Application Note
AN-61

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Low Cost, DIY, Microwave Up & Down Converters

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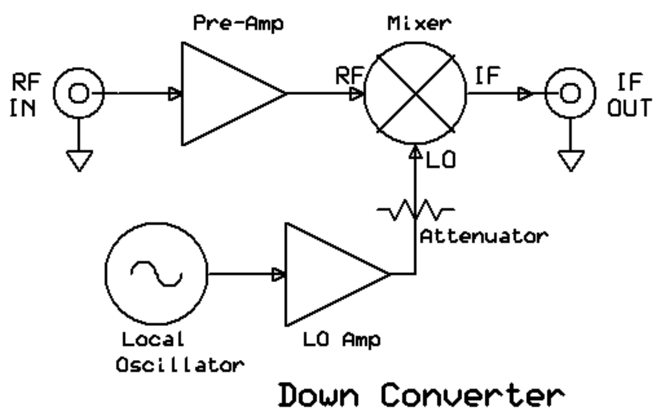


Fig. 1 Block Diagram for a microwave down converter.

Down-Converter: This is the basic diagram showing the key components required for a down converter. The most basic down-converter consists of only two components, namely a Local Oscillator and a Mixer. The other items shown are "frosting on the cake" to improve performance. Today, there are a lot of RF and microwave components available from China at low cost. They can be found by searching on the internet on Amazon, E-Bay, etc. This application note will discuss how to DIY (Do It Yourself) assemble both up and down converters for the amateur 23cm, 13cm and 9cm bands, i.e. up to 3.4 GHz. The total parts cost is of the order of $100 or less.

For higher quality, better performance, up/down converters, there would be added to the basic circuit additional filtering. Band-Pass filters would be beneficial on the RF & LO circuits. A low pass filter would be beneficial on the IF circuit. Unfortunately, these filters will increase the total cost. They can be omitted with a sacrifice in performance, but for some hams on tight budgets, this is a necessary sacrifice.

It should be noted that a down-converter, and the up-converter presented later in this app. note (see Fig. 7) are linear devices. They will work with any signals, be they analog, VUSB-TV, analog FM-TV, digital TV, SSB, etc.

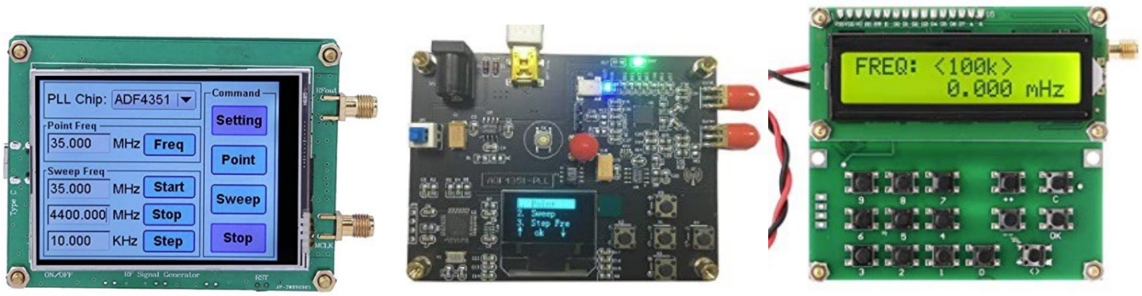


Fig. 2 Three versions of a Chinese, ADF-4351, Frequency Synthesizer board

LO: The key element, and typically the most expensive, is to find a good Local Oscillator (LO). The recent availability of the Analog Devices frequency synthesizer ICs has made a quantum leap forward in designing, microwave gear, such as a down converter. For the low end of the microwave band, the Analog Devices model ADF-4351 is ideal. It covers from 35 MHz up to 4.4 GHz. It can be set to any arbitrary frequency to 1kHz resolution. It is available from China already mounted on a printed circuit board, complete with the support electronics to enable the user to easily set the desired frequency. The photo, Fig. 2, shows examples of several different versions found on Amazon. Prices range from about \$25 to \$55.

