

# Building and Using the WB6DHW AD995x DDS/QSD Board and Companion Band Pass Filter Board

SIXTH DRAFT Last revised **Friday, October 26, 2007, 4:01 PM**  
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[Requests for further information from the developers are enclosed in square brackets [like this] and/or contain three question marks ????. Please search on these strings to find them. Also please comment on any text anywhere. Don't worry about putting new information in all the right places – I'll take care of that. Please leave MS Word's (or Open Office's) Track Changes features on, so I can locate new material and changes. -- Rick]

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## INTRODUCTION

The AD995x direct digital synthesis and quadrature sampling detector (DDS/QSD) board and companion band pass filter (BPF) board was designed by Dave Brainerd, WB6DHW, in collaboration with other radio amateurs. It can be used as the front end for a powerful software-defined radio (SDR) communications receiver for the 160 to 10 meter amateur radio bands and intervening shortwave bands, with a tuning range from 1.5– 30 MHz. Additional user-designed filters could extend the tuning range from VLF to 54 MHz and possibly higher. Software to support this application is usable but still in development and testing.

The hardware design is generalized for other uses such as a local oscillator for a SoftRock RXTX or other external QSD or QSE, or as an RF signal generator at frequencies up to 160 MHz. Other uses, such as a spectrum analyzer with tracking signal generator and bandwidth up to 192 kHz, and a vector network analyzer (VNA), are possible but software to support these additional applications had not been developed when this was written. This document focuses on the receiver application, with hints about the other possibilities.

There will be errors and omissions in this document; please forgive the authors and send corrections and suggestions and outdated links to [rmeyer@cruzio.com](mailto:rmeyer@cruzio.com). If you have numerous comments, you may edit a copy of the manual and send the marked up copy,

A receiver based on these boards consists of the following main components:

<b>Component</b>	<b>Function</b>
<b>Band pass filter PCB</b>	takes antenna input and selects one of 6 bands pass filters covering 1.5 – 30 MHz, under firmware control
<b>AD995x PCB</b>	contains a direct digital synthesis (DDS) VFO oscillator for tuning, a quadrature sampling detector (QSD), audio preamp, and a PIC microcontroller with USB interface
<b>Microcontroller firmware</b>	controls the functions on the 995x board such as tuning
<b>A Windows PC</b>	hosts SDR receiver software and drivers. Contains USB 2.0 interface to the 995x board, and a sound card, preferably a high performance one, to take in the I and Q outputs of the 995x board, and put out sound through speakers
<b>SDR receiver software</b>	includes receiver user interface, control and DSP software. Examples are PowerSDR, Rocky, or KGKSDR.
<b>PC DDS Software</b>	allows you to set the VFO operating frequency in combination with the SDR software, and other settings

The 995x board also contains an optional signal generator section.

Like the popular SoftRock software defined radios (see <http://groups.yahoo.com/group/softrock40>), the 995x system contains a Tayloe quadrature sampling detector (QSD) at its core. (Note: this document contains many webpage links. Apologies if some of them are out of date by the time you read this.) The QSD converts RF from an antenna directly to “baseband” audio IF that can be fed into a PC sound card. Unlike the simple but effective SoftRocks, which have a limited crystal-controlled tuning range, the 995x board contains a state of the art AD9954 direct digital synthesis (DDS) chip, made by Analog Devices, as a local oscillator. This remarkable chip creates a very clean and stable signal directly using a 14-bit DAC that permits full range HF coverage. One possible use for the 995x board is as a quadrature clock generator for a SoftRock.

The new AD995x DDS chip family has a spurious free dynamic range about 12 db better than the popular AD98xx series predecessor, because it has a 14 bit instead of 10 bit DAC. This significantly improves the performance of a receiver or signal generator using the chip as a local oscillator. The new part has phase noise better than  $-120$  dBc/Hz, excellent dynamic performance and  $>80$  dB narrowband spurious free dynamic range, according to the manufacturer. The dynamic range on the amateur HF bands is even better.

When used with the companion BPF, the system has a continuous tuning range similar to many 160 -10 meter HF amateur transceivers, with tuning controlled over USB by a small application in the PC. An external BFP can extend the range to 6 meters.

For a good introduction to software-defined radio, see Gerald Youngblood’s excellent QEX article series entitled “A Software Defined Radio for the Masses” that led to the company FlexRadio and to the free, open source PowerSDR software you may want to use with the 995x. These and other articles are here: <http://www.arrl.org/tis/info/sdr.html>. The system Youngblood describes is very similar in architecture to the 995x and there is a good overview of DSP receiver algorithms.

### ***Can You Build One?***

This is not a project for beginners and it is not a full kit, just bare printed circuit boards and documentation. It is definitely an advanced project. You should have a technical background, previous surface mount (SMT) experience and have the necessary tools and materials. The boards contain a large number of tiny surface mount components, and ICs with very fine pitch leads, for which you need the right tools and materials, good eyes, and some magnification. You will not have a technical support department backing up the project, but volunteers on the [http://groups.yahoo.com/group/dds\\_controller](http://groups.yahoo.com/group/dds_controller) board might help some. If you ruin a board, you may lose a substantial investment in parts and labor. You will need an oscilloscope and multimeter at a minimum to aid you in testing, and other tools. It is up to you to put the boards in a suitable housing and supply connectors and power. The SoftRock would be an easier project with which to get started if you are new to SDR because you can get a kit, there are fewer parts, most of them are not surface mount, and none of the ICs has as fine a pitch. At this point the SoftRock series is also more mature. Later, a 995x board can be used as a tunable local oscillator for your SoftRock, although the 995x contains its own QSD receiver. There is a SoftRock model that contains an exciter, which the 995x project currently lacks.

Dave Brainerd, the designer of the 995x and BPF boards, only supplies the bare PCBs and some documentation. Collaborators have developed firmware and PC tuning software you can use with the boards. If you undertake the project, you will have to buy all other parts yourself. Most of them are available from Digikey. You will have to load the Microchip bootloader program into the PIC microcontroller yourself, or find someone to help you do it. You will need to select a cabinet, external connectors, and regulated 12V input power source yourself, and you will have to assemble, test and debug the project yourself, and then make it work with the firmware and the third-party SDR receiver software of your choice. Installation of related software is currently largely a manual process. Note that while the system works with several I/Q based third party SDR software packages, as of this writing, it is not fully integrated with them, because band switching and coarse tuning must be done with a separate software applet. Hopefully the authors of these SDR packages will be motivated to support this project as it matures.

The 995x project has an optional band pass filter board covering 1.5 to 30 MHz in six bands. If you only want to cover one band, or if you want to use a band not covered, you can design and build a simple one band filter in place of or in addition to the BPF board. There are switched connections to the BPF board that can be used to select among two outboard filters, based on what frequency the DDS is tuned to.

### ***Project Documentation***

The schematics, bills of materials (BOMs), and other documents for the boards are kept at <http://wb6dhw.com/AD995x.html> , and <http://wb6dhw.com/BPF.html> . Before building the project, you will want to printout and study the schematics, BOMs and the board layouts. There is a simplified theory of operation later in this document. Note that the BOM for the 995x board has two spreadsheet pages in it. A couple of the schematic pages are B sized drawings and are hard to read when printed unless you print them on large paper, or in sections. If you are using Acrobat Reader to view a document, you can print enlargements using `Tools | Select and Zoom | Marquee` to select an area to magnify, and `Print | Print Range | Current View`, to print what you selected with the marquee. Last minute changes, errata, tips and the like are likely to appear in the YahooGroup first before they appear in the system documentation, so look for relevant messages at [http://groups.yahoo.com/group/dds\\_controller/](http://groups.yahoo.com/group/dds_controller/) before starting.

## **ORDERING PARTS**

Please read this entire section before ordering parts. There are several options and considerations to think about.

### ***Adapting the Board for Intended Uses***

There are at least three possible uses for the 995x board made possible by the current “group software”:

1. An SDR receiver.

2. A signal generator
3. A DDS quadrature local oscillator for SoftRock series or other QSD or QSE.

None of these individual uses requires that you populate and power all sections of the board. In addition, you can populate the entire board, and use it for all of these uses, although there might be some small performance degradation if you do.

You should decide what uses you want before ordering parts. The assembly instructions below include lists of components for each section of the board. The bill of materials contains parts for all uses. If you decide to omit sections, you can refer to the tables of parts in the assembly instructions to determine which parts to omit. The beginning of each section of instructions describes the uses that require the parts in that section.

### ***Circuit Boards***

Dave Brainerd will sell you one or both boards for this project, if you order them directly from his web pages <http://wb6dhw.com/AD995x.html> and <http://wb6dhw.com/BPF.html> using PayPal. He is serving the amateur community by providing the boards at a price near his costs. The 995x board contains a DDS, QSD, and PIC microcontroller. It is a complete receiver front end, except for the RF filtering between the antenna and detector to select a band of interest. It can also be used as a RF signal generator, spectrum analyzer or VNA if software is developed for these applications. If you want to build a 1.5 to 30 MHz HF SDR receiver, you should probably get Dave's companion BPF board. It covers the HF range in six bands with band switching for two outboard filters. An interface between the two boards allows software to automatically select the right filter depending on the frequency you tune the DDS to. If you are only interested in a single band, or lower or higher frequencies you may want to design different or additional filters yourself. If you can't decide, you could try using an antenna tuner as a preselector to start with, before deciding on filters.

### ***Free Sample Parts***

The most expensive parts for this project are the Analog Devices AD9954YSVZ DDS chip and AD8310ARMZ logarithmic amplifier, and the MicroChip PIC18F2550-I/SO microcontroller. Luckily, both Analog Devices and Microchip have free sample programs. If you are able to get free samples, then you can leave these parts off of your Digikey order. Click the *Sample* link at [www.microchip.com](http://www.microchip.com), and the *Order Samples* link at [www.analog.com/en](http://www.analog.com/en) to request samples.

In addition to the AD9951, the hardware design can also support the other DDSs in the same series, the AD9952, AD9953 and AD9954, which are pin-compatible 400 MHz, 14 bit DDS parts. The initial "group" PIC software that is available is also compatible with all four variations, but does not yet take advantage of the increased functionality of the AD9952, AD9953, or AD9954. Future PIC and PC software could use the added capabilities of these parts, such as frequency sweeping. The latest part with the most added features is the AD9954, and it costs only a few dollars more than the AD9951. If you order from Digikey, uncheck all but one of the parts.

You could use a PIC18F2455 PIC to save a little money, but the PIC18F2550 has more program memory to accommodate expansion of the firmware. Unless you know the size of the firmware you will be using, order the PIC18F2550.

### ***Digikey Orders***

A readymade Digikey order for all parts to populate the 995x board corresponding to the bill of materials (BOM), except for transformers T1, T2, and T3, is here:

[http://sales.digikey.com/scripts/ru.dll?action=pb\\_view&pb\\_glue=1015789](http://sales.digikey.com/scripts/ru.dll?action=pb_view&pb_glue=1015789)

Refrain from clicking that button to order just yet, because you will need to tailor your order, depending on various options described further below. Also, group purchasing may be worthwhile, as some components cost significantly less when ordered in larger quantities than it takes to build a single unit.

Also, a readymade Digikey order for all the parts to populate the BPF board, except for transformer T1, is here:

[http://sales.digikey.com/scripts/ru.dll?action=pb\\_view&pb\\_glue=1015502](http://sales.digikey.com/scripts/ru.dll?action=pb_view&pb_glue=1015502)

The *BOM Multi source* link at <http://wb6dhw.com/BPF.html> can also be used for ordering. It contains alternative BPF parts lists for Digikey, Mouser, and Farnell UK in case you prefer to order from other suppliers.

Before ordering BPF parts, consider if you want to add or substitute your own custom filters – there are provisions for two added filters in the band switching on the BPF board. You may not even need a filter if you have other forms of selectivity in your rig, such as a highly selective antenna. You could populate the existing BPF board with 7 pole elliptical filters of similar design and compatible component physical sizes, but different passbands and component values. Inductors can be any size from 0603 to 1810. You could also build high or low pass filters by leaving off capacitors or inductors off the existing design or your design. You could use a second, partially populated BPF board to provide two extra bands. If you decide to design your own filters, you may find the free tool that was used to design the BPF, the AADE Filter Design (see <http://www.aade.com/filter.htm>) to be useful. Design files from this tool for the existing filters are on this page: <http://wb6dhw.com/BPF.html>. The input and output impedance of filters should be 50 ohms.

There are many inductors on BPF BOM. There are equivalent Coilcraft parts that can give somewhat less insertion loss in the BPF filters, and they also will fit the pads on the board, but Digikey does not carry them. The multivendor BOM spreadsheet has a separate page with the Coilcraft part numbers. In this case, delete the corresponding inductors from the parts ordered from the main supplier. It has been proposed that hand wound toroids might give still better performance, but this has not yet been tried.

The 995x board is flexible in the type of clock oscillator it accepts. The schematic shows a default choice of an SMD oscillator – any standard 5 mm x 7 mm or 9 mm x 14 mm CMOS

oscillator may be used on the board. The parts for three versions of a low pass filter that follows the DDS chip, at different frequencies, are on the BOM and you need to choose just one for DDS internal clock frequencies of 400, 500, or 700 MHz. Note that the low pass filter frequency is designed to suppress the frequency feeding the DDS accumulator and DAC internal to the AD995x. That frequency is calculated by multiplying the DDS master clock input times the internal DDS PLL clock multiplier as set in the PC tuning applet's Config menu. For example, 500 MHz should be chosen if a 125 MHz SMD oscillator is used with a DDS PLL multiplier of X4 ( $125 \text{ MHz} * 4 = 500 \text{ MHz}$ ).

Analog Devices specifies AD995x devices for a maximum clock of 400 MHz, but experiments have shown that some individual parts may provide useful output using up to a 700 MHz clock, for a 300 DDS MHz sine wave output. Choose the 400 MHz clock to get reliable operation from any part – this will also support the full frequency range for which the receiver application and the BPF are designed. Choose the higher speeds if you want to experiment or to see if you can use the board as a VHF signal generator, bearing in mind that a particular AD995x part may not work at the higher frequencies. The values in the low pass filter at the output of the AD995x must correspond to the clock frequency you choose. Uncheck the values for L1, L2 and L3 in the Digikey order as well as C26-C32 for the LPF frequencies you are not using. You may also experiment with a CMOS or LVDS oscillator of your choosing. In that case, follow the clock options instructions on sheet 2 of the schematic and modify your Digikey order accordingly.

The minimum detectable signal of the board when used as a receiver is determined in part by the noise voltage of U15, a dual low noise op amp that amplifies the microvolt range audio signal following the quadrature detector. The MC33078 part in the bill of materials is an inexpensive part with a good noise specification. You may be able to gain a couple dBm better performance by substituting a more expensive part with better noise performance, such as the Linear LT6231CS8. Check the DDS\_CONTROLLER board for suggestions by those who may have tried this or other parts.

There is a USB mini-B connector on the BOM that mounts on the edge of the board. If you can mount the board close to the edge of your enclosure, you can expose the connector to the outside. If this not possible, you may want to order a panel mount USB connector and connect it to H19 and not order the PCB mount connector in the BOM, although it wouldn't hurt to have both.

If you need a DC-coupled QSD, for example for a VNA, then C61, C62, and C64 can be replaced with jumpers, R22 and R23 removed, and the junction of C71 and C72 would need to be connected to the center tap of T1 to bias U15 the same as the QSD switches. Of course new software, not yet developed, would be required for this application.

