EVLA Memo #184
Gain and Pdiff Compression in the EVLA IF Signal Path: Strategies for Identification and Mitigation

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1 Introduction

Despite the anticipated high dynamic range headroom guaranteed by the EVLA system design, we continue to experience gain compression (and in pathological cases, gain expansion), particularly in the switched power signal, when observing strong sources. The causes of these phenomena have been elusive, and repeatable test results have been difficult to acquire. This memo looks at methods for identifying the origins within the system, and eventual mitigation once patterns of behavior have been established.

Variation of power levels within an antenna, and between antennas, has obscured the gain compression behavior. We seek a method for determining and setting appropriate power levels, from the receiver output through the digitizer input, to ensure that we are maximizing the available dynamic range headroom.

2 Method

We are proposing a plan to go forward with receiver power-level measuring. We are agreed that simply measuring all output levels of all receivers on all antennas at once is possibly too burdensome, and that we should focus the effort on a smaller subset of antennas and receivers.

We propose the following plan to get started, which we believe would produce the best outcome with the least risk of wasted effort. We will start with X-band, since that involves the fewest electronic components intervening between receiver and digitizer, and presents the minimum-complexity case. In addition, the lessons of X-band are readily applied to other receiver bands.

1. In the lab, measure the 1dB compression point (at the output) of some X-band receiver. Compare this to the Noise Model and by extension the power level called out in the system block diagram.

2. Survey total power measurements from T304s and choose candidate antennas. These would include "typical" performing antennas, as well as antennas from either tail of the distribution.

3. Survey the results of the moon compression tests, again with an eye towards a "typical" antenna, a "perfectly linear" and a "highly-compressed" antenna. Ideally, there will be some overlap between the candidates selected in (2) and (3).

4. From the list of candidate "bad" antennas, apply the result of (1) to one or more receivers in the field, and repeat (2) and (3).

5. Extend the surveys to include C and Ku bands, thereby including the effects of the converter modules, and repeat steps (1) through (4).

6. Finally, apply the method to the remaining five cryogenic receiver bands. (P-band will be studied separately, due to its narrow bandwidth, and other considerations)

In this way, we can have some confidence that we are identifying the correct power levels, and that the effects are what we predict from both the monitored total power data and the moon compression tests, before we dispatch teams of FE techs to measure and set levels in all the antennas. If we work quickly enough, we can still hit the target of setting levels while we're in D configuration, but from a prioritized list rather than willy-nilly, and eventually we can extend this technique to include all receivers.

3 Assessing Total Power as Measured in the Field

The total power detectors in the LSC (T302) , UX (T303) , and Baseband (T304) converters can tell us much about the relative behavior across IF paths and between antennas. These are easily surveyed using the Monitor Data Archive, or the Monitor Point Table feature of the Device Browser. The T304 in particular provides a means of recording input-level variation across antennas and IFs, namely the Corrected Total Power method detailed in EVLA Memo 185. Using X-band data as a starting point, we turn to some examples of the analysis.

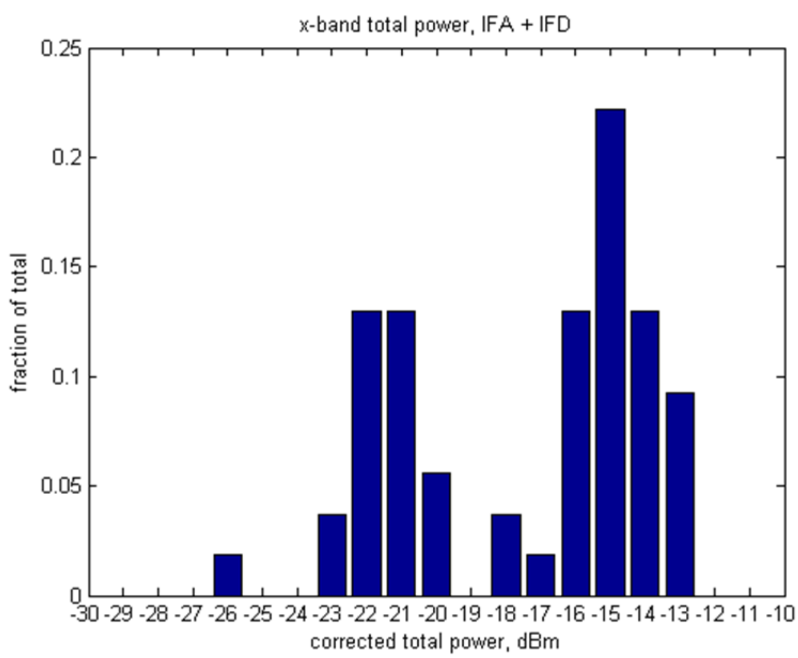

Figure 1: Distribution of X-band receiver total power across all antennas

3.1 Distribution of corrected total power measurements across all antennas

Plot histograms of Corrected Total Power (Total Power + baseband attenuator setting) for two IFs: A and D (one at each tuning at each polarization), and determine a value that represents a "typical" or "well-behaved" case, and one that represents an atypical or poorly-behaved case. From Figure 1, we can see that the distribution of receiver output total power is bimodal; about 1/3 of the receivers have a median value about 8dB lower than the other 2/3 of receivers.

3.2 Total Power by Antenna

Create antenna-based graphs of Total Power+ baseband attenuator setting for two IFs: A and D (one at each tuning at each polarization). Identify candidate "good" and "bad" antennas. From Figure 2, we would like to identify antennas where both IFs have total power in the lower mode of the distribution. By these criteria, we can identify the following antennas as "poor-performers" based on total power.

Antennas where both polarizations are near the median in the "good-performing" total power group: ea01, ea02, ea03, ea08, ea10, ea12, ea13, ea14, ea19, ea20, ea24, ea26, ea27

Antennas with low Total Power: ea06, ea07, ea10, ea13, ea17, ea18, ea21, ea22, ea25

