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Microwave TV Transmitters & Receivers

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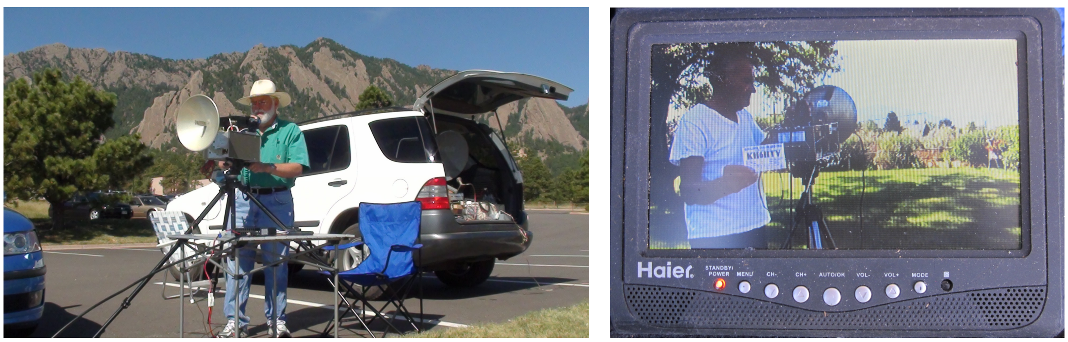

Fig. 1 DVB-T QSO on 10 GHz between N0YE & KH6HTV

The FCC allows wide bandwidth TV transmissions on all amateur radio bands starting at the 70 cm band and all shorter wavelengths (higher frequencies). Most amateur TV activity occurs in the UHF region, predominantly on the 70 cm (420-450 MHz) amateur radio band and to a lesser extent, the 23 cm (1240-1300MHz) band. We have more bands with many 100s of MHz available, on higher microwave frequencies. They include: 33 cm (902-928 MHz), 13 cm (2.3-2.31 & 2.39-2.45 GHz), 9 cm (3.3-3.5 GHz), 5 cm (5.65-5.925 GHz), and 3 cm (10-10.5 GHz) bands.

