TechTalk #76

Digital-ATV – Understanding Symbol-Rates, FEC and RF Bandwidth

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In the May 2009 newsletter, TechTalk presented an introduction to D-ATV. Then in the June newsletter, Robbie-KB6CJZ and I teamed-up to present a top-down approach for planning a DATV Station that resulted in selecting the DVB-S standard. This month, TechTalk will explain a few Digital-ATV concepts that are typically not understood by hams and even analog ATVers.

Using the DVB-S standard to transmit a digital ATV signal involves:
- QPSK (Quadrature Phase Shift Keying) modulation
- FEC (Forward Error Correction) algorithms
- MPEG-2 compression data rates for video
- Video bit-rate needed
- Net Data bit-rate available
- Symbol-Rates
- RF Bandwidth

This article will now walk through these various DATV factors and arrive at determining the resulting RF bandwidth for DVB-S.

Video Data-Rate and Compression

For DATV, the analog camera output is first digitized by the MPEG-2 Encoder board shown in **Fig 1**, and then compressed by the MPEG-2 algorithm. The reason the compressed video data rate varies in **Table 1** is that the low value means little motion in the video scene and the higher value means a lot of motion.

Notice in **Table 1** that the uncompressed NTSC camera video stream is 168 Mbits/sec, while the uncompressed PAL camera video stream is 216 Mbits/sec. The NTSC video stream data-rate is a 22% reduction from PAL.
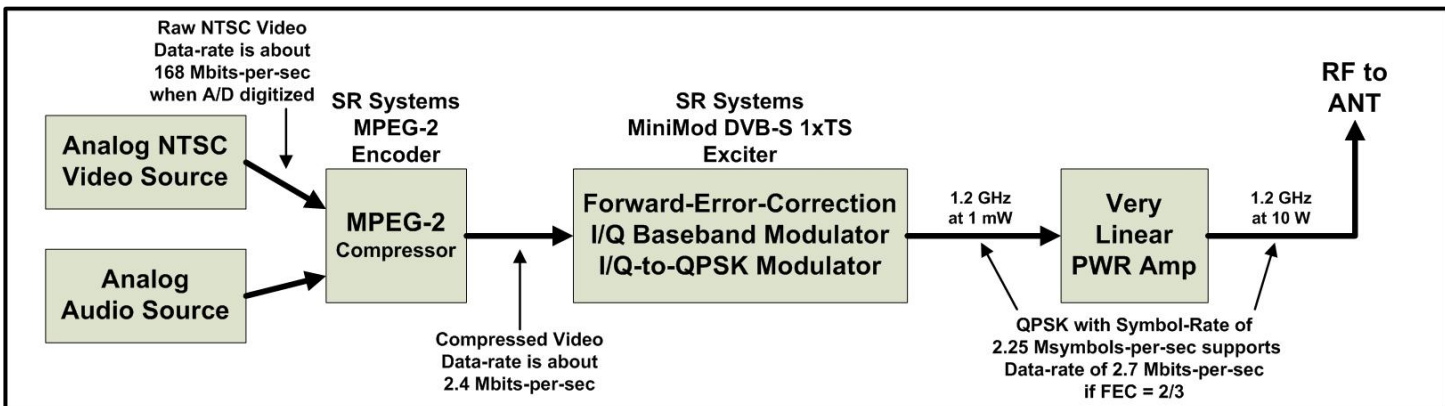
Table 1 – Camera Video Data Streams and MPEG-2 Data Streams

Video Data Stream	Data-Rate	Notes
Analog NTSC camera	168 Mbits/sec	A/D digitized, uncompressed
NTSC MPEG-2	2-3 Mbits/sec	compressed
VHS MPEG-2	1-2 Mbits/sec	compressed
Analog PAL camera	216 Mbits/sec	A/D digitized, uncompressed
PAL MPEG-2	2.5-6 Mbits/sec	compressed
HDTV camera	1-1.5 Gbits/sec	uncompressed
HDTV MPEG-2	12-20 Mbits/sec	compressed

