we will talk about 4K development in the area of fiber optics, 4K development in the areas of IP encoding and decoding, but today we are concentrating on wireless.

60GHz Wireless History

VidOvation known for 60 GHz Wireless Video and Ethernet. We do have systems that use other frequencies, but we known as the people who built a wireless video transmission and camera system for inside the goals of the National Hockey League. It is in use today, later today, during the Stanley Cup Playoffs. This is our 4th season in operation with 60 GHz Uncompressed Wireless Video in a compact camera system, but we do other technologies as well. We do licensed bands and unlicensed bands.

Figure 3, NHL 60GHz Wireless Goal Camera

We are going to concentrate on higher frequency, 60 Gigahertz and above. The higher frequencies lend themselves to higher bandwidth, higher throughput, which is what we are looking for. As I mentioned, 60 GHz today gives us the ability for a 1080i59.94, 60 or 720p59.94, 60 or a 1.5 Gigabit per Second HD-SDI signal. This is commonplace for us; we do this all day long, 1.5 Gigabit per Second video, or 1.25 Gigabit per Second bi-directional Gigabit Ethernet.

Simple AM Modulation

These systems today use relatively simple modulation schemes, On-Off keying, or Amplitude-Shift keying. We have a carrier, and we are turning it on and off, AM modulation or amplitude modulation. It is simple, rudimentary, it helps keep the cost lower if there is not a lot of modulation, encoding, decoding, or complex modulation. It simplifies the electronics involved in the front-end and the back-end. In the front-end is a transmitter, and the back-end is a receiver.

Figure 4, 60GHz Wireless Ethernet Link

AM modulation, the presence or absence of a carrier wave is another way of looking at it. Because it is a simple system, it is typically 1 Bit per Symbol. Thinking of it like a computer, we have a bus that's only 1 Bit wide. We can only get 1 Bit at a time thought the system.

Future Development

Our future development, to be able to get a higher order bandwidth, or higher bandwidth, up to 10 or even 12 Gigabits per Second, we need more complex modulation and more complex encoding algorithms. If we want to get a UHD 3840 by 1260 at 60 hertz, we are going to need a 10 Gig pipe, and the way we can do that is through advanced modulation, whether it is uncompressed 4K video or Gigabit Ethernet, or 10 Gig Ethernet. We are going to need a fatter pipe, and we can get more through the pipe if we use more sophisticated modulation schemes.

We did not invent this; it is just that we are applying this state of the art modulation technology to 60 GHz. In the past, it was not necessary to add these more advanced modulation schemes. These products haven't been released yet, so we haven't set pricing, but it is understandable that a 10 Gigabit per Second link is going to cost a little bit more money that a 1 Gigabit per Second link.

Quadrature Phase Shift Keying - QPSK

You can see here we use Quadrature Phase Shift Keying. You see here you have a phase and then an amplitude, so you have this I and Q grid and you have a vector, a certain amount of I and a certain amount Q, and then there is a phase vector and an amplitude vector. This particular quadrant here, 1, 1, 1, 1 gives you negative 2 units of I and negative two units of Q with a certain phase, that gives you a particular symbol.

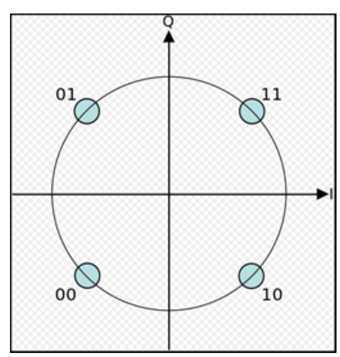
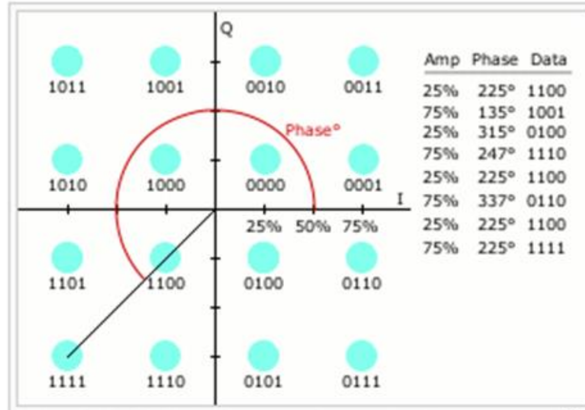