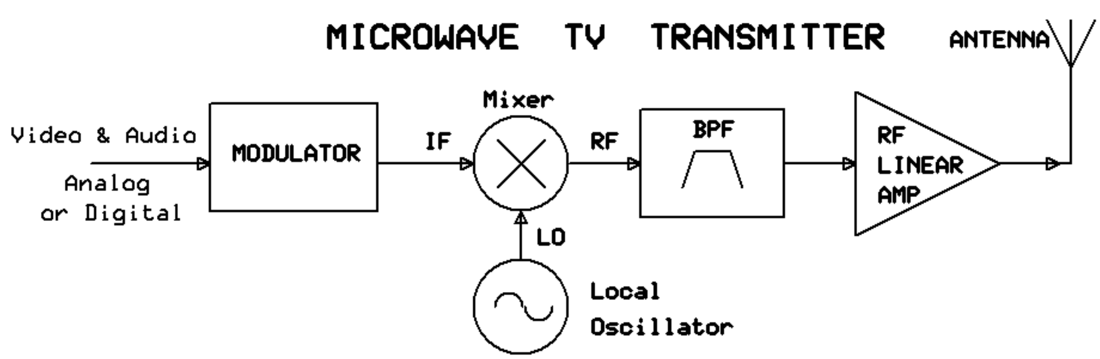

Fig.2 Block Diagram of a Microwave TV Transmitter

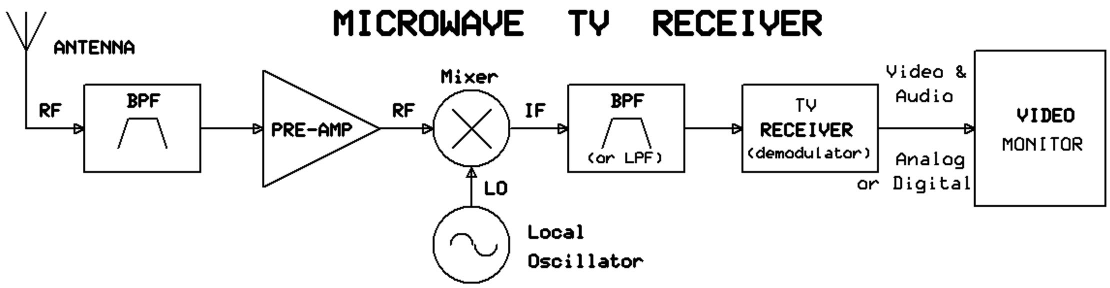

Fig. 3 Block Diagram of a Microwave TV Receiver

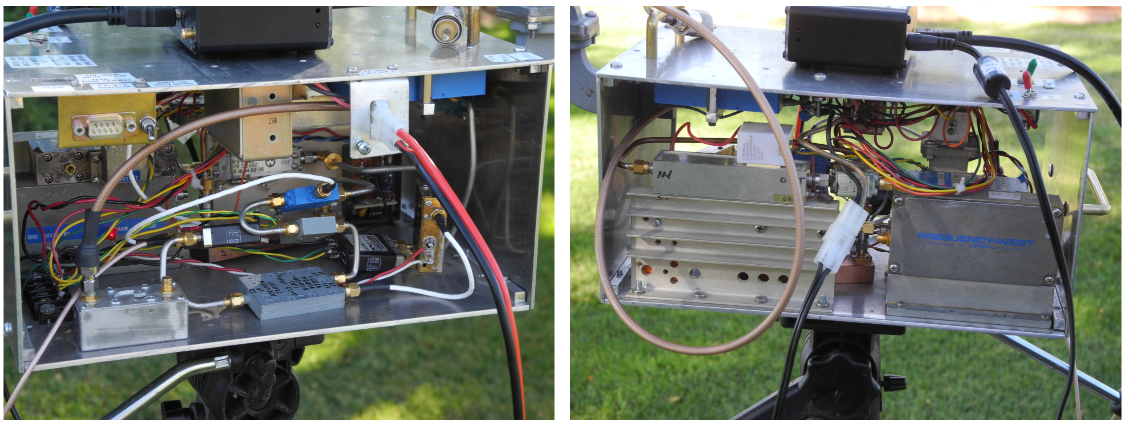

Fig. 4 Example of a 10 GHz transverter rig built of surplus microwave components

Most amateur TV activity occurs on the 70 cm band because "appliance operator" equipment for both transmitting and receiving is available and to a lesser extent on the 23 cm band. More effort is often required to work the higher microwave bands because of the unavailability of complete, turn-key, TV transmitters and/or receivers. Thus we usually have to "roll our own" connecting together various modules. In the past this usually involved finding surplus military, microwave components at ham radio swap fests. This also means that we will typically be assembling our gear from discrete modules with coax connectors and using short pieces of coax cable or coax adapters to provide the interconnections. Our gear will not be small, like your highly integrated cell phone. We will not enjoy the economies of high volumes and surface mounting all components. The purpose of this application note is to address this issue of how to build your own gear with commercially available components. It will still however mean buying individual modules and interconnecting them. Some engineering and electronic contruction ability required.

There are also a couple of suppliers of turn-key, or kit, amateur microwave equipment. They should also be considered. They are: Down East Microwave in the USA https://www.downeastmicrowave.com/ and Kuhne in Germany https://www.kuhne-electronic.de/

Figs. 2 & 3 above, show the basic block diagrams of the major components required to assemble microwave TV transmitters and receivers. Most TV modulators and demodulators (receivers) operate in the below 1 GHz frequency region and we will designate this as our IF (intermediate frequency). The fundamentals are the same whether we are talking about using analog (VUSB-TV or FM-TV) or digital (DVB-T, DVB-S, etc.) TV modulation methods. The common elements in both the microwave transmitter and receiver are a mixer and local oscillator (LO) for performing up and down frequency conversion. For a transmitter, the frequency conversion is: RFout = LO ± IFin. For the receiver, the frequency conversion is IFout = RFin - LO. If you used a common IF frequency for both your modulator and demodulator, then you could use a single LO for both your transmitter and receiver.

LOCAL OSCILLATORS

A major issue in getting up to the microwave frequencies, is finding a suitable, affordable, local oscillator. The technical requirements on the LO depend upon the type of modulation. For analog TV with VUSB-TV (essentially AM) or wide deviation FM-TV, the LO requirements are quite loose. A simple, free-running oscillator usually suffices. The main issue with such oscillators is frequency drift. They are suitable for home installations where the operator can occasionally "tweak" the tuning control. They should not be used for remote, unattended installations, such as long distance microwave links or repeaters.

DTV LO Requirements: For digital TV, the LO requirements are much more severe. Even using synthesized oscillators with crystal control does not assure success. DTV requires the LO have quite low phase noise. I have run experiments using a Hi-Des DVB-T modulator and receiver along with a mixer and a laboratory grade, Fluke model 6060 RF signal generator as the LO. The system worked fine with the pure sine wave from the Fluke generator, until I turned on the internal FM modulation. Even a very low deviation FM with an audio tone was sufficient to cause the DVB-T receiver to stop decoding the signal. I next tested the requirement for frequency accuracy. With no FM on the signal, but offsetting the LO from being on the center of the 6 MHz bandwidth channel, I found that I could move the LO frequency several hundred kHz either side of the channel center frequency and the receiver would still decode the signal. So what phase noise specification is really required ? Unfortunately, I don't have sufficient instrumentation to answer that question. The answer is the typical ham response - "I don't know, but try something to see if it works ! " I have - some worked while some did not. Read on.

