UITF RF Survey
John Musson – 02/17/2021

Introduction

A brief assessment of the DR RF incursion was performed, to quantify the amount of masking, as well as isolate the leakage path to either the vault or the gallery/mezzanine. Presently, the two RF amplifiers (cavity klystrons) are in an open frame, located about 10' from the equipment racks containing the diagnostics receivers. In the tunnel, the mux/pre-amplifiers are located as close to the beamline sensors as is practical, and free from excessive cable runs. The crowded beamline results in very close proximity to active RF elements, particularly the cryomodule containing the SRF booster cavities.

Measurements

Since the mezzanine is accessible during operation, a survey of the klystron installation was performed (T. Plawski) using a Narda RF Field Probe, indicating the presence of fields (> 30W/m^2, or ~ 1V/cm) near the circulator and waveguide assembly. This level is recognized to be far below any safety or typical CEBAF operational level, but due to the unprecedented proximity to sensitive receiver electronics, >180 dB of path loss is necessary to ensure proper diagnostics performance.
Some initial shielding was attempted using aluminum foil and a mu-metal shield for a cryomodule, with some degree of improvement.

Subsequently, a beam-base test was performed, allowing booster RF ("Q1" and "Q2") to be exercised independently. Since beam is operationally limited after the cryomodule, a Faraday cup was used to prevent the keV beam from reaching the booster and downstream components. In addition, no beam current limitations are in effect for keV beam, allowing studies at ~100 nA, a known beam current for which solid SNR and expected BPM performance occurs.

The test began (02/09/21: 1150h) by delivering 30 nA of CW beam to the first Faraday cup, with no RF to either booster amplifier. At that time, beam was apparent on all KeV BPMs, properly reporting positions, as demonstrated by the typical "fuzzy ball" on the expert screens, as shown in Figure 1.

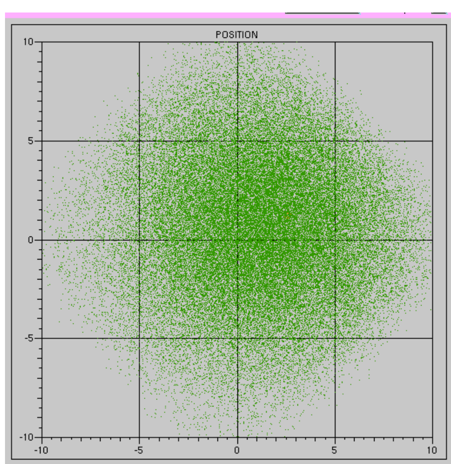


Figure 1. Gaussian "Fuzzy Ball" plot of position for ~30 nA of CW beam. Radial component decreases with respective improvement to SNR, eventually collapsing onto a centroid, or the reported beam position.

With reference to Figure 2, the beam was then ramped to 100 nA (1152), which shrank the position balls, appropriate for the SNR improvement, and without adding significant position offsets.
From there, "Q1" was switched on (1155, maintaining the 100 nA CW beam), followed by "Q1 + Q2," (1157) and finally "Q2" by itself (1200). With RF on to both systems, beam was removed, and the individual pre-amplifier/multiplexers were individually shut down by removing the respective fuses, upstairs, demonstrating (and hopefully isolating!) the possible source of interference.