These ADF-4351 boards typically require +5Vdc for power. I highly recommend that you do **NOT** use the typical wall-wort 5V supply as they are usually switching regulators which put out a lot of switching transient noise on the 5V line. It is important, especially for DVB-T, that the phase noise of the LO be kept to an absolute minimum. A clean, no noise, power source is key to keeping the phase noise down on these synthesizers. I recommend that you use a linear voltage regulator, such as a 7805, or an even lower noise, linear. I even put a 470 µF cap. on the output of my 7805 for the LO supply to further suppress noise.

Fig.3 Typical low cost, RF/Microwave Mixers from China

MIXER: The mixer is used to beat the RF signal against the LO and creates sum and difference products IF = RF - LO, IF = RF + LO, etc. For our example, we want to down convert signals in either the 23cm (1240-1300 MHz) or 13cm (2.4 GHz) bands down to a suitable lower frequency where we have an ATV receiver. For analog TV signals we typically want to use an IF in the VHF Hi-Band of channels 7-13 (174 - 216 MHz). For digital TV (such as DVB-T) we want to use an IF in either VHF Hi-Band or the amateur 70cm band (420-450 MHz). Most mixers for microwaves are semiconductor diodes (usually GaAs) and use the double-balanced, diode design. The typical conversion loss of a good double-balanced diode mixer is of the order of 6-8 dB. They come typically in a couple of categories requiring either +7dBm or +13dBm of LO drive power.

On Amazon, we find a couple of suitable, and really low cost, microwave mixers. They are advertised under the model ADE-25 and HMC-213. These are actually model numbers from Mini-Circuits and Hittite respectively. You can download the spec. sheets from them. The Chinese units come assembled on pc boards or in a nice metal enclosure with SMA connectors. Prices range from \$7 - \$20. Both mixers require +13dBm of LO drive power. The ADE-25 is specified for RF/LO (5 MHz - 2.5 GHz) and IF (5 MHz - 1.5 GHz). The HMC213 is specified for RF/LO (1.5 - 4.5 GHz) and IF (DC - 1.5 GHz). The exact drive power level is not critical and can range from +10dBm to +16dBm.

Fig. 4 Typical, low cost, amplifier modules from China

AMPLIFIERS: We need two different type amplifiers for a down converter. Typically, the output from an ADF4351 LO is of the order of 0dBm (1 mW) and is insufficient to drive a mixer, so we need to boost the LO power to at least +7 or +13dBm, depending upon the mixer used. This requires a driver amplifier capable of at least that much output power. Plus, it also beneficial to use a low noise preamplifier in front of the mixer to improve the noise figure and the receiver sensitivity. Most of the amplifiers from China, such as shown in Fig. 4, all require DC voltage of +5Vdc. I recommend that a +5V linear voltage regulator, such as a 7805 be used to power them.

An attenuator is shown in the block diagram, Fig. 1. This may or may not be necessary. It depends upon the actual RF output power you get from your driver amplifier. Use it to limit the RF drive power to a +13dBm mixer to no more than +16dBm. SMA attenuators are now available on Amazon. They are typically specified up to 6GHz and do work quite well up to 6. Typical cost is about $10 each.

TOTAL PARTS COST: So what are we looking at for total cost for a down-converter ? ADF-4351 LO ($50), LO driver amp ($10), preamp ($10), mixer ($15), attenuator ($10), three SMA cables ($3), two 7805 voltage regulators ($1)

Total estimated cost ≈ $100

It should be noted that this is only the cost for the basic components, suitable for bread-board style construction such as shown in the below photo. The cost for packaging in a nice enclosure is additional.