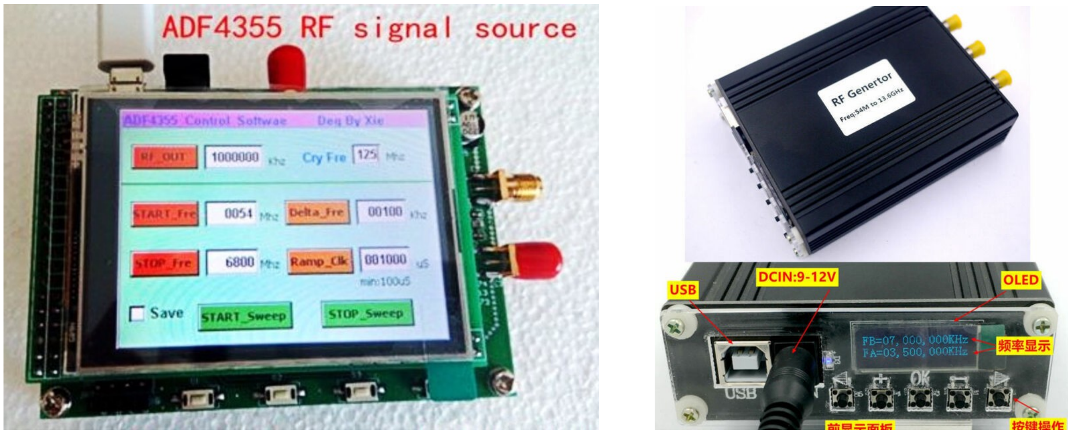

Fig. 3 Inexpensive synthesized local oscillators - up to 13.6 GHz

Analog Devices Frequency Synthesizers: Recently, inexpensive, synthesized, pc board style, microwave signal generators have become available from China, Fig. 3. Three models of particular interest use the Analog Devices model ADF-4351, ADF-4355 & AD-5355 VCOs. The VCO tuning range of the 4351 is 2.2 to 4.4 GHz while the 4355 is 3.4 to 6.8 GHz, and the 5355 is 6.8 to 13.6 GHz. In addition to the VCO, these ICs also include programmable dividers so they can also produce lower frequencies down to 35 MHz for the 4351 and 54 MHz for the 4355 & 5355. Complete assemblies can now be found including the necessary microcontroller and LCD touch panel display for directly programming the desired frequency, Fig. 3. Computer skills are no longer required to use these ICs. The ADF-4351 units can be found from several sources on the internet for prices as low as $55, while the ADF-4355 can be found for about $95 and the ADF-5355 for about $150. For a complete technical review of the ADF-5355, see the Boulder ATV Club's newsletter for October, 2019, issue #21, pages 6-9. (available at: https://kh6htv.com/newsletter/)

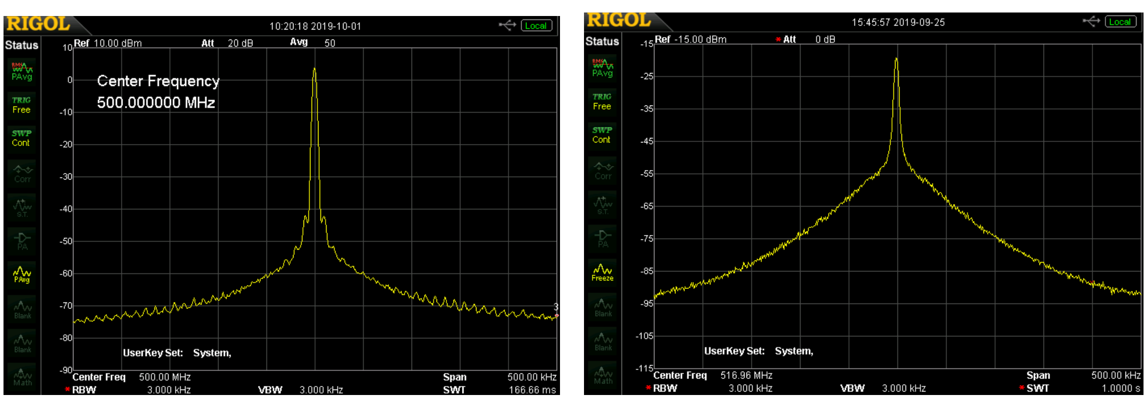

Fig. 4 ADF-5355 Phase Noise Measurement: at 500 MHz (left) & 10.368 GHz (right)
10dB/div, 500 kHz span, 50 kHz/div, 3 kHz band-width

