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Introduction to Amateur Digital Television

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Fig. 1 High-Definition, Digital, Amateur Television --- Confirmation photo showing an image received over a distance of 77 miles using a 3 watt, DVB-T transmitter

INTRODUCTION: High definition (1080P), digital Television, DTV, is a new, exciting, aspect of amateur radio. Since almost the birth of television in the 1940s, the FCC has permitted radio amateurs to experiment with TV on the UHF, 70cm band and the higher microwave bands. The commercial broadcast TV industry has transitioned completely from the old analog, NTSC, TV to hi-def, DTV. Radio amateurs across the country are now following suit and achieving amazing success with very low power, QRP level, transmitters. The purpose of this book is to introduce the radio amateur to the basics of what is required to get on the air with amateur DTV. Topics covered include: DTV Modulation Standards, TV Bands, Video Sources, Transmitters (modulators & amplifiers), Receivers, Antennas, Propagation, Repeaters and ARES. This book pulls together a lot of the information that is scattered in over 40 KH6HTV Video application notes on ATV & DTV that have been published since 2011 on the KH6HTV Video web site: www.kh6htv.com

Chapter 1 -- Modulation Standard

For delivery of TV signals, there are several methods in use, including: cable (C), satellite (S), terrestrial (T), internet streaming (www), DVD, etc. Each delivery system has its own advantages and disadvantages. As a result, different digital encoding mechanisms are used for each method. The cable, satellite and terrestrial all use RF carriers, while satellite and terrestrial are truly over the air rf paths. As radio amateurs, we use over the air rf transmission paths. In the early days of DTV (early 2000s), some DTV hams were experimenting with using satellite TV equipment, mainly due to the low cost (\approx \$25) of free-to-air (FTA) satellite, L-band (1-2GHz) receivers. Their work was primarily on the 23cm (1.2GHz) band. Other early adopter, DTV hams experimented using cable TV equipment for the same low cost reasons.

The normal amateur radio environment is really the over the air, Terrestrial, rf transmission with radio waves being transmitted horizontally over the surface of the earth. The major issues encountered with such radio waves is the presence of multi-path, RFI and weak signals. Multi-path refers to multiple rf signals bouncing off of various reflectors, such as hills, buildings, etc. and arriving at the receiving antenna with various time delays. In the days of analog TV, this was readily evidenced by the presence of "ghost" signals on the TV screen.

DTV transmission in a cable TV environment is rf transmission in an almost perfect environment. It is almost a perfect, echo free environment due to the efforts made to maintain very low VSWR in the cable TV system. Signal strengths can also be kept up to relatively high levels. Thus the digital modulation method for cable TV does not need to make many corrections for its good environment.

DTV transmission from broadcast TV satellites is again in a relatively clean rf environment. Because of the high gain and directivity of the receive antennas, there is essentially no multi-path to contend with from satellites. The main issue for satellite rf signals is very low signal strength at the receive antennas.

Terrestrial rf transmission is the worst possible rf environment. It must deal with multi-path, RFI, and weak signals and still deliver a perfect DTV picture.

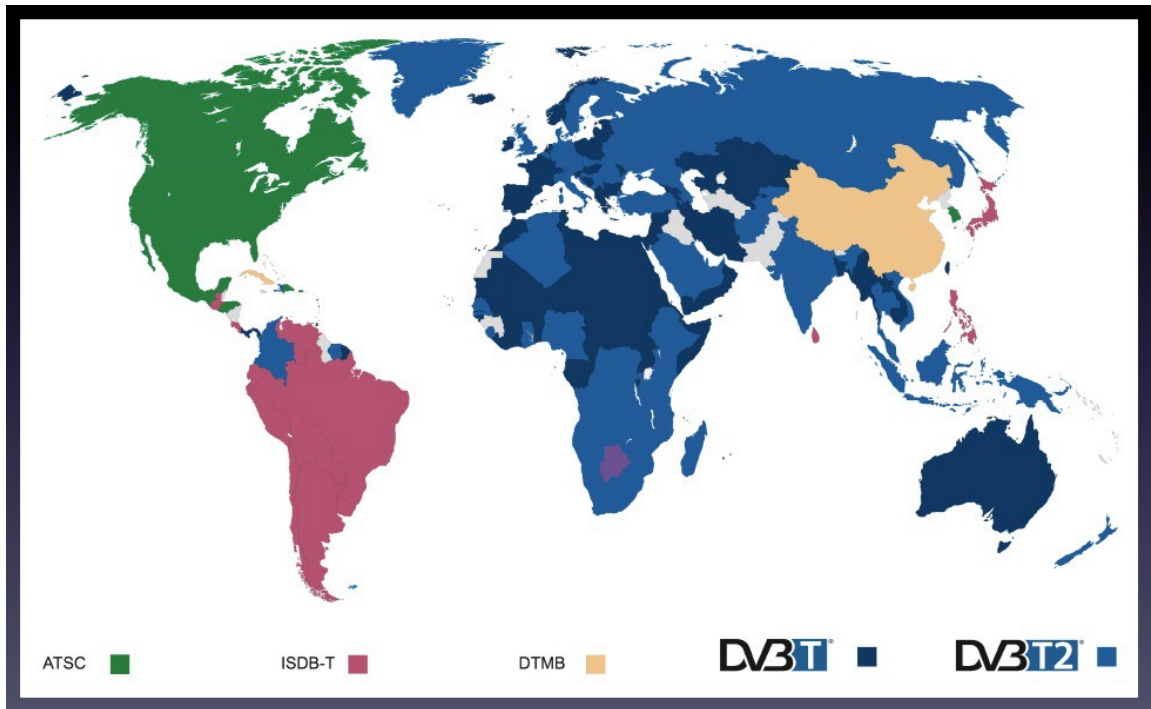


Fig. 2 DTV broadcast standards used around the world

Fig. 2 [1] shows the various DTV standards used around the world for commercial, terrestrial, TV broadcast. ATSC was developed by the USA and is only used in the US, Canada, Mexico and S. Korea. ISDB-T was developed in Japan and is used in Japan, Philippines and most of S. America. DTMB was developed by China and is only used there. DVB-T was developed in Europe and is used throughout the rest of the world.

For us radio amateurs in the US, the choices for DTV mainly come down to ATSC, DVB-S, and DVB-T. Note: DVB-S is the European standard for DTV from satellites, while DVB-T is their standard for terrestrial DTV. Amateurs in various regions of the US are in fact presently experimenting with all three of these systems. DVB-T seems at this time to be gaining the most popularity across the US. In the Boulder, Colorado area, we chose to go with DVB-T [2 & 3]. The remainder of this book will be devoted to DVB-T. The major reasons for our choosing DVB-T versus DVB-S or ATSC were:

1. DVB-T is superior over DVB-S for dealing with multi-path, because it includes additional encoding to remove multi-path signals at the receiver.
2. DVB-T has been proven technically to perform better than ATSC in real world environments. Even the FCC admitted DVB-T was superior to ATSC [4]. Unfortunately, this was after they had already selected ATSC for USA DTV.
3. The cost of DVB-T modulators has been considerably less than for ATSC, in the \$300 to \$500 range. Also open source, no sole suppliers, nor patent restrictions.
4. DVB-T is capable of up to 1080P high-definition. USA ATSC, broadcast TV does a max. of either 720P or 1080i resolution.

5. DVB-T was found to be very tolerant of other RFI interfering signals [5]. An interfering CW signal in the channel must be >20dB stronger than the DVB-T signal to cause the receiver to lock up.

DVB-T comes with a lot of flexibility built into it. Many of the various encoding parameters can be altered to optimize it under various conditions [6]. The DVB-T receivers are very smart and can actually track changes made in the encoding parameters on the fly. The first and most major choice of parameters is the basic modulation method. There are three choices, QPSK, 16-QAM, or 64-QAM. The higher the complexity of the modulation, the higher the possible data rate, but at the expense of receiver sensitivity [7]. In the USA, TV channels historically have been 6 MHz wide and this continues for DTV. For a 6 MHz channel, using DVB-T with QPSK, the max. data rate possible is 7.92 Mbps, for 16-QAM, 15.83 Mbps and for 64-QAM, 23.75 Mbps. For QPSK, the typical receiver sensitivity is of the order of -95dBm. Going to 16-QAM, it degrades by 5 dB and 64-QAM is even worse by 13 dB. Because of the receiver sensitivity issue, all amateur DVB-T transmissions are done typically using QPSK. This is because most amateur DTV transmitters are typically very low, QRP power levels of ≤ 10 Watts, whereas commercial broadcast TV transmitters are in the kilowatt range.

It should also be noted that we are dealing not only with video images, but also audio sound. All of the various older analog TV and the newer digital TV systems also transported audio. With the new DTV, in addition to high-definition video, we also get noise free, CD quality, stereo audio as a side benefit.

If you want to learn a lot more technical details about DVB-T, then I highly recommend the "DVB-T Bible" written by W. Fisher. He is an engineer at Rhode & Schwartz in Germany, a major supplier of DVB-T broadcast transmitters. See reference [8].

