Subject: Results of IF2 Power Alignment of RR Correlator	**Date:** April 2, 2007 2007-DK002	**From:** Derek Kubo Peter Oshiro
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Reference: Memo 2007-DK001

Introduction

The Marki correlator modules have been empirically characterized to operate at maximum efficiency with IF input signal levels of -12 dBm (0.063 mW). Operating with either more or less input power tends to lower the SNR due to compression or backend noise contributions. Thus it is our desire to set the operating point to -12 dBm for all 42 correlator modules (21 modules per correlator frame).

The challenge in accomplishing this task lies with the fact that all of the hardware resides in an outdoor mountain environment where temperature variations are quite large. Amplifier gain generally increases with lower operating temperature. The IF path between the SHM outputs and the correlator module inputs consist of five individual sections of amplification, each of which contribute to gain variations.

This problem of gain variation with respect to temperature is presently being addressed in two ways. The first is with the use of actively servoed fan controllers to stabilize the temperatures of the Receiver IF/LO boxes (qty of 7), 1st Section Electronic boxes (7), and Correlator frames (2). The goal of this approach is to provide constant temperature and gain over periods of one to two hours. Calibration on strong astronomical sources can verify the gain stability over these timescales. The second approach is the use of the Total Power Detector system to periodically servo the gain of the VGAs. This will be done only occasionally such as at the beginning of an observing run, and possibly a few times during the night if deemed necessary. It should be noted that calibration will be required each time the VGAs are servoed to accommodate for changes in gain and phase.

This memo documents the approach, hardware configuration changes, and the results of establishing -12 dBm into the correlator modules within the RR Correlator frame.

Summary

The IF2 system was aligned over a period of several days to achieve the target levels at the specified interfaces shown below. With the exception of the correlator module inputs, these interfaces are easily accessible. The target levels were empirically derived to ensure that we are operating well below the P1dBc for each section.

Receiver IF/LO box output:	0 dBm
1st Section Input:	-12 dBm
1st Section Output:	-7 dBm (target counts are associated to this level)
Correlator Frame Input:	-23 dBm
Correlator Module Input:	-12 dBm

We can accommodate for gain variations up to and including the 1st Section outputs by reading the counts from the TP Detectors and adjusting the VGAs accordingly. During this process of alignment, we discovered that the counts generated by the TP Detector system is sensitive to temperature and therefore limits its accuracy. We will have to re-characterize the power to counts map after the 1st Section electronics boxes have been stabilized with fan speed controllers.

In addition, we aligned the attenuators within the RR correlator frame with it retracted from the platform and with both covers removed. The ambient shelter temperature during this alignment was 12 degrees C. We expect the component temperatures to increase with the doors installed and result in a corresponding drop in input power to correlator modules. Counter to this, however, is that normal operation with the shelter open will reduce the ambient temperature (it was 3 degrees C outside of the shelter at 2AM). We have outfitted the RR correlator frame to monitor the output levels of five horizontal power dividers to quantify any change in gain. We can accommodate for gain changes by adjusting the VGA or by changing pads at the Correlator frame inputs.

We plan to evaluate the results of the of this IF2 alignment effort prior to proceeding with IF1.

IF System Alignment Overview

Figure 1 depicts the IF2 system schematic up to the 1st Section module outputs. The Miteq VGA within the Receiver IF/LO box is controlled by an ADAM controller module which is physically located within the 1st Section Electronic box. The VGA is adjusted to provide ~0 dBm at the IF/LO box output. Pads AT3 and AT4 are SIT (select in test) adjusted to produce approximately -12 dBm at the 1st Section input connector. AT5 (flange pad) is SIT adjusted to provide the desired 5 dB gain through the 1st Section module, thus producing -7 dBm at the power divider output. AT10 is universally changed from 9 dB to 12 dB for all modules. Access to both AT5 and AT10 require the removal of the module from Electronics box. Pot SVR1 (SVR2 for IF1) of the TP Readout board is left in its stock setting of producing 0.000V at IC2-6 (IC5-6 for IF1) with the input disconnected and terminated to 50 Ohms. Common pot SVR3 is adjusted to produce 1.200V instead of the stock 1.500V setting at IC7-1 (IC7-2 for IF1) with the input still terminated to 50 Ohms.

With the above alignment complete, the VGA control voltage is stepped in increments while recording the 1st Section output power (using a power meter) and TP counts from the mbtp terminal window of the correlator program. Once that is complete a relationship between counts and output power is established and a unique target count is assigned to each antenna IF. A software utility generated by Chia-Hao Chang automatically adjusts the VGA control voltage to achieve the target counts. This action establishes a 1st Section output power level of approximately -7 dBm for each of the antenna IFs.