Figure 5, QPSK or 4QAM

This symbol here is 4 bits wide, so we have gone from a 1-Bit bus to a 4 bit bus, if we implement, in this particular example, 16QAM. You can see how we have quadrupled the throughput in our AM modulated system. We have gone from a single bit to ... 4, 8 and 16 Bits per symbol. That is in respect to 16QAM, 64QAM, and 256QAM. By QAM we mean Quadrature Amplitude Modulation or Quadrature Phase-Shift Keying. Chipsets are available to do this. Again, it is not anything new, we've been doing this for years. We are just applying it to our 60, 80, 90 or 100 GHz radios. This is how we are able to achieve higher bandwidth and higher throughput.



Digital 16-QAM with example constellation points.

Figure 6, 16QAM

Research at NYU Polytechnic

NYU has been working on some of these technologies. They have a Millimeter-wave and a 5 GHz Wireless Research Department at NYU, and they have been doing some interesting developments. They have been able to demonstrate some interesting studies in both the lab and real world. They have been able to push 10 Gigabits per Second on a 74 Gigahertz carrier. The technology is starting to come out. We have plans later this year to come out with some 60, 70, and 80 Gigahertz solutions that will push upwards of 10 Gigabits.

Figure 7, NYU Wireless

Single Carrier Null Cycle Prefix Modulation – SC-CP

Like any university, there is corporate sponsors, so NYU has been working with Nokia and National Instruments to develop some of these technologies. They have been using some 2 by 2 MIMO antennae schemes, and they have been using a Single Carrier Null Cycle Prefix modulation.

The interesting thing about this is, in our industry we have heard of COFDM or OFDM type modulation. You do not hear SC-CP modulation that often, and it does show some increased efficiencies in power consumption as well as better dynamic range for the transmitted signal versus OFDM or COFDM.

Battelle Petitions FCC 100GHz Spectral Use

Battelle has also done some interesting work in the 100 Gigahertz spectrum and above. They have actually filed a petition with the FCC, that appears to be bypassing opposition to operate either license free or with a license in the 102 to just under 110 Gigahertz spectrum. If you Google Battelle and the FCC you can see some of the public notices about this petition that they have put forth, and it looks like it is going to go through.

For those of you that do not know, Battelle is a non-profit engineering research entity. I am not sure if they are affiliate with any universities. I think they kind of stand on their own. They develop technology with the intention of licensing it to the commercial sector, so they are doing this research. I think they are looking for investors or licensees to take this technology once it has been FCC approved and commercialize it.

Battelle
The Business of Innovation

Figure 8, Battelle Wireless Research

They have had some successful tests, 10 Gigabits per Second and above. I have seen some of this equipment at NAB in years past. Again, it is still in its infancy. It is not commercially available yet, but there have been some successful demos and trials done with this technology. There have been some regulatory barriers above 100 Gigahertz. It is encouraging that Battelle is leading the charge in this area. It serves all of us, for us to petition, to get the FCC to open up more spectrum for wireless communication, video communication in particular.

German 237GHz Research

There is been some German research were they have been able to push 100 Gigabits per Second on a 237 Gigahertz carrier. Some of the universities over in Germany had done some successful trials and research in this area. The Japanese put into operation a 10 Gigabits per Second Ethernet link, operating at a 120 Gigahertz for the 2008 Beijing Olympics. That was a successful commercial usage of a 120 Gigahertz radios.

As far as German institutions, we have the KIT, the Karlsruhe Institute of Technology, the Fraunhofer Institute for Applied Solid