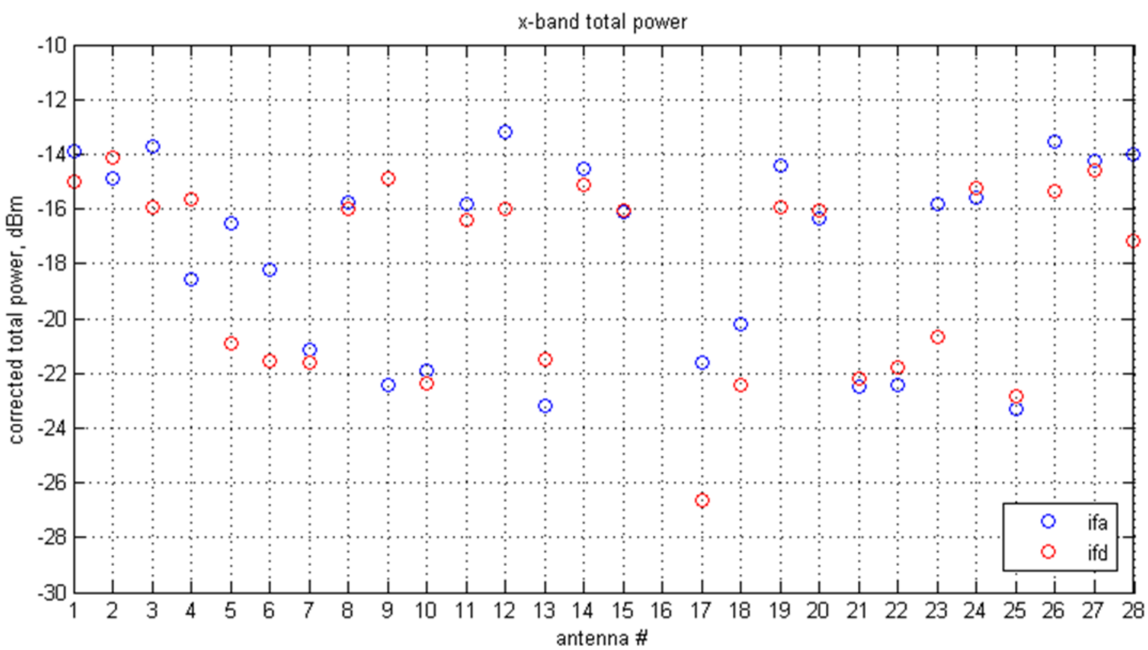

Figure 2: X-band receiver total power, by antenna

4 Moon Gain Compression Test

The moon presents a hot load to the VLA which is (a) resolved at all frequencies, (b) significantly increases system temperature at all frequencies, and (c) sufficiently constant in time (varies less than +/- 20% at all bands, for all moon phases) to provide a test of the linearity of the switched power signal in the presence of strong sources. The test consists of alternately observing cold sky and the moon, and measuring both P_{sum} (total power) and P_{diff} (switched power) at each. The resulting data can be used to identify and locate linearity bottlenecks in the EVLA signal path. Table 1 lists the sky frequencies and mean expected increase in system temperature at each band.

Table 1: Sky frequencies, beam coverage, and expected change in Tsys for moon versus cold sky.

Band	AC (MHz)	BD (MHz)	Beamwidth ratio $\theta_{Rx}/\theta_{moon}$	Mean T_B(K)	T_{SYS}	T_B/ T_{SYS}
L	1445	1804	0.98	240	30	8.0
S	2436	3328	0.56	240	30	8.0
C	4376	6498	0.30	242	30	8.1
X	8236	11108	0.17	242	30	8.1
U	13136	16608	0.11	242	30	8.1
K	25436	19436	0.071	245	40	6.1
A	36436	29436	0.048	245	45	5.4
Q	41936	47936	0.035	245	65	3.8

4.1 Repeatability

The test, if it is to be of any use in diagnosing the analog signal path, must produce repeatable results on different days, other things being equal. Maintenance activities occur sufficiently frequently that over any two-day period, the system can be said to be in the same state, but a month later is sufficiently different as to warrant another test. Therefore, TCAL0002 should be run twice per month, with no more than a two-day separation between instances.

4.2 Procedure

For each test, we look at the P_{sum} and P_{diff} ratios – on-moon versus off-moon. For each data set, we compare each receiver, at each antenna, to receiver band's median for all antennas. Antennas or receivers whose P_{sum} is sufficiently far from the median, either high or low, for all antennas requires further diagnostic attention. The specific mechanism for this is not yet understood.

4.3 Observe Script

The script *compression.evla* which runs as TCAL0002 uses an RFI-free subband at each receiver band so that the Pdiff and Psum solutions are free from external contamination. At L-band, this conditions requires a 32MHz-wide subband. All other bands use 128MHz subbands.

At each receiver band, the script runs one "dummy scan" of the moon, which is used to set the analog IF power levels, followed by one moon scan and one off-source scan. Once each of these three scans has been run for each receiver band, there is a final termination scan, which ensures that the final (in this case, Q-band off-source) scan completes.

4.4 Data Processing

The data processing routine consist of:

a) processing the visibility data in AIPS and writing one text file per IF for each quantity; and
b) calculating statistics by antenna and receiver band for each set of text files.

4.5 Distribution of P_{sum} and P_{diff} Across All Antennas

Plot histograms of P_{sum} and P_{diff} from the Moon Compression tests and identify candidate "good" and "bad" antennas, based on strong-source gain compression and fidelity of moon temperature measure. We shall start with the example of X-band data once again. Refer to the Appendix section for full data sets for four moon compression tests from two days in June 2014 and two days in September 2014.

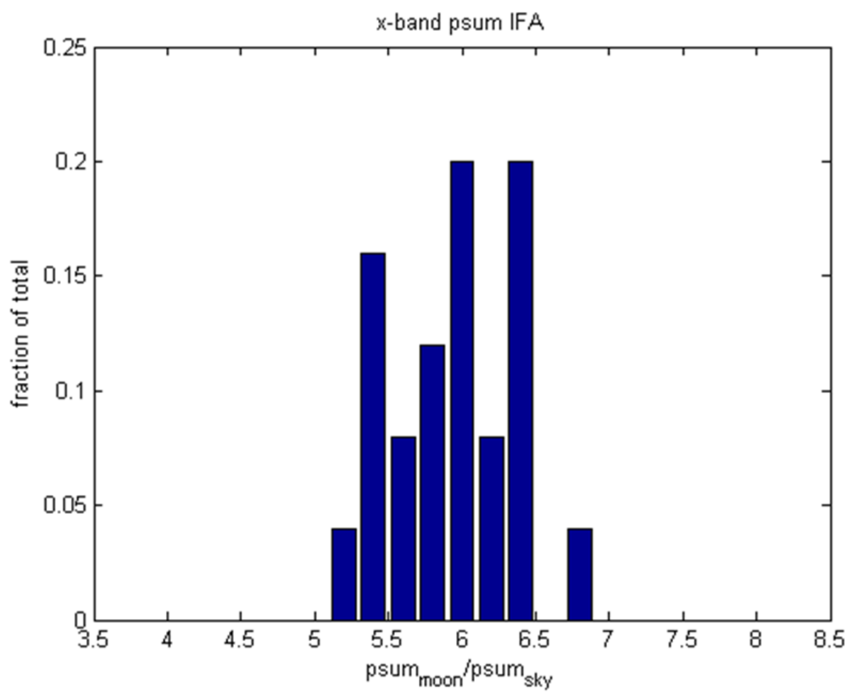

Figure 3: P_{sum} ratio (T_{moon}/T_{sky}) for X-band IFA.

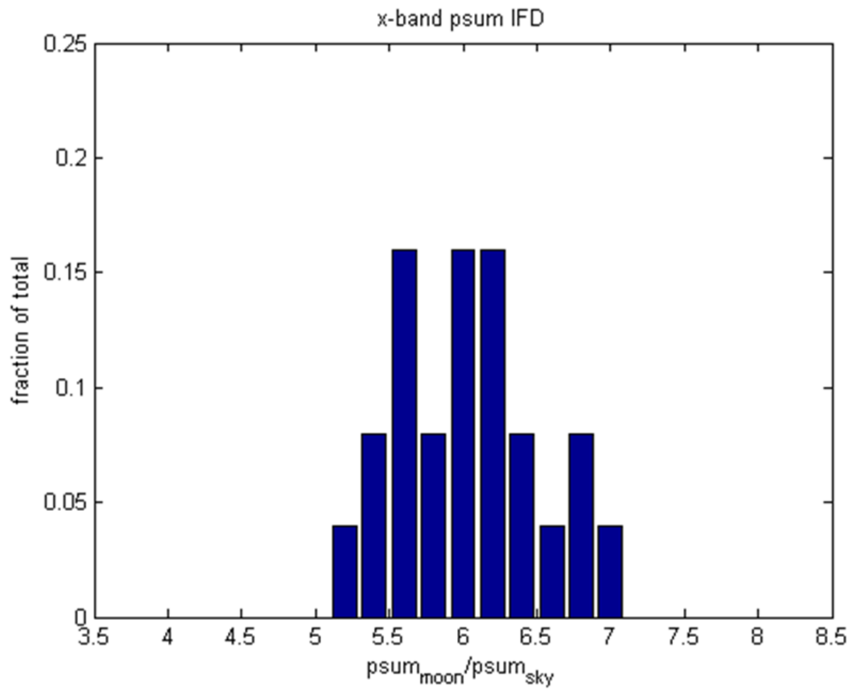

Figure 4: P_{sum} ratio (T_{moon}/T_{sky}) for X-band IFD.

