KH6HTV VIDEO

Application Note AN-53e

"e" - Rev. December, 2024

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W0BTV, Boulder, Colorado Digital ATV Repeater Current Technical Details & Tech History

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Application Note, AN-31, [1] in 2016 discussed in detail the completely rebuilt Boulder, Colorado ATV Repeater.

Prior to 2016, the repeater was strictly analog transmitting VUSB-TV on 70cm (ch57) and receiving on 70cm (ch60) or FM-TV on 23cm. In 2016, the repeater rebuild added the capability to both receive (23 & 70cm) and transmit (70cm) high definition (1080P), digital television using the European digital broadcast TV standard, DVB-T in addition to it's previous existing analog TV capabilities.

AN-53 was first published in Oct., 2019, and discussed the major rebuild in 2019. After three years of experience with the completely new digital TV repeater, we had learned several lessons. The major defects in the first design were difficulty in changing operating modes plus extremely long delays encountered when changing modes and reacquiring a DTV signal. All of these issues traced to our poor choice of a particular HDMI switch used to select various A/V sounrces. The cure was finding a newer, better switch. AN-53 then provided complete documentation for the repeater.

Fig. 1 W0BTV TV Repeater

AN-53a, in 2020, discussed the major change being in the 23cm receiver with a new Band-Pass Filter designed by WB9AIA and the removal of the FM-TV receiver, plus the additon of a 5.9 GHz, 2 Watt, FM-TV transmitter.

AN-53b, also in 2020, documented some additional minor changes over the "a" version.

AN-53c revision documented the changes made in Spring, 2023 The major changes were: (1) The elimination of the analog, NTSC, 421.25 MHz transmit mode capability. (2) The addition of a narrow, 2 MHz bandwidth, DVB-T receiver for 70 cm in place of the old analog, NTSC, 439.25 MHz receiver. The repeater is now strictly a digital DATV, 70cm/23cm repeater.

AN-53d revision documented additional minor changes made in Aug/Sept 2023 to correct some residual issues.

AN-53e This lastest revision "e" (December, 2024) documents a recent major changes made in the receiving antennas and adding a 3cm input while deleting the 70cm/2MHz BW input. The fall, 2024 new configuration of the W0BTV, ATV repeater now is:

Inputs: All digital, DVB-T with 6 MHz TV channels. Primary 23 cm (*CCARC coordinated*) = 1243 MHz Secondary #1 is 70 cm (*un-coordinated*) = 441 MHz. Secondary #2 is 3 cm (*un-coordinated*) = 10.380 GHz. *The use of the 70cm input is discouraged due to extreme RFI at the repeater site. The 441 MHz input is primarily retained to support BCARES ATV operation.*

Outputs: Primary 70 cm (*CCARC coordinated*) = digital, DVB-T, 423 MHz / 6 MHz band-width. Secondary 5 cm (*un-coordinated*) = analog FM-TV, 5.905 MHz

Note: The 5 cm, FM-TV transmitter runs 24/7 for use as a microwave beacon

New Antennas: The previous receive antenna was a tri-band (2m/70cm/23cm), omni-directional vertical antenna. Diamond X-6000A. It was giving disappointing performance and not receiving as well as predicted. We replaced it in May, 2024 with different antennas. For 2m/70cm, we are now using a Diamond X-50NA, omni-directional. For 23cm, we are now using a stacked arrary of two, offset, patch antennas to give us a somewhat cardiod pattern to the north-east with about 115 deg beam-width. For the new 3cm receiver, we added an additional antenna on the roof-top. It is an Alford slot antenna made of WR-90 waveguide. It is horizontally polarized with a wide beam-width.

The other major repeater change was to eliminate one of the two 70 cm receivers. We deleted the Channel 60 (441 MHz / 2 MHz BW). We reconfigured that receiver to function as the IF receiver for 3 cm, 10 GHz, DVB-T. It is on 10,380 MHz with a 6 MHz band-width.

DTMF: A minor change was also made in the repeater's controller box. We have suffered several failures in the expensive ($140) DTMF touch-tone decoder / 8 relay board made by Intuitive Circuits. It was their model DTMF-8. After the last failure, we gave up on them. Bill, AB0MY, offered to design new board for us based upon using an Arduino micro-processor. His new board was installed in the repeater in Nov. 2025. It seems to work flawlessly and offers a lot more programming flexibiltity for future growth compared to the old Intuitive Circuits board.

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Fig. 2 HDMI Quad Viewer -- the heart of the 2019 DTV repeater rebuild

The 2016 repeater design's major defect was the cheap HDMI switch used. It caused a lot of grief, especially very long switching times. In the spring of 2019, while surfing the internet, I stumbled across a new HDMI device which looked like it had the potential of solving our basic HDMI switch issues. It was a Quad Viewer, also sometimes called a Quad Processor. This is a device which accepts up to four separate A/V inputs and combines them into a single video signal in which each input occupies one of the four quadrants of the picture. If desired, one can also view just one of the four inputs in full screen mode. What was unique about this particular Quad Viewer was that it also had an RS-232 control input in addition to it's front panel push buttons and it's IR remote control. We didn't need nor want the push buttons nor remote control. What we really needed for our ATV repeater was the RS-232 capability to control the box with our repeater's Arduino controller.

The Quad Viewer was the model HD-401MR, made by the OREI company. (www.orei.com) It sold for $90. The instruction manual that came with the HD-401MR gave no details about the RS-232 interface and the commands to control it. However, by contacting OREI customer service via e-mail (info@orei.com) we were able to obtain the command codes. With these in hand, Don Nelson, N0YE, was then able to experiment writing Arduino code and eventually learned how to control the Quad Viewer over the RS-232 line. After Don accomplished this, he and I made the decision to thus do a complete redesign and rebuild of the Boulder ATV repeater using this Quad Viewer / HDMI switch box. Don wrote the new Arduino computer code, while I did the necessary hardware modifications.

Sept. 2023 Note: OREI still sells a model HD-401MR. Buyer Beware ! --- it no longer includes the RS-232 interface.

New Quad - Nov. 2024: In Nov. 2024, we replaced the old OREI quad viewer with a newer model, the HDS-402MV ($100). We did this because of some concerns about the switching irregularities in the older unit. Plus this new on offered an additional feature of Picture-In-Picture (PIP). It was advertised to have an RS-232 computer interface. False adversizing ! Yes, it had a computer interface, but in fact it was USB, nor RS-232. We thus had to learn once again how to program this new unit, plus totally rewrite our Arduino controller code to control the quad viewer and run our repeater. The new code was written by Bill, AB0MY.

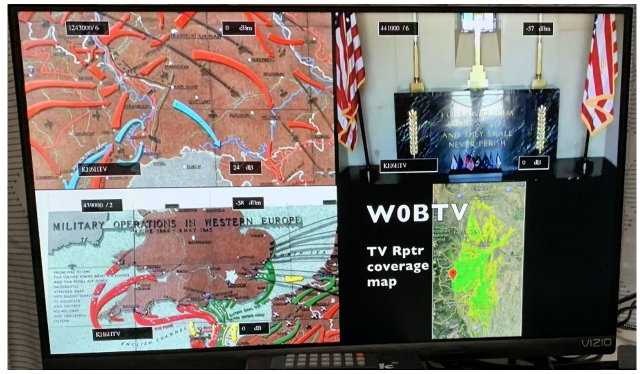

Fig. 3 TV Repeater's Quad Mode

Having the computer controlled Quad Viewer allowed us to add new features in 2019. First was the ability to actually see a quad display. This does however require one to command over the 2 meter FM control frequency the repeater to shift to quad display and turn on the transmitter. In the quad display mode, the 23 cm, 1243/6 MHz DTV receiver's video is in the upper left quadrant. The 70 cm, 441/6 MHz DTV receiver's video is in the upper right quadrant. The 70 cm, 441/2 MHz DTV receiver's video is in the lower left quadrant. The repeater's ID slide show is displayed in the lower right quadrant. The quad display is also presented whenever the repeater is first keyed up. The quad display comes on for about 10 seconds and then switches to whichever receiver is picking up a valid TV signal. To meet FCC ID requirements, for long duration (> 10 minutes) transmissions, the repeater automatically switches to the quad display for ID for a few seconds every 9 1/2 minutes. With the ID slide show in the lower right quadrant, we are always able to ID with the club's call sign, W0BTV.

At the end of each TV transmission, the repeater also automatically IDs with an ID trailer. The quad viewer, thus switches to a full screen display of the ID slide show. This trailer runs for 30 seconds after the incoming TV signal drops. The trailer is long enough for a user to try to "kerchunk" the TV repeater and then watch the output to see if he was successful. If a new, valid TV signal comes on during this trailer, the trailer is instantly terminated and the repeater automatically switches to the new TV signal. The BEACON mode was retained. If the Beacon command is sent on the 2 meter FM control frequency, the 70cm transmitter is turned on and transmits in full screen mode the ID slide show. There is no audio with the slide show. The slide show is a continuously looping video provided by a AGPTEK Media Player reading an .mp4 video file stored on a USB memory stick.

A key improvement made in 2019 in the repeater operation is that now any valid TV signal appearing on either the 3cm, 23 cm or 70 cm band will automatically key up the repeater. One no longer needs a control operator to reconfigure the TV receiver inputs. A priority hierarchy was established in the event of multiple TV signals being on the air simultaneously. Priority #1 is the 23 cm input (1243/6 MHz). Priority #2 is 70cm, 441/2 MHz. In third place is 3cm, 10,380/6 MHz. Turning on either the Beacon or Quad Display will override any incoming TV signal. However, in quad display, if there is any valid incoming TV signal, it will be displayed in it's respective quadrant.

The digital receivers have been programmed to continuously display the On-Screen-Display (OSD). The OSD parameters displayed are Frequency/Bandwidth (upper left), received station Call Sign (lower left), S meter Power in dBm (upper right) and Signal/Noise ratio in dB (lower right). It should be noted that the S meter reading is not true. It has significant offsets (they read too high). However, it is accurate for relative changes, i.e. 1 dB change in input power causes a 1 dB change in the S meter reading. The S meter and S/N can be used as a tuning aid for antenna alignment. The S meter offsets are due to the insertion loss of the input band-pass filters and the gain of the pre-amps. For the 70 cm receiver, the offset is +13dB. For the 23 cm receiver, the offset is +41dB. For the 3 cm receiver, the offset is estimated to be about +25 dB.

The following table lists the control codes to select the various features of the TV repeater. Control Code 8 does a re-boot of all the various digital components by dropping the DC power for 10 seconds. It also resets all the control functions back to the normal (#) state. Note: The 5 cm, FM-TV transmitter runs 24/7 for use as a microwave beacon.

Table 1 -- TV REPEATER CONTROL FUNCTIONS (Sept. 2024)

Control Code	Function	(*)	(#)
1	70cm BEACON (xmit on)	ON	OFF
2	5cm FM-TV BEACON	OFF	ON
3	Picture-In-Picture, PIP mode	ON	OFF
4	Not Used	-- na --	-- na --
5	70cm Transmitter	ON	Stand-By
6	QUAD Display (xmit on)	ON	Stand-By
7	70cm Transmitter Disable	OFF	Enabled
8	RESET (reboot all digital eqpt)	Reset to # state	--- na ---

February, 2020 - REPEATER MODIFICATIONS: The 2019 version of the Boulder ATV repeater was documented in a previous version of this App. Note, AN-53 (Oct. 2019). We were having issues with receiving 23cm DVB-T signals during 2019. Spectrum observations showed the 23cm band to be very quiet with the sole exception of very powerful radar signals coming from the FAA radar site near Parker, Colorado. The FAA radar signals were measured to be bi-modal with peaks at 1261.25 & 1266.5 MHz and energy extending from 1259 to 1269MHz. Thus, we felt we needed to make major changes in our band-pass filtering on the front end of our 23 cm receiver. The previous filter arrangement was a compromise because we were trying to have both a DVB-T receiver on 1243 MHz (6 MHz BW) and also an FM-TV receiver on 1247 MHz (15 MHz BW). The 23cm FM-TV input has not been used recently by any of the BATVC members, except for one individual. Thus the decision was made to remove the FM-TV receiver and also the old 23 cm band-pass filter (BPF). We needed to find a new BPF which would only pass the 6 MHz wide, 1243 MHz DVB-T signal and give us extreme rejection of the FAA radar. A new 23 cm BPF filter was designed for us by Dan, WB9AIA and built for us by Mark, N0IO.

