The FCC allows wide bandwidth TV transmissions on all amateur radio bands starting at the 70cm band and all shorter wavelengths (higher frequencies). Most amateur TV activity occurs in the UHF region, predominantly on the 70cm (420-450MHz) amateur radio band and to a lesser extent, the 23cm (1240-1300MHz) band. We have more bands with many 100s of MHz available, on higher microwave frequencies. They include: 33cm (902-928MHz), 13cm (2.3-2.31 & 2.39-2.45GHz), 9cm (3.3-3.5GHz), 5cm (5.65-5.925GHz), and 3cm (10-10.5GHz) bands. AN-36 discussed the principles and some of the components required to be able to get to these higher bands [1]. This application note will discuss the actual construction of a Transceiver to use 70cm, DTV equipment on the 13cm, 2.4 GHz band.
Fig. 2  Interior View (left) and Rear View (right) of 2.4GHz DTV Transceiver

Fig. 5 at the end of this app. note shows the actual schematic diagram of the transceiver. It was assembled from various modules and interconnected using short SMA cables. Fig. 2 is a photo of the interior showing the various modules. The design follows the basic principles laid out in AN-36. A single, common mixer was used for both transmit and receive. The RF signals at 2.4GHz are split/combined for the RF port of the mixer using a 2-8 GHz, 3dB power divider. At the antenna connector, a high quality (dc-18GHz), SMA coaxial relay was used to switch between receive and transmit modes.

For the transmit side, the RF power amplifier was a junk box salvage. It had been purchased over the internet at least 10 years ago for use with a Wavecom-Jr, FM-TV exciter. It's manufacturer and detailed specs. were unknown. Tests showed it to have a gain of about 17dB and a 220MHz, -3dB bandwidth centered on the 2.4GHz band. It's max. saturated output power for FM-TV service was about 300mW. A KH6HTV Video, model WB-LNA-2, was used as the driver amplifier. It provided 18dB gain at 2GHz. To reject the lower sideband mixing products at 1.5GHz coming from the mixer, a band-stop filter was placed on the input of the driver amplifier. This consisted of a short piece of RG-174/U coax cable shunted across the input SMA of the driver amplifier. This open-circuited stub line was trimmed in length to provide a deep (-20dB) notch at the 1.5GHz, LO-IF frequency.

For the 2.4GHz receive side, a pair of KH6HTV Video, low-noise, WB-LNA series amplifiers was used. The first amplifier was a WB-LNA-1 with 9dB of gain and 1.5dB noise figure. The second amplifier was a WB-LNA-2 with 18dB of gain and 2.5dB noise figure. The output of the second amplifier was routed to the mixer through the 3dB power divider. The amplifiers used were installed as bare boards, mounted on stand-offs. Normally, they are sold packaged into a die-cast enclosure.

The synthesized, local oscillator used was an import from China which used an Analog Devices 4351 VCO chip. The first attempt at building the 2.4 GHz transceiver was a failure. I tried to use the $60 frequency synthesizer board shown in Fig. 3 of AN-36. I mounted this VCO on the outside of the top lid of the enclosure, because this board had
no back-up memory. It had to be programmed on the touch-screen every time the dc power was applied. I then used another WB-LNA-2 amplifier to boost its +2dBm output to +12dBm to drive the mixer. I got extremely disappointing results. I finally traced the problem to extremely poor phase noise coming from the VCO. At some frequencies, the phase noise was quiet, but at others, it was like sitting in a hurricane. It raised the noise floor of the receiver by over 40dB! Also the phase noise was intermittent.

I solved the problem by scrapping out the $60 VCO and replacing it with a higher quality, $140, AD-4351, signal generator. It was also an internet, import from China. It is the unit shown in the right side of the photo, Fig. 5, in AN-36. It is also seen sitting on top of the transceiver in Figs. 1 & 2. This unit gave much cleaner phase noise performance. It also includes a built-in step attenuator (0.5dB steps) and an output power amplifier (+13dBm max.). It also has a built-in memory function, so it will retain a frequency even after powering down. With the higher output power available from this VCO, I was able to remove the LO amplifier module. The LO frequency was set to 1970MHz, +10dBm. This gave an IF frequency starting at 420MHz with an RF in/out starting at 2390 MHz (i.e. low end of the authorized amateur band).