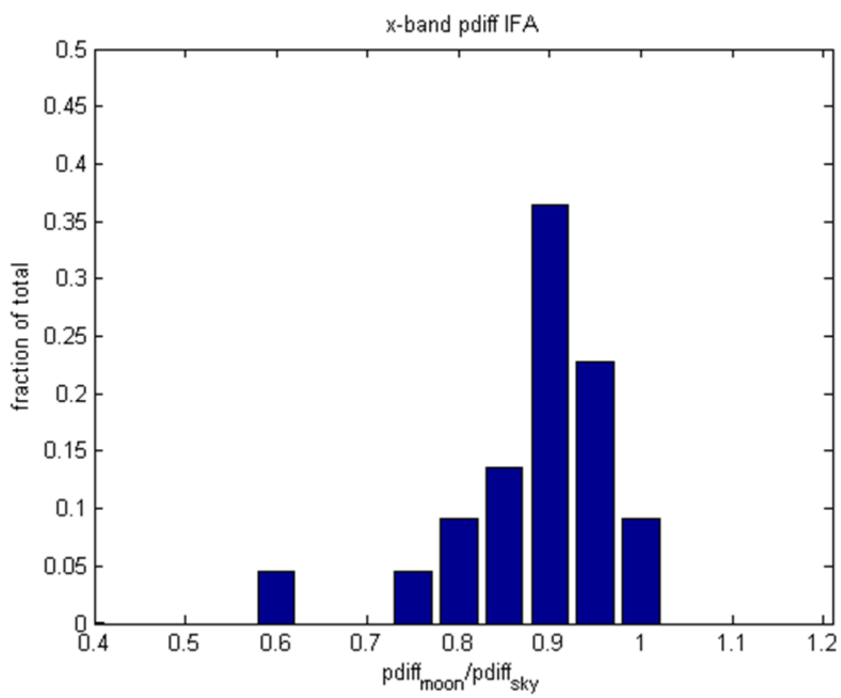

Figure 5: Pdiff compression ratio (moon/sky) for X-band IFA.

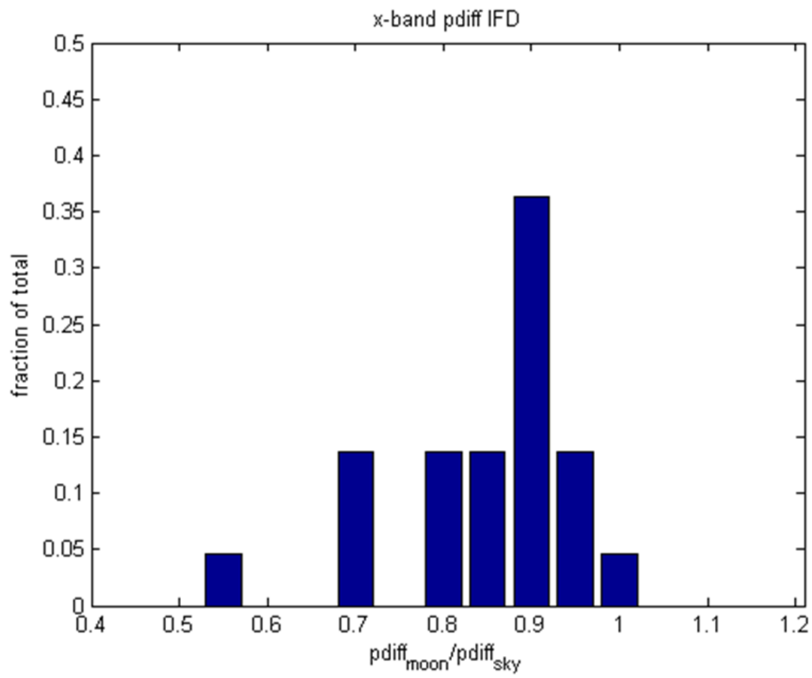

Figure 6: Pdiff compression ratio (moon/sky) for X-band IFD.

4.6 P_{SUM} and P_{DIFF} Measurements by Antenna

Create antenna-based graphs of P_{SUM} and P_{DIFF} from the Moon Compression tests, and identify candidates for "good" and "bad" antennas. For P_{SUM}, "good" appears to mean antennas with P_{SUM} ratio measurements near the median value of 6. For P_{DIFF}, "good" is defined as "close to unity", while "typical" is taken to mean "near the median value of 0.9".