2023 - REPEATER MODIFICATIONS: The 70 cm analog, NTSC capabilities were removed. The 421.25 MHz modulator and the 439.25 MHz receiver were removed. All of the old analog control circuits, some dating back to the mid-90s were removed. All of the control circuits were consolidated within the 19" rack enclosure for the HDMI switch matrix. A Hi-Des model HV-110, DVB-T receiver was added to replace the old 70 cm CATV/NTSC receiver. The new receiver was set to 441 MHz center frequency with 2 MHz band-width. An additional 3 MHz band-width, band-pass filter was added in front of the 441/2 MHz, HV-110 receiver.

2024 - REPEATER MODIFICATIONS: All new receive antennas were installed. The 2 MHz BW, 441 MHz receiver was deleted. In it's place, we installed a 3 cm microwave receiver.

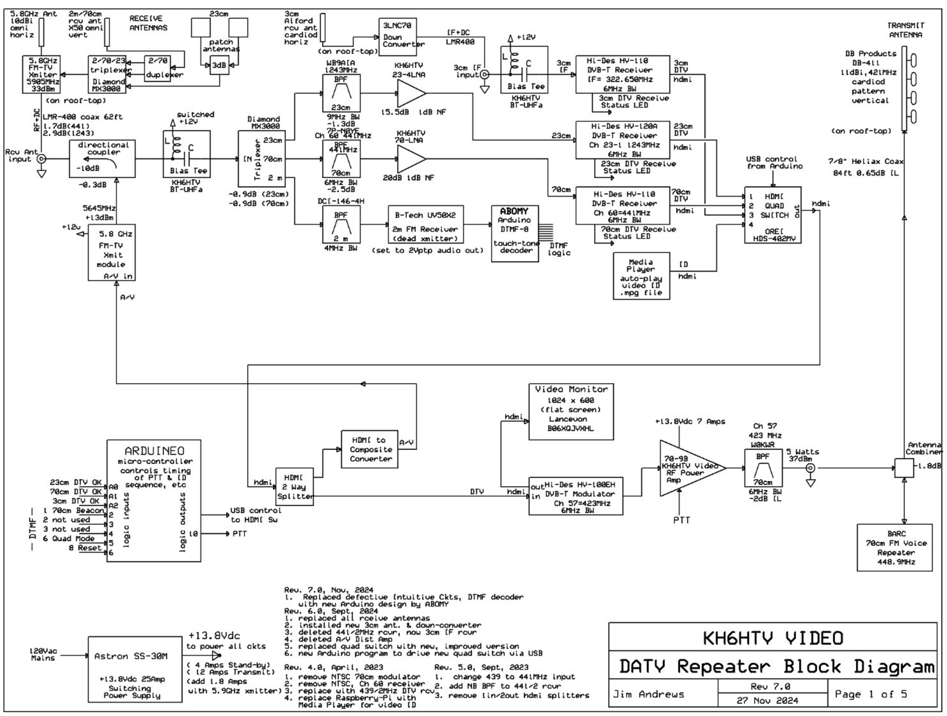

Fig. 4 Block Diagram of the W0BTV ATV/DTV Repeater, Rev.7.0, Nov. 2024

The remainder of this application note will discuss the technical details of the TV repeater (Nov.. 2024 version). Fig. 4 above & Fig. 31 is the block diagram. This and all of the detailed schematic diagrams are found at the end of this application note as full page drawings.

W0BTV ANTENNAS

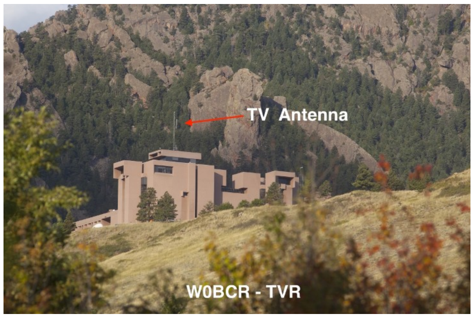


Fig. 5 The NCAR - W0BTV antenna installation

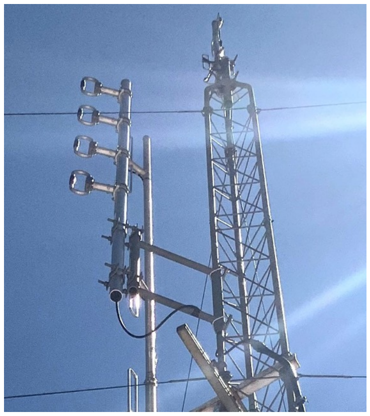

Fig. 6 70cm transmit antenna

70 cm Transmit Antenna is an Andrew model DB-411. 11 dBi gain, cardiod pattern, oriented to 30º from true north. Polarization is vertical. The antenna height is about 120 ft. above ground level. The coax feedline is 7/8" heliax. Approximate estimated length is 50 ft. Coax loss is approximately 0.5 dB. This antenna is shared with the Boulder Amateur Radio Club (BARC), 70 cm, FM voice repeater. The W0DK repeater transmits on 448.90 MHz. A duplexing antenna combiner network was designed and built by Don, NOYE. The insertion loss of the combiner for the 423 MHz DTV signal is -1.8 dB. Thus total coax system loss is about - 2.3 dB.

5 cm Transmit Antenna is a Laird model OC515010H. The mfgr's spec. is 10 dBi gain with an omni-directional pattern. 10 dBi has been confirmed by Don, N0YE, in his antenna range tests. Polarization is horizontal. 9.5 deg. 3 dB beamwidth. The antenna height is approximately 100 ft. above ground level. The coax feedline is LMR-400. The approximate length is 3 ft. Coax loss is approximately 0.4 dB.

Fig. 7 5.9GHz Ant

2m/70cm Receive Antenna
In summer of 2024, we replaced the Diamond X6000 tri-band antenna. For the 2 m control receiver and the 70 cm DTV

Fig. 8 2m/70cm X50 Antenna

receiver, we are now using a Diamond model X50NA. It is a 5 ft. high, omni-directional, vertically polarized, base station antenna for both the 2 meter and 70 cm bands. It 's gain is specified to be 4.5 dBi on 2 meters and 7.2 dBi on 70 cms.

23 cm Receive Antennas: The new (2024) antennas are now a stacked, phased array of two patch antennas. The patch antenna itself is a phased array of 8 dipoles printed on a pc board. It is made by Linatcho in China. It is their model LC120012BG. The mfgr. specs. are: 12 dBi gain, 55 deg. beam-width, 1.1 to 1.3 GHz, 25x30x6 cm. Tests showed the specs. to be accurate.

Fig. 9 23cm Stacked Patch Antennas

For our desired coverage area, we needed a beam-width at least 2X of the patch antenna. So, we used EZNEC computer modeling to design an array of a pair of these antennas. to achieve about a 115 deg. beam-width. This was accomplished by stacking the two antennas as shown in this photo with an offset azimuth angle of 60 degrees. We then used two coaxial cables of the same length and a 3 dB power divider as a combiner. For EZNEC, we were not able to model the patch antenna directly, so we simulated it using a six element yagi antenna with the same gain and beam-width. Full details were reported in our ATV newsletter issue #159, April, 2024.

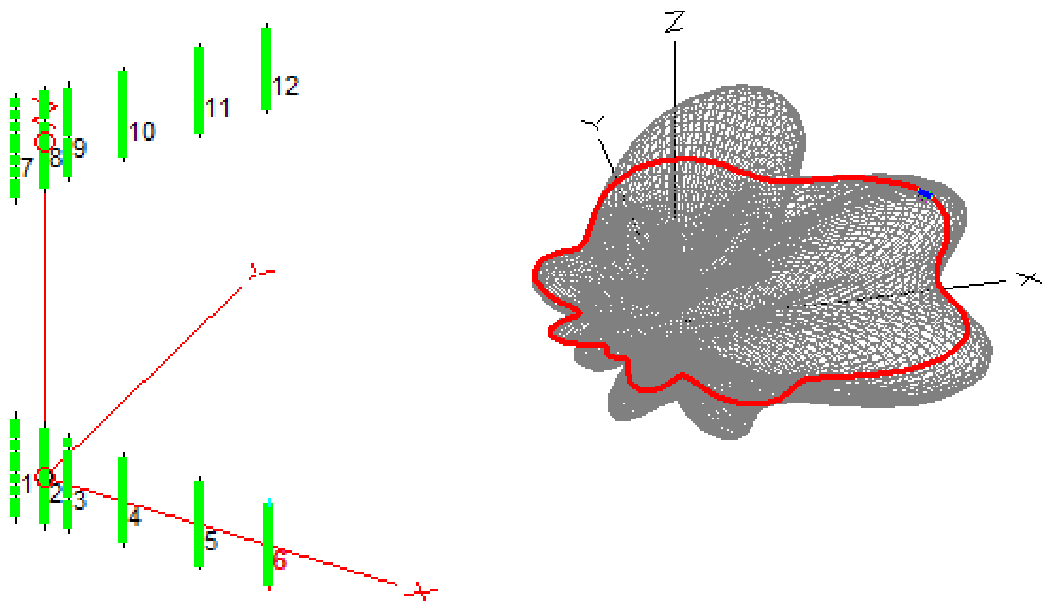

Fig. 10 EZNEC model of 23cm antenna array and the computed 3D antenna pattern

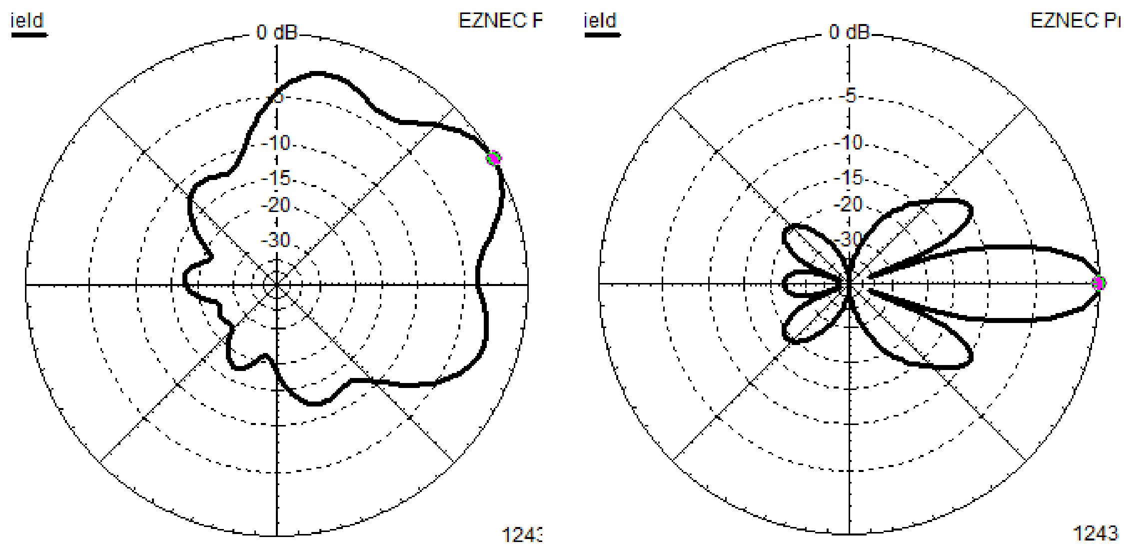

Fig. 11 Azimuth Pattern (left) and Elevation Pattern (right) of 23 cm Antenna
Gain = 10.7dBi, Az. BW = 40 deg., El BW = 18 deg.

The azimuth pattern is not totally flat over the service area, but still quite acceptable. The useful beam-width is now of the order of about 115 degrees. When we installed the antennas at NCAR, we pointed the top antenna to 35 deg TN and the bottom antenna to 95 deg TN. The resultant max. gain of 10.7dBi was thus pointing to 66 deg TN. The gain was down -6 dB at 0 deg and 129 deg. Down -10dB at 351 deg and 138 deg. The front to back ratio F/B was 23 dB. The following table can be used by members to determine the actual antenna gain on their beam headings from the repeater.

Table 2 -- 23 cm Antenna Gain vs. Compass Bearing (true north)

Bearing	Gain	Bearing	Gain	Bearing	Gain
0	4.4	45	7.7	90	7.1
5	6.0	50	8.8	95	6.9
10	7.2	55	9.8	100	7.4
15	7.9	60	10.5	105	7.9
20	8.1	65	10.7	110	8.1
25	7.9	70	10.5	115	7.9
30	7.4	75	9.5	120	7.2
35	6.9	80	8.8	125	6.0
40	7.0	85	7.7	130	4.4

Roof Top Antenna Combiner: We were limited by the number of coaxial cables we had available to run from the NCAR radio room up to the roof top. The 70 cm transmitter shared the BARC 70cm repeater's coax cable. We had one other coax available for our VHF/UHF receive antennas. On the roof-top we thus were forced to use both a 2m/70cm duplexer and a 2m/70cm/23cm triplexer as an antenna combiner.