The mixer used was a Mini-Circuits, model ZFM-150. It was given to me by Don Nelson, N0YE. It was only specified for use over the RF/LO range of 10 MHz to 2 GHz with +10dBm LO drive. Don assured me that it would probably work ok at 2.4 GHz. I tested it and found that it did perform ok at 2.4GHz with about -7dB conversion loss.

MEASURED PERFORMANCE: To measure the performance of the transceiver, I used the following instruments: Rigol DSA-815, 1.5GHz spectrum analyzer; HP-432A power meter; Fluke 6060B, 1GHz, signal generator; and Polarad 1105E, 0.8-2.4GHz, signal generator, plus an assortment of amps, mixers, attenuators, etc.. Measurements were made with LO = 1970MHz, IF = 423MHz, RF = 2393MHz.

In the transmit mode, the up-conversion gain was 22dB. The max. saturated output power was +24.5dBm (280mW). The -1dB gain compression output was +22dBm (160mW). Thus for SSB service, the output would be +22dBm (PEP). For DVB-T service, the drive level needs to be set to avoid overdriving the amplifier and creating distortion and excessive, out-of-channel, sideband noise. The industry standard is to set the spectrum shoulder break-points at about -30dB. At this -30dB level, the DVB-T rms, average, output power was +15dBm (30mW). This is typical of most amplifiers used for DTV service with a peak signal head-room of typically 8dB above the average power level.

In the receive mode, the down-conversion gain was 17dB. The noise figure was not measured, but earlier measurements on the WB-LNA-1 amplifier by Don Nelson, N0YE, with an HP noise figure meter showed a noise figure of 1.5dB. Using the calibrated Polarad 2.4GHz signal generator, the sensitivity was measured for 3dB S/N as displayed on the Rigol spectrum analyzer. The sensitivity was found to be -107dBm (1MHz BW) and -124dBm (30kHz BW).
Fig. 3  2.4GHz RFI spectrum measurement showing intense Wi-Fi activity.  Center frequency = 2.420 GHz.  Span = 100MHz, i.e. 10MHz/div.

Fig. 4  2.4GHz RFI spectrum measurement showing Wi-Fi activity in the amateur radio only portion of the band (2.39-2.4 GHz).  Center frequency = 2.395 GHz.  Span = 20MHz, i.e. 2MHz/div.
OPERATING EXPERIENCE: Actual on the air tests were performed with Don, N0YE. The antenna used at KH6HTV was an L-Com, parabolic reflector, grid dish antenna with 24dBi gain, mounted at the 30 ft. level on my 50 ft. antenna tower. The feed line from the shack was a 50ft. run of 1/2" Heliax (1.8dB at 2.4GHz). A successful, two-way, DVB-T contact was made on 2.393GHz over a 5 mile, line-of-sight path. Don was using a +20dBm transmitter and a 20 element yaggi antenna.

The 2.4 GHz band is fundamentally a "junk" band for amateur radio due to it's very wide use for Wi-Fi. We opted to use horizontal polarization because we felt that most Wi-Fi routers seemed to be using vertical polarized antennas. Spectrum observations were made at the KH6HTV qth using the dish antenna pointed towards the city of Boulder. Figs. 3 & 4 show the observed results using peak hold over a several minute time interval. The really only quiet portion of the entire amateur band from 2.39-2.45GHz is the lowest 5MHz, i.e. 2.39-2.395. Thus for 6 MHz bandwidth, DTV, we really only have one TV channel on the 2.4GHz band where we can reasonably expect to have success. It is at 2.393 GHz. The next higher channel at 2.399 GHz, could also be used. Anything above 2.4 GHz is unusable due to extreme Wi-Fi RFI.

REFERENCES:

Fig. 5  Schematic diagram of 2.4GHz Transceiver