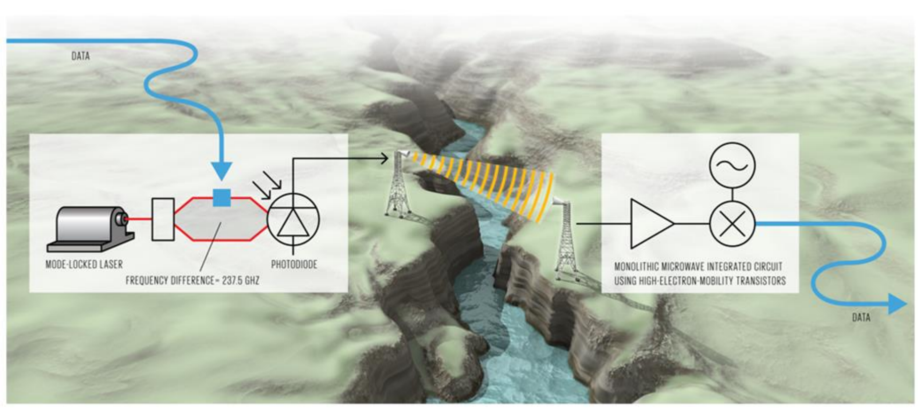


Illustration: Emily Cooper

Figure 9, German Research at 237GHz

State Physics, and the University of Stuttgart. They have successfully modulated some radios to operate 100 Gigabits per Second on a 237 Gigahertz system. They actually modulated a laser on a photodiode to produce a near Terahertz radiation, so this combination of lasers and photodetectors as the emitter or the exciter for this high frequency transmission.

Beijing Olympics use of 120GHz

The Beijing Olympics utilized the first commercial use of 120GHz. We need the regulatory approval to operate at 120 GHz in United States and Europe. It is relatively easy to get an experimental license to do this type of testing, but it does take some regulatory/political lobbying to get your application approved, and to get a specific channel, or a new slice of spectrum approved for Ethernet or video communication use.

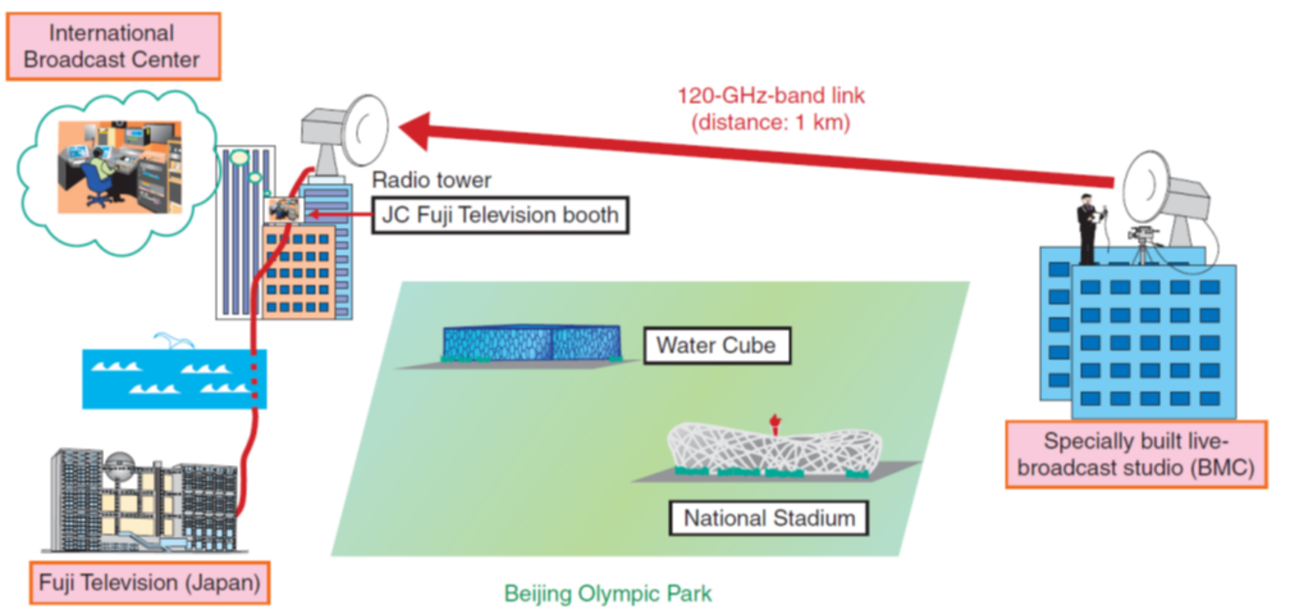


Figure 10, Wireless HD at 120GHz

Commercial Use of 60GHz by Samsung

It is encouraging that the technology is there, It is not just theoretical, it is not just experimental, the commercial viability is there. Samsung has been very instrumental in promoting 60 Gigahertz when it comes to short range WiFi. They've developed chipsets and have come up with some small form factor radios to push 3.6 Gigabits per Second and the 577 Megabits per Second for mobile devices.