The output from the Diamond X50 antenna was split into 2 m and 70 cm coaxes using a Diamond MX-72A duplexer. These were then fed into the 2 m and 70 cm ports of a Diamond MX-3000N triplexer. The 23 cm patch antenna was connected to the 23 cm port.

3 cm Receive Antenna: For our NEW (Sept. 2024), 10 GHz receiver we are using a home built, waveguide antenna. It is a straight piece of WR-90 waveguide mounted vertically. It has a set of 8 slot holes machined in it on one side of the waveguide to provide slot dipole antennas. The result is a phased array of dipoles giving a gain of about 14 dBi with horizontal polarization and about 80 degree (-6dB) beam-width.

Fig. 12 Alford Slot Antenna + Down-Converter

The antenna is a length of WR-90, X-band, wave-guide. It has a total of 16 slots machined in it. 8 on the front and 8 on the rear. As built, it was intended for use as an omni-directional antenna. We wanted instead an antenna with preferably only a 180 degree radiation pattern. We have the very steep Flatiron mountains on the west side of our W0BTV repeater. We want to discriminate against reflections coming off of the Flatirons. So to that end, Don, N0YE, covered up the 8 slots on the back side of the wave-guide with copper tape. Don, then mounted the antenna in this weather-tight, tough plastic enclosure. As mounted, the antenna radiates with horizontal polarization. There is a WR-90 to SMA adapter mounted on the top of the antenna. A type N feed-thru coax connector is on the bottom of the enclosure. Also shown in the box is the newly purchased Hi-Des model 3LNC70 down-converter. In normal service, a weather-proof cover is then installed over the antenna.

EZNEC Model: Prior to any testing, we have tried to do some EZNEC modeling of the antenna to guess-timate what to expect. Our local antenna expert, Prof. Ed Joy, K0JOY, suggested we simply model it as a vertical stack of 2 element wire yagis. i.e. simple driven element with reflector. Then space them the same as the actual slot spacings, but not with the offset pattern. Ed said the predicted gain would be too high, but the pattern should be close.

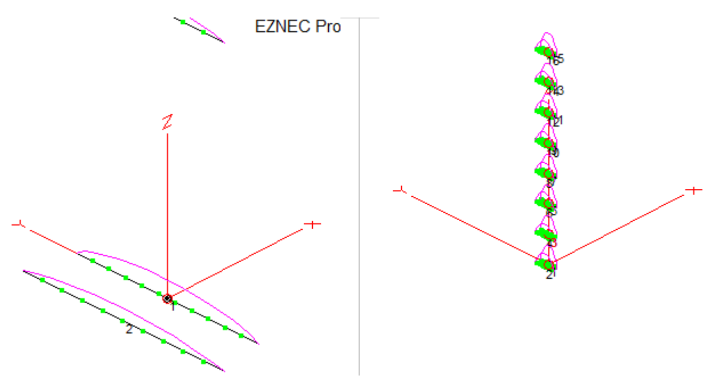

Fig. 13 EZNEC simple model of Alford Slot Antenna

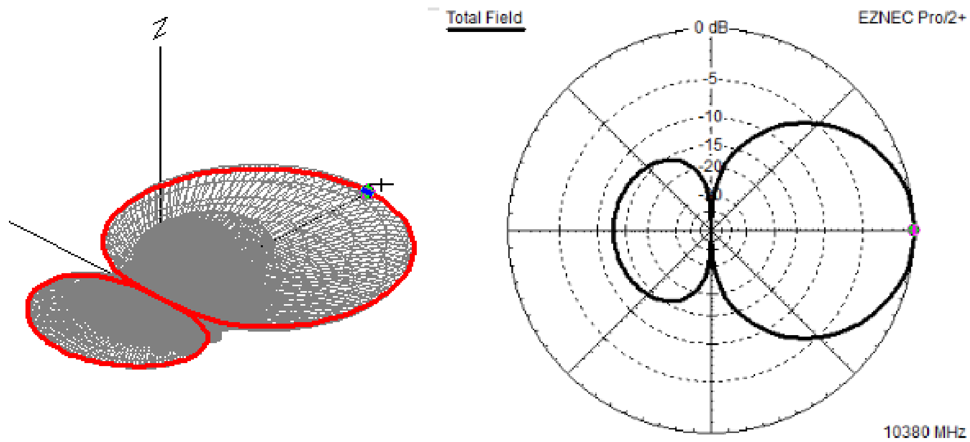

Fig. 14 Azimuth Pattern of Alford Slot Antenna

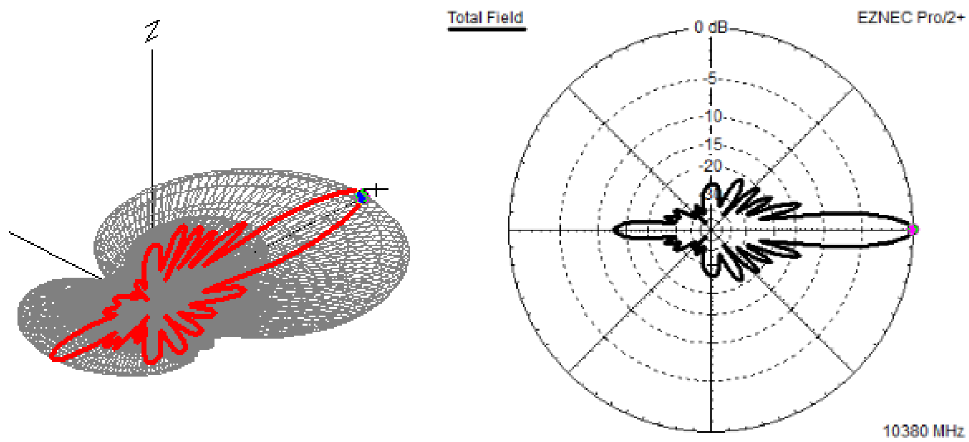

Fig. 15 Elevation Pattern of Alford Slot Antenna

Our simple EZNEC model predicted a max. gain of 16.7dBi (Ed said it would be too high). Front to Back ratio of -13dB. Azimuth -3 dB BW of 70° -6 dB BW of 100° Elevation -3 dB BW of 10°

Real World Antenna Test: We have setup an antenna range and measured the gain of the 3cm Alford antenna with the cover attached at about +14 dBi. We found that attaching the cover enhanced the bore-sight gain by +1 dB due to dielectric focusing. There was 2 to 3 dB ripple noticed in the pattern for just a few degrees variation in the bore-sight beam heading. The -6 dB azimuth beam-width was approximately 80 degrees (±40 degrees). The -10 dB azimuth beam-width was approximately 100 degrees. The front to back F/B ratio was about -30 dB. We also measured the -3 dB elevation beam-width and found it to be approximately 15 degrees. For this test, the Alford antenna was used as the transmit antenna.

Because of the somewhat irregular pattern measured, we elected to return to the test site and repeat the measurements, but with a different test arrangement. For this second test, we were only concerned with the antenna pattern, not the max. gain. We felt comfortable with the +14 dBi gain figure we measured in the first test session. For this test, we reversed the arrangement. The antenna under test became the receive antenna. We installed the new 3LNC70 down-converter in the slot antenna enclosure and used it along with a TinySA-Ultra spectrum analyzer plus bias tee as the receiver.

Conclusions: Max. Antenna Gain = +14 dBi F/B = -35 dB

-3 dB Beam Width = 30 deg, but then recovers to 65 deg after ripple to -6 dB

-6 dB Beam Width = 40 deg, again recovers with ripple to 70 deg

-10 dB Beam Width = 120 deg

Back Side Rejection of reflections from the Flatirons will be > -15 dB

The plot in Fig. 16 shows the experimentally measured antenna pattern.

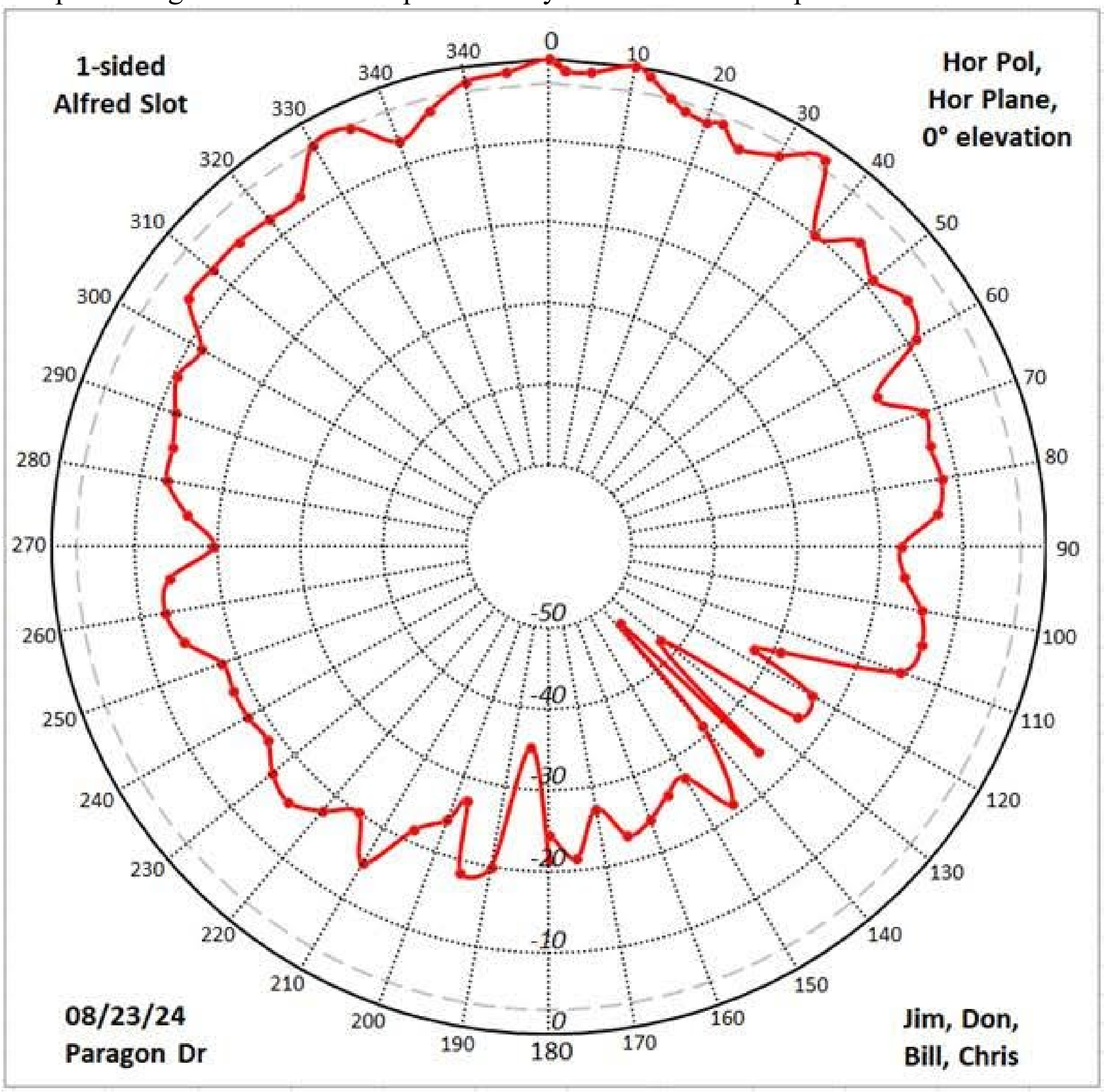

Fig. 16 Measured Antenna Pattern of 3 cm Alford Slot Antenna, max. gain = 14dBi

BAND-PASS FILTERS:

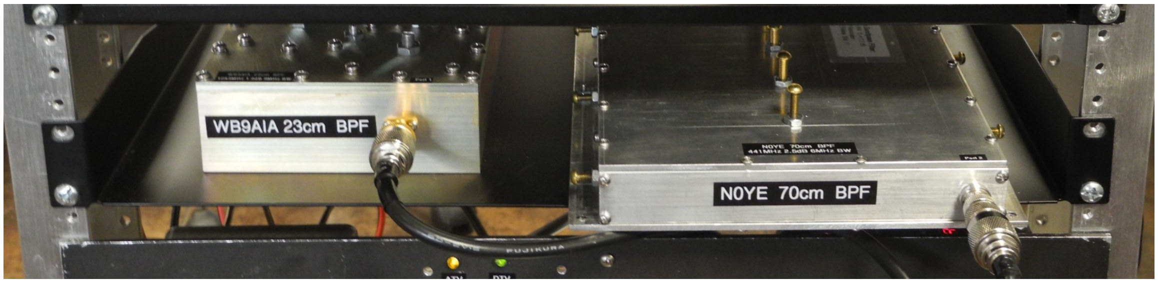

Fig. 17 23 cm (left) & 70 cm (right) Receive Band-Pass Filters

Key elements in building any repeater, be it a voice or TV repeater are excellant band-pass filters. They are required to keep the very strong transmitter signal from interfering with the very weak, incoming signals to the receiver. Fig. 17 above shows the two main BPFs for the receiver. A similar BPF is also on the output of the transmitter.