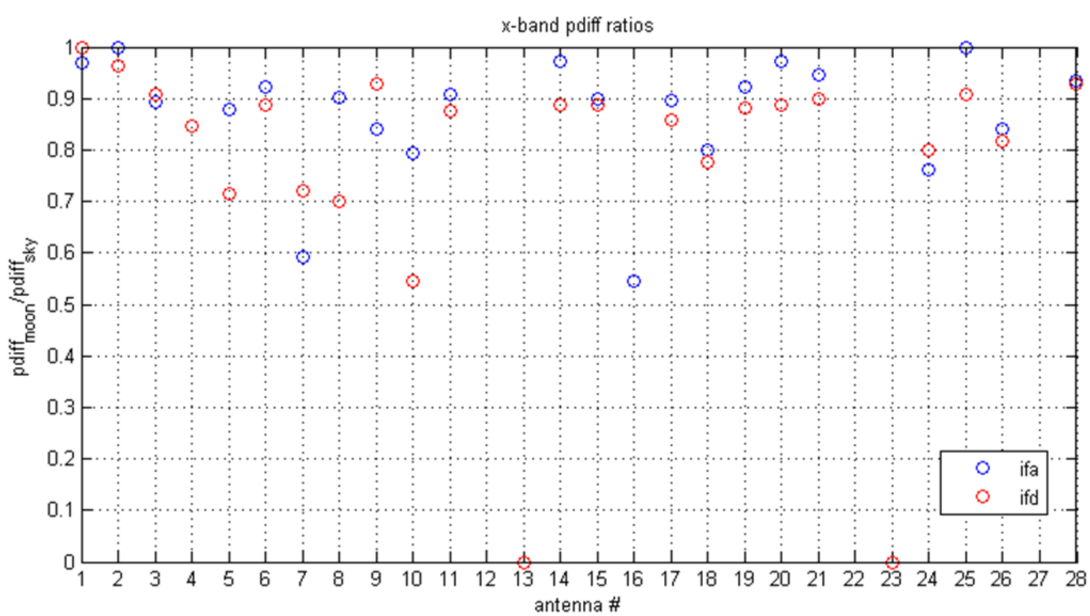

Figure 7: Pdiff compression ratio by antenna number

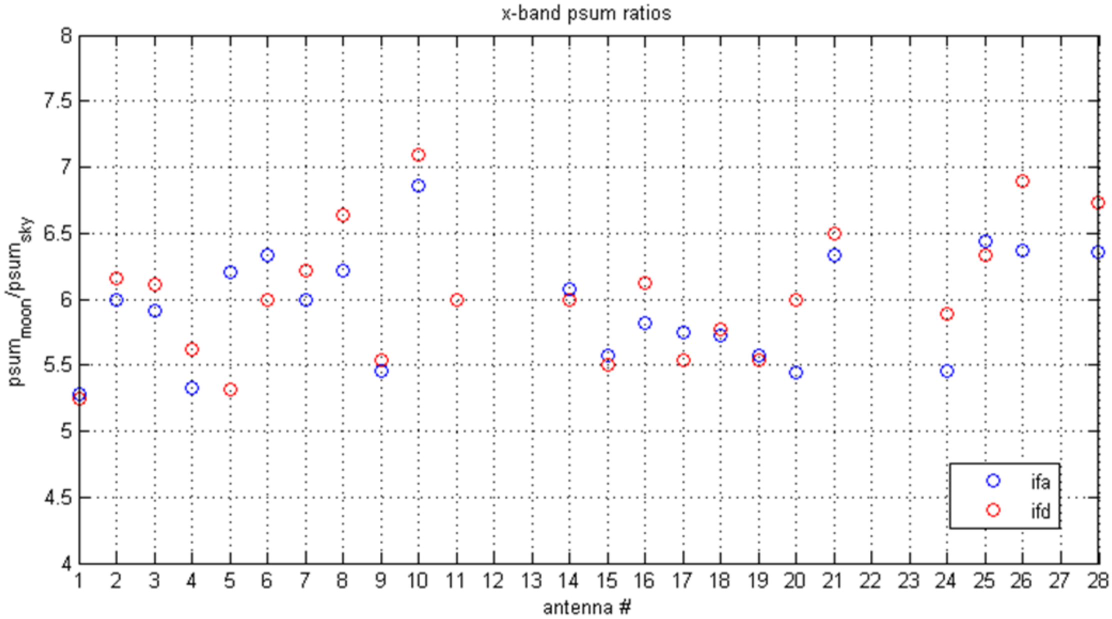

Figure 8: Psum ratio by antenna number

4.7 Results

Table 2 shows the median Psum and Pdiff by receiver band across all participating antennas, from the four observations summer 2014. In addition, we have listed the median of all four observations for each quantity.

Table 2: Summary statistics from the four observations, by receiver band

	Band	**L**	**S**	**C**	**X**	**U**	**K**	**A**	**Q**
June 20 Median	Psum	2.6	3.8	5.0	5.8	5.7	3.9	3.3	2.1
	Pdiff	0.99	0.88	0.88	0.90	0.88	0.92	0.92	0.96
June 26 Median	Psum	2.6	3.8	5.0	5.8	5.7	3.9	3.3	2.1
	Pdiff	0.99	0.88	0.88	0.90	0.88	0.92	0.92	0.96
September 8 Median	Psum	2.9	4.8	5.3	6.1	5.7	3.7	3.5	2.3
	Pdiff	0.99	0.98	0.85	0.89	0.88	0.88	0.92	0.95
September 10 Median	Psum	2.8	4.2	5.3	5.9	5.5	3.3	3.2	2.2
	Pdiff	0.99	0.90	0.85	0.90	0.89	0.90	0.91	0.95
Aggregate Median	Psum	2.7	4.0	5.2	5.9	5.7	3.8	3.3	2.2
	Pdiff	0.99	0.89	0.87	0.90	0.88	0.91	0.92	0.96

4.8 Non-systematic/non-repeatable

The non-repeatable/non-systematic cases require the least urgency, at least for diagnostic purposes. This case affects only one receiver on one antenna.

4.9 Systematic by converter module

Systematic by converter module will generally show [L,S,C] (and possibly P), or [U,K,A,Q] exhibiting different P_{diff} linearity responses. All receiver bands to a specific converter module within an antenna (or across multiple antennas) will show similar Pdiff linearity response. These results imply that the converter configuration is limiting the headroom for that system.

4.10 Systematic by receiver band

Systematic by receiver band implies that something in the receiver, or the receiver's specific interface to the system, requires further study.

4.11 Systematic by antenna/IF

Systematic by antenna/IF implies that the baseband converter and/or DTS is limiting the dynamic range headroom. All receiver bands for a given antenna will show a similar linearity response.

5 Recommendations and Conclusion

If we look for overlap across the good and bad list from the different metrics – Total Power, P_{SUM} and P_{DIFF} -- we can select two antennas for each list, antenna/receivers that are either "uniformly good" or "uniformly bad", i.e. they are good or bad according to at least two, and ideally three, of these three metrics. Of the two sets of moon compression tests, ea10 consistently shows up as a "bad" antenna, while ea14 consistently shows up as a "good" antenna. End-to-end examination of the signal paths in these two antennas may provide clues as to the origin of the behavior seen in ea10. Also, ea10 is a great starting point and platform for testing.

Table 3: List of "good" and "bad" antennas as measured by total power and pdiff measurements

Total Power	
Good	ea01, ea02, ea03, ea08, ea10, ea12, ea13, ea14, ea19, ea20, ea24, ea26, ea27
Bad	ea06, ea07, ea10, ea13, ea17, ea18, ea21, ea22, ea25
P_{SUM}	
Good	ea02, ea03, ea07, ea14
Bad	ea01, ea10, ea26, ea28
P_{DIFF}	
Good	ea01, ea02, ea14, ea15, ea17, ea20, ea21, ea25, ea28
Bad	ea07, ea10, ea16, ea24
Total	
Good (three metrics)	ea02, ea14
Good (two or more metrics)	ea01, ea02, ea03, ea14, ea20
Bad (three metrics)	ea10
Bad (two or more metrics)	ea07, ea10

