Uses for California Amplifier MMDS Downconverters

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Introduction

I purchased a box of California Amplifier model 130001 and 130002 MMDS (Multichannel Multipoint Distribution Service) downconverters from an online auction for less than $1.50 each, including shipping. Since the days of AO-13, many MMDS downconverters like the Drake 2880[1] and California Amplifier models 31732[2] and 130016[3] have been modified for amateur satellite reception. I have been looking into other possible modifications and applications. Like many downconverters designed for MMDS, the RF input range is 2,500 – 2,686 MHz and the IF output range is 222 – 408 MHz. Some downconverters like the California Amplifier model 31732 are designed to cover bands: 2.152 – 2.162 GHz to an IF of 116 – 128 MHz and 2.5 – 2.686 GHz to an IF of 222 – 408 MHz respectively. In all but a few cases, the local oscillator frequency is 2278.0 MHz and the internal reference crystal frequency is 8.8944 MHz. A California Amplifier downconverter without a cover is shown in Photo A.

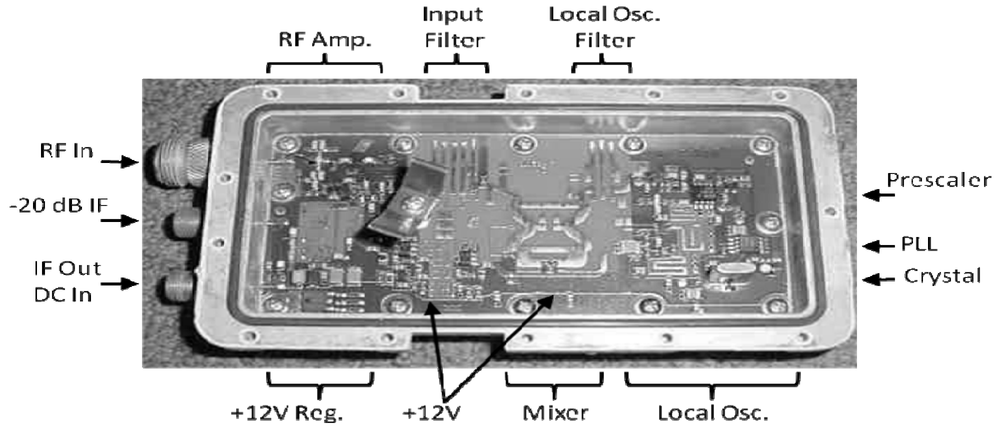

Photo A: California Amplifier Downconverter with Cover Removed

What an interesting collection of microwave components and circuits! Fortunately, I did find a schematic for a downconverter local oscillator on the Internet at: http://www.cqham.ru/image2/cal-amp-dc_big.gif . The schematic appears to cover at least the models 130001, 130002, 130007, and 31732 downconverters or is close enough to get me started.

The downconverters typically have a type “N” RF input connector and two type “F” IF output connecters. One F connector serves double duty as the IF output and the dc power input. The second F connector provides an output test port 20 dB down from the normal IF output. The downconverters are powered from an external +16 to +24V supply and have an internal 78M12A 12V three-terminal voltage regulator. While this article focuses on the 130001 and 130002 downconverters, the information is general enough for a multitude of California Amplifier MMDS converters.

The downconverter components and circuits this article addresses include the PLL (phase locked loop) local oscillator and within the local oscillator, the reference oscillator and VCO (voltage controlled oscillator) prescaler integrated circuit chip.

PLL Local Oscillator

It is easy to visually separate the local oscillator section from the rest of the circuitry. The local oscillator, with bandpass filter, occupies a little less than half of the printed circuit board. One project that immediately came to mind was to salvage and remount the local oscillator in its own shielded enclosure. The local oscillator would make a nice marker beacon for 2.25 GHz, 2.304 GHz and 2.4 GHz, or a local oscillator for other frequencies. Why 2.25 GHz? It is a convenient marker for a receiver covering the 2.2 to 2.3 GHz scientific satellite downlink band.