These ADF boards supply two, SMA rf outputs (Q & Q). The rf output is not a pure sine wave, but is instead a logic square wave of about 1/2 Vptp into 50 Ω. As such it is very rich in harmonics, especially the odd (3ed, 7th, etc.). The RF power output is of the order of 0dBm or less. Thus with this low rf power level, a driver amplifier will be required to drive a typical diode mixer at +7dBm.

Fig. 4 shows my measurement of the phase noise of the ADF-5355. It was my experience that the phase noise was excessive at microwave frequencies. At lower frequencies where the fundamental VCO has been divided down by a large amount, the phase noise becomes acceptable. With the high phase noise, I found that these synthesizers were unusable, especially as the LO in a DVB-T receiver. The high phase noise severely degraded the receiver's sensitivity. They could be used for high level applications however as the LO in a transmitter. For either AM-TV, VUSB-TV, or FM-TV service, where phase noise is not such a major issue they could be used as the LO.

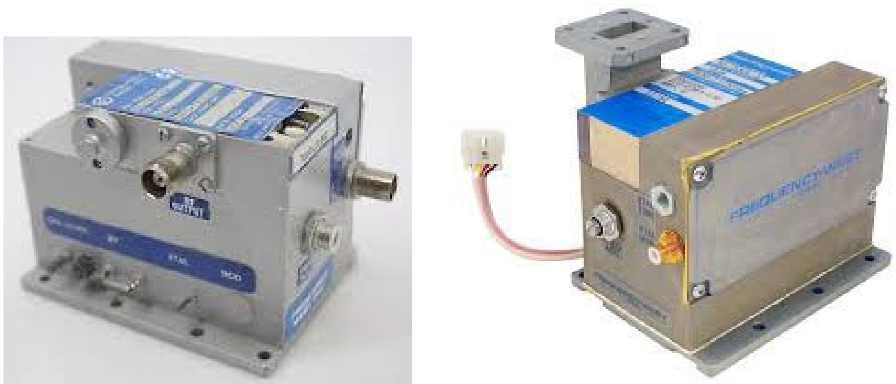

Fig. 5 Frequency West - Microwave Local Oscillators

Frequency West - LOs: The fundamental building block used by most ham, microwave enthusiasts for many years has been a Local Oscillator (LO) built by Frequency West. We call them LO Bricks due to their size and weight. These LOs are very stable and hams have been able even to use them for single-sideband (SSB) rigs at 10 GHz. The frequency stability required for narrow-band, SSB voice at 10 GHz is phenomenal. I have found them also to be suitable for use with DVB-T at 10 GHz. These are vintage items dating from the 1980s and were used in a lot of microwave relay stations. As shown in the above photos there are several variations in their construction. These are available at ham radio swapfests, on E-Bay, and also from commercial, used microwave equipment dealers. Current prices are found to range all over the place from as low as $20 to over $500. At $20, "Buyer Beware !", it probably is a non-functioning unit.

The basic configuration starts with an oven controlled crystal oscillator in the 100-110 MHz range. Next is a free running voltage controlled oscillator (VCO) running in the 1-2 GHz range. The VCO is phase locked to a harmonic of the crystal oscillator. For outputs higher than 2 GHz, a step recovery diode (SRD) multiplier is then used to generate higher order harmonics. A narrow band, band-pass filter is then used to pick off the desired harmonic. The FW bricks were all designed to run off of -20 Vdc and draw typically about 400 mA. For more details about the FW brick LOs, see the Boulder ATV Club's newsletter for Nov. 2019, issue #23, pages 8-10 (available from https://kh6htv.com/newsletter/)

Frequency Multiplier: Another technique to achieve the higher microwave frequencies is to use a Frequency Multiplier. Frequency Multipliers are semiconductor diodes driven by a strong rf signal to generate harmonics followed by either a band-pass or a high-pass filter. The company Mini-Circuits (www.minicircuits.com) sells such devices, both as surface mount parts (SMD) and also packaged with SMA connectors. An example 2X Multiplier would be their model ZX90-2-50+, which sells for $42. It requires an rf input drive of +7 to +12dBm. The 2ed harmonic output conversion loss is typically -12 to -15dB. Thus, rf amplifiers will be required both on the input and the output of the multiplier to achieve the necessary LO power to drive a mixer.