The BOMs for both projects contain housings and pins that mate with all the headers on the board for jumpers and cables to the "outside world." You may need to order ribbon cable to make connecting cables. The widest ribbon cable you might need is 12 wires for H4 near the PIC.

If you intend to program the bootloader firmware into the microcontroller in place on the board rather than in a programmer with a compatible socket for the part, you may need to build a special cable. See details in the Software section below.

If you decide to leave off certain sections of the 995x board, you may want to cross out the assembly steps below relating to the parts you will leave off. This could save confusion while you are building the board.

### ***Transformers***

There are three transformers in the 995x BOM and one on the BPF board that are not in the Digikey orders because Digikey does not carry them. They are very much cheaper in quantities of 10, so some builders have been pooling their orders – check the DDS\_CONTROLLER board for open offers. They are available directly from MiniCircuits Labs at:

[http://minicircuits.com/cgi-bin/modelsearch?search\\_type=model&model=ADT1-1&tb\\_no=TB-02](http://minicircuits.com/cgi-bin/modelsearch?search_type=model&model=ADT1-1&tb_no=TB-02)

The Coilcraft WBC1-1TLB is a substitute for the 2 transformers in the DDS section of the 995x board and the Coilcraft WBC4-1TLB is a substitute for the transformer in the QSD section. See [www.coilcraft.com](http://www.coilcraft.com).

### ***Cabinet, Power, etc.***

The BOMs for the two boards only contain the parts necessary to populate the boards and connect to their headers. You will need to design the rest of the system and choose and order other parts. You will need at least a housing, a 12 VDC, 350 ma regulated power source, RF in connector, RCA or mini phono audio connector(s), power connector or battery pack, a USB mini-B to standard USB cable (as used with some digital cameras), some small diameter 50 ohm coax for RF connections, shielded audio cable and ribbon cable. Maybe you will want a power switch and pilot light. The best housings have a tight RF seal to keep out interference from a nearby PC and other noise sources – die cast boxes are good for this reason.

U19 is a 5 volt regulator in a TO-220 package. If possible, attach it to the inside of an aluminum case. If this is not possible, you should order and use a heat sink.

Make sure the two push buttons and two LEDs on the 995x board are accessible. The 12 volt DC adaptor or other power source should be well regulated with low ripple, and, if it contains a switcher, good RFI filtering to keep switching noise out of your sensitive receiver. It should be capable of supplying 350 ma. Include a battery pack and external 12 volt regulator if you plan mobile use with a laptop computer.

## **BEFORE YOU BEGIN ASSEMBLY**

### ***Surface Mount Techniques***

You need prior surface mount (SMT) experience, and the necessary SMT tools and materials before attempting this project. There are several good tutorials and tool and materials suppliers available on the Web. One supplier who is participating in the 995x project is Cash Olsen, KD5SSJ. See the *SMT Soldering* and *Solder Paste* links on his site: <http://www.zianet.com/erg>. Among other tools, you will need a grounded tip soldering iron, as the project contains CMOS circuits that are easily damaged by static electricity. If you live in a dry region where static is a special problem, you may also need a wrist ground strap and to take other special precautions. Use a conical tip with a .2 mm radius (about .015 inch diameter) plus a larger tip for the larger components and grounds, (0.05 - 0.1 inch diameter), and the power range of 15 to 20 watts. A 2% silver-bearing solder with diameter of 0.015 inches works well for SMT work, such as Radio Shack P/N 664-035. Parts can also be applied individually or en masse using solder paste and hot air or an oven. Hobbyists have adapted tools like embossing heat guns, pancake grills, cup warmers, toaster ovens and the like to avoid the high cost of professional SMT gear.

One of several tricky areas is the QFN package devices, U6, U11, U12, and U20. You can recognize these board locations by the square pad with the hole in it that is inside the pin pattern. Dave Brainerd suggests the following technique:

"I put a dab of solder paste in the center hole and a dab on one of the pins on the side with only 2 pins. Then I position the IC best I can and hold it there while I heat the one pin with the soldering iron. I then recheck the positioning. If necessary, I re-heat the one pin and re-position. Once positioned correctly, then I run solder paste around the other pins and heat with the hot air until the paste melts. I then use the solder wick to suck up the excess solder. Then a final inspection with the microscope. If any pins are not soldered, I add a dab of solder paste and re-heat with the soldering iron."

### ***Program the Bootloader First?***

The PIC microcontroller needs to have the bootloader firmware loaded into it before it can be used. If you have access to a programmer with the right adaptor for the PIC's 28-SOIC package, you may want to program in the bootloader before you solder the chip to the board. If you don't have a suitable programmer and adaptor, check the DDS\_CONTROLLER board to look for offers from people willing to do the programming for you. The PIC can also have the bootloader loaded into it while it is in place on the board, but then you may want to temporarily leave off C1 and C2, and you will need to build a special cable for your programmer. (See Install Bootloader section below.) These capacitors can interfere with certain programmers.

### ***Pilot Production Run Board Notes***

These notes apply only to the single run of 30 pilot production 995x boards distributed in August 2007. If you have a later production board, it will be labeled 995X\_Rx, where x is the revision number. Note the following before you begin assembly:

1. The silk screen label for C15 is missing. You can find it on the bottom of board between C14 and C16.
2. The silkscreen label for U21 is missing. It is surrounded by C66, C69 and H16.
3. There is no thermal relief on ground side of C88, but there is no problem soldering in the part.
4. D3 pins 1 and 2 are reversed on the PCB but not the latest layout document, which corrects the problem. Also pin 3 connects to the cathode, not pin 2. If D3 is installed normally and then pins 2 (nearest to pin 1 on the ICSP connector) and pin 3 (on the side with only one pin) are jumpered together, it should work.
5. The pads for the SOT-23 package voltage regulators, U3, U4 and U18, are a little wider spaced than necessary, but you can still mount the parts successfully.
6. Jumpers required to use the board's attenuator are optional and are software dependent. They are not shown in the design documents, but are described below. Pads to facilitate jumpering the PIC to the attenuator were added to production boards but are not on pilot production boards.
7. Jumpers required for the PIC to control the DDS are software dependent and are not shown in the design documents but are described below or in documentation for your firmware.
8. C56, C61, C64, C70 and C71 are polarized capacitors, but the polarization is not marked on pilot production boards. The layout diagram for the production boards contains the proper polarity.
9. The 995x board is capable of supplying 5 V power to the BPF board. Production boards have two pads marked +5 and GND that can be used for BPF power, but the pilot production run lacked these.
10. On pin 6 of U10, a 65LVDS390, there is a circuit board trace going to ground that is unintentional and is not shown on the schematic. It does not cause much of a problem, but it can be fixed by cutting the trace between the feed through hole between pins 6 and 7 and the ground plane. Be sure to leave the connections between pins 6 and 7 and the feed through hole. This problem was corrected in the first production run of 100 boards.

You may want to mark these areas on your copy of the board layout and/or the PCB itself, to remind you when you get to these places in the assembly process.

## ASSEMBLING THE 995x BOARD

If you are building both the 995x and BPF boards and would like a refresher exercise with surface mount soldering, try the simpler BFP board first. You may find it useful to study the Theory of Operation section below before beginning assembly.

### *Overview*

There are two possible ways to assemble the boards, incrementally using methods that mount individual components or all-at-once methods that can mount all components in bulk using solder paste and heat over the whole board. The incremental method, described below, gives step by step instructions for building one stage of the circuitry, and testing it before proceeding. If you are very confident of your surface mount skills and have the necessary equipment, the bulk method can also work, although troubleshooting problems may be more difficult. Otherwise, proceed with the steps below. Even if you plan to proceed incrementally, you will still have to mount some very fine pitch ICs using solder paste and hot air, one at a time.

At various stages after the voltage regulators are installed, you will apply power to the board. You should use a well regulated 12 VDC supply. If possible, set the current limit to a little over the expected drain, as described in the instructions, never more than 350 ma. maximum, since the board should never draw more than this, even with all components mounted and the BPF attached. It is also useful to be able to measure the current drawn, as we will be checking this after each stage of assembly. After the board is fully assembled, it is much harder to identify a component that is drawing too much or too little current.

At various stages, we suggest that you make measurements with your multimeter. The probes that come with most multimeters are much too large to make measurements on fine pitched ICs. You will need to improvise fine, needle-sharp probes to work on the 995x board, or you will easily short out adjacent pins. An actual sewing needle or pin can be used. Even with such a probe, we suggest you not probe the AD995x part directly, but only adjacent connected parts.

At certain stages we ask you to make certain tests whose results are dependent on the PIC firmware you are using. For the sake of clarity, we assume that you are using the “group” firmware dated August 20, 2007 or later. If your firmware is different, your test results may differ. If you intend to use other firmware, you may want to install the group firmware first, to be able to follow the testing procedure below, and then once the board is fully working, download the other firmware.

Make sure that all diodes and polarized capacitors are installed on the board in the right orientation. Polarity markings are included in the board layout document and board markings.

We will be leaving some headers off the board until the end, as they could make it more difficult to install other nearby components. Otherwise, we proceed stage by stage.

If any measurement you make is off, go back and correct the problem before proceeding, or you may damage components installed later or make troubleshooting more difficult. There are

a number of jumpers and 0 ohm resistors that can be used to interrupt power to various devices and block other connections. You may find it useful to remove these to aid in debugging any stage that is not working as expected.

[TF NOTE: I think a Jumper table is needed. It is hard to figure out, especially since not all jumper connections are clearly shown on the board. For example, unless you look at the schematics, etc, you will not have any idea where Jumper TP-12 to TP-13 should go. The silkscreen only shows 12V, no TP12, or TP13, etc. A diagram, with jumper end-points would be VERY helpful. Test points should also be shown.

### ***Voltage Regulators***

Install the four voltage regulators that are required for all uses of the board, and associated parts:

√	No.	Part	Value	Size	S*	Notes
	1	U19**	MC7805 5 V regulator	TO-220	T	Heatsink recommended** On sheet 1
	2	U4	LP2992AIM5-1.8 regulator	SOT23-5	T	
	3	U18	LP2992AIM5-1.8 regulator	SOT23-5	T	
	4	U3	LP2992AIM5 -3.3 regulator	SOT23-5	T	
	5	C82	10 uF, 16v	0805	B-U19	
	6	C83	10 uF, 16v	0805	B-U19	
	7	C6	10 uF, 16v	0805	B-U3	
	8	C7	10 uF, 16v	0805	B-U3	
	9	C77	.01 uF	0805	B-U3	
	10	C8	10 uF, 16v	0805	B-U4	Designation is unreadable, located above C9
	11	C9	10 uF, 16v	0805	B-U4	
	12	C78	.01 uF	0805	B-U4	
	13	C80	10 uF, 16v	0805	B-U18	
	14	C81	10 uF, 16v	0805	B-U18	
	15	C79	.01 uF	0805	B-U18	Designation is unreadable, located above C80
	16	Jump***	TP12 to TP13, +5V	Wire	B	Install jumper
	17	H17****	2-pin header	.1"	T	Board 12V power

\* Column S indicates whether the part is on **Top** or **Bottom** of the PCB and the location of a nearby major component. There may be no connection to the component; the reference is for physical location only.

\*\* A small heat sink is recommended for U19 or it can be mounted against a metal chassis. On a fully populated board it would otherwise run too hot.

\*\*\* One end of the jumper is first in a series of three points marked +5 at the output of U19 and the other end is under U3 at a point marked +5 on the top of the board. This and many other jumpers are shown as thin white lines in the silk screen printing.

\*\*\*\* Pin 1 on this and other headers has a square pad. Other pads are round.

Measure the resistance from H7, pin 1, the 12VDC supply input, to ground. The resistance will start low, but increase to over 1 megohm as the input capacitors charge.

Apply +12 VDC power to H7 pin 1 and GND to H7, pin 2 with current limiting set to 5 ma. if possible. The total input current drawn by the board should be approximately 3.3 ma at this point. Measure the outputs of the regulators as described below and if any voltage is wrong, disconnect power immediately. You can expect output voltages to vary up to 5% from the nominal values.

The + side of C83 should be +5V.

The + side of C7 should be +3.3V.  
The + side of C9 should be +1.8V.  
The + side of C81 should be +1.8 V.

U19, the 5V regulator should not be warm to the touch after running power for a minute. Later, when everything is powered, the heat sink on U19 will be warm.

### ***PIC***

Install the parts below, which correspond to all parts on sheet 7 of the schematic. These parts are required for all uses of the board.

√	No.	Part	Value	Size	S	Notes
	18	U1	PIC18F2550	28-SOIC	T	
	19	C2*	.1 uF	0805	B-SW2	Leave off if no bootloader
	20	C1*	10 uF	0805	B-SW2	Leave off if no bootloader
	21	C3	.47 uF	0805	T-D1	
	22	C4	18 pF	0805	T-H2	
	23	C5	18 pF	0805	T-H2	
	24	X1	20 MHz crystal	6 x 3.5 mm	T-U1	Solder paste and hot air works well
	25					
	26	SW1	Push button		B	Reset
	27	SW2	Push button		B	Program
	28	R4	330	0805	T-X1	Install before LED's
	29	D1	LED green	3 mm	T-H1	Power. Long lead is + & goes towards +5, the square pad
	30	D2	LED red	5 mm	T-H1	Firmware state. Long lead to square pad.
	31	D3	BAS21 diode	SOT-23	T-H3	Long lead to square pad.
	32	J1	Mini USB connector		T-H19	Or use external USB connector wired to H19
	33	R1	330	0805	T-H1	
	34	R2	10K	0805	B-SW1	
	35	R3	10K	0805	B-SW2	
	36	R48	10K	0805	B-H3	
	37	R49	3.3K	0805	T-H2	
	38	R50	3.3K	0805	T-H4	
	39	R51	3.3K	0805	T-H4	
	40	R52	3.3K	0805	T-H3	
	41	R53	5.6K	0805	B-H2	
	42	R54	5.6K	0805	B-H4	
	43	R55	5.6K	0805	B-H4	
	44	R56	5.6K	0805	B-H4	
	45	Jump**	Jumper TP14 to TP15	wire	B	5V power to PIC
	46	H1	3 pins	3 x 0.1"	T	PIC power selector
	47	Jump	H1-1 to H1-2	Shunt jumper		5V to PIC from board's regulator, not USB port
	48	H3	7 pins	7 x 0.1"	T	For ICSP programmer

\* If you intend to program the PIC, U1, with the bootloader while U1 is in place on the board, and you are not using the PICKit 2 programmer, we suggest you leave off C1 and C2 until the bootloader is programmed.

\*\* From a point marked 5V near U19 to the point marked 5V near H1.

## CAUTION

Once the PIC section of the board is completed, it is very easy to accidentally reset the PIC, since the Reset push button is on the bottom of the board. Whenever the board is in use, it is recommended that the board be placed in a small vice, or some other method used to prevent accidental SW1 or SW2 activation.

Measure the resistance between pin 20 of U1 and ground. It should be at least 5 K.

Apply 12 volt power to the board and measure the current consumption. It should be about 13 ma. if no bootloader has been programmed into the PIC. Pressing the Program key should cause the firmware to toggle the red LED alternately on and off. The red LED is used by the group firmware to indicate PIC programming mode. Initially, the red LED may not be lit at all. Some versions of the firmware listed in the Files section have a “heartbeat” that flashes the red LED about once a second. If the board is connected via USB and you press and hold the Program button while pressing Reset, the firmware will switch to bootloader mode and the red LED will flash several times per second.

