TechTalk 92

DATV – Looking at DVB-S2 Modulation

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Most 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-S2 modulation technology.

While the majority of DATV hams use DVB-S modulation and some hams use DVB-T modulation (see TechTalk86), I have had some conversations with hams who propose that ham radio should move on to DVB-S2 modulation for Digital-ATV. I am a big advocate of understanding all the competing DATV technologies and protocols, since each technology has its own set of strengths and weaknesses (aka: PROs and CONs). So let us see, if DVB-S2 can improve ham radio Digital-ATV?

Commercial World of Television

The Digital Video Broadcasting organization (DVB) approved DVB-S2 to be the modulation technology for commercial High Definition TV (HDTV) broadcast satellite transmissions (uplinks and downlinks). The DVB organization succeeded in getting DVB-S2 approved as a ETSI standard in March 2005. The DVB organization states that “DVB-S2 will not replace DVB-S in the short or even the medium term, but makes possible the delivery of services that could never have been delivered using DVB-S”.

Some of the commercial TV design goals for DVB-S2 are:

- Quasi-Error-Free operation at about 0.7dB to 1 dB from the Shannon limit
- Optimized for multi-stream HDTV
- Interactive Services (IS) Interactive data services including Internet access
- Digital TV Contribution and Satellite News Gathering (DTVC/DSNG)
- Data content distribution/trunking and other professional applications (PS)

I find it interesting to note that other than the first bullet above, none of the services and features in the other bullets are not of much interest to hams.

Typical Transmitter Block Diagram

DATV pioneer and enthusiast Stefan Reimann DG8FAC of SR-Systems in Germany has shown that DVB-S2 digital technology is possible for hams (see the SR-Sys model 2TS-MidiMOD2). **Fig 1** is a block diagram of a basic DVB-S2 ham station for DATV. The analog camera and video is compressed by a MPEG-2 encoder board. The TransportStream (TS) digital data is fed to the DVB-S2 exciter board that does a lot of complicated data processing and then converts the digital data directly into 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 1**, 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.

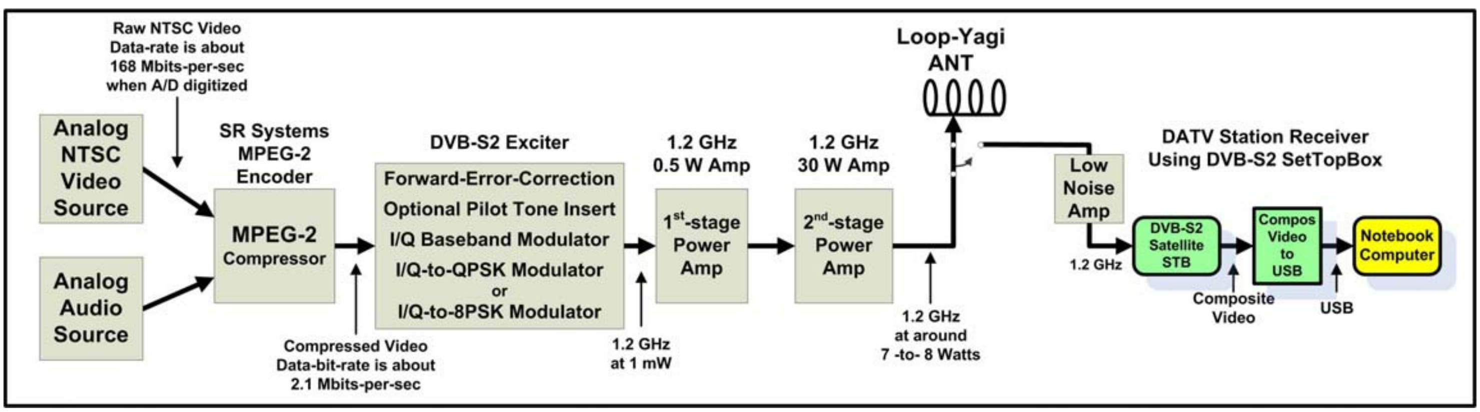

Figure 1 – Block Diagram of Basic DVB-S2 Station for DATV

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
NTSC H.264/MPEG-4	~1.5 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 H.264/MPEG-4	12-20 Mbits/sec	compressed

Notice in **Table 1** that the digitized NTSC camera video stream data-bit-rate 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 in the data rate,

The newer video CODEC, H.264, can be also used with DVB-S2. This CODEC is sometime called H.264, sometimes called MPEG-4-Part-10, and sometimes called Advanced Video Coding (AVC). But, all of these terms mean the same standard, technically. H.264/MPEG-4 can reduce the bit-rate by a factor of 50% over MPEG-2. However, the MPEG-4 encoding adds considerably to the latency of the transmitted signal, compared to MPEG-2.