Chapter 2 -- Amateur TV Bands

Radio amateurs are transmitting images on most all of our frequency bands starting from the medium frequency (MF) band of 160 meters and on up. Allowable bandwidths are quite narrow on the MF, HF and VHF bands. On these bands, the limited, voice channel bandwidth only supports Slow Scan TV (SSTV) which consists of sending single, still frame, low resolution, images at frame rates of perhaps one/ minute.

To transmit, live images requires much higher data rates and attendant bandwidths in the rf channel used. Commercial TV broadcast, in various countries, has historically used 6, 7 or 8 MHz bandwidths and carrier frequencies starting as low as our 6 meter band at 50 MHz. In the USA for broadcast TV, 6 MHz bandwidth is used and the TV bands are low-VHF (54-88MHz), hi-VHF (174-216MHz) and UHF (470-806MHz). Cable TV (CATV) used the same 6 MHz channel spacing but filled in every frequency from 54MHz to 1 GHz with 157 channels. The original analog TV was what we now refer to standard definition of 480i lines of resolution. With the transition to digital TV, the same 6 MHz channels were retained but the available resolution became high-definition of either 720P or 1080i - or several 480i simultaneous transmissions. Digital TV channels are described by both the center frequency and the bandwidth. For example, channel CATV-57 is 423 MHz / 6 MHz.

70cm TV Channels				
57	58	59*	60	(61)
423	429	435	441	(447)
420 - 426	426 - 432	432 - 438	438 - 444	444 - 450
repeater output	simplex		repeater input	FM repeaters

Fig. 3 Amateur Radio 70cm TV Channels

70cm: The lowest band that the FCC allows radio amateurs to transmit wide-bandwidth, live, TV images is the UHF, 70cm band (420-450 MHz). We can also transmit TV on any of the higher microwave bands of 33cm, 23cm, 13cm, 10cm, 5cm, 3cm, etc. The UHF, 70cm band is the most popular and in general, most useful for TV, in terms of propagation and penetration. The second most popular band is the 23cm band (1240-1300MHz). Dividing each band by 6 MHz shows that 70cm can support up to five, 6 MHz channels, while 23cm can support ten channels. As it turns out, some of the CATV channels land exactly in the amateur 70cm band. They are channels 57 through 61. We typically say what channel we are on by saying "channel 57" or "423". In the ARRL national band plan for 70cm band, channel 58 is designated for simplex TV, channel 60 for TV repeater's input and channel 57 for TV repeater's output. It should be

noted that some local frequency coordinators and band plans do not adhere to the ARRL's national band plan and do not allow 70cm in-band TV repeaters, or require different frequencies. We avoid using channel 61 because that region is used for FM voice repeaters. Channel 59 is also usually avoided because of weak signal (SSB/CW) and satellite usage.

33cm: The 33cm band covers from 902 to 926MHz with room for up to four TV channels. Three CATV channels land in this band. The ARRL has designated three different channels for the band (912, 918 & 924MHz). The band is fragmented and there is not much standardization. It is also a "junk band" due to the proliferation of unlicensed ISM users. As a result, the background RFI noise level is considerably higher in this band. Most TV hams avoid this band.

23cm: The 23cm band covers 1240 to 1300MHz with room for up to ten TV channels. The ARRL band plan has designated three TV channels in the 23cm band (1243, 1255 & 1279MHz). It is the second most popular band for ATV. A lot of analog, FM-TV transmitters are found on this band using 4 MHz deviation and occupying wider than 6 MHz channels. Most of these are found at 1255MHz. A major RFI issue on 23cm in some metro areas is the presence of new FAA radars. These radars have made portions of the band unusable. In addition, the FAA has notified some amateur TV repeaters to cease operations because of their interference with the radar receivers. Government radars are primary users of the 23cm band. Amateur operations are secondary and must cease if they cause RFI to the radars.

For more information about amateur TV frequencies, see reference [9].

Chapter 3 -- Video Sources

For amateur DTV, we will be primarily using consumer grade, video equipment. This means our primary A/V connections will be made using HDMI cables. If we are still using some older, analog TV equipment, we will also be using the three conductor, RCA, A/V cables. Yellow plug = composite video; Red & White plugs = right & left, line level, stereo audio. Professional video (= \$\$\$) uses different inter-connects, such as SDI, etc. Low cost converters to/from composite video and HDMI are readily available on the internet. Also available, at low cost, on the internet are various other HDMI accessories, such as 1 in - 2 out splitters, selector switches, quad processors, etc.



Fig. 4 Canon, high definition, camcorder

Camcorders: Obviously, to get into amateur TV, one needs a source of video. The first purchase should be a TV camera. If you are going to be doing digital TV, you might as well go for a high definition camera. If you already have an older TV camera, you can still use it, but with lower resolution. The best choice, and most economical TV camera, is to purchase a consumer grade, camcorder. Excellent, high definition (1080P) camcorders from camera companies, such as Canon, are available in the \$200-\$300 price range. See Fig. 4. Such a camera includes a wide range (up to 57X) zoom lens, built-in stereo microphone, a 3" color LCD viewfinder screen, built-in solid-state memory, slot for SD memory card, HDMI digital, hi-def A/V output, plus std. def. (480i) composite A/V output, and battery. A camera tripod is also a recommended accessory. Be sure to carefully check out completely any camcorder you purchase to make sure it is appropriate for DTV use. Some of the recent Sony camcorders have been reported that they do NOT provide audio output, except when playing back pre-recorded videos. They are thus unacceptable for amateur DTV.

DVD: Other sources of video are probably already found in your ham shack or home. Your home DVD or Blu-Ray video disc player is an obvious source of video. If you record your family activities, such as vacation trips, school activities, etc. on DVDs, then they can be used as source material for your ham TV transmissions.

Computer: Your home computer is another excellent video source. Newer computers come equipped with an HDMI output to drive an external monitor. Instead of driving a monitor, you route it instead to your DTV transmitter's HDMI input. Older computers provided a VGA output. VGA to HDMI converters are readily available on the internet for under \$20. Using your computer, you have many video options. The first obvious one is to use the built-in web camera to look directly at your smiling face sitting in front of the computer. The web camera will also pick up your voice. If you have pre-recorded videos stored on your computer, you can play them. Also, you can play streaming videos from You Tube, etc. Perhaps you are working on some home brew project and want to show the schematic diagram. Do you have a bunch of photos stored on your computer? You can also show them to your ham TV friends via your computer screen. How about a Power Point presentation?

Another, not so obvious, video source is a Raspberry-Pi micro computer. They come equipped with an HDMI output to drive a monitor. They also have a USB connector. The Boulder, Colorado TV repeater uses a R-Pi computer as a video source for ID purposes. A video slide show is stored on a USB memory stick as a movie .mp4 file. It is plugged into the R-Pi's USB port and a R-Pi program plays the .mp4 file continuously to provide on the HDMI output a video slide show.

Chapter Four -- DVB-T Modulators

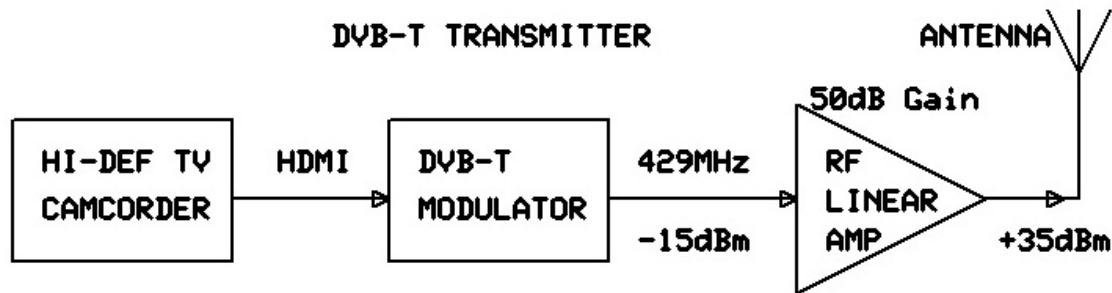


Fig. 5 Block Diagram of a typical amateur DTV Transmitter



Fig. 6 A typical amateur DVB-T transmitter consisting of a camcorder, DVB-T modulator and an RF power amplifier. Shown is a Canon camcorder, Hi-Des model HV-100EH modulator and a KH6HTV Video model 70-7B amplifier.

A typical amateur DTV transmitter consists of two parts. See Figs. 5&6. The first is the modulator, followed by a linear, rf power amplifier. The function of the modulator is to accept an incoming A/V signal (either as composite, analog, or HDMI digital audio & video) and then process it into the DVB-T standard format with suitable Forward Error Correction (FEC) encoding, synthesize an RF carrier, and modulate the data stream onto

the RF carrier. A typical modulator only puts out a weak RF signal of the order of a milliwatt (0dBm). This weak signal is sufficient only to propagate across your ham shack. To radiate it to the outside world requires boosting the level up to the watt level. Thus an RF power amplifier is also required.

