New CEBAF Booster Performance and Test

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Abstract

This Tech note describes results of new CEBAF Booster operation, cavity field stability, and microphonics background in the Upgrade Injector Test Facility (UITF).

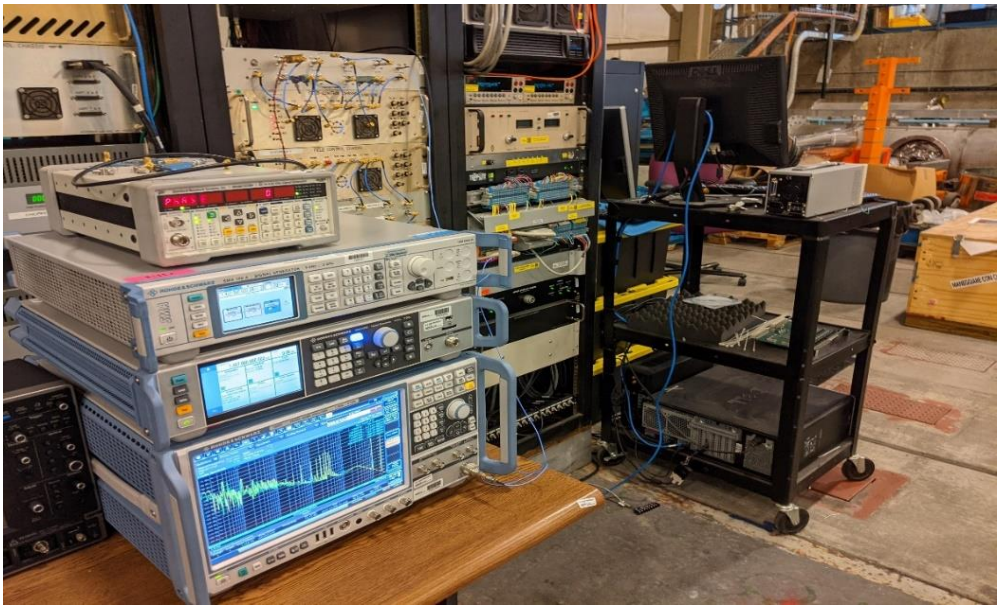

Figure 1 UITF LLRF testing area with RF instrumentation

Introduction

For Booster characterization we used LLRF 2.0 system [1] and SEL/GDR field control code. For both cavities additional directional couplers were installed. A high performance signal analyzer (FSWP8) was used to measure amplitude and phase stability, in addition to the LLRF 2.0 data acquisition system. In addition to UITF MO (master oscillator) system we used 1427 MHz external signal sources for dual frequency operation (isolation measurements). The LLRF system was optimized (gains and filters) for best performance at the intended operational cavity gradients.

Measurements results

LLRF Tests

1. Optimize gains for both two and seven cell. Booster Energy: 6.3 MeV

For these measurements both cavities were operated in Generator Driven Mode (GDR), which is the normal mode for beam acceleration.
For proportional gain of 200 and integral gain of 64, field stability measurements were as follow:

Cavity 1 (2-cell)
Gradient:
Integrated [1Hz-3 MHz] phase noise 240 fs
Amplitude regulation (GDR) 0.02 %

Cavity 2 (7-cell)
Gradient:
Integrated [1Hz-3 MHz] phase noise 227 fs (Figure 2)
Amplitude regulation (GDR) 0.048 % (Figure 3)

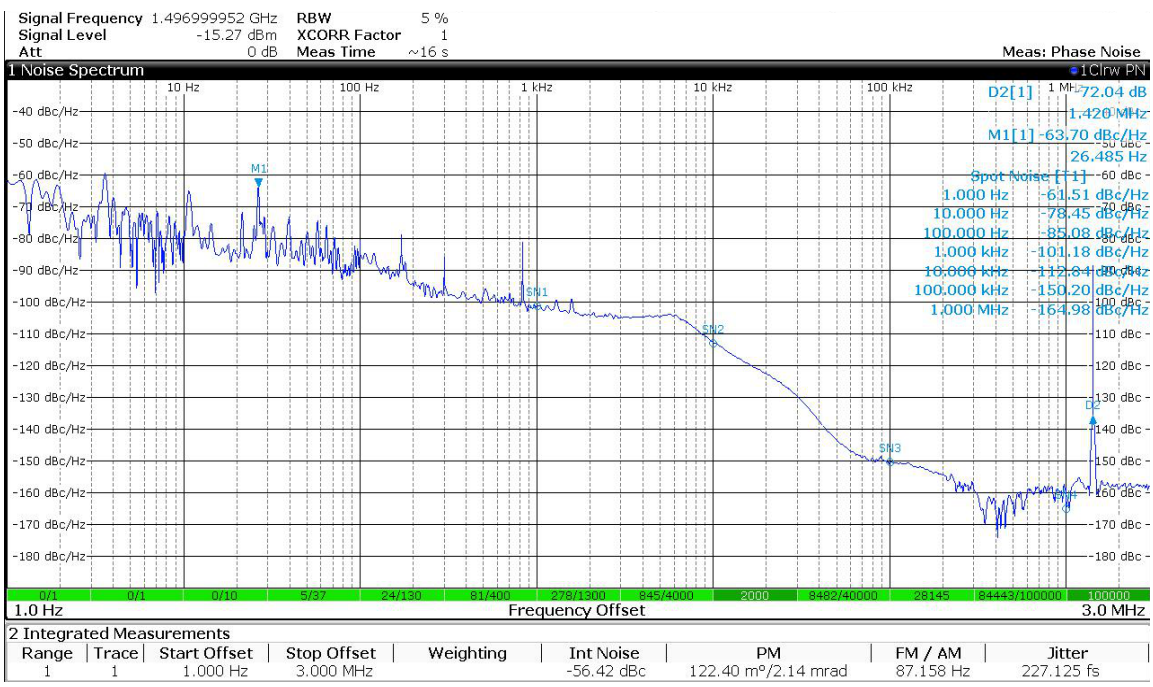

Figure 2 Cavity 2 - Phase Noise Power Spectrum

In Figure 2 we noticed a strong spur at 1.4 MHz. This is actually cavity 2's 6/7 Pi mode. Implementing a single pole IIR with 35 kHz cut-off frequency, the 6/7 pi mode excited was enough to significantly deteriorate the quality of field regulation. We switched to an FIR with a 200 kHz cut-off frequency, and the 6/7 pi mode was filtered sufficiently without affecting field stability requirements.

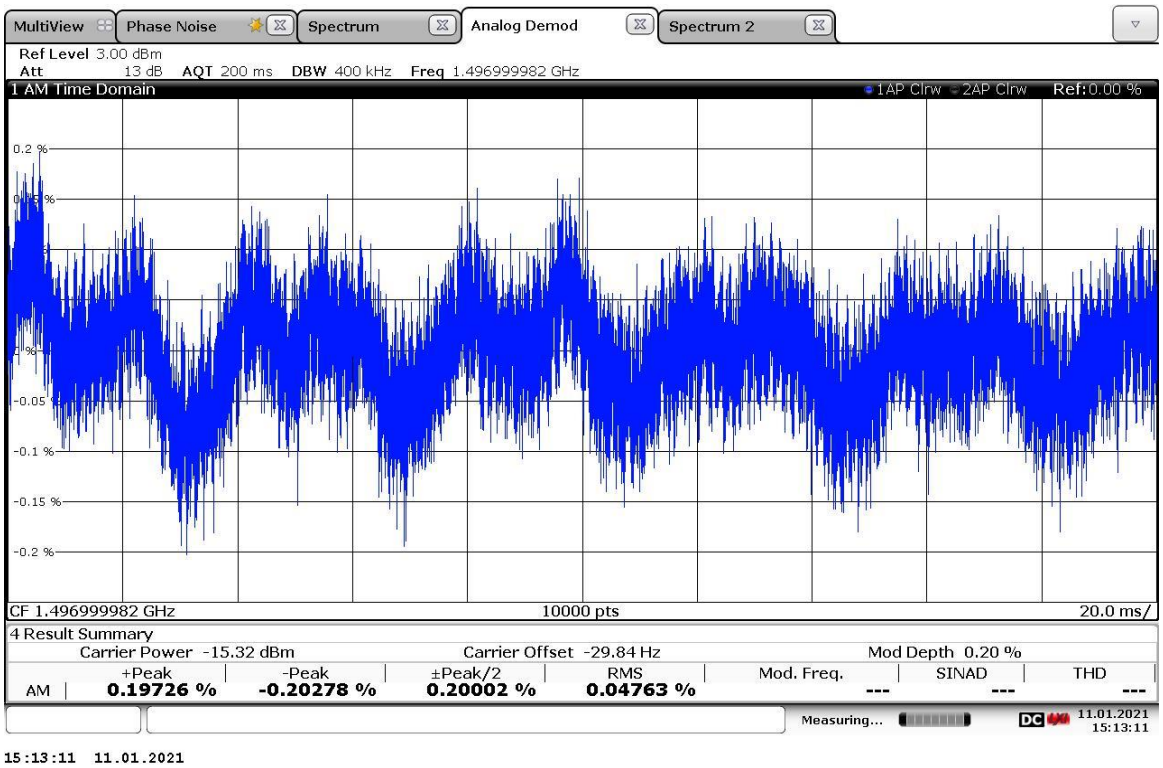

Figure 3 Cavity 2 - Amplitude Noise

The amplitude RMS error regulation in Figure 3 is showing results from the "noisy" period. It comes from the fact that CMTF/UITF area is very noisy and the helium pressure is not very stable, something we do not expect in the injector enclosure. Even with the eleveted background noise the regulation meets performance requirements.

2. Microphonic background at nominal gradient

Cavity 1 (2-cell)
½ Bandwidth: 113 Hz (Qext ~ 6e6)
Typical microphonics detuning 20 Hz rms

Cavity 2 (7-cell)
½ Bandwidth: 78 Hz (Qext ~9e6)
Typical microphonics detuning 8 Hz rms

Most dominant mechanical modes: 3-4 Hz, 11 Hz, 26 Hz (Figure 4). The strong 59 Hz detuning peak observed during HDice experiment run (target refrigerator) was not observed during these measurements.

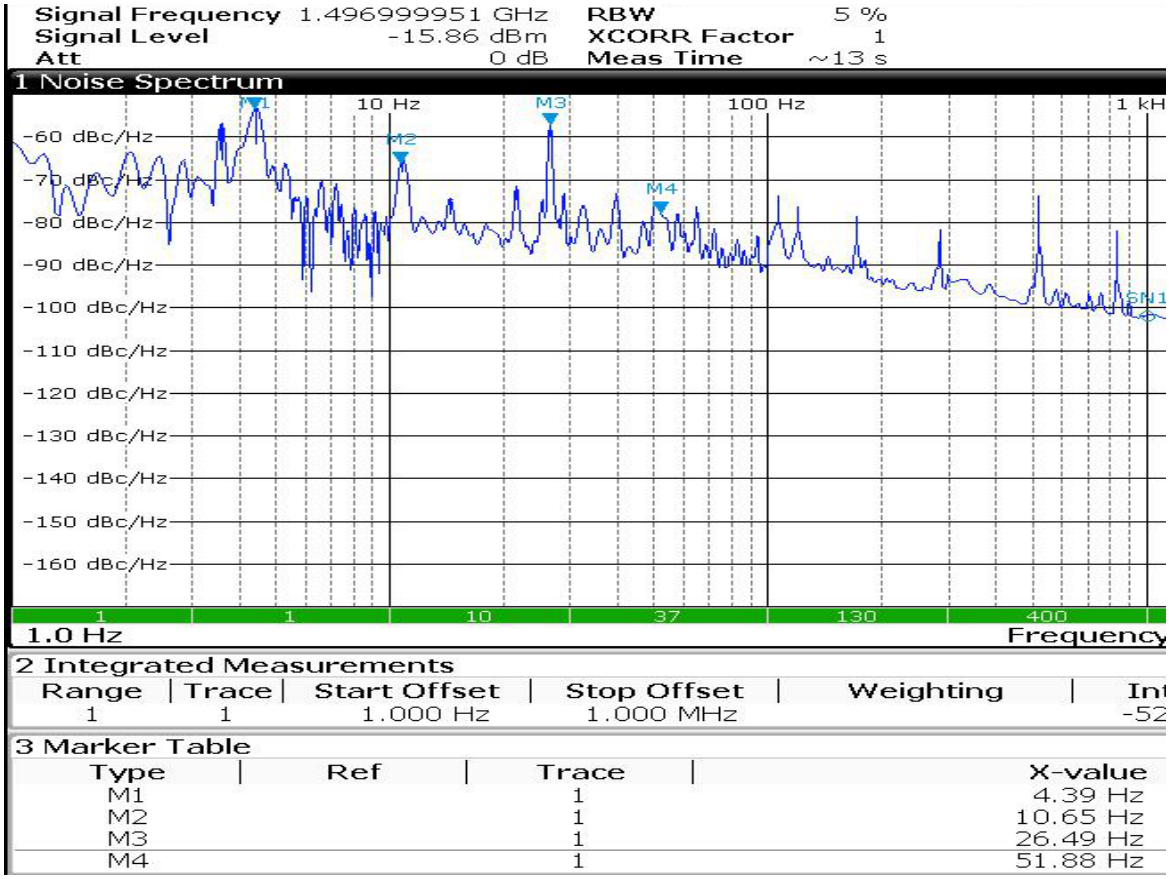

Figure 4 Cavity 2 phase noise with mechanical modes marked

3. Crosstalk between the two and seven cell cavity

The cross-talk measurements used two independent LLRF LO oscillators.
Cavity 1 LO was set to 1.426998 GHz, cavity 2 was set to 1.427002 GHz. Both cavities were operated in GDR mode. Measured crosstalk between the cavities is 65 dB (Figure 5).

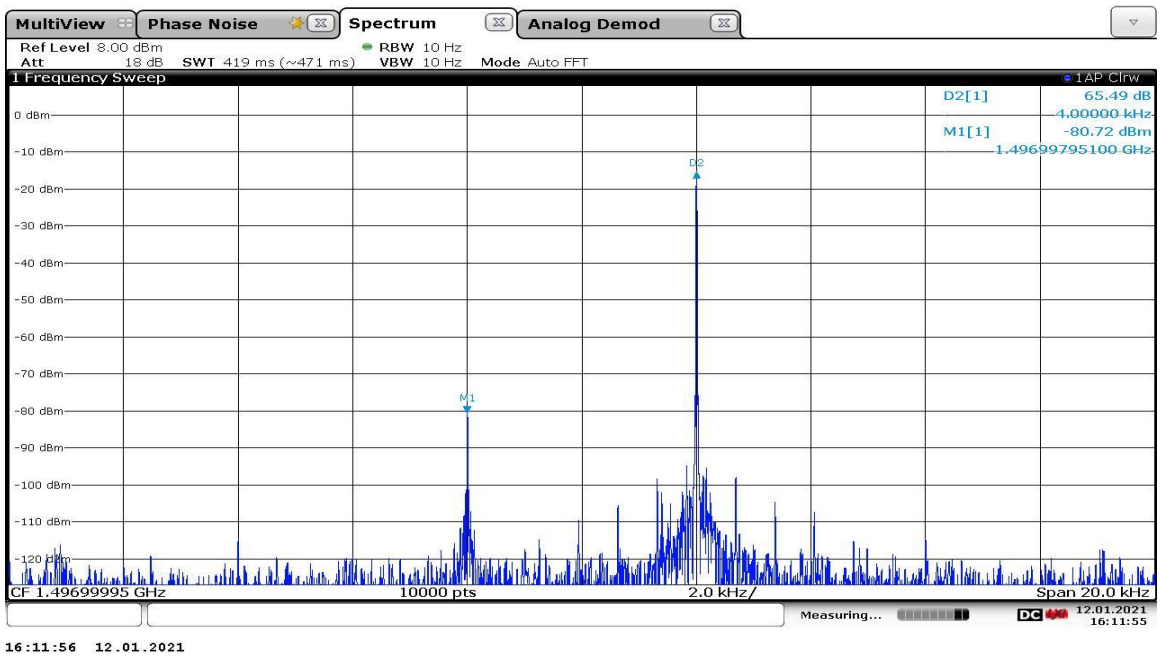

Figure 5 Crosstalk Measurement

4. Mechanical crosstalk between the two cavities

The mechanical cross-talk between cavities in the C100 cryomodules is a known issue, with that in mind a measurement was made between the Booster cavities. For this measurement both cavities were operated in Self Excited Loop (SEL) mode. SEL mode allows the RF system to track the cavity detuning while maintain gradient in the cavity. The resonance control of one cavity was disabled and detuned by 1000 Hz. The other cavity observed no measurably detuning from the adjacent cavity forced detuning. A similar test was done by using the Lorentz force detuning (RF OFF – red trace) of one cavity. The adjacent cavity did not show any measurable detuning (yellow trace) (Figure 6).

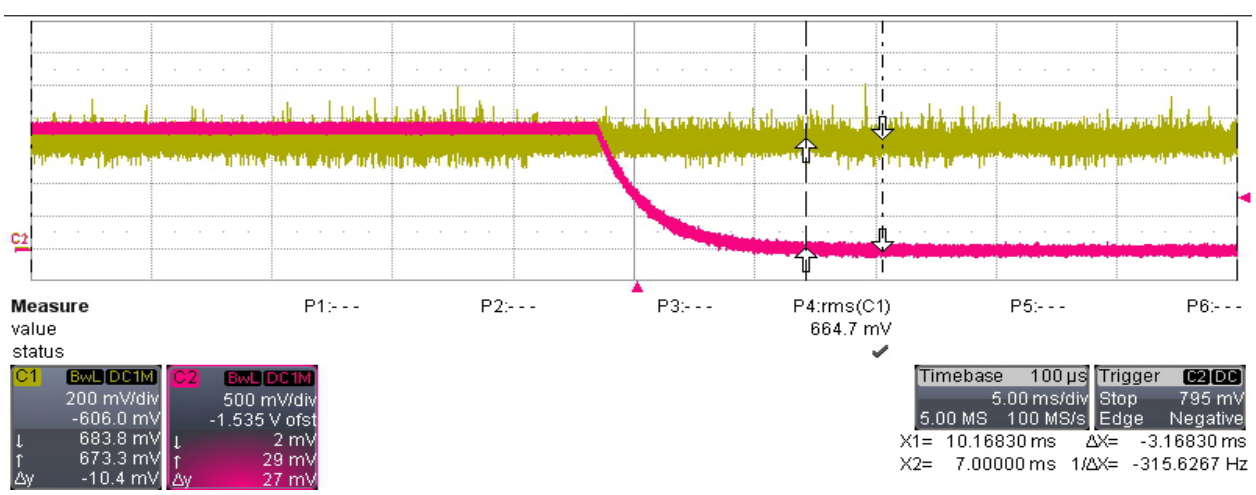

Figure 6 Mechanical Crosstalk Measurement

5. 4 kHz spurs (present during C100 operation)

An issue with the CEBAF C100 cavities is a 4 kHz control loop sideband excitation. This is mitigated in CEBAF by applying additional phase offset in the control loop. In the case of the new Booster, 4 kHz spur was not visible (excitable) in both cavities. The phase offset was varied from -70 deg up to +80 deg and the 4 kHz was not observed. Above and below these phase values system becomes, as expected unstable.

Summary

When not operating the HDice refrigerator, the booster experiences reasonable microphonic detuning. The 59 Hz spur seen when the refrigerator was insignificant. Cavity field stability was well regulated despite the noisy Test Lab environment (external mechanical vibration and helium pressure drift). Given that the CEBAF enclosure is a much better microphonic environment than the Test Lab we believe the Booster will have no issues operating in the injector area of the CEBAF tunnel.

References

[1] T. L. Allison, J. R. Delayen, C. Hovater, J. Musson, and T. E. Plawski, “A Digital Self Excited Loop for Accelerating Cavity Field Control,” in Proceedings of the 2007 IEEE Particle Accelerator Conference (PAC 07). 25-29 Jun 2007, Albuquerque, New Mexico. 22nd IEEE Particle Accelerator Conference, p.2481, 2007, p. 2481