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 band-width. 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 FEC algorithms used in the DVB-S2 protocol are different that those used in the older DVB-S and DVB-T protocols. The DVB-S commercial television standard uses a first FEC algorithm called the inner-Punctured-Convolutional-Code encoding specification and then decoded by Viterbi. The second FEC algorithm is called Reed-Solomon. Combining the Convolutional encoding with Viterbi decoding is an FEC technique that is well suited to a channel in which the transmitted signal has been corrupted by Gaussian noise.

The DVB-S2 FEC specification originated with the desire for improved efficiency. In DVB-S2, the DVB-S inner convolutional coding has been replaced with Low Density Parity Check (LDPC) coding and the DVB-S Reed-Solomon encoding is replaced with the Bose-Chaudhuri-Hocquenghem (BCH) algorithm for outer encoding.

The inner LDPC FEC algorithm can be configured for different levels of error correction. These different redundancy settings are usually called: 1/2, 3/5, 2/3, 3/4, 5/6, 8/9 and 9/10. (See **Table 2**) 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. In the case of "1/2", the data "inflation rate" is 100%

The second algorithm that is used is the BCH FEC algorithm produces a variable length overhead. It adds an overhead of typically 192 bits to a long data body frame for the FECFRAME length of 64,000 bits. Its data stream "inflation rate" is very small, typically around 0.5% or less depending on the FEC Rate (see **Table 3** for exact values).

Table 2 – FEC rates for DVB-S2 Broadcasts

FEC	QPSK	8PSK	16APSK	32APSK
1/4	Optional	No	No	No
1/3	Optional	No	No	No
2/5	Optional	No	No	No
1/2	Yes	No	No	No
3/5	Yes	Yes	No	No
2/3	Yes	Yes	Optional	No
3/4	Yes	Yes	Optional	Optional
4/5	Yes	No	Optional	Optional
5/6	Yes	Yes	Optional	Optional
8/9	Yes	Yes	Optional	Optional
9/10	Yes	Yes	Optional	Optional

Table 3 – Value of BCH "inflation" for 64,800-bit Frame

FEC Rate	Frame lengths	CR_{BCH}
1/4	16,008 / 16,008 + 192	0.98815
1/3	21,408 / 21,408 + 192	0.99111
2/5	25,728 / 25,728 + 192	0.99256
1/2	32,208 / 32,208 + 192	0.99407
3/5	38,688 / 38,688 + 192	0.99506
2/3	43,040 / 43,040 + 160	0.99630
3/4	48,408 / 48,408 + 192	0.99810
4/5	51,648 / 51,648 + 192	0.99630
5/6	53,840 / 53,840 + 160	0.99704
8/9	57,472 / 57,472 + 128	0.99778
9/10	58,192 / 58,192 + 128	0.99780

Digital Modulation Symbols and Symbol-Rates

Digital modulation technologies like BPSK (an example is PSK-31), QPSK (Quad Phase Shift Keying), 8PSK and 32APSK (Amplitude and Phase Shift Modulation with 32 "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 4** lists out how many data bits can be packed into a symbol for several well known digital modulation technologies.

Table 4 – Symbol Bit-Packing for Various Digital Modulation Technologies

Modulation Scheme	Data Bits per Symbol (Me)
BPSK	1
GMSK	1
QPSK	**2**
8PSK	**3**
8-VSB	3
16APSK	**4**
QAM-16	4
32APSK	**5**
QAM-64	6
QAM-256	8

The higher-order modulations schemes, like 16APSK and 32APSK, can "pack" more bits into the symbol rate than QPSK. But, the complexities for 16APSK and 32APSK modulation make them more susceptible to noise and interference than QPSK. The DVB-S2 protocol provides for QPSK, 8PSK, 32APSK, and 32APSK (marked in **BLUE** in **Table 4**. The drawings in **Fig 2**, **Fig 3**, **Fig 4**, and **Fig 5** are intended to give an appreciation of the increasing complexities for these modulation schemes.