As shown in Photo B, I fabricated a small plate with a BNC connector having a bent wire probe and temporarily mounted it on the sidewall of a downconverter near the local oscillator output stripline filter. I could easily see the 2,278 MHz local oscillator signal using a Hewlett-Packard 8441A swept YIG preselector I use as a spectrum analyzer[4] and I could also read the frequency on my homemade 12.5 GHz frequency counter[5]. There is such a wonderful feeling seeing a piece of discarded electronics power up and actually work. The signal level was influenced by cable position and hand waving, but my hands were now free while I was making measurements. Even with the crude coupling, I measured a local oscillator output power of 0dBm (1mW).

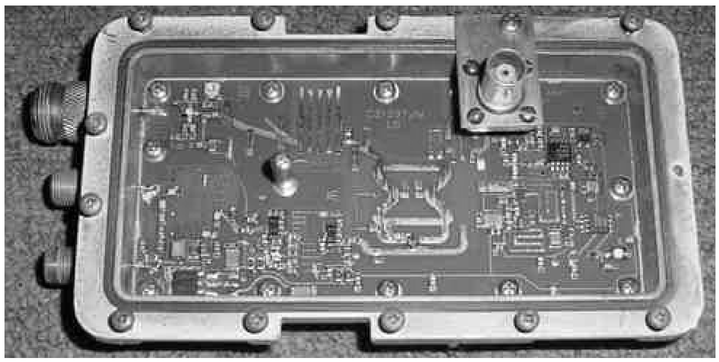

Photo B: BNC Probe Temporarily Mounted Near Oscillator Filter

Applying +18V, the converter drew 190mA. The regulated 12V power bus runs along the bottom edge of the circuit board. Cutting circuit traces to remove unused sections from the internal voltage regulator load, the current drain dropped by more than half to 80mA.

Remounting the PLL Circuitry

Whenever I can find a nice shielded box at a hamfest, I latch on to it no matter what is inside. I did find a couple used enclosures that would be large enough to contain a PLL oscillator along with a 12V three-terminal voltage regulator. I cut the local oscillator section from the main printed circuit board of a 130001 downconverter using a 4” hobby table saw. For later salvage operations, I used an Adel hand nibbler. Microwave experimentation has become cut and paste!

My first attempt at attaching a RF output cable to the printed circuit board was tricky. I used two U-shaped wires to ground the coax braid and physically restrain the cable. Later, I used printed circuit board SMA edge connectors to make the RF connections. I was able to mount the local oscillator printed circuit board directly to a shelf plate with seven 4-40 screws, lock washers, and hex nuts using the original holes in the circuit board. I drilled a 1/2” diameter hole through the shelf plate under the crystal connections and a 3/8” diameter hole under the coax connections to prevent shorts and allow the circuit board to sit flush on the shelf. Sitting flush reduces the chances of flexing the circuit board which can damage the surface mount components. Some downconverters, having the crystal under the circuit board, will require a larger cutout. Unused circuit traces were cut and peeled from the circuit board using a razor blade and needle-nose pliers. With direct coupling, the RF output power measured +10dBm and the second and third harmonics were at least 20 dB below the fundamental. 10 milliwatts is very strong for use as a frequency marker and is at the threshold of the power level needed for beacon operation. All that is need is a 10 dB or greater amplifier. The enclosure cover plate being on or off had no noticeable effects. Later, I fabricated and installed a three-terminal voltage regulator, 7812, using a short piece of angle aluminum. Photo C shows the local oscillator in the new enclosure with the 7812. In future conversions, I used a piece of #30 wire-wrap wire between the regulator and the oscillator circuit board to reduce the stress on the circuit traces.

