Application Note
AN-17

DVB-T the Solution for Ham Digital Television

Jim Andrews, KH6HTV
www.kh6htv.com

CATV 64-QAM: My first experiences [1] with amateur radio, high-definition, digital television (DTV) was in 2011. At that time, I experimented with the system used in North American cable TV (CATV) systems. It is Quadrature Amplitude Modulation (QAM) of either 64QAM or 256QAM, as specified by the standard ITU-T/J.83B, Annex B. I used a QAM modulator produced by R.L. Drake, their model DSE24 ($1,200). The DSE24 covered 5 MHz to 1 GHz with 6 MHz QAM-DTV channels. It would handle up to 1080i video input, with HDMI, VGA, component and composite video inputs. The RF output power was about -4dBm. Thus, an RF power amplifier was necessary to boost the power to useable watt levels for radiation from an antenna for ham TV purposes.

In the fall of 2011, a set of field trial experiments were run in Boulder, Colorado to compare the propagation characteristics of VUSB-TV, FM-TV, DVB-S, and CATV 64-QAM analog and digital TV systems. The results were documented in KH6HTV VIDEO application note, AN-3, [2]. CATV 64-QAM worked, but it was judged that it was not going to be particularly useful for any emergency, field portable, ARES situations. The major use for ham TV in Boulder, Colorado is for ARES support of the local sheriff, police and fire agencies [3]. The CATV 64-QAM issues discovered included:

(1) Receiver Sensitivity --- the 64-QAM digital threshold sensitivity of typical commercial analog/digital TV receivers was -78dBm. 256-QAM was 8dB worse at -70dBm. The sensitivity of the other systems were 10 to 20dB better than 64-QAM.

(2) Multi-Path --- multi-path distortions of the rf spectrum exceeding 10dB caused the receiver to stop decoding the signal. In many situations when we had a true, visual, line-of-sight path between the transmit and receive antennas, we were still unable to receive the DTV signal due to multi-path.

(3) Mobile --- in general, except in extremely strong signal areas, mobile operation simply did not work at all. The DTV receiver seemed to take one to two seconds to achieve lock. With mobile "flutter" of varying signal strengths and multi-paths, the receiver simply could not keep up and thus -- no picture.

(4) Unfriendly Receivers --- The first decision to use CATV QAM versus some other systems, such as DVB-S, was strongly driven by the idea that users would not have to purchase a special converter box, but would be able to use any commercial analog/digital TV receiver, such as they might purchase at Best Buy, Wal-Mart, etc. The CATV channels covered directly the ham 70cm band with channels 57-61. However, we got unexpectedly burned on this issue of using commercial receivers. Yes, these receivers would receive directly the 70cm, CATV analog or digital TV signals, but they were definitely not user friendly to TV hams wanting to receive unknown, intermittently transmitted, weak ham DTV signals. We discovered to our dismay that the vast majority of TV receivers on the market did not provide "random access" to any arbitrary digital TV channel via the remote control. They demanded that an "Auto Scan" must be made when ever looking for a new digital channel. They were designed to be connected to a real CATV cable, auto scanned once to determine all available channels and then never done again. We quickly discovered that we had to purchase a separate TV receiver for ham DTV and then "train" it to receive the desired DTV channel by connecting it directly to the output of their Drake DSE24 modulator. It could not then be used for any other purpose.

DVB-T for Hams I have just discovered the benefits of DVB-T for ham DTV and they far surpass those of CATV 64-QAM. The spring 2014 issue of Amateur Television Quarterly was most enlightening [4]. The propagation results reported by WB8ELK, W4HTB AND W8ZCF were very encouraging. Also the DVB-T equipment offered by a new ATVQ advertiser was appealing. The company, HiDes Technologies in Taiwan (www.HiDes.com.tw) was advertising DVB-T modulators and receivers in both complete packages or as "USB Dongles" for use with a supporting PC computer. Their prices were quite reasonable and within the range of a typical ham's budget. I thus ordered their model HV-100EH Modulator ($560) and their HV-110 Receiver ($169). The results reported here are based upon using these two pieces of equipment.

