Manufacturing Test of RF Systems

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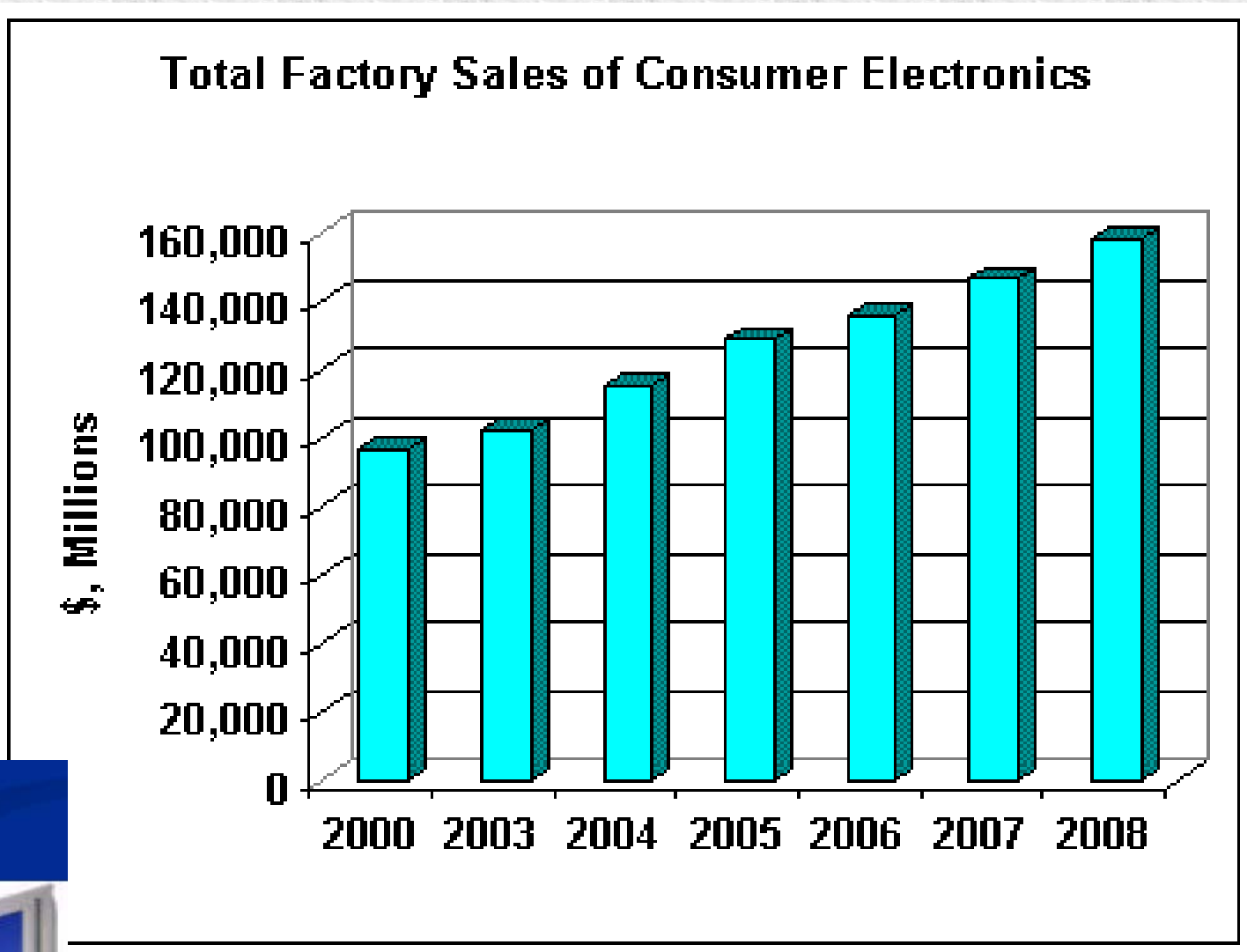
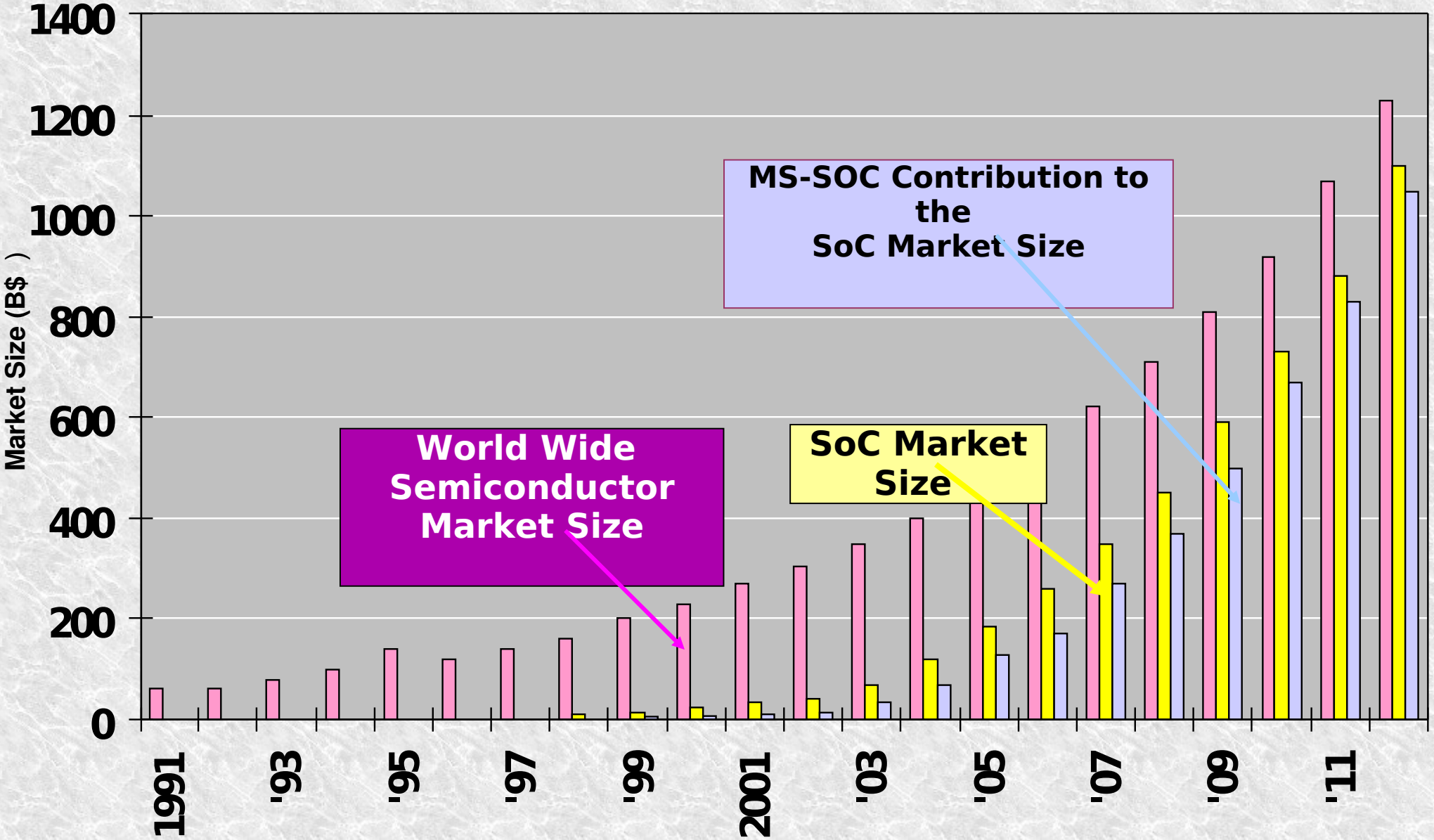
Motivation: Consumer Electronics



Source: Consumer Electronics Marketing Association, Jan. 2005

System-on-Chip Market Size

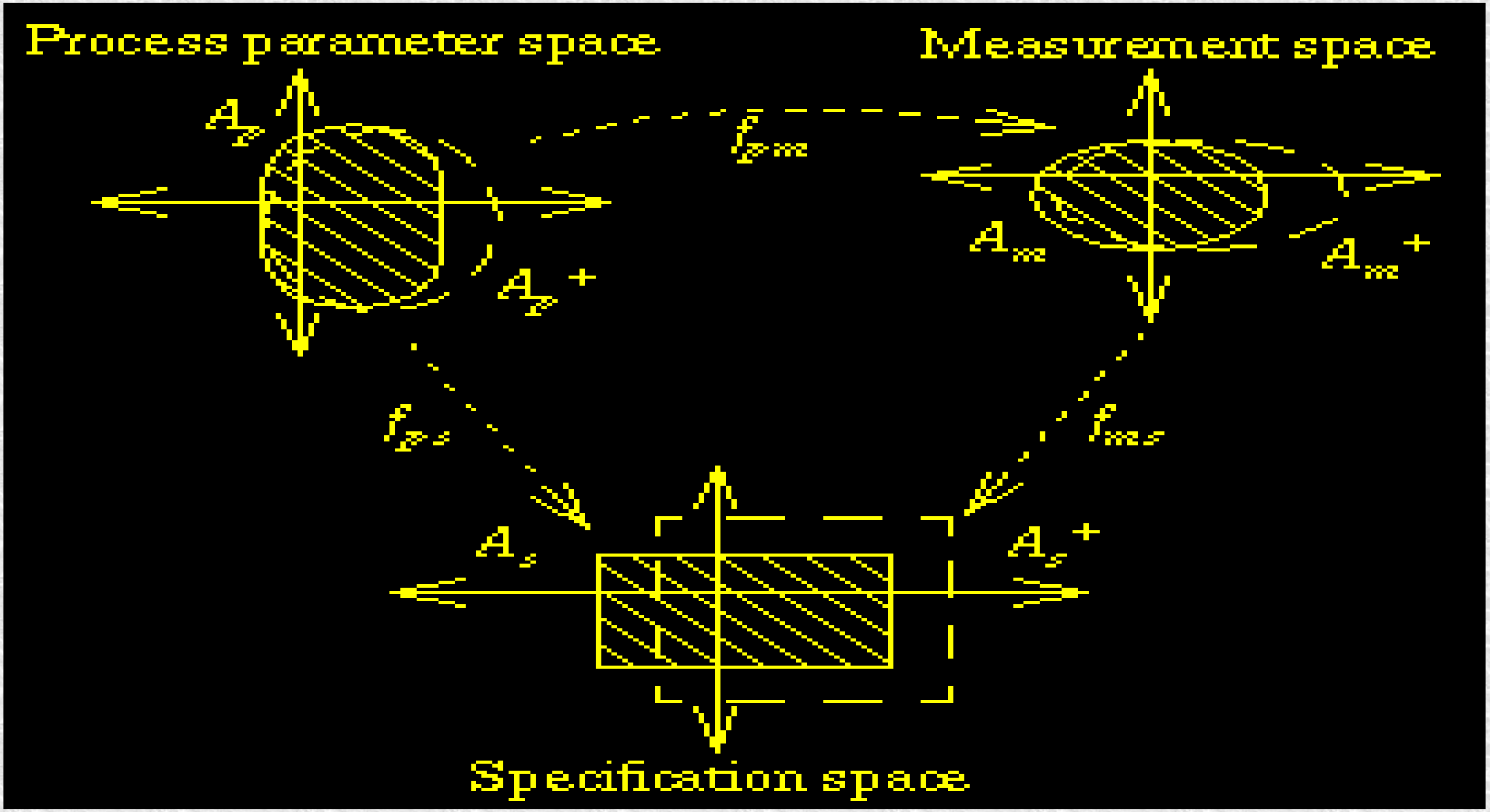


New test problem: dealing with embedded mixed-signal blocks

Testing Analog/Mixed-Signal/RF

- Have to deal with **continuous signals**
- Customers want a guarantee of ***specifications***
- ***Regulatory agency limits energy outside allocated spectrum (ex. FCC)***
  - Testing for third harmonic requires very expensive tester
- A defect may or may not affect the desired behavior of a chip
- **Tests are for the specifications, not for defects**
- Similar trend in digital: testing for distributed path delays
- Costs very high if every specification has to be tested

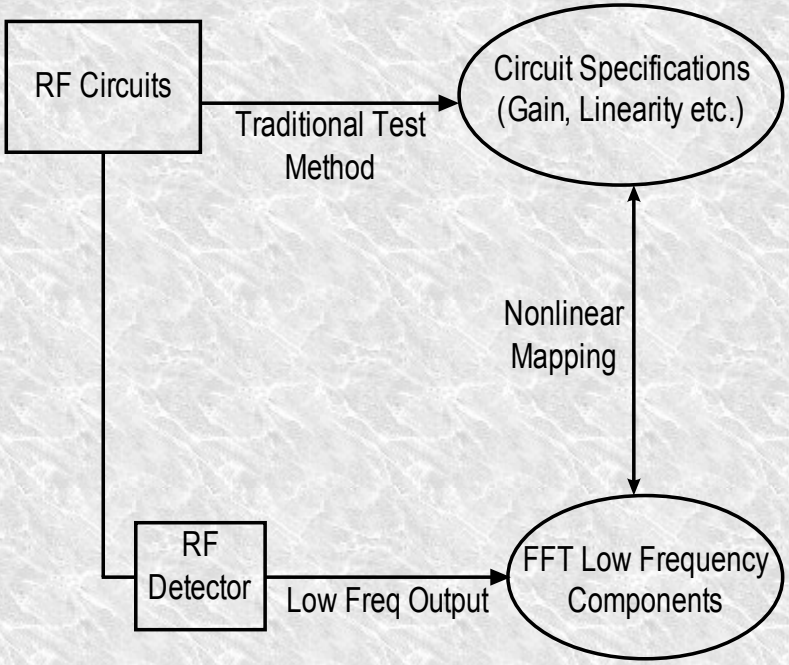
"Alternate Tests"

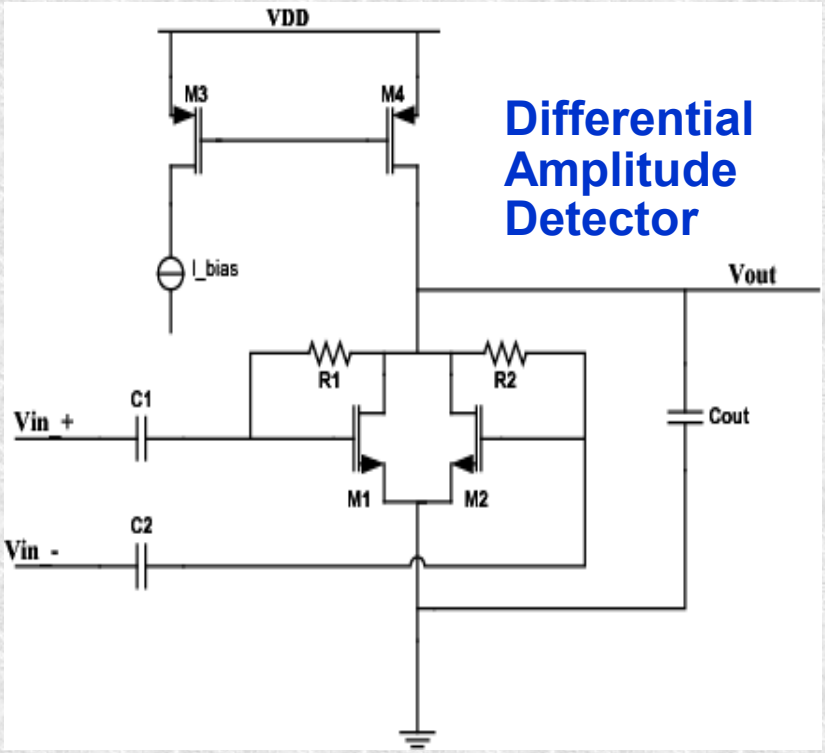


Mapping between measurement and specification spaces is derived using regression (MARS)

Source: Chatterjee

RF Built-In Test using Amplitude Detectors

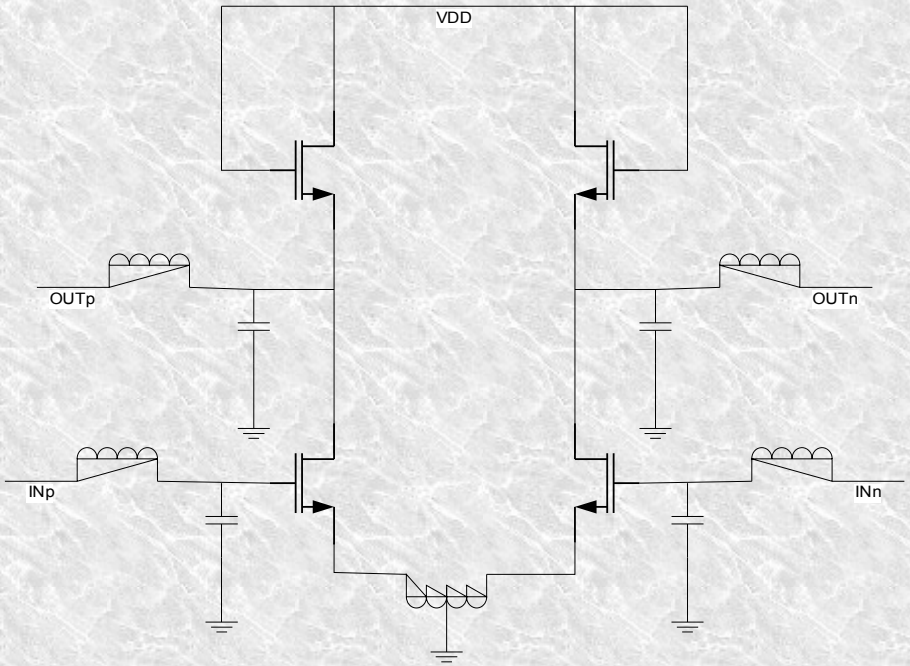




- Alternate test methodology
- High input impedance (7.6KOhm@1GHz) for detector
- Detector output mapped to RF circuit specifications
- Low frequency output signal (sampling frequency of 10MHz for mixer test, DC for amplifier test)
- Strong correlations with RF circuit parameters

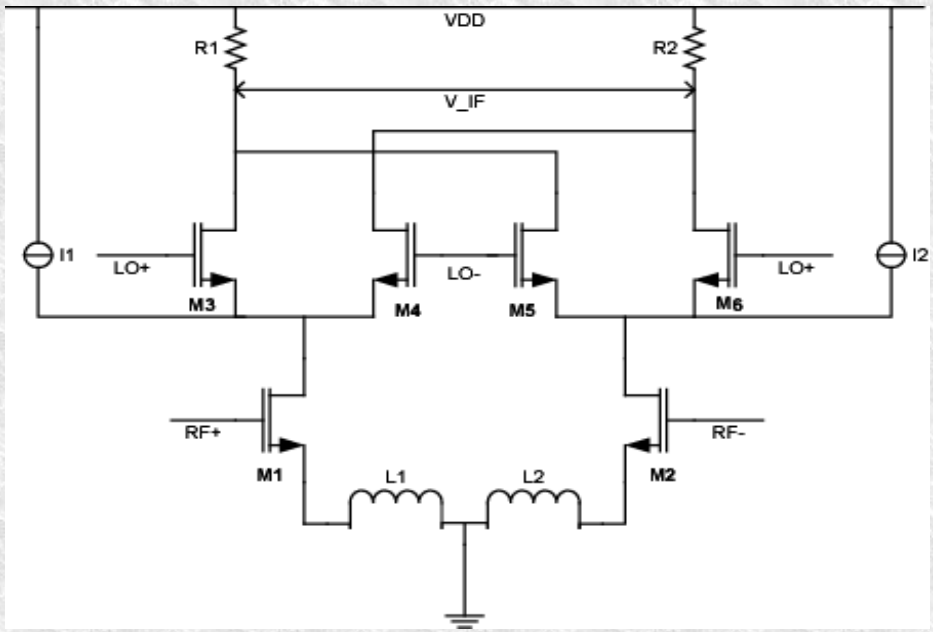
Receiver RF Front End: LNA, Mixer

- Differential LNA



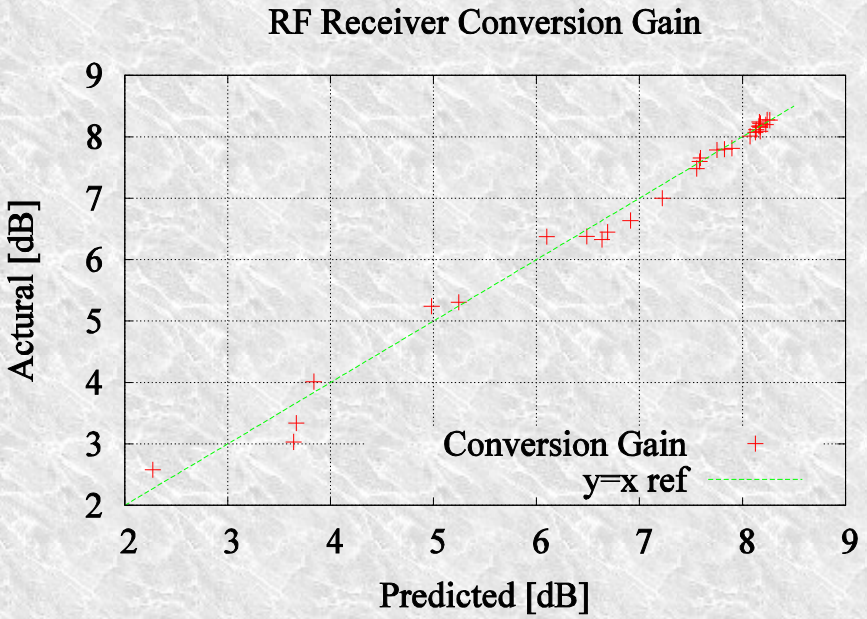
  - Fully differential structure with inductive source degeneration

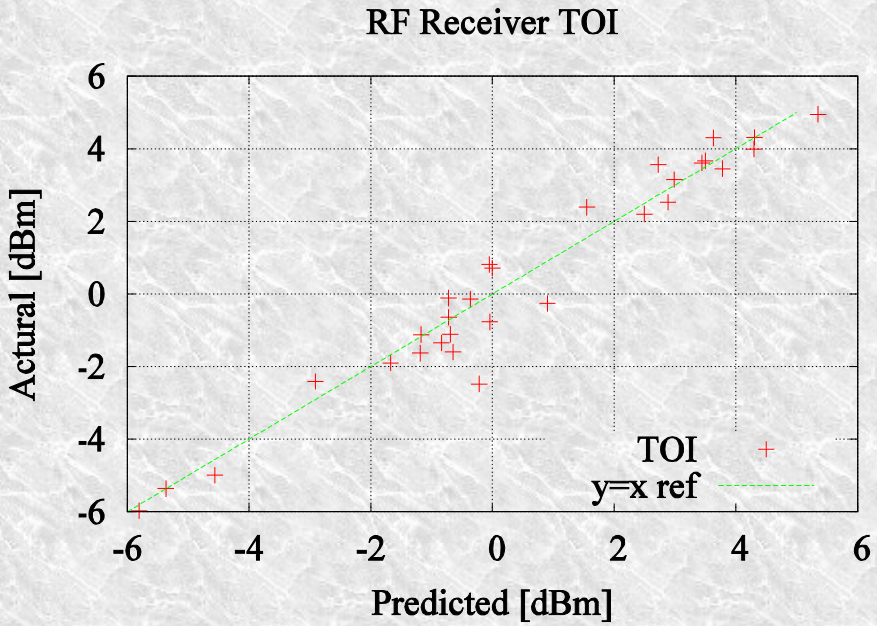
- RF Mixer



  - Gilbert Cell Differential RF Mixer
  - Current Injection (+Gain,+Linearity)
  - Inductive Source Degeneration (+Linearity)

Simulation Results



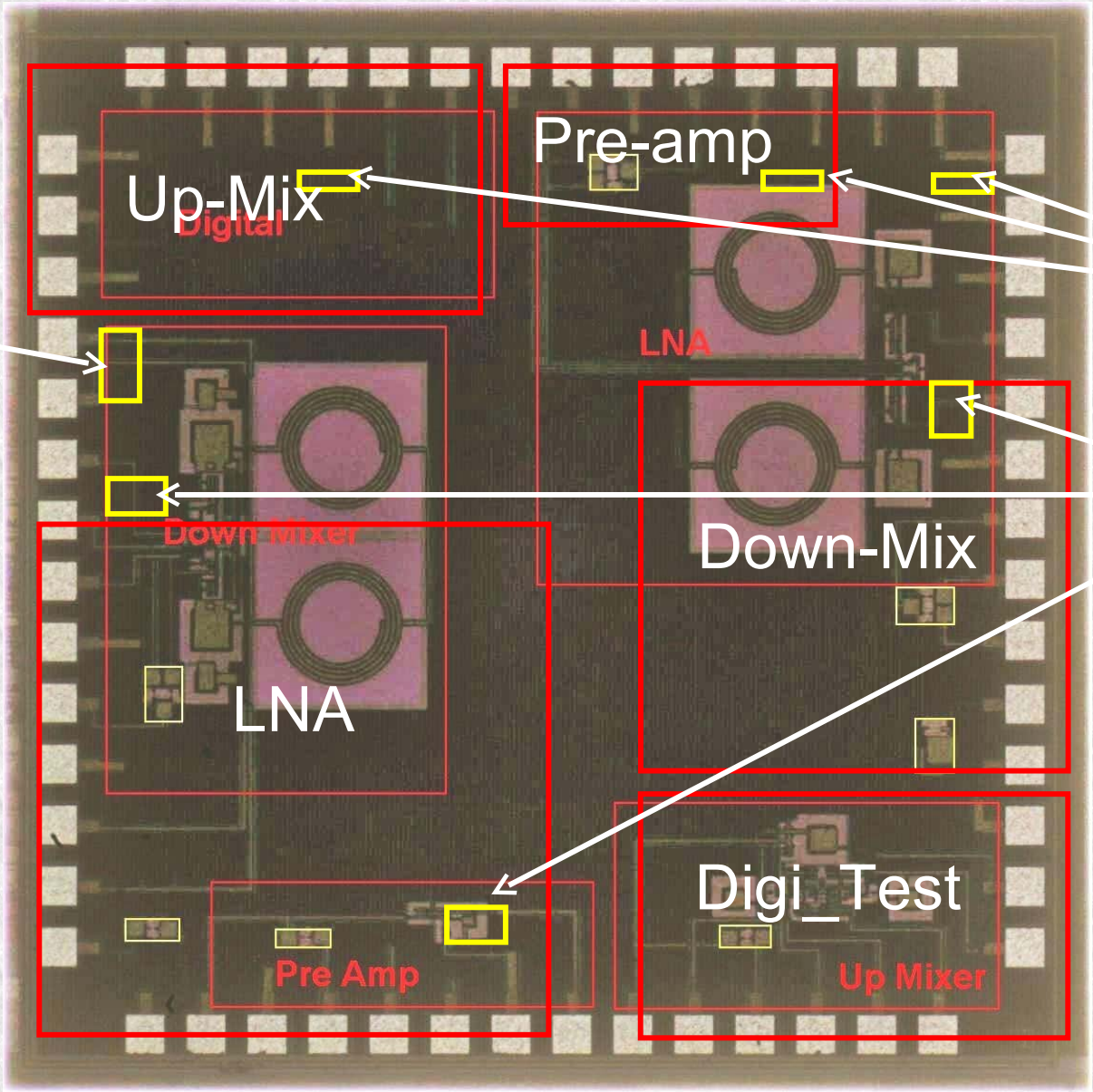


	Conversion Gain	TOI (IIP3)
RMS Error	0.187 dB	0.653 dBm
Relative Error	3.5%	5.1%

- LNA gain RMS error: 0.69dB
- LNA IIP3 RMS error:0.2 dBm

940 MHz RF Transceiver (UMC 0.18µ CMOS)

10 MHz output from sensors used to predict specifications



Envelope Detector

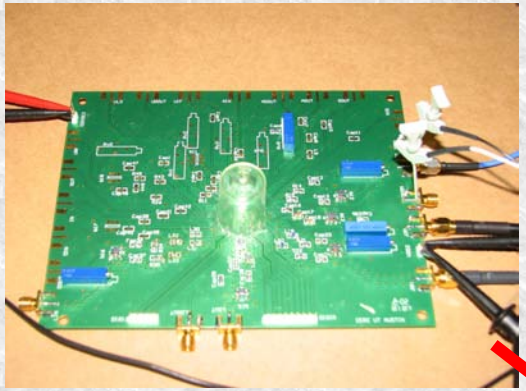
Single ended detectors

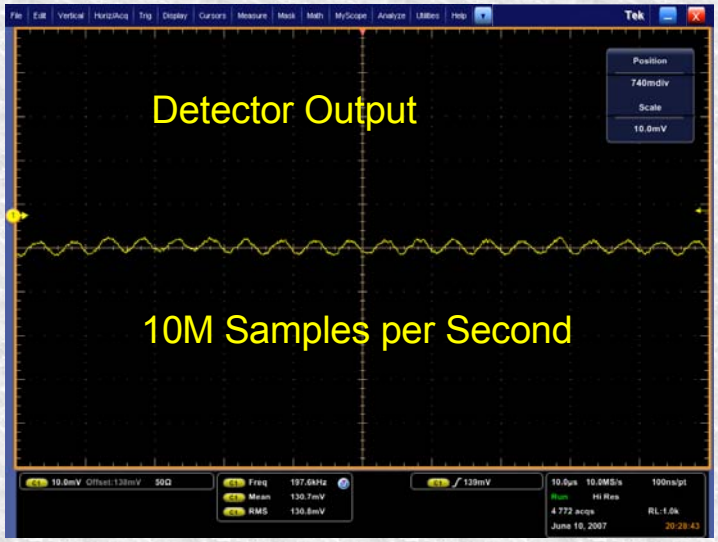
Differential detectors

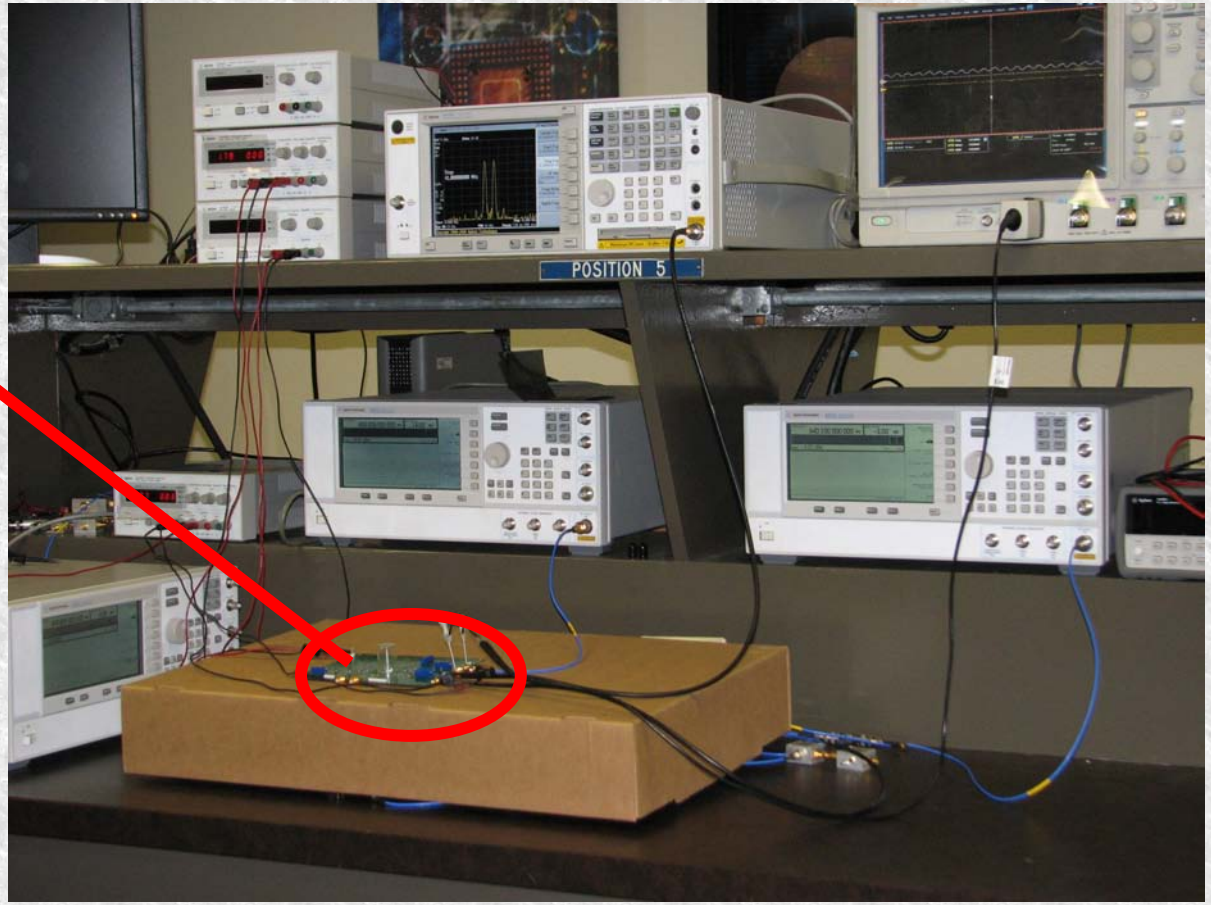
- 1525 x 1525 microns
- Detector area overhead less than 1%

Chip Measurement Setup

- Agilent E8257D Signal Generator
- Agilent E4448A Spectrum Analyzer
- Tektronix DPO 7104 Digital Oscilloscope



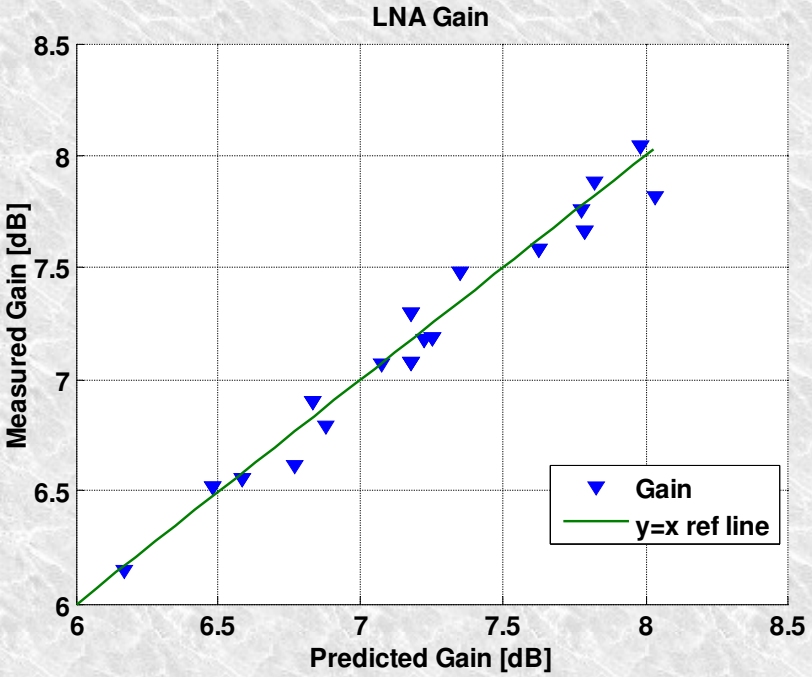


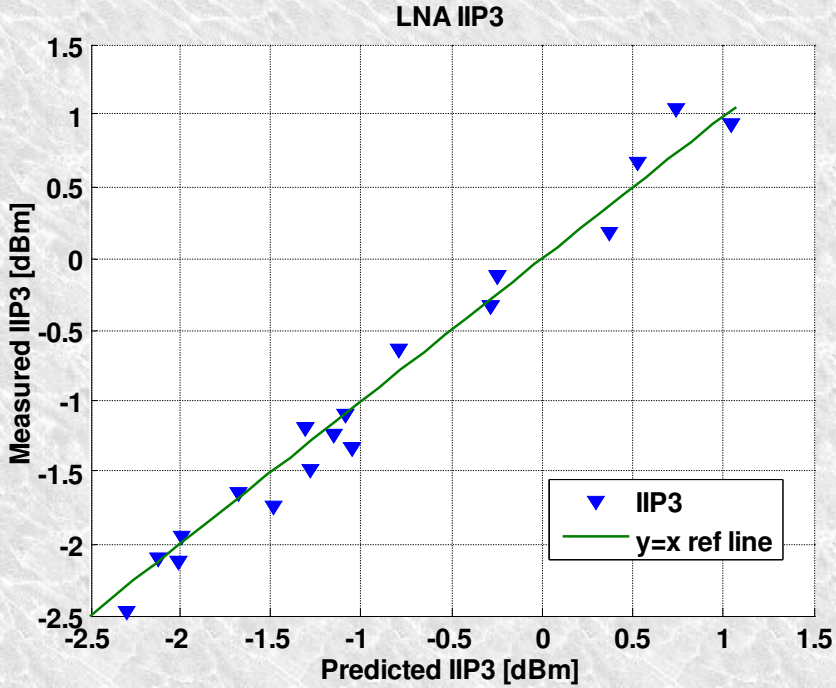


Experiment Procedure

- Sweep chip supply and biasing conditions (10% variations), measure corresponding circuit specifications (gain, IIP3 etc.)
- At the same conditions, capture detector outputs with oscilloscope at 10 MS/s
- Obtain 150 instances
- Use 120 instances as training cases, with Multivariate Adaptive Regression Splines (MARS), get the function between detector outputs and circuit specifications
- Use the other 30 instances as the function input to obtain predicted circuit specifications
- Draw comparison plots with the measurement results, and calculate RMS errors and relative errors

Measurement Results



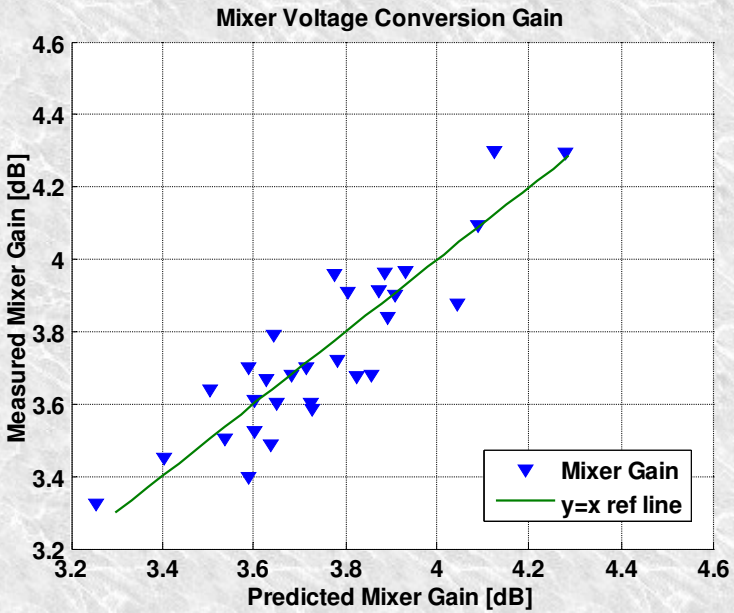


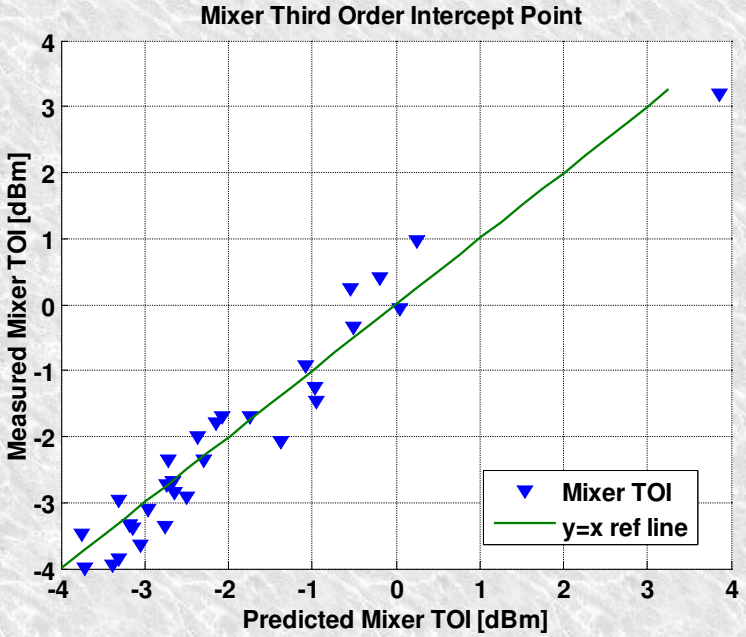
	LNA Gain	LNA IIP3
RMS Error	0.09 dB	0.15 dBm
Relative Error	4.8%	4.4%

$$RMS_{error} = \sqrt{\frac{1}{N}\sum (P_{true} - P_{estimated})^2}$$

$$\mathrm{Re}lative_{error} = \frac{RMS_{error}}{Variation\ Range}$$

Measurement Results





	Mixer Gain	Mixer TOI
RMS Error	0.11 dB	0.42 dBm
Relative Error	10.8%	5.9%

Comment: The high gain relative error is due to the limited gain variation range (only about1 dB)

Loopback RF Test