Rapid Multichannel Goniometer Hardware Manual

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Draft

Overview

The Rapid Multichannel Goniometer (RMG) consists of four sections- the antenna, preamplifiers, receiver, and software. The antenna is an array of four dipoles equally spaced on a circle. The preamplifiers provide amplification and filtering of the intended signal. The receiver tunes the intended signals to baseband and digitally samples them. The software does more filtering and then performs detection and estimation on the separated signals.

Antenna

Note: This description is for a vertically polarized antenna with center frequency at 164.5 MHz.

The antenna array consists of four dipoles, each consisting of two aluminum rods configured end-to-end connected to a coaxial cable at the center (see Figures 1, 11). The dipoles are located at the corners of a square 95.3 cm on a side. The dimensions of the array are critical and are determined by the center frequency. Critical dimensions are:

Length of dipole (end-to-end): 85.7 cm
Distance of each dipole from center of array: 67.4 cm (measured to rod center)
Diameter of dipole rod: 0.95 cm +/- 1 mm
Separation of screw heads at center of dipole (Figure 11): 1 cm approximately.

The dipoles are aluminum tubes of outer diameter 0.954 cm. In the developmental model these tubes were tapped for screws to attach the cables as in Figs. 8 and 11. Brass or hard drawn copper rods or tubing of the same diameter (within one percent) could also be used. Attachment screws and lugs should be of non-corroding metal. Lugs should be soldered to the cable conductors. Dipole rods or tubes must be 42.35 cm long, within 1 mm. and must be spaced so that the screw heads are separated by 1.0 cm, approximately, so that the overall end-to-end length of the dipole is 85.7cm. See Fig.11. The overall length is the critical parameter.

The cables are RG-6/U type coaxial cables of 75 ohm characteristic impedance. They can be obtained in bulk from building supply stores or electronic wholesale houses. Be sure to order "quad-shielded" cables. Four cables are needed, of exactly the same length, sufficient to reach from the dipoles, through the horizontal arm, down the vertical mast, to the cabinet for the four preselector amplifiers (to be supplied with the rest of the electronics). The preselectors can be mounted anywhere on the mast below the exit port, but not more than, say, ten meters below the cruciform antenna structure. Allow ½ meter extra length of cable for a drip loop at the preselector cabinet. A type "N" male connector is required at the lower end of each cable. Do not install these connectors until the rest of the electronic modules are in hand.

Rather than a balanced-to-unbalanced transformer to match the balanced dipole to the RG-6 coaxial cable, a tubular ferrite choke designed for Very High Frequencies (VHF) is used (Figs. 8, 11). Cable runs from the dipole centers to the hub at the array centers and

down to the preamplifier box lower on the tower cannot be avoided. Thus, in order to eliminate radio frequency currents on the outer conductors of the cables, VHF ferrite chokes (also known as "beads" or "cores"} are to be placed at approximately 13 cm intervals on all coaxial cables inside the white PVC tubes of the antenna structure (Figs. 6, 7, 8, 11). They can be cemented, taped, or tied in place. The four cables are bundled together within the vertical mast and these chokes (“cores”) are large enough to surround the bundle (Figs. 6. 7). Below the point at which the cables exit from the mast, no chokes are needed. Four large "cores" are needed for each array; an appropriate type is F-114A, Mix 43 from Palomar Engineers, Inc. Sixteen of the smaller chokes are needed: type FB-102, Mix 43 "beads" also from Palomar Engineers, Inc. There are other suppliers such as Amidon and Panasonic.

The antenna array must be rigidly supported. The developmental array was built of PVC plumbing components which were obtained at building supply stores. As shown in the figures, the dipoles are supported by a horizontal cruciform structure consisting of a 4-way hub ("4-way socket cross") and four arms. These arms are 6.02 cm in diameter and extend about 47 cm from the center of the hub. Inside these tubes are tubes 4.83 cm in diameter and long enough so that the combination can be adjusted (by sliding inner tube within outer tube) to be from 58 to 68 cm in length from the center of the hub. The outer tube has a wide slot cut in it so it can be clamped tightly to the inner tube by a hose clamp, as in Figure 5.

The transition between the central hub (a four-way "socket Tee") and the vertical mast must be torsionally rigid. A hole is drilled entirely through the hub at right angles to the arms and a short tube of outer diameter approximately 2.6 cm is set snugly into this passage to reinforce the connection between hub and vertical mast. Four holes must be drilled into this short tube to permit the cables to descend into the vertical mast, and the cables must be inserted before the tube and the other transition pieces are cemented together. It may be that other methods of connecting the central hub to the vertical mast will suggest themselves, especially if PVC welding facilities are available. Any method of providing the necessary rigidity is acceptable. This comment applies to the entire PVC structure. The vertical PVC mast should extend about one meter to the port where the cables exit from the mast. Below that point the cables reach to the position of the weather-proof housing for the preamplifiers (see below).

The antenna towers may be of metal or wood or synthetic materials and may be of any form, as long as the antennas are supported securely in fixed position. Metal guy wires are acceptable provided they are attached below the exit port on the PVC mast. The antenna structure must be oriented in direction before being permanently attached to the tower.