Notice in **Fig 4** and **Fig 5** that not only is the angle from the origin to the state important, but the amplitude from the origin is critical, also. Think of APSK as a modulation that is similar to QAM modulation...but providing a circular constellation.

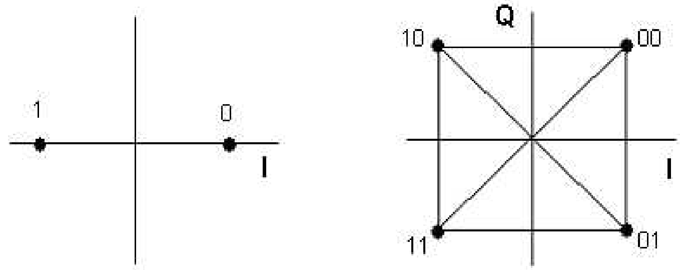

Figure 2 – The modulation constellations of BPSK (on the left) with two states and by QPSK with four states.

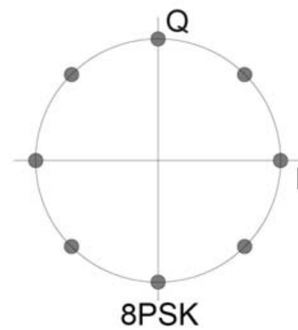

Figure 3 – The constellation for 8PSK modulation contains 8 states. Each state defines three bits of data.

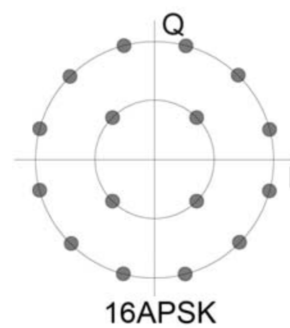

Figure 4 – The constellation for 16APSK modulation contains 16 states. Each state defines four bits of data.

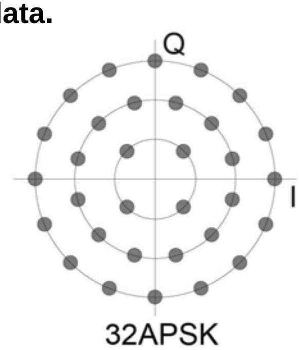

Figure 5 – The constellation for 32APSK modulation contains 32 states. Each state defines five bits of data.

Hans Hass DC8UE in Hamburg has conducted DATV testing to compare DVB-S2 to DVB-S. When testing with DVB-S (QPSK with FEC equal 1/2) he needs the signal to be 5.5 dB above the noise (C/N). With DVB-S2 QPSK (FEC = 1/2) he needed C/N = 2.2 and with 8PSK (FEC = 3/5) he needed C/N = 6.5. Clearly the more complicated 8PSK modulation is more susceptible to noise.

For commercial DVB-S2 satellite broadcasting, only the QPSK and 8PSK modulations are currently being used. Stefan DG8FAC of SR-Systems explains that commercially, “16APSK and 32APSK modulations are only for Ground Links [and for portable Uplinks] at the moment”. I do not know of any ham DATV installations that are currently using 16APSK or 32APSK modulation.

DVB-S2 Bandwidth

Table 4 shows for example that 8PSK modulation will pack three 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-third of that gross data-bit-rate. That is: each symbol will produce three bits of data.

For example:

Gross Data-Bit-Rate = 4.5 Mbits/sec

Symbol-Rate Needed = 1.5 Msymbols/sec

The formula to calculate the Symbol-Rate setting that is needed for a DVB-S2 transmitter is:

$$\textbf{Symbol-Rate Needed} = NDBR / (Me \times CR_{LDCP} \times CR_{BCH})$$

Where:

NDBR = Net Data Bit Rate (aka the information rate) Same as MPEG-2 output data rate in Fig 1
Me = Modulation Efficiency (3 for 8PSK in Table 4)
CR_{LDPC} = Correction Rate setting for LDPC (1/2, 3/4, etc)
CR_{BCH} = Correction Rate value for BCH found in Table 3

I will now calculate an example for 8PSK modulation where the output of MPEG-2 encoder is 2.4 Mbits/sec and the FEC rate is set to a value of 3/5.