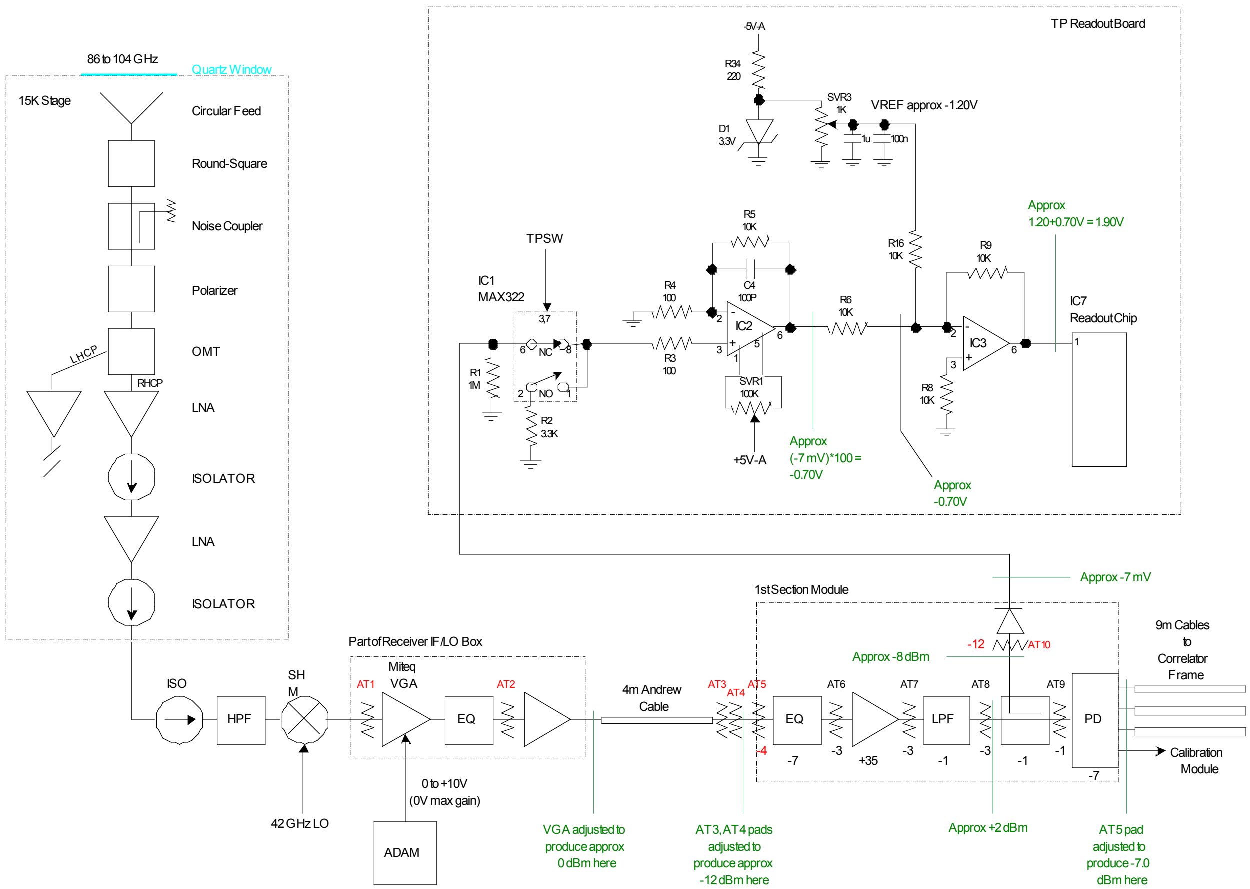

Figure 1 Power Profile Diagram of Receiver Output to 1st Section Output

Figure 2 depicts the IF power profile for the Correlator frame. The 2nd Section in the figure represents the -1 design which includes two input channels, phase shifters, and switch SW. The output of the -1 design feeds the vertical 3rd Section power dividers. The -2 design deletes the second input, phase shifters, and switch and is replaced by a length of coax to equalize the delays between the two designs. The output of the -2 design feeds the horizontal 3rd Section power dividers. Both -1 and -2 plate designs contain six channels. Because of limited accessibility, we do not attempt to SIT the internal pad values of the 2nd Section plate. With the VGAs converged to output -7 dBm from the 1st Section outputs, pad AT11 is adjusted to produce -23 dBm at the Correlator frame input. Thereafter, AT18 is SIT adjusted to produce -12 dBm at the 3rd Section outputs which interface directly to the correlator modules via the BMA connectors.

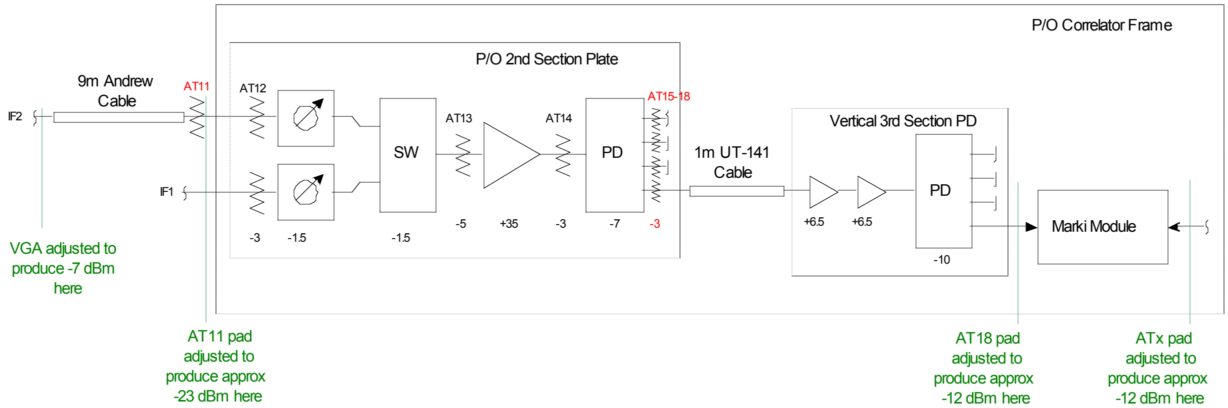

Figure 2 Power Profile Diagram of Correlator Frame

Detailed Alignment Results

1) Determination of Operating Point for Receiver IF/LO Box Output: With all of the VGAs set to 0V (minimum attenuation), we looked at the sky through the shelter and measured the 14 receiver output power levels with the results shown in *Table I*. Note the large variation with minimum and maximum values of +2.7 and +9.2 dBm, respectively. Based on these values we selected a nominal Receiver IF output operating point of 0 dBm while looking at the sky.

Table I Receiver IF Output Levels with VGA Control = 0V, Load = Sky (through shelter)

ANTENNA	1	2	3	4	5	6	7
IF1	+8.8	+6.7	+7.0	+6.3	+4.2	+3.5	+5.8 dBm
IF2	+2.7	+8.9	+9.2	+3.7	+9.0	+5.0	+7.3 dBm

2) Adjustment of Pads at End of 4m Cables: With the absorbers[1] on each of the receivers, we adjusted the VGAs to produce 0 dBm at the IF2 outputs of all 7 Receiver IF/LO boxes. Next we adjusted the pads at the end of the 4m Andrew cables to produce -12 dBm at the input to the 1st Section modules. There are two pads in cascade, Inmet (short), and JFW (long), *Table II* shows the values before and after the adjustments. Note that the reduction in pad values enables the capability to either increase or decrease the Receiver IF/LO output levels.

