TechTalk 86

Overview of DVB-T Modulation for Digital-ATV

by Ken Konechy W6HHC

Many of the earlier OCARC TechTalk articles about Digital-ATV have provided details about how DVB-S modulation works. DVB-S is currently the most popular modulation standard being used by hams for DATV. This month I will look at some of the technical details of DVB-T modulation.

The "T" in DVB-T means that it is designed to work well for terrestrial transmissions to your commercial DTV set at home. **Fig 1** shows a typical home terrestrial broadcast receiving station using a STB.

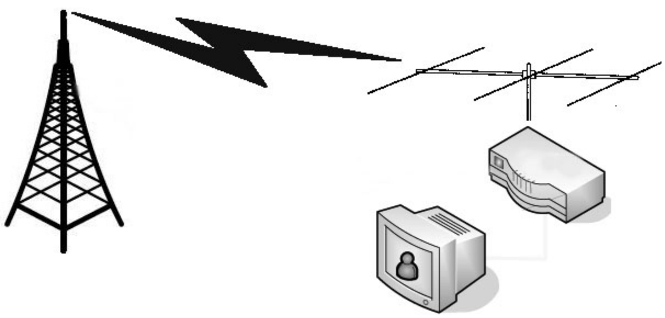

Figure 1 - Terrestrial Reception using a Commercial Set-Top-Box (STB)

DVB-T is used for home terrestrial reception in much of the world (Europe, Asia, and Pacific). In the United States and Canada, the competing DTV broadcast standard for terrestrial reception is called ATSC. A comparison table for the PROs and CONs between DVB-T and ATSC and DVB-S technologies can be found near the end of this article.

Typical Transmitter Block Diagram

Groups and clubs of DATV enthusiasts have shown that DVB-T digital technology is possible for hams. **Fig 2** is a block diagram of a basic DVB-T transmitter used by several groups in Europe and Australia for DATV. The analog camera and video is compressed by a MPEG-2 encoder board. The TransportStream (TS) digital data is fed to the exciter board that does a lot of complicated data processing and then converts the digital data directly to modulated RF at a desired frequency. The small RF output signal of the exciter board is typically amplified by two stages of very linear RF amplifiers.

Video Data-Rate and Compression

For DATV, the analog camera output is first digitized by the MPEG-2 Encoder board shown in **Fig 2**, and then compressed by the MPEG-2 algorithm. The reason the compressed video data rate varies in **Table 1** is that the small value means little motion in the video scene and the larger value means a lot of motion. MPEG-2 encoding can be used in two modes: (a) constant output mode per frame with null packets inserted as needed and (b) variable data per frame.

a) Encoding for DVB-T uses constant data rate with null inserts as needed
b) Encoding for DVD burning uses variable data per frame

Notice in **Table 1** that the digitized NTSC camera video data-bit-stream is 168 Mbits/sec before compression, and MPEG-2 will reduce this to a Net-Bit-Data-Rate between 1 and 3 Mbps, which is quite a reduction.

