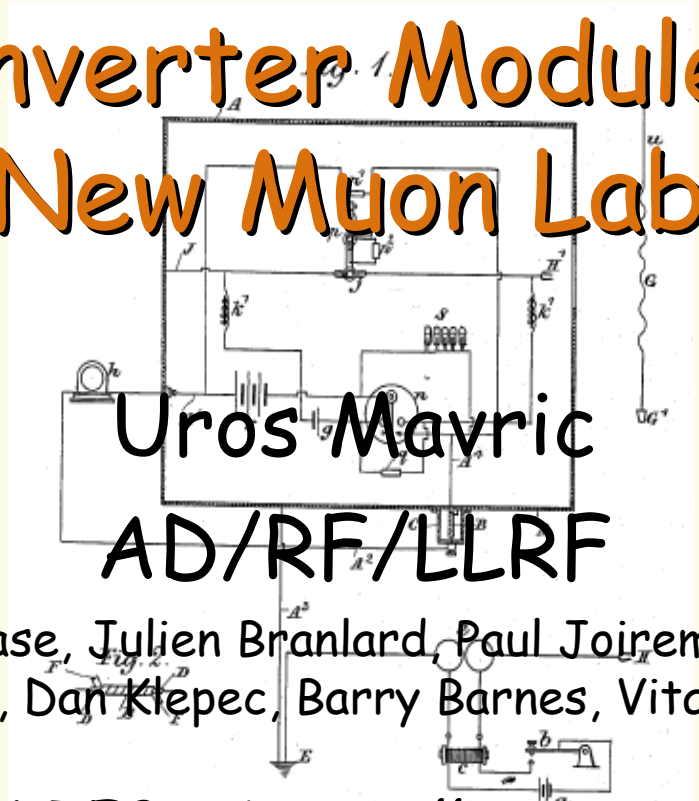
Measurements of the 8-Channel Down Converter Module for the New Muon Lab



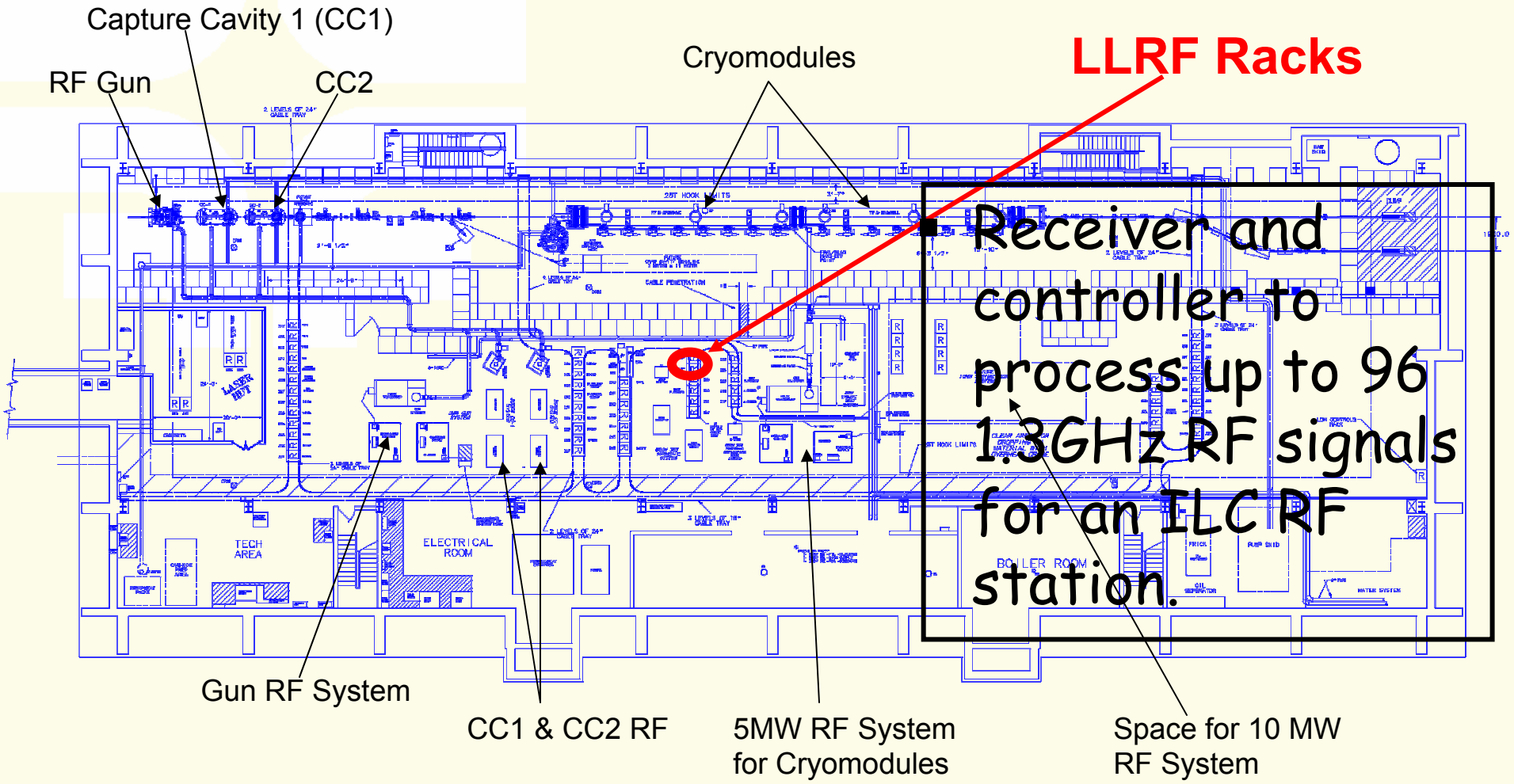
Uros Mavric

AD/RF/LLRF

Brian Chase, Julien Branlard, Paul Joireman, Philip Varghese, Dan Klepec, Barry Barnes, Vitali Tupikov

LLRF07, Knoxville, Oct. 2007

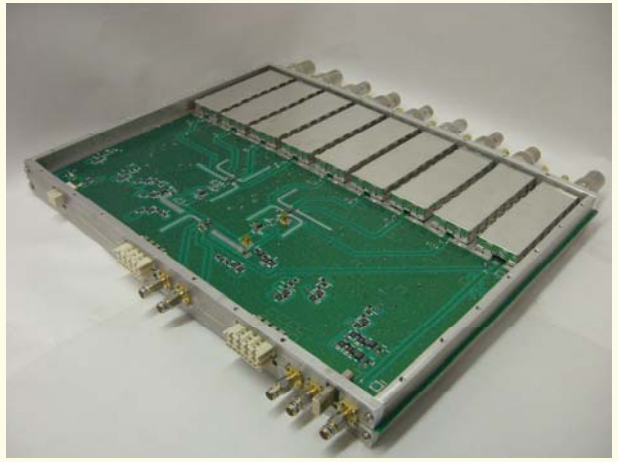
LLRF at NML

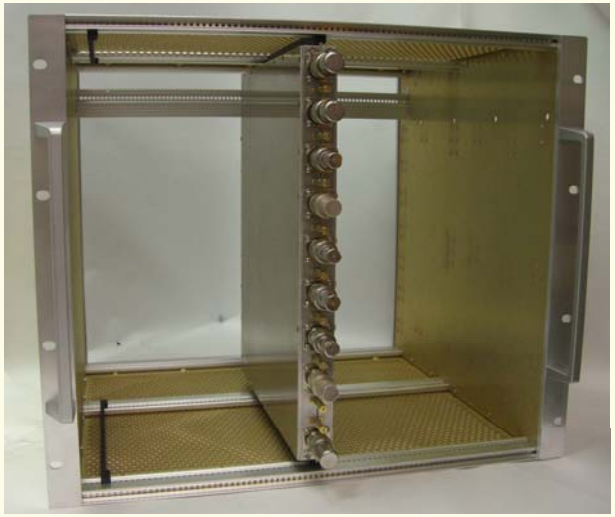

Capture Cavity 1 (CC1)
RF Gun
CC2
Cryomodules
LLRF Racks
Receiver and controller to process up to 96 1.3GHz RF signals for an ILC RF station.
TECH AREA
ELECTRICAL ROOM
BOILER ROOM
Gun RF System
CC1 & CC2 RF
5MW RF System for Cryomodules
Space for 10 MW RF System