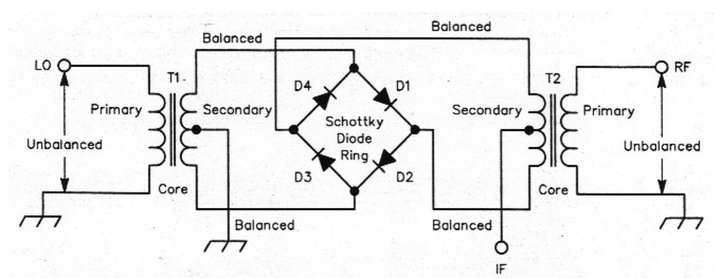

Fig. 6 Double Balanced Diode Mixers

MIXERS

Diode Mixers: The most commonly used microwave mixers are the double balanced design (DBM) using Schottky diodes, Fig. 6. There are several microwave component manufacturers of such mixers. Again Mini-Circuits (www.minicircuits.com) is a good source. The cost for a Mini-Circuits mixer in a metal package with coaxial connectors will typically run between $40 and $80. Equivalent SMD versions are considerably less expensive. They offer a very wide selection of mixers. The design criteria is to specify the desired LO/RF and IF frequency ranges and also the LO drive power requirements. The typical RF/IF conversion loss is about 6-7dB. Models with LO drive powers as low as +3dBm are available. They offer models with up to +23dBm drive. The third order intercept (IP3) is better with a stronger LO drive. However, getting high LO power often requires adding an additional amplifier on the output of your local oscillator source. For more money, you can also get mixers from Mini-Circuits and other manufacturers with built-in image rejection and integrated RF, LO and IF amplifiers.

Unfortunately not all mixers are equal. I was recently burned with a low cost mixer from China which used an HMC219N diode mixer IC. While it behaved identical to other mixers at high levels, and had good specs., it was a very poor choice as a mixer for a receiver. I was building a 5.8 GHz transverter and I found even when using a Frequency West LO, the receiver's sensitivity was degraded by 10dB with this mixer. Conclusion: test, test, test

TV MODULATORS

There are many possible sources for TV modulators. I have my own personal recommendations. All of these have frequency outputs in the UHF range.

Fig. 7 Pico-Macom MPCMA VUSB-TV Modulator

VUSB-TV: My personal choice is to use a Pico-Macom (http://www.picodigital.com/) model MPCMA, Fig. 7. This modulator was designed to be used at the head end in a cable TV network. Thus, it had ideal specifications in terms of spectral purity to keep all of it's energy within the designated 6 MHz channel bandwidth. It can be purchased for $210 from ATV Research (www.atvresearch.com) It works on all standard CATV channels, plus USA broadcast channels. It also has available IRC (+125 kHz) and HRC (-1.25 MHz) offsets. It's frequency range extends from 54 MHz to 860 MHz. It's max. rf output power is 0 dBm.

Fig. 8 KH6HTV Video model 23-8 FM-TV Modulator

FM-TV: I use an FM-TV modulator of my own design. (www.kh6htv.com) It is my Model 23-8, which I sell for $375, Fig. 8. It is available for any frequency from 700

MHz to 1400 MHz. It uses a frequency synthesizer with three, selectable preset frequencies. The max. output power is +20 dBm.

Fig. 9 Hi-Des Model HV-320E, DVB-T Modulator

DVB-T: For digital TV, I recommend a DVB-T Modulator from Hi-Des in Taiwan (www.hides.com.tw), Fig. 9. It is their model HV-320E which sells for $315. It is frequency synthesized and covers from 100 to 2500 MHz, thus covering the 70 cm, 33 cm, 23 cm & 13 cm amateur bands. The max. rf output power ranges from +7 dBm to 0 dBm depending upon frequency. The bandwidth is programmable from 1 MHz to 8 MHz in 1 MHz steps.

DEMODULATORS

As with modulators, there are many possible sources for TV demodulators. I have my own personal recommendations.

Fig. 10 Pico-Macom MPCD Demodulator

VUSB-TV: Any modern, conventional home TV receiver is capable of receiving analog, NTSC, TV signals. Using the cable TV mode, it will cover all standard 6 MHz channels from 54 to 860 MHz. For a separate demodulator (less monitor screen) my personal choice is the Pico-Macom model MPCD, Fig. 10. This demodulator was designed to be used at the head end in a cable TV network and as such has excellent performance. It can be purchased for $140 from ATV Research (www.atvresearch.com) It works on all standard CATV channels, plus USA broadcast channels.

