SDR Input Power Estimation Algorithms

Jennifer Nappier

NASA Glenn Research Center, Cleveland, Ohio

Co-Author: Janette Briones

NASA Glenn Research Center, Cleveland, Ohio

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BACKGROUND INFORMATION
Space Communication and Navigation (SCaN) Testbed Flight System Overview

- 2 S-band SDRs
- 1 Ka-band SDR
- Ka-band TWTA
- S-band switch network
- Antennas
  - 2 - low gain S-band antennas
  - 1 - L-band GPS antenna
  - Medium gain S-band and Ka-band antenna on antenna pointing subsystem.
- Antenna pointing system
- Flight Computer/Avionics

- Launched on Japanese HTV-3 on July 20, 2012
- Installed on ISS August 7, 2012
- Checkout and Commissioning is in progress
Pictures of Installation and First Operations

Ka-band Antenna
SCaN Testbed aboard International Space Station
SCaN Testbed General Dynamics SDR Description

- TDRSS S-band Transponder
  - 8 receive waveform configurations
  - 30 transmit waveform configurations
- 1 Xilinx Virtex II QPro FPGA, 3 M gate
- ColdFire microprocessor
- Analog and Digital automatic gain controls (AGCs)

<table>
<thead>
<tr>
<th>Waveform Number</th>
<th>Center Frequency (GHz)</th>
<th>Data Rate (kbps)</th>
<th>Forward Error Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SA</td>
<td>18</td>
<td>Coded</td>
</tr>
<tr>
<td>2</td>
<td>SA</td>
<td>18</td>
<td>Uncoded</td>
</tr>
<tr>
<td>3</td>
<td>SA</td>
<td>72</td>
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<td>4</td>
<td>SA</td>
<td>72</td>
<td>Uncoded</td>
</tr>
<tr>
<td>5</td>
<td>MA</td>
<td>18</td>
<td>Coded</td>
</tr>
<tr>
<td>6</td>
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</tr>
<tr>
<td>8</td>
<td>MA</td>
<td>72</td>
<td>Uncoded</td>
</tr>
</tbody>
</table>

- TDRSS: Tracking Relay Data Satellite System
- SA: Single Access (2.041 GHz)
- MA: Multiple Access (2.106 GHz)
SDR Input Power Estimators Description

Motivation
• The received power can be used to characterize and estimate link performance
• The estimated link performance can be used to update predicted performance calculated from link budgets
• GD SDR did not implement an SDR input power estimator

Expected On-orbit Operating Conditions
• SDR Input Power Range: -130 dBm to -100 dBm
• Temperature: -15 °C to +45 °C

Estimator Method
• Utilize digital and analog AGCs and baseplate temperature to estimate SDR input power
AGC Characterization Results at Ambient Temperature

**Analog AGC at 26 °C**

**Digital AGC at 26 °C**

- Analog AGC varies with center frequency (MA/SA)
- Digital AGC varies with symbol rate (coding + data rate)
Both analog and digital AGCs vary over temperature. The analog AGC variation is more significant.
SDR INPUT POWER ESTIMATOR DESCRIPTIONS
Straight Line Estimator
Algorithm Description

- Straight line equations created to estimate power based on linear region of digital AGC
- 3 equations created for each waveform in 3 temperature regions:
  - Cold: <10 °C
  - Ambient: 10 °C – 35 °C
  - Hot: >35 °C
- SDR input power range limited to linear region of the digital AGC
Adaptive Linear Combiner Estimator Block Diagram

1. \( X = [DAGC \ AAGC \ Temp \ 50] \)

2. \( W = \begin{bmatrix} W_{DAGC} \\ W_{AAGC} \\ W_{TEMP} \\ W_{const} \end{bmatrix} \)

3. \( W_{n+1} = W_n + \alpha [A_n - W_nX_n]X_n' \)

4. \( Y_n = W_nX \)
Adaptive Linear Combiner Estimator
Training Algorithm Description

- Input the training data set
- Sort the data into 3 temperature bins
  - Cold: <10 °C
  - Ambient: 10 °C – 35 °C
  - Hot: >35 °C
- Randomize the data in each bin
- Initialize the weight vector, W
- Compute the weight vector for each temperature bin
- Repeat the previous step until the weight vector converges
- Calculate the estimated output power
SDR input power is a function of 2 temperature bins. For example, at 17.5 °C:

\[ Y = 0.2W_c X + 0.8W_a X + 0W_h X \]
Neural Network Estimator
Block Diagram

1. \( X = [\text{DAGC} \ \text{AAGC} \ \text{Temp} \ \text{WFID} \ \text{T}] \)

2. \( [\text{IW}], [\text{LW}], [\text{bias1}], [\text{bias2}] \)

3. \( y_n = \sum a' \text{LW}' + \text{bias}_2 \)

4. \( y = m \times x \)

\[
\begin{align*}
\text{Inputs (X)} & \quad \text{Digital AGC} \\
\quad & \quad \text{Analog AGC} \\
\quad & \quad \text{Baseplate Temp} \\
\quad & \quad \text{WF ID} \\
\quad & \quad \text{SDR Input Power Calculated Data (Targets, T)} \\
\rightarrow & \quad \text{Neural Network (weights and bias)} \\
\rightarrow & \quad \text{SDR Input Power Estimate} \\
\rightarrow & \quad \text{Output (Y)} \\
\quad & \quad \text{Error} \\
\rightarrow & \quad \text{SDR Input Power Measured Target Data (T)}
\end{align*}
\]
Neural Network Estimator Algorithm Description

• Input the training data set
• Train neural network (60% data used for training)
• Simulate neural network (20% data used for validation)
• Obtain weights and bias
• Compare the output ($Y$) to SDR input power measured target data, $T$.
• Analyze the error; train and simulate the neural network to obtained new weights and bias if necessary.
The training process is repeated until there is a good fit between the target and estimated power.
ESTIMATOR ERROR ANALYSIS
The histograms show that the neural network estimator has the lowest error (+/- 0.5 dB), while the straight line and linear adaptive estimators are about the same (+/- 1.0 dB).
The straight line estimator and linear adaptive estimator have about the same error, but the linear adaptive has a higher SDR input power level (-90 dBm).
ON-ORBIT TESTING
EXPERIMENTAL RESULTS
On-orbit Testing Experimental Results

Initial test results show all three estimators are within 2 dB of predicted.

The estimators were implemented in the SCaN Testbed Ground Software.
On-orbit Testing Experimental Results

GD SDR Checkout 09/13/2012
18kbps/uncoded/SA waveform, 5.5-7.3 °C

An unknown interferer is shown in the middle of this event.
Summary / Future Work

Summary

• 3 estimators have been implemented and tested on the ground
• Initial on-orbit tests indicate that the estimators are within 2 dB of predicted SDR input power
• Algorithm dependence on the AGCs can lead to invalid results in the presence of interfering signals

Future Work

• Continue to characterize the SDR input power algorithms during on-orbit operations on ISS
• Utilize the engineering model (EM) characterization data to create SDR input power estimators for the EM
• A method for extending these algorithms for future waveforms could be developed
Questions?

jennifer.m.nappier@nasa.gov
216-433-6521