Overview of DVB-S Modulation for Digital-ATV

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DVB-S is a standard for commercial digital television broadcasting used throughout most the world (Europe, Asia, and Pacific). The "-S" suffix indicates that this particular standard is used for uplinks and downlinks of satellite television service. DVB-S is also one of the primary standards used by ham radio for Digital-ATV (DATV).

ATSC is the standard for commercial terrestrial digital broadcasting used in the USA and Canada. Choosing between ATSC and DVB-S technologies for DATV is an exercise in trade-offs.

DVB-S Standard: 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

DVB-S Standard: Cons

- Multipath interference immunity not as strong as ATSC, but plenty of FEC correction is available

ATSC Standard: Pros

- Best multipath interference immunity
- Cheap Set Top Boxes in USA
- 6 MHz bandwidth can support multiple video streams

ATSC Standard: Cons

- 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

Both authors have chosen DVB-S for their home DATV stations. Ken, W6HHC, further explains that he did not want to deal on a trial-and-error basis to see if equipment he purchased for receivers would really work with the current "MPEG-2 audio substitution" issue of ATSC DATV transmissions.

The purpose of this article is to introduce a few DATV DVB-S 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
- MPEG-2 compression data rates for video
- FEC (Forward Error Correction) algorithms
- Knowing the video bit-rate to be supported
- Setting the net payload data bit-rate capacity for modulator
- Symbol rates
- RF bandwidth
- Effects of non-linearity in RF power amplifiers

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 Figure 1, and then compressed by the MPEG-2 algorithm. The reason the compressed video data rate shows a range of values in Table 1 is that the low value means little motion in the video scene and the higher value is required for video with 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-S 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 rate between 1 and 3 Mbps, which is quite a reduction.

Table 1. Camera Video Data Streams & MPEG 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

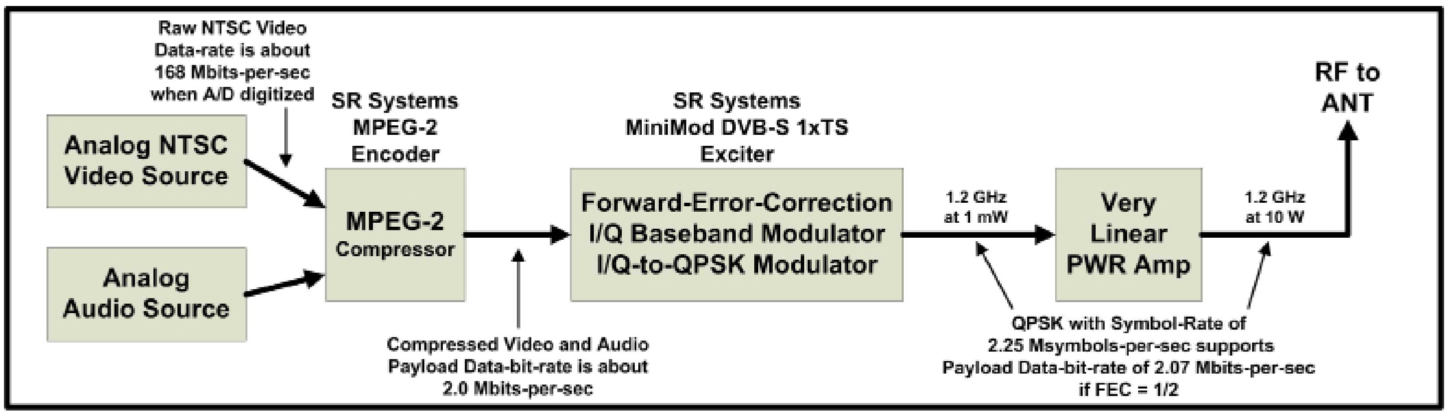

Figure 1. DATV Block Diagram Showing Various Data-Rates and Symbol-Rates for DVB-S QPSK

The MPEG-2 encoder we 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.

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 RF bandwidth. 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.

DVB-S 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 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 FECviterbi algorithm. So the MPEG2 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 FECviterbi 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 FECreed-solomon algorithm, 204 bits come out for 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
GMSK	1
QPSK	2
8-VSB	3
QAM16	4
QAM256	8

Table 2 means that QPSK modulation will pack two data bits into each symbol being modulated. If we know the final output data bit-rate (we 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 Gross 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 is needed for our 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

We will now calculate an example for QPSK where the output of MPEG-2 is 2.05 Mbits/sec and FECviterbi is set to 1/2.

Symbol-Rate Needed = 2.05 Mbits/sec
2 bits/symb * (1/2) * (188/204)

Symbol-Rate Needed = 2.05 Mbits/sec
0.921 bits/symbol

Symbol-Rate Needed = 2.23 Msymbol/sec

Confusion About The Word "Bandwidth"

While talking to hams in Europe about DATV repeater designs, we noticed that sometimes we were given unexpected bandwidths being used by the European repeaters. The Symbol-rates (S/R) being reported by the repeaters were always accurate (Symbol-rate is always a setting in the transmitter, so it is well known), but the RF bandwidth reported sometimes had an unexpected relationship to Symbol-rate. A little searching on the Internet (love Google and Bing search engines) showed that there are at least three popular ways methods of defining RF bandwidth for DVB-S.

- "minus 3 dB" bandwidth method
- "occupied" bandwidth method
- "allocation" bandwidth method

So if you were to ask three different hams "what DATV bandwidth are you using?", you may get three different answers when talking about the same DATV repeater!!!

The authors agree that the most important purpose of describing bandwidth for DATV hams is to provide a value that can be used for band-plan spacing and frequency coordination to avoid adjacent interference.

Now we will look at these three methods of describing RF Bandwidth for DVB-S (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 an analog filter bandwidth and represents the "half-power point" if you are looking at voltage on a spectrum-analyzer.

Mathematically, BW-3dB ≈ S/R for this definition.

While the BW-3dB method is very familiar to analog engineers and analog ATVers, it is not very useful for DATV to define the bandwidth of a digital signal transmission link for two reasons.

First, a modulation with a digital-(pulse-)modulation signal produces a non-Gaussian signal-flank.

Second, you would not want to space several DATV stations "shoulder-to-shoulder" on their 1/2–power points, since significant power would overlap neighboring frequencies. This approach to spacing of stations would create potential receiving interference, especially if several DATV repeaters are located together on the same hilltop or tower and receiving antennas are pointing in the same direction toward adjacent DATV repeaters.

As a note, the bandwidth of the DVB-S carrier at the minus 3.8 dB points is approximately the same as the symbol rate (S/R).

"Occupied" Bandwidth Method

As defined by the commercial satellite standard, 3GPP TS 34.121, section 5.8, the Occupied Band-Width (OBW) is the bandwidth containing 99% of the total integrated power of the transmitted spectrum, centered on the assigned channel frequency.

Mathematically for hams: BWoccupied = 1.19 x S/R

How is the occupied bandwidth measurement determined?

During this measurement, a Gaussian filter with a bandwidth greater than 10MHz and a resolution bandwidth (RBW) of 30 kHz or less is used to measure the distribution of the power spectrum.

First, the total power found in the measured frequency range is calculated.

Then, starting at the lowest frequency in the range and moving upward, the power distributed in each frequency is summed until this sum is 0.5% of the total power. This gives the lower frequency value for measuring the bandwidth.

Next, starting at the highest frequency in the range and moving downward, the power distributed in each frequency is summed until 0.5% of the total power is reached. This gives the upper frequency value. The bandwidth between the 0.5% power frequency points is called the "occupied bandwidth."

While the "occupied" bandwidth spacing of repeater frequencies is better at preventing adjacent interference than "minus 3 dB" bandwidth spacing, it still lacks one feature. The spacing should have a little guard-band to allow for unplanned obstacles like signal-path nonlinearity, etc.

"Allocation" Bandwidth Method

This method for describing bandwidth provides a little guard band between adjacent DATV signals. The allocation bandwidth for DVB-S is calculated as

BWallocation = (1 + Roll-off-Factor) x Symbol-rate

BWallocation = 1.35 x S/R

when using a 0.35 Roll-off-factor. The Roll-off-factor (as shown in Figure 2) controls the grade of the slope of a DVB-S signal-edge.

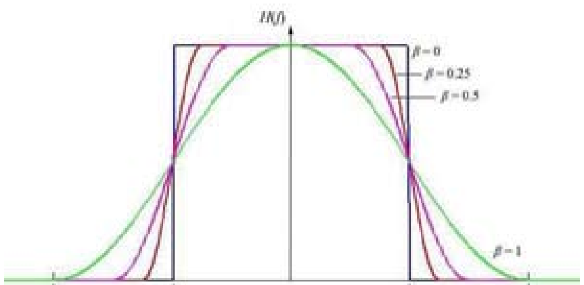

Figure 2. Different roll-off slopes for different Roll-off-factors

The "allocation bandwidth" is determined by the big commercial satellite-providers (like inside the Intelsat Earth Station Standard 420: (IESS420e.pdf) as an area, inside that the power-level will be not be lower than –26dB. There will be a filtering necessary on the signal borders (mostly performed by software), which takes care, that the borders rolls out weakly. The grade (slope) of this roll off will be described by the Rolloff-factor. It shows the relationship between half of the roll off area to half of the wanted channel-bandwidth.

DVB-S specifies the Roll-off-factor at 0.35. A raised cosine filtering at the edge region for the transmission path is required. The used filter generates in a first step only a root raised cosine shape. Only in combination with the same filtering inside the receiver you will get the wanted raised cosine form of the filter shape. After the transmitter, inside the "on the air" signal, you will find the larger signal shape (shown as the dotted larger signal shape (that is shown as the dotted line) in Figure 3.

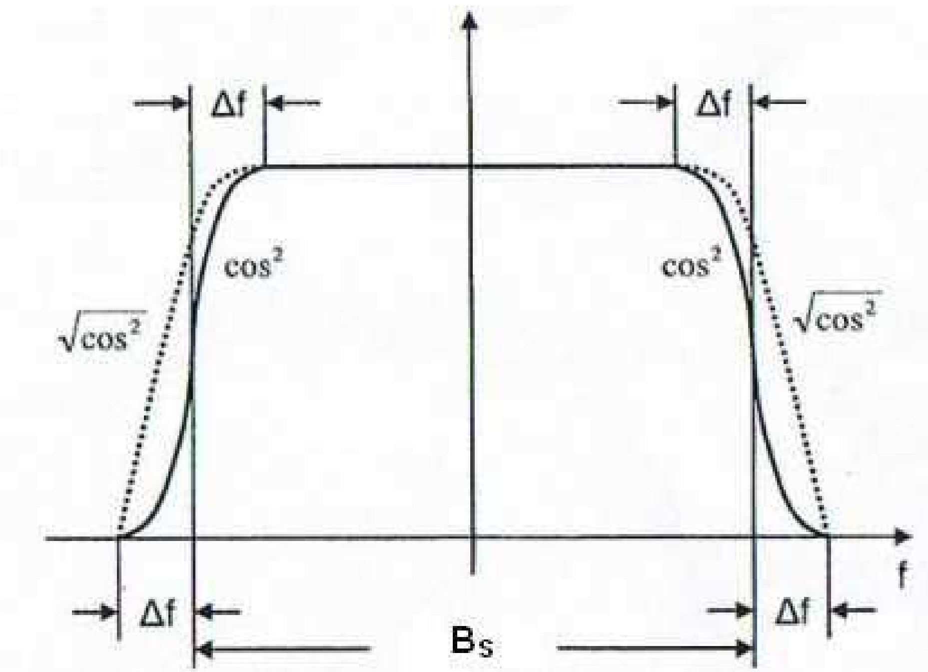

Figure 3. "On the Air" DVB-S signal has the shape shown as dotted lines

The DVB-S Standard uses a Roll-off-factor of 0.35 for video-transmissions and a Roll-off of 0.4 for data-transmission equipment. You may find that newer professional hardware utilizes a Roll-off-factor of 0.25.

The new DVB-S2-standard (for high definition TV - HDTV) also utilizes a Roll-off-factor of 0.2. This means, the DVB-S2 used bandwidth is only 20% bigger than the Symbol-rate. Hans, DC8UE, further explained that the DVB-S2 standard is now being used in Europe for transmissions from commercial broadcast-studios and also from an OB-van (outside broadcasting) to the uplink transmission center.

Figure 4 shows a DATV DVB-S QPSK signal using a 1.5 MSymbols/sec symbol-rate of (generated by a MiniMod). It shows clearly 2.025 MHz of used bandwidth.

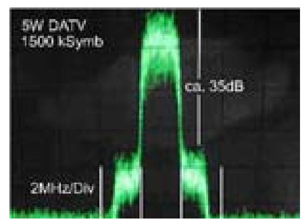

Figure 4. DATV QPSK signal at 1.5 M Symbol/sec produces 2.025 MHz of bandwidth

Below 35 dB you can see the additional shoulders, generated by intermodulation on the non-linear characteristic curves of the equipment being used. There is more on non-linearity, later in this article.

The "allocation bandwidth" is in practice really very useful to describe the real used bandwidth for spacing DATV repeater frequencies. However, for ham radio, Ken, W6HHC, prefers to "adjust" the allocation formula slightly to

BWallocation ~ = 1.33 x S/R

Ken explains that this "adjusted value" is less than a 2% error and is much easier to calculate in his head. The authors both agree that hams should only use the term BWallocation when they talk about DVB-S.

Choosing a Bandwidth

An advantage of digital ATV using the DVB-S standard is that the bandwidth can be narrower than the analog-ATV technology. Table 3 shows that a 3 MHz RF bandwidth can be achieved with plenty of error correction capacity (FEC = 1/2) by selecting a Symbol-rate of 2.25 M Symbols/sec.

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

Modulation	FEC Coderate	DVB-S RF BANDWIDTH for DATV (RF BWallocation = 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

Notes:

1: NTSC Analog Camera produces about 2.0 Mbits/sec MPEG-2 output for ham radio type broadcasts

2: The Net Data Bit-Rate values inside the Table need to be at 2.05 Mbps or larger to support the expected camera and audio data rates coming from MPEG-2 encoder

3: The Net Data Bit-Rate values inside the table shown in RED (with strike-through) are Net Data Bit Rates that are too small to support the payload data stream.

Non-Linearity Effects on QPSK Bandwidth

Digital modulation using phase shifting (PSK) like BPSK or QPSK transitions from one state to another state. For QPSK, you are always in one of four states and your next transition can be to any of those four states, as shown in Figure 5.

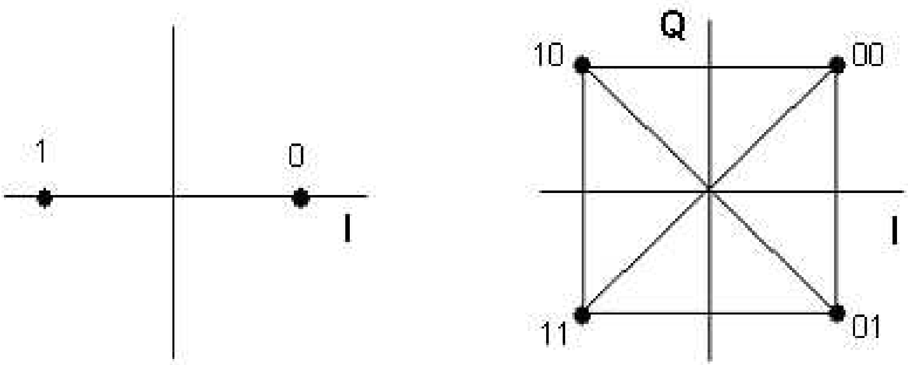

Figure 5. Theoretical transitions in the I-Q plane made by BPSK (on the left) with two states and by QPSK with four states.

However, non-linearity in the RF amplifiers can cause the received values of I and Q to contain errors from the theoretical. It is extremely important to avoid compression in the power amplifier and to operate the signal path and PA in a linear mode. Figures 6 through 9 show the effects of increasing non-linearity on the transition of states for QPSK modulation. Notice in Figure 9 that the non-linearity in the RF power amplifiers has brought the power level of shoulders much closer to the power level of the carrier. You can see in Figure 10 that the power levels of the shoulders have grown to 20 dB below the carrier. This will splatter power into adjacent frequencies outside of the allocated bandwidth.

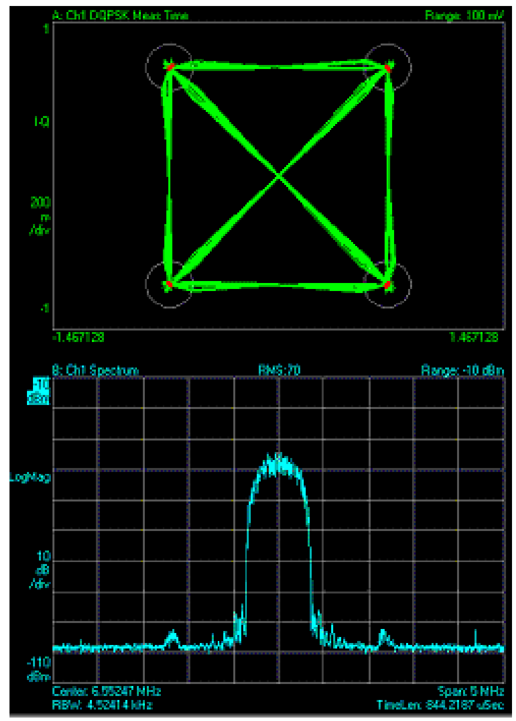

Figure 6. Real-world QPSK state transitions closely match theoretical with good linearity. (Photo courtesy of PE1JOK PE1OBW.)

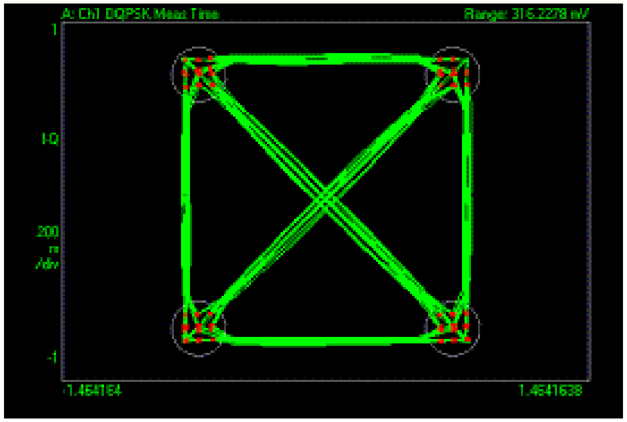

Figure 7. Increased non-linearity causes small errors in values of I and Q. (Photo courtesy of PE1JOK PE1OBW.)

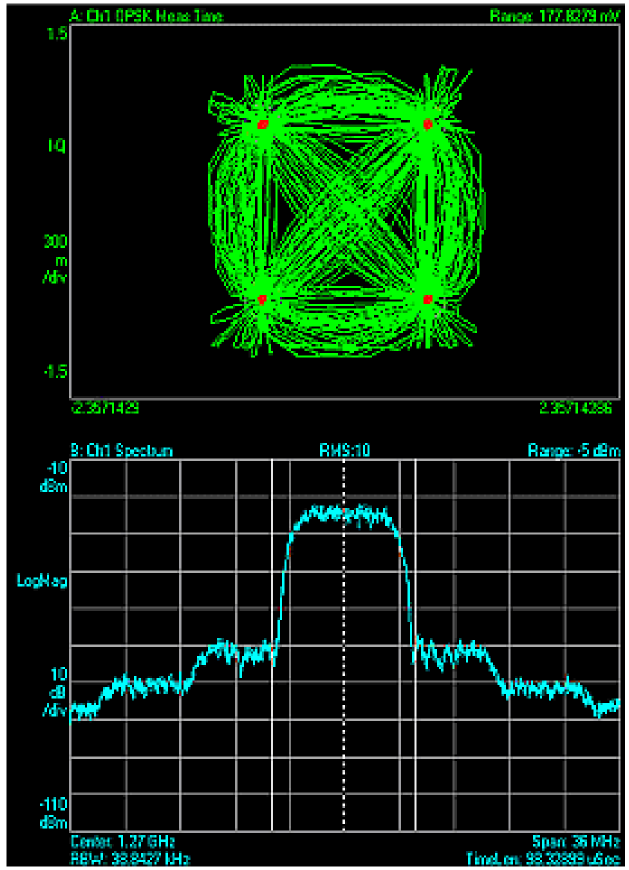

Figure 8. More amplifier non-linearity increases errors. (Photo courtesy of PE1JOK PE1OBW.)

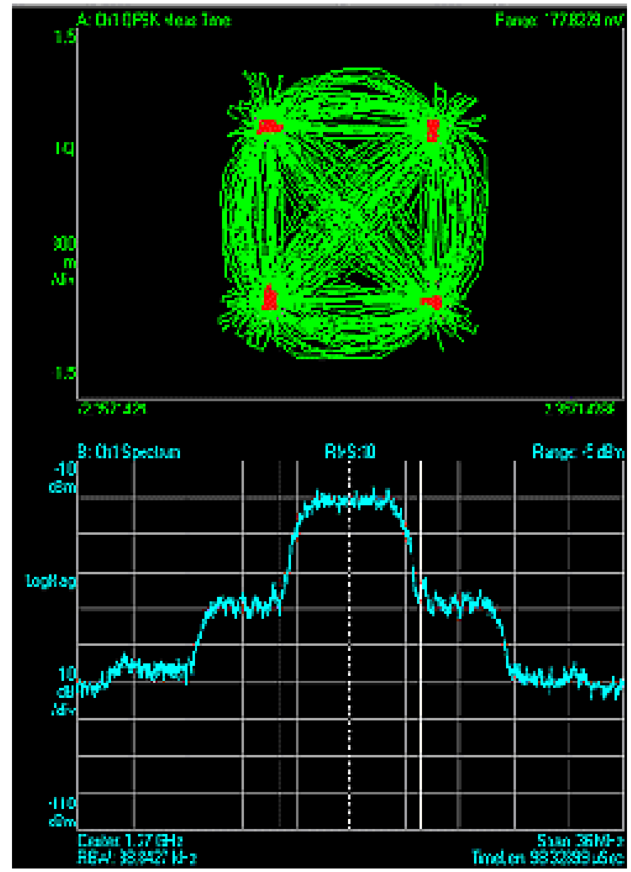

Figure 9. Amplifier non-linearity brings shoulders up. (Photo courtesy of PE1JOK PE1OBW.)

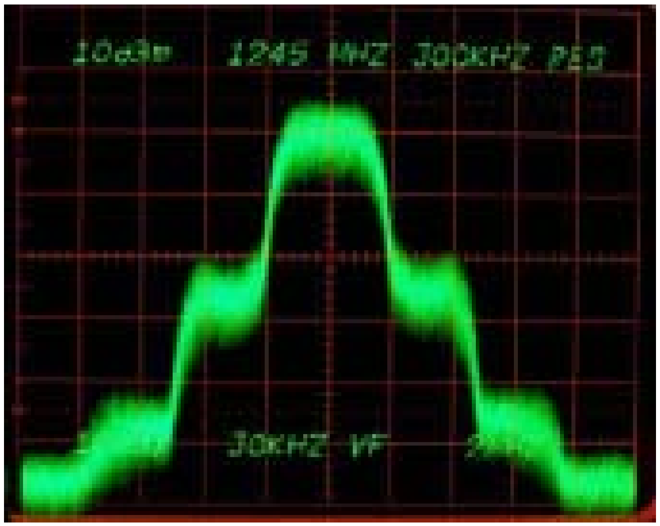

Figure 10. Spectral regrowth after amplification with shoulders now only 20 dB below the carrier. (Photo courtesy of Art, WA8RMC.)

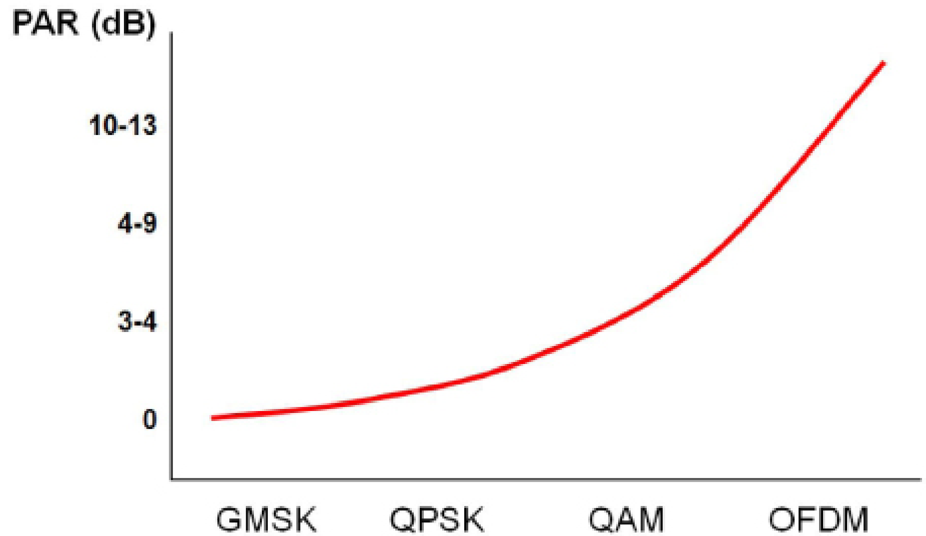

Figure 11. PAR for amplifier output power when processing signals with various digital modulation technologies. (Graph courtesy of Robert Green - Keithley Instruments, Inc.)

One concept that DATV hams need to understand with DATV amplification is that the DATV signal has a very high Peak-to-Average-Ratio, as shown as the parameter called PAR in Figure 11. So while the average power level may seem low, the peaks can be going into compression (or even flat-topping in saturation), hence non-linearity and hence stronger shoulder power levels.

Commercial satellite-uplink operators adjust their shoulders to be more than 26 dB below the main carrier. Likewise, it should be the duty of hams who operate DVB-S repeaters and transmitters to not allow the shoulders to get within 26 dB of their main carrier in order to avoid interference to nearby frequencies.

Interesting DATV Links

• Digital Video Broadcasting organization (DVB) – commercial TV – www.DVB.org

• Amateur Television of Central Ohio – www.ATCO.TV

• British ATV Club - Digital Forum – www.BATC.org.UK/forum/

• Thomas Sailer-HB9JNX/AE4WA, et al on "Digital AmateurTeleVision (D-ATV)" – www.baycom.org/~tom/ham/dcc2001/datv.pdf

• Jean-François Fourcadier-F4DAY on "The POOR MAN's DIGITAL ATV TRANSMITTER" – http://pagesperso-orange.fr/jf.fourcadier/television/exciter/exciter_e.htm

• Rob Swinbank-MØDTS on details of "Poor Man's Digital ATV Transmitter – LIVE update" – www.M0DTS.co.uk/datv.htm

• PE1JOK and PE1OBW on "The Ultimate Resource for Digital Amateur Television" – www.D-ATV.com

• Nick Sayer N6QQQ site for his future DATV repeater – www.N6QQQ.org

• Orange County ARC newsletter series of DATV articles – www.W6ZE.org/DATV/

• AGAF D-ATV components (Boards) –www.datv-agaf.de and www.AGAF.de

• Kuhne Electronics (DB6NT) microwave RF Amplifiers – www.Kuhne-Electronic.de

• SR-Systems D-ATV components (Boards) – www.SR-systems.de and www.D-ATV.org

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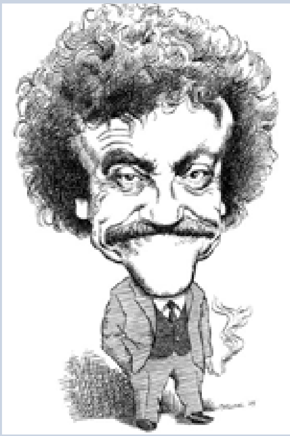
Write Early and Write Often



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