Appendix A: Psum and Pdiff Plots by Antenna Number

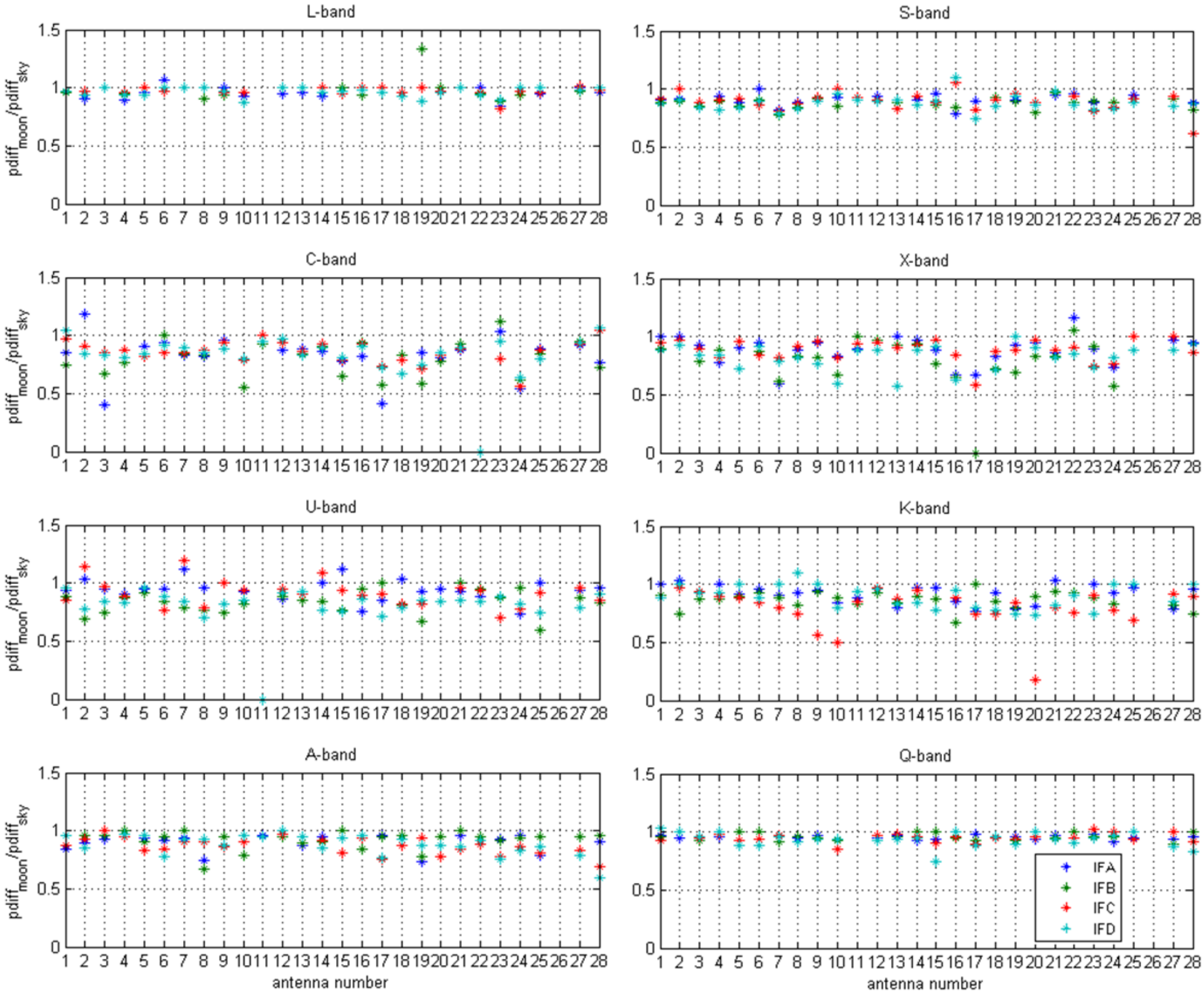

Figure 9: Pdiff June 202014

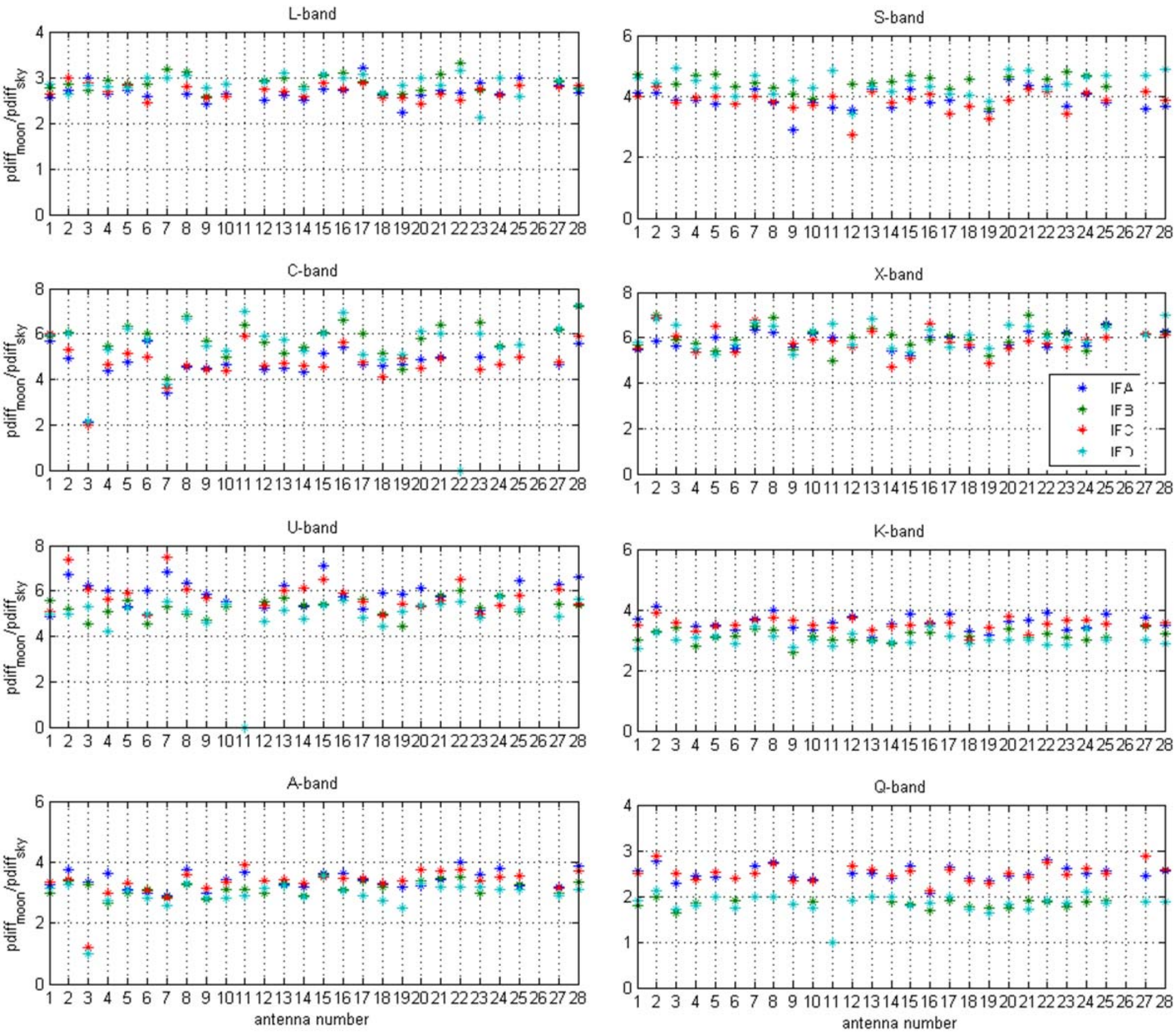