Fig. 11 KH6HTV Video Model 23-5, FM-TV Demodulator

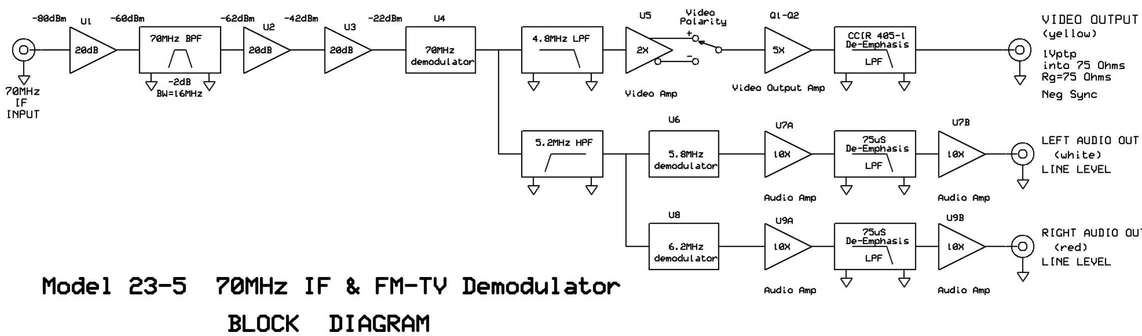

Fig. 12 Model 23-5 Block Diagram

FM-TV: I use an FM-TV demodulator of my own design. (www.kh6htv.com) It is my Model 23-5, which I sell for $375, Figs. 11 & 12. It consists of a high gain, 70 MHz IF amplifier plus a PLL FM-TV demodulator and PLL stereo FM audio demodulators. The IF frequency for an FM-TV microwave receiver needs to be fixed at 70 MHz when used with this demodulator.

Fig. 13 Hi-Des HV-120 DVB-T Receiver

DTV: For digital TV using the European DVB-T standard, there are several choices. For receiving standard 6, 7 or 8 MHz bandwidth signals, there are consumer grade, set-top boxes available at very low cost ($30) on the internet. Caution: many of them do not tune the amateur 70cm band.. Another low cost ($20) option is to use a TV tuner, USB dongle along with a PC computer. The best choice for receiving all DVB-T bandwidths from 2 MHz to 8 MHz, and all frequencies is from Hi-Des in Taiwan. They make a couple of excellent receivers, either their HV-110 ($169) or their HV-120 ($210), Fig. 13. The HV-110 receives 170 to 950 MHz. The HV-120 receives 100-950 MHz and also 1150-2650 MHz. They also have a newer model HV-122 dual diversity receiver which works up to 2.55 GHz. It sells for $230.

Fig. 14 Coaxial & SMD Filters

FILTERS:

This is an area where one needs to become a good detective to find suitable filters to buy. Or the alternative often times becomes needing to build your own. MiniCircuits does offer a selection of filters, including low-pass, high-pass, band-pass and band-reject. As an example, their model VBFZ-5500 is a 5.5 GHz band pass filter in an SMA coax tubular housing and sells for $40. It is rated to handle up to 7 Watts.

If you need a Notch filter to reject a particular frequency, a simple filter to build is to use an SMA tee adapter. On the third arm of the tee, attach a length of coax cable with an SMA connector. Leave the far end of the coax open-circuited. When the coax is cut to precisely 1/4 λ, it will present a short circuit at the tee junction and notch at that particular frequency. With this technique you can easily create a notch of -25 to -30dB in depth.

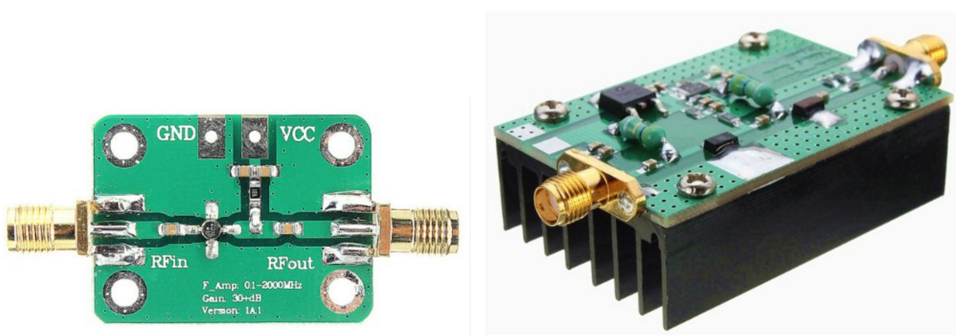

Fig. 15 Inexpensive, un-packaged, pc board RF Amplifiers

AMPLIFIERS

We always need amplifiers in either our transmitters or receivers. As we go higher in frequency, the prices tend to rise dramatically. This is where we will probably spend the most money, especially if we want to obtain several Watts of power. For FM service, we do not need a linear amplifier as we will typically drive it to saturation to get the most rf output power. Class C amplifiers are preferred for FM service as they are the most efficient. For VUSB-TV or DTV we need linear amplifiers, typically class A or A-B, which means they will be less efficient. With careful shopping, you might find some great military surplus amplifiers at swap fests or on the internet.

