Application Note
AN-2a

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DIGITAL TV - the Good, the Bad & the Ugly

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Note: The original AN-2 was written in 2011 and the cable TV modulation method of 64-QAM was used. Since then, the author has discovered the European Digital Video Broadcast - Terrestrial, DVB-T, modulation scheme. It has been found to be far superior for over-the-air transmissions than CATV 64-QAM, particularly in terms of receiver sensitivity and tolerance of multi-path. The reader of this app. note is also encouraged to read about DVB-T in application note, AN-17.

The "Good News" is when it works, Digital TV (DTV) produces a far superior picture quality compared to the older analog TV even for standard definition, 480i, signals. Plus, it has the added benefit of providing much higher resolution (up to 1080i), high-definition pictures. The "Bad News" is it is truly digital with either a "1" state or a "0" state. You either get a perfect picture -- or no picture. There are also some other "bad & ugly" issues which I will address further.

In the Oct. 2008 issue of the Boulder Amateur Radio Club's newsletter, BARC's Bark, I published an article on "Digital Television" (DTV). At that time, I discussed the forthcoming transition of the TV broadcast industry from the old (1930s vintage) NTSC, VUSB, analog TV to the new ATSC - 8VSB, digital TV. I showed off-the-air spectrum plots, compared TV pictures for various signal strengths and reported on sensitivity measurements for modern, digital TV receivers for both broadcast ATSC and CATV, QAM digital signals. By now with the FCC mandated change over in effect, you all are either watching digital TV or no TV at all.

For several years now, I have been hoping to be able to put on the air a live, ham TV, high definition (1080i) DTV signal from my home qth. I wanted to accomplish the following:

1. Use conventional, consumer quality, TV receivers
2. For item (1), this means using either ATSC-8VSB or CATV - QAM modulation. ATSC would be preferred because it was designed for terrestrial broadcasts with multi-path present.
3. Use the ham, 70cm band (420-450 MHz).
4. Transmit true, full 1080i, 16:9, high-definition, live video.
5. Use conventional, consumer grade, Hi-Def. camcorders and Blu-Ray, DVD players as the program material source.
6. Affordable cost comparable to a good HF ham rig.

HAM DTV ACTIVITY: To date, there does not seem to be much ham activity in DTV. From what I have been able to discover on the internet, the bulk of the ham DTV activity is in western Europe, Australia, New Zealand, southern California, the bay area of California and in Ohio. There is only one ham in the Denver area active on DTV. He is Ed Mersich, WA6RZW. Ed wrote up an excellent article recently in the May and June, 2011 issues of the Denver Radio Club Round Table, newsletter. It was entitled "Amateur Digital TV Comes to Denver". Ed and almost all of the other USA - DTV hams are using the DVB-S protocol for their DTV. This is the same as used for the TV satellite down-links from DirecTV and the Dish Network For receivers, they are using low cost, unencrypted, "Free to Air" (FTA) satellite TV receivers which cover the ham 23cm band. Thus most DTV activity is on the 23cm band. To date, there only seems to be a couple of DVB-S modulators available. They both come from Europe. They are a PCI board modulator (plugs into an old style tower model PC computer), model DTA-107, from Dek Tec Digital Video in Holland and a "Komplettsender" from SR-Systems in Germany. From what I can gather, none of the DTV hams are yet transmitting true, high definition video. They all seem to be transmitting, standard definition, 480i, video using DVB-S. The sole exception seems to be N6QQQ in the San Francisco bay area who is assembling an ATSC DTV repeater. I don't pretend to fully understand exactly how the DVB-S stuff is working, but it seems that they still need a lot of extra computer number crunching on their video if they use the Dek-Tek PCI card. The Komplettsender does have conventional, NTSC, composite (RCA) video and audio inputs.

Every six months or so, I would go on an intensive, internet, goggle search for DTV modulators. The only ATSC modulators I ever found were extremely expensive ($10K to $80K !) plus they needed specialized video streams that had to be generated by a lot of computer number crunching. Earlier this summer, I finally found a box that got me excited for DTV. While it wouldn't do ATSC, it did meet all of my other criteria. It accepted as video inputs, either (480i, 480p, 720p or 1080i) HDMI, VGA, component or composite (480i only) and encoded the video to a compressed MPEG-2 video stream and then output as RF, CATV type QAM signals. Plus, it didn't break the bank.

I bought this new QAM modulator and proceeded to do a whole lot of DTV experiments and have now built several 70cm, DTV transmitters. I demonstrated my first transmitters at the recent BARC SwapFest. The rest of this paper summarizes my findings to date. Some are good (it does work !) and some were disappointing.

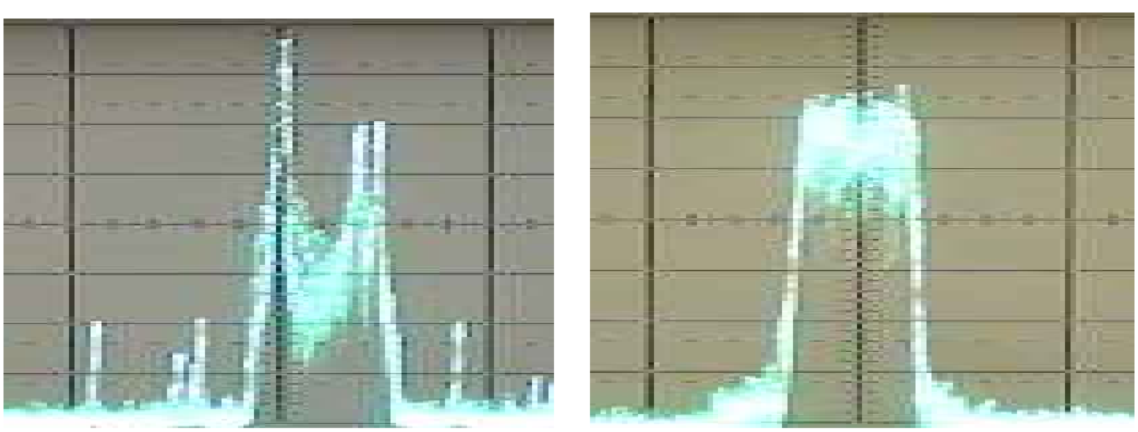

Fig. 1 Typical Spectrums for an NTSC, VUSB, analog TV (left) and a digital DTV signal (right). Vert = 10dB/div, Horiz = 10 MHz/div, analyzer bandwidth = 100 kHz

SPECTRUM COMPARISONS: Figure 1 compares the spectrums for the older, VUSB, analog TV and new, digital DTV signals. Both signals occupy a 6 MHz wide channel. The VUSB signal is characterized by it's peak envelope power (PEP) which occurs on the sync tips.

The average power in a VUSB signal is not constant, but varies as a function of the picture content. The DTV signal is characterized by it's total RMS power, which is constant and not a function of the picture content. When viewed on a spectrum analyzer, the DTV peak power observed is a function of the analyzer's bandwidth.

For the VUSB, analog TV signal, most of it's energy is clustered within a few hundred kHz of the video carrier frequency. The video carrier is located 1.25 MHz above the lower band edge. Other significant features are the color sub-carrier located 3.58 MHz above the video carrier and the FM sound sub-carrier located 4.5 MHz above the video carrier. The bulk of the energy found beyond 1/2 MHz above the video carrier is typically -40 dBc. When using a narrow-band, SSB receiver to listen to a VUSB-TV signal, buzzing sounds are found every 15 kHz at the horizontal sync frequency. A VUSB-TV signal can easily be identified by this characteristic.

A DTV signal appears as random, white noise, but pushed up to a high power level on a wide, rectangular pedestal. Thus the DTV signal has a uniform distribution of power over most of it's 6 MHz channel. When using a narrow-band, SSB receiver to listen to a DTV signal, it sounds like conventional, white noise, except that the S-meter will show an elevated reading due to the higher noise floor. Signal strength measurements made with an amateur SSB transceiver on a 64QAM DTV signal have shown the bandwidths to be: -3dB = 5.2 MHz, -10dB = 5.4 MHz, -20dB = 5.6 MHz, -30dB = 5.8 MHz and -40dB = 6.0 MHz. Thus there are guard bands provided on the band edges of each 6 MHz channel.

In the 70cm ham band, TV operators share it with a lot of different narrow-band, users, including cw, FM voice, SSB voice, packet radio, satellite up/down links, repeater control links, etc. In many cases, the VUSB-TV signal can co-exist with these other signals within the 6 MHz wide channel. The narrow-band signals create minor interference on the TV signals and likewise, TV signals create minor interference to narrow-band users, except for within perhaps ±2 or 300 kHz of the video carrier and near the color sub-carrier and the FM audio carrier.. This would definitely NOT be the case with a DTV signal. It's uniform, high-power noise-like signal would raise the noise threshold for every narrow-band user within most of the 6 MHz channel. With this in mind, we should definitely not use DTV in the 70 cm band, except for the lowest portion of the band on channels 57 and 58. The ARRL band plan designates 420-426 MHz (CATV channel 57) for TV repeater outputs or simplex operation, 426-432 MHz (channel 58) for TV simplex operation and 438-444 MHz (channel 59) for TV repeater inputs. With the guard band on the DTV signal, a properly tuned (i.e. MER >-40dB) DTV transmitter can be used on channel 58 and not cause interference with weak-signal, EME, CW and SSB operations at 432-433 MHz. DTV operations on channel 59 would definitely cause interference with these operations. Thus DTV operations on Ch. 58 are discouraged. Likewise to avoid interference with FM voice operations in the high end (440-450 MHz), DTV should not be used on channel 60 or 61.

RECEIVER SENSITIVITY: A set of tests was performed to determine the minimum RF signal level required to successfully receive DTV. As noted in my Oct. 2008, BARC's Bark article, DTV is characterized as either a "1" or a "0". In other words, either you have a perfect picture -- or no picture at all. The difference between a 1 or 0, is typically only ±1 dB. For my measurements, I first measured the max. output from the QAM modulator with my General Microwave power meter to be -5dBm. I then used a Weinschel precision, step attenuator (1dB steps) to set the input power level to the TV receiver under test. I tested several TV receivers ranging from a $50, 7" LCD to $3,000, 40" LCD-TV. The best receiver tested was a 22", LCD, Insignia model NS-L22X-10A (date code = June, 2009) ($225, Best Buy). (note: this particular model # is now discontinued and no longer available from Best Buy). For a 64-QAM signal, the threshold was -80dBm. Other TV receivers tested had a typical threshold of about -78dBm. As shown in the Oct, 2008 BARC's Bark article, at this low rf power level, an NTSC, VUSB, analog signal gives a useful, but degraded, P3, picture with a lot of colorful, confetti snow. Adding a 0.5dB noise figure, 18dB gain preamp improved by 5 to 7 dB the 64-QAM threshold from -78 or -80dBm to -85dBm for all of the receivers tested.

On the cable system, both 64 level and 256 level QAM is used. I also tested 256-QAM and found the receiver sensitivity degraded by 8 dB. Thus, for ham DTV transmissions, we should not use 256-QAM. I also tested the receivers for their ATSC-8VSB sensitivity. I used off-the-air signals from Denver commercial broadcast transmitters. I measured their signal strength using my HP-8558 spectrum analyzer. For the 22" Insignia, it's sensitivity to 8VSB was -83dBm which was a 3 dB improvement over 64-QAM.

The "Bad & Ugly News" for digital TV receivers relative to ham DTV is the poorly engineered human interface. Ideally for any TV receiver, we should be able to do "random access" with the remote control to any TV channel, either analog or digital. Of all the TV receivers, I have tested so far, only two allowed me full random access. One was my 22" Insignia. The other was my Elgato Eye TV Hybrid, USB, TV-Tuner stick for my Apple MacBook Pro laptop computer. Most (but not all) other TV sets would allow random access for analog signals, but not digital. Modern TV receivers have been designed that the user does a one-time setup when the TV is first unpacked. The user either connects his new TV to a cable feed or an outside VHF/UHF broadcast antenna. He then, via the remote control, selects either CATV or Antenna and lets the TV do an Auto-Scan to find all the available channels. Once these channels are stored in memory, the TV can easily go to these channels, but not any others. For some TV sets, this auto-scan process can consume from 5 up to 60 minutes to be accomplished. So what is the impact on ham DTV ? This means that to receive a ham DTV signal on say channel 57.1, one needs to first "teach" the TV to receive the desired channel. This is done by connecting directly to the TV set a known, strong 57.1 DTV signal and then tell the TV set to do a new "auto-scan". When this is finished, the TV set will report that it has only found a single, useable DTV signal and it will have wiped out from memory all other channels, except for 57.1. Bummer ! A royal pain in the neck (plus other parts of my anatomy !). Thus for receiving ham DTV on 70cm typically will require having a dedicated TV solely for this purpose.

Fig. 2 KH6HTV, new 70cm, NTSC-VUSB & DTV Transmitter & Hi-Def. Camcorder

DTV TRANSMITTERS: The output at -5dBm from the 64-QAM modulator is only sufficient to transmit a DTV signal around one's own ham shack. To transmit it over any significant distance, it must be amplified. I have found that a very linear amplifier is required. For DTV transmitters and other components, I have found that the most important parameter is called the Modulation Error Ratio (or MER for short). This is a measure of the amount of distortion present in the DTV signal. If the MER is less than -27dB for 64-QAM or -31dB for 256-QAM, then the digital TV receiver can not decode the signal, regardless of the signal strength. I have found a good way to measure the MER is to observe the level at which the sloping noise skirts start outside of the 6 MHz channel spectrum. See Fig. 1 (right) for an example. Down at the bottom of the pedestal, near the analyzer's noise floor, one will find skirts on either side of the pedestal. In Fig. 1, these skirts start -50 dB down relative to the top of the DTV signal. Thus for this example, the MER = -50 dB. Most references found on the internet recommend that the MER be > -40 dB. Many typical linear amplifiers used by hams do not meet this spec. The inter-modulation created in the amplifier causes the skirts on the DTV signal to rise well above the example in Fig. 1. I have done considerable research on making a very linear amplifier. My first proto-type, Model 70-6, is shown in Fig. 2. It works with both NTSC-VUSB and also DTV. The small black module attached to the side of the amplifier is an NTSC-VUSB modulator (0dBm peak sync max.). The amplifier is sitting atop of a larger unit which is the DTV 64-QAM modulator (-5dBm max.). With this combination, I am able to transmit a 1 watt (+30dBm) DTV signal with an MER of -40dB, or a 5 watt (+37dBm), NTSC-VUSB signal on the 70 cm band.

QAM - DTV PROPAGATION: A series of tests have been run to determine how well a 64-QAM DTV signal will propagate as an over-the-air broadcast. I have been assisted in these tests by BARC members: Bill McCaa, K0RZ, Don Nelson, N0YE, and Roger Salaman, K0IHX. The best results to date have been over a 7 mile path between Bill's qth on Davidson Mesa and Flagstaff mountain. For this test, I was operating mobile with the DTV transmitter in my car and using a Larsen 5/8 wave, mag mount antenna. For the tests with Bill, he also observed the received signal on his HP spectrum analyzer. All tests were run using vertical polarization. For the other tests, I have transmitted from my home qth with a 4 element, co-linear, omni-directional, 6 dBd, antenna at 30 ft. We were successful in getting a DTV signal to Don's (2 miles) and Roger's (3.6 miles) qths. I also have drove all around Boulder attempting to receive my QAM-DTV signal while mobile. I had good results from NCAR (1.9 miles), Flagstaff Mountain's Panorama Point (2.7 miles), Flagstaff summit (3.1 miles) and the Chautauqua Park TV repeater site (1.9 miles). At each location, I used my step attenuator ahead of the 0.5dB noise figure preamp to determine the signal margin above -85dBm. Other line-of-sight path locations tested that were unsuccessful included: US-36, Davidson Mesa scenic overlook (3.6 miles), Colo-93, 1 mile south of Marshall near crest of Mesa (4.1 miles) and K0RZ's Davidson Mesa qth (4.1 miles). From these tests, I have come to several conclusions:

1. In general, in-motion, mobile, QAM-DTV does not work. The DTV receiver takes one to two seconds typically to acquire a signal. With rapidly fluctuating signal levels and also various multi-paths, the DTV receiver has insufficient time to acquire lock. Similar effects were also noted when attempting to receive mobile ATSC-8VSB signals from the commercial broadcast Denver DTV stations on Lookout mountain.
2. Mobile QAM-DTV does work well in the near-field. I was successful in receiving it while in motion when I was within two to three blocks of my home qth.
3. A true, "line-of-sight" RF path is required. Mountains, hill tops, ridge lines, large buildings, etc. block QAM-DTV.
4. QAM-DTV signals are susceptible to blocking by multi-path.

5. Usually a directional, Yaggi antenna is required to minimize the multi-path interference. Sometimes, the best antenna orientation is not on 'bore-sight', but in some other direction to put the multi-path signal in a null of the antenna pattern.
6. If the received DTV spectrum has one or more "suck-out" notches due to multi-path(s) it will not work.
7. Multi-path which caused a simple up or down slope on the top of the spectrum of up to 10 dB is OK. The DTV receiver can still decode this.
8. Multi-path which caused a tent-like spectrum with an up slope and then a down slope of up to 10 dB is OK.

CONCLUSIONS: While I would have loved to say that high definition, 1080i, DTV will totally replace the old VUSB, 480i, analog TV, I am wrong. This is especially true for ham TV operations for ARES operations which require the use of portable and mobile TV transmitters from any number of arbitrary locations. The digital "cliff effect" at -85dBm could be lived with. An analog TV signal at or below that level is of marginal use anyway. This is the same effect as having a 'tight squelch' on our FM voice rigs. The lack of "random digital channel access" on TV receivers is an big annoyance, but can be lived with. The requirement of ultra-linear RF power amplifiers is not an impossible hurdle. What is the major technical limiting factor, at least for 64-QAM, is it's intolerance for severe multi-path interference, even in strong signal areas. True, high definition, 1080i, ham DTV video is possible, but mostlly for point-to-point transmissions with directional Yaggi antennas on pre-proven paths. It is not suitable for emergency situations.