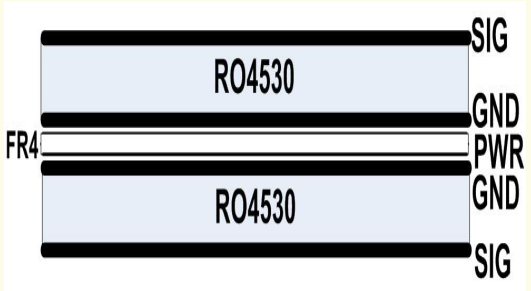
System Design Goals

- High channel count
- Low noise
- high linearity
- low crosstalk
- Small connector and cable count
- Reliable, modular, maintainable

Pictures of the Receiver

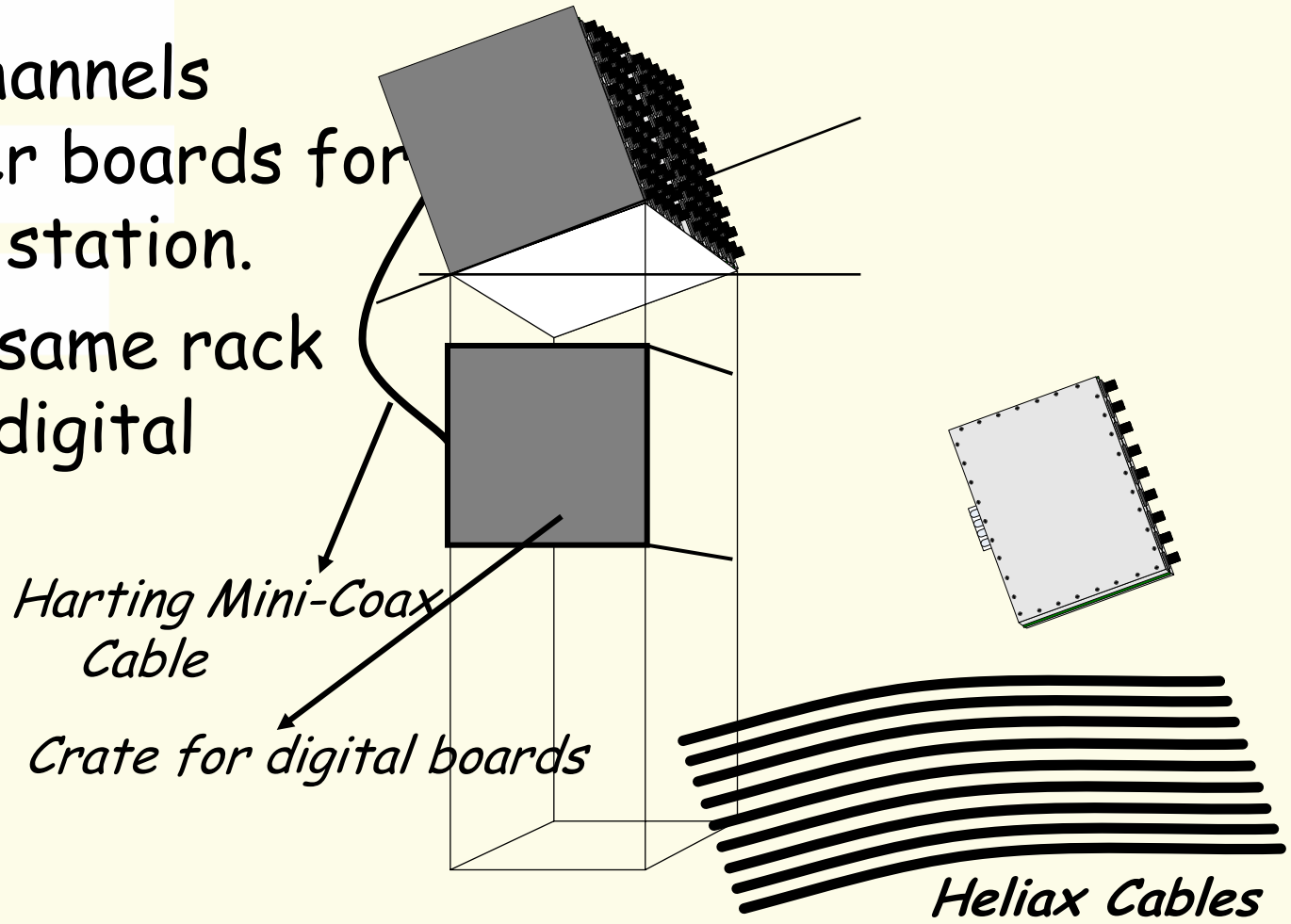




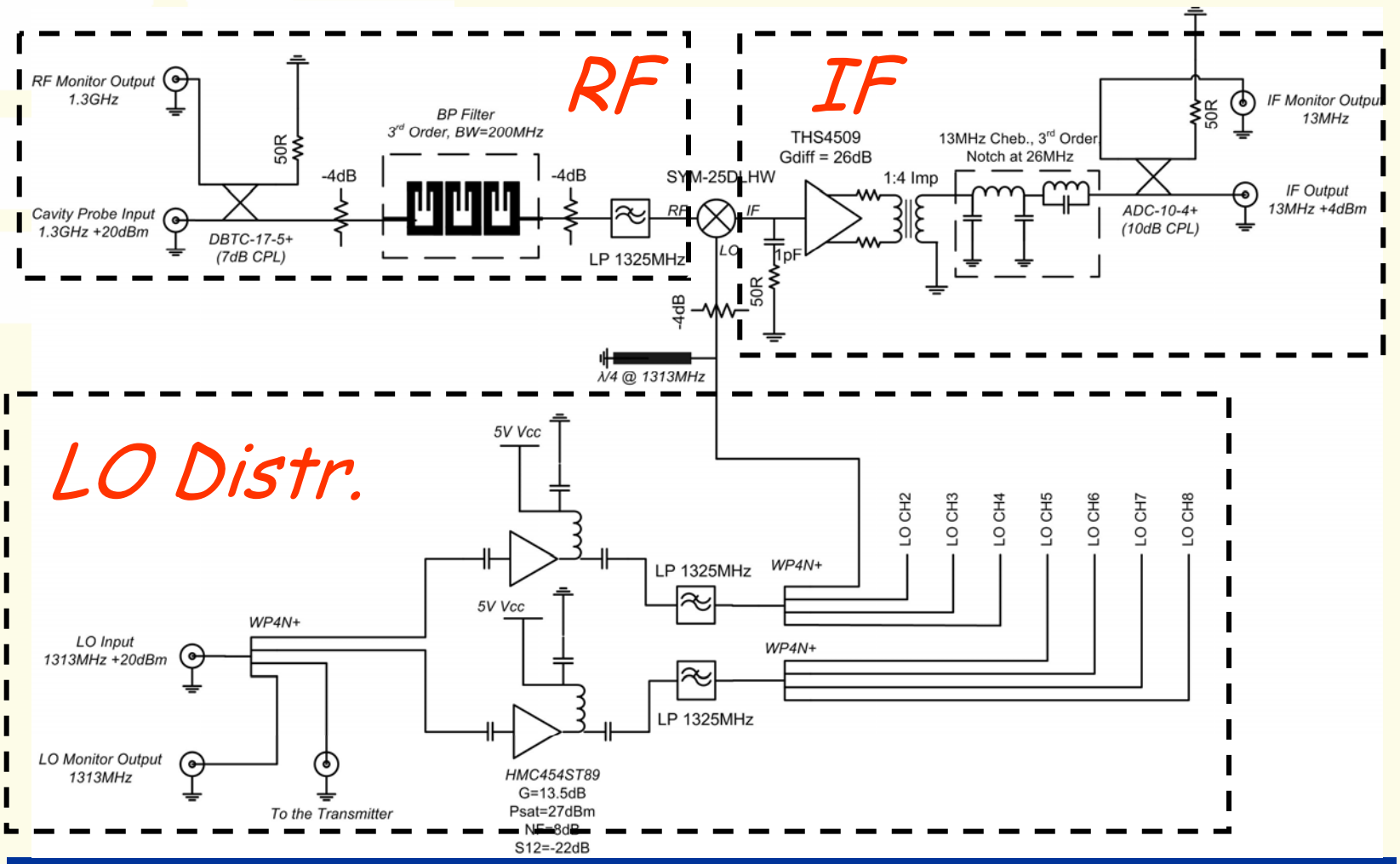


96 Channels Receiver

- 12 8-channels receiver boards for one RF station.
- In the same rack as the digital board.



