NLC - The Next Linear Collider Project

Linearizing Intra-Train Beam-Beam Deflection Feedback

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SLAC

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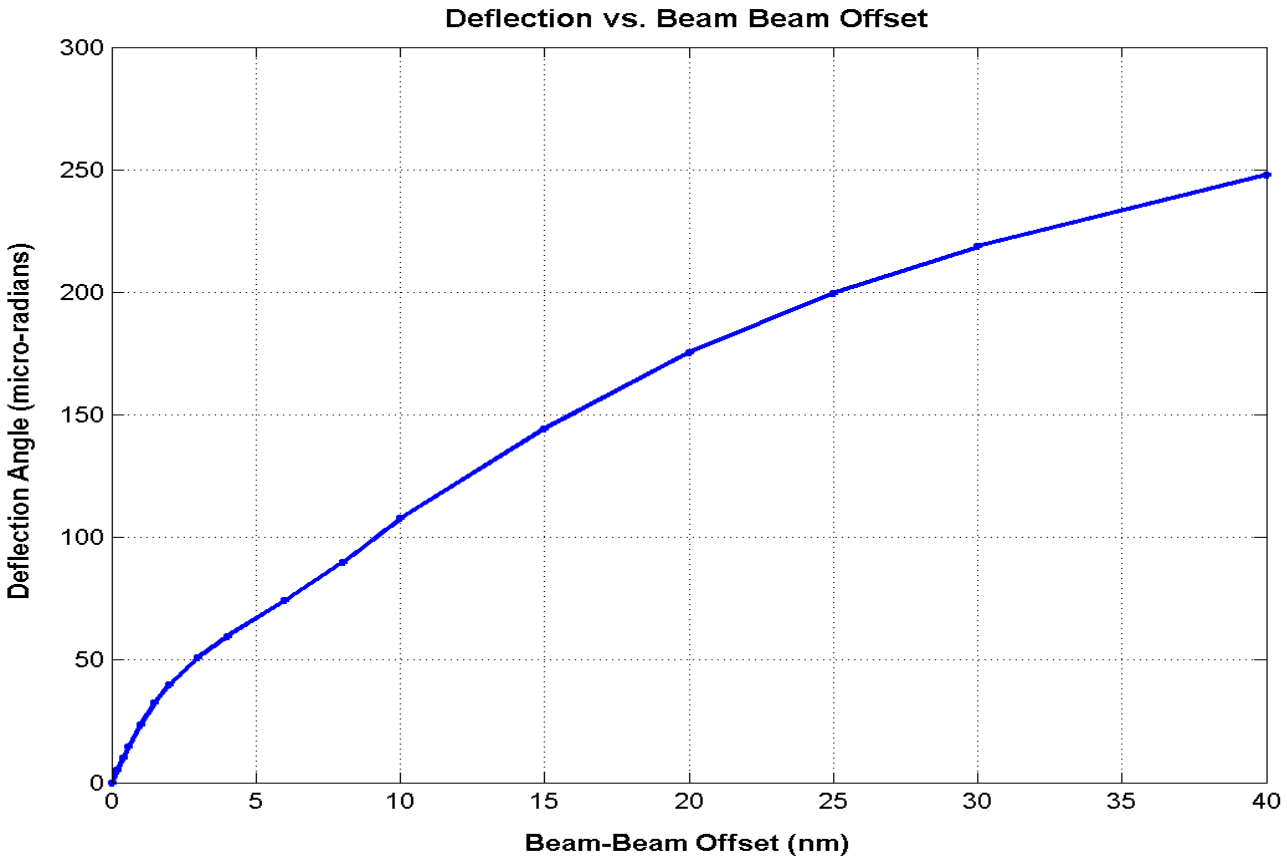
Intra-pulse Feedback

- Fix interaction point jitter within the crossing time of a single bunch train (266 ns)
- BPM measures beam-beam deflection on outgoing beam
  - Fast (few ns rise time)
  - Precise (micron resolution)
  - Close (~4 meters from IP?)
- Kicker steers incoming beam
  - Close to IP (~4 meters)
  - Close to BPM (minimal cable delay)
  - Fast rise-time amplifier
- Feedback algorithm is complicated by:
  - round-trip propagation delay to interaction point in the feedback loop.
  - transfer function non-linearity

Limits to Beam-Beam Feedback

- Must close loop fast
  - Propagation delays are painful
- Beam-Beam deflection response is non-linear
  - slope flattens within 1 σ
- Linear feedback converges too slowly beyond ~ 10 σ to recover most of lost luminosity.
- May be able to fix misalignments of 100 nm with modest kicker amplifiers.
- Amplifier power goes like square of misalignment.

Non-linear Response Challenges Feedback



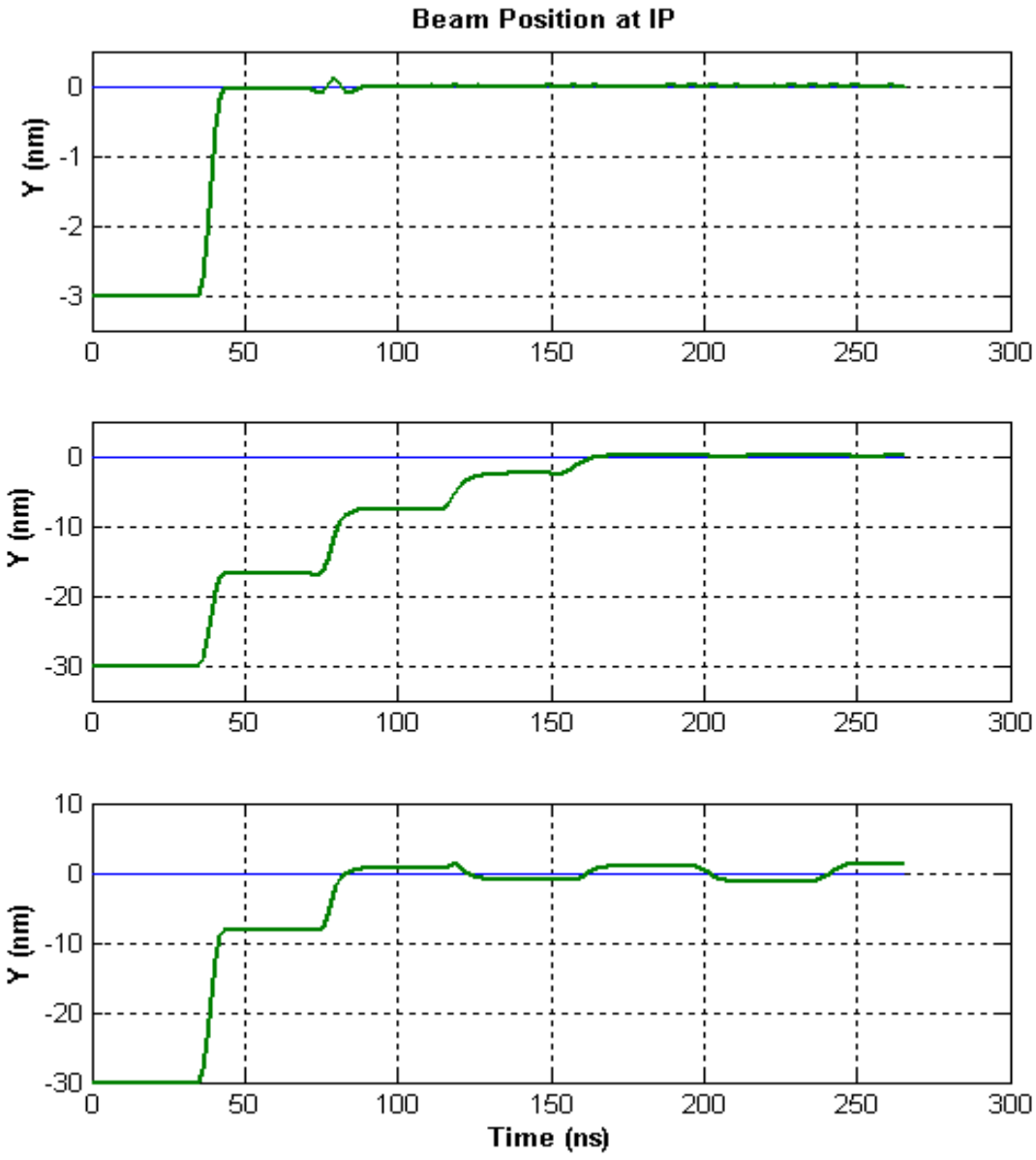
- Beam-beam deflection non-linearity limits:
  - Limits useful (timely) range of convergence
  - Limits stability in collision

Non-linear Response Challenges Feedback

Optimize gain for small initial offset:

Then convergence is poor from far out:

Set gain for good convergence, then high gain at origin causes oscillation when near center:



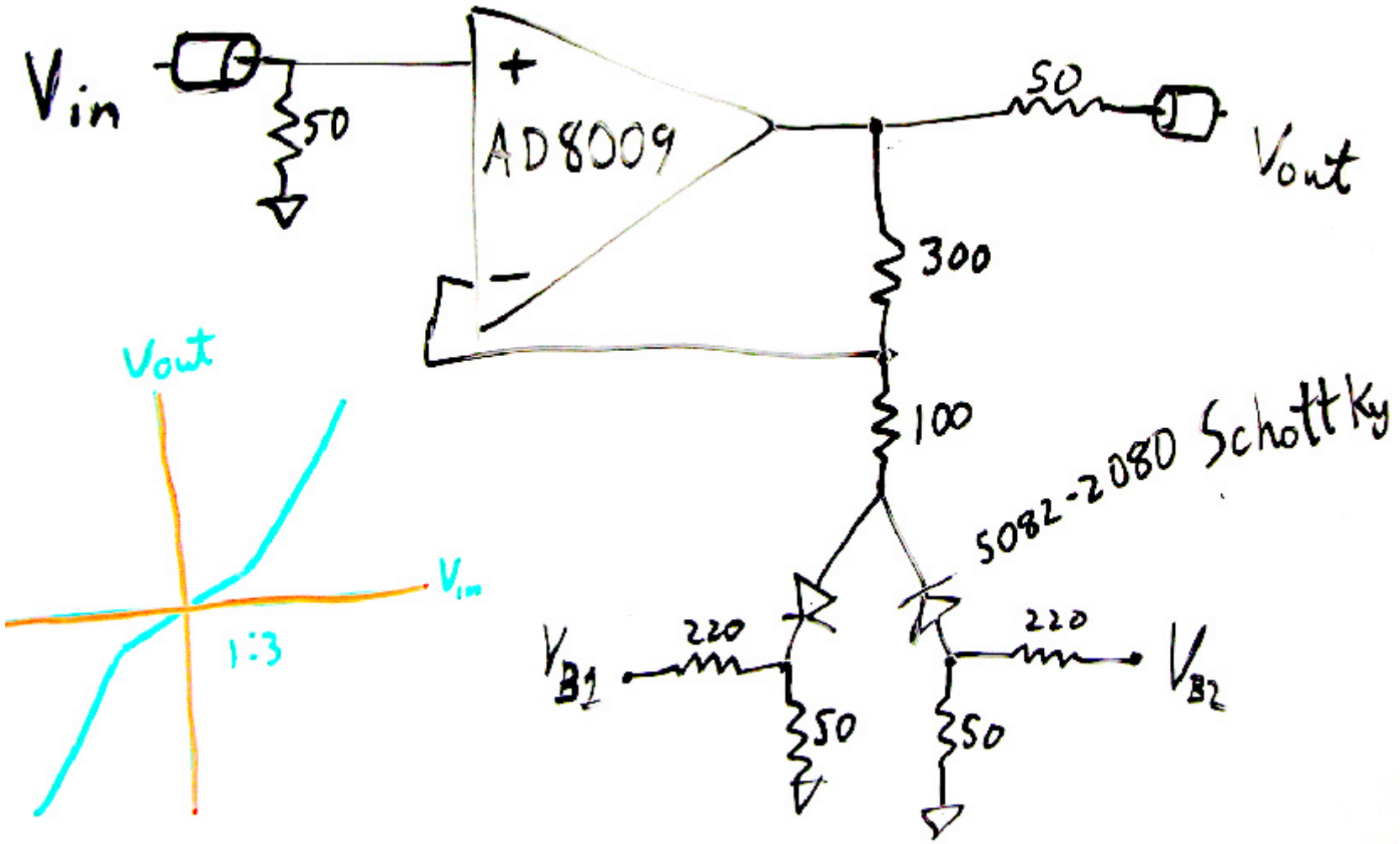
Linearize Feedback

- Can we compensate non-linearity?
  - Fast?
    - Bandwidth
    - propagation delay
  - Accurately?

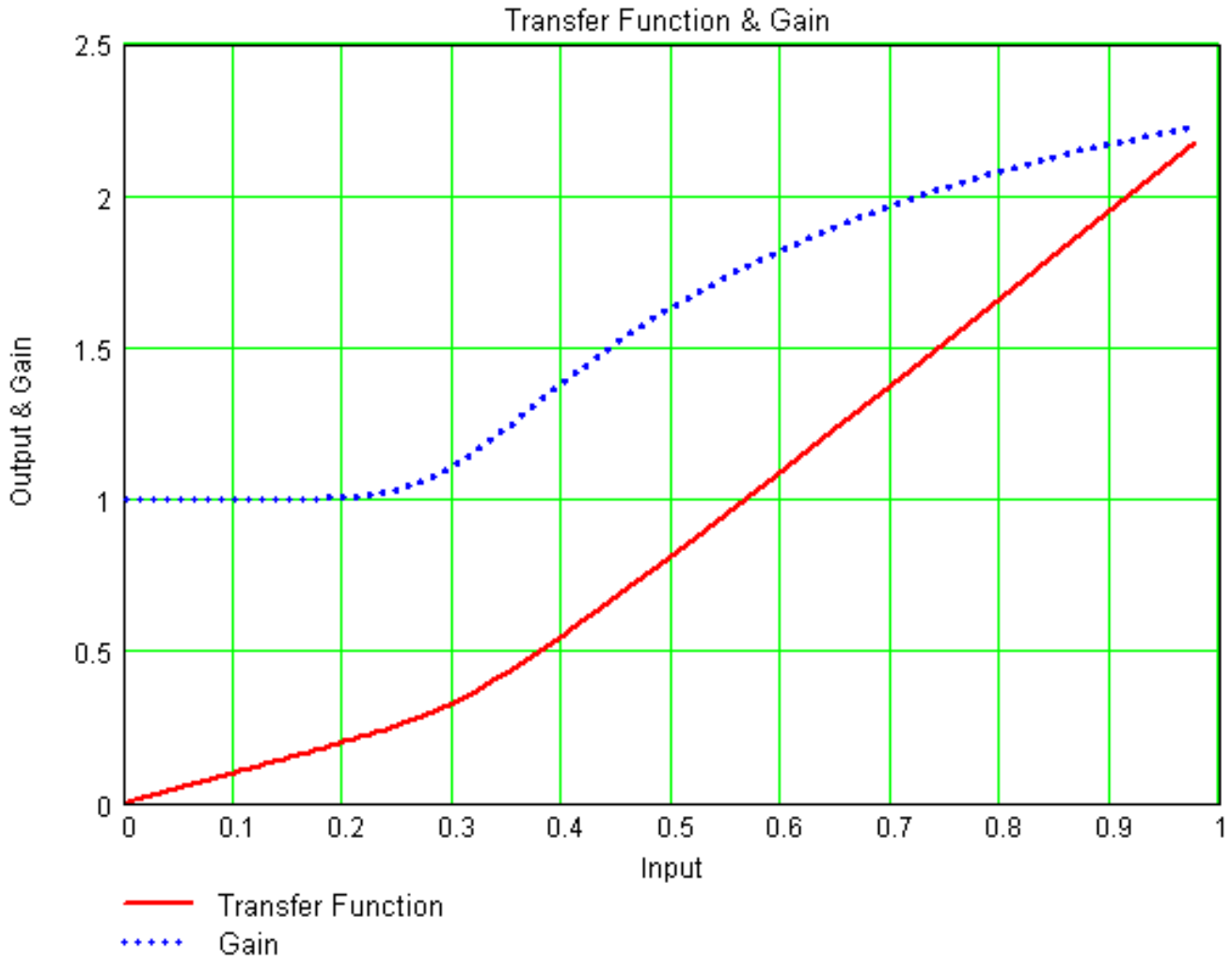
- Yes!

- Compensation Amplifier
  - Op-amp
  - Diodes
  - Bias adjust (knee or breakpoint)

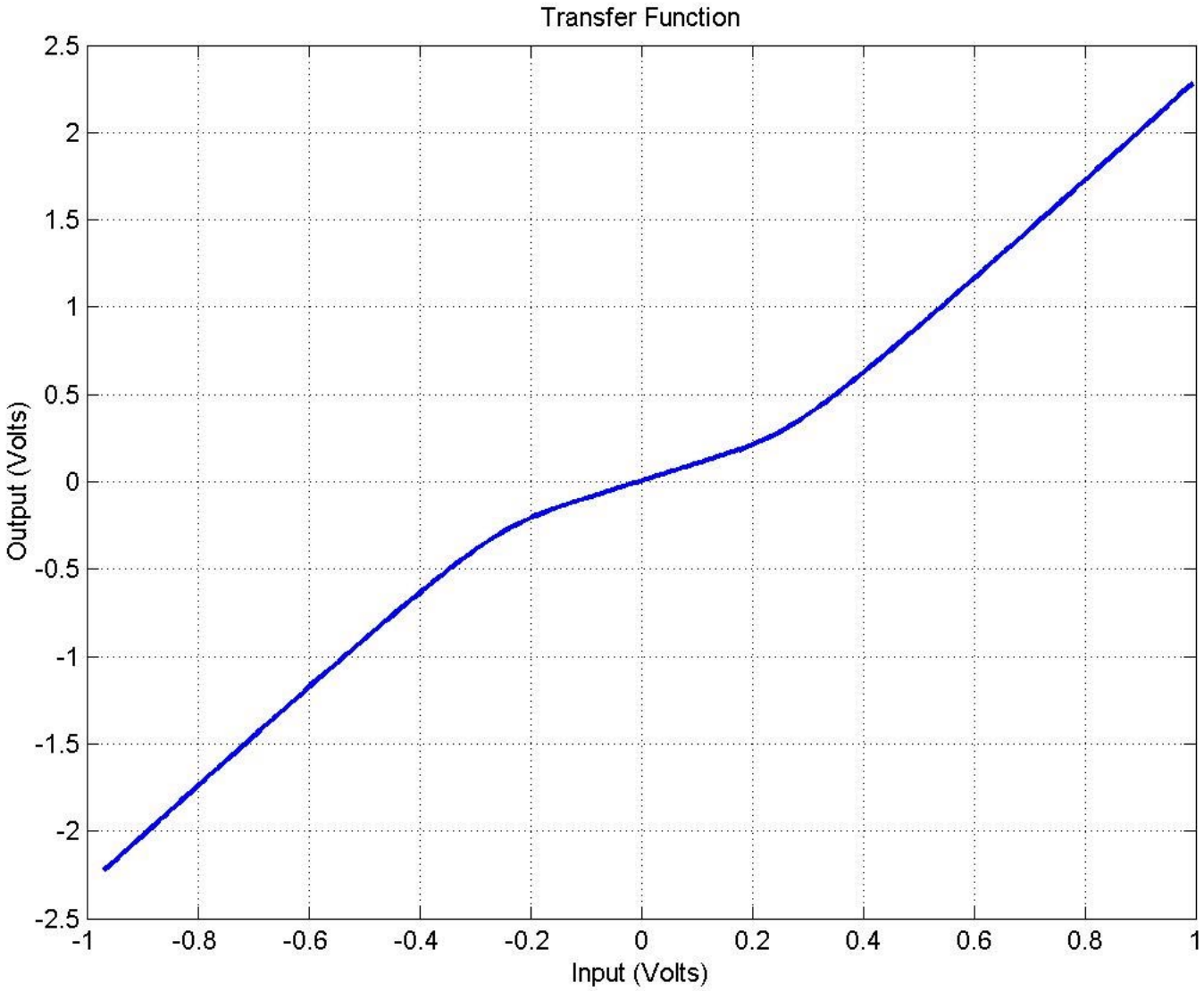
Schematic


Vin
50
AD8009
+
−
50
Vout
300
100
5082-2080 Schottky
220
220
VB1
VB2
50
50
Vout
Vin
1:3

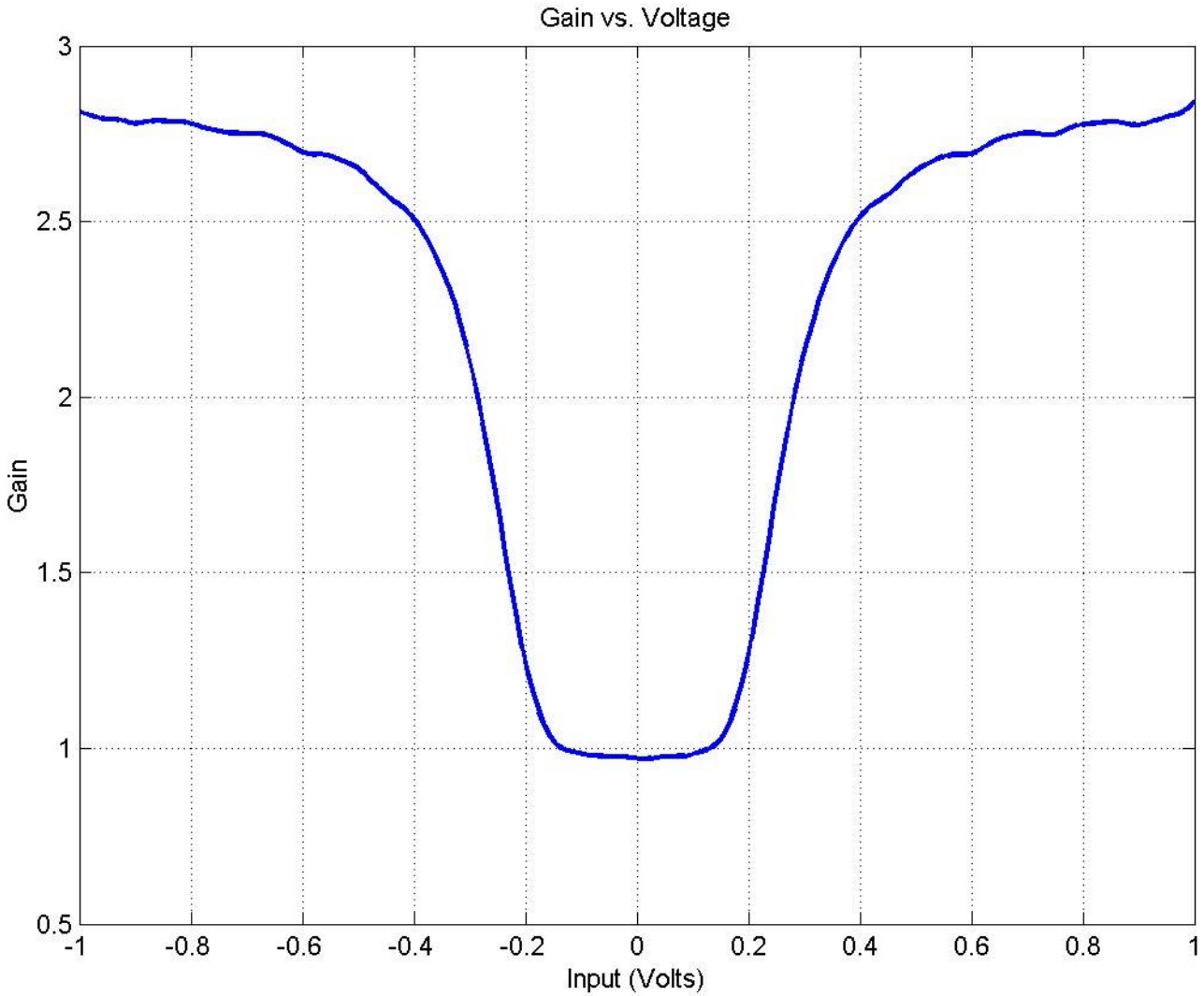
Model

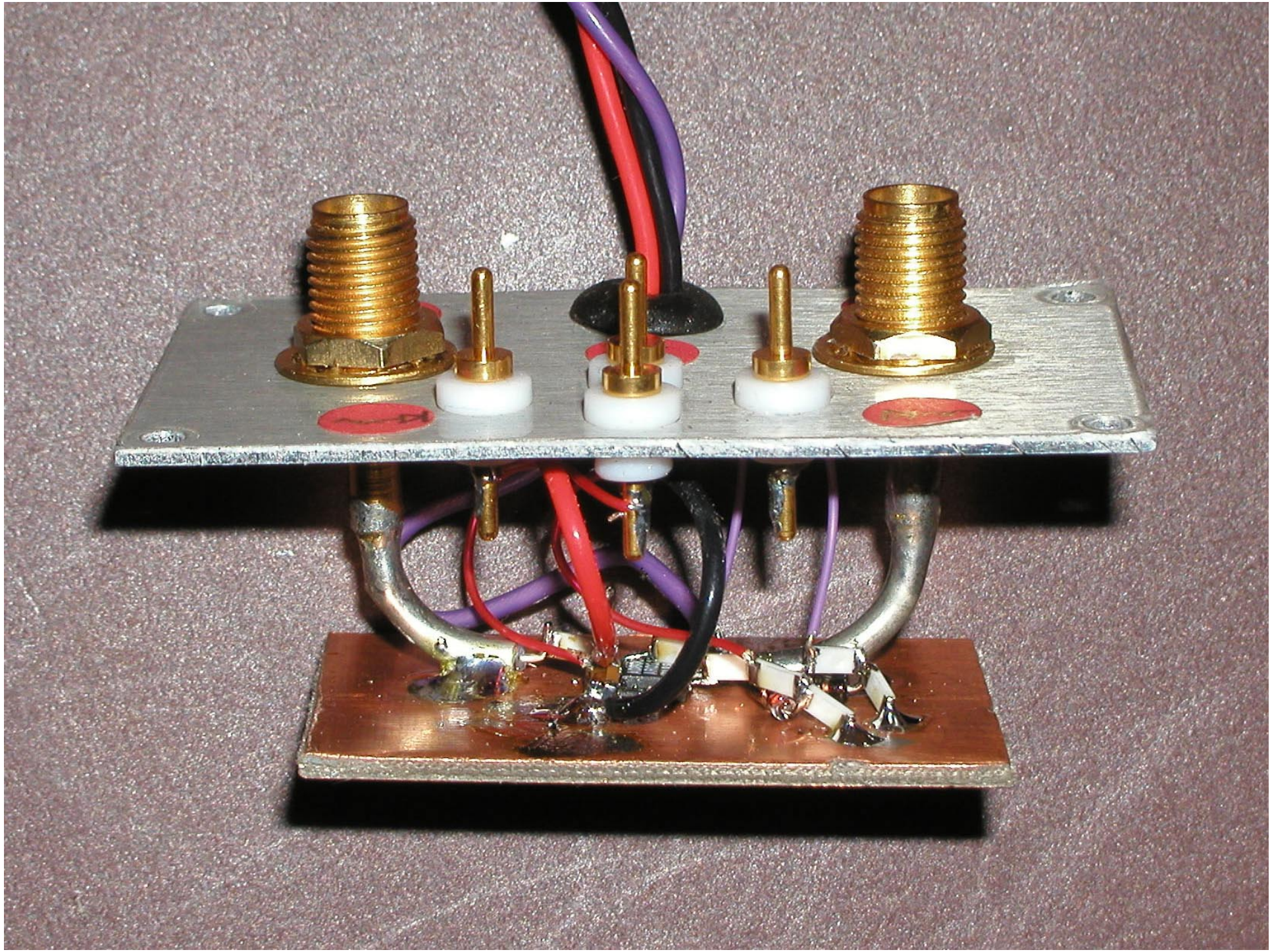

Transfer Function & Gain
Output & Gain
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Input
Transfer Function
Gain

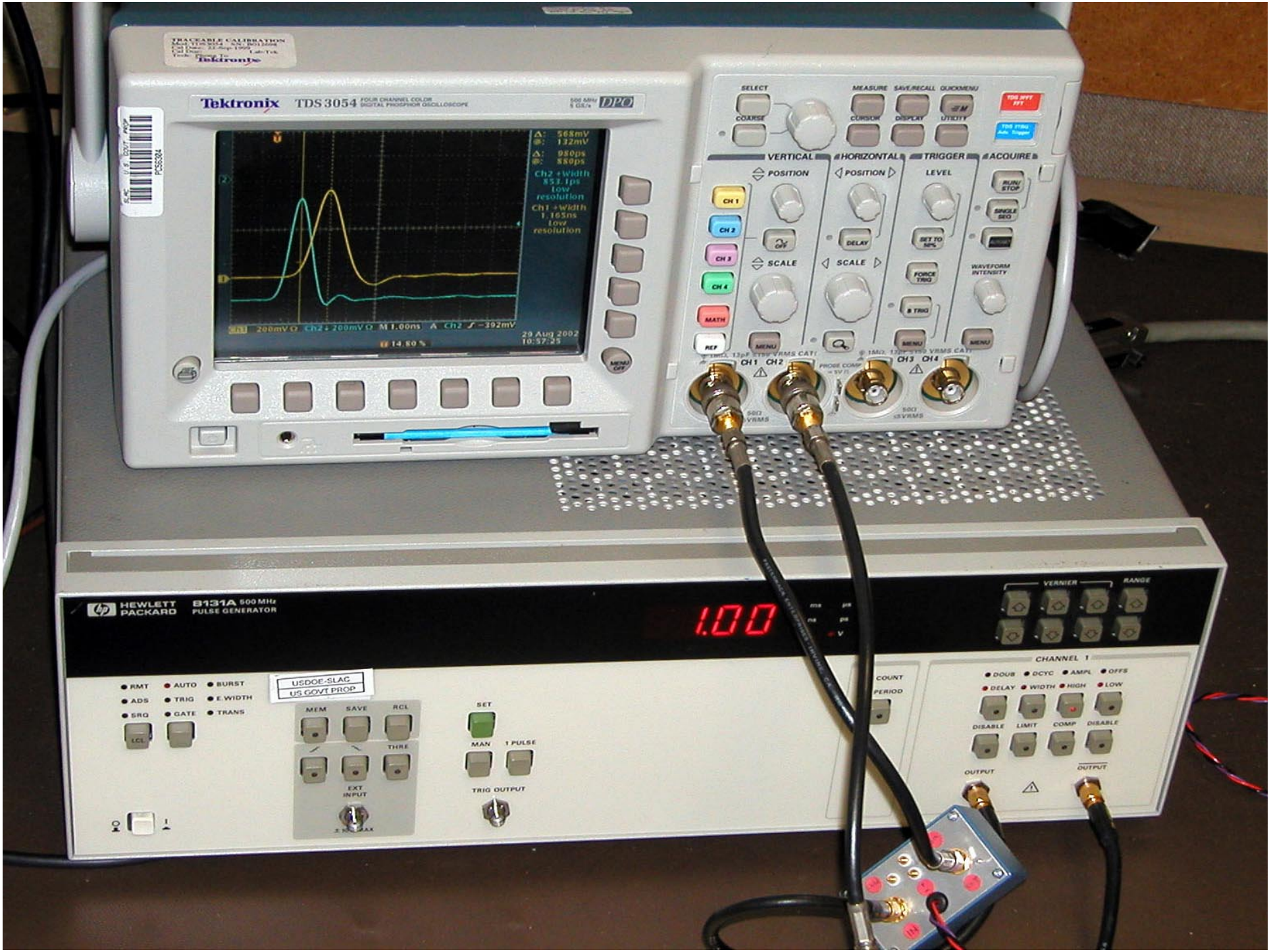
Measured Transfer Function



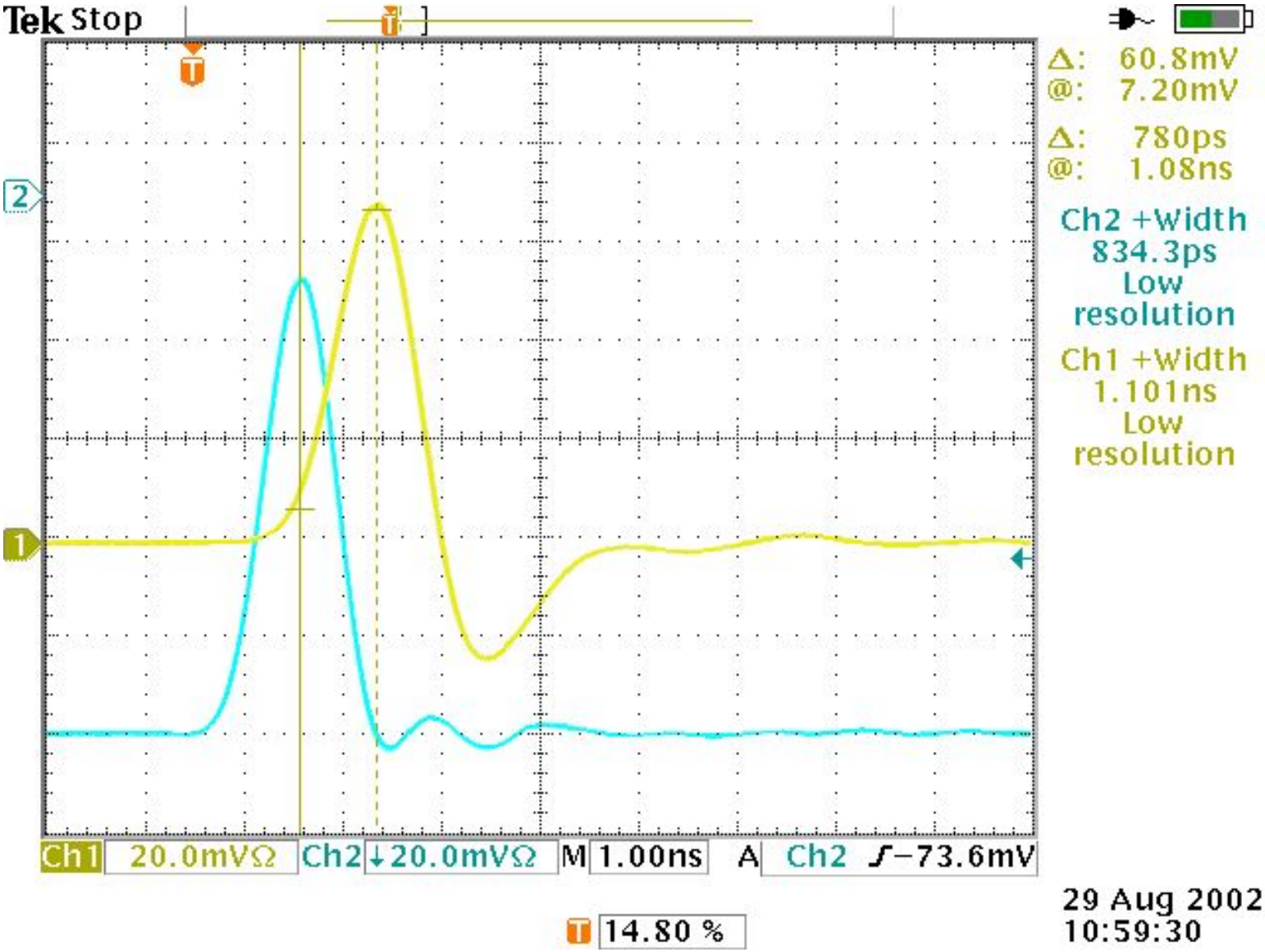
Differential Gain vs. Amplitude



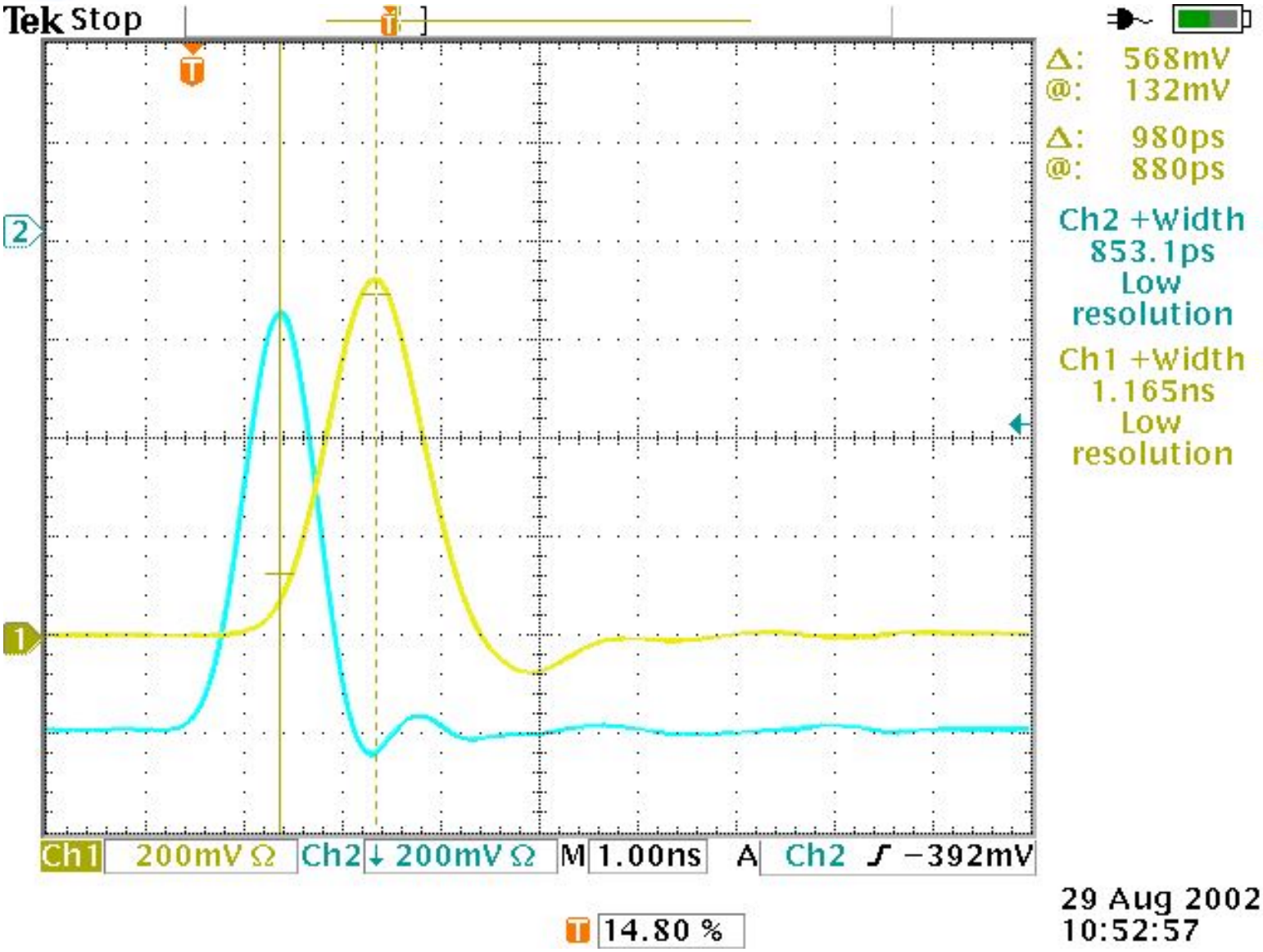



Tektronix TDS 3054 FOUR CHANNEL COLOR DIGITAL PHOSPHOR OSCILLOSCOPE
DPO
SELECT
MEASURE
SAVE/RECALL
QUICKMENU
VERTICAL
HORIZONTAL
TRIGGER
ACQUIRE
POSITION
SCALE
LEVEL
CH 1
CH 2
CH 3
CH 4
MATH
REF
MENU
RUN/STOP
SINGLE SEQ
WAVEFORM INTENSITY
Ch2 +Width
853.1ps
Low resolution
Ch1 +Width
1.165ns
Low resolution
29 Aug 2002
10:57:25
HEWLETT PACKARD
8131A 500 MHz
PULSE GENERATOR
1.00
VERNIER
RANGE
CHANNEL 1
RMT
ADS
SRQ
AUTO
TRIG
GATE
BURST
E.WIDTH
TRANS
USDOE-SLAC
US GOVT PROP
MEM
SAVE
RCL
THRE
EXT INPUT
SET
MAN
1 PULSE
TRIG OUTPUT
COUNT
PERIOD
DOUB
DCYC
AMPL
OFFS
DELAY
WIDTH
HIGH
LOW
DISABLE
LIMIT
COMP
OUTPUT

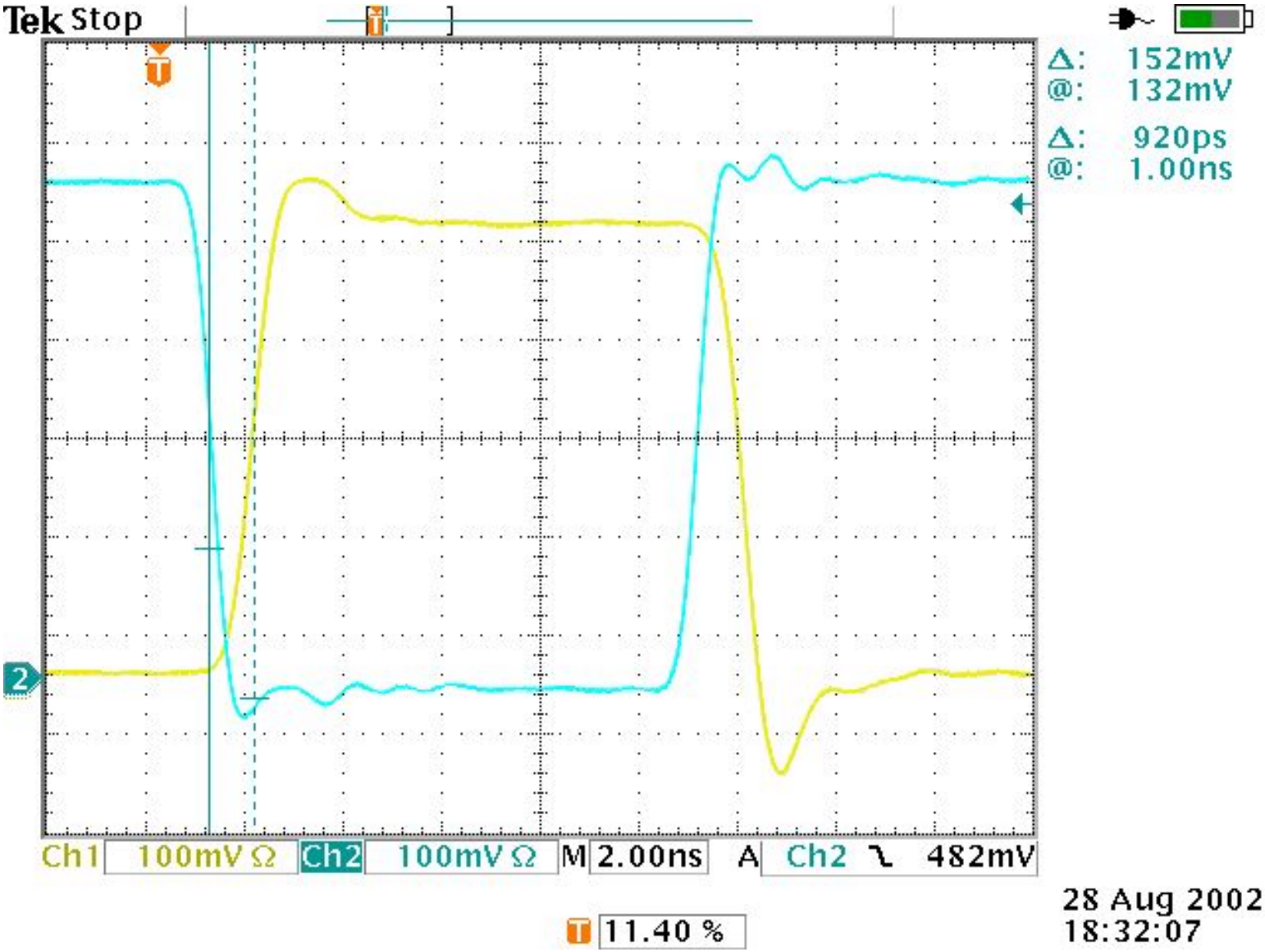
Small-Signal Impulse Response



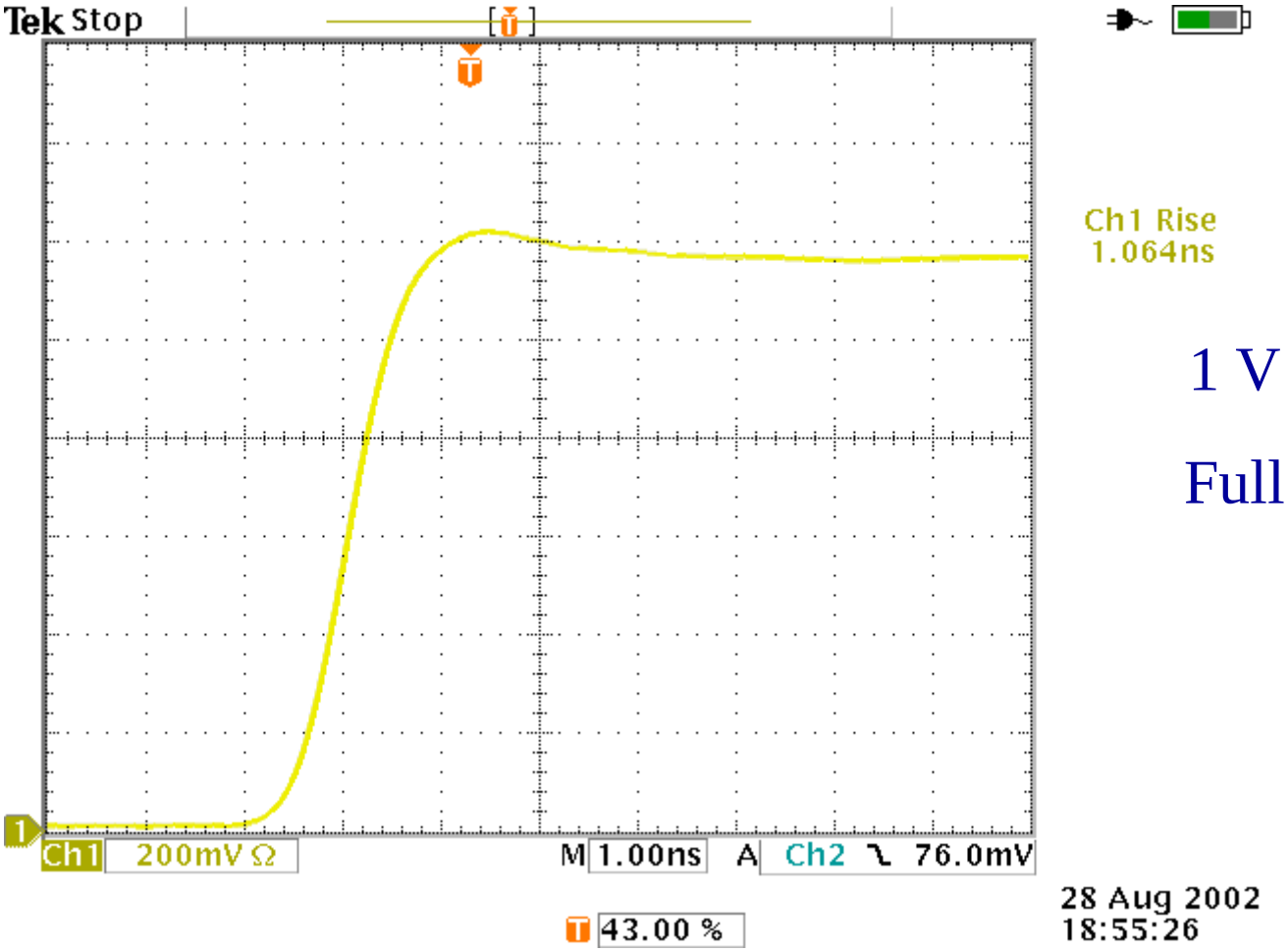
Large Signal Impulse Response



Propagation Delay



Large Signal Waveform

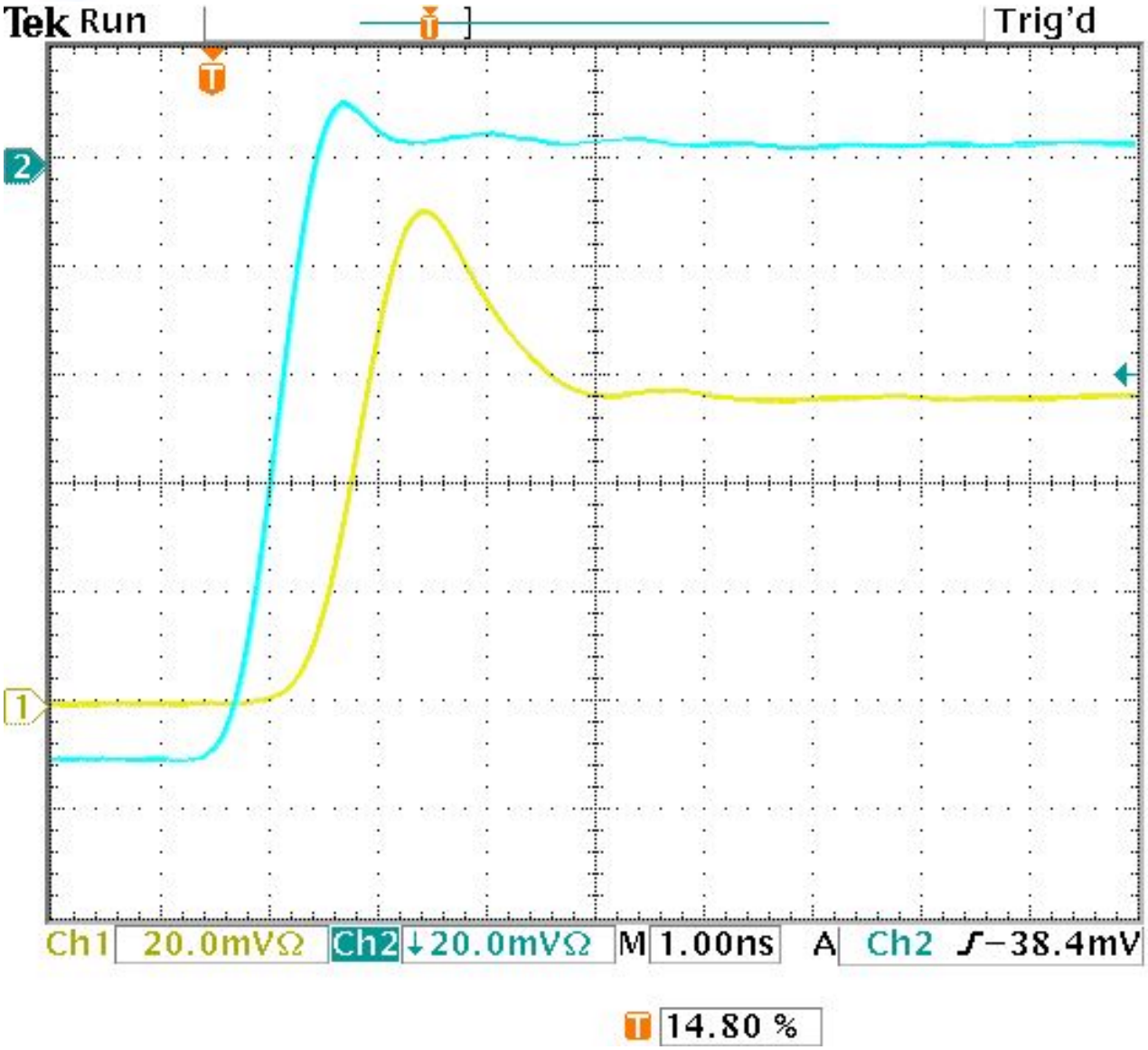


1 V step

Full BW

Settles to DC response in several ns

Small-Signal Waveform

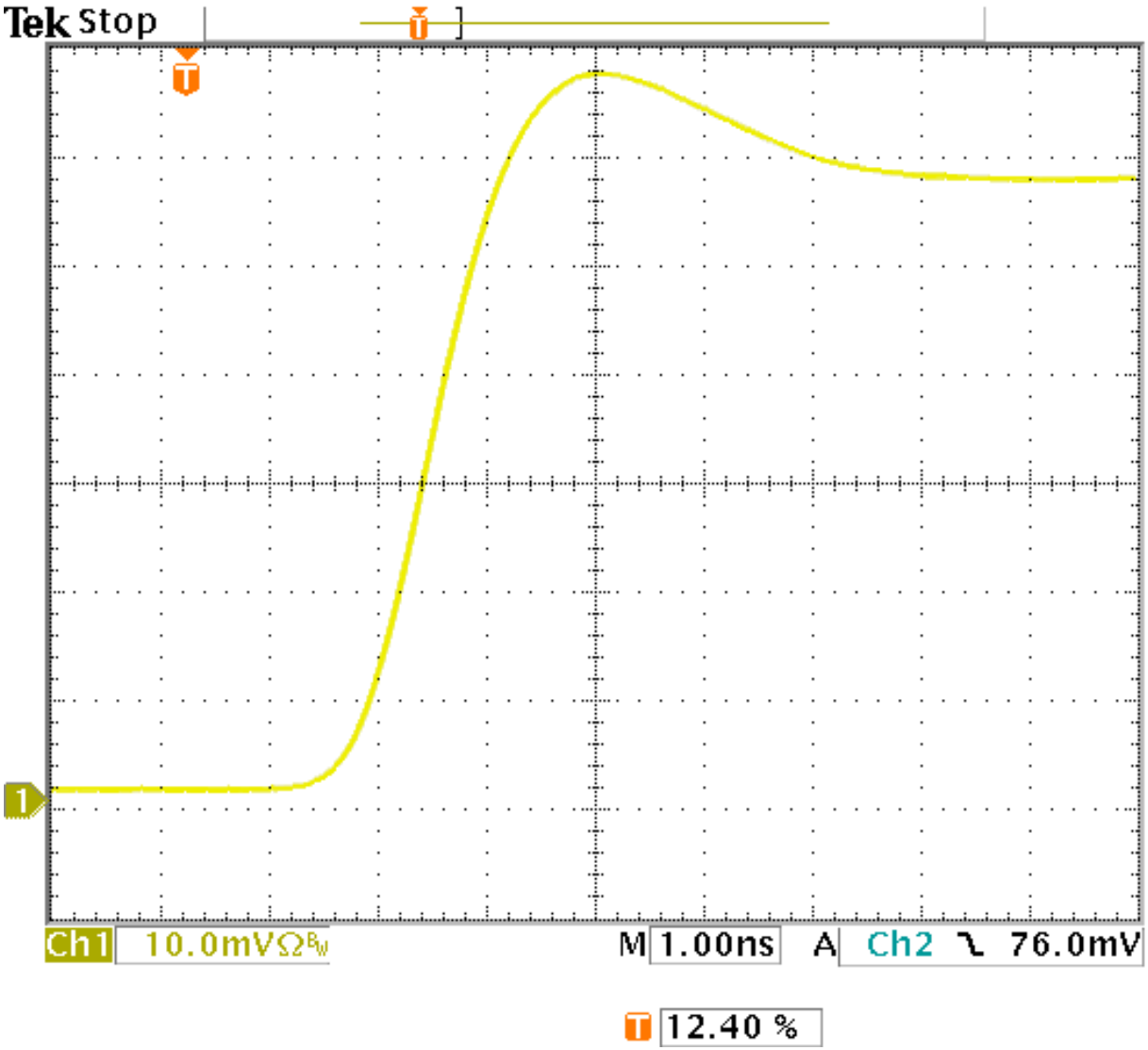


10 mV step

Full BW

~500 MHz

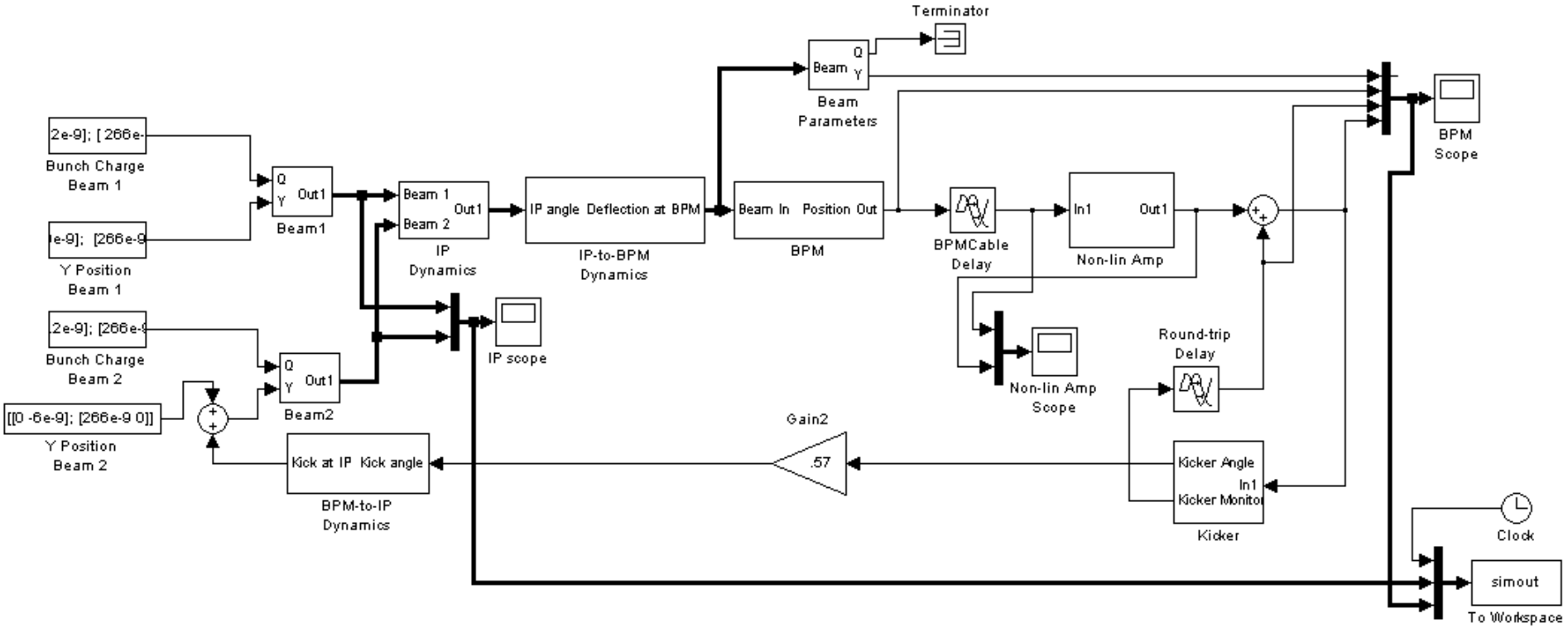
Small-Signal Limited Bandwidth



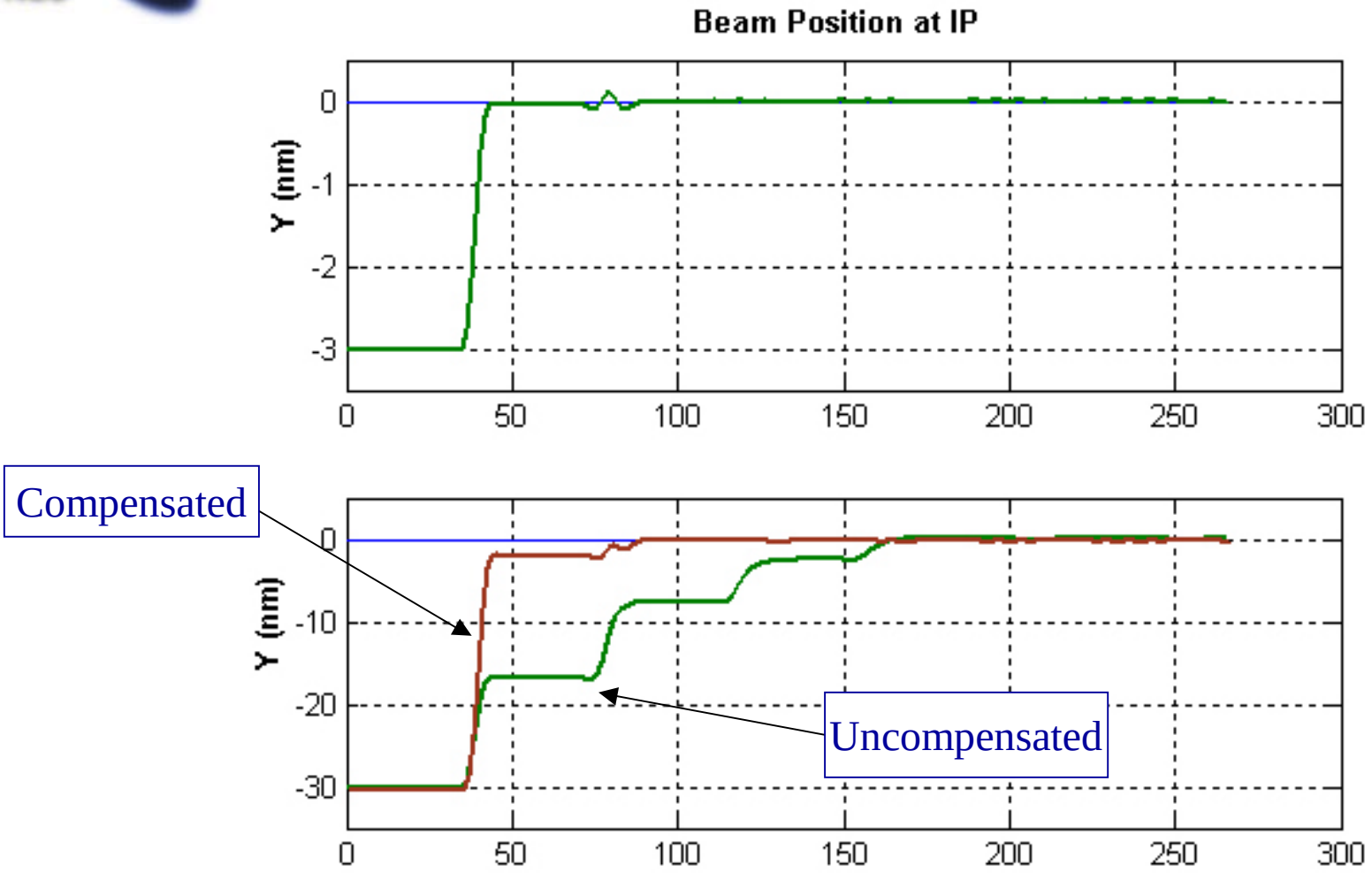
10 mV step

150 MHz BW

Simulink Model



Non-Linear Feedback Simulation



Full luminosity recovered in one round-trip time

for 10 σ initial offset.

Conclusions

- Simple op-amp based non-linear amp is sufficient to improve:
  - Stability
  - Convergence speed ⇔ capture range
  - Programmable linearity compensation
- Low propagation delay: ~ 1 ns
- High bandwidth > 200 MHz
- Sufficient to achieve:
  - Single round-trip convergence to $< 1\ \sigma$ from $10\ \sigma$ initial offset.
  - Two-cycle convergence to $< 0.1\ \sigma$ from $10\ \sigma$ initial offset.
    - Limited by dynamic range of present op-amp,
    - not by accuracy of compensation
      - Fix with another amplifier
      - Or diode bias
- Breadboard prototype slightly peaky for small signals
  - Likely to be fixed with chip diodes in real layout
  - Ideally would make large signal response as peaky as small-signal response
  - (to compensate kicker fill time)