Here's the statement from Samsung, "Samsung has successfully overcome the barriers to the commercialization of 60 Gigahertz millimeter-wave band WiFi technology, and they look forward to commercializing this breakthrough technology." A lot of us broadcast manufacturers, when we are on the bleeding edge, when things are in experimental ages, or in the early stages, a lot of the components are extremely expensive, and it makes it cost prohibitive.

The fact that Samsung is commercializing the technology and the chipsets to achieve this, this just helps us in other areas. If we can build a broadcast, or HD-SDI, or Gigabit Ethernet radio based on consumer chipsets that could help bring the cost down. A company like Samsung, of course, will do large volume, which helps to lower the cost of the technology.

You can see here, "New and innovative changes await Samsung's next-generation device, while new possibilities have been opened up for the future development of WiFi technology." This from Kim Chang Yong, head of R&D at Samsung Electronics. Samsung has a big think tank, world of engineers, like a university type environment. I've read some stories about it. There is a lot of innovation that comes out of the South Korean Samsung electronics R&D think tank. It is encouraging that the likes of Samsung are promoting this technology.

802.11ad and 60GHz

As some of you probably know, the 802.11ad standard does address 60 Gigahertz WiFi, but there is not a lot of implementation. Even though it is part of the 802.11ad spec, not much has been done with it. I commend Samsung for being that player, so the chipsets would be made available for all of us to use.

Samsung has been able to eliminate the co-channel interference. You have two channels operating in close proximity, many times you have interference. The nice thing about 60 Gigahertz, because it is a shorter wavelength the beams are very narrow, but then they will bounce off obstacles and obstructions, that sort of thing.

As I mentioned, Samsung has been instrumental in making the leap from theoretical to practical, or from the R&D lab to the real world. They are making that leap already. They have been able to get speed ten times faster than typical WiFi, whether it is 2.4 Gig or 5 Gig. Again, this is real world. We will probably see the next generation of cellphones starting to have this type of technology build into them. Again, this does help serve the greater needs that we have when it comes to wireless communications.

Again, we have talked about this all the time that 60 Gigahertz may not be applicable for everything. 60 Gigs is highly directional, it doesn't go well through objects, it bounces off of objects. In the case of the National Hockey League, we have a clear line of sight above the goal to a receiver in the ceiling. The goal can have some movements on it is pylon, but if you're a camera operator and you're operating a small mobile camera, whether it is ENG or sports, you need to move around, a 60 Gigahertz radio is probably not going to be the ideal solution for that. Probably a 2 Gig, or a 5 Gig, or a 7 Gig radio would be a better choice.

Beam Steering and Beam Forming

Samsung has overcome some of these. There is a technique in wireless communication of beam steering or beam forming. Through phase-shifting you can make signals, cancel each other, or amplify each other. With beam forming or steering, a mobile recipient can be standing in a crowd and try to make a connection to a local cell tower, the cell tower will actually triangulate the signal using beam steering to make a little hotspot right around that person.

There is some interesting whitepapers on this type of technology out there, but I do not want to get too deep into it. Through beam steering and waveform shaping you can triangulate on a given mobile device, or a given receiver, or recipient of data and amplify, or put them in their own kind of small hotspot. It is a very interesting technology. Samsung is putting some of these technologies into some of their mobile solutions.

The system will optimize the communications in less than 1/3,000 of a second, in case of any changes in the communications environment. Say you're in Times Square and it is new year's eve. The ball is going to drop and you have thousands of subscribers. Perhaps you are at a sports venue and you want to upload your video or your image to Instagram. This type of beam steering and beam forming technology can put your subscriber, that user, in their own little bubble, in their own little hotspot, and it is a means of getting the signal. This exciting technology is becoming a reality.

Multiple-antenna configurations using beam-steering are an optional feature of the 802.11ad specifications. Beam-steering can be employed to circumnavigate minor obstacles like people moving around a room or a piece of furniture blocking line-of-sight transmission.

Future Development

What is VidOvation's plan for all this new wireless video transport technology? Currently, we have on our timeline 10 Gigabits per Second solutions in the V band as we call it. The FCC designates different bands, they have different names or different designations. 60 GHz falls in the V band. Initially, we are going to come out with radios that will do up to 10 Gigabits per Second throughput either for video or for IP Ethernet.

