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A Microwave Transverter Controller

Flexible, sophisticated control of multiple transverters from a single point.

For many years I have been interested in VHF, UHF and microwave experimentation, and this controller is one of the outcomes of these interests. The unit is self-contained, and collects many of the functions needed to operate and control a microwave station on many bands from 1296 MHz upwards. Incorporated in the design is a formalized and relatively simple interface to connect the controller to any high or low power microwave transverter (such as 1296 MHz, 10 GHz, 24 GHz and higher frequencies), so that full multi-band station control can be made from a single unit, and band selection can be made also, with direct readout of the transmit frequency and/or receive frequency. Up to four different transverters can be connected at any one time to the controller.

A conventional way to proceed to make a microwave station, especially for portable operating, is to use a small commercial transceiver (such as an ICOM IC-706 or similar) at 144 MHz, then use it to drive the microwave transverter(s). For fixed station use a similar approach is used, but with perhaps a higher quality transceiver being employed. A collection of additional control and sequencing units, interfaces to computers, frequency stabilizing units and so on are employed to complete the station. As most commercial transceivers with acceptable performance are generally able to deliver up to 100 W PEP SSB, the electrical efficiency is somewhat low at the level needed for a typical transverter, which is generally 1 to 10 mW, or maybe up to a few watts if the transverter has an appropriate attenuator either built in or used externally.

Figure 1 shows the block diagram of the OH2GAQ Microwave Transverter Controller, while Figures 2, 3 and 4 show photos of the finished prototype. The overall unit size is 260 mm wide × 95 mm high × 315 mm deep, which is quite comparable to a typical table-top transceiver. The power supply for the controller is 12 V and 26 V dc.

The functions included in the Controller are:

- Microphone preamp and simple audio clipping, level control and band-pass filtering.
- Transformer-isolated input from a computer-generated analog audio signal.
- Switch selected audio source.
- Upper/Lower SSB generation (at 9 MHz, filter type) and up-conversion to an output signal in the range of 28 to 30 MHz.
- A direct digital frequency synthesizer to generate the LO for up-conversion of the 9 MHz SSB signal. The DDS reference is derived from a 10 MHz Rubidium reference oscillator incorporated in the unit.
- A Rubidium reference oscillator and low-noise distribution amplifier, including a 50 Ω line driver to route the reference to a bank of remotely located microwave transverters.
- A 144 MHz transverter, with 10 mW output, using the same reference oscillator at 116 MHz as the DDS to ensure adequate frequency stability. The transmit side is supplied with 28 MHz SSB; the receive side is fed to an external receiver.
- An ICOM compatible CI/V output to allow control of a typical ICOM receiver such as the R75, used by the author as a tuneable IF at 28 MHz.
- Muting control for the receiver during transmit.
- Receiver audio conditioning and an isolation transformer to allow connection of the received signal to a computer analog audio interface.
- Control input from a computer to allow computer-controlled receive/transmit switching when this mode is selected.
- A microprocessor-based control module to control and monitor all of the above, and with interfaces to a computer (using either R232 or USB-2) and up to four microwave transverters. The transverter interface has a transmit signal output, a transmitter health signal input and a couple of analog monitoring signal inputs as well.

Implementation Details

The main functional blocks in the controller are made from a combination of commercially available units or kits, possibly with some modifications, and some items that are designed as part of the controller. The commercial items used have generally been chosen on the basis of performance versus cost and/or availability.

Modules that have been designed as part of the project have normally had schematic capture and layout done by using the *Eagle CAD* tool, although the SSB generator and crystal PLL were originally designed using a simple computer drawing tool. *Eagle* has been an excellent tool for schematic capture and later layout. The main controller board was manufactured by a circuit board manufacturer, because it has large numbers of through holes. All the others were made at home by using a laser printer onto photo paper, then thermally transferring the pattern onto the circuit board stock before etching. There have been several good descriptions of this method, which can generally be found by searching the Internet or looking at the ARRL or RSGB *Handbooks*. The most challenging board was the crystal PLL oscillator, where the PLL chip (ADF4112)

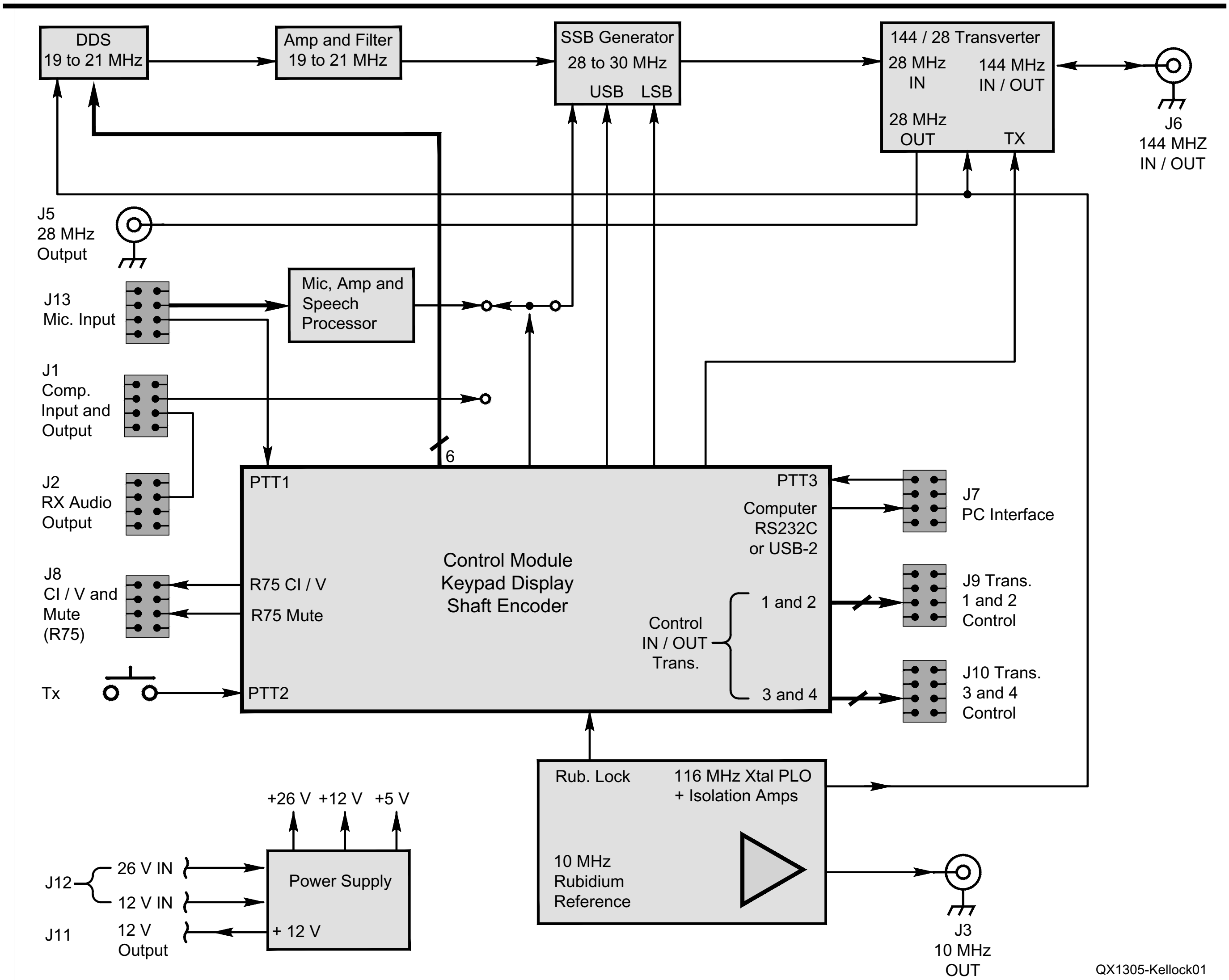


Figure 1 — Block diagram of the microwave transverter controller showing all the main functional blocks and external interface connectors.

Figure 2 — An overall view of the microwave transverter controller.

was in one of those incredibly small TSSOP packages.