What is DVB-T ? It stands for **D**igital **V**ideo **B**roadcasting - **T**errestrial. [4, 5] It is the high-definition (also supports standard definition) digital TV broadcasting system now used in Europe and several other areas world-wide. It was developed by the European Broadcast Union. It is not compatible with the DTV system used in North America called ATSC, 8-VSB. Hams in general are not experimenting with ATSC because the cost of modulators has been extremely expensive. The DVB-T system seems to be ideally optimized for terrestrial use where multi-path is a major issue. Many reports claim that DVB-T is superior in performance to ATSC. I myself have experienced the inability to receive ATSC while mobile, whereas DVB-T works in a mobile environment.

DVB-T has a choice of three different basic modulation methods. They are Quadrature Phase Shift Keying (QPSK), or Quadrature Amplitude Modulation (QAM) with either 16 or 64 states. The max. data rates increase going from QPSK up to 64QAM. Commercial broadcast systems in different countries allow different bandwidths from 5 MHz up to 8 MHz. In the USA, we are constrained to a max. 6 MHz bandwidth. Hams in Europe, Australia and New Zealand have been experimenting with bandwidths down as low as 2 MHz (at lower data rates & standard definition). HiDes is catering to the ham DTV market by providing modulators and receivers which will operate from 2 to 8 MHz bandwidths.

DVB-T uses COFDM i.e. Coded Orthoganl Frequency Division Multiplex. Thus a DVB-T signal consists of a large number of discrete carriers (2K, 4K or 8K approx). An 8K system allows reception with longer multi-path echos. There are also embedded Pilot Carriers, either continual (same location in symbol) or "scattered" (puesdo random location in symbol). Pilots are at higher power levels and are used to estimate channel characteristics. A "Guard Interval" is always included within each OFDM symbol. The Guard Interval is used to sychronize the receiver, i.e. same as sync pulses in NTSC. The Guard Interval can be adjusted from 1/32, 1/16, 1/8 or 1/4. A larger guard inteval implies a lower bit-rate efficiency and is thus a trade-off between bit-rate and network tolerance to echos and reflections. Forward Error Correction (FEC) is also included in the data overhead. FEC choices are: 1/2, 2/3, 3/4, 5/6 or 7/8. 1/2 means for every real data bit there is also a FEC bit, i.e. 100% overhead. 7/8 means for every 7 real data bits there will be one FEC bit.

HV-100EH DVB-T Modulator: There are a large number of parameters that can be adjusted in the HiDes HV-100EH Modulator. The parameters are all set using a PC computer and a USB connection. HiDes supplies the necessary software on a DVD disc. The program is called: *AVsenderUART-GUI*. For the incoming video/audio media adjustable parameters include: input (HDMI or composite); Encoding (MPEG2 or H.264); Data Rate Control, Aspect Ratio and max. Bit Rate. The HV-100EH automatically determines the parameters of the incoming video/audio stream and sets other parameters accordingly. The Transmission mode parameters that can be adjusted include: Bandwidth (2, 3, 4, 5, 6, 7 or 8 MHz); Modulation (QPSK, 16QAM or 64QAM); FFT (2K, 4K or 8K), FEC (1/2, 2/3, 3/4, 5/6 or 7/8) and Guard Interval (1/32, 1/16, 1/8 or 1/4).

The HV-100EH is capable of operating from 70 to 950 MHz (includes 70cm & 33cm amateur bands) and also 1200-1350 MHz (23cm band). The software comes preprogammed with the standard commercial broadcast channels used world wide. The modulator is intended to normally be operated on one of these commercial broadcast channels 01 thru 99. The appropriate channel table is loaded into the modulator. While Hi-Des does include a few special channels in the ham bands, they are not all inclusive of all the available channels we might want to use. Fortunately, HiDes does allow the user to program their own custom frequency into channel 00. This must be done using a Windows PC computer via the USB cable. The PC doesn't need to be permanently connected. It can be removed after uploading the new frequency, etc. parameters. The channel center frequency can be entered to any arbitrary frequency with 1 kHz resolution. The bandwidth can be from 2 to 8 MHz. The output power from the modulator is -3dBm average. The modulator includes an accurate attenuator/gain control. It's range is +6dB gain to -20dB loss.

Obviously at this low power level of only -3dBm an RF power amplifier will be required to boost the power level to anything useful for radiation from an antenna. DC power requirements for the modulator are +12Vdc at 465mA.