If you have not previously installed the bootloader, the group firmware and firmware specific jumpers, you may do so now using an in circuit programmer, as described in the Software section below. After installing the bootloader and firmware, apply power, press the Reset button and make sure the red LED responds to presses of the Program key. Total board current should be about 50-70 ma. If you put the board into bootloader mode, the red LED should flash more quickly and current consumption will be about 63 ma. If you have left off C1 and C2, you may now safely mount them.

From this point on, supply current will depend on what “mode” the PIC is in. This is primarily due to the flash rate of the red LED. There are four modes:

1. Normal mode. The PIC DDS control software is functioning. The RED is flashing about once per second.
2. Bootloader mode. The red LED is flashing quickly, and the PIC is waiting to load new software into the PIC. Cleared by programming, hitting reset, or unplugging the board.
3. Board is “hung” with red LED off. Usually a forced mode, by disconnecting the USB from the computer while the LED is off.
4. Board is “hung” with the red LED on. Same as 3 above, except board current will be higher due to the red LED being on.

Once the bootloader and firmware are loaded into the PIC, the PIC may not always start up properly. Pushing the Reset button may correct this. Occasionally, the firmware gets hung up if there is no USB connection to a computer. This often happens when the PIC is put into bootloader mode without being hooked to a computer. If you cannot put the PIC into bootloader mode, make sure the board is connected via USB to a computer.

## ***Clock Generator***

If you are installing the standard clock circuit shown on the schematic, install the parts below, which are required for all uses. These parts correspond to sheet two of the schematic.

√	No.	Part	Value	Size	S	Notes
	49	U9*	SMD oscillator	5x7 mm to 9x14 mm	T-U19	See BOM and theory of operation for alternatives
	50	R5	220	0805	T-H12	
	51	R6	68	0805	T-U9	
	52	R31	0 ohms	0805	T-U9	
	53	R32	100	0805	T-U2	
	54	C22	.1 uF	0805	B-U9	
	55	C23	1 NF (= 1000 pF, "PCC102CGCT")	0805	T-U2	
	56	C24	1 NF	0805	T-U2	

\* U9 has four pins, but mounts on a pattern with 6 pads. The printing on the top of its case should have the same orientation as the horizontal silk screen legends on the board. Solder a very short jumper from the case of the oscillator to the nearby hole in the ground plane near the edge of the board. On the bottom of the board, bend the wire over to touch the shiny edge of the ground plane and solder it to ground there.

The following measurements may vary depending on the oscillator manufacturer and part selected. Make sure the resistance between pin 6 of the SMD oscillator (if installed) is greater than 150 ohms, after capacitors fully charge.

Apply 12 volt power with current limiting set to 125 ma. Make sure that current drawn is under 100 ma. If you are using group firmware with the heartbeat, with the red LED flashing slowly in normal mode, the current should fluctuate from 85 - 95 ma. In bootloader mode, the current should be near 91 ma.

If you have an oscilloscope with sufficient bandwidth, you should be able to observe the CLK RF output on pin 2 of H12. With the CMOS oscillator in the parts list, you should see a 125 MHz 3.3V square wave. The output could be checked with a freq. counter.

If a heat sink is not used, U19, the 5 V regulator will be hot to the touch from this point forward.

## ***DDS and LPF***

Install the parts below from sheets 6 and 2 of the schematic, required for all uses:

√	No.	Part	Value	Size	S	Notes
	57	U2	AD9954	48-TFP	T	Could use other 995x parts
	58	T3	MiniCircuits TC1-1T+		T-U2	Or Coilcraft WBC1-1TLB
	59	L1	See table below.	2.5 x 2 mm	T-U4	
	60	L2	See table below.	2.5 x 2 mm	T-U4	
	61	L3	See table below.	2.5 x 2 mm	T-U5	
	62	C26	See table below.	0805	T-U4	
	63	C27	See table below.	0805	T-U4	
	64	C28	See table below.	0805	T-L2	
	65	C29	See table below.	0805	T-L2	
	66	C30	See table below.	0805	T-L2	
	67	C31	See table below.	0805	T-L3	
	68	C32	See table below.	0805	T-L3	
	69	R8	0 ohms	0805	T-U2	
	70	R9	3.92K	0805	T-U2	
	71	R10	24.9	0805	T-T3	
	72	R11	24.9	0805	T-T3	
	73	R26	10 K	0805	B-H5	
	74	R27	10 K	0805	B-H5	
	75	R28	10 K	0805	B-H5	
	76	R29	10 K	0805	B-H5	
	77	R30	10 K	0805	B-H5	
	78	R57	10 K	0805	B-H5	
	79	C10- C11	.1	0805	T-U2	
	80	C12- C21	.1	0805	B-U2	
	81	H5	2 rows of 6 pins	6 x 0.2"		

The inductors and capacitors in the low pass filter have values that depend on your choice of internal DDS clock frequency:

	<b>400 MHz</b>	<b>500 MHz</b>	<b>700 MHz</b>
L1	39 nH	33 nH	22 nH
L2	56 nH	47 nH	33 nH
L3	68 nH	56 nH	39 nH
C26	12 pf	10 pf	6.8 pf
C27	12 pf	10 pf	6.8 pf
C28	27 pf	22 pf	12 pf
C29	6.8 pf	5.6 pf	3.9 pf
C30	33 pf	27 pf	18 pf
C31	2.2 pf	1.8 pf	1.2 pf
C32	22 pf	18 pf	12 pf

## PIC Jumpers

Interconnections between the PIC and the DDS, the attenuator circuit, and the transmit/receive switching circuitry are dependent on the PIC firmware you are using. The firmware will not run correctly without matching sets of jumpers. Make sure you install jumpers specific to the firmware you are using. Jumpers described in this section assume use of the “group firmware” and further testing instructions assumes this firmware.

All of the DDS programming pins are brought out to H5. Normally only Reset-H5 pin 11, SCLK-H5 pin 7, and IOUPDATE-H5 pin 2 are required. These pins are usually jumpered to I/O lines from the PIC. Other programming lines may be left unconnected, as they are pulled down. If you will never use them, you may jumper them to ground for less noise emission. Note that the DDS programming pins are 3.3 V logic and the PIC pins are 5 V logic, requiring voltage dividers. Dividers are provided for the 4 signals listed below.

Jumpers may be installed by first installing headers and using pins and housings, or by omitting headers and soldering wires directly to the pads.

To use the group firmware, install the following PIC to DDS jumpers:

	<b>FROM SHEET 6*</b>		<b>TO SHEET 7</b>	
<b>Jumper</b>	<b>DDS Signal</b>	<b>Connection</b>	<b>PIC I/O Signal</b>	<b>Connection</b>
A	Reset	H5-11	A5	DDSR
B	SCLK	H5-7	B6	DSC pad just above H4-12
C	IOUPDATE	H5-2	B5	DDSUI pad above H4-8
D	SDIO	H5-8	B7	DSIO pad just above DSC pad

\* Sheet numbers refer to schematic pages.

Measure the resistance of Dvdd, on pin 5 of U18, to ground. It should be about 53 K ohms.

Measure the resistance of Avdd, on pin 5 of U4 to ground. It should be about 69 K ohms.

Measure the resistance of Dvdd IO, on pin 5 of U3 to ground. It should be about 153 K ohms.

Apply 12 volt power to the board with current limit set to 250 ma. The current should be about 200 ma. in bootloader mode. In normal mode the current should vary around 190 – 200 ma. If the red LED is off, the current should be about 180 ma.

If you have previously programmed a bootloader and DDS control program into the PIC, upon power-up the PIC should program the DDS to produce an output of approximately 14.11 MHz (7.055 \*2) if you used a 125 MHz oscillator. You should be able to see approx. 450 mV peak-to-peak at T3's secondary, or the input side of L1.

Some DC voltages to aid in troubleshooting around the AD995x DDS chip are given below. Measure the AD995x chip only indirectly. Even with a needle sharp probe, it is easy to short adjacent pins. To measure a pin, find a part that connects to that pin and probe it instead as in the measurements below.

- |                                |        |                        |
|--------------------------------|--------|------------------------|
| 1. U3-5:                       | 3.3 V  | (DVDD_IO power)        |
| 2. U18-5:                      | 1.8 V  | (DVDD power)           |
| 3. U4-5:                       | 1.8 V  | (AVDD power)           |
| 4. R9 bottom:                  | 1.24 V | (DAC Reset)            |
| 5. R8 (0-ohm jumper):          | 0.36 V | (Loop Filter)          |
| 6. R32 Left pad:               | 1.26 V | (DDS /CLK in)          |
| 7. R32 Right pad:              | 1.26 V | (DDS CLK in)           |
| 8. T3, all three primary pins: | 1.8 V  | (DDS I & /I outs)      |
| 9. DSIO:                       | 3.1 V  | (DDS SDIO – Data)      |
| 10. DSC:                       | 0 V    | (DDS CLK – Clock)      |
| 11. DDSUI:                     | 0 V    | (DDS IOUD – IO Update) |
| 12. DDSR:                      | 0 V    | (DDS RESET – Reset)    |

Install the following four resistors according to your uses:

√	No.	Part	Value	Size	S	Notes
	82	R40	See table below	0805	T-L3	
	83	R37	See table below	0805	T-T2	
	84	R39	See table below	0805	T-U5	
	85	R43	See table below	0805	T-T2	

<b>Uses</b>	<b>R40</b>	<b>R37</b>	<b>R39</b>	<b>R43</b>
All uses (all components)	16.5	0	16.5	62
Signal gen., no quad. gen.	0	Omit	0	Omit
Quad. gen., no signal gen.	0	0	Omit	52.3
No, quad gen, no signal gen.	0	Omit	0	52.3

You should see approximately 500 mV p-p at 14.1 MHz at the junction of L3 & R40. If so, congratulations – the PIC and DDS are functioning properly. If not, go back and verify that the jumpers are installed correctly, and look carefully at the solder connections on U2. It is very easy to have a solder short between pins, even in the upper shoulder area of the DDS IC pins.

The remaining sections of assembly procedure are optional, except for the headers in the final assembly section. Only build a section if you need the specific functions of the section.

### ***Signal Generator Section***

Install the parts in the three subsections below only if you want to include general signal generator capabilities or use the board as a local sine wave oscillator for other receivers or transmitters. Clock generation for any QSD or QSE, including the on board QSD does not require these parts. [Installation of these parts may cause minor performance degradation of the on board QSD???) [TF note: Not confirmed at this point, but Reid’s experience suggests this.]

√	No.	Part	Value	Size	S	Notes
	86	U5*	MSA-1105 MMIC	05-SMD	T	Bump/dot near top edge PCB. "A" to the left.
	87	C34	.01 uF	0805	T-U5	
	88	C76	.01 uF	0805	T-U6	
	89	C40	.01 uF	0805	T-U6	
	90	C37	.01 uF	0805	B-U7	
	91	C38	.01 uF	0805	T-U7	
	92	C42	.01 uF	0805	T-U7 H8	
	93	C33	.1 uF	0805	T-U5 L2	
	94	C36	.1 uF	0805	B-U6	
	95	C87	1 uF	0805	B-R12	
	96	C35	10 uF	0805	T-U6	
	97	C75	10 uF	0805	B-U7	
	98	C41	10 uF	0805	T-U7	
	99	C39	10 uF	0805	T-U6	
	100	C43	10 uF	0805	T-U6	
	101	L4	1 uH	1210	T-T3	
	102	R12**	115 ohms, 1 watt	2512	T-H10	
	103	R13	10 K	0805	T-T3	
	104	R14	499	0805	T-H10	
	105	R15	52.3	0805	T-U7	
	106	H4	2 rows of 6 pins header	6 x 0.2"	T	PIC signal header
	107	H10	2-pin header	2 x .1"	T-U7	RF out

\* U5, the MMIC amp is installed with the input, which is closest to the "A", and has an angled-cut lead, pointed down toward C33. The bump/dot is the output, and is toward the top edge of the board. The "A" should point to the left.

\*\* R12 may be reduced to improve second-harmonic performance. A second 115 ohm resistor may be placed in parallel with the existing one. If done, the two should be mounted on edge, separated from one another, allowing room for air circulation, not stacked on top of each other.

Because of their delicate installation, U6 and U7 will be installed after the MMIC amplifier is verified to be working properly.

Temporarily solder a short jumper wire between the top of C35 and the bottom of C40. This will connect the MMIC amplifier output directly to H10, the RF output connector. Do not get any solder on the traces for U6.

Resistance from TP8 to ground should be approx. 7.9 K ohms. If so, install a jumper from TP8 to TP9. This connects 12V power to R12 and the MMIC amplifier.

Apply 12 V power with current limiting set to 300 ma. Current consumption should rise to about:

- 250-260ma in normal PIC mode
- 255 ma. in bootloader mode
- 240 ma. in red LED off mode.

If the DDS is running at this point, and you are using the group firmware you should see a 14.1 MHz (7.055 \* 2 ) sine wave of about 2 volts peak-to-peak at the H10 connector, without a load. Other voltages in the RF chain should be:

1. L1/T3 (DDS out): 250mV p-p.
2. L3/R40 (LP filter out) & MMIC in: 300mV p-p.
3. H10 (or MMIC output on pin 3 of U5) open: 2V p-p.
4. H10 (or MMIC output U5 pin 3) with 50-ohm load: 1V p-p.

Some approximate DC voltages for troubleshooting are given below, assuming R12 is 115 ohms. Both 12 V and 10 V power to the board are shown:

- |                        |        |        |
|------------------------|--------|--------|
| 1. R12 top (power in): | 12 V.  | 10 V   |
| 2. R12 bottom:         | 5.25 V | 4.96 V |
| 3. U5 (MMIC) in:       | 1.8 V  | 1.7 V  |
| 4. U5 (MMIC) out:      | 5.3 V  | 5.0 V  |

If these tests are successful, turn off the power and remove the temporary jumper between C35 & C40. Install:

√	No.	Part	Value	Size	S	Notes
	108	U6*	HRF-AT4611	16-VQFN	T	Careful! Use solder paste.
	109	U7	AD8310	8-MSOP	T	

\* CAUTION: Be very careful when installing U6 using solder paste. Unlike most QFN parts, the bottom plate of the part must be soldered to the square ground pad underneath. The “pin” contacts are hidden under the package. One successful technique is to apply individual tiny specs of solder paste to each contact on the part and then place it very accurately on the board pattern. Solder bridges on this part are hard to remove and missing connections are common. Some experienced builders have taken three or more attempts before U6 is properly functioning. It is not uncommon for parts of U6 to work fine, and others not work. This often shows up as having missing attenuation steps as the level is changed, “jumps” in level control instead of smooth operation. If this happens, reheating U6 to further solder flow will likely help. Rarely does U6 need to be completely removed and soldered down again from scratch.

Resistance from TP10 to ground should be more than 10 megohms. If so, install a jumper from TP10 to TP11, which connects 5V power to U6 & U7.