Modulators: There are quite a few different manufacturers world-wide offering DVB-T modulators. Some are intended for use in commercial broadcast transmitters, while others are aimed at the closed circuit market. A simple Google search will come up with many "hits". Most USA DTV radio amateurs doing DVB-T are using modulators from the Taiwan company, Hi-Des (www.hides.com.tw) Hi-Des is actively supporting the amateur radio/DTV market. Their products have some unique features, particularly oriented towards our market. Most noticeably is their support for lower channel bandwidths. Commercial broadcast TV, depending upon the country, uses either 5, 6, 7 or 8 MHz bandwidths. We use 6 MHz in the USA. However, in some areas in the USA, especially the large metro areas, like Los Angeles, hams have had to go to lower bandwidths on the 70cm band due to the high spectrum occupancy of the 70cm band. Hi-Des products support lower bandwidths down to 1 MHz. They also offer excellent technical support and service. Their products are also very reasonably priced. It should be noted that high definition is not possible at the lowest bandwidths, but excellent, standard definition (480i) DTV pictures are still possible.



Fig. 7 Most popular Hi-Des DVB-T Modulators. HV-100EH (top) & HV-320E (bottom)

The most commonly used Hi-Des modulators are their model HV-100EH and their more recent models HV-310E and HV-320E, Fig. 7. Their prices are \$560, \$279 and \$369 respectively. I recommend buying the HV-320E. See reference [10] for a complete technical evaluation of these modulators.

The key features of the Hi-Des model HV-320E are:

1. Very broad frequency coverage from 100 MHz to 2.5GHz (covering the amateur 70cm, 33cm, 23cm & 13cm bands) (note: not legal to use on the USA 2m or 220 bands)

2. max. RF out of +6.5dBm (VHF/UHF), +5.5dBm (1GHz) to 0dBm (2.5GHz) with adjustable internal attenuator of 0 to 25dB in 1dB steps
3. Channel Bandwidth 8 MHz to 1 MHz in 1 MHz steps (plus 1.5 & 2.5 MHz)
4. A/V inputs: HDMI (digital) or composite video plus line level stereo audio (analog)
5. Resolution: 480i up to 1080P

The only front panel control on either of these modulators is Up/Down buttons for channel selection. The front panel displays channel number (00 to 99), not frequency. There is no power switch. This is accomplished by plugging or unplugging the 12 Vdc power connector. All of the operating parameters, including a custom channel table, are set using an external Windows computer over a USB cable. The computer does not need to be connected for normal operation. Ref. [11] gives the details on how to initially set up either modulator.

DVB-T Parameters: Reference [6] discusses what parameters should be used for amateur DTV. The key parameters determining the rf propagation characteristics are: constellation, FFT, code rate, guard interval, and modulation data rate. The constellation choices are: QPSK, 16-QAM, or 64-QAM. As previously discussed in Chapter 1, hams with low power transmitters should always use QPSK. FFT is the number of subcarriers with choices of 2K, 4K or 8K. 8K works best for long delayed echoes, i.e. multi-path, 2K is recommended for high speed, doppler shift situations. Code Rate determines the amount of Forward Error Correction (FEC). It's choices are ratios of 7/8 to 1/2. 7/8 means for every 8 bits, 7 bits consist of real data and 1 bit is dedicated to FEC. Guard Interval is again a ratio ranging from 1/32 to 1/4. It essentially is the same as the sync pulse in analog TV. It also determines the length of time in which multi-path can be cancelled out. It needs to be set to longer than the longest, significant echo (multi-path) delay time. The permissible modulation data rate is set by the choices of the other parameters. Hi-Des recommends that one set the actual max. data rate to no more than 80% of this value. The table below lists my recommendations [6].

Common Parameters: *Media Configuration* = HDMI input, H.264 Video Encoding, CBR Data Rate Control, 29.97fps Frame Rate, 16:9 Aspect Ratio, 30 GOP Length, 0 B Frame Number, MPEG2 Audio Encoding, 96Kbps Audio Encoding Rate,
Transmission Configuration = 8K FFT, 1/16 Guard (sync) Interval
TS Info Configuration = PMT PID 0x640, Video PID 0x641, Audio PID 0x642, Service Name = your station's call sign

PARAMETER	Perfect Channel	Normal Channel	Poor Channel	Weakest Signal
Bandwidth	6 MHz	6 MHz	6 MHz	2 MHz
Modulation	16-QAM	QPSK	QPSK	QPSK
Resolution	1080P	1080P	720P	480i
lines	1920x1080	1920x1080	1280x720	720x480
Forward Error Correction (Code Rate)	5/6	5/6	1/2	1/2
Bit Rate	12 Mbps	5.5 Mbps	3.5 Mbps	1.2 Mbps
Receiver Sensitivity	-91dBm	-96dBm	-100dBm	-103dBm
with Pre-Amp	-94dBm	-100dBm	-104dBm	-108dBm

Chapter Five -- Amplifiers for DVB-T Transmitters

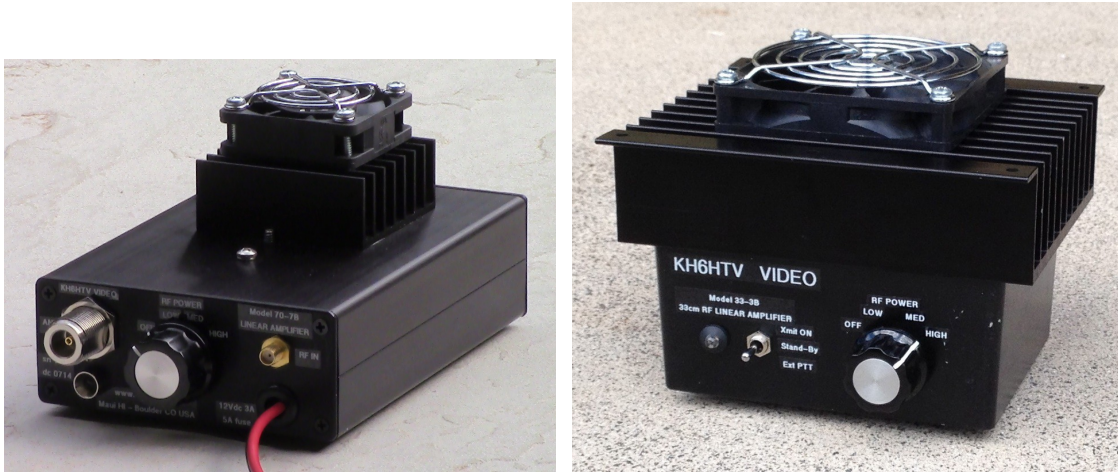


Fig. 8 KH6HTV Video RF Linear Power Amplifiers

To boost the milliwatt level rf signal from the DVB-T modulator up to a useable watt level for radiation, an RF power amplifier is required. For digital TV, the amplifier must be extremely linear. Non-linearities will lead to a dramatic increase in the bit error rate for the transmitter and inhibit the receiver from properly decoding the DTV signal. Class C amplifiers are absolutely unsuitable. The amplifier must either be ideally a class A or class A-B. This means that a significant amount of DC power will be required for a DTV amplifier and the efficiency will be low. The user must be very careful to avoid overdriving a DTV amplifier.

Depending upon the service, rf amplifier's output powers are rated in different manners. For an FM transmitter, it is the max. saturated power. For a single sideband transmitter, it is rated in terms of the Peak Envelope Power (PEP). For an analog TV transmitter it is rated again in PEP by measuring the peak of the sync pulse. For a DTV transmitter, there is no easily measured peak feature. The time domain waveform of a DTV signal is more like a random noise waveform. So DTV transmitters are measured in terms of their average, rms, power. A true RMS power meter must be used for DTV transmitters, not a diode detector. Diode detectors typically measure a peak voltage, but then the meter is calibrated in rms power. They are only valid for measuring sine waves. Thermistor power heads are ideal RMS detectors for measuring DTV signals [12].

The average power of a DTV amplifier must always be considerably lower than the peak, saturated power rating of the DTV transmitter. Typically for a DTV transmitter, it's average rms, output power is about -8 to -10dB below the peak power rating.