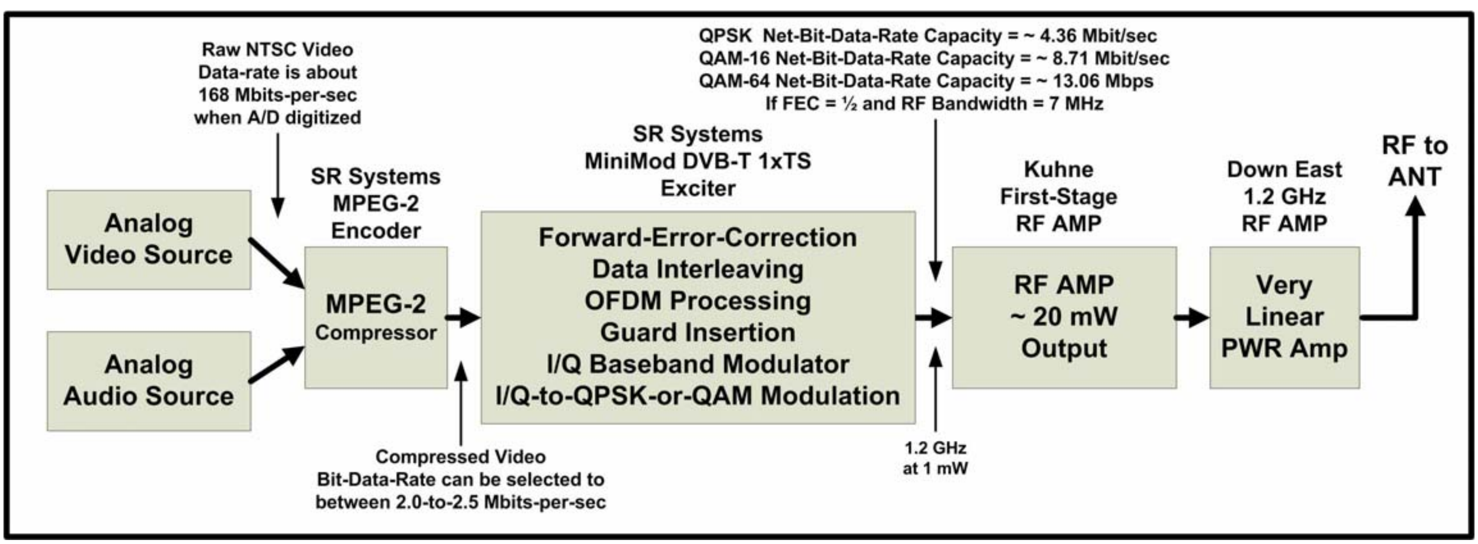

Figure 2 – Block Diagram of Typical DVB-T Transmitter for DATV

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	15-60 Mbits/sec	compressed
HDTV MPEG-4	12-20 Mbits/sec	compressed

The MPEG-2 encoder I use makes a direct measurement of the compressed video rate not practical. Discussions with many hams in Europe reveal that they plan for the MPEG-2 output payload data-rate to be set typically between 2.0 and 2.5 Mbits/sec for PAL with excellent results for D1 video resolution. My own DATV tests show that settings of either 2.0 or 2.1 Mbps provide excellent video quality for NTSC. [As a note: TechTalk85 provided a detailed look at how the MPEG-2 processing works.]

FEC Inflation of Payload Data Stream Data-Rate

Forward Error Correction (FEC) is a technology that not only can detect errors on the received signal, but adds enough redundancy of the data so that it can correct several wrong bits. But, there is a trade-off when choosing the amount of redundancy. Since redundancy inflates the data-rate of the output stream, the trade-off is between more redundancy or keeping the inflated data-rate smaller. As we will see a little later in this article, the larger the inflated output data-rate, the higher the required symbol rate. Higher symbol rates may force you to a wider-bandwidth or a more noise-sensitive modulation scheme. So at some point the FEC algorithm will not have enough redundancy to correct too many errors, and the DATV receiver screen will go blank or freeze.

The DVB-T commercial television standard uses a combination of two different Forward-Error-Correction (FEC) algorithms together in order to provide protection against noise errors and multipath errors. The first FEC algorithm is called the inner-Punctured-Convolutional-Code by the DVB-T specification (and typically called Viterbi in DVB-S articles). The second FEC algorithm is called Reed-Solomon. These two algorithms are the same as those used in DVB-S technology.

Convolutional encoding with Viterbi decoding is a FEC technique that is well suited to a channel in which the transmitted signal has been corrupted by Gaussian noise. The inner-Punctured-Convolutional-Code FEC algorithm can be configured for different levels of error correction. These different Puncture-Table redundancy settings are usually called: 1/2, 2/3, 3/4, 5/6 and 7/8. Where 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 this FEC algorithm.

So the MPEG2 output data stream is "inflated" 100% by this $FEC_{viterbi}$ 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 second algorithm that is used, 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 $FEC_{reed\text{-}solomon}$ 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 DVB-T) and QAM-256 (Quadrature Amplitude Modulation with 256 "constellation points") have the ability to put more information into a more 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.

DVB-T technology users can choose between QPSK, QAM-16, or QAM-64 modulation schemes (shown in BLUE) for the COFDM sub-carriers discussed latter.

Table 2 – Symbol Bit-Packing for Various Digital Modulation Technologies Modulations in BLUE can be selected for DVB-T

Modulation Scheme	Data Bits per Symbol (Me)
BPSK	1
GMSK	1
QPSK	**2**
8-VSB	3
QAM-16	**4**
QAM-64	**6**
QAM-256	8

The higher-order modulations schemes, like QAM-16 and QAM-64) can "pack" more bits into the symbol rate than QPSK. But, the complexities for QAM-16 and QAM-64 modulation make them more susceptible to noise and interference. **Fig 3**, **Fig 4**, and **Fig 5** are intended to give an appreciation of the increasing complexities for these three modulation schemes.