CHINA AMPLIFIERS: Fig. 15 shows some examples of really inexpensive rf amplifiers that can be found from China. A search on the internet for rf amplifiers results in several thousand hits with many similar to those shown. Most of these amplifiers are not packaged, but open pc boards with SMA connectors. Low power signal amplifiers with responses up to several GHz can be found for prices as low as $10. RF power amplifies with powers in the 1 Watt range and frequencies up to the low GHz range can be found for prices as low as $20.

Fig. 16 2.4 & 5.8GHz Wi-Fi Bi-Directional Amplifiers

Wi-Fi AMPLIFIERS: Another inexpensive alternative are those amplifiers available on the internet for use with Wi-Fi on either the 2.4 or 5.8 GHz band, Fig 16. Most of these amplifiers are bi-directional. This means they can be used as either a pre-amplifier for a receiver, or if the input rf signal level on the opposite side exceeds a preset value (typically about 0dBm), they automatically switch over to amplifying in the opposite direction as a power amplifier. Extra heat sinking will probably be required with these amplifiers as they are not designed for 100% transmit duty cycles, but instead bi-directional data flow with at most 50% duty cycles and usually even less. A reliable manufacturer is L-Com (www.l-com.com) Prices for their amplifiers start at about $175 for a 2.4 GHz, 1 watt unit and go up from there. Even less expensive Wi-Fi amplifiers from China can be found searching the internet. Prices as low as $30 have been found. A 2.4 GHz amplifier sold on the internet for a low $30 had the following advertised specs: Receive 12 dB gain & 3 dB NF, Transmit 17 dB gain, Pout = 33 dBm (2 W) max.

"BUYER BEWARE". These amplifiers and other rf devices typically come from unknown manufacturers, often with questionable or no specs. Always carefully test any amplifier purchased from the internet, especially from China. Use your network of ham friends to find out which ones are real "duds". I certainly have been burned often enough myself. For example, I recently purchased several like the one shown on the left in Fig. 15 which were DOA or did not even come close to the minimal advertised specs. ! I also purchased the bi-directional amplifier shown on the right in Fig. 18 and got mixed results. The receive amplifier was DOA, i.e. non-functioning. The transmit amplifier did work, but did NOT put out the advertised +33 dBm, 2 Watts. It's saturated output was -4 dB down at +29 dBm (800 mW). False Advertising ! It's Pout(-1dB) was +26 dBm and it's gain was 14 dB. Other ATV hams in Boulder have had similar experiences with these Wi-Fi amplifiers from China falling far short of their advertised high output powers. *Bottom Line -- We get what we pay for ! -- but sometimes we luck out.*

Fig. 17 Microwave Antennas -- loop Yagi, Open-Grid Parabolic & Dish antenna

ANTENNAS

Fort the 2.4 GHz, 3.5 GHz and 5.8 GHz bands, a good place to look for low cost antennas first is the Wi-Fi suppliers. For the 10 GHz band, hams often use salvaged satellite TV dish antennas. A good amateur supplier of loop yagi antennas for the low microwave bands and a dish antenna for 10 GHz is Directive Systems (www.directivesystems.com)

MICROWAVE COMPONENT SUPPLIERS

E-BAY: Of course, another source of amplifiers and other components is military surplus gear from main-line, microwave component manufactures. This stuff is found at ham radio swap-fests, and today predominantly on the internet at E-Bay. Quality is never guaranteed, it might work and then again it might simply be a non-functioning box. Prices? -- they range all over the place.

RELIABLE SOURCES: There are some amateur radio suppliers, who are hams themselves, that are reliable sources. Be prepared to pay more. In the USA, the major supplier for many years of ham microwave gear has been Down East Microwave (www.downeastmicrowave.com) They offer rf products from 50 MHz to 10 GHz, amplifiers, preamps, transverters, etc. A similar supplier in Germany is Kuhne Electronics (www.kuhne-electronic.de) Others to check out are: W6POL & PE1RKI.

