**document/nh\_rex\_radiometer\_cal\_4.2cm\_v2.2.1.pdf**

**1. Which Radiometer Calibration Report?** This document appears only in data set nh-p-rex-3-pluto-v1.0; it should be included in all eight REX data sets. Since it covers the same ground as document/nh\_rex\_radiometer\_calib.pdf (and appears to do it better), the earlier document should be removed from all data sets.

**2. Lesser Issues**: The PDF has been annotated with many detailed comments and questions, most of which are not repeated here. Problematical statements are usually enclosed by red rectangles; the issue (or suggested rewording) is typically in the left or right margin on the same line. For problems that involve more than a few words, red lines may be used to connect the problem and the suggested correction (or question).

**3. Integration interval and Time Tags**: The integration time for samples used in this study is never stated explicitly — apparently because there isn't one. The integration time for some samples is 1.024 s, while for others it is 0.1024 s. The points plotted in Figure 3.2.2 clearly have ~1 s spacing; but the standard deviation relative to the mean in Figure 2.0.1 is too large by a factor of ~3, which would be consistent with 0.1024 s integrations.

ICD 12.3.1.2 notes that the first radiometry sample in each calibrated ROF is the accumulation from the entire previous ROF (an integration over 1.024 s). It then explains that the other 9 samples in the calibrated ROF are calculated from the step-by-step differences within the ROF at 0.1024 s intervals; those difference values are then multiplied by 10 to give them magnitudes comparable to the first sample. This unusual sampling scheme is described in more detail in catalog/rex.cat; the table below (adapted from the rex.cat file) illustrates how it works. S0 is a reference time, such as the time tag of the first ROF of interest. Note that every tenth radiometer value has a 1.024 s integration and is also out of strict time order.

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| Index |Original Time Tag| Integration Time | Cal Radiometer Time |

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| 0 | S0 + 0.0 ms | **1024.0 ms** | **S0 - 512.0 ms** |

| 1 | S0 + 102.4 ms | 102.4 ms | S0 + 51.2 ms |

| 2 | S0 + 204.8 ms | 102.4 ms | S0 + 153.6 ms |

| 3 | S0 + 307.2 ms | 102.4 ms | S0 + 256.0 ms |

| 4 | S0 + 409.6 ms | 102.4 ms | S0 + 358.4 ms |

| 5 | S0 + 512.0 ms | 102.4 ms | S0 + 460.8 ms |

| 6 | S0 + 614.4 ms | 102.4 ms | S0 + 563.2 ms |

| 7 | S0 + 716.8 ms | 102.4 ms | S0 + 665.6 ms |

| 8 | S0 + 819.2 ms | 102.4 ms | S0 + 768.0 ms |

| 9 | S0 + 921.6 ms | 102.4 ms | S0 + 870.4 ms |

| 10 | S0 + 1024.0 ms | **1024.0 ms** | **S0 + 512.0 ms** |

| 11 | S0 + 1146.4 ms | 102.4 ms | S0 + 1075.2 ms |

| 12 | S0 + 1248.8 ms | 102.4 ms | S0 + 1177.6 ms |

| 13 | ... | ... | ... |

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It would be helpful to readers of the Calibration Report if the sampling, time tagging, and integration time scheme were summarized at some point. The explanation in ICD 12.3.1.2 that the SOC pipeline cannot work with more than one ROF at a time seems lame; but perhaps REX was negligent in not placing radiometer values at the ends of sample acquisitions rather than at the beginnings. In any case, some users, seeking higher fidelity, may want to work with the raw data, do their own differencing, and apply their own amplitude calibrations. The measured standard deviations (STDs), as in the Figure 2.0.1 captions, are suspect if the samples have different integration times.

**4. How to Pick the Best Estimate for Calibration** **Coefficients**: Calibration coefficients are derived in Sections 3.2, 3.3, and 3.4. The most information on the method is the text in Section 3.2 and the equations in Section 3.3. But the coefficients from Section 3.4 (where there is almost no discussion of solution method) appear to have been adopted for use with the data. The results from the various sections differ by up to 20%; the coefficients in Section 3.2 are more than 100 times the standard deviation from the values quoted in Table 3.3.1. How were the various methods weighted and why have the values in Table 3.4.2 been chosen?

**5. What Calibration Measurements Were Collected and Used?** The dates/times when calibration data were acquired should be listed in a table, and the example data should be clearly labeled in the document.

The abstract says calibration data were collected "during Integration and Test, … after launch in April 2006, and [during] an 'additional' Calibration Campaign in July 2016." But the next page refers to "four calibrations over the course of the mission" and expands the post-launch campaign to April-June 2006, while Figure 2.2.1 shows data from January 2013 and Section 2.1 says the "X-band receiver was measured … at every annual checkout". This is very confusing to the reader who is trying to understand what measurements were taken, when, and how they fit together to nail down the conversion of REX units to dBm (or antenna temperature) for both channels/polarizations.

**6. Conflict in Labeling between Sides and Cold Sky Targets:** Labeling of receiver channels (or 'sides' or polarizations) and cold sky sources using the same letters 'A', 'B', etc. is confusing. For example, the two parts of Figure 2.0.2 are labeled "Cold Sky A RCP" and "Cold Sky B LCP". Only a single (unlettered) Cold Sky has been defined at this point (top of page 3) while Channels A and B were introduced in the captions to Figures 2.0.1a,b; so one is tempted to assume that the figures show Cold Sky data from the RCP channel (A) and the LCP channel (B). But Figure 2.0.3 has Cold Sky A, B, and C. The Cold Sky A, B, and C targets are not actually specified until page 19, more than halfway through the document. The descriptions and labeling of channels and targets should be explicit, unambiguous, and consistent in both figures and text.

This problem could be cured by omitting all references to Channels A and B in the Calibration Report; there aren't many in the document, though readers who have arrived at the Calibration Report after reading other texts may still be confused. The document can note that Channels/Sides A and B have been defined elsewhere but that discussion here will be in terms of RCP and LCP only. Mention early that there are multiple Cold Sky targets, which will be denoted A, B, and C. The question of what to do with 'Cold Sky' at the top of page 3 remains open.

**7. Complete List of Power Measurements Is Needed:** A summary table showing cold sky and radio source measurements (average and standard deviation) in each polarization over the length of the mission would be an important addition. Gain settings should be included in the table. *There is no information in this report about amplitude stability of the receiving system over time scales of months to years; that is important because Pluto/Charon measurements are being calibrated using measurements made years earlier and later*. This table could be combined with the table mentioned in Comment 5 above.

**8. Inconsistent Numbering of Figures and Sections:** Two different figures have the same number (2.3.1), and captions on pages 8-9 need to be corrected so they describe what is shown. The associated text needs to be checked for consistency. The color bar and vertical scale for the top right panel on page 9 are not correct if gain is relative to boresight. There is a gap in numbering between Section 2.1 and Section 2.3. There is no Figure 3.5.3. Figures are incorrectly referenced throughout Section 3.

**9. Value of Jupiter Thermal Calibrations to This Exercise (Section 3.1):** The section "Calibration using Thermal Emission from Jupiter" (3.1) doesn't seem to use the thermal emission from Jupiter to do any calibration. It is a geometrical exercise for determining the effective beamwidth of the HGA that, although interesting, is largely irrelevant to the raw-to-physical value conversion. The parameter optimization procedure yielding estimates of receiver temperature and REX-to-Kelvin conversion factor apparently converges well but the results are suspicious when compared against other estimates.

**10. Legibility of Figures**: Some figures are difficult to read, even when magnified on a display with good resolution and contrast — Figures 3.2.1 and 3.2.2 are the worst. The vertical axes for panel 3 in both Figures 3.4.3 and 3.4.4 have been partly lost to layering.

**11. Confusion in Describing Sun Calibrations (Section 3.2):** Determination of the radio temperature of the Sun needs to be explained better. Text at the bottom of page 17 and the top of page 18 needs to be integrated so that the method and its results are clear. The 1759 Jy flux value apparently comes from DRAO measurements on 14 July 2015 interpolated to 7.2 GHz and scaled to 32.91 AU. That value cannot be obtained by scaling 1.5 MJy.

**12a. Confusion in Derivation of Receiver Temperatures from Cold Sky (and Sun?) Measurements (Section 3.3):** There seems to be a complete disconnect between the equations developed at the top of page 22 and Table 3.3.1, which summarizes the results of using the equations. The equations are introduced by the following text (edited slightly to correct errors and improve clarity):

Assuming that the conversion from REX units to kelvins (obtained from observations of the Sun on page 18) is trustworthy, the temperature *TColdSkyNP* associated with each of the three cold sky locations is found by dividing its cold sky mean power value *PREXunitsNP*  by the conversion constant *GP* computed for that polarization.

The final equation is an expression for the temperature of the corresponding X-band receiver

*TXBP* = *PREXunitsNP*/*GP* - *TCMB*

where *TCMB* is half of the cosmic microwave background temperature, or about 1.35 K. Everything to this point makes sense. In the annotated PDF I have suggested that *TCMB* be replaced by *TCMB*/2.

Table 3.3.1 then presents solution results for *GP* based on measurements of the Cosmic Microwave Background (CMB) without explaining how *GP* can be obtained in the absence of *TXBP*. CMB-based values for *GRCP* are in the range 82.20±0.01; values for *GLCP* are 192.60±0.02.

Values of *GP* from Sun calibrations are also listed in Table 3.3.1; they are in excellent agreement with the CMB values and have similar uncertainties. But the source of the listed Sun *GP* values and uncertainties is not disclosed. In Section 3.2, which is devoted to Sun calibrations, the coefficients were found to be 90.04 and 207.20 (page 18; no uncertainties were given). If the values on page 18 have any relevance whatsoever, the uncertainties given in Table 3.3.1 are in error by 2-3 orders of magnitude!

**12b. Consistency of Cold Sky Measurements (Section 3.3)**: The discussion about whether Cold Sky targets A, B, and C have the same temperature should be based on the Radiometer values (REX Units) and their uncertainties, not the REX to kelvin derived conversion factors. If done correctly, B and C appear to be about 0.1 K (not 0.3 K) warmer than A. Whether A is 2.7K is impossible to confirm.

**12c. Derivation of REX Tsys**: In the middle of page 23 values for the RCP and LCP noise temperatures are given as 153.7 and 148.5 K, respectively, without explanation. I can get 141.4 K and 138.1 K using the original conversion values (page 18). The conversion values in Table 3.3.1 lead to receiver temperatures of 155.1 K and 148.7 K; but the unknown source of these conversion coefficients is a big problem.

**13. Summary Results Are Not Supported by the Calibration Report (Table 3.4.2):** Three conclusions are presented at the end of Section 3.4. (a) The REX-to-K conversion coefficients *GP* in Table 3.4.2 have been copied from Table 3.3.1; however, as noted above, their derivation is unexplained. The Sun coefficients, which were derived in the report, are 5-10% larger but hugely out of line in terms of the quoted uncertainties. (b) The receiver noise temperatures *TXB* in Table 3.4.2 appear nowhere else in the document. The values quoted at the end of the cold sky calibration section (page 23) are ~15K larger. (c) The 0.6 "effective aperture" mentioned in conjunction with Table 3.4.2 must be the aperture efficiency 0.61 on page 9; the effective aperture on page 9 is 2.098 m2. Why either needed to be 'optimized' is not discussed.

**14. Frequency Reversal**: The frequencies in Figures 3.5.4 and 3.5.5 appear to be reversed from those in Figure 3.5.2. In Figure 3.5.2 the lowest frequency uplink is from a 34 m RCP transmitter (DSS 24 according to Hinson *et al*., **Icarus**, 2017). The next three uplinks in order of increasing frequency are 70 m RCP (DSS 43), 34 m LCP (DSS 34), and 70 m LCP (DSS 14). In Figures 3.5.4 and 3.5.5 the UpSNR values and the placement of neighboring spikes (and their apparent SNRs) only make sense if negative frequencies have become positive and vice versa. I have annotated the figures in the PDF with what I believe are the uplink stations and their polarizations.

**15. Capitalization of Units and Abbreviations**: Units named after people should be lower case (hertz, watts, newtons, kelvins, janskys, etc.) but their abbreviations should be capitalized (Hz, W, N, K, Jy, etc.). See http://physics.nist.gov/cuu/Units/units.html for more information.

**16. Conversion of REX Units to Physical Units:** Equation (4.1) is not correct. *RG* should not be included; and there needs to be an additional "+30" included for dB to dBm conversion. Units should be dBm/Hz (rather than dBm) everywhere per the note on page 35.

The two examples have multiple errors. Assuming the result is a power density, the PdBm for each polarization has a value that is smaller than the receiver noise power density itself — that is, -176.89 dBm/Hz and -176.41 dBm/Hz are both less than -176 dBm/Hz, which is the value given at the bottom of page 34. There is a sign error before the R0 term in the first line on page 35. The R0\_RCP value in line 3 (page 35) differs from the R0\_RCP value in line 21. The RCP example at the bottom of page 34 gives a different result from the value quoted on page 35:

PdBmRCP = -176 dBm + 10\*log10(RREX\_RCP) - 0.475\*\*(GAGC – G0) + R0\_RCP

= -176 + 101.10 - 0 - 106.2

= -181.2

dBm (which is much less than -176.89 dBm on page 35)

For equation (4.1) I would recommend something like the following:

Pdbm/Hz = 10\*log10(RU) + gstep\*(GAGC - G0) + 10\*log10(k/GP) + 30

**document/nh\_rex\_radiometer\_calib.pdf**

1. This document appears in all data sets. It has never been corrected/updated. Should be replaced by nh\_radiometer\_cal\_4.2cm\_v2.2.1.pdf. All references to nh\_rex\_radiometer\_calib.pdf should be replaced by references to nh\_radiometer\_cal\_4.2cm\_v2.2.1.pdf. No further comments on this document. See the newer calibration report.