Radar Receiver Calibration Toolkit

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Group 108

WPI Major Qualifying Project

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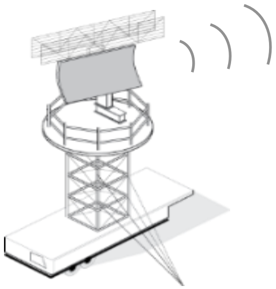
Outline

- **Project Overview**
- **Background**
- **Receiver Simulation**
- **Calibration Tool**
- **Calibration Tool Results**
- **Conclusion**

Motivation

- Group 108 tests aircraft vulnerability using radar systems
- Fielded radars exposed to varying temperatures and frequencies
- Receiver gain calibration ensures accurate mission data
  - Flight tests are expensive, involved, and time consuming
- Limitations of current calibration practices:
  - Requires insertion of test equipment into hardware
  - Restricts test signal waveform to continuous wave
  - Results are not readily available
  - Calibration practices not consistent among operators



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Project Overview

– **Motivated need for improved calibration process**
  - **Modeled hardware components in Matlab/Simulink**
  - **Simulated gain variation over temperature and frequency**

– **Developed versatile software toolkit**
  - **Rapidly displays calibration results**
  - **Processes both continuous and pulsed waveform data**

– **Validated radar calibration model**
  - **Performed hardware receiver test measurements**
  - **Compared software calibration against hardware test measurements**

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Radar Cross Section and Gain

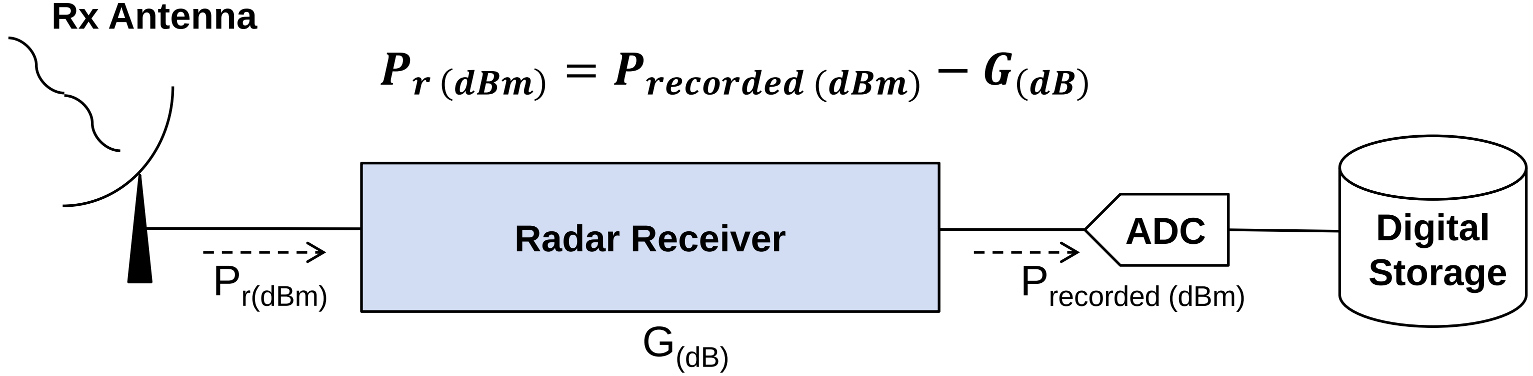
- **Radar range equation describes power at receive antenna returning from a target:**

$$P_r = P_t \frac{G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4}$$

Pt = Power to transmit antenna
Pr = Power from receive antenna
Gt = Transmit antenna gain
Gr = Receive antenna gain
λ = Wavelength
σ = Radar cross section (RCS)
R = Range

- **Radar cross section sets maximum detection range of target**
- **Received power P_r directly proportional to RCS**
- **Known receiver gain is needed to determine receive power (P_r)**

$$P_{r\,(dBm)} = P_{recorded\,(dBm)} - G_{(dB)}$$



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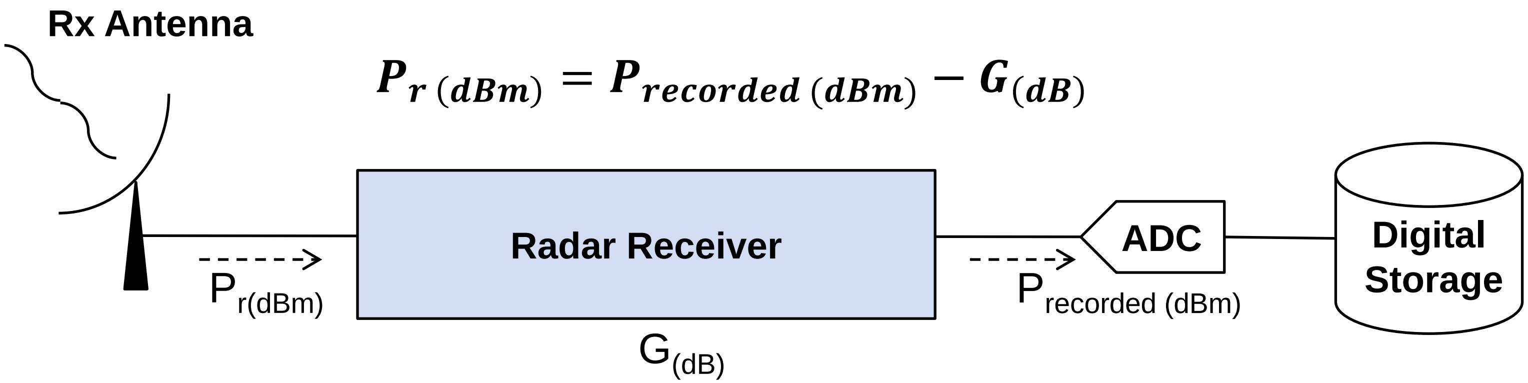

