# RF Measurements: Techniques and Data

CWRF 2010
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With help from Hengjie Ma and in collaboration with
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# Original talk was to be
# "Experience with the RF Systems at NSLS-II


But as you can see we are not quite ready………

# Outline

- Motivations
- Traditional  RF phase measurements on a seeded FEL RF system and on the Canadian Light Source
  - Measurements with Spectrum/dynamic spectrum analyzer
  - Mixer measurements with digital scope and post processing on the PC
- Digital cavity controller based measurements
- Summary

# Motivations

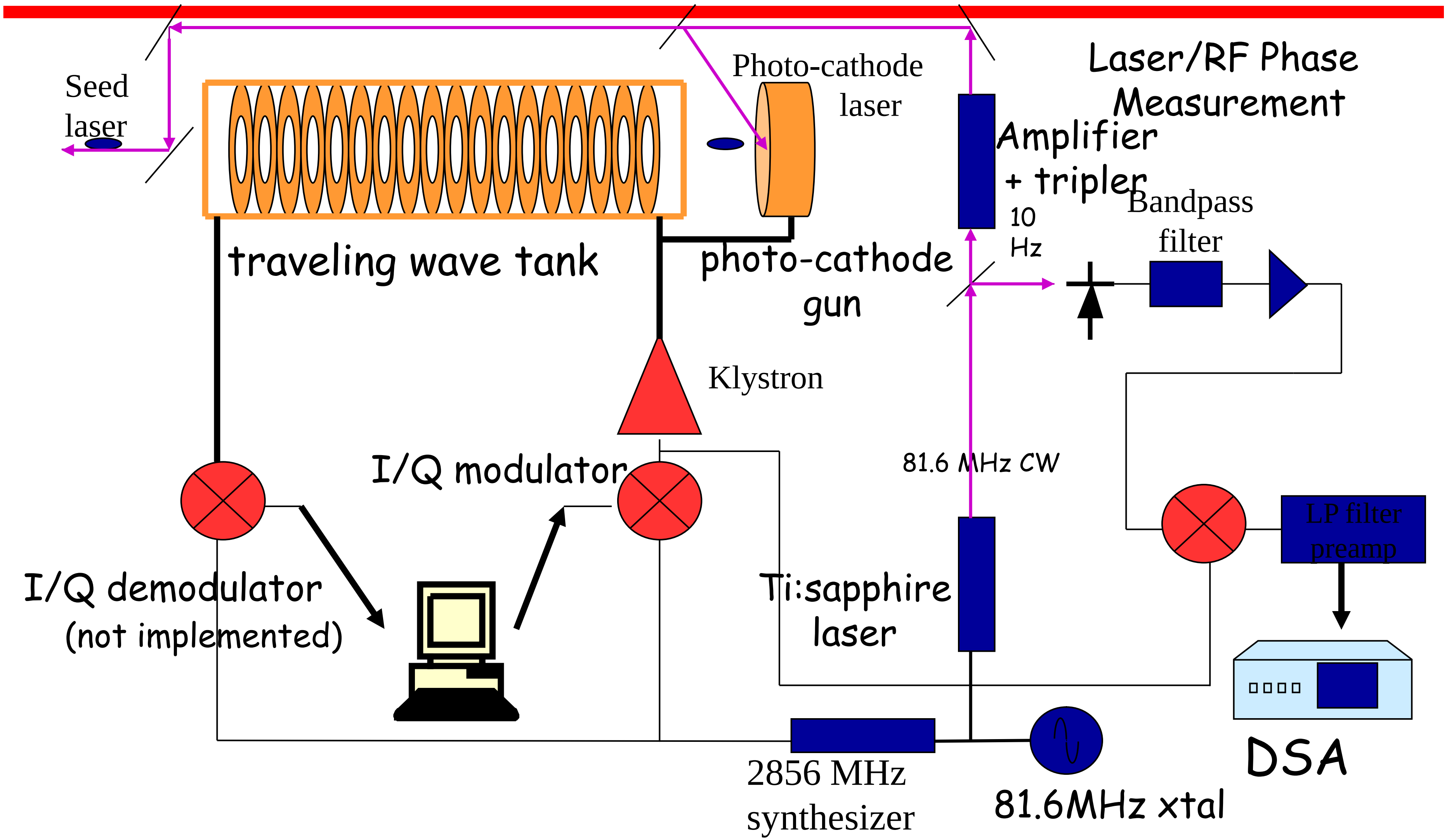
The NSLS-2 program has requirements of <0.15 degree phase jitter; need to characterize potential RF sources.

- Solid state and IOT have better phase jitter performance than the klystron with its large cathode voltage-to-RF phase transfer function. Since the NSLS-2 is a virtual machine, we went to CLS to measure the klystron amplifier to quantify the phase jitter

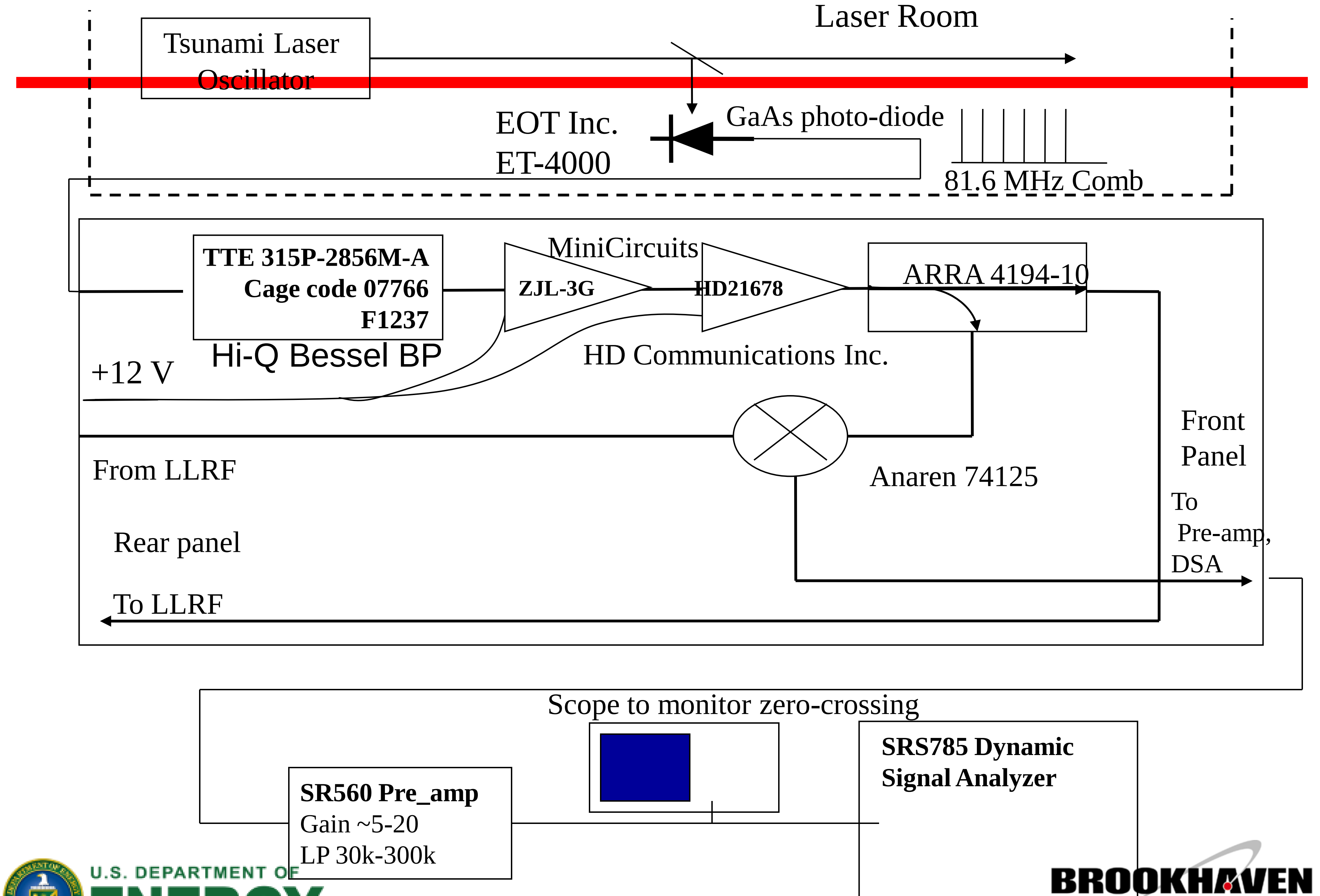
- Commitment: The other mother of invention.
  - ~9 years ago, while interviewing to change departments at BNL I was asked if I could measure jitter between a 100fs cathode driver/seed laser and the RF system to characterize and improve system- said yes even though I was not exactly sure how. This became the finger-pointing circuit to resolve arguments between RF and laser stability (we always won after this)

I would like to begin by describing this latter circuit as an example of the accuracy of the mixer based phase measurement

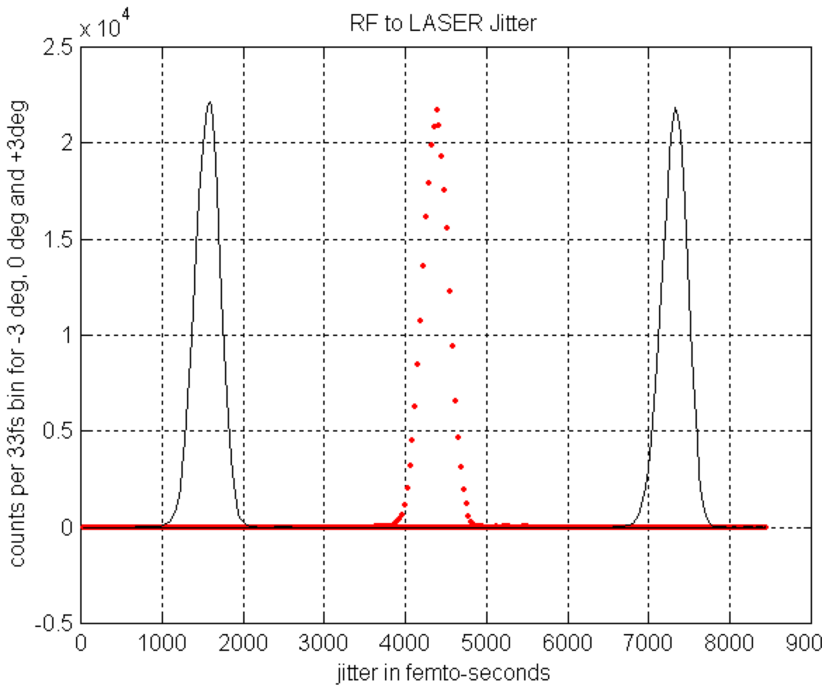
# Seeded-FEL Laser and S-Band LINAC RF system

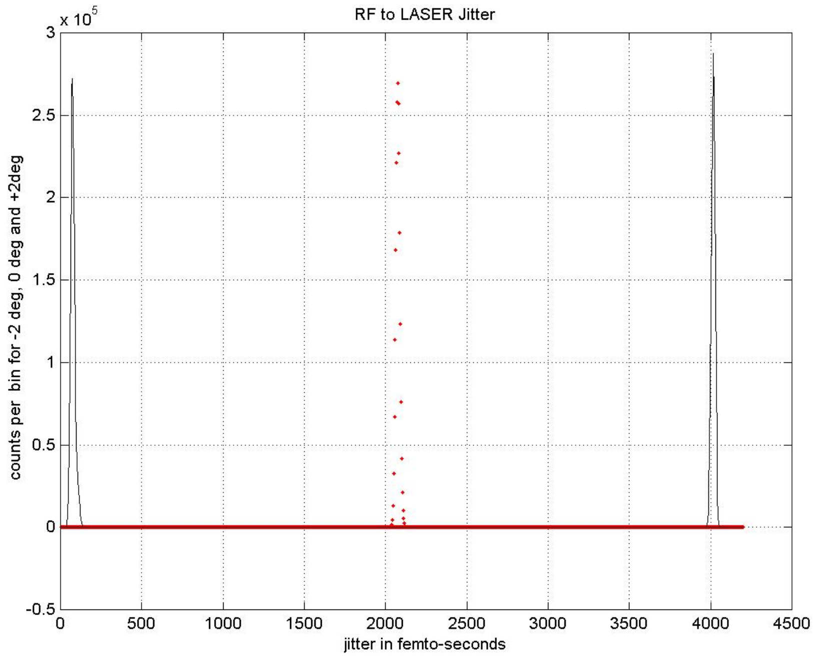



Laser and RF synthesizer independently locked to Oscillator


Laser Room
Tsunami Laser Oscillator
EOT Inc. ET-4000
GaAs photo-diode
81.6 MHz Comb
TTE 315P-2856M-A
Cage code 07766
F1237
Hi-Q Bessel BP
MiniCircuits
ZJL-3G
HD21678
ARRA 4194-10
HD Communications Inc.
+12 V
Front Panel
From LLRF
Anaren 74125
To Pre-amp, DSA
Rear panel
To LLRF
Scope to monitor zero-crossing
SRS785 Dynamic Signal Analyzer
SR560 Pre_amp
Gain ~5-20
LP 30k-300k

# Phase Jitter Measured between Laser Oscillator and RF Drive

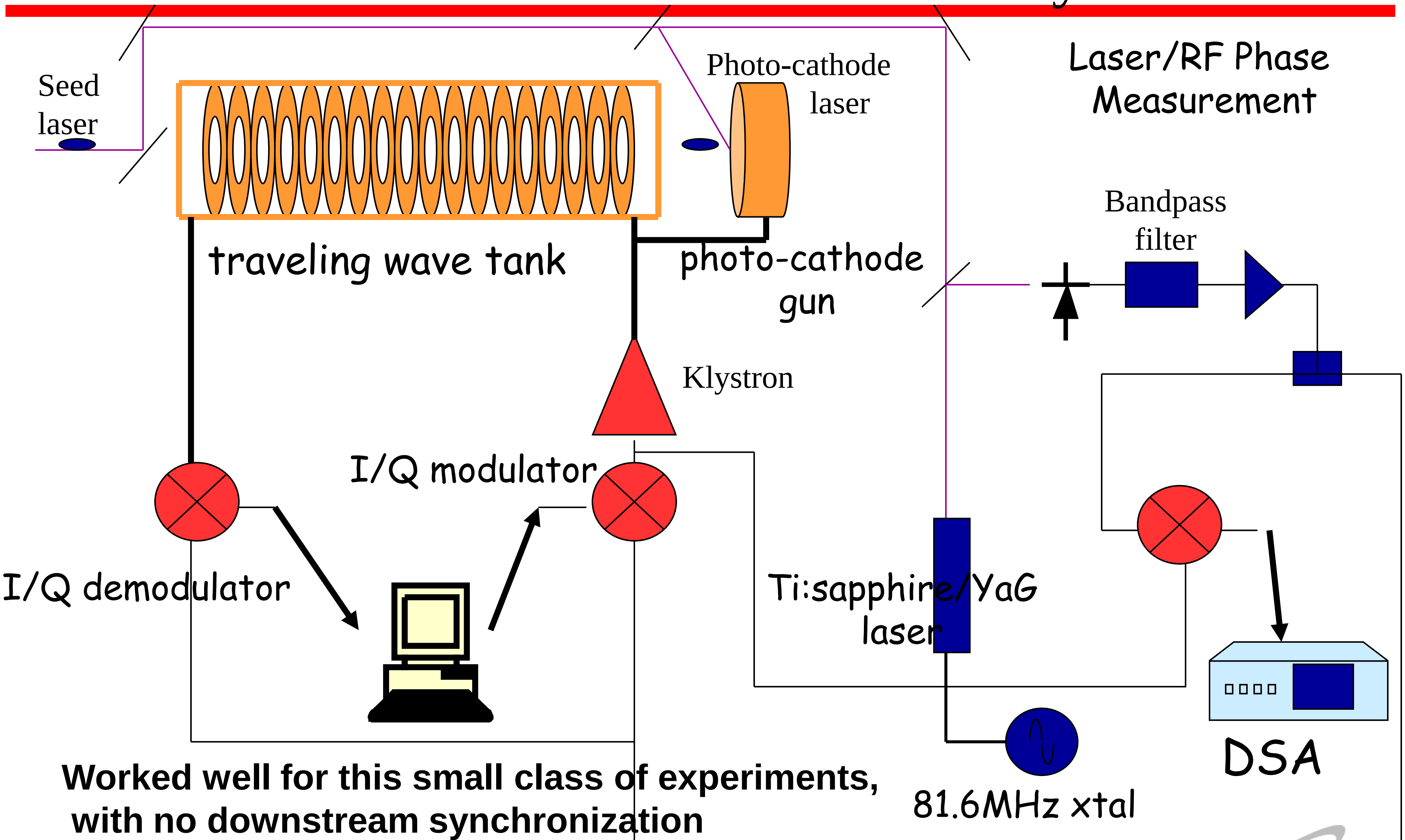



Each plot consists of histograms of 8 second duration of a mixer-based phase error measurement. Left plot is for laser oscillator and RF synthesizer driven from same crystal, on right laser output pulses are filtered to drive RF directly.In each plot the outside histograms are data taken by programming+/- 3 degree and +/- 2 degree steps, respectively, in the RF path  for calibration.

Side Note: shot to shot jitter from 40 MW klystron is ~150fs FWHM with 0.05% regulated charging PS

# Don't fix the jitter, join it:
# Laser-Driven and LINAC RF system



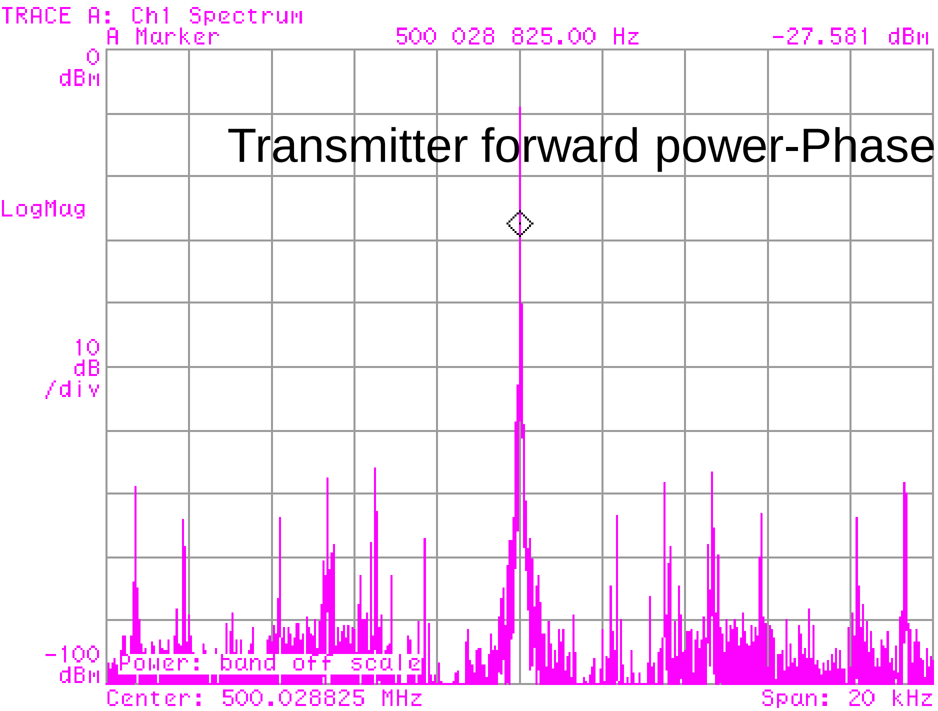

**Worked well for this small class of experiments, with no downstream synchronization**

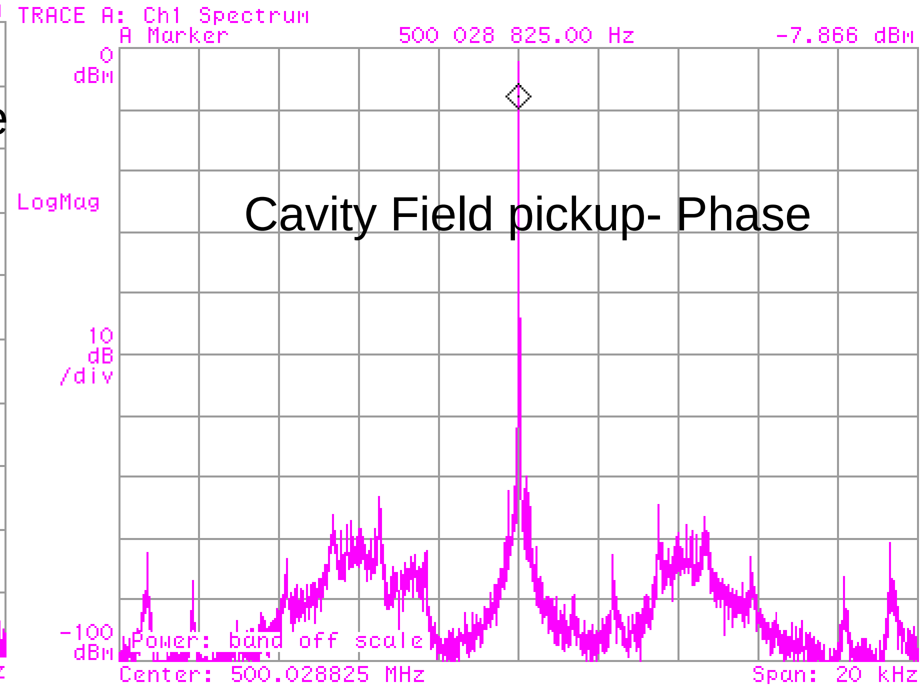
# Characterization of the CLS klystron transmitter

- Part of a broader collaboration between CLS and NSLS-II on RF systems
- NSLS-II must meet the <0.15 deg phase jitter specification: factor of ~3 beyond existing LS machines (I think)- past experience is no guarantee of future success. Decision to use the CLS system to determine whether klystron system can meet specification
- Thanks to Mark deJong, Jonathon Stampe, Hengjie Ma, Nathan Towne and Song Hu for contributing to this work

# Spectrum/Dynamic Signal Analyzer

**Data taken with Agilent 89441A DSA**



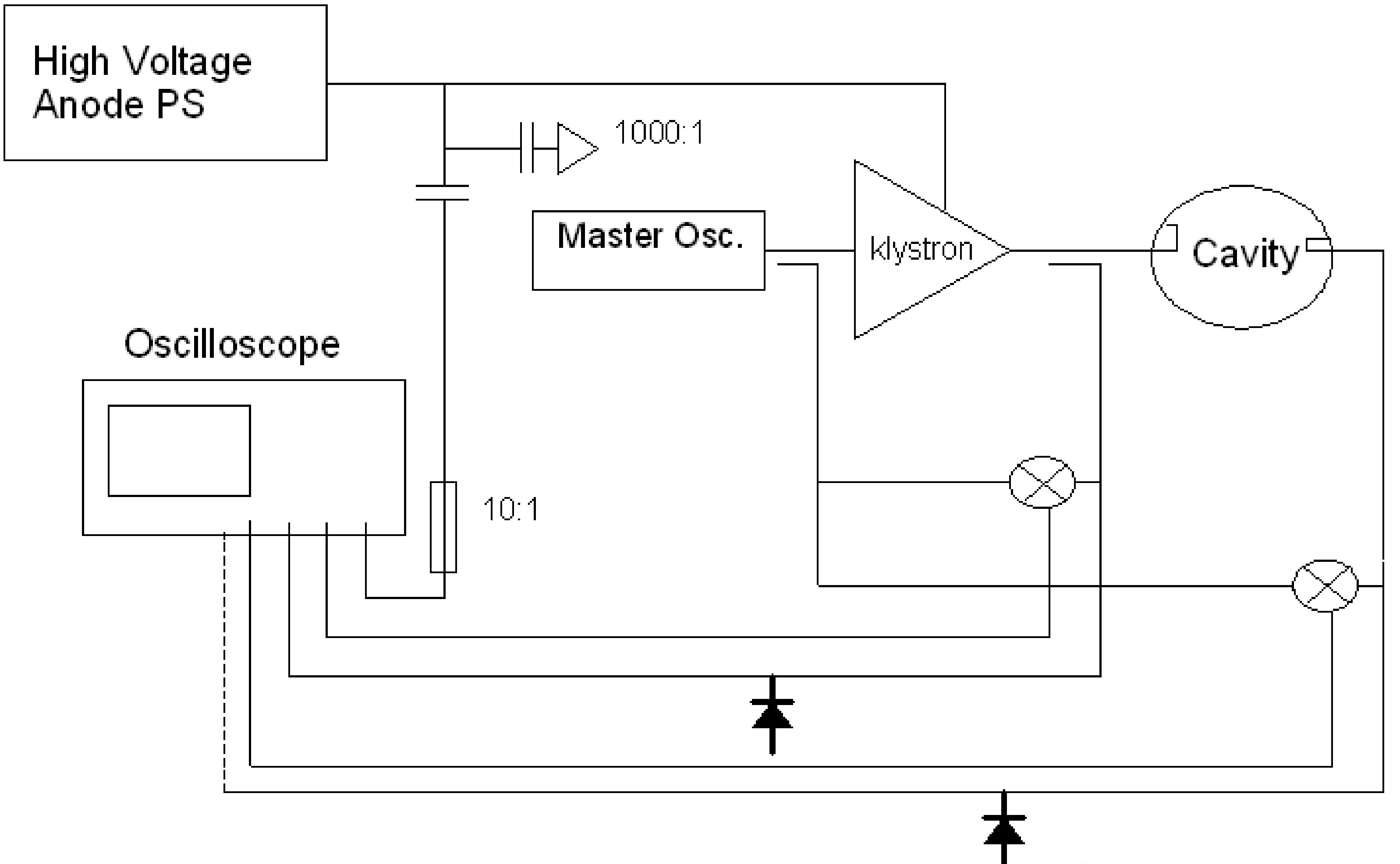




Due to machine returning to normal operations measurements had to be taken closed loop, Cavity field response with 20 dB of gain in feedback masks effect of transmitter noise-transmitter forward power shows switching noise

- Pro/Con of DSA:
  - High resolution, easy to configure
  - High dynamic range

- **Only one RF channel**
- **Few points (3201 max in89441A)**
- **Need to configure and calibrate TP**

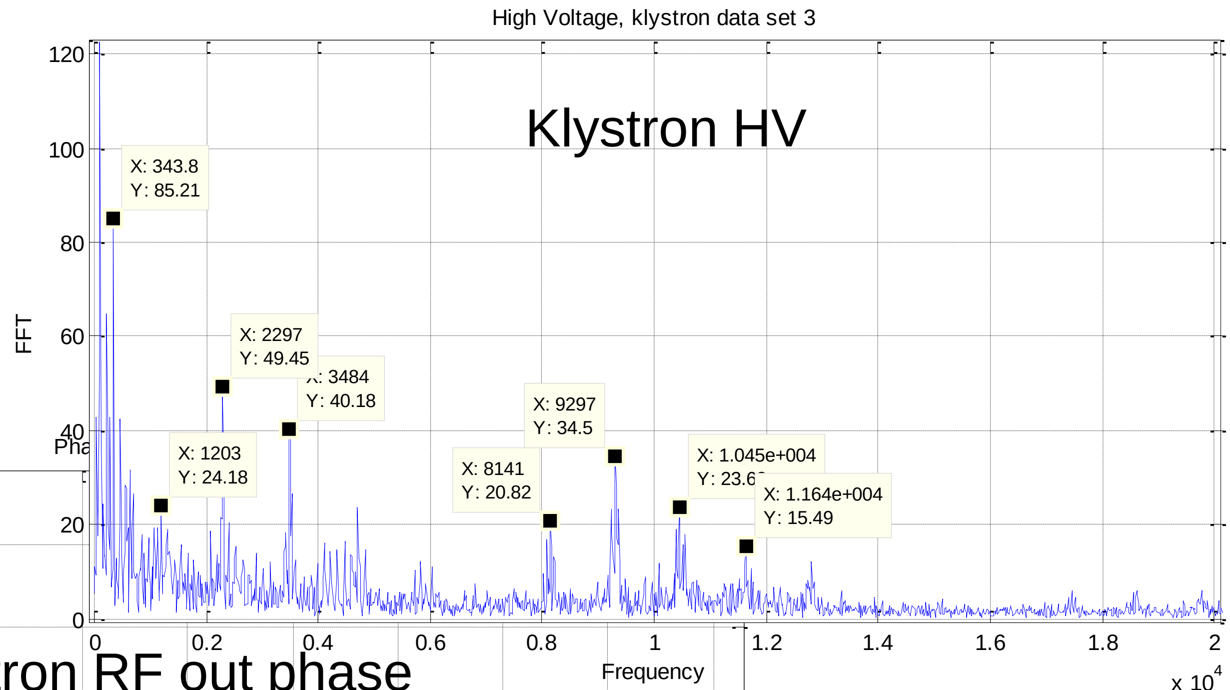
# Traditional detector/mixer based RF measurements- Using Scope as digitizer

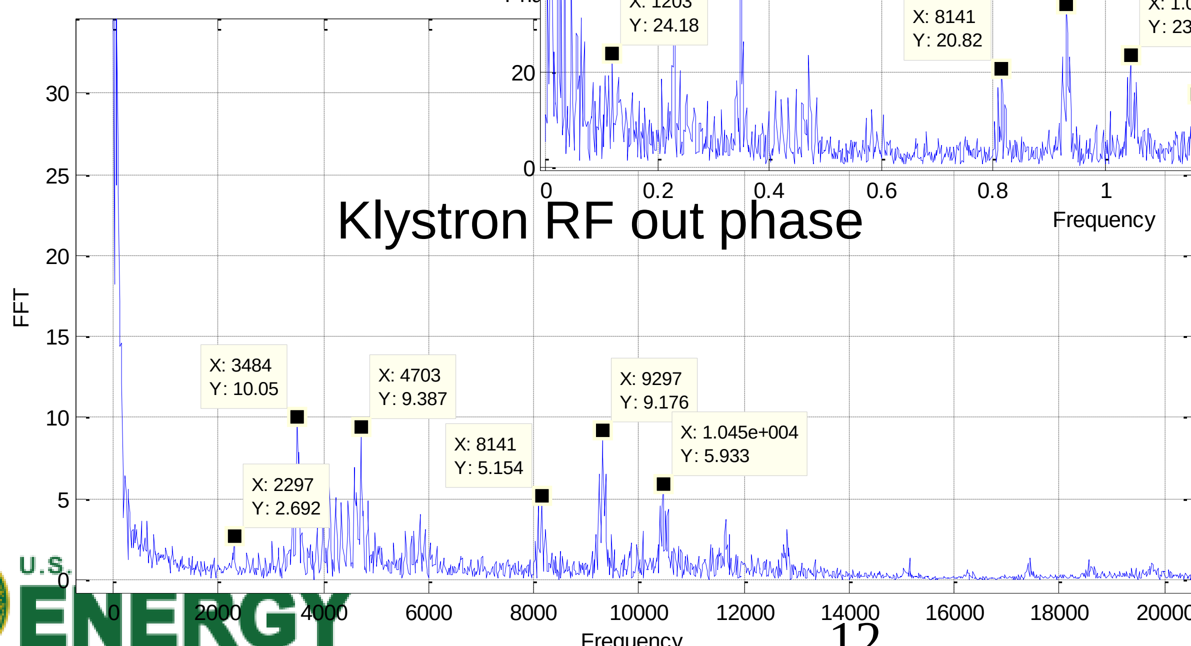



**Simple system with components costing a few hundred $ (even less € ) plus digital scope allows high resolution four channel correlated measurements**

# PSM modulated HV power supply switching lines and klystron RF phase

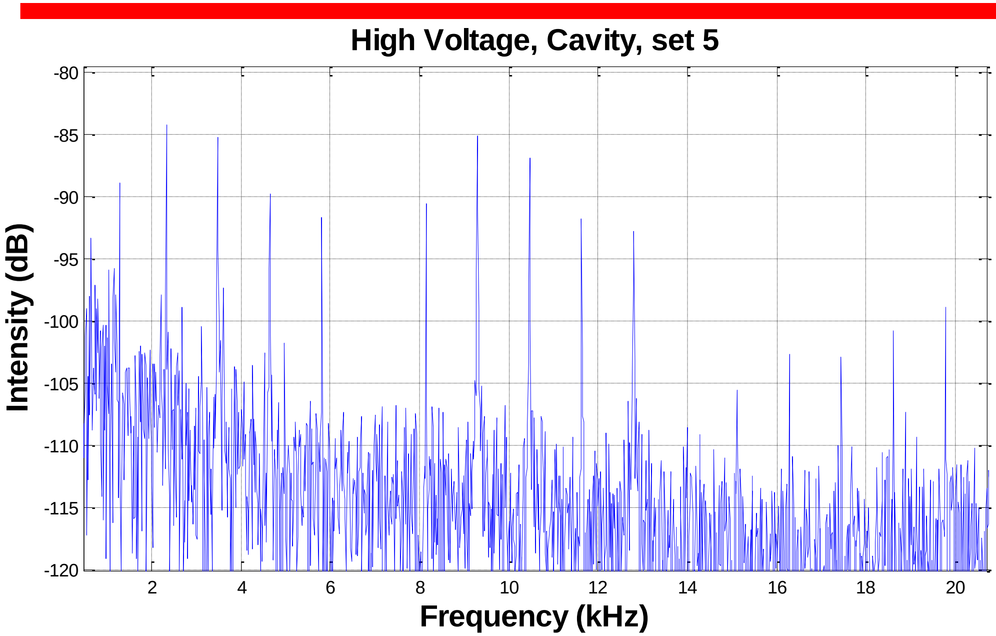
Switching frequency of 100kHz over 86 switch modules creates sub-harmonics of ~ 1.2kHz This is a concern for NSLS2 since the synchrotron frequency is between 3-4 kHz

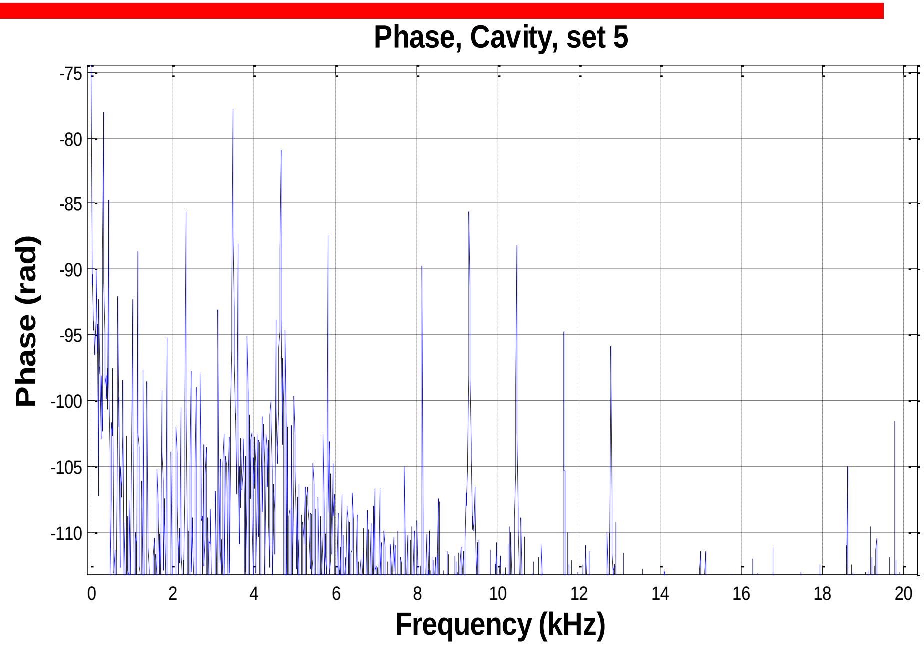


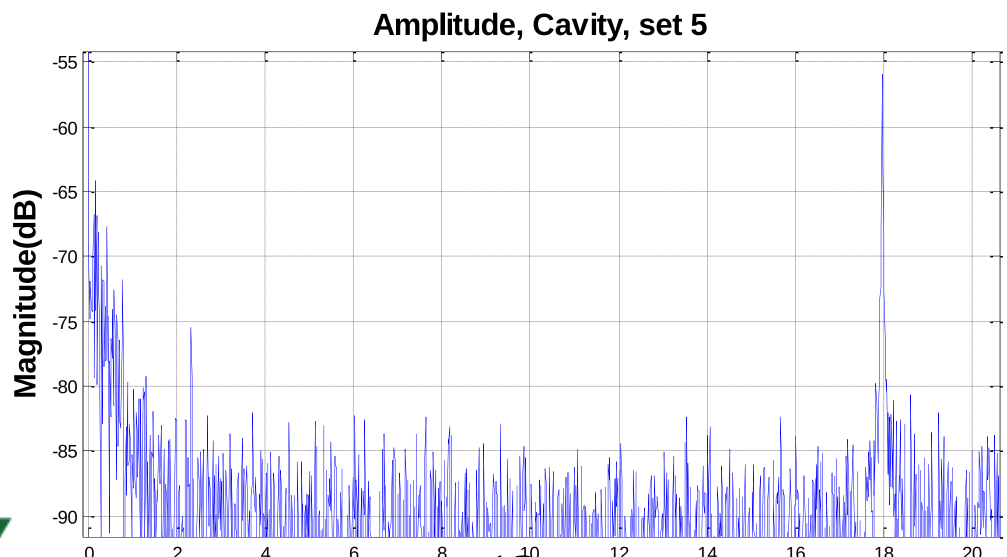




Although the harmonics are <-75dBc, they can be suppressed further by filtering with modest effort

# CLS PSM HV supply + klystron Transmitter.

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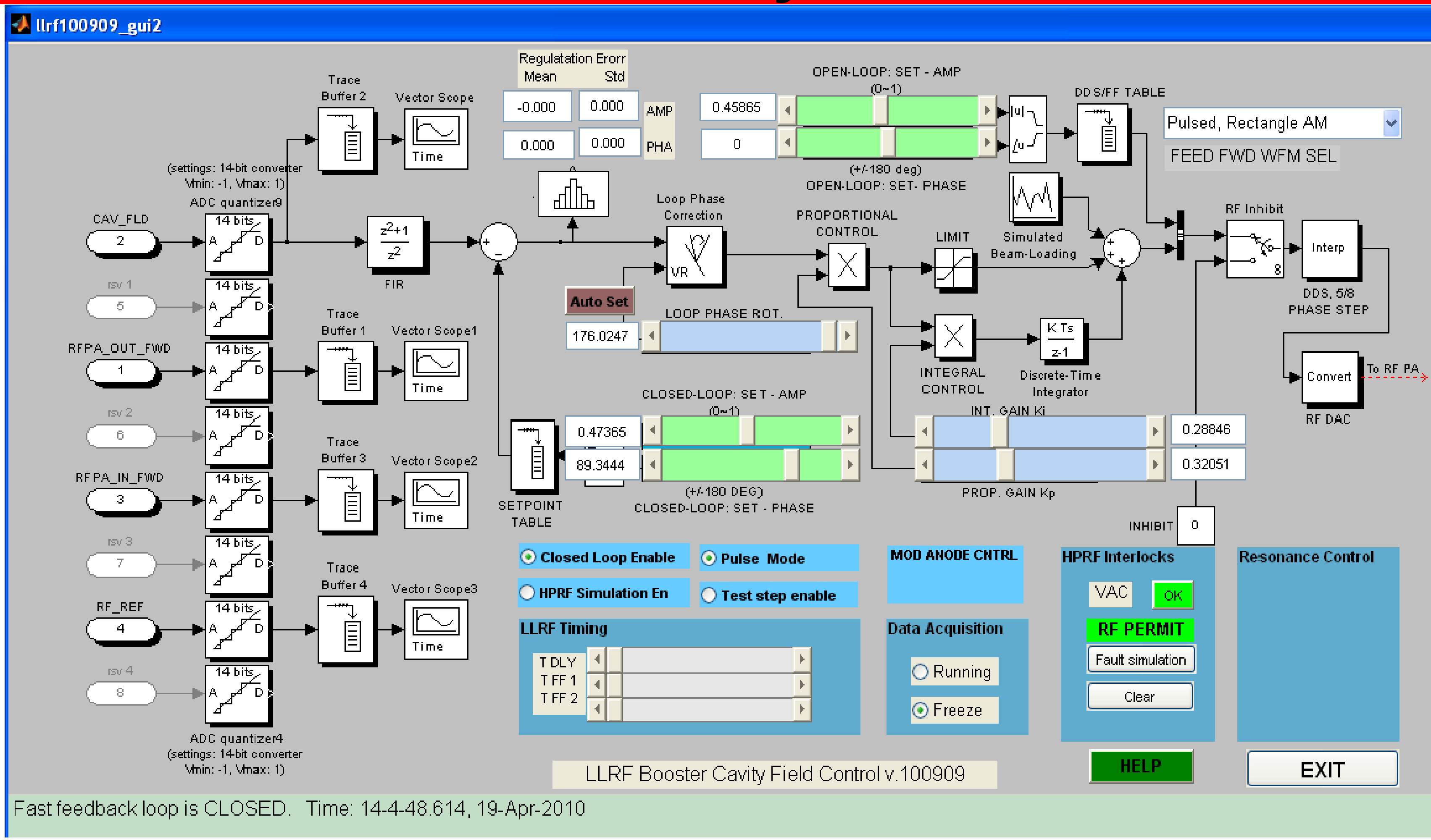
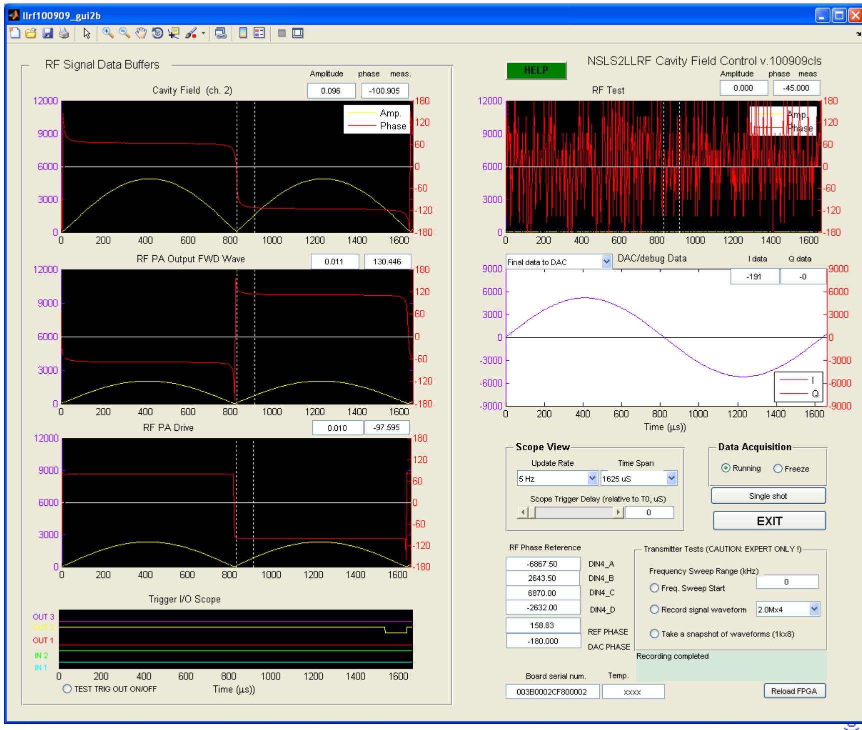
# Digital RF Controller for data measurement and analysis




Example of NSLS-II controller GUI in MATLAB- 8 fast ADC channels with display, +history, + signal processing.

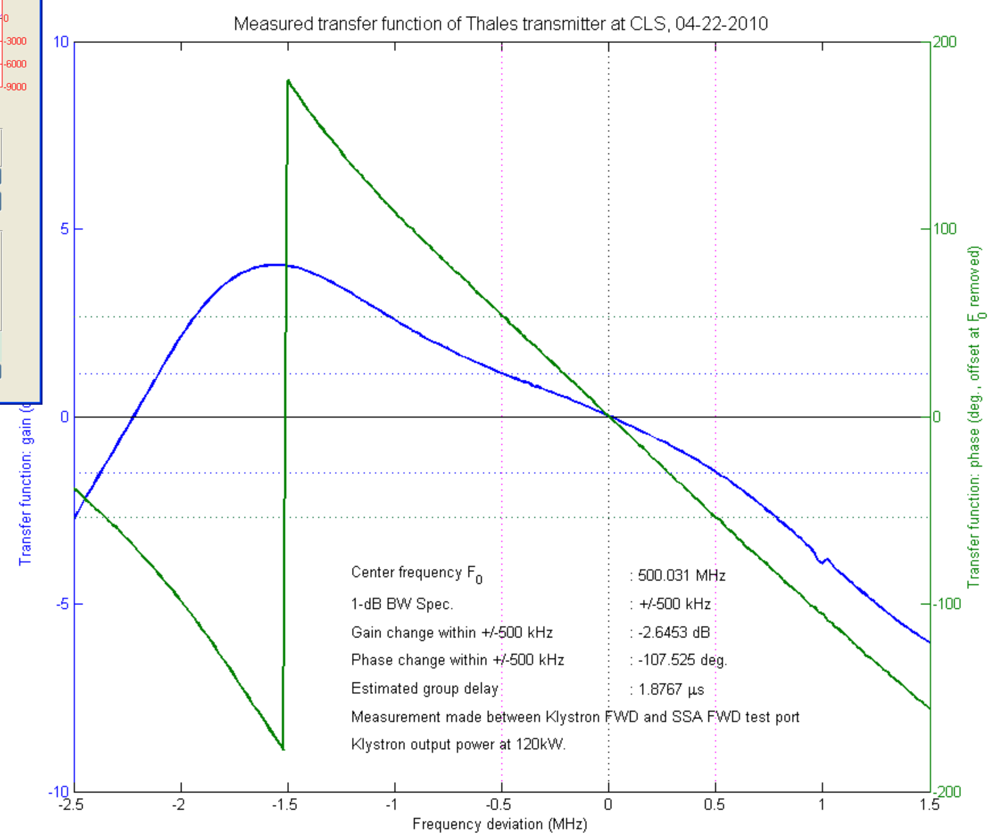
Built in AM, FM modulation

# Digital RF controllers as DSA

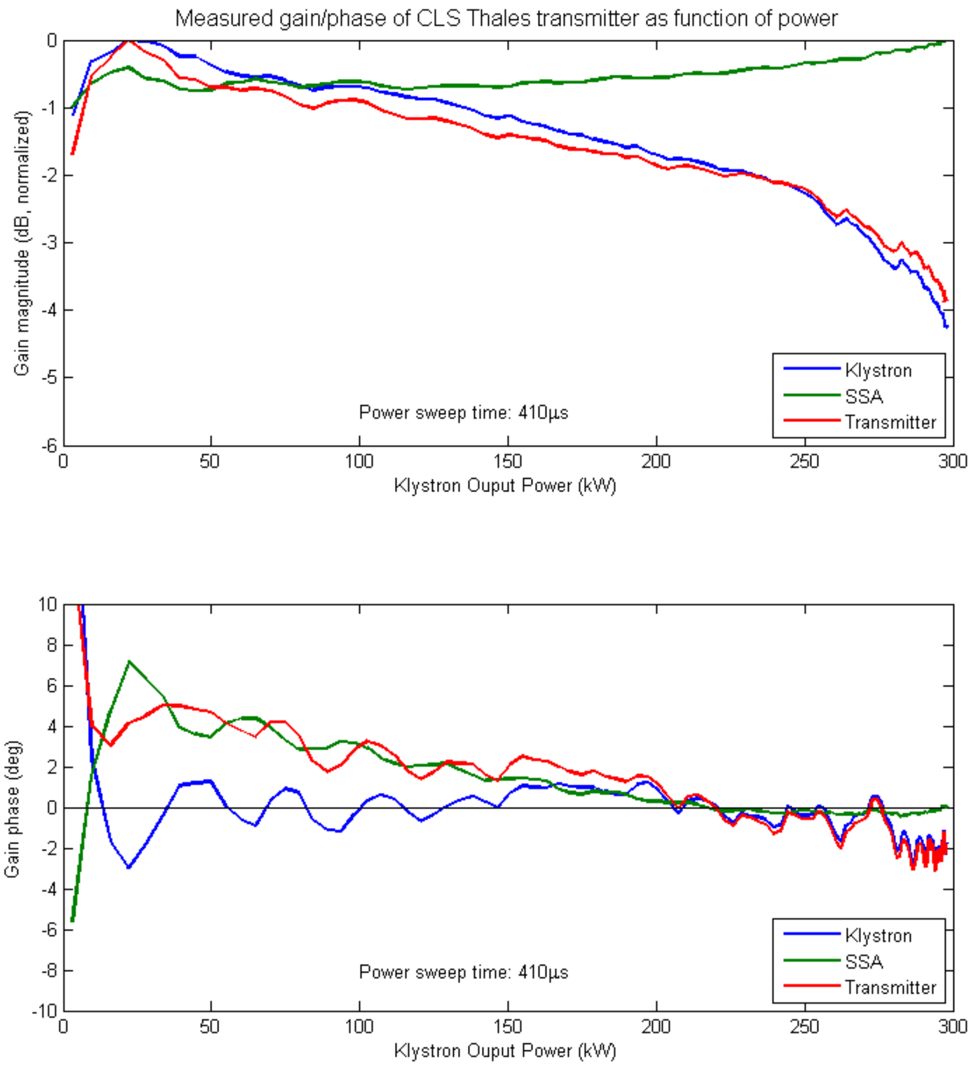



Built in sweep features allows AM, PM and FM modulation of Reference input via feed-forward

Transfer functions can be measured easily



# Klystron Power sweep

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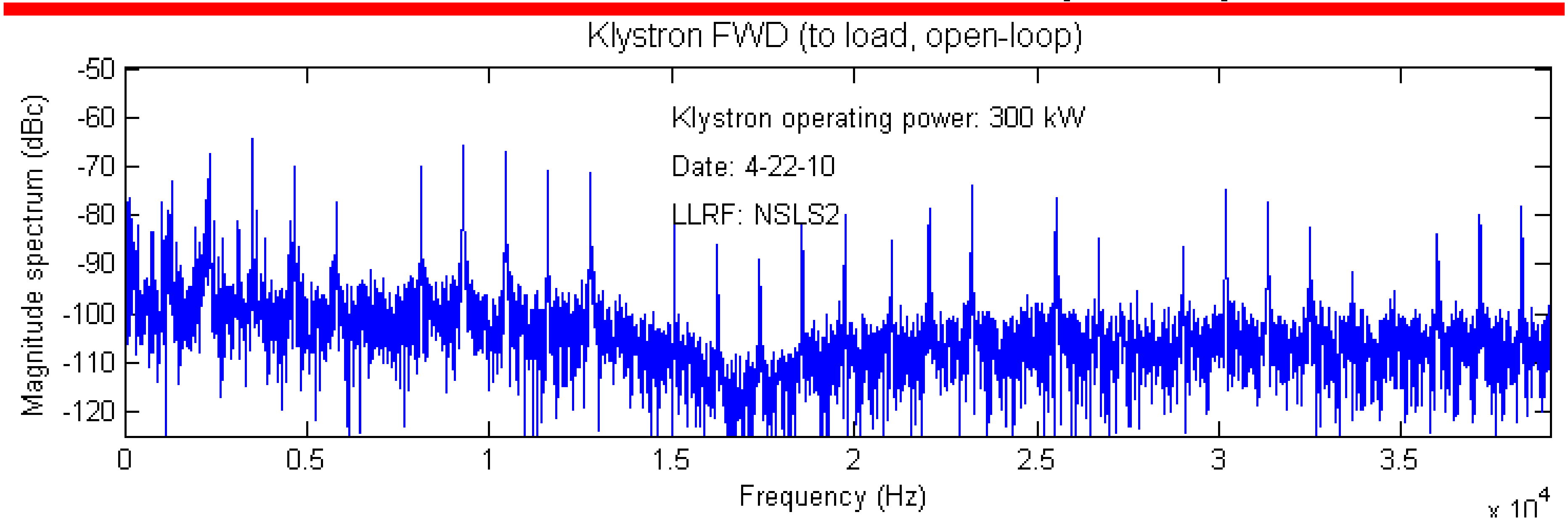
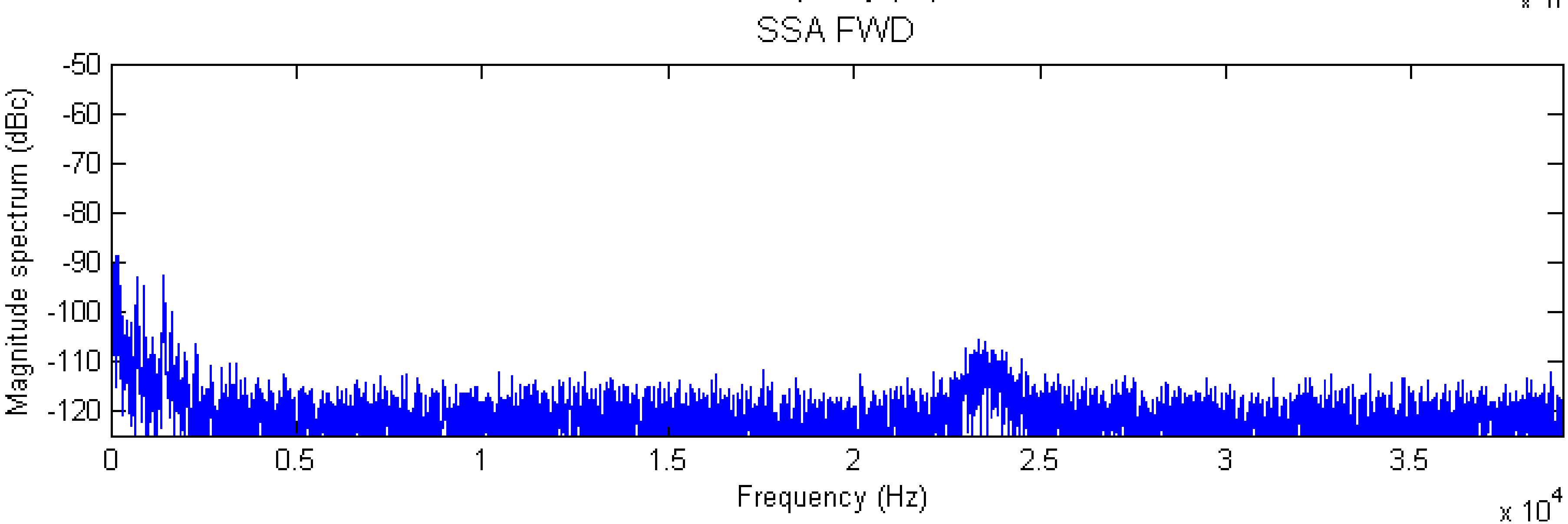
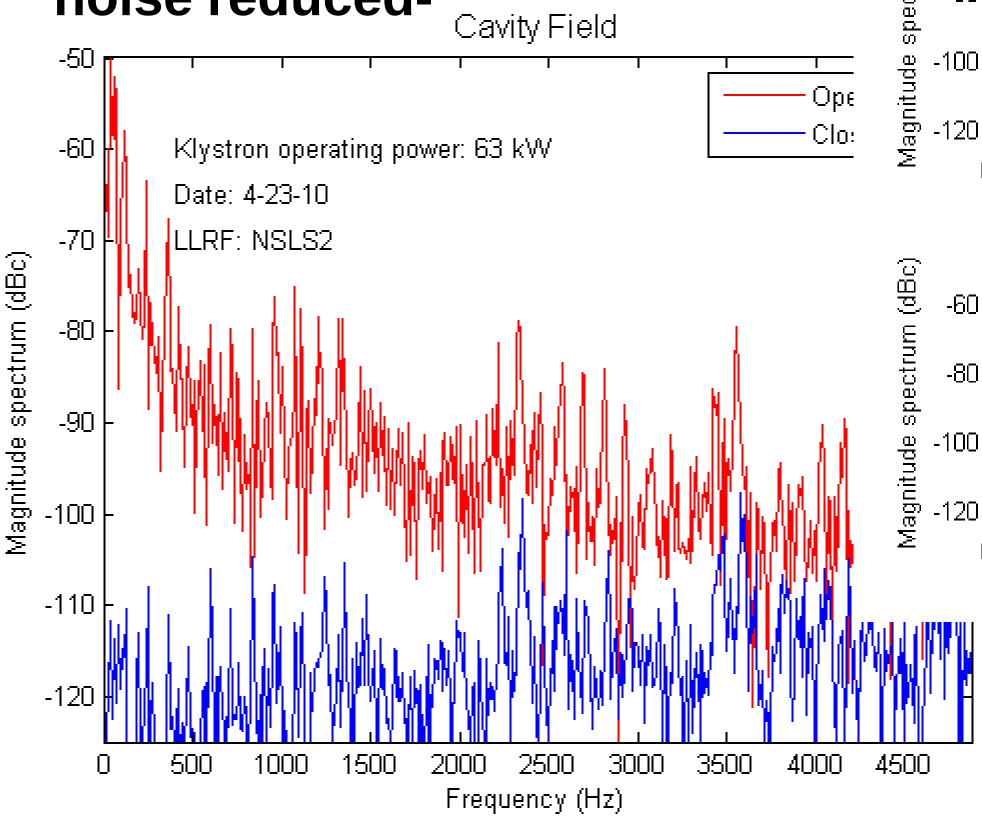
# Matlab processing allows power spectrum measurements online - 300kW-open loop into load

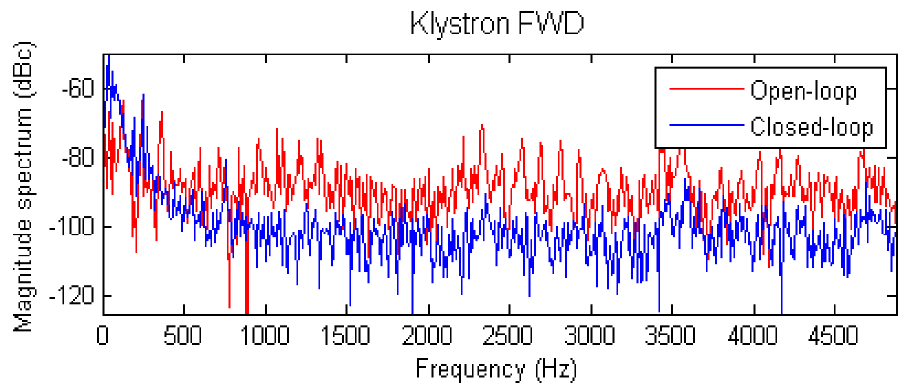


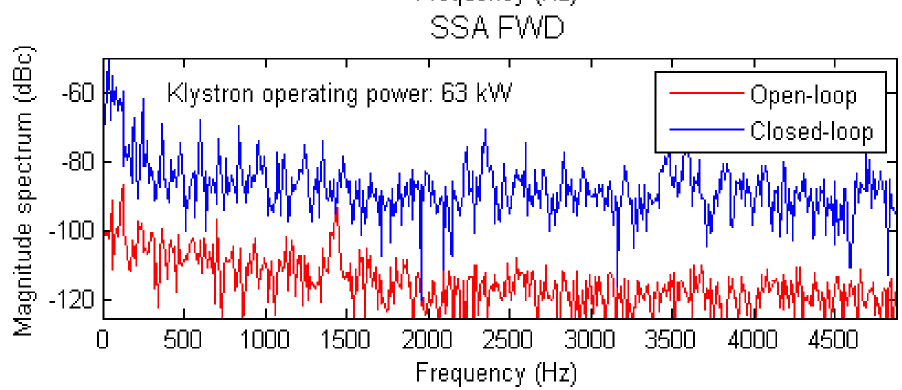



# Digital controller as SA measuring Analog controller closed loop response

**Cavity field open and closed loop response: closed loop noise reduced-**




**At cost of increased closed loop amplifier power**

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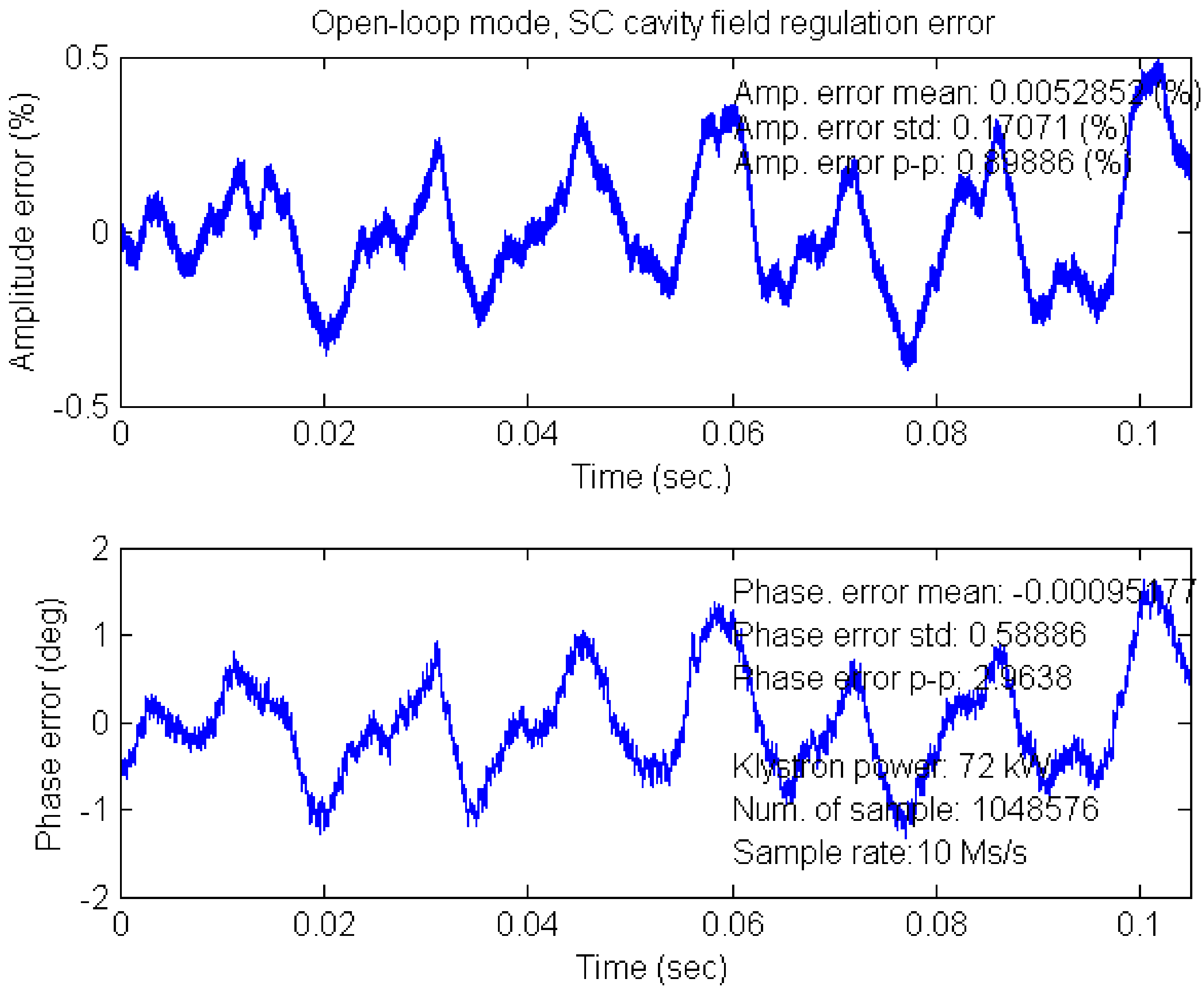
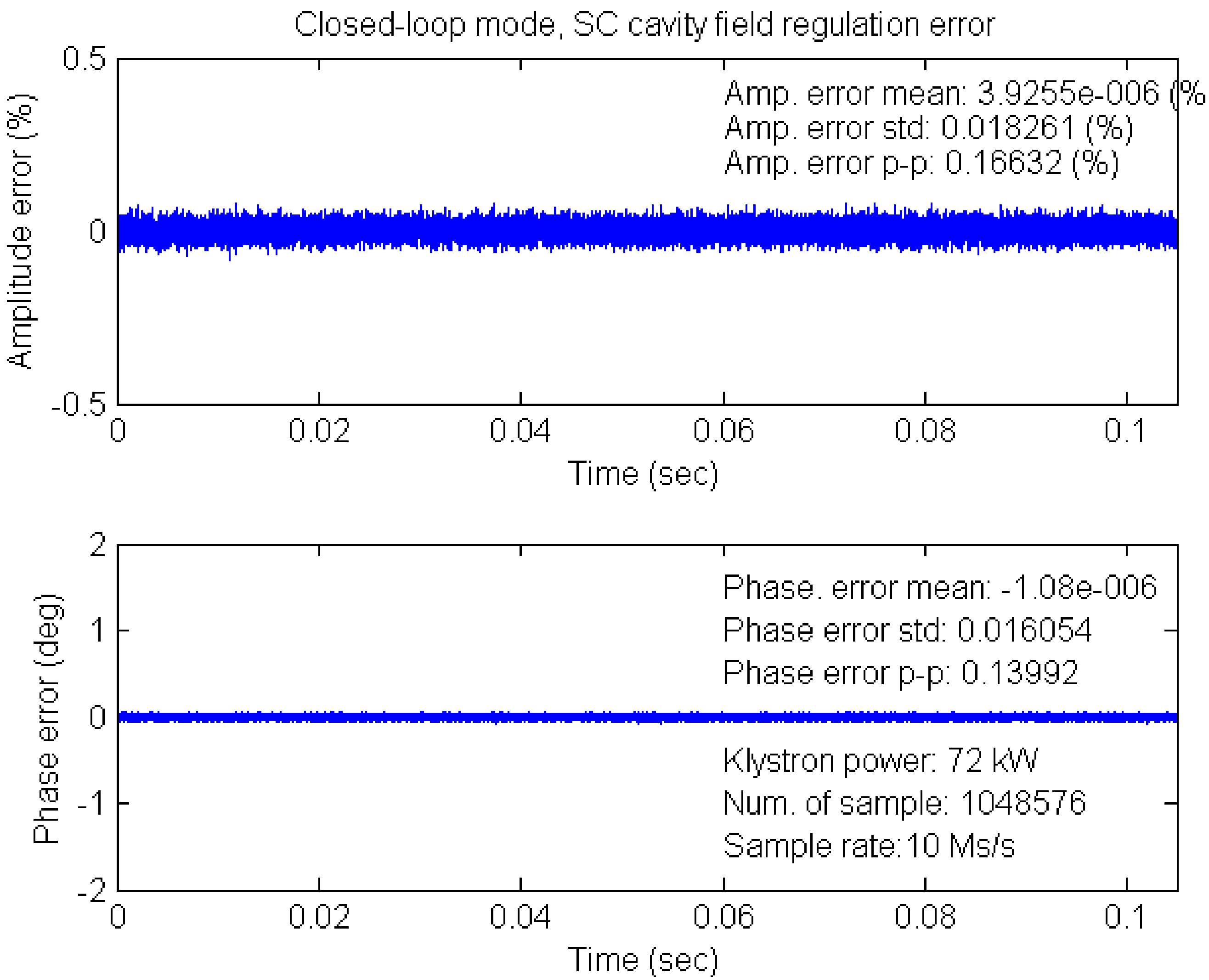
# Open loop response

## **Digital Controller** Cavity Voltage 2.4MV klystron power 72kW, no beam



# Closed loop response

**Digital Controller** Cavity Voltage 2.4MV klystron power 72kW, no beam



# Summary-Measurements

- Traditional spectrum analyzer measurements can be complemented by mixer based measurements extended to four channels for correlation between PS HV and RF
- These measurements can be built into digital RF controllers and displayed and put into history buffers for post-mortem
- Digital controller based measurements are flexible, always online. No need to hook up equipment, calibration easier to keep correct

# Summary- Switching PS/Klystron phase noise

- Open loop measurements of klystron at full power shows switching harmonics at {switching frequency/#modules}- for CLS case these are within the synchrotron frequency band of the NSLS-II
- Closed loop measurements show this noise to be reduced greater than 20db: within requirements. The 20 dB loop gain is not a fundamental limit, the firmware gain needs to be increased- we reached the end of the ‘knob’
- The PSM PS klystron transmitter can easily meet the NSLS-II requirements