Table II IF2 Pad Values at End of 4m Andrew Cable (input to 1st Section)

ANTENNA	1	2	3	4	5	6	7
was (short)	10	10	10	10	10	10	10 dB
was (long)	2	7	7	7	6	4	7 dB
Total	12	17	17	17	16	14	17 dB
now (short)	1	2	2	2	2	2	2 dB
now (long)	7	7	7	6	7	7	7 dB
Total	8	9	9	8	9	9	9 dB
Delta	-4	-8	-8	-9	-7	-5	-8 dB

3) Characterization of VGA Control vs 1st Section Input Power: With the above pad adjustments complete, we characterized the 1st Section input power (mW) verses the VGA control voltage during the day with the shelter closed (absorbers still on receivers). Refer to *Figure 3* for plots. Note that the absolute gain of the IF/LO box will change with temperature and will in effect shift the vertical axis (more power at night). The 1st Section target input level of -12 dBm is equavalent 0.063 mW. Adjusting the VGA control from 0 to 1 V produced no noticeable change in power.

[1] Absorbers were used to maintain a constant receiver output level independent of atmospheric conditions.

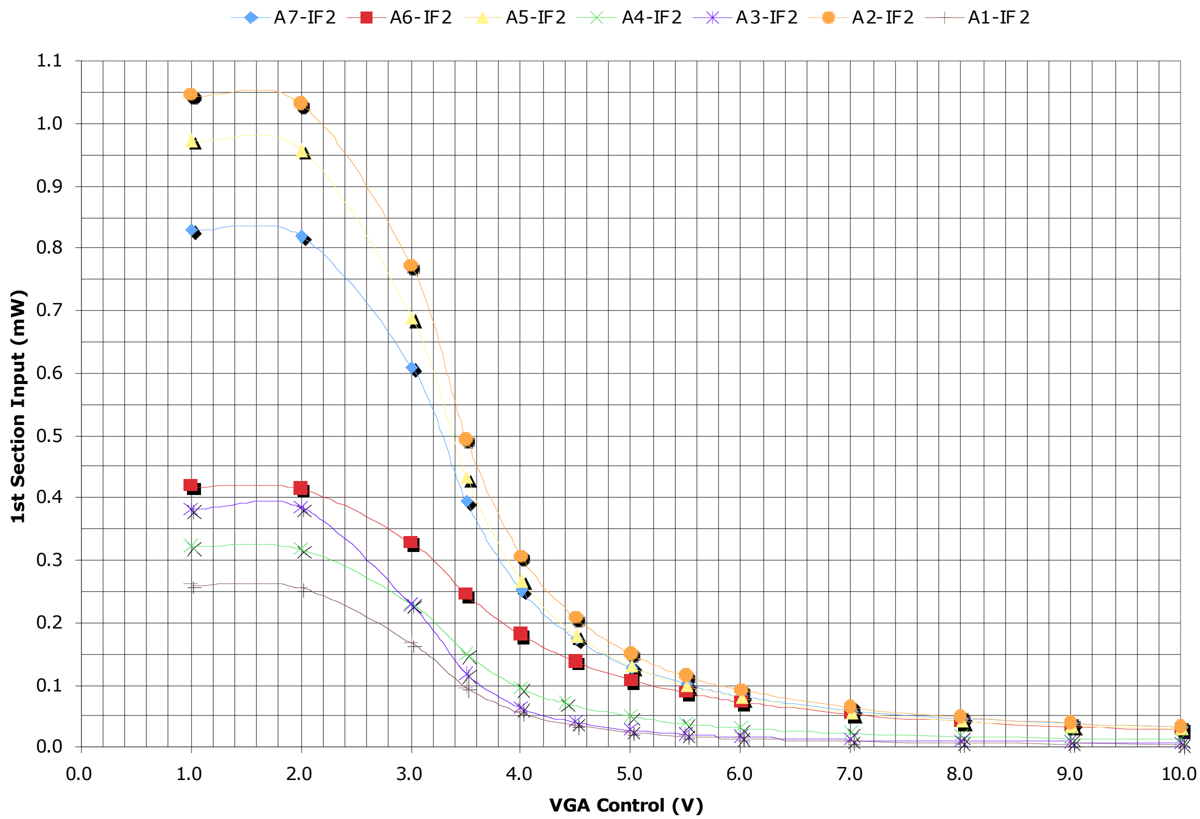

Figure 3 1st Section Input Power verses VGA Control Voltage

4) Adjustment of 1st Section Module Gains: We characterized the input P1dBc of A7-IF2s 1st Section module to be -1.2 dBm, or +3.8 dBm as referred to the output. Based on this compression value, we established a desired output operating point of -7.0 dBm which is well into the linear regime.

Since we knew we had to increase AT10 from 9 dB to 12 dB for all modules, we decided to SIT adjust AT5 to produce a consistent gain of 5 dB. The stock value for AT5 is 4 dB, refer to Table III for updated values. The plots shown in *Figure 4* represent the input verses output levels for all seven modules. The module for A4-IF2 had to be replaced due to a bad filter and we neglected to update the flange pad (should be changed to 6 dB), hence the additional gain.

Table III 1st Section Module Configuration

Antenna	1	2	3	4	5[2]	6	7
SN	008	007	006	016[3]	002	014	001
AT5	4	5	4	4	4	6	4
AT7	3	3	3	3	2	3	3

5) Characterization of Total Power Detector System: *Figure 5* shows plots for the Krytar detector output voltage verses the 1st Section output power. Note that the additional gain for antenna 4 does not show up here because we are plotting output detector voltage against output power. The outputs appear nicely consistent. *Figure 6* represents the input voltage to the readout chip (IC7-1 in *Figure 1*) verses output power. Notice again the nice consistency with the exception of antenna 4. We've isolated this problem to antenna 4's TP Readout board but I believe we can live with it for now. *Figures 7* and *8* represent TP counts verses the 1st Section output power. The counts were read from the mbtp terminal window using the rms command. I separated the plots for antennas 6 and 7 because these counts read significantly higher than the others. As a quick test to isolate these high counts we took the readout ribbon cable from antenna 2 and plugged it into antenna 7's data acquisition input. The counts increased by a factor of 1.99 which indicates the problem is related to the data acquisition board. Again, we can live with it for now.