The group firmware makes use of the programmable attenuator and logarithmic detector. To use these features, install jumpers between three attenuator lines and three PIC lines as follows and a jumper between the logarithmic detector and the PIC:

Jumper No.	FROM SHEET 6		TO SHEET 7	
	Atten. Signal	Connection	PIC Signal	Connection
E	ATT-Clock	U6 "C"-TP2	RC0	H4-1
F	ATT-Data	U6 "D"-TP3	RC6	H4-2
G	ATT-Out Enable	U6 "E"-TP1	RC7	H4-3
H	PWR_Level	U6 "PL"-TP4	AN0/RA0	H2-1

Apply 12 V power with current limiting set to 300 ma. If the firmware is running normally, there should be a signal at the MMIC output. Some expected approximate current readings are:

CONDITION	FULL SIGNAL	NO SIGNAL
Normal (LED slow)	260-280 ma.	230 – 240 ma.
Bootloader (LED fast)	270 ma.	230 ma.
PIC stalled (LED off)	240 ma.	220 ma.

A no signal condition can occur if the board is connected to a computer with USB, but the tuning software is not running, or is running but the frequency has not yet been changed. Once the four jumpers above are installed and power is again applied, the PIC firmware will set U6 to 0 dB attenuation at power-up, with no USB connection and therefore no control by PC software.

Temporarily terminate H10 with a spare 52.3 ohm resistor, make the measurements below, and then measure again without the termination. You should see approximate 14.1 MHz RF levels as follows:

LOCATION	52.3 OHM TERMINATION	NO TERMINATION
L1/C26 (DDS out)	230 mV p-p	--
L3/C32, (LPF out, U5 in)	270 mV p-p	--
U5 pin 3/C34 (MMIC out)	1.2 V p-p	--
H10 (RF out)	810 mV p-p (~ +1 dBm)	1.9 V p-p

U7 detects the output of U6 and puts out a DC voltage corresponding to the log of its amplitude. With U6 set to 0 dB attenuation in the current test setup, you should see an output voltage of about 1.88 VDC at the "PL" (power level) test point on the board. The range of this voltage will go from the 1.88VDC at 0 dB attenuation, to about 1.08VDC with 31.5 dB of attenuation, once PC software is controlling the attenuation.

You can test the attenuator without a USB connection. After a power up or reset, attenuation is set to 0 dB. Every other time you press Program button, attenuation in dB will double from .5 to 1 to 2, to 4 dB, etc.

With R12 at 115 ohms, the second-harmonic of 14 MHz is down about 46 dB. An additional 8 dB of second-harmonic reduction can be obtained by putting a second 115 ohm resistor in parallel. That improvement comes at the cost of an additional 40 ma. of power supply current.

Congratulations, the signal generator section of the DDS board is now completed and working.

### ***Quadrature Clock Generator Section***

The components in this section, shown on page 5 of the schematic, are only needed if you will use the board as a receiver, or as a quadrature clock generator for a SoftRock or other external QSD or QSE.

√	No.	Part	Value	Size	S	Notes
	110	U16	LE33CZ 3.3 V regulator	TO-92	T	
	111	C69	.1 uF	0805	T-U16	
	112	C70	2.2 uF, Tantalum	0805	T-U16	Observe polarity
	113	Jump *	TP5 to TP6 +12V	Wire	B	Install jumper
	114	U10	65LVDS390	16-SOIC	T	Band marks pin 1
	115	U11	74AUC74	QFN-14	T	
	116	T2	TC1-1T+		T	Or Coilcraft WBC1-1TLB
	117	R45	1.21 K	0805	T-U10	
	118	R46	3.00 K	0805	T-U10	
	119	R47	5.76 K	0805	B-U10	
	120	R59	2.0 K	0805	B-T2	
	121	R60	1.21 K	0805	T-T2	
	122	C88* *	.01 uF	0805	T-T2	
	123	C54	.1 uF	0805	B-U10	
	124	C55	.1 uF	0805	B-U11	

\* This jumper goes from a pad marked 12V near C69 to another pad marked 12V near H17. The silk screen shows this jumper.

\*\* Ground side of C88 attaches directly to ground plane. There is no separate pad.

Resistance on the 3.3 V supply line, measured on pin 16 of U10, or pin 14 of U11 should be more than 2K??? ohms.

Install a jumper temporarily between pins 1 and 2 of H18 to select a /2 clock division.

Apply 12 volt power to the board, with current limit set to 300 ma. Verify 3.3 V output from U16. The current drain should increase to about 210 ma. from its previously measured value, assuming the firmware is running.

On pins 1 and 3 of H18 (no headers are mounted yet) you should see the opposite phases of a square wave with a frequency of 7.055??? MHz.

On pins 1 and 2 of H13 and pins 1 and 2 of H14, you should see four phases of the 7.055 MHz clock, starting at 0, 90, 180 and 270 degrees. These clock pulses should have a duty cycle of 50%.

### ***QSD***

Install the components in this section only if you will use the board as a receiver, making use of the QSD on the board. Components from sheets 5 and 3 are shown. As well as the QSD and audio preamp, parts installed include an IC that disables clock input to the QSD during transmitting and another that modifies the quadrature clock pulse lengths.

√	No.	Part	Value	Size	S	Notes
	125	U21	78L09	SOT-89	T	No silkscreen designation
	126	C66	.33 uF	0805	T	
	127	C67	.1 uF	0805	T	

After installing these parts, apply 12 V power and check that the output voltage of U21 is about +9 VDC. This regulator supplies the following parts:

√	No.	Part	Value	Size	S	Notes
	128	U20	74AUC02	QFN-14	T	
	129	U12	74AUC08	QFN-14	T	Pin 1 near the U12 legend
	130	U13	74AUC2G66	8-SSOP	T	
	131	U14	74AUC2G66	8-SSOP	T	White band towards R19
	132	U15	MC3307B	8-SOIC	T	Or LT6231CS8 with beveled edge facing R24
	133	R17	10 K	0805	T-T1	
	134	R18	10 K	0805	T-T1	
	135	R19	10 ohms	0805	T-U14	
	136	R20	10 ohms	0805	T-U15	
	137	R22	10 K	0805	B-U12	
	138	R23	10 K	0805	B-U12	
	139	R24	4.99 K	0805	T-U15	
	140	R25	4.99 K	0805	T-U15	
	141	R33	3.3 K	0805	T-U16	
	142	R34	5.6 K	0805	B-U10	
	143	R35	10 ohms	0805	T-T1	
	144	R36	10 ohms	0805	T-T1	
	145	R58	0 ohms	0805	T-U15	
	146	C56	47 uF, tantalum	1206	T-T1	Observe polarity-banded side closer to T1
	147	C61	47 uF, tantalum	1206	T-U15	Observe polarity- banded side closer to U15
	148	C64	47 uF, tantalum	1206	T-U10	Observe polarity-banded side away from U10
	149	C71	47 uF, tantalum	1206	B-U15	Observe polarity-banded side closer to R22
	150	C62	10 uF	0805	T-H16	
	151	C65	10 uF	0805	T-H16	
	152	C66	.33 uF	0805	T-U21	
	153	C70	2.2 uF Tantalum	0805	T-U16	Polarity: the + (line) side goes to the long lead going down the board edge.
	154	C57	.1 uF	0805	T-T1	
	155	C58	.1 uF	0805	T-U13	
	156	C59	.1 uF	0805	B-U14	
	157	C60	.1 uF	0805	T-U10	
	158	C63	.1 uF	0805	T-U10	
	159	C67	.1 uF	0805	T-U21	
	160	C69	.1 uF	0805	T-U16	
	161	C72	.1 uF	0805	B-U15	
	162	C84	.1 uF	0805	B-U14	
	163	T1	ADT4-6T		T	Or Coilcraft WBC4-1TLB

Resistance from the 3.3 V supply on the positive side of C70 and pin 14 of U12 should be about 2K ohms.

Apply 12 volt power with current limiting set to 350 ma. There should be about 100 ma. more current drain compared with the previous measurement. U16 runs hot. Assuming you have built all the sections you intend to, this will be the total current drawn by your board. The BPF draws only about 1 ma. more.

There should be about 1.65 V bias on pins 1 and 5 of both U13 and U14.

Observe the quadrature clock signals on the output of U20 on pin 4, 1, 10 and 13. The T/R input can be left open for this test. You should observe the same clock signals you observed in the previous stage on headers H13 and H14.

Observe the modified quadrature clock signals on TP16 – TP19. The board legend for these test points are marked as 0, 90, 180, and 270. You should see square waves like the previous measurement, but clock pulses are shortened to 90 degrees duration, corresponding to the four lower patterns on schematic sheet 3.

With nothing connected to the antenna header connections, on the outputs of U15A and U15B, you should see no measureable noise, and a DC voltage of about 4.5 V.

Congratulations, you have completed assembly of the board and can proceed to final testing! You have not fallen by the wayside...

### ***Transmitter Jumpers***

If you will be using the firmware in conjunction with a transmitter and want to take advantage of transmit/receive switching, you need to install additional jumpers:

<b>Jumper No.</b>	<b>FROM PAGE</b>		<b>TO PAGE</b>	
	<b>TX Signal</b>	<b>Connection</b>	<b>PIC Signal</b>	<b>Connection</b>
I	T/R	T/R pad near U?	???	???
J	TX Input		B4	Pin 25
K	TX Output		B3	Pin 24

### ***Remaining Headers***

If your board has passed all testing to this point, you can install all headers not previously installed. If your board has problems and you need to do further testing or replace parts, some headers might interfere with this work. The section Connections to Headers below gives information on what should be connected to each header.

√	No.	Part	Value	Size	S	Notes
	164	H11	2 pin header	2 x 0.1"	T	
	165	H15	2 pin header	2 x 0.1"	T	
	166	H12	3 pin header	3 x 0.1"	T	
	167	H13	3 pin header	3 x 0.1"	T	
	168	H14	3 pin header	3 x 0.1"	T	
	169	H16	3 pin header	3 x 0.1"	T	
	170	H8	4 pin header	4 x 0.1"	T	
	171	H18	4 pin header	4 x 0.1"	T	
	172	H19	4 pin header	4 x 0.1"	T	
	173	H2	7 pin header	7 x 0.1"	T	

## ***Final Testing***

Current drain should be under 200 ma when PIC is not running before the bootloader is installed and under 300 ma with bootloader running (red LED flashing).

## **Receiver Test**

You can test the receive capabilities of the board with no USB connection to a PC, provided all necessary jumpers are in place and the group firmware is running. The firmware sets the default receive center frequency to 7.055 Mhz. Connect H16 to shielded audio cables to your sound card.

With nothing connected to the antenna, run your favorite SDR receiver software. The Software section lists some available SDR packages. Tell the software that it is interfaced to a SoftRock with a center frequency of 7.055 MHz. You should hear and see the receiver's noise floor, which will be determined by the quality of the sound card you are using. It will usually be -80 to -130 dBm. Depending on your sound card, there may be some mild roll off at the edges of the passband. You may see a noise peak at the center frequency. This is usually caused by the sound card or a ground loop, not the 995x card. As you tune up and down the 40 meter band using the tuning control within the SDR package, you may see some spurs but you should see no huge birdies or other aberrations. You cannot expect excellent performance until shielding has been applied to the 995x board in a later step???

Next, connect a 50 ohm mini coax to H15, and the other end to a 40 meter antenna or other weak signal source. The 995x board, like all QSD-based receiver designs, is sensitive to input impedance. Any filters and/or antennas connected directly to the RF input to the 995x board should have a 50-ohm impedance. Running a 40 meter transmitter with a tone generator or CW carrier in the same room with no direct connection to the board can often provide sufficient signal. You should be able to find the signal within the receiver's panadaptor display, and after setting an appropriate filter, hear the signal.

You should now be able to use the system as a receiver. Bear in mind that an antenna without the BPF or other preselector may overload the QSD receiver, if there are strong out of band

signals present. Nearby AM, FM, or television broadcast stations are a prime source of out-of-band signals. The onboard QSD uses very fast components, and can successfully receive signals at many multiples of the intended receive frequency, into the VHF region, unless some method of limiting those signals is employed. At this point you will be receiving images as well as the intended signals.

Next, use the calibration procedure for your SDR software to attempt to remove image responses. Image calibration needs to be done either with an antenna connected and receiving a single strong carrier signal, such as at night with 40 meter shortwave broadcasters there, or by feeding in a fairly strong signal generator. If the calibration process does not succeed, one possible cause is major phase or amplitude imbalance between the I and Q outputs of U15, or one of the two signal is not reaching the sound card.

Next, complete the software installation and configuration process described in the Software section below, run the PC tuning applet, and connect a USB cable between the 995x board and the host PC. The software and the firmware should recognize one another, and you should be able to tune, using the tuning software, with the band set to 40 meters. Bear in mind that as you tune with the tuning software, the 7.055 MHz frequency calibration in the SDR will not match the DDS frequency. If you have not installed the QSD section, you can skip the receiver tests, but you should still be able to tune the quadrature clock using the PC software.

At this point you can any BPF you may have built by connecting it between the antenna and the H15. If you are using the companion Brainerd BPF, as you tune to different bands in the PC software, the PIC should automatically switch filters. You can expect to see an insertion loss of about 5 to 7 dB due to the filters, with a little more loss possible at the filter band edges. See the BPF assembly and test instructions for additional filter tests.

### **Attenuator Test**

Conduct this test only if you have populated the signal generator section of the board.

With the PC tuning applet controlling the 995x board, reinstall the temporary 52.3 ohm termination on H10, and measure the RF output on H10. With the attenuator control set to 0 dB, you should see about 810 mV p-p. As you very slowly increase the attenuation, the signal level should smoothly drop to less than 1 mV p-p. If the response is not smooth, i.e., if there are discontinuities, then there may be an installation problem with U6. Check for shorted or open pins. Another possible problem area is the jumpers between U6 and the PIC.

### **Install Shielding, Enclose**

After you have tested the clock, receiver/QSD and signal generator sections, you need to install shielding. First measure the resistance from the 5V and 12V supply points to ground, as reference, and note the current drawn by the board. [Details of shielding construction here.] Now measure the 5V and 12V supply resistances to make sure they haven't changed. Make sure to apply power only with the current limit set a little above your measured drain., in case you shorted a component with the shielding. Apply power and confirm receiver, local oscillator and/or signal generator functions as appropriate. [Are any spurs or harmonics expected to

disappear or noise floor reduction???) If nothing goes wrong, you are ready to enclose and package the board(s), and repeat the final tests. [Any layout suggestions to avoid interfering radiation, noise avoidance, etc.???)

### ***Jumpers***

1. A jumper is required from the 5V output of U19 to the 5V pad between U3 and U18.
2. If you plan to use the signal generator/oscillator capabilities provided by MMIC U5, programmable attenuator U6 and the logarithmic amplifier U7, which are not needed in receiver applications then you must install a power jumper from the 12V input to the 12V pin near R12 at the top of the board. Software-dependent jumpers to the PIC are also need. See the Software section below.
3. Jumpers that connect PIC signals to the DDS and to the programmable attenuator circuit are software dependant and are covered in the Software section below.
4. A connection for T/R switching appears near U16. A plus five volt signal to the T/R input disables the QSD thereby disabling the receiver during transmit; open or ground enables it. It can also be used by PIC and PC software to control T/R, under control of an SDR receiver application for instance, using a software specific jumper described below.
5. The QSD circuit requires a jumper from the 12V pad just above H17 to the 12V pad at the top of U16.
6. A 0 ohm resistor connects the V- supply pin of U15, the low noise amplifier to ground. If a higher dynamic range is needed, the 0 ohm resistor can be omitted, and V- applied from a -9 VDC regulated supply. Such a supply must have no measureable noise or RFI – additional regulation or filtering may be needed if it originates in a switching power supply.
7. You can supply 5V power to the companion BPF board using test points marked +5 and GND just above the 5 V regulator chip. (Pilot production and prototype boards lacked these pads—but you can still connect directly to the regulator pins.)