I used a Datum LPRO Rubidium frequency reference. In order to ensure that the reference signal was as clean as possible with reasonably low phase noise, the 24 to 26 V dc power supply should have very low ripple and noise. The external power supply I used is a linear supply with less than 6 mV of ripple and noise. Of course, a GPS disciplined crystal oscillator could also be used, but the Rb reference provides adequate stability, and was available at low cost.

The 10 MHz signal from the reference is passed on to a buffer amp using an LM7171 op amp to drive the remote transverters and a signal conditioner using a 74AC04 CMOS buffer and signal shaper. This provides the input to the crystal PLL oscillator, which in turn provides the internal 116 MHz reference for the DDS and 144 MHz transverter. A simple transformer is used at the input to provide impedance matching and a voltage step-up. Figure 5 shows the schematic of the signal conditioning following the LPRO oscillator. It includes the 116 MHz isolation amplifiers, which are in the same module. A photo of the distribution amplifier module is shown in Figure 6.

The DDS unit uses James (WA1FFL) Hagerty's Advanced Direct Digital VFO circuit board employing the AD9951 DDS chip. (See the Further Reading section at the end of this article.) The reference oscillator is replaced with the 116 MHz from the crystal PLL and the AD9951 is directly controlled by the main controller unit without using the microcontroller on Jim's board. Other functions are used as-is. The filters have been replaced with lower frequency cut-off units since the DDS has to only generate signals from 19 to 21 MHz. This board provided a quick and effective way to get the DDS functionality. The DDS has adequate performance for this application with broadband noise and general spurs being more than 60 dB down. There are a couple of DDS spurs that exceed this level. This board is followed by a band pass filter and amplifier using a 2N5109 transistor to increase the available output to drive the 9 to 28 MHz double balanced mixer in the SSB generator.

I used a Down East Microwave model 144-28INT kit as the 28 to 144 MHz transverter, with the major modification being to supply the 116 MHz LO from the external crystal PLL oscillator unit. The modification can be accommodated on the 144-28INT board quite simply, with only one short wire link being needed.

The 116 MHz crystal PLL (the same circuit with slightly different component values is used in all my crystal PLL applications in various transverters) uses

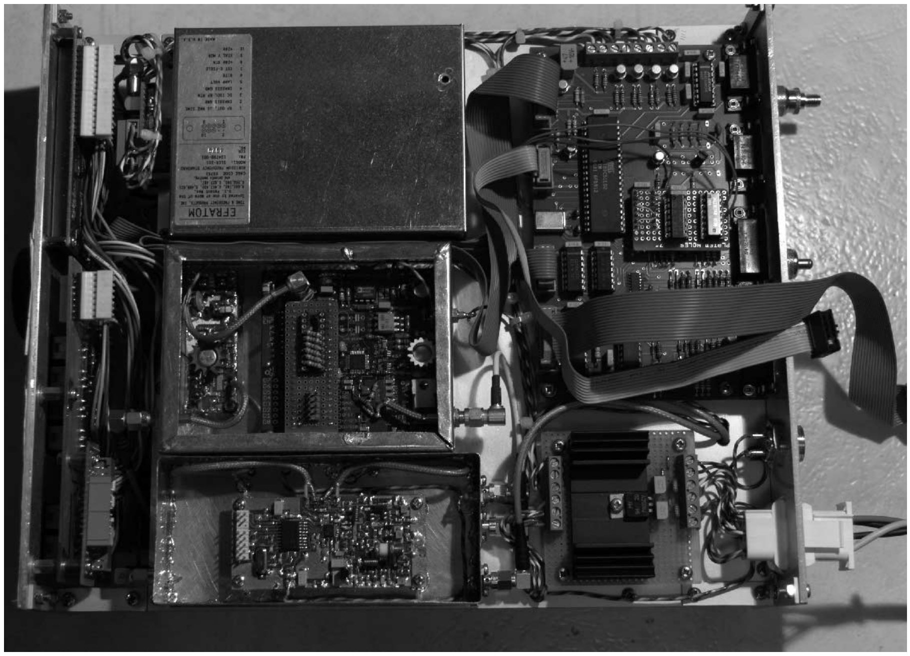


Figure 3 — Top view of the prototype controller, showing (clockwise from the top left) the 10 MHz Rubidium reference, the controller board with external interfaces, a small power supply, the 116 MHz PLL oscillator and distribution amplifiers and the DDS synthesizer and amplifier. Note that the small protoboard plugged into the main controller board allows programming the processor in-situ. It is not needed for normal operation. Some cables have been unplugged to better show the DDS unit.

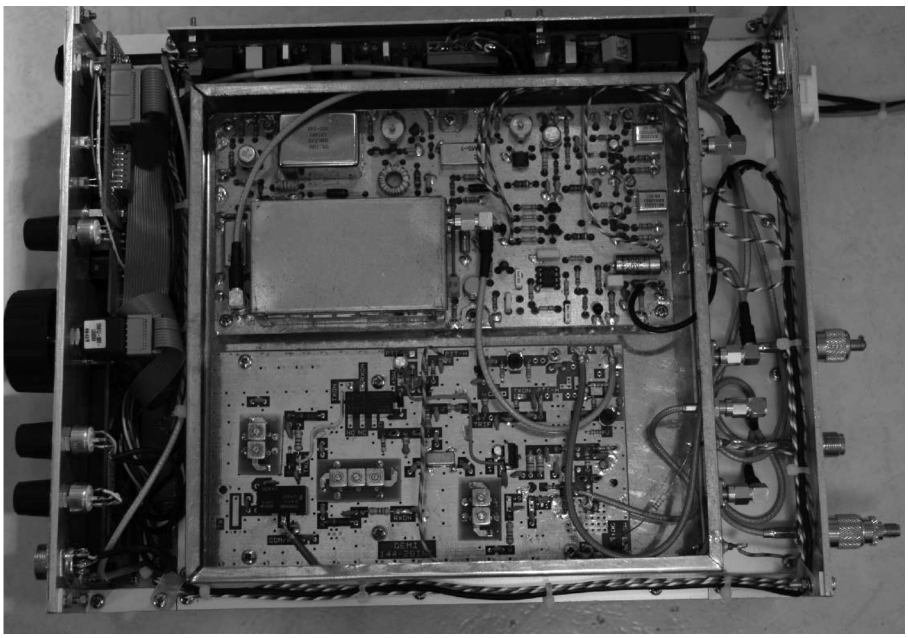


Figure 4 — Bottom view of the controller, starting from the bottom is the Down East Microwave transverter and the 28 MHz SSB generator, both in a tinplate enclosure. Above them is the audio processing amplifier and computer interface.