[2] Minimum flange pad value on hand is 4 dB so we changed AT7 from 3 to 2 dB.
[3] Originally SN011 but damaged while replacing pads, replaced with SN016 on March 13, 2007.

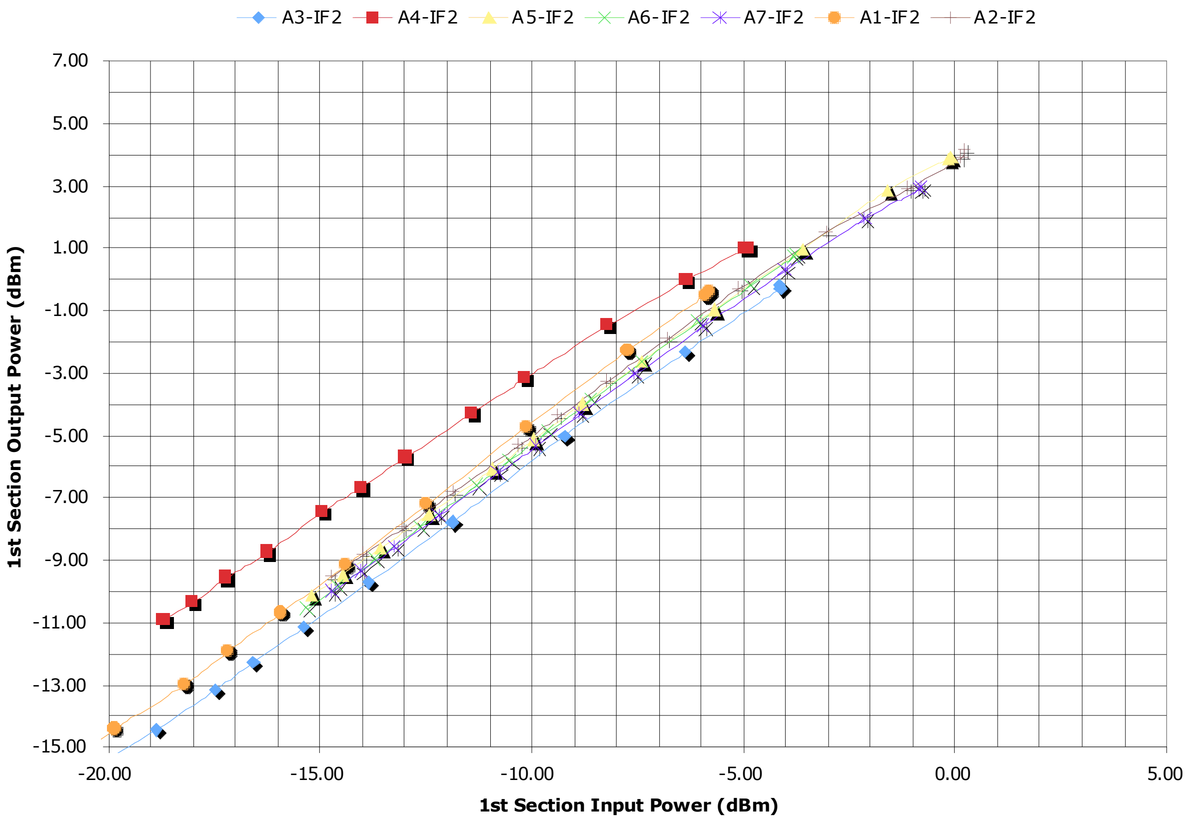

Figure 4 1st Section Output vs Input Power

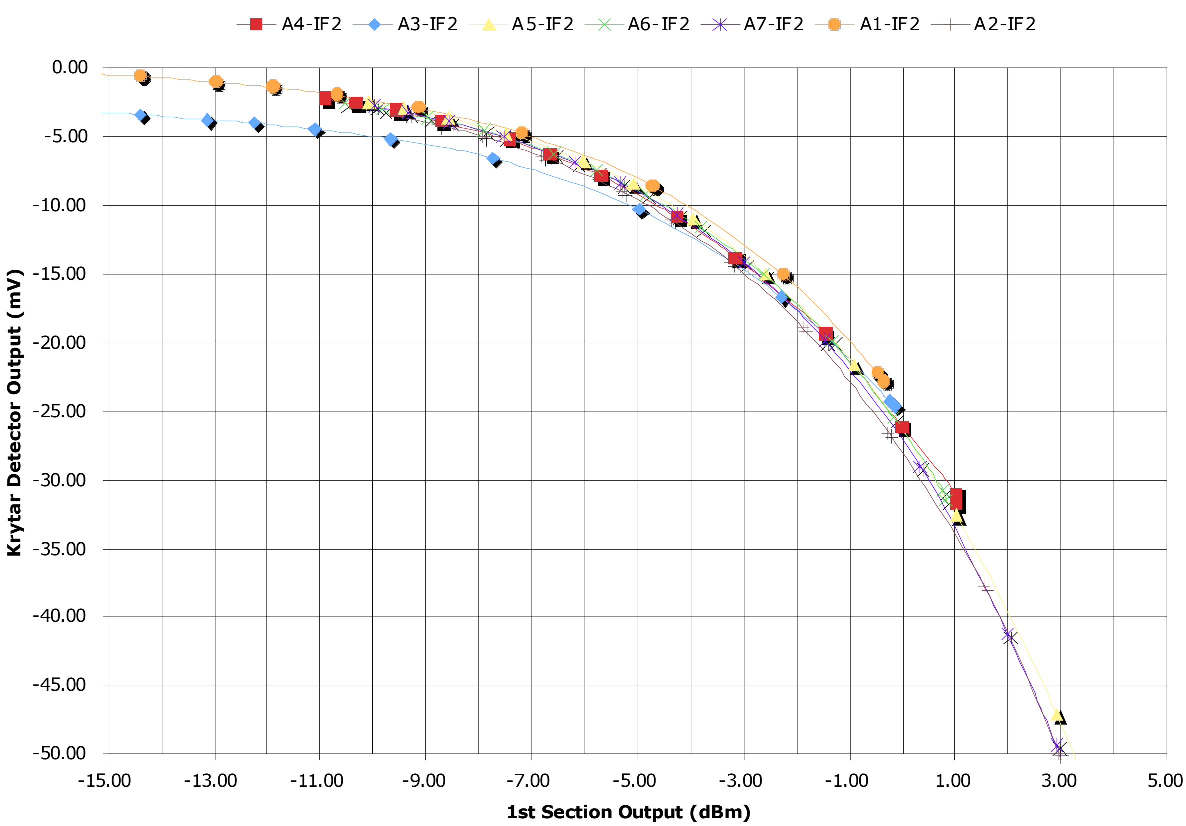

Figure 5 Krytar Detector Output verses 1st Section Output Power

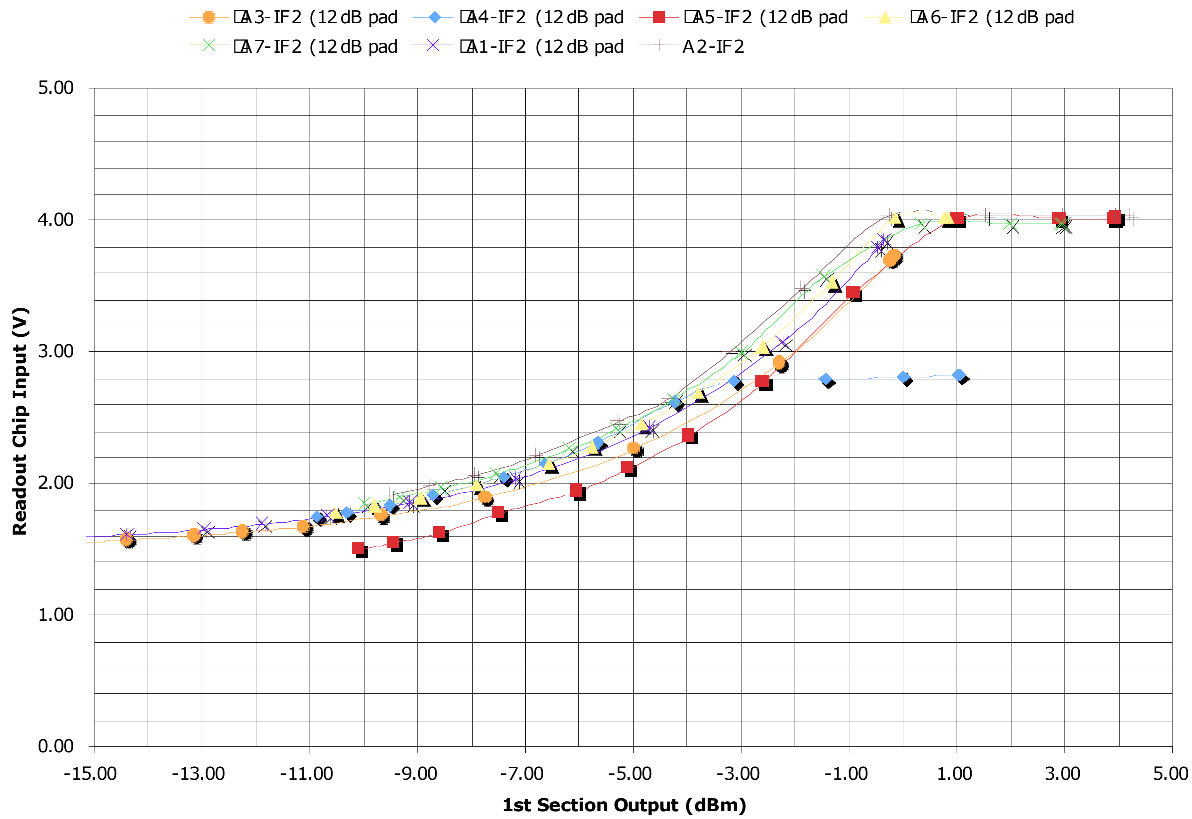

Figure 6 Readout Chip Input Voltage verses 1st Section Output Power

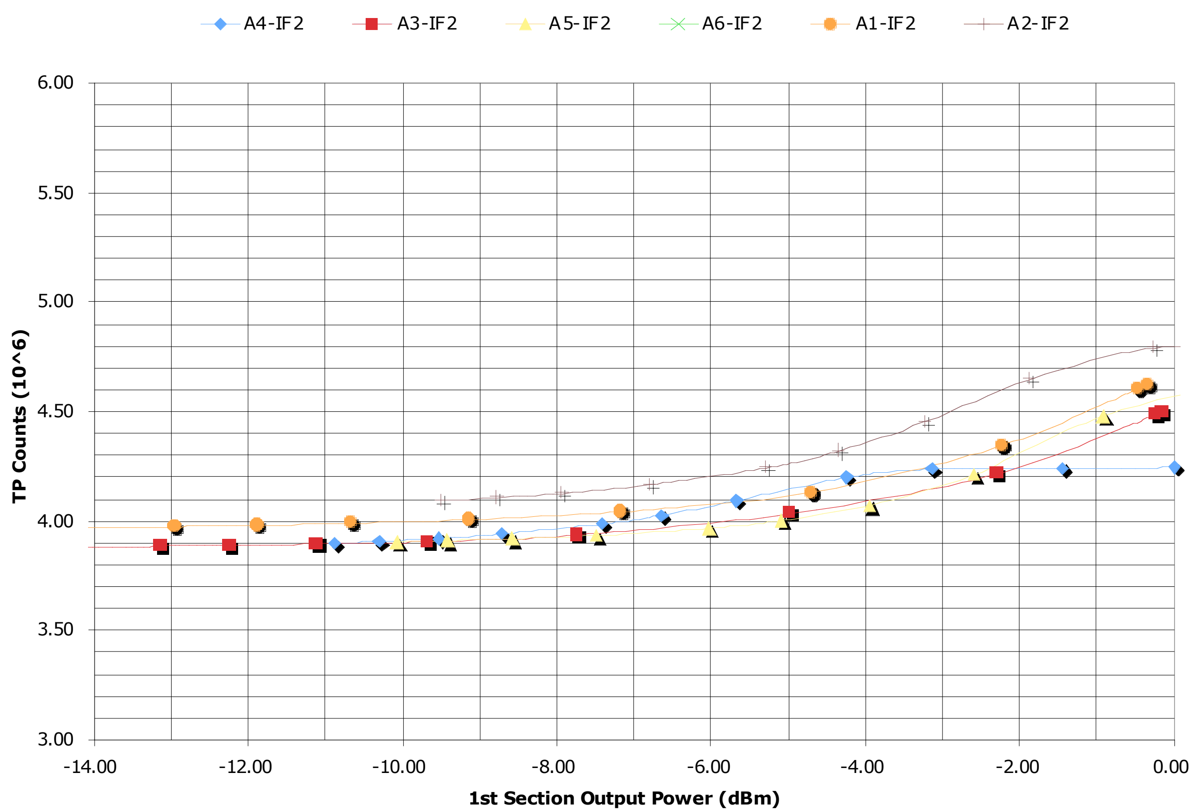

Figure 7 Counts verses 1st Section Output Power, Antennas 1-5

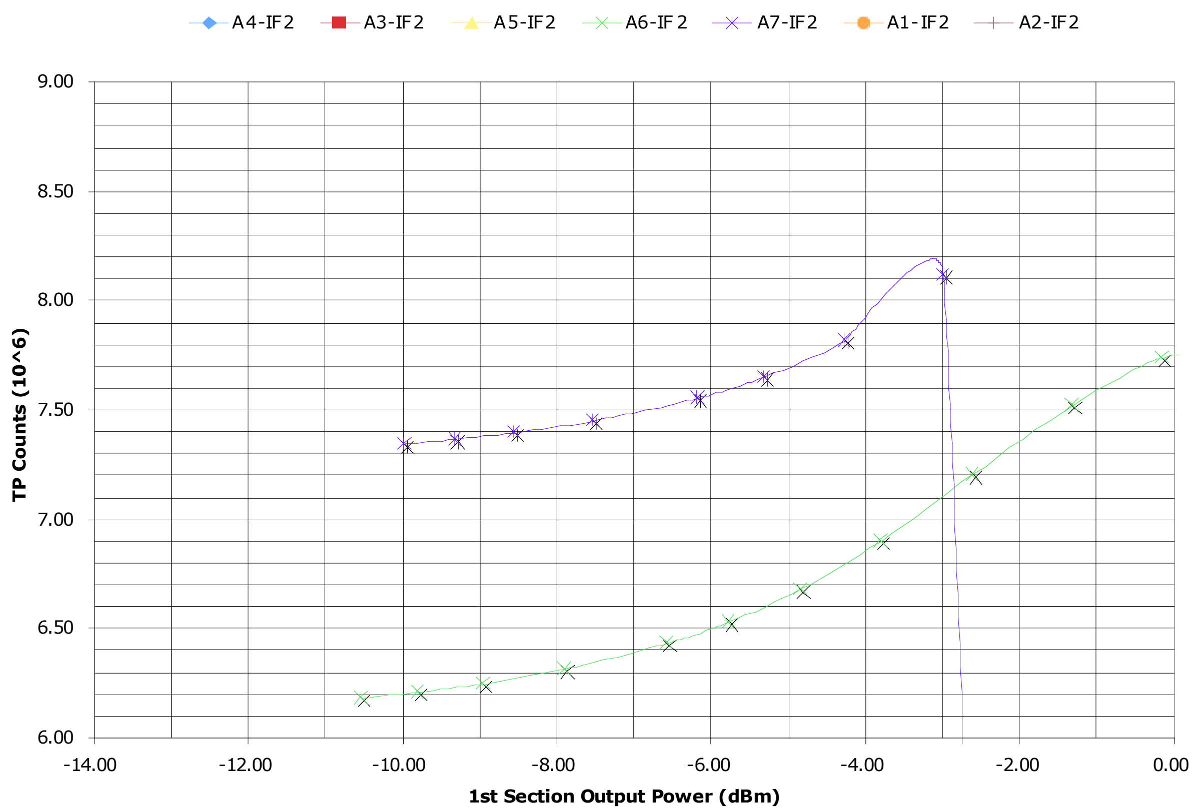

Figure 8 Counts verses 1st Section Output Power, Antennas 6 and 7[4]