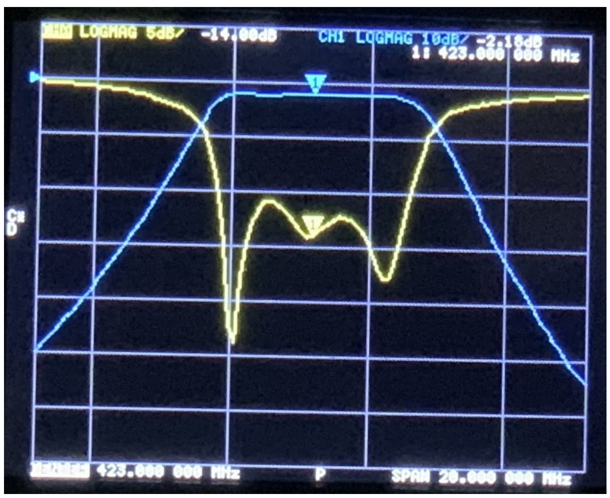

Fig. 18. W0KWR, 7 pole, Ch 57, Transmitter's Band-Pass Filter -- S21 (blue) at 10dB/div & S11 (yellow) at 5dB/div. Center Freq. = 423 MHz, Span = 20 MHz. measured on NanoVNA model SAA-2.

Ch 57 - 70cm BPF: Since the early 90s, the TV repeater has used a pair of inter-digital, band-pass filters made by Spectrum International. In 2019, we removed the SI, Ch 57 filter from the transmitter this time. We replaced it with actually a much older, but better filter. The filter we installed was made by John Shafer, W0KWR, (now SK) in the late 1970s. John built it for the very first Boulder ATV repeater. It was a 7 pole, inter-digital design. The filter was recently re-tuned using a Rigol Spectrum Analyzer with built-in tracking generator. The filter was tuned centered on 423 MHz. Insertion loss, S21 at 423MHz was -1.7dB. It's -3 dB bandwidth was 7.9 MHz. It gives -31 dB (429), -75dB (435) and -117 dB (441) rejection for the upper adjacent TV channels. This filter is used on the output of the 70 cm transmitter. The filter's response is shown above in Fig. 18.

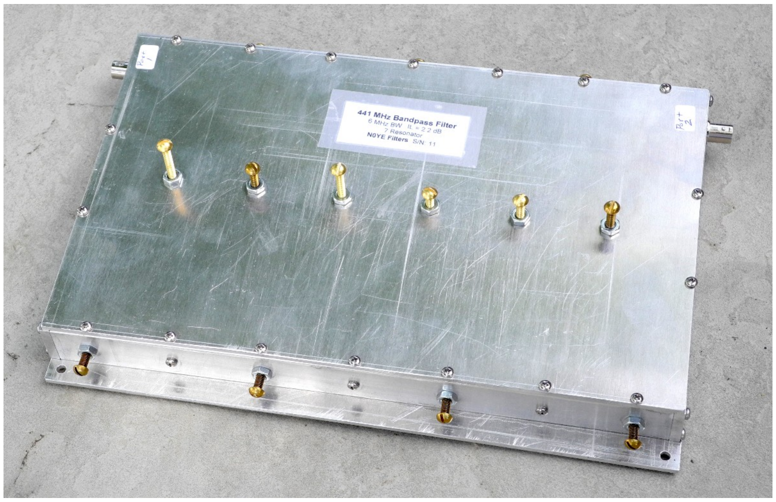

Fig. 19 Channel 60, 7 pole, 70cm, Band-Pass Filter built by Don, N0YE.

Ch 60 - 70cm BPF: We removed the old Spectrum International, inter-digital, band-pass filters from the repeater. We replaced the 70cm, Ch 60 receive filter with a new, home-brew, 7 pole, inter-digital, BPF built by Don, N0YE. It has much steeper skirts on it. Particularly important for filtering out the severe 70 cm RFI we have been encountering from strong ham FM repeaters in the 446-450 MHz range and commercial FM signals in the 450-460 MHz range. Don's new filter, Fig. 19, has 40 dB rejection at 446 MHz and up to 130 dB rejection at 460 MHz. Fig. 11 shows the measured S21 & S11 of the filter. Don's new filter is considerably larger than the old SI-BPF. Thus, there was not room for it on the existing 19" rack panel. It was thus mounted on a separate 19" shelf. See. Fig. 17 This filter was re-tuned in 2023 to assure as flat as possible frequency response across the Ch 60 pass band from 438-444 MHz.

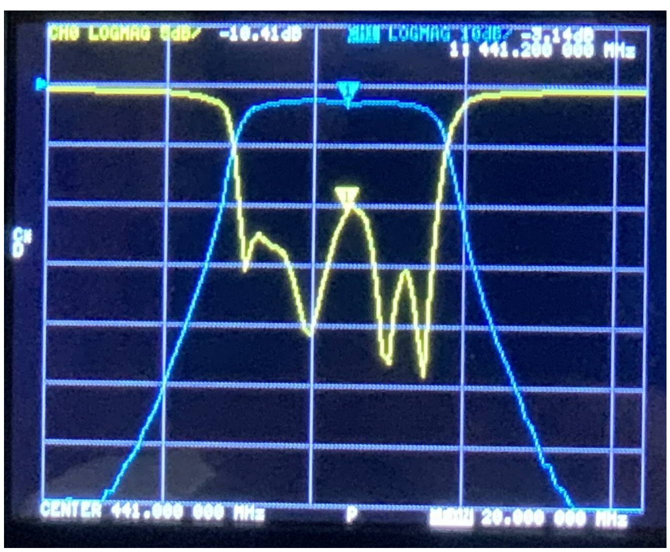

Fig. 20 Channel 60, 70 cm, 7 pole, inter-digital, Band-Pass Filter built by Don, N0YE. Used as the front end for the 70 cm receivers. S21 (blue) at 10dB/div. S11 (yellow) at 5dB/div. Center Freq. = 441 MHz, Span = 20 MHz. Measured with NanoVNA.

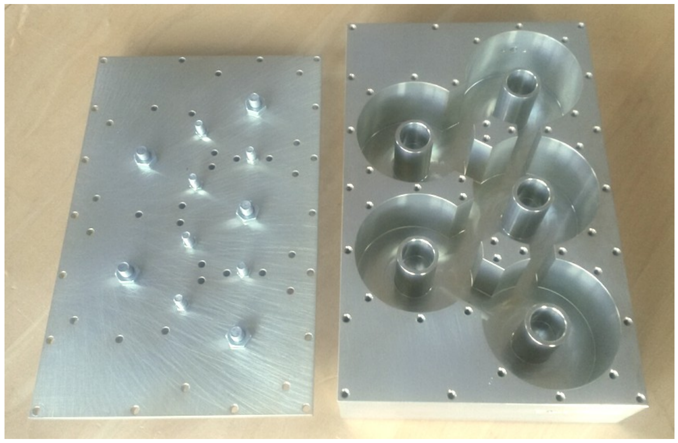

Fig. 21 Receive BPF for 23 cm shown opened up

23 cm - BPF: Our ATV repeater has suffered from RFI issues on the 23 cm input. In 2012, the FAA installed a new radar near Parker, Colorado. At the time our input frequency at 1277 MHz was quite close to the radar's frequency and it totally clobbered us. We received permission from the CCARC, the Colorado frequency coordinating body, to move to the bottom end of the 23 cm band. Don, N0YE, scrounged thru his microwave junk box and found a 1.5 GHz band-pass filter that he modified down to the 23 cm band. With it we were able to suppress most of the radar energy. But not enough. Boulder ATV hams with weak DVB-T signals into our repeater have been suffering from loss of audio and lots of freeze frames. Monitoring the signal to noise ratio on incoming signals showed a definite flucutation in S/N. Even for very strong signals showing S/N of 23dB, (the max. with QPSK), we saw a periodic drop in S/N. The S/N drop rate corresponded to the 5 rpm rotatation rate of the radar antenna. Tests with a spectrum analyzer showed the radar energy was spread from 1259 to 1269 MHz with dual peaks at 1261.25 & 1266.5 MHz.

Thus, in the Fall of 2019, we decided we needed a new, better BPF for our 23cm receiver. We also decided to eliminate the 1247 MHz FM-TV receiver. The new BPF would be designed to only pass our 6 MHz wide, 1243 MHz DVB-T signals. Plus we needed the ultimate rejection of the FAA radar pulse from 1259-1270 MHz.

We enlisted the help of our local, resident filter expert, Dan Swanson, WB9AIA. (*new call is now K0DGS*) Dan is a fellow of the IEEE and makes his living designing filters. (***www.dgsboulder.com***) After Dan came up with a design, the next question was how to build it. Dan's design required the services of a precision machine shop. Don, N0YE, said he knew of just the place and it was run by another ham. Don and Dan then contacted Mark Lewis, N0IO, in Grand Junction, Colorado. Mark's company - Rocky Mountain Manufacturing is a precision machine shop specializing in medical equipment products. The photo above, Fig. 21, shows the beautiful machined filter Mark built for us.

The BPF Dan designed for us is a 5th order, comb-line, cavity filter with two inductive cross-couplings. The cross-couplings put "zeros" on the high side of the pass-band. Mark then fabricated it by machinging it out of a solid piece of aluminum of 8 1/4" x 5 1/4" x 1 5/8". The above photo, Fig. 9, shows the interior along with the cover plate. The tuning screws are in the cover plate. The photo on the right, Fig. 10, shows the input coupling from an SMA connector.

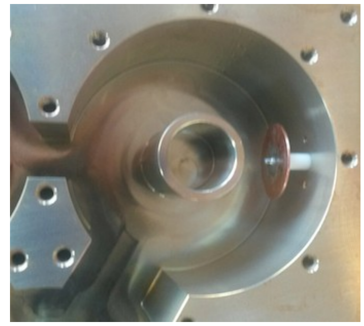

Fig. 22 Input Coupling

Dan pre-tuned the filter by setting the tuning screws to his design dimensions. He then tested the BPF on a vector network analyzer. His predictions were extremely close. The initial passband was only about 4 MHz too high. The plot below, Fig. 23, of S21 and S11 shows the results after he then fine tuned the filter. The traces in blue are the theoretical predicted responses while the red traces are the actual measured performance after fine tuning. Fig. 24 shows our measurement with a NanoVNA. Our measurements showed that the insertion loss in the center of the pass-band at 1243 MHz was only -1.3dB with a very flat reponse across the desired 6 MHz pass band. The -3dB bandwidth was 9 MHz. For -10dB BW, it was 11.1 MHz. For -20dB BW, it was 14 MHz. For -30dB BW, it was 17.5 MHz. They confirmed Dan's results.

