STRS RADIO SERVICE SOFTWARE FOR NASA'S SCAN TESTBED

Dale Mortensen, P.E., Vantage Partners, LLC, USA; Daniel Bishop, Vantage Partners, LLC, USA; David Chelmins, NASA Glenn Research Center, USA

ABSTRACT

NASA's Space Communication and Navigation (SCaN) Testbed was launched to the International Space Station in 2012. The objective is to promote new software defined radio technologies and associated software application reuse, enabled by this first flight of NASA's Space Telecommunications Radio System (STRS) architecture standard. Pre-launch testing with the testbed's software defined radios was performed as part of system integration. Radio services for the JPL SDR were developed during system integration to allow the waveform application to operate properly in the space environment, especially considering thermal effects. These services include receiver gain control, frequency offset, IQ modulator balance, and transmit level control. Development, integration, and environmental testing of the radio services will be described. The added software allows the waveform application to operate properly in the space environment, and can be reused by future experimenters testing different waveform applications. Integrating such services with the platform-provided STRS operating environment will attract more users, and these services are candidates for STRS interface standardization.

1. INTRODUCTION

The Space Telecommunications Radio System (STRS) architecture is becoming a standard across the National Aeronautics and Space Administration (NASA) as software defined radios (SDRs) become more common for missions. Radio application portability between SDR platforms and reusability among missions are major objectives. The STRS architecture emphasizes platform abstraction and standard interfaces to aid portability and reuse. Implicit in these goals is separating the roles of platform and waveform developers.

NASA has developed an on-orbit, adaptable, SDR-based and STRS-based testbed facility to conduct a suite of

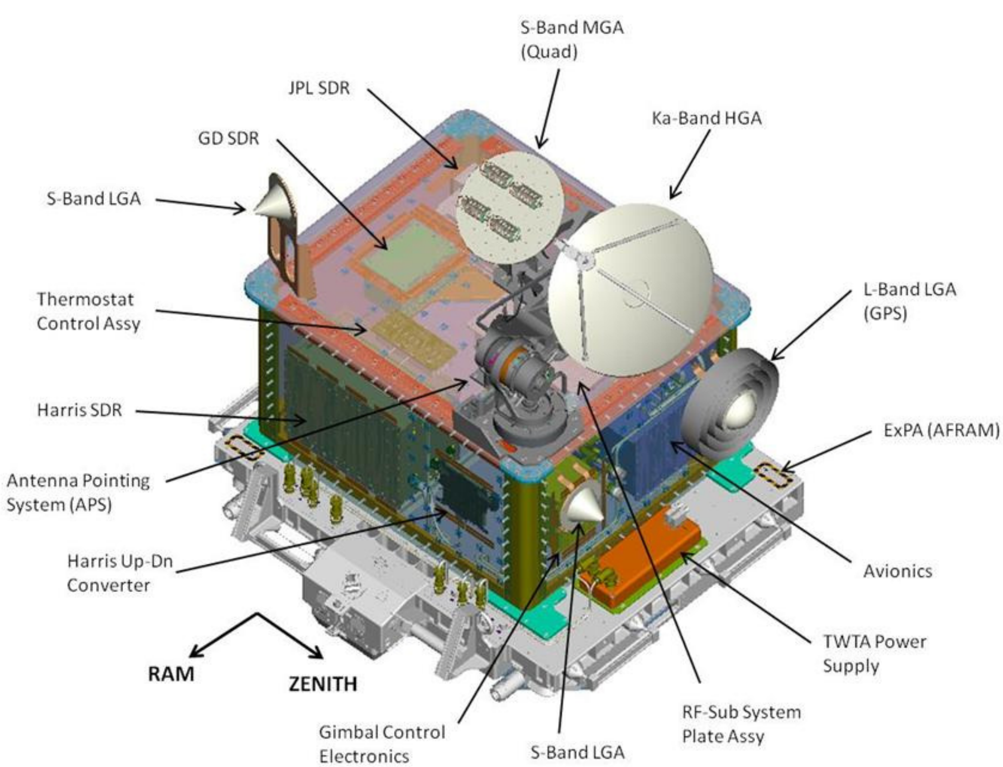

Figure 1: SCaN Testbed ISS Payload

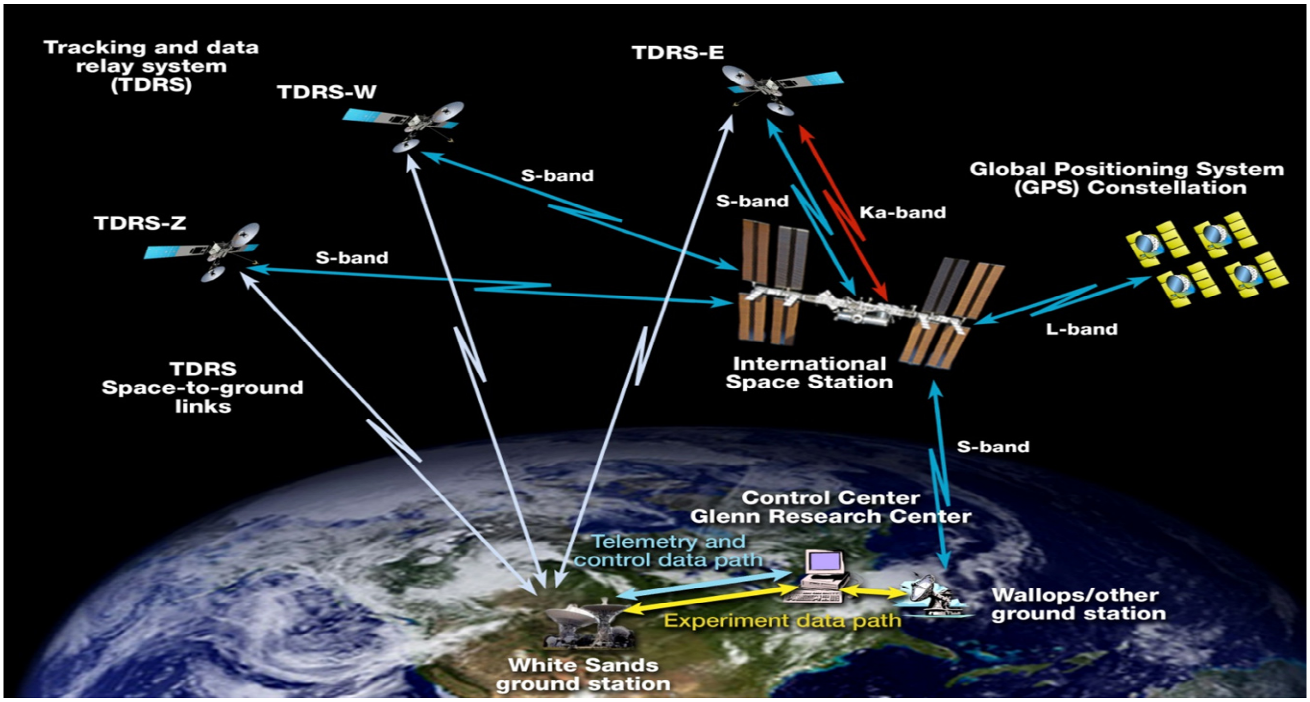

Figure 2: SCaN Testbed Communication Links

experiments to advance technologies, reduce risk, and enable future mission capabilities on the International Space Station (ISS). The Space Communications and Navigation (SCaN) Testbed Project provides NASA, industry, other Government agencies, and academic partners the opportunity to develop and field communications, navigation, and networking technologies in the laboratory and space environment based on SDR platforms and the STRS Architecture. The project was previously known as the Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT). This paper will give a brief overview of the SCaN Testbed, the development and use of radio services for the Jet Propulsion Laboratory (JPL) SDR, related space environmental testing, and the STRS waveform application repository.

2. SCAN TESTBED OVERVIEW

The SCaN Testbed consists of three radios provided by the Harris Corporation, JPL, and General Dynamics (GD). The testbed also contains an avionics controller, radio frequency (RF) subsystem, three space-facing antennas, one Earth-facing antenna, a Ka-band travelling wave tube amplifier (TWTA), and gimbal control electronics. A diagram of the ISS payload portion of the Testbed is shown in Figure 1. The various RF link capabilities are illustrated in Figure 2.

The Harris radio operates in the Ka-Band frequency band, which allows the link to support high rate waveforms. The Harris radio contains four field programmable gate arrays (FPGA), a general-purpose processor (GPP), and a digital signal processor (DSP) on which complex waveforms can operate. The Harris radio hardware is capable of RF data rates greater than 100 Mbps.

The JPL radio transceiver operates in the S-Band frequency band and additionally contains an L-Band global positioning system (GPS) receiver hardware slice. The radio can generate both space-to-space and space-to-ground RF links. The radio contains two FPGAs and a GPP on which the waveforms can be loaded for S-Band and GPS experiments.

The GD radio operates at S-Band frequencies and is also capable of space-to-space and space-to-ground RF links. The radio contains one FPGA and a GPP, as well as experimental chalcogenide phase-change memory.

3. RADIO SERVICES

One of the main objectives of the STRS standard is to promote waveform portability. According to STRS release 1.02, “Services are software programs running on the software radio that provide functionality available for use by other applications” [2]. Services are usually underlying tasks that handle various aspects of the radio, such as timekeeping or signal level control. Every STRS-compliant platform should provide common functions that all waveform applications need, and these functions may vary depending on the radio’s hardware. These functions are the

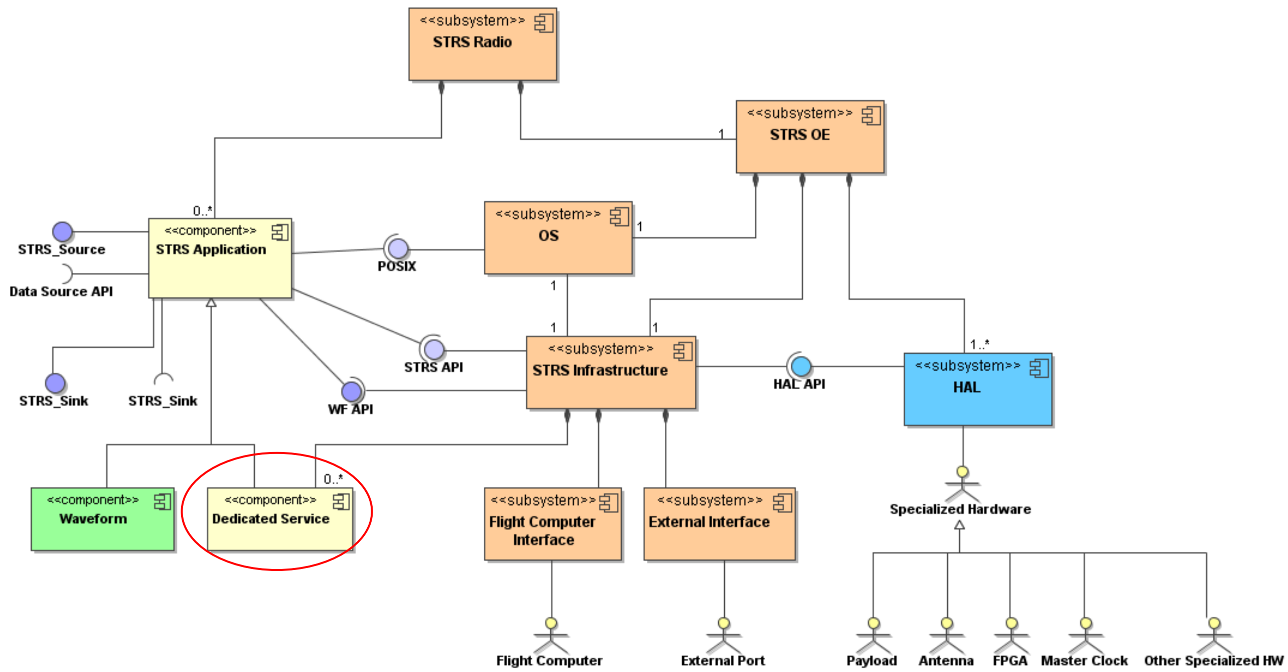

Figure 3: STRS Architecture Components - services circled

hardware-dependent portion of the waveform, and ideally are provided by the platform developer. The waveform becomes more portable when these radio services have standard interfaces and are part of the platform instead of the waveform. At the same time different waveform applications are more easily developed on the platform because of the common radio services with standard interfaces.

Figure 3 is a diagram from the STRS standard of the platform operating environment (OE) that depicts the boundaries between the STRS infrastructure provided by the platform developer and the components that can be developed by third party vendors (e.g., waveform applications and services). This approach clarifies the interfaces between components. The STRS architecture defines services along with waveforms as applications running on the platform, making use of the OE and the provided STRS standard APIs.

In the case of the JPL SDR on the SCaN Testbed, the first operational waveform integration required the development of several radio services: receiver gain control, oscillator frequency compensation, IQ constellation compensation, SpaceWire (SpW) interface, and transmit level control. Figure 4 illustrates these services in the waveform flow. Each of these functions is required for most operational waveforms on this platform. Instead of implementing the functions in each waveform, a standard service could be provided by the platform developer along with the radio's operating environment.

3.1 Receiver Gain Control

The input power level into an Analog-to-Digital Converter (ADC) is critical for proper operation of a waveform receive chain. The level can be controlled via analog feedback loop or a digital feedback loop as in the JPL radio. The digital feedback loop provides additional flexibility because it gives the developer some latitude on the structure of the loop. For example, the received power measurement could be made using the entire ADC bandwidth, a narrow band measurement, or a combination of both. For this reason the single structure provided for the launch waveform may not be optimal for all waveforms, but can serve as a starting point for new waveform developers. However, there is a configurable lock range and target level which gives some flexibility for reuse with other waveforms.

For waveform development, generating a complete, high-fidelity software model of the SDR hardware can be very difficult. Modeling certain components as needed, such as the receiver gain control, is a more reasonable approach. A model was built to simulate some of the real world effects that the receiver gain control could see which included noise, continuous wave (CW) interference, direct sequence spread spectrum (DSSS) signal interference, and Doppler shift. The model proved to be a valuable tool for adjusting the algorithm's response to various cases prior to loading it on the hardware.

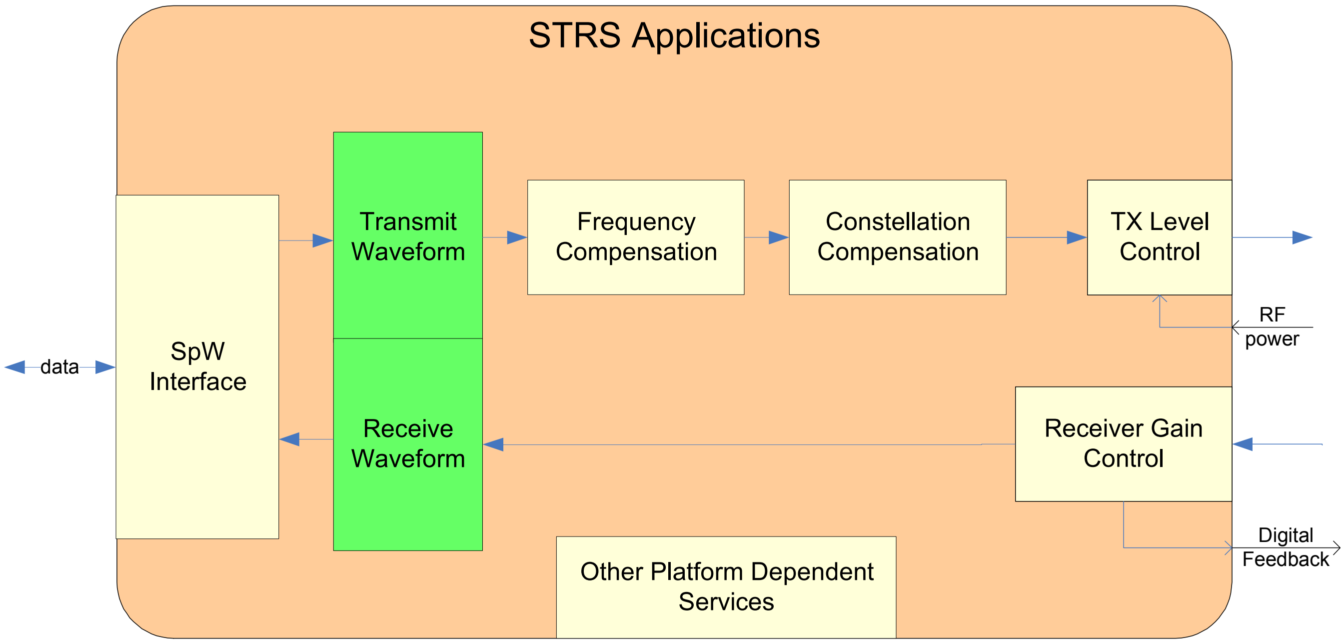

Figure 4: Radio Services in Waveform Signal Flow

3.2 Oscillator Frequency Compensation

A temperature compensated crystal oscillator (TCXO) is designed to compensate for temperature effects, but the frequency error is generally still a few parts-per-million. For an S-band SDR this means the error can exceed the specified frequency tolerance of the space network. The problem becomes even worse at the Ka-Band frequencies. However, with digital baseband offsets the TCXO error can be compensated so as to allow for proper operation with the space network. The compensation required is non-linear and therefore must be measured at various temperatures, which was performed during thermal vacuum system testing as described in section 4.2.

3.3 IQ Constellation compensation

An analog IQ modulator is a popular component in many wireless transmitters. It provides a convenient method to directly convert digital data symbols to RF. However, the IQ modulator is non-ideal and will contort the perfect constellation (Figure 5A). The common effects are IQ imbalance (Figure 5B), IQ skew (Figure 5C), and origin offset (Figure 5D). The imbalance, skew, and offset affect the error vector magnitude (EVM), which will negatively affect the Bit Error Rate (BER) performance of a receiver. The higher order modulation schemas are affected more by such imperfections in the modulator. Figure 7 illustrates the effect of an increasing imbalance with a QPSK waveform.

The IQ modulator compensations are needed to control the RF spectrum as well. The NASA Space Network has a strict spectral mask that the transmitter must meet. An uncompensated modulator can have additional spurs that may cause mixing products and violate the spectral mask. Figure 6 shows two spectral traces comparing the JPL SDR IQ modulator uncompensated (red trace), and the compensated (blue trace). The spectral spurs were reduced considerably with the IQ constellation compensation.

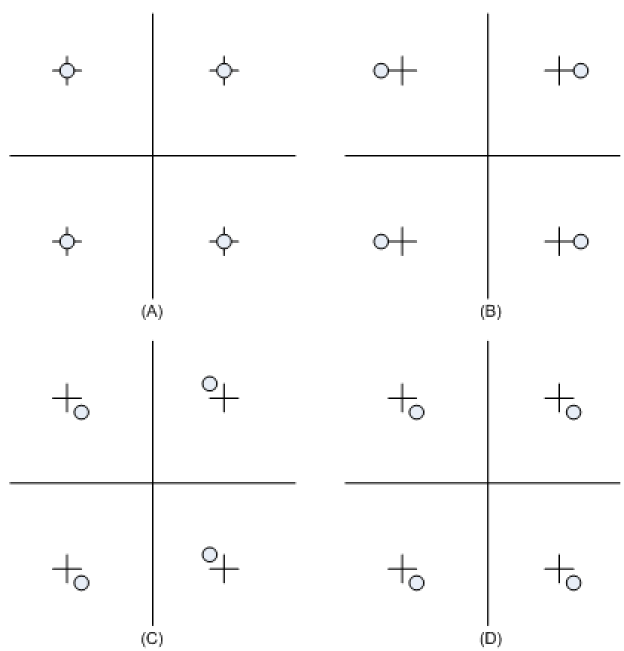

Figure 5: non-ideal IQ constellation effects

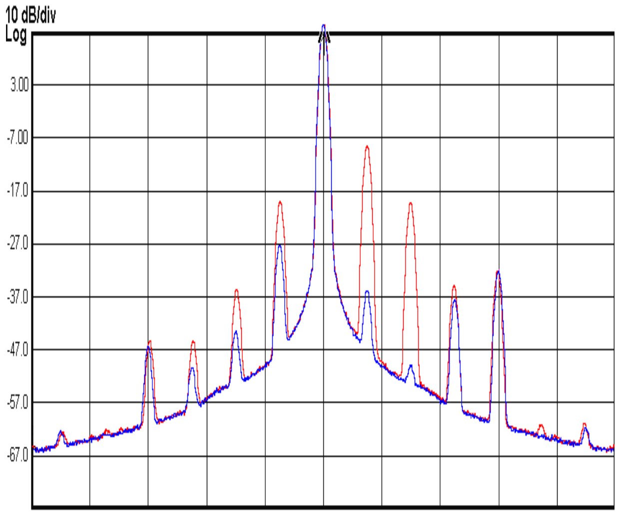

Figure 6: Transmit CW – compensated (blue) versus uncompensated (red)

3.4 Tx Level Control

The space links typically operate with minimal link margin, which means that the transmitter power needs to be kept near the optimal operating point. The typical power amplifier can vary by a few dB over the temperature extremes in space, which could cause a loss of acquisition or poor BER performance. This makes it critical to compensate for changes in gain of the transmit power amplifier. The JPL radio provides a power measurement reading from an RF sensor at the power amplifier output. A service was developed that monitors the sensor and computes the appropriate change to set the transmit levels with the DAC outputs. The sensor is also temperature dependent so a calibration over the operating temperature is required to obtain an accurate operating power.

3.5 SpaceWire

SpaceWire is being used worldwide by several different agencies including the Japanese Space Agency, the European Space Agency, and NASA. The SCaN Testbed uses this interface for data transmissions between the Avionics and the SDRs. On the JPL SDR, SpaceWire functionality has been implemented as a module within the FPGA [3]. A wrapper around the platform-provided SpaceWire module was developed to convert from the parallel data interface of the module to the serial stream of the waveform functions. Along with this conversion is buffering and SpaceWire packet formation control, including under/overflow monitoring. All together these functions form a radio service useable by future waveforms.

4. ENVIRONMENTAL TESTING

Being a flight project, the SCaN Testbed required space environmental testing. The major tests were thermal vacuum (TVAC), electromagnetic interference (EMI), communications compatibility with the space and ground networks, and bench testing.

4.1 Thermal Vacuum (TVAC)

To simulate low earth orbit conditions of vacuum and thermal gradients, the integrated payload was tested in a thermal vacuum chamber for 10 days. The temperature was ramped 4 times from hot to cold and cold to hot. Between the ramps the temperature was held at either the hot or cold extremes to allow for some additional testing at equilibrium. The heating profile difference between vacuum and ambient pressure is significant, causing each of the critical SDR components to heat differently. For example, the thermal relationship between the radio frequency module (RFM) and the power amplifier (PA) in Figure 8 shows a significant change outside of the thermal chamber. Temperature compensation needs to be determined at the box (i.e. SDR) level, but the component interactions are not always strictly cumulative.

The temperature dependent radio services of frequency and IQ constellation compensation were calibrated and verified during the TVAC testing cycles. From the calibration portion a lookup table was derived containing frequency offset and the IQ compensations with a temperature index. There are five IQ parameters that the baseband Tx waveform adjusts with temperature: I and Q DC offset, I and Q level/gain, and Q phase offset. This data is waveform independent and is applicable and available to SCaN Testbed experiments developing new waveforms for the JPL SDR.

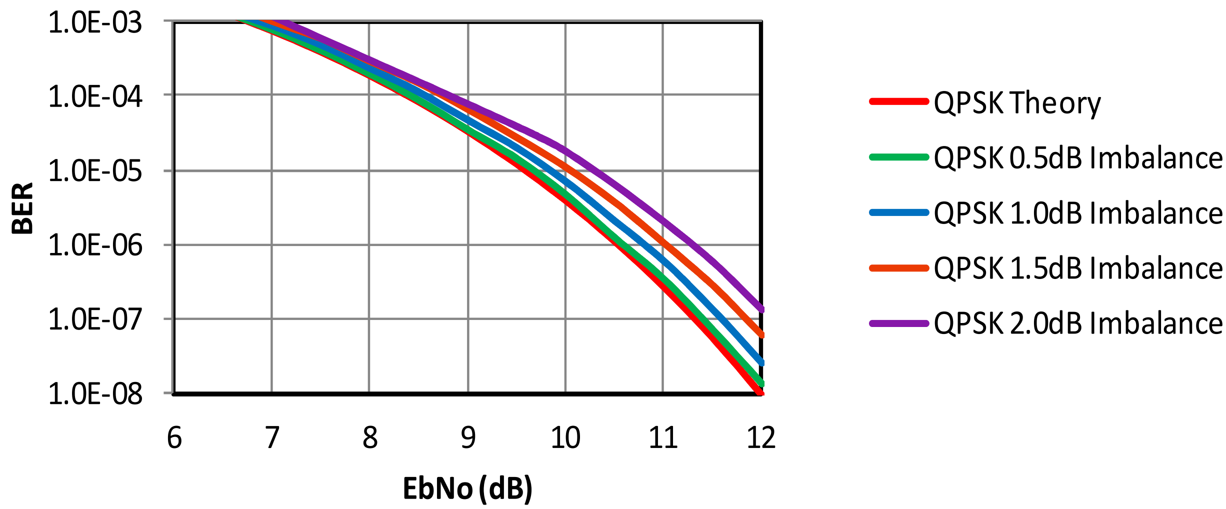

Figure 7: IQ Modulator Effects on BER

4.2 EMI Testing

The physical environment of the radio on ISS could have extraneous RF signals from others devices. These signals could cause unexpected behavior in any portion of the SDR. This makes EMI testing of the payload, the waveform, and the waveform services critical. The SCaN testbed was subject to over 5 days of EMI testing which included radiated and conducted emissions. The tests concluded with no significant issues.

4.3 Network Compatibility

Compatibility with the NASA Space Network and Near Earth Network is a critical requirement for the SCaN Testbed. Ground-based testing was performed with the actual space network relay satellites via external up-/down-link equipment, providing real-world links for the SDRs. The ground network compatibility was tested using NASA-certified test equipment racks. All of the radio services described previously performed as designed under these conditions, although network compatibility testing was done at ambient temperature and pressure.

4.4 Bench Testing

Time spent testing the various capabilities of the radio is important. Finding potential bugs or edge conditions is more likely the more tests are run. This is where bench testing is very useful since it can provide additional time on the unit. The bench testing time helps test the robustness of the radio and waveform application when it is running in steady state for long durations. During this testing is when performance testing such as introducing interferers, signal variations, and Doppler compensation occur. This type of testing, especially when targeted directly at evaluating an underlying service, can uncover waveform bugs that could lead to issues during expensive environmental testing.

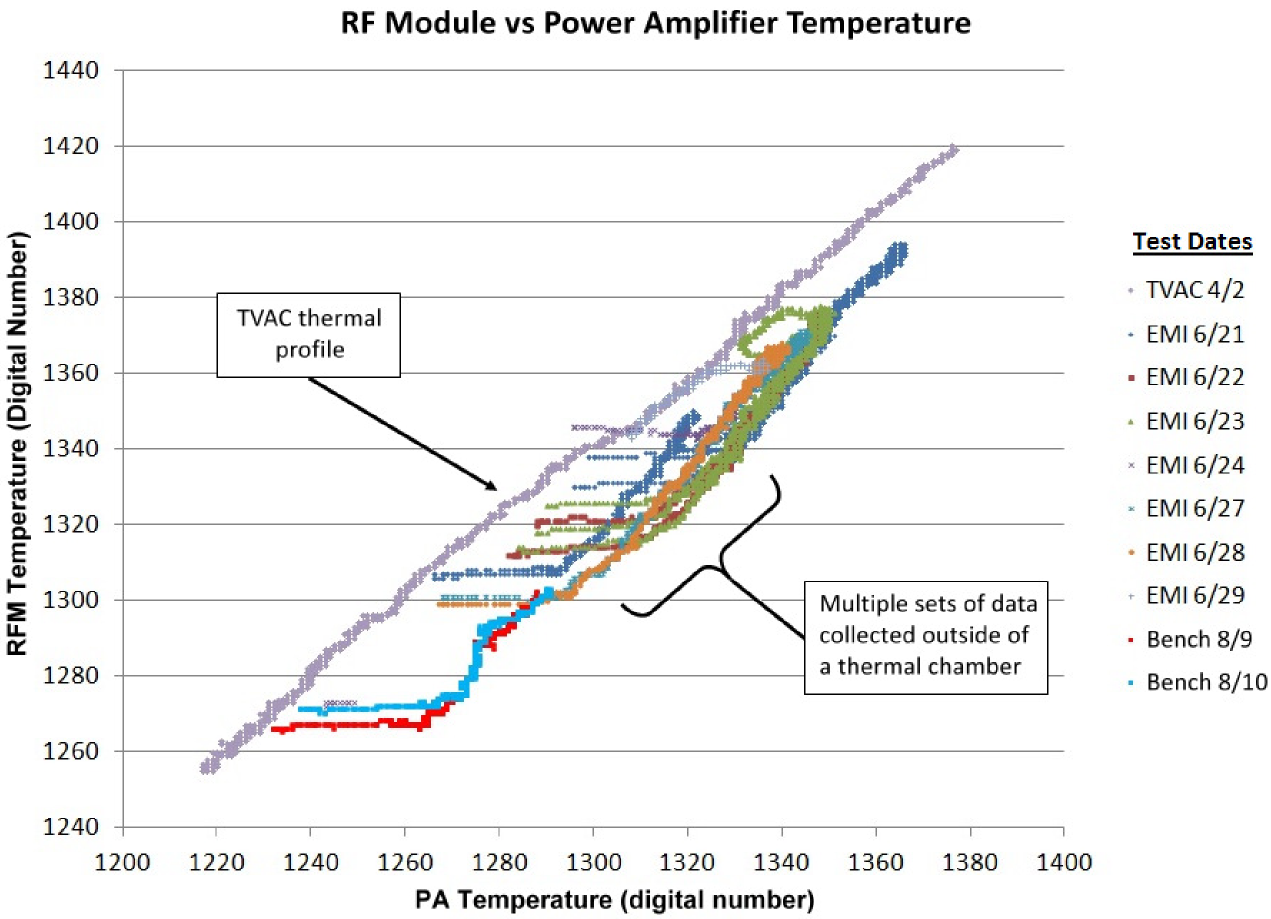

Figure 8: JPL SDR Heating Profile

5. STRS REPOSITORY

With NASA considering employing more software defined radios, STRS is intended to reduce cost for missions by promoting code reuse. However, if the original waveform was not written to be portable then porting can prove more costly than re-writing it. This was the finding of the government accounting office when it evaluated the JTRS standard [1]. There is a need to track the portability metrics of waveforms and waveform components to verify that a given architecture adds value to the process.

The STRS architecture developers are working to build a waveform application repository that will classify the portability of each waveform and waveform component. The repository will also track the mission classification for which it was developed. The repository will be instrumental in helping the developer generate a waveform quicker and at less cost. In addition, the STRS repository should help maintain the associated documentation required to meet NASA's flight software standards.

The SCaN Testbed baseline waveforms will be some of the first entries for the STRS repository. The portability classification process will be tested and refined with the entry and reuse of SCaN Testbed experiment software. Over time the repository process will aid in measuring the utility of STRS.

6. CONCLUSION

STRS waveform development for the SCaN Testbed's JPL SDR produced some waveform independent functions. Frequency compensation, IQ constellation compensation, transmit level control, and SpaceWire translation were described. These can be reused by future waveforms on this platform, and should be incorporated as STRS radio services for the platform, perhaps with closer ties to the OE. STRS architecture developers should consider adopting some standard radio services such as those presented here. In this manner waveform developers could begin to leverage more standard radio functionality as well as the standard APIs.

7. ACKNOWLEDGEMENTS

The authors would like to thank Steve Hall for his contributions to the waveform software.

9. REFERENCES

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