SDR Input Power Estimation Algorithms

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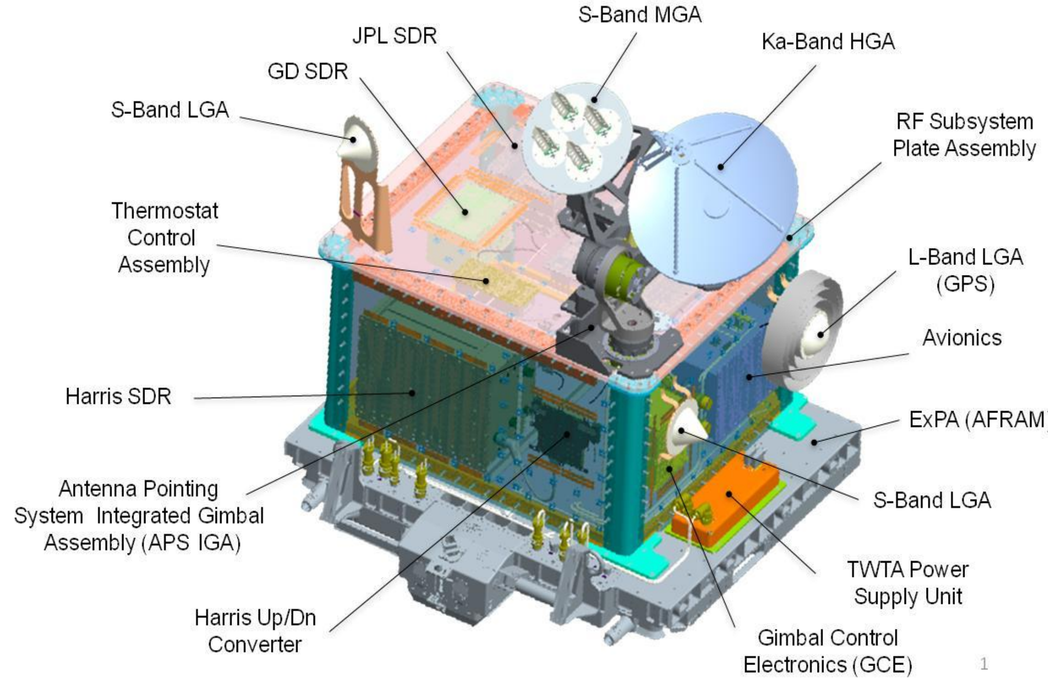
BACKGROUND INFORMATION

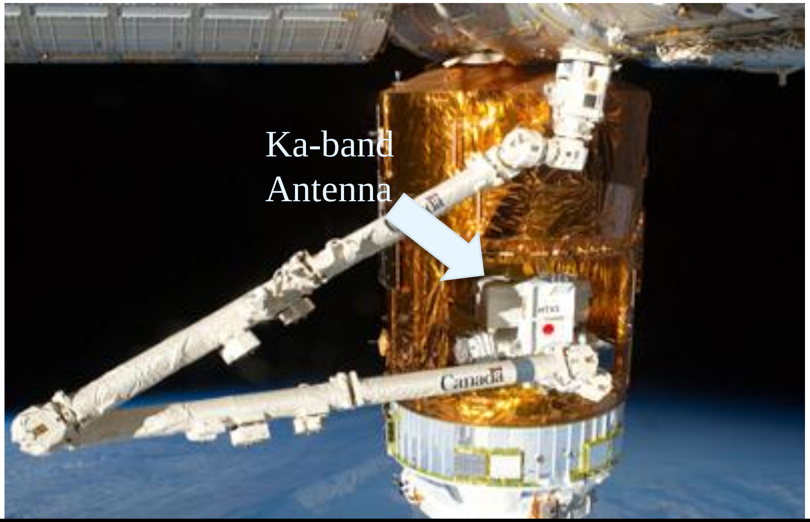
Space Communication and Navigation (SCaN) Testbed Flight System Overview

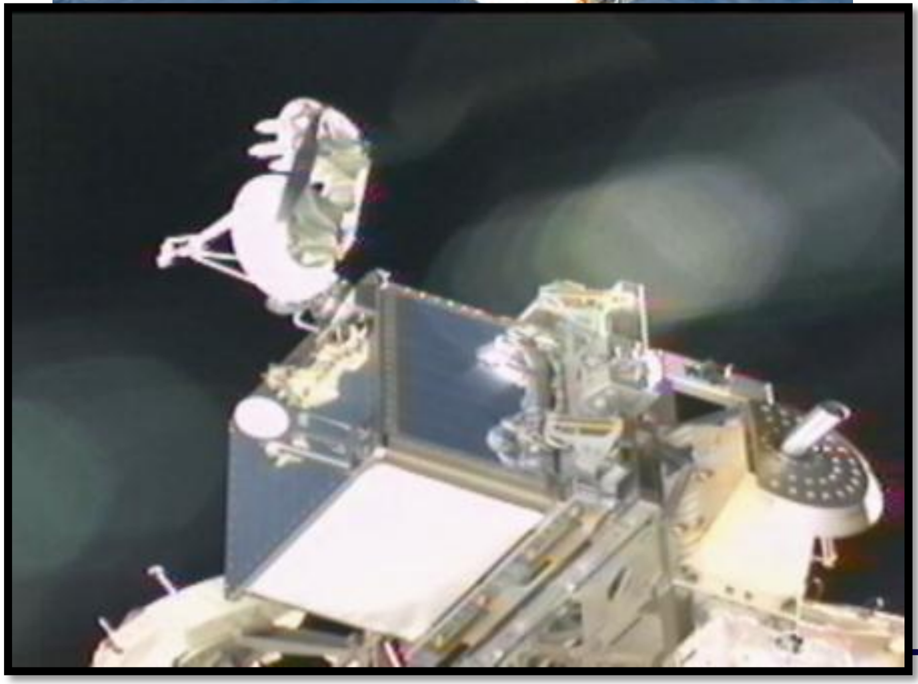
- 2 S-band SDRs
- 1 Ka-band SDR
- Ka-band TWTA
- S-band switch network
- Antennas
  - 2 - low gain S-band antennas
  - 1 - L-band GPS antenna
  - Medium gain S-band and Ka-band antenna on antenna pointing subsystem.
- Antenna pointing system
- Flight Computer/Avionics

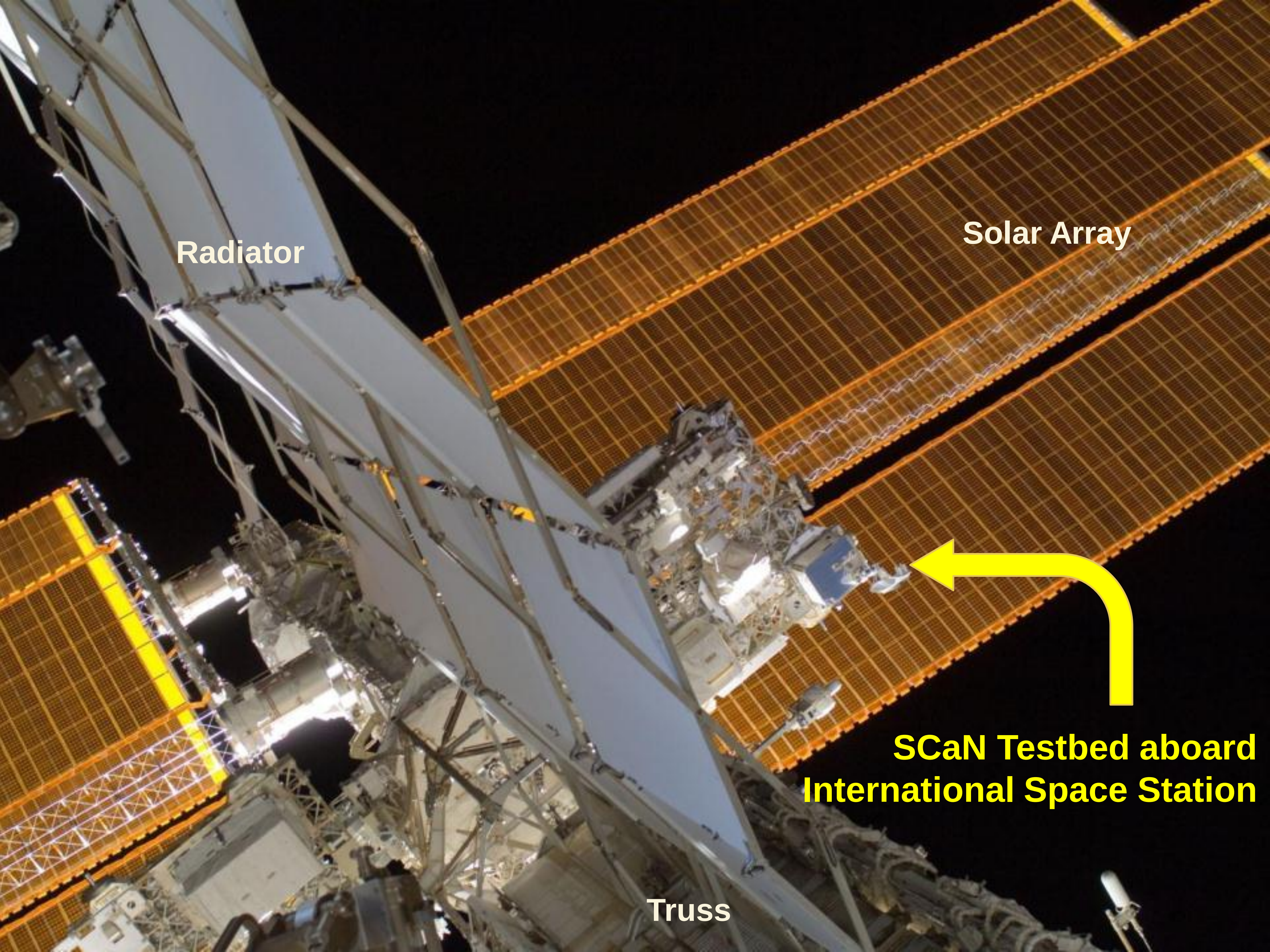


- Launched on Japanese HTV-3 on July 20, 2012
- Installed on ISS August 7, 2012
- Checkout and Commissioning is in progress

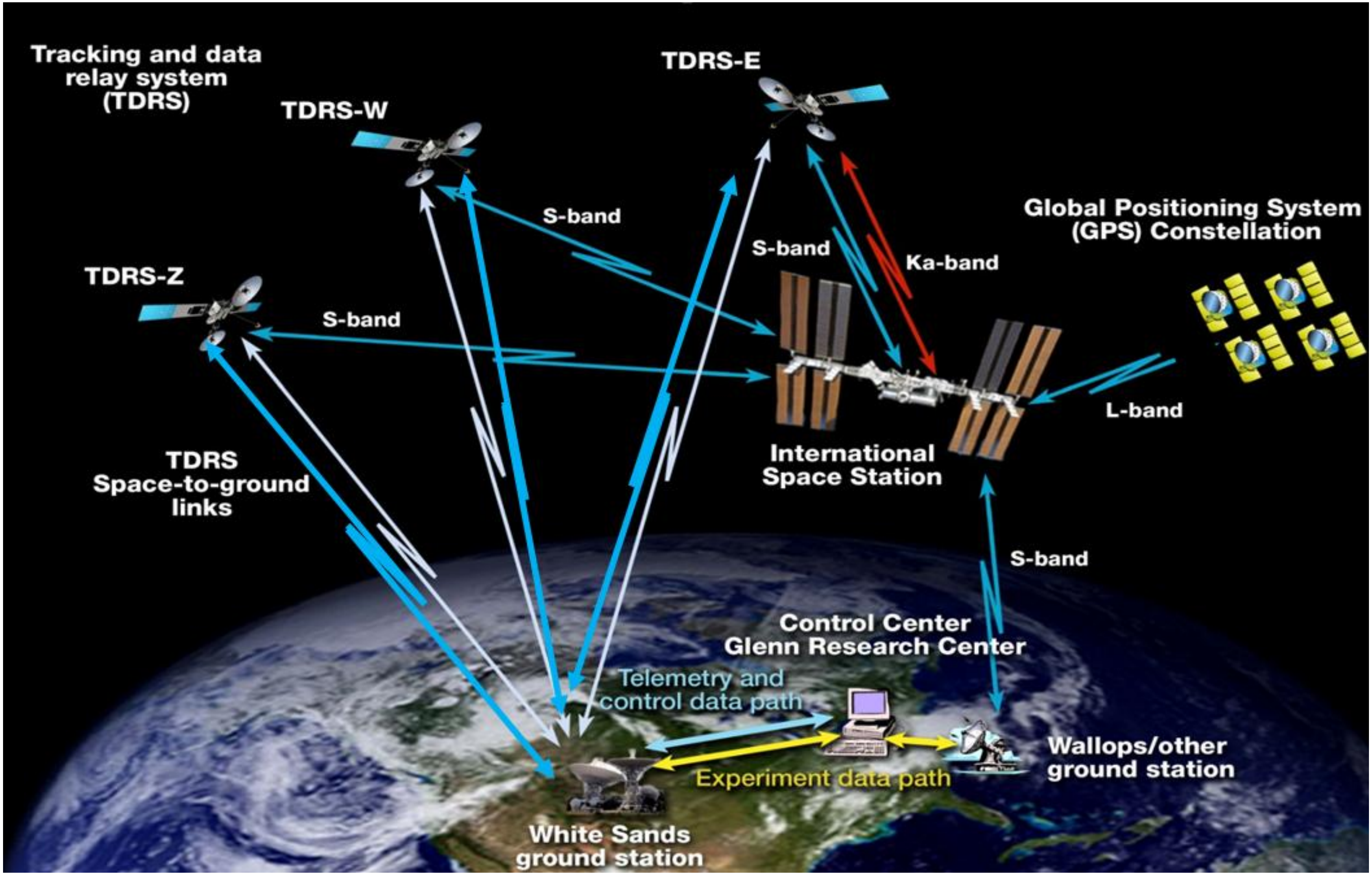
Pictures of Installation and First Operations





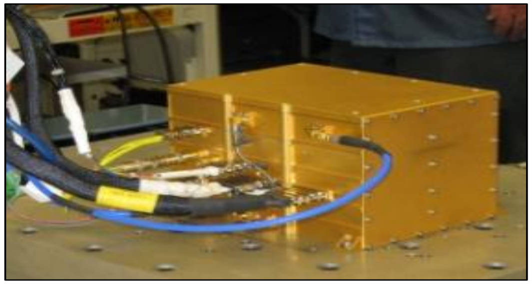

Radiator
Solar Array
SCaN Testbed aboard
International Space Station
Truss

SCaN Testbed Experiment System



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)



Waveform Number	Center Frequency (GHz)	Data Rate (kbps)	Forward Error Correction
1	SA	18	Coded
2	SA	18	Uncoded
3	SA	72	Coded
4	SA	72	Uncoded
5	MA	18	Coded
6	MA	18	Uncoded
7	MA	72	Coded
8	MA	72	Uncoded

- 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

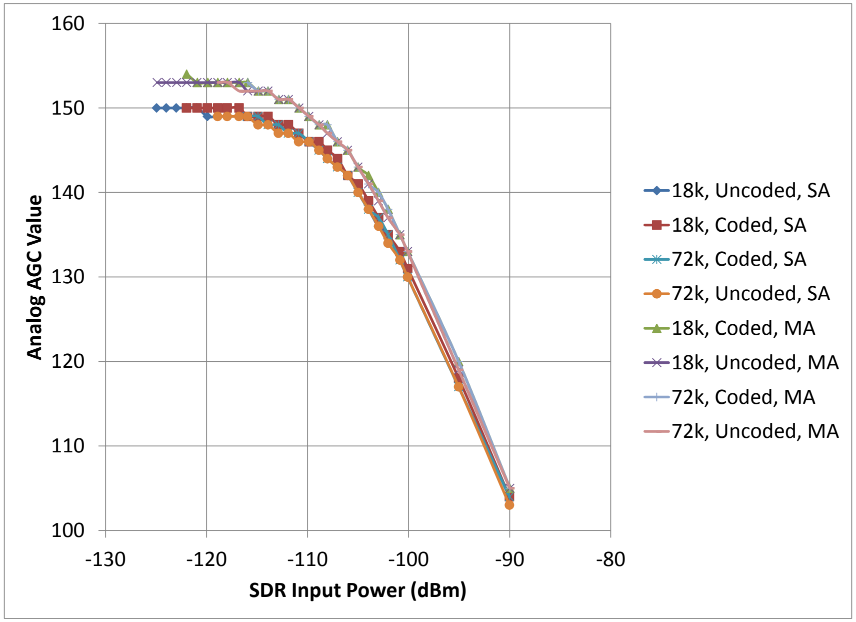
- SDR Input Power Range: -130 dBm to -100 dBm
- Temperature: -15 °C to +45 °C

Estimator Method

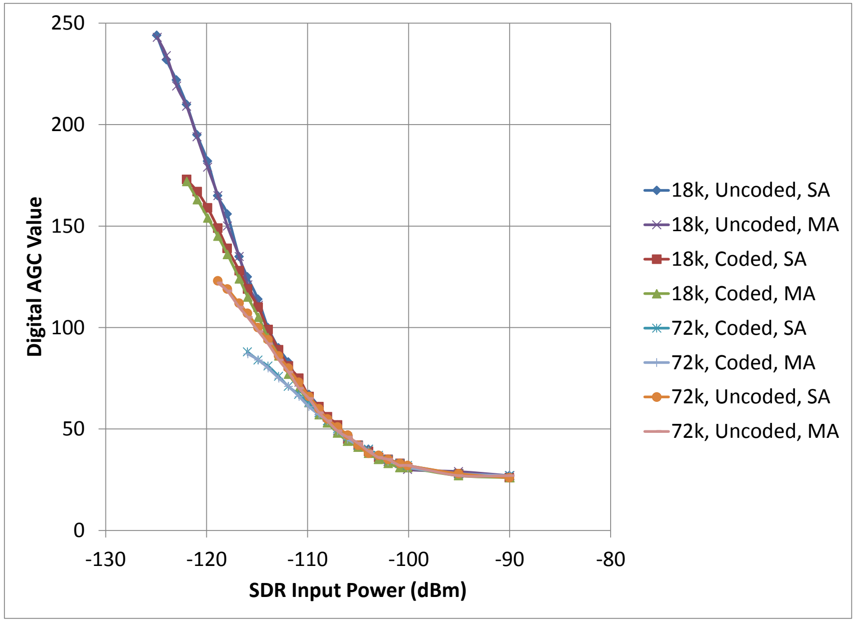
- Utilize digital and analog AGCs and baseplate temperature to estimate SDR input power

AGC Characterization Results at Ambient Temperature

Analog AGC at 26 °C



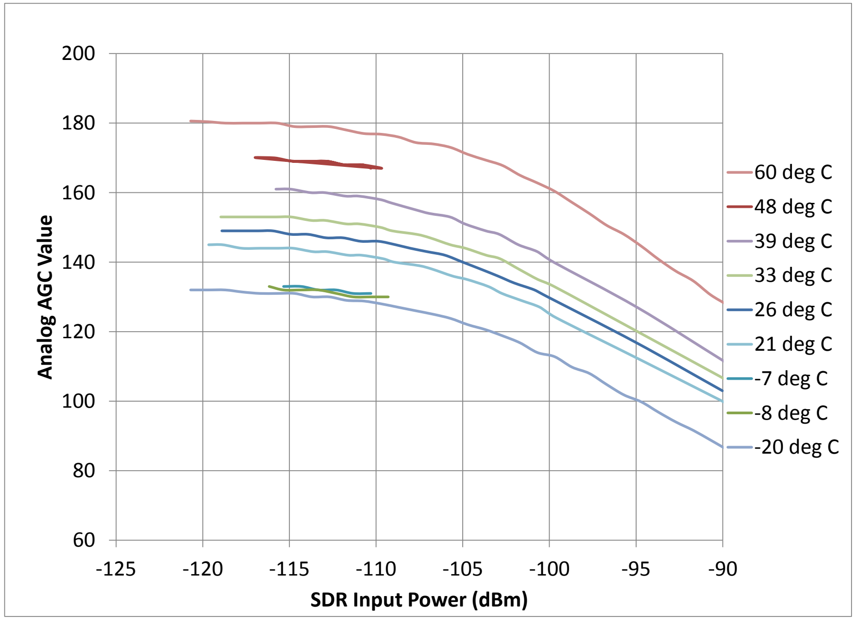
Digital AGC at 26 °C



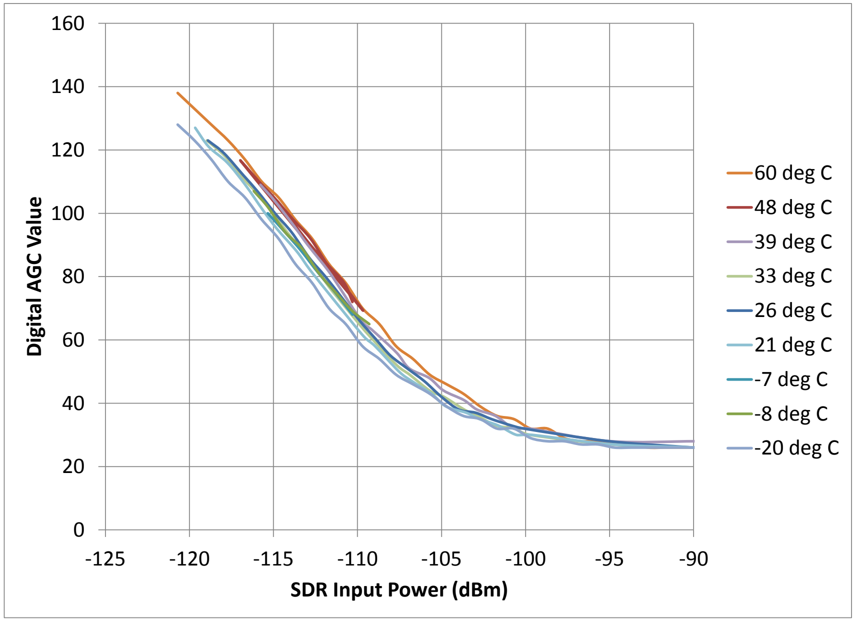
- Analog AGC varies with center frequency (MA/SA)
- Digital AGC varies with symbol rate (coding + data rate)

AGC Characterization Results over Temperature

Analog AGC



Digital AGC

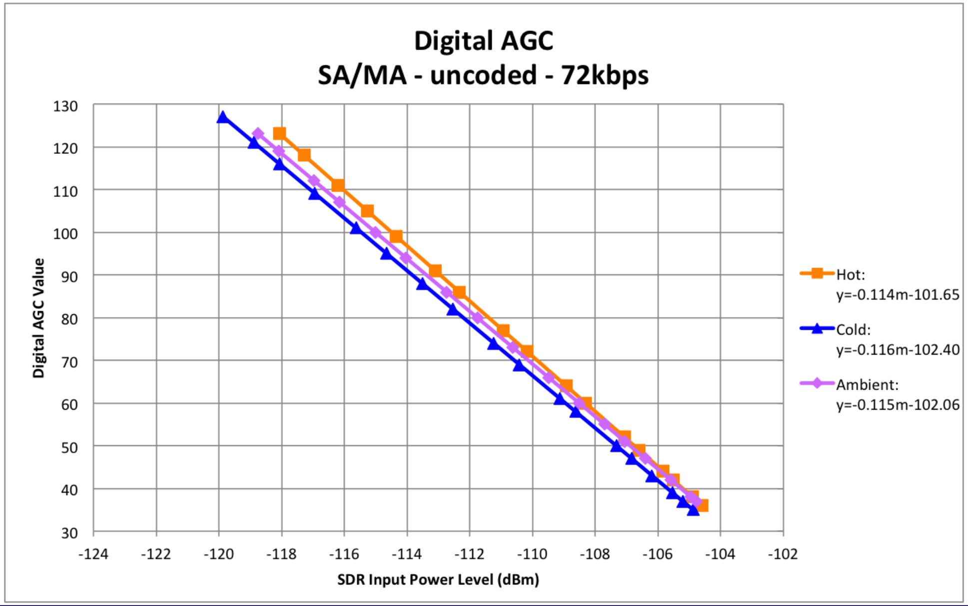


- Both analog and digital AGCs vary over temperature. The analog AGC variation is more significant.

SDR INPUT POWER ESTIMATOR DESCRIPTIONS

Straight Line Estimator Algorithm Description

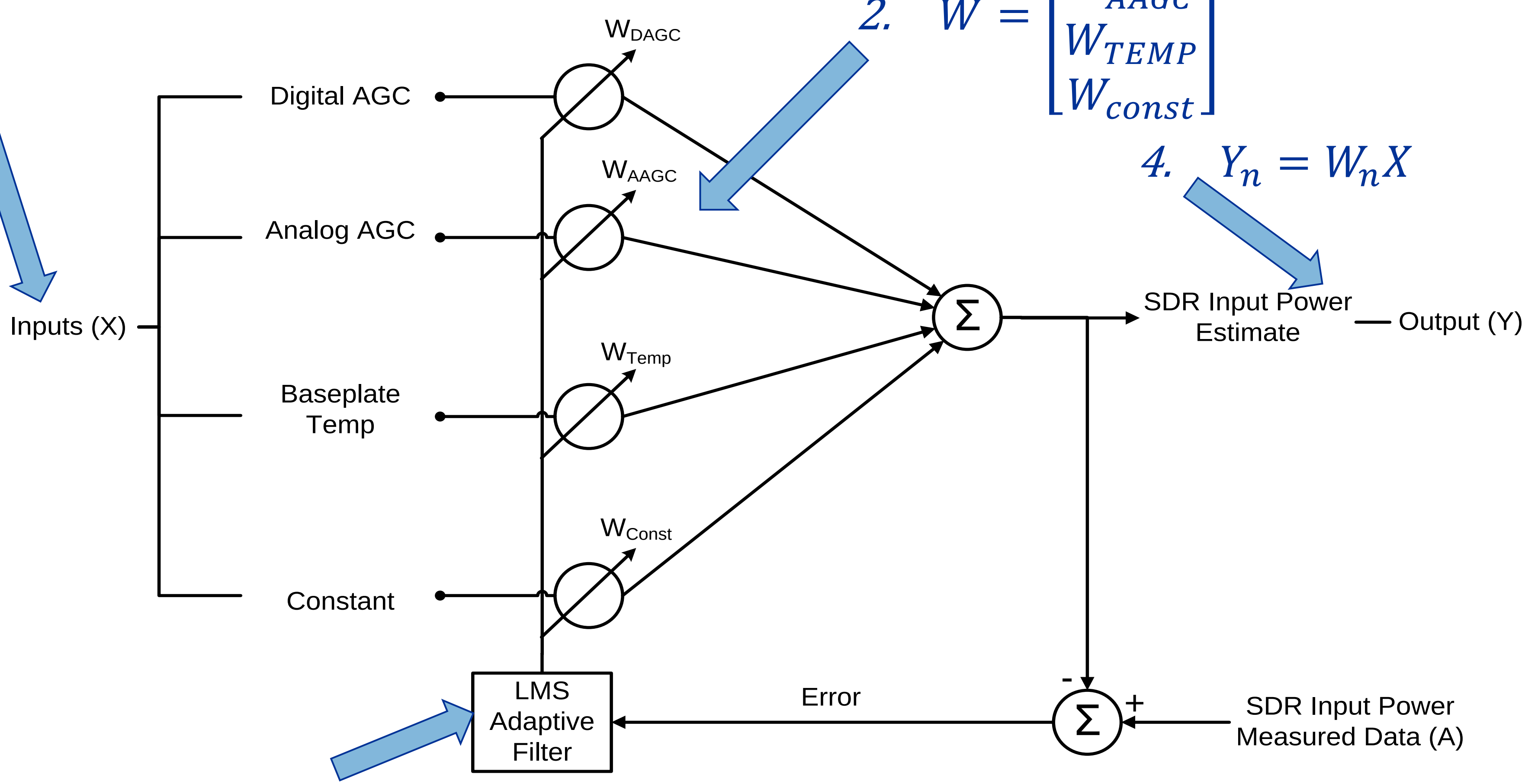
- Straight line equations created to estimate power based on linear region of digital AGC
- 3 equations created for each waveform in 3 temperature regions:
  - Cold: <10 °C
  - Ambient: 10 °C – 35 °C
  - Hot: >35 °C
- SDR input power range limited to linear region of the digital AGC



Adaptive Linear Combiner Estimator Block Diagram

1. $X = [DAGC\ AAGC\ Temp\ 50]$

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



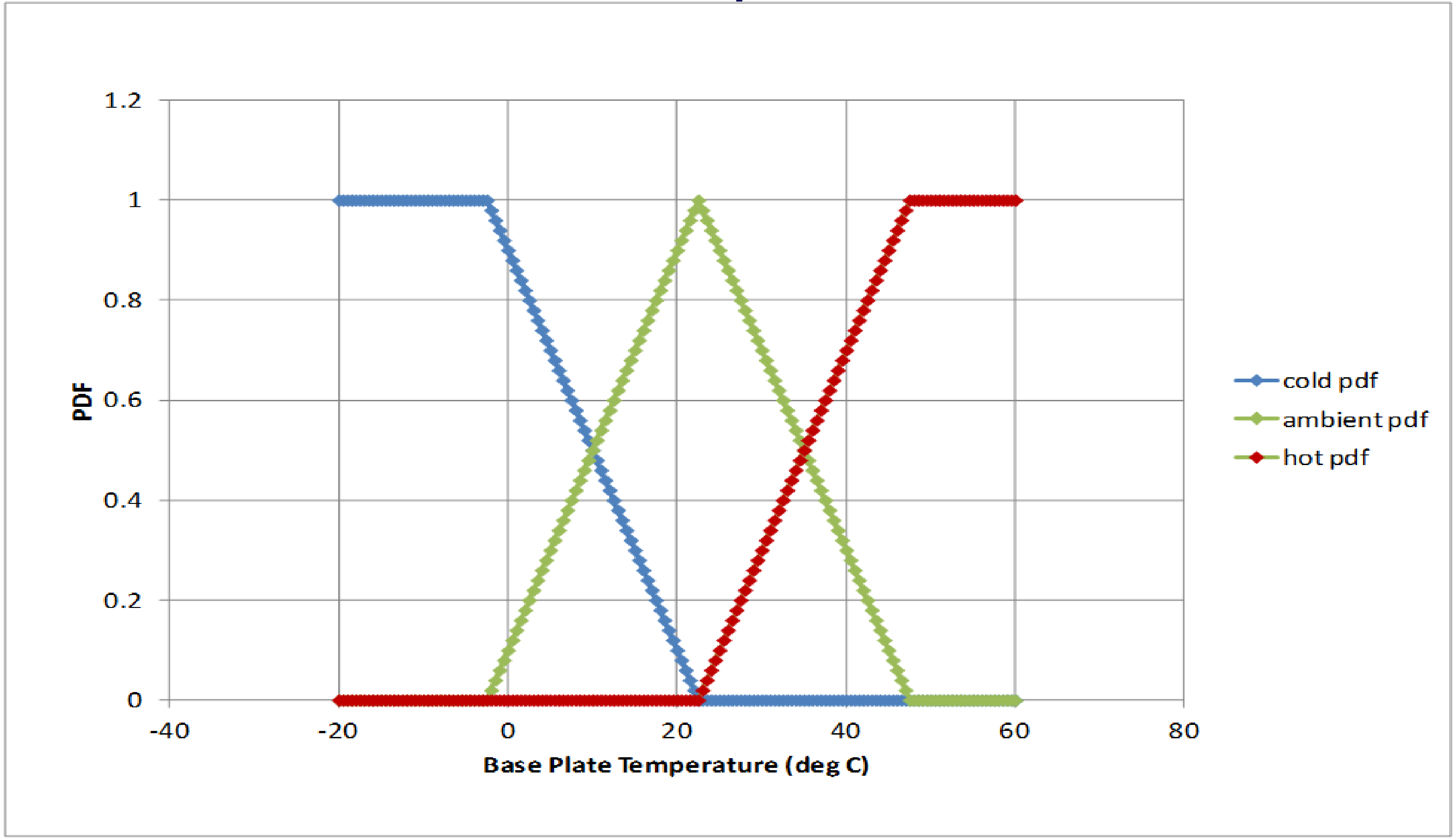
4. $Y_n = W_n X$

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

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

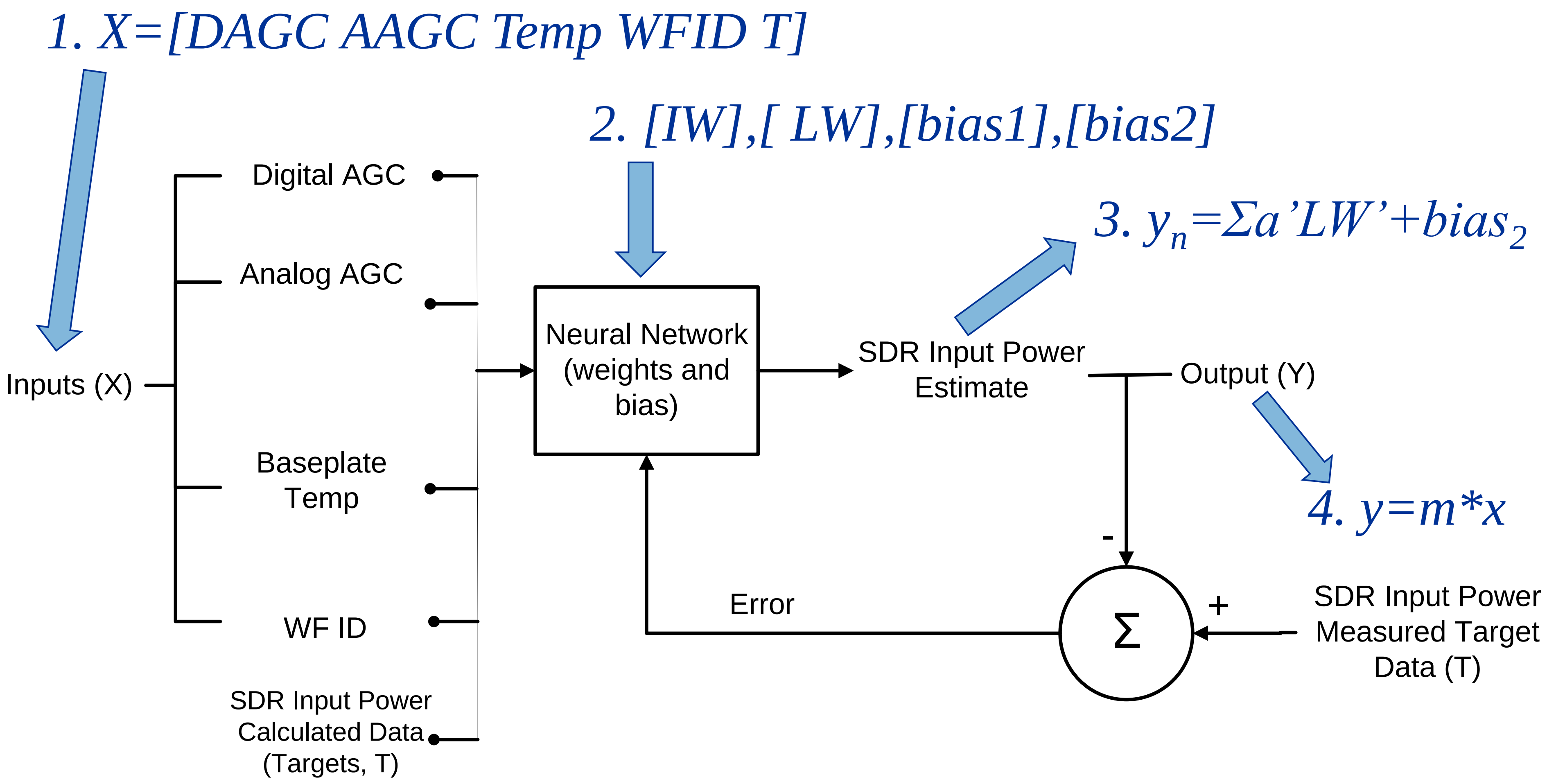
Adaptive Linear Combiner Estimator Membership Functions



- SDR input power is a function of 2 temperature bins. For example, at 17.5 °C:

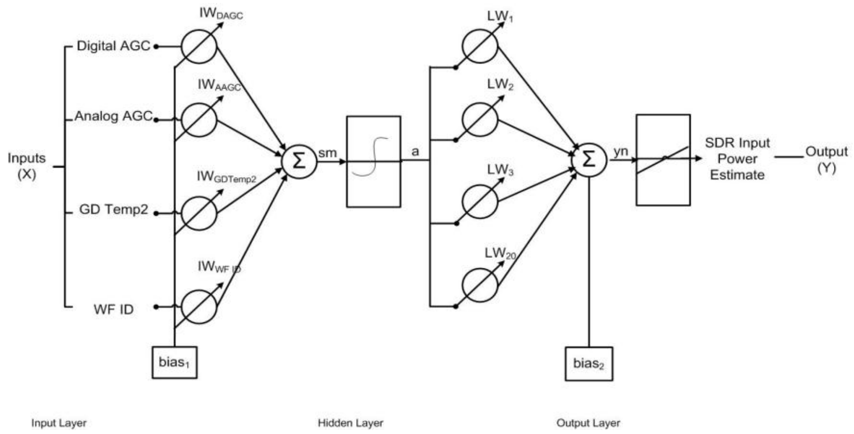
$$Y = .2W_c X + .8W_a X + 0W_h X$$

Neural Network Estimator Block Diagram



Neural Network Estimator Algorithm Description

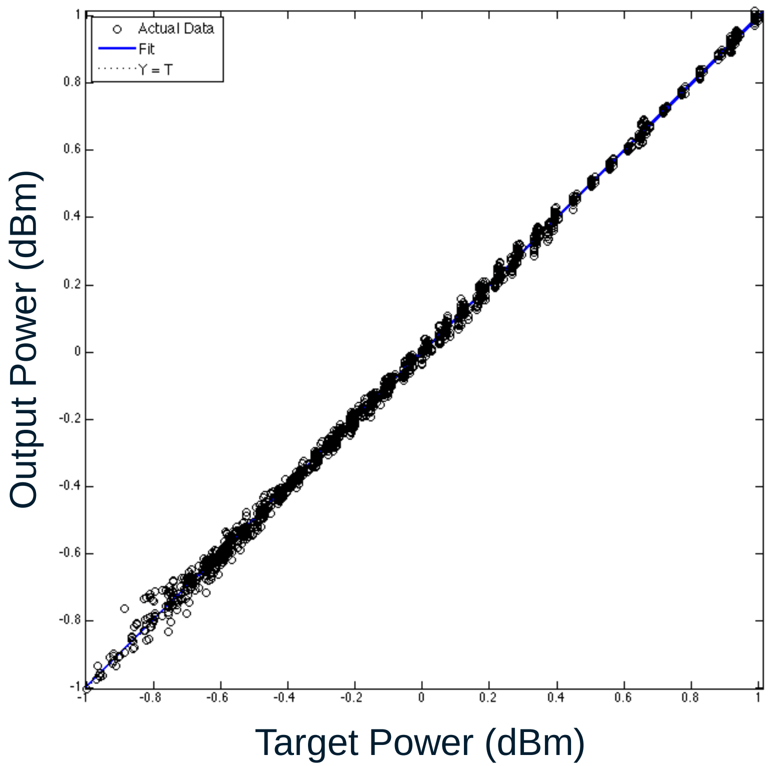
- Input the training data set
- Train neural network (60% data used for training)
- Simulate neural network (20% data used for validation)
- Obtain weights and bias
- Compare the output (*Y*) to SDR input power measured target data, *T*.



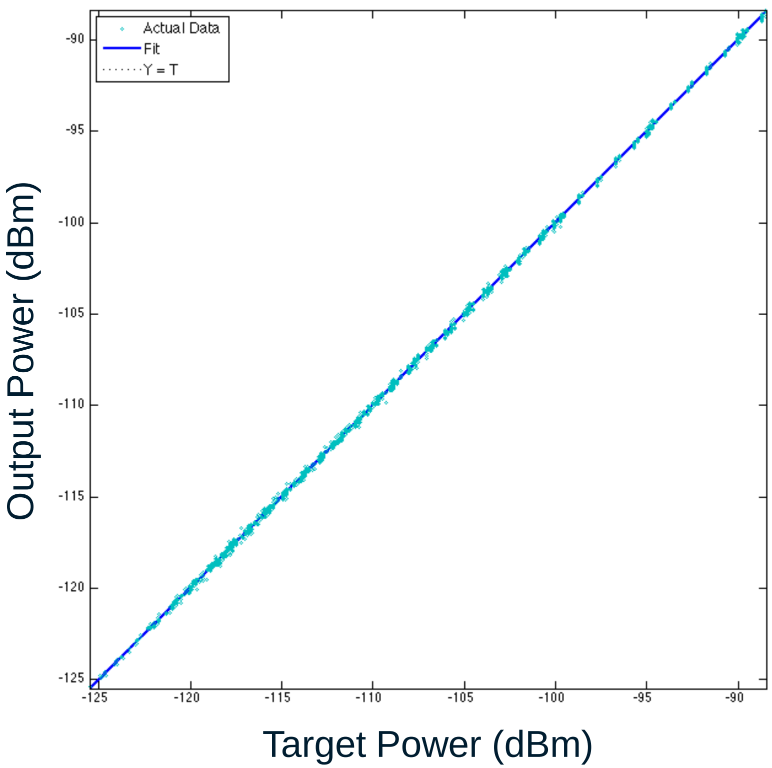
- Analyze the error; train and simulate the neural network to obtained new weights and bias if necessary.

Neural Network Estimator Regression Analysis

Training Regression Plot



Final Regression Plot

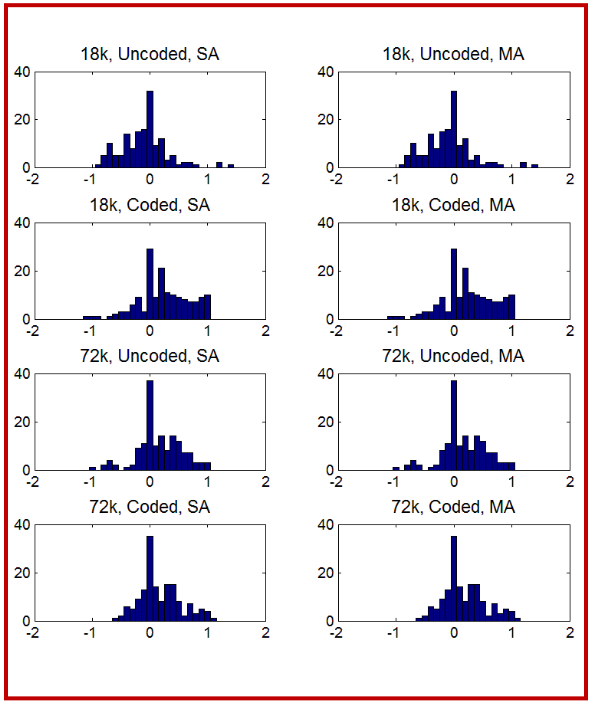


The training process is repeated until there is a good fit between the target and estimated power.

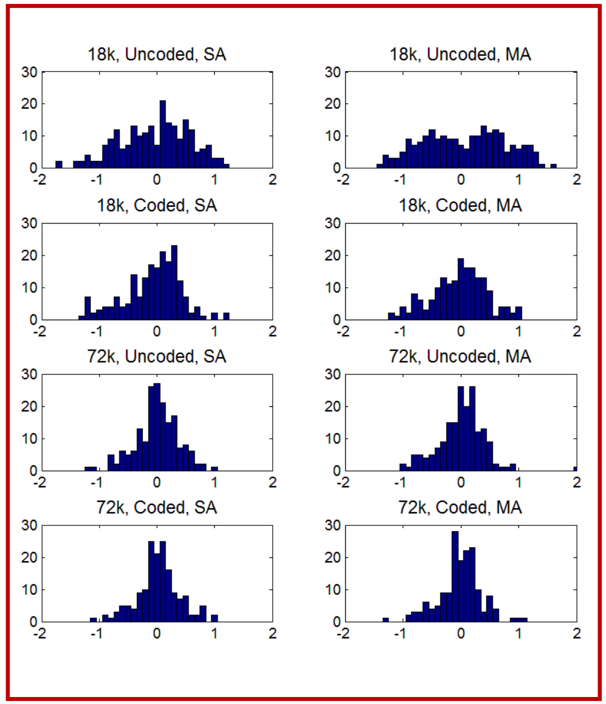
ESTIMATOR ERROR ANALYSIS

Histogram Error Analysis

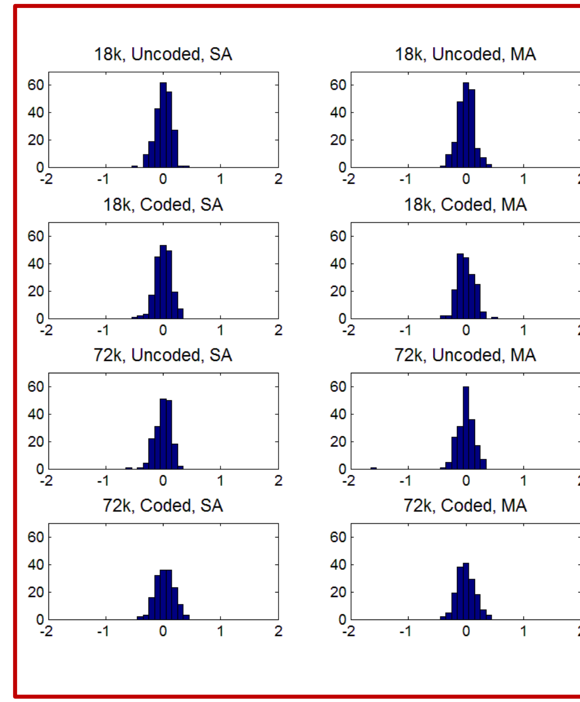
Straight Line



Linear Adaptive



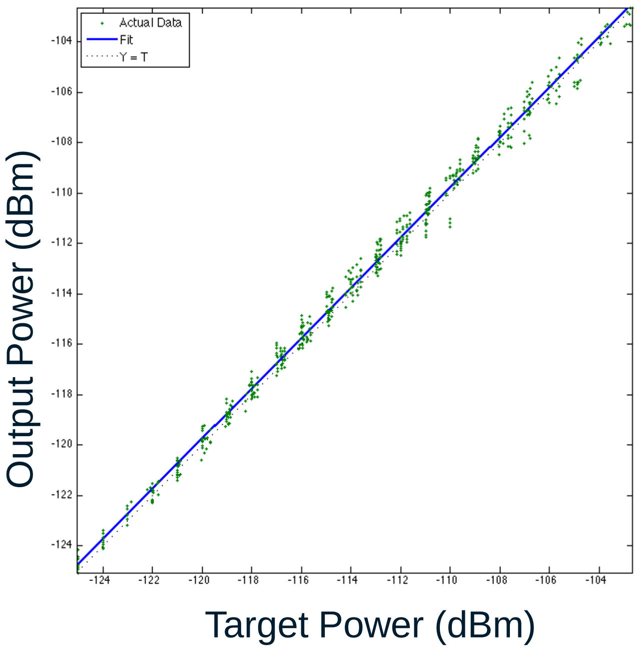
Neural Network



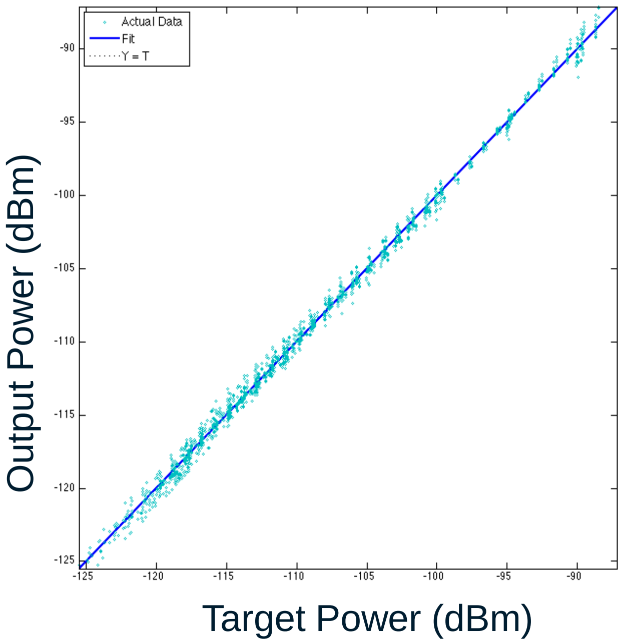
The histograms show that the neural network estimator has the lowest error (+/- 0.5 dB), while the straight line and linear adaptive estimators are about the same (+/- 1.0 dB).

Regression Error Analysis

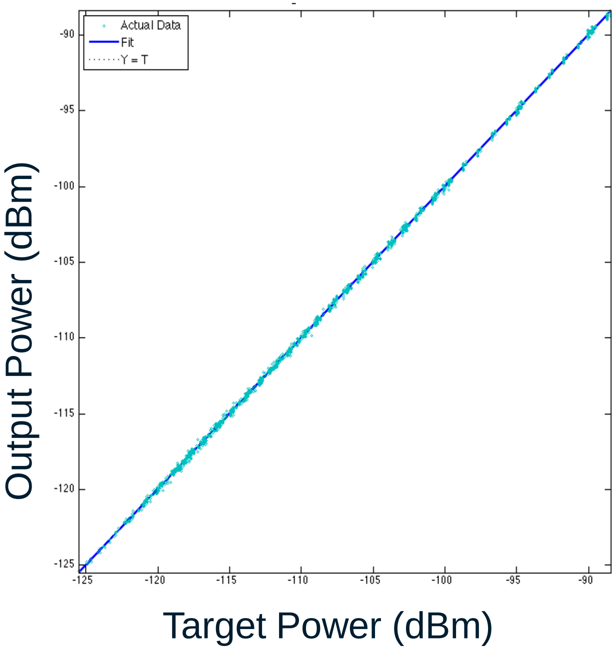
Straight Line



Linear Adaptive



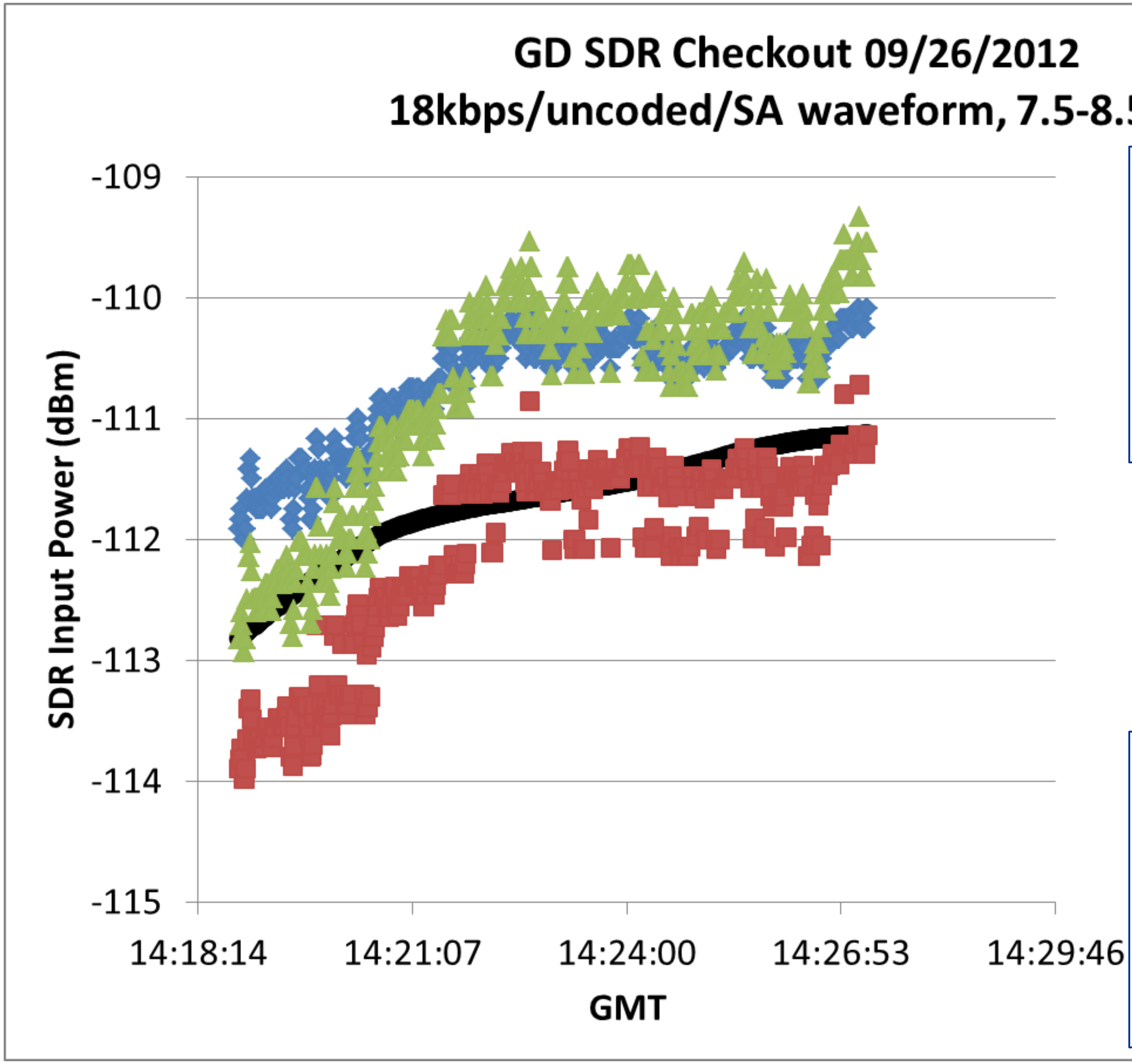
Neural Network



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

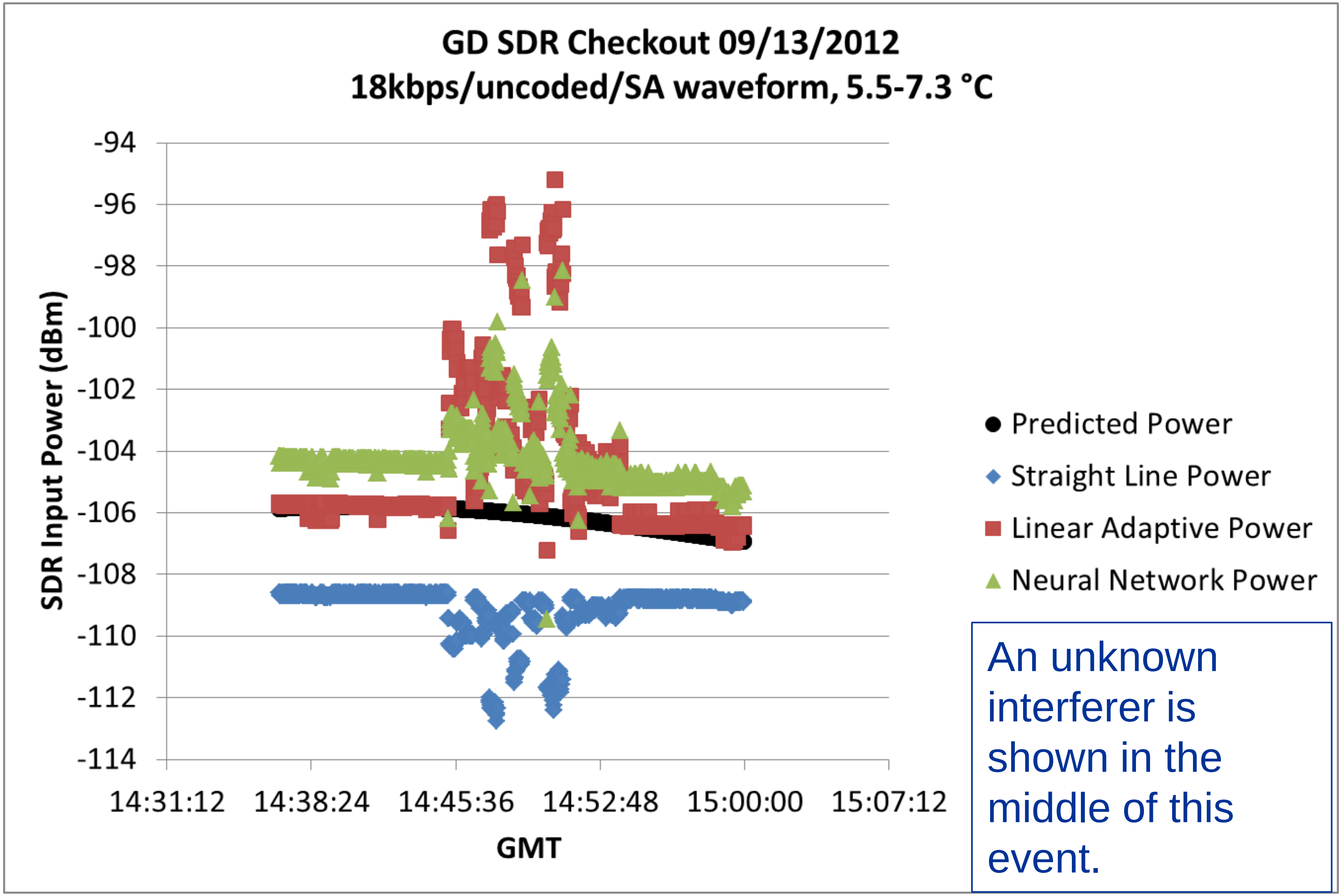
On-orbit Testing Experimental Results



The estimators were implemented in the SCaN Testbed Ground Software.

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

On-orbit Testing Experimental Results



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?

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