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Long Term Performance Metrics of the GD SDR on the SCaN Testbed

The First Year on the ISS

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Abstract

The General Dynamics (GD) S-Band software defined radio (SDR) in the Space Communications and Navigation (SCaN) Testbed on the International Space Station (ISS) provides experimenters an opportunity to develop and demonstrate experimental waveforms in space. The SCaN Testbed was installed on the ISS in August of 2012. After installation, the initial checkout and commissioning phases were completed and experimental operations commenced. One goal of the SCaN Testbed is to collect long term performance metrics for SDRs operating in space in order to demonstrate long term reliability. These metrics include the time the SDR powered on, the time the power amplifier (PA) is powered on, temperature trends, error detection and correction (EDAC) behavior, and waveform operational usage time. This paper describes the performance of the GD SDR over the first year of operations on the ISS.

1.0 Introduction

As of August 2013, the GD SDR has been operating on the ISS for one year. Long term performance metrics for the GD SDR on the ISS have been captured and analyzed from the SCaN Testbed telemetry, which is collected and stored in a database at a rate of one sample per second when the SDR and Avionics are powered on. The long term performance metrics of interest include the SDR and PA power on time, receive and transmit waveform operational use time, and temperature trending. This paper provides an overview of the GD SDR, the temperature sensors, and the transmit and receive waveforms in Section 2.0. The results are discussed in Section 3.0. Suggested future work is described in Section 4.0 and a summary is given is Section 5.0.

2.0 Background Information

2.1 GD SDR Overview

The GD S-Band SDR is one of three SDRs in the SCaN Testbed (Ref. 1) on the ISS. The GD SDR contains five hardware slices—a digital electronics slice, two power conditioning slices, a power amplifier (PA) slice, and an S-Band RF up and down converter slice. There are four temperature sensors for the GD SDR, and they are located both internal and external to the radio. The digital electronics slice consists of an Actel RTAX field programmable gate array (FPGA), a Xilinx Virtex II FPGA and a ColdFire microprocessor. The memory consists of EEPROM for permanent storage as well as SDRAM and SRAM for volatile storage. The GD SDR is capable of compensating for single event upsets (SEUs) in memory caused by radiation in space. A SEU in the memory would be seen in the EDAC telemetry. The waveforms running on the GD SDR are compatible with the Tracking Relay Data Satellite System (TDRSS) (Ref. 2).

2.2 Temperature Sensors

There are four temperature sensors for the GD SDR on the SCaN Testbed. The temperature sensors internal to the SDR are located on the PA and the temperature controlled crystal oscillator (TCXO). These sensors are named GD PA TEMP and GD TCXO TEMP. The telemetry from these temperature sensors is sent from the SDR to the Avionics to be transmitted to the ground, so measurements from these sensors are only available when the SDR is powered on. There are also two temperature sensors placed on the baseplate of the SDR. These sensors are connected directly to the Avionics, so readings are available anytime the Avionics is powered on. The Avionics sensor names are AV GD TEMP1 and AV GD TEMP2.

2.3 Error Detection and Correction

There is telemetry for both correctable and uncorrectable error detection and corrections (EDACs) from the GD SDR. The telemetry is for the EEPROM, the SDRAM, and the SRAM memories. A single error in memory is correctable while a double error in memory is not correctable, but it is detectable. EDACS are caused by radiation in space.

2.4 GD SDR Waveform Description

2.4.1 Receive Waveform

The initial GD SDR receive waveform includes three reconfigurable parameters—data rate, coding on/off, and center frequency. The S-Band RF center frequency can be changed to operate with the TDRSS Single Access (SA) or Multiple Access (MA) modes. The receive waveform can be configured to operate at two data rates—18 and 72 kbps. The Viterbi decoder for forward error correction can be enabled and disabled. These three parameters lead to the eight different receive waveform mode combinations.

2.4.2 Transmit Waveform

The transmit waveform is capable of operating in the TDRSS Data Group (DG) 1, Modes 1, 2, and 3, as well as DG 2 configurations. The data rates can be configured to 24, 192, and 1 Mbps and forward error correction can be enabled and disabled. The RF center frequency can be selected to operate with the TDRSS SA or MA modes. These parameters lead to 28 different waveform mode combinations. For the SCaN Testbed operations, each unique transmit and receive waveform mode combination was given a unique waveform number, which can be seen in the waveform tables in Section 3.0 (Tables 4 and 5).

3.0 Results

The telemetry from the first year on ISS was processed and results for the SDR power on time, the PA power on time, EDAC occurrence, waveform operational use, as well as temperature were analyzed. These performance metrics for the first year of on-orbit operation on the ISS are discussed in this section.

3.1 SDR Power on Time

The GD SDR has been powered on and operating in space for a total of 268.7 hr. The power on time by calendar month is shown in Table 1. The SDR was powered on for the first time in August 2012 and initial checkout tests were completed in September and October 2012. In November, the GD SDR was primarily used during the RF subsystem checkout. The SDR was not used in the month of December 2012 due to a project stand down. The testing in 2013 included commissioning, RF characterization, and the start of experiments on the GD SDR.

3.2 PA Power on Time

The PA on the GD SDR has been powered on and transmitting in space for 41.3 hr. The power on time by calendar month is shown in Table 2. Transmit tests started in October 2012 during the checkout phases of the project. The testing completed in 2013 is listed in Section 3.1.

3.3 Temperature

This section details the results of the temperature sensor analysis. Table 3 contains some overall statistics for each temperature sensor for the GD SDR during the year from August 2012 to August 2013. Figure 1 shows histograms of the temperatures recorded from each sensor over the year. The mean temperatures were between 7.5 to 11.5 °C. The temperature operating range was primarily between 0 to 20 °C.

The GD radio was not powered on during December, so data from this month can be used as a control group against which data from when the radio was powered on can be compared. In all of the temperature data from December, a 90 min period was observed during which the temperature increases and decreases (Fig. 2). This temperature change corresponds to the ISS's 90-min orbit around Earth. This trend is also evident in most other temperature plots.

TABLE 1.—GD SDR POWER ON TIME

Month	Year	Time on, hr
August	2012	5.7
September	2012	14.3
October	2012	11.4
November	2012	70.4
December	2012	0.0
January	2013	11.0
February	2013	24.5
March	2013	51.9
April	2013	15.8
May	2013	30.0
June	2013	5.4
July	2013	28.2
Total		268.7

TABLE 2.—GD SDR PA POWER ON TIME

Month	Year	Time on, hr
August	2012	0.0
September	2012	0.0
October	2012	1.6
November	2012	7.9
December	2012	0.0
January	2013	2.5
February	2013	3.7
March	2013	8.3
April	2013	2.8
May	2013	4.9
June	2013	1.2
July	2013	8.4
Total		41.3

TABLE 3.—GD SDR TEMPERATURE STATISTICS

	AV GD TEMP1, °C	AV GD TEMP2 °C	GD PA TEMP, °C	GD TCXO TEMP, °C
Mean	7.6	7.5	11.5	9.8
Median	7.1	7.1	10.8	10.0
Max	24.1	24.9	24.6	23.8
Min	0.3	–1.2	3.3	–2.8
Standard deviation	3.3	3.3	3.5	3.5

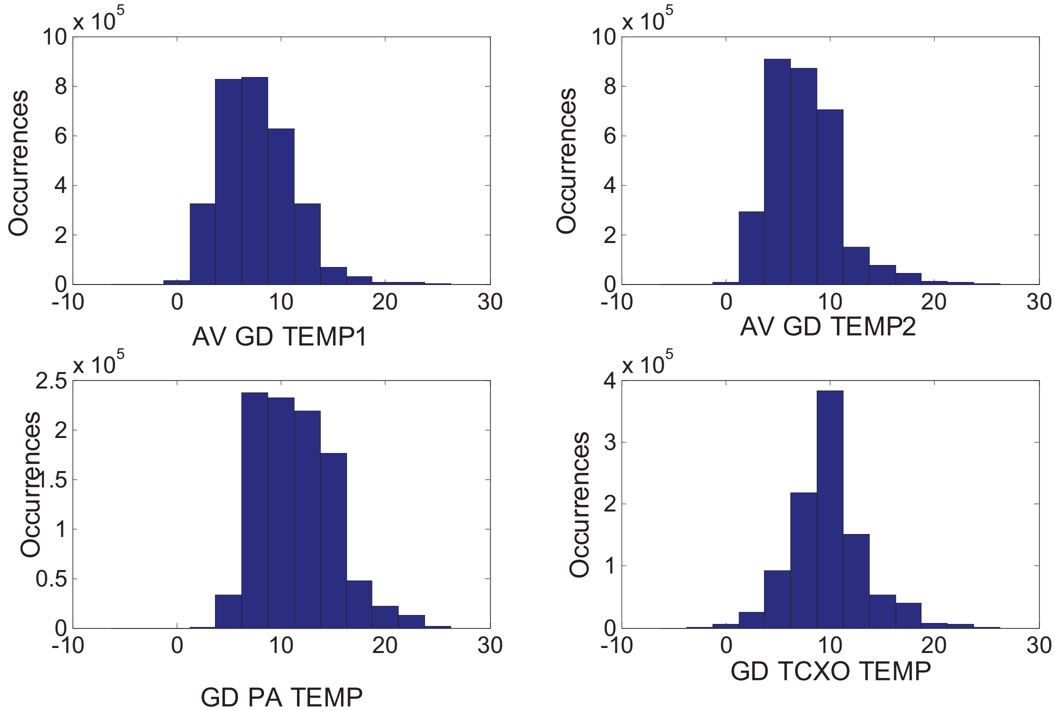

Figure 1.—GD SDR temperature histograms.

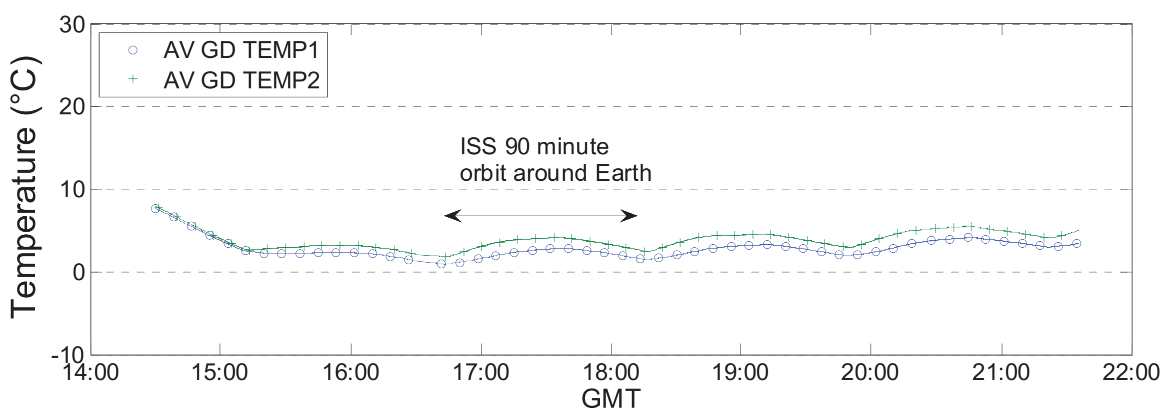

Figure 2.—GD SDR baseplate temperature (December 3, 2012).

Figure 3 shows an example of the behavior of all four temperature sensors after the SDR has been powered on. In 17 out of 40 cases where the radio is powered on, the overall temperature increases after power on and this can be seen in Figure 3. However, there are 19 cases where the radio is powered on and the temperature does not change outside of the 90-min period, and 4 cases where the radio is powered on and the temperature decreases overall. In addition, there are 8 cases where the radio is powered off and the temperature increases.

When the PA is powered on and the SDR is transmitting, an increase in temperature can be seen. In Figure 4, the vertical lines indicate when the power amplifier is being powered on or off; when the line is horizontal at 25°, the PA is on, and when it is horizontal at 0°, the PA is off. There is a clear increase in temperature when the radio is transmitting. This increase is most noticeable in the PA sensor, but can also be observed more subtly in the data from the other sensors.

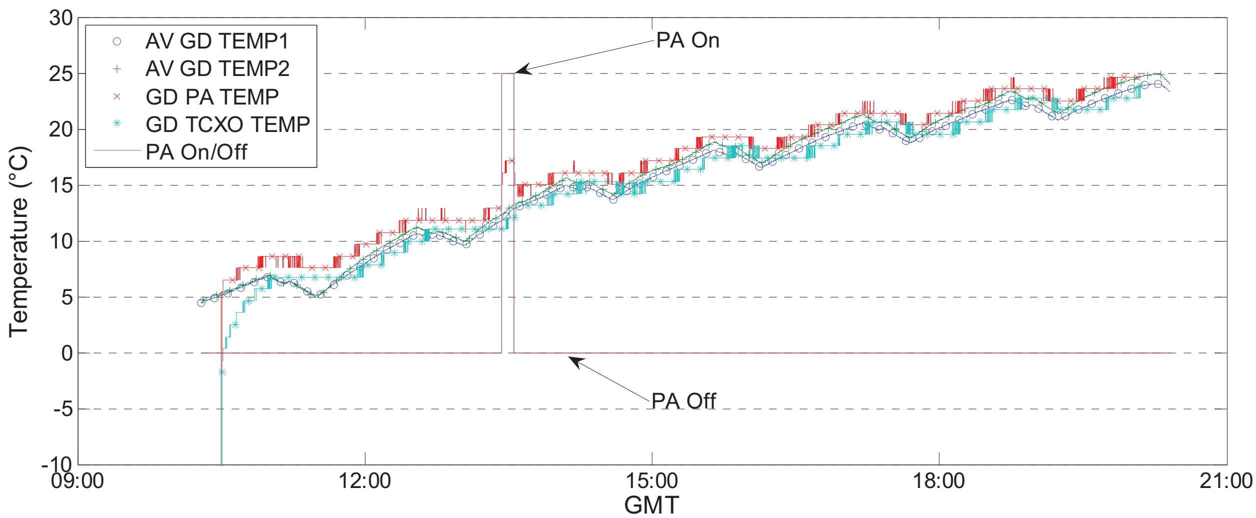

Figure 3.—GD SDR temperature after power on (November 6, 2012).

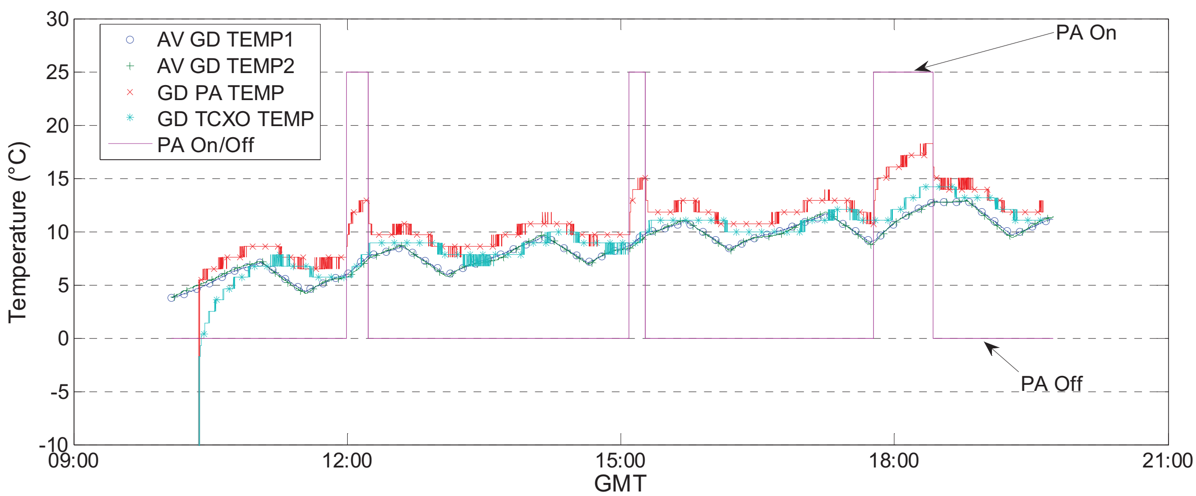

Figure 4.—Temperature increase when the SDR is transmitting (November 2, 2012).

It was hypothesized that there would be a correlation between the beta angle of the ISS and the temperature of the payload. The beta angle (seen in the upper portion of the figure) and the mean temperature from the GD SDR temperature sensor 1 (seen in the lower portion of the figure) are plotted in Figure 5. There was no correlation between the beta angle of the ISS and the mean temperature from Avionics GD Temperature Sensor 1.

3.4 Error Detection and Correction

As of August 1, 2013, no EDACs have been detected on the GD SDR. This means that any radiation in space has not caused either a correctable or detectable error in memory. Since the GD SDR is operating on the ISS in low Earth orbit, which is a low radiation environment, the fact that no EDACS have been detected is consistent with expectations.

3.5 Waveform Operational Time

The operational time for the receive and transmit waveforms can be seen in Tables 4 and 5. The most used waveform pair was the low rate (18 kbps receive; 24 kbps transmit), uncoded, SA, DG1 M2 waveform. This waveform was used frequently during the RF Subsystem checkout tests.

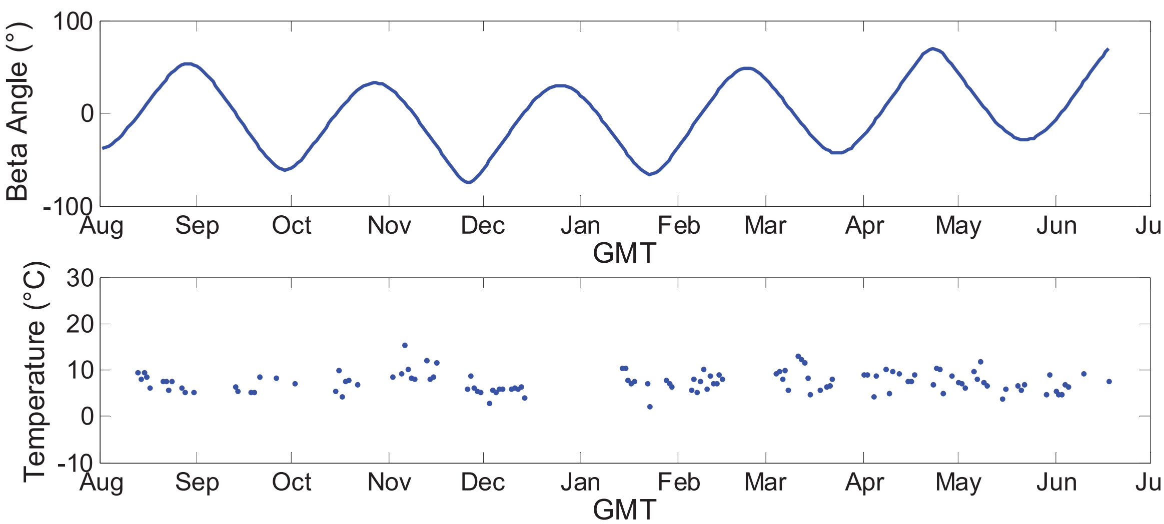

Figure 5.—Beta angle and GD SDR baseplate temperature.

TABLE 4.—GD SDR RECEIVE WAVEFORM OPERATIONAL TIME

Waveform number	Data rate, kbps	Forward error correction	Frequency	Time used, hr
180/182	18	Uncoded	SA	26.4
179/181	18	Coded	SA	3.0
184/186	18	Uncoded	MA	3.8
183/185	18	Coded	MA	3.5
204/206	72	Uncoded	SA	4.4
203/205	72	Coded	SA	1.2
208/210	72	Uncoded	MA	1.4
207/208	72	Coded	MA	1.5

TABLE 5.—GD SDR TRANSMIT WAVEFORM OPERATIONAL TIME

Waveform number	Frequency	Waveform type	Data rate, kbps	FEC	Coherency	Time used, hr
165	SA	DG1, Mode 1 and 2	24	Coded	Enabled	0.4
213	SA	DG1, Mode 1 and 2	24	Coded	Disabled	1.9
166	SA	DG1, Mode 1 and 2	24	Uncoded	Enabled	0.0
214	SA	DG1, Mode 1 and 2	24	Uncoded	Disabled	23
173	MA	DG1, Mode 1 and 2	24	Coded	Enabled	0.9
221	MA	DG1, Mode 1 and 2	24	Coded	Disabled	2.3
174	MA	DG1, Mode 1 and 2	24	Uncoded	Enabled	0.6
222	MA	DG1, Mode 1 and 2	24	Uncoded	Disabled	3.2
189	SA	DG1, Mode 1 and 2	192	Coded	Enabled	1.1
237	SA	DG1, Mode 1 and 2	192	Coded	Disabled	0.0
190	SA	DG1, Mode 1 and 2	192	Uncoded	Enabled	1.6
238	SA	DG1, Mode 1 and 2	192	Uncoded	Disabled	0.7
197	MA	DG1, Mode 1 and 2	192	Coded	Enabled	1.3
245	MA	DG1, Mode 1 and 2	192	Coded	Disabled	0.0
198	MA	DG1, Mode 1 and 2	192	Uncoded	Enabled	0.0
246	MA	DG1, Mode 1 and 2	192	Uncoded	Disabled	1.3
299	SA	DG1, Mode 3	1000	Coded	Enabled	0.0
300	SA	DG1, Mode 3	1000	Uncoded	Enabled	1.1
303	MA	DG1, Mode 3	1000	Coded	Enabled	0.0
304	MA	DG1, Mode 3	1000	Uncoded	Enabled	0.0
261	SA	DG2	1000	Coded	Enabled	0.0
262	SA	DG2	1000	Uncoded	Enabled	0.0
381	SA	DG2	1000	Coded	Disabled	0.0
382	SA	DG2	1000	Uncoded	Disabled	2.0
385	MA	DG2	1000	Coded	Enabled	0.0
386	MA	DG2	1000	Uncoded	Enabled	0.0

4.0 Future Work

While there were many temperature trends that are easily explainable as described in Section 3.3, there are also several unexplained trends. This section suggests possible investigations relating to the behavior of the GD SDR temperature in space. Figure 6(b) is a magnified section of the Figure 6(a). From the magnified image, we can see that the period of temperature increase and decrease due to the ISS orbit around the Earth is still about 90 min, as it should be. The unusual behavior seen in this graph is the miniscule change in the temperature magnitude. It is less than half a degree, where in December (the baseline in Figure 2) the change in temperature due to being exposed to Sun and shade was about 2° or 3°. In other months, the change is greater than this, but only on a few days in June is the change so small.

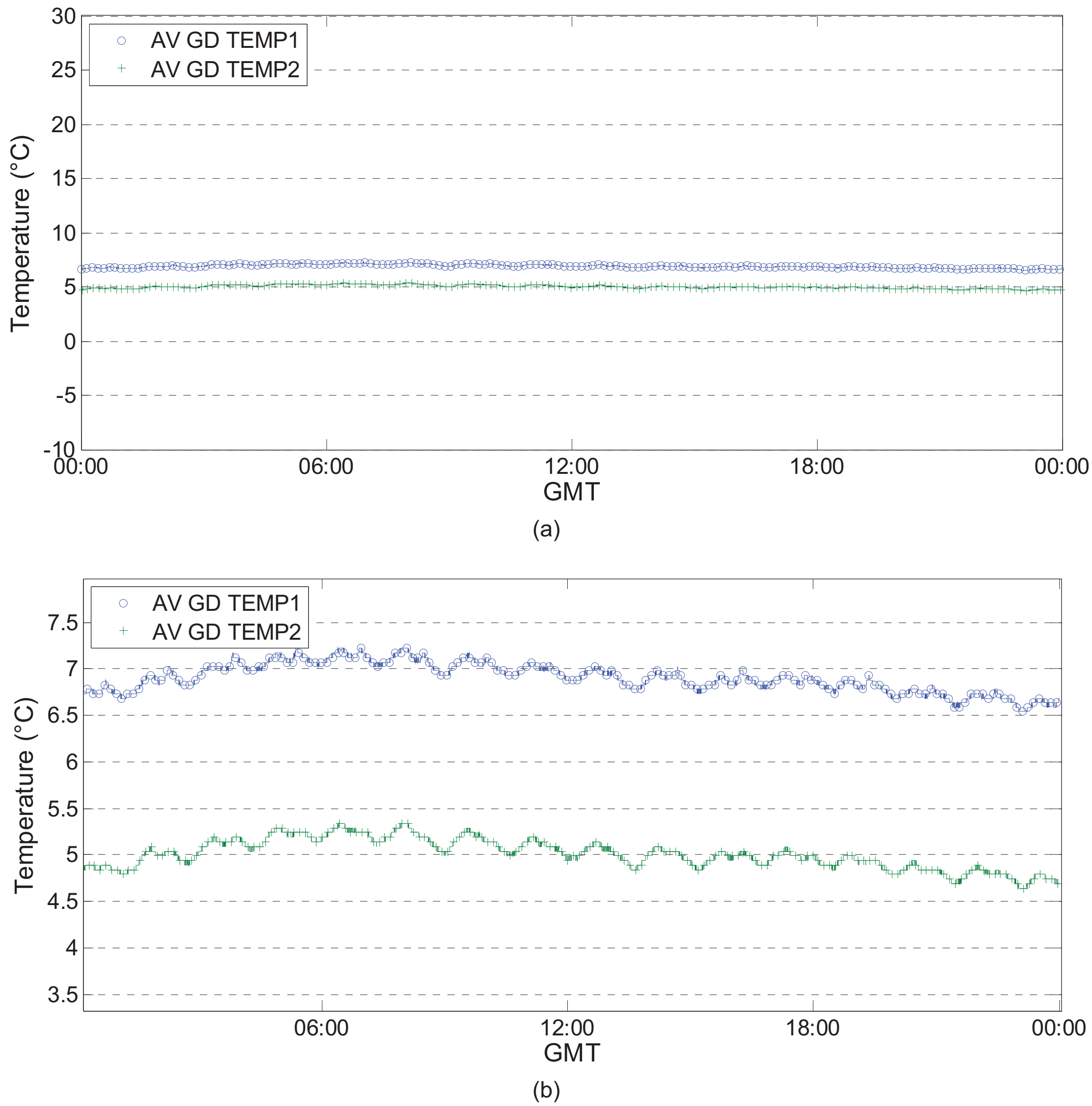

Figure 6.—(a) Baseplate temperature magnitude, (b) zoomed (June 4, 2013).

In Figure 7, the temperature is trending down even though the radio is on. This decrease while the radio is on happens four times during the year of data. This is the biggest decrease; in the other three occurrences, the decrease is very slight (the other occurrences are July 8, July 11, and September 13).

In Figure 8, the overall temperature is trending up even though the radio is not on. Perhaps another radio has in the testbed has been turned on and is causing the increase in temperature.

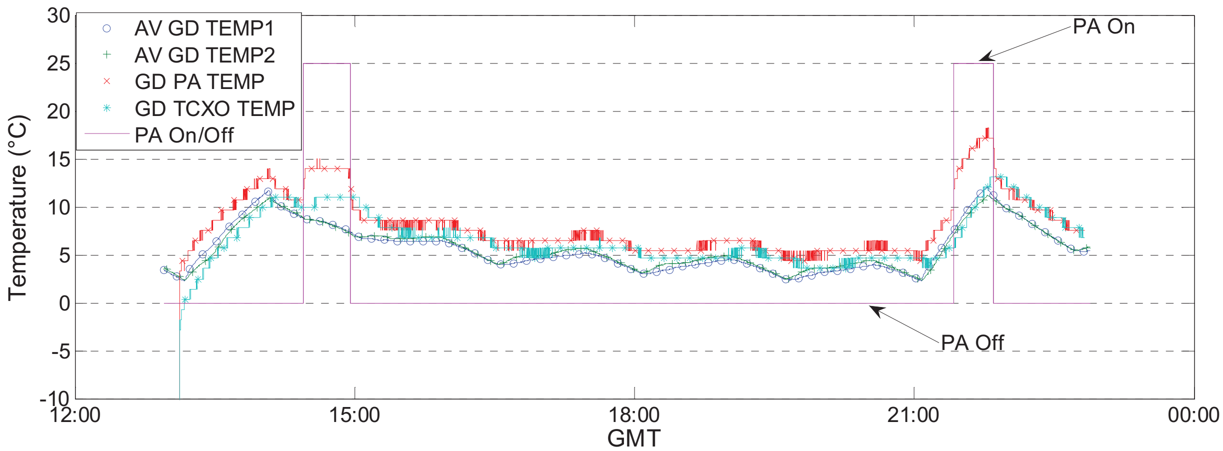

Figure 7.—Downward temperature trend (March 18, 2013).

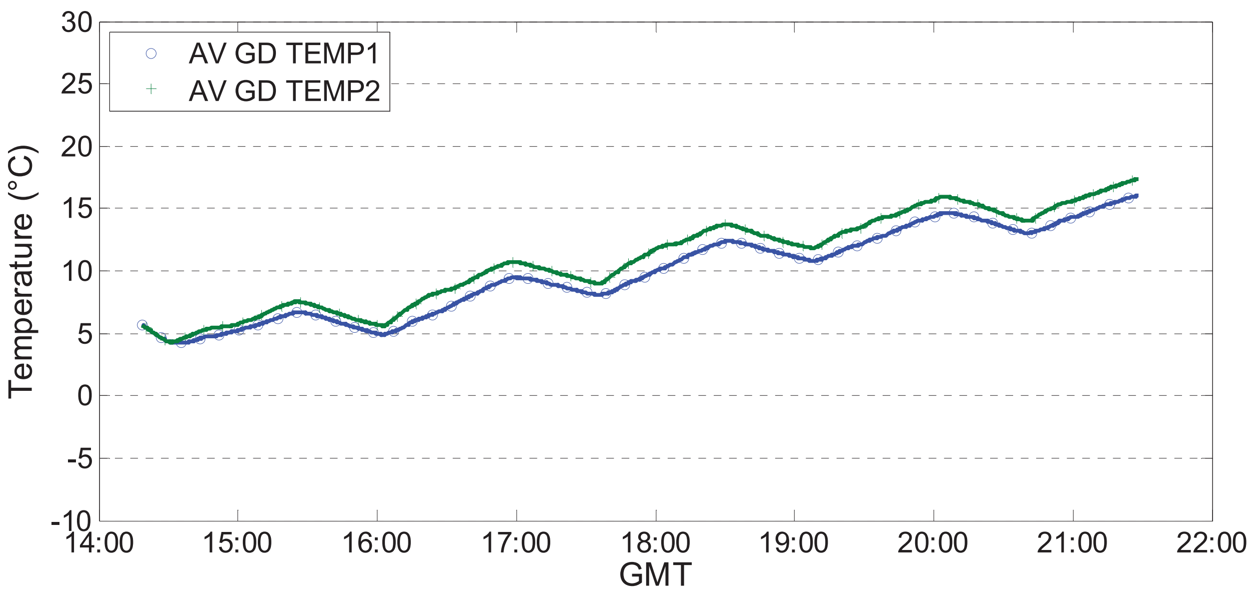

Figure 8.—Upward temperature trend (May 6, 2013).

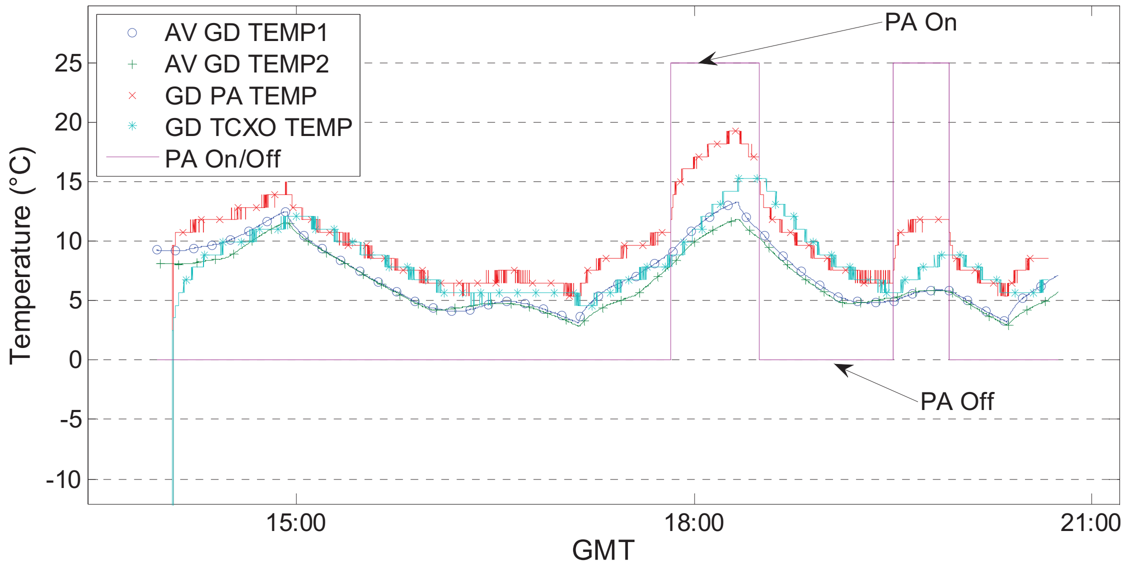

Figure 9.—Unexplained temperature trend pattern (February 12, 2013).

Figure 9 shows a longer 3-hr temperature pattern consisting of a longer maximum followed by a shorter, local maximum. This occurs on 34 of the 124 days on which data was taken. It happens when the radio is both on and off; six of the times this pattern occurs the radio is on, and 28 of the times the radio is off. It happened throughout the year; the only months that do not have temperature data that follow this pattern are November and December.

5.0 Summary

The GD SDR long term performance metrics analysis for the first year on the ISS has been completed. The analysis included SDR (269 hr) and PA (41 hr) power on time; and waveform operational time. A check on the EDAC counts showed that there have been no EDACs so far. The temperature analysis revealed a warming and cooling period consistent with the revolution of the ISS around the Earth. There does not appear to be a correlation between beta angle and SDR temperature. The future work section (Section 4.0) lists some unexplained temperature trends that could be the subject of further investigation.

References

1. S. Johnson, R. Reinhart, and T. Kacpura. "CoNNeCT's Approach for the Development of Three Software Defined Radios for Space Application," presented at the IEEE Aerospace Conference, March 2012.
2. Space Network (SN) User's Guide, 450-SNUG (Revision 9, August 2007).