# Fast DAQ for Machine Learning

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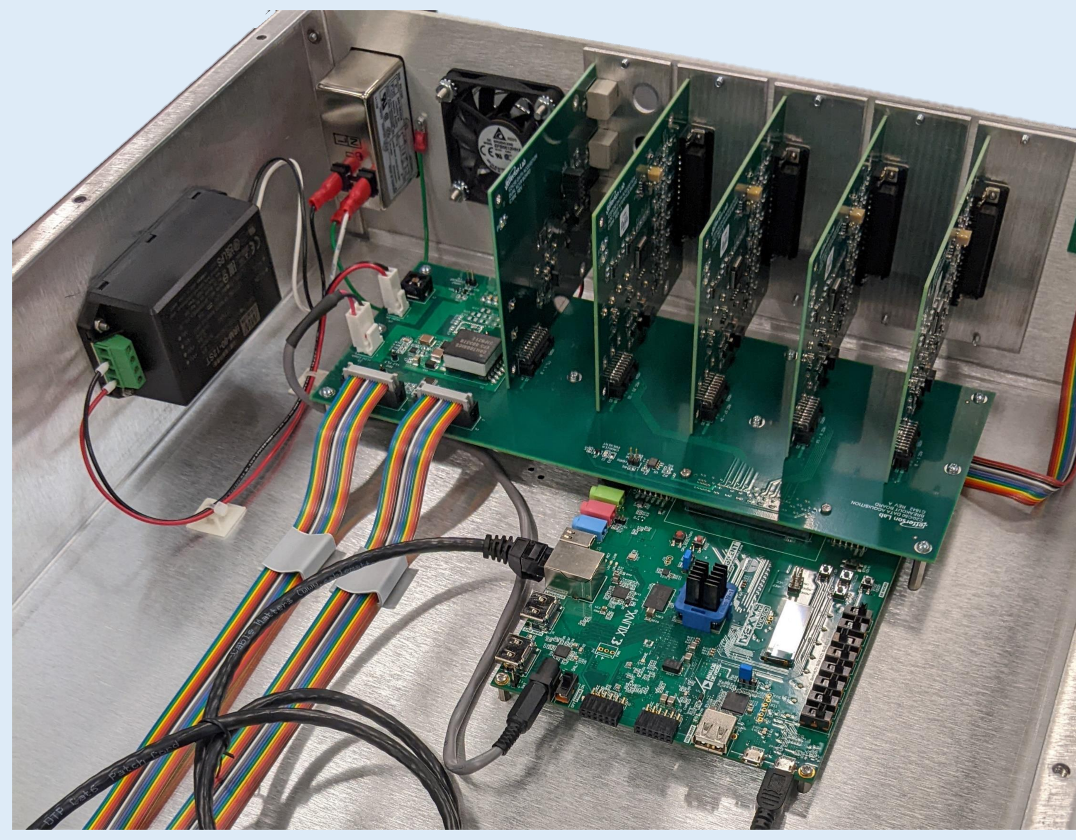
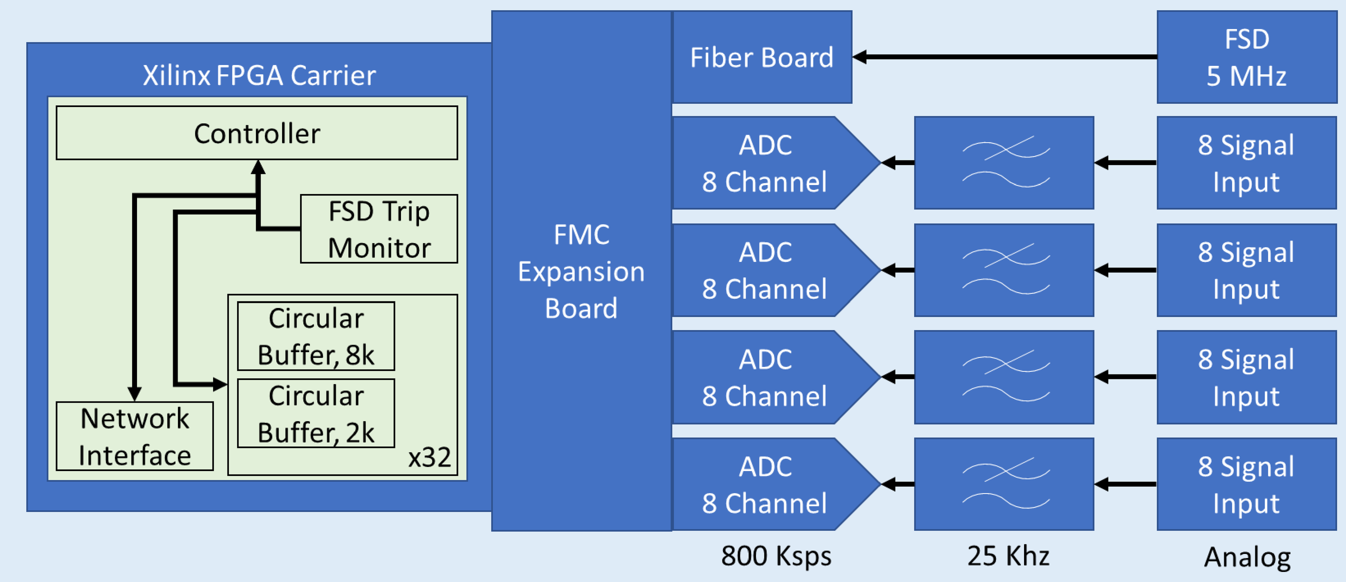
## Abstract