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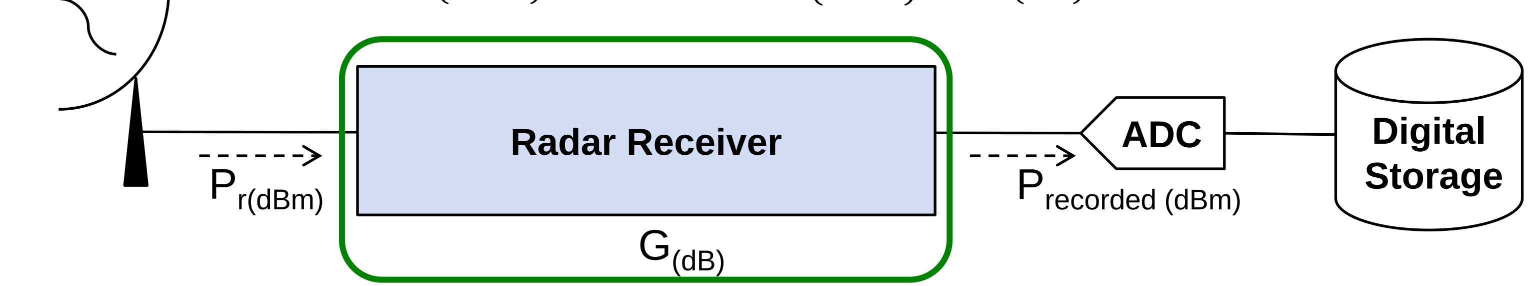
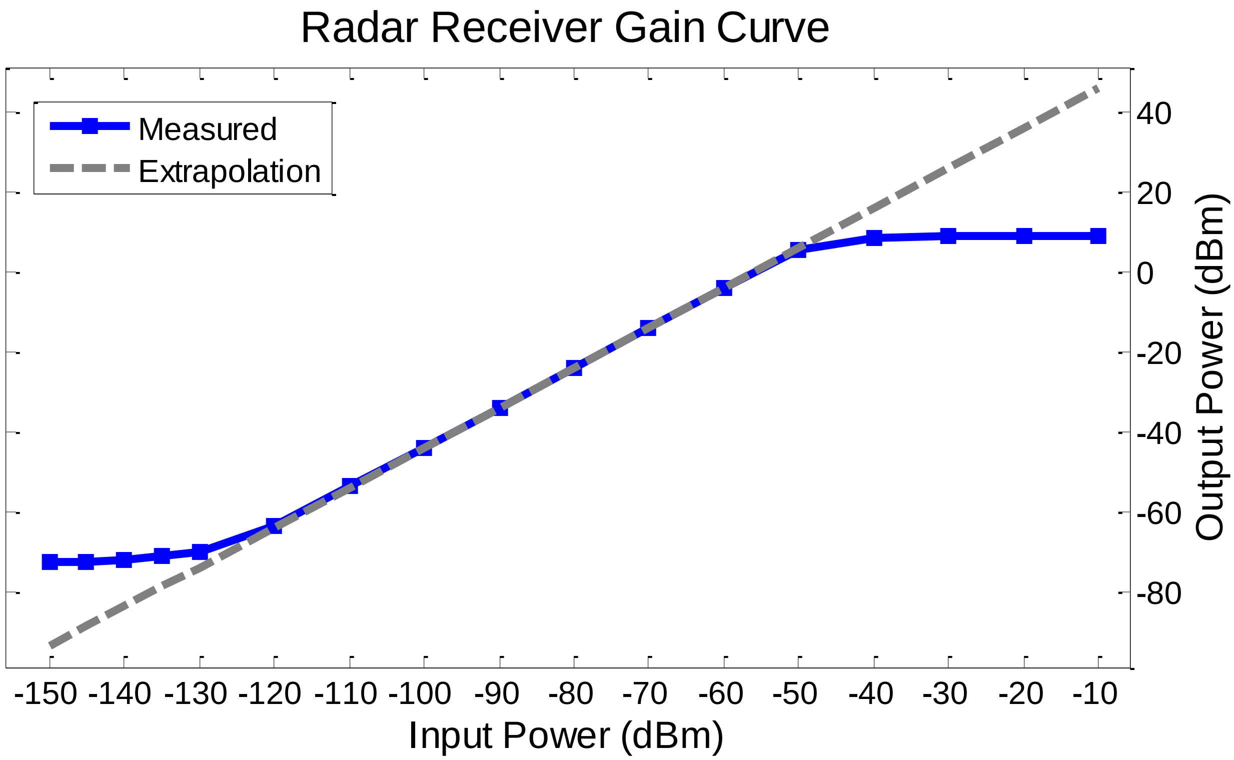


Radar Receiver Gain Calibration

- **Calibration procedure**
  - **Bypass receive antenna and input known test signal into receiver**
  - **Compare input power to output power**
  - **Increment input power and repeat over entire dynamic range**

- **Signals below noise floor cannot be detected**
- **1 dB compression point marks onset of gain saturation**



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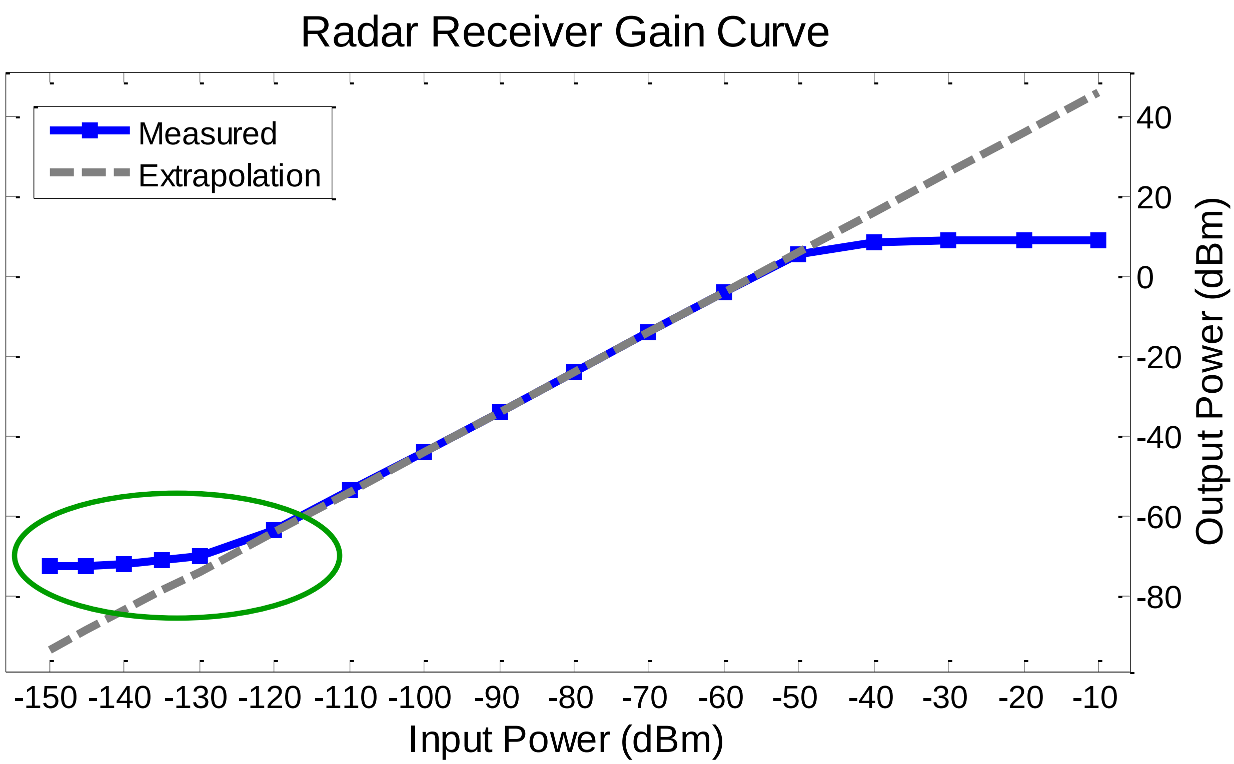

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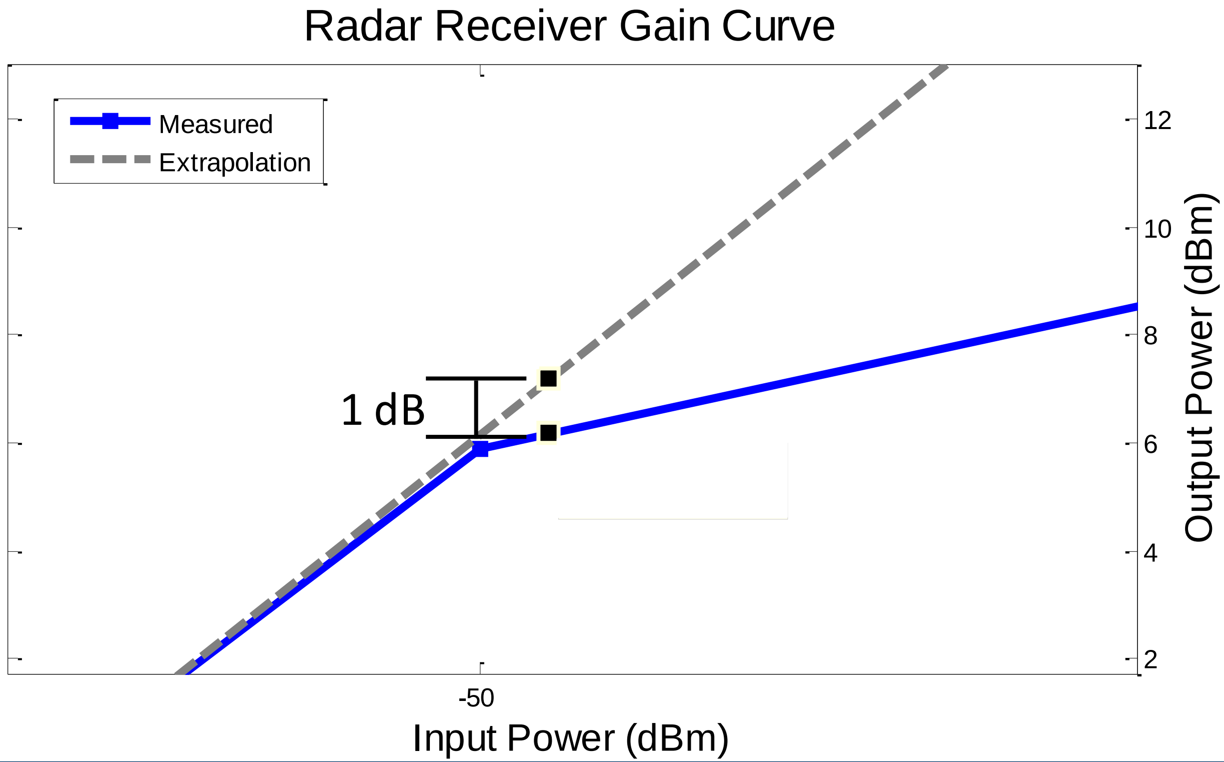

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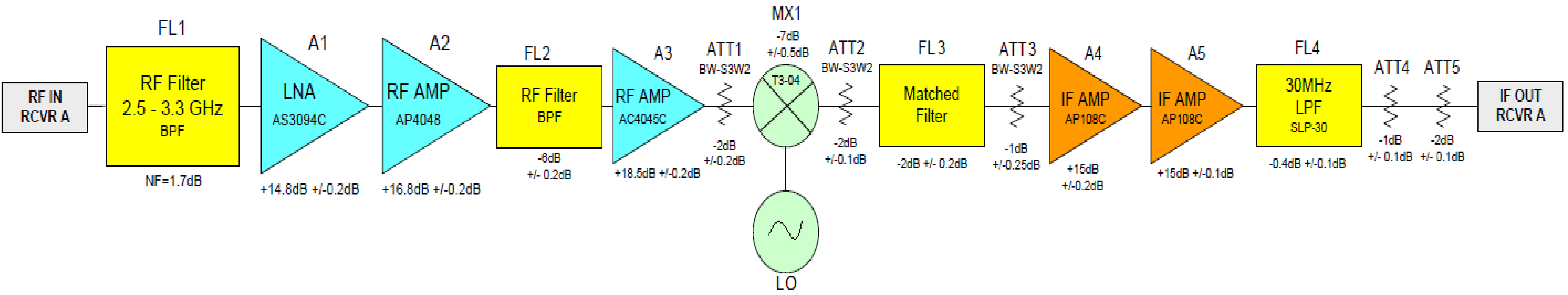
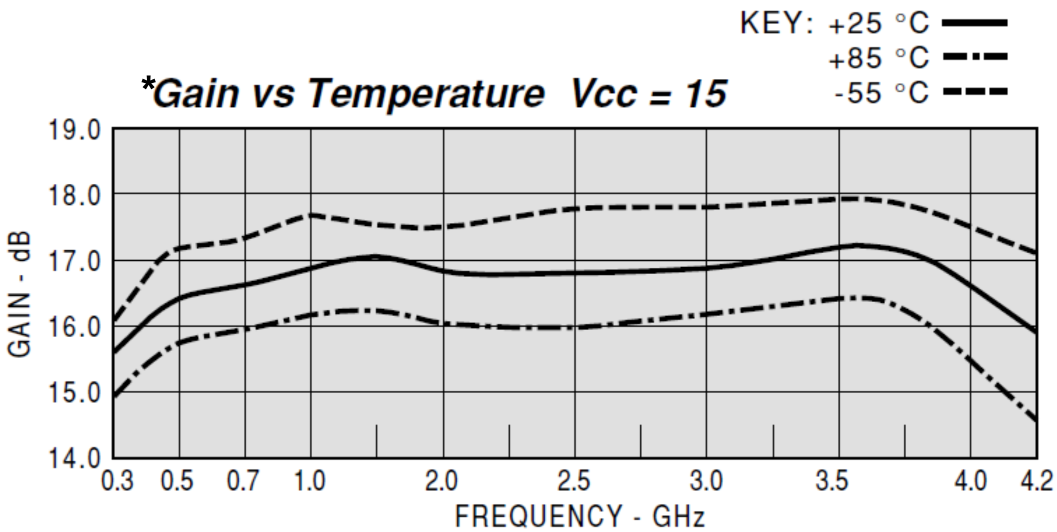
Receiver Hardware Modeling

- **Model hardware for simulation of gain performance**
- **Determine how gain varies with frequency and temperature**
- **Quantify need for calibration and encourage use of toolkit**



Model Data

- **Model uses vendor-tested performance data for standard parts**
- **No vendor-tested data available for custom parts**
  - **Obtained temperature, frequency variation data through testing**
- **Implemented in Matlab & Simulink**



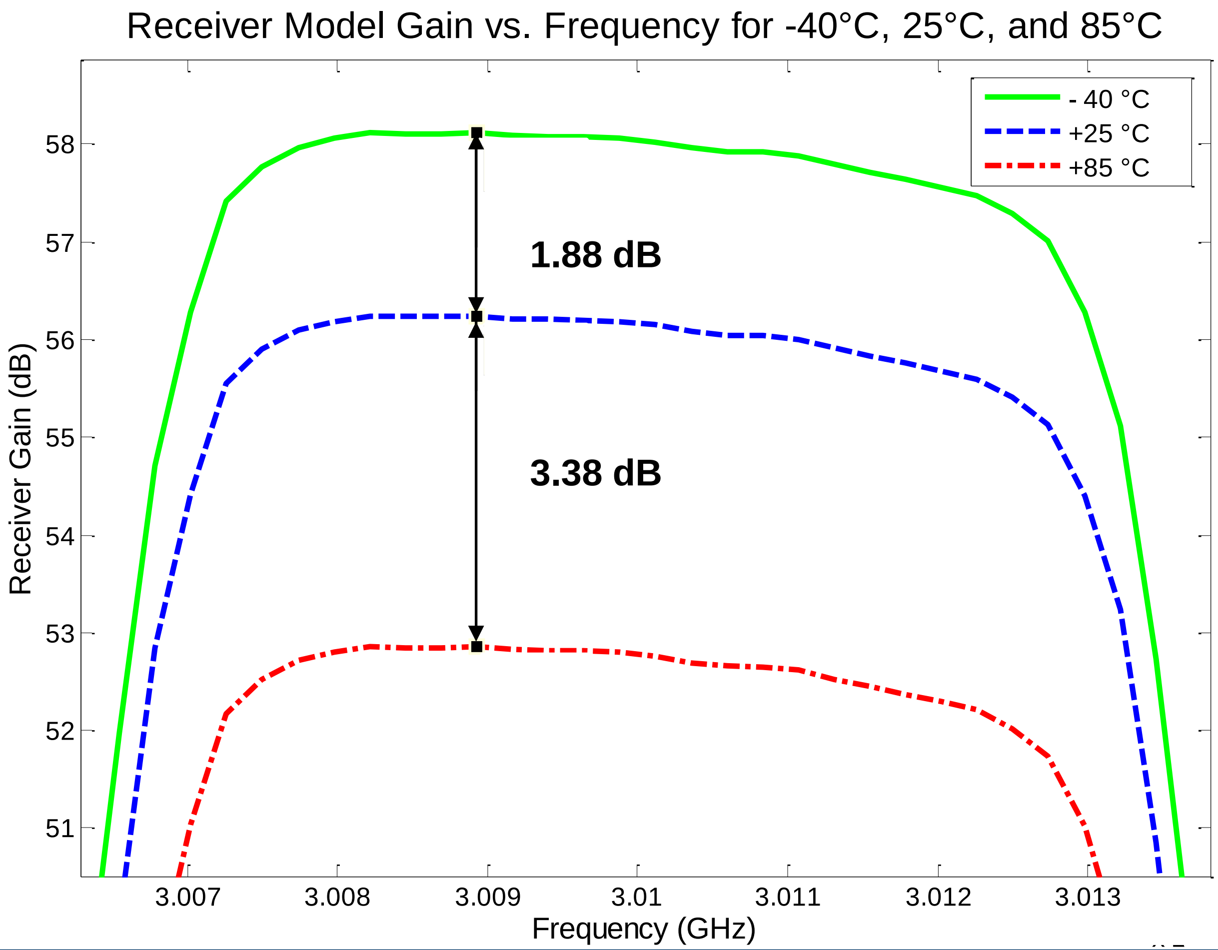
*** Typical Performance Data**

Frequency (MHz)	Insertion Loss (dB) x̄	σ
1.00	0.07	0.1
10.00	0.21	0.1
19.00	0.29	0.1
28.00	0.37	0.1
31.00	0.48	0.1
32.00	0.55	0.1
33.50	0.62	0.1
34.00	0.76	0.1
35.00	1.30	0.3
38.00	6.09	0.9
40.00	10.78	0.9
43.00	17.56	0.8
45.00	21.65	0.7
46.00	23.56	0.7
47.00	25.39	0.7
48.00	27.19	0.7
50.00	30.58	0.6
55.00	38.32	0.6
59.00	43.69	0.7
60.00	45.01	0.7
61.00	46.27	0.5
91.50	76.88	4.1
109.50	80.77	5.3
127.50	79.89	2.8
145.50	77.20	3.0
164.00	74.52	3.4
173.00	74.92	3.8
182.00	78.05	5.9
191.00	79.62	6.8
200.00	80.65	6.9

*** Vendor gain plot and typical data table**

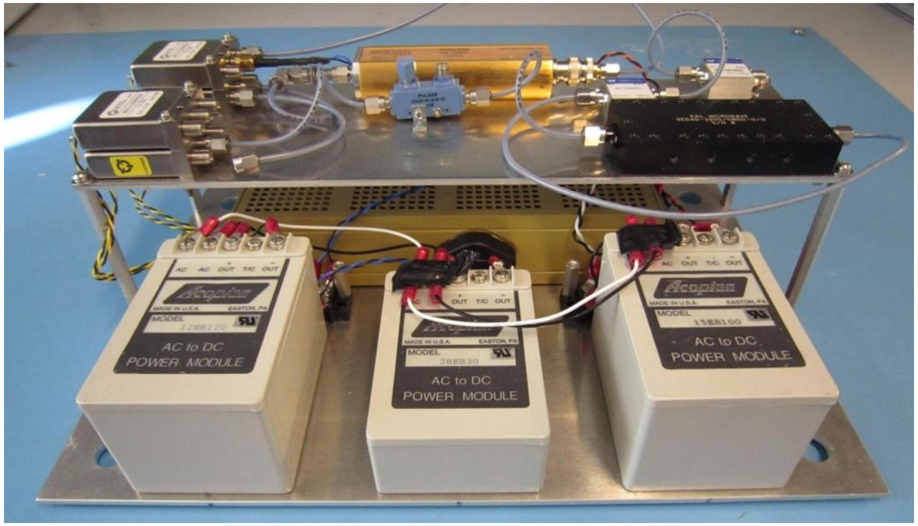
Model Results

- **Gain can vary >4 dB over entire temperature range**
- **4 dB → 60.2% error**



Receiver Hardware

- **S-band radar receiver used to validate model**



Low Noise Amplifier

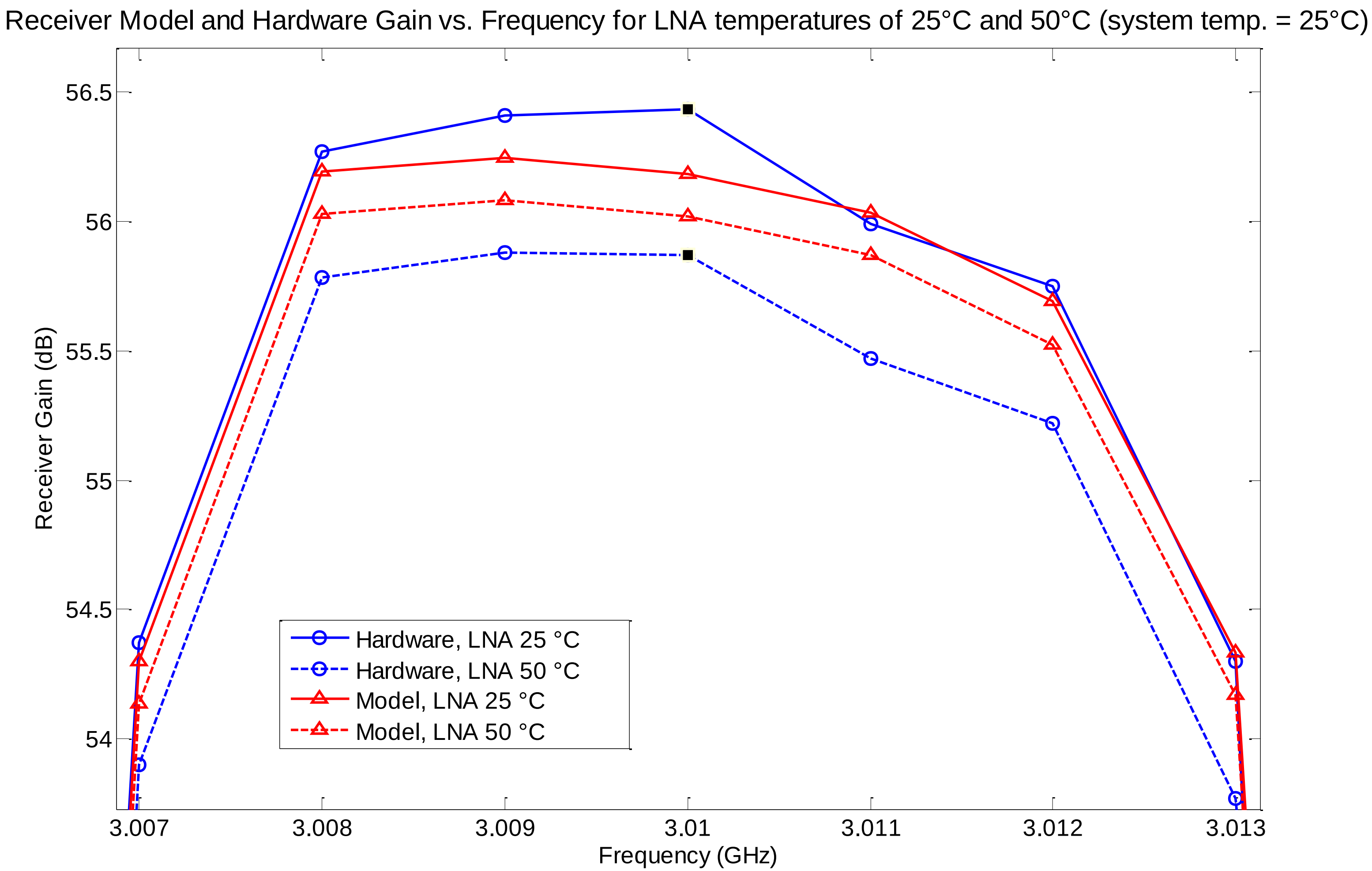
Downconverter

Hardware Test Measurements

- Temperature chamber not available to test gain variation on entire receiver
- Measured receiver gain for different low noise amplifier temperatures
  – 0 °C, 25 °C, and 50 °C
  – Tested over receiver's band of operation
- Performed temperature testing using a heat gun and EFFA duster

Model and Hardware Test Comparison

- **Simulation of model with LNA at 25 °C and 50 °C follows same trend as test measurements to within 1 dB**



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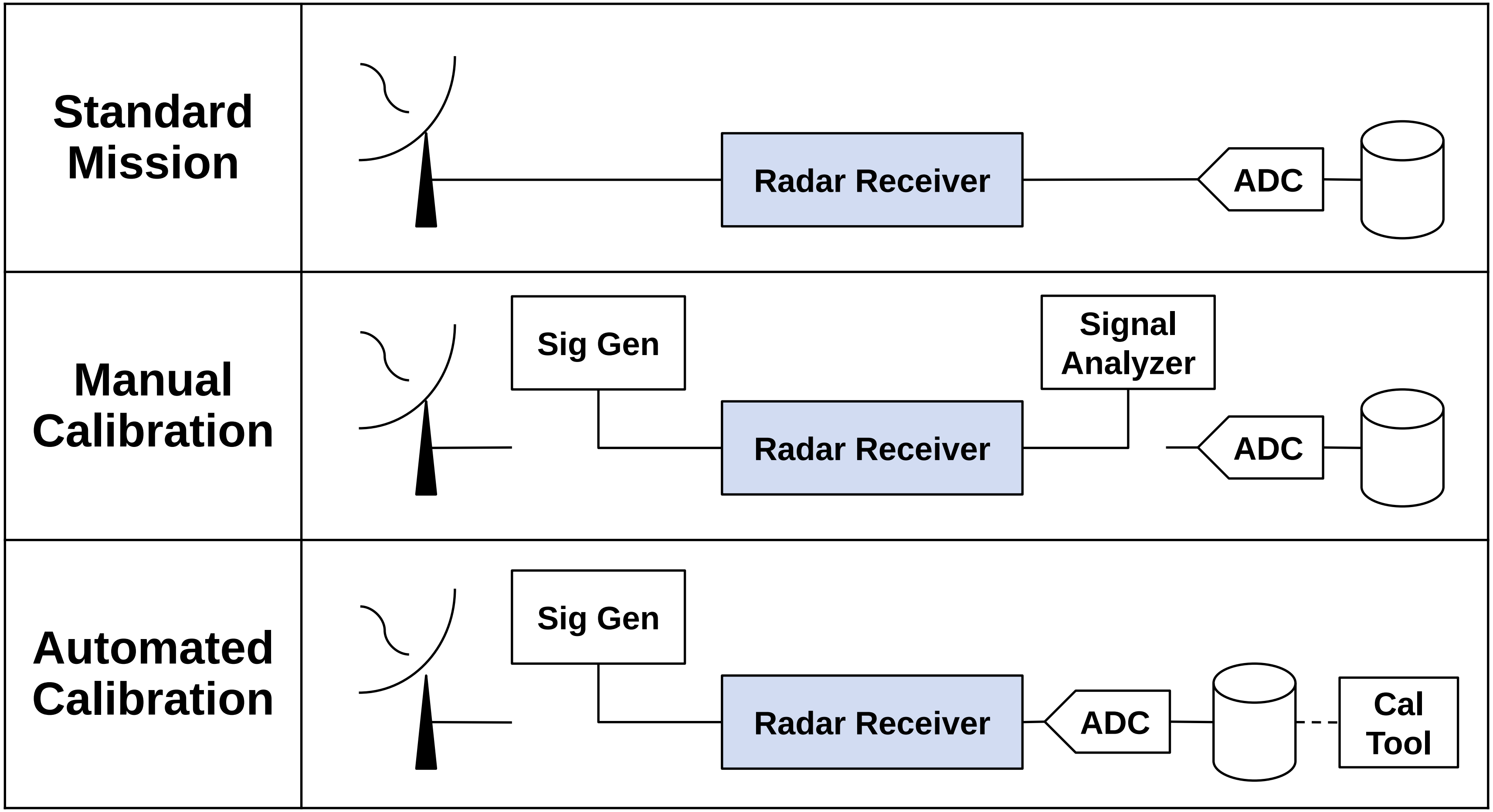
Receiver Gain Calibration Setup



Automated calibration tool simplifies hardware configuration

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Signal Power Computation

- **Signal data stored as In-phase and Quadrature (I/Q) values**

$$P_{out(dBm)} = 10log_{10}\left(\frac{V_{rms}{}^2/50\Omega}{1\ mW}\right)$$

$$V_{rms} = \frac{A_{ADC} * d}{\sqrt{2}}$$

Where d = ADC counts per volt
A_{ADC} = ADC value of signal amplitude

$$A_{ADC} = \sqrt{I^2 + Q^2}$$

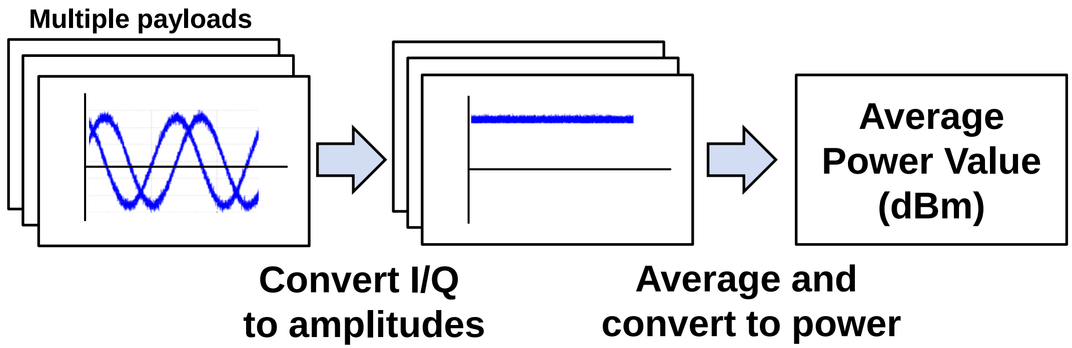
Where I = In-phase component of data point
Q = Quadrature component of data point

$$P_{out(dBm)} = 10log_{10}\left(\frac{(I^2 + Q^2)}{0.1 * d^2}\right)$$

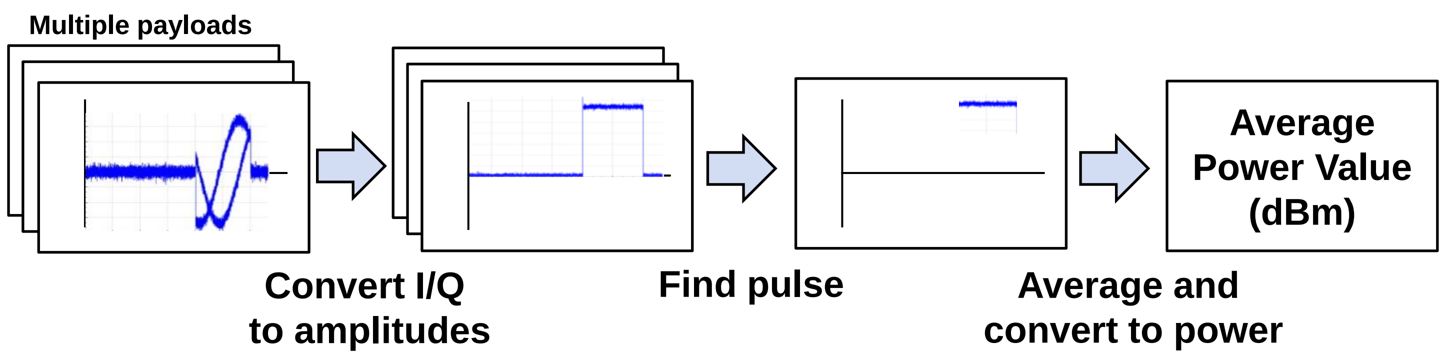
$$Gain_{(dB)} = P_{out\ (dBm)} - P_{in\ (dBm)}$$

Signal Power Algorithms

Continuous Waveform Signal Power

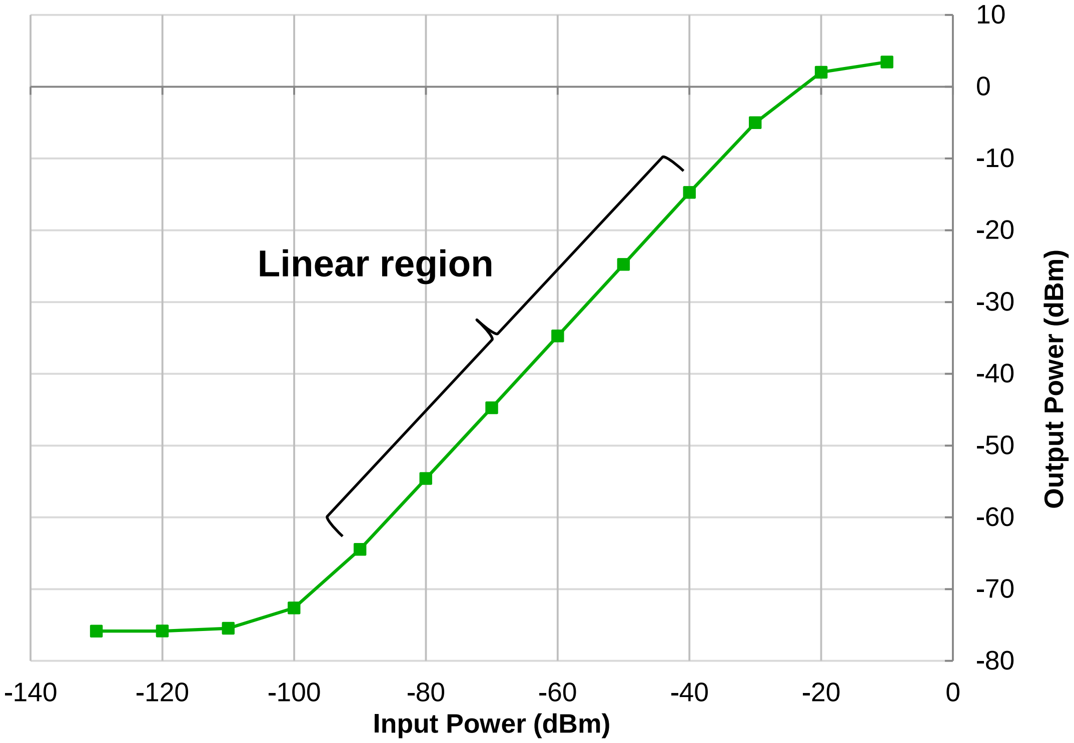


Pulsed Signal Power



Calibration Factor Computation

- **Calculate signal power of each recording**
- **Calibration factor: gain of receiver in linear region**



Calibration Factor Algorithm

- **Determine most linear region**
  - **Compute standard deviation of consecutive gain values**
  - **Sliding window method**
  - **Lowest result is most linear region**
- **Average gain values**

File Name	Input Power (dBm)	Output Power (dBm)	Gain (dB)
Chan-1.pst	-90	-66.4757	23.5243
Chan-1.pst	-80	-56.6678	23.3322
Chan-1.pst	-70	-46.7959	23.2041
Chan-1.pst	-60	-36.8108	23.1892
Chan-1.pst	-50	-26.8193	23.1807
Chan-1.pst	-40	-16.6733	23.3267
Chan-1.pst	-30	-8.69975	21.3003

Lowest standard deviation (rows -70, -60, -50)

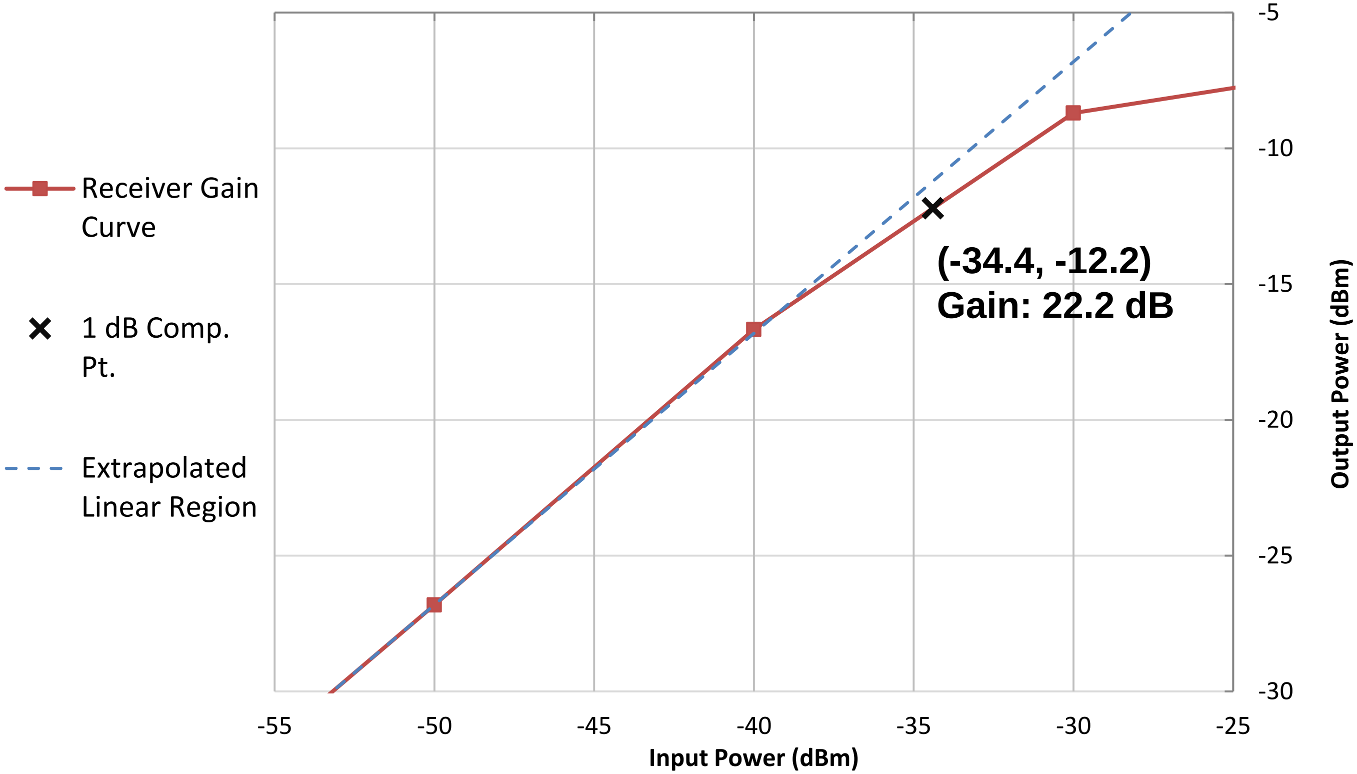
Cal factor = average gain = 23.1913 dB

1 dB Compression Point Computation

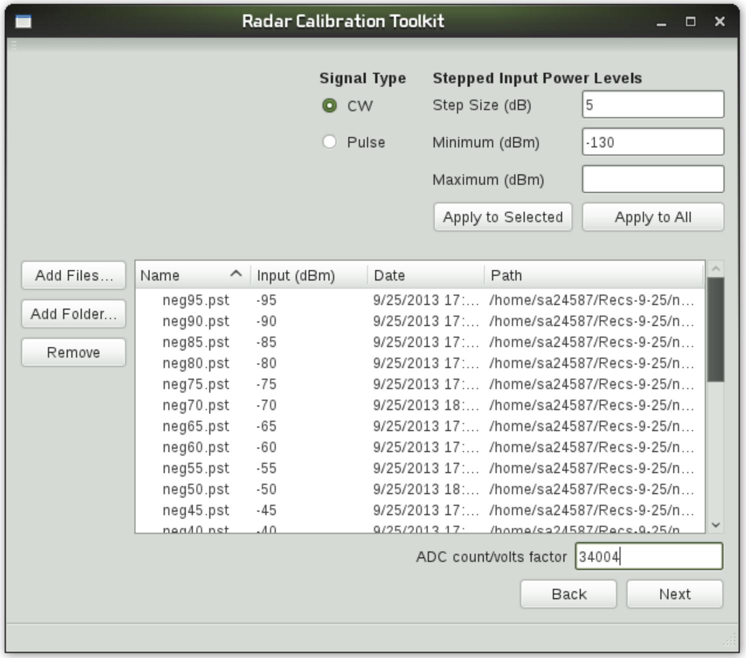
- **Input power at which the gain is 1 dB less than the cal factor**
- **Linear interpolation**

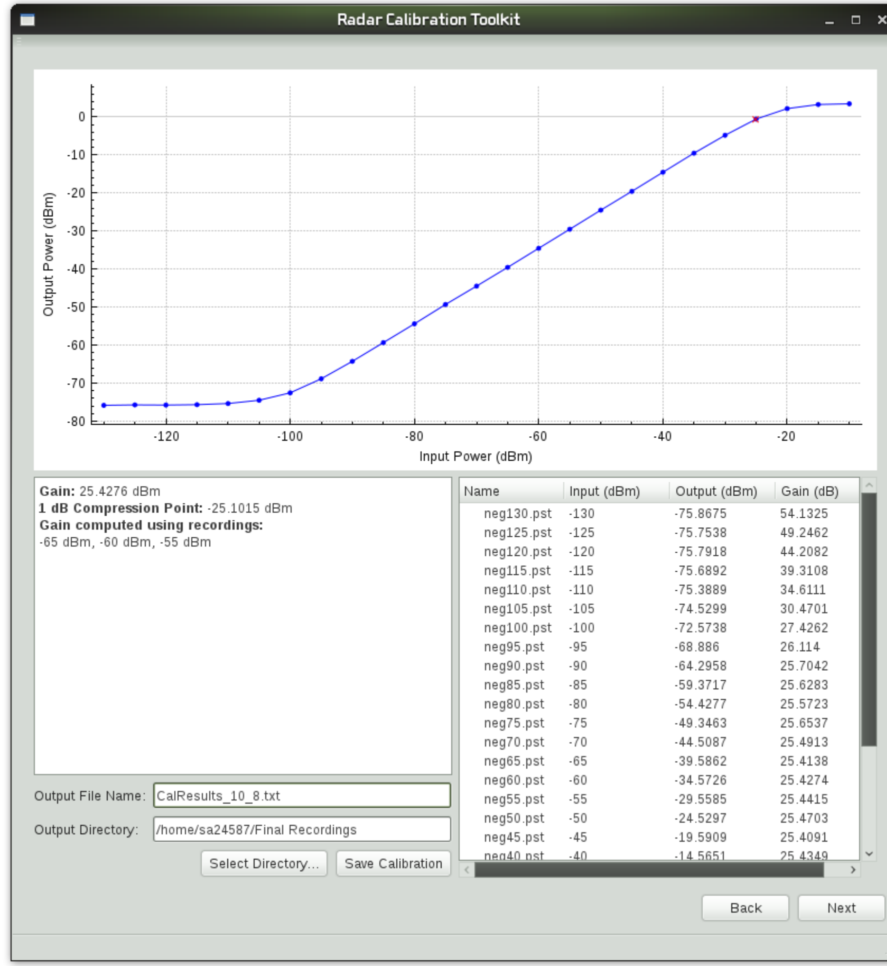
Cal Factor: 23.2 dB

P1dB: -34.4 dBm



Calibration Tool





Immediate calibration results displayed to operator

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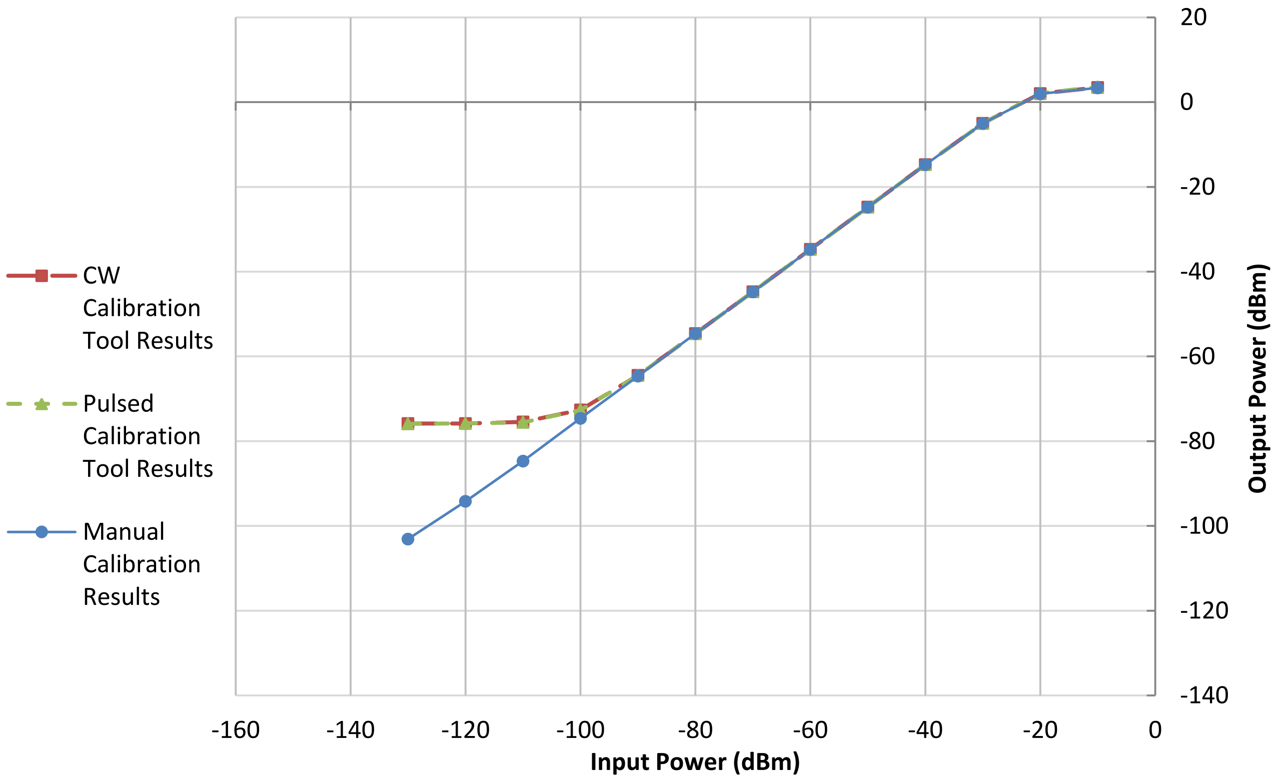


Calibration Factor:

CW: 25.257 dB

Pulsed: 25.240 dB

1 dB Compression Point:

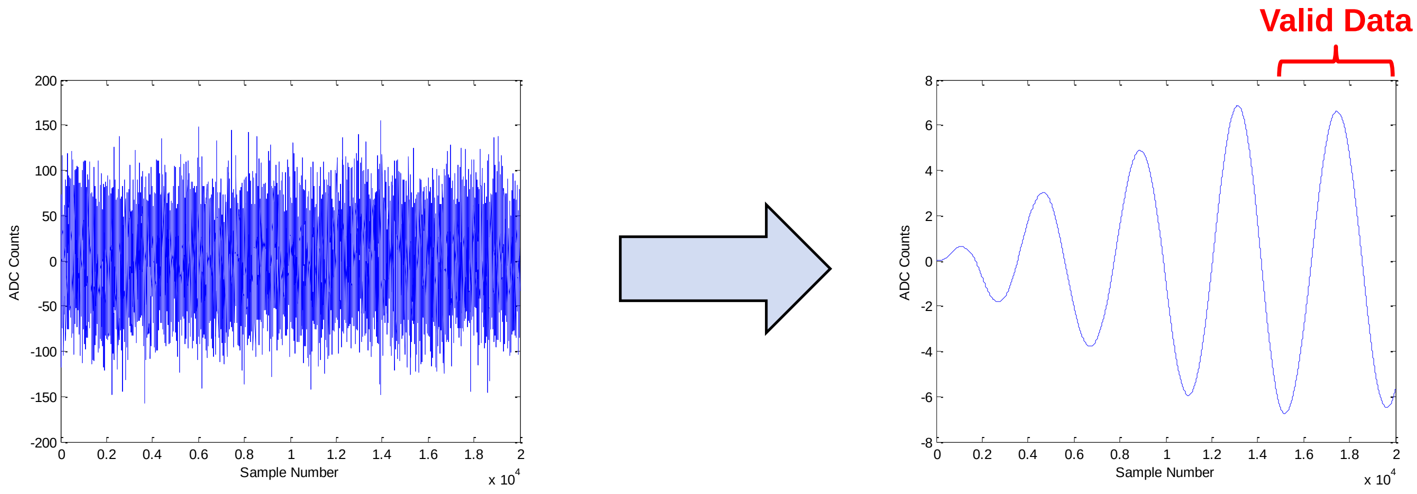
CW: -27.55 dBm

Pulsed: -27.46 dBm

Broadband noise obscures signal at low signal power levels

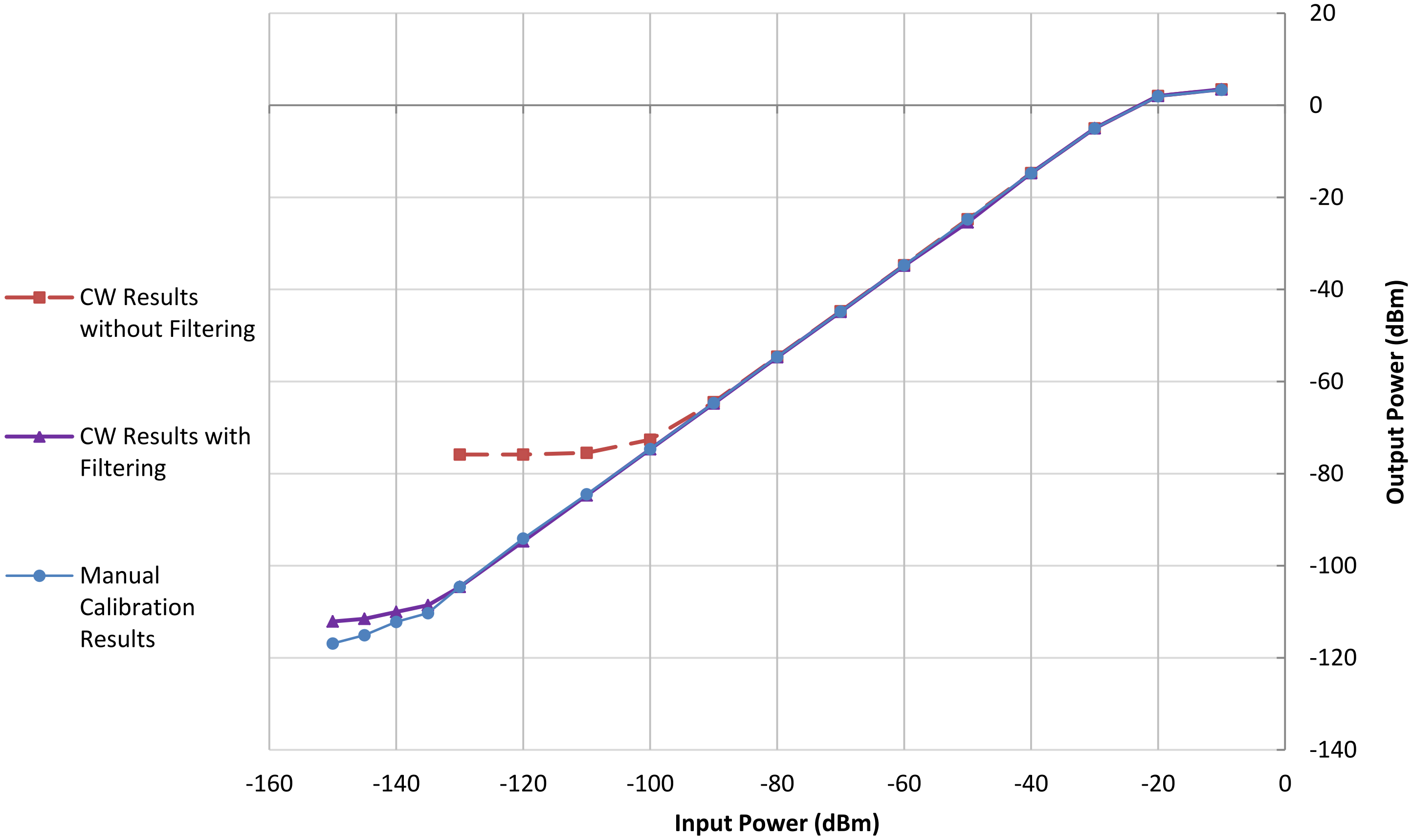
Improving SNR

- **Recordings for low power input signals have low SNR**
- **2nd order Butterworth bandpass filter applied**
- **First 15,000 out of 20,000 samples discarded due to filter startup time**



Recording for -120 dBm input power, before and after filtering

Receiver Calibration with Bandpass Filtering



Improved results for low power signals

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Conclusion

- **Analyzed and quantified radar receiver gain variation through simulation and testing**
- **Developed a software toolkit for radar receiver calibration and performance measurement**
  - **Provides rapid feedback on receiver performance**
  - **Simplifies calibration setup**
  - **Versatile, useable for many radar systems**
- **Tested calibration tool performance with real data**
- **Our toolkit will benefit flight test operations in Group 108**

Acknowledgments

- **Prof. Ted Clancy**
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- **Bill Cantrell**
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