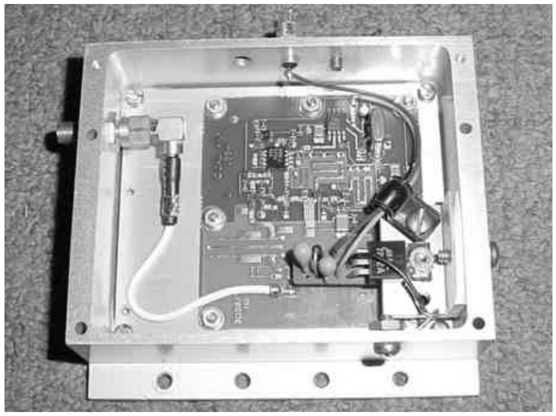

Photo C: Remounted Local Oscillator and 12V Regulator

For other salvaged PLL local oscillators, I used a different method for mounting. The SMA edge connectors I use have a 0.25” square base flange, which means the distance between diagonal corners is 0.25 X 1.414 = 0.3535”, matching well to 11/32” (0.34375”). I first drill the enclosure wall with a number 43 drill bit, forming a guide hole. Then I counterbore the inner or rear wall face with an 11/32” pilot point drill bit. The depth is equal to the base flange thickness or less. Finally, the hole is drilled clear through with a standard 1/4” drill bit. The SMA connector is installed from the rear face. A nut is added, and used to draw the flange into the 11/32’ bore until it bottoms out. The four corners of the base flange dig into the side wall of the hole and provide an anti-rotation function. The connector can be backed out of the hole by removing the nut and pressing the connector out using a piece of wood to prevent damage to the connector threads. This method also works with SMA connectors having a hexagonal base.

Internal Reference

The local oscillator typically operates at 2,278 MHz with a reference crystal frequency of 8.89844 MHz, which indicates a multiplication factor of 256. The physical location of the crystal varies from one downconverter to the next and even among examples of the same model. The crystal can be found underneath the circuit board or on the component surface. If on the component surface, the crystal can be standing upright or lying down. Judging from figures for similar downconverters, the frequency accuracy of the local oscillator is +/-20 kHz and the frequency stability is +/-30-50 kHz. But, the figures are based on the downconverter being mounted on a roof and directly exposed to the weather. Better stability can be expected with operation in the ham shack or if provisions are made to limit temperature variations. Or, an external reference can be used. I did order crystals to produce output frequencies of 2256 MHz and 2400 MHz from ICM. I used their catalog number 525345. The price per crystal was $22 and delivery was three weeks. The crystals were right on and did not need any trimming. One potential application for the local oscillators would be as marker generators for 2304 MHz. 2304 MHz falls well within the typical PLL range of 2,171 MHz to 2,337 MHz. The reference frequency calculated to be 9.000 MHz. I did not have any 9.000 MHz crystals in HC-49/U or HC-18/U holders to directly replace the original crystal, but I did have several of the crystals in HC-6/U holders. I ran leads from the circuit board to a crystal socket, which worked fine.

External Reference

Wanting to try using an external reference, I removed the onboard crystal. The crystal had been connected between pins 1 and 2 of the PLL chip, marked FS4347E. I wanted to verify the connections to pins 1&2 of the crystal oscillator/phase detector integrated circuit. The first test using long unterminated leads from my signal generator was inconclusive. Later testing using a terminated coax cable, shorter leads, and after removing the chip capacitors and trimmer from around pins 1 & 2 showed that pin 1 is the proper pin to use. Applying an external signal to pin 1, I could see a signal on pin 2. The reverse, applying a signal on pin 2 produced no signal on pin 1. Hence, pin 1 is the input pin for the oscillator and pin 2 is the output pin. The VCO locked with a -12dBm or stronger reference signal to pin 1 or +3 dBm or stronger reference signal to pin 2. To check the range, I applied an external 0dBm signal though a 1000 pF series blocking capacitor to pin 1 (the crystal pin that was connected to the trimmer capacitor) of the FS4347E. I terminated the external source near the FS437E with a 47 Ohm ¼ Watt resistor to ground. No connections were made to pin 2. The VCO would lock for drive frequencies from 8.48 MHz to 9.13 MHz. The corresponding output frequencies are 2,171 MHz and 2,337 MHz, a range of +59 MHz to -107 MHz with respect to the design frequency of 2278 MHz or a total range of 166 MHz. Remember that this, and any other results, was with one specific circuit board, results may vary.