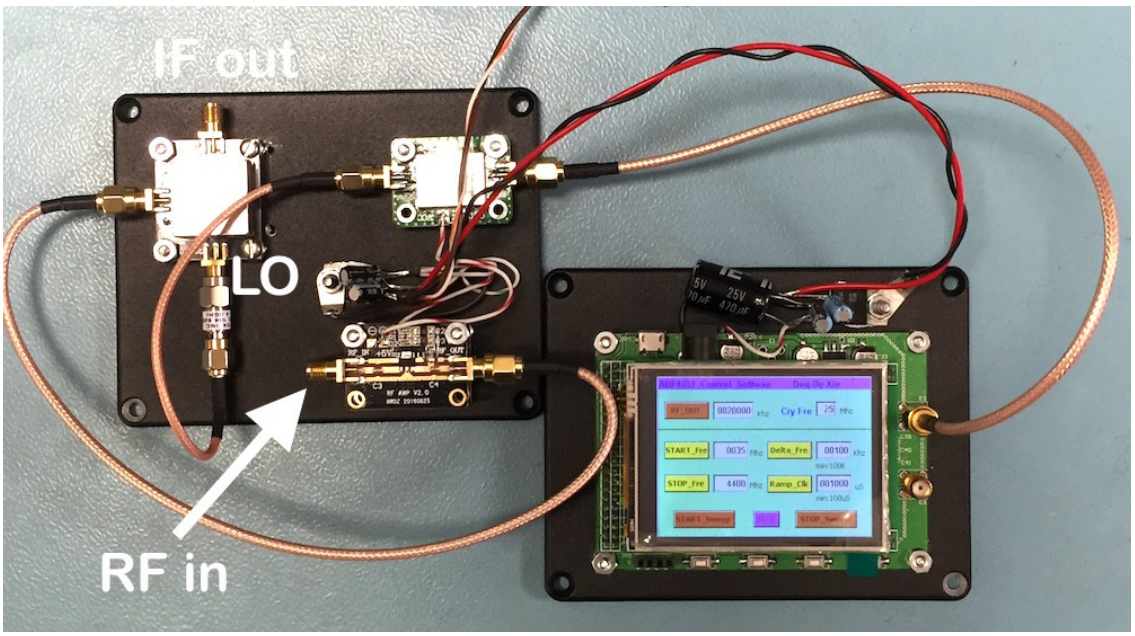


Fig. 5 Prototype, 23cm & 13cm Down-Converter made from low cost, Chinese microwave components.

23cm, 1.2GHz, Down-Converter: Fig. 5 shows an actual down-converter built for both 23 & 13cm bands with these low cost, Chinese microwave components. There are two 7805, 5V regulators. One for the LO and the other for the amplifiers. They are mounted on the metal plates for heat sinking. The LO, ADF-4351 synthesizer is the module on the separate metal plate on the lower right. The LO output drives a 20dB gain amplifier which puts out about +20dBm of rf power. This is attenuated with a 6dB, SMA pad to +14dBm to drive the mixer. The mixer is an ADE-25. The mixer's conversion loss was about -7dB. The preamp is a low noise amp module on a bare pc board. It has a gain of about 15dB at 23cm. The LO frequency is set to 820 MHz. For 23cm band the frequency is from 1240 to 1300 MHz. Thus the IF comes out on the 70cm band from 420 to 480 MHz.

So, how well does it perform for digital ATV service with DVB-T ? I set up on my test bench to measure sensitivity. I used a Hi-Des HV-320E modulator to generate a test

DVB-T signal on 1243 MHz. I set up the digital parameters for typical, ham service. They were: 6 MHz BW, QPSK, 1080P resolution, 5/6 FEC, 1/16 guard, and 5.5 Mbps data rate. I ran a DVD with "live" typical video and audio. The rf output from the HV-320 was +5dBm on 23cm band. I used fixed SMA attenuators and a rotary step attenuator with 10 & 1dB steps to attenuate the test signal in known amounts. I dropped the signal level to just above digital threshold. At this level, a solid P5 picture and Q5 audio was obtained. One more dB and the video and audio started breaking up. At this level the S/N is about 8dB. I tested using three different receivers. They were a Hi-Des HV-110, HV-120A and a GT-Media V7 Plus. I got the same results on each. They were set to receive 423 MHz / 6 MHz BW.

