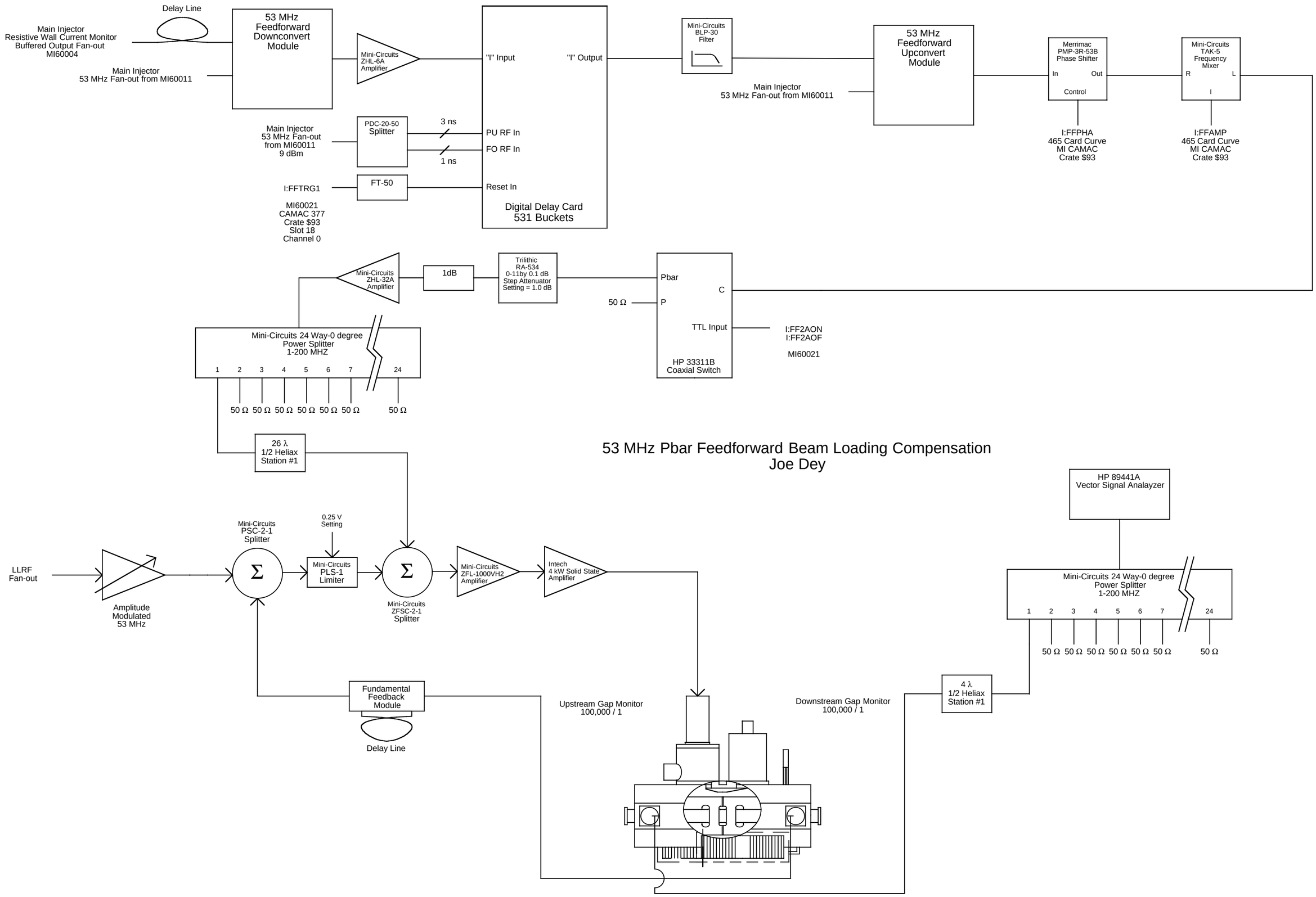
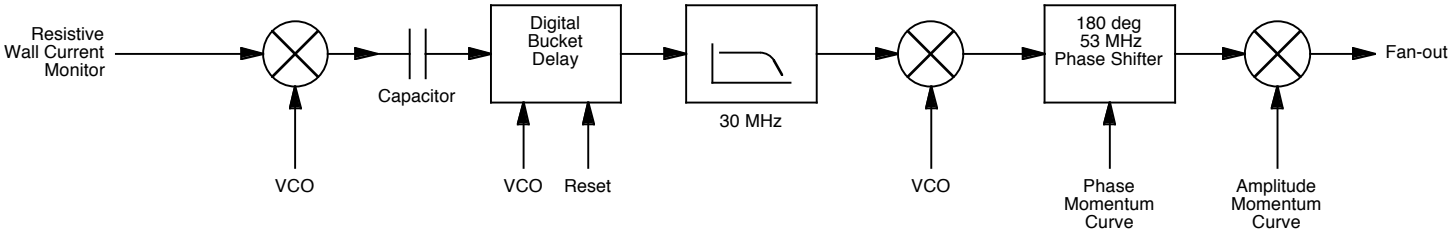
53 MHz
Beam Loading Compensation

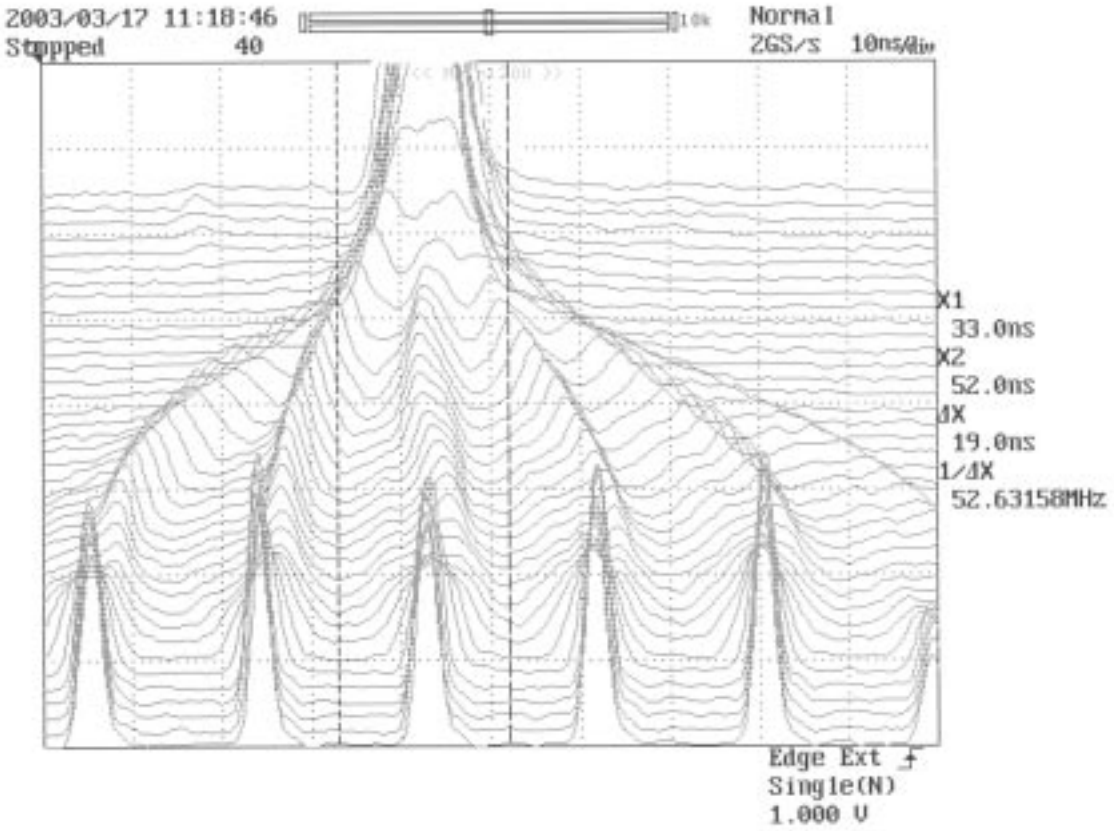
Joe Dey
Ioanis Kourbanis
John Reid
Jim Steimel

Fermilab

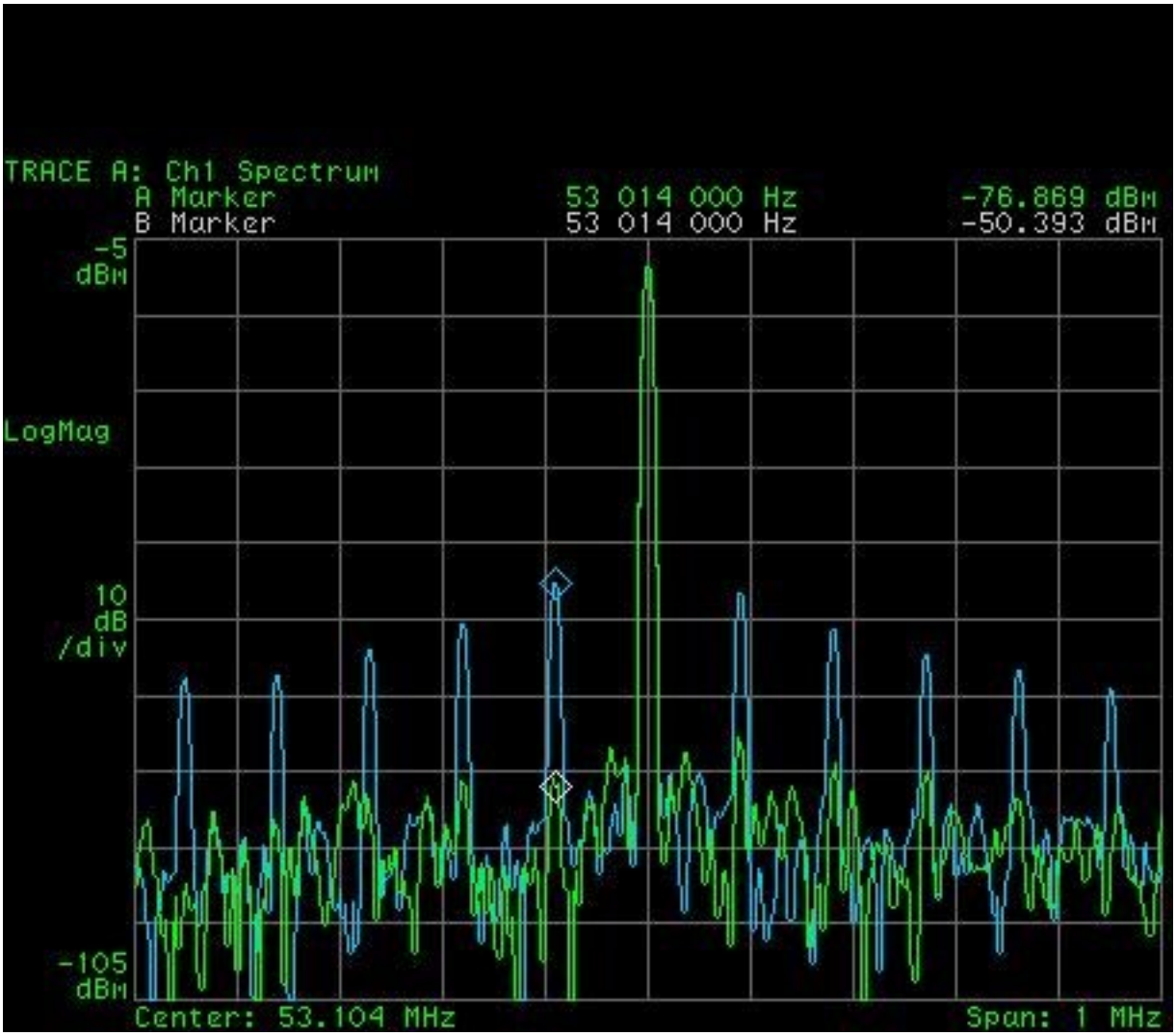

Delay Line
Main Injector
Resistive Wall Current Monitor
Buffered Output Fan-out
MI60004
Main Injector
53 MHz Fan-out from MI60011
53 MHz
Feedforward
Downconvert
Module
Mini-Circuits
ZHL-6A
Amplifier
"I" Input
"I" Output
Mini-Circuits
BLP-30
Filter
53 MHz
Feedforward
Upconvert
Module
Main Injector
53 MHz Fan-out from MI60011
Merrimac
PMP-3R-53B
Phase Shifter
In
Out
Control
Mini-Circuits
TAK-5
Frequency
Mixer
R
L
I
I:FFPHA
465 Card Curve
MI CAMAC
Crate $93
I:FFAMP
465 Card Curve
MI CAMAC
Crate $93
Main Injector
53 MHz Fan-out
from MI60011
9 dBm
PDC-20-50
Splitter
3 ns
1 ns
PU RF In
FO RF In
I:FFTRG1
FT-50
Reset In
MI60021
CAMAC 377
Crate $93
Slot 18
Channel 0
Digital Delay Card
531 Buckets
Mini-Circuits
ZHL-32A
Amplifier
1dB
Trilithic
RA-534
0-11by 0.1 dB
Step Attenuator
Setting = 1.0 dB
Pbar
C
50 Ω
P
TTL Input
HP 33311B
Coaxial Switch
I:FF2AON
I:FF2AOF
MI60021
Mini-Circuits 24 Way-0 degree
Power Splitter
1-200 MHZ
1 2 3 4 5 6 7 24
50 Ω 50 Ω 50 Ω 50 Ω 50 Ω 50 Ω 50 Ω
26 λ
1/2 Heliax
Station #1
53 MHz Pbar Feedforward Beam Loading Compensation
Joe Dey
HP 89441A
Vector Signal Analayzer
LLRF
Fan-out
Amplitude
Modulated
53 MHz
Mini-Circuits
PSC-2-1
Splitter
0.25 V
Setting
Mini-Circuits
PLS-1
Limiter
Mini-Circuits
ZFSC-2-1
Splitter
Mini-Circuits
ZFL-1000VH2
Amplifier
Intech
4 kW Solid State
Amplifier
Mini-Circuits 24 Way-0 degree
Power Splitter
1-200 MHZ
1 2 3 4 5 6 7 24
50 Ω 50 Ω 50 Ω 50 Ω 50 Ω 50 Ω 50 Ω
Fundamental
Feedback
Module
Delay Line
Upstream Gap Monitor
100,000 / 1
Downstream Gap Monitor
100,000 / 1
4 λ
1/2 Heliax
Station #1

In-Phase

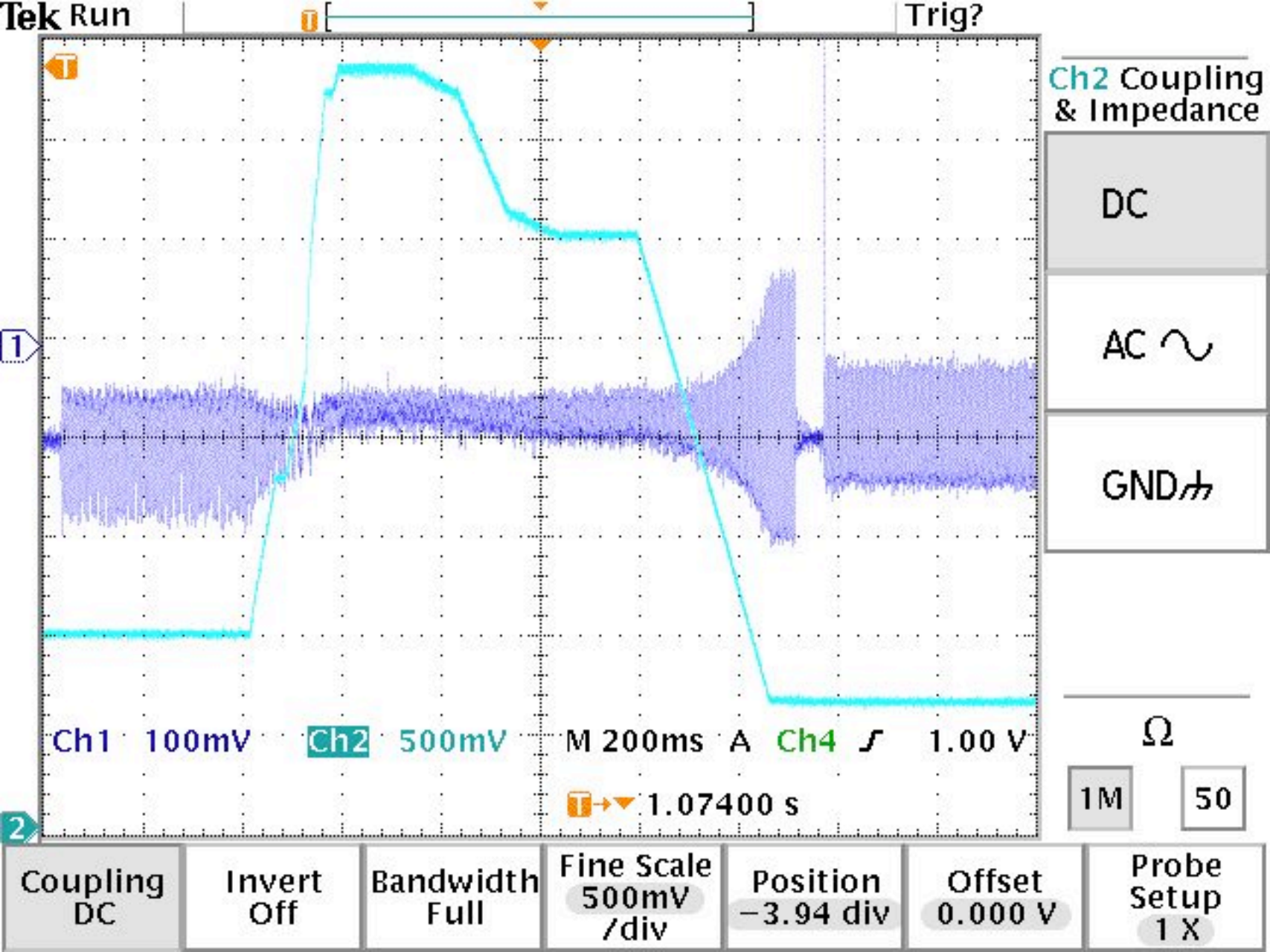

Resistive
Wall Current
Monitor
VCO
Capacitor
Digital
Bucket
Delay
VCO
Reset
30 MHz
VCO
180 deg
53 MHz
Phase Shifter
Phase
Momentum
Curve
Amplitude
Momentum
Curve
Fan-out

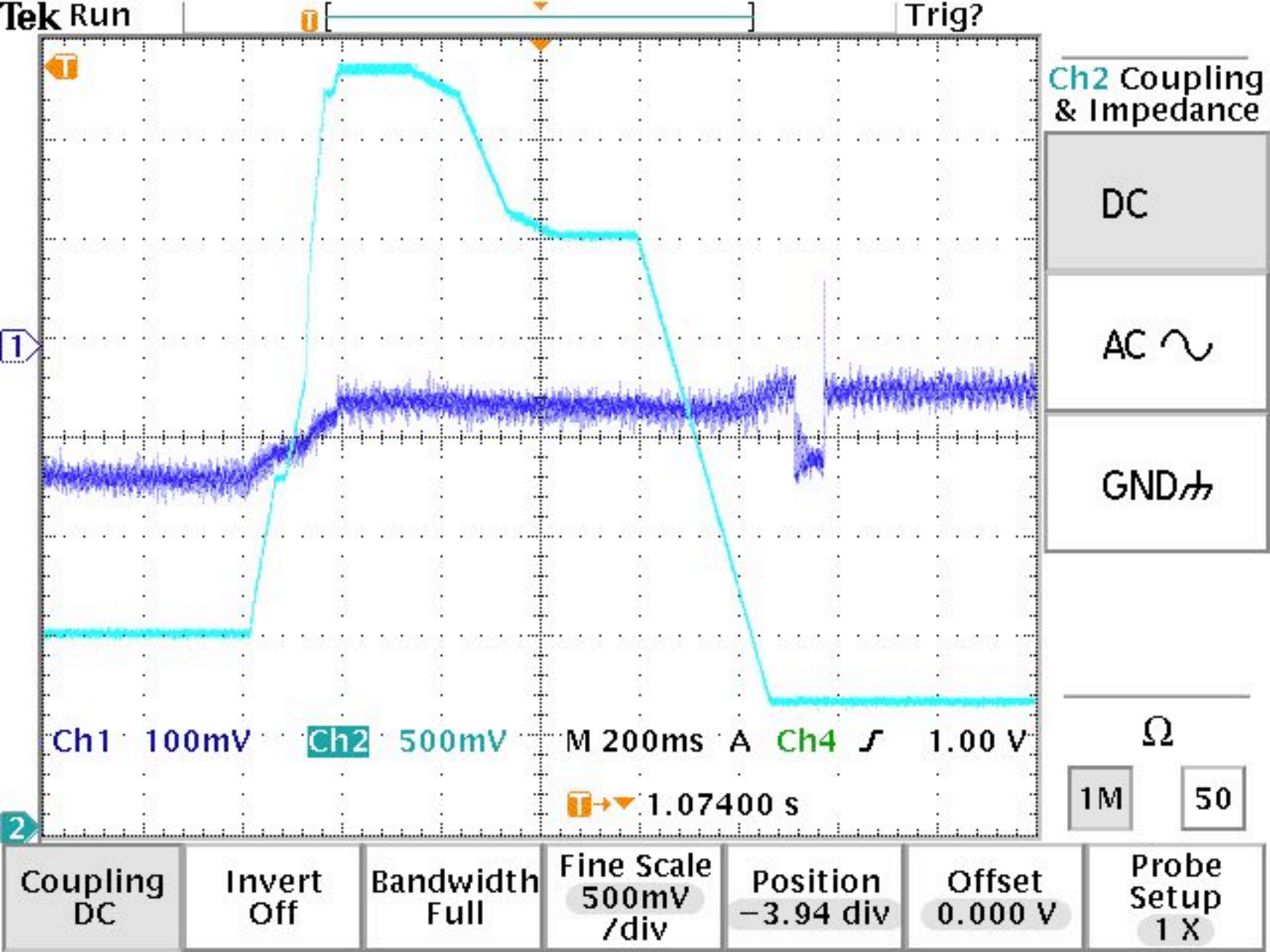


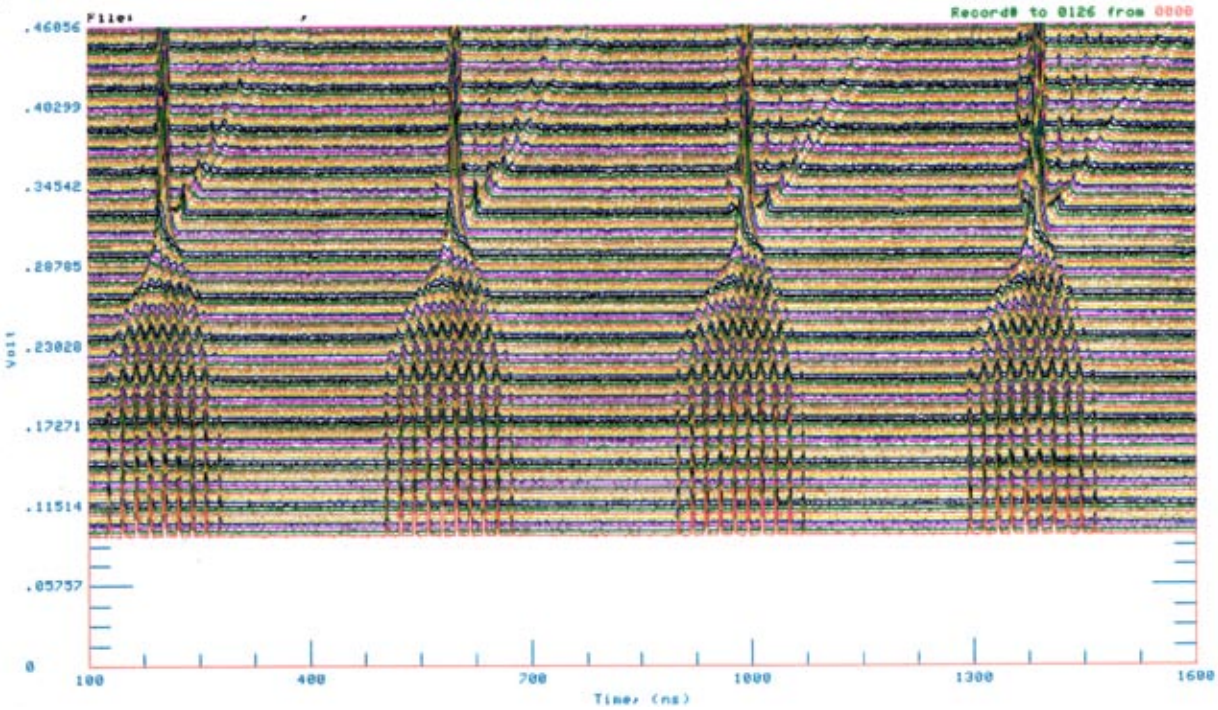
Proton Coalescing of
283E9 Protons



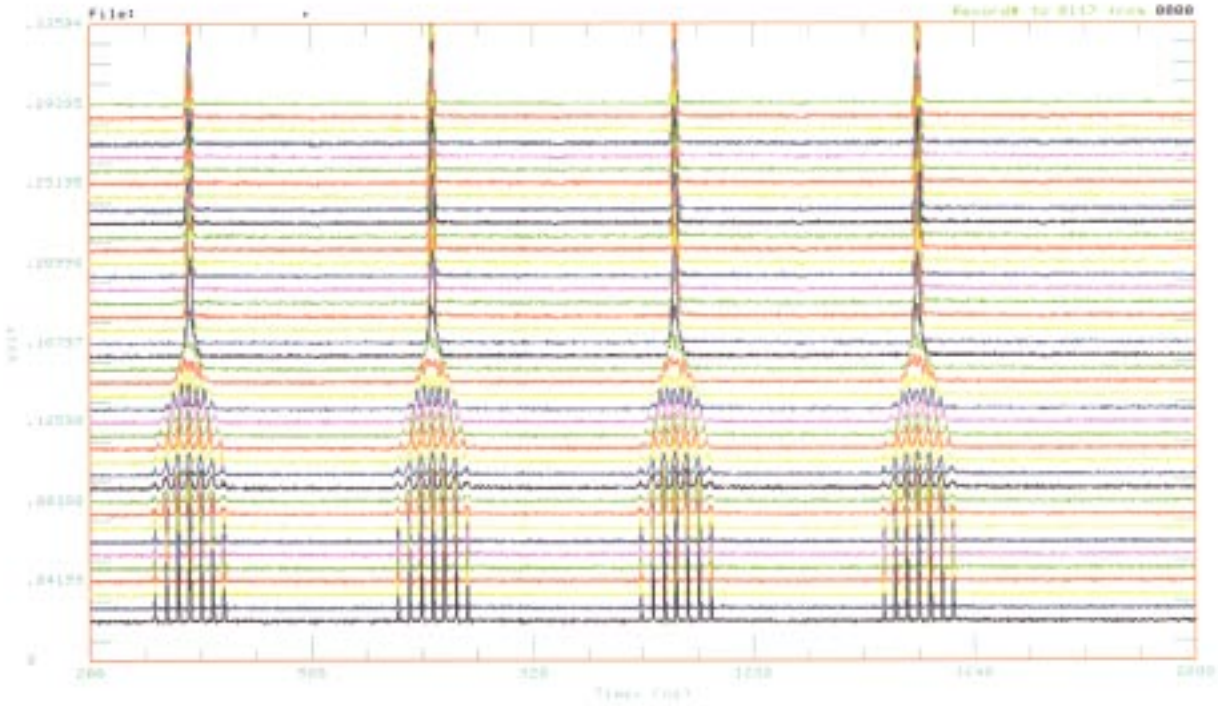
Beam Loading Compensation on Proton Coalescing


Tek Run
Trig?
Ch2 Coupling & Impedance
DC
AC
GND
Ch1 100mV
Ch2 500mV
M 200ms A Ch4 1.00 V
1.07400 s
Ω
1M
50
Coupling DC
Invert Off
Bandwidth Full
Fine Scale 500mV /div
Position −3.94 div
Offset 0.000 V
Probe Setup 1 X

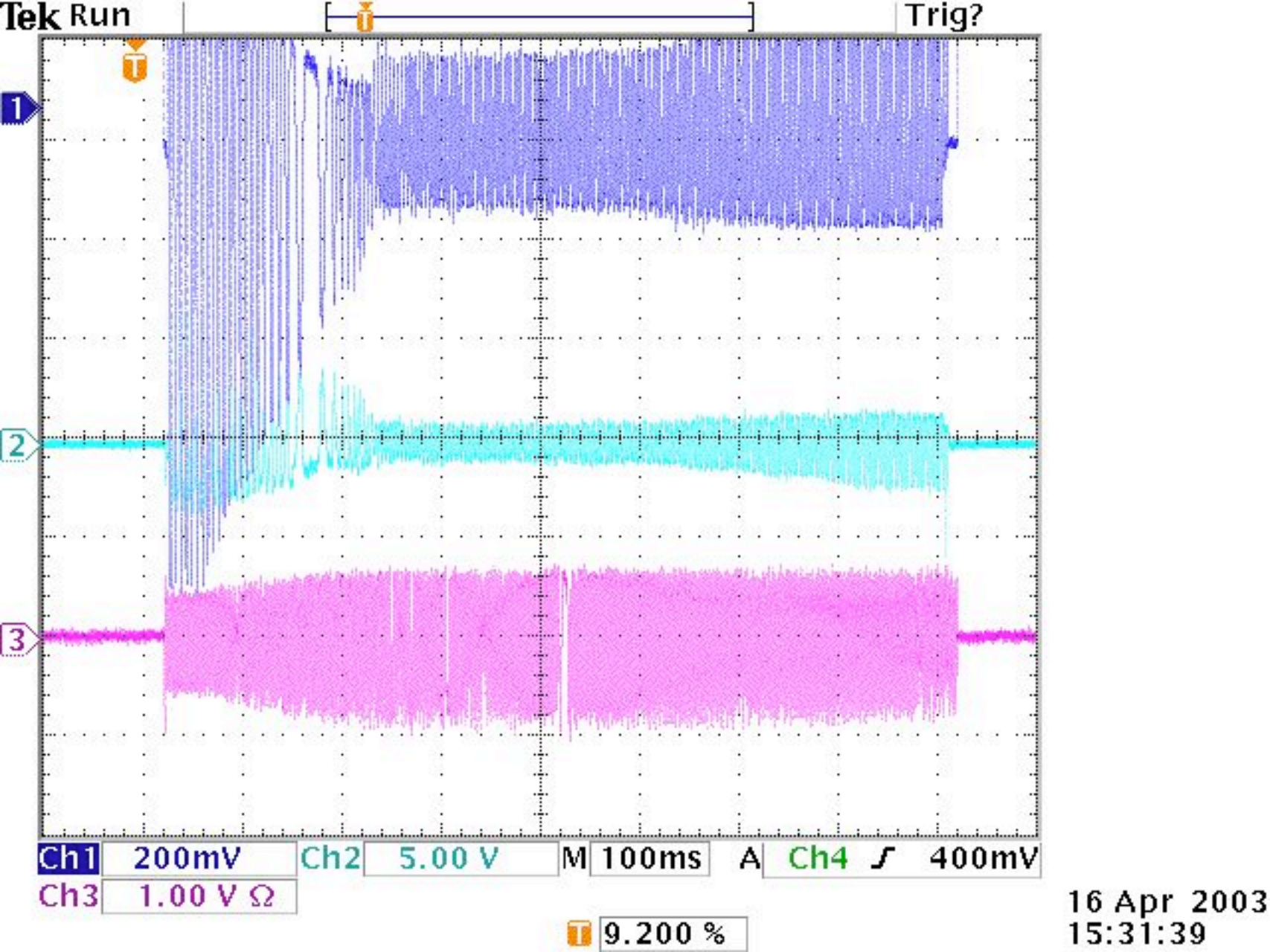

Tek Run
Trig?
Ch2 Coupling & Impedance
DC
AC
GND
Ch1 100mV
Ch2 500mV
M 200ms A Ch4 1.00 V
1.07400 s
Ω
1M
50
Coupling DC
Invert Off
Bandwidth Full
Fine Scale 500mV /div
Position −3.94 div
Offset 0.000 V
Probe Setup 1 X

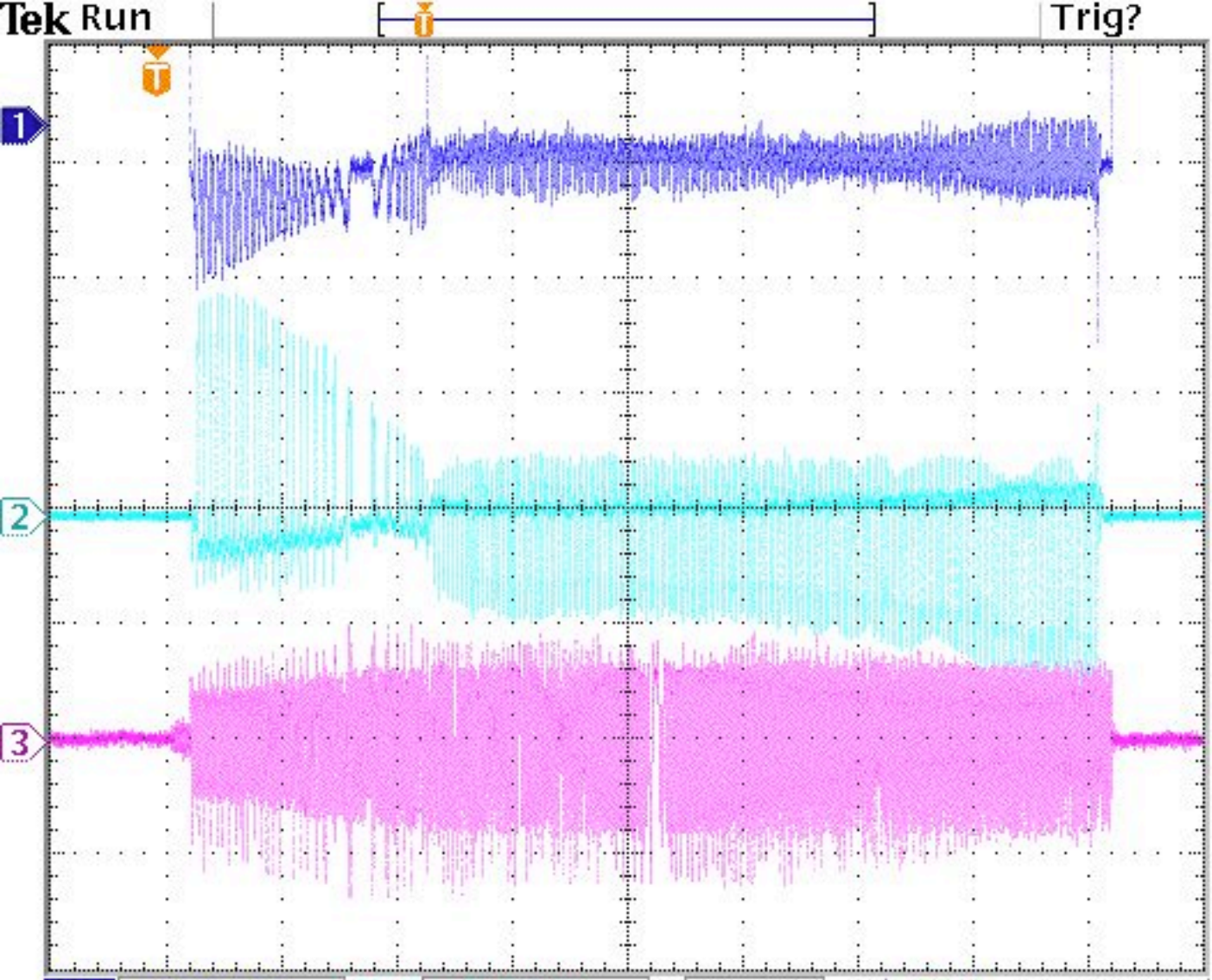


Pbar Coalescing with Feedforward BLC Off



Pbar Coalescing with Feedforward BLC On

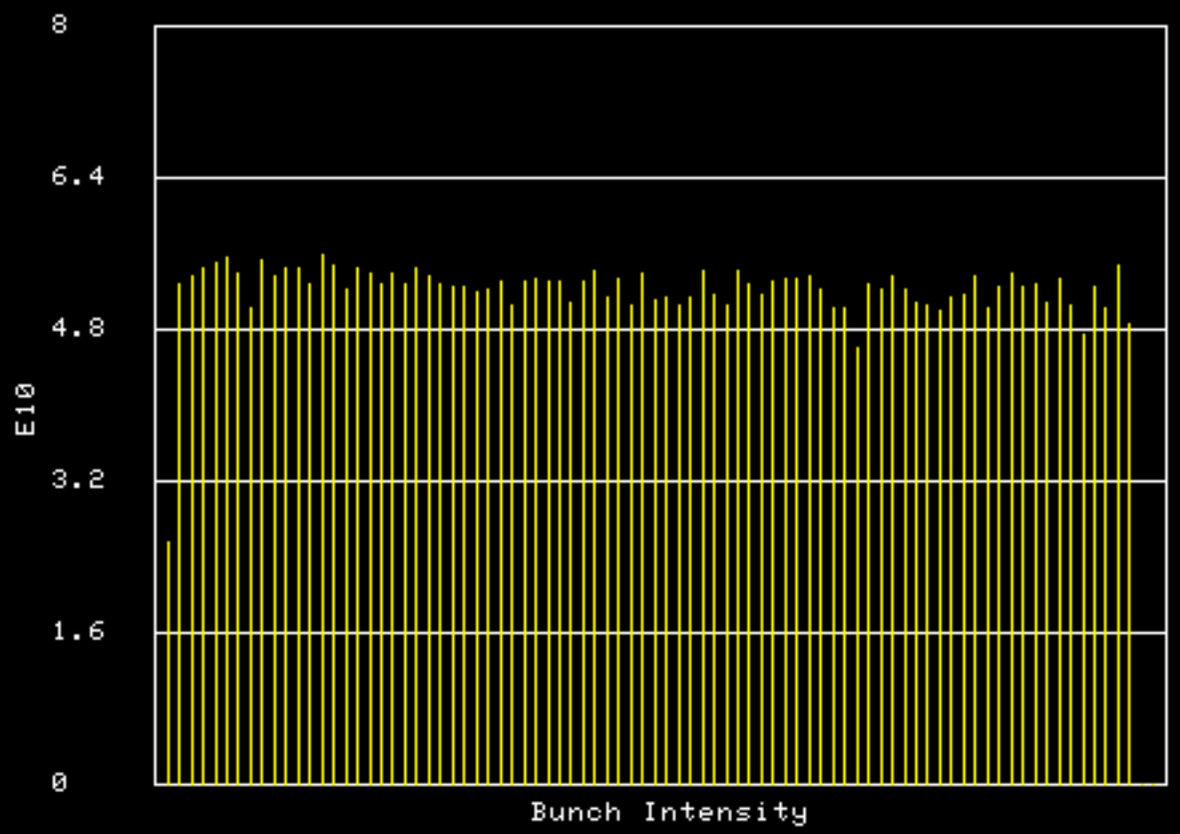

Tek Run
Trig?
Ch1 200mV
Ch2 5.00 V
M 100ms
A Ch4 ∫ 400mV
Ch3 1.00 V Ω
9.200 %
16 Apr 2003
15:31:39

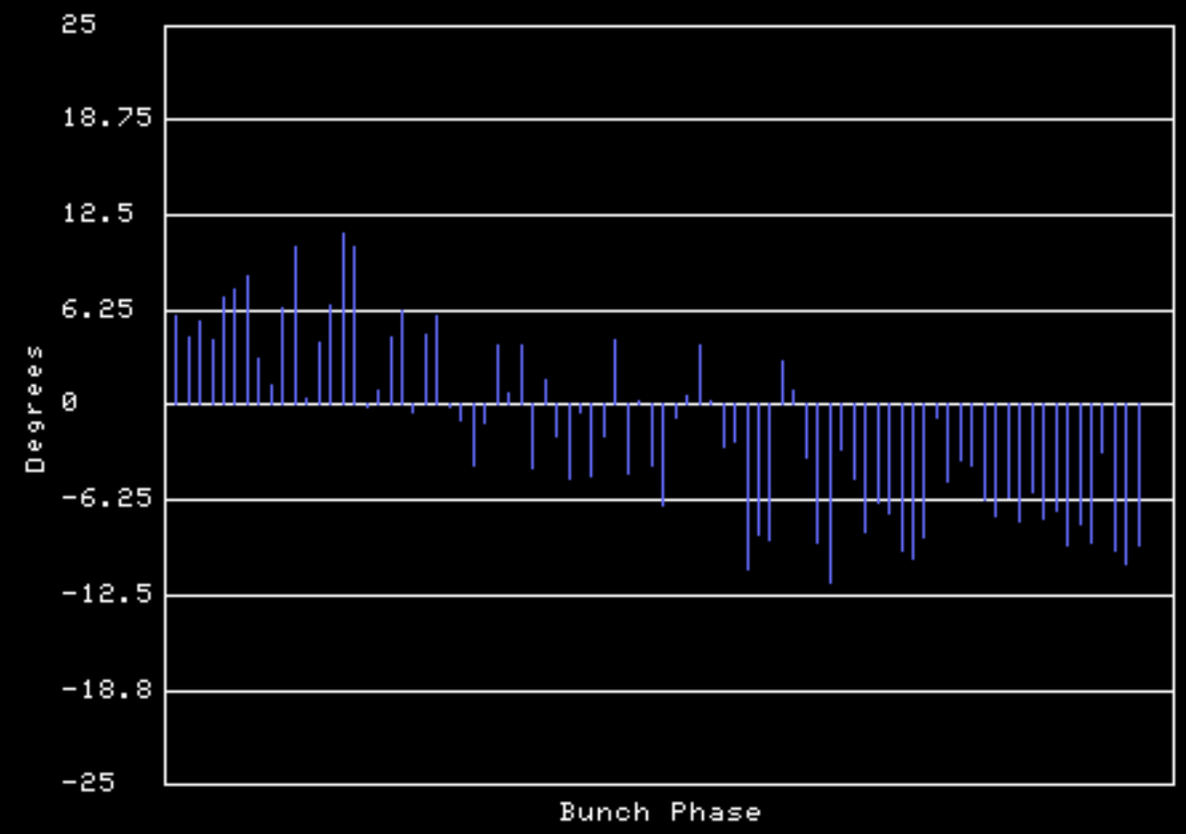


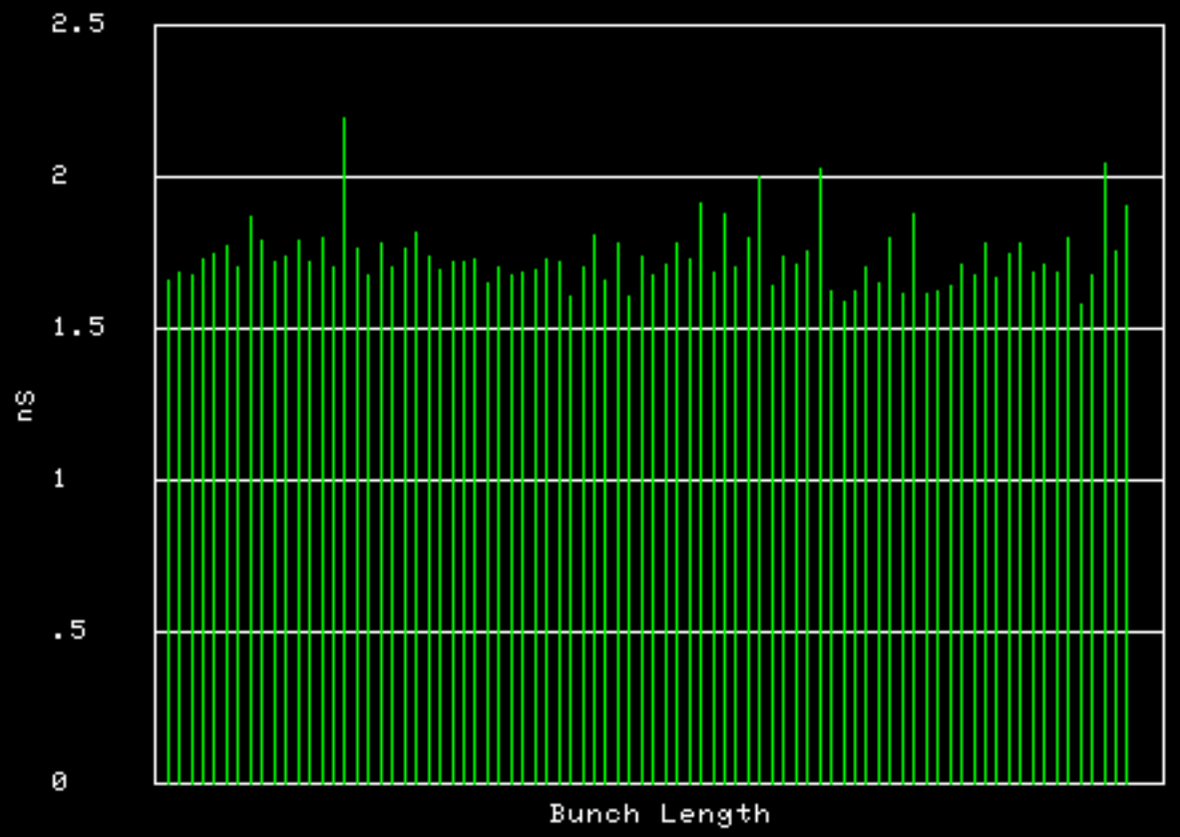
16 Apr 2003
15:28:08

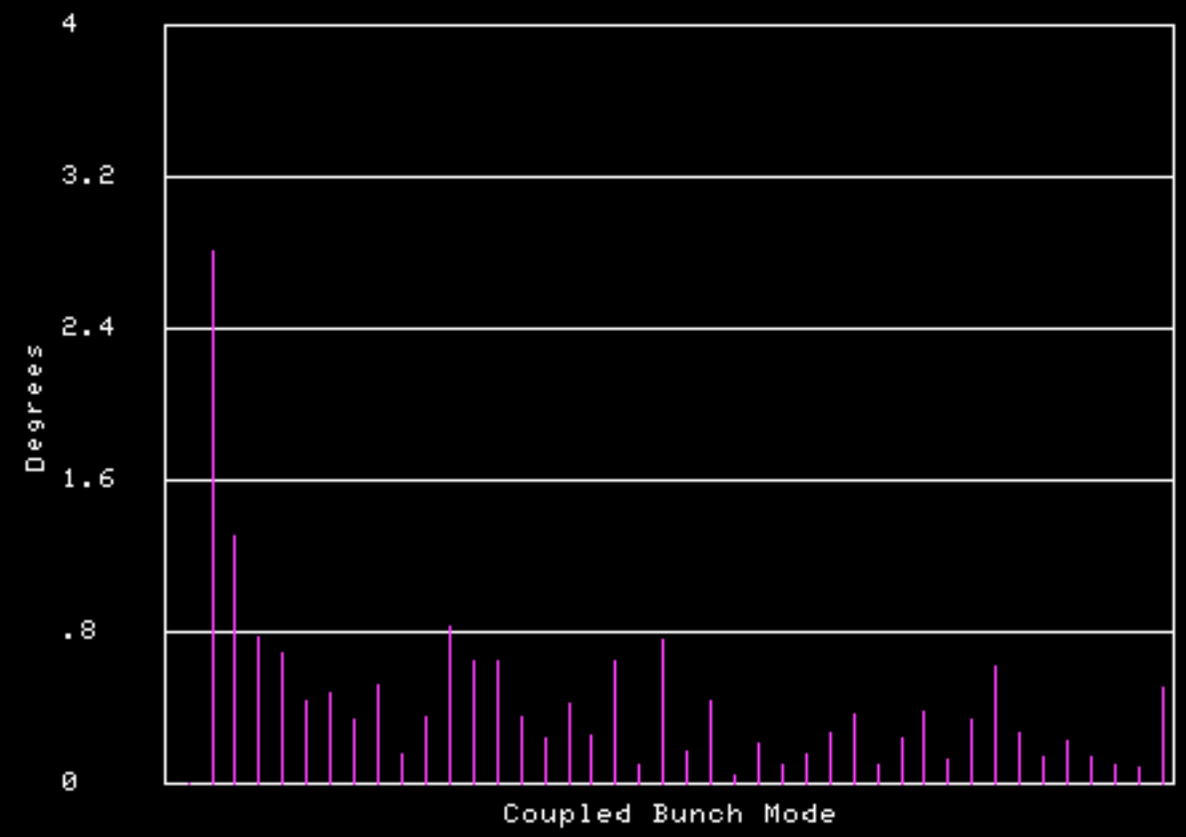
GxSA: PROTON TORPEDO RESULTS

16-APR-03 16:02:26 Setting next DATA:START and DATA:STOP values



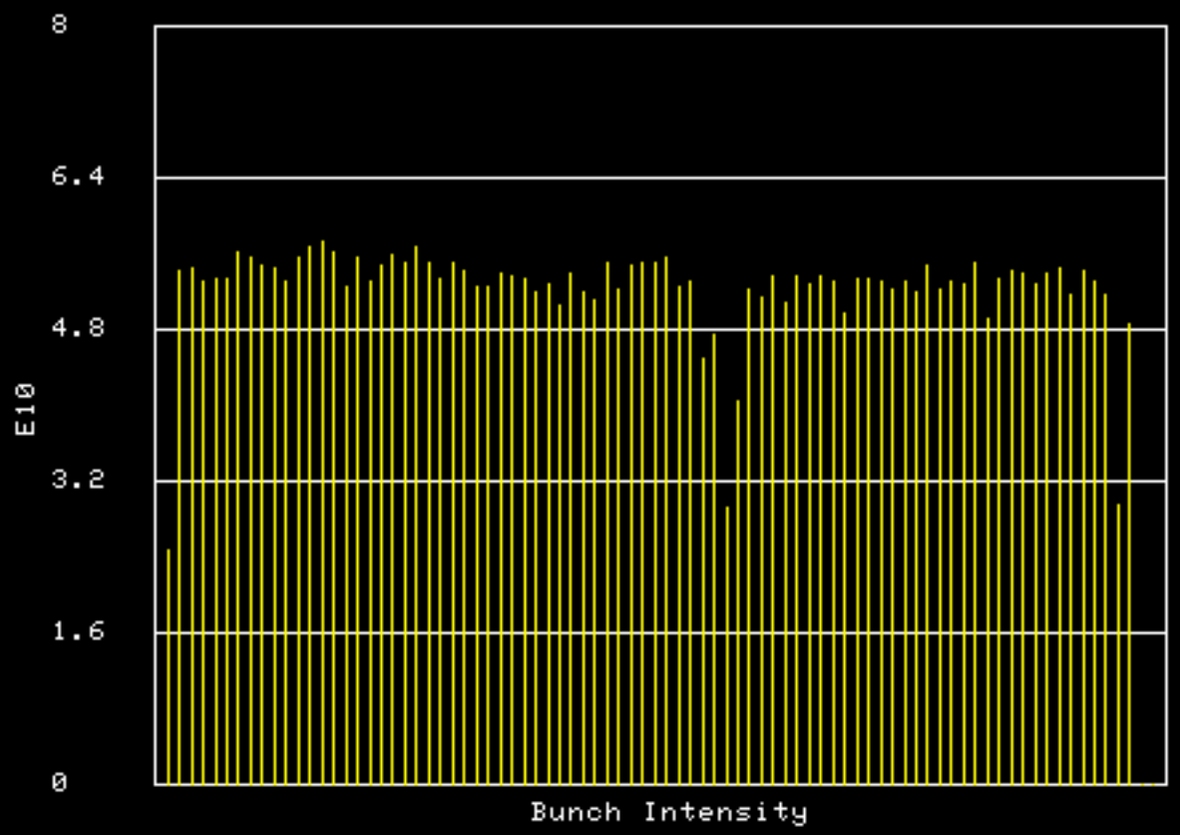


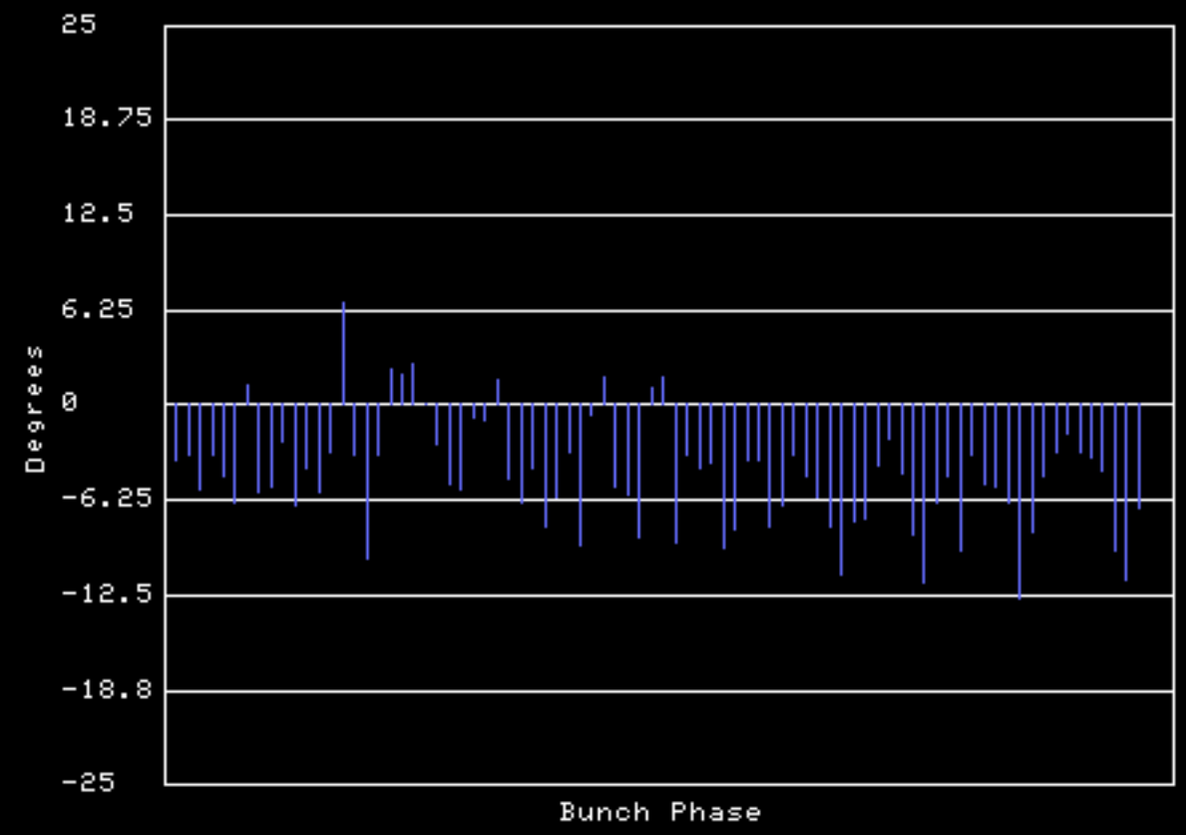


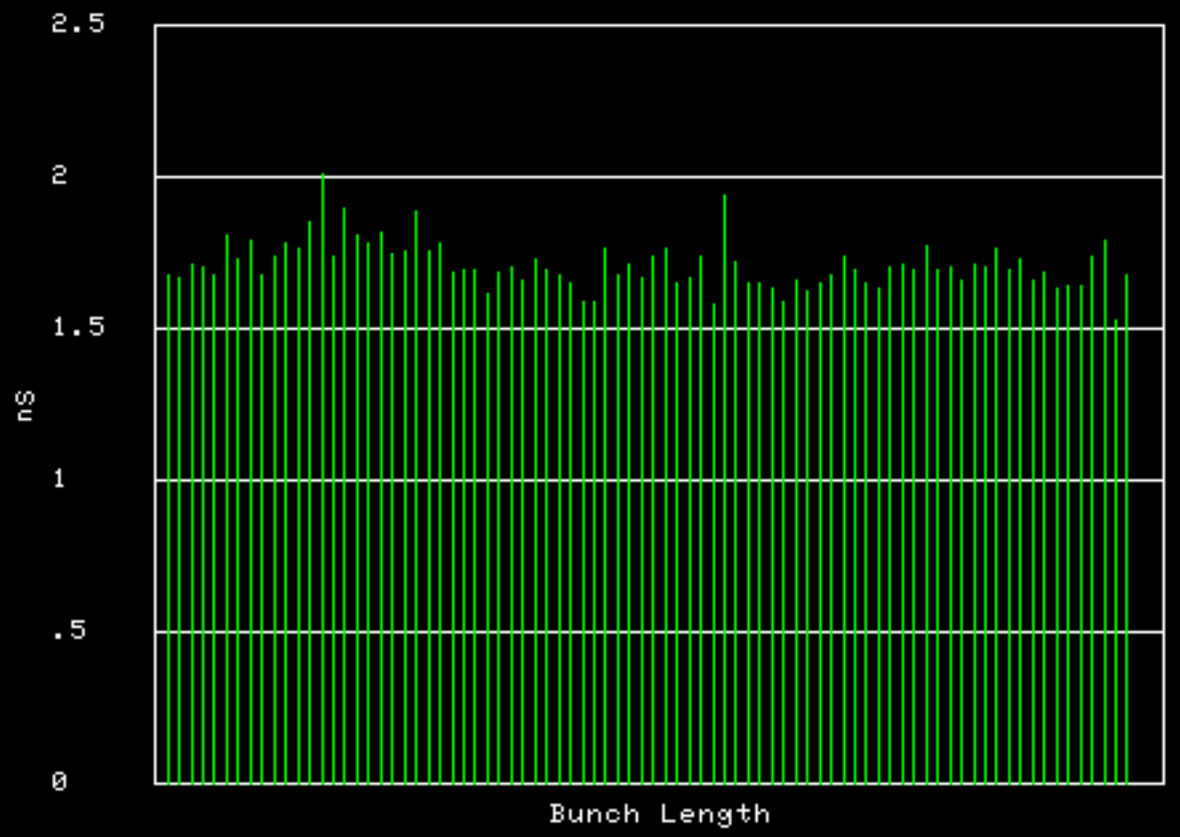


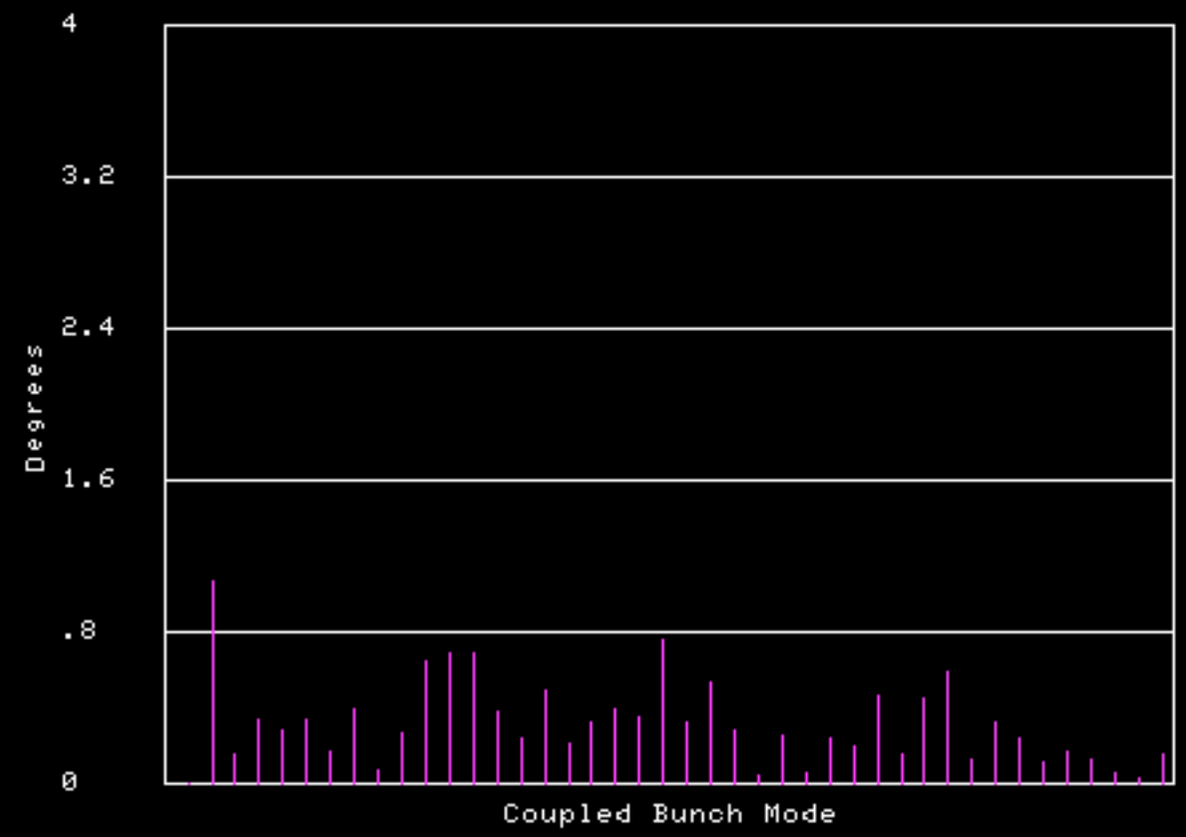
GxSA: PROTON TORPEDO RESULTS

16-APR-03 16:06:07 Setting device values

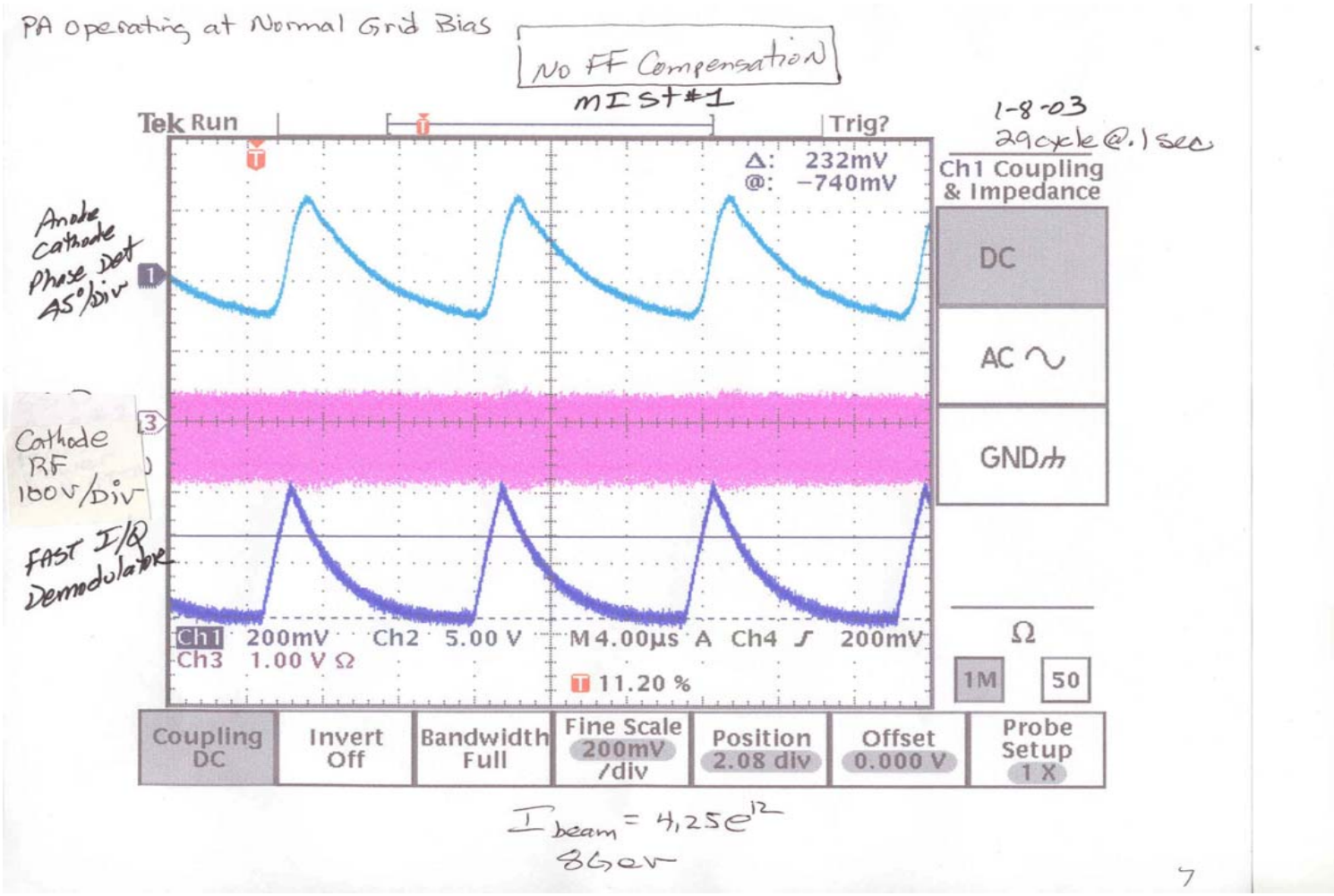




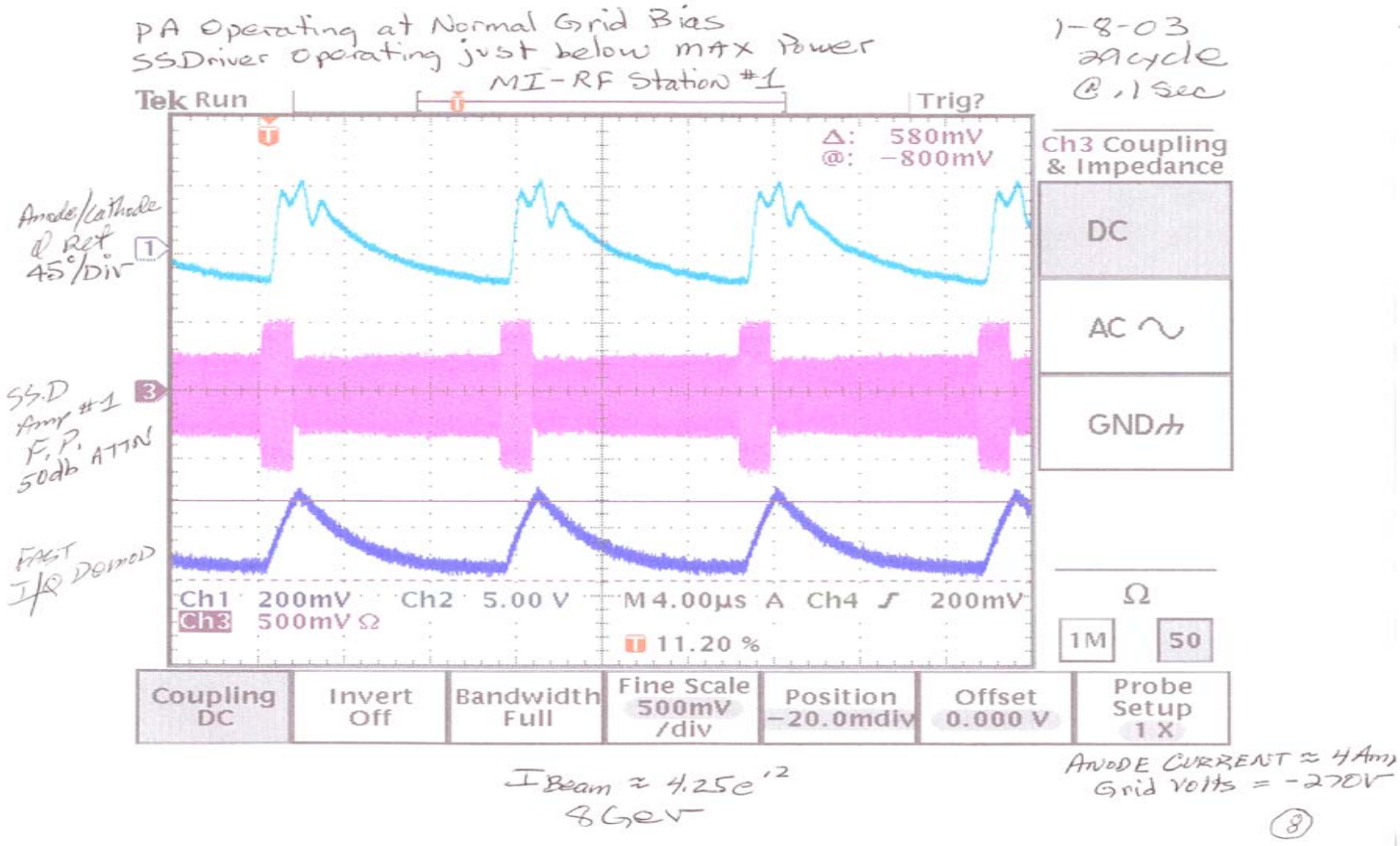




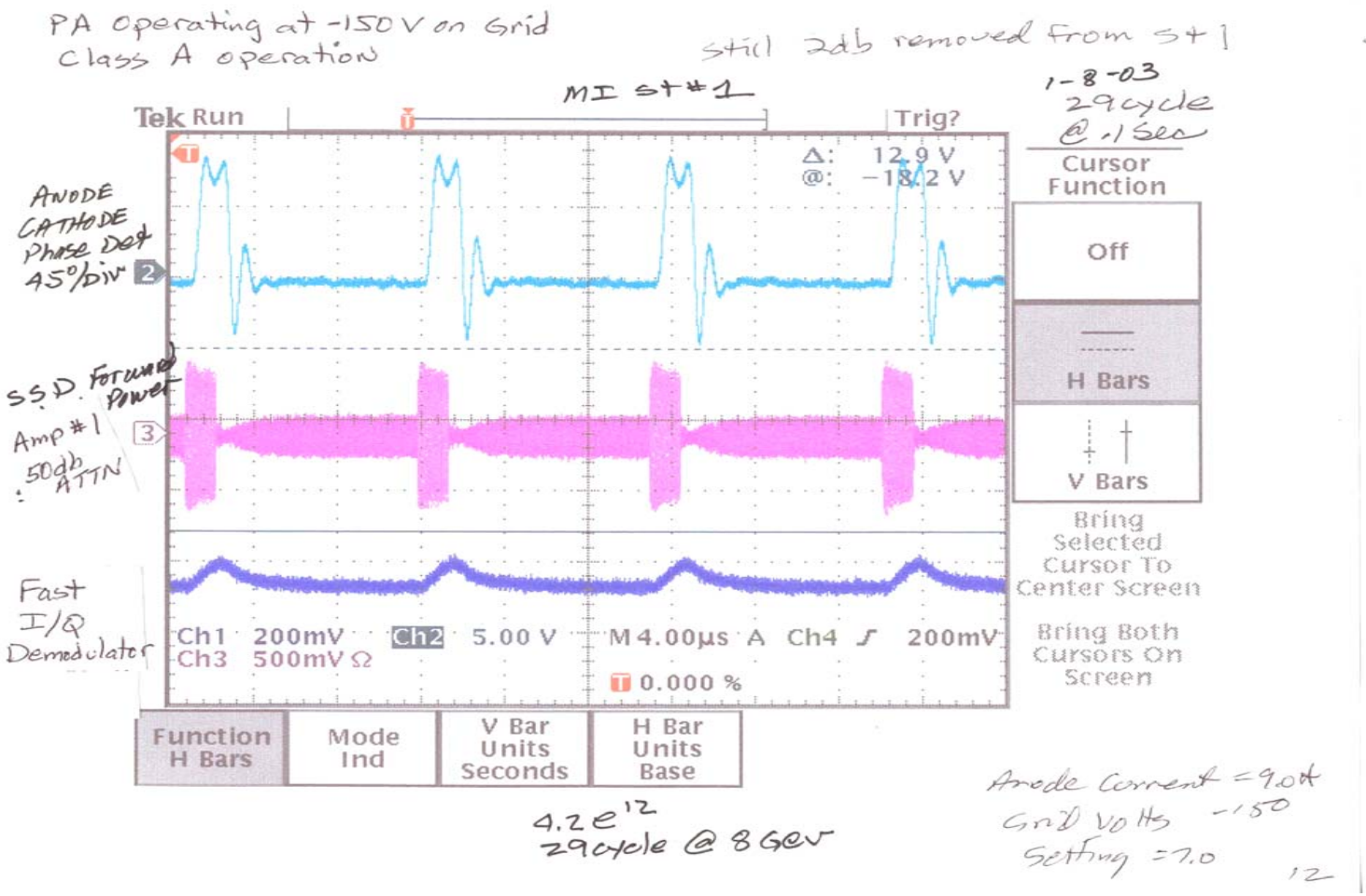
No FF Compensation



Class AB and FF Compensation On



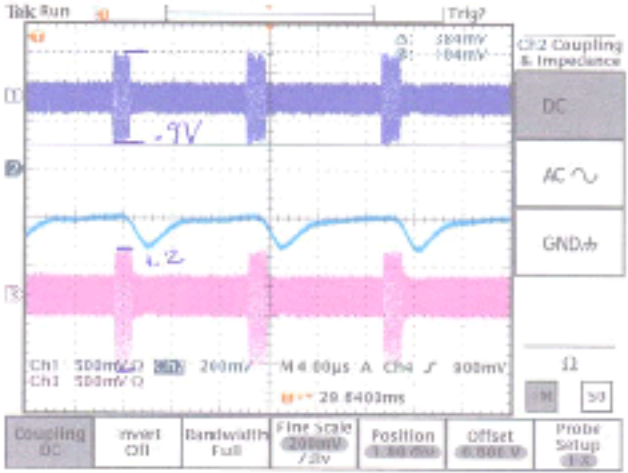
Class A and FF Compensation On



29 cycle
$4.8e^{12}$

Net 2db FF
Gain increase

FB Gain
increased by
6db



GB = -170V

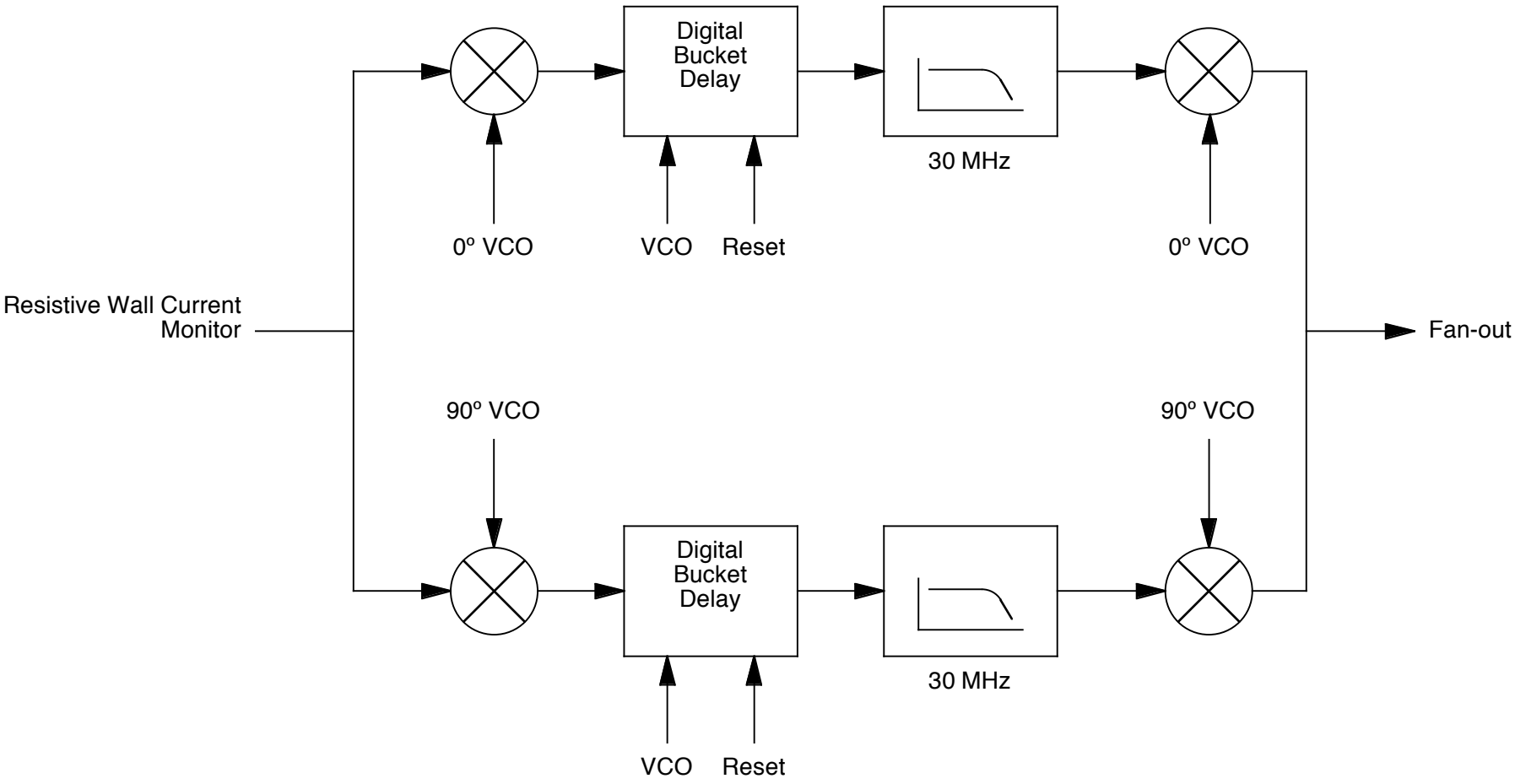
Cathode rf = 1.2 x 191 = 229.2 V_{pp} = 81 V_{rms}

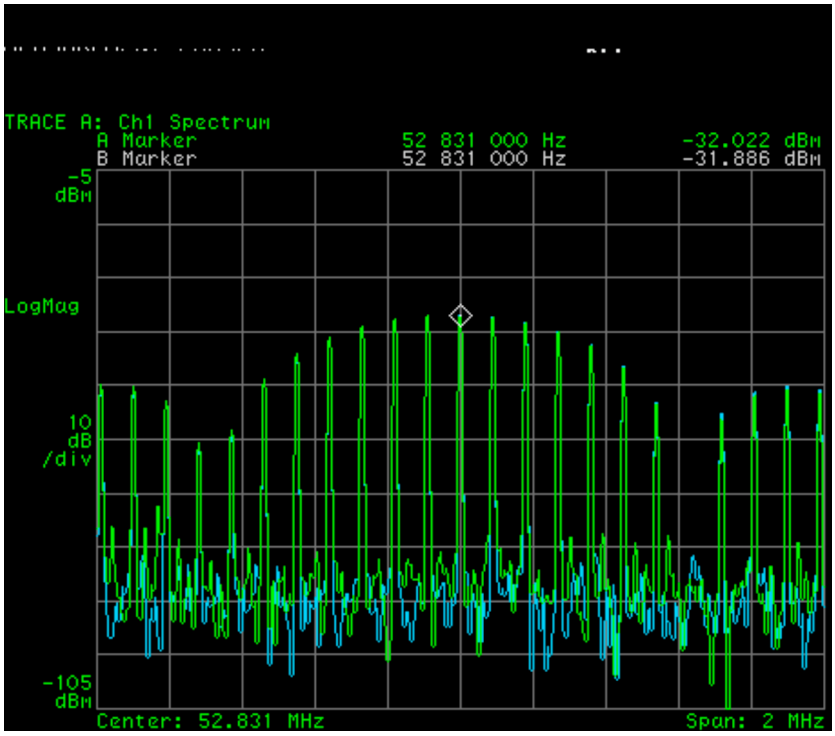
Power Forward = .9 x 316 = 809 watts

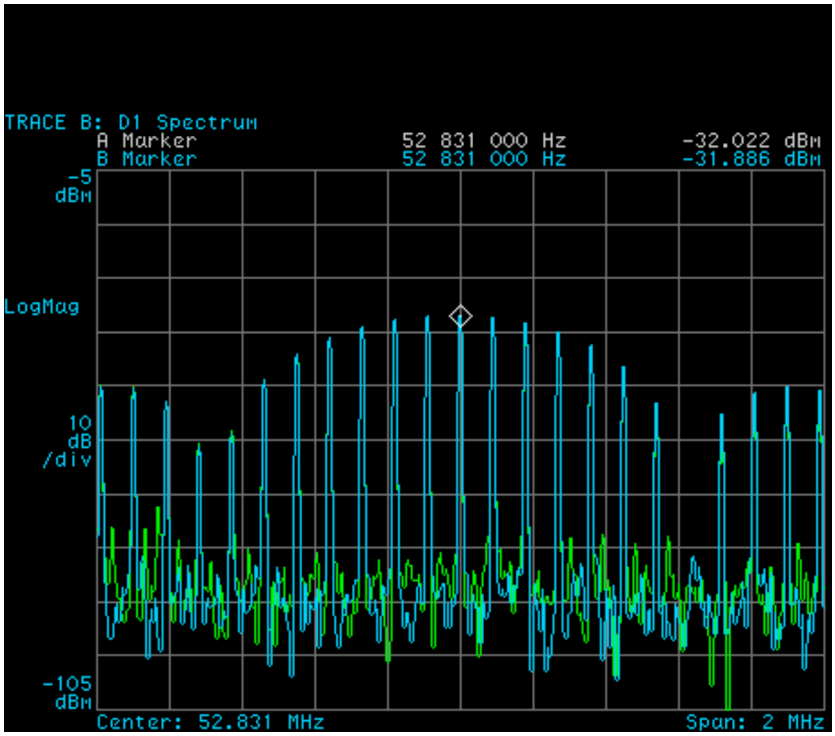
Cathode $Z = \frac{V^2}{P} = 8.1$ ohms

Cathode $I = \frac{V}{Z} = \frac{81}{8.1} = 10$ Amps

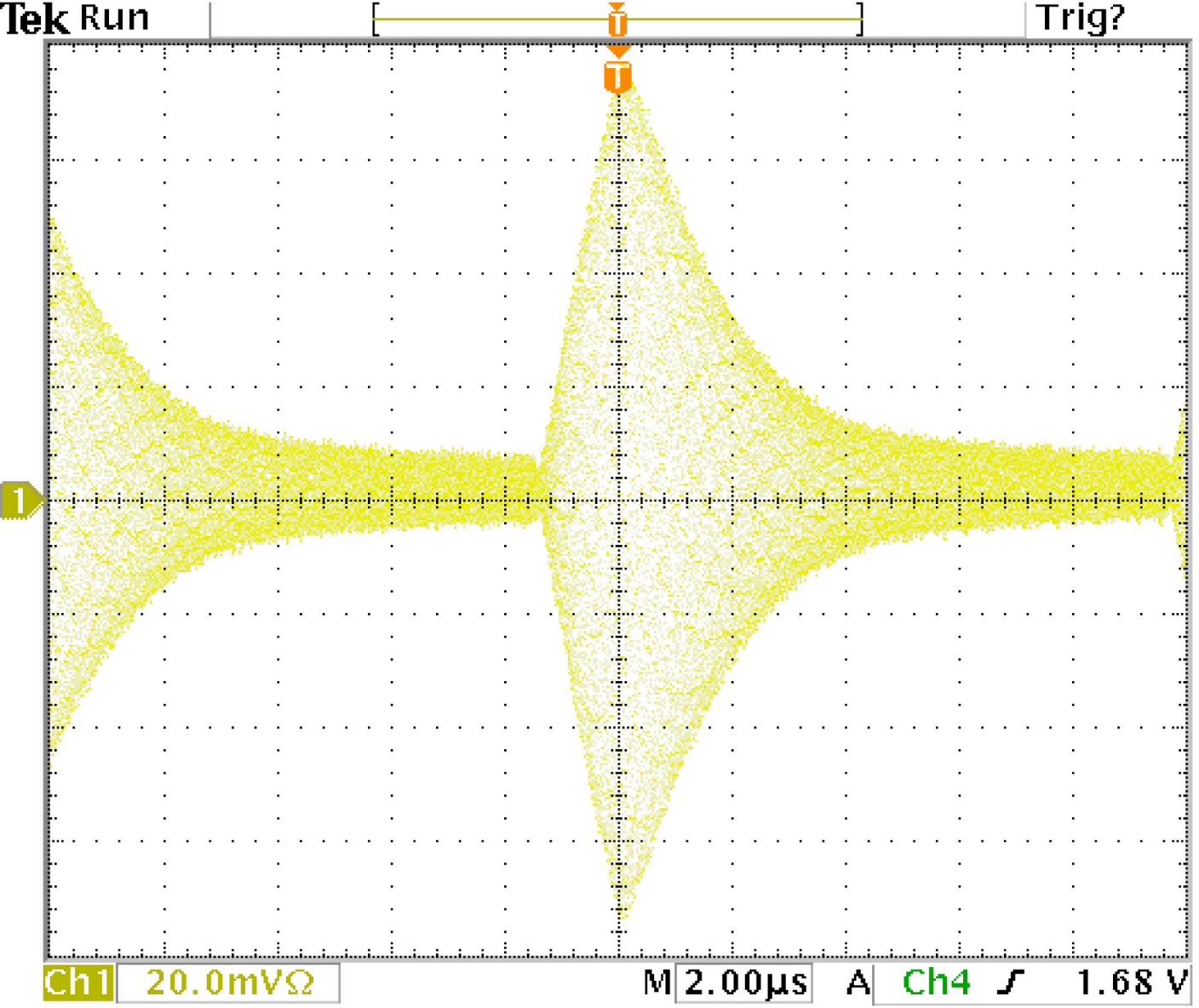
In-Phase and Quadrature







Green: I&Q Output Signal
Blue: Resistive Wall Monitor Signal



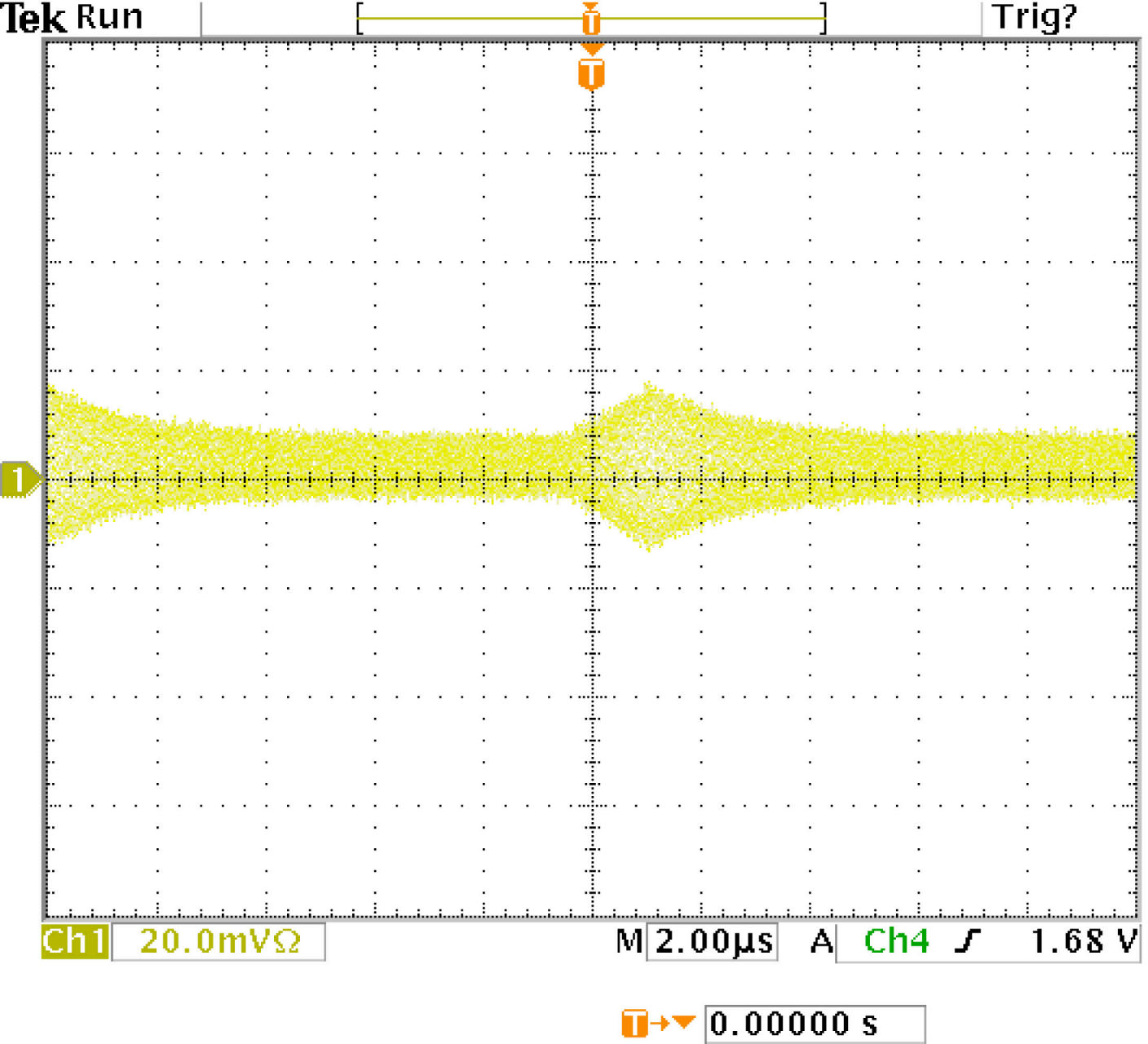
Main Injector
Station #2
Turned OFF
on $29
at 8 GeV

RF Gap Monitor

Fundamental
Feedback

Q = 313

24 Jun 2003
17:29:18



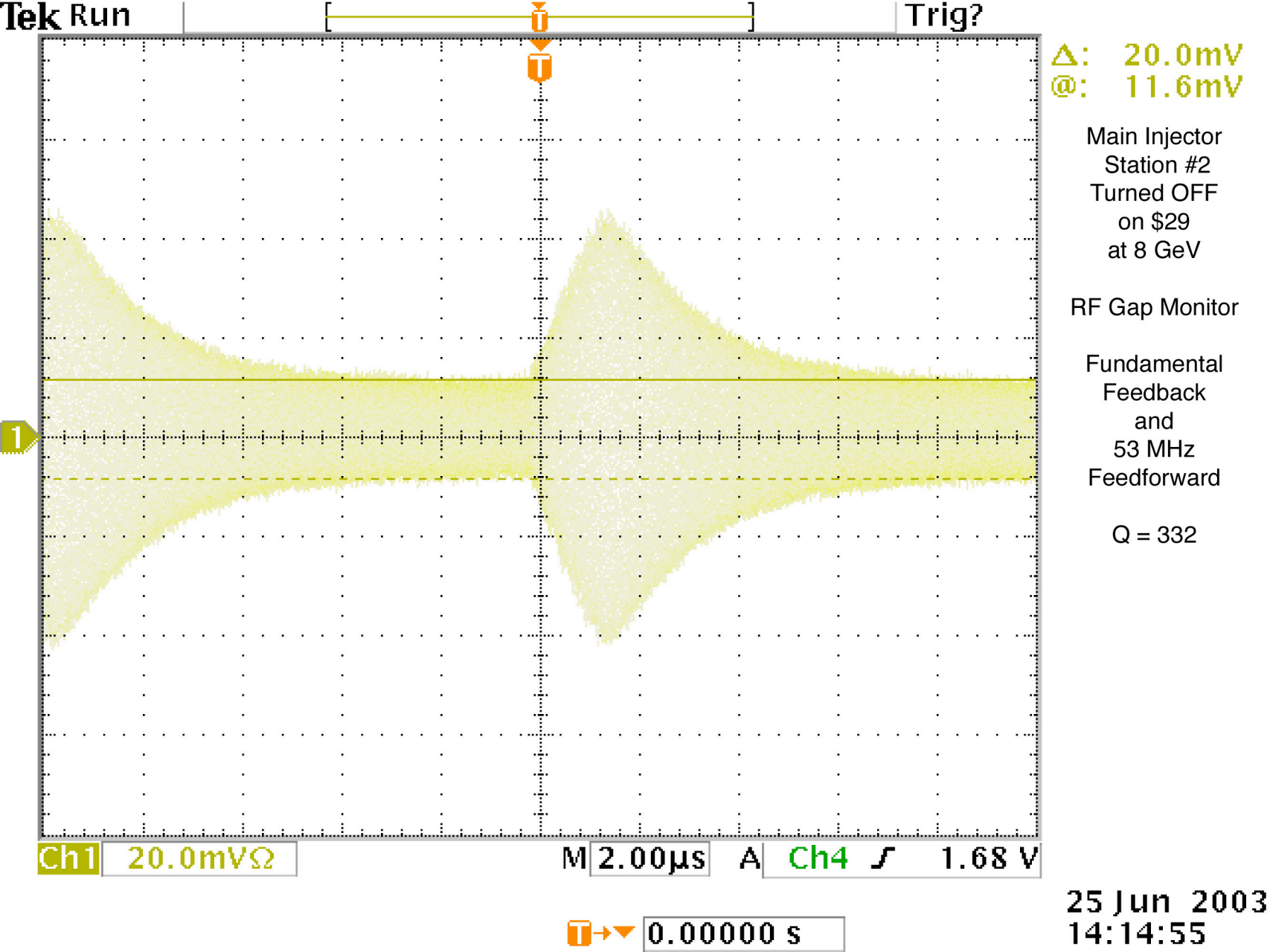
Main Injector
Station #2
Turned OFF
on $29
at 8 GeV

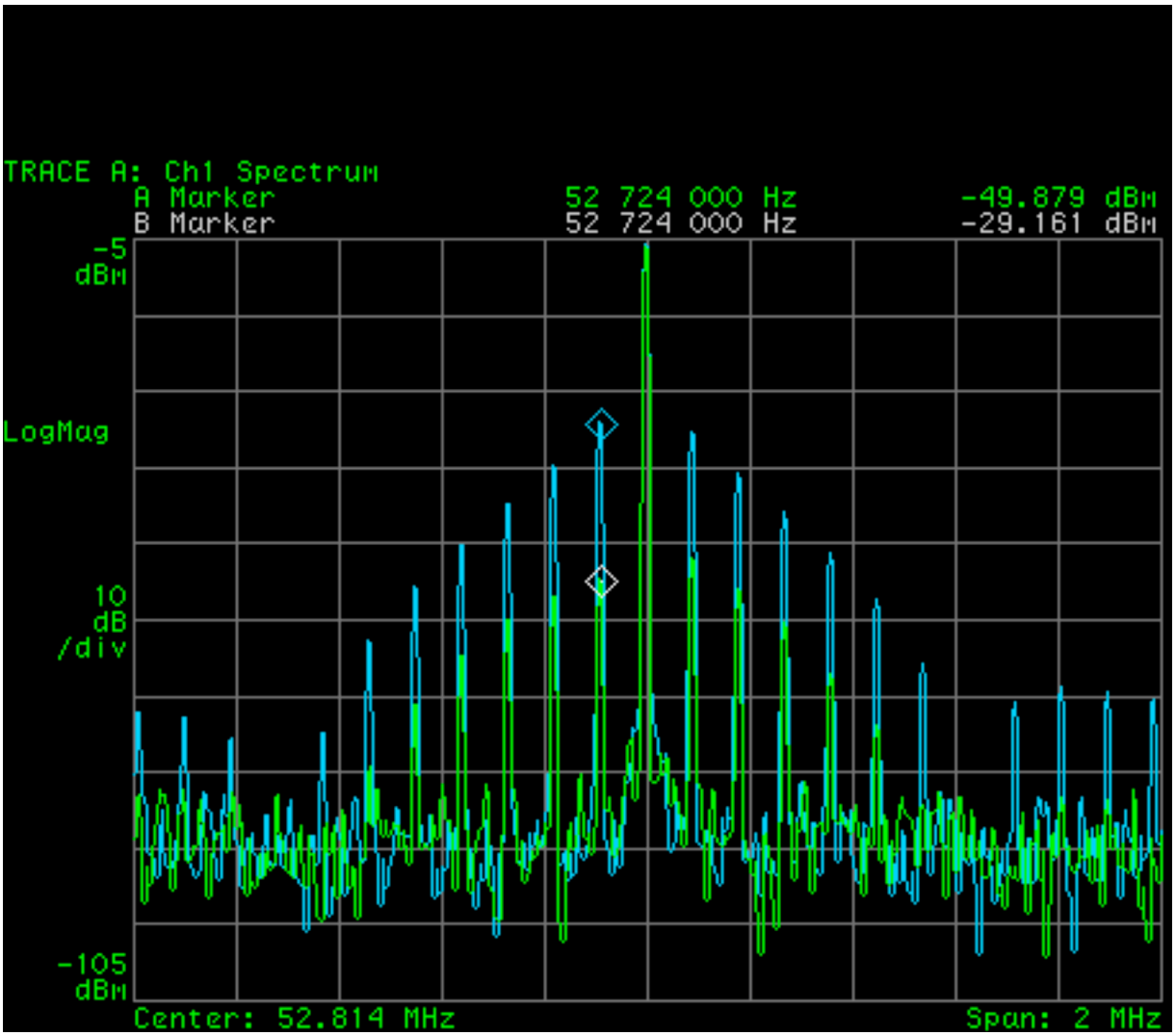
RF Gap Monitor

Fundamental
Feedback
and
49 MHz
Feedforward

Q = 263

24 Jun 2003
17:29:56

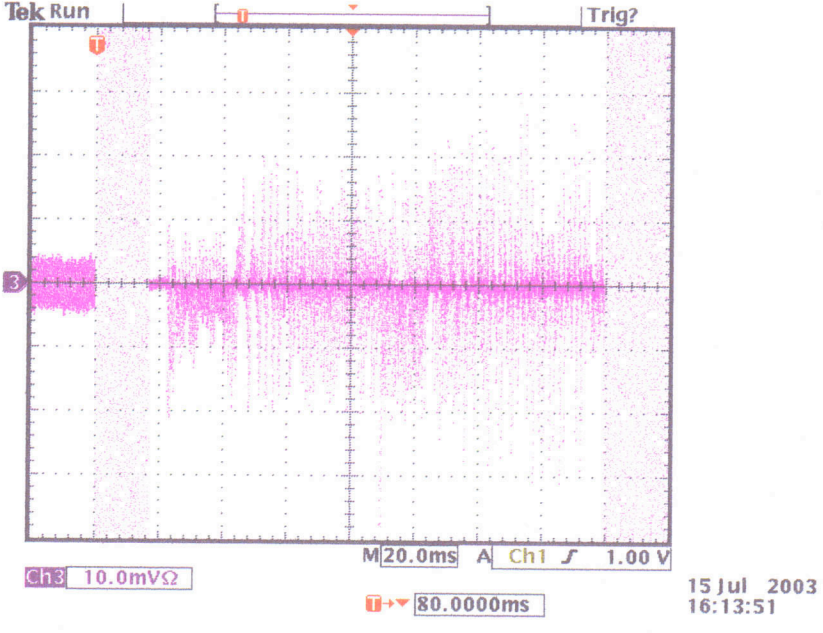

Tek Run
Trig?
Δ: 20.0mV
@: 11.6mV
Main Injector
Station #2
Turned OFF
on $29
at 8 GeV
RF Gap Monitor
Fundamental
Feedback
and
53 MHz
Feedforward
Q = 332
Ch1 20.0mVΩ
M 2.00µs
A Ch4 1.68 V
0.00000 s
25 Jun 2003
14:14:55



In-phase and Quadrature Feedforward on a $29 with 4.5e12 Protons at 8 GeV

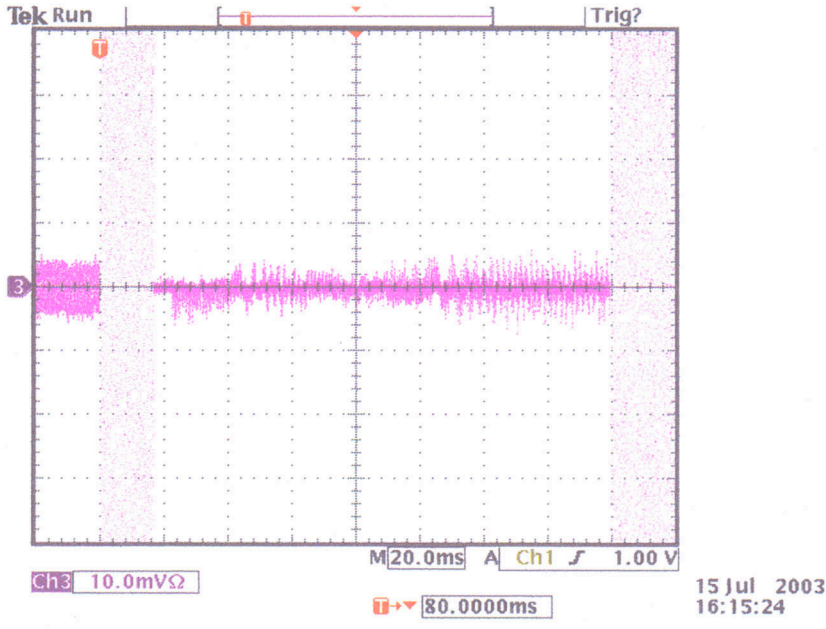
Slip Stacking with Feedforward OFF
2.25e12 Protons/batch
Class A/B Operation

MI Station #1
RF Gap Monitor
2322 V/div



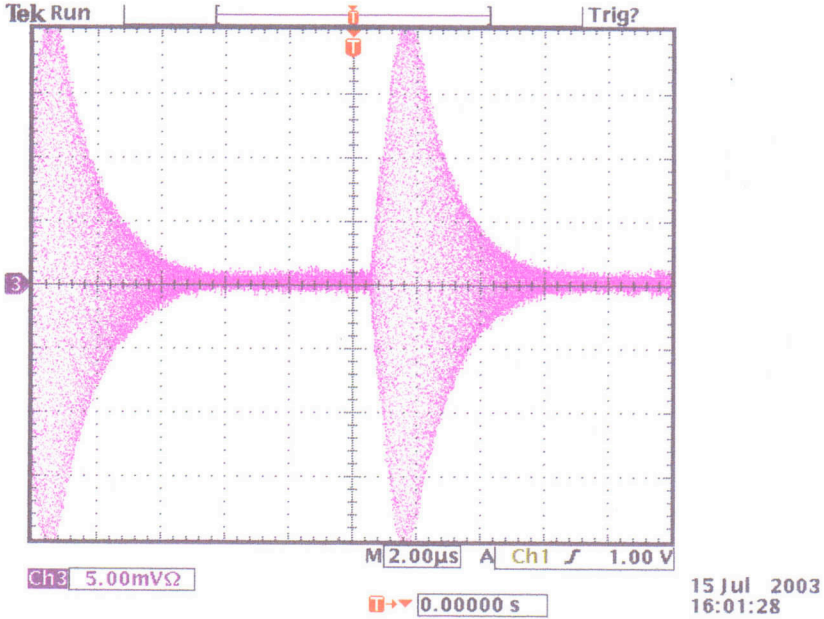
Slip Stacking with Feedforward ON
2.25e12 Protons/batch
Class A/B Operation

MI Station #1
RF Gap Monitor
2322 V/div



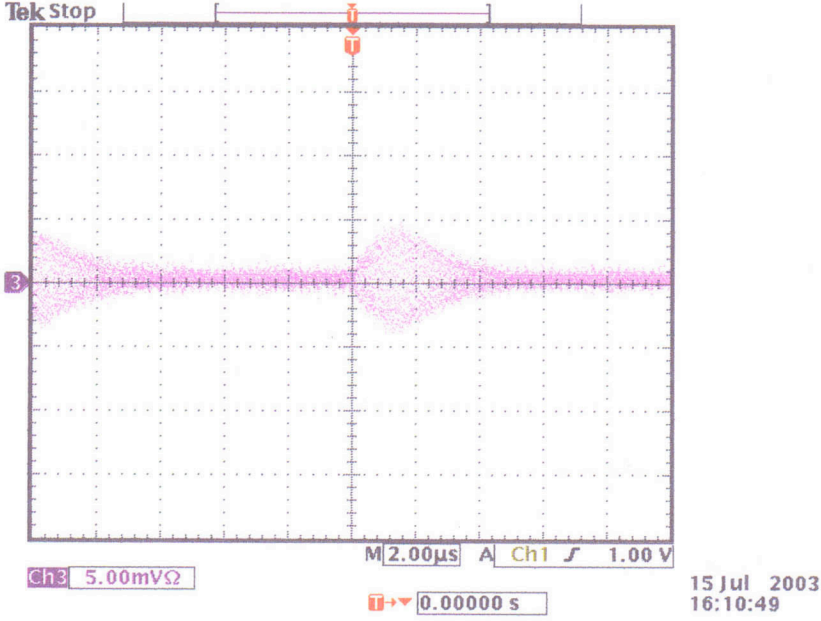
Slip Stacking with Feedforward OFF at 0.08 sec
2.25e12 Protons/batch
Class A/B Operation

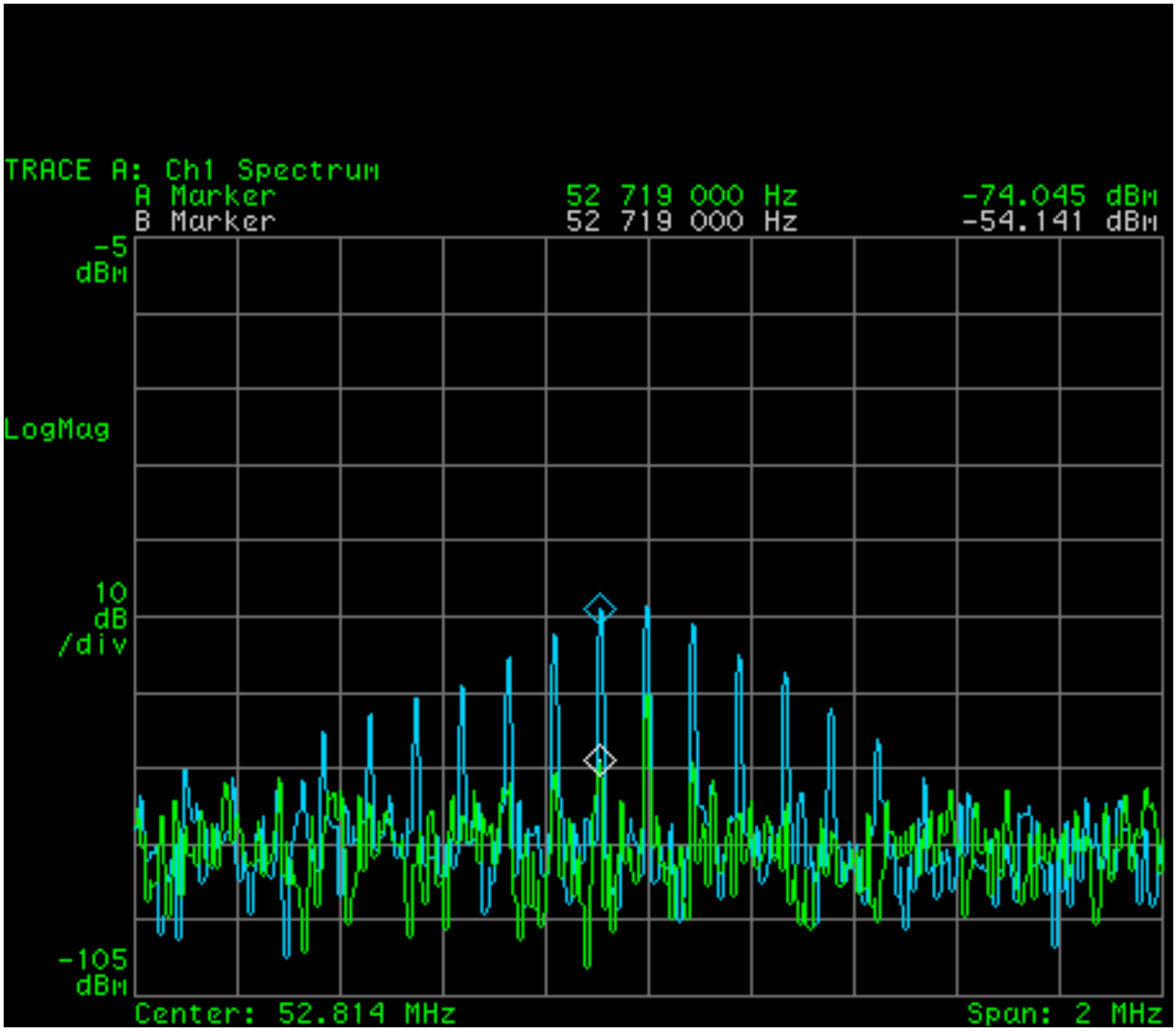
MI Station #1
RF Gap Monitor
1161 V/div



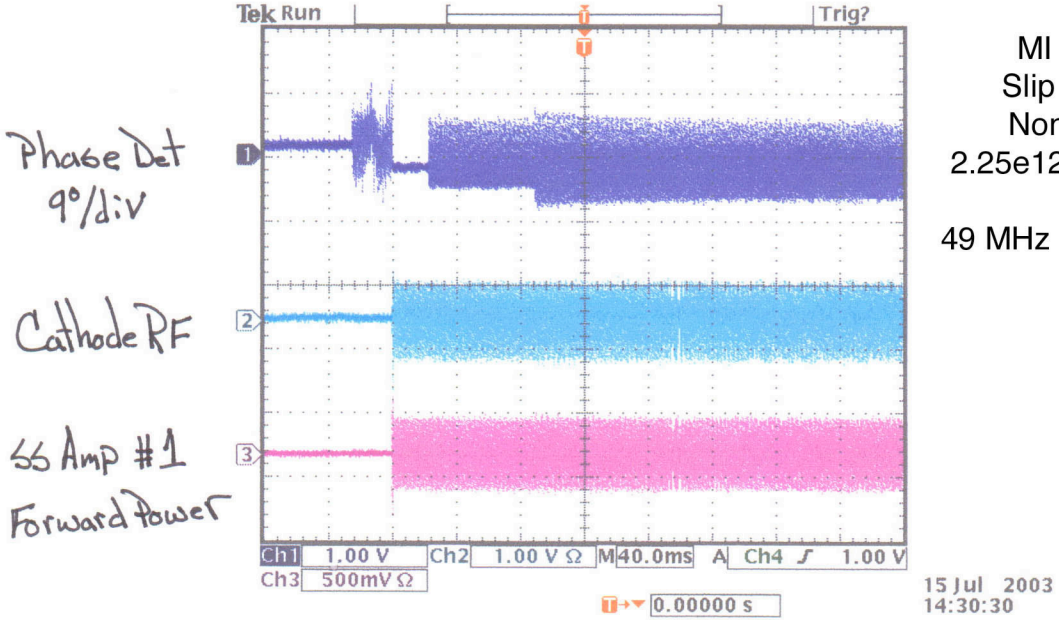
Slip Stacking with Feedforward ON at 0.08 sec
2.25e12 Protons/batch
Class A/B Operation

MI Station #1
RF Gap Monitor
1161 V/div





Main Injector Station #1
49 MHz IQ Feedforward Beam Loading Compensation on a $2E with 2.25e12 protons/batch at 0.08 sec
Blue: FF OFF Green: FF ON

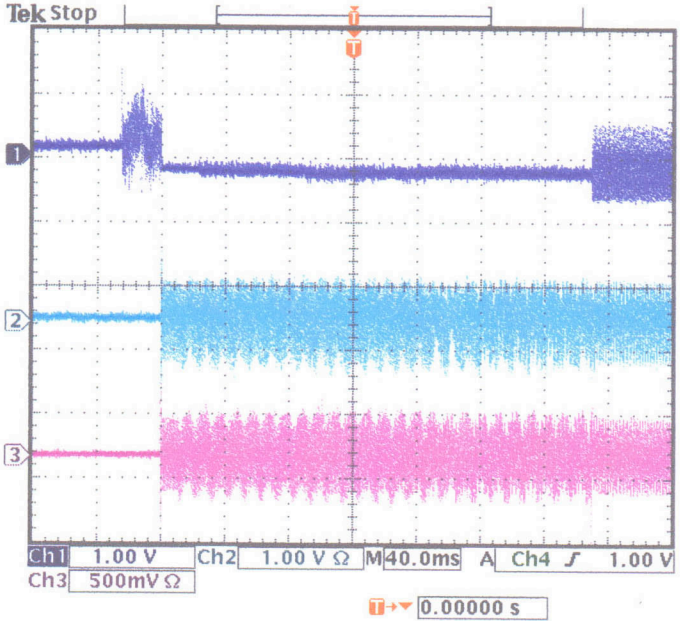


MI Station 18
Slip Stacking in
Non-Slip Case
2.25e12 Protons/batch
without
49 MHz IQ Feedforward

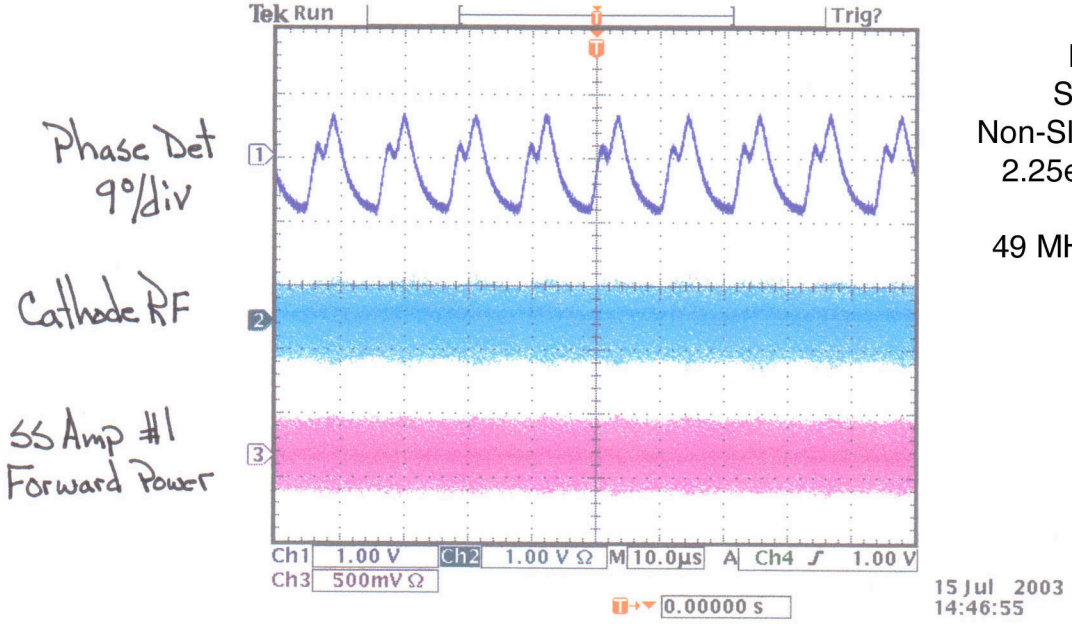
Phase Det
9°/div

Cathode RF
1.52V

55 Amp #1
Forward
Power
0.75V



MI Station 18
Slip Stacking in
Non-Slip Case
2.25e12 Protons/batch
with
49 MHz IQ Feedforward

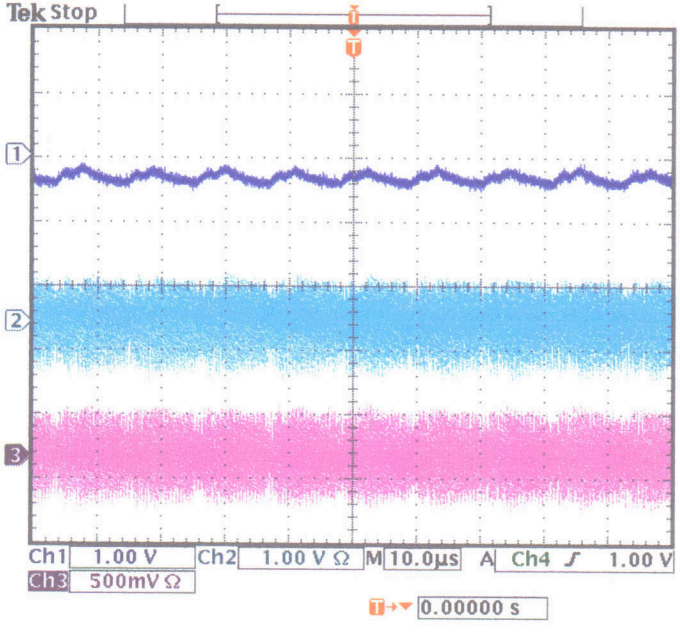


MI Station 18
Slip Stacking in
Non-Slip Case at 0.13 sec
2.25e12 Protons/batch
without
49 MHz IQ Feedforward

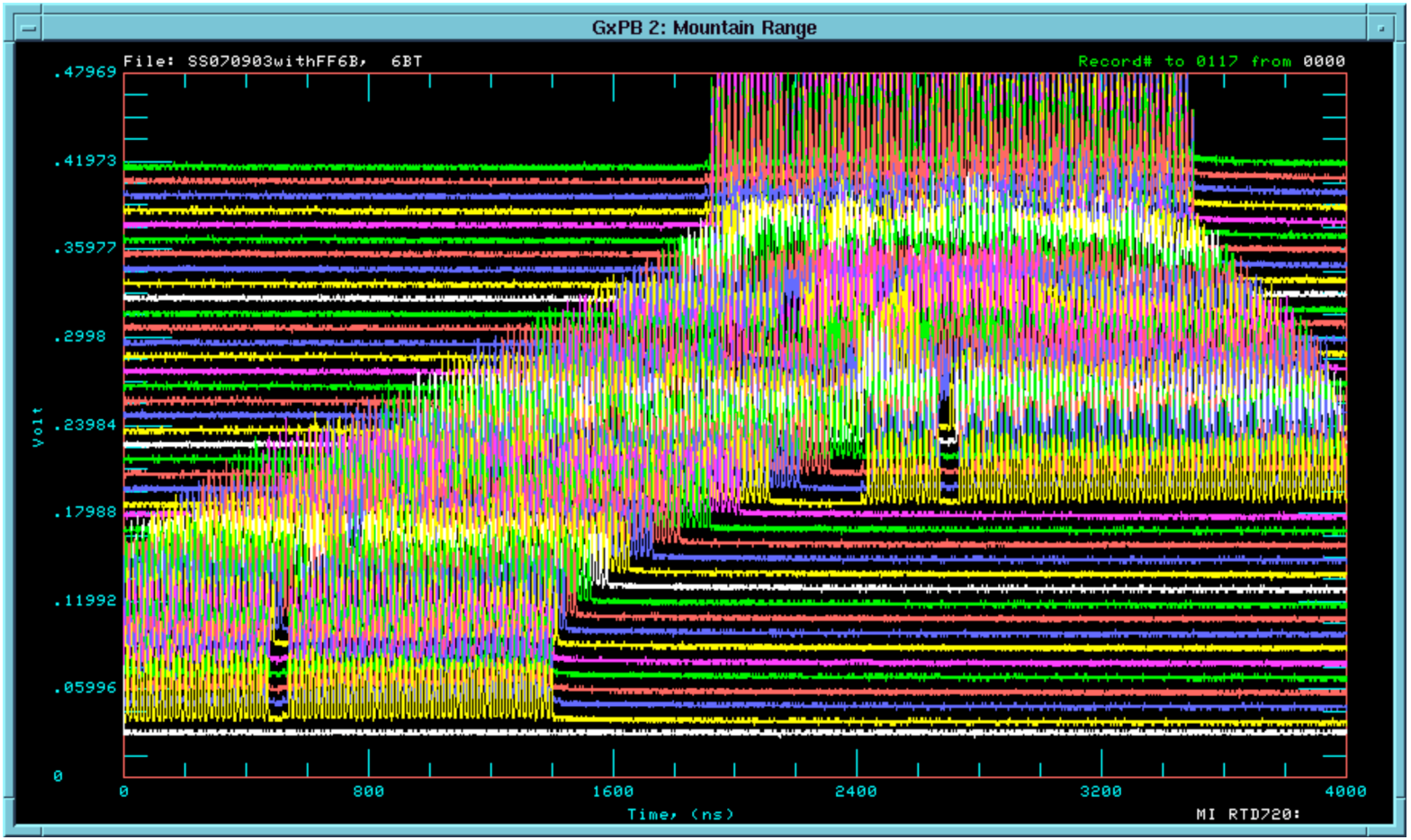
Phase Det
9°/div

Cathode RF
1.66V

SS Amp # 1
Forward Power
800mV



MI Station 18
Slip Stacking in
Non-Slip Case at 0.13 sec
2.25e12 Protons/batch
with
49 MHz IQ Feedforward



Slip Stacking Mountain Range
49 MHz In-phase and Quadrature
Feedforward Beam Loading Compensation
on 2.5e12 protons/batch