REX Radiometer Calibration

Ivan Linscott
Stanford RadioScience Group
Stanford University

The radiometric measurement of total power in REX was calibrated during the Commissioning of the New Horizons Spacecraft shortly after launch and during April and June 2006. During Commissioning REX made measurements related to radiometric calibration consisting of: (a) X-band receiver stability, (b) X-band receiver linearity, (c) the High Gain Antenna (HGA) response, (d) radio sky background, and (e) standard radio source power. Discussed next is the relevance of each of these measurements and their inter-dependency on the calibration.

a. X-band Receiver Stability

To achieve New Horizons radiometric science objectives, integration of total REX power is needed on time scales of 1, 10 and 100 seconds, and possibly 1000 seconds. In these integrations, it is important for the total power integral to scale as the square root of the integration time. For this scaling to be successful the X-band receiver must be free of correlated instabilities on these time scales. The measurements of the X-band Receiver's stability consisted of a long duration REX acquisition of a Cold Sky target. The target was chosen as a location on the sky where the X-band thermal background was according to radio sky maps close to the 2.7 K Cosmic Microwave background. During this acquisition the spacecraft's High Gain Antenna (HGA), was pointed at RA 15.2 deg, and dec, -8.1 deg, in a pointing deadband of 0.1 degree in angle.

A key result of this acquisition was the determination of the standard deviation (STD) of the total power as sampled by REX in the X-band receiver's radiometric channel. Figure 1, detail the process of deriving the STD from these measurements. In particular, Figure 1e, shows the STD of the total power evaluated over the range of temporal integration relevant epochs identified above. The trend in Figure 1e, of the STD with integration time confirms the desired 1/square-root scaling up to integration times of the order of 100 seconds. Longer integrations continue to improve statistical resolution but at a slower rate, due presumably to the existence of flicker-type noise fluctuations in the X-band receiver's gain.

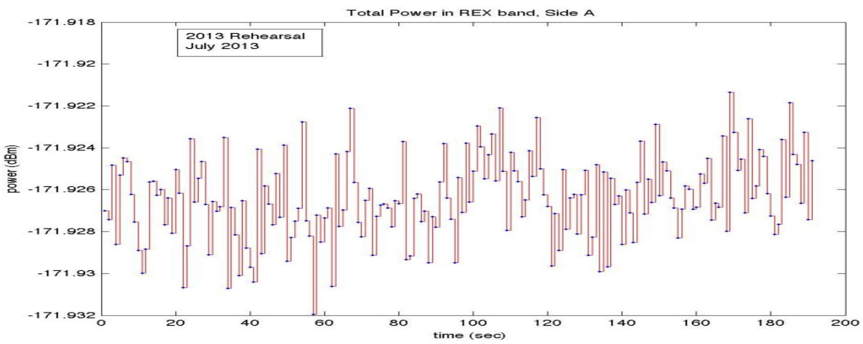

Figure 1a. Samples of total power on side-A, in the NH Radiometrics Channel, as sampled by REX. HGA pointing to Cold Sky.

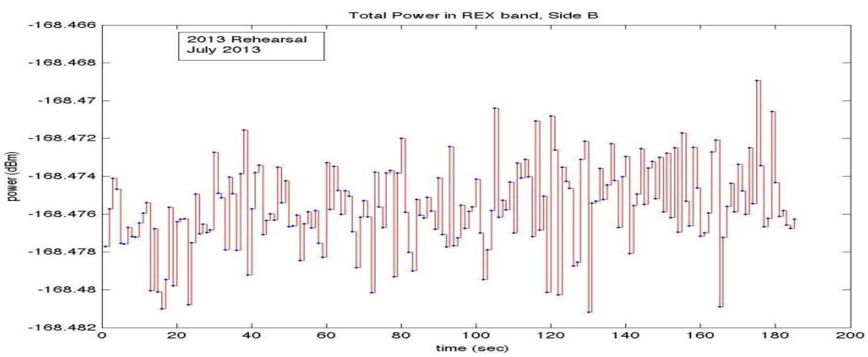

Figure 1b. Samples of total power on side-B, in the NH Radiometrics Channel, as sampled by REX. HGA pointing to Cold Sky.

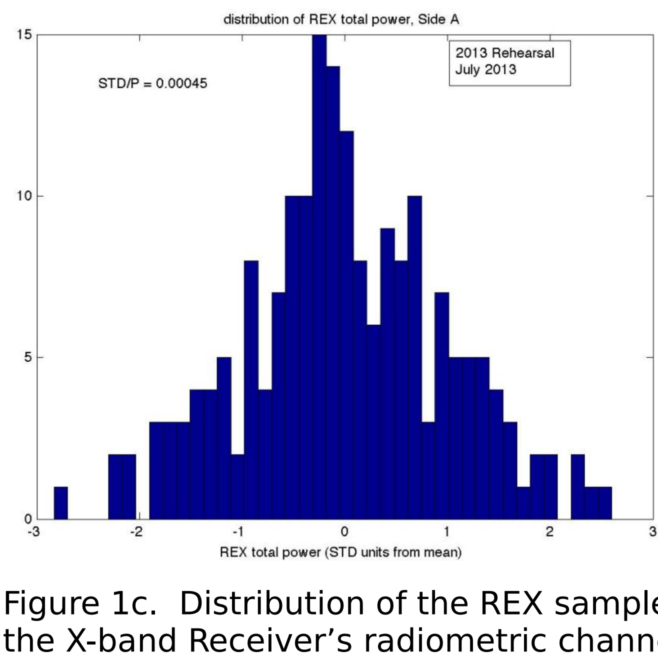

Figure 1c. Distribution of the REX samples of total power on Side-A, in the X-band Receiver's radiometric channel.

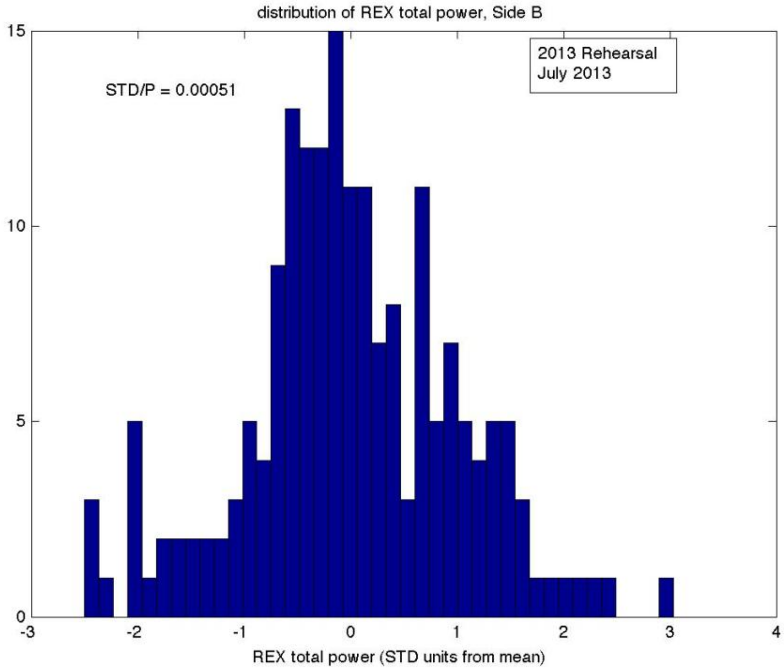

Figure 1d. Distribution of the REX samples of total power on Side-B, in the X-band Receiver’s radiometric channel.

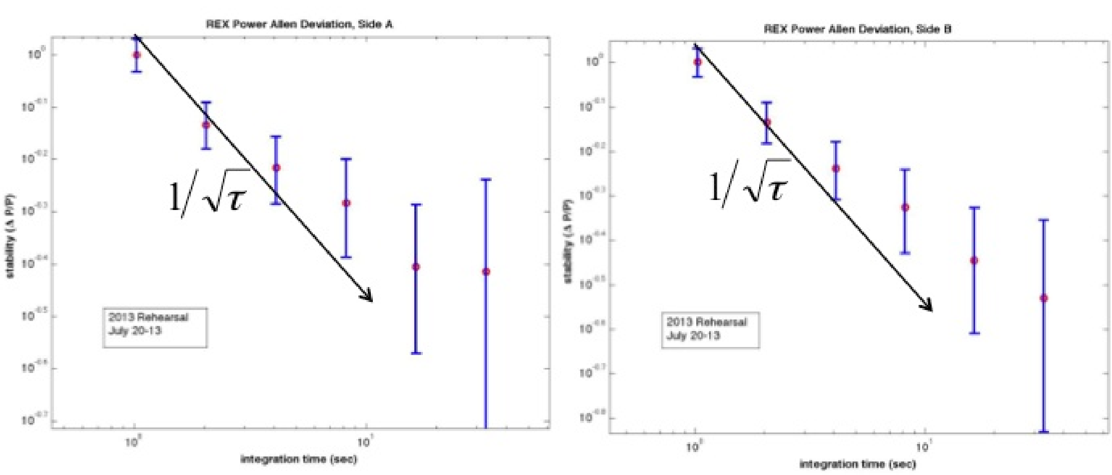

Figure 1e. The standard deviation (STD) of REX total power samples, evaluated over the range of integration times appropriate for the radiometer measurement objectives.

b. X-band Receiver Linearity

A companion requirement for predictable radiometric measurement, in addition to receiver stability is receiver linearity, where the emphasis is on the reliability of the X-band receiver’s gain. During Commissioning, and at every annual checkout, the gain of the receiver was stepped in intervals set by its programmable values (which were twice the minimum gain step of 0.48 dB) while REX acquired a nominal uplink from the DSN. This acquisition afforded measuring the gain steps to a precision of ~0.025 dB. An example of this measurement is shown in Figure 2. The variation power in the REX band within each of the gain steps is attributed to the variation in the uplink power due to both small variations in transmitted power at the source and propagation effects along the ~30 AU radio path from earth to the spacecraft.

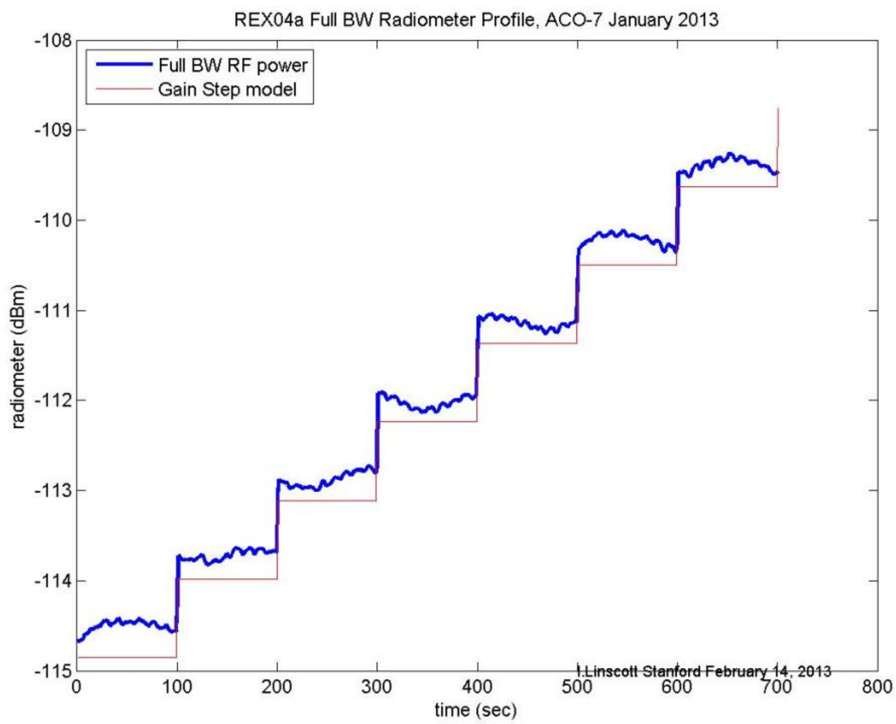

Figure 2. Steps in the X-band receiver’s gain with the HGA pointed to Earth, while a nominal uplink was transmitted to the spacecraft.

(c) High Gain Antenna (HGA) response

The High Gain Antenna’s (HGA) response to illumination by a distant thermal radio source was determined both by a full characterization of the antenna prior to integration on the NH spacecraft before launch, and subsequently during spacecraft commissioning. During the latter, the HGA’s response was measured by using the spacecraft’s pointing to raster scan the HGA across an uplink. While scanning the pointing

REX acquired the uplink waveform in the REX band. The SNR of the uplink in the REX band was ~60 dB, resolved to a frequency resolution of 1 Hz, and provided a measure of the HGA's response suitable to resolve the HGA's sidelobes within the scan region. Figure 3cd, is a display of the HGA's response obtained by this means, and Figure 3ab, is the comparison with the HGA's response characterized before launch.

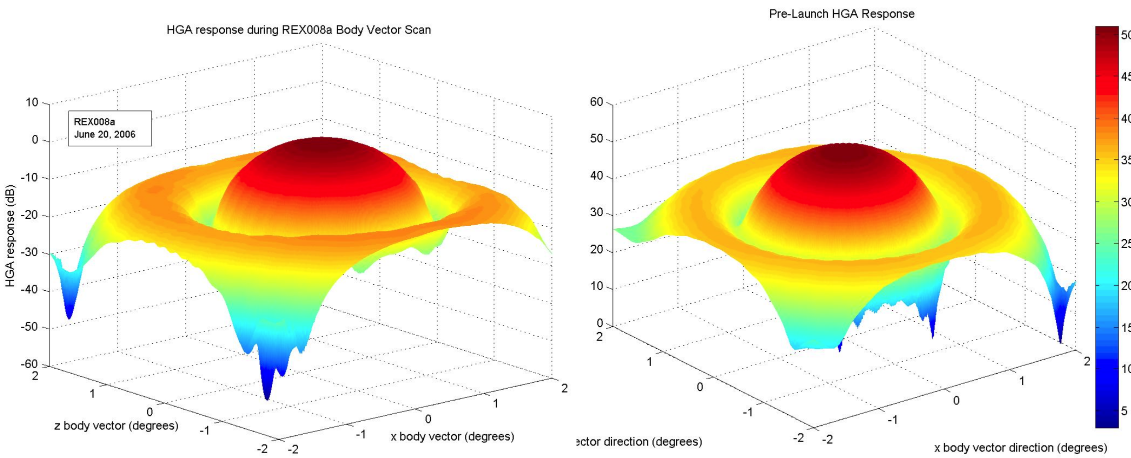

Figure 3 ab. Left hand figure is the HGA's response in REX. Right hand figure is the HGA's response as measured before launch.

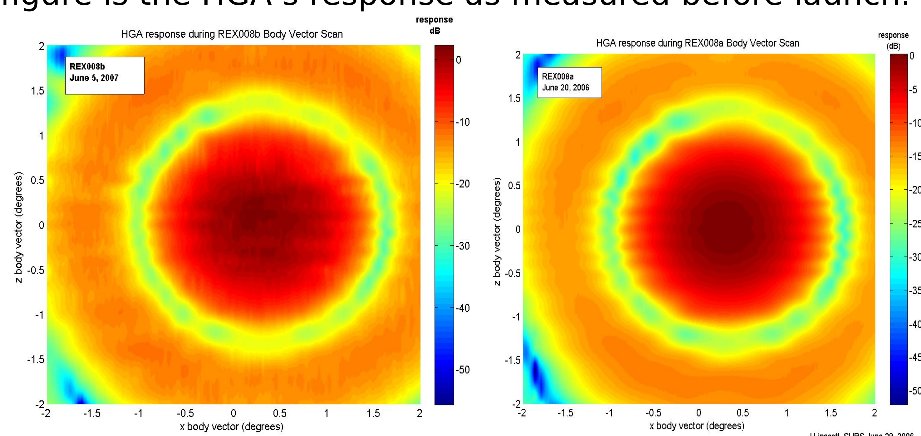

Figure 3cd. HGA response as measured by scanning the HGA across an uplink. Left hand figure is HGA response for Left Hand Circular polarization (LCP), and the right hand plot is the HGA's response for Right Hand circular polarization (RCP)

(d) Radio Sky Background

The REX radiometer calibration combined total power measurements of Cold Sky and standard radio sources. Through the use of maps of the radio sky, locations were found where the sky temperature was within a few tenth's of a Kelvin of the Cosmic Microwave Background CMB), over a larger section of the sky than several times the half-power beam width of the HGA. The location RA 15.2 deg, and dec -8.1 deg, was suitable for this purpose. Long acquisitions of REX, lasting several hundred seconds afforded measurement of the X-band receiver stability, as discussed in section (a) above, and a precise estimate of the combined power to REX of the CMB and the X-band Receiver temperature.

(e) Standard Radio Source Power Measurement

The principal objective of the REX Radiometer calibration was to obtain the X-band Receiver temperature. By comparing the REX Radiometer power for combinations of HGA targets with known X-band radio flux, the Receiver's temperature was obtained. In addition to Cold Sky, the REX radiometer power was recorded from standard radio sources, Cass-A, Taurus-A, Cygnus-A, and Virgo-A. Figure 4, is a summary of the radio flux expected from these standards. The radio flux models were collected from published archival observations. The supernova remnant Cass-A, flux decays sufficiently rapidly that an additional decay model was used to predict the radio flux at the time of the REX measurement.

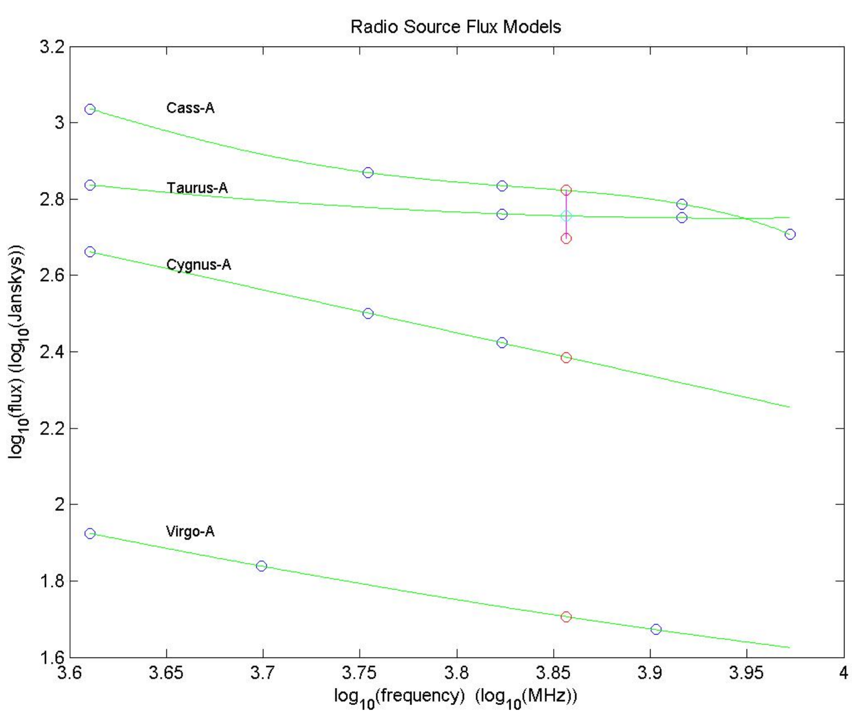

Figure 4. Radio Flux Models of Standard Radio Sources.

The radiometric power measured with REX for selected standard sources is shown in Figure 5, as scans of the HGA across the position of the source on the sky. In most cases the radio source is not just a point-source located on a uniform background. The scans, in orthogonal directions, in comparison with published radio sky images, allowed for a peak flux to background estimate.

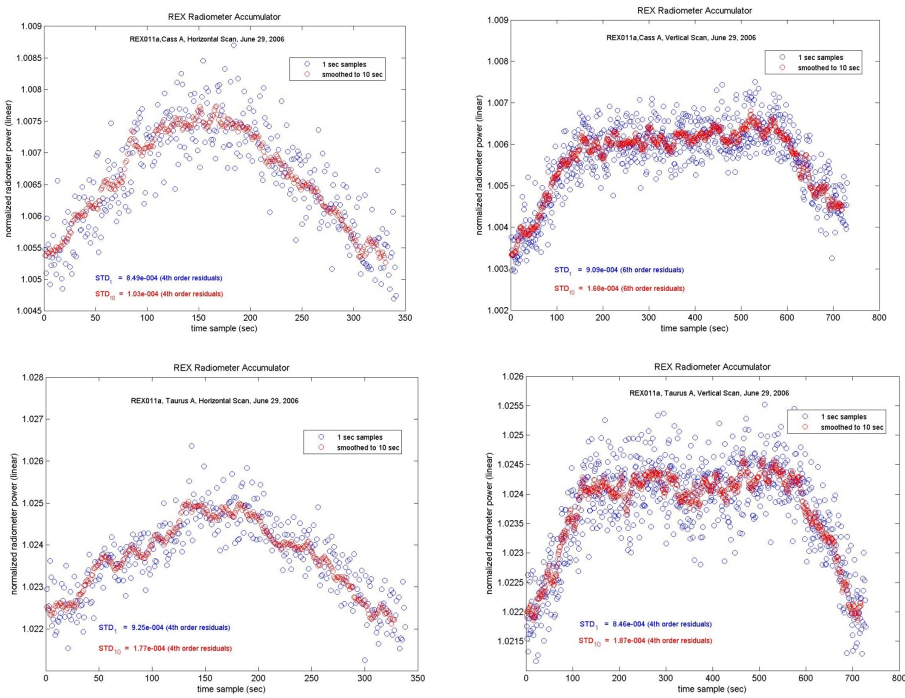

Figure 5. Scans Across Standard Radio Sources.

The estimates of SNR, obtained via peak to background measurements in the scans of the standard sources, are then compared to the published radio flux, via a scaling law model. This scaling is shown if Figure 6, where the REX SNR's are plotted vs. the estimated flux from the models in Figure 4. The log-log plot of Figure 6, contains a linear best fit to the scaling, with a slope attractively consistent with unity, implying the REX measurements are a faithful representation of the radiometric power from the HGA. From these measurements, a set of linear equations in the combined radiometric power is formulated and allows a solution in the principal unknown, the X-band receiver's temperature to be obtained. These equations have the form:

$$P_{REX_n} = g(\Phi_{source_n} + kT_o)$$

Where

P_{REX_n} = Power from source(n)

Φ_{source_n} = Radio Flux of source(n)

T_o = Temperature of X-Band Rx

g = X-Band receiver's gain conversion

The solution for T_o is a temperature of 152 K, for the X-Band Receiver and is the basic calibration constant for the REX Radiometric measurements.

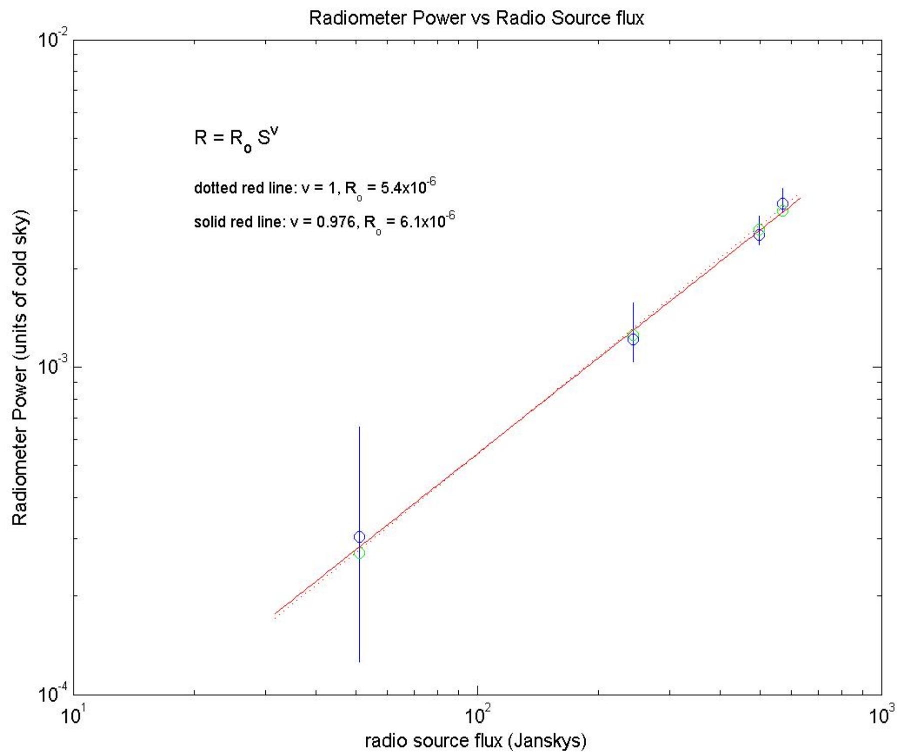

Figure 6. Scaling of the REX radiometer power measurement with the radio flux from standard sources. The REX to flux relationship is linear on the log-log plot.