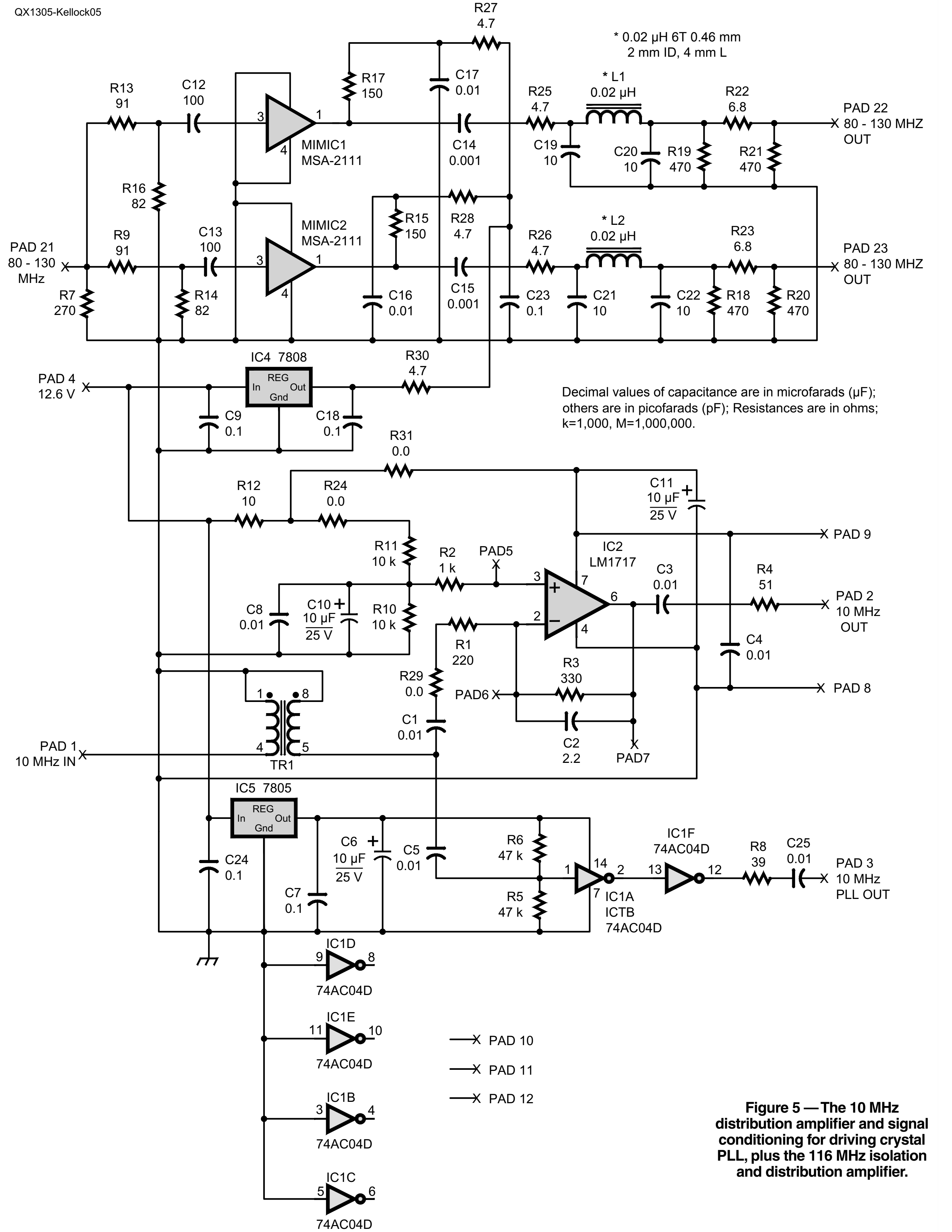


Figure 5 — The 10 MHz distribution amplifier and signal conditioning for driving crystal PLL, plus the 116 MHz isolation and distribution amplifier.

the stable and low-noise oscillator circuit developed by John Hazell, G8ACE, which seems to be similar to in approach to the work of John Stephensen, KD6OZH. To phase lock the crystal oscillator, a simple PLL using the ADF4112 has been added and a PIC 16F84A has been used to load the ADF4112 parameters at power up. A 40°C heater (Kuhne QH40A) is used to ensure the crystal temperature is constant. The circuit board is shown in Figure 7.

The circuit board has a solid ground plane on the back side; the crystal with its heater and one power regulator are mounted there. In order to reduce noise in the crystal oscillator, the ground plane on the component side is divided into two parts, with the digital ground being separated from the oscillator and PLL analog grounds in an attempt to reduce noise. There is a pin header on the right side of the board, which is used to program the PIC and later during operation to select which crystal frequency is being used (so a single program can be used for many applications such as LO for 1296 MHz, 2320 MHz, 24048 MHz or other bands). The software for the PIC is developed using Microchip's *MPLAB IDE*, where it is also possible to simulate the software operation and debug it, including the state of the input pins.

After the 116 MHz oscillator, a pair of simple resistive attenuators divides the 116 MHz signal, which is then amplified with a couple of HP MSA2111 MMICs to provide some isolation between the DDS and the 144/28 MHz transverter. The output level for each channel is about +8 dBm. These isolation amps have been combined with the 10 MHz reference distribution as mentioned earlier. The whole sub-system, including the 116 MHz PLL oscillator, is shielded in a small tinplate box.

Now let's have a look at the SSB generation. There are a few small circuit boards used to pre-condition the audio signal from a dynamic microphone. The signal is first amplified, filtered and clipped. Then, a relay is used to select either the microphone-derived audio, or that from a computer sound card (for JT65 or similar operating). Following this, the audio is passed on to the main SSB generator circuit board. Figure 8 is the schematic of the AF Preamp and switching scheme.

The main board for the SSB generator was designed and built many years ago and is a completely conventional 9 MHz filter type SSB generator. Two separate crystal oscillators generate 8.985 and 9.015 MHz carriers, one of which is applied to an SBL-1 mixer depending on whether USB or LSB is desired. The DSB output from the mixer is amplified, filtered and the resulting SSB is amplified before being mixed with the DDS-derived LO to up-convert the 9 MHz signal to 28 to 30 MHz. A band pass filter and amplifier follows the mixer. The resultant 28 to 30 MHz signal is applied to the Down East Microwave 28 to 144 MHz transverter. Figures 9 and 10 show the SSB generator schematic.

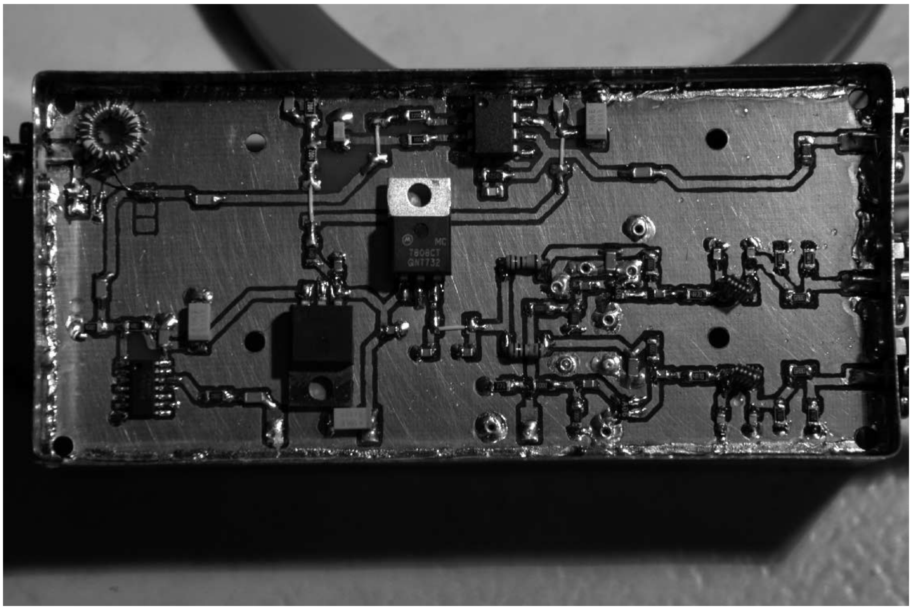


Figure 6 — The 10 MHz amplifier (top of module), 10 MHz interface for crystal PLL oscillator (lower left of module) and the two 116 MHz isolation amplifiers (lower right).

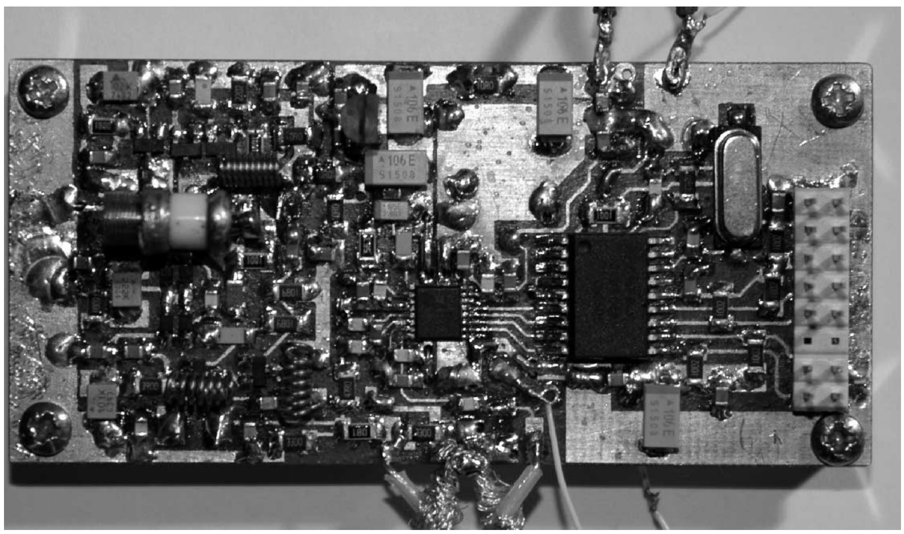


Figure 7 — The 116 MHz crystal PLL oscillator. The crystal and heater are mounted on the backside of the circuit board. The small HC-49 crystal seen here is for the PIC16F84A microcontroller (the largest chip on the board). The ADF4112 is the small chip almost in the middle of the board. Note the cut in the ground plane which extends under the ADF4112 chip. This separates the digital and analog ground planes.