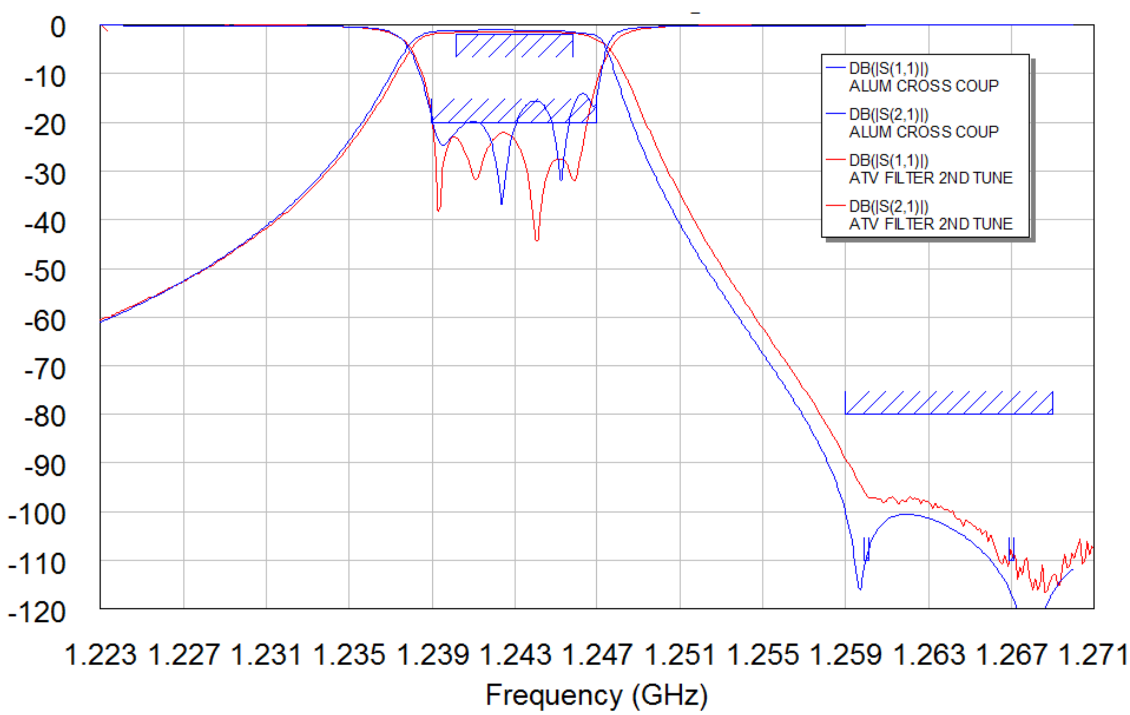

Fig. 23 Dan's, WB9AIA, New 23cm BPF showing Dan's predictions in blue and his measured results in red.

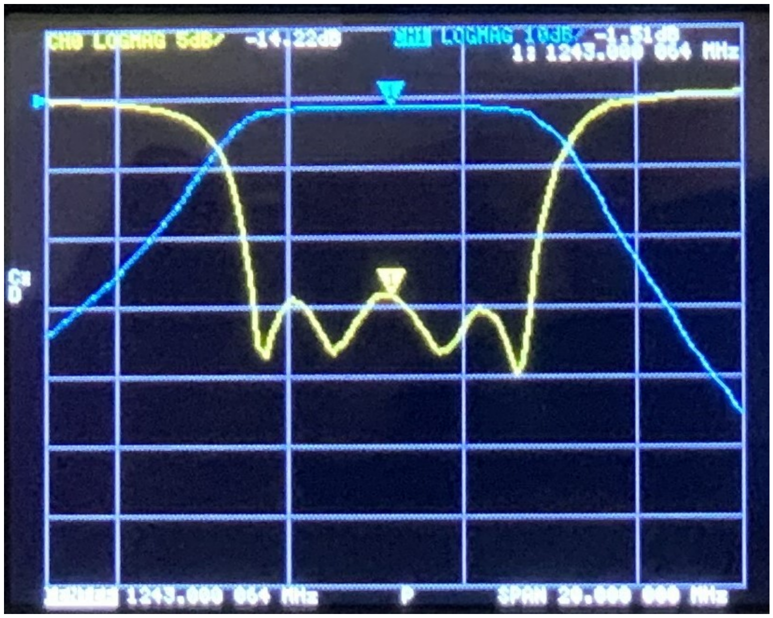

Fig. 24 WB9AIA, 23 cm, Band-Pass Filter --- S21 (blue) at 10dB/div & S11 (yellow) at 5dB/div. Center Freq. = 1243 MHz, Span = 20 MHz. Measured with NanoVNA.

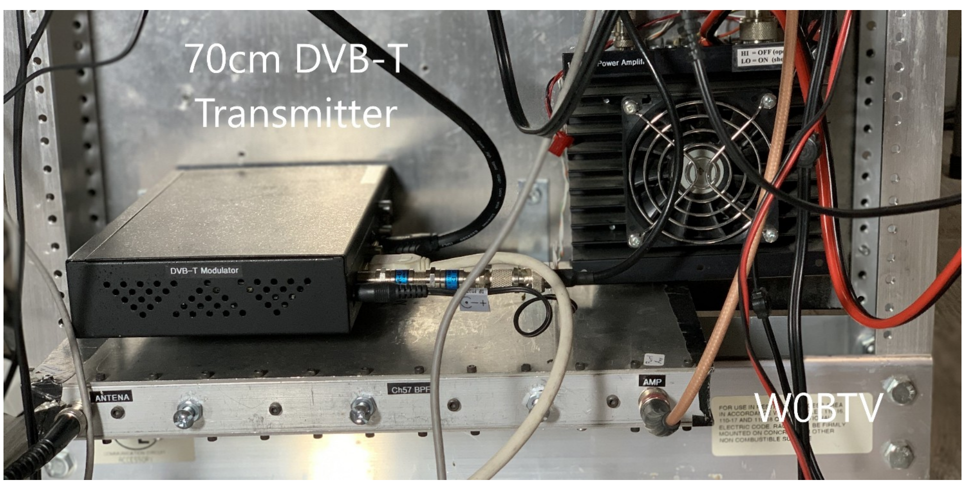

Fig. 25 W0BTV 70 cm, digital TV repeater transmitter

70 cm Digital TV TRANSMITTER:

Fig. 32 at the rear of this app. note shows the wiring for the transmitter panel. The main TV transmitter is only for 70 cm on channel 57 (420-426MHz). The digital, DVB-T signal is created by a Hi-Des model HV-100EH, DVB-T modulator. It is a very pure signal with essentially nothing outside of the 6 MHz wide TV channel. The output of the modulator goes to a KH6HTV Video model 70-9B, 10 Watt, RF Linear Power Amplifier. The photo above, Fig. 25, shows the assembled 70 cm transmitter. It is assembled on a

19" rack panel. The Ch 57 BPF is on the bottom. The black box above the BPF is the Hi-Des, DVB-T modulator. The black box on the right with the cooling fan is the rf linear power amplifier.

In digital TV mode, the amplifier puts out 10 Watts (avg). The output of the amplifier is then routed to a Ch 57, 6 MHz, band-pass filter. The transmitter's output power from the BPF to the antenna is +37 dBm (5 Watts) for DVB-T. Fig. 26 shows the resultant spectrum of the digital transmitter. The digital modulator has been programmed to output full 1080P, 16:9, high-definition video. The digital modulation parameters have been set to "*normal*" settings of: H.264 video encoding, 5.5 Mbps, QPSK, 8K FFT, 5/6 FEC, & 1/16 Guard.

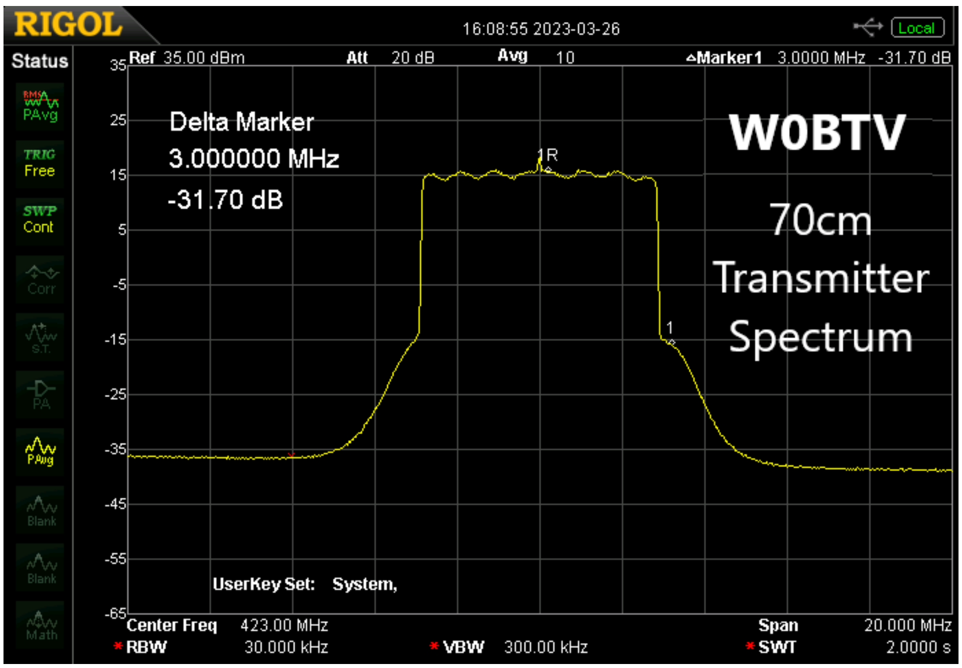

Fig. 26 W0BTV TV repeater transmitter's output spectrum in digital, DVB-T mode. Center frequency is 423 MHz, 20 MHz span. 10 dB/div & 2 MHz/div. The flat lines on the left and right are the measurment noise floor. The small spike at the center frequency is a defect artifact of the old HV-100EH modulator. It is LO leakage.

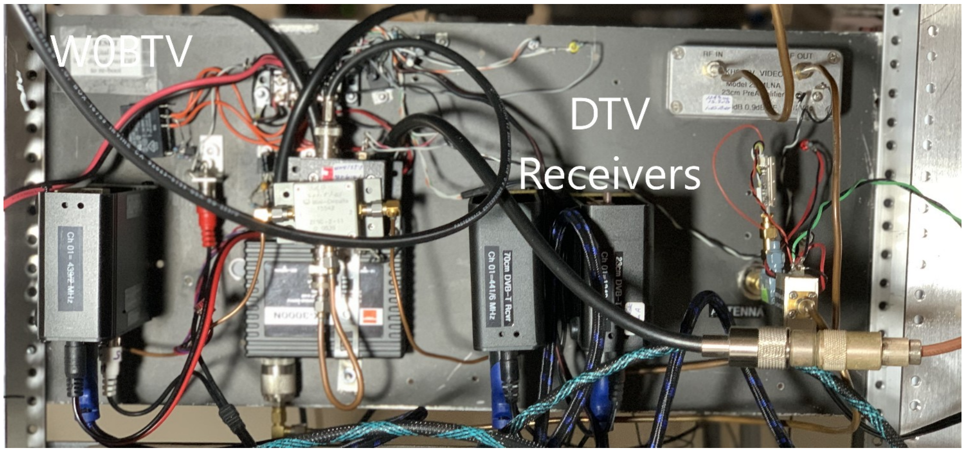

Fig. 27 W0BTV repeater digital TV receivers mounted on 19" rack panel.

DIGITAL TV RECEIVERS:

The TV receivers are shown above in Fig. 27. Fig. 33 at the rear of this app. note shows the wiring for the receiver panel. It has one common antenna input which goes to a Diamond triplexer which splits the receive signals into 2 meter FM (control), 70 cm (TV) & 23 cm (TV). There is a BPF following for each band. These were described earlier. The 70 cm & 23 cm BPFs are mounted on a separate, 19" rack shelf, Fig. 17. For both 70 cm & 23 cm, there next are low noise pre-amps. The 23 cm preamp is a KH6HTV Video model 23-4LNA (16dB gain, 1dB NF). The 70 cm preamp is a KH6HTV Video model 70-L20 (18dB gain, 1dB NF). For 441 MHz we use an HV-110. For 23 cm, 1243 MHz, we use a Hi-Des, model HV-120A receiver. The 2 meter FM control receiver is a salvaged B-Tech model UV50X2 which had it's transmitter blown out, but it's receiver was functional.

3cm, 10GHz Rcvr: New, as of Sept. 2024, we have added a 3 cm (10 GHz) receiver. We are using a Hi-Des HV-110 as the IF for it. We purchased from Hi-Des a model 3LNC70, 3cm to 70cm down-converter. It is seen mounted in the Alford slot antenna enclosure in Fig. 12. We send +12Vdc power up the IF coax cable to the remotely located down-converter. We use a bias tee mounted on the receiver front panel to insert dc power into the coax line. The LO frequency in the down-converter is set with a crystal oscillator. It is running at 10.05735 GHz. The desired rf receive frequency is 10.380 GHz. Thus our IF frequency is 322.650 MHz. The HV-110 receiver is set to that frequency.