### ***Connections to Headers, Cables***

- H7: Connect 12 volt DC regulated, RFI free power, capable of supplying 350 ma. for both the 995x board and the BPF filter board, which draws very little.
- H12: An external DDS clock oscillator may be connected to H12, provided corresponding parts changes have been made.
- H11: Disable the internal oscillator by putting a jumper across pins 1 and 2 if you use an external oscillator.

- H1: Jumper pins 2 and 3 to supply 5 VDC power to the PIC from the USB port, or pins 1 and 2 for external power. Always use one jumper or the other. [Does running the PIC from USB causes spurs???)
- H2: Connects to PIC Port A pins, several of which are used by the DDS. Interconnections between the PIC and DDS depend on the PIC firmware in use. See tables of necessary jumper connections in the Software section below or documents for your firmware.
- H4: Connects to PIC Port B and C pins. The use of these pins also depends on the PIC firmware in use. See Software section below or documents for your firmware.
- H15 Connect a 50 ohm mini coax cable to the ANT input on H15. The other end can connect to H5 on the BPF board, or to a band filter of your own choice. The 995x board, like all QSD-based receiver designs, is sensitive to input impedance. Any filters and/or antennas connected directly to the RF input to the 995x board should have a 50-ohm impedance. If your antenna does not present a 50 ohm load at the operating frequency, it is more important to use an antenna tuner for impedance matching.
- H16 Connect two separate shielded audio cables to header H16 and the other ends to whatever audio connectors you have chosen to mate with your sound card cable.
- H3: This header is used for loading software into the PIC. If the PIC did not have the bootloader previously installed, you can connect it to an in-circuit programmer with a specially built cable. See bootloader section below.
- H10: This output provides a clean sine wave output that has been through the programmable attenuator. It can be connected to an accurate frequency counter to calibrate the system, although you could also calibrate by receiving WWV or another frequency standard. It can also be used as a programmable signal generator output (once software is developed for this application) or as a VFO for a transmitter, for example. It is not needed except possibly during calibration when the board is used only as a receiver. You may want to connect H10 to a BNC or other RF connector for these purposes. Use 50 ohm mini coax. It is also possible to solder an end launch SMA connector at the top of the board at H10. See photo at [http://wb6dhw.com/995x\\_front.jpg](http://wb6dhw.com/995x_front.jpg).
- H18: Jumper pins 1 and 2 to divide the I/Q by 2, or pins 2 and 3 to divide by 4. Dividing by 2 allows higher frequency operation but potentially is not as accurate due to the 180 degrees developed by the transformer. Dividing by 4 will produce the most accurate phase difference since both flip flops are clocked from the same source. The VFO Multiplier setting in the tuning software should correspond to the jumper setting.
- H13, 14: These provide four phases of 50% duty cycle quadrature I/Q clock for driving a future Quadrature Sampling Exciter (QSE). It is possible to devise an interface to the

SoftRock RXTXs' QSE that would use these signals.

- H5: All DDS programming pins are brought to H5 for jumpering to pins on the PIC. Jumpers are firmware dependent. See Software section below.
- H8: Connects to the input and output pins on the DDS's high speed comparator circuit. This header is not used in current receiver applications. The comparator is designed to be able to square the sine wave output of the DDS. The LVDS receiver on the 995x board now performs this function.
- H19: H19 can be used for an optional externally mounted USB connector if you cannot easily mount the board in a cabinet with the onboard connector exposed to the outside. It can also be used for debugging the USB signals.
- H6, H9, H17:  
These designations are no longer used.

## **ASSEMBLING THE BPF BOARD**

The BPF board is easier to assemble than the 995x board because there are only two chips and their pin spacing is less fine than those on the 995x board, and there are fewer parts overall. If you want a refresher SMD warm-up exercise before tackling the 995x board, the BPF board is the place to start.

There are no known errors or problem with the pilot production BPF boards.  
[Dave has determined that it's better to rearrange the filters to put the 23 MHz filter closer to the switches. Waiting for permanent change in board legend, schematic and firmware.]

### ***PCB Components***

We will be leaving the headers off the board until the end, because they could interfere with the process of mounting nearby parts.

The TDK inductors and capacitors used on the board do not have their values printed on them, so you must use extreme care in placing the correct value parts. It can be difficult to pinpoint a improperly placed part after the BPF is assembled, so we have a way of incrementally testing some of our work as we proceed. To make sure we get all the inductors in the right places we will follow a procedure of placing the four series inductors in a filter strip, confirming some resistance measurements, using Table 1 below, and only then proceeding to mount the grounded inductors. The AADE L/C Meter IIB is a handy low cost LC meter useful in case the inductors get separated from their containers before putting on the board.

Many of the inductors used have DC resistance less than one ohm and may be hard to measure with your multimeter. Many multimeters, however, can measure resistances is the tenths of ohms, which may be sufficient to tell if you have the right inductor in the right place. At these sub-ohm resistance levels, the connection of the test leads to the meter and to the

part under test can easily disturb measurements. Once the grounded inductors installed in a particular filter, you can no longer measure its resistance but need to know the resistance between two nodes of the network as given in Table 2 below.

To assemble the first 2.1 MHz filter strip:

1. Mount the four series inductors for this strip, skipping the grounded inductors.

√	No.	Part	Value	Size	S	Notes
	1	L2	3.9 uH	1008	T	Skip L1, L4 & L7 for now
	2	L3	22 uH	1008	T	
	3	L5	2.2 uH	1008	T	
	4	L6	8.2 uH	1008	T	

2. Measure the total resistance across the chain, from the input of L2 to the output of L6. The measurement should be within 7% of the value in the Total field for the 2.0 MHz filter in Table 1 below.
3. Confirm the resistance across each of the four mounted inductors, as shown in Table 1 below. Each unique inductance value used in the BPF luckily has a unique resistance. However, this method of testing will not catch all placement errors because some of the differences in resistance values used are less than .1 ohms, which probably makes them impossible to distinguish if your ohmmeter only has .1 ohm accuracy. But it can catch a high proportion of placement errors. (To make more accurate readings, you could create your own ohmmeter by passing 100 ma through any inductor, or any series of inductors using a bench power supply, and measuring millivolts of voltage drop. The lowest rated maximum current of any of the inductors is 125 ma.)
4. TDK does not specify a tolerance in the resistance values, only the inductance tolerance, but it is probably close to the inductance tolerance, which is + or – 5%. If any resistance measurement is more than say 7% off, you may have a problem and if so, you should correct it before proceeding.
5. Mount the grounded inductors:

√	No.	Part	Value	Size	S	Notes
	5	L1	1.5 uH	1008	T	
	6	L5	1.0 uH	1008	T	
	7	L7	1.5 uH	1008	T	

6. Measure the node resistances for the 2.1 MHz filter in Table 2 below. If any node's resistance is substantially off, measure the adjacent node resistances. The inductor

between two nodes whose resistance is the farthest off is likely to have an incorrect value, or be shorted or open. Again, if resistance tolerances of the inductors are possibly near 7%, then node tolerances are probably similar.

7. Mount the capacitors for this filter strip:

√	No.	Part	Value	Size	S	Notes
	8	C1	.0047	0805	T	
	9	C2	270 pF	0805	T	
	10	C3	.0018	0805	T	
	11	C4	.0068	0805	T	
	12	C5	820 pF	0805	T	
	13	C6	.0027	0805	T	
	14	C7	.0047	0805	T	

Unfortunately, most multimeters cannot be used to confirm accurately the placement of capacitors the way we have been confirming inductor placements.

- Repeat the node resistance measurements to make sure you have not shorted out any of the capacitors.
- This 2.0 MHz filter is finished. Repeat steps 1 – 14 for each of the other five filters using components L8 – L42 and C8 – C42. All these components are on the top of the board. Capacitors are in 0805 or 0603 packages.

The next assembly steps follow the tables below.

<p align="center"><b>Table 1</b>  <b>Band Pass Filter TDK Inductor Resistance (ohms)</b></p>								
Band	La Input	Lb	Lc	Ld	Le	Lf	Lg Output	Total (4)
<b>2.1 MHz</b> L1-7	1.3	2.1	5.5	1.1	1.55	3.05	1.3	12.2
<b>3.5 MHz</b> L8-14	.85	1.7	3.8	.75	1.3	2.3	.85	9.1
<b>5.9 MHz</b> L15-21	.65	1.45	3.05	.55	1.1	1.7	.65	7.3
<b>9.3MHz</b> L22-28	.55	1.1	2.3	.5	.68	1.45	.8	5.53
<b>14.7 MHz</b> L29-35	.4	.75	1.9	.3	.6	1.1	.4	4.35
<b>24.7 MHz</b> L36-42	.3	.65	1.45	.75	.5	.85	.3	3.45

La through Lg represent the seven inductors used in each filter starting with the input and ending with the output. For example, in the 2 MHz filter, La = L1, Lb = L2 ... Lg = L7, etc. As a visual aid, the grounded inductors are shown in the bottoms of the table's shaded cells, the series inductors in the tops of cells. The Total (4) column gives the total resistance across the four series inductors before any of the grounded inductors have been mounted.

<b>Table 2 Band Pass Filter TDK Node Resistance</b>					
<b>Band</b>	<b>Node</b>				
	<b>La-Lb Input</b>	<b>Lb-Lc</b>	<b>Lc-Ld-Le</b>	<b>Le-Lf</b>	<b>Lf-Lg Output</b>
<b>2.11 MHz L1-7</b>	1.13	2.22	0.84	1.60	0.83
<b>3.51 MHz L8-14</b>	0.75	1.62	0.58	1.21	0.58
<b>5.89 MHz L15-21</b>	0.57	1.32	0.43	0.95	0.43
<b>9.27 MHz L22-28</b>	0.48	1.03	0.39	0.75	0.38
<b>14.73 MHz L29-35</b>	0.35	0.75	0.24	0.55	0.24
<b>24.71 MHz L36-42</b>	0.27	0.64	0.42	0.55	0.44

Next, install the remaining (non filter strip) components:

√	No.	Part	Value	Size	S	Notes
	15	U1	FST3251	16-SSOP	T	
	16	U2	FST3251	16-SSOP	T	
	17	T1	ADT1-1		T	
	18	C43- C54	.1	0805	T	
	19	C55	.1	0805	B	
	20	C56	.1	0805	B	
	21	C57	.1	0805	T	
	22	C58	10 uF	0805	B	
	23	C59	10 uF	0805	B	
	24	L43	100 uH	1210	T	
	25	L44	100 uH	1210	B	
	26	R1	3.3K	0805	B	
	27	R2	3.3K	0805	B	
	28	R3	10K	0805	B	
	29	R4	10K	0805	B	
	30	R5	10K	0805	B	
	31	H10	2 pin header	.1 "	T	
	32	H11	2 pins	.1 "	T	
	33	H15	2 pins	.1 "	T	
	34	H17	2 pins	.1 "	T	
	35	H1	3 pins		T	
	36	H12	3 pins		T	
	37	H13	3 pins		T	
	38	H14	3 pins		T	
	39	H16	3 pins		T	
	40	H8	4 pins		T	
	41	H18	4 pins		T	
	42	H19	4 pins		T	
	43	H2	7 pins		T	
	44	H4	2 rows of 6 pins		T	

### ***Headers and Cables***

- H6: Use small diameter 50 ohm coax to connect H6, the RF input, to the RF connector of your choice.
- H5: Connect this RF output to the ANT input on H15, on the 995x board using small 50 ohm coax.
- H2: Supply 5 volt power to the BPF board through H2. You can find +5 and GND pads on the 995x board near the 5 volt regulator.

H3/8: You can connect a custom designed filter of your own design between H8 and H3, using 50 ohm mini coax, or short wires if to a daughtercard. Alternatively, you can connect a coax jumper between the two headers to create a BPF bypass position, automatically switched into position [if the PC software supports this???

H7/4: Use for a second custom filter.

### ***Testing and Troubleshooting the BPF***

Before powering up the board, make sure the resistance from the +5 V supply input to ground is at least ??? ohms.

When you first apply power to the BPF board, you can check to make sure that the board draws only about 0.75 ma. If you apply +5 VDC to the board, but leave the band switching inputs on H1 disconnected connected, the highest frequency filter, 24.71 MHz, will be active. There will be a low resistance, less than 15 ohms, between pins 5 and 12 of both U1 and U2. All other switches will be open, at high impedance. [Can this be measured with an ohmmeter???probably need a voltmeter shunted by a resistor(1 to 10K?) to check the voltage on the output. The DC voltage would mess up an ohmeter. Granted there is a DC bias at one end, but the other sides of the switches are open circuits for DC.]

You can inject an RF frequency into H6, and see the same signal, very slightly attenuated, on the output of a switch. You can also inject RF into the output header, H5, and see signal on the pins of U2. You should see no signal or highly attenuated signals (due to stray capacitive coupling and a high impedance scope probe, for instance) on the inactive pins.

Pulling combinations of signals S0, S1 and S2 low with jumpers or a temporary DIP switch can be used to test the various bands as follows:

<b>S2</b>	<b>S1</b>	<b>S0</b>	<b>U1, U2 Pin</b>	<b>Band</b>
<b>L</b>	<b>L</b>	<b>L</b>	<b>4</b>	<b>2.1 MHz</b>
L	L	H	3	3.5 MHz
L	H	L	2	5.9 MHz
L	H	H	1	H3 to H8
H	L	L	15	H7 to H4
H	L	H	14	9.3 MHz
H	H	L	13	14.7 MHz
H	H	H	12	24.7 MHz

Each of the filters has a pass band that overlaps the others slightly. Insertion losses of the filters are around 4 - 7 dB, using the TDK inductors in the main BOM, not the Coilcraft parts, which will give a little less loss.

You can sweep a signal generator through each of the filters, using a signal below 4 volts peak to peak to confirm that there are no major anomalies in the responses, using the input and output headers, while using jumpers to select bands. Alternatively, you could use a transmitter on low power, run into a dummy load, and use an attenuator set to about 4 V peak to peak output, and connect it to the BPF, making sure the transmitter power output stays constant as you change frequency.

The characteristics of one sample BPF board made with TDK inductors were measured and the results are summarized in the table below. The test was conducted on the bench and not in an enclosure, which might have affected the results. Your measurements may differ by several percent, due to the combined component tolerance variations of the sample tested and your board. All the filters except the 23.2 MHz filter slope evenly away from a central passband peak to the -6 dB points. The 23.2 filter has two peaks and a slight dip in the center.

<b>Summary Measurement of BPF filters (TDK Inductors)</b>							
<b>Nominal Center Freq. MHz*</b>	<b>Actual Center Freq. MHz</b>	<b>Min. Loss Freq. MHz</b>	<b>Insertion Loss dB</b>	<b>Lower 6 B point MHz</b>	<b>Upper 6 dB point MHz</b>	<b>Lower 30dB Point MHz</b>	<b>Upper 30 dB Point MHz</b>
<b>2.1</b>	2.11	2.09	6.28	1.43	2.79	1.24	3.28
<b>3.5</b>	3.51	3.37	4.91	2.60	4.42	2.30	4.91
<b>5.9</b>	5.91	5.89	6.98	4.19	6.62	3.67	7.53
<b>9.3</b>	9.27	9.28	6.89	6.53	12.00	5.66	13.92
<b>14.7</b>	14.73	14.01	4.77	10.76	18.87	9.39	21.92
<b>24.7</b>	24.71	25.73	4.83	17.66	31.75	15.60	38.60

\*Nominal center frequency is the value given on the schematic. Actual center frequency is the measured midpoint between the two 6 db points. Min. Loss Freq. is the frequency where attenuation is least, this attenuation is defined as the Insertion Loss. 6 dB and 30 dB attenuation points are measured relative to the minimum loss attenuation: measured attenuation at these points, relative to the input, will be the figures in the table plus the insertion loss. This table summarizes detailed measurements available at: <http://wb6dhw.com/BPF.html>.