During the operation of CEBAF, one or more unstable superconducting radio-frequency (SRF) cavities often cause beam loss trips while the unstable cavities themselves do not necessarily trip off. For example, beam lost due to a cavity tripping offline from an ARC event may be caused by instabilities on another upstream cavity. In this example, the instabilities in one cavity facilitated the circumstances that led to an ARC event in another cavity. Identifying an unstable cavity out of the hundreds of cavities installed at CEBAF is difficult and time-consuming. The present RF controls for the legacy cavities report at only 1 Hz, which is too slow to detect fast transient instabilities. A fast data acquisition system for the legacy SRF cavities is being developed which samples and reports at 5 kHz to allow for detection of transients (or really just anything with a bandwidth of more than 1 Hz). Most of the North LINAC CAMAC zones have a DAQ deployed. An auto encoder based machine learning model [1] as well as a PCA based model [2] are being developed to identify anomalous SRF cavity behavior and report these to operators.

The Fast DAQ chassis are useful to technicians because they allow for debugging and diagnosis of a specific cavity issues in real time. They also provide fault data which can be useful in identifying which cavities require attention. However, the main hope with the DAQ is that it will, eventually, be a tool that can identify and label active issues in a given cavity and provide recommendations on how the cavity instability can be corrected. Ideally this will be predictive and prevent trips, but even post mortem analysis will be useful in identifying that an instability exists which, when corrected, will hopefully prevent future trips.





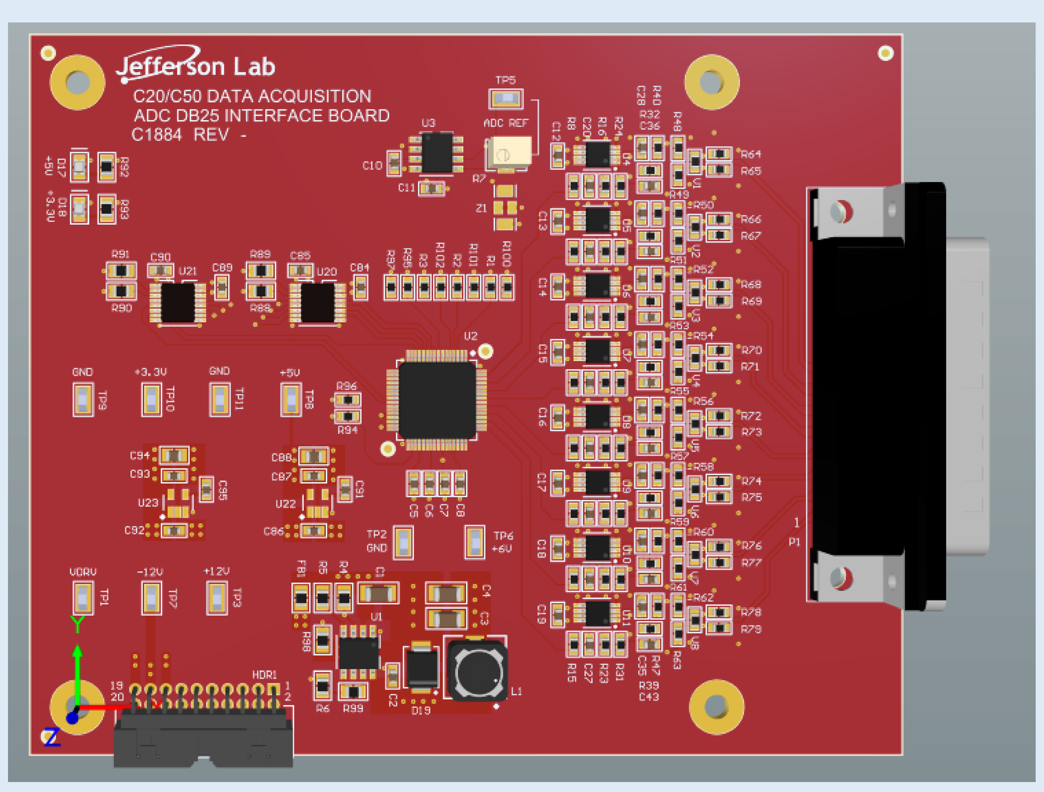

## DAQ Chassis