I put together an external 9.000 MHz reference source using an ICM model OF-1 oscillator I picked up at a hamfest and a junk box crystal. The OF-1 circuit boards are approximately 1.5" square. The OF-1 oscillator has roughly the same size circuit board as the model ICM OX series, but without the slug tuned coil. For a quick test, I used a 9V battery instead of a dc power supply. The oscillator worked great and the final output frequency was 2304.2 MHz. The OF-1 output frequency was 9.00079 MHz. The system works well with a supply voltage of 12V. With a 12V supply, the OF-1 oscillator draws 6.5mA. Either a separate 78L12 regulator can be used, or the reference oscillator could be powered from the same 12V regulated power fed to the multiplier PLL. I found a suitable mini-box, used as many of the existing holes as possible and drilled all of the necessary additional holes. I printed a label on peel-n-stick paper and applied it to the reference oscillator enclosure. Without such labels, I often forget what a module does or the power requirements. The reference oscillator and the PLL make a nice looking set, see Photo D.

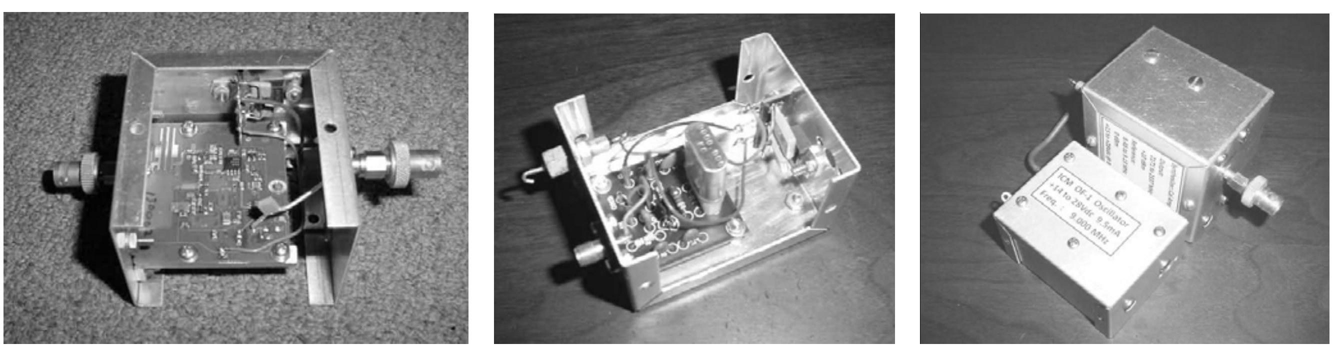

Photo D: Remounted PLL Oscillator, Crystal Reference Oscillator, and finished Unit

By applying +5V to combinations of programming pins 3 and 6 on the onboard FB506 prescaler chip, see later section, I was able to achieve lock for an output frequency of 2.304 GHz with reference input frequencies of 9.000, 18.000, and 36.000 MHz (9.000 MHz, all pins floating; 18.000 MHz, +5V to pin 3 or pin 6; and 36.000 MHz, +5V to pins 3 and pin 6).

Voltage Controlled Oscillator
I tried an assortment of six crystals from my junk box in the test oscillator. The highest frequency crystals, 9.2250 and 9.1750 MHz, produced the same output frequency, 2,342 MHz, which is below the expected frequencies of 2,361.6 MHz and 2,348.8 MHz. So I believe the upper frequency limit of the unmodified VCO was 2,342 MHz. The other test crystals; 9.075, 8.975, 8.875, and 8.625 MHz, all produced the expected output frequencies and power. With no crystal, the output frequency was 2,167.0 MHz. The output power does begin to drop off a couple dB at the frequency limits. Based on the simple tests, the absolute VCO range is 2,167 MHz to 2,342 MHz and the output bandpass filter is a little wider. The absolute VCO range implied a crystal range of >8.465 MHz to <9.148 MHz. Many amateurs have reported no problems with using an 8.8125 MHz crystal to get a downconverter IF frequency of 145 MHz for a RF input frequency of 2,401 MHz. Later experiments with other salvaged VCOs produced slightly different ranges. If the VCO range is not what is needed, it can be changed.

