**Comments on NH REX data from the Pluto Encounter**

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**A. Comments based primarily on examination of Level 2 (nh-p-rex-2-pluto-v1.0) label and data file:**

**/data/20150714\_029918/rex\_0299180727\_0x7b1\_eng.{lbl,fit}**

A1. ICD section 12.2.1.2 is very helpful for writing code while ICD 12.2.1.3 helps with visualization of the storage.

A2. Use of ^IMAGE to point to the raw data in some labels while ^ARRAY is used in others makes bulk processing of the data difficult. AAREADME.TXT lines 685-686 say the pointer should be ^IMAGE; most (but not all) labels in this data set use ^ARRAY.

**B. Comments based primarily on examination of Level 3 (nh-p-rex-3-pluto-v1.0) label and data file:**

**/data/20150714\_029918/rex\_0299180727\_0x7b1\_sci.{lbl,fit}**

B1. ICD 12.3.1.1 says I/Q samples are scaled by (1000/213) to achieve ±1000 mv full scale range. Why not 211 (the ADC outputs 12-bit samples) or 215 (the FPGA outputs 16 bit samples)? I agree that this is a meaningless calibration; but I'm curious.

B2. ICD 12.3.2 says all EDU 1 and EDU 2 values are stored as 32-bit calibrated floats; this appears to be true. But this label file shows radiometer and time tag values stored as integers — unchanged from the Level 2 descriptions.

B3. When the label error above is corrected, INVALID\_CONSTANT should be included in the radiometer column definition to represent values such as log10(0.). My software shows these as "-Infinity", but that is a happy coincidental circumstance; other platforms may handle whatever is stored in those bytes differently. A fixed numerical value defined using INVALID\_CONSTANT is a better long-term solution for the archive.

B4. The calibrated radiometer values are puzzling.

(a) The values themselves are slightly different from what I calculate using the formula in ICD 12.3.1.2 even though all the terms are fixed. For example, the first non-zero raw radiometer value in the example file is deltasamp = 1281789321. The ICD equation then gives

dBm = -172 + 10\*log10(4.5e6\*deltasamp) + Ro – (16\*AGC – AGCoffset)/dBstep + ant\_dBm

For the ICD 12.3.1.2 and Table 12-1 0x7b1 values

Ro=-93.170

AGC=167

AGCoffset=2512

dBstep=32.5

ant\_dBm=1.33

This becomes dBm = -111.08279; but the value in EXTENSION\_RAD\_TIME\_TAGS\_TABLE is

-111.15279. From a scientific standpoint, this is a *nearly* insignificant difference; but it is not clear why there should be a difference at all.

(b) Many of the radiometry values are physically impossible if the nominal system temperature has the value (Ts = 152 K) quoted in the radiometry calibration report (nh\_rex\_radiometer\_calib.pdf). That is, the power generated within the receiver itself is dBm = 10\*log10(kB\*Ts\*BW) = -110.24861, which is more than 1 dB higher than either of the values in (a) above. For reference, a +1 K change in system temperature is equivalent to about +0.03 dB change in power.

These problems were raised in the original Jupiter/Pluto Cruise review; they don't seem to have been resolved.

**C. Comments which apply to both the Level 2 and Level 3 data sets:**

C1. The first file in 20150714\_029918 has START\_TIME=2015-07-14T11:53:28.876 and STOP\_TIME=2015-07-14T11:53:29.900. But conversion of MET in the file name (0299180727) using /DOCUMENT/nh\_met2utc.tab gives START\_TIME=2015-07-14T11:53:29.884, a difference of 1.008 and putting it within milliseconds of the STOP\_TIME. The label file /DOCUMENT/nh\_met2utc.lbl warns that these conversions are approximate, but the 1+ second difference seems large considering the generally good behavior of the clock.

C2. Is the effective time tag for a raw radiometry measurement the midpoint of the previous deciROF — that is, is the time of the *second* radiometry value in 20150714\_029918 +0.0512 s relative to START\_TIME? Successive time tags should then step forward at 0.1024 s per deciROF.

C3. What is the effective time tag of each I/Q pair? The time tag of the first 10 MHz sample is probably the same as the first recorded time tag, but the down conversion process to 1250 sps presumably introduces a delay which may be corrected by clever storage (or not).

C4. There doesn't appear to be any way to tell how sides A and B are connected to the NH antenna — that is, which polarization is going through each side? REX.CAT *implies* that A is RCP and B is LCP; but they can apparently be swapped.

C5. To achieve the SNR improvement suggested in REX.CAT, there might be reason to feed from the same polarization (but via different LNAs). I'm not convinced that feeding sides A and B from different polarizations helps unless we're talking about SNR from one completely unpolarized radio source compared to another.

C6. Where can I find information on the polarization of the signals being transmitted from the DSN — when they were being used, such as for tests, occultation, and BSR?

C7. Labels REX\_AGCGAIN{A,B}.LBL have ASCII art figures showing the layout of their respective tables. (a) There is no description of the GAIN column in the figure. (b) The UTC calendar and UTC DOY positions should be swapped in the figure.

C8. Data files REX\_AGCGAIN{A,B}.CSV have no values later than 2013-07-13. Both files were created on 2014-08-27, and neither label has a LABEL\_REVISION\_NOTE. Were there no gain changes between mid-2013 and the Pluto encounter?

C9. It appears that, when REX is powered on in the default mode (status byte = 0000 0000 binary), the first ROF contains data in the default mode, the next two ROFs contain data in 'all zero' mode (status byte = 0111 0000 binary), and the remainder of the ROFs are then in the default mode. This should be documented, possibly in a note appended to ICD section 12.2.1.1.2).

C10. introdoc2.pdf and introdoc3.pdf are identical. They both describe raw and calibrated data sets, and neither makes any distinction among mission phases; so the same introdoc.pdf applies to every NH REX data set. They could be tailored to each data set, providing more specific guidance to users. There is one error: file names are given as *rex\_mmm\_0xaaa\_nnn\_v.fit*; in fact, there is no "\_*v*" in actual file names. Also, the label fragment under Raw Data is not quite right for the calibrated data.

C11. A calibration report (nh\_rex\_radiometer\_calib.pdf) is included in the DOCUMENT directory. This is a new document, added for the 'delta' review of the Jupiter and Pluto-Cruise data sets. Some questions were submitted for the delta review; they apply equally well here, since this is the same document. See Appendix A for details.

C12. Test data may benefit from more explanation.

**Appendix A — Comments on document/nh\_rex\_radiometer\_calib.pdf:**

The new document is a vast improvement over what was available in the original review. However, section (e) of this document is very difficult to follow and/or appears to have omissions or errors. There are several other issues that need to be addressed.

A (Fig 1a): The vertical axis is mislabeled. If this is total power from side A, the bandwidth is B=4.5 MHz, and the receiver system temperature is Tsys=155K (from section e), then the power is

PN = kTsysB = 1.38\*10-23\*155\*4.5\*106 = 9.63 10-15 w or -110.2 dBm

not the -171.9 dBm shown.

A (Fig 1b): Same problem as for Fig 1a except that the axis shows values near -168.5 dBm.

B. It would be helpful if the "published archival observations" were cited; the number of surveys and catalogs available on the Internet is enormous, and most aren't useful. After some searching, I conclude that Baars et al. (1964, 1977) provide basic flux data which establish the source flux values for Cas-A, Cyg-A, Tau-A, and Vir-A at 7182 MHz. A decay rate of -0.97±0.04 percent per year (Wikipedia) may be used to project the Cas-A flux for epoch 1980 to 2006. These are then the x-coordinates for the four points plotted in Figure 6.

C. There is a larger problem finding the y-coordinates for each of these points. The "vertical" scans in Figure 5 cover 800 s with a relatively flat response over the central 450 s. The "horizontal" scans have the expected increase to a peak, then decrease over 350 s. Were the horizontal scans paused 450 s when the boresight was presumed to be pointing at the source? The catalog file *rex.cat* mentions 300 s dwells, not 450 s.

D. Is "normalized" in Figure 5 the radiometer power level when the antenna was pointing at cold sky? If so, why are the peak values for Cas-A (~0.07) and Tau-A (~0.025) so different? In Figures 4 and 6 these two sources appear to differ by no more than about 25%. If not, what is the meaning of "normalized" and how should we interpret the numerical values in Figures 4-6?

E. I don't believe the equation at the top of page 8 can be solved for the system temperature. First, I believe there is a typo and it should it be written:

PREX = gsource + kTo

Second, I don't believe this can be solved for To using REX measurements of radio sources alone. To is set primarily by the RF front end (low noise amplifier, or LNA) and there is no way to isolate its performance with radio source measurements alone; we need to know LNA performance (for both sides) in the laboratory before launch. See below for details.

REX Radiometer Model



The figure above is a model for REX in radiometer mode when observing radio sources. S0 denotes the 2.7K cosmic microwave background (CMB); Si is a discrete source used to 'calibrate' the instrument. Discrete sources are point sources so far as REX is concerned since they are not resolved by the HGA. They are assumed to be small in angular extent — they do not mask any CMB. When there is no discrete source within the field of view all flux reaching the HGA is from S0.

The gain of the HGA/LNA combination is g. The LNA is also assumed to be the source of system noise kTsys. There are other sources of noise, but to first order the LNA dominates. The multipliers g and k include things like bandwidth; k is at most *proportional* to the Boltzmann constant. There is additional gain downstream in other amplifiers and mixers (G) and in the REX signal processing unit; but the additional gain multiplies the gSi and kTsys equally, so we can set the downstream gain to "1" and deal only with g and k.

The radiometer output of REX may then be given as

Pi =  gSi + kTsys

where the summation includes S0 and any single discrete radio source, if present.

For each calibration measurement, we have an expression of the form above. Assume there is one cold sky measurement and measurements of four different, discrete sources:

P0 = gS0 + kTsys

P1 = gS0 + gS1 + kTsys

P2 = gS0 + gS2 + kTsys

P3 = gS0 + gS3 + kTsys

P4 = gS0 + gS4 + kTsys

Each Pi is a known measurement. Each Si can be estimated from literature sources interpolated to 7182 MHz and 2006; S0 is the flux equivalent of the cosmic microwave background. The multipliers g and k are assumed constant but unknown. Tsys is unknown and of great interest.

Substituting the first equation into the other four and rearranging slightly gives us

P1 – P0 = gS1

P2 – P0 = gS2

P3 – P0 = gS3

P4 – P0 = gS4

or

(P1/P0) - 1 = (g/P0)S1

(P2/P0) - 1 = (g/P0)S2

(P3/P0) - 1 = (g/P0)S3

(P4/P0) - 1 = (g/P0)S4

which appears to be what is plotted in log-log coordinates in Figure 6 of the radiometer calibration report. A straight line can be fitted to the points; its slope  in a linear (as opposed to log-log) world is (g/P0).

Then from the first of the linear equations we can obtain

P0 = P0S0 + kTsys

or

kTsys = P0(1 - S0)

but there doesn't seem to be any way to separate k from Tsys without additional information, such as a laboratory measurement of LNA performance prior to launch. In fact, the laboratory measurement may be all we need; the radio source tests simply confirm continued proper performance.

Whatever the outcome of this calibration exercise, it would be helpful to users if the results of the radiometer calibration could be linked somehow to the calibration equation in section 12.3.1.2 of *soc\_inst\_icd.pdf*.

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