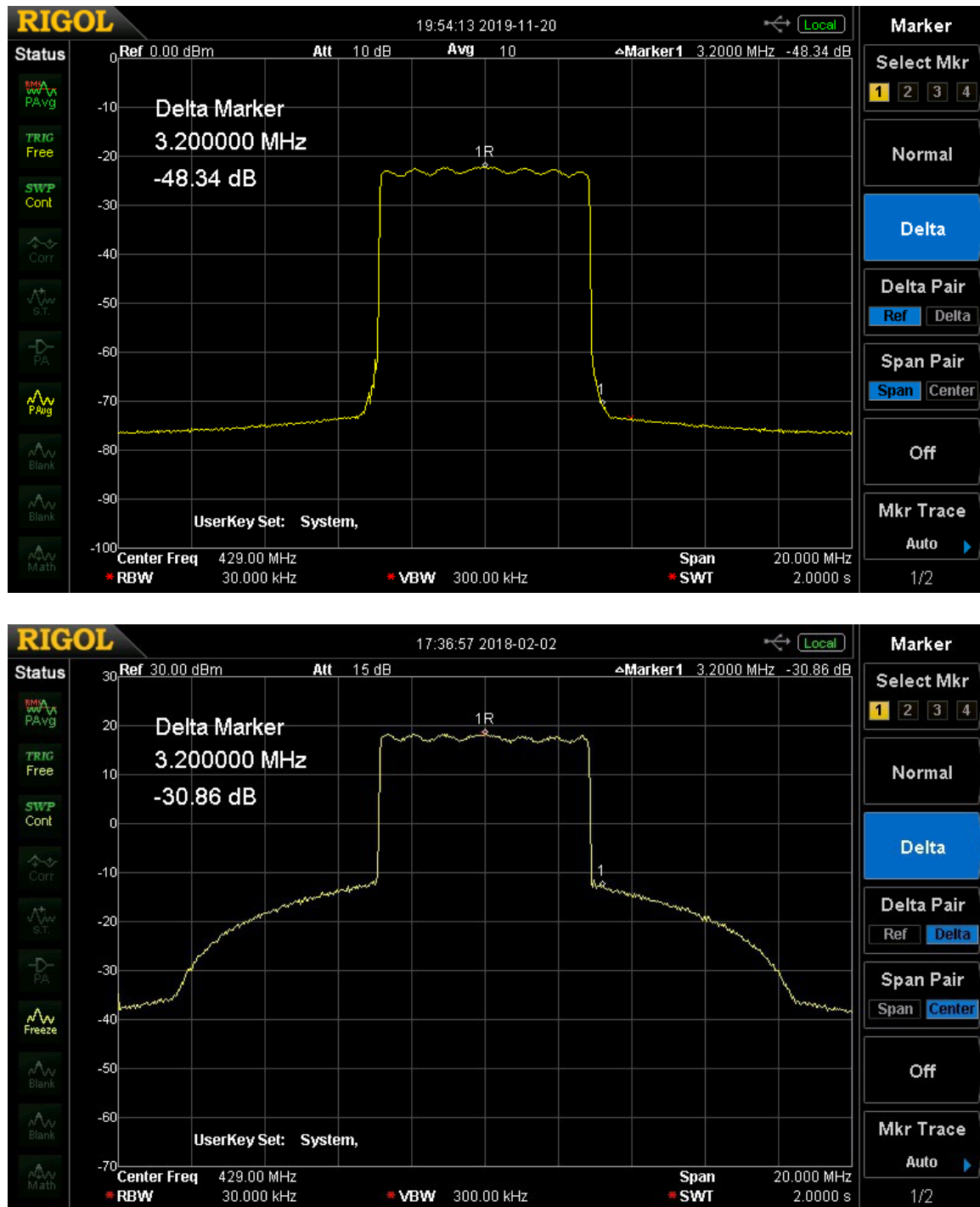


Fig. 9 Typical rf spectrum of a DVB-T signal. Top photo is output from an HV-320E modulator. Bottom photo is the output of an amateur DVB-T transmitter. Vert = 10dB/div, Horiz = 2 MHz/div.

The spectrum of a DVB-T signal looks like white noise riding on top of a rectangular pedestal that is 6 MHz wide. The output of the modulators is very close to this with the pedestal being about 45-50 dB above the noise floor. Fig. 9 shows the typical spectrum

of a DVB-T transmitter. This is not the ideal due to the broad shoulders on either side of the rectangular pedestal. These shoulders are created by the non-linearities in the rf power amplifier. The common quality measurement is the shoulder breakpoint $\pm 200\text{kHz}$ beyond the channel edges. In commercial broadcast TV, the drive is increased until the amplifier's shoulder break-point reaches -28dB . In commercial (i.e. expensive \$\$\$), broadcast, DTV transmitters, they then use exotic rf/digital feedback equalization to pre-distort the drive signal and thus lower the shoulder to -38dB . They next add a band-pass filter with extremely sharp skirts to further lower the shoulder to about -52dB . [8, p. 447] For amateur DTV, we can not afford to buy expensive digital equalizers, etc. -- so our compromise is to set the drive level to our power amplifiers so the shoulder breakpoint is at about -30dB , as shown in Fig. 9. For this example, this particular amplifier's DVB-T output was 10 Watts (rms), while it's max. saturated output power in FM service was 70 Watts. Thus about an 8dB difference. For DTV service, amplifiers must be capable of operating for very long periods of time with 100% duty cycles.

KH6HTV Video is a supplier of rf linear power amplifiers suitable for use in DVB-T service. Amplifiers are offered for the 70cm (430MHz) and 23cm (1.2GHz) bands. See Fig. 8. These amplifiers are rated for 100% duty cycles. They all have high gains, typically $>50\text{dB}$, sufficient to be driven by low level modulators of less than 0dBm . They all include a 20dB , $+20\text{dBm}$ driver amplifier. They have adjustable rf power outputs with -5dB and -10dB steps. At lower output powers, the dc current draw drops proportionally. They all are designed to operate from $+12\text{Vdc}$ power. The following table lists the available amplifiers.

KH6HTV Video RF Linear Power Amplifiers

Model Number	Band	Digital TV (rms, avg)	VUSB-TV or SSB (pep)	Saturated FM - CW
70-7B	70 cm	3 W	10 W	20 W
70-9B	70 cm	10 W	25 W	60 W
23-11A	23 cm	3 W	10 W	40 W

Note: VUSB means Vestigial Upper Side-Band, VUSB-TV was the modulation method used by old, analog TV transmitters. It was basically an AM transmitter with a large portion of the lower sideband filtered off to conserve spectrum.

Chapter Six -- DVB-T Receivers

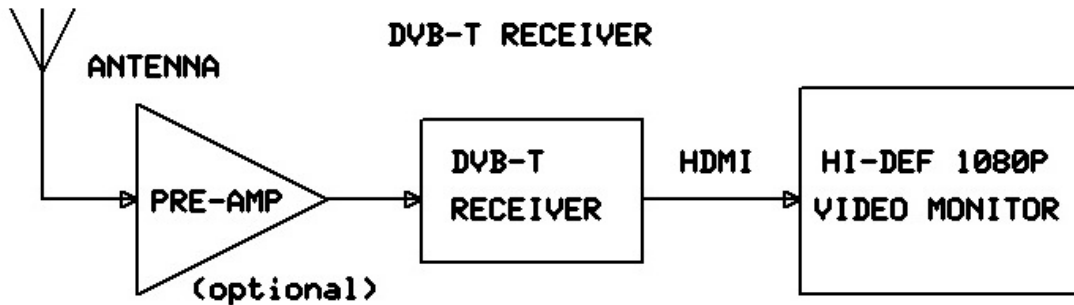


Fig. 10 Block Diagram for DVB-T Receiver

To receive DVB-T transmissions, we can not just go to Wal-Mart, Best-Buy, etc. and buy an off the shelf TV receiver, like we would do for the USA ATSC standard. Instead, we need to treat it the same as a satellite TV or cable TV setup requiring a separate set-top box and a video monitor. Reference [13] discusses in detail the various options. For high-definition, we will use an HDMI cable to connect the two units. If only receiving standard definition, then the composite, RCA cables suffice. Most receivers have acceptable sensitivity. However, for the ultimate station, a good, low noise, preamplifier is needed. It will typically enhance the receiver sensitivity by 3 to 4dB. For 70cm, the KH6HTV Video model 70-LNA is recommended. For 23cm, the KH6HTV Video model 23-4LNA is recommended.



Fig. 11 DVB-T Receivers from Hi-Des -- model HV-110 (top) & HV-120 (bottom)

Hi-Des: The real KISS (Keep It Simple Stupid !), and guaranteed to work, solution to receiving amateur DVB-T on both the 70cm and 33cm bands is to purchase from Hi-Des, their Model HV-110, set-top box, DVB-T receiver (\$169). This is the receiver being used by most radio amateurs experimenting with DVB-T because it allows them to experiment with both conventional wide bandwidths (6-8 MHz) and also narrow bandwidths (down to 2 MHz). It is easy to setup [11] and operate. It can be trained to receive any arbitrary frequency from 170 to 950 MHz, including the amateur 70cm and 33cm bands. Hi-Des also offers their newer model HV-120A, which features enhanced frequency coverage from 100-950 MHz and also 1150-2650 MHz, thus adding the 23 and 13cm bands (\$209). The HV-120A does however require an extra preamp for the 23cm band as it's sensitivity on 23cm is poor. Adding a good low noise preamp, like the KH6HTV Video 70-LNA is recommended. For more details about these receivers, see references [13&14].



Fig. 12 Other possible DVB-T receivers.
consumer set-top box (left) & USB TV tuner dongle (right)

Set-Top Boxes: Another very low cost (as low as \$25) possibility is to search on the internet for consumer set-top boxes out of China, such as the example in Fig. 12. However, **Buyer Beware !** While these are advertised to tune from 50 to 850 MHz, most of these will NOT tune the amateur 70cm band. A few brands have been found to work on 70cm, but most do not. Most only tune the authorized TV broadcast bands. **2020 addition:** We have recently found one set-top box that does work on the 70cm band. It is the GT Media, V7 Plus available for about \$50 from Amazon [15]. It works however only for bandwidths of 6, 7 or 8 MHz.