Hi-Des Receiver HDMI Issues (2023): When we tried to install new (2022-23 mfgr dates) HV-110 receivers for both of our 70cm receivers, we ran into a whole lot of issues, particularly with the HDMI output. The new receivers refused to communicate over the HDMI cable with many different video monitors. They also didn't like our HDMI quad processor. We tried to work with the factory and tried various versions of firm-ware, to no avail. We tried to buffer them using 1 in / 2 out HDMI splitters, but they didn't help either. The final solution was to ask our local ATV hams to supply a very old (2016 version) HV-110. The older units seemed to work much better than current production units. So we retained the old HV-120A for the 441/6 MHz receiver and used an old HV-110 for the 441/2 MHz receiver (note: 9/24 now used as the 3cm IF receiver).

Receiver Sensitivity: The sensitivity was measured at the Receive Antenna, type N, input connector on the front panel of the receiver assembly. Digital threshold is defined as the lowest signal with perfect P5 video and Q5 audio and no freeze framing. The 6 MHz BW, DVB-T receivers were all calibrated using amateur TV, "Normal" DVB-T, QPSK, 1080P parameters. (H.264 encoding, 1080P, 5.5Mbs - 6 MHz BW, QPSK, 8K FFT, 5/6 FEC, 1/16 Guard) For "Normal QPSK" parameters, this occurs with a S/N = 8dB. This is also the level required to key up the repeater.

23 cm, 1243 MHz, DVB-T Receiver = -92 dBm
70 cm, 441 MHz, DVB-T Receiver = -89 dBm
3 cm, 10.380 GHz, DVB-T Receiver = -93 dBm

5.9 GHz, FM-TV TRANSMITTER:

Fig. 34 at the rear of this app. note shows the block diagram of the (*NEW for 2020*), 5.9 GHz, FM-TV transmitter. This transmitter uses the new, low cost transmitters and receivers marketed for the drone market. They are available from many sources on the internet, including Amazon, E-Bay, etc. The transmiter is analog, transmitting standard definition, 480i, NTSC, video and mono audio. It uses FM-TV modulation with a 6.5 MHz sound sub-carrier. The transmitter consists of a TX-35, mini-xmit module. It is frequency synthesized with 40 channels. It then drives a 2 Watt power amplifier. The transmitter's frequency is 5.905 GHz and it's rf output power is +33dBm (2 Watts). The antenna is an omni-directional, horizontally polarized monopole with about 9-10dBi gain. Thus the ERP is about 20 Watts.

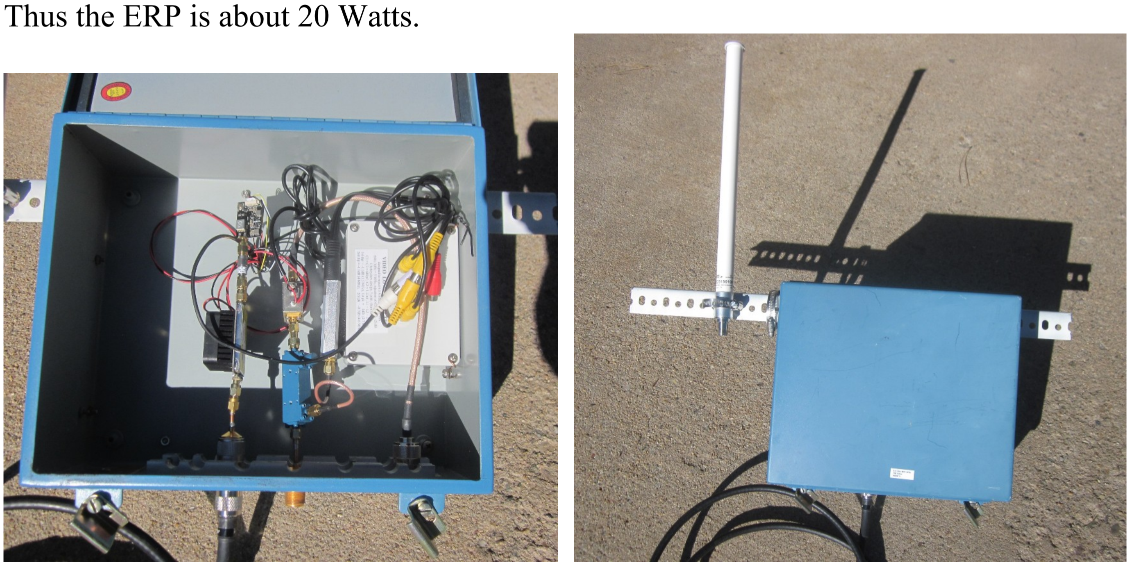

Fig. 28 5.9GHz, FM-TV Transmitter enclosure & antenna -- roof top mounted.

The actual transmitter is separate from the rest of the 19" rack mounted repeater. It is housed in a weather-proof enclosure and mounted on the roof of the repeater site's south tower building at about 100 ft above ground level. Fig. 28 above shows this enclosure along with the antenna.

+13.8Vdc power for the transmitter is fed up to it from the radio room using the repeater's receive antenna's coaxial cable. There are Bias Tees in the repeater rack and also in the 5.9 GHz transmitter box to insert and pick-off the dc power.

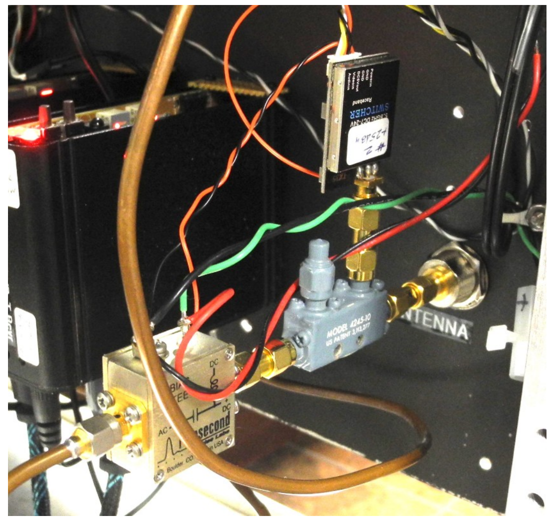

Fig. 29 FM-TV Up-Link showing mini transmitter module, directional coupler & bias tee.

The A/V modulation for the FM-TV transmitter is also fed up the receive antenna's coaxial cable. It is done in a unique, "repeater within a repeater" scheme. Down in the radio room, in the repeater rack, we have a mini FM-TV transmitter module which is driven by the analog A/V signals. This mini transmitter module is on 5.645 GHz and puts out +13 dBm of rf. This is then coupled onto the receive antenna coaxial cable using a 10 dB directional coupler. Up on the roof-top, in the transmitter box, there is another 10 dB directional coupler to pick off this 5.645 GHz FM-TV signal. It is then demodulated by an FM-TV receiver tuned to 5.645 GHz. The composite video plus audio from this receiver then is used to again modulate the 5.905 GHz FM-TV transmitter. We found it necessary to also add a 5 MHz, Chebeyshev, low-pass filter on the video line to help remove some of the residual sound sub-carrier from the up-link signal. Using this scheme, we are able to make multiple service out of the repeater's receive antenna coaxial cable. Plus, our repeater site host, would not allow us to install more cables.

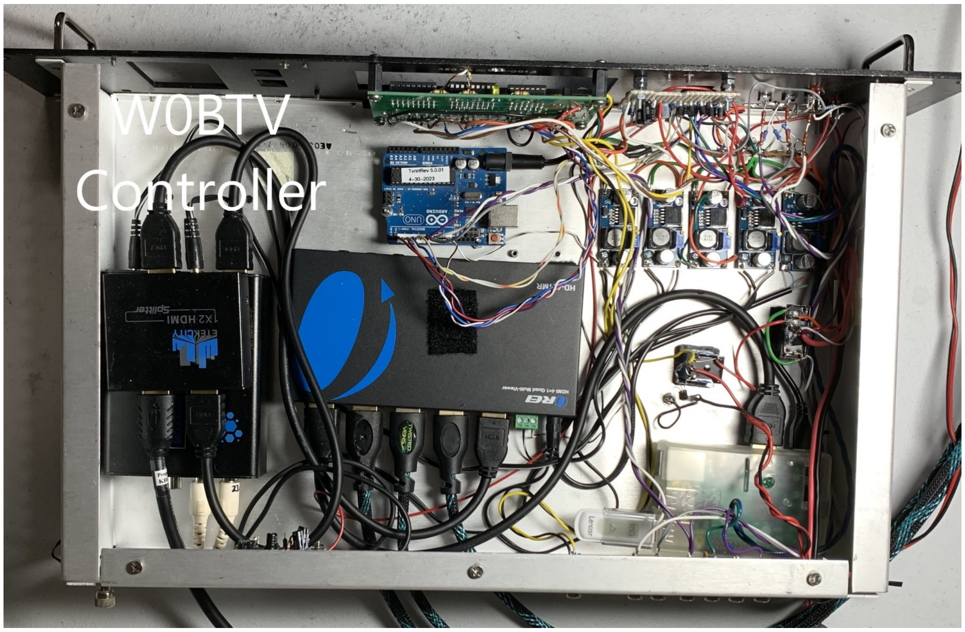

Fig. 30 W0BTV Repeater Controller
(Feb. 2020 photo - present configuration slightly different)

Repeater Controller & HDMI Switch

Figs. 35 & 36 show the block/wiring diagrams of the HDMI switch circuitry and repeater controller. As mentioned earlier, the key component is the OREI, model HDS-402MV Quad Viewer. Fig. 30 above shows all of these components mounted in a 19" rack mount cabinet. The Quad Viewer/Switch is the large black box in the center. The blue module on top of the quad viewer is a Media Player which replaced the previous Raspberry-Pi. The Media Player generates the video slide show used as the ID for the repeater. It plays continuously a video movie, .mp4 file stored on a USB memory stick. The HDMI to Composite Video converter is on the far left. For the Quad Viewer/Switch, the HDMI Input #1 comes from the 1243 MHz digital receiver. Input #2 comes from the 441 MHz digital receiver. Input #3 comes from the 322MHz, IF digital receiver. Input #4 is the HDMI monitor output from the ID media player. The blue pc board in the top center is an Arduino micro-computer which is used as the system controller. The vertical board at the top, mounted to the front panel, is the DTMF touch-tone decoder and relay board. The latest (Dec. 2024) modification installed a new DTMF decoder/relay designed by Bill, AB0MY. It is based upon an Arduino.

HDMI Switch Matrix: The quad HDMI output from the quad viewer first goes to an HDMI 1 in / 2 out active splitter. One output of which goes directly to the Hi-Des HV-100EH, DVB-T modulator in the transmitter. The HV-100s HDMI loop-thru output drives a small, 7", flat-screen, hi-res, video monitor. The other output from the 1in/2out splitter goes to an HDMI to composite video (+ stereo audio) converter. The audio output from this converter was too low, so it is first amplified 5X by an LM741 audio amplifier. The mono audio from the 741 along with the composite video from the HDMI-A/V converter are then sent to the 5.9 GHz, FM-TV up-link. The 7" monitor is mounted on the top 19" rack shelf along with the 2 meter FM control receiver and the +13.8Vdc power supply for the whole system.

Each module in the HDMI switch is provided with it's own source of +5 Vdc power using DSN2596 switching regulators. Provision was also provided, if needed, to apply a RESET pulse to the assembly. Resetting temporarily removes for 10 seconds the +5V DC power to every digital module, thus causing a re-booting. RESET has been found to be absolutely necessary. It is a feature which should be included in every DATV repeater.

TV REPEATER CONTROLLER: Fig. 36 shows the wiring of the repeater controller. The key elements are the DTMF decoder and the Arduino micro-computer. The AB0MY Arduino tone decoder is the pc board mounted vertically behind the front panel. The Arduino controller is the blue pc board in the center of the photo photo, Fig. 30. The DTMF decoder receives it's audio from the 2 meter, FM receiver. It was designed and built by AB0MY. It contains eight relays. They can be programmed to various modes. Relays # 1 through 7 were set to be latching relays while #8 was set to be a momentary contact to initiate the RESET mode. The momentary contact was used to trigger a 10 second monostable to generate the RESET pulse. A RESET was found to be necessary, because all equipment with built-in microprocessors have been found to "glitch" at sometime or another and need to occasioanlly be "Re-Booted". The Arduino receives inputs from the DTMF decoder and *Video OK* signals from the various receivers. It then determines the settings for the HDMI switch which it controls over the RS-232 line. It also controls the PTT (Push To Transmit) control line for the transmitter. The original program codes for the Arduino were written by Don, N0YE. The current version installed as of December, 2024 was written by Bill Eberle, AB0MY. It is labeled as revision "Repeater_Master_V0_9_4.ino"

Problems Encountered in 2023 Modifications:

HDMI Issues: The 2023 modification of removing the 70 cm analog receiver and transmitter and installing the 439/2 MHz digital receiver should have been very straight forward and simple. It didn't turn out that way. The previous version of the repeater used Hi-Des model HV-120 receivers for both 23 cm and 70 cm band. Using an expensive HV-120 ($250) was overkill for 70 cm where an HV-120 ($120) should have worked just as well. So I removed the 70 cm HV-120 and replaced it with a new HV-110. For the new, 441/2MHz receiver, I also installed a new HV-110. The biggest issue faced was HDMI bugginess of the Hi-Des HV-110 receivers. I had had considerable HDMI difficulties with new (2022-23) purchased Hi-Des receivers (both HV-110s & HV-120-1.2G). They didn't want to talk to some monitors. And they were also tempermental, in that they sometimes worked and sometimes didn't. Why ? Unknown. I tried to work with the factory and tried various firmwares they supplied. None were completely satisfactory. I might add that the older HV-120s (from 2018) worked flawlessly with absolutely no HDMI bugs. Even trying the old HV-120 firmware in newer production didn't solve the HDMI issues in the new production.