Schematic of the Rc



Architecture Choices

- Mixers
  - Passive vs. Active (low LO power vs. better close-in noise performances)
  - LO power vs. linearity
  - Single DBM vs. SSB (Simple LO generation vs. good spurs suppression)
  - We chose SYM-25DLHW (L13, Pip3=+35dBm, IL=7dB, low close-in phase noise)
- LO distribution
  - 1, 2 or 8 amplifiers
    - *Crosstalk*
    - *Size and power of amplifiers*
    - *Cost*
    - *Matching*
  - 2 amps was best for all factors

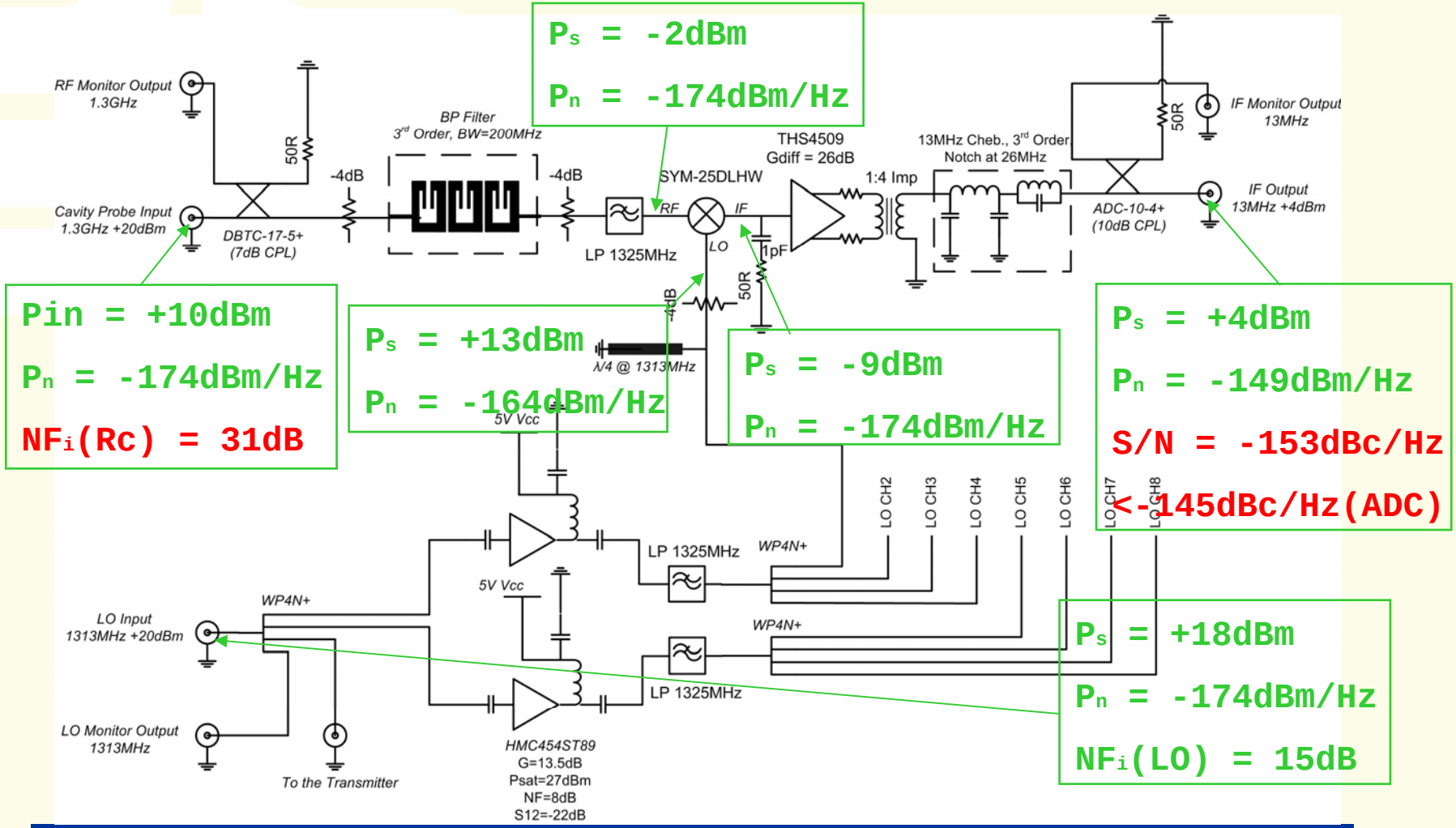
Architecture Choices (Cont'd)

- IF amplifier (IF=13MHz)
  - VGA (e.g. AD833x) or Op-amp
    - *Do we need variable gain?*
    - *Noise should not be dominated by the IF amp*
    - *Good linearity*
    - *50 ohm system at the input and output (additional losses)*

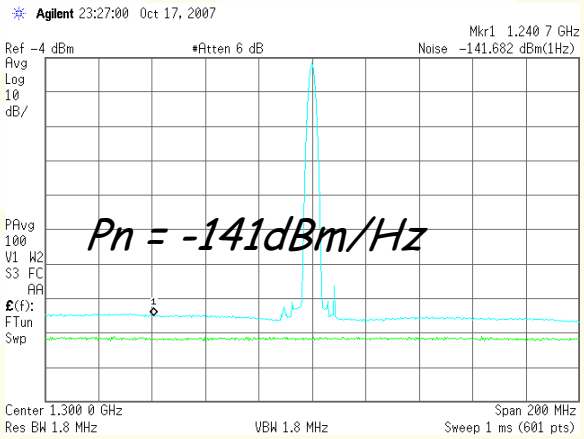
Measurements

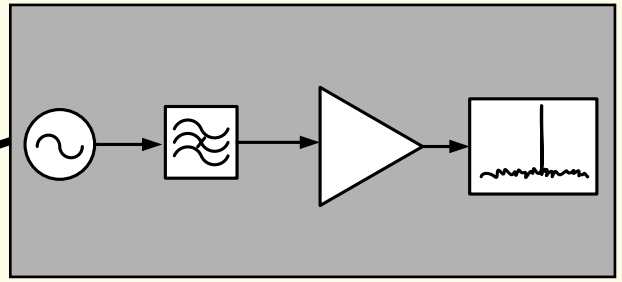
- Amplitude noise
- Close-in phase noise
- Linearity
- Cross-talk
- S-parameters of RF, LO, IF sections

Signal and Noise Power Levels



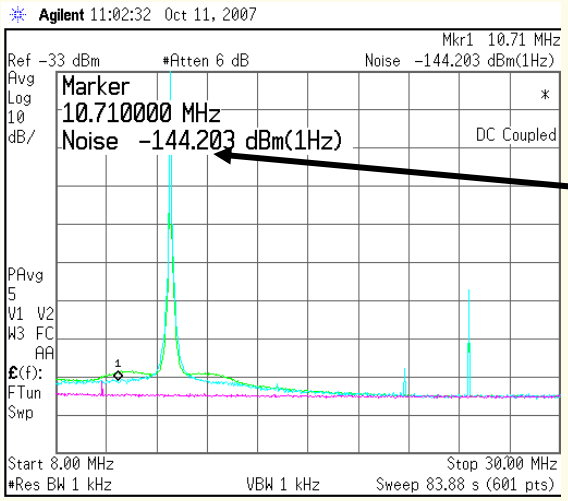
Amplitude Noise Measurements





P_{n_gen} = -141dBm/Hz -27dB -1dB

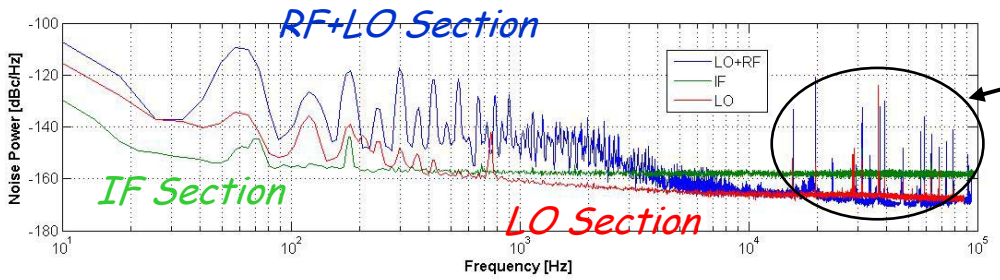
= -169dBm/Hz (AM Noise from the Source)