The plots shown in *Figures 7* and 8 can be approximate with the following quadratic relation:

Counts (10^6) = Ax^2 + Bx + C, where x is the output power in mW.

Similarly, given counts one can calculate the output power from the 1st Section using the following:

Power (mW) = [-B + sqrt(B^2 - 4A(C - y)]/2A, where y is given in Mega-counts

Table IV TP Detector Coefficients and Target Values

	A (day)	B (day)	C (day)	Target (day)	Target (night)
A1-IF2	0.3008	0.4584	3.9544	4.0580M	4.033977M
A2-IF2	0.4750	0.6903	4.0091	4.1660M	4.095708M
A3-IF2	0.1787	0.4925	3.8626	3.9690M	3.975241M
A4-IF2	0.3700	0.8747	3.8257	4.0150M	3.987288M
A5-IF2	0.8896	0.1004	3.8919	3.9480M	3.935159M
A6-IF2	0.7081	1.8126	6.0117	6.4030M	6.221052M
A7-IF2	1.6269	0.9528	7.2363	7.4920M	7.312401M

CAVEAT! – The characterization of the Total Power Detector system was conducted during the day and as we found out later the values in *Table IV* were not applicable during the evening when the hardware temperature has cooled down. Converging the VGA using the daytime values during the evening resulted in the following 1st Section output levels: -5.9, -5.3, -5.9, -6.5, -5.2, -5.1, -5.0 dBm for antennas 1 through 7, respectively. Re-converging using the night time values resulted in: -7.0, -7.0, -6.8, -7.1, -7.0, -7.0, -7.1 dBm. So it is clear that the TP Detector system is not stable with respect to temperature.