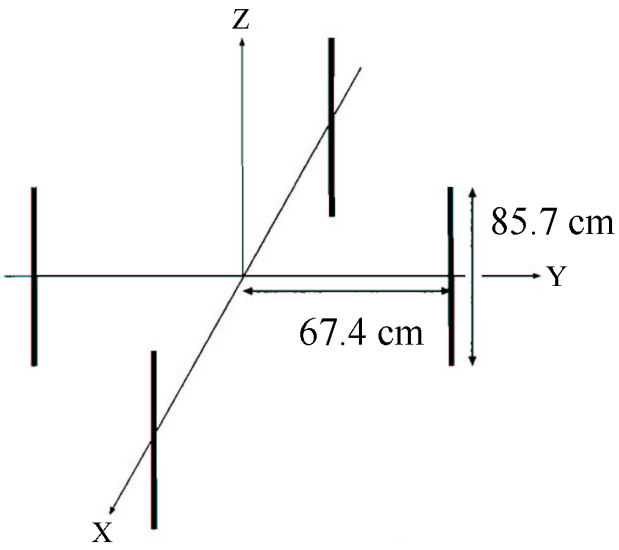

Figure 1: Layout of four-element vertical dipole array.

Figure 2: Completed Antenna.

Figure 3: Completed Antenna

Figure 4: Completed Antenna.

Figure 5: Detail of the cross arm telescoping length adjustment.

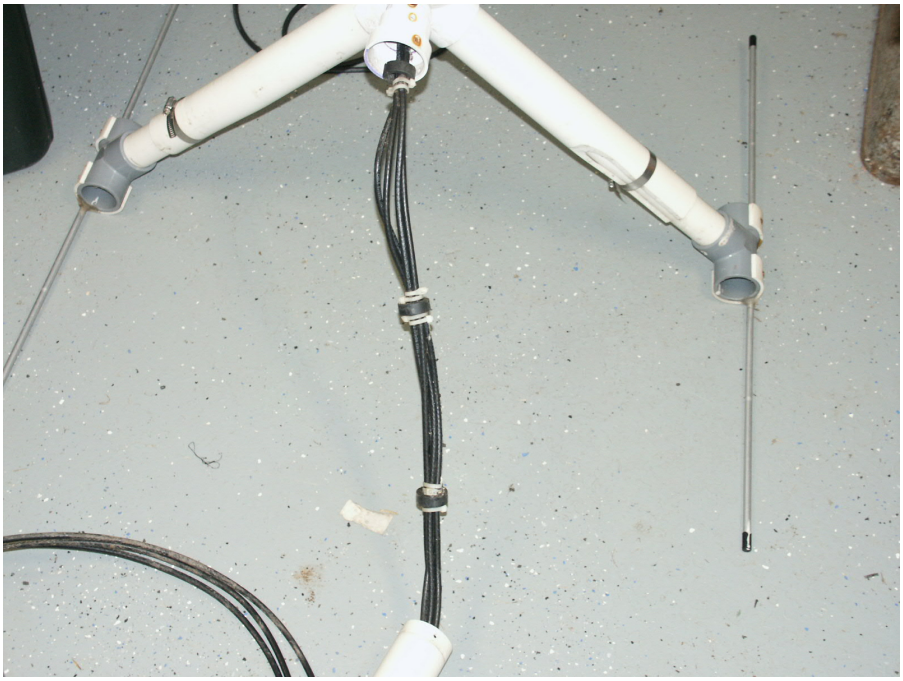

Figure 6: Detail of the VHF ferrite chokes in the interior of the mast. There are four chokes placed approximately 13 cm apart.

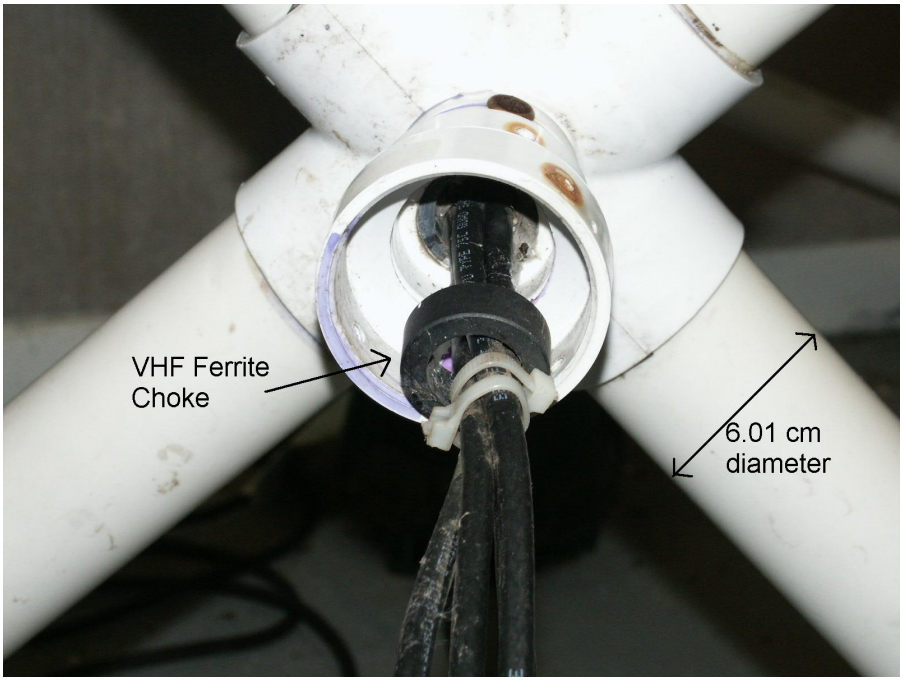

Figure 7: Detail of the four RG-6/U cables coming from the central hub, into the vertical mast.