HV-110 DVB-T Receiver: The receiver is in a very small package. It has absolutely no controls. It can only be controlled via the supplied IR remote control. On the rear panel, there is an SMA jack for the antenna input. Video output is simultaneously via HDMI and composite. The composite output is a video - stereo audio, 1/8" jack. The output display resolution can be adjusted in the "Set Up" menu anywhere from 480i up to 1080p. However, the composite output only works when the resolution is set to 480i, thus also forcing the HDMI output to also be 480i. There is also a switch on the rear panel for selecting bandwidth. Down is 2-4 MHz. Up is 5-8 MHz. This switch is only read upon DC power up. The HV-110 operates on +5Vdc and is powered via either a DC plug or via mini-USB. When powered using a mobile USB power adapter (12V to 5V switcher), it draws 315mA from a 12 V battery. On the front panel is a two digit LED display for the channel number. There is also a red/green LED power indicator. Green means a valid DTV signal is being received. Red means no signal present. To select or program the channel, the remote control must be used. To program a custom receive channel 00, push the MENU button (note: the "Back" button is the Menu / Exit button) and work thru the "Installation" menu to set the desired bandwidth and channel center frequency.

DVB-T Receiver Sensitivity: The first tests that were run were receiver sensitivity. The HV-100EH modulator was the signal source. A Sony camcorder playing pre-recorded video provided the "live" HDMI or composite video/audio input. To provide good rf isolation, the modulator was placed in another room and a long run of RG-58 coax was used to route the test signal to the measurement bench. Low level receiver sensitivity tests can not be performed accurately when the rf source is on the same test bench. This is due to minute rf leakage from the imperfectly shielded source and imperfect shielding in the receiver. The modulator was set to -3dBm output and the power at the end of coax cable was measured accurately using an HP-432A RF Power Meter. 40dB of attenuation was then installed on the output of the modulator. At the test bench a Weinschel 1dB/10dB step attenuator was used to precisely set the input power to the receiver under test. Attenuation was increased until the DTV receiver "froze" and the front LED light turned red. Backing off 1dB typically resulted in a "live", P5 picture with audio. The digital cliff effect was typically a range of 1dB, or at most 2dB. The lowest level at which the receiver decoded was recorded as the sensitivity. Tests were run on a 70cm frequency of 429MHz (ch 58) for both 6 MHz and 2 MHz bandwidths. The receiver was tested for all three modes of QPSK, 16QAM and 64QAM. The tests were also then repeated using a low noise (0.5dB NF, 18dB) preamplifier in front of the HV-110 receiver. The preamp used was an ARR model P432VDG. The results are tabulated in the following table.

HiDes Model HV-110 DVB-T Receiver Sensitivity

Mode	6 MHz rcvr only	6 MHz with preamp	2 MHz rcvr only	2 MHz with preamp

QPSK	-97 dBm	-100 dBm	-100 dBm	-102 dBm
16QAM	-92 dBm	-94 dBm	-97 dBm	-98 dBm
64QAM	-82 dBm	-85 dBm	-83 dBm	-85 dBm

As expected the most sensitive mode was QPSK. There was a 15 dB spread between QPSK and 64QAM. Thus for typical ham weak signal work, we should restrict ourselves to using the QPSK mode. The results obtained with 64QAM were very comparable to those previously measured with CATV 64QAM. Using a good, low-noise, preamp typically improved the sensitivity by 2 to 3 dB. It should be noted that I was unable to duplicate the results reported by OE7DBH in ATVQ [6]. He reported getting a sensitivty of -102 dBm with 16QAM, 2 MHz BW at 436 MHz. There is a 5 dB difference in our measurements.

DVB-T Transmitter Performance: A DVB-T transmitter was assembled using the HV-100EH modulator driving the RF power amplifier in a KH6HTV VIDEO model 70-10AD, analog TV transmitter. The 70-10AD has adjustable RF output power levels of 10W, 3W or 1W(pep). The 70-10AD includes a commercial CATV, NTSC, VSB-TV modulator. Jumpers on it's rear panel allow the NTSC modulator to be disconnected and an external DTV modulator used to drive the rf power amplifier module. Bench tests were run on this transmitter using the DVB-T QPSK and QAM modes under different drive conditions. The output from the transmitter was attenuated 30dB with a Narda high power attenuator. A directional coupler after the 30dB attenuator was used to supply a signal to the DVB-T receiver. A Rigol model DSA815 spectrum analyzer was used to accurately measure the spectrum. Average rf power was measured using the HP-432A power meter.