We are strongly thinking that since the world is going more towards IP, an Uncompressed 4 Gig video link may not be what the industry wants, but we will wait and see. The first challenge is to build the radios. It usually starts with the radios and you work your way backwards to the IOs, front end or the physical layer.

Figure 11, Wireless GigaBit Ethernet at 1.25Gbps

The challenge is getting the 10 Gig throughput, getting the bits through the pipe, getting the bits through the transmission link. We have plans to do V band and E band. E band is the 70 Gig and 80 Gig bands. The parts are available. Again, it is not theoretical, we are putting systems together, we are testing systems, so the parts are here.

Long term, we'd like to investigate what Battelle, and some of the Japanese, and the Germans are doing in these higher bands, particularly between 100 and 150 Gigahertz. We'd like to see what's happening up there. Having a higher order frequency gives you more bandwidth, so maybe we don't need the complex modulation and encoding techniques if the FCC opens these higher frequencies to us.

The problem is that there is not a lot of components. The components that Battelle is building for their systems, and I'm sure the components in NTT and Fuji Television were using were on the experimental side. Experimental, to me, usually means the parts are expensive or have a limited availability.

Output power requirements, we have available for us today power amplifiers in V and the E bands, so we have to come up with amplifiers at these higher frequencies to pump out the 10 Milliwatts or more of power. There are amplifiers available to us today. These amplifiers need to be very linear. We need 1 Watt power saturation and a compression point of 1 db at 27 Watts or more.

Figure 12, 70GHz Ethernet Link

Again it comes to getting enough power, some of these shorter range tasks that are done in the lab are great, but in the real world we need enough power to go 500 meters, a kilometer, several kilometers, or 20 kilometers. We need to have amplifiers that will give us the power we need at some of these other bands.

We can combine different amplifiers together to get the power that we need, but it is not just crude amplification. We need amplifiers that don't have distortion, or third-order intercept issues, or intermodulation issues, it is got to be clean signals. If the signals are distorted during amplification that limits our transmission capability, since everything is digital now, the availability of fast A/Ds, D/As and FPGAs to do the modulation and the encoding, those are available today, but at the data rates that we need, they are expensive. With volume, these costs will go down.

64 to 128 QAM is achievable for a 10 Gbps link in a carrier bandwidth 5GHz wide, so within the FCC standards we can achieve this at 60, 70, and 80 Gigs. We are looking at the feasibility of doing 512 QAM. Again, with higher order modulation, you lose your noise floor, distance,

fidelity, and your link budget, there is always is a tradeoff. We have to be careful not to over encode our signal.

Another approach is to take several 1 Gig Ethernet radios and modems, combine them together take, say, 10 of them to make a 10 Gig E. This requires some load balancing in the IP realm, it is non-ideal for video communications; you prefer the packets to all travel together through one pipe. These systems have such low, low latency that if video packets were split apart and put over 10 different pipes that are virtually and identically in phase, and I delay, I do not see a big problem with that, but typically, you do not want to do that with video communications. That is one approach, that we can use lower cost components to combine, putting 10 pips together to get 1 fatter 10 Gig pipe. You can take that approach.

Cross Polarization is another possibility. If you Cross Polarize you can cancel out any interference. This is called XPIC or Cross Polarization Interference Cancellation. This adds to the complexity of the antennae system, it is more expensive. We are able to do 5 Gigabits per Second using this technique.

Here is another, the approach of taking multiple channels, N times Gigabit Ethernet or N times HD-SDI links to push through more bandwidth. Many of the 4K cameras will be 4 3G HD-SDI coaxial feeds or fiber optics feeds, so 3Gbps times 4 will give us 10 to 12 Gigabits per Second. We can use this similar type technique when it comes to radios, just put radios at different polarization, radios at different frequencies.

Figure 13, 80GHz Ethernet Link

By polarization, what we mean is, the radio waves will come out of 0 polarization or at 90, the receiving antennae has isolation. One element will only see the 0 polarization waves as the waves come out at this way, the other polarization element will see only the wave that way. We rather co-locate 2 radio waves on the same frequency, or if we combine slightly different frequencies with polarization, we can get better channel isolation to co-locate or cooperate multiple pass through a given link.

There are many different ways to do this. This type of technology we expect to have by the end of this summer of 2015. A single in, single out full duplex 10 Gigabit link, we expect to have out later this fall or later in in the year.