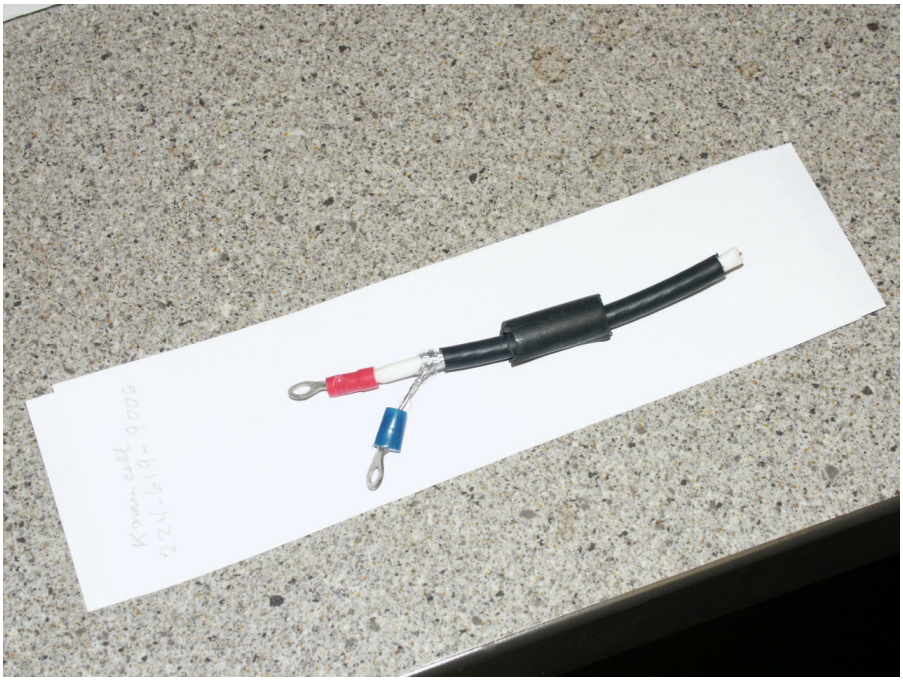

Figure 8: Detail of the RG-6/U cable connection to the dipole located in the cross arms.

Figure 9: Detail of the dipole connection.

Figure 10: Detail of the dipole connection.

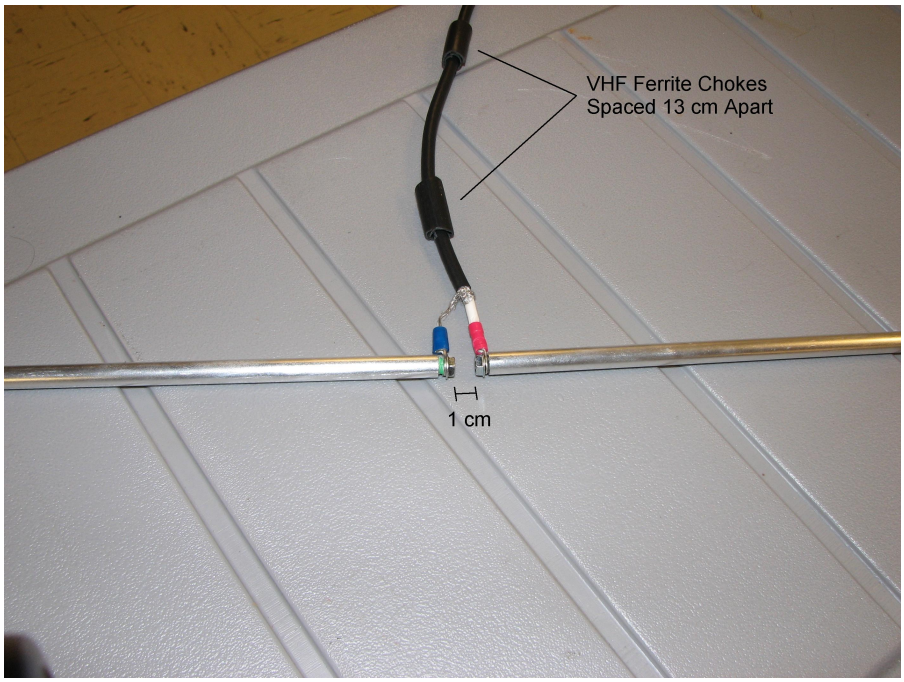

Figure 11: Detail of the dipole connection without support arm.

Preamplifiers

The preamplifier box contains four modified Hamtronics LNP-160 preselectors. Female N-connectors have replaced the original RCA-connectors at both the input and output. The preamplifiers have been tuned for 164.5 MHz with a 75-Ohm input impedance and a 50-Ohm output impedance. The preamplifiers are housed in individual "bud boxes."