Before changing the tuning range, it is always best to measure the tuning range of a VCO. There are two ways to determine the range. The first is as I initially did, try assorted crystals or use an external reference. One could even slowly sweep the external reference and observe the output sweep range. A second method is a bit easier and leads to a way of checking the lock state of the PLL. The method involves forcing the VCO control voltage high and low. With the control voltage high, the VCO operates at the high end of the range and at the low end with the control voltage low. The VCO operates from a source of approximately 6V. This voltage is also the highest level of control voltage. The location of the test point for the PLL chip voltage is shown on Photo E. There is also a test point on the circuit board for measuring the control voltage. The location is shown on Photo E. Shorting the control voltage test point to ground drives the VCO to its lowest frequency. Coupling the PLL chip voltage test point to the PLL chip voltage test point drives the VCO to its highest frequency. In normal operation, the control voltage test point will be between 0 and 6V. With the correct internal or external reference; if the voltage reads near zero, the VCO cannot tune low enough to lock, if it reads near the PLL voltage, the VCO cannot tune high enough. Shifting the VCO range is accomplished by trimming or extending a trace on the circuit board. The trace is labeled “VCO tuning line” in Photo E. To shift the VCO range higher, merely trim the free end of the trace. I use 0.5mm or smaller steps. To shift the VCO range lower, solder a short bare piece of #30 gauge wire-wrap wire extending past the free end of the trace and then trim the wire as appropriate. This technique is useable for changes on the order of +/- 100 MHz.

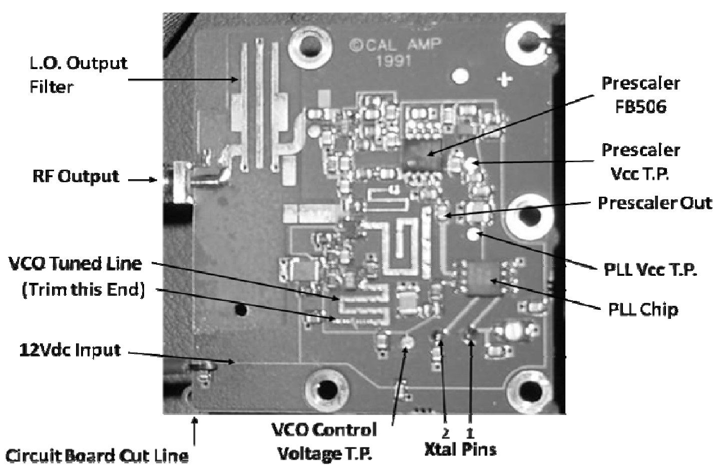

Photo E: PLL Portion of Downconverter Circuit Board

Exceeding this range could result in unstable operation. While shifting the VCO range, do not be concerned about the output power. The output filter may need to be trimmed as well. In going to 2.4 GHz, I experienced the output power dropping from 10mW to 1.5mW but was able to trim the output filter and return to 9mW. As will be shown later, the output filter can be eliminated and the output power should double.

Output Bandpass Filter

The local oscillator output bandpass filter should not need trimming for frequencies within +/-50 MHz of the design frequency of 2.278 GHz. If necessary, the output filter can be shifted to a higher frequency by carefully trimming the free ends of the filter traces. Go slow. I use increments smaller than 0.5mm. If you make a mistake, solder a piece of #30 gauge wire to the trace to extend its length and start again. The filter can be shifted lower by applying layers of Teflon® tape. There is also the option of removing the filter.

After dealing with having to retune the output bandpass filter several times, I decided to see what would happen if I went ahead and removed the output filter. I removed the local oscillator from a California Amplifier model 130001 downconverter. Instead of cutting the board length at 2-1/8", I cut the board length at 1-5/8", which resulted in the bandpass filter being removed. For the first test, I left the original 8.89844 MHz crystal installed. I added a SMA connector to the salvaged circuit board and applied 12Vdc. The RF output power now measured 22mW, a healthy increase of slightly over 3dB. The second harmonic was approximately 12dB down. I could not observe any other harmonic or spurious outputs on my swept YIG filter spectrum analyzer. Later experiments with other circuit boards and operating frequencies yielded RF output levels between 17 and 23mW and second harmonic levels between 11 and 15 dB below the fundamental output. Some spurious output did occur when the output line was shorted or open circuited, but they were rare.