There is a "Gotcha" for almost all digital TV receivers, whether it is a new SONY that you buy at Best-Buy, a set-top box receiver, or whatever. Note: this includes the Hi-Des receivers. Unlike the old analog TV receivers, we can not simply enter on the remote control any arbitrary channel number and the receiver will automatically tune to that frequency and start working. Due to unfortunate, poor human interface design by receiver engineers, they require that DTV receivers must be "taught" each and every new channel by exposing it to the actual rf signal. This is typically done once when unpacking your TV, connecting it to the cable system or outside antenna and doing an "Auto-Scan". The TV receiver scans all frequencies and memorizes only those on which

it found a valid signal. Thus no matter what DTV receiver you are using -- you will have to teach it first to find and memorize a specific frequency (channel). This means you need to either (1) own your own DVB-T modulator, (2) carry your receiver to another ham's house and train it on his modulator, or (3) if you have a really good RF path, have the other ham point his antenna at you and transmit a DTV signal on each frequency of interest. You have the same issues when trying to receive over the air broadcast tv signals. For modern DTV, this is the absolutely the biggest "Pain in the Neck & A....." !!!

USB TV Tuner Dongle: There is another solution which fortunately does not have to be trained to receive a signal. The only info one needs to enter is the center frequency and the bandwidth of the desired channel. This solution is to use a USB TV tuner dongle, like that shown in Fig. 12. These can be found on the internet for ridiculously low prices of \$10 - \$25. Don't use the software that comes with the dongle. The free software called VLC (www.videolan.org) has been found to work with these dongles to receive DVB-T transmissions. However, not every ham has been able to get them to work, particularly on the newest Windows 10 computers. There seem to be a multitude of driver issues. The driver required is special for DVB-T and it will not work with applications, such as SDR-Sharp which is for a general purpose SDR radio receiver [16] There is also a wide variation in rf sensitivity among the various dongles available [7].

Chapter Seven -- Antennas



Fig. 13 Typical Antennas for Amateur TV -- left to right: 2m/70cm/23cm rudder duck, 2m/70cm/23cm mobile whip & 2m/70cm base station top to bottom: 70cm Yaggi and 23cm Loop Yaggi

One word summarizes the major specification requirement for amateur TV antennas -- ***Broad-Band.*** Buyers should be cautioned before buying any antenna for ham TV to verify that it has sufficient bandwidth to cover the entire ham band. Many antenna manufacturers' specs. fail to include sufficient bandwidth information. For example many 70cm yaggis are quite narrowband and tuned to operate only on 432 MHz for ssb, moon-bounce, etc. Likewise, many 70cm base station and mobile antennas are designed only to operate on the high end, 440-450 MHz, FM voice portion of the band. None of these have adequate bandwidth for ham TV service.

As a side-note, the question always comes up among hams --- "Should I use horizontal or vertical polarization ?" This question may already be answered in your local area if there is already an active ATV community of hams. You definitely want to use what your

neighbors are using. Selecting the opposite polarity immediately results in at least a 20dB penalty. In Boulder, Colorado we have always used vertical polarization. Our reason is that the major usage of amateur TV has been for ARES serving our local sheriff, police and fire departments. Many of our ARES field operations involve portable, TV pack-sets with small, rubber-duck style antennas and also mobile operations with mag. mount, vertical, whip antennas. Also we use TV repeaters and it is far easier to obtain omni-directional vertical antennas for repeater use. For directional antennas, Yaggi antennas are useful for either vertical or horizontal polarization by simply mounting them in a 0° or 90° orientation.

We have made measurements on a variety of 70cm and 23cm antennas. The results are found in reference [17 & 18]. Our recommendations for ATV antennas boil down to a very few antennas. See Fig. 13 above.

70cm Base Station Antenna: Diamond model X-50NA, dual-band (2m/70cm), omni-directional, 5.6ft, vertical polarization. covers full 70cm band with gain of 7 to 11dBi

23cm Base Station Antenna: Diamond model X-6000, tri-band (2m/70cm/23cm), omni-directional, 10.5ft., vertical polarization. covers full 23cm band with gain of 7 to 10dBi. Useful on 70cm only on the high end of the band. Gain = 13dBi (440-450MHz). Gain drops to 3dBi at low end of the 70cm band.

70cm Yaggi Antenna: M-Squared model 440-6SS, 6 element, 3 ft. boom, covers full 70cm band with gain of typically 11dBi

23cm Yaggi Antenna: Directive Systems model 2414LY, 14 element loop yaggi, 3 ft. boom. flat gain of typically 15-17dBi

70cm/23cm Mobile Antenna: Diamond model NR-2000NA, tri-band (2m/70cm/23cm), 39" length, covers completely both 70cm and 23cm bands. For 70cm, the gain is typically 3dBi rising to 7dBi at 441MHz. For 23cm, the gain is typically 7 to 8dBi

70cm/23cm HT Whip Antenna: Diamond model RH951S, tri-band (2m/70cm/23cm), BNC, 14" flexible whip 70cm gain is typically about -3dBi 23cm gain is typically of the order of +1dBi.

Chapter Eight -- TV Propagation

I am often asked the question by other hams. "How far can a ham TV signal go ?" Fig. 1 on page 1 is a good example of long distance DTV DX. My typical response is "Line-of-Sight". If you can see the other location, chances are good that you can get a TV signal to it. This has been borne out by many years of experience in ham TV. As opposed to very high power TV broadcast stations, DTV hams are typically running low power (≤ 10 watts) and our signals just don't have the oomph to get much energy diffracted over and around path obstacles. Recommended reading is AN-33a [19].

For line of sight, UHF and microwave propagation, there also becomes the question of "Where is the radio horizon ?" If we lived on a flat earth, the answer would be infinity. Because we live on a spherical earth (radius = 6370 km), the curvature of the earth limits our horizon. It effectively puts a "hump" in the middle of our rf path. The line of sight horizon is set by pure geometry. Note this may not be your personal optical line of sight set by the resolution of your eyes, even using binoculars. The distance to the horizon is set by our observation height (or antenna height) above ground level. It is given by these equations:

$$\text{optical distance (km)} \approx 3.57 * \sqrt{\text{height (m)}} \quad \text{- or -} \quad \text{in miles} \approx 1.23 * \sqrt{\text{height (ft)}}$$

The radio horizon is actually a bit further than the geometrical horizon. The refractive effects of the atmosphere cause a bit of bending in the radio waves and will push them typically about 15% further..

$$\text{RF distance (km)} \approx 4.12 * \sqrt{\text{height (m)}} \quad \text{RF distance (miles)} \approx 1.41 * \sqrt{\text{height (ft)}}$$

However, these atmospheric effects are totally dependent upon local weather conditions. In extreme cases, strong ducting might occur sending our RF waves far beyond the predicted RF horizon, while severe local storms might drop it back dramatically.

A few quick examples are: 5' => 3.2 miles, 30' => 7.7 miles, 100' => 14 miles, 1000 ft => 45 miles. Adding antenna height at the receive site, we add the numbers for the two heights. For example transmitting from an automobile with an antenna height of 5 ft. to a remote base station with the antenna on a 30 ft. tower, the radio horizon = $3.2 + 7.7 \approx 11$ miles. This calculation really only works over flat earth. On a large lake or the ocean, we do have such a flat surface. Obviously either putting up a higher tower or finding a high hill or mountain top works wonders. But of course, this is not news to us hams !

So after determining our radio horizon, the next issue to contend with is RF Path Loss. Path loss is the natural phenomena of radiating a certain amount of power but this power, again due to spherical geometry, gets spread equally over an ever expanding globe as it propagates away from the source. Thus the power density in watts/m² gets much smaller the further we get from the source. The formula for free space path loss based upon this geometry alone is:

$$\text{Free Space RF Path Loss(dB)} = 20 * \log_{10}(\text{f in MHz}) + 20 * \log_{10}(\text{D in Miles}) + 36.6\text{dB}$$

Note in this equation the frequency dependency, For example, going from 70cm to 23cm bands we suffer about a 10 dB hit in path loss. A few quick calculations will give you an appreciation of the importance of path loss. As an example, for the 70cm band (430 MHz) we get: 0.1 mile => 69dB, 1 mile => 89dB, 10 miles => 109dB, etc.

To determine the best case situation for a particular rf path we need to include all of the major rf components. Calculations are done easiest in dB with power levels expressed in dBm and antenna gains expressed in dBi. To determine the power input into the distant receiver, we need to know:

$$\text{Rcvr Pwr(dBm)} = \text{Trans Pwr (dBm)} - \text{Trans Cable Loss (dB)} + \text{Trans Ant Gain (dBi)} \\ - \text{RF Path Loss (dB)} + \text{Rcvr Ant Gain (dBi)} - \text{Rcvr Cable Loss (dB)}$$

As an example using this calculator, let's enter the parameters of a typical 70cm ham TV station:

Transmitter Power = 5 watts (+37dBm) Cable Loss = 1dB each end
 Yaggi Antenna Gain = 11dBi each end
 Desired Receiver Power = -65dBm (40 dB s/n, P5 for analog,VUSB-TV)

The calculator gives the answer of 43 miles for pure, unobstructed, free space, line of sight path. The theoretical results really only apply for outer space applications. In the real, terrestrial world, we encounter a lot of other obstacles and we would never achieve this ideal. In the fall of 2011 and again in Sept., 2016, several Boulder area TV hams have run TV propagation field trials. See Application Note, AN-3 [20] for details. We made measurements of the actual received signal strength in dBm. One observation that stood out was "Over very clear, line-of-sight paths, even with directional antennas, where multi-path was not a major issue, the actual path loss was typically 5 to 15 dB worse than the calculated, theoretical path loss." For obstructed paths, even more loss was typically encountered. Thus the likelihood of our ever experiencing just free space path loss is extremely rare.