Stefan-DG8FAC of SR-Systems (located in Germany...see links at the end) has explained to me that in Europe many hams set the MPEG-2 output data-rate to be 2.5 Mbits/sec for PAL. Stephan further suggests that the MPEG-2 output data-rate for NTSC would be about the same. I suspect that there should be about a 22% reduction in MPEG-2 output data-rate from PAL, to about 2.0 Mbits/sec. I will plan for a 2.5 Mbits/sec video stream, but when I finally put together my station DVB-S transmitter, I will measure the NTSC MPEG-2 output to see if the data-rate can be reduced to a 2.0 Mbits/sec video stream.

FEC Inflation of Video Stream Data-Rate

Forward Error Correction (FEC) is a technology that not only can detect an error on the received signal, but adds enough redundancy of the data so that it can correct the wrong bit. It can correct two wrong bits. Since redundancy increases the data-rate of the video stream, there is a trade-off between more redundancy and the required video data-rate becoming too large. As we will see a little later in this article, the larger the video stream data-rate, the higher the required RF bandwidth. So at some point the FEC algorithm will not have enough redundancy to correct too many errors, and the DATV screen will go blank.

Figure 1 – DATV Block Diagram Showing Various Data-Rates and Symbol-Rates for DVB-S QPSK
(for 2.25 Msymbols-per-sec, the Bandwidth is 3 MHz)

DVB-S commercial television standard uses two different Forward-Error-Correction (FEC) algorithms together in order to provide protection against noise errors and multi-path errors. The first FEC algorithm is called Viterbi. The second FEC algorithm is called Reed-Solomon.

The Viterbi FEC algorithm can be configured for different levels of error correction. Theses different Viterbi configuration/redundancy settings are usually called: 1/2, 2/3, 3/4, 5/6 and 7/8. The first number ("1" in the case of configuration 1/2) is the number of input bits. The second number ("2" in the case of configuration 1/2) is the number of output bits from the FEC$_{viterbi}$ algorithm. So the MPEG-2 output data stream is "inflated" 100% by this FEC algorithm configured for 1/2. That is...for every bit going into the FEC engine, two bits come out. A FEC$_{viterbi}$ algorithm configured for 3/4, for example, would inflate the MPEG-2 output data stream by 33%. So FEC levels can really inflate the data-bit-rate going to the RF modulator; the MPEG-2 algorithm compresses the video stream, but the FEC algorithms start to expand the required data-bit-rates again.

The Reed-Solomon FEC algorithm has a fixed configuration. Its data stream "inflation rate" is 188/204. So for every 188 bits going into the FEC$_{reed-solomon}$ algorithm, 204 bits come out...an additional FEC inflation of 8.5%.

Digital Modulation Symbols and Symbol-Rates

Digital modulation technology like BPSK (for example PSK-31), QPSK (Quad Phase Shift Keying – like DVB-S) and QAM256 (Quadrature Amplitude Modulation with 256 "constellation points") have the ability to put more information into a narrow frequency spectrum than analog modulation. The complexity of the digital modulation scheme, allows us to pack more "data bits" into each SYMBOL. Table 2 lists out how many data bits can be packed into a symbol for several well known digital modulation technologies.

**Table 2 – Symbol Bit-Packing for
Various Digital Modulation Technologies**

Modulation Scheme	Data Bits per Symbol (Me)
BPSK	1
QPSK	2
8-VSB	3
QAM16	4
QAM256	8

Table 2 means that QPSK will pack two data bits into each symbol being modulated. If we know the final output data-bit-rate (I will call this inflated data rate the "Gross Data-Bit-Rate") we need for the television signal, then the "symbol-rate" we need is exactly one-half of that data-bit-rate. For example:

