Comparing On-Orbit and Ground Performance for an S-Band Software-Defined Radio

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Overview

♦ Introduction to Software Defined Radio (SDR)
  • Why SDR?
  • Space Communications and Navigation (SCaN) Testbed

♦ Pre-launch Characterization

♦ Design of a Received Power Estimator
  • Ground development
  • Space performance
Why Software-Defined Radio?

- Software-defined radio (SDR) – a modern communication platform
  - Radio frequency module
  - Signal processing module [waveform]
  - General processing module

- SDR is…

  ADAPTABLE!

  FLEXIBLE!

  PREDICTABLE…?
NASA’s SCaN Testbed (STB)

- **Space Communications and Navigation (SCaN) Testbed**
  - External payload on the International Space Station (ELC-3 location)

![SCaN Testbed installed to the ExPRESS Logistics Carrier-3](image1)

![SCaN Testbed hardware block diagram](image2)

**SCaN Testbed hardware block diagram**
STB Experiment Communication
Jet Propulsion Laboratory (JPL) SDR – part of STB
- S-band transceiver (7 Watts) with L-band receive capability
- 66 MHz SPARC (RTEMS) processor and 2 Virtex-II FPGAs

Three JPL SDRs!
- Flight model (FM)
  - Radio Frequency Module, Global Positioning System Module, Baseband Processing Module, Power Amplifier / Power Supply Module
- Engineering model (EM)
  - Same as FM, except commercial grade parts.
- Breadboard
  - Baseband Processing Module only.

Int’l Space Station

Ground

Ground
Ground Testing

- **Flight model SDR testing prior to launch**
  - Establish a performance baseline in a controlled environment
  - Collect data useful for future waveform capabilities

- **Lesson Learned – test the hardware independent of the waveform**
  - Test very close to hardware interfaces
  - Do not make testing dependent on software implementation

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**Diagram:**

- Diplexer
- PLL / Down-conversion
- AGC
- ADC
- Signal Processing Module
- PA
- PLL / Up-conversion
- DAC

**Abbreviations:**

- **ADC** – Analog-to-Digital Converter
- **DAC** – Digital-to-Analog Converter
- **PLL** – Phase Lock Loop
- **AGC** – Automatic Gain Control
- **PA** – Power Amplifier
Received Power Estimator (PE) Design

- Estimating received power is a useful diagnostic feature
- Uses existing waveform despreader digital filters
  - Performed at the intermediate frequency (IF) after downconversion
  - BPSK filter bandwidth = 2*(signal bandwidth) + (Doppler allowance)
  - Despreader PN generator is bypassed for non-spread modes.

![Block Diagram of JPL SDR with various signal processing components: ADC, Automatic Gain Control (AGC), PN Code Generator, Despreader State Machine, Power Estimator Output, FPGAs, and On-Time Code.](image)
PE Ground Calibration

- Performed testing on the engineering model
  - Map the “Integrate & Dump” value to the corresponding input power
  - Swept input power level across realistic space received power range
  - Power Estimate = Signal Power + Noise Power
- Waveform “mode” → data rate, frequency, spreading, etc.

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<th>Freq. MHz</th>
<th>Filter BW (kHz)</th>
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PE Space Test Considerations

- **Limited power range and test time in space**
  - Space link varies by ~2 dB due to distance over ~40 minutes
  - NASA satellites have 2 fixed transmit power levels

- **Implemented spiral motion on the MGA**
  - Swept elevation over a wide range of power (~20 dB) during 1 pass
  - Used 1-degree lap size based on in-situ antenna pattern
Spread-spectrum results versus engineering model performance

- 0.1 dB error
- 0.3 dB error
- 0.6 dB error
- 0.8 dB error
Non-spread BPSK results versus engineering model performance

- 2.2 dB error
- 1.5 dB error
- 0.4 dB error
- 11 dB error
Results

- Overall the power estimator performance is acceptable.
  - Spread waveform modes show less than 1 dB average error
  - Non-spread modes show 1 to 2 dB average error (except mode H)

- The power estimator is sensitive to AGC fluctuation.
  - AGC level directly affects the IF power level
  - Mode H has a very low AGC set point → 11 dB average error!

- Future work
  - Improve understanding of how wideband noise affects the AGC algorithm
  - Incorporate AGC level into the power estimator
  - Look into narrower filter bandwidths for lower received power levels