[4] Negative counts for antenna 7 is a result of overflow into the 24th sign bit.

6) Adjustment of Pads at End of 9m Cables: With the 1st Section output levels set to -7 dBm, we adjusted the pads at the end of the 9m cables to produce approximately -23 dBm at the inputs to the Correlator frame. *Table V* shows the results of this effort.

Table V IF2 Pad Values at End of 9m Andrew Cable (input to RR Correlator frame)

ANTENNA	1	2	3	4	5	6	7
Pad Value, was (front)		4	2	1	3	5	2 dB
Pad Value, now (front)		8	9	9	10	9	9 dB
Delta	NA	+4	+7	+8	+7	+4	+7 dB
Pad Value, was (rear)	2	5	3	2	4	5 dB	
Pad Value, now (rear)	9	8	10	9	12	8 dB	
Delta	+7	+3	+7	+7	+8	+3 dB	NA
Input Pwr, now (front)	NA	-22.6	-22.6	-22.9	-21.9	-23.5	-23.1
Input Pwr, now (rear)	-22.5	-21.6	-23.3	-22.7	-23.3	-22.6	NA

7) Adjustment of Pads at 2nd Section Outputs: The final adjustment involved the SIT of pads at the 2nd Section Merrimac power divider outputs (refer to *Figure 2*) to achieve -12 dBm at the 3rd Section power divider outputs. This selection of pads compensates for gain variations in both the 2nd and 3rd Sections. The stock pad values for all of the 2nd Section outputs are 3 dB. There is one pad associated to each 3rd Section power divider.

Figure 9 depicts the physical configuration of the correlator frame as viewed from the front. Inputs to the ten horizontal power dividers come from the upper 2nd Section plate labeled with 1R, 2R, .. 6R. Both sets of SMA(f) connectors physically face forward toward the viewer. The inputs to the eight vertical power dividers come from the lower 2nd Section plate. Both sets of these SMA(f) connectors face rearward away from the viewer.

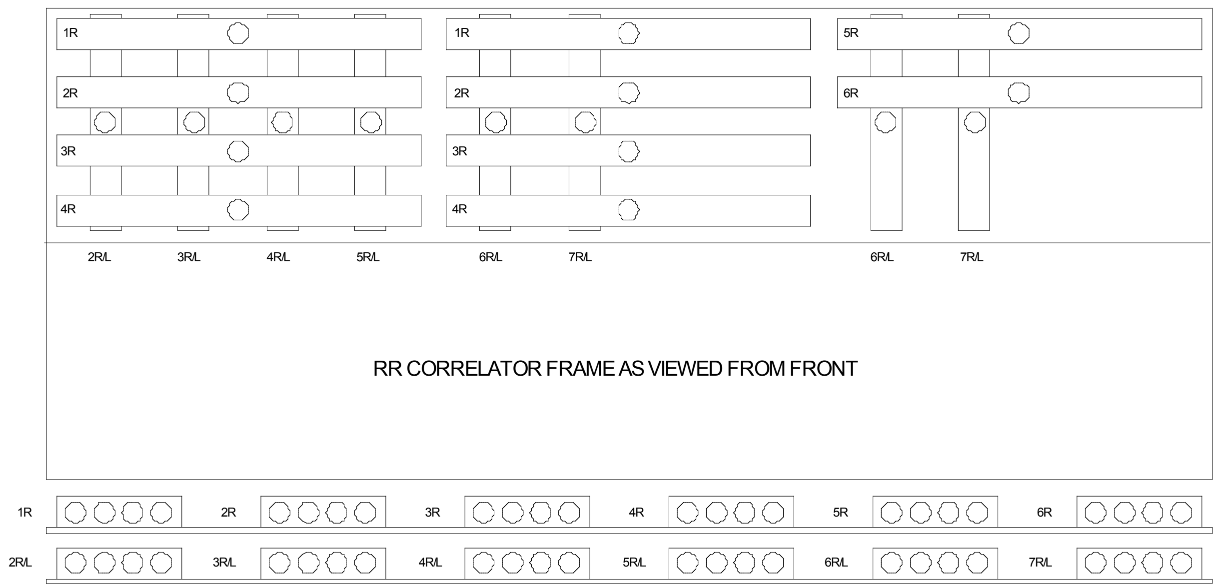

Figure 9 View of Correlator Frame from Front

Table VI Pad Values at Merrimac Power Divider Outputs (stock value = 3 dB)

<table>
<tr><td colspan="4">1R = 6 dB</td><td colspan="4">1R = 5 dB</td><td colspan="4">5R = 7 dB</td></tr>
<tr><td colspan="4">2R = 4 dB</td><td colspan="4">2R = 5 dB</td><td colspan="4">6R = 8 dB</td></tr>
<tr><td colspan="4">3R = 7 dB</td><td colspan="4">3R = 7 dB</td><td colspan="4"></td></tr>
<tr><td colspan="4">4R = 5 dB</td><td colspan="4">4R = 2 dB</td><td colspan="4"></td></tr>
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7 dB</td><td></td><td></td></tr>
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Table VII Final 3rd Section Power Divider Output Levels (dBm)

1R = -11.2				1R = -11.1				5R = -12.3			
2R = -10.9				2R = -11.3				6R = -11.7			
3R = -11.6				3R = -11.8							
4R = -11.5				4R = -12.5							
2R/L -11.5	3R/L -11.9	4R/L -11.6	5R/L -11.9	6R/L -12.4	7R/L -11.8			6R/L -12.2	7R/L -11.5		

Table VI shows the updated pad values (initial stock values are 3 dB). The resulting 3rd Section power divider output levels are shown in *Table VII*. We performed the measurement on only one output port for each power divider with the other three ports terminated to either the correlator modules or 50 Ohm BMA termination. Thus we are making the assumption that all four output ports of the 3rd Section power divider have equal outputs. Note that these values are fairly close to our target of -12 dBm, with minimum and maximum values of -12.5 and -10.9 dBm. As an example of how to read the table, the input levels to the 1R3R correlator module are -11.2 dBm (front) and -11.9 dBm (rear). 3R6R is -11.8 dBm (front), -12.4 dBm (rear).