The preamplifiers are powered by a 12 Volt DC source on channel one that is supplied by the receiver unit. This supply is then connected in parallel to the other preamplifiers. This connection is inside of the inner box. This box is held inside of an outer rain skirt by a central rod and the outer rain skirt is to be mounted on the antenna tower near to the direction finding antenna.

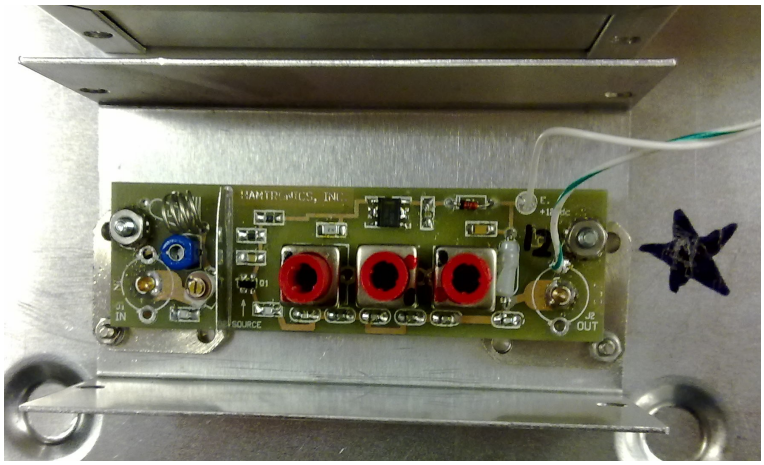

Figure 12: Channel 1 Preamplifier with DC filter installed.

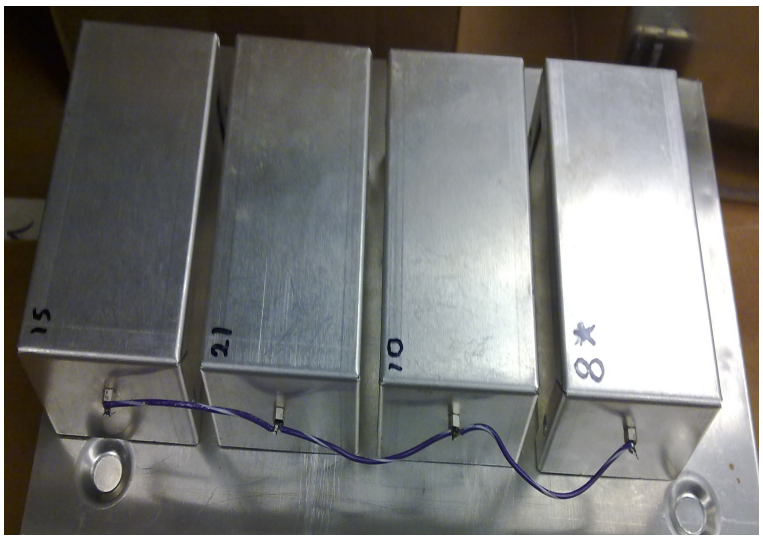

Figure 13: The individual preamplifiers are connected to 12VDC in parallel. These individual boxes are attached to the top panel of the inner box.

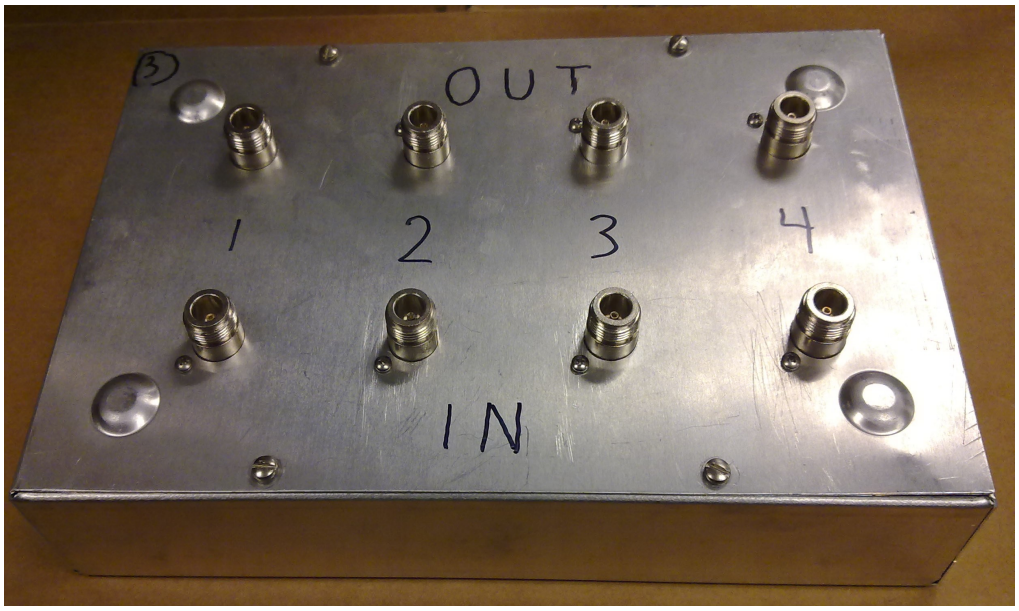

Figure 14: The inner box

Figure 15: Completed preamplifier box with center rod in place.