If you don't have test equipment to measure the filter outputs, you can monitor them, once your full receiver is up and running, by using the S-Meter in the SDR receiver software of your choice. PowerSDR's meter can be set to dB for better accuracy. Rocky and KGKSDR currently only have conventional S-meters and so can only do a rough job.

## **INSTALLING and USING FIRMWARE and SOFTWARE**

### ***Introduction***

The 995x project is an open source system – it can be used with any firmware and PC software you want, including software for applications beyond receiving. So far, those who have written software are making source code freely available. Different versions of PIC

firmware can be readily downloaded into a PC and then into the 995x board from the PC. There are several existing SDR software packages that receive I/Q signals from previously designed hardware such as the FlexRadio products and the SoftRock series. They should work with the 995x in receive mode, as described further below, although they are not fully integrated at this time.

This section focuses on the installation and use of the bootloader, PC drivers and some of the first firmware and PC software that has been developed for the board, but much of the information will apply to other software. Monitor the DDS\_CONTROLLER board for announcements of new compatible software and look in the *Files* section in the folder “Current Release” and other folders.

There are several pieces of necessary PIC firmware and PC software associated with the 995x board when used as a receiver:

1. Bootloader software permanently loaded into the PIC
2. A Windows driver from Microchip that provides low level USB communications
3. Another Windows driver, usbser.sys, supplied with Windows, provides RS232C emulation
4. PIC firmware written for the 995x that is downloaded from the PC to the PIC to handling tuning, band switching and other tasks
5. A Microchip utility, PDFUSB.EXE, to do the download described above
6. Free PC SDR of your choice that implements receiver functions, from various sources, and written for previous hardware from other sources such as the SoftRock series. See Exploring PC SDR Software below.
7. A small PC application in the PC to control DDS frequency and other parameters and communicate with the PIC over USB, written for the 995x. It expects to see the Microchip driver and the RS232C emulation driver. This little application may become optional if support is integrated into your favorite SDR package

Reid, W0CNN, Tom, W2TER, and Terry, WB4JFI, and others have collaborated on PIC firmware and corresponding PC software, with bits of code from still other engineers, that is currently called the group software, for want of a better name. It is kept at

[http://groups.yahoo.com/group/dds\\_controller/files/Current%20Software%20Release](http://groups.yahoo.com/group/dds_controller/files/Current%20Software%20Release)

The procedure for installing and using other such software is similar to that described in the rest of this section.

### ***System Requirements***

You must have a Windows PC to run the PC software that allows firmware to be downloaded to the 995x, the MicroChip drivers, and most SDR receiver software also requires Windows. Testing so far has been on Windows XP. In one test, the MicroChip downloader application failed to run under Windows Vista. If you are successful using the software under Windows Vista or other versions of Windows, please report your success on the DDS\_CONTROLLER

board. The PC needs to have an available USB 2.0 port, or a USB 1.0 high speed port. The USB interface on the board has a maximum speed of "Full Speed," not "Hi Speed."

To process the I/Q signals that the 995x board generates, you need a stereo sound card. The best performance is obtained with a professional quality sound card with 24 bit stereo "recording" input at a 192 KHz sampling rate. Rates of 96 kHz or even 48 kHz will also work but will result in corresponding restriction on the portion of a ham band that can be visualized in the SDR program's panadaptor display. It is important that the sound card have a high signal to noise ratio, as this will determine the ultimate dynamic range of the receiver. Other specifications also matter. Almost any card or even motherboard sound can be used to confirm that the 995x is working, but good performance requires a better one. Cards have been tested for SDR use by FlexRadio and ARRL.

The requirements of the SDR software you choose must also be taken into account in choosing the host PC because real time graphics and signal processing used in the packages can use a lot of processing resources. A newer, high power machine is preferable, especially if you expect other applications to run concurrently with the SDR software.

### ***Download Bootloader***

A bootloader program from Spark Fun Electronics must be installed in the PIC's flash memory before any other firmware will work. You may be able to find someone on the DDS\_CONTROLLER board who will program it into your PIC. If not, you will need to download it and install it using a programmer device, such as the MicroChip PICKit 2.

After the bootloader is installed, when you power up the 995x board, or press the Reset switch, the bootloader gets control of the PIC. It checks to see if the Program switch is pressed. If so, it runs its own USB code that enumerates the 995x board as a PIC18F2550 Family Device under Other Devices in the Windows Device Manager, which communicates with the PC via Microchip's custom driver. You then run a MicroChip application on the PC to erase the flash memory on your 995x board used for firmware (except for the bootloader itself) read it and write it. This permits you to quickly and easily put new firmware on your 995x without ever using a programmer again.

Download the Bootloader from this page:

<http://greta.dhs.org/UBW/index.html>

under the link

Bootloader Hex File for Spark Fun UBW board (uses 20 MHz resonator instead of 4MHz)

You need to place the Bootloader in a known folder. Its filename will be

FW\_B\_20.hex

## ***Install MicroChip Software***

You also need MicroChip software to aid you in downloading firmware, once the Bootloader is installed. To download the standard Microchip package, go to

[http://www.microchip.com/stellent/groups/picmicro\\_sg/documents/devicedoc/en021826.zip](http://www.microchip.com/stellent/groups/picmicro_sg/documents/devicedoc/en021826.zip)

Despite the filename, you need to use the Spark Fun Bootloader you downloaded above, not the MicroChip Bootloader that is included in the MicroChip package. The MicroChip Bootloader has been found to be not compatible because it assumes a 4 MHz PIC clock, but we use 20 MHz.

When you run `USB Bootloader Setup.EXE`, it will ask for a license agreement confirmation and then create a folder `C:\MCHPFSUSB`. Use only this default folder. It then asks if you want to keep backup files of any previous version, which is a good idea. Then it installs over 12 megabytes of files in the new folder. See the installed readme file for a description of directory contents. The Documents section of the readme describes documentation available elsewhere, not an installed folder. The filename of the setup program is a misnomer – the package installs many files, not just the bootloader, including necessary Windows drivers, a little firmware download applet, a demo program, and lots of source code.

## ***Install Bootloader***

Installing the bootloader can be done in certain types of programmers before the PIC is soldered to the board, but you will need an adaptor that fits the PIC's 28-SOIC package and the programmer. If you don't have a programmer and the necessary skills, you may be able to find someone on the DDS\_CONTROLLER board who is willing to program unmounted chips for you.

An alternative is to program in the bootloader while the chip is in place on the board, using a cable between H3 and your programmer. Sheet 7 of the schematic shows which PIC signals connect to H3. Documentation for your programmer and the PIC part will allow you to construct a cable if needed.

Some users of the 995x board have been using the low cost PICKit 2 programmer (<http://pickit2.com>.) The programming connector is on one end of the device and the whole programmer will plug into the first 6 pins of the ICSP connector on the 995x board. Pin 7 is left open. The other end of the programmer has a jack for a mini USB cable. It also will allow you to debug chips that have the debugger version of the bootloader built in. No cable needs to be fabricated for this particular programmer, and it is not necessary to leave off C1 and C2 before programming. Appendix A explains how to use the PICKit 2 to install the 995x's bootloader.

If you use another in-circuit programmer (ICSP) to program the bootloader in place, we recommended earlier that you leave off C1 (10uF) and C2 (.1 uF) across the VDD supply. They seem to interfere with some programmers' control of VDD. After the bootloader is

loaded, you will not need to use the programmer again and can mount C1 and C2. These parts are on the bottom of the board near SW2.

If you have successfully programmed in the bootloader, when you next apply power, or press the Reset switch, the red LED should begin flashing.

### ***Run the Bootloader the First Time to Install PC Drivers***

With the 995x board powered from 12 V, or the PIC alone powered through USB via a jumper on H1 between pins 2 and 3. [is it safe to power the whole board with 12 V at this point in the hardware assembly process???] and plugged into an available PC USB port with a cable,

1. Press and hold the Program switch on the 995x board.
2. Press and release the Reset switch on the 995x board.
3. Release the Program switch.

This will start the bootloader running. The red LED may not be flashing. If this is the first time you've run the 995x in bootloader mode with your PC attached, Windows will play the "found USB device" music and ask you to install a new device. Point the dialog box to the place where the INF file is located:

```
C:\MCHPFSUSB\pc\MCHPUSB Driver\Release\mchpusb.inf
```

Click through the dialog boxes to install using the INF file. The exact sequence of installation depends upon your version of Windows. The driver will be installed. Ignore any Windows warnings about verification of the driver. You can confirm success of device installation by looking for PIC18F2550 Family Device immediately after installing the driver or UBW Firmware C vx.y, after downloading firmware and Resetting or powering up and down under Other Devices in the Windows Device Manager. Note that Device Manager will report that no driver has been installed, even though there is one. Driver installation is not complete until usbser.sys has been installed. Once the driver is installed, the red LED should begin flashing rapidly.

Now disconnect and reconnect the USB cable, or press Reset. Windows should find the existing device driver and say it found UBW Firmware C vx.Y, and ask to install another driver. Now install from this INF file

```
C:\MCHPFSUSB\fw\Cdc\inf\win2k_winxp\MCHPCDC.INF
```

This process will install `usbser.sys`, an RS-232C emulation driver that the Windows tuning applet will expect to see. This driver is included with Windows but is only installed by applications that need it. After successful installation of `usbser.sys`, Device Manager will show the board as Unsupported Device. Look at the Ports in Device Manager for the COM ports. When you list the properties of the COM ports on the General tab, and the board is

running and connected, one of them should show MicroChip as the Manufacturer. Remember which COM port this is, as you will need it to configure the tuning software.

You should only have to do this new device procedure in this section once, unless your system becomes corrupted or you want new versions of the driver files to be installed.

### ***Download PIC Firmware into the PIC***

Use the procedure in this section to load initial PIC firmware and later to reload new versions. You must have previously loaded the bootloader firmware and the Microchip downloader Windows application and PC drivers as described in previous sections.

PIC firmware for receiver applications, currently called the “group software”, for want of a better name, is kept at

[http://groups.yahoo.com/group/dds\\_controller/files/Current%20Software%20Release](http://groups.yahoo.com/group/dds_controller/files/Current%20Software%20Release)

Some of the other sections of this manual assume that you are using this firmware.

1. Download the current release to the PC host you will be using and make note of the folder containing the HEX file for the firmware.
2. Apply 12 volt power to the 995x board, or set the board to power the PIC from the USB port by [temporarily???] jumpering pins 2 and 3 on H1.
3. Connect the 995x to an available PC USB port using a USB cable.
4. Press and hold the Program switch on the 995x board.
5. Press and release the Reset switch on the 995x board.
6. Release the Program switch. This sequence activates the bootloader.
7. Locate on your PC the HEX file for the firmware you want to download.
8. Run the PC bootloader Application:

`C:\MCHPFSUSB\Pc\Pdfsub\PDFSUSB.exe`

(Actually, it doesn't matter if you start `PDFSUSB.exe` first or put your board into bootloader mode first.)

9. Once running, select the `PICDEM FS USB 0 (boot)` selection from the `Select PICDEM FS USB Board` pulldown menu, which connects the bootloader PC app with the PIC bootloader code.

10. Click `Load HEX File` and navigate to where the new firmware HEX file is that you want to download. All other buttons should be grayed out.
11. Click `Program Device`. When You will see a window saying `Message - Erasing and Programming Flash` and the red LED on the 995x board should flash a little slower, indicating that programming is in process.
12. After a delay of up to 10 second, you will see the message `Message - Programming Flash completed`, and the 995x red LED will again flash more quickly.
13. Close the PICDEM FS USB Windows program.
14. Unplug the 995x board the USB cable at either end. Windows should play the “USB device disconnected music.”
15. Plug the USB cable back in. Windows should play the “USB device connected” music, but this time there should be no messages about a new device. In certain versions the red LED on the 995x board should begin flashing about once per second, indicating that the newly downloaded firmware is running. The current release does not flash the LED, but you can confirm it is running if the red LED toggles on and off as you press the `Program` button repeatedly.
16. Congratulations – you’re done!

This all sounds complicated, but once you do it a couple times it becomes fast. The same procedure described in this subsection can be used to download a new version of the group software or software for another purpose. Make sure to use jumpers on the 995x board consistent with the firmware version you will be using.

### ***Testing the Firmware***

After the bootloader and firmware are loaded, and without a USB connection to a PC, you can apply power to the 995 board. It will detect that there is no USB connection and set a default DDS frequency of 7.055??? MHz and set the corresponding 9.27 MHz filter on the BPF board???. [In current firmware one extra band position is assumed shorted and the other open. Has this been enhanced yet to permit flexible band switching??? Check before releasing this manual.] Some versions of the group firmware start the red LED flashing about once per second, but not the current production release.

There is a test function built into the firmware. If you press the `Program` push button, the red LED should turn on, and then off with a second button press. Also, every other button press the attenuation should double, i.e. .5 dB, 1 dB, 2 dB, 4 dB, etc. You should be able to confirm this by looking at the sine wave output on H10 on a scope.

You should be able to trace the I/Q clock circuitry running at this frequency and receive antenna signals around this center frequency with compatible I/Q receiver software. If you

don't yet have a band pass filter installed, you can experiment with receiving using an antenna tuner, or RF preamp for front end selectivity. The input of the 995x board expects to see a 50 ohm impedance.

[The current version of the group firmware does not actually set the two off-board band pass filter positions that the board supports. Instead, when you \_\_\_\_\_???, the firmware assumes that jumpers have been placed between H8 and H3???, bypassing the entire BPF. When you \_\_\_\_\_???, the firmware assumes there is an open circuit between H7 and H4???)

### ***Install and Use the USB VFO Controller Software***

The current release version of the DDS frequency tuning software for Windows is kept in the Files section of the DDS\_CONTROLLER board, in the *Current Software Release* folder. Currently, only a Windows version for this firmware is available. Install the software using the `setup.exe` file. It will first verify that system requirements are met before installing. You can ignore the Windows security warning, since we are not a registered publisher. There are no choices to make during installation.

Make sure the board is running, and then run the program, which shows up in the Programs menu as USB VFO Controller. Set the USB pull down menu to the COM port you are using to communicate with the 995x board. If the 995x is already plugged into the PC USB port at the time you start the application, the port will be listed in the pull down menu. You can find the port by going to `My Computer | System Information | Hardware | Device Manager | Communications Ports` and looking for the newly assigned port whose properties show MicroChip as the Manufacturer. Alternatively, you can start the PC application and then plug in the 995x USB cable. The application will recognize the newly assigned port and automatically select and open it for use.???)

Use the Open Port radio button to open the currently selected port before attempting to tune . It is not necessary to use the Close Port radio button before exiting the application, unless you have other uses for the port.

