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National Radio Astronomy Observatory

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

FPGA Spectrometer for the GBT

ADC Characterization

Srikanth Bussa

NRAO and U.C. Berkeley Joint Conceptual Design Review
January 31, 2011

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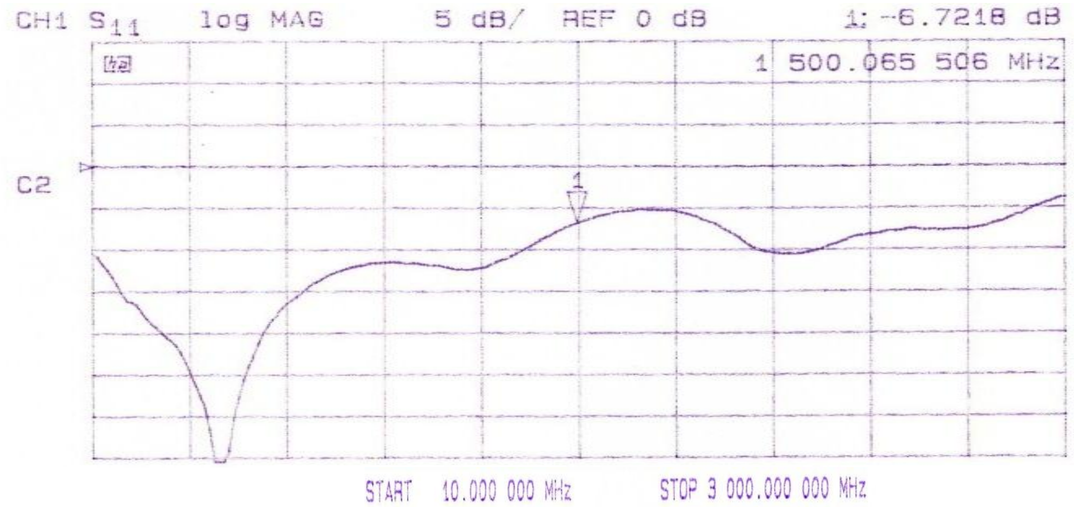
- ✓ Ken Ward

ADC Board

Analog input

Clock input

Return Loss for clock inputs measured using Network Analyzer

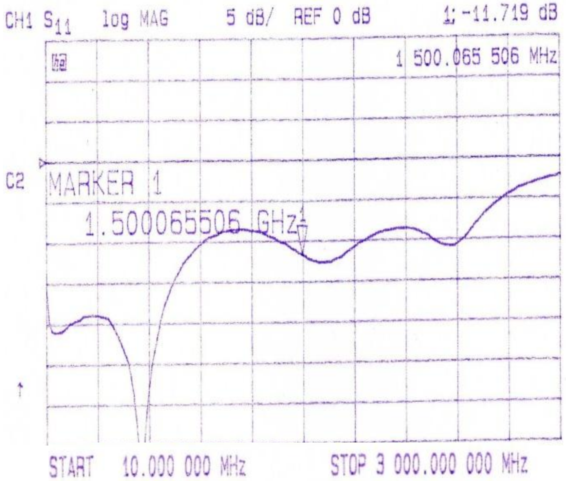


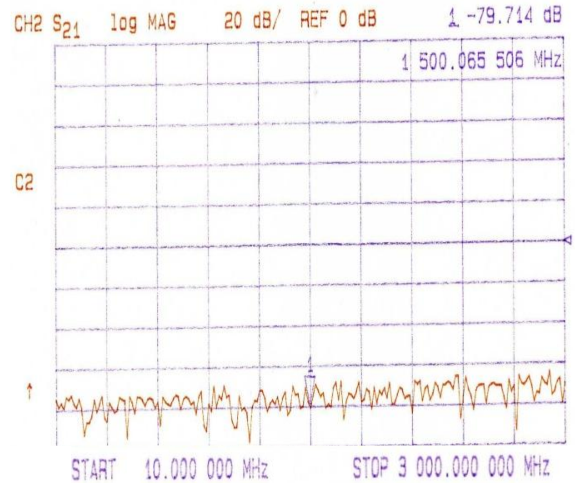
ADC0 CLOCK

ADC1 CLOCK

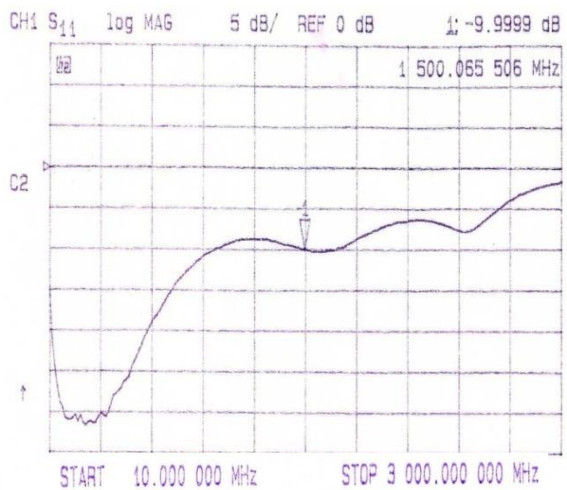
GBT

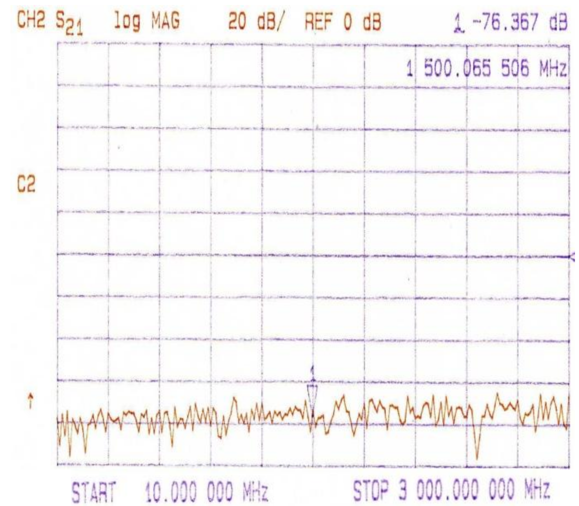
Return Loss & Coupling for analog inputs measured using Network Analyzer





ADC0
ANALOG
INPUT





ADC1
ANALOG
INPUT

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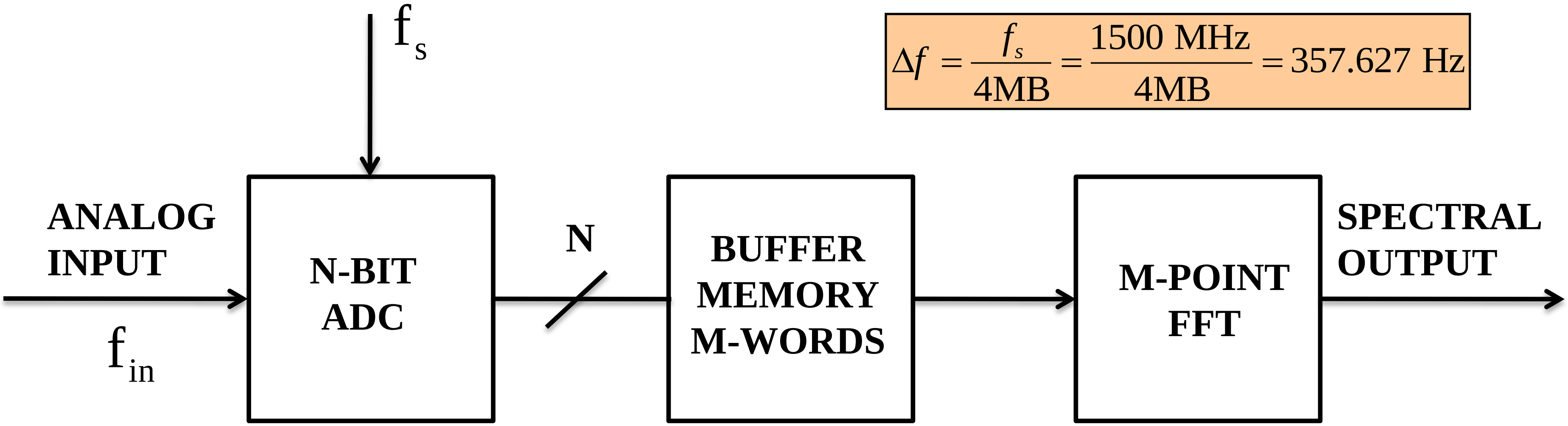
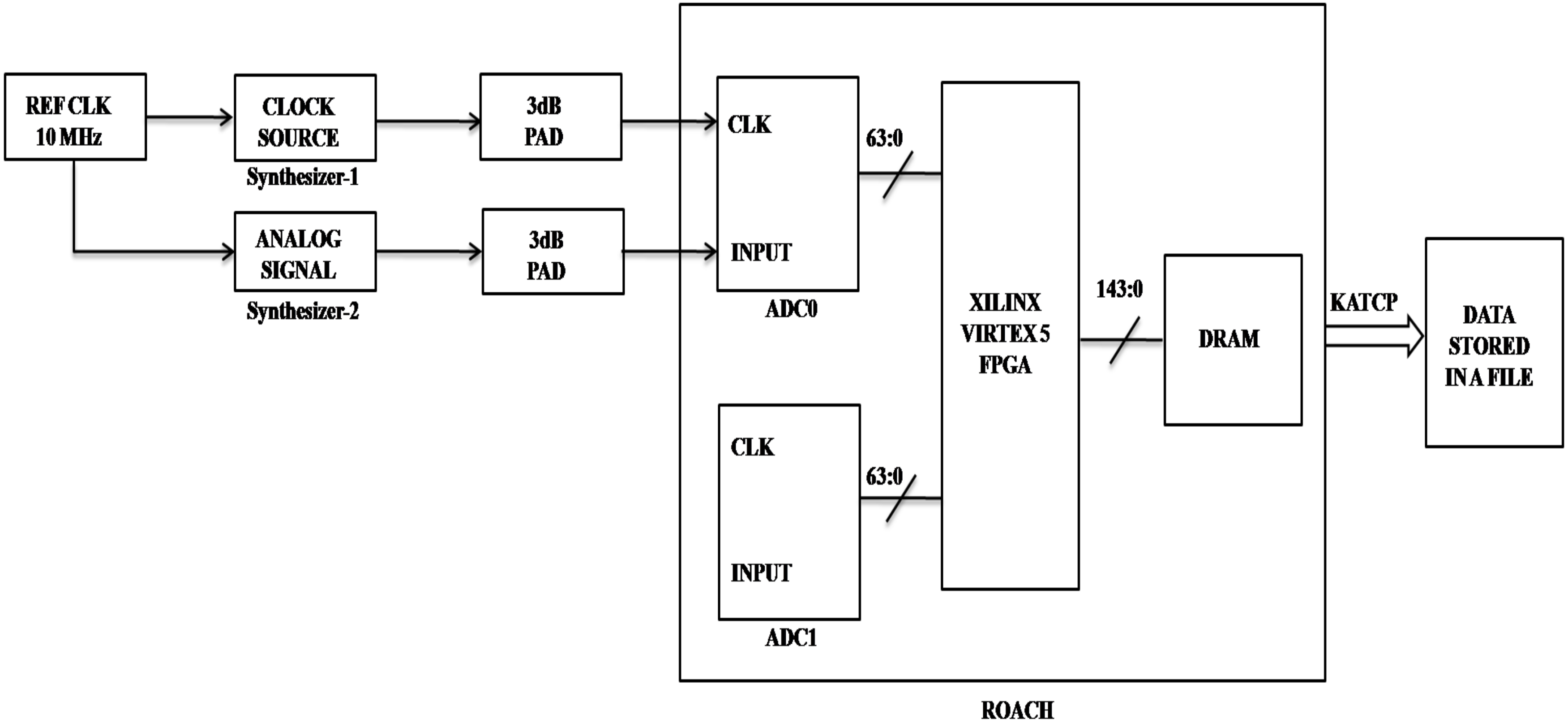
Test Setup – Frequency Domain Measurements

$$\Delta f = \frac{f_s}{4MB} = \frac{1500\text{ MHz}}{4MB} = 357.627\text{ Hz}$$



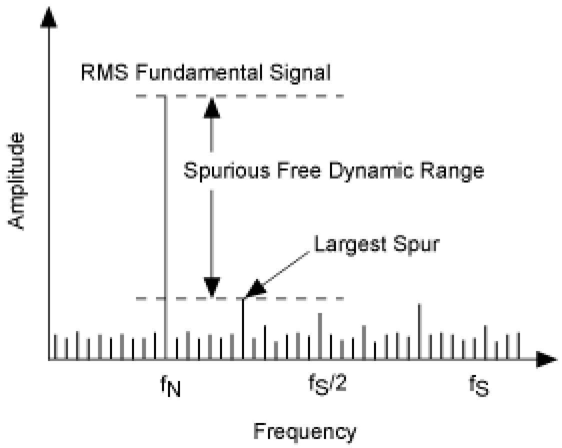
- SPUR LEVEL
- INTERMODULATION
- PHASE NOISE
- CROSS COUPLING WITHOUT NOISE
- CROSS COUPLING WITH 50Ω TERMINATED INPUTS
- CROSS COUPLING WITH NOISE INPUT

Test Setup – Frequency Domain Measurements



Note: All the results presented here is the average of 20sets of 4MB data from each ADC.

Spurious Free Dynamic Range (SFDR)



$$SFDR = 20 \log\left(\frac{\text{Fundamental}}{\text{Highest Spurious}}\right)$$

Table 1.1: Specifications from datasheet

f_{in} (MHz)	SPUR LEVEL (ADC0) dBFS
373	57
748	54.5
1498	52

Table 1.2: Measurement Results

f_{in} (MHz)	SPUR LEVEL (ADC0) dBFS	SPUR LEVEL (ADC1) dBFS
187.5	72.145	71.44
375	73.37	69.216
748.168945	62.437	49.396
937.5	64.61	65.229
1125	63.607	63.105
1312.5	61.796	61.383
1498.168945	48.623	47.784

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Meets specifications at most of the frequencies !!!!!

Spurious Free Dynamic Range (SFDR)

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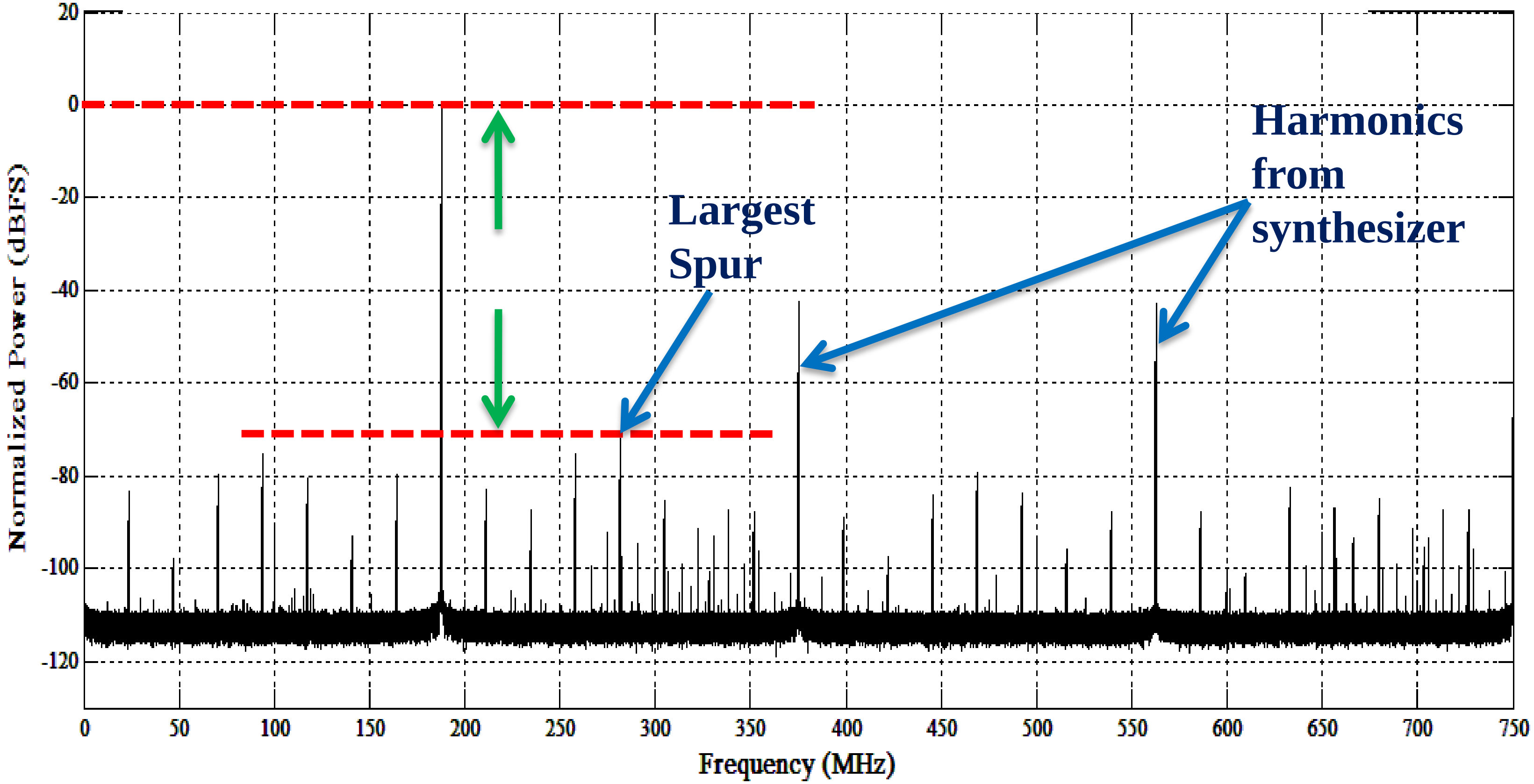
Power spectrum of ADC0 output with f_{in}=187.5 MHz



SNR=6.02N+1.76 dB=49.92 dB

Noise Averaged =10log((4x1024x1024)/2)=63.21 dB

FFT Noise Floor = 49.92+63.21=113.136 dB !!!

Intermodulation Distortion (IMD)

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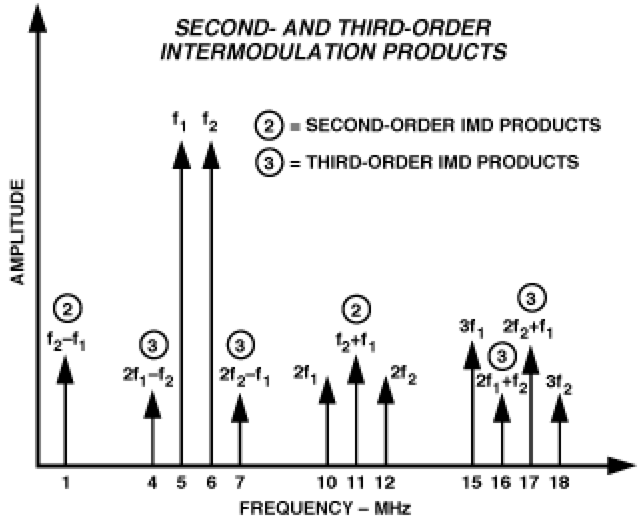

Table 2.1: Specifications from datasheet

f_{in1} (MHz)	f_{in2} (MHz)	IMD (dBFS)
749.084 (FSR-7) dB	756.042 (FSR-7) dB	-52

Table 2.2: Measurement results for ADC0

f_{in1} (MHz)	f_{in2} (MHz)	IMD (dBFS)
187.5	188.598632	-70.57
375	376.464843	-68.58
744.140625	745.239257	-72.56

Table 2.3: Measurement results for ADC1

f_{in1} (MHz)	f_{in2} (MHz)	IMD (dBFS)
187.5	188.598632	-64.92
375	376.464843	-56.68
744.140625	745.239257	-65.16

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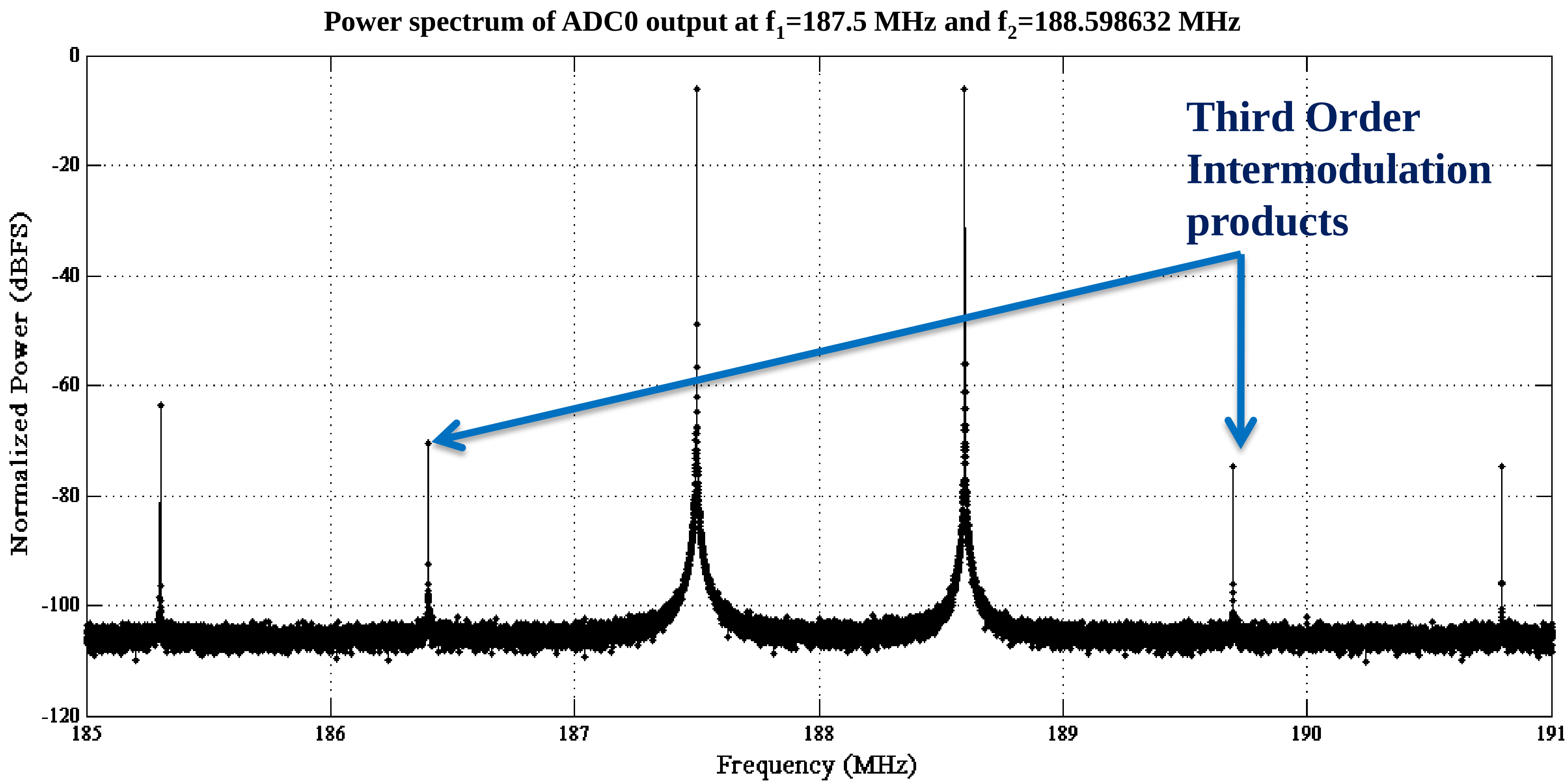
Meets specifications !!!!!

Intermodulation Distortion (IMD)



Phase noise comparison between Fourier Transform of Raw data & as measured using spectrum analyzer

✓**Phase noise is the frequency domain representation of rapid, short-term, random fluctuations in the phase of a waveform, caused by time domain instabilities ("jitter").**

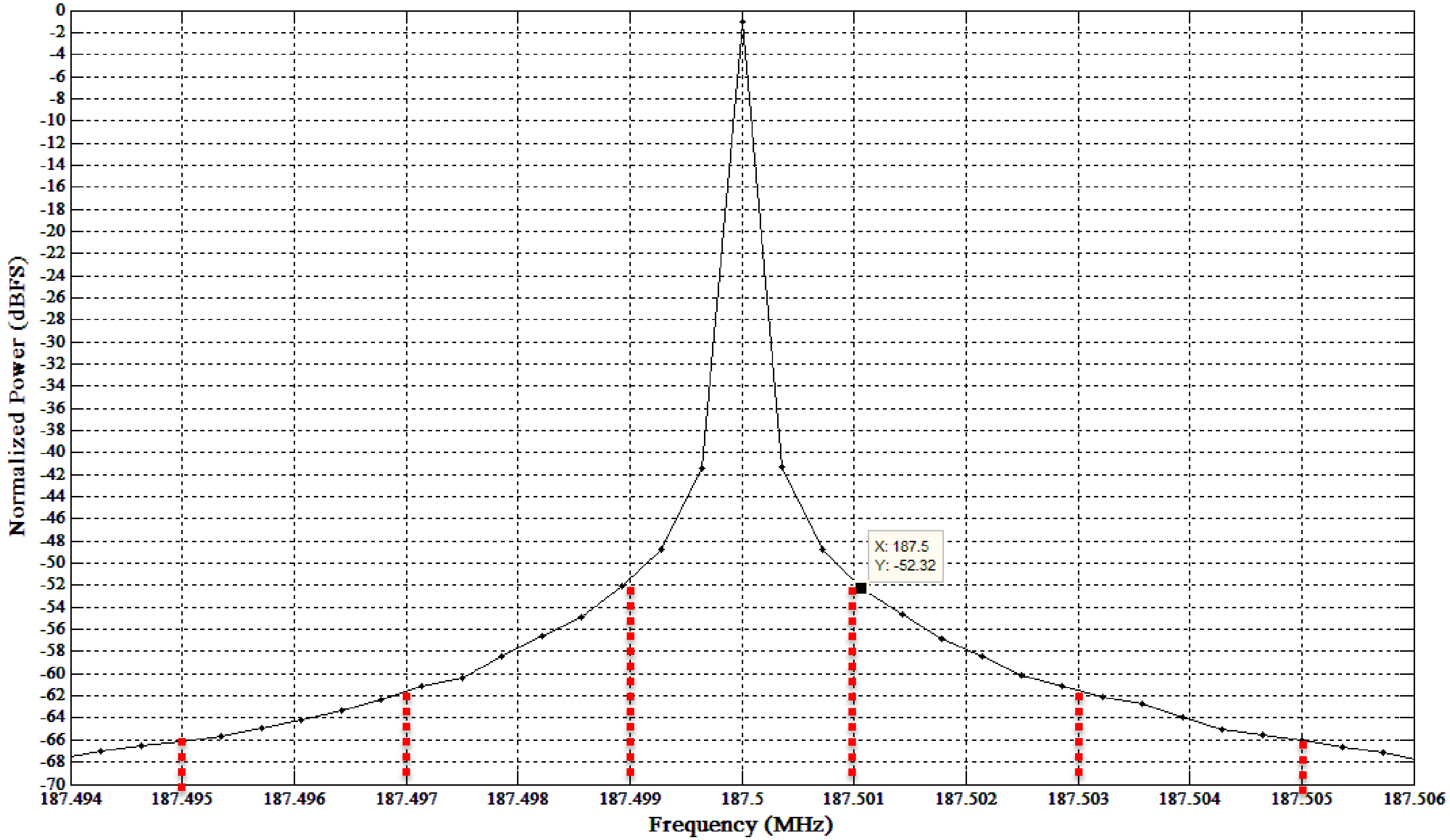
Table 3.1: Phase noise measured after computing fft of the raw data & using spectrum analyzer

Frequency (MHz)	Phase Noise (dBc/Hz) @ Offset (-5 KHz)	Phase Noise (dBc/Hz) @ Offset (-3 KHz)	Phase Noise (dBc/Hz) @ Offset (-1 KHz)	Phase Noise (dBc/Hz) @ Offset (1 KHz)	Phase Noise (dBc/Hz) @ Offset (3 KHz)	Phase Noise (dBc/Hz) @ Offset (5 KHz)
187.5	-66 (-85.55)	-61 (-79.91)	-51.5 (-65.29)	-52 (-65.88)	-61 (-81.13)	-66 (-85.01)
375	-64.2 (-80.69)	-59 (-74.92)	-49 (-60.09)	-49 (-58.92)	-59 (-74.91)	-64 (-81.19)
748.168945	-63.4 (-77.84)	-58.5 (-71.29)	-50 (-66.59)	-50.5 (-67.15)	-58.7 (-70.86)	-63.2 (-77.02)
937.5	-56 (-75.76)	-51.8 (-69.15)	-41.8 (-64.05)	-42 (-63.85)	-52 (-68.32)	-56.1 (-75.71)
1125	-55 (-70.79)	-51.5 (-64.95)	-42.1 (-62.03)	-42.3 (-62.12)	-51.5 (-65.25)	-55.2 (-70.3)
1490.478515	-49.3 (-76.80)	-47.08 (-65.44)	-37 (-60.95)	-37.03 (-61.08)	-47.03 (-66.38)	-49.23 (-71.84)

Degrades !!

Phase noise is more than what is measured using spectrum analyzer; Jitter and sampling frequency might be the possible cause !!!

Phase noise measured at f=187.5 MHz (ADC0)



Cross Coupling without Noise

Table 4.1: Measurement Results

ADC0	ADC1	AMOUNT OF COUPLING (dB)
187.5 MHz	Input terminated with 50 Ω	-87.33
375 MHz	Input terminated with 50 Ω	-51.81
748.168945 MHz	Input terminated with 50 Ω	-114.9
Input terminated with 50 Ω	937.5 MHz	-77.91
Input terminated with 50 Ω	1125 MHz	-53.78
Input terminated with 50 Ω	1490.478515 MHz	-95.16

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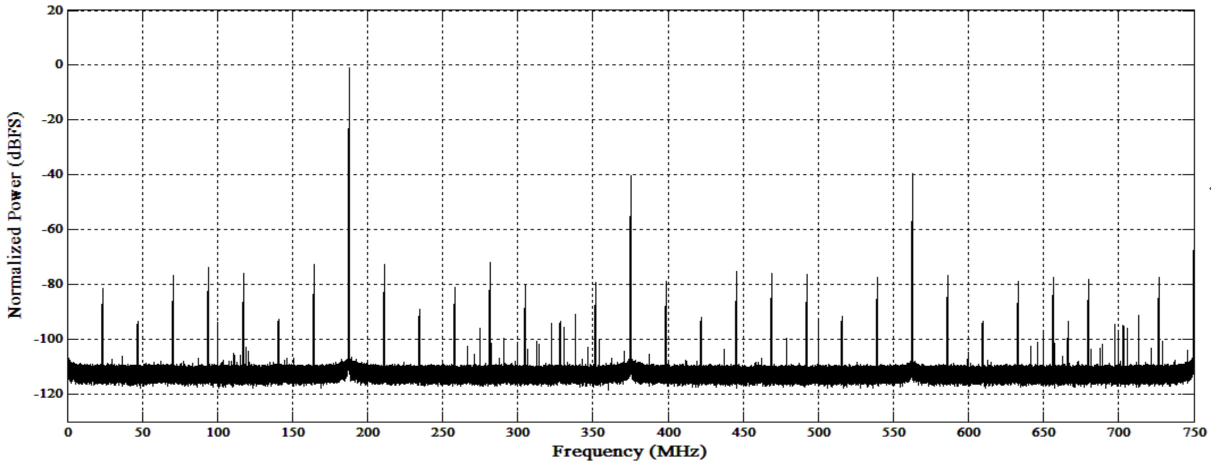
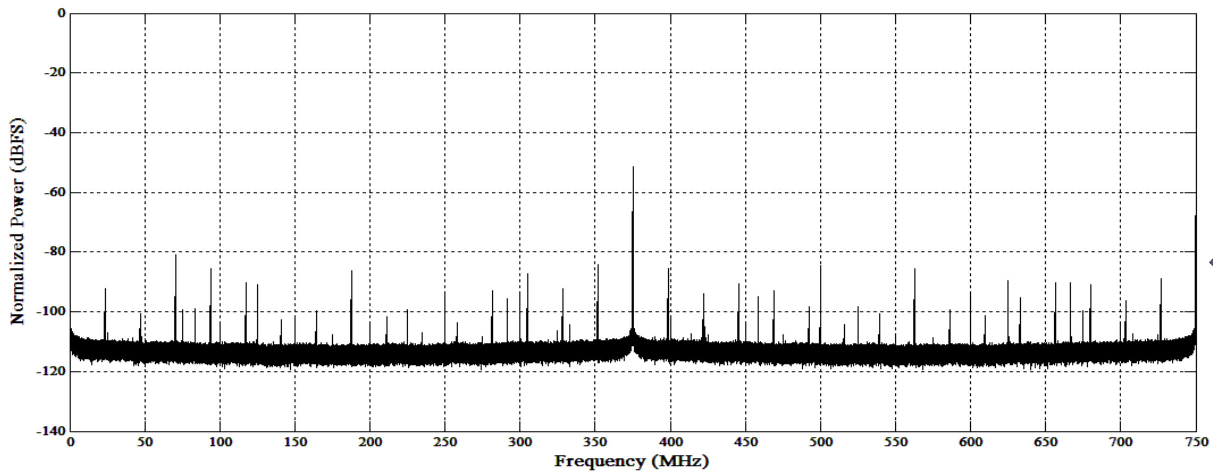
Self Power Plots



Self Power of ADC0 with f_{in}=187.5 MHz



Self Power of ADC1 with 50Ω input

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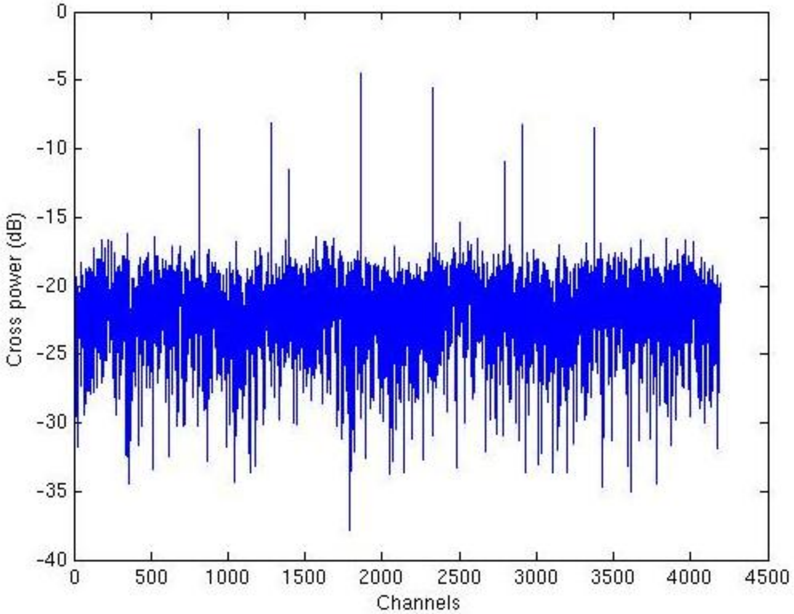
Cross coupling with 50 Ω terminated input

ADC0	ADC1	AMOUNT OF COUPLING (dB)
Input terminated with 50 Ω	Input terminated with 50 Ω	-34.07
After averaging cross power over frequency and removing pickups		***-40.55***



Cross power after averaging (1001 channels) over frequency

$$\rho = \frac{\text{Cross Power}}{\sqrt{P_1 \times P_2}}$$

$$\text{Mean}(\text{Re}(\rho)) = \text{-3.9129e-004}$$

$$\text{Mean}(\text{Im}(\rho)) = \text{-3.7202e-018}$$

$$Coupling\ (\text{dB}) = 10\log\left(\sqrt{\text{Re}(\rho)^2 + \text{Im}(\rho)^2}\right)$$

Cross Coupling with Noise input

ADC0	ADC1	AMOUNT OF COUPLING (dB)
Input fed with Noise	Input fed with Noise	-46.4729

$$\rho = \frac{\text{Cross Power}}{\sqrt{P_1 \times P_2}}$$

$$\text{Mean}(\text{Re}(\rho)) = -2.2527\text{e}-005$$

$$\text{Mean}(\text{Im}(\rho)) = 1.2892\text{e}-018$$

$$Coupling\ (\text{dB}) = 10\log\left(\sqrt{\text{Re}(\rho)^2 + \text{Im}(\rho)^2}\right)$$