The above equations were for ideal, unobstructed, line of sight situations. What can limit us in the real world? Lots of things including: ground reflections, vegetation, tall buildings, urban building clutter, hills, ridge lines, mountains, etc. The absorption by vegetation, due to water content, goes up with increasing frequency. I have noticed a significant difference in the signal strength hitting our local TV repeater between summer and winter. When the leaves were gone from the trees between my former qth and the repeater, my signal strength at the repeater, especially on 23cm significantly improved. Getting over obstructions to our line of sight path involves diffraction which can introduce considerable extra dB loss. Most of the rest of the losses result from Multi-Path. This is reflected waves from other objects which arrive at the receive site later in time and can cause standing wave patterns in the receive signal which at certain frequencies might totally null out the desired direct path signal. Another perturbing effect can be "Doppler" shift due to moving objects disturbing the various multi-paths.

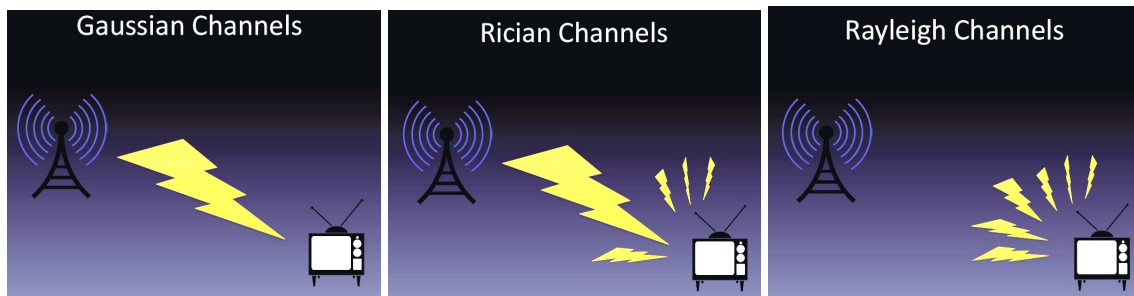


Fig. 14 Different types of rf channels

A pure, free space, channel is called a "Gaussian". It is very rare in a terrestrial environment. If there is a direct line-of-sight path, but also multi-path signals arriving at the receive antenna, then this is called a "Ricean" channel. If there is no direct line-of-sight path, but multi-path signals arrive at the receive antenna, this is then called a "Rayleigh" channel. See Fig. 14 above [1]. Each type progressively degrades the channel performance and leads to more path loss.

RADIO MOBILE: There is an excellent free, on-line, computer program for calculating rf propagation in the real world. It is called *Radio Mobile* [21]. This program was written and copyrighted by Rodger Coudé, VE2DBE. The on-line version is dedicated to amateur radio use and as such will only accept input frequencies in the amateur radio bands. The mathematical model is a mix of the Longley-Rice model, the two rays method, and the land cover path loss estimation. *Radio Mobile* first calculates the free space path loss. It then adds estimates for the excess path loss contributions from: Obstruction Loss, Forest Loss, Urban Loss, and Statistical Loss (typically always set to about 6.5dB). *Radio Mobile* can calculate point-to-point rf path profiles and also wide area rf coverage maps. Comparing *Radio Mobile's* point-to-point predictions with the results from actual, mobile, field measurements has shown good agreement. The Boulder ATV repeater coverage maps correlate well with the field measurements [22].

Fig. 15 shows a typical rf path calculation from *Radio Mobile*. The top plot is the topographical rf path, elevation profile. The large table consists of data input to the program and also the various parameters calculated. For this particular example, *Radio Mobile* predicted that the received signal strength would be -50.3dBm. The actual measured signal strength was -51.5dBm, a difference of only about 1dB.

Fig. 16 shows the rf coverage area of the Boulder, Colorado, 70cm, DVB-T repeater, (from it's new, 2018 location) as predicted by *Radio Mobile*. The yellow shaded areas are the "weak" signal areas with signal strengths of -90 to -80dBm. The green shaded areas are the "strong" signal areas with signal strengths > -80dBm. Actual mobile field surveys have verified this map. The photo shown on page 1, Fig. 1, is documentation of a successful, DVB-T, DXpedition to the farthest point on the map. This was on the border between Colorado and Wyoming, near Cheyenne, Wyoming. The distance to the repeater was 77 miles. Successful two way QSOs were held on both 70cm and 23cm.

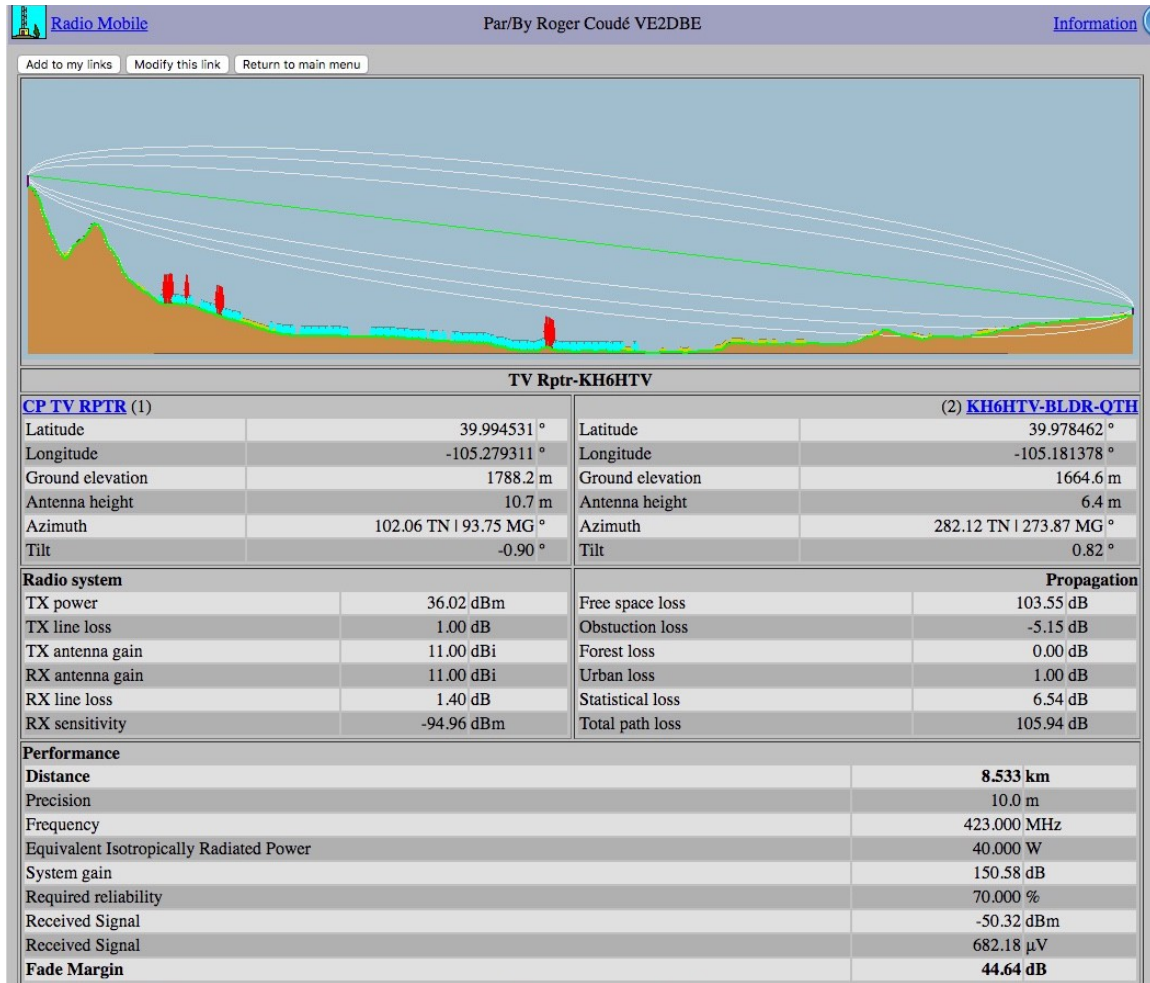


Fig. 15 *Radio Mobile* - Path Profile prediction for TV Repeater (from its former site) to KH6HTV-QTH. Direct line-of-sight, 5.3 mile path between transmitter and receiver. The transmitter is plotted on the left and the receiver is plotted on the right side. The green trace is the direct ray. Note: 1st, 2nd & 3rd Fresnel zone ellipsoids (white lines) and intermediate path obstructions are shown.