EXAMPLES of Home-Brew Microwave Tranverters

Figs. 1 & 4 at the beginning of this app. note showed a home-brew, DVB-T, 10 GHz tranverter built by Don, NOYE. The below Figs. 18-20 are a home-brew, DVB-T, 5.8 GHz tranverter built by Jim, KH6HTV. It used a Frequency West brick as the LO. The preamp was from Down-East Microwave. The other components were military surplus. The DVB-T rf output power was +14dBm. The receiver sensitivity was -96 dBm.

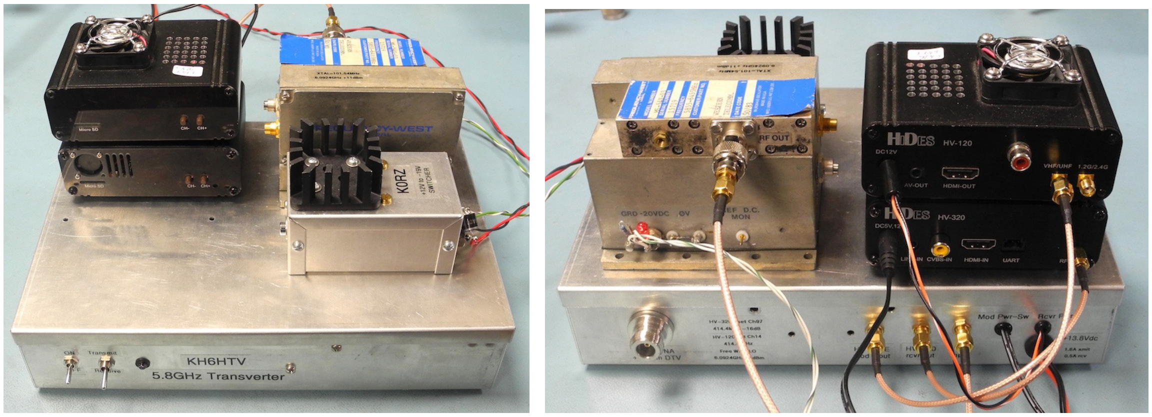

Fig. 18 Front & Rear views of KH6HTV, 5.8 GHz Transverter for DVB-T

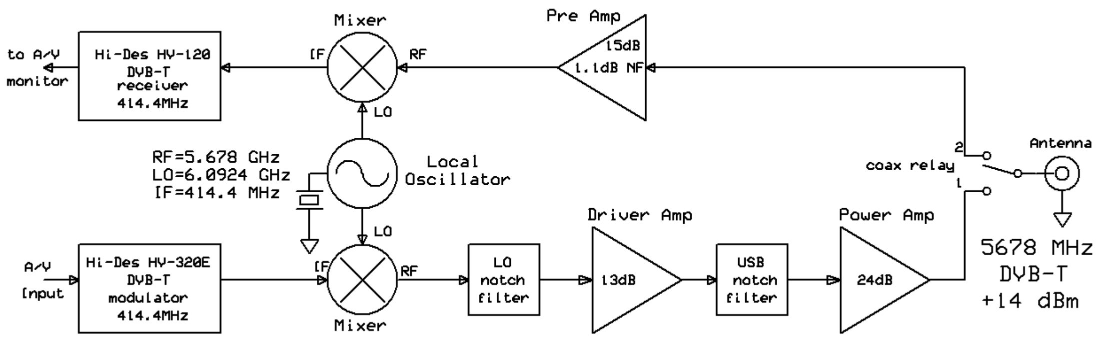

Fig. 19 Block Diagram of 5.8 GHz Transverter

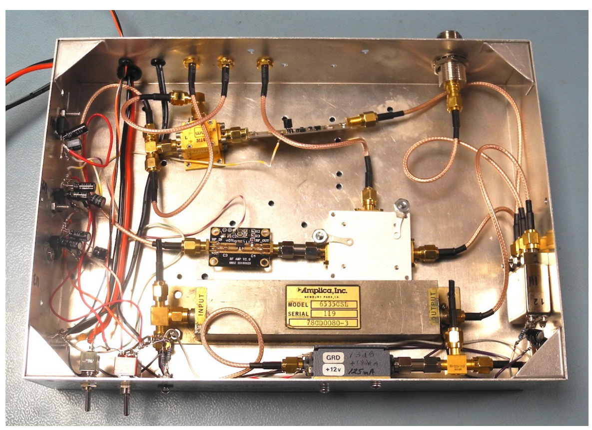

Fig. 20 Interior view of 5.8 GHz Transverter

GOOD LUCK ! Hope to see your TV pictures on microwaves soon. -- KH6HTV