The overall performance of the SSB generation system is such that the carrier is suppressed by at least 60 dB and spurious outputs are at least 50 dB below the carrier level when measured at 144.5 MHz.

Miscellaneous analog signal functions like the computer interface are handled by a small unit. In order to keep noise down, isolated transformer coupling has been used between the computer soundcard (a Delta 44 card in my case) and the transverter controller.

The heart of the controller is the microprocessor based control board. A separate file, *kellock.zip*, downloadable from the *QEX* files website (**www.arrl.org/qexfiles**), contains schematics of the control

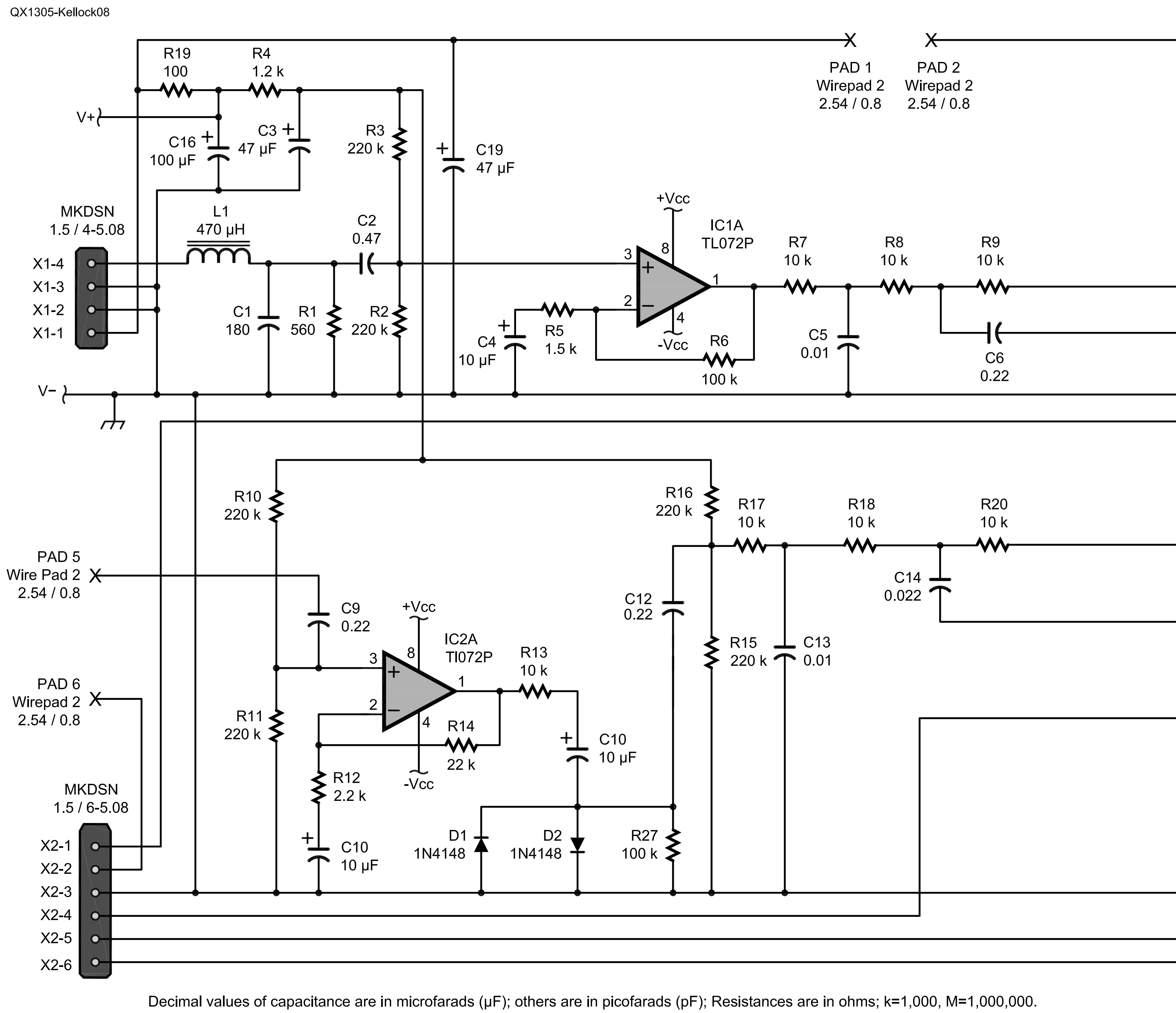
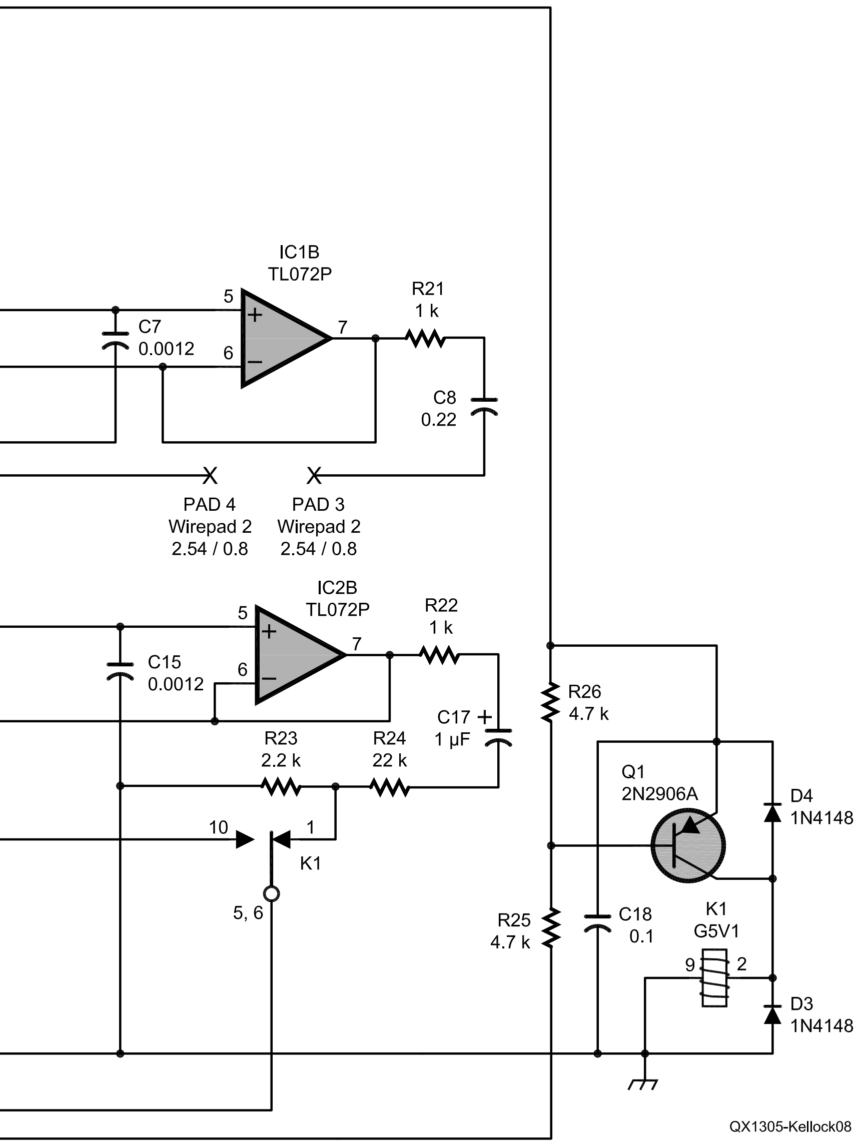


Figure 8 — Microphone pre-amp, audio clipping and local/remote switching for audio selection. P pads 1, 2 and 3, 4 and 5, 6 are used to place wire bridges, allowing a single sided circuit board. The microphone is connected to X1-4 and 12 V power to X1-1. Gain control (a 10 or 20 kΩ potentiometer) is connected to X2-1, X2-2 and X2-3. A second 10 kΩ potentiometer (for level adjustment) is connected to X2-5 and X2-3; the wiper is connected to the microphone input on the SSB generator in Figure 10.