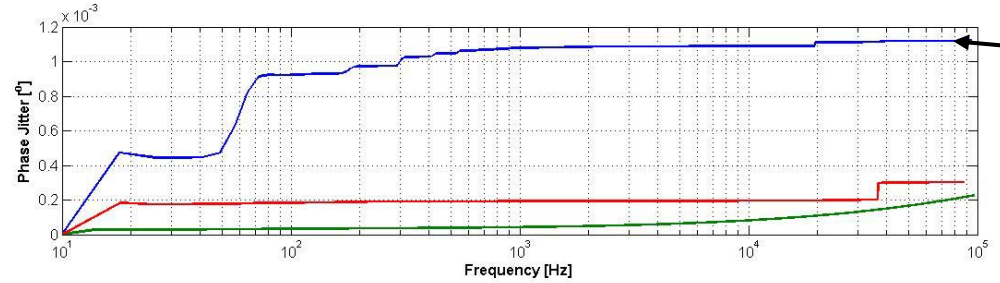


$P_{n\_Rc\_Out}$ = -169dBm/Hz +31dB -6dB

= -144dBm/Hz (Measured AM Noise at the Output of the Rc)

Residual Phase Noise Measurements



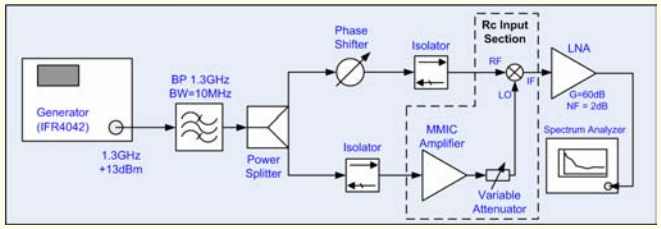


Structure on amplitude (~20kHz)

1e-3°@100kHz

(similar to what we sampled)

Measurement Setup



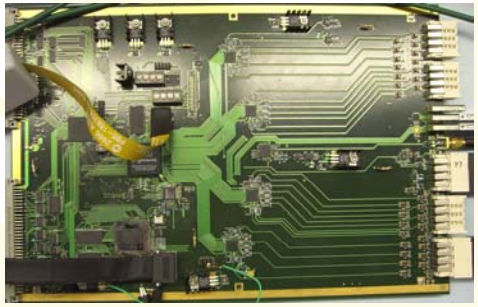
Noise from the aperture jitter of the ADC is not an issue at 13MHz:

SNR@fs/2 = $20\log_{10}(2\pi 13\text{MHz} 0.8\text{e-}12\text{s})$ = 84dB (>70dB)

Higher IF frequencies? Depends also on the ADC.

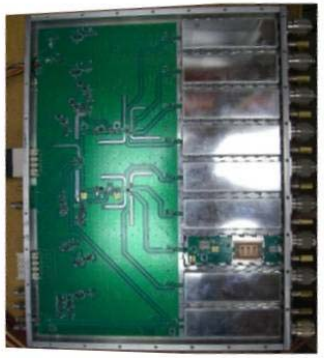
Sampling of the IF Signal

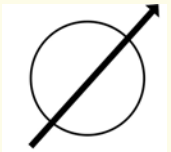
Multi-Channel Field Control Module

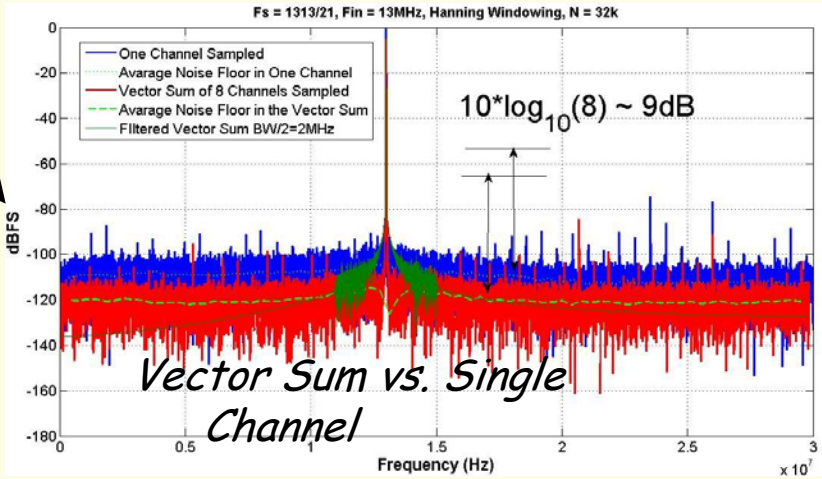


Harting IF Mini-coax Connector

8 Channel Rc







Vector Sum vs. Single Channel

Measured SNR for one channel (12bit ADC):

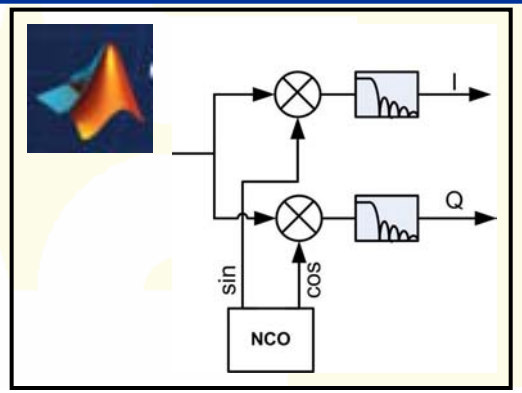
SNR@fs/2 = 112dB - 10log10(32k/2) = 70dB

Measured SNR for vector sum (8x12bit ADC):

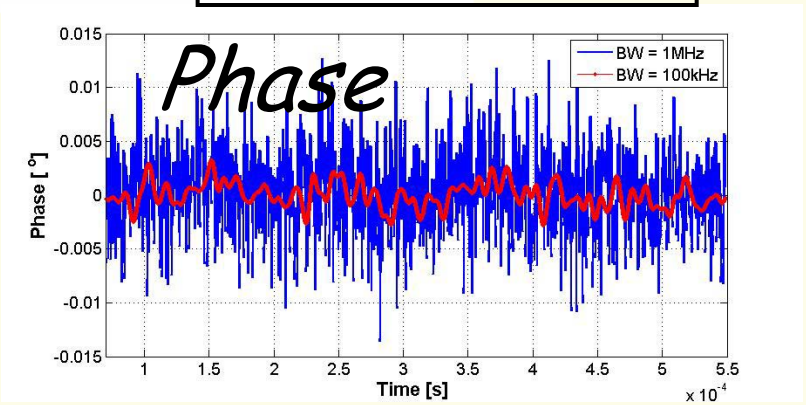
SNR@fs/2 + 10log10(8) = 79dB

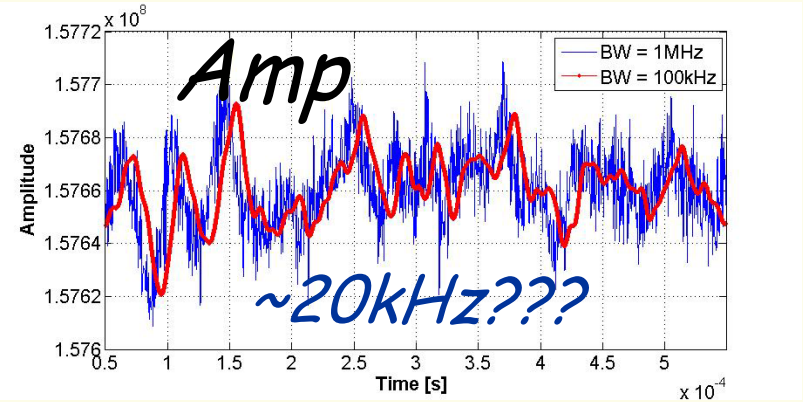
The SNR -154dBc/Hz (0.002% BW:1MHz) is expected.

Sampling of the IF Signal Cont'd



BW = 1MHz, 100kHz





σ(100kHz) = 1.1e-3°

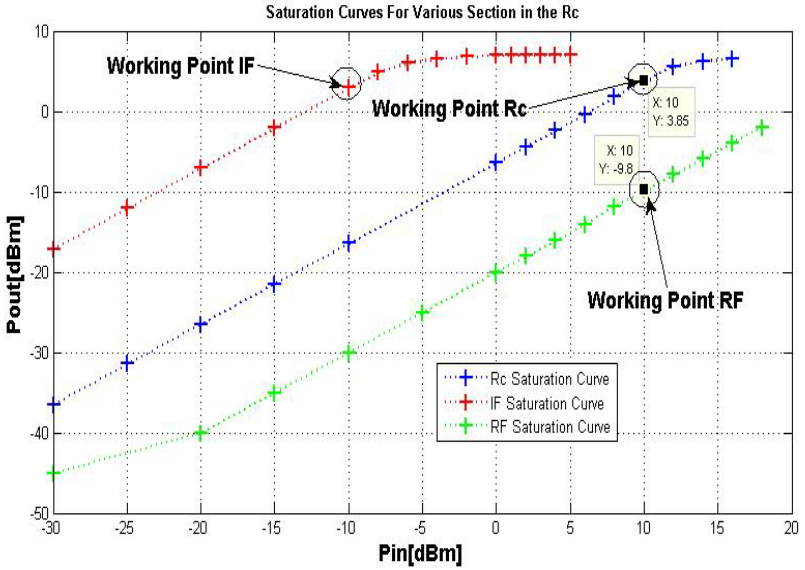
σ(1MHz) = 3.7e-3°

σ(100kHz) = 0.008%

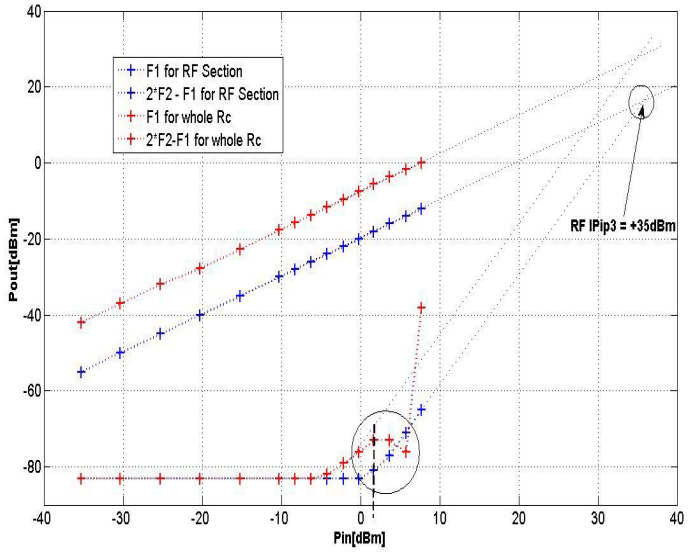
σ(1MHz) = 0.01%

Linearity Measurements

Saturation Curves for various sections:



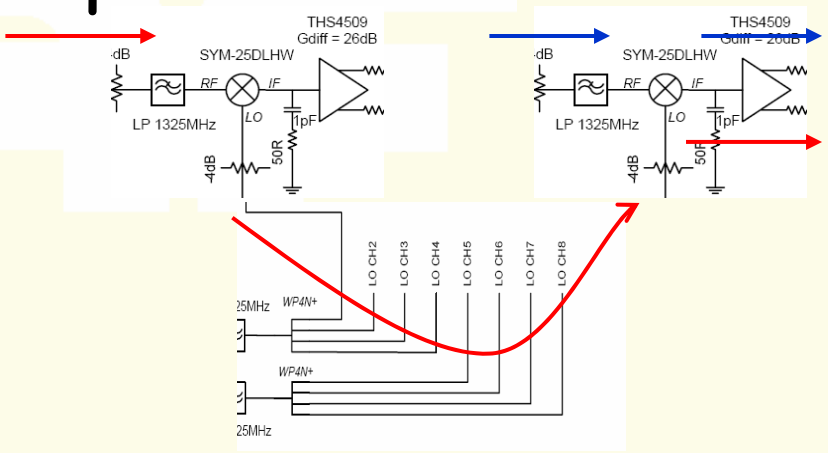
Two-Tone Test:

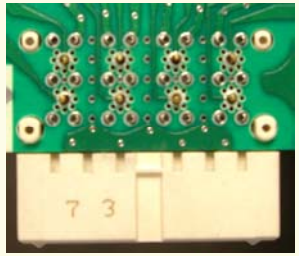


IPip3=+35dBm

Coupling Between Channels

- Main coupling through the LO-RF ports of the mixer (SYM-25DLHW).



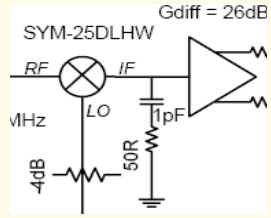


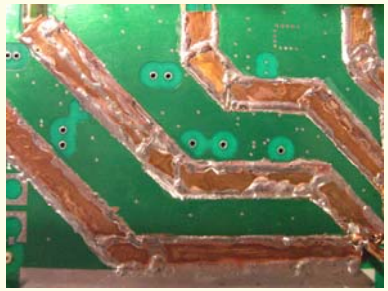
- Other sources : Output connector, improper grounding and shielding.

Coupling Between Channels Cont'd

To avoid coupling:

- It is important to achieve broadband matching (~2*LO) on all ports of the mixer *[1,2].*
- *Shielding, stack-up structure, grounding*



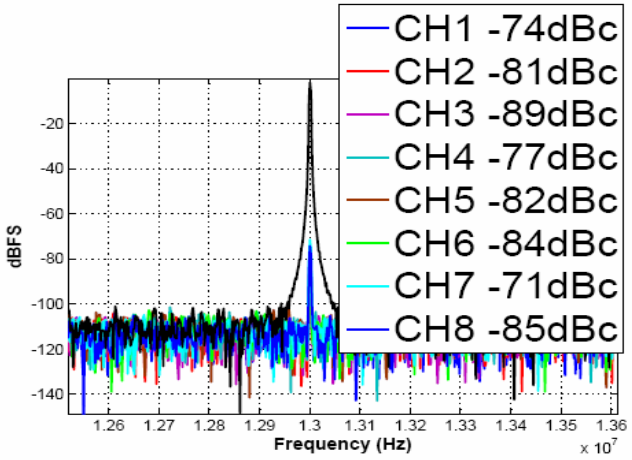


Coupling Measurements

- Coupling Matrix (Single Input – Single Output):

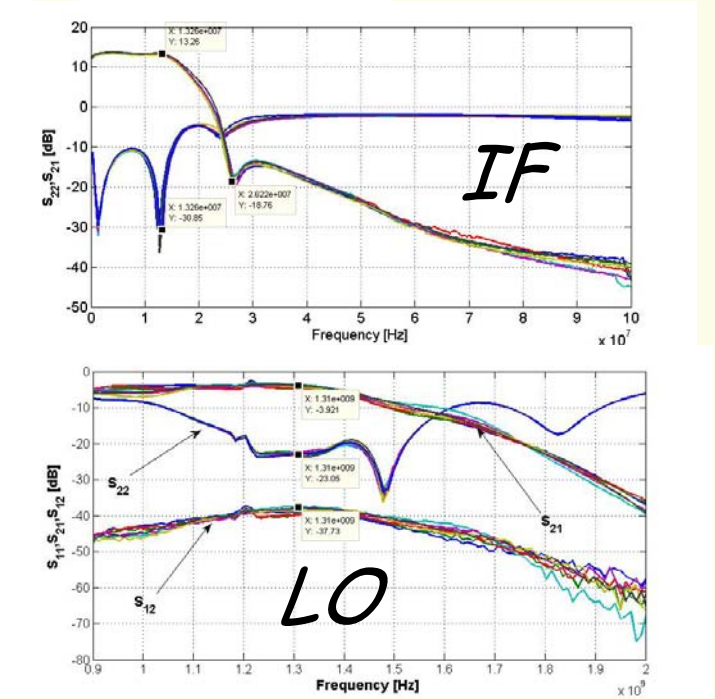
INPUT \ OUTPUT	1	2	3	4	5	6	7	8
1	X	-80	-88	-86	-88	-87	-84	-87
2	-86	X	-87	-83	-88	-88	-89	-87
3	-87	-83	X	-81	-88	-90	-90	-87
4	-88	-88	-82	X	-81	-87	-90	-88
5	-89	-89	-89	-85	X	-80	-89	-88
6	-89	-89	-90	-87	-80	X	-86	-88
7	-86	-89	-89	-87	-86	-84	X	-83
8	-88	-89	-90	-87	-88	-88	-87	X

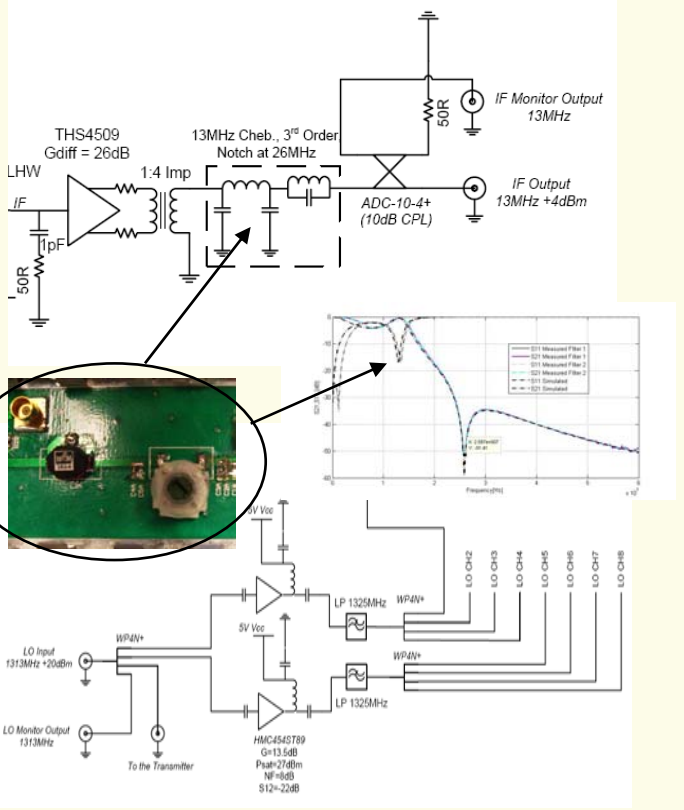
- 7 Channels Input – Single Channel Output (Sampled):



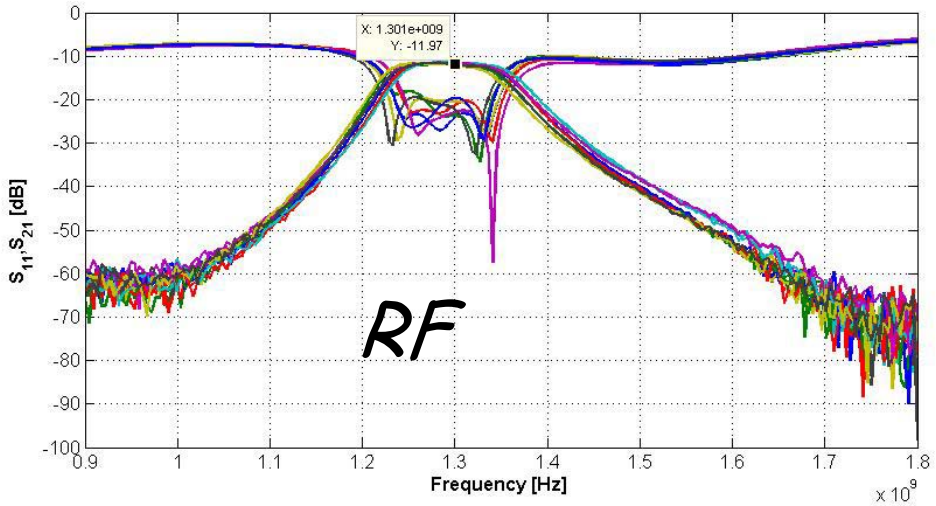
Transfer Functions

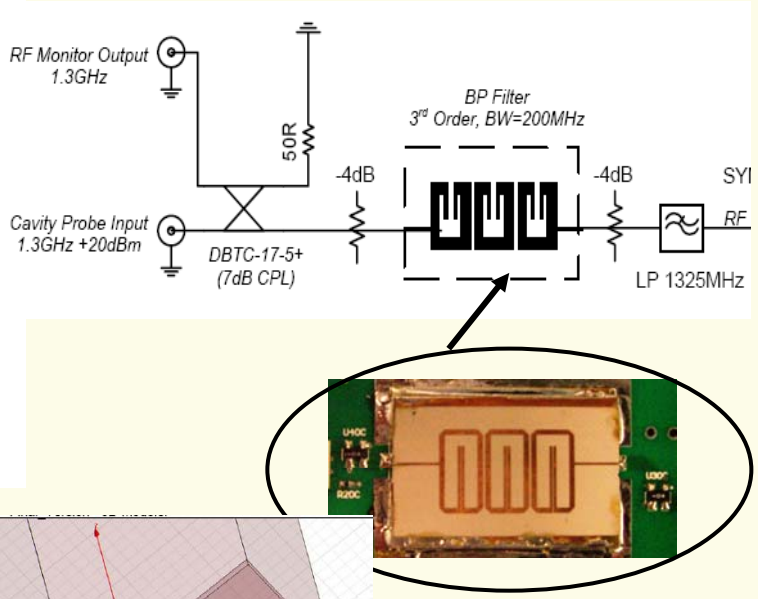
- S Parameters of IF, RF and LO Sections





Transfer Functions Cont'd

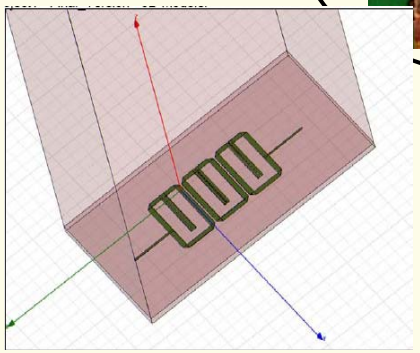




Dispersion Between Channels:

Amp: IF~0.5dB , RF~0.3dB , LO~1.2dB

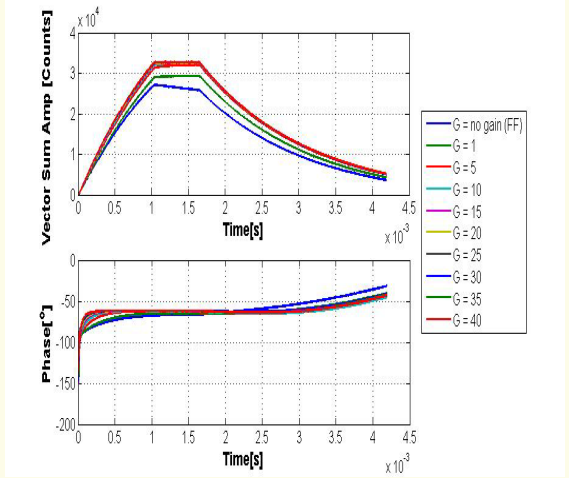
Phase : IF~40°, RF~33° , LO~200°

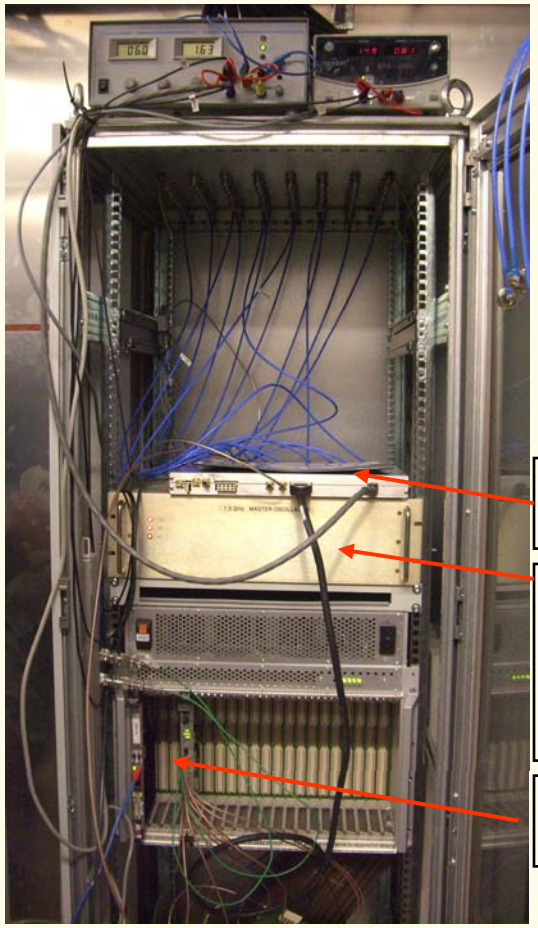


Main Parameters Table

Parameter	*Value*
Amplitude Noise	31dB (Input Noise Figure)
Residual Phase Noise	1e-3 (10-100kHz)
Linearity	+35dBm (Input Pip3)
Cross-Talk	71-90 dB (7 Ch. Connected)
Power Consumption	8W (1A@+6V/0.4A@-6V)
Number of Channels per board	8Rc + 1Tx
Cost/Channel	200$

Measurements on ACC1 at DESY





8 Channel Rc/Tx

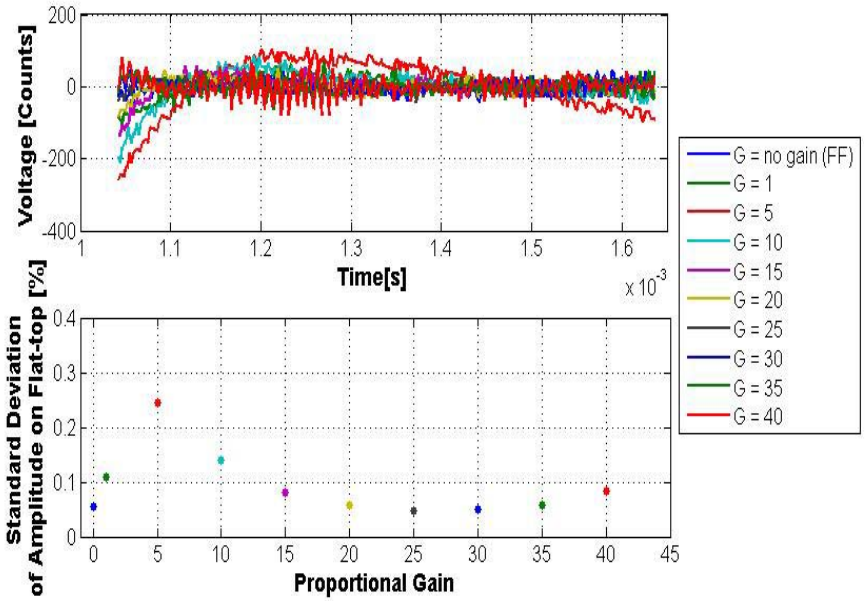
Master Oscillator

LO Generation

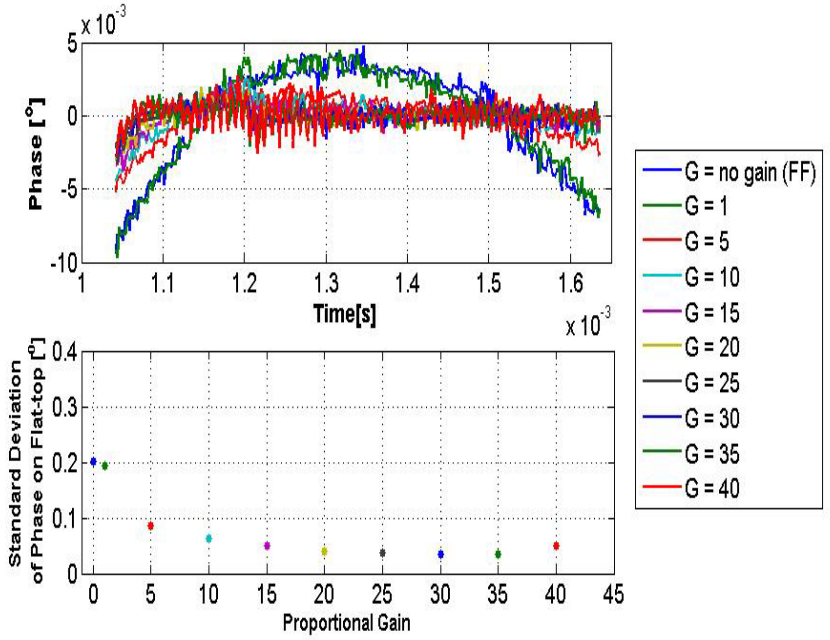
ESECON

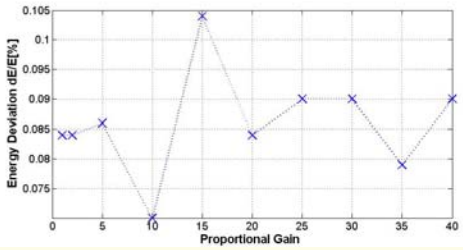
Measurements on ACC1 at DESY

Amp dev. vs. Loop Gain



Phase dev. vs. Loop Gain





Energy Spread of the beam

Acknowledgments

- AD LLRF Group
  - Brian Chase, Ed Cullerton, Julien Branlard, Paul Joireman, Philip Varghese, Dan Klepec, Barry Barnes, Vitali Tupikov
- Thanks to:
  - CD LLRF Group (G. Cancelo)
  - DESY (F. Ludwig)
  - JLab (J. Musson)
  - NIST (A. Hati)

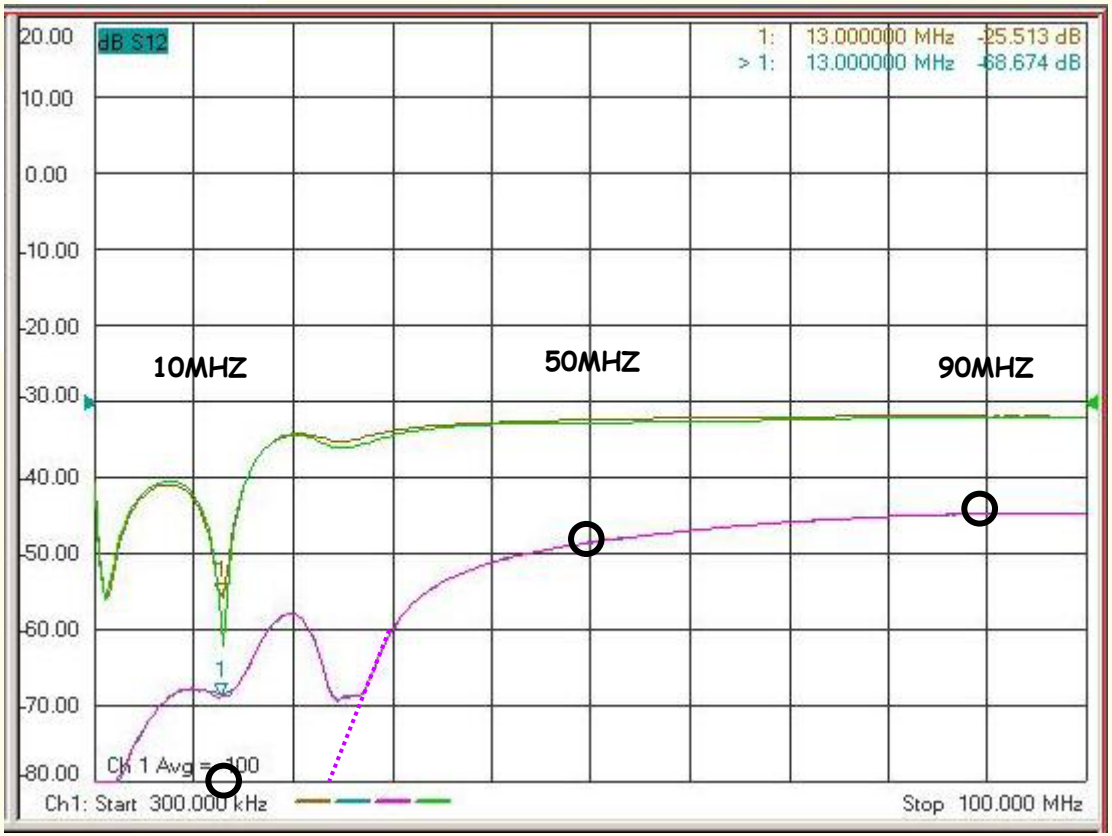
References

[1] P. Will, "Reactive Loads – The Big Mixer Menace," *Microwave*, pp. 38-42, April 1971

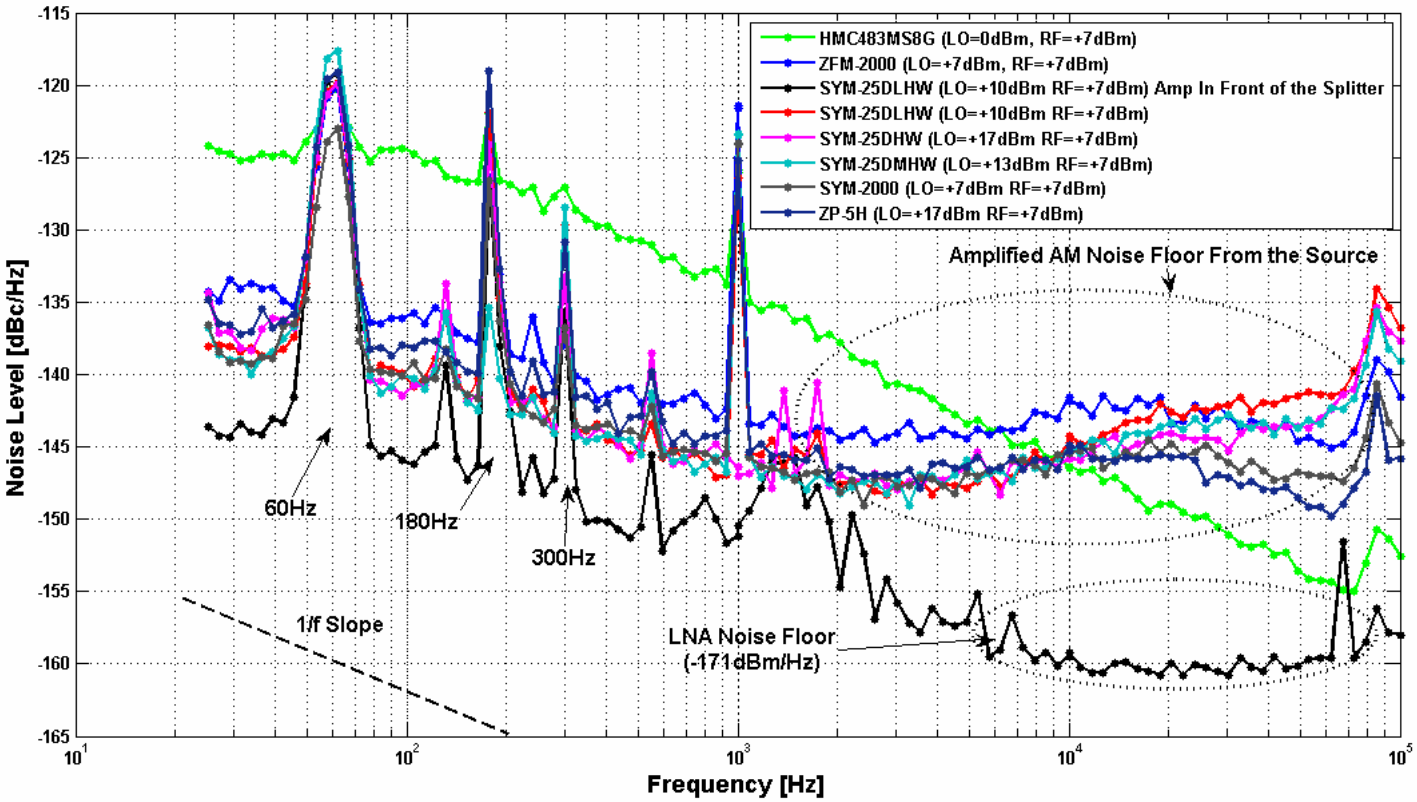
[2] M. W. Muterspaugh et al., "Single Balanced Mixer Output Filter," *United States Patent – 5,034,994, July, 1991*

Backup Slides

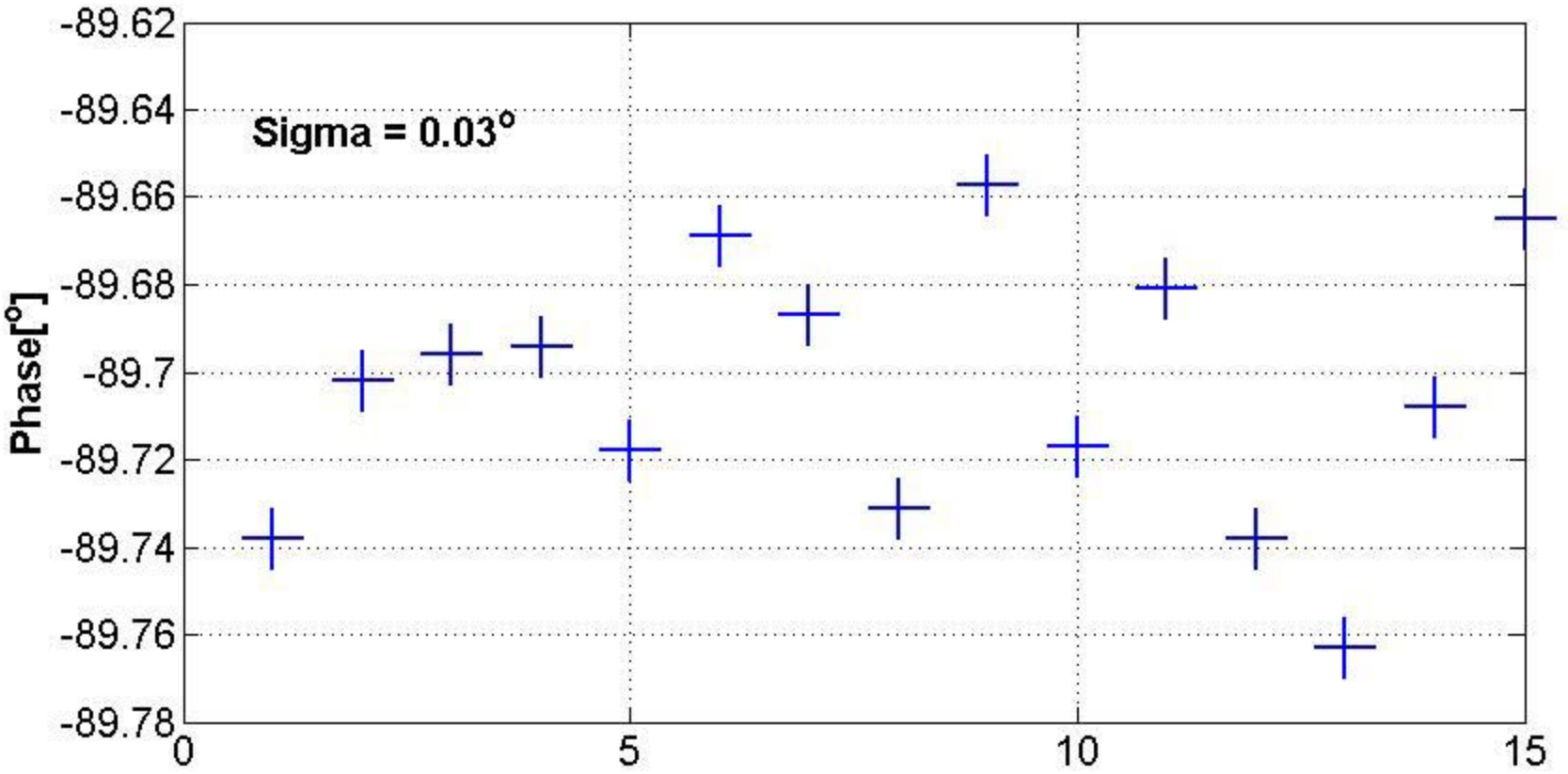
Coupling vs. Frequency



Input Stage Residual Phase Noise



Phase Stability of Harting Mini-Coax Connectors



Temperature Stability of the Rc