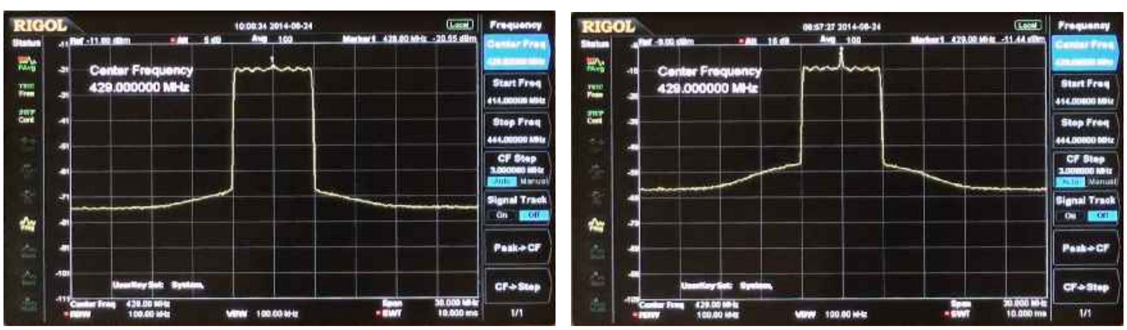

Fig.1 DVB-T, 6 MHz BW Spectrums. Left is modulator output at -3dBm. Right is DVB-T Transmitter output at +30dBm. 10dB/div & 3MHz/div.

The first test was to determine what linearity is required for the various modes. The key measure of non-linearity was to observe on the spectrum analyzer the spectral regrowth outside the DTV bandwidth. The ideal DTV signal appears as a noise signal riding on a 6 MHz (or 2 MHz) wide, rectangular pedestal. Non-linear spectral regrowth appears as an increase in the noise on shoulders on either side of the pedestal. Fig. 1 shows the 6 MHz BW, DTV outputs from both the HV-100EH modulator and the transmitter.. The modulator's shoulder break-point is about -46dB down. At 1 Watt (+30dBm) output, the transmitter's break-point is -37dB. If the transmitter is severely overdriven to saturation, the output power is +43dBm, but with a breakpoint of only -12dB. The out of band spectrum is excessive with the -20dB bandwidth being 14 MHz. The spectral regrowth shoulder breakpoints improve with lower RF output power. They are respectively: -27dB, -32dB, -35dB & -37dB at average output powers of +37, +35, +33 and +30dBm respectively. The acceptable limit for spectrum regrowth was considered to be -30dB. At this level, the rf output from the 70-10AD amplifier was +35dBm avg.

The testing of the different modes consisted of turning up the rf drive level until the DVB-T receiver's video output locked up. With QPSK, the receiver still decoded even when the amplifier was fully saturated. With 16QAM, the receiver locked up when the shoulder break-point just reached -12dB. With 64QAM, the receiver video started pixelating when the shoulder break-point reached -27dB and totally locked up at -23dB. Identical results were obtained with either 2 MHz or 6 MHz bandwidths.

Based upon the better receiver sensitivity of QPSK, it was decided that this mode should be used for all ARES operations. Thus, all of the remaining tests were performed with hi-def, 1080i, video with 6 MHz bandwidth and QPSK modulation. The 2 MHz bandwidth will also be considered, but only when it becomes necessary to field a lot of TV cameras/transmitters simultaneously or in an extremely weak signal situation.