$$\textbf{Symbol-Rate Needed} = \frac{2.4 \text{ Mbit/sec}}{3 \text{ bits/symb} * (3/5) * (0.99506)}$$

$$\textbf{Symbol-Rate Needed} = \frac{2.4 \text{ Mbit/sec}}{1.791 \text{ bits/symb}}$$

$$\textbf{Symbol-Rate Needed} = 1.34 \text{ Msymbols/sec}$$

The final formula is for DATV Bandwidth (BW). The “roll-off” factor affecting **$BW_{allocation}$** for DVB-S2 is 0.2; compared to DVB-S where roll-off is 0.35. For the DVB-S2 modulations, the formula for (allocation) RF BW is:

$$\textbf{RF } BW_{allocation} = 1.2 \times \textbf{Symbol-Rate}$$

Figure 6 shows a spectrum analyser capture of a 1.2 GHz DVB-S2 signal, using 8PSK modulation (13.5MSymb/sec, FEC=3/5, Pilots ON, RollOff = 20%). The Bandwidth shown is about 16.2 MHz.

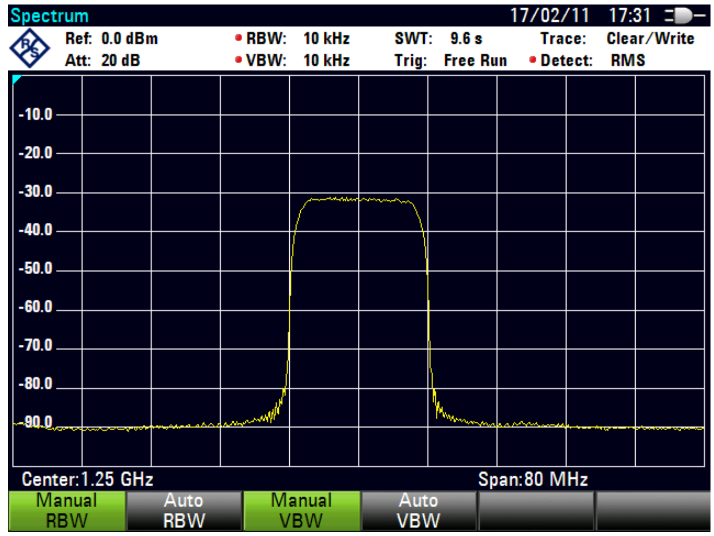

Fig 6 - A DVB-S2 MidiMOD2 exciter 8PSK output transmission is seen on a Spectrum Analyzer (Courtesy of Stefan DG8FAC)

The Net-Data-Bit-Rate (NDBR) capacity that can be supported in a particular bandwidth is listed in **Table 6**. Note that these values do not include the overhead introduced by inserting Pilot Tones for improved receiving robustness.

Receiving DVB-S2

In **Fig 1**, the block diagram shows a typical DVB-2 receiving station used for DATV. The DVB-S2 SetTopBox (STB) can be purchased on e-bay and other online stores here in the USA. The output of many S2 STB’s include: composite video, S-video, component video, and HDMI interfaces. It is interesting to note that the DVB-S2 STB usually will receive old DATV DVB-S transmissions using a “modified 8PSK mode” setting that is backward compatible to DVB-S.

PRO’s and CON’s

Table 7 attempts to compare the strengths and weaknesses of DVB-S2 against DVB-S for Digital-ATV. There is no question that DVB-S2 provides a more robust signal and can pack multiple TS video streams into a small bandwidth. But, most of the DVB-S2 STB receivers currently are not designed to tune down below 10 MSymb/sec, and so this limitation makes it difficult to receive a signal with a 2 MHz bandwidth.