The XPIC solution with the polarization cancellation makes the antennae become more complex, which adds to the cost. We are not sure how viable that is. In addition, in some metro areas, if the antennae element or the dish becomes too large there can be fees associated upwards of $500 per month per foot of aperture of your dish.

A lot of our products, you can see the devices themselves, the antennae elements are small on purpose. Microwave horn technology tends to be smaller, but has less gain. A dish tends to have more gain but then it is larger and less aesthetic. Some building owners do not like having large dishes on their roofs. The more spectrum we can get from the FCC, obviously we can have higher data rates. The higher the frequency, the higher data rates we can push through.

Opening larger channels above 100 Gigs, if we can get the FCC to approve a 10 Gigahertz wide channel in a spectrum from a 100 to 120 Gigahertz will be ideal. We commend Battelle for leading the charge. As 5G data and 4K video become a commonality, we are going to need 10 or 12 Gigabits per Second to push this through. We do see a need out there for this type of technology, whether it is more IP based versus baseband video. My gut is telling me it is going to be more IP based.

Figure 14, 60GHz Wireless Uncompressed HD SDI Link

4K Video over Wireless IP

You can run very low latency encoders at very high bit rate for 4K, still maintain good fidelity, and just have the flexibility of a more diverse IP link as opposed to a dedicated SDI link, or 4K SDI link. We also see the merger of data and RF systems, RF over fiber. Still a lot of content is delivered to the home via the cable operator, via RF and we see that going away… we are doing many IPTV projects lately.

Video is being put more commonly on a traditional IP network. You look at companies like AT&T U-verse, they are delivering a true IPTV triple play service to the home with video, internet, and television… all IP based. There is no RF over coax, or RF over fiber. This all leads to the demand for fatter pipes, higher bit rates, and in rural areas where you do not have access to a fiber or telecom connection, higher wireless bit rate really lends itself.

Network Bottlenecks - First Mile and Last Mile

The bottleneck in any network is the first mile and the last mile, how you get on and off the network. If you don't have a high bit rate telco, a PoP, or connection in your building, you might have to put one of these radios up on your roof and beam to an adjacent building in the metro area to get to that PoP. We see demand for this type of technology growing.

We have also done projects where these higher frequency radios with extremely low latency are used for high frequency trading. We have sold them to commodities traders and stock traders. They will set up shop across the street from the given exchange; they don't want to go through a public telecom circuit where there could be latency. They want to make their trades directly. Everything is down to the millisecond. There is high-speed computers making these trades.

This technology is used for anything from wireless video cameras inside of a hockey net to getting your facility on or off the network for that first mile or last mile. If you are a high frequency trader, or someone that needs to move high speed data at a high bit rate with very low latency this technology is right for you. Another example is the link we provided for the NFL Carolina Panthers stadium. They needed to pipe video to a studio about a kilometer away, and they were able to beam video reliably from the top of the venue to that studio a few blocks away.

They did not feel like spending the money to dig up the street and to run a fiber. A lot of our systems, I like to call them fibers that go through the air. It is like a wireless fiber, they are that reliable. When you do not have access to a cable or a fiber, or you have that first mile and last mile bottleneck, that's really where we can help you.

The applications are infinite. We have done military applications, sports, broadcast, pro AV, cellular backhaul, etc. A lot of this technology is used to get the signal from a local cell site back to the central office. We can support Uncompressed HD-SDI, AFI, 1 Gig Ethernet, and 10 Gig Ethernet and 4K SDI are on the horizon.

There is been plenty of government support, a lot of technology that ends up in the commercial sector started out in the government or military sector. DARPA is a big proponent of high-speed data, so some of this technology is classified. Once it is been declassified, it trickles down into the commercial sector. We should see more things coming out on the horizon because of some of the initiatives happening at DARPA. We can do this 100 Gigabits per Second over a millimeter wave spectrum. DARPA is doing some work, and again it is classified, so there is not a lot of detail floating around, but we know they are doing work in these areas.

The microwave band and the millimeter wave is the 60 Gig band, this is where we are operating. Even at 100 GHz or 120GHz we are still within the microwave band. We have a long gap before you get to visible light, infrared, ultraviolet, x-rays, and gamma.