Receiver

The receiver is a four channel VHF radio with a 12-bit ADC operating at 64 Msamples/second. It contains four modules (USRP, Quad IF, PLL/VCO, and PIC controller) as well as a power harness running along the metal partition.

Front Panel

The front panel of the receiver contains an LCD which displays information as to the operation of the RMG, such as the current RF center frequency. The green LED indicates that the unit is on. The red LED indicates an error with the tuning (usually the PLL in the unlocked state) or operation of the unit. Communication to the receiver is done through the RS232 connection (DB-9) and the USB connection (Type B). The RS232 connection controls the tuning of the receiver through the PLL/VCO and the status updates (LEDs and LCD). The USB connection controls the USRP module which contains the ADC, filtering and down-conversion of the digital signal. The digital samples are transmitted to the computer by the USB connection as well.

Back Panel

The back panel contains the power connection and the RF connections. The RMG requires 12VDC power supply. On the power connection the top pin is positive, the middle pin is ground and the bottom pin is negative. This corresponds to the provided connector as positive – red, negative – black, and ground – green. The ground pin is connected directly to the chassis while the negative pin is connected to the chassis ground through the various boards. Therefore it is acceptable to tie the ground and negative pins together at the power source.

The RF inputs are SMA connections. They are numbered 1-4 with 1 being closest to the power connection. Channel 1 provides 12 VDC (center conductor +, outer conductor -) which is used to power the preamplifiers. Channels 2, 3 and 4 do not contain this bias. Care should be taken to connect the preamplifier channels to the corresponding receiver channels to insure proper operation.

Power Harness

The 12 VDC power supply runs through a 12V, 4A fuse to a break-out/pre-regulator board. From there 12V lines go to the PIC Controller, PLL/VCO, and Quad IF boards and a 5V regulated line goes to the USRP.

Quad IF

The Quad IF board contains a 4 channel dual-stage downconverter as well as a 80.7 MHz oscillator, used as the second stage local oscillator (LO2). The first stage uses mixes the RF signal with LO1 to produce a 70 MHz signal which is filtered by a 500 kHz wide SAW filter. The second stages mixes the 70 MHz signal with LO2 to produce a 10.7 MHz signal which is filtered by a 200 kHz wide ceramic filter. This IF signal is sent to the USRP for sampling and further down conversion. The channel outputs are on the

underside of the board and color-coded, along with the LO1 input. The colors are: Channel 1 – pink, Channel 2 – orange, Channel 3 – yellow, Channel 4 – green, and LO1 – blue.
Near the RF input to channel 1 there is a 12 V, 1/8 A fuse between the 12 V supply line and the RF line. This is to protect the board from faults in the preamplifier unit or cabling.

USRP

The Universal Software Radio Peripheral (USRP) is an open platform ADC produced by Ettus Research Inc. The receiver contains two BasicRX (some cases it is two LFRX) daughterboards. These produce a four channel, 12-bit ADC which operates at 64 Msamples/second. The FPGA on the USRP filters and decimates the data samples to produce an interleaved data stream which contains four complex float streams at 256 ksamples/second. This interleaved data stream is then sent through the USB connection to the operating computer. More information can be found in the software section.

PIC Controller

The PIC Controller communicates with the operating computer, sets the frequency of the PLL/VCO and controls the status displays on the front of the receiver. For more information on the PIC Controller interface, please see the software section.

PLL/VCO

The PLL/VCO produces the first local oscillator signal (LO1) for the down conversion on the Quad IF board. It produces a 15 dBm tone, tunable to 218.5-248 MHz. With the use of high-side and low-side LO, this allows the RMG to tune frequencies from 148.5-178 and 288.5-318 MHz depending on the preamplifier used in the system. The PLL/VCO is controlled by the PIC Controller over a five pin cable.

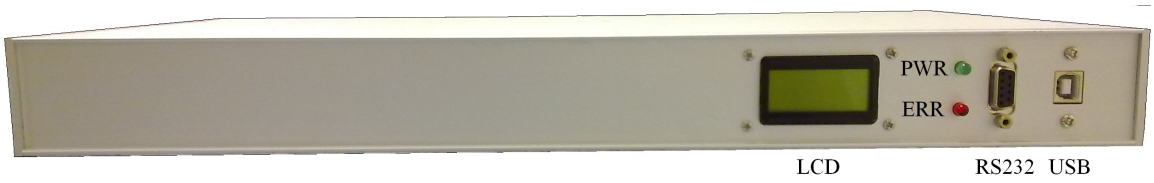

Figure 14: Front panel of receiver unit.

Figure 15: Back panel of receiver unit.

Figure 16: Top view of the receiver unit. Upper Left: Quad IF Board, Upper Right: USRP, Lower Left: PLL/VCO, Lower Right, attached to front panel: PIC Controller.