IC1B
TL072P
5
6
7
R21
1 k
C7
0.0012
C8
0.22
PAD 4
Wirepad 2
2.54 / 0.8
PAD 3
Wirepad 2
2.54 / 0.8
IC2B
TL072P
5
6
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R22
1 k
C15
0.0012
C17
1 µF
R23
2.2 k
R24
22 k
R26
4.7 k
Q1
2N2906A
D4
1N4148
10
1
K1
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R25
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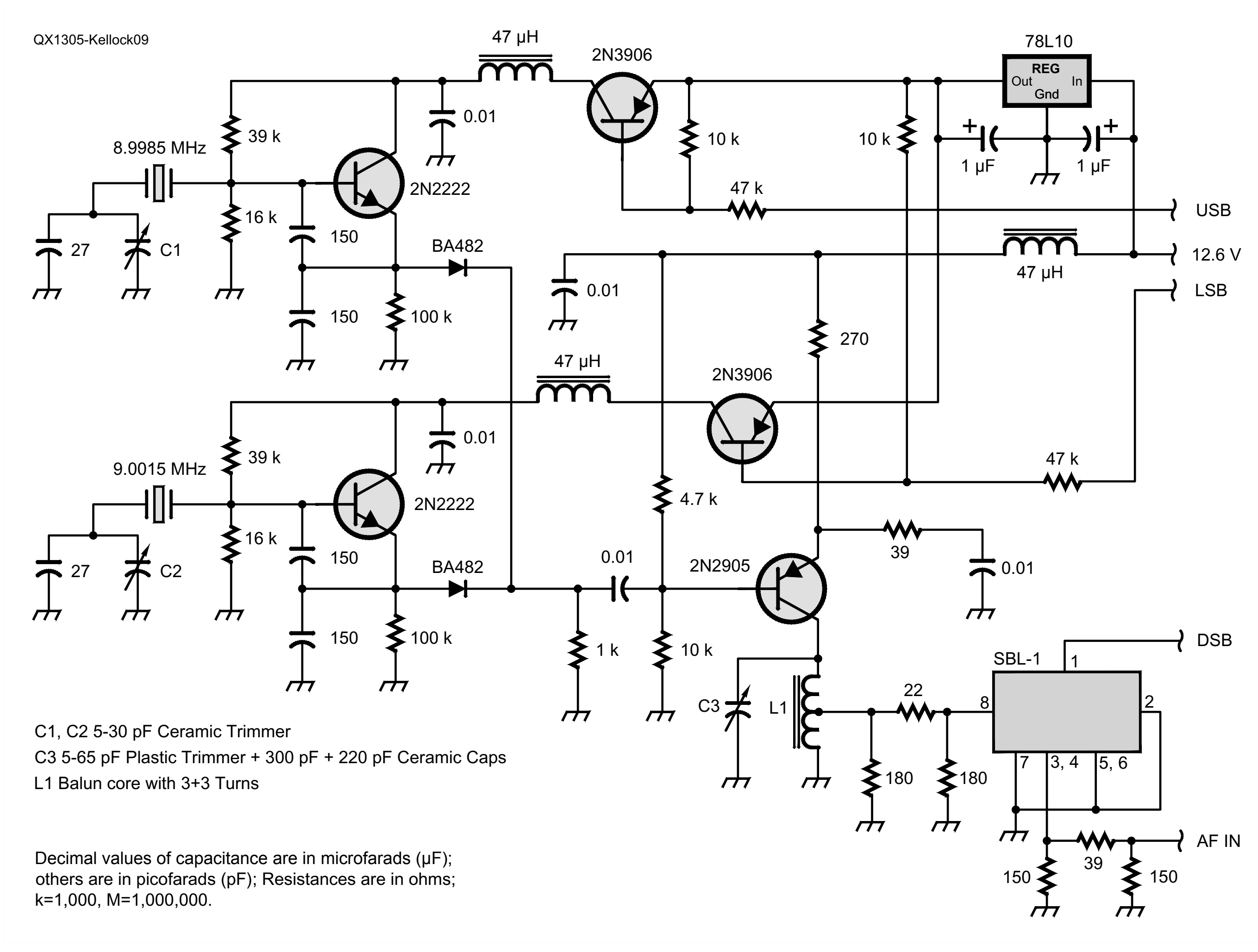


Figure 9 — The 9 MHz carrier oscillators, switching circuit and DSB modulator.