23cm (1.2GHz) DVB-T Receiver Configuration	**DVB-T Sensitivity**
Hi-Des HV-120A Receiver (*reference*)	-93dBm
ADE-25 Mixer Only	-85dBm
Generic Chinese low noise Pre-Amp + ADE-25 Mixer	-92dBm
KH6HTV 23-4LNA Pre-Amp (2 stage) + ADE-25 Mixer	-100dBm
KH6HTV 23-4LNA Pre-Amp (1 stage) + HV-120A	-98dBm
KH6HTV 23-7 Down Converter	-99dBm

The first test for comparison purposes was a Hi-Des model HV-120A, DVB-T receiver. The above table shows the results for various configurations. It should be noted that there is no band-pass filter in the setup of Fig. 1, nor on the input to the Hi-Des HV-120A receiver. Thus the mixer passes through to the IF the noise contributions of both the upper and lower sideband mixer products. If the input preamp is replaced with a low noise preamp which includes a band-pass filter, such as the KH6HTV model 23-4LNA, the sensitivity is improved dramatically. The last item in the table, the model 23-7, is a completely assembled, commercially available, 23cm down-converter.

13cm, 2.4GHz, Down-Converter: The same components can be used for the 13cm (2.4 GHz) band. One simply needs to change the LO frequency. An LO of 1970 MHz is suggested. With it, the most useable 2.4 GHz frequency of 2.393 GHz will down convert to 423 MHz in the 70cm band. The Chinese generic preamp has about 10dB of gain at 2.4 GHz. I tried two different mixers for 13cm.

The ADE-25 mixer was found to have about -13dB conversion loss. The Mini-Circuits spec. is -7dB with max. of -10dB. I tested two of these mixers from Amazon and found that both were about -13dB and thus out of Mini-Circuits spec. They did work fine at 23cm. Thus, the Chinese mixes may have been using factory rejects?

For the HMC213 mixer, I found it's conversion loss to be a bit better at about -10dB. The Hittite spec. at 2.5GHz is -7.5dB (max. -10dB). It was thus at the extreme limit of Hittite's spec. and may have also been a factory reject ?

The sensitivity was tested in the same fashion as previously for 23cm. I used a Hi-Des HV-320E modulator to generate a test DVB-T signal on 2393 MHz. The results are shown in the following table. The ADE-25 mixer was found to perform worse than the HMC-213 by 4dB. This is consistent with the differences found measuring their conversion loss. Similar sensitivities as 23cm were obtained using the generic preamp, but with the HMC-213 mixer replacing the ADE-25.

13cm (2.4GHz) DVB-T Receiver Configuration	**DVB-T Sensitivity**
Hi-Des HV-120A Receiver (*reference*)	-93dBm
ADE-25 Mixer Only	-81dBm
HMC-213 Mixer Only	-85dBm
Generic Chinese low noise Pre-Amp -> ADE-25 Mixer	-87dBm
Generic Chinese low noise Pre-Amp -> HMC-213 Mixer	-91dBm
KH6HTV WB-LNA-3 PreAmp -> ADE-25 Mixer	-87dBm
KH6HTV WB-LNA-3 PreAmp -> Taoglas BPF -> ADE-25Mixer	-89dBm
KH6HTV WB-LNA-3 PreAmp -> HMC-213 Mixer	-91dBm
KH6HTV WB-LNA-3 PreAmp -> Taoglas BPF -> HMC-213 Mixer	-92dBm
KH6HTV WB-LNA-3 PreAmp -> Taoglas BPF -> HV-120A	-99dBm

Fig. 6 A Band-Pass Filter for 2.4 GHz

Also tested was the KH6HTV model WB-LNA-3 preamplifier. Both amplifiers are wide-open, broad-band, with no band-pass filtering. They thus pass through noise from both the upper and lower sideband mixing products. Adding a 2.4GHz band-pass filter on the output of the preamp before going to the mixer is thus beneficial. A low cost ($24) BPF is the Taoglas BPF24.01. It has 100 MHz bandwidth and 1.3dB insertion loss. It is available from both Digi-Key and Mouser. The only drawback to this filter is it comes with reverse polarity SMAs. Thus you will have to also purchase RP-SMA to SMA adapters to use it. Adding the WB-LNA-3 preamp plus the Taoglas BPF improved the Hi-Des model HV-120A's receiver sensitivity from -93dBm to -99dBm. The improvement was not as dramatic with the DIY setup using the ADF-4351 LO and the HMC-213 mixer. If the wide-band preamp is overloaded with out of band signals, then the BPF can be installed instead on the input with a slight decrease in sensitivity due to the insertion loss of the filter..