MEDIA PLAYER for ID (5/23) In 2023, we replaced the Raspberry-Pi video player with a new dedicated Media Player. The Media Player was made by AGPTEK and only cost about $25 from Amazon. It was designed to play either videos or photo slide shows from computer files stored on a USB memory stick. It included auto repeat capability. It has both HDMI and composite video outputs. We use the HDMI output.

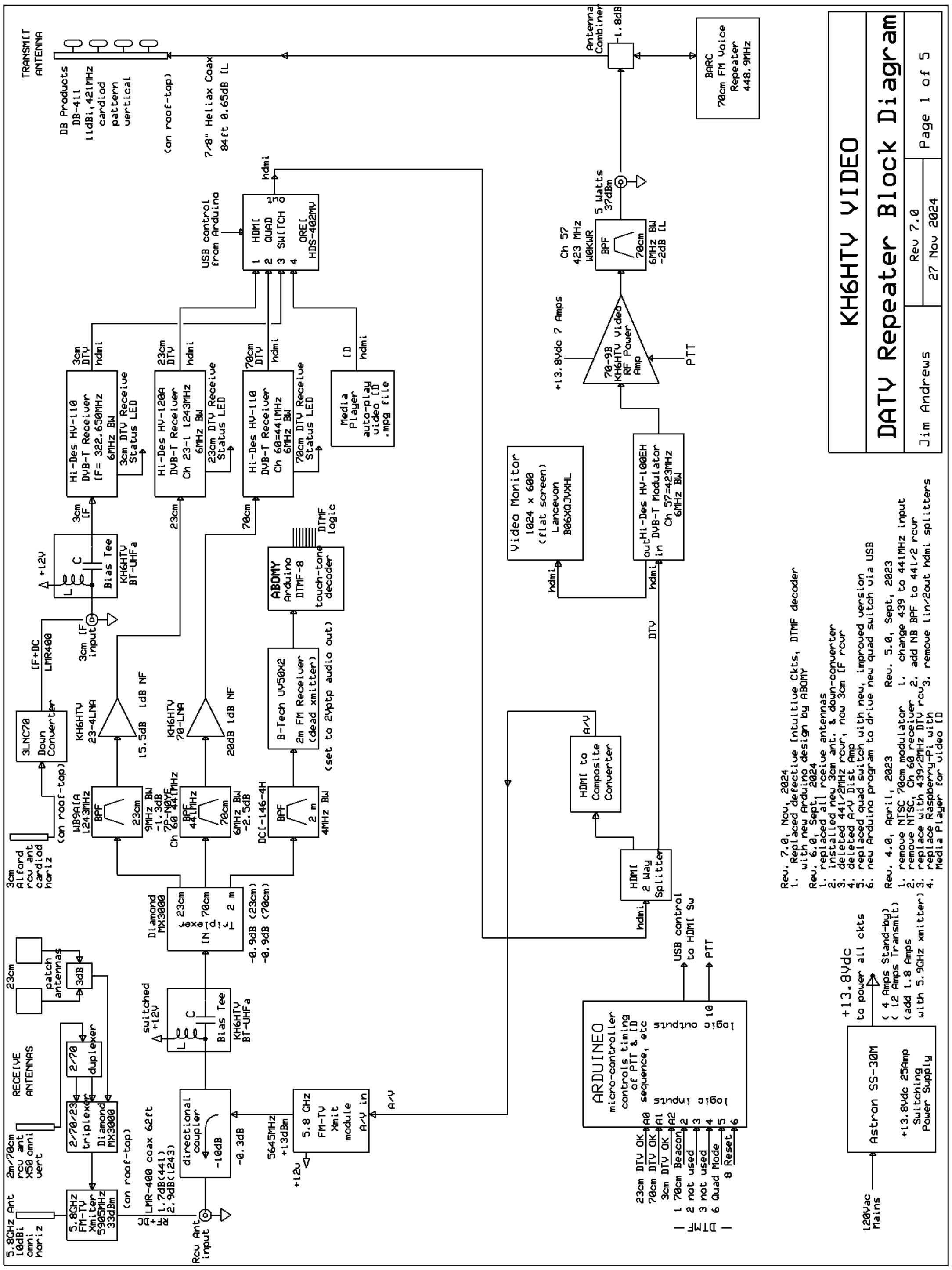