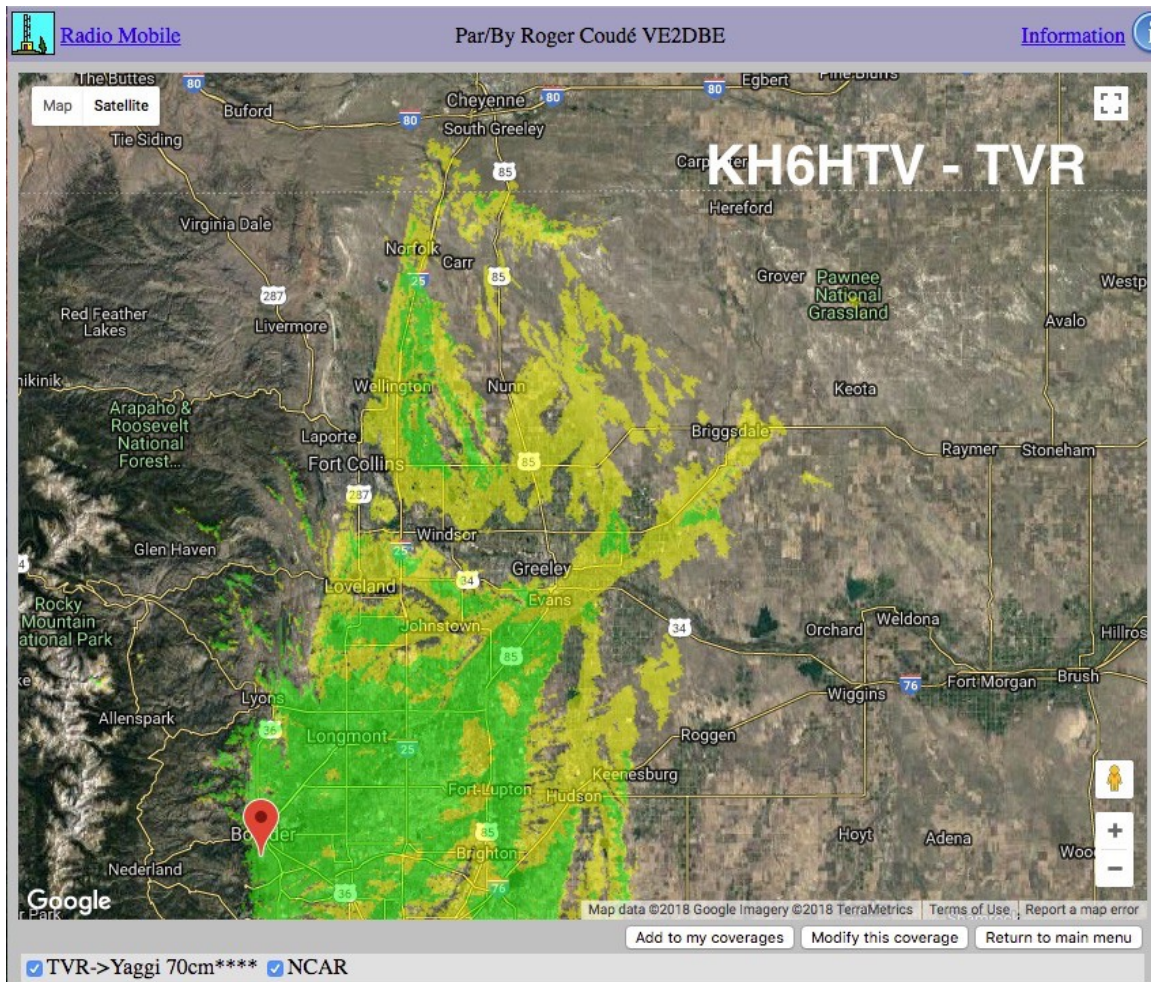
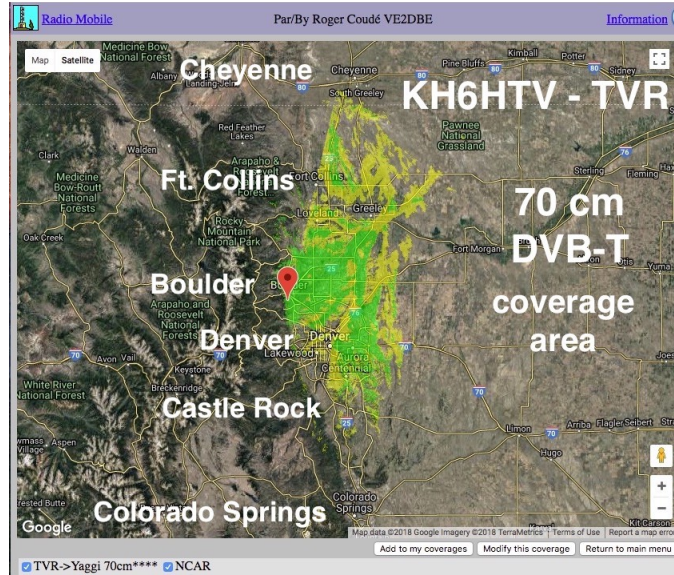


Fig. 16 Radio Mobile predicted coverage maps for Boulder, Colorado DVB-T Repeater

Chapter Nine -- DTV Repeaters

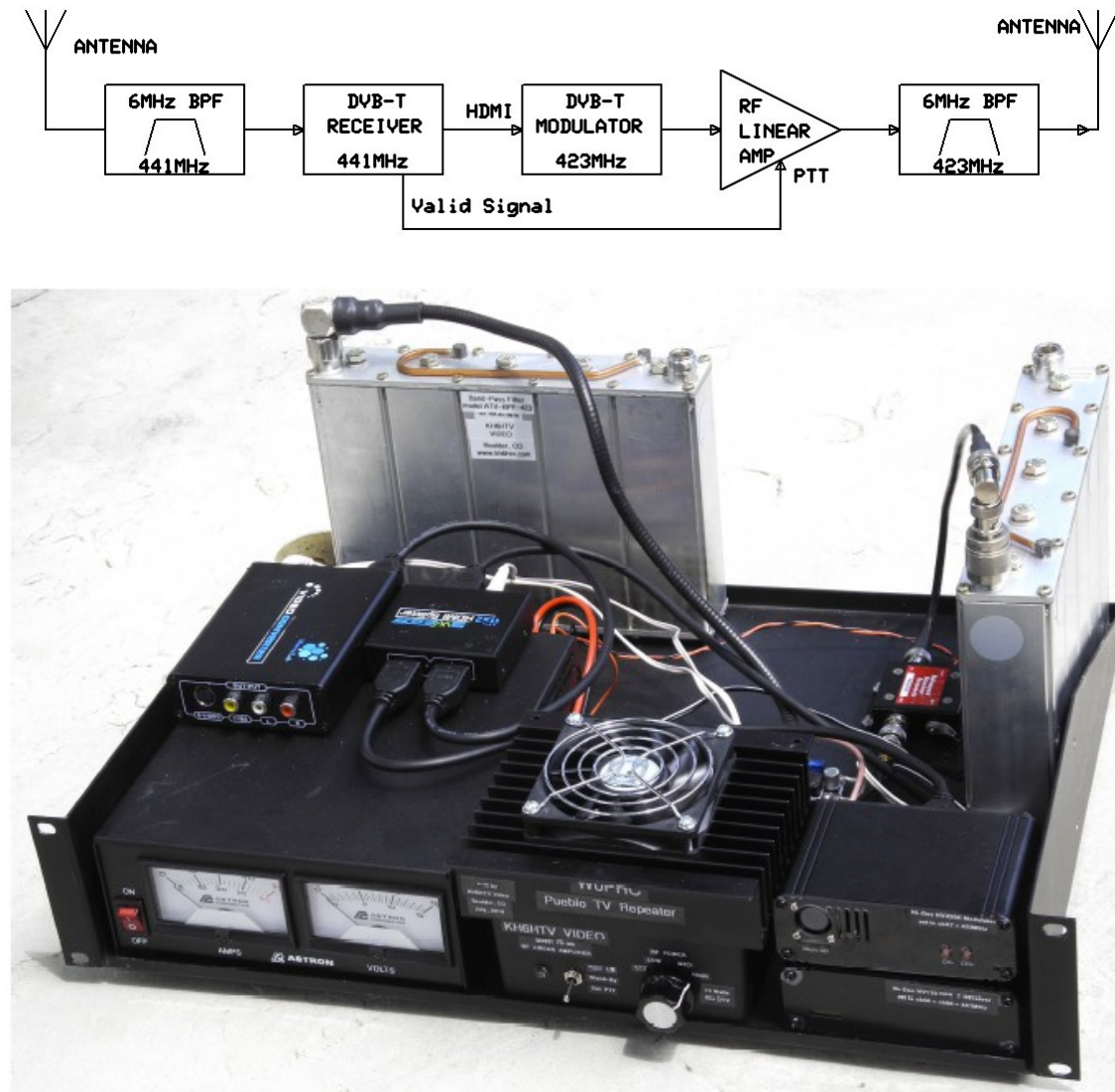


Fig. 17 A 70cm, Digital TV Repeater -- Top is block diagram.
Bottom is actual DVB-T repeater built for Pueblo, Colorado ham club

A basic TV repeater for DVB-T is actually quite easy to assemble [23 & 24]. Fig. 17 above shows the basic elements needed. It is far easier to build compared to a typical FM voice repeater, or an older NTSC, analog, TV repeater. Many of the elements needed for those repeaters are not needed for the DVB-T repeater. The basic elements required are just the DVB-T receiver, the DVB-T modulator and an RF linear power amplifier. This is all that suffices for a cross-band repeater, plus the appropriate antennas. However, if any other features are added to the repeater, such as multiple receivers, dual-mode, extra video sources, etc., then it becomes a very complex engineering project quickly [22 & 25].

BPF: If assembling an in-band repeater, then Band-Pass Filters (BPF) are also required on the input and output. These BPFs need to be wide-band to match the channel bandwidth, in the usual case, 6 MHz. They also need to be low loss and have steep skirts. Most TV repeaters are using inter-digital BPFs., see Fig. 18. Reference [26] gives details on how to build your own.

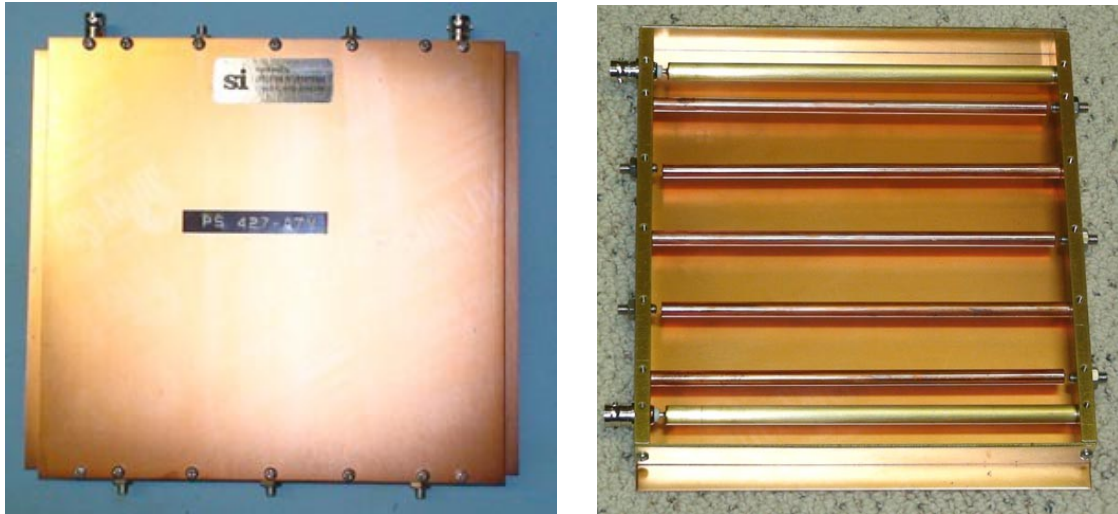


Fig. 18 Typical, 70cm, Inter-Digital Band-Pass Filter.

Valid Signal: Notice that the interconnection, in Fig. 17 block diagram, consists simply of an HDMI cable between the receiver and modulator, coax cables for the rf circuits and one single logic data wire from the receiver to the power amplifier. If this is a local, manually controlled repeater, simply set up on the fly for an emergency situation, even this wire is not needed, just the control operator operating the power amplifier's On/Off switch. For automatic repeater operation, we do need the "Valid Signal" control line. Most DVB-T receivers include an LED front panel indicator showing when the receiver is actually receiving a valid DVB-T signal. The LED typically goes from red to green when a valid signal is received. What we thus need is to get inside of the receiver and pick off from the circuit board the LED drive signal and buffer it with a simple transistor circuit to provide an open collector to ground logic output. This is then used to connect to the Push-to-Talk (PTT) input on the rf linear power amplifier to key on/off the repeater's transmitter. Bingo at this point, you now have already easily assembled your own DVB-T television repeater !!! Congratulations ! Reference [23] gives the details on how to get the Valid Signal out of the Hi-Des model HV-110 receiver.

ID: OK, you say, "But what about meeting the FCC's requirement to identify the transmissions at least every 10 minutes." SIMPLE with DVB-T !! With DVB-T, you are automatically identifying your signal, not every 10 minutes, but with every frame of video. Included in the digital data stream is a header of meta-data describing for the receivers, the modulation parameters used, including the call sign of the transmitter. Bingo, you have immediately satisfied the FCC's requirement to ID. Recall on today's TV sets, a simple push of the INFO button on the remote control puts up on the screen a

display of the channel number, station call sign, resolution, and program description. This is from the meta-data header. If you don't feel comfortable with this form of ID, then the repeater starts to become more complex with the need to switch in a local video source with an ID test pattern.

Antennas & Isolation: Most FM voice repeaters are using a single common antenna for receive and transmit. To accomplish this then requires the use of an expensive duplexer to separate the signals and isolate the transmitter from the receiver. For TV signals with bandwidths of 6 MHz, the ratio of transmit/receive separation to bandwidth on 70cm band is only $18 \text{ MHz} / 6 \text{ MHz} = 3:1$. It is very difficult to build a duplexer which can provide sufficient isolation for such a condition. Thus for TV repeaters, we typically use two separate antennas for receive and transmit. Isolation is achieved by separation of the antennas. The best arrangement is for the antennas to be mounted vertically on a common axis. Reference [27] is a good, free, on-line, calculator to determine the isolation. As an example, for two, 70cm, vertically polarized antennas mounted vertically on the same common axis, and separated by 10ft, the isolation is 54dB. To achieve the same isolation if they are instead separated horizontally from each other, would require a separation of 100 ft. For cross band repeaters, additional isolation is provided by the frequency selectivity of the antennas.

For new hams wishing to get involved in ATV, there are ATV repeaters across the USA. The ARRL has discontinued listing them in their repeater directory, but they do in fact exist. Reference [28] is an ATV repeater directory for the USA which the author has compiled. Several of these repeaters are now converting to digital TV.

Many ATV repeaters also stream their video over the inter-net. Thus, if you want to see what other ATV hams are doing, you can easily watch their video activity on your computer or cell-phone. Some groups are using You-Tube. The majority are streaming via a server in the U.K. hosted by the British Amateur TV Club (BATC). The link to the BATC is: <https://batc.org.uk/live/> There you will find over 60 ATV repeaters from around the world, plus streams from individual ATV hams.



For details: www.qrz.com & www.kh6htv.com

Chapter Ten -- Amateur TV & ARES



Fig. 19 BCARES live video feed on 70cm from mountain top to Boulder 911-EOC of slurry bomber fighting the Four Mile Canyon forest fire.



Fig. 20 Dave, KI0HG & Mark, KB0LRS, BCARES TV net control in the University of Colorado, police chief's command post receiving four simultaneous, TV signals on channels 57, 58, 59 & 60 (70cm), from BCARES TV cameras/transmitters.

Amateur TV, also called ATV, is an often overlooked communication mode which radio amateurs can offer in times of emergencies to our public safety agencies. In Boulder, Colorado, the local ARES group (BCARES) [29] has been providing ATV for almost 30 years now [30 & 31]. It is the most often requested BCARES service, far exceeding HF, VHF or UHF voice radio or packet radio. BCARES gets called several times a year by the Sheriff, Police and Fire depts. to provide ATV coverage of events ranging from forest fires, floods, political demonstrations, protest rallies, riots, SWAT operations, university football games, campus visits by VIPs, and large (50,000 runners) 10K races.

FREE DVD: I have also prepared a DVD lecture on this subject. It is entitled "*Amateur, High-Definition, Digital TV*". This talk was originally presented at the Seattle, Washington, MicroSoft ham club's annual, Micro-Hams conference in the spring of 2020. The talk covers the same topics in this DATV Hand-Book with many Power-Point slides. The talk runs for 45 minutes. It is excellent material if you are looking for a speaker on ATV for your local ham club. For a free copy of this DVD, send an e-mail to: kh6htv@arrl.net

Free Newsletters: If you want to keep up on the latest happenings in amateur TV there are a couple of free publications relating to ATV. The first is an on-line, electronic magazine from the U.K. called **CQ-DATV**. It comes out monthly. Free copies in several formats (pdf, ePub, mobi, and azw3) can be down-loaded from the web site: <https://www.cq-datv.mobi/index.php>

The Boulder Amateur TV club also puts out a free ATV newsletter. It is distributed in .pdf format to over 400 ATV hams via e-mail. It comes out at least every month and often times more often. Past issues are archived on the web site: <https://kh6htv.com/newsletter/> If you want to be added to the mailing list, send your request to: kh6htv@arrl.net

CONCLUSION: I have also written a newer, 40 page, ATV handbook in 2020 which also addresses analog ATV in addition to DTV [32] I hope I have given you enough information to first whet your interest in getting into ATV, and hopefully DVB-T, and second to be able to assemble your own amateur, digital TV station. If after reading these hand-books and consulting the various application notes cited, you still have questions, please do not hesitate to contact me. I can be reached by e-mail at: kh6htv@arrl.net

73 de Jim, KH6HTV

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(note: all KH6HTV Video application notes and newsletters are available to be downloaded in .pdf format from www.kh6htv.com)

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