9cm, 3.4GHz, Down Converter: To receive 3.4 GHz, the LO frequency should be chosen to put the IF in the 900 MHz (33cm) band. LO = RF - IF = 3400 - 900 ≈ 2500 MHz. The HMC213 mixer should be used. I measured it's conversion loss at about -11dB. The Hittite spec. is -8dB nominal. The generic preamp used for 23 & 13cm is not suitable for the 9cm band.

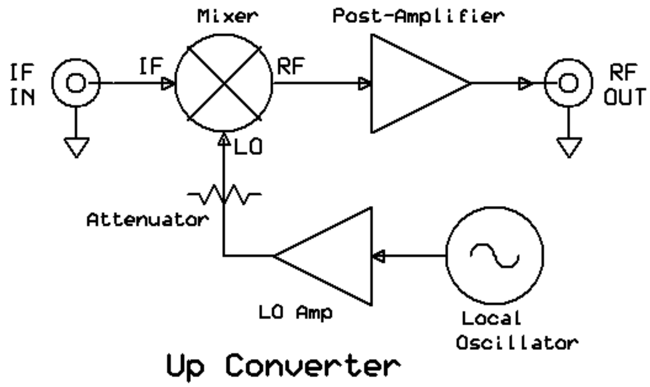
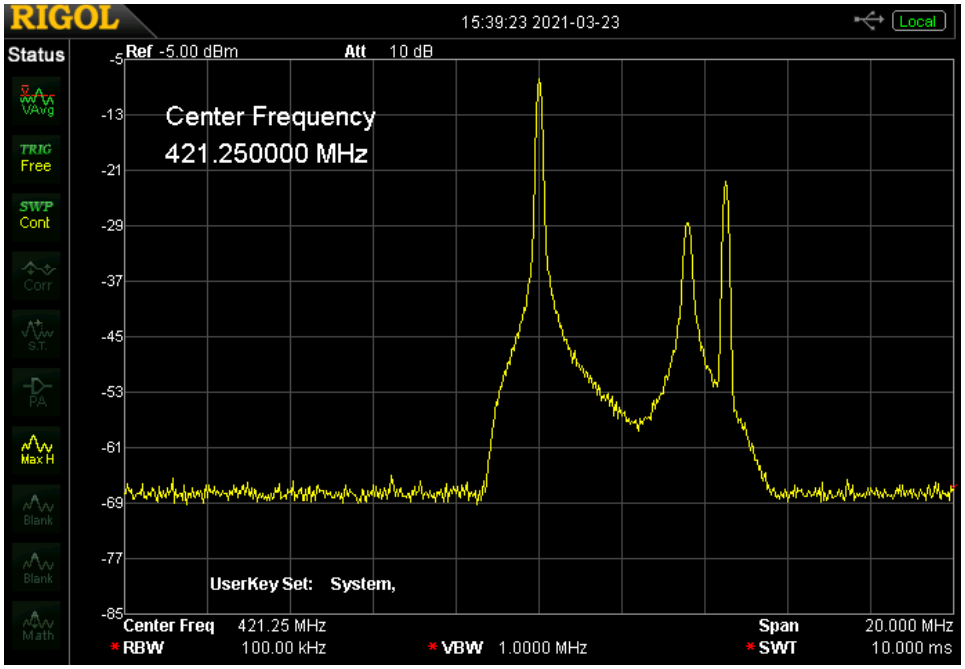