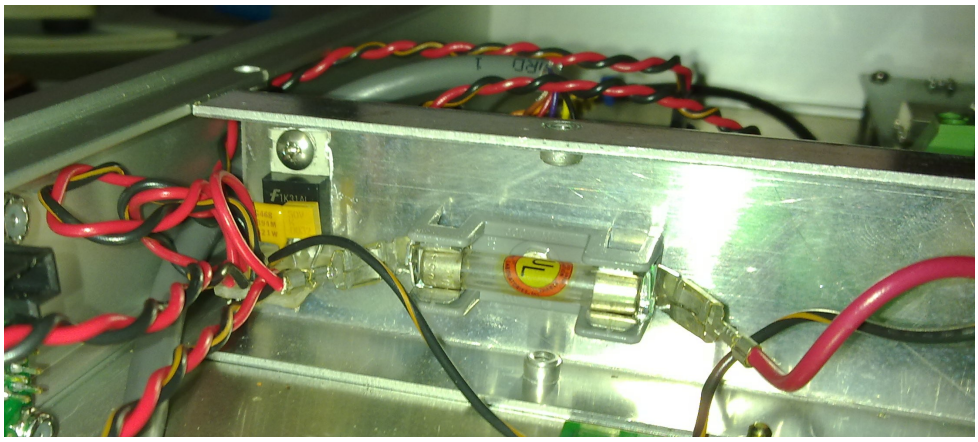

Figure 17: Power harness and fuse on center divider.

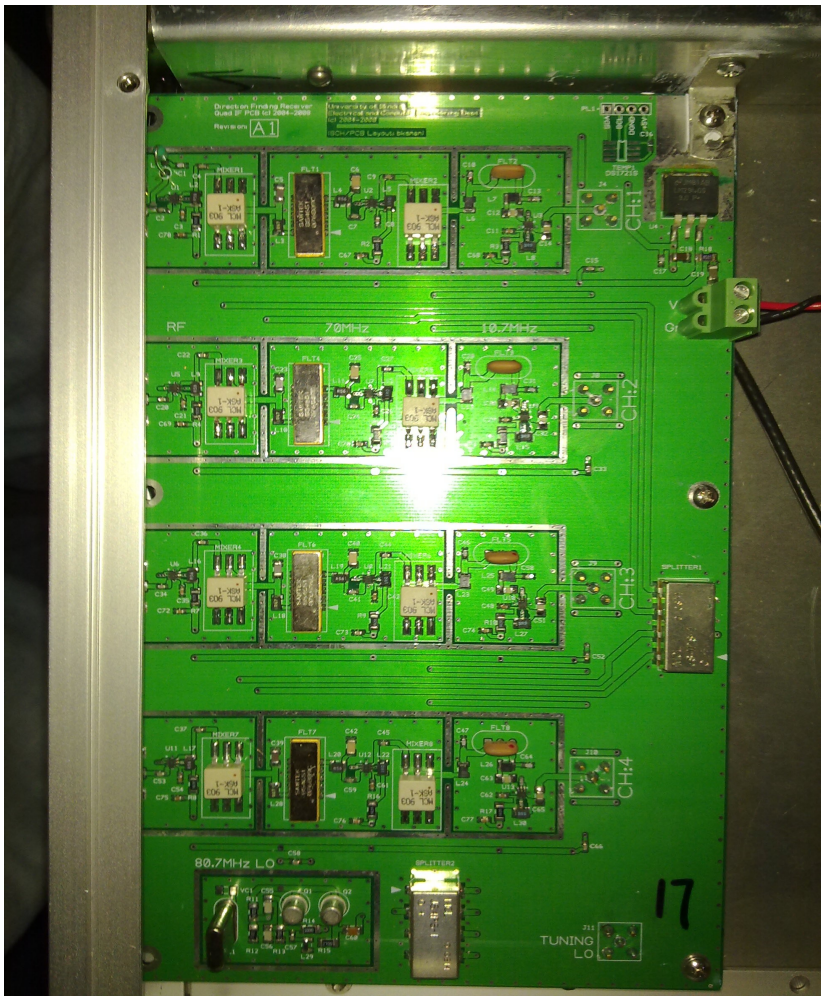

Figure 18: Quad IF Board.