DVB-T Propagation Tests: A field test was performed to compare the performance of classical, analog, NTSC, VUSB-TV versus DVB-T QPSK. Identical test conditions were used. The operating frequency was channel 58 (426-432 MHz), 6 MHz bandwidth. The rf power levels were both set at 1 Watt. The analog transmitter was the model 70-10AD with the output power set to 1 Watt. The major DVB-T media and transmission parameters used were HDMI (1080i), H.264 encoding, 6 Mbps max. bit rate, Channel 00, freq = 429 MHz, 6 MHz bandwidth, QPSK modulation, 8K FFT, 5/6 FEC code rate, 1/16 guard interval, and modulation data rate 7.32Mbps

A Sony camcorder playing back pre-recorded video and audio provided the "live" video, both in hi-def (1080i) HDMI and std. def. (480i) composite. The TV camera/transmitter was set up in the back yard of my residence. Two seperate transmit antennas were used. To simulate a real world ARES portable operation, a flexible whip antenna (2.4dBi) was attached to the camera tripod. The other test used an omni-directional base station antenna (6dBd) at 20 ft. elevation with 3/8" hardline coax. The immediate neighborhood was a very typical suburban environment with a mix of one and two story houses, on flat terrain. The neighborhood is an older one with lots of landscaping vegatation and lots of very large trees in full leaf. There was no open terrain. The rf signal had to fight it's way out through lots of houses, cars, trees, etc.

The mobile receiving setup consisted of a mag. mount tri-band (2m/70cm/23cm) antenna with 6dBi gain on ch 58. The antenna was connected to the 1dB/10dB step attenuator, then the ARR preamp and then into the HV-110 DVB-T receiver. The video output from the DTV receiver was displayed on a small 7", portable, Haier LCD TV receiver/monitor. To test the analog NTSC signal, the output from the preamp was connected directly to the antenna input of the 7" LCD TV receiver. With the step attenuator, it was possible to make calibrated field strength measurements by cranking in attenuation until the calibrated receiver locked up or the analog squelch closed.

The mobile DTV receiver was driven all around the immediate neighborhood to determine the total, 100% coverage area and radius. It was then driven at various speeds elsewhere within the Boulder valley and up into the foothills of the Rocky mountains. The most distant point tested was about 4 miles from the transmitter site. Solid P5, DVB-T pictures were received at numerous locations out to the max. tested radius of 4 miles from both transmit antennas.

BOTTOM LINE DVB-T PROPAGATION CONCLUSIONS

(1) If you can receive a P2 analog, NTSC, picture, in all likelyhood, you will get a P5 DVB-T picture. If it is a P3 analog, I guarantee you a P5 DVB-T picture.

(2) For a guaranteed P5 digital TV or P3 or better analog picture, the immediate, 100% service area in a typical suburban environment, using a 1 watt, 70cm TV transmitter, would be: (a) With both antennas at ground level (i.e. 5 ft) = approx. 1/4 mile or 450 yard radius (b) With one antenna at ground level (5ft) and the other at 20ft = approx. 1/2 mile or 900 yard radius.

(3) Multi-path ghosting was almost always present on the analog picture. The DVB-T algorithums removed completely all ghosting. Always a perfect P5 picture.

(4) Mobile operation always results in "mobile flutter" on the analog picture, even in strong signal areas. I ran mobile reception at speeds up to 65mph and always got perfect P5 pictures with no breakups with DVB-T. Thus, the DVB-T algorithums correct for doppler shifts well.

(5) Very long distance propagation is possible with low power DVB-T when a true line of sight path is available. Even when multi-path is present on this path, a perfect P5 picture results.

REFERENCES:

1. "Digital TV -- the Good, the Bad & the Ugly", Jim Andrews, KH6HTV VIDEO Application Note, AN-2, rev. Nov. 2011 www.kh6htv.com

2. "Field Trials Comparing VUSB, FM, DVB-S & 64-QAM Television", Jim Andrews, KH6HTV VIDEO Application Note, AN-3, Sept. 2011 www.kh6htv.com

3. "ATV & Public Safety", Jim Andrews, talk presented at ATV Forum, 2013 Dayton Hamvention. available at www.kh6htv.com

4. Amateur Television Quarterly, spring 2014 --- in particular see pages 10,11, 17 and 28 for editorials, articles and advertisements related to DVB-T. www.atvquarterly.com

5. DVB-T http://en.wikipedia.org/wiki/DVB-T

6. "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television", standard ETSI EN 300 744. V1.5.1 (2004-06), European Broadcast Union

7. "HiDes HV-110 DVB-T Receiver Test Results", Darko Banko, OE7DBH, Amateur Televsion Quarterly, spring 2014, page 11.