Table 6 - Net Data Bit-Rates for DVB-S2 at a given RF Bandwidth

Modulation	FEC Coderate	DVB-S2 RF BANDWIDTH for DATV (RF BW = SymbolRate x 1.2)						
		1.5 MHz (SR = 1.25 MS/sec)	2.0 MHz (SR = 1.67 MS/sec)	2.5 MHz (SR = 2.08 MS/sec)	3.0 MHz (SR = 2.5 MS/sec)	4.0 MHz (SR = 3.33 MS/sec)	5.0 MHz (SR = 4.17 MS/sec)	6.0 MHz (SR = 5.0 MS/sec)
QPSK	1/4	~~0.62~~	~~0.83~~	~~1.03~~	~~1.24~~	~~1.65~~	2.06	2.47
	1/3	~~0.83~~	~~1.10~~	~~1.37~~	~~1.65~~	~~2.20~~	2.76	3.30
	2/5	~~0.99~~	~~1.33~~	~~1.65~~	~~1.99~~	2.64	3.31	3.97
	1/2	~~1.24~~	~~1.66~~	~~2.07~~	2.49	3.31	4.15	4.97
	3/5	~~1.49~~	~~1.99~~	2.48	2.99	3.98	4.98	5.97
	2/3	~~1.66~~	~~2.22~~	2.76	3.32	4.42	5.54	6.64
	3/4	~~1.87~~	2.50	3.11	3.74	4.99	6.24	7.49
	4/5	~~1.99~~	2.66	3.32	3.99	5.31	6.65	7.97
	5/6	~~2.08~~	2.78	3.46	4.15	5.53	6.93	8.31
	8/9	~~2.22~~	2.96	3.69	4.43	5.91	7.40	8.87
	9/10	~~2.25~~	3.00	3.74	4.49	5.98	7.49	8.98
8PSK	3/5	~~2.24~~	2.99	3.73	4.48	5.96	7.47	8.96
	2/3	2.49	3.33	4.14	4.98	6.64	8.31	9.96
	3/4	2.81	3.75	4.67	5.61	7.48	9.36	11.23
	5/6	3.12	4.16	5.18	6.23	8.30	10.39	12.46
	8/9	3.33	~~4.44~~	5.53	6.65	8.86	11.10	13.30
	9/10	3.37	4.50	5.60	6.74	8.97	11.23	13.47
16APSK	2/3	3.32	4.43	5.52	6.63	8.84	11.07	13.27
	3/4	3.74	4.99	6.22	7.47	9.95	12.46	14.94
	4/5	3.99	5.33	6.64	7.98	10.64	13.32	15.97
	5/6	4.15	5.55	6.91	8.31	11.07	13.86	16.62
	8/9	4.43	5.92	7.38	8.87	11.81	14.79	17.74
	9/10	4.49	6.00	7.47	8.98	11.96	14.98	17.96

(NOTE-1: NTSC Analog Camera produces about 2.1 to 2.4 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 of 2.4 Mbits/sec.)

(NOTE-4: The Net Data Bit-Rate values are based on using a DVB-S2 FEC FRAME length of 64,800 bits.)

(NOTE-5: 16APSK and 32APSK modulations are currently not used for commercial TV broadcasts. 16APSK is shown only for comparison.)

Table 7 – Comparing DVB-S2 with DVB-S

	DVB-S2	DVB-S
PROs	Quasi-Error-Free operation at about 0.7dB to 1 dB from the Shannon limit 1xTS Bandwidth can be as small as 1 or 1.5 or 2 MHz with 8PSK Cheap Set Top Boxes (STB) on eBay and online 3 MHz bandwidth can support multiple video streams	1xTS 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 Newer DVB-S2 STB will receive DVB-S
CONs	Most DVB-S2 STB receivers will only tune down to 10 MSymbol/sec (12 MHz bandwidth) Currently DVB-S2 exciter board is 100% more expensive than DVB-S	QPSK modulation requires larger bandwidth than 8PSK modulation

Conclusion

I am not yet convinced that DVB-S2 is the correct technology direction for ham D-ATV. Most new features provided by DVB-S2 technology (like "news gathering" and "data content trunking") are not of much interest to ham DATV. My main DATV interest is fitting narrow DATV 1xTS bandwidth into crowded ham band spectrum plans. I can envision placing three 2 MHz DATV repeater signals into the band space that used to be occupied by a single 6 MHz analog ATV signal. But, the STB inability to tune in a 1.5 MSymb/sec signal…blocks my goal. Certainly DVB-S2 can provide a great technology for multiple video streams that can be used by DATV repeater operators.

(see interesting DATV URL links on next page)

Interesting DATV Links

- Digital Video Broadcasting organization (DVB commercial standards) – see **www.DVB.org**
- Digital Video Broadcasting standard for DVB-S2 – see ETSI EN 302 307 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**
- 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**
- Down East Microwave RF amplifiers – see **www.DownEastMicrowave.com**
- Orange County ARC TechTalk76-DATV on DVB-S modulation – see **www.W6ZE.org/DATV/**
- Orange County ARC TechTalk86-DATV on DVB-T modulation – see **www.W6ZE.org/DATV/**
- Orange County ARC newsletter entire series of DATV articles – see **www.W6ZE.org/DATV/**
- Wikipedia on DVB-S2 – see **http://en.wikipedia.org/wiki/DVB-S2**
- Wikipedia on H.264/MPEG-4 – see **http://en.wikipedia.org/wiki/H.264**