Microwave TV Transmitters & Receivers
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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.

Most amateur TV activity occurs on the 70cm band because "appliance operator" equipment for both transmitting and receiving is available and to a lesser extent on the 23cm 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 modern day, commercially available components. It will still however mean buying individual modules and interconnecting them.

![Block Diagram of a Microwave TV Receiver](image)

**Fig. 2** Block Diagram of a Microwave TV Receiver

Figs. 1 & 2 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 transmitter and receiver are a mixer and local oscillator (LO) for performing up and down frequency conversion. For a transmitter, the frequency conversion is: \( RF_{out} = LO + IF_{in} \). For the receiver, the frequency conversion is \( IF_{out} = RF_{in} - LO \). 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.

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!"

Fig. 3 An inexpensive synthesized local oscillator

Recently, inexpensive, synthesized, pc board style, microwave signal generators have become available from China, Fig. 3. Two models of particular interest use the Analog Devices model ADF-4351 and AD-4355 VCOs. The VCO tuning range of the 4351 is 2.2 to 4.4 GHz while the 4355 is 3.4 to 6.8GHz. In addition to the VCO, these ICs also include programmable dividers so they can also produce lower frequencies down to 35MHz for the 4351 and 54MHz for the 4355. 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.
Fig. 4  Spectrum Analyzer measurement of ADF-4351 phase noise at 1 GHz.

The ADF-4351 would be suitable as a local oscillator for working up to the 9cm (3.5GHz) band while the ADF-4355 would be suitable for the 5cm (5.8GHz) band. I have found that the phase noise of the ADF-4351 is low enough to work with DVB-T. See Fig. 4. The boards supply two, identical SMA rf outputs. 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 odd harmonics (3ed, 7th, etc.). The fundamental output from the Chinese ADF-4351 oscillator board is about -0.5dB for low frequencies (<200MHz), 0dBm (500MHz), +1dBm (1GHz), +2.5dBm (1.25GHz), +2dBm (2.4GHz), -3dBm (3.5GHz) and -2dBm (4.4GHz). Thus with this low rf power level, a driver amplifier will typically be required to drive a typical diode mixer at +7dBm. A major defect of this particular Chinese ADF-4351 board is its lack of a backup memory for the stored frequency. Upon loss of DC power and repowering, it reverts back to its initial state of 200MHz. This can cause considerable problems for use in an unattended microwave system, such as at a repeater site.

Fig. 5  Inexpensive microwave signal generators, 35MHz to 4.4GHz
The ADF-4351 can also be purchased from China as a complete packaged signal generator for about $100 to $140. Fig. 5 shows a couple of versions available from China. They cover the range from 35MHz to 4.4GHz with an internal adjustable attenuator with a 60dB range. The unit on the right includes an rf power amplifier, plus a BNC input for an external 10 MHz reference oscillator.

To reach the 3cm (10GHz) band requires an LO with an even higher frequency of about 10GHz. 10GHz oscillators tend to be very expensive. Recently, Analog Devices introduced a new VCO in their ADF line which reaches all the way up to 13.6GHz !!! It is the ADF-5355. With it's programmable dividers, it will cover in one IC the very wide range of 125MHz to 13.6GHz. It is hoped that a stand-alone version similar to that shown in Fig. 3 will soon become available.

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. A suitable 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.

![FET Mixer Block Diagram](image)

**Fig. 7** FET Mixer Block Diagram

**FET Mixers:** There now are also newer designs using FETs as microwave mixers, Fig. 7. In one design, the mixer element is a single-ended, passive FET. The LO signal drives the gate of the FET to vary the drain to source conductance and thus provide the mixing action. Being a FET based device, it is a straight forward process to thus also include an amplifier for the LO, thus lowering the LO drive requirements. The performance specs. of the DBM vs. the FET designs are dramatically different, thus entailing different design criteria for the auxiliary networks associated with the mixer. The RF to IF conversion losses are typically the same, i.e. about -6dB. The -1dB gain (loss) compression points are dramatically different. For a DBM, they are typically about -6dB below the LO drive requirement. For a typical +7dBm LO drive DBM, the -1dB point is thus +1dBm with an IP3 point of +9dBm. For the FET mixer, it is far superior and much higher, typically Pin(-1dB) = +19dBm and IP3 = +25dBm. The DBM however is far superior in terms of isolation between the various ports. There is absolutely no isolation between the RF and IF ports on the FET mixer. As seen in the Fig. 7 block diagram, the FET is a single ended device sharing the RF and IF connection. Whatever isolation there is between RF and IF must be provided by external LC filter networks. Whereas the RF/IF isolation in a DBM is typically 30dB or greater. There is isolation between the LO input and the RF or IF ports provided by the active driver amplifier.

**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.
VUSB-TV: My personal choice is to use a Pico-Macom (http://www.picodigital.com/) model MPCMA, Fig. 8. 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 its 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 (+125kHz) and HRC (-1.25MHz) offsets. It's frequency range extends from 54MHz to 860MHz. Its max. rf output power is 0 dBm.

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. 9. It is available for any frequency from 700MHz to 1400MHz. It uses a frequency synthesizer with three, selectable preset frequencies. The max. output power is +20dBm.
**DVB-T:** For digital TV, I recommend a DVB-T Modulator from Hi-Des in Taiwan (www.hides.com.tw), Fig. 10. It is their model HV-100EH which sells for $560. It is frequency synthesized and covers from 50 to 950 MHz and also 1200 to 1350 MHz, thus covering the 70cm, 33cm and 23cm amateur bands. The max. rf output power is -3dBm. The bandwidth is programmable from 2 MHz to 8 MHz.

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

**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. 11. 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. It's frequency range extends from 54 MHz to 860 MHz.

![Fig. 12 KH6HTV Video Model 23-5, FM-TV Demodulator](image)

**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. 12 & 13. 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.

![Model 23-5 70MHz IF & FM-TV Demodulator Block Diagram](image)

![Fig. 13 Model 23-5 Block Diagram](image)

![Fig. 14 KH6HTV Video Model 70-14, 70cm DVB-T & 23cm DVB-S Receiver](image)
DTV: For digital TV using the European DVB-T standard, I have two preferences. For receiving standard 6, 7 or 8 MHz bandwidth signals, I prefer to use a consumer grade, set-top box, DVB-T & DVB-S receiver which I import from China. It is my model 70-14 which I sell for $90, Fig. 14. For DVB-T, it covers 48-866 MHz. For DVB-S, it covers 950-2150 MHz. For receiving all DVB-T bandwidths from 2 MHz to 8 MHz, Hi-Des in Taiwan makes a couple of excellent receivers, either their HV-110 ($169) or their HV-120 ($210), Fig. 15. The HV-110 receives 170 to 950 MHz. The HV-120 receives 100-950 MHz and also 1150-2650 MHz.

FILTERS:
This is an area where one needs to become a good detective to find suitable filters to buy. Or the alternative sometimes 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.

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. For VUSB-TV or DTV we need linear amplifiers, which means they will be less efficient.

Fig. 17 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 amplifiers with powers in the 1 Watt range and frequencies up to the low GHz range can be found for prices as low as $20.

Another inexpensive alternative are those amplifiers available on the internet for use with Wi-Fi on either the 2.4 or 5.8GHz band, Fig 15. 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 2.4GHz, 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 2.4GHz amplifier sold on the internet for a low $30 had the following advertised specs: Receive 12dB gain & 3dB NF, Transmit 17dB gain, Pout = 33dBm(2W) max.

However, "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. 17 which were DOA! 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 +33dBm, 2 Watts. It's saturated output was -4dB down at +29dBm (800mW). False Advertising! It's Pout(-1dB) was +26dBm and it's gain was 14dB. Other 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!

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