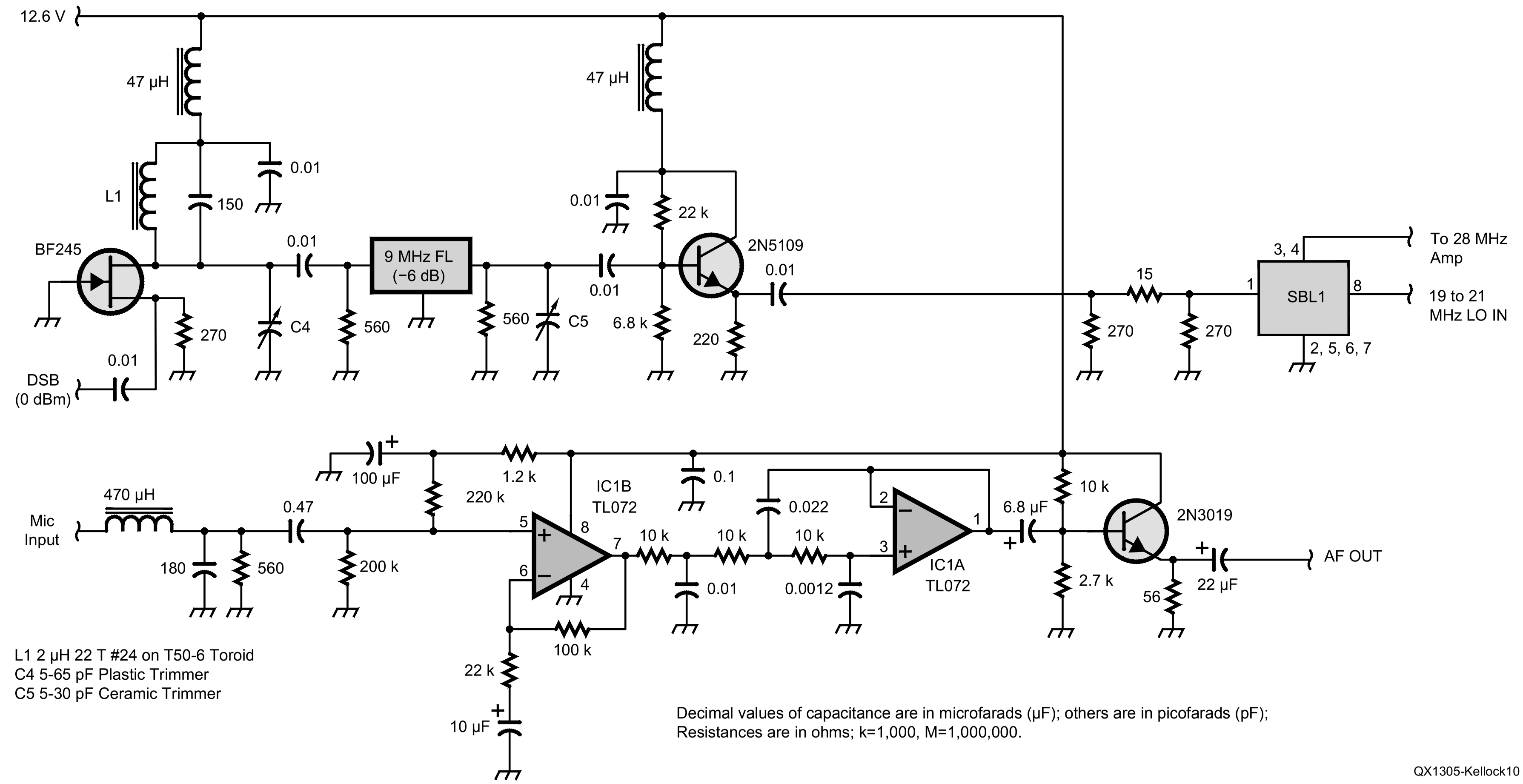


Figure 10 — The DSB/SSB filter and second mixer, along with the audio amplifier. The microphone input comes from the level control in Figure 8.

board and the PLL oscillator.[1] The processor used is one of the 8051 derivative processors, an Atmel AT89C51ED2. The circuit board was made for the 40 pin DIP variant of this processor, which is no longer generally available (other package versions are). The processor is augmented by adding a couple of MCP23S17 I/O extenders to give a few more input and output bits, plus an Analog Devices AD7888 8 channel A/D converter. The dial function is implemented by using a Bourns optical encoder, and IC9, IC8 and part of IC7 are used to implement an up/down direction sensing counter, which generates an interrupt to the processor for each count. The actual counting is done in the processor software. The CI/V interface (J8) is implemented using the remainder of IC7s inverters, plus a couple of transistors.

A partial RS232 or USB-2 interface (RXD, TXD and RTS) is implemented using either a MAX232 chip plus a DB9-F connector if RS232 is required, or an FTDI type DB9-USBD5-F module, which replaces the DB9-F connector on the circuit board. In that case, three wire jumpers replace the MAX232 chip, which is not required if a USB-2 interface is provided.

The interface to the external transverters is via J9 (two transverters) and J10 (two transverters). The digital outputs are driven by transistors, and the digital inputs are via transistors with resistor/diode clamping. The idea is that the actual transverters may be remotely located, and this scheme provides some protection and noise immunity for the digital inputs. The analog channels (two per transverter) are diode clamped. The outputs feeding them from each transverter should have a series resistance to limit the clamping current.

Transverter Interface Operation

Figure 11 shows the generic functions expected to be found in a transverter, which can be controlled by this unit. This is illustrated by the particular example of a 1296 MHz transverter.

First a word about the simple interface signals. I considered using a serial interface between the transverter controller and the transverter, however, I decided that the added complexity and potential reliability issues, versus the better monitoring and control that could be obtained, were not worth the complexity. The main disadvantage of the simple interface in practice is that fault causes are not explicitly shown remotely, and the analog monitoring of the forward and reflected power may be subject to a bit of noise if the cable run is particularly long.

The control signals to and from each transverter are:

- To transverter: Transmit Request.
- From transverter: Transmit OK

The transmit command is generated by the controller based on the band selected, and the PTT or remote transmit request. Following application of the transmit command, the controller waits for the transverter to signal TX OK. If this is not received within the specified time interval (set to 400 ms by default), the transmit command is de-activated and the transmit fault indicator is activated. Similarly, if a transmit fault condition occurs in a transverter during a commanded transmission, the same happens. In my transverters all the "fast" protection is self-contained in the transverter itself to ensure that any expensive amplifier transistors are protected and that the protection is not dependent on any remote signals.

The analog monitoring signals from each transverter are:

- From transverter: Forward power (analog voltage)
- From transverter: Reflected power (analog voltage)

The forward power is displayed as a bar graph reading on the bottom line of the 20 × 4 line display used in the controller. The scale factor can be individually set in software for each of the four transverters. Reflected power is also displayed.

Software Functions Implemented in the Controller

Figure 12 shows the display presently implemented in the controller, while Figure 13 shows the keyboard layout.

The software is implemented using 8051 assembler language compiled by the Systronix 8051 RAD51 IDE environment (which is available as a free download). Extensive use has been made of readily available math libraries for the 8051 (used in the frequency control of the DDS), plus some additional modules developed to handle 64 bit arithmetic. The software is downloaded to the processor flash over a serial line, using a small modification to the processor circuit board (a plug-in board and a couple of jumpers), with the *Atmel FLIP* (version 3.2.0) program.

User Interface Features

Band selection is done by simply incrementing/decrementing by each push of the **Band Up** and **Band Down** buttons. As there are only four bands it's quite quick. The readout is updated to give the full frequency readout of the selected band.

USB and LSB selection is toggled by successive depressions of the **USB/LSB** button. The current mode is shown on the display.

Local or remote control is selected by successive depressions of the **Remote/Local** button, and the current selection is shown on the display. Remote control is used with JT65, for example.

The receive and transmit frequencies can be separate or locked. The transmit frequency is controlled by the controller DDS. The receive frequency is controlled by the companion receiver, in my case an ICOM R75. This is the state in the "Split" mode. In the "Combined" mode, the controller queries the frequency set on the R75 through the CI/V interface, and sets the transmit frequency to the same value. Therefore, the tuning of the whole system can be done by the R75 tuning dial (and if the R75 frequency is not correct, there will be a small offset between receive and transmit). Successive depressions of the **Split/Comb** button toggle the mode.

The frequency increment represented by each unit of rotation of the tuning knob is selected from 1 Hz, 100 Hz, 1 kHz or 10 kHz. These are presented by successive depressions of the **Resolution Up** or **Resolution Down** buttons, with the presently selected resolution being shown on the display.

The current settings of USB/LSB, Local/Remote, Split/Combined, Tuning Resolution together with the Current Frequency (which also gives the band selected) can be stored into non-volatile memory with the **Save** button, and the last saved set can be recalled by depressing the **Recall** button

The state of the internal Rubidium standard is shown on the display. During the warm-up or if some other fault occurs, it is shown as either NOK or OK.