Prescaler

Having had success with the PLLs, I decided to experiment with the PLL preselector integrated circuit. The preselector chip is labeled FB506. The data sheets for the Fujitsu FB506 can be found at http://pdf1.alldatasheet.com/datasheet-pdf/view/95687/FUJITSU/MB506.html . Rather than try to layout and etch a new printed circuit for testing, I nibbled a 1-3/8" by 1-1/8" section containing the prescaler integrated circuit chip, in/out coupling capacitors, output bias resistor, and other components from a downconverter printed circuit board. Unused parts and circuit traces were removed from the board to reduce clutter. The printed circuit board was easily reduced to 3/4" by 11/16" as shown in the right hand image in Photo F. The prescaler chip has two input pins, 1 & 8. Either pin can be used for the input, but the other must be bypassed to ground with a capacitor. The downconverter used a 220 pF capacitor. The output pin, 4, needs a resistor to ground to set internal bias. In the downconverters, the load resistance is 2K. I decided there was no reason to change the resistance. The prescaled output is capacitively coupled to the output connector. The input and output coupling capacitors are each 220 pF. I soldered two SMA connectors to the nibbled circuit board and then mounted the board on a small scrap aluminum plate with 4-40 hardware using two preexisting circuit board mounting holes. The preselector integrated circuit draws 20mA at 5V. Later, I added a 7805 three terminal 5V regulator circuit so I could draw power from whatever circuit I was testing and not have to use another power supply for the prescaler. Two examples of the completed test board are shown in Photo F. I tested the prescaler using RF inputs at 2400.0 MHz, 2304.0 MHz, 256.0 MHz, and even 25.60 MHz. In each case, the divisor ratio was 256:1. The upper frequency limit among the several prescalers I tested varied between 2.8 and 3.2 GHz. The sensitivity varied between -26 dBm and -38 dBm. The maximum recommended input power is 5.5dBm or 3.55mW.

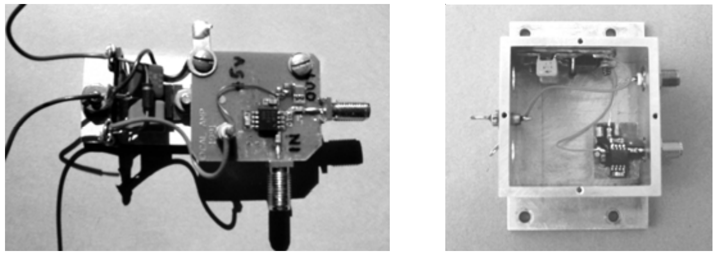

Photo F: Prescaler Chips Salvaged from Downconverter

As with many microwave prescaler chips, when there is no input, the chip will oscillate. Programming the prescaler division ratio is easy. There are two programming pins; 3(SW1) and 6(SW2). With both pins left open-circuited (floating), as is done in the downconverter, the chip divides by 256. If either pin is pulled high (+5V) while the other is open-circuited or floats, the chip divides by 128. If both pins are pulled high, the chip divides by 64. I easily verified all of the programming pin combinations. So, if you need a prescaler for another project, the downconverters are a cheap source. So far I have not tried to make my own prescaler circuit board, but I have found it easy to remove the prescaler chips from downconverter circuit boards. I place a small diameter soldering iron tip across all four pins on one side of the prescaler chip and then gently use a screwdriver to pry and tilt the chip up until the four pins are free. Then, holding the chip with a pair of needle-nose pliers, I heat the other four pins until I can pull the chip free and clear from the circuit board.

I did use one FB506 as the heart of a prescaler to convert my Hewlett-Packard 5381A frequency counter, which had an upper frequency limit of 80 MHz into a 2.8 GHz frequency counter. I multiplied the counter timebase frequency by 1000/640 to get the display to read directly in MHz.

Conclusion

Playing with these inexpensive sources of microwave components and circuits is fun and I can see the fun continuing as I move on to explore using the mixers and then the RF and IF amplifier stages. The inexpensive downconverters provide a wonderful opportunity to explore microwaves, make mistakes, and learn. I hope the information and experiences I have shared encourages you to heat up the soldering iron and do some tinkering.

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