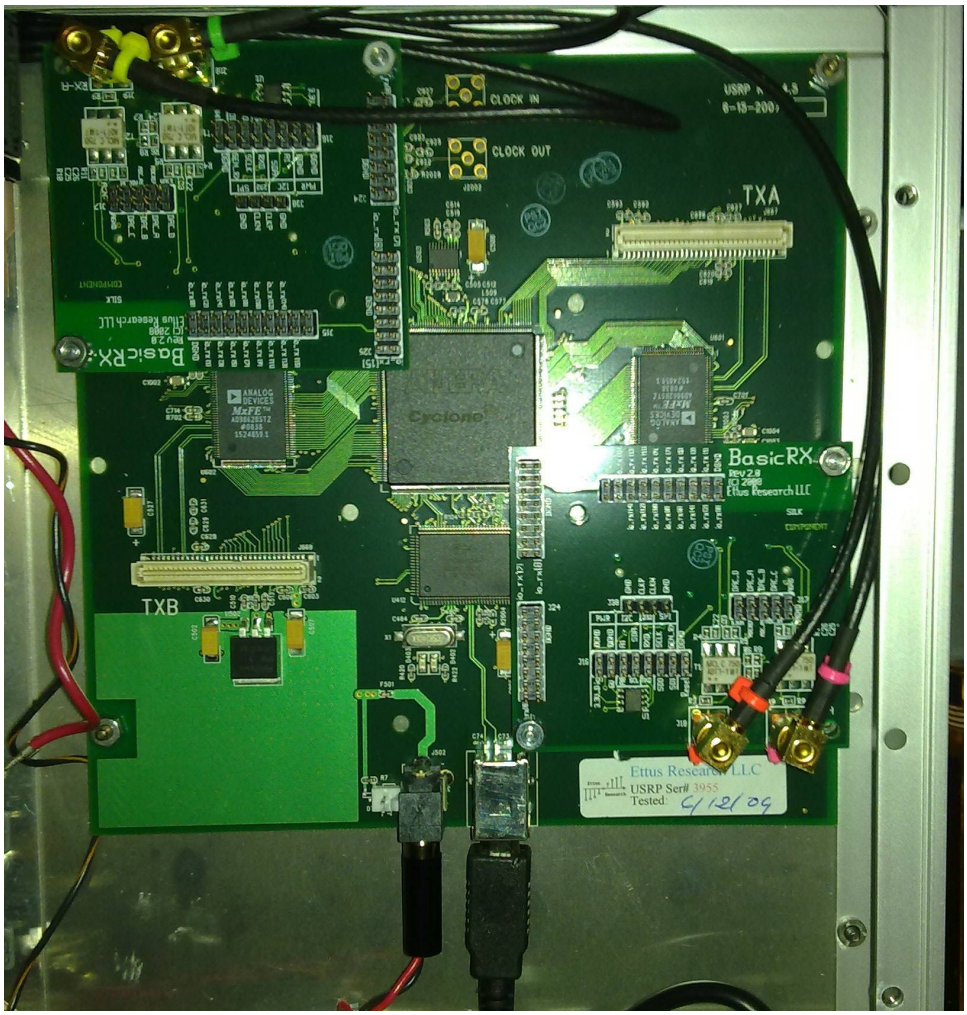

Figure 19: USRP motherboard with two BasicRX daughterboards.