Gross Data-Bit-Rate = 4.5 Mbits/sec

Symbol-Rate Needed = 2.25 Msymbols/sec

The formula to calculate the Symbol-Rate setting that I need for my DVB-S transmitter is:

Symbol-Rate Needed = NDBR / (Me x CRv x CRrs)

Where:
NDBR = Net Data Bit Rate (aka the information rate)
　　　　　Same as MPEG-2 output data rate in Table 1
Me = Modulation Efficiency (2 for QPSK in Table 2)
CRv = Correction Rate setting for Viterbi (1/2, 3/4, etc)
CRrs = Correction Rate value for Reed-Solomon is
　　　　　188/204

I will now calculate an example for QPSK where the output of MPEG-2 is 2.4 Mbits/sec and FEC$_{viterbi}$ is set to 1/2.

Table 3- Net Data Bit-Rates for DVB-S at a given RF Bandwidth

Modulation	FEC Coderate	DVB-S RF BANDWIDTH for DATV (RF BW = SymbolRate x 1.33)					
		2.0 MHz (SR = 1.5 MS/sec)	2.5 MHz (SR = 1.88 MS/sec)	3.0 MHz (SR = 2.25 MS/sec)	4.0 MHz (SR = 3.0 MS/sec)	5.0 MHz (SR = 3.75 MS/sec)	6.0 MHz (SR = 4.50 MS/sec)
QPSK	1/2	~~1.38~~	~~1.73~~	~~2.07~~	2.76	3.46	4.15
	2/3	~~1.84~~	~~2.30~~	2.76	3.69	4.61	5.53
	3/4	~~2.07~~	2.59	3.11	4.15	5.18	6.22
	5/6	~~2.30~~	2.88	3.46	4.61	5.76	6.91
	7/8	2.42	3.02	3.63	4.84	6.05	7.26

(NOTE-1: NTSC Analog Camera produces about 2.4 to 2.5 Mbits-per-sec of MPEG-2 output for Ham Radio type broadcasts)

(NOTE-2: The Net Data Bit-Rate values inside the Table need to be at 2.4 Mbps or larger to support the expected camera data rate coming from MPEG-2 encoder)

(NOTE-3: The Net Data Bit-Rate values inside the Table shown in RED (with strikethrough) are Net Data Bit-Rates that will not support the video data stream.)

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Symbol-Rate Needed = $\dfrac{2.4 \text{ Mbit/sec}}{2 \text{ bits/symb} * (1/2) * (188/204)}$

Symbol-Rate Needed = $\dfrac{2.4 \text{ Mbit/sec}}{0.921 \text{ bits/symbol}}$

Symbol-Rate Needed = 2.65 Msymbol/sec

If I change the $FEC_{viterbi}$ setting to 3/4, then the CRv value becomes 3/4 and the results are:

Symbol-Rate Needed = 1.73 Msymbol/sec

The Symbol-Rate that is needed was reduced because the "inflated data-rate" caused by a lot of FEC redundancy was reduced. If you look at **Table 3** on the preceding page, it shows the Net Data Bit Rate that can be supported by a particular Symbol-Rate using several FEC settings. The FEC setting needs to result in a number of Net Data Bit Rate that is at least 2.4 Mbits/sec. The red values in the table show FEC settings or Symbol-Rates that result in a Net Data Rate of less than 2.4 Mbits/sec that I set as my goal for MPEG-2 video stream output.

RF Bandwidth for DVB-S DATV
It turns out, one of the advantages of digital-ATV is it can be more bandwidth-efficient than analog ATV. With QSPK modulation you actually have the ability to easily make the DATV RF bandwidth as narrow as 2 MHz or 3 MHz without giving up any noticeable quality. This is because the commercial DTV standards planned to transmit several Television streams inside one normal (old) RF TV bandwidth.

The final formula is for DATV Bandwidth (BW). For QPSK modulation, the formula for (allocation) RF BW is:

RF BW$_{allocation}$ ~= 1.33 x Symbol-Rate

This Bandwidth is the spacing that can be used for placing adjacent DATV station center-frequencies. This value of Bandwidth is where the signal is down about -15 dB or more.