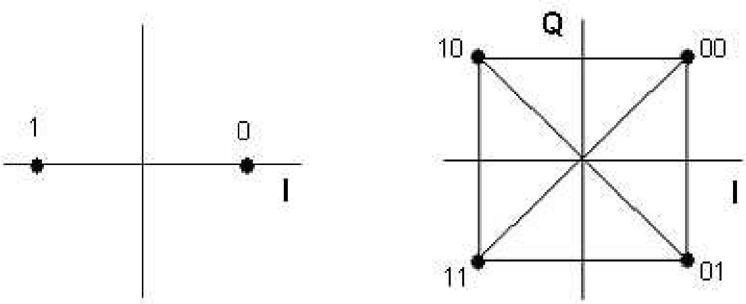

Figure 3 – The constellations of BPSK (on the left) with two states and by QPSK with four states.

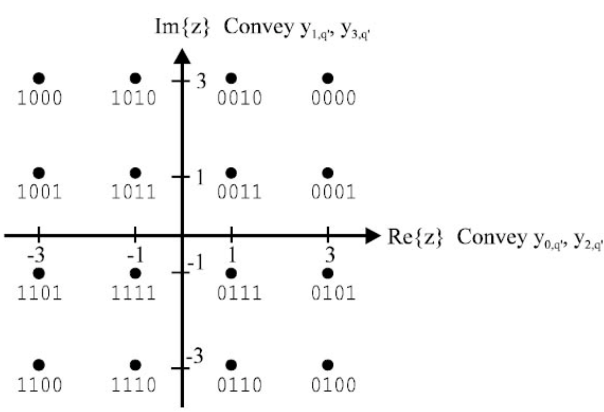

Figure 4 – The constellation for QAM-16 modulation contains 16 states. Each state defines four bits of data.

Notice in **Fig 4** that not only is the angle from the origin to the state important, but the amplitude from the origin is critical, also. The I-axis amplitude of the signal can have four different values. The Q-axis (shown as the R-axis in this drawing) can also have four amplitude values.

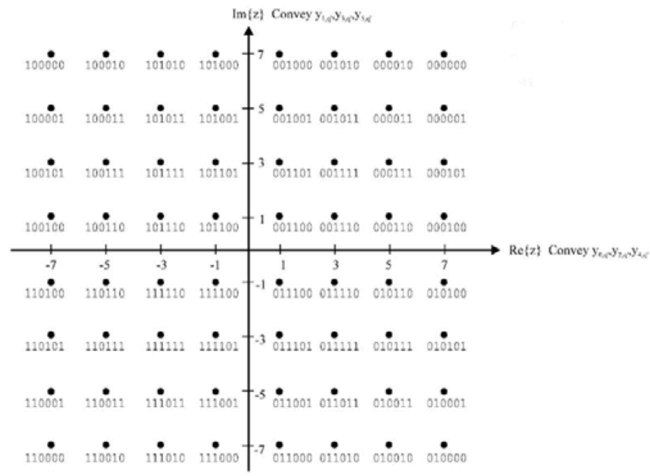

Figure 5 – The constellation for QAM-64 modulation contains 64 states. Each state defines six bits of data.

I use **Fig 3** and **4** and **5** to help me to visualize the differences between the complexities of QPSK, QAM-16 and QAM-64 modulation technologies. There is a balance between the rate at which data can be transmitted and the signal-to-noise ratio that can be tolerated. The lower order modulation schemes like QPSK do not transmit data as fast as the higher modulation formats such as QAM-64, but they can be received better when signal strengths are weaker.

COFDM

The DVB-T technology adds a process to the modulation of the RF signal that is very different form either DVB-S or ATSC modulations. The negative effects of multipath reflections can be reduced, by using 16QAM modulation with a low effective bitrate per carrier. To reduce the effective bitrate per carrier, DVB-T spreads out the bitrate over a large amount of carriers. This spreading out will result in 1,705 closely spaced sub-carriers (using COFDM.....aka Coded Orthogonal