Figure 10: Psum June 20 2014

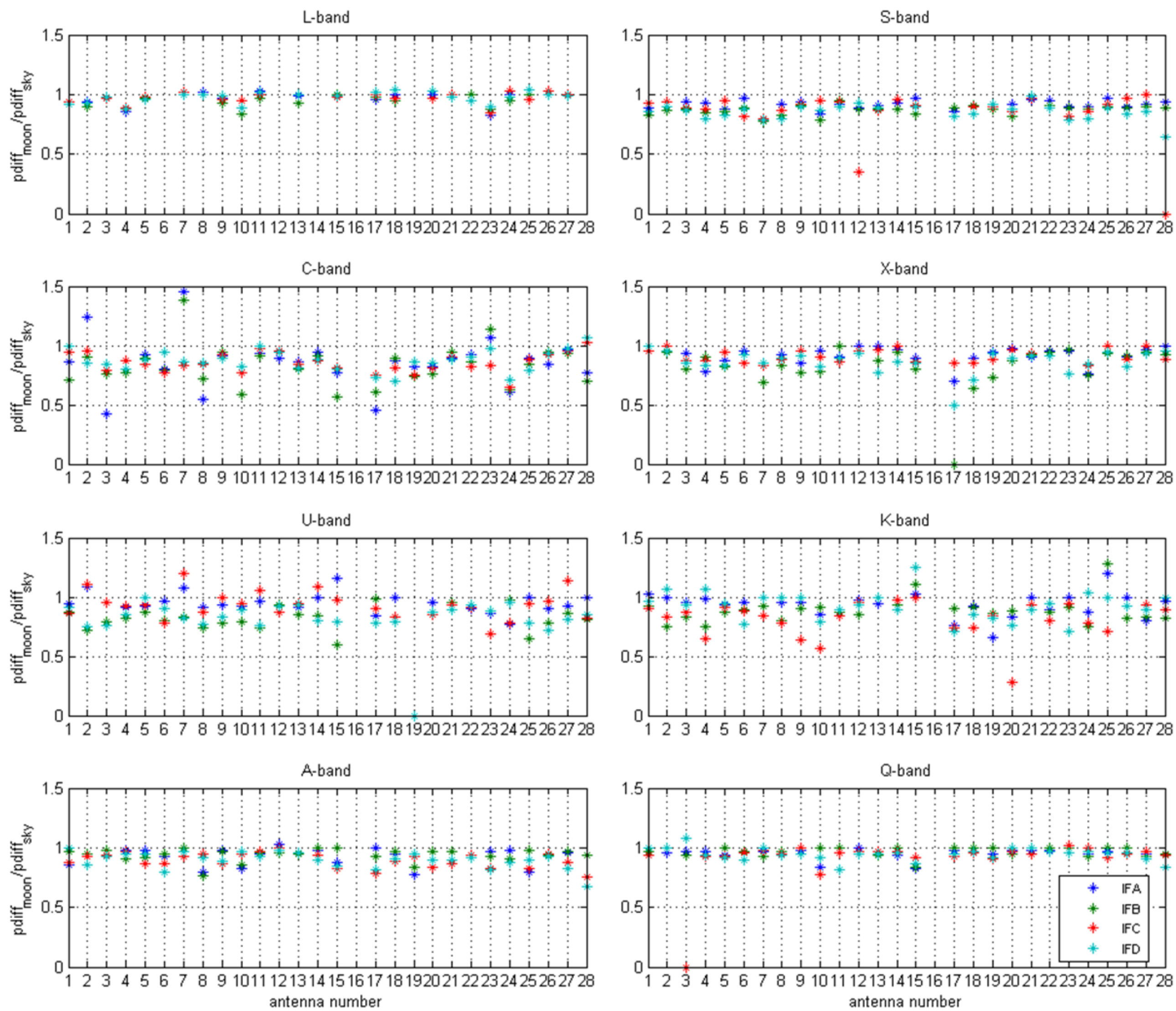

Figure 11: Pdiff June 26, 2014

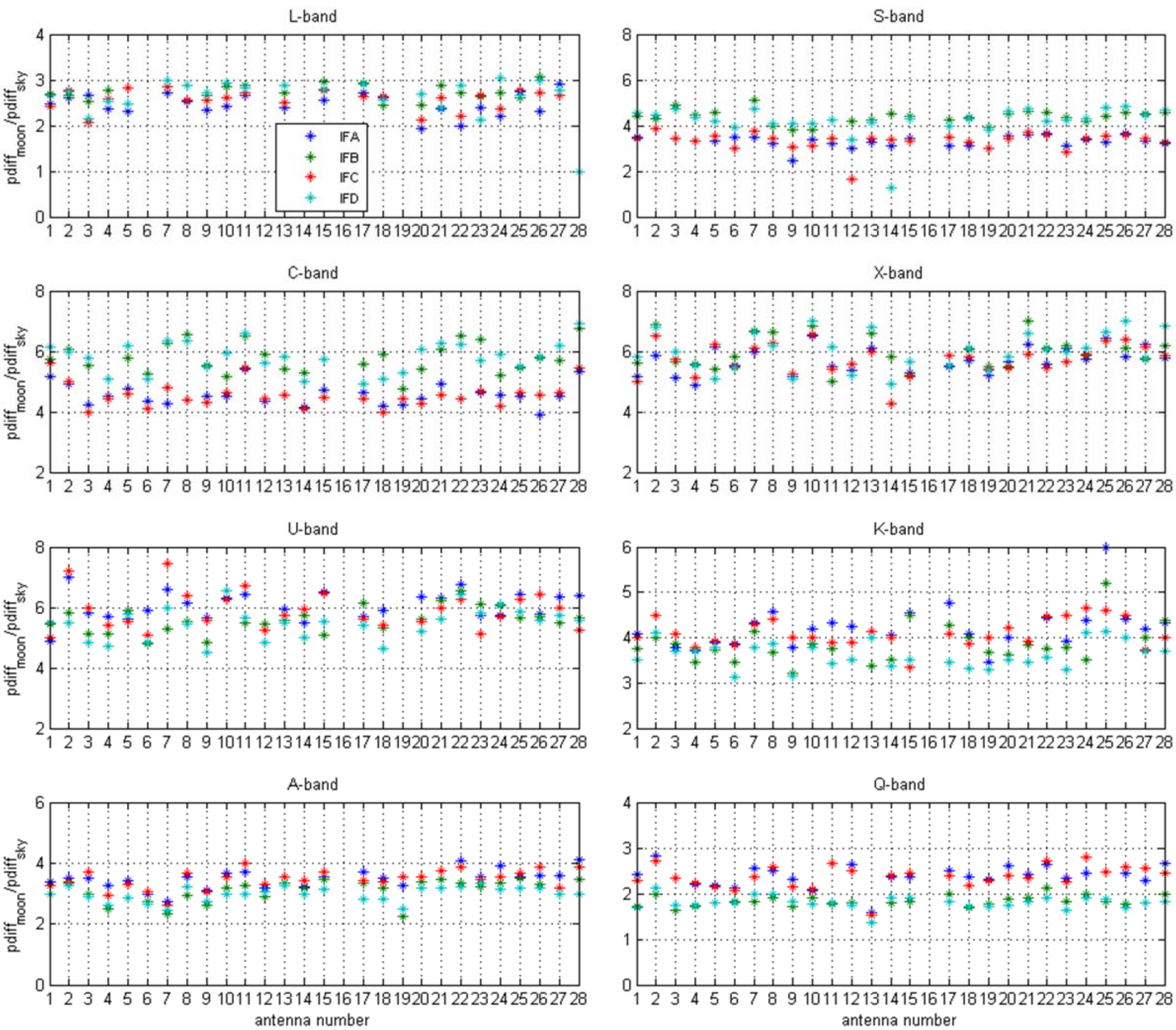

Figure 12: Psum June 26, 2014

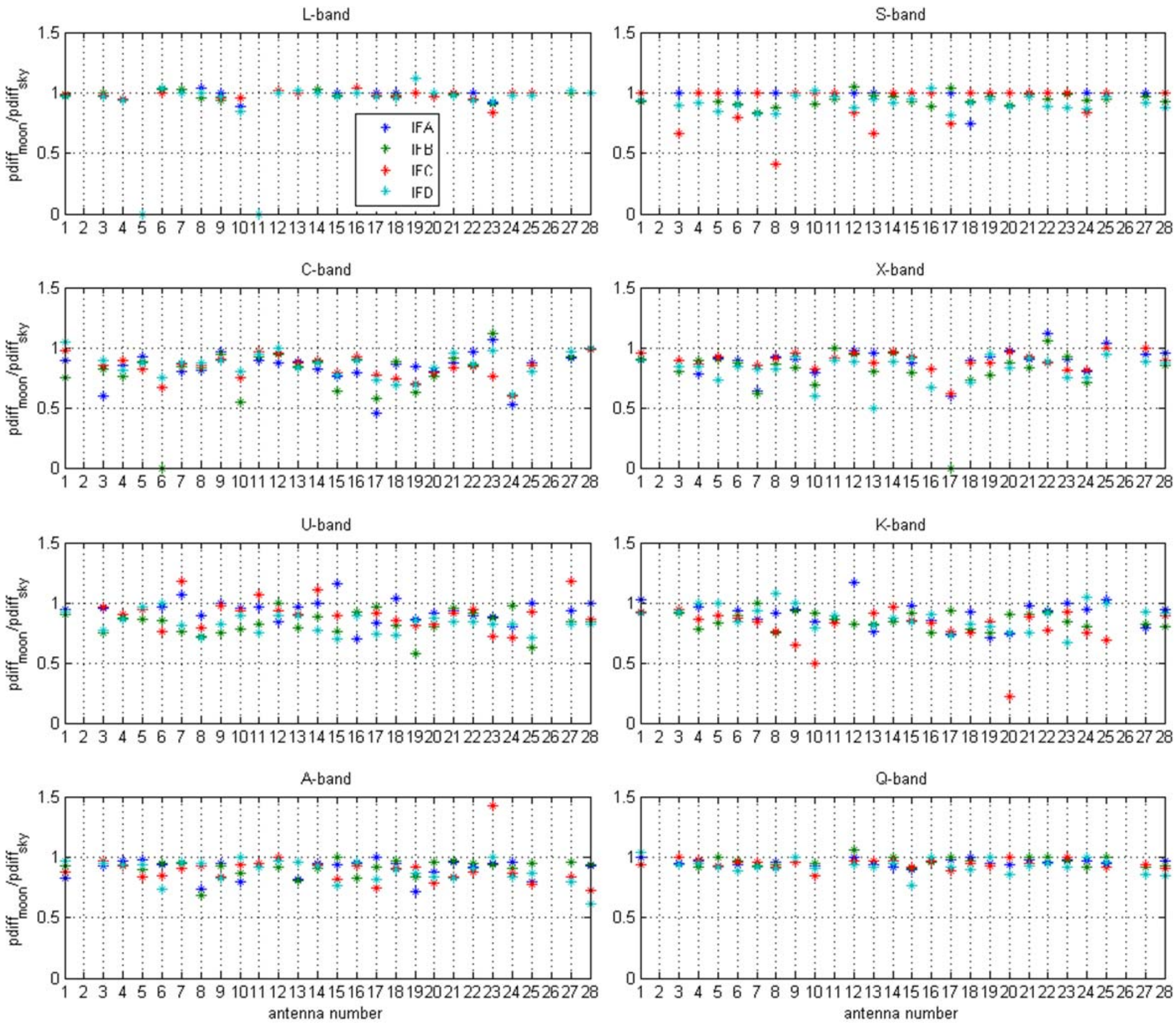

Figure 13: Pdiff September 07 2014

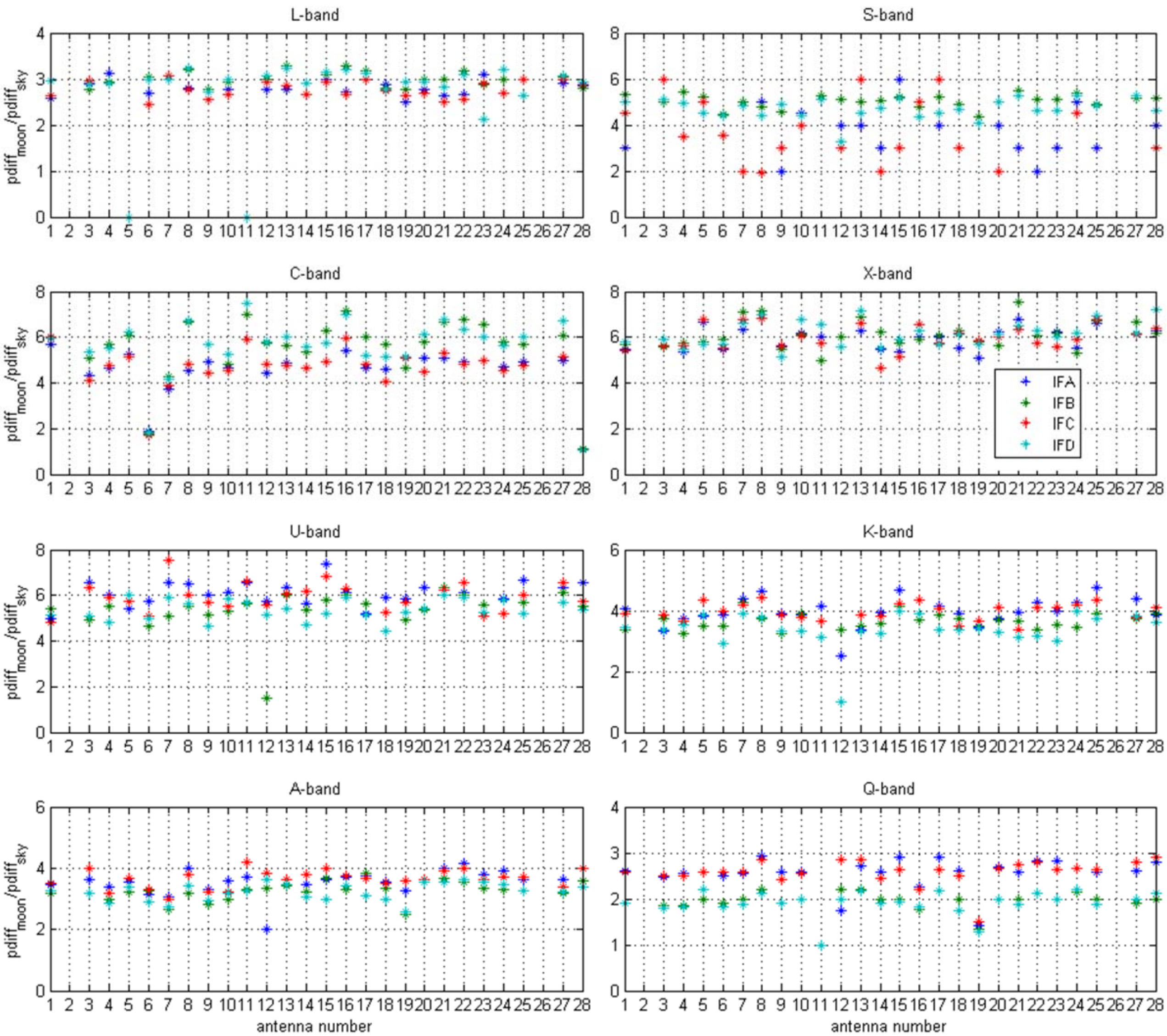

Figure 14: Psum September 07 2014

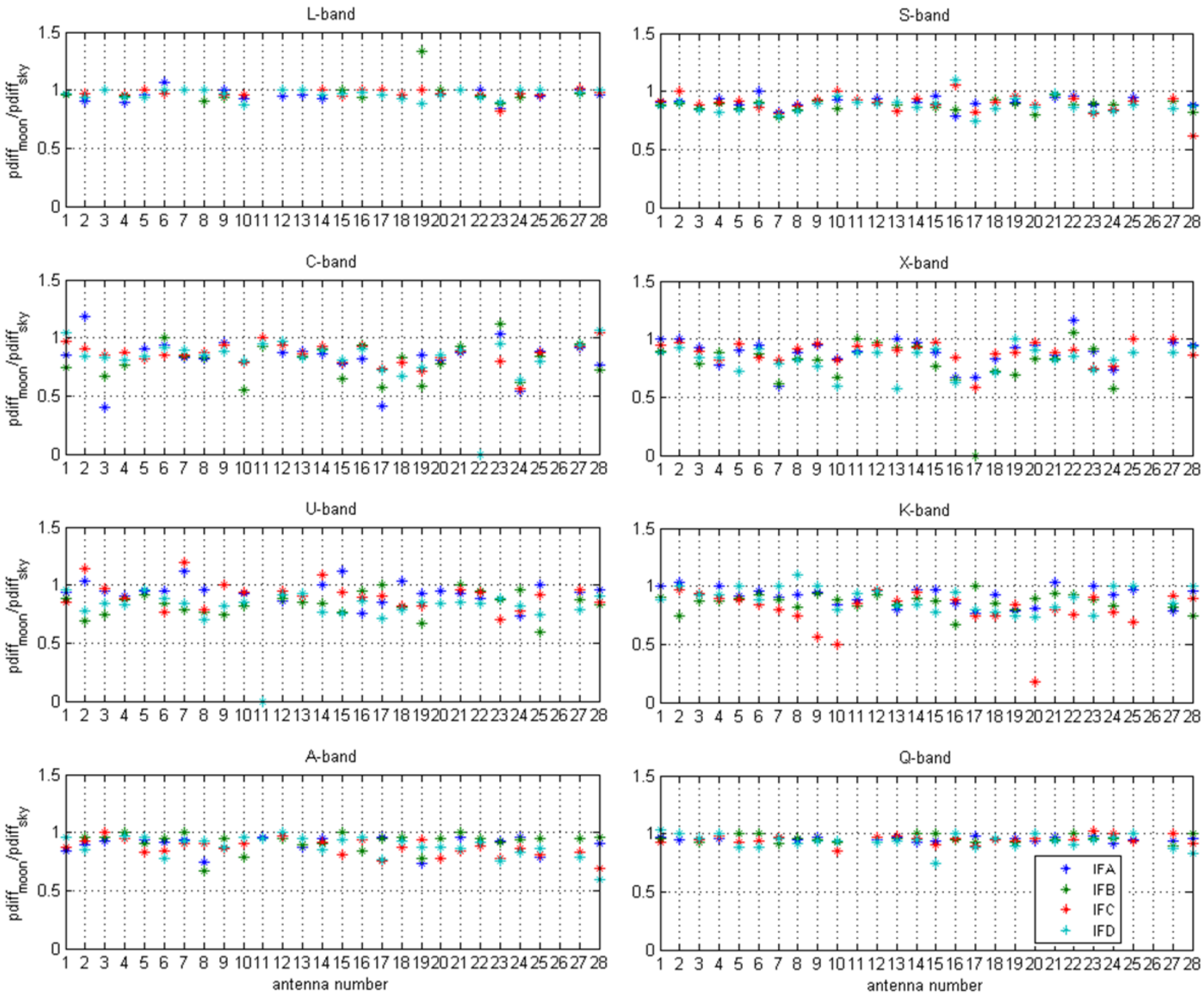

Figure 15: Pdiff, September 09 2014

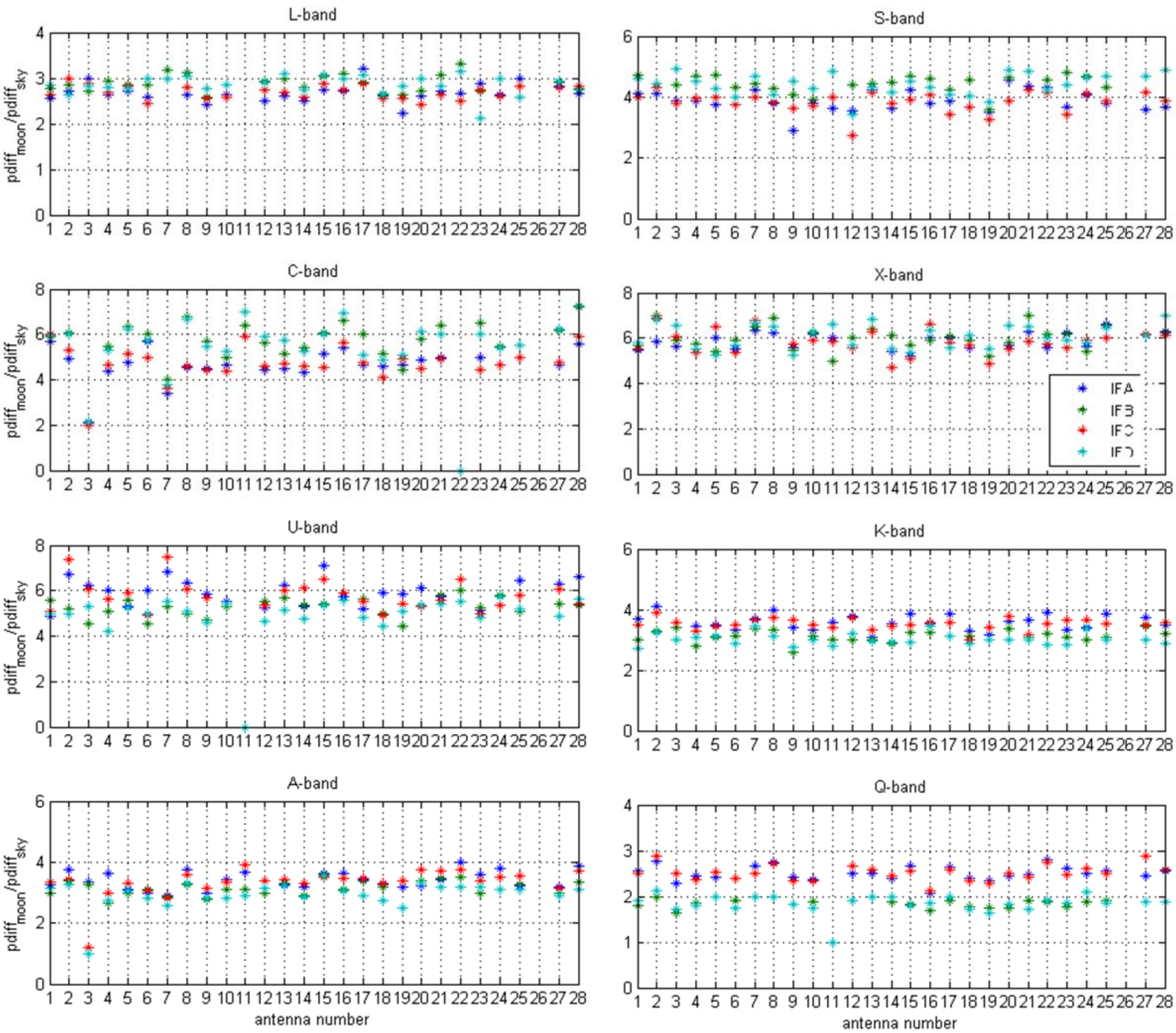

Figure 16: Psum September 09, 2014