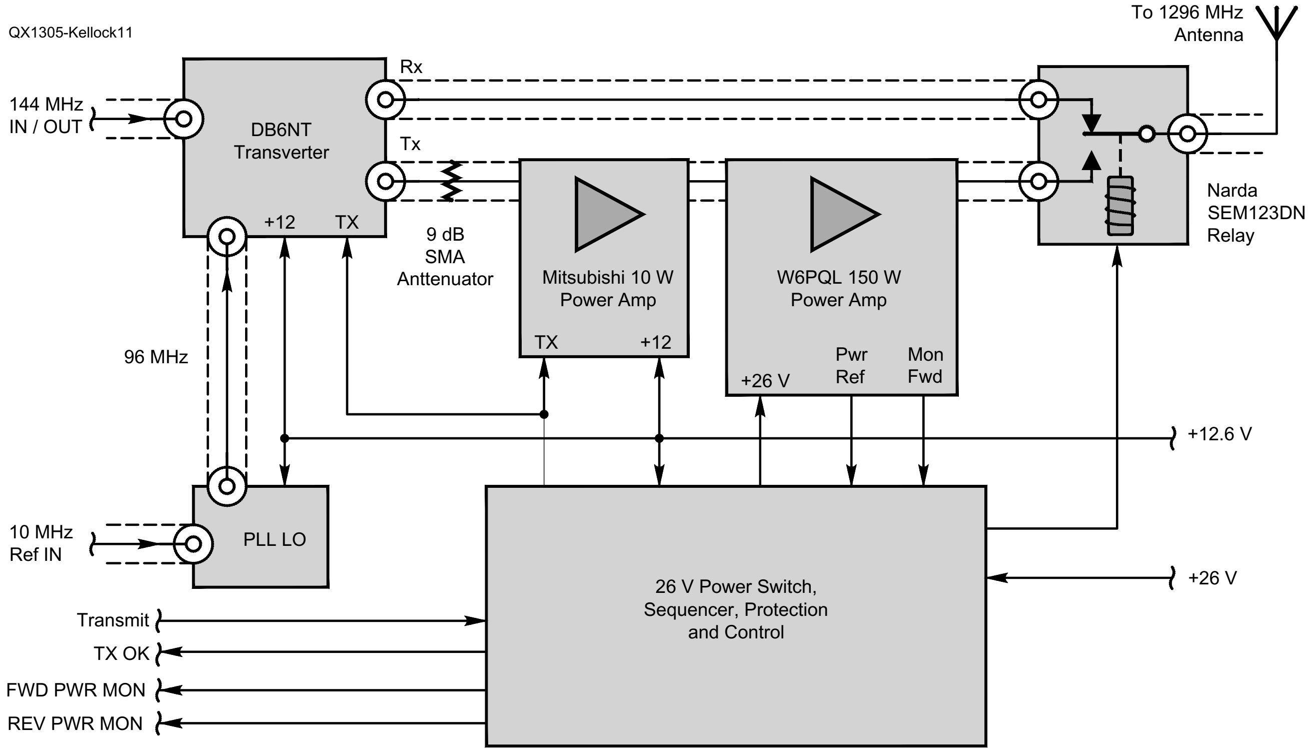
In addition to these features, the needed transmit and receive change-over functions are carried out by depressing the **Transmit** button on the panel, or by the remote control from the computer interface, if this is enabled. When in transmit mode, transmit frequency changes and USB/LSB mode changes are inhibited.

Operational Software Functions

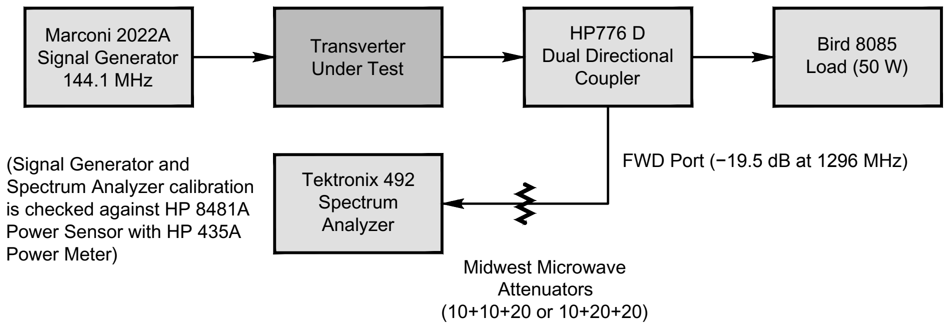
The main functionality going on behind the scenes is the monitoring that's taking place in transmit mode. Any faults notified by the attached transverters cause immediate removal of the RF drive at 144 to 146 MHz and the removal of the transmit command from the selected transverter. An alarm condition LED (**TX Fault**) is illuminated. Scanning the KB, updating the display and LED status, updating the DDS frequency and so on also proceeds in the background.

There are many planned additions to the software, but if and when they will be

[1]Notes appear on page 19.



Control Wiring

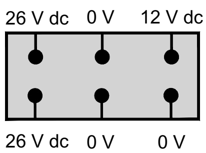


Measuring Setup

Power Connector

Connector is AMP MNL 6 Pin. View is "front view" of socket on TX/RX. Socket pins are male.

All wires are 2 × 0.5 mm^2, ground connections taken to multiple ground points.



Control Connector

The connector is a 9 pin DB-9S (Female).

All wires are 0.5 mm^2, ground connections taken to multiple ground points

Pin	Signal
1	GND
2	Transmit/Input
3	GND
4	LP Monitor Output
5	HP Monitor Output
6	GND
7	Reflected Power Monitor Output
8	GND
9	TX OK/Output

TX/RX Power Supply and Control - Connectors

Central Power Supply Connection Layout

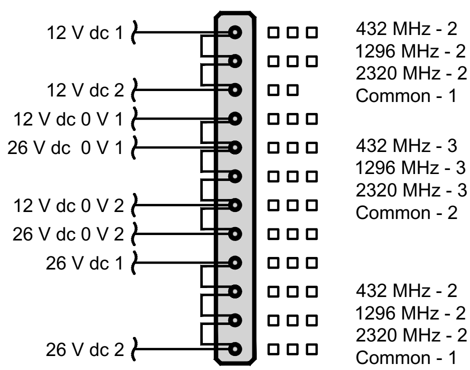


Figure 11 — A medium power microwave transverter for 1296 MHz, showing the main functional blocks and the control and monitoring signals.

implemented is another issue. The main future feature is implementation of a small subset of the CI/V commands on the controller so that a common computer can command both the R75 and MTC.

Figure 14 shows a picture of a subrack designed for three high-power transverters with the power supplies in the left hand side (26 V at 10 A and 12 V at 10 A) and fitted with a 1296 MHz transverter. The 1296 MHz transverter is mounted in a disused base station aluminum housing, which provides a good heat sink for the 150 W PEP power amplifier (built using one of Jim (W6PQL) Klitzing's 150 W kits). A DB6NT 1 W transverter drives a 10 W amp using a Mitsubishi MOSFET module, which then drives the 150 W amplifier.

Acknowledgements and References

There are many hams and others who have, generally unknowingly, contributed to the design and implementation of this system. The many excellent websites maintained by hams who wish to share their ideas and/or kits with others are too numerous to mention. More details of the implementation of some parts of the controller, such as the PLL oscillator, are contained on my website at **http://personal.inet.fi/private/oh2gaq/**. For those who are interested in more exact constructional details of some parts of the system, including *Eagle* design files or software source code, you can contact me at the e-mail address shown at the beginning of this article

Figure 12 — Display of the MTC with present software. The top line shows the frequency, and implicitly the band in use (in this case 24 GHz). The mode is Combined (common receive and transmit frequency control). The transmit mode is USB. The transmit tuning resolution is 1 kHz (selected from 1 Hz, 100 Hz, 1 kHz and 10 kHz), but this is not relevant in Combined mode. The Rubidium Health is indicating OK. The microphone input is selected and the MTC is under Local control. The bottom line is used for the transmit output display. The 16 leftmost positions show forward power; the four rightmost positions show reflected power.