It should be noted that the SIT alignment of the Correlator frame pads were conducted with the frame retracted from the platform and with both front and rear covers removed. The adjustments and measurements were conducted between midnight and 2AM with the shelter closed. The internal temperature of the shelter was held at 12 degrees C throughout the alignment period. Adding the covers back on will likely increase the operating temperature within the correlator frame, however, operating with the shelter open will likely have the opposite effect of cooling it down (outdoor temperature at 2AM was 3 degrees C). In order to monitor the effect we added test point cables to the unused outputs of horizontal power dividers 2R, 3R, 4R, 5R, and 6R, and brought them out via unused feed-through connectors at the bottom of the correlator frame. The measured levels with the frame open were: -15.7(?), -12.7, -13.8, -13.1, and -12.9 dBm for 2R through 6R, respectively. We plan to re-measure these levels during a typical observing evening with the shelter open.

<u>8) Correlator Drive Levels Prior to Alignment:</u> We did not make an attempt to characterize the drive levels out of the 3rd Section modules prior to this alignment effort due to the difficulty involved. We did, however, take spot measurements on at least two occasions when replacing correlator modules and saw levels of -4 and -5 dBm during the day with the shelter closed. This lead me to believe that the actual drive levels during an evening observational run was possibly around 0 dBm if the VGAs were all set to 0V which was normally the case.

Prior to this alignment effort, we took a set of power level measurements at the RR Correlator frame input while the receivers were looking at the sky through the shelter and with the VGAs all set to 0V. Comparing these previous input values with those listed in *Table V* and the updated internal pad values shown in *Table VI*, we can indirectly determine the amount of offset to add to the values listed in *Table VII*. *Table VIII* shows the final results of input power to the Marki correlator modules.

Table VIII Estimate of 3rd Section Power Divider Output Levels (dBm) Prior to Leveling Effort

1R = -2.3				1R = -3.2				5R = -1.6			
2R = -5.7				2R = -5.1				6R = -1.9			
3R = -1.5				3R = -1.7							
4R = -7.2				4R = -11.2							
2R/L -3.3	3R/L -1.6	4R/L -2.9	5R/L -0.6	6R/L -4.4	7R/L -0.6			6R/L -3.2	7R/L -1.3		

Note that these results are a mixture of different operating temperatures. The input levels to the RR Correlator frame were measured during the day, and the relative 3rd Section power divider output levels were measured during the evening with the frame doors removed. The most significant aspect to realize is that the gain from the Receiver IF/LO box output to the Correlator frame input varies significantly from day to night. For a fixed VGA setting we've seen the power increase by approximately 4 dB from day to night. Thus, during a normal evening observing run the drives to the correlator modules may actually be ~4 dB higher than those shown in *Table VIII*. This is a significant departure from our desired drive of -12 dBm.

Conclusions and Recommendations

1) The IF system gain varies by more than 4 dB from day to night (more gain at night).

2) The VGA system can compensate for all of this variation up to the 1st Section outputs. Gain variations within the 2nd and 3rd Sections can be compensated for as well, however, we do not at present have a convenient feedback metric to accomplish this. We should investigate and experiment with the possibility of using the correlator RMS as feedback.

3) The VGA controls for IF1 and IF2 are currently swapped for antennas 1 and 2. I.e., when you control IF1 in software you affect the IF2 VGA and visa-versa. This needs to be fixed.

4) The TP Detector system provides useful feedback for setting the VGA gains. We have also found that we can transform counts to power which provides us with useful metrics about the absolute receiver stability performance. The down side for the TP Detector system is that its accuracy is temperature dependent. We need to stabilize the temperature of the Electronic boxes, and thereafter re-characterize the relationship between counts and power.

5) The TP Detector readout board for A4-IF2 needs to eventually be replaced due to a clamping effect shown in *Figure 6*. Replacement of this board will require re-characterization of counts to power so this should be done only after the completion of the thermal stabilization efforts.

6) The TP Detector counts for A6-IF2 and A7-IF2 read about a factor of two higher than the rest. I believe the cause is within the Data Acquisition board(s). These two issues should be investigated further and fixed.

7) Chia-Hao Chang's VGA software convergence routing works well (see his blog entry on March 26 for instructions). The error margin is currently set to +/-5000 counts which translate to approximately +/-0.2 dB power error. The software is a bit cumbersome to use but I am hoping it will be more user friendly once it is incorporated into the rpfits program.

8) The Receiver IF/LO boxes need to be thermally stabilized to minimize gain variations between VGA updates.

9) The Correlator frames need to be thermally stabilized to maintain 2nd and 3rd Section gains.

10) The 1st Section module for A4-IF2 was swapped due to a damaged LPF. We still need to increase the flange pad value from the stock 4 dB to 6 dB. I should also mention that there will likely be a small delay change for this IF path due to the module swap.

11) The delay compensation cables located at the bottom of the Correlator frames are quite fragile. Peter and I broke one each and were fortunate to find exact replacement lengths. I am recommending that we place the delay cables within the correlator frame. In fact, it would be best if these custom length delay cables can replace the existing semi-rigid cables which span from the feed-through connectors to the 2nd Section inputs. This cable within the frame should be the same flexible type but with SMA(m) connectors at both ends.

12) We replaced correlator modules 1R4R and 2R4R at Chao-Te's request.