Fig. 31 Block Diagram of W0BTV Repeater

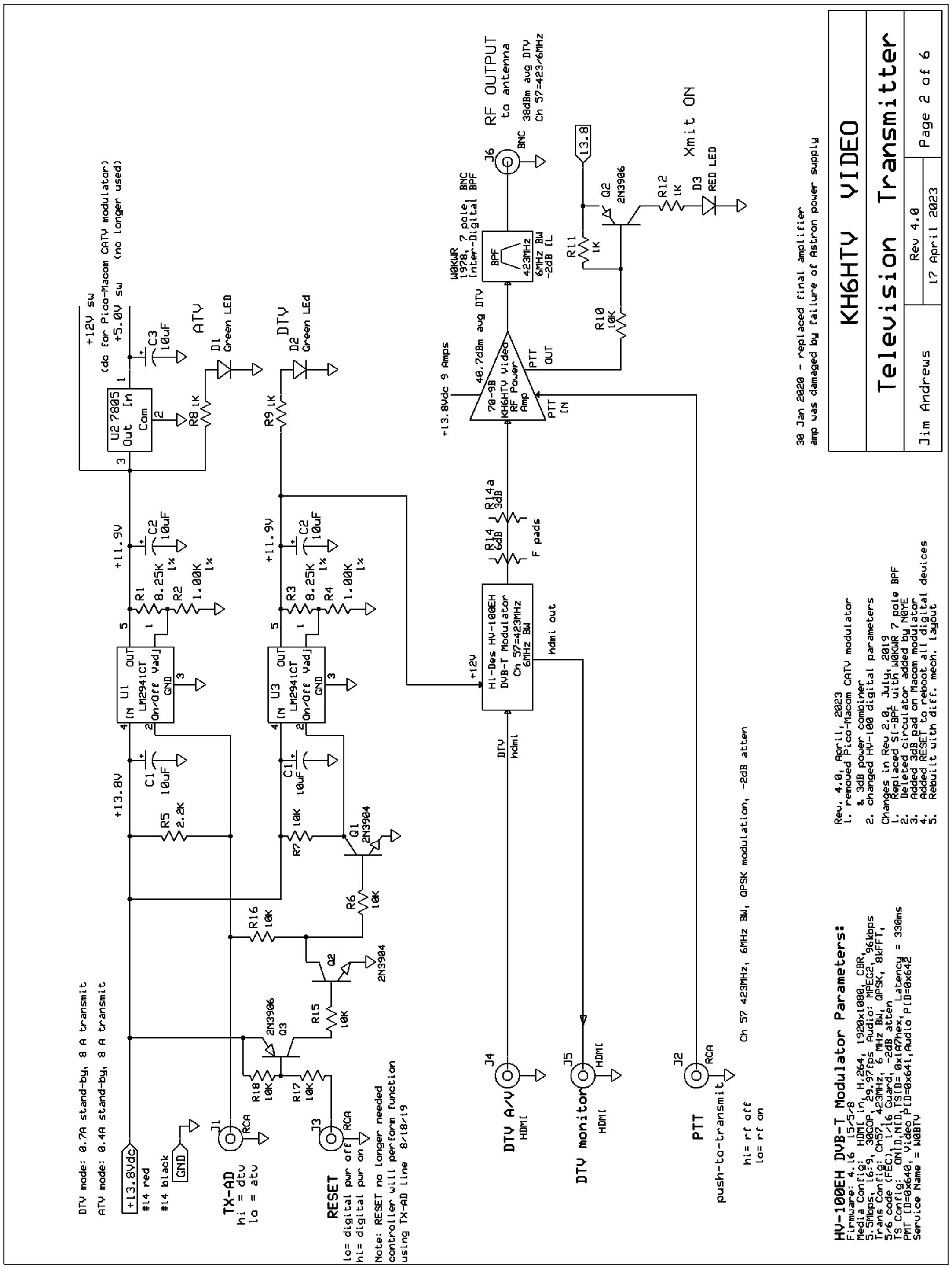

Fig. 32 70cm, Digital TV Transmitter

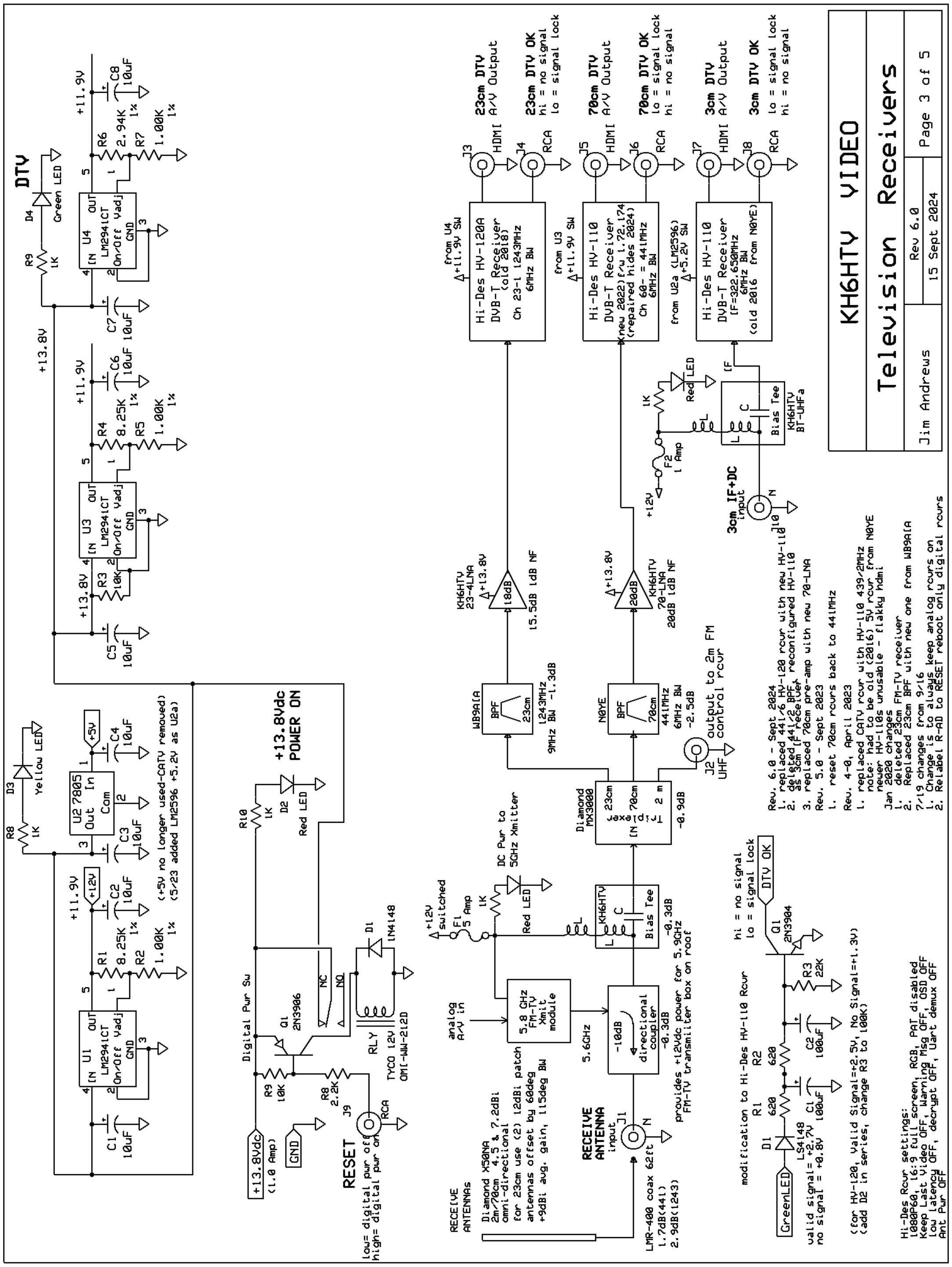

Fig. 33   70 cm & 23 cm digital TV receivers

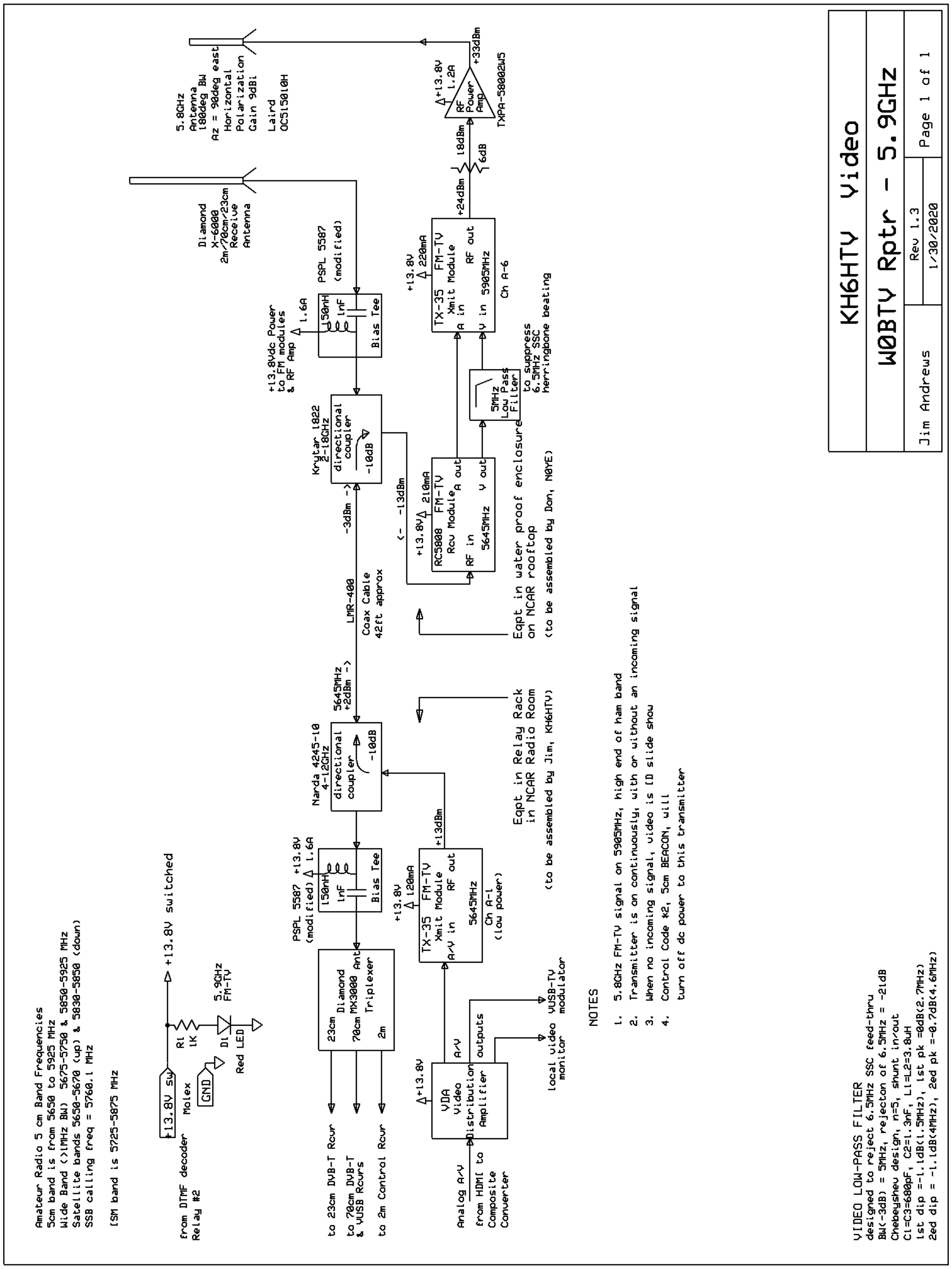

Fig. 34 5.9 GHz, 2 Watt, FM-TV Transmitter

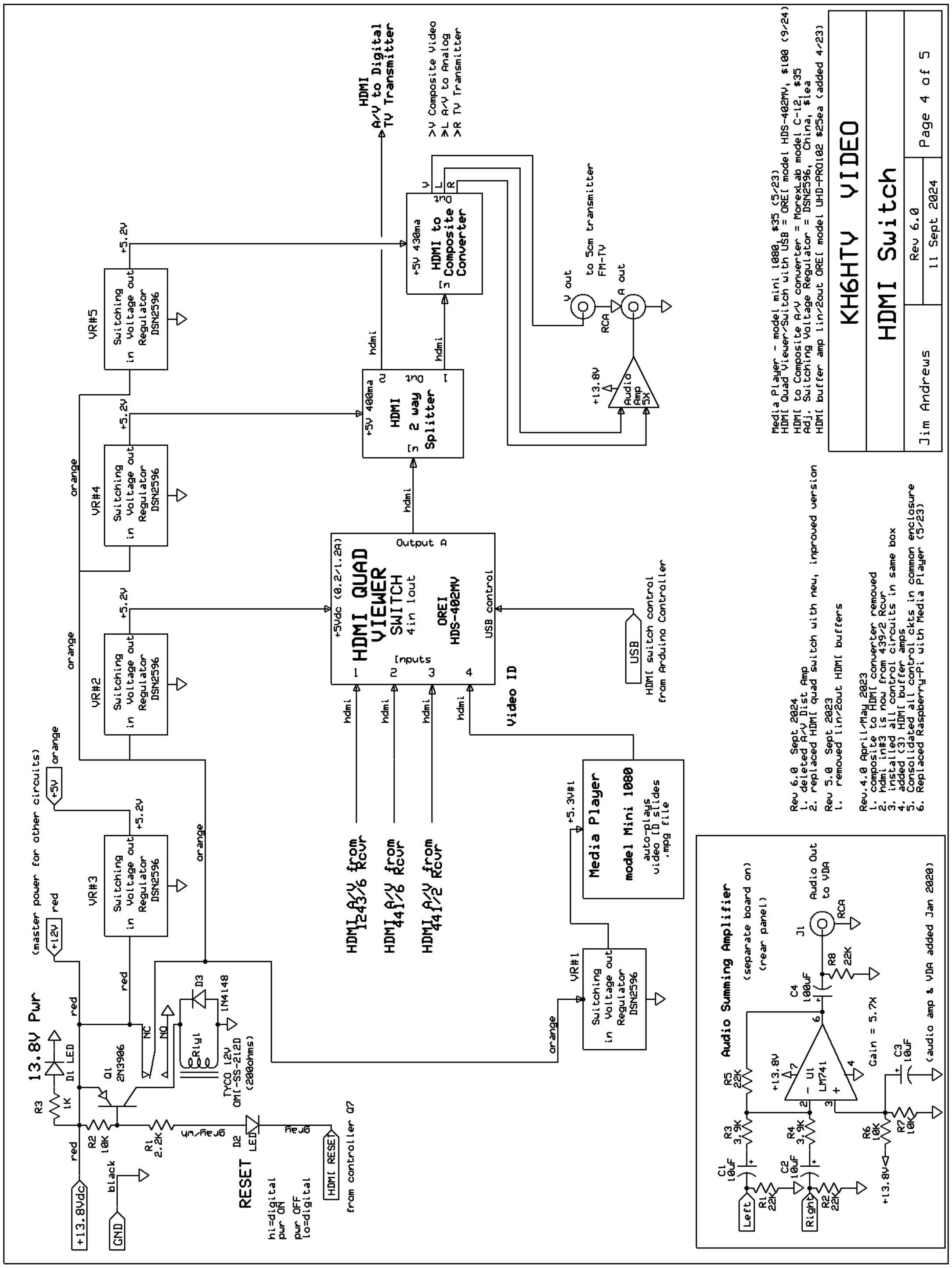

Fig. 35 HDMI quad switch for W0BTV TV repeater

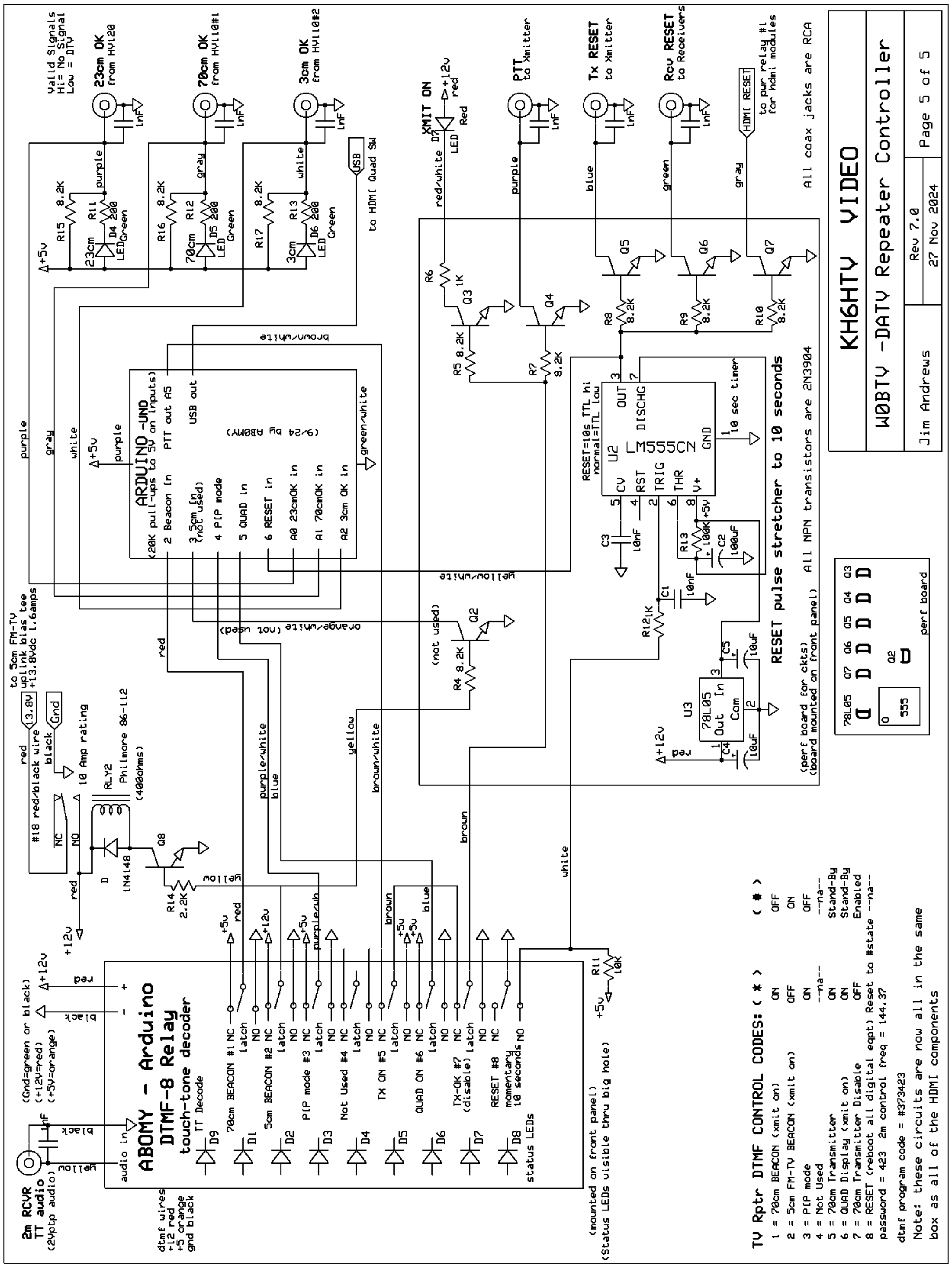

Fig. 36 Controller for W0BTV TV Repeater