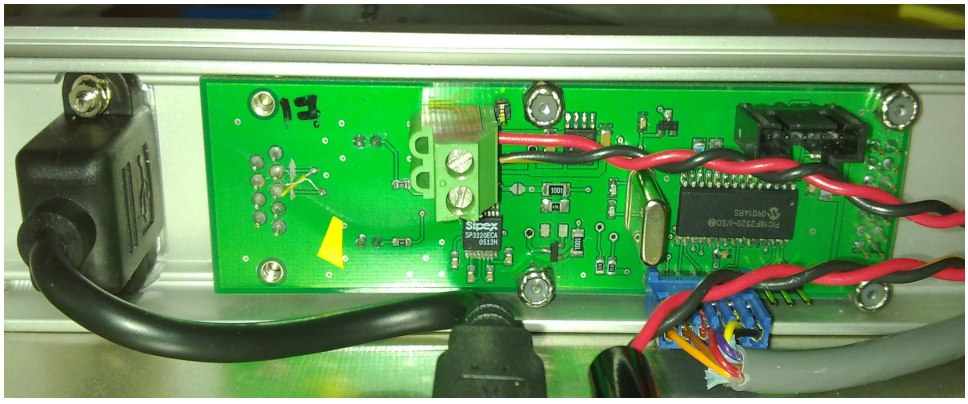

Figure 20: PIC Controller

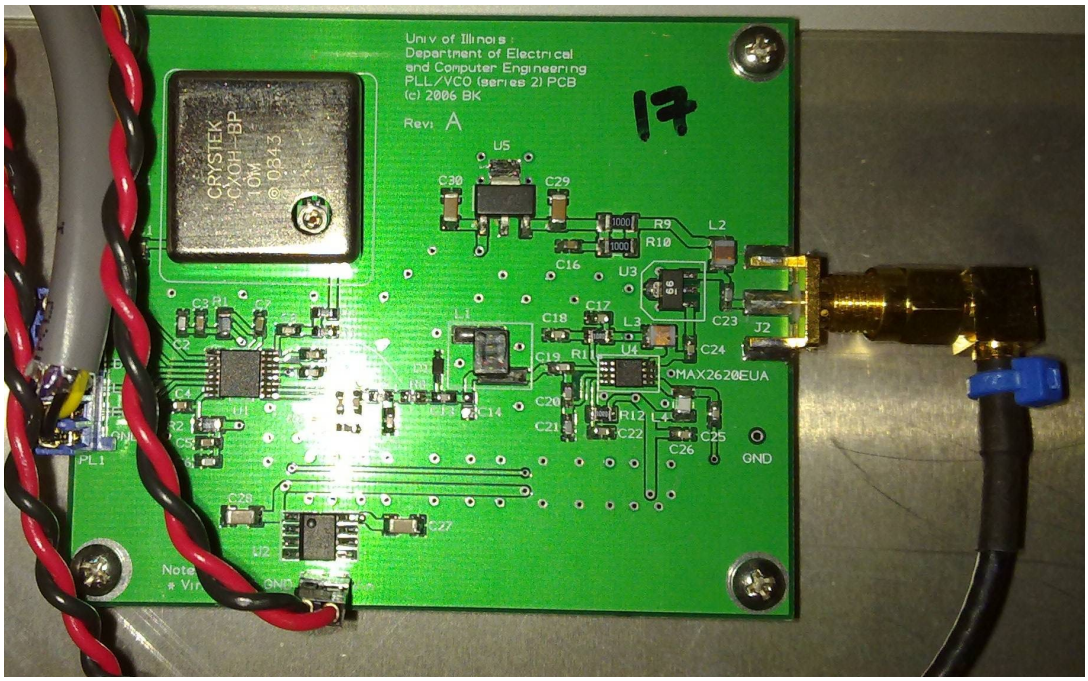

Figure 21: PLL/VCO

RMG Controller Firmware v1.0

The first local oscillator (1st LO) and LCD panel is controlled by a 18F2520 PIC processor. Communication to and from this processor takes place over the DB-9 connector by a 9600 baud 8n1 serial interface. When the RMG is used in the automated direction finding manner the software automatically handles the receiver tuning. However the following commands are available for manual operation.

All modes:
/ : Displays a brief status update
? : Brings up the command menu

Basic mode:
While in Basic Mode only these commands are available. For normal operations these are the only ones needed.
L : Loads the saved settings from the non-volatile memory (EEPROM)
S : Saves the current settings to the EEPROM
The settings that are saved are :

- Local oscillator reference frequency
- Channel spacing
- Current frequency
- R_counter register
- N_counter register
- Function register
- Maximum allowable frequency
- Minimum allowable frequency
- Display mode for the frequency on the LCD
- Contrast setting for the LCD

V : Toggles verbose mode
Verbose mode is off by default. With this enabled every command is echoed back with a short description.
0 : Reboots the PIC Controller
1 : Displays the restart reason
T : Changes the contrast of the LCD
Enter a number between 1-9, 1 being darkest and 9 being lightest. If the LCD does not seem to be on change this to 3 or lower.
P : Prints to LCD
First enter row (1 or 2), then the column (1-8), and then the string to be displayed. The second row updates with the lock status, therefore the second row is overwritten fairly quickly. The first row is only written to upon startup.
A : Toggles advanced mode
+ : Increases the current frequency by one channel spacing
- : Decreases the current frequency by one channel spacing

F : Changes the current frequency
Enter the new frequency in Hz. If it is not divisible by the channel spacing, the frequency is set to the closest multiple. If the new frequency is out of range the old frequency is retained. Verbose Mode is suggested for frequency changes as otherwise there is no feedback if the frequency is invalid.

Basic Mode menu:
University of IL - Electrical and Computer Engineering
RMG Tuner Controller v1.0 (c) 2007-9
(firmware by bkamen@benkamen.net)
(modified by serwy@illinois.edu)
==========
----System Actions:
L : Load settings from EEPROM
S : Save settings to EEPROM - Saved: No
V : Verbose mode toggle - (Off)
0 : 'Reboot' Controller
T : Set Contrast 1-9 (3)
P : Print to LCD (Row, Column, String)
A : Advanced Mode
----Frequency Actions:
+/- : Freq Up/Down (by 100000 Hz)
F : Set Output Freq
----PLL Status----------
PLL is LOCKED : Freq is 234500000 Hz

Advanced Mode:
While in Advanced Mode both these commands and the Basic Mode commands are available. These commands will only be needed if there is a change in the hardware configuration of the RMG.

I : Initialize the pll
This is performed on start up. This writes all of the PLL Registers.
W : Writes the N register to the pll
This is automatically performed after any change in frequency.
C : Sets the channel spacing
X : Sets the reference oscillator spacing
R : Sets the R_counter
N : Sets the N_counter
U : Sets the function register
O : Changes the calculation for the frequency display
    0 : Displays the pll frequency with no adjustment
    1 : Displays the RF center frequency based on High LO (PLL – IF [70 MHz])
    2 : Displays the RF center frequency based on Low LO (PLL + IF [70 MHz])
Q : Changes the maximum allowable pll frequency
Enter the frequency in Hz. There is no sanity checking so be sure the value is valid.

Z : Changes the minimum allowable pll frequency
Enter the frequency in Hz. There is no sanity checking so be sure the value is valid.

Advanced Mode menu:

Advanced Mode - Be Careful
----PLL Actions:
I : Init
W : Write N (ONLY)
----PLL Registers (non-volatile) - Written: No
C : Set Ch Spacing (100000 Hz / 0x000186A0)
X : Set Ref OSC Frq (10000000 Hz / 0x00989680)
R : Set R Counter   (000100d / 0x00000064)
N : Set N Counter   (271521d / 0x000424A1)
U : Set Function Reg(0x00000024)
----Frequency Settings
O : Set LO Display Calc - High LO
Q : Set Frequency Max (248000000 Hz)
Z : Set Frequency Min (218500000 Hz)

A : Return to Basic Mode