A typical system in the 60 Gig spectrum can go up to about a kilometer. If we do a 70 or 80 Gig radio, we can go much further. Those bands have a little bit of licensing, an annual usage fee for those bands. Licensing is not a bad thing. The FCC will mandate that you own the spectrum from this mountaintop to that mountaintop or from this building to that building, and no one can put a radio next to your radio operating on that frequency. Sometimes it is worth paying that small annual fee for that peace of mind.

60 GHz is unlicensed and you can put radios in close proximity to each other, because the band is so narrow, but if you are going from the same pole, the same rooftop to the other rooftop, and you're on the same tower, you might need to coordinate what frequencies or what

polarizations you're using. Again, lightly licensed is not always a bad thing. Whatever your application, we can help you pick the right technology for your application.

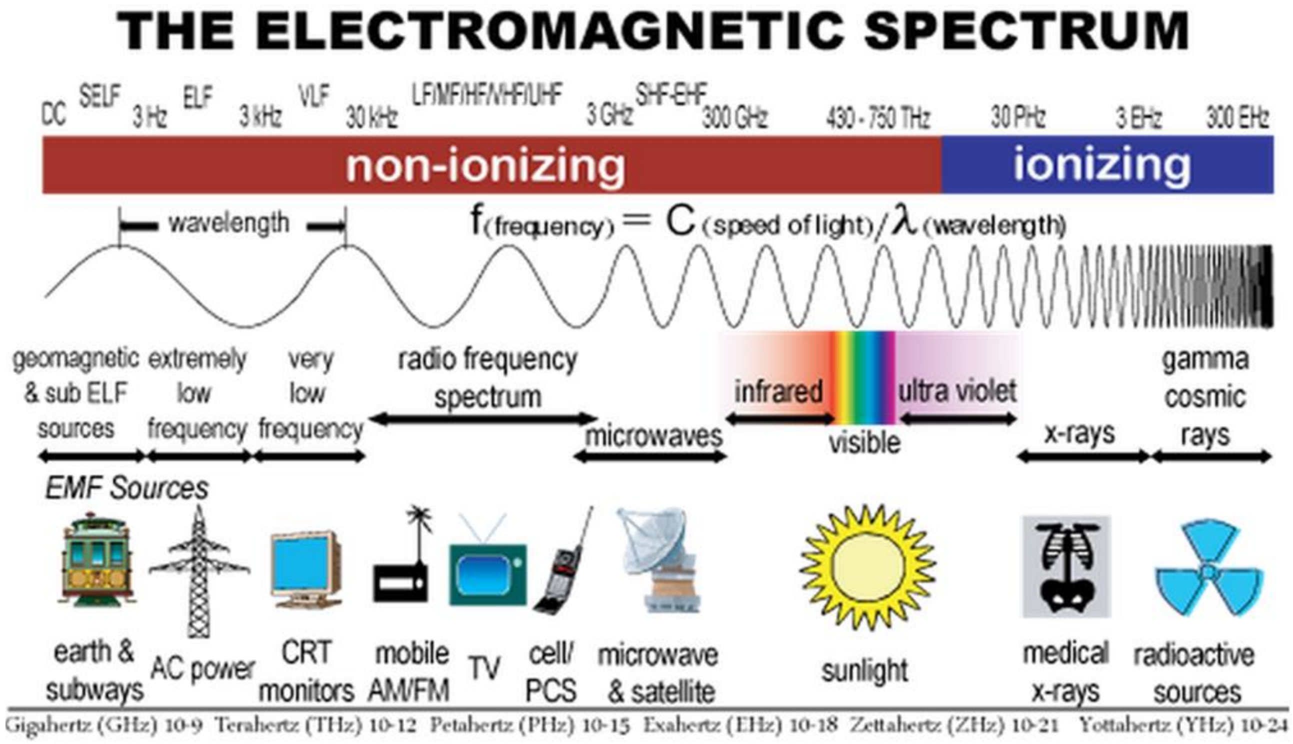


Figure 15, Electromagnetic Spectrum

Conclusion

The wireless transmission of 4K video and television signals will be hear soon. The technology is available and system will be available within a year. Infrastructure for 10 Gigabit Wireless Ethernet is on the way and ready for IP based 4K video. Lossless or near loss less compression for 4K will help facilitate this transition. The FCC is sure to approve the 102-109 GHz band for data communications opening up even higher bandwidth. I hope to follow up with updates as the technology progresses.