Use `Config | PIC Device | AD995x` command to select the 995x as the DDS device. On the popup box that appears for this device, choose as `DDS Clock` the frequency of the SMD or other oscillator you are using as a clock for the 995x and a clock multiplier setting. The clock multiplier must be set corresponding to the low pass filter values (LPF) you installed on the output of the DDS (L1 – L3, C26 – C32.) Multiplying the DDS Clock input frequency times the multiplier, gives the internal DDS clock frequency. This value must be at or under the frequency of the low pass filter. For example, if you installed a 400 MHz. LPF and a 125 MHz oscillator, choose the 3x multiplier, since  $125 \text{ MHz} \times 3 = 375 \text{ MHz}$ . Other common settings are:  $125 \text{ MHz} \times 4 = 500 \text{ MHz}$ , and  $125 \text{ MHz} \times 5 = 625 \text{ MHz}$  (for 700 MHz filter) Multiplier values above 5 have been found not to lock on the proper clock frequency in at least some 995x parts.

The settings you have made so far are not saved in the current version of the software. You will need to set them again each time you run the application. Improvements are planned in this area.

Next set the VFO multiplier radio button to 2X, if you have set the clock divider to 2X on H18 on the 995x board, and to 4X if you used the 4X jumper position. The 995x does not support a 1X multiplier. (If you want to tune higher than 54 MHz, you can set the software to 4X but use the 2X jumper. The DDS output frequency will then be twice the frequency you set and you can then tune up to 108 MHz) Note that the VFO multiplier is different than the DDS PLL internal clock multiplier, which is set by firmware. This setting will remain the same when you exit and restart the application.

The DDS frequency will be close to accurate without calibration, but you can use `Config | Calibrate` to attain more accuracy. If you have included the signal generator circuitry on the board and installed the necessary jumpers as described above, you can measure the sine wave output on H10 using an accurate frequency counter. [Is the default attenuation 0 dB??? What is the voltage level of the expected sine signal???] You can also connect a counter to the square wave quadrature outputs on H18. With the 995x board settled at normal room temperature, drag the Calibrate slider left and right, until the output is exactly 10.000000 MHz on the counter. You can fine tune in one hertz increments using the left and right cursor control keys.

If you do not have access to a counter, once you have the 995x board operating as a receiver, you may be able to receive WWV on 10 MHz and calibrate using their very accurate signal. Set your SDR receiver software to CW and zero beat on the WWV carrier using the Calibrate slider. Make sure your audio output makes it possible to hear low frequencies.

You may want to recalibrate every a few months for a year or two, to compensate for the aging of the new crystal in the oscillator. The need for this will depend on the type of oscillator you used. It is not necessary to recalibrate otherwise unless you change the DDS clock oscillator circuit, or plan to operate outdoors in subzero temperatures in the Arctic (or Antarctic) on a regular basis, or in Death Valley, California.

You can use the Coverage pull down menu to select the band you wish to tune, or you can select General and then use the entire tuning range from 500 Hz to 54 MHz. [Is there automatic band switching for the BPF yet???] when used with General???] Note however, that if you are using the companion BPF without any of your own add-on filters, your useful tuning range will be 1.5 – 30 MHz. If a filter for 6 meters has been designed and connected between H8 and H3, [or is it expected between H3 and H7, Terry???], the 6M band setting will be used. If you have built filters for other bands, you will need to use the General band setting???. [There is a way planned to edit a configuration file to define filter bandpass frequencies that will need to be described here once implemented.]

When you select a specific band, your tuning range is limited to that band. However, the Precise Frequency control will allow you to tune one kHz higher than the ham band limit. The tuning command will not currently prevent you from transmitting outside a ham band, if you are

using the 995x board as a transmit VFO. Neither will it prevent you from using lower sideband when tuned to the lowest end of the band.

Coarse tuning is done with the Frequency slider. Click on the arrow buttons at either end of the scroll bar to tune in 1 kHz increments. Click inside the bar itself but outside the slider to tune by 10 kHz increments, or by 1 MHz increments in General band only.

Fine tuning over a 1 kHz range uses the Precise Frequency slider. While Precise Frequency is being used and the locus of control is on the slider, you can also tune in 1 kHz increments using the arrow buttons on either side of the Frequency slider and in 1 Hz increments with the up and down or the left and right arrow keys on your keyboard. The PageUp and PageDown keys will tune in 10 Hz increments.

The 995x board will retain its last set frequency, even when the tuning software is not running, and even when the 995x board is powered down or the Reset button is pressed. The Hex Command field shows the hexadecimal frequency tuning byte string that will be programmed into the DDS chip by your choice of frequency. If the 995x board is reset or momentarily loses power, do not attempt further tuning. Shut down the software, then press Reset or cycle the power and start up the software again.

The Attenuator slider control only works if you have installed the signal generator section of the 995x board. It provides from 0 to 31.5 dB of attenuation of the signal level of the RF sine wave output that appears on H10. It does not affect receiver functions. However, to avoid interference with the QSD, it is best to leave it set at 31.5, maximum attenuation, when not in use. The current version of the PC software does not read U7's output (the logarithmic detector) to adjust the RF output to a known level – this is a planned enhancement.

Both the firmware and PC software are in active development, and not all features of the most recent version may have been described here.

## **EXPLORING PC SDR SOFTWARE**

The 995x board puts out typical I and Q audio signals that are compatible with much SDR software. There are several different free SDR software packages for Windows PCs that accept I/Q input through sound cards and are compatible with the 995x's I/Q signals. [Who has actually tried them and can report hints, tips and problems connected with the 995x???] Below is a description of four such packages.

**PowerSDR** This is very full featured transceiver software developed using open source collaboration. It was originally designed for FlexRadio's groundbreaking SDR transceivers developed by Gerald Youngblood, K6SDR. The software is distributed by FlexRadio ([www.flex-radio.com](http://www.flex-radio.com)), but do not try to use the software from the FlexRadio site; instead use a version adapted for the SoftRock. An adaptation of PowerSDR version 1.9.0.6 by Guido, PE1NZZ, made in March 2007 is available at

[http://sourceforge.net/project/showfiles.php?group\\_id=172695](http://sourceforge.net/project/showfiles.php?group_id=172695).

Guido has written instructions for using the software with the SoftRock, available at [www.zs6buj.com/files/PowerSDR-sr40\\_Setup.pdf](http://www.zs6buj.com/files/PowerSDR-sr40_Setup.pdf) , and many of his points apply to the 995x. Get the extensive manual for the PowerSDR software directly from the FlexRadio website. You may be able to learn of other adaptations of PowerSDR for SoftRock on the DDS\_CONTROLLER or FlexRadio boards. There are a number of people collaborating continuously on improving this software and a feature request and bug database are on the FlexRadio website. The software contains an S-meter that can be configured to read in dB, a help in testing band pass filters.

**Rocky** This is freeware written by Alex, VE3NEA, [ve3nea@dxatlas.com](mailto:ve3nea@dxatlas.com). It was written for the SoftRock but it should work with the 995x. It has a full screen spectral panadapter display that is exciting to use and a sophisticated automated background method for eliminating image responses. Download from here: <http://www.dxatlas.com/rocky>.

**KGKSDR** This is also freeware originally used with the SoftRock, written by Duncan, K0KGK. It features automatic calibration, auto notch and noise reduction among many other features. Learn about and download the software from <http://www.m0kgk.co.uk/sdr/index.php> and discuss it at <http://groups.yahoo.com/group/kgksdr> .

**SDRadio** A nice, free receive-only package from Alberto I2PHD is available at <http://www.sdradio.eu/sdradio>. It was designed for use with the SoftRock but can also accommodate simple mixers that do not produce I/Q outputs, with the tunable bandwidth reduced by half.

There may be other equally good packages in existence. This list is meant to be illustrative, not exhaustive.

All of these packages contain controls for frequency tuning, but currently you must use the separate software widget to tune the 995x, since these packages have not yet been customized to interface with the 995x. You can however, usually use the 995x widget to set a round center frequency such as 7.200 MHz, and then use the tuning controls within the SDR package to move around within the limits of the sound card's bandwidth, which will be either 48 kHz, 96 kHz, or 192 kHz if you have a high end card. In this case the frequency you are receiving will be the base frequency set by the 995x plus or minus an offset from the center IF frequency as set within the SDR package.

Some of the SDR programs let you set the center frequency to a round number to facilitate offset calculation. To facilitate frequency calculation in PowerSDR or Rocky, you can set the center frequency to 0, so that the frequency display shows plus and minus offsets that can be added directly to the 995x frequency. In Rocky, go to View | Settings | DSP. Under the Local Oscillator section, click on single-band, and set the frequency to 0. In

PowerSDR, go to Setup | General | Radio Model and set it to Soft Rock and also set Center Frequency MHz to 0.

The 995x board generates sharp spurs when it is tuned to specific frequencies. These are apparently due to undesired interactions between various sections of the board. You can avoid these sharp spurs by tuning a couple kilohertz away from the problematic frequency and using the tuning controls within the SDR software to select your operating frequency. Operating with a /4 rather than a /2 clock divider can also improve performance somewhat. If you devise other methods of avoiding spurs, such as shielding, please report your success on the DDS\_CONTROLLER board.

Three of the packages described above can transmit as well as receive, when used with transceiver hardware such as the SoftRock RXTX series. The 995x board does not yet have a companion exciter, so the transmit functions of your software will not work. You may be able to interface another transmitter, if you have the necessary engineering skills. The board puts out a VFO sine wave that you may be able to use as the transmit as well as receive VFO and there is a header supplying the I/Q clock signals necessary for an external quadrature sampling exciter (QSE). A 5V CMOS T/R signal on TP7 on sheet 5 will disable the receiver by stopping the clock to the QSD. Dave Brainerd, designer of the 995x board, is designing a companion QSE daughtercard. Check his website for progress.

## **SIMPLIFIED THEORY OF OPERATION**

The simple description below gives an overview of the circuitry to help you appreciate, test and troubleshoot the circuit. It avoids math, but skips over many details and focuses primarily on the receiver application.

### ***995x Board***

#### **Quadrature Sampling Detector (QSD)**

The heart of the 995x system is on sheet 3 of the schematic. The antenna will connect to the companion BPF board or another preselection filter (see band pass filter documentation) and the output of the filter to the ANT header on the 995x board, shown on the left of sheet 3. Note that there has been no RF amplification here or on the BPF and will be none in this circuit. Transformer T1 splits the signal into two phases 180 degrees apart. Each phase goes into one side of the QSD detector, U13 and U14. A DC bias of 1.65 volts is supplied through the secondary of T1 by R18, R18, C56 and C57.

The detector is a commutator, a set of four sequenced switches. At any time, one and only one switch is closed. A different switch closes at 0, 90, 180 and 270 degrees of a clock cycle and it stays closed for 90 degrees of the cycle. The four phase clock waveforms are shown on sheet 3 as I\*Q, /I\*Q, I\*/Q and /I\*/Q. While a switch is closed it charges or discharges a capacitor, C60 or C63, integrating the instantaneous amplitude of the RF input signal during the sampling period. The capacitor then holds the charge for another portion of the clock cycle. This sample and hold property is what makes this a sampling detector.

One capacitor, C60, is connected to the 0 and 180 phase switches, and the other, C63, to the 90 and 270 phase switches. The 0/180 capacitor accumulates the I or in-phase signal that will make its way to one of the two inputs to the sound card. The 90/270 capacitor, C63, accumulates the Q or quadrature signal which makes its way to the other sound card input. The four phase quadrature clock is running at a frequency close to the frequency that we want to receive, so the RF is converted directly to an audio or baseband signal.

The I and Q signals contain both amplitude and phase information about the signal, so they can form the raw input for nearly any type of demodulation process, CW, AM, FM, PM, SSB, and the digital modes. Actual demodulation is performed in DSP software on the PC sound card, so that new software can be added easily for new modes, providing a good platform for experimentation. Because the DSP can be easily programmed for new or improved types of demodulation, filtering and other processing, we have a software defined radio.

The I/Q signals contain information about a band segment that will be seen as limited in bandwidth to 44, 96 or 192 kHz, depending on your sound card, a segment that can be viewed on a panadapter spectrum display in your SDR software. DSP and PC software provides fine tuning within the band segment, image rejection and variable band pass filtering as well as demodulation, so you can have a 100 Hz CW filter, a 3 KHz SSB filter and many other choices.

An image is contained in the signals reaching the DSP, but luckily its phase information is different than the signals of interest, so that DSP software can remove the image, provided you have carefully calibrated the SDR software. A more detailed and rigorous discussion of *Taylor* detectors and typical DSP algorithms such as are used in the Power SDR software you can use with this circuit is contained in Gerald Youngblood's articles cited earlier.

The I and Q signals from C60 and C63 go through R19, R20 and DC blocking capacitors C61 and C64, R22, R23, C71 and C72, which bias the amplifier to one half the supply voltage. I and Q are amplified in U15, a very low noise amplifier, and sent out to the sound card via a header. A jumper connects the V- supply pin of U15 to ground. If a higher desired dynamic range is needed, the jumper can be omitted, and V- applied from a -9 VDC regulated supply.

## **DDS and Quadrature Clock Generator**

Next, let's look at how the clock is generated, on sheet 6, then sheet 5, then back to sheet 3. The key component on sheet 5 is U2, the DDS chip. This powerful and flexible chip is described in literature you can find on Analog Devices website. It takes a clock signal of 400, 500 or perhaps even 700 MHz, and puts out a stepwise sine wave and its inverse on pins IOU and its inverted counterpart, at frequencies up to about 170, 212 or 300 MHz, depending on your choice of clock. The DAC used to generate the stepwise sine wave have a resolution of 14 bits, up from 12 in predecessor parts that had some spur problems, increasing the spurious free dynamic range by about 12 db to >80 db. R9 determines the DAC maximum output current. The 3.92K value sets the peak current to 10 Ma. R8 and C10 are the loop filter for the clock PLL, if used.

The clock signal for U2 can be generated in three optional ways, as shown on sheet 2. An external clock can be brought in on H2, or CMOS or LVDS oscillators can be used with parts changes noted on the sheet 2. The method shown in the schematic and BOM uses an integrated SMD oscillator, U9. The chip puts out the clock and an inverted clock signal on CLK and /CLK which go fairly directly into the two clock inputs of the DDS. A signal brought to H1 can turn the clock on and off.

Turning back to sheet 6, the frequency of the DDS, U2, is controlled by lines from the PIC, not shown on the schematic. These lines control an internal phase-locked loop (PLL) clock multiplier that can be set to multiply the external clock signal up to several hundred MHz to operate the internal phase accumulator and DAC.

The sine and inverted sine outputs of the DDS are combined in transformer T3. The primary center tap provides the voltage for the output DAC. The two 24.9 ohm resistors on the primary, R10 and R11, provide the proper impedance matching for the 50 ohm low pass filter following the transformer.

Because the DAC outputs contain quantization noise and alias responses, a low pass filter of several poles, C26 – C32 and L1 – L3, smoothes the sine wave and eliminates aliases. Three different sets of values for this filter are given in the bill of materials, depending on whether a 400, 500 or 700 MHz internal clock is used. The clock frequency, as explained earlier is the frequency of the external clock times the PLL multiplier as set by the PIC firmware. A different internal clock frequency would require a custom-designed filter. The chosen values provide a cut-off frequency of approximately 40% of the clock frequency. At the LPF output, a splitter consisting of R40, R37 and R39 directs the signal  $I_{sine}$  to both to the quadrature clock generator circuit, and on to MMIC amplifier U5.

