



The 60Hz Problem

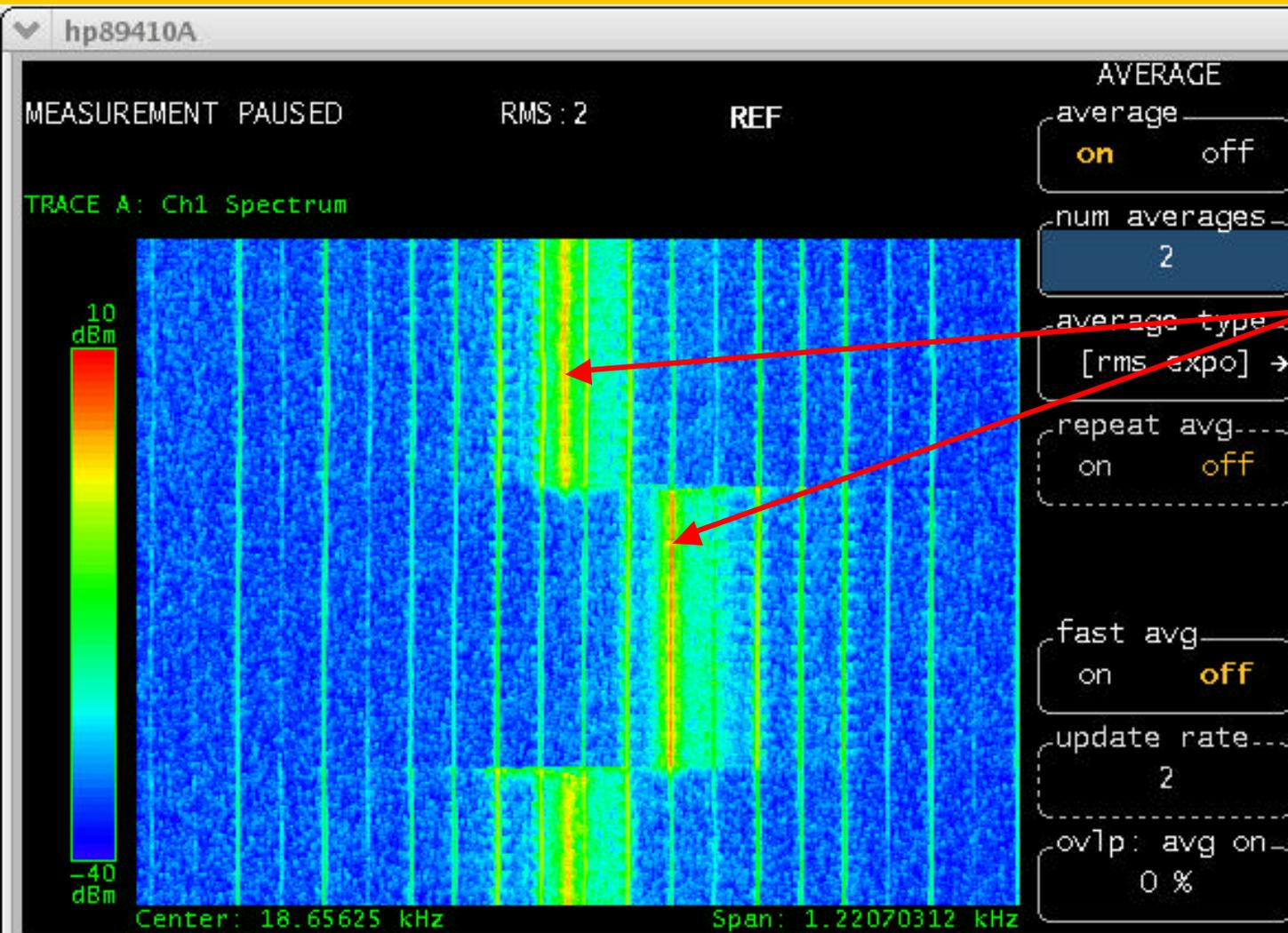
Peter Cameron

The Evolution



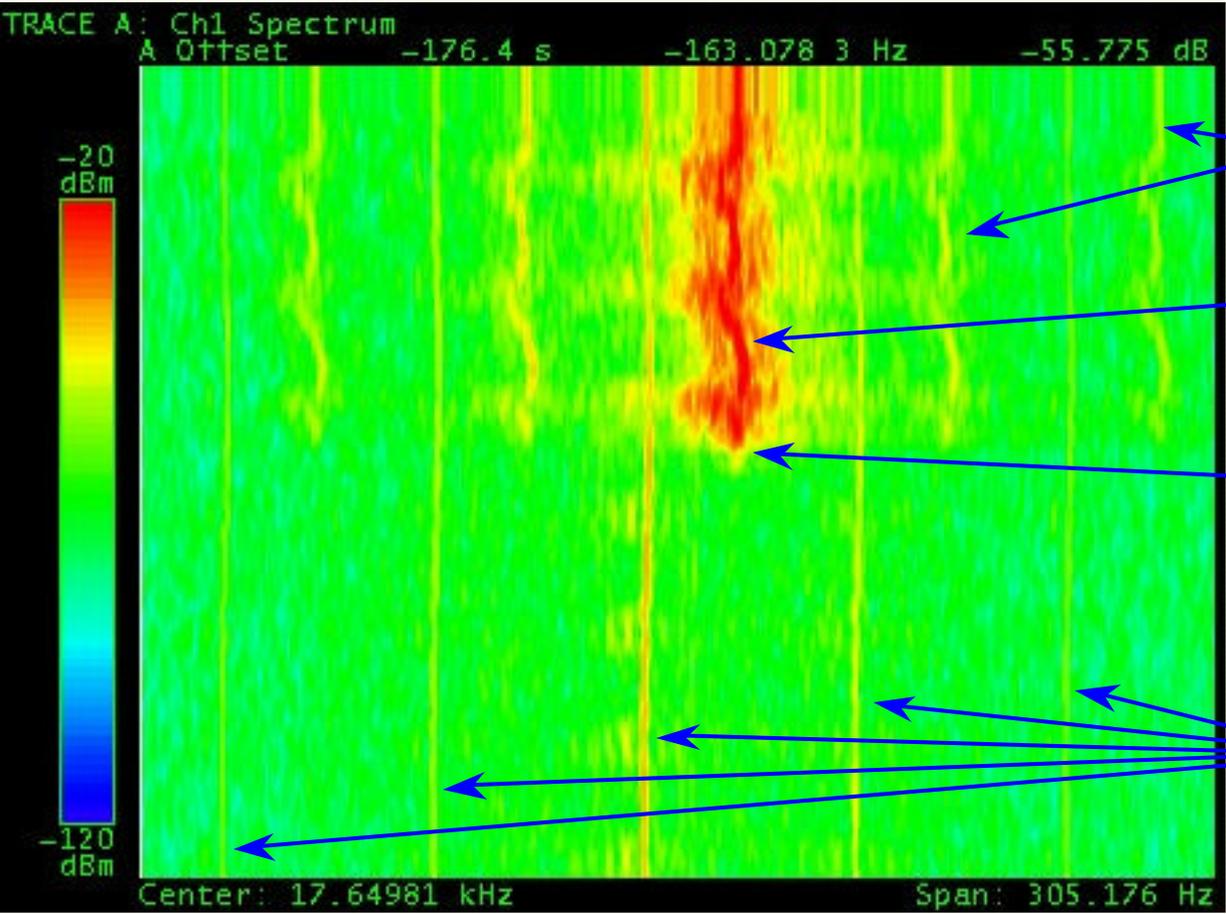
- Observation of 60Hz harmonics at CERN, FNAL, BNL
- Tune shift - 60Hz harmonics don't move, not sidebands!
- Still present with 3D move into tunnel
- Still present with isolation transformers in the signal path
- Still present running the 3D on batteries (Tevatron)
- Present on homodyne and 245MHz pickups
- Still present with 50MHz high pass in front of the diodes
- Observation on million turn BPM - not conclusive
- Variation with helix on and off (Tevatron)
- Variation of vertical harmonics with coupling - **on the main dipole bus**

Tune Shift - 60Hz lines don't move



PLL
excitation

Tune sidebands at 60Hz



sidebands

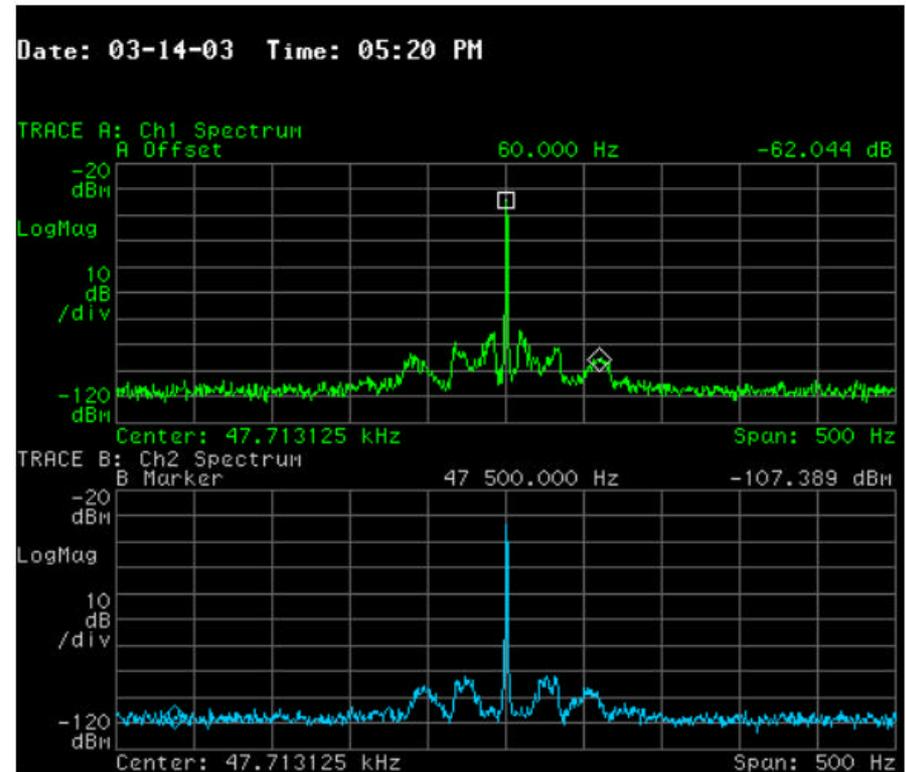
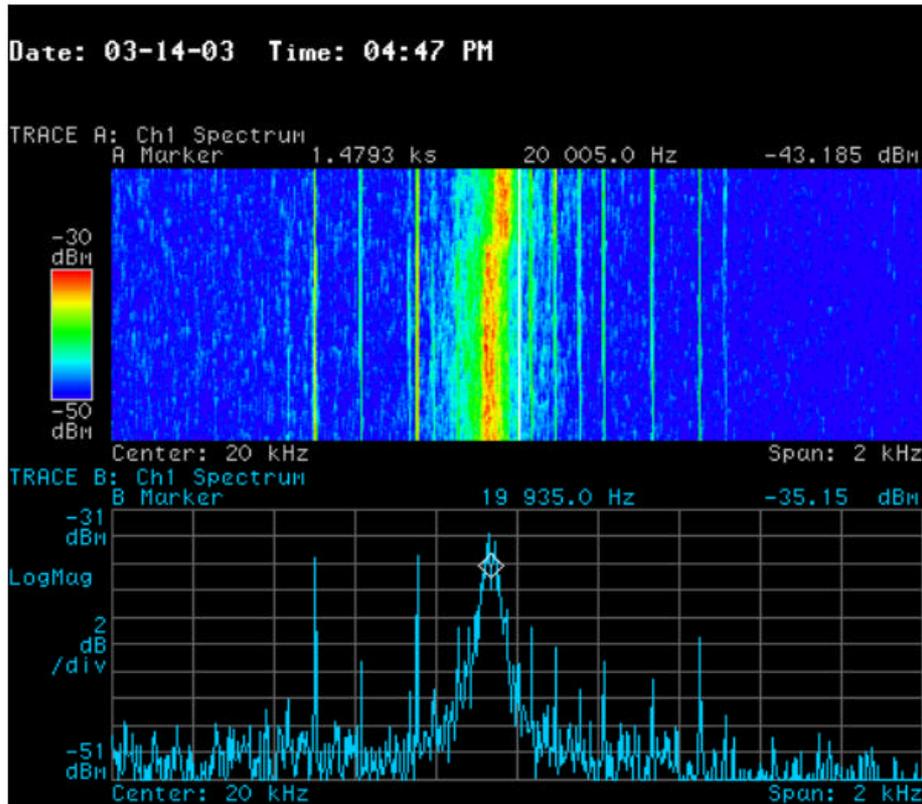
PLL locked

Kicker off

continuous
60Hz lines

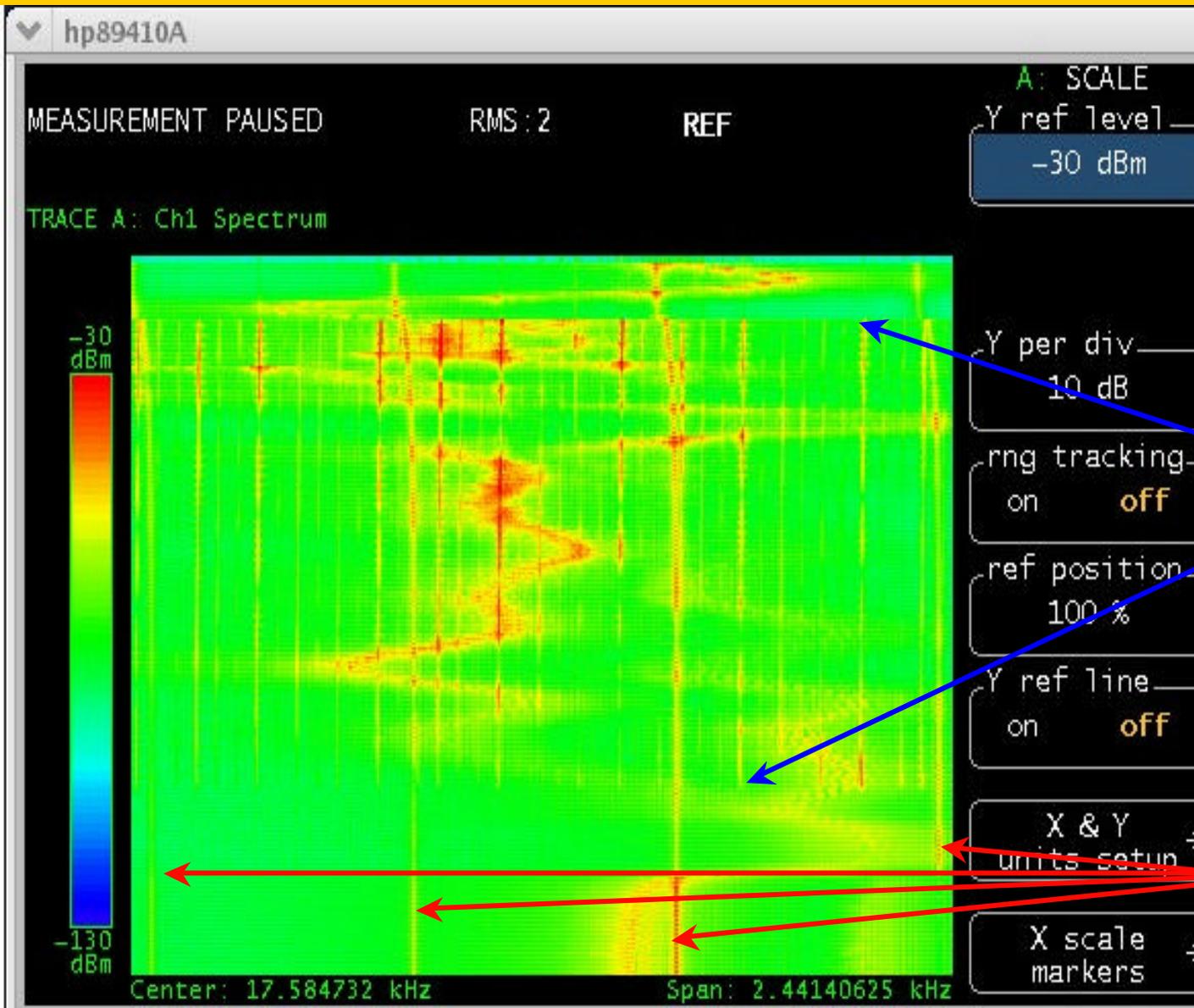
span 305Hz

60Hz Characteristics



60Hz does not move when the tune moves.
No 60Hz around revolution harmonics

3D Ramp - 1 Jan 05



dominant
spacing
is 360Hz

60Hz onset
60Hz end

IPM every
100 turns?
(780 Hz)

MEASUREMENT PAUSED

RMS : 2

REF

A: MARKER

marker on off

enter marker position

offset mkr on off

zero offset

offset posn setup

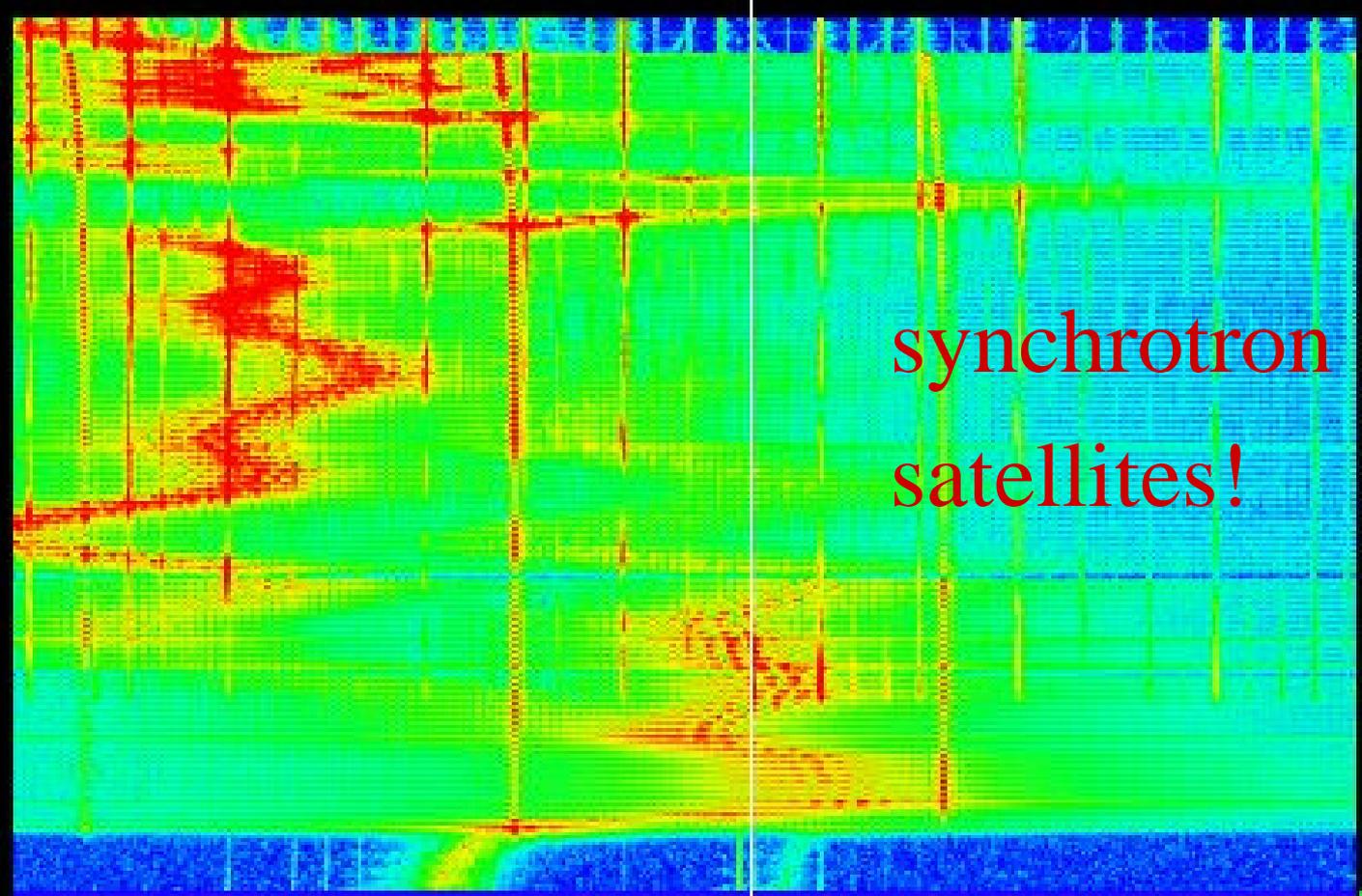
couple mkrs on off

Ch1 Spectrum
A Offset

0 s

39.672 9 Hz

2.477 dB



synchrotron
satellites!

Center: 18.294323 kHz

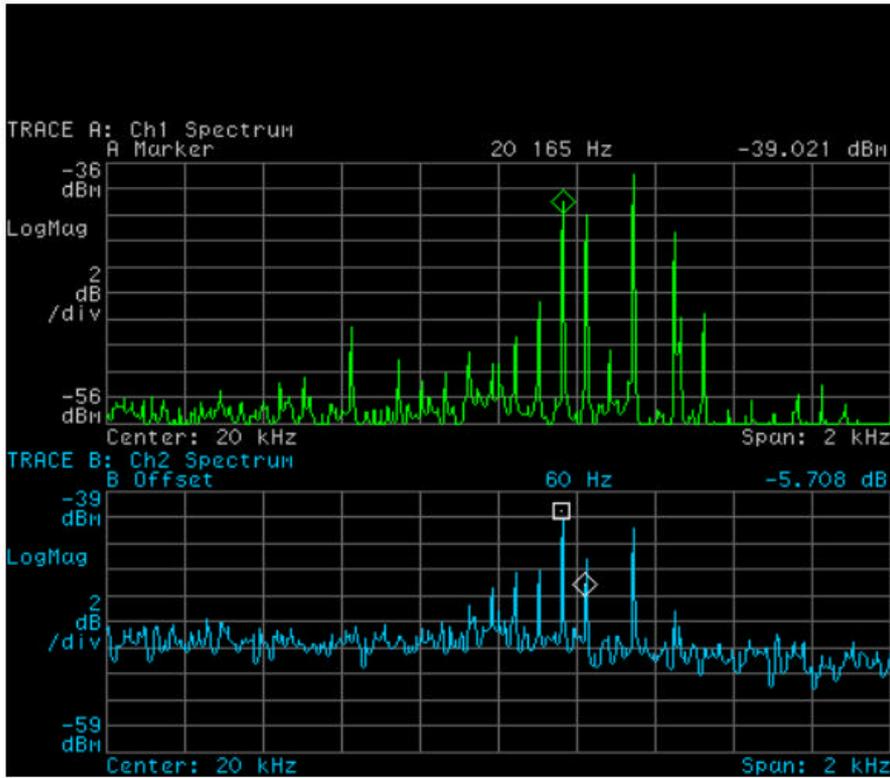
Span: 2.44140625 kHz

The Evolution

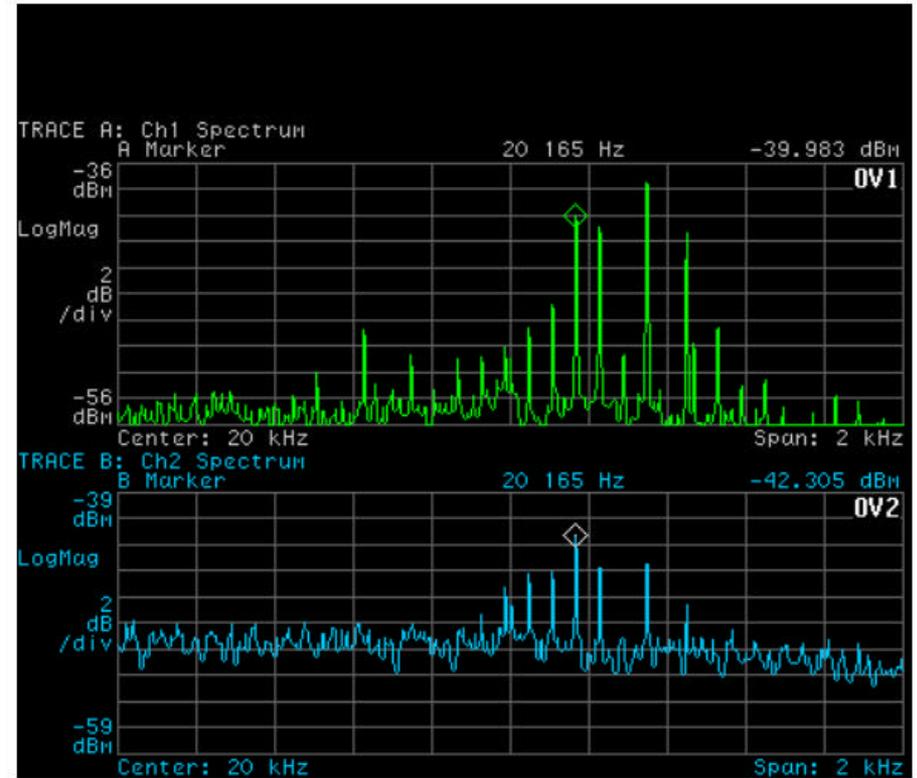


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Checking that 60Hz is not from the BBQ Frontend

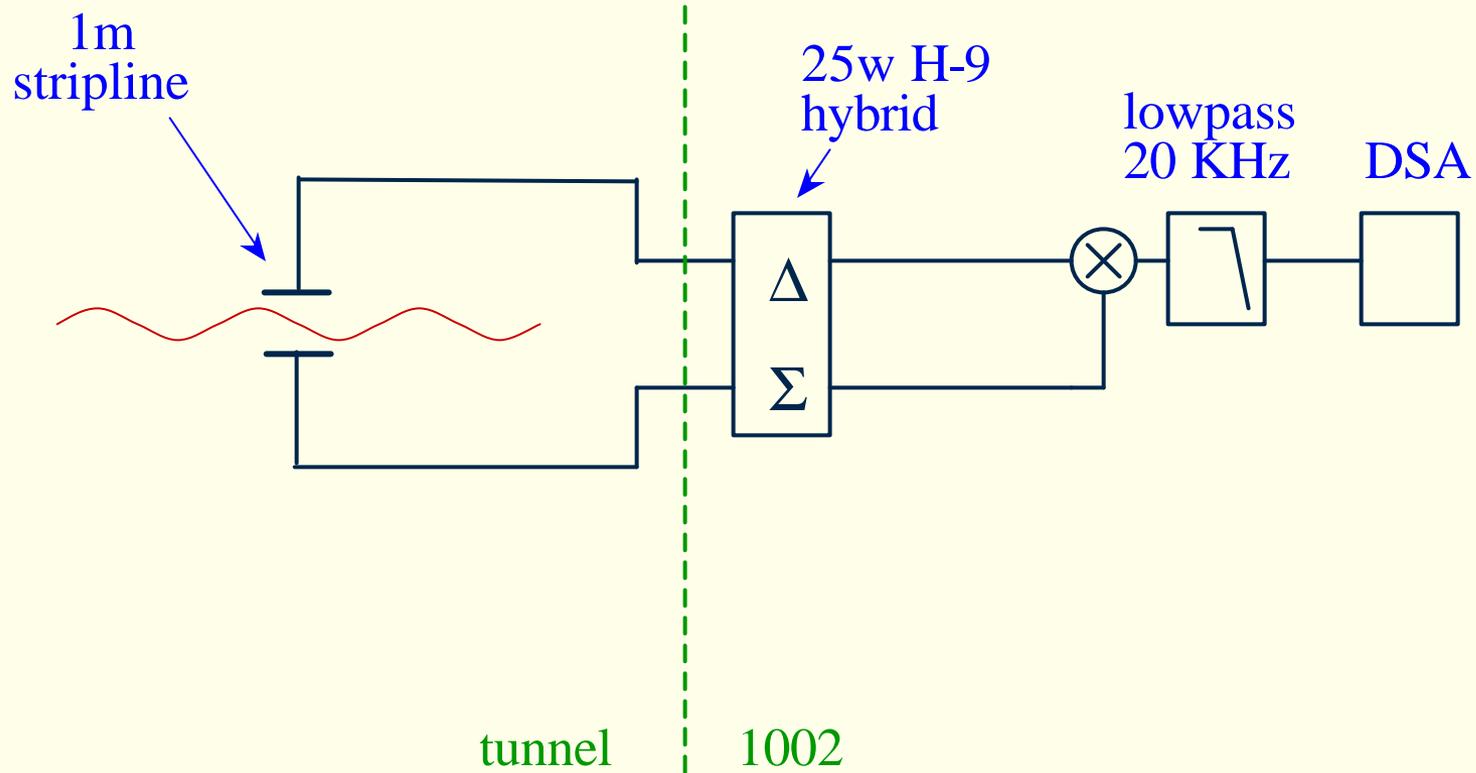


Mains supply

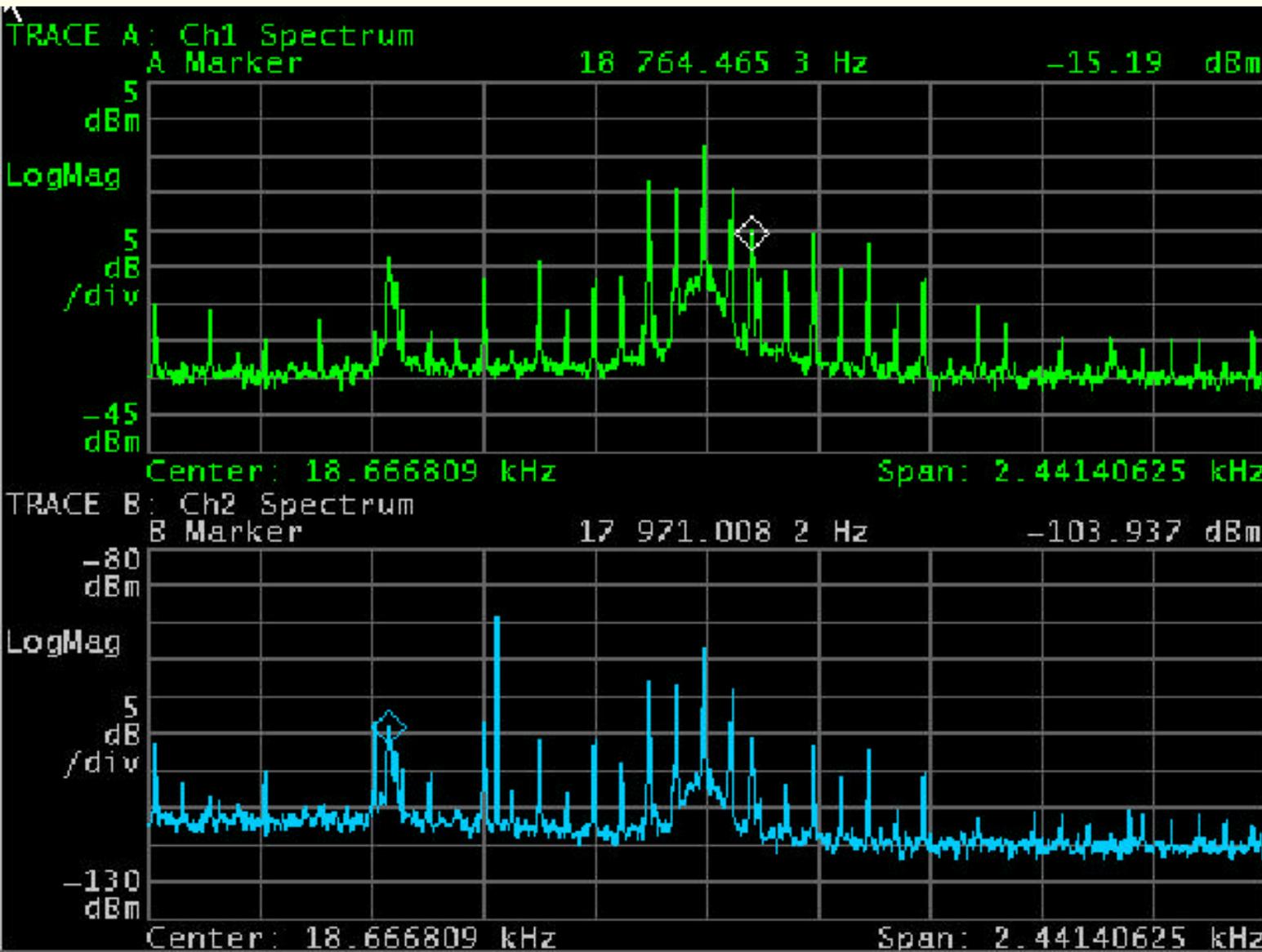


Batteries supply

Homodyne detection method



3D and Homodyne - 'identical'



3D

at store
37 bunches
200MHz on

hdyne

3D and 245MHz - need 200MHz RF!



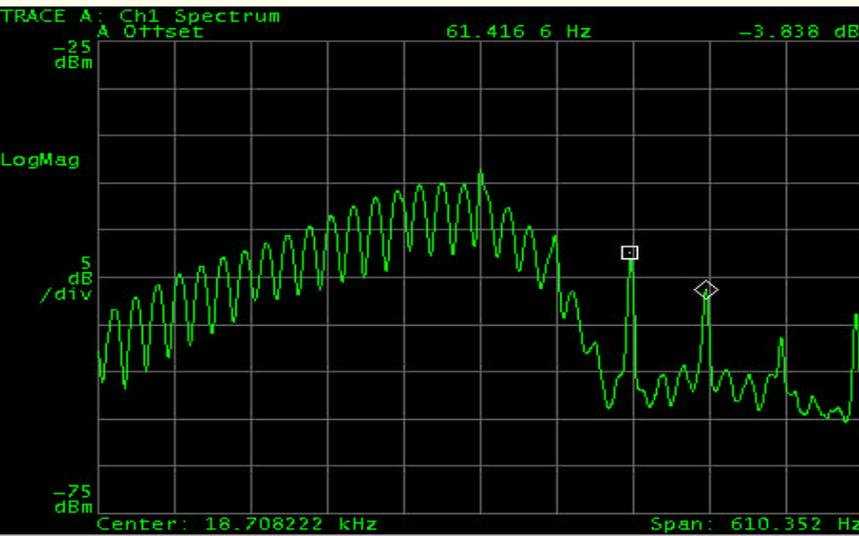
245



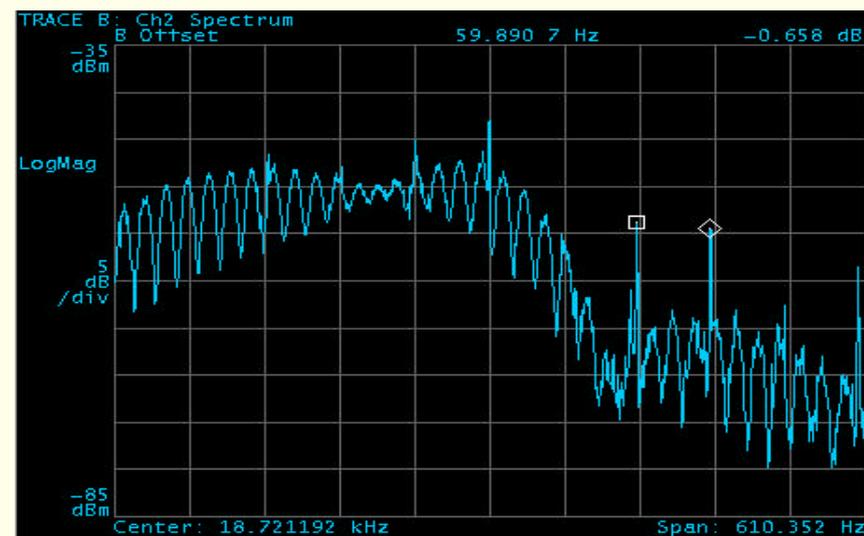
horiz

span 600Hz, 5dB/div on all

vert



3D

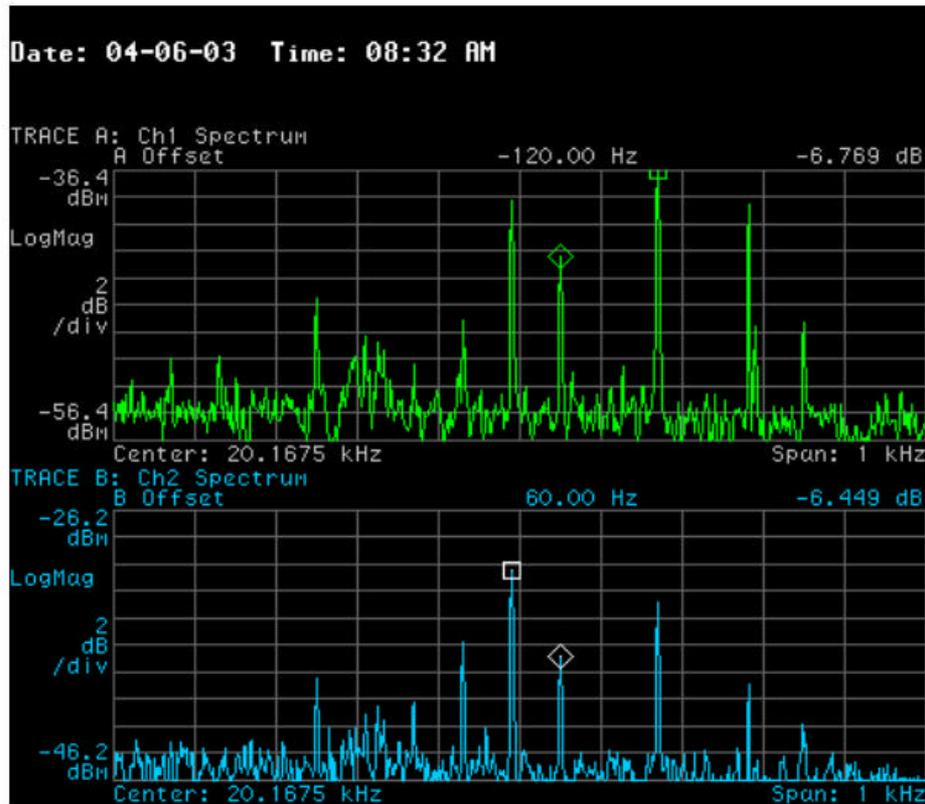


The Evolution

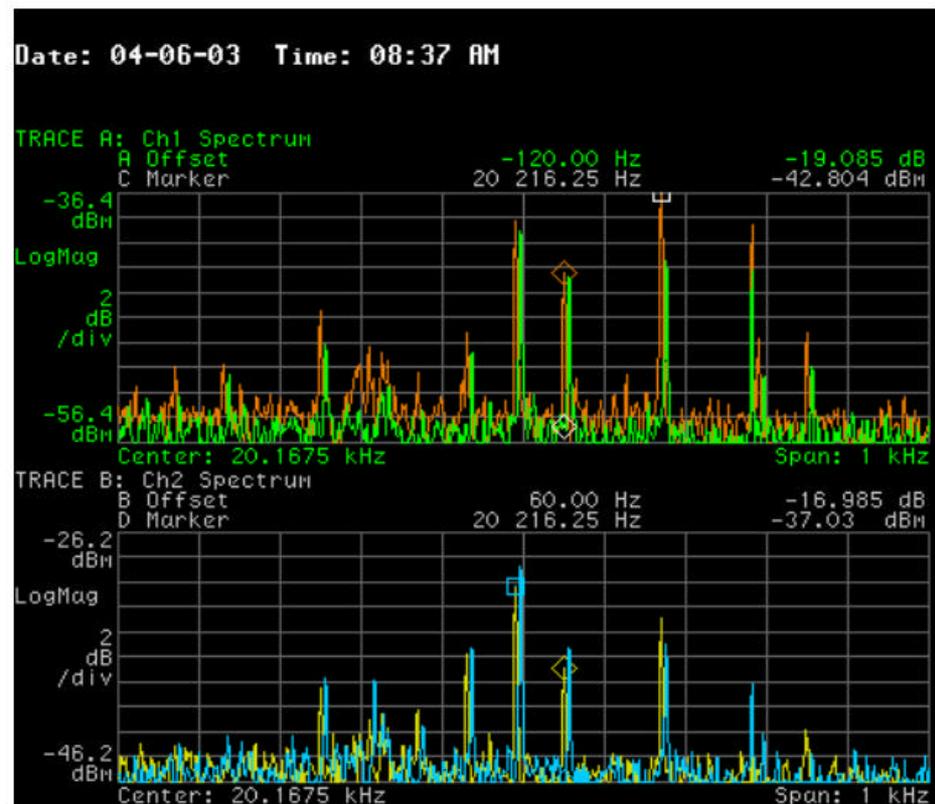


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Inserting 25MHz HPF (another store)

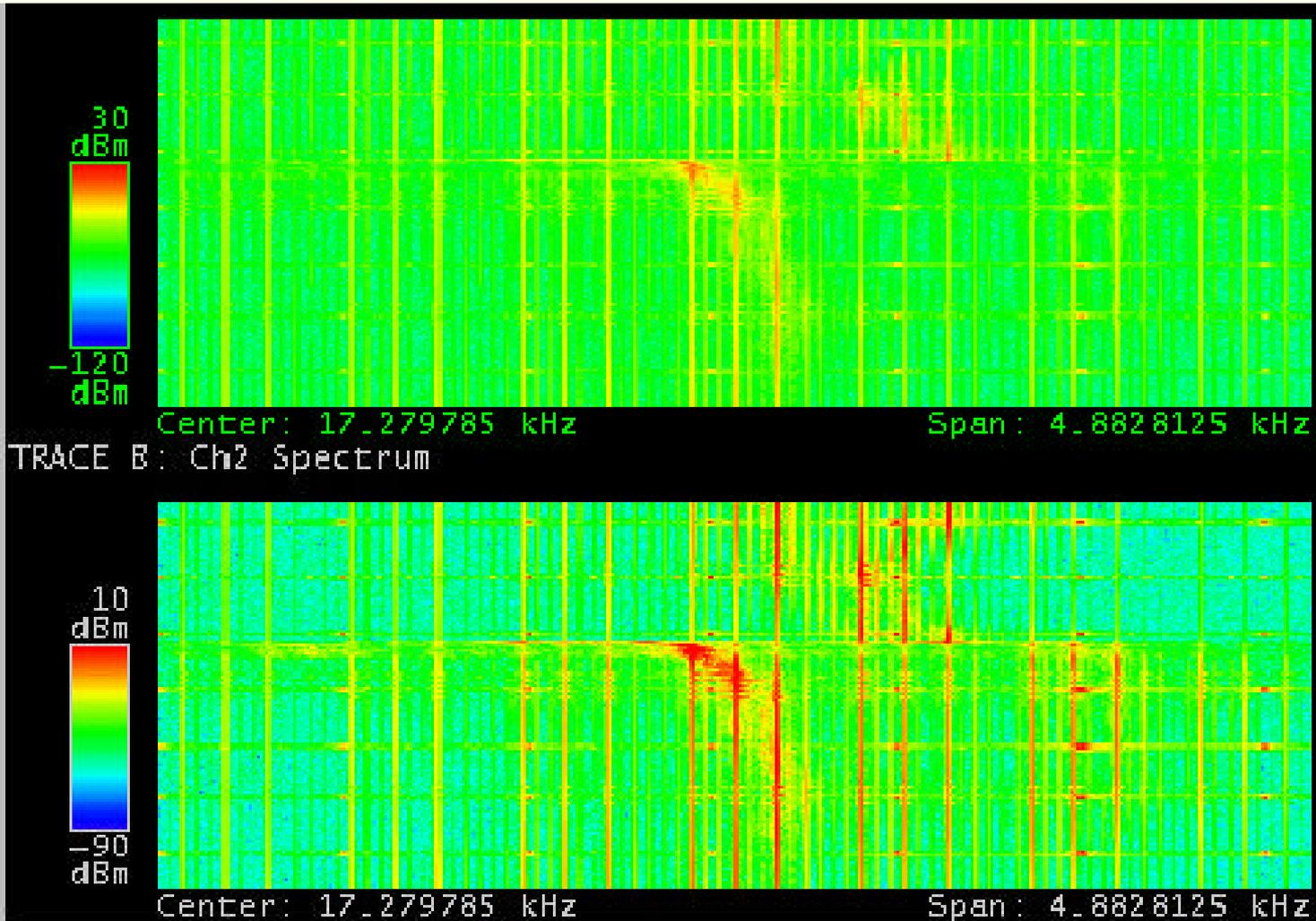


No filter



25 Mhz HPF

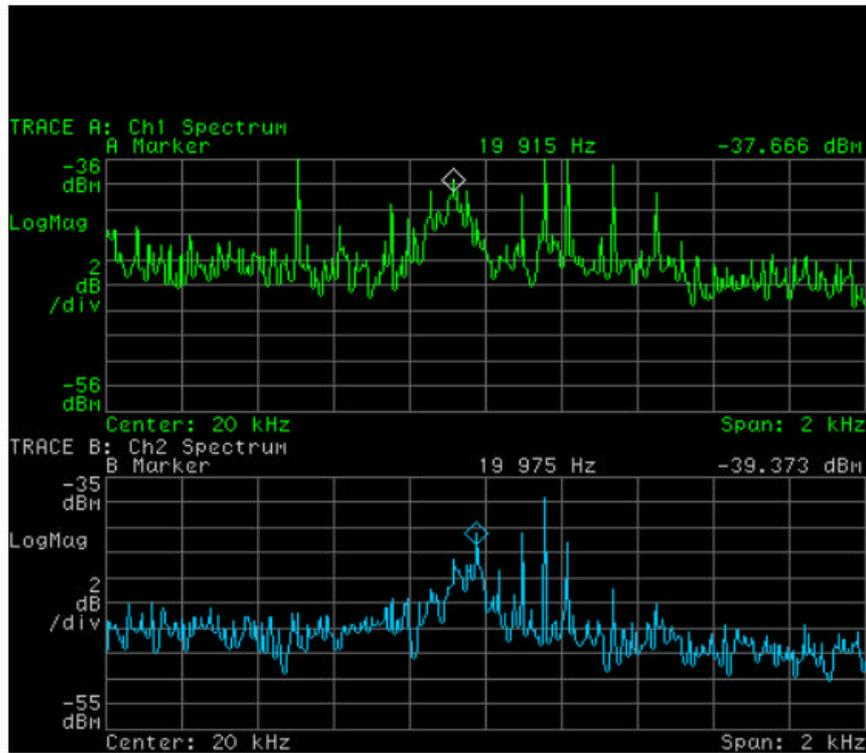
3D with 50MHz high pass



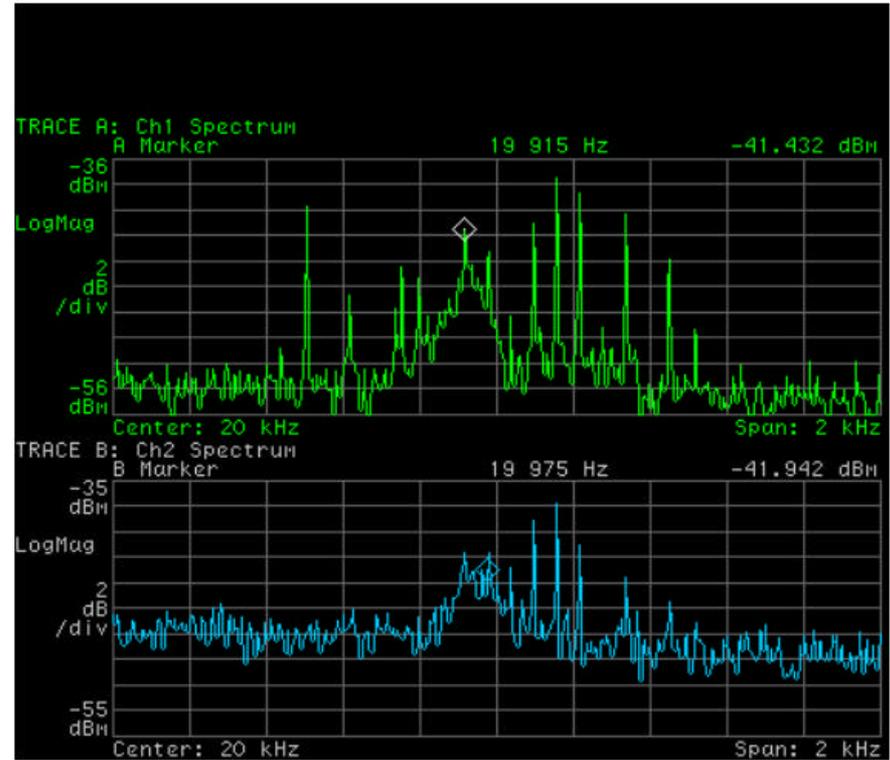
3D
horiz

3D
vert,
with 50MHz
hipass

Results of Adding 70MHz filter



No filter

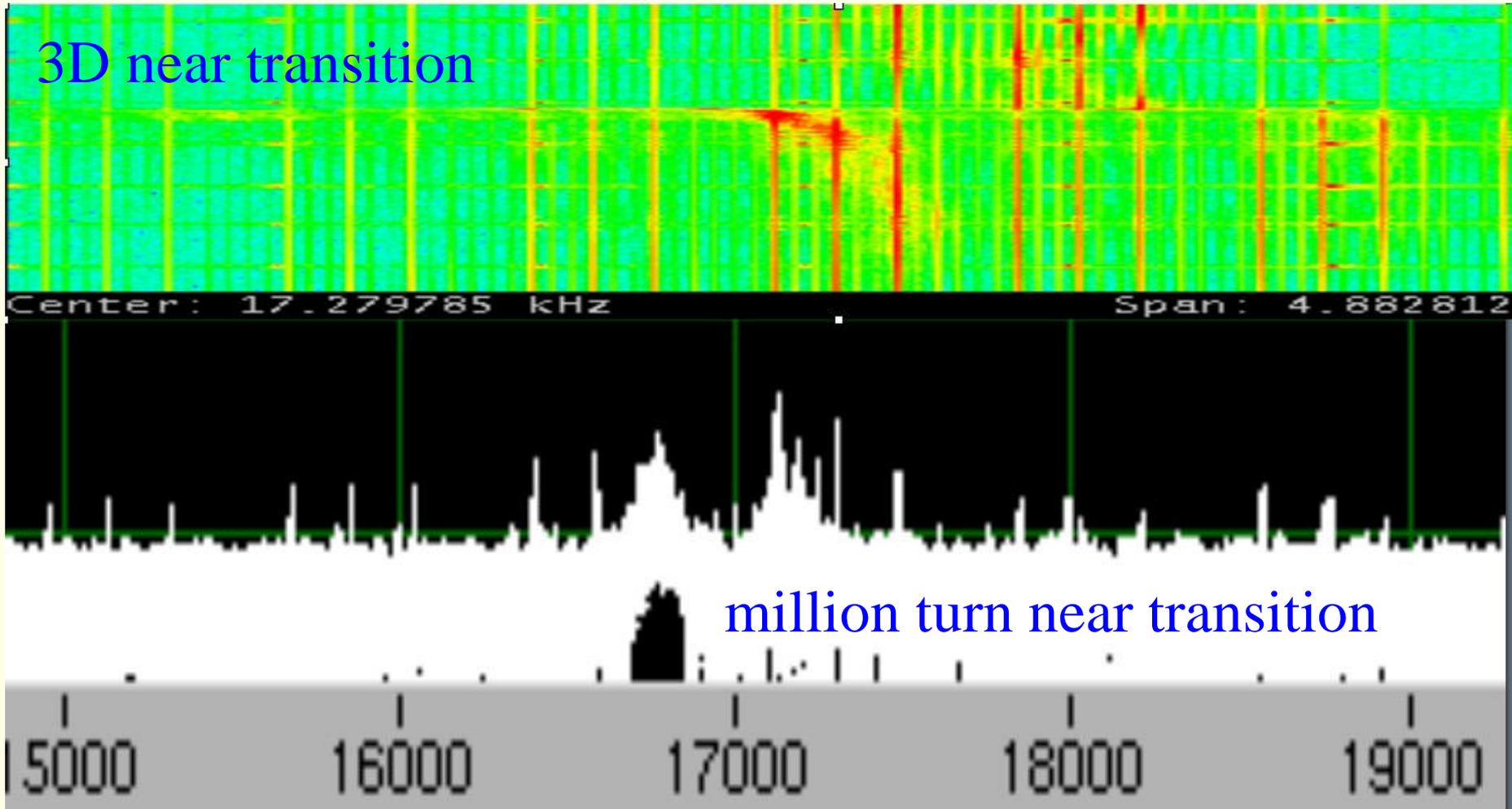


70MHz LPF

Million Turn BPM 1



3D near transition

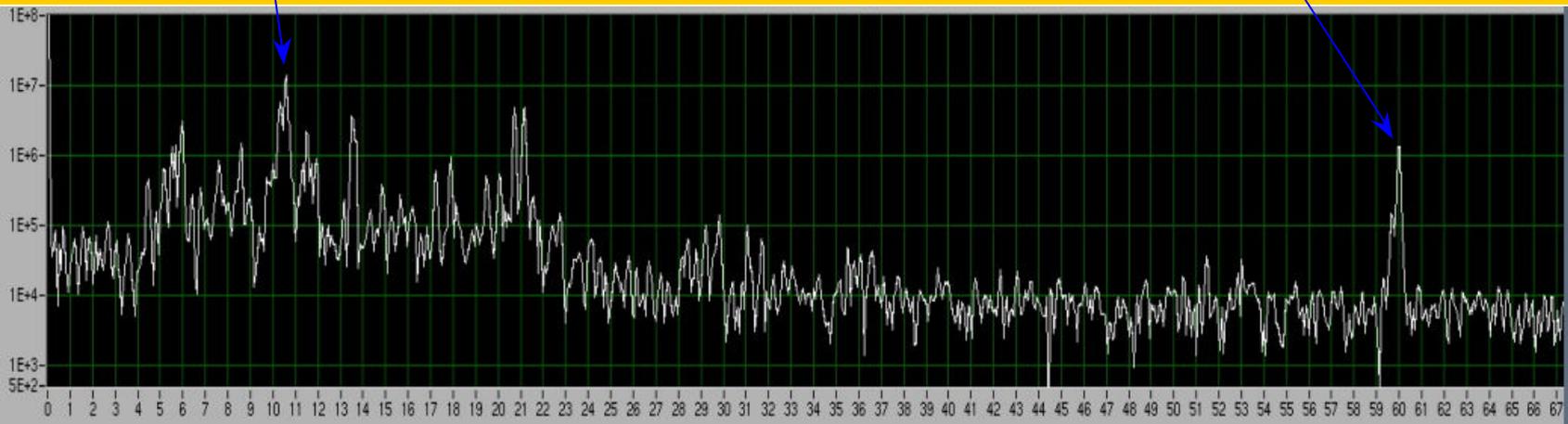


300 micron 10Hz
cryostat vibration
(0dB)

estimate ~5m at betatron line

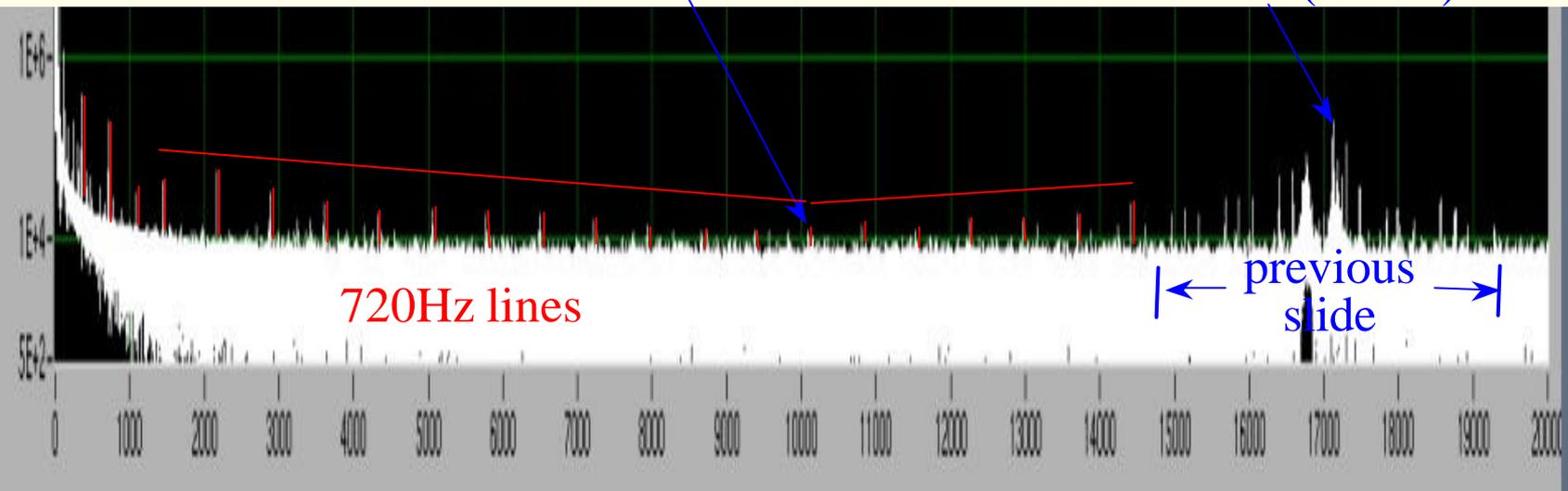


60Hz (-20dB)



720Hz x 14 (-60dB)

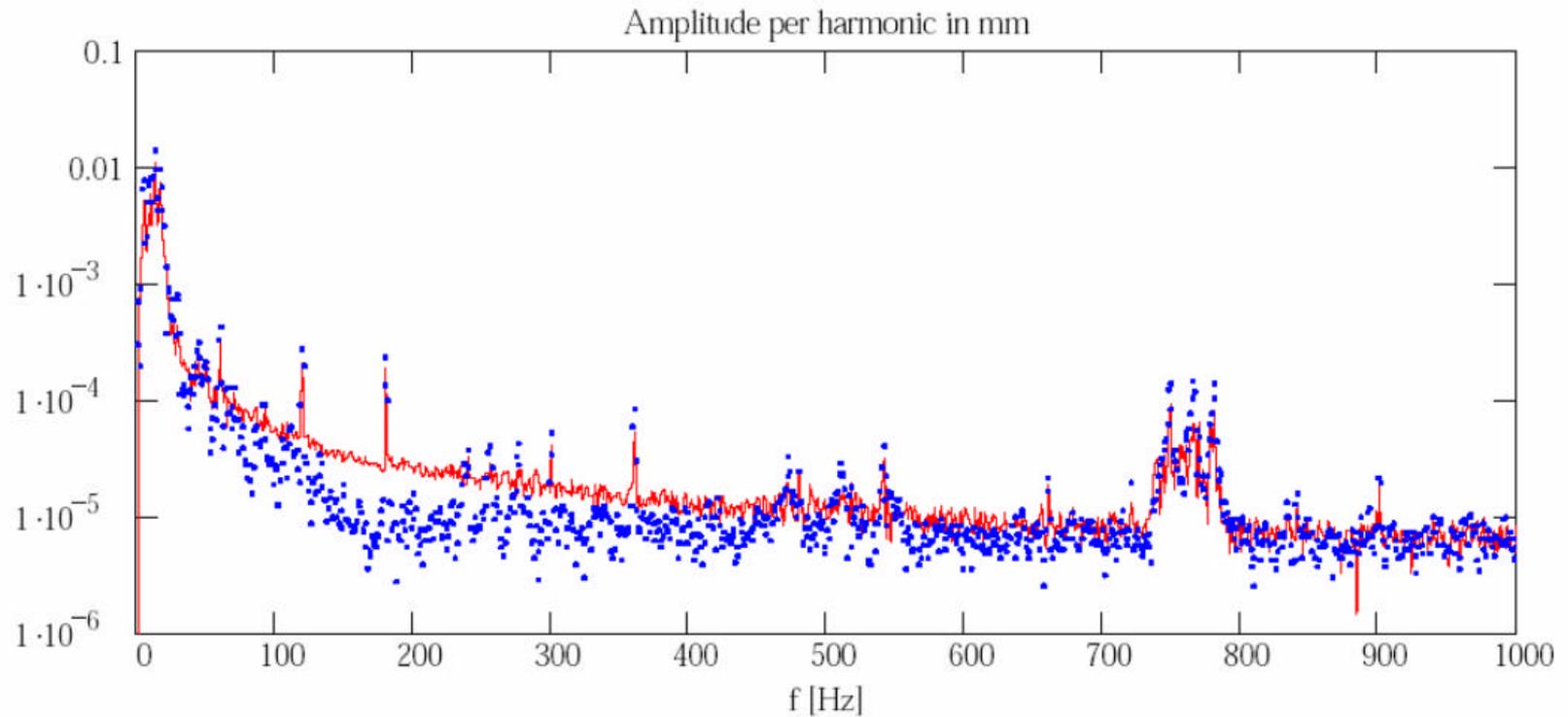
betatron line (-35dB)



TF Design Review 4-5 April 2005

also gives 3D resolution <~10nm

Position Spectrum (V. Lebedev, V. Scarpine, V. Ranjbar)

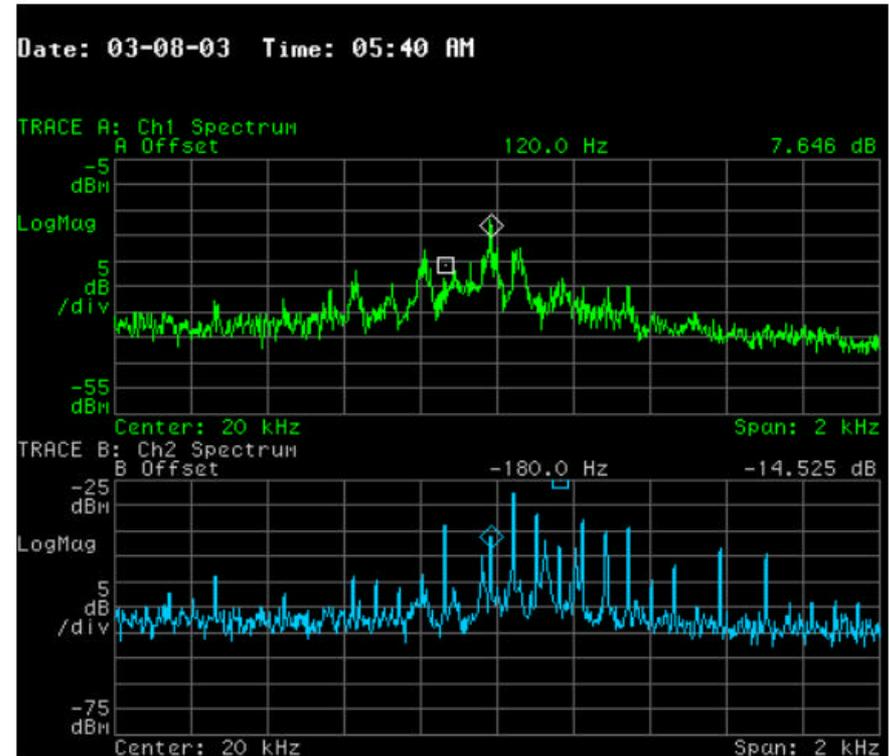
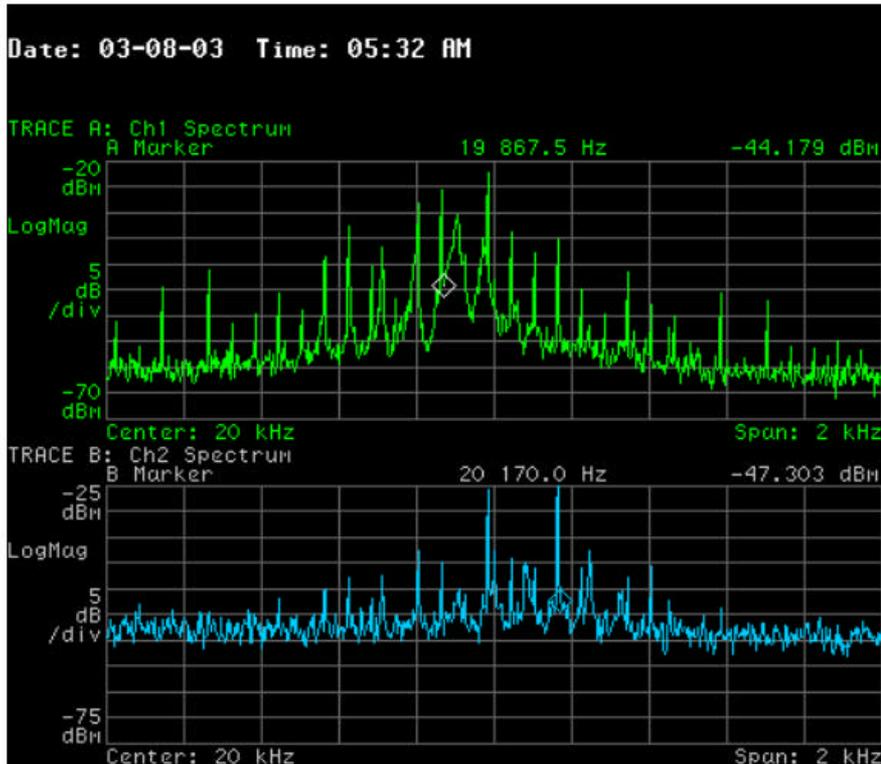


The Evolution



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36x0 at 150GeV (VTICK off)



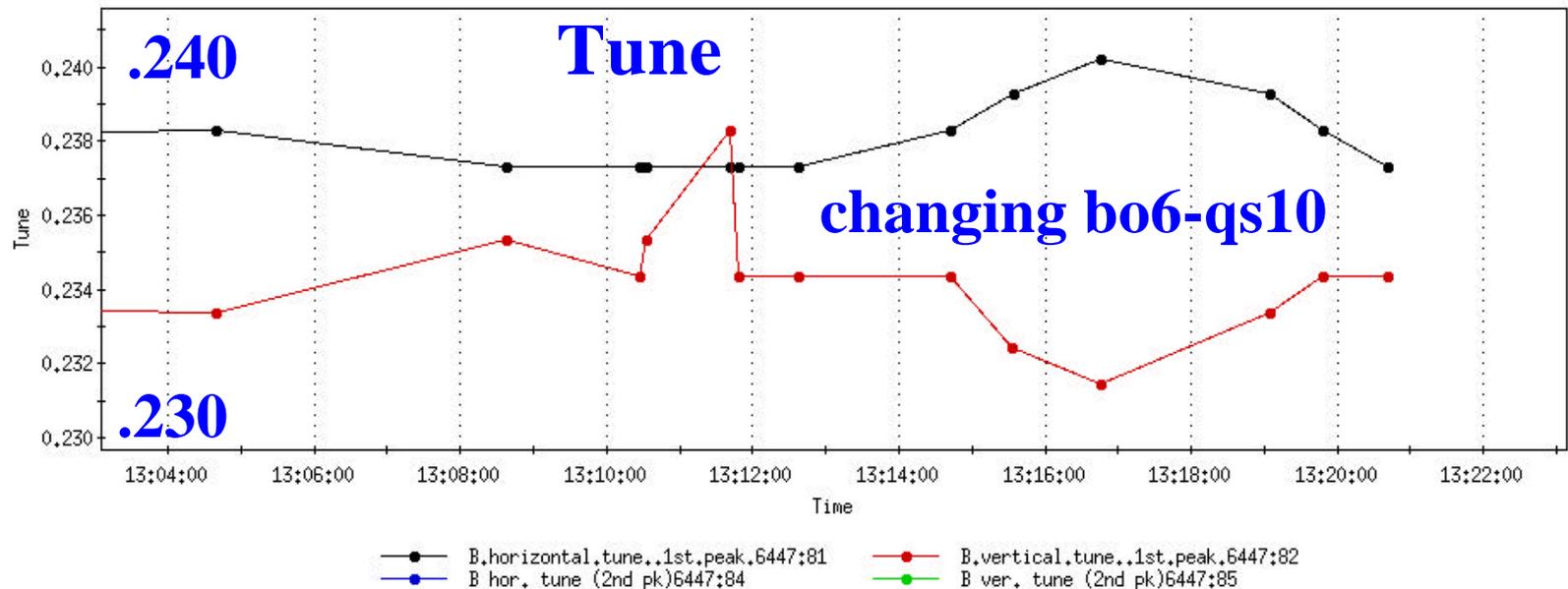
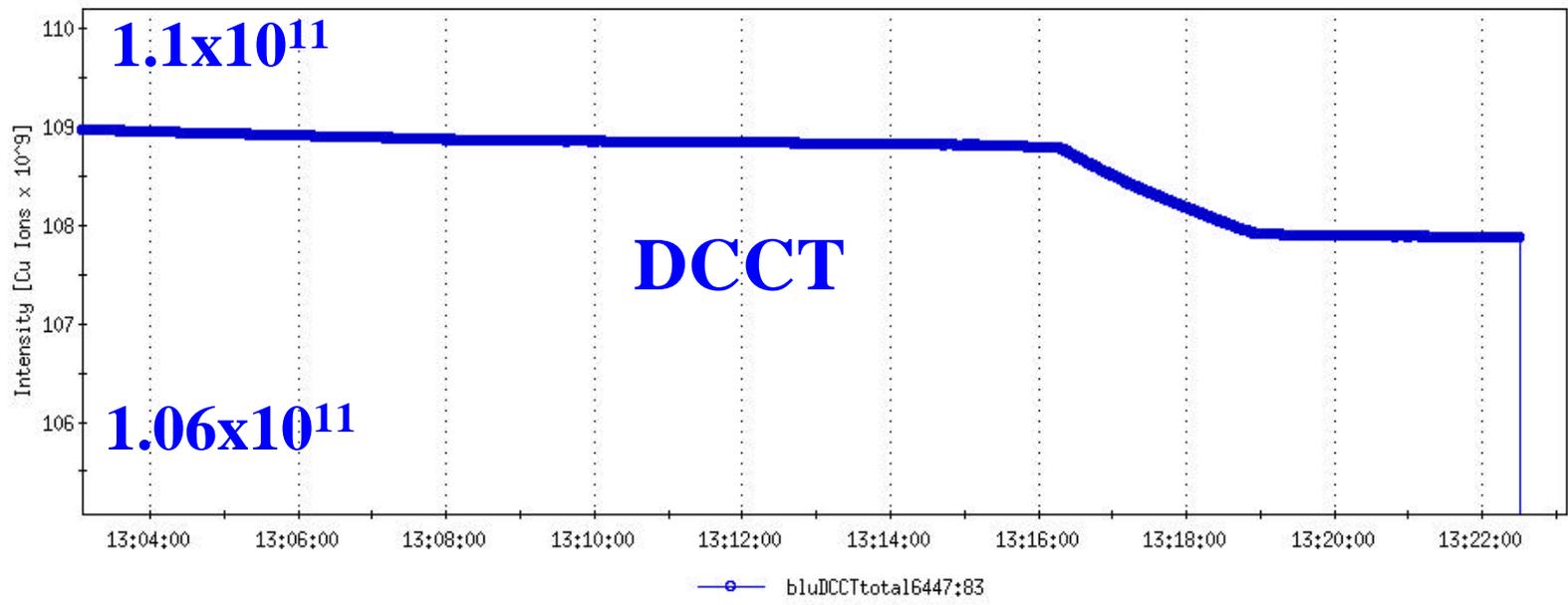
Helix off

Note: 60Hz lines disappears on helix for horz but not vert. Vert pos changes by approx -4mm and horz by +3mm. Electronics?

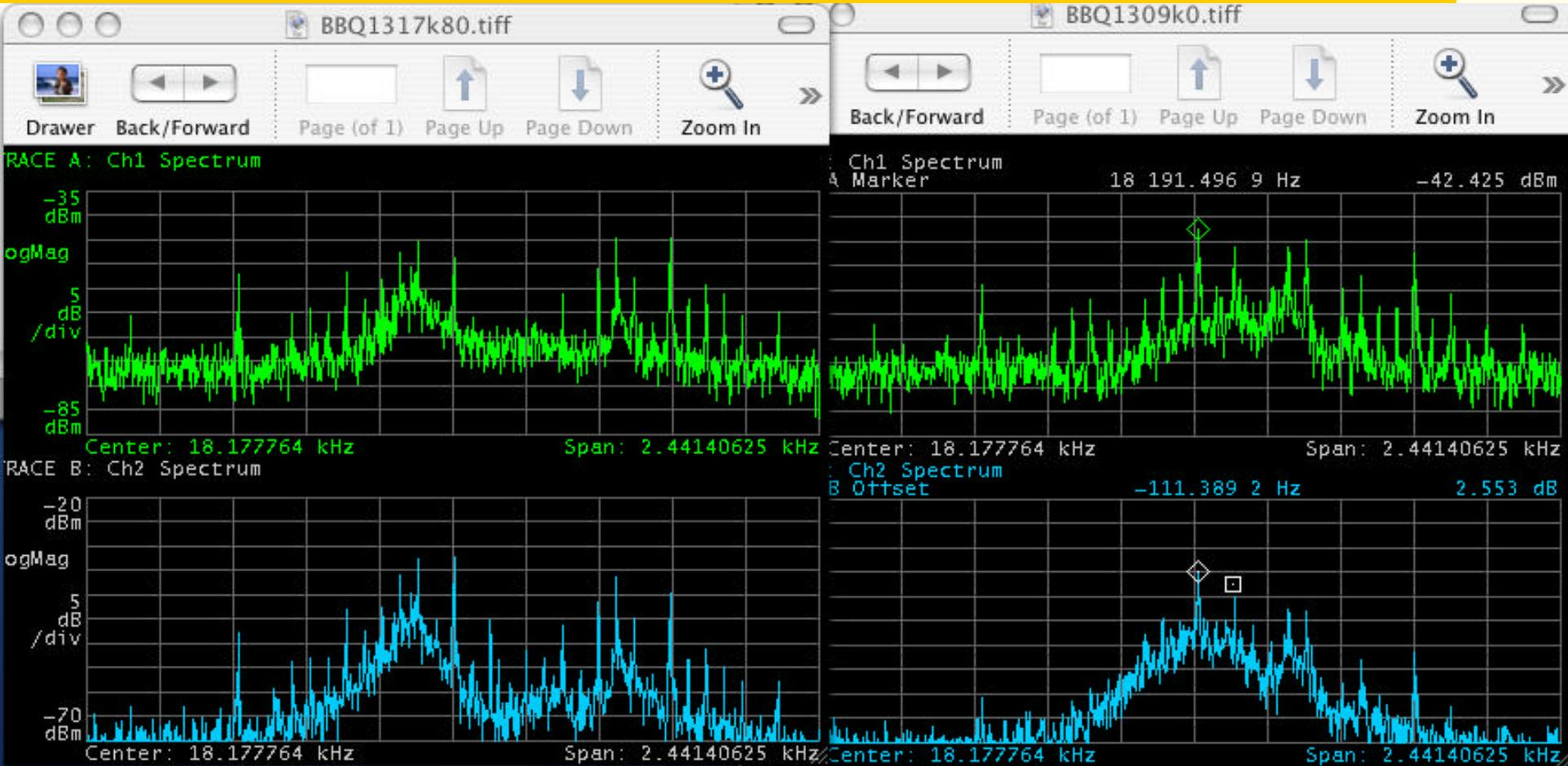
Helix on



Window Event



Effect of Coupling on Spectrum



$k = -0.0008$

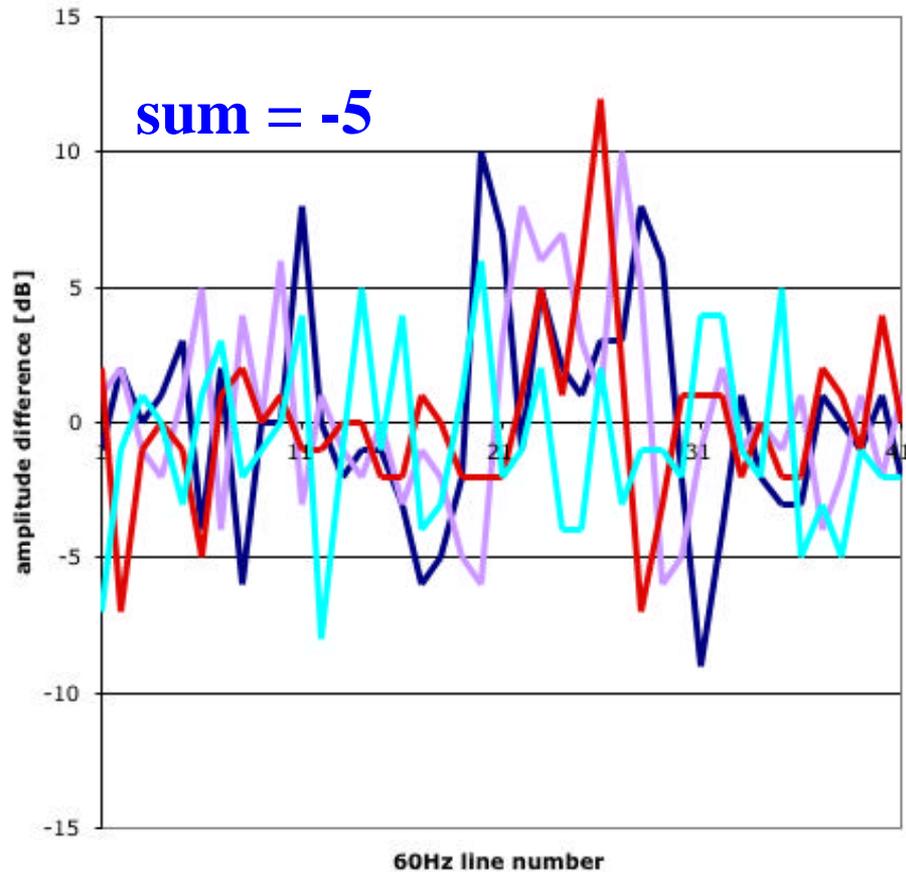
$k = 0$

TF Design Review 4-5 April 2005 upper is horiz, lower vert

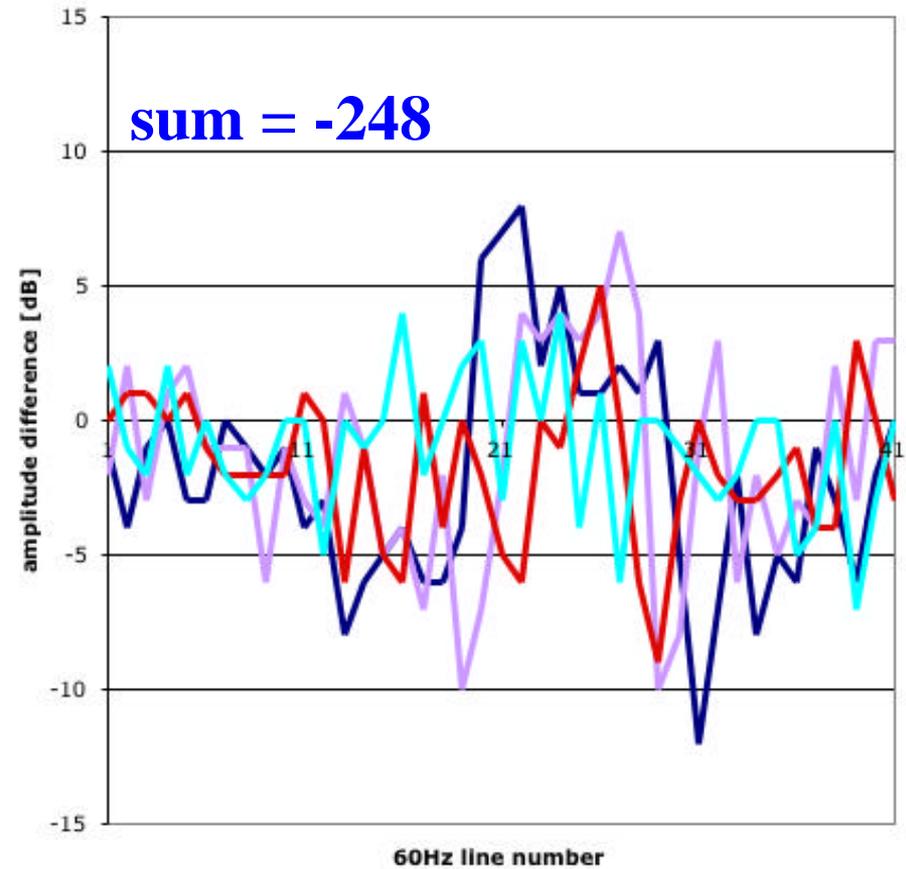
Coupling difference



Variation of Line Strength with Coupling - Horizontal



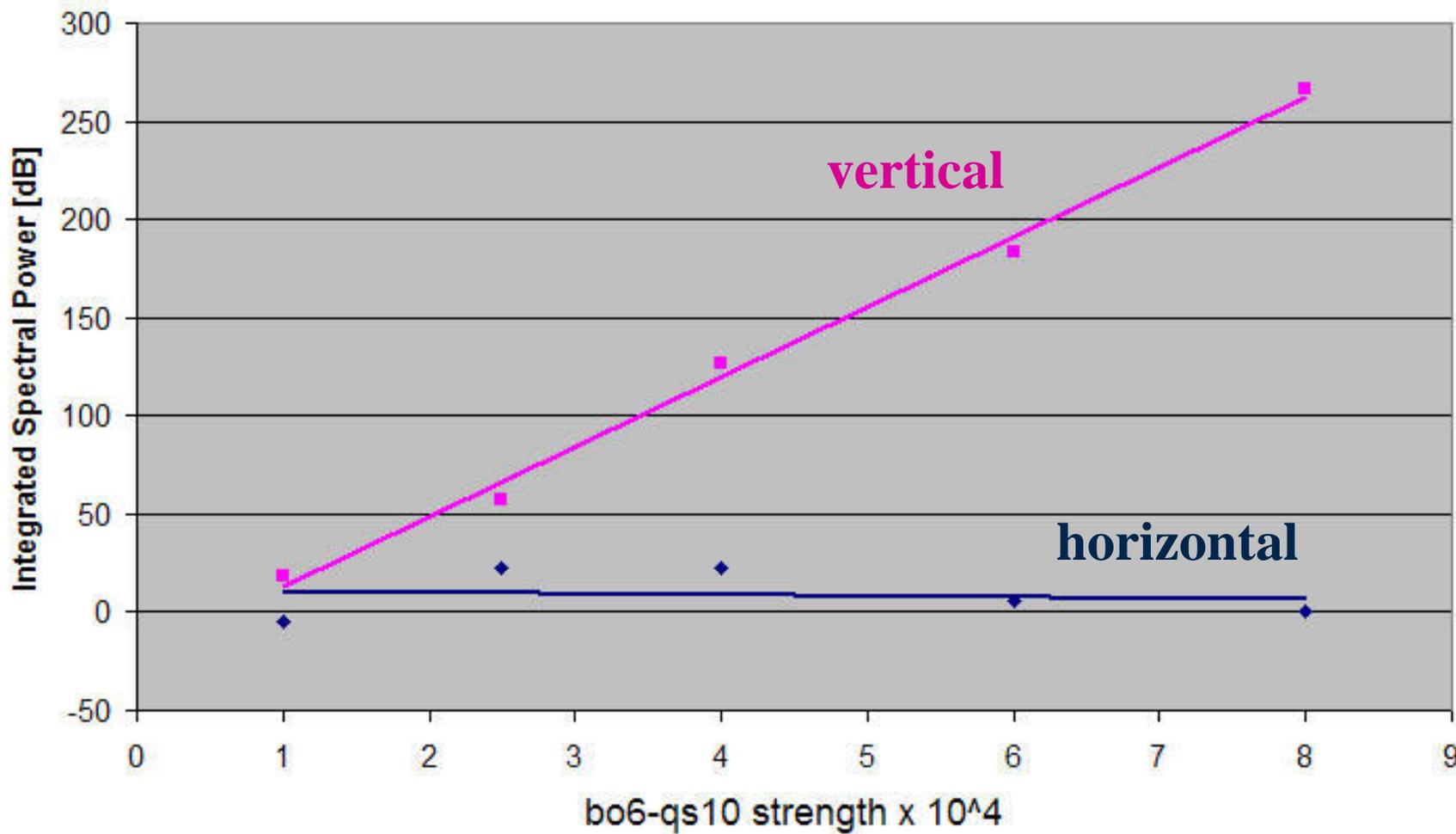
Variation of Line Strength with Coupling - Vertical



coupling 60Hz plot

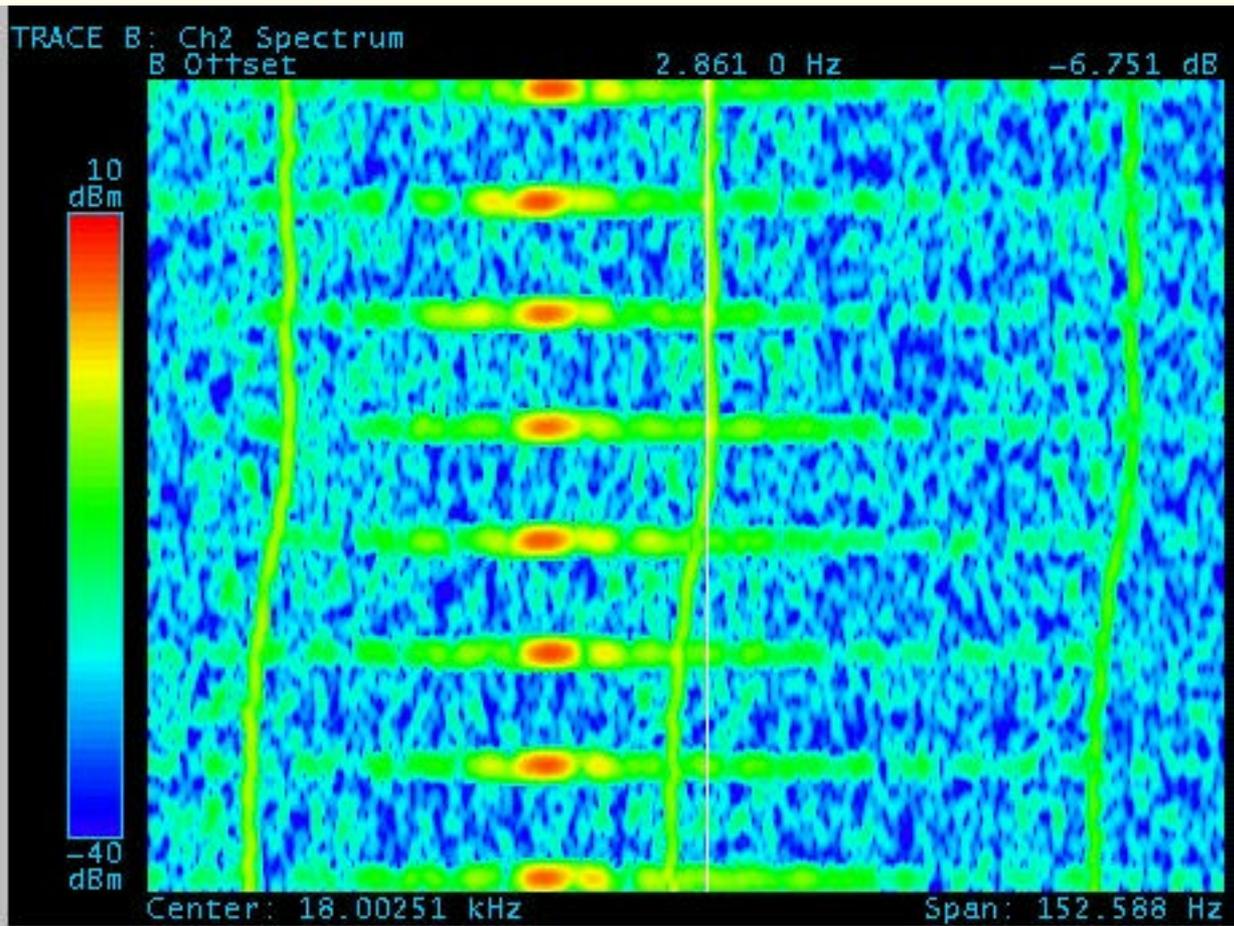


Variation of Integrated Linestrength with Coupling





60Hz lines move (but not sidebands)!



over 30 seconds,
variation is $\sim 3\text{Hz}$ at
 $h \sim 300$, or 0.01Hz at
 60Hz

span = 152Hz

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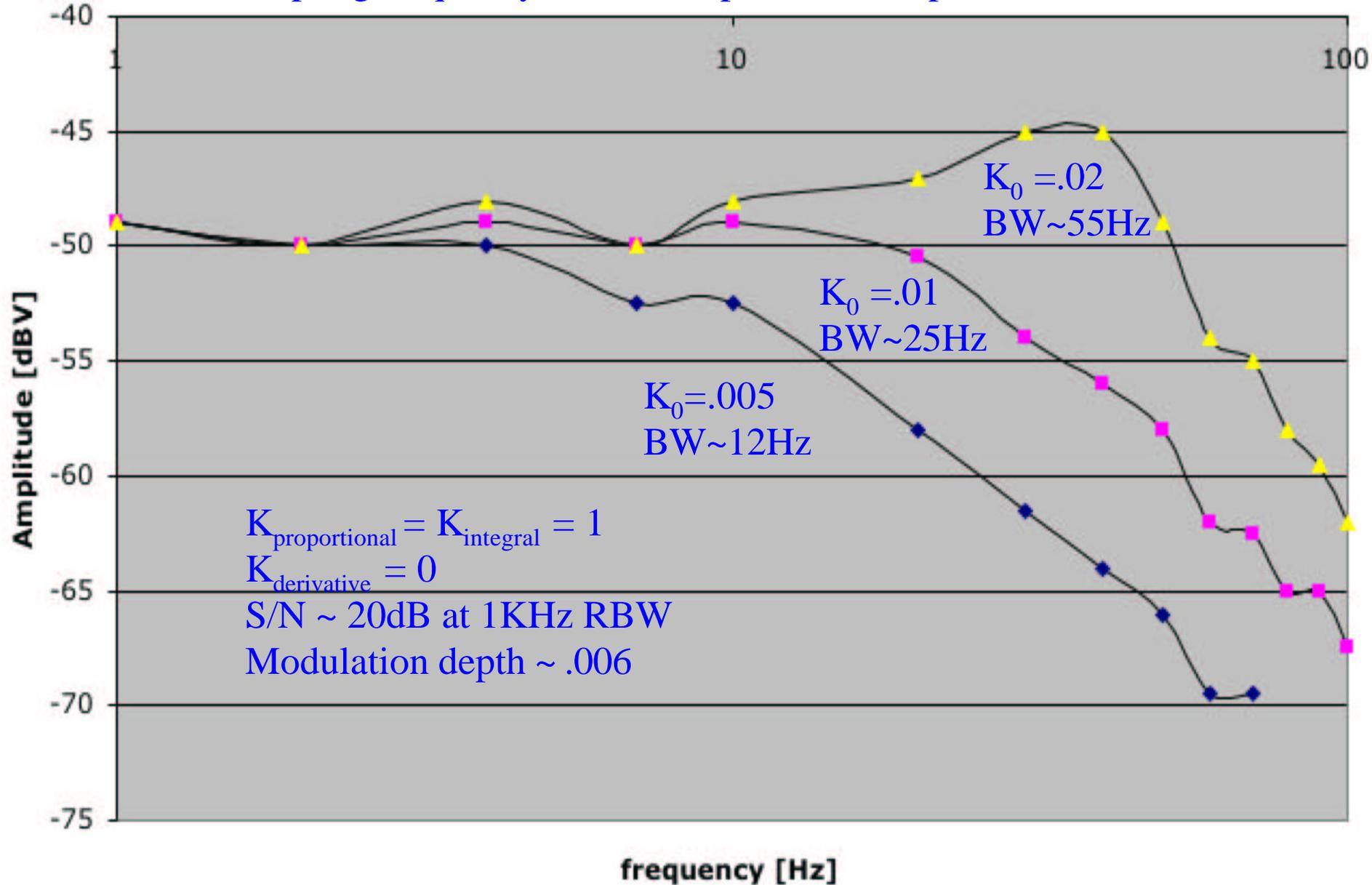
Testing without Beam



- pre-beam testing is essential to begin sorting out approaches to 60Hz problem
- we have good validated mathcad model
- modulated resonator for testing
- can also mix in 60Hz harmonics

PLL Closed Loop Response

Sampling frequency 1777Hz, 3 pole IIR low-pass filter at 100Hz



Plane Selection

Blue Horizontal

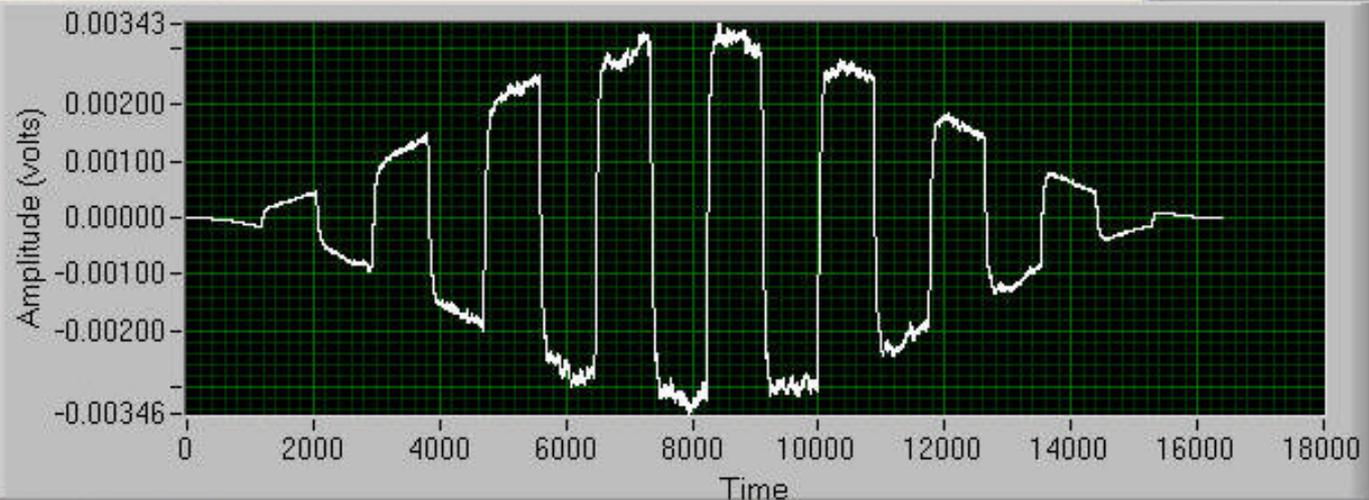
$K_0 = .005$

1Hz square wave

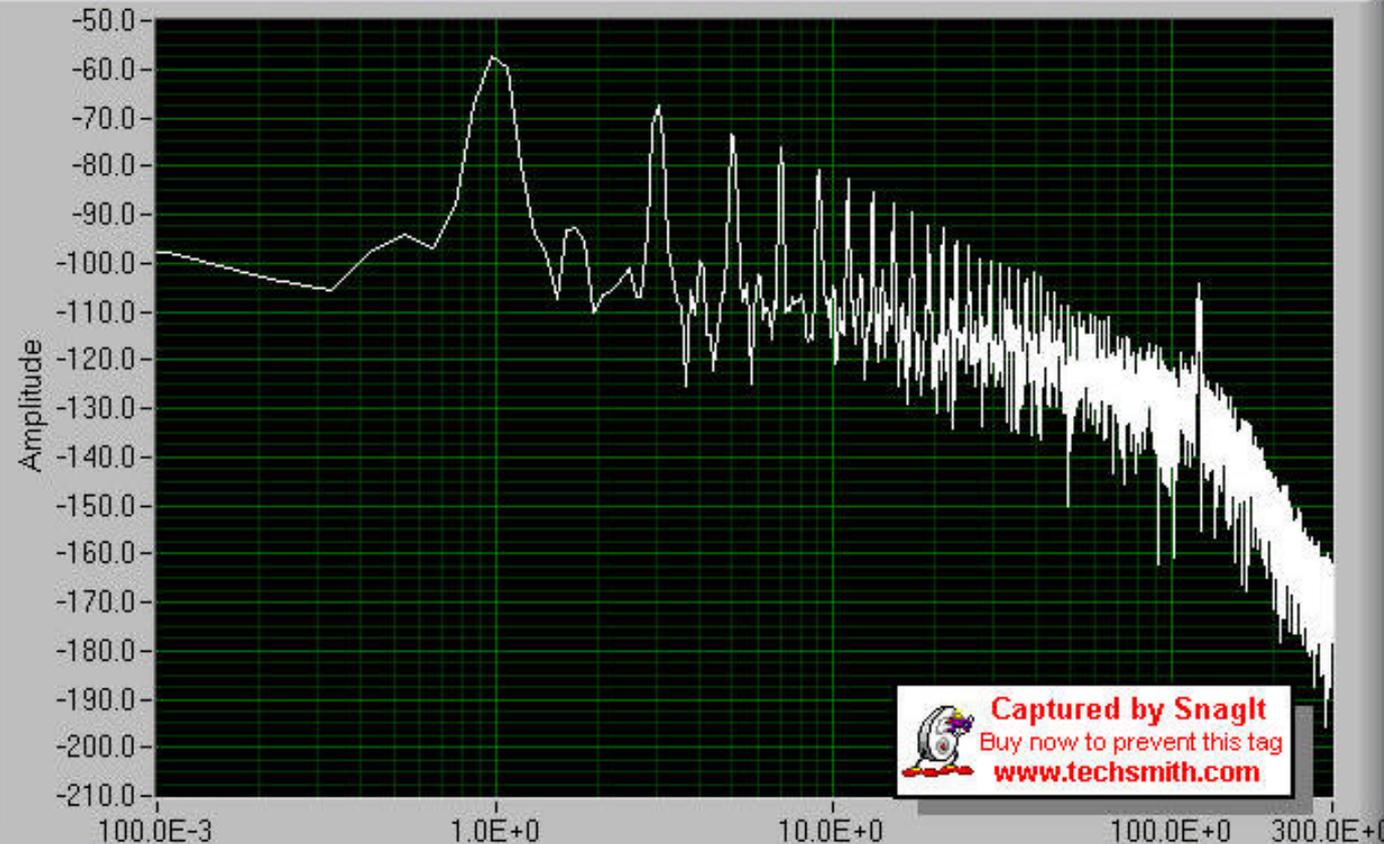
BW ~ 12Hz

Slight undershoot

Dither ~ .0002



Power Spectrum



Spectrum Unit dBVrms

Sample Rate

1777.00

Log/Linear

dB

display unit

Vrms

window

Hanning

Est Freq peak

1.0075

Est Power peak

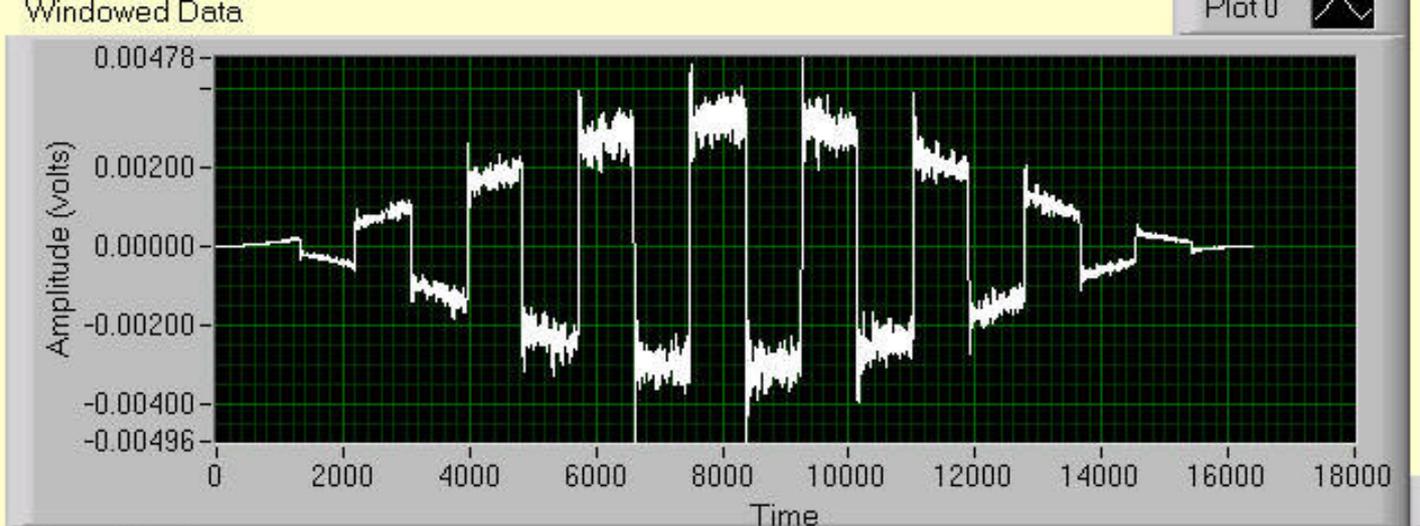
0.0000

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Plane Selection

Blue Horizontal

$K_0 = .02$
1Hz square wave
BW ~ 55Hz
Significant overshoot
Dither ~ .001



Spectrum Unit dBVrms

Sample Rate

1777.00

Log/Linear

dB

display unit

Vrms

window

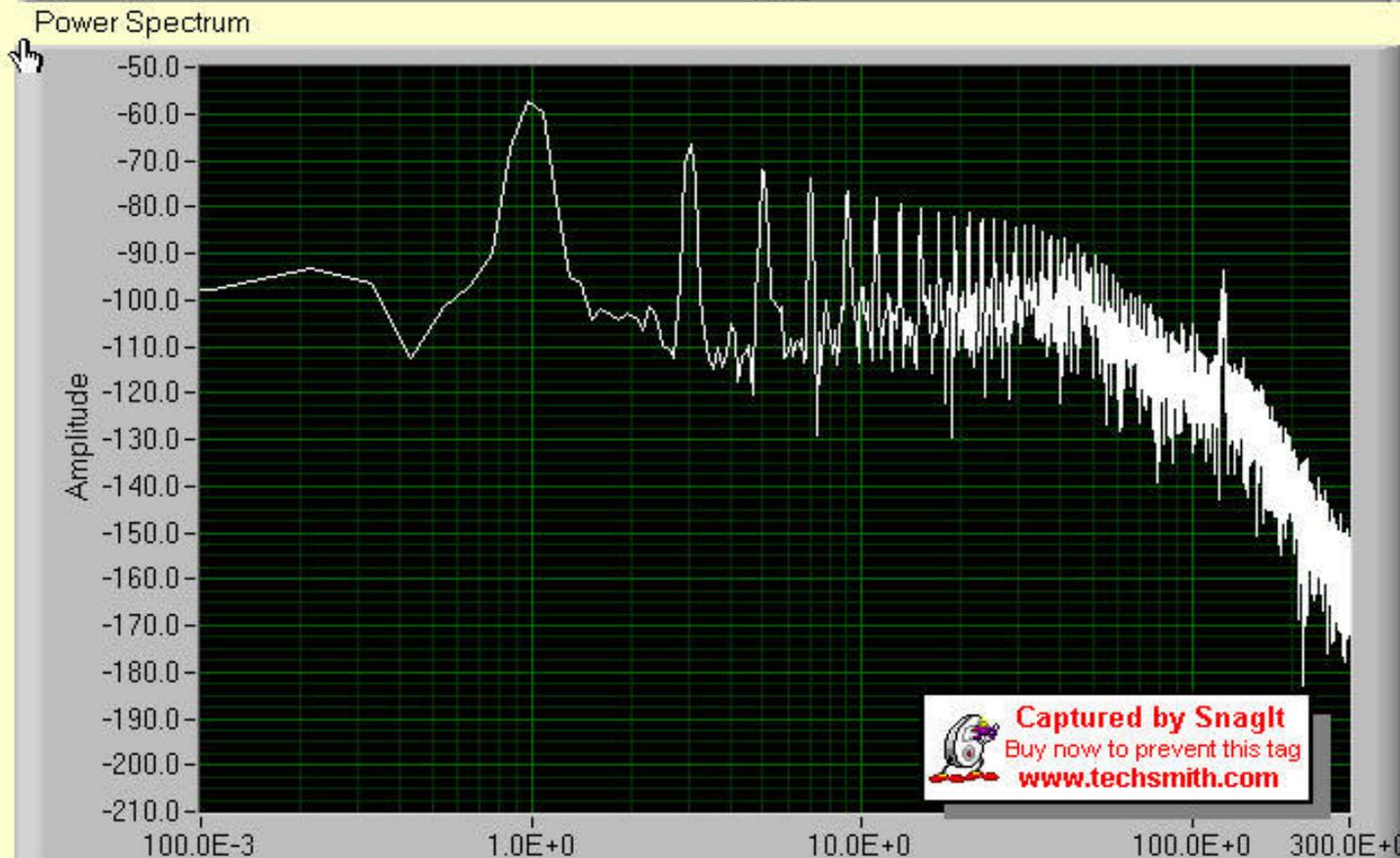
Hanning

Est Freq peak

1.0073

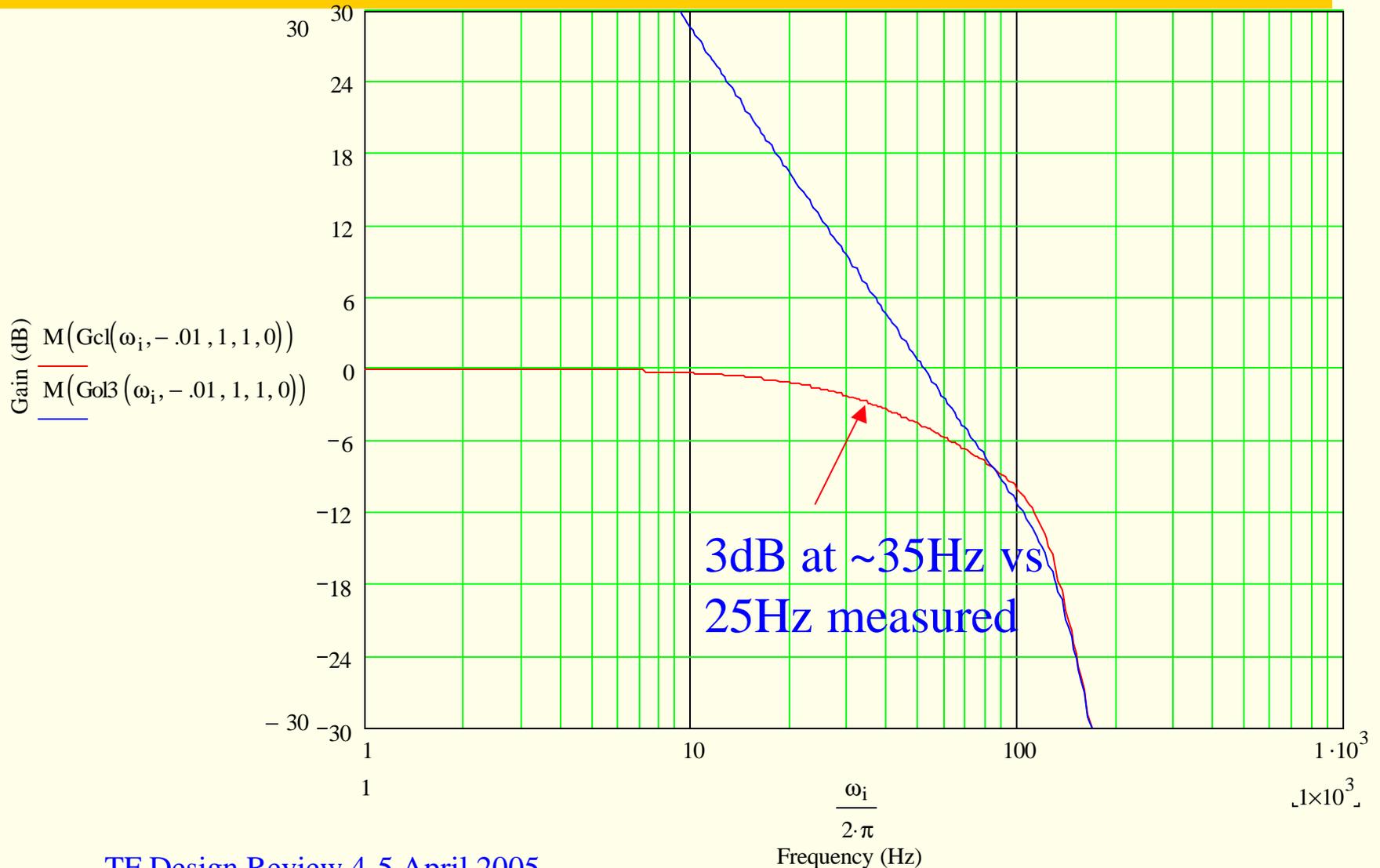
Est Power peak

0.0000



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Magnitude of open and closed loop gains



Conclusions



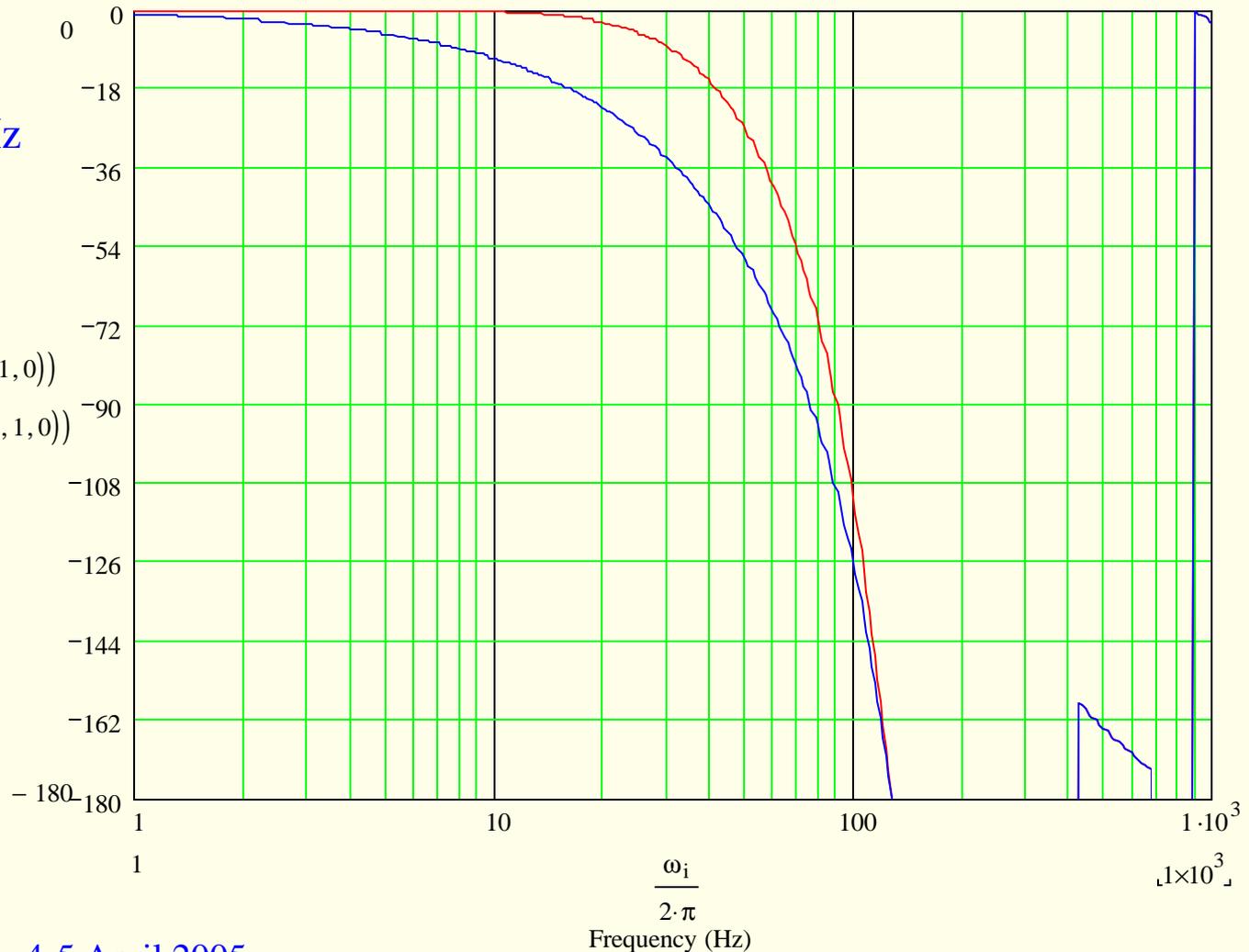
- 60Hz harmonics **are** on the beam
- Statement of excellent sensitivity of BBQ (and million turn BPM)
- It is at baseband, will show up everywhere in the spectrum - we can't escape it
- Required modulation of dipole current at harmonic ~ 300 is actually pretty small - one part in 10^{11}
- High Priority - 720Hz balancing circuit
- pre-beam modeling and testing is essential

Phase of open and closed loop gains



90 degrees at 90Hz
180 degrees at 130Hz

Gain (dB) $\Phi(G_{cl}(\omega_i, -0.01, 1, 1, 0))$
 $\Phi(G_{ol3}(\omega_i, -0.01, 1, 1, 0))$



Plane Selection

Blue Horizontal

Sum

2.88

$K_0 = .01$

1Hz square wave

BW ~ 25Hz

No overshoot

Dither ~ .0004

Spectrum Unit dBVrms

Sample Rate

1777.00

Log/Linear

dB

display unit

Vrms

window

Hanning

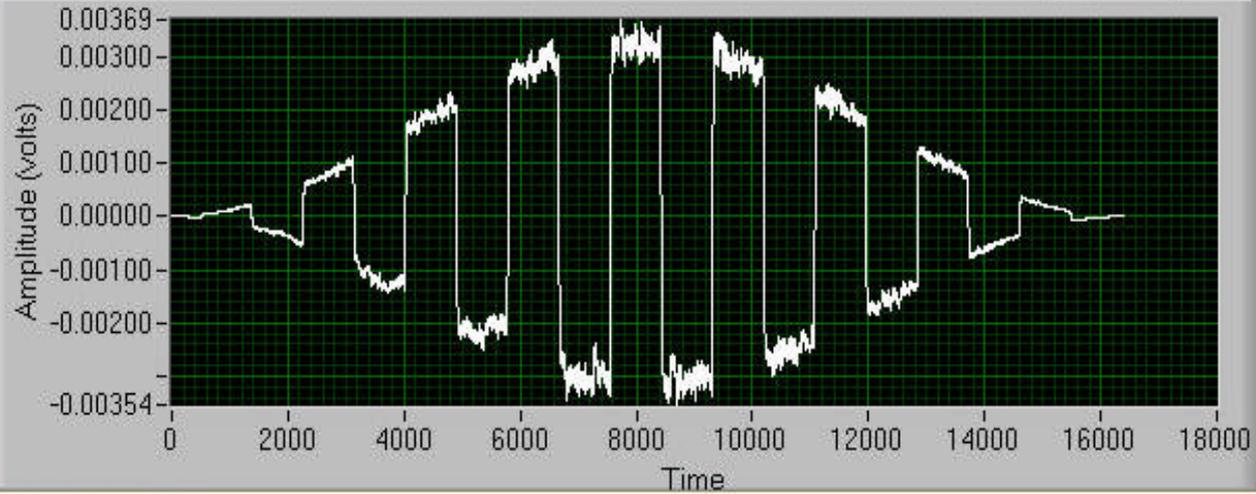
Est Freq peak

1.0063

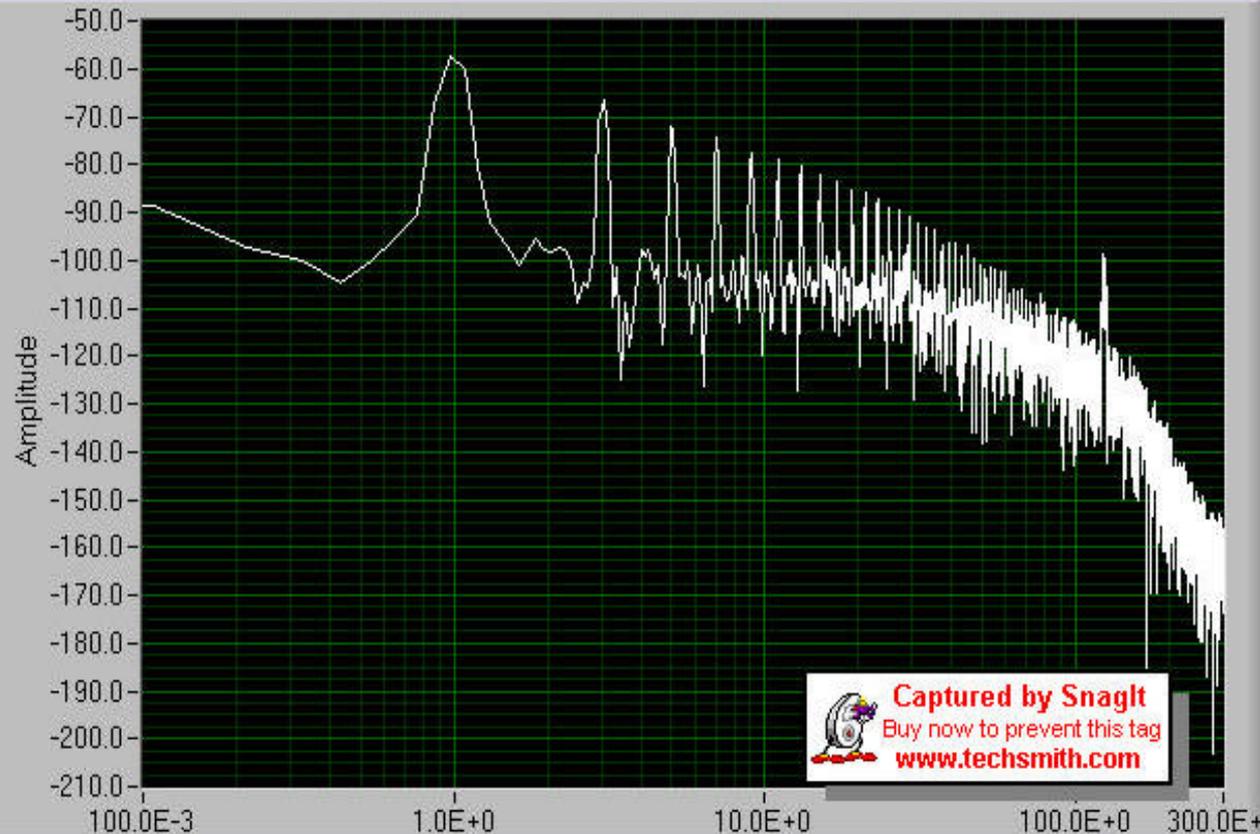
Est Power peak

0.0000

Windowed Data



Power Spectrum



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