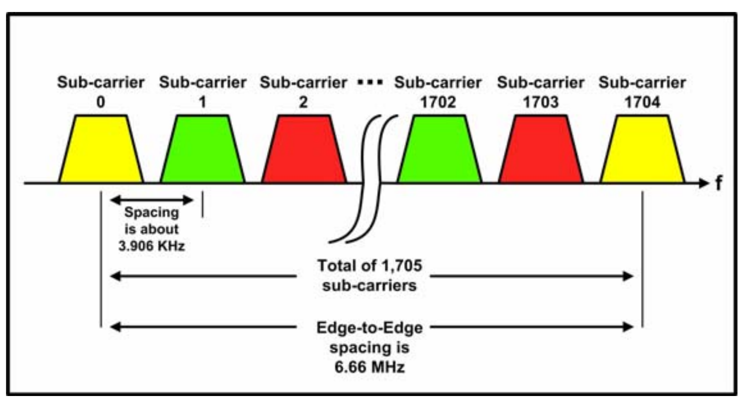

Figure 6 – COFDM spreads the DATV signal over 1705 sub-carriers (7 MHz bandwidth is shown)

Frequency Division Multiplexing) to create a bandwidth that can be chosen to 6MHz or 7MHz or 8MHz wide. **Fig 6** shows an example where there 1,705 sub-carriers spaced at about 3.906 KHz apart...to create a 7MHz bandwidth signal.

Normally these sub-carrier signals would be expected to interfere with each other, but by making the signals orthogonal to each another there is no mutual interference. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period. This means that when the signals are demodulated they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution.

When I read different articles on DVB-T technology, I observed that some articles use the term COFDM, and other articles use the term OFDM. What is the difference?? Wikipedia just says “they are the same” for DVB-T articles?? Hans Hass DC8UE was kind enough to dig up a better explanation for the difference between COFDM and OFDM. He found the following information

COFDM
Coded Orthogonal Frequency Division Multiplex

C=Coded – means it uses FEC
O=Orthogonal -means no cross talk between sub-carriers
FDM=Frequency Division Multiplex – means distribution of datastream over a lot of sub-carriers

So OFDM just is a similar communication protocol that does not use Forward-Error-Correction (FEC). In a way, Wikipedia is correct, the use of FEC does not affect the number of sub-carriers or the frequency bandwidth...FEC just changes the amount of data overhead added to the datastream. So many technical details stay the same between COFDM and OFDM.

Actually, COFDM can be chosen for 1,705 sub-carriers called the 2K mode, or for 6,816 sub-carriers, called the 8K mode. Stefan Reimann DG8FAC of SR-System explained that ham radio DATV only uses the 2K mode of DVB-T. Stefan DG8FAC detailed that the 8K mode is only used in commercial DTV broadcasts to create Single-Frequency-Networks (SFN) where two or more transmitters carrying the same data operate on the same frequency (to provided geographically overlapping coverage) without causing interference to each other. This SFN concept is too complex for ham radio applications and also the size of the FPGA needed for the 8K mode becomes larger and more expensive than the current MiniMod board design.

A final point about COFDM in DVB-T is that the sub-carriers, as shown in **Fig 6**, can all be modulated with either QPSK or with QAM-16 or with QAM-64.

The Role of the DVB-T Guard Insertion.

Wikipedia explains that the purpose of the guard interval is to introduce immunity to propagation delays, echoes and reflections, to which digital data is normally very sensitive. In COFDM, the beginning of each symbol is preceded by a guard interval. As long as the echoes fall within this interval, they will not affect the receiver's ability to safely decode the actual data, as data is only interpreted outside the guard interval.

Longer guard periods allow more distant echoes to be tolerated. However, longer guard intervals reduce the channel efficiency. With DVB-T, four guard intervals are available (given as fractions of a symbol period):

1/32 1/16 1/8 1/4

Therefore, choosing a guard interval of 1/32 gives lowest protection from long echoes and the highest data rate. A guard interval of 1/4 results in the best protection but the lowest data rate.

Table 3 provides details of Guard Interval delay times for 6 MHz and 7 MHz configurations

Table 3 – Details of Guard Interval timing for 6 MHz and 7 MHz Bandwidths

	6 MHz - 2K Mode				7 MHz - 2K Mode			
Guard Interval	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Duration of Symbol w/o padding	2048 x T 298.67 uSec				2048 x T 256 uSec			
Duration of Guard Interval	74.67 uSec	37.33 uSec	18.67 uSec	9.33 uSec	64 uSec	32 uSec	16 uSec	8 uSec
Guarded Symbol Duration	373.3 uSec	336.0 uSec	317.3 uSec	308.0 uSec	320 uSec	288 uSec	272 uSec	264 uSec

Modulation and RF Bandwidth with DVB-T

As discussed earlier, DVB-T transmissions can be chosen to use QPSK, QAM-16, or QAM-64 for modulation. In addition, the transmitter can be chosen for 6 MHz, 7 MHz or 8 MHz bandwidth. The choice of the modulation does not affect the RF bandwidth because the carrier has been divided into so many evenly-spaced sub-carriers (1,705 sub-carriers for DATV). **Fig 7** shows the typical spectrum analyzer view of a DVB-T transmission with 8 MHz bandwidth.

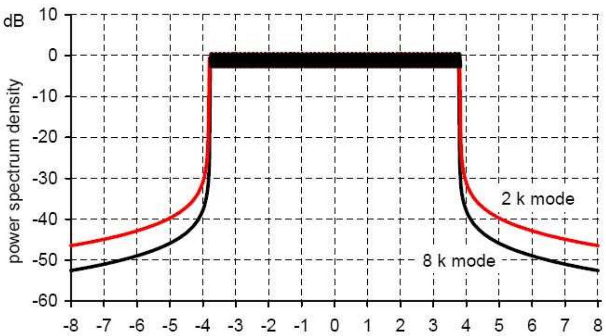

Figure 7 – Theoretical spectrum for an 8 MHz wide DVB-T signal
(NOTE: bottom axis is labelled in MHz)

The only difference in the choice of modulation is the amount of payload for Net-Data-Bit-Rate that is available in the transmission, for a given bandwidth. The Net-Data-Rate that the transmission can provide is shown in **Table 4**. For a given bandwidth, the efficiency that is available is affected by the FEC setting and the Guard Interval setting. Notice that QAM-64 modulation in **Table 4** provides approximately 50% more payload (NDBR) than the same settings for QAM-16 modulation. Also, QPSK modulation provides approximately 50% less payload than QAM-16 modulation.

Table 5 – Example of DVB-T Transmission "Payload" for different Modulation Schemes

	Net-Data-Bit-Rate for FEC=1/2 Guard = 1/4	
Modulation	**6 MHz BW**	**7 MHz BW**
QPSK	**3.74 Mbps**	**4.36 Mbps**
QAM-16	**7.46 Mbps**	**8.71 Mbps**
QAM-64	**11.20 Mbps**	**13.06 Mbps**

Table 5 is a sample of "payloads" (NDBR) for different modulation schemes using same FEC setting and same Guard Intervals. If you remember that NTSC MPEG2 TS can be selected to be around 2.0 Mbps NDBR (see **Table 1**), then you can see that two video TS can be carried by a single QPSK 7 MHz carrier. QAM-16 and QAM-64 can carry even more TS videos at the same time. Essential, this how commercial DTV broadcast stations can carry six DTV "sub-channels" on the same transmitter.

I wondered why wider bandwidths provided a higher payload data-rate, if each bandwidth used exactly the same number of sub-carriers?? Then, I remembered that the Symbol-rate for each bandwidth is adjusted based on the spacing of the sub-carriers to provide the orthogonal interference protection. So, narrower bandwidths do require the use of slower Symbol-rates.

Table 4 – Net-Data-Rate for a Chosen RF Bandwidth and Modulation Scheme
(Table courtesy of SR-Systems)

Modulation	FEC Coderate	Channel bandwidth/Kanalbandbreite (MBit/sec)															
		8 MHz				7 MHz				6 MHz				5 MHz			
		Schutzintervall/Guard				Schutzintervall/Guard				Schutzintervall/Guard				Schutzintervall/Guard			
		1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
QPSK	1/2	4,98	5,53	5,85	6,03	4,36	4,84	5,12	5,28	3,74	4,15	4,39	4,52	3,11	3,46	3,66	3,77
	2/3	6,64	7,37	7,81	8,04	5,81	6,45	6,83	7,04	4,98	5,53	5,86	6,03	4,15	4,61	4,88	5,03
	3/4	7,46	8,29	8,78	9,05	6,53	7,25	7,68	7,92	5,60	6,22	6,59	6,79	4,66	5,18	5,49	5,66
	5/6	8,29	9,22	9,76	10,05	7,25	8,07	8,54	8,79	6,22	6,92	7,32	7,54	5,18	5,76	6,10	6,28
	7/8	8,71	9,68	10,25	10,56	7,62	8,47	8,97	9,24	6,53	7,26	7,69	7,92	5,44	6,05	6,41	6,60
16-QAM	1/2	9,95	11,06	11,71	12,06	8,71	9,68	10,25	10,55	7,46	8,30	8,78	9,05	6,22	6,91	7,32	7,54
	2/3	13,27	14,75	15,61	16,09	11,61	12,91	13,66	14,08	9,95	11,06	11,71	12,07	8,29	9,22	9,76	10,06
	3/4	14,93	16,59	17,56	18,10	13,06	14,52	15,37	15,84	11,20	12,44	13,17	13,58	9,33	10,37	10,98	11,31
	5/6	16,59	18,43	19,52	20,11	14,52	16,13	17,08	17,60	12,44	13,82	14,64	15,08	10,37	11,52	12,20	12,57
	7/8	17,42	19,35	20,49	21,11	15,24	16,93	17,93	18,47	13,07	14,51	15,37	15,83	10,89	12,09	12,81	13,19
64-QAM	1/2	14,93	16,59	17,56	18,10	13,06	14,52	15,37	15,84	11,20	12,44	13,17	13,58	9,33	10,37	10,98	11,31
	2/3	19,91	22,12	23,42	24,13	17,42	19,36	20,49	21,11	14,93	16,59	17,57	18,10	12,44	13,83	14,64	15,08
	3/4	22,39	24,88	26,35	27,14	19,59	21,77	23,06	23,75	16,79	18,66	19,76	20,36	13,99	15,55	16,47	19,96
	5/6	24,88	27,65	29,27	30,16	21,77	24,19	25,61	26,39	18,66	20,74	21,95	22,62	15,55	17,28	18,29	18,85
	7/8	26,13	29,03	30,74	31,67	22,86	25,40	26,90	27,71	19,60	21,77	23,06	23,75	16,33	18,14	19,21	19,79

Die angegebenen Datenraten gelten für den 8k-, 4k- und 2k-Modus und beziehen sich auf 188-Byte DVB Pakete.

The specified data rates are valid for 8k, 4k, and 2k modes and apply for 188 bytes DVB packets.

An interesting note about DVB-T RF Bandwidth is that SR-Systems has designed their MiniMOD exciter boards to allow for selection of DVB-T transmission bandwidths of 8, 7 ,6, 5, 4, 3 MHz and down to only 2 MHz BW. These narrow bandwidths of 5 –to– 2 MHz are not covered by the commercial DVB-T standard. But, as Stefan DG8FAC explains "...we transmit on 70cm with 2MHz in QAM-16, 1/2FEC and 1/4 Guard, and this works perfectly." The NIM receiver boards that are available from SR-Systems, have modified firmware used with the DiBcom7000 chip used in the NIM DVB-T board to receive the 2 MHz BW. But, this "not-normal" bandwidth choice will not work with commercially available SetTopBoxes that were not intended to be used with a 2 MHz bandwidth.

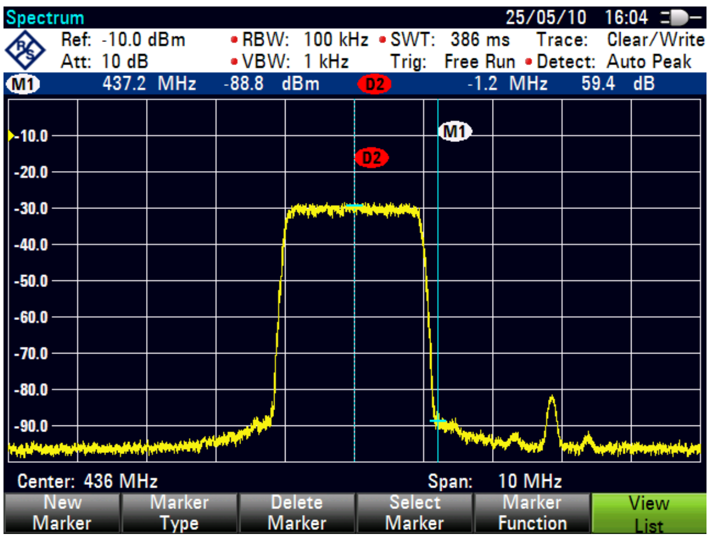

Figure 8 – A DVB-T MiniMOD exciter output transmission is seen on a Spectrum Analyzer (Courtesy of Stefan DG8FAC)

Fig 8 shows a DVB-T transmission spectrum produced at the output of a MiniMOD exciter board. This picture shows the direct resemblance to the theoretical DVB-T spectrum shown in **Fig 7**.

The spectrum display in **Fig 9** looks quite different than the theoretical shown in **Fig 7.** Peter Cossins VK3BFG who has contributed much to the VK3RTV repeater DATV progress explains "...The DVB-T spectrum from the final amp sampled via a directional coupler to a dummy load is quite rectangular. This spectrum **[Fig 9]** tapers off with increasing frequency ....it should be fairly flat on the top! The spectrum photo I have provided is live off a 49 element J beam ....I checked a local commercial UHF on the same antenna which is very close in freq and it looks somewhat similar, but a bit more rectangular as it should be. The repeater antenna up the hill is the original analogue one optimized for 444.25 MHz, not 446.5 Mhz.

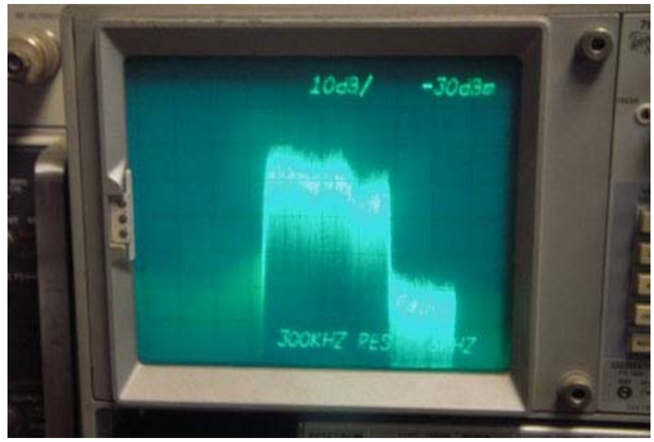

Figure 9 – DVB-T transmission as seen on a Receiving Station shows effects of VK3RTV Transmit Antenna tuned off-frequency (Courtesy of Peter VK3BFG)

This seems to be confirmed as 'performance' is better at the bottom end rather than the top end. The repeater antenna is quite OK to about 4 MHz+ so it was satisfactory for the analogue system.

I think what you are seeing is the variations in gain performance of both antennas over the bandwidth... "

De-rating the PA Output

It is finally worth noting that DVB-T is more sensitive to non-linearity of a power amplifier than DVB-S technology. This is because the QAM modulations have a very large "Peak-to-Average Ratio" called PAR. The graph in **Fig 10** shows that OFDM (think QAM-64) is very much worse than QPSK. Because you can not allow distortion from "flat-topping" the power peaks, the average power out of the amplifier will be set low.

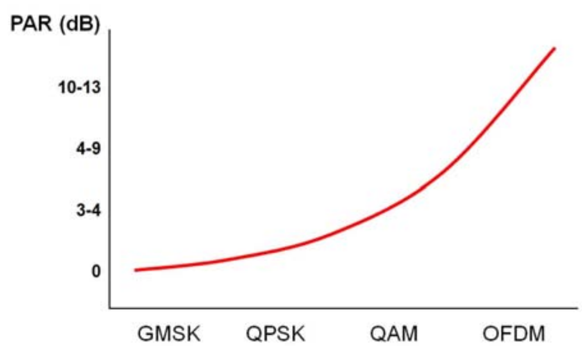

Fig 10 – PAR for amplifier output power when processing signals with various digital modulation technologies (Graph courtesy of Robert Green – Keithley Instruments, Inc.)

Peter VK3BFG confirms by explaining "...Digital television [DVB-T] requires extremely linear RF amplifiers and hence it was necessary to bias the module close to Class A. This is an extremely inefficient mode with a maximum efficiency of 50%. The actual efficiency obtained for DVB-T was about 14 % !!!.

Driving the amp is extremely non-linear and the spectrum growth occurs at an alarmingly fast rate after a certain point has been reached...."

Hans Hass DC8UE has experience as a satellite communications engineer at a commercial TV station and has access to good communications instrumentation. Hans explains that "...On measurements with my own DATV DVB-T transmitter, I can operate the linear 6Watt PA only at 300mW (in QAM-16 mode). That is 13db below saturation or 5% from the possible FM-power (not DC-input power). If I increase the power, the MER [digital Modulation Error Ratio] will get poor values."

Stefan DG8FAC wrote: The exciter power output settings in DVB-T mode with a 6W Power Amplifier are made with ETL measuring equipment as follows:
GAIN = 08 yields MER 40dB [good] at 100mW OUT
GAIN = 10 yields MER 39dB [acceptable] at 250mW OUT
GAIN = 13 yields MER 34dB [poor] at 500mW OUT

On the web site from Alberto (DGØVE) you can read (in German): All amplifiers can also be used for DVB-S and DVB-T with reduced power. You will notice that in the DVB-S mode only about 20% to 25% of the maximal power (P-1dB) can be used. Working in the DVB-T mode you will get only approximately 8% to 10% of the P–1dB power level.

Comparing DVB-T with DVB-S and ATSC

Table 6 goes though an exercise of PROs and CONs for each of the primary technologies considered for ham DATV. Many hams see the primary disadvantage of DVB-T for DATV as squeezing the fixed bandwidth of normally 6 MHz or wider into crowded band plans. But, on the opposite side of the coin is the DVB-T capability to easily carry more than one video picture simultaneously on the same carrier. Choosing a DATV technology really depends on your requirements.

Conclusion

DVB-T technology offers many interesting concepts and capabilities for ham DATV. There can be no doubt that its design to deal with multi-path noise is impressive. My main reason for selecting DVB-S for my home station was to take advantage of the narrow bandwidth offered for DATV. But, I enjoy studying the competing DATV technologies and understanding how they work. My philosophy in this TechTalk article is that it is good to know the strengths and weaknesses of each DATV technology.

Table 6 – Comparing PROs and CONs between DVB-S, DVB-T and ATSC DATV Technologies

	DVB-S	DVB-T	ATSC
PROs	Bandwidth can be as small as 2 or 3 MHz Cheap FTA Set Top Boxes (STB) on eBay Wide-spread experience and knowledge is provided by European hams on the Internet	Excellent multipath interference immunity Cheap Set Top Boxes (STB) on eBay 6 MHz bandwidth can support multiple video streams	Excellent multipath interference immunity Cheap Set Top Boxes (STB) in USA 6 MHz bandwidth can support multiple video streams
CONs	Multipath interference immunity not as strong as DVB-T or ATSC, but plenty of FEC correction is available	Standard 6, 7, or 8 MHz fixed bandwidth is no advantage over analog-ATV High Peak-to-Average of power for QAM modulation requires very linear power amps and large de-rating of average output power. Typically DVB-T exciter board is 100% more expensive than DVB-S	6 MHz fixed bandwidth is no advantage over analog-ATV Dolby audio AC3 encoder licensing issue unfeasible for hams Current ham transmitter boards for ATSC cannot provide AC3 audio (Dolby) Use of substitute MPEG-2 audio does not work with ATSC STBs, but can (may?) work with cable-ready DTV receivers

Interesting DATV Links

- Digital Video Broadcasting organization (DVB commercial standards) – see **www.DVB.org**
- Digital Video Broadcasting standard for DVB-T – see ETSI EN 300 744 V1.6.1 specification
- TAPR PSR Quarterly Journal Issue 111 on DVB-S Modulation – see **www.TAPR.org/psr.html**
- British ATV Club - Digital Forum – see **www.BATC.org.UK/forum/**
- German portal for DATV streaming repeaters and downloads – see **www.D-ATV.net** (in German)
- AGAF D-ATV components (Boards) – see **www.datv-agaf.de** and **www.AGAF.de**
- Lechner DATV Boards - **http://lechner-cctv.de/d-atv-dvb.151.de.html?mwdSID=9agn7phuiu46fvm2ok3aueltf3**
- Complete ready-to-go DATV transmitters – see **www.d-atv.org/D-ATV-Modulator.pdf**
- SR-Systems D-ATV components (Boards) – see **www.SR-systems.de**
- DGØVE microwave amps, up-converters, down-converters – see **www.DG0VE.de**
- Kuhne Electronics (DB6NT) RF Amplifiers – see **www.Kuhne-Electronic.de**
- Charles Brain G4GUO blog on programming SDR for DVB-T transmitter – see **http://G4GUO.blogspot.com/**
- Melbourne DATV Repeater VK3RTV – see **www.VK3RTV.com/latest.html**
- Orange County ARC newsletter entire series of DATV articles – see **www.W6ZE.org/DATV/**
- Wikipedia on DVB-T – see **http://en.wikipedia.org/wiki/DVB-T**
- Wikipedia on Guard Band – see **http://en.wikipedia.org/wiki/Guard_interval**