The filtered  $I_{sine}$  VFO signal from sheet 6 goes to the quadrature clock generator on sheet 5. The signal is divided into in phase and inverted phase signals in T2 and then turned into two square waves by the differential line receivers in U10, 180 degrees out of phase. A resistor divider on the center tap of T2 provides bias for the line receivers' inputs. The signals from the line receivers clock two type-D flip flops, U11A and U11B. The output clock frequency is divided by two if pins 1 and 2 on H18 are jumpered or by four if pins 2 and 3 are jumpered. Applying the same signal to both clock inputs produces output at  $\frac{1}{4}$  the inputs. Applying a signal to the second clock that is 180 degrees out of phase with the first clock produces output at  $\frac{1}{2}$  the inputs. Dividing by two allows the maximum clock frequency but dividing by four gives higher phase accuracy and therefore a better spurious free dynamic range in receiver applications. Their outputs contain four clock phases we will need for the QSD, but at 50% duty cycle.

These signals go to headers H13 and H14 for routing to a planned companion exciter board. A transmit/receive switching signal T/R that would be received from such an exciter or other transmitter controls the four gates in quad 2-input NOR gate, U20, to shut down the clock signals to the QSD while transmitting, thereby disabling the receive function. A plus five volt signal to the T/R input disables the QSD; open or ground enables it.

The four clock phases we have so far are all symmetrical square waves, with rising edges starting every 90 degrees, but the pulses last for 180 degrees. We need 90 degree pulses to run the QSD as we saw earlier, so the clocks are ANDed in the four gates in U12 on sheet 3 in various combinations, to generate the four phase 90 degree pulse clocks the QSD requires, as shown in the waveforms.

## **RF Output Level Control**

From MMIC U5 the in-phase filtered and amplified sine wave from the DDS flows to U6, a programmable attenuator with a range of 0 to 31.5 db attenuation in .5 db steps with +- .4 db accuracy. The three programming lines for U6, OE, clock and data must be connected to three PIC Port C lines – these connections are not shown on the schematic, because some builders may decide not to connect them and to use the free PIC Port C bits for another purpose. The firmware you use will have an associated table of the necessary jumpers.

The output of the DDS DAC varies somewhat over its wide range and the attenuator can be used to provide a constant or otherwise precisely controlled output. The attenuated sine wave is made available off the board on H10. It also goes to U7, a logarithmic amplifier that detects the RF signal amplitude and puts out a voltage proportional to the RF signal level in decibels, shown as the signal PWR\_Level on the schematic, at the rate of 24 mV per db. This permits the output of the programmable attenuator to be measured accurately, and supplied through signal PWR\_Level from test point “PL” and used by PIC in a feedback loop to control the attenuator.

Jumpers that connect PWR\_Level to an A/D converter within the PIC, and connections between the Clock, Enable, and Data on the attenuator and the PIC are not shown on the schematic because they are dependent on the firmware used. The firmware will have an associated jumper table.

## **PIC USB Microcontroller**

That's the basic receiver. The only thing remaining is a way to change bands and VFO frequency and connect to a PC. This is done by the PIC microcontroller, U1 on sheet 7. The controller circuit was patterned after the Universal Bit Whacker (see <http://greta.dhs.org/UBW>.) The PIC includes a clock oscillator that uses 20 MHz clock crystal X1. It also includes a full speed USB 2.0 interface to your PC that is connected directly to USB mini-B connector J1. To operate, the PIC must first have been programmed with the bootloader program as described above. Programming is done via connecting an external programmer via a special cable to In-Circuit Serial Programming (ICSP) connector, H3.

On power up the PIC runs the firmware that has been loaded into it. The particular software described above starts with various initialization tasks, including setting modes in the DDS and then waits for a frequency tuning or other command sent from the PC over the USB interface. When the user selects a new frequency, the PC program calculates a new frequency tuning command and sends it over the USB link to the PIC which, in turn forwards it to the DDS. The PIC program also knows what band it is operating on or receives band switching instructions

from the PC and sends appropriate band switching commands to the companion band pass filter board over the signals available on the PIC headers.

If you design your own preselector filter(s), you could also use the band switching signals. If the PIC firmware crashes or gets stuck in a loop, the reset button, SW1, can be used. This is a hardware reset which will restart the firmware from the beginning as well as resetting all the I/O pins to their default states; it is also used when loading firmware. The Program pushbutton, SW2 is used during firmware loading and the firmware can give it additional functions. The red LED, D2 is connected to bit 1 of PIC Port C and is thereby under control of the PIC software. Depending on the PIC software, the LED could flash to indicate the software is running correctly, but future PIC software could use it as a programmable indicator, like the “check engine” light on the dashboard of some modern cars. LED D1 illuminates when power is applied.

### **Other Circuits**

The PIC operates on 5 volt TTL levels. To interface to 3.3 V parts, there are several voltage dividers for several signals shown on sheet 7. There are also several voltage regulators on the board for use with ICs that require different supply voltages. U3 supplies 3.3V to Dvdd\_IO. U4 supplies 1.8V to Avdd. U18 supplies 1.8V to Dvdd.

Many components have not been described above because this is intended to be a brief, simplified overview.

### ***Band Pass Filter Board***

The band pass filter board contains six receive filters that cover the 1.5 to 30 MHz range in six bands, switched by three signals normally driven by the PIC on the 995x board. Input and output impedances are both 50 ohms.

Each of the six filters is a seven pole elliptical filter of similar design and similar layout on the board, but different component values. The one page schematic shows the center frequency of each of the filters. The bandwidth of each filter overlaps the others a little to facilitate full spectrum coverage. Dave Brainerd provides filter design files and measurements made on the filters here: <http://wb6dhw.com/BPF.html>. These files may help in designing other compatible filters.

The appropriate filter is selected by a coordinated pair of 8-channel switches, U1 and U2, one on the input and one on the output. The switches are designed for use as multiplexer/demultiplexers, but the circuit uses them as simple analog switches, and they have low loss and low noise. The three bits of control signals from H1, namely S0, S1 and S2 have eight possible combinations for eight possible bands, and the same bits control both switches in tandem. These three lines are pulled high by R3, R4 and R5. Only 6 bands are used – two are spares for expansion. A table describing which filter is selected by which bits is in the BPF section above. If nothing is connected to H1, the 24.7 MHz filter is selected.

A bias voltage of 2.5 volts is created by R1 and R2. It is applied to switch U2 by RF choke L43, and to U1 through the secondary of T1.

The input signal from an antenna on H1 is transformer-coupled to the all the input switches and six of the eight outputs are connection to the inputs of filters. The inverse is true at the output of the filters, with the final output appearing on H5.

There are eight switch positions but only six filters. The extra two switch positions are brought out to four headers, so that one extra filter can be connected between H8 and H3, and another between H7 and H4. This way a 6 meter filter or low frequency filters could be added, or other filters with special characteristics substituted. Alternatively a jumper can be used to bypass the BPF. Note that if the 995x board is used at frequencies higher than 30 MHz, it may be necessary to include an RF amplifier to get really good performance. The group's firmware can select any of the eight filters, if the appropriate command is sent to it from PC software.

The 5 volt power for the pair of switches, supplied on H2, is RFI filtered by a pi network to make sure there are no spurious signals received in this sensitive circuit, which may operate in the microvolt range.

## **THE DEVELOPERS**

Five men are primarily responsible for the development of the 995x system and its documentation. Dave designed the hardware. Reid tested the hardware and worked on software. Terry and Tom developed firmware and software. Rick asked stupid questions, wrote this manual and is probably responsible for the mistakes in it. Other contributors include Cash Olsen who provided DDS initialization code, and Tom Hall who wrote asynchronous receive code in the PC software. You can reach several of these developers or offer to contribute your skills to this project by posting to [http://groups.yahoo.com/group/dds\\_controller](http://groups.yahoo.com/group/dds_controller).

### ***David Brainerd***

Retired electronic engineer. Worked for the Navy Civil Service for 30 years, testing and evaluating air to air missiles. He took an early retirement offer during a downsizing at China Lake and moved with the XYL to Idaho to build a house on 10 acres. Nine years later they are still working on the house but have lived in it for the last 6 years. David also took flying lessons in 1979, but, never completed the license as he got married and the XYL didn't like flying. David has been a ham (WB6DHW) since 1963 and got his extra class license in 1976. Since retiring, David has built some test equipment and designed some small projects. He is currently trying to make a small business out of designing ham projects to pay for his toys!

### ***Terry Fox***

Retired television broadcast engineer and corporate engineering manager for 23 television stations, with over 30 years broadcast experience. Amateur operator WB4JFI with 40 years experience "fiddling with the hardware". Co-founder and original president of Metrovision, the

first licensed amateur television repeater. Past-president of, and continuing contributor to AMRAD, the Amateur Radio Research and Development Corporation, based in Washington DC. One of the developers of AX.25, and author of the AX.25 packet protocol document. Other past areas of interest include Linux, LF, spread spectrum, HF transceiver design, DDS, and DSP as related to amateur radio. Presently living in Charleston, SC with my wife Judy, and am involved with SDR hardware design, PIC programming, and learning about Windows/Linux user-interface programming. Private pilot since 2005.

### ***Reid Bishop***

Senior Network Systems Engineer for large Telecommunications company for 15 years. Have spent some 25 years tinkering in all sorts of electronic fields as a hobby, including PC hardware design, Remote Control components for the model aircraft & helicopter fields, and various RF components. Amateur Radio operator W0CNN, licensed relatively short time since 2003. Experienced systems design in everything from the smallest 2K microcontroller, all the way up to IBM mainframe systems. Colorado native which has contributed to my favorite hobbies of extreme four-wheeling with my purpose built Jeep Wrangler, RC flying, camping and fishing in extreme remote locations in the Rocky Mtn. West, and teaching challenging survival skills to my children.

### ***Tom Rowley***

Currently CEO of a public VOIP telephone company; founder of a dozen technology companies in areas of voice processing, internet security, computer hardware and software equipment. Author of two patents - voice processing and cryptography. Experimenter in robotics - founder of the Robot Sumo competition in the US - and ham radio electronics and antennas. Founded this group in Jan 2007 to experiment with USB-controlled HAM devices. Also a pilot (Single Engine Land) but I also build and fly gyrocopters.

### ***Rick Meyer***

Retired senior product manager for personal computer products and high tech consultant. Was technical publications manager for an early personal computer company. Ran small company manufacturing multimedia projection equipment. Author of two patents, a facsimile testing system and a simple sensor circuit. Artist responsible for a one-man touring multimedia show that was exhibited at the San Francisco Museum of Modern art and several other museums and colleges. Held ham license K1LZY as a teenager and recently took up radio again as KI6LQL with an interest in SDR. Recently designed a magnetic loop antenna that eventually should handle 1.5 KW on 80 and 40 meters. First Tenor in the globe-trotting Cabrillo Symphonic Chorus. Lives above the beach near the surfing town of Santa Cruz, California with wife, small cat and occasional insects.

## **APPENDIX A: INSTALLING BOOTLOADER WITH MICROCHIP PICKIT2**

These steps will first install the Microchip PICKit2 support software, then program a bootloader into the PIC chip on the 995x board. After this, the PIC DDS control program can be programmed into the PIC using the bootloader.

A new PIC chip usually has the program area completely blank. If looked at with a PICKit2, or other tool, it will read back as all 0xFF. The PIC18F2455/2550/4550 family allows different sections of the erasable/reprogrammable program memory to be independently erased and programmed. Many PIC users have taken advantage of this feature. Microchip has created a “bootloader”, which can take over control of the PIC chip and reprogram the larger remainder of program memory. The bootloader will reside in program memory 0x0000 to 0x07FF, it takes up about 2k of program space.

Once the bootloader is installed, it will look at PIC pin RC2 after PIC reset. If RC2 is low, the bootloader takes over control of the PIC, and the PIC enters “bootloader” mode. This mode is determined by the red LED flashing rapidly. Bootloader mode is normally entered by:

1. Pushing and holding the PIC “PROGRAM” pushbutton/switch
2. Pushing and releasing the PIC “RESET” pushbutton/switch
3. Releasing the “PROGRAM” pushbutton/switch

### ***Installing the PickIt 2 Software***

(to be done by Terry)

(don't forget to place the bootloader .hex file in a proper location)

### ***Installing the Bootloader into the PIC***

The next step will program the PIC with a bootloader. This normally only need to be done once. Once the bootloader is in the PIC, it will enable the user to update the actual PIC DDS control at any time with only a USB connection.

1. On the Brainerd DDS board, temporarily move the H1 jumper to pins 2&3. The PIC will now receive power from the USB connector.
2. Plug the PICKit2 USB connector into an available computer USB port. Windows should recognize the PICKit2 and play the normal “found USB device” music.
3. Start the PICKit2 software, by clicking on the PICKit2 icon on the Windows desktop, or selecting it with the Start/All Programs/Microchip/PICKit2 menu.
4. In the PICKit2 window information window (upper-middle of screen), a message saying “PICKit 2 found and connected” should show up.
5. in the top menu, click on the “Device Family” tab, then select PIC18F.
6. Plug the DDS board into the PICKit2 ICSP connector, being careful to observe polarity. Pin 1 on the DDS board (closest to H2) should line-up with the PICKit2 arrow. You only need six pins on the DDS board when using the PICKit2.

7. Just under the Microchip name and red “Meatball” trademark in the PICKit2 software, you will find the VDD PICKit2 groupbox. Make sure 5.0 is selected for voltage, then click the “ON” checkbox. That will turn power on to the DDS board from the PICKit2. The amber PICKit2 LED, and the DDS board green LED should both come on after a few seconds.
8. Click on the “Blank check” button. After a few seconds, a message should appear. Normally it will be “Configuration is not blank”. This just means some internal configuration bits are still set, they are normally set at the manufacturer. If the device is NOT blank, you can click on the “Erase” button to clear out the PIC program memory.
9. Click on the “Auto Import & Write Device” button.
10. Select the bootloader HEX file to program into the PIC program memory. If using the Spark Fun bootloader, the file name is FW\_B\_20.HEX.
11. The PICKit2 software will now program the bootloader into the PIC program memory. This will take about 5 seconds or so.
12. When it’s done programming, a message saying “Programming successful, waiting for file update” will be displayed. Click the “Auto Import...” button again to exit program mode. It will then say that it exited Auto Import...” mode.
13. To double-check proper programming, click on the “verify” button. The software will read the PIC for about 5 seconds, then it should say “Verification Successful”.
14. Click on the VDD PICKit2 checkbox to turn OFF the VDD to the DDS board. The amber PICKit2 LED and the green LED on the DDS board should go out.
15. Unplug the DDS board from the PICKit2.
16. Close the PICKit2 software on the computer.
17. Unplug the PICKit2 hardware from the computer USB port.
18. To verify the bootloader is working, plug the DDS board into an available USB port on a computer. If the Windows Microchip USB driver has not yet been installed on the computer, the board may not be recognized by windows. For this test, that doesn’t matter. While the DDS board is plugged into the computer, push and hold the DDS “PROGRAM” switch (SW2). Then push and release the DDS RESET (SW1) button. Finally, release the PROGRAM button. After a second or two, the red LED on the DDS board should start flashing quickly, indicating the DDS board is in bootloader mode.
19. Unplug the DDS board from the computer. Move the H1 jumper back to pins 1&2. The PIC power will now come from the board’s 5V regulator.