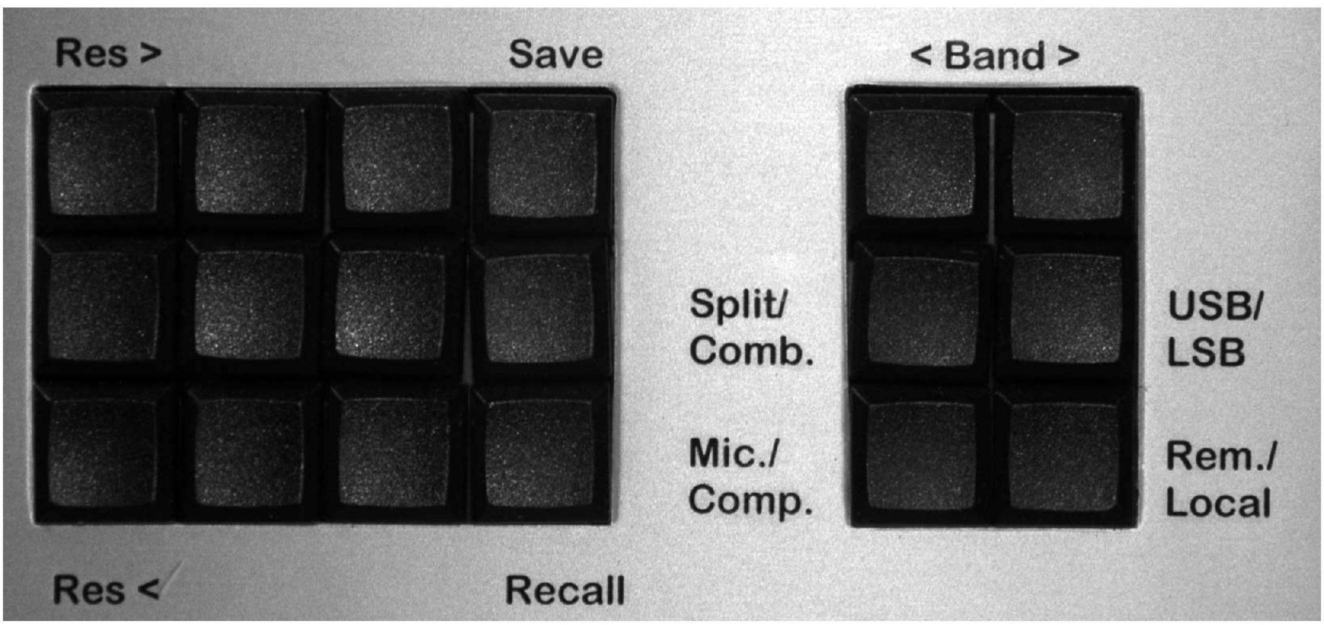


Figure 13 — The keyboard layout and key functionality with present software version. The main tuning functionality is controlled by the optically encoded main tuning knob when in Split mode

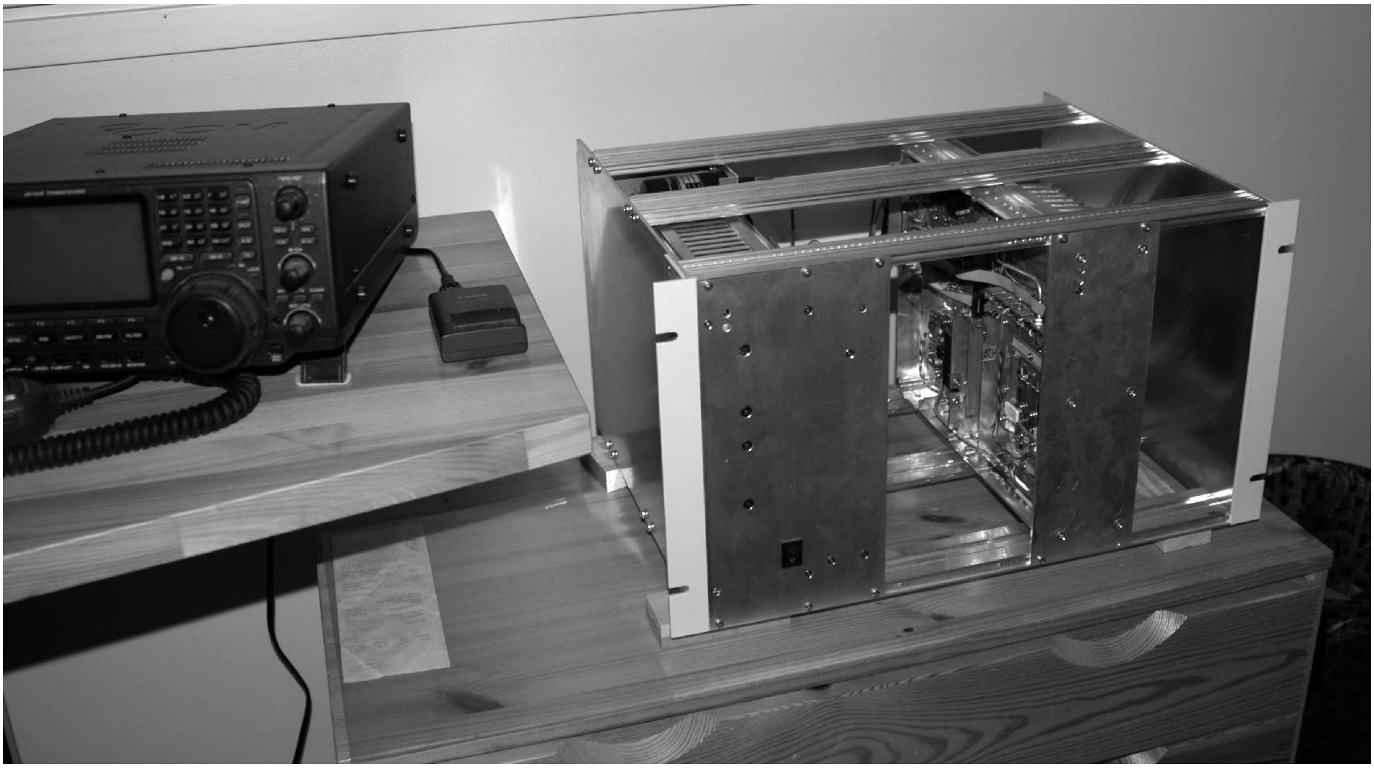


Figure 14 — Transverter subrack with the 1296 MHz transverter.

For Further Reading

I recommend the following articles and websites.

John Stephensen, KD6OZH, "A Stable, Low-Noise Crystal Oscillator for Microwave and Millimeter-Wave Transverters," *QEX*, Nov/Dec 1999.

John Hazel, G8ACE, "Constructional Notes for G8ACE MKII OCXO Sept 2010 V2," available from the G8ACE website at **www.microwaves.dsl.pipex.com/**.

The Analog Devices Data Sheet for ADF411x RF PLL Frequency Synthesizers.

The W6PQL website at **www.w6pql.com**. This site has several excellent articles covering microwave transverters and useful sub-systems, as well as actual kits for many items.

James D. Hagerty, WA1FFL "An Advanced Direct-Digital VFO," *QEX*, May/June 2008. See his website at **www.wa1ffl.com/** for DDS kits using the Analog Devices AD9951 DDS.

KO4BB's website at **www.ko4bb.com** has information about time and frequency control, measuring equipment and generally useful microwave related material.

KE5FX's website at **www.thegleam.com/ke5fx/** also offers time and frequency control information, measuring equipment and other useful microwave related material.

The Down East Microwave website at **http://downeastmicrowave.com/**.

The Kuhne Electronic website at **www.kuhne-electronic.de/en/home.html**.

Systronix RAD51 website at **www.systronix.com/RAD51/RAD51.htm**. This site details the Rapid Application Development Environment for 8051 family processors.

Note

[1]You can download a zip file of various files related to this article from the ARRL *QEX* files website. Go to **www.arrl.org/qexfiles** and look for the file **7x13_Kellock.zip**.

Hamish Kellock, OH2GAQ, lives in Espoo, Finland. He has a Diploma in Applied Physics from the Royal Melbourne Institute of Technology (Melbourne, Victoria, Australia). He worked for several years in research associated with lasers and later with computer controlled measurements and instrumentation for RF measurements in Melbourne. For a short time he worked in the mineral processing industry, responsible for the development of computer controlled ore sorting equipment. In 1982 he moved to Finland to work in the telecommunications industry with Nokia. He held several positions over 28 years in the R&D area, covering network management, SDH transmission products, V5.2 multiplexers, microwave radio links and IP DSLAM products. He is now retired. Hamish has published several articles covering work with lasers, and holds patents in the mineral processing field as well as telecommunications.

Hamish was first licensed as VK3ZMV in Ballarat, Australia in 1960. Two meters was his main band of interest, followed later by 70 cm. His equipment was all home-built, mainly using surplus World War II parts. When reasonable solid-state devices appeared, he turned his interests to semi-portable operation with home-built rigs, and also published some articles in local newsletters covering TTL logic based frequency synthesizers and 2 meter solid state amplifiers. Hamish was absent from Amateur Radio for a while afterward until the early 2000s, when he took the Finnish Radio Amateurs examination and was licensed as OH2GAQ. He is now gradually putting together equipment for the various microwave bands including, particularly in a portable form, for the SHF bands.

Hamish is married and has five children. His wife is a building engineer. Much of his spare time is taken up with building projects for the family, including house renovations for the various grown-up children. During the summer he enjoys boating in the local archipelago in southern Finland, not to mention installing more electronic gadgets in the boat. Of course the next summer house project is always around the corner!