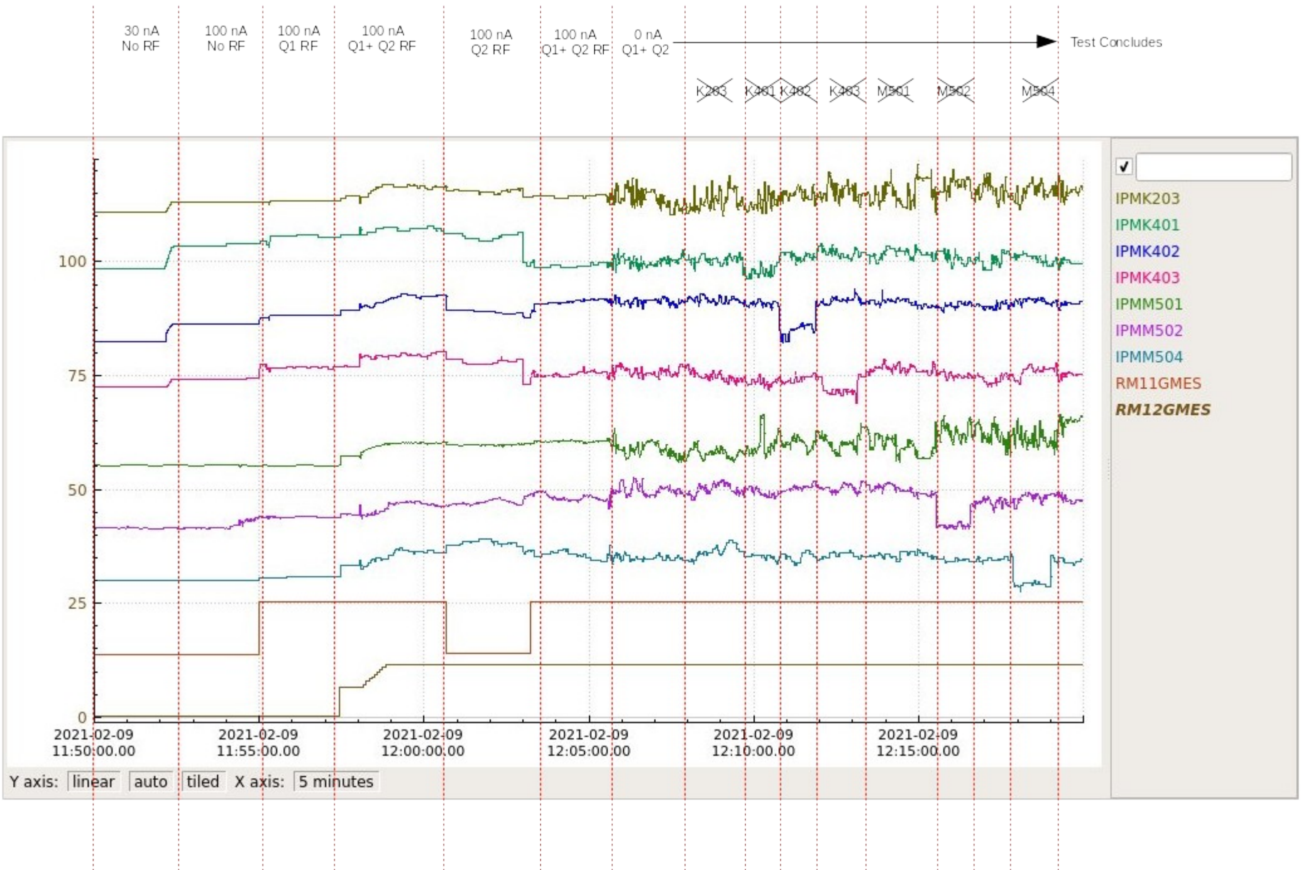


Figure 2. Plots of data obtained during the beam/RF study for BPM receiver interference. Normal,expected operation is seen at 30 nA and 100 nA with no RF present. However, as "Q1" and "Q2" are switched on and ramped, significant interference is observed, with perceived magnitude of ~100 nA. Selectively switching off vault electronics indicates improvement (hence suspected location), but subsequent tests also uncovered leakage in the mezzanine.

Interestingly, the DC levels representing the 4-wire sums remains close to ~100nA, but with a large increase in AC noise. Automatic gain switching occurs within each receiver, which was not being recorded during this particular test. It may be the case that a different range was used, with subsequent change to resolution. Or, the vector sum of several RF leakage paths could result in a Rayleigh Fading scenario. Nevertheless, the effect is to shield the electronics from effectively measuring below 100 nA. Figure 3 presents a visual no-beam/no-RF versus no-beam with "Q2" RF interference comparison, indicating hostile disruption and distortion of Gaussian behavior. Initially, the data implied that the majority of effects might be from the vault, as observed by the improvement to the 4-wire sum as the mux units were switched off. However, real-time observation from the mezzanine as various shielding scenarios were tried resulted in obvious attacks on beam position and symmetry, as demonstrated in the figure. Various degrees of improvement to the sizes and shapes of the beam position plot occurred both in the mezzanine and with the selective elimination of the vault electronics . It is clear from these observations that both locations must be addressed.

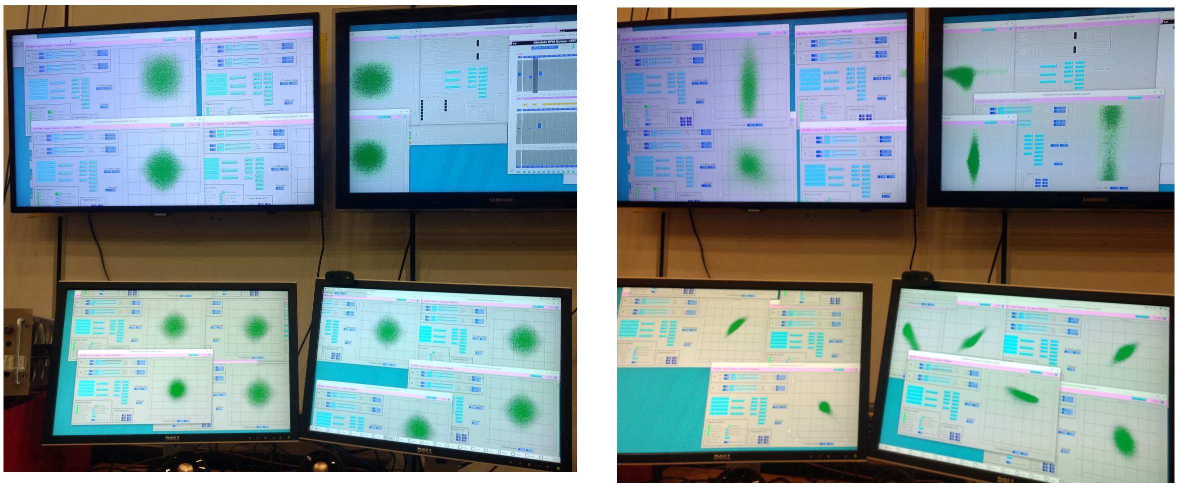


Figure 3. Comparison of no-beam/no RF to no-beam with "Q2" RF enabled. Non-Gaussian behavior is observed in both KeV and MeV regions, as well as rather large centroid (ie. position) offsets. Effective sensitivity is well above 100 nA, severely limiting the utility for lower currents.

After discussing the situation with the HPPRF Group, they agreed to positioning some shielding and Ecosorb around the klystron stand, hopefully removing the bulk of reflected RF. In addition, EESIC is installing rear doors on the equipment racks, to further increase path loss. The next battery of testing should discern improvement (we are hoping for 10-20 dB, which would restore sensitivity to < 10 nA), from which we can propose additional shielding strategies. Of particular concern is the placement and performance of the soon-to-be-installed BCM system for MPS. Upcoming runs insist on a ~100 nA current limit, which will require significant SNR, and resolution at the nA-level. While it is the case that the BCM sensor produces significantly more signal than the BPM, it is essential that any leakage be minimised to ensure confidence in the measurement, hence effective machine protection.

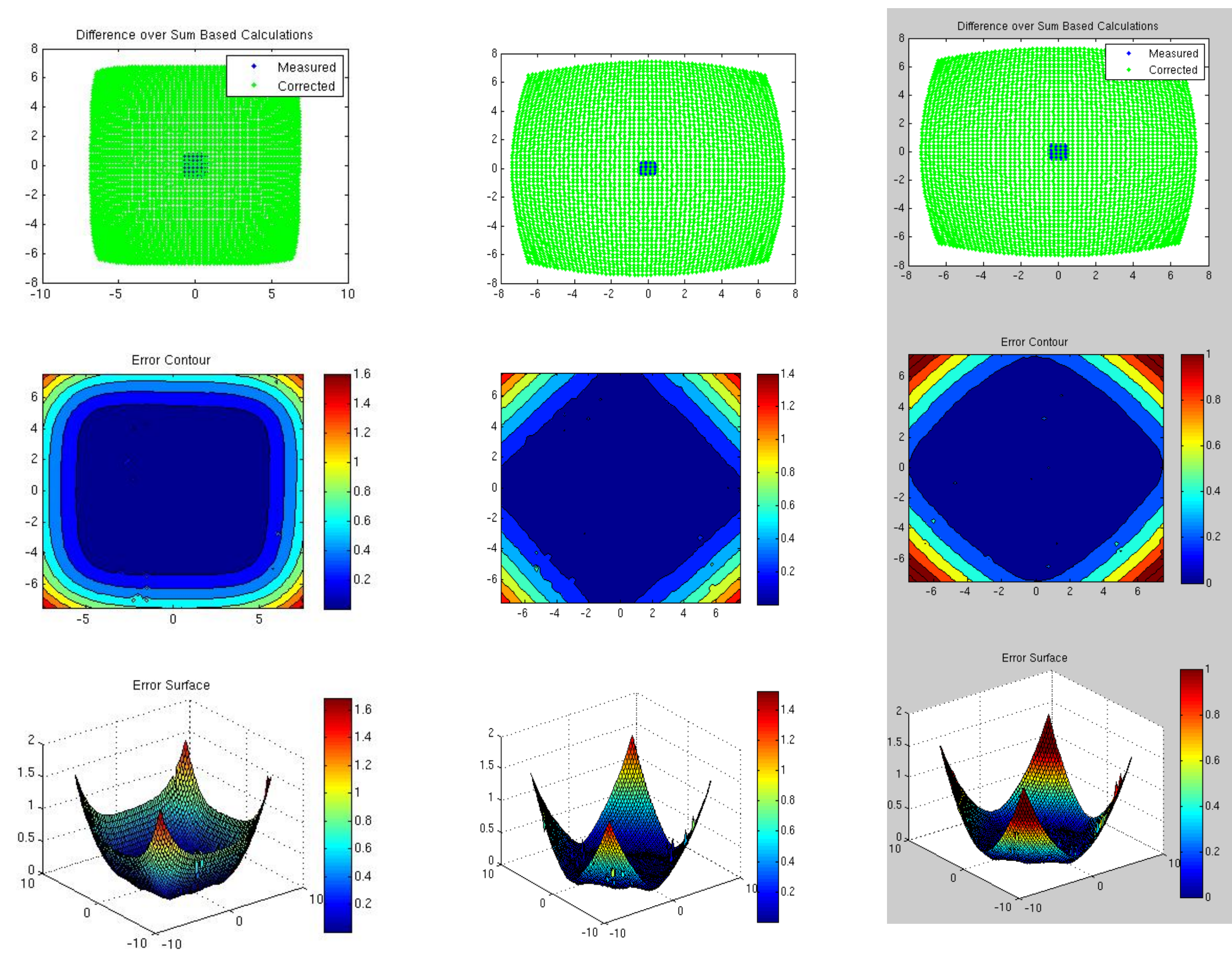
Discussion

Again, we realize the klystron installation is solid, and following sound JLAB emission standards. It is unfortunate that our sandbox is rather small, and we greatly appreciate the attention and guidance from the EESRF Group. Alas, if we are unable to provide a passive solution to the interference, we will explore active options, including beam modulation and lock-in receiver functions, which would also likely benefit CEBAF and LERF applications.

Finally, there has been discussion relating the susceptibility of interference in the actual beamline sensor. Traditional M15 antenna-based sensors (200 Ohm*) and stripline-based sensors (50 Ohm*) are inherently shielded by the beamline and corpus, for which the stripline has the thickness advantage. The interference imposed on IPMM502 and IPMM504 is at least an order of magnitude greater than for IPMM501 and IPMM503, which are all placed within a matter of feet of each other, with alternating

* The impedance, here, describes not the load impedance, but rather the transmission line impedance inherent to the sensor.

impact. Neither structure is resonant (Q=1), and feedthroughs are all welded. Figure 4 is a comparison of bench-derived field map data for a UITF stripline and an M15. Anomalous behavior would likely be apparent, not to mention the years of run history in the CEBAF Hall D line (33 BPMs).



(a) (b) (c)

Figure 4. Field map comparisons between UITF-style stripline (a), a CEBAF M15 (b), and a modified, “stubby” M14 as used in the CEBAF injector (c). Error maps are derived from the difference between the rotary encoders and the electrically-calculated positions, employing a difference-over-sum algorithm. The units are all in mm.