Fig. 7 Block Diagram for an Up-Converter   Fig. 8 CATV analog VUSB-TV modulator

UP CONVERTER: The same components can be used to up-convert ATV signals (or others) from < 1 GHz to the microwave bands. A typical example would be to generate a VUSB-TV signal in the 23cm or 13cm band. An excellent source for a VUSB-TV signal are the analog modulators used in older cable TV systems and closed circuit TV systems. See Fig. 8. CATV modulators from firms such as Pico-Macom, Drake & Holland cover all of the cable TV channels from 50 to 850 MHz. They typically cost about $125 for a single channel unit and $175-$225 for units which will cover all CATV frequencies. Used units can be obtained for even less money on E-Bay. A commercially available, 23cm up-converter built according to this block diagram is the KH6HTV Video model 23-6. It has additional band-pass filtering.

Whereas a down-converter is used to receive very weak signals, an up-converter is typically used for medium level signals that will be further amplified to higher power levels in a transmitter. In this case, the LO amplifier and the Post-Amplifier will be the same type amplifier. For the proto-type system shown in Fig 7, the generic amplifier has 20dB of gain and +20dBm max. output power.

For linear operation, it is important to keep the input power to the IF port low enough such that the RF output from the mixer is well below the -1dB compression point. The -1dB compression point occurs typically for an input about -3dB below the LO drive power level. Fig. 9 shows an example of using the prototype system of Fig. 5 to up-convert a 70cm, 421.25 MHz VUSB-TV signal to 23cm, 1241.25MHz. Again, the LO was set to 820 MHz. The up-conversion gain is +13dB. (mixer loss + amplifier gain = -7dB +20dB = 13dB)



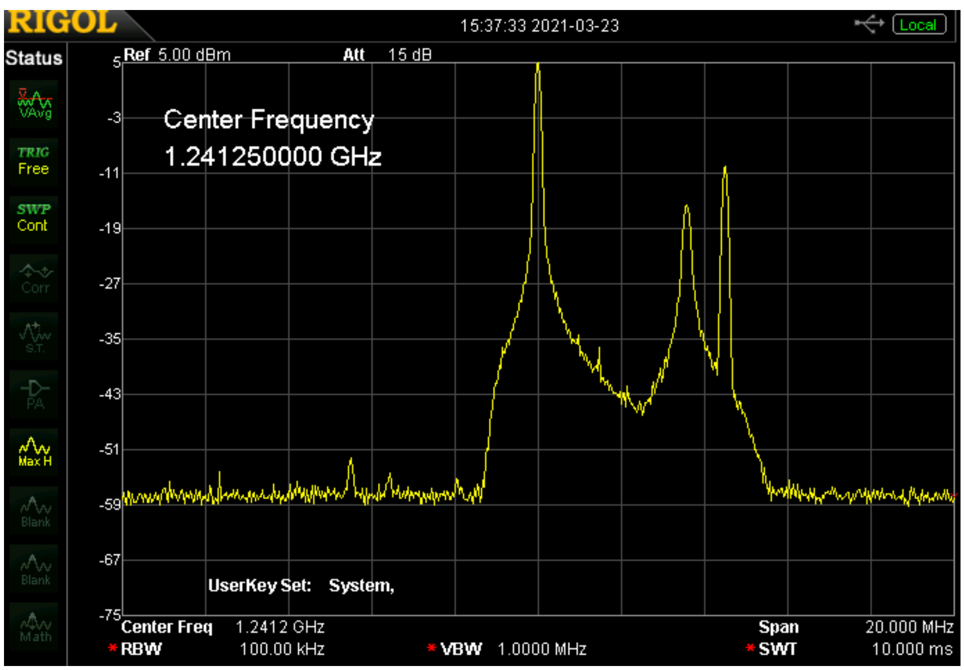


Fig. 9 Up-Conversion of VUSB-TV signal from 70cm band to 23cm band. Top photo is IF input at 421.25MHz. Bottom photo is RF output at 1241.25 MHz. 20 MHz span, 8 dB/div & 2 MHz/div. The video test signal was NTSC color bars. The up-conversion gain is +13dB.