The expression "occupied bandwidth" is sometimes used to refer to a bandwidth that is 1.19 times the symbol rate, where the signal is down by approximately -10 dB.

If the Symbol-Rate used is 2.25 Msymbols-per-sec, then:

RF BW = 1.33 x 2.25 Msymbols/sec = 3.0 MHz

If we can use a Symbol-Rate of only 1.5 Msymbols/sec, then the bandwidth would reduce to:

RF BW = 1.33 x 1.5 Msymbols/sec = 2.0 MHz

Again, **Table 3** on the preceding page provides an overview of what RF Bandwidth you can choose and what the resulting Net Data Bit Rate will be for various FEC selections.

Conclusion
In reviewing the results in **Table 3**, I have concluded that I will use an RF Bandwidth of 2.5 MHz to support an NTSC MPEG-2 output of 2.4 Mbits/sec by selecting FEC to be 3/4. I plan to put together a DATV station soon. When I do, I will measure the NTSC MPEG-2 video stream that is really required. If my suspicions that I will see a NTSC MPEG-2 video stream at around 2Mbits/sec are confirmed, then I probably will change to a 3 MHz RF BW by using the FEC setting of 1/2. This FEC setting will produce high DATV signal correction capability in one-half of the normal 6 MHz analog ATV bandwidth.

Useful DATV Links
- AGAF D-ATV components (Boards) – see **www.datv-agaf.de** and **www.AGAF.de**
- SR-Systems D-ATV components (Boards) – see **www.SR-systems.de**
- British ATV Club - Digital Forum – see **www.BATC.org.UK/forum/**
- DXzone links on Digital-ATV – see **www.DXzone.com/catalog/Operating_Modes/Digital_ATV/**
- Amateur Television of Central Ohio – see **www.ATCO.TV**
- OCARC newsletter introduction article "ATV – the Digital Fork in the Road" – see **www.W6ZE.org/DATV/TechTalk74-DATV.pdf**
- OCARC newsletter article "Planning a Digital-ATV Station" – see **www.W6ZE.org/DATV/TechTalk75-DATV.pdf**
- Orange County ARC newsletter entire series of DATV articles – see **www.W6ZE.org/DATV/**
- Rob-MØDTS D-ATV site including details of F4DAY-design – see **www.M0DTS.co.uk/datv.htm**
- RF Bandwidth online calculator for DVB-S & DVB-S2 – see **www.satellite-calculations.com/Satellite/bitrates.htm**
- Ultimate Resource for Digital Amateur Television – see **www.D-ATV.com**

Further Discussions on DVB-S RF Bandwidth

Through research on the internet, I have confirmed that there are three methods for defining RF BandWidth for QPSK modulation.

"minus 3 dB" bandwidth method

With this method, the bandwidth is measured at the points that are down 3 dB. This is a typical method for measuring a filter bandwidth and represents the "half-power point" if you are looking at voltage on a spectrum-analyzer.

Mathematically, $BW_{-3dB} \approx S/R$ for this definition.

"occupied" bandwidth method

This occupied bandwidth is defined as $BW_{occupied} = 1.19 \times S/R$

The signal level is down by about 10dB at the edges of the occupied bandwidth

"allocation" bandwidth method

This method provides a little guard-band between adjacent DATV signals.

Allocation bandwidth methods uses formula $BW_{allocation} = 1.33 \times S/R$

This formula is equivalent to measuring at down about 16 dB

An ONLINE BW CALCULATOR is listed in Useful DATV Links.

It seems to me that the "allocation" bandwidth is the most meaningful value of bandwidth for people trying to determine how many DATV stations to squeeze into a band plan. Significant power would overlap neighboring frequencies if we spaced several DATV stations "shoulder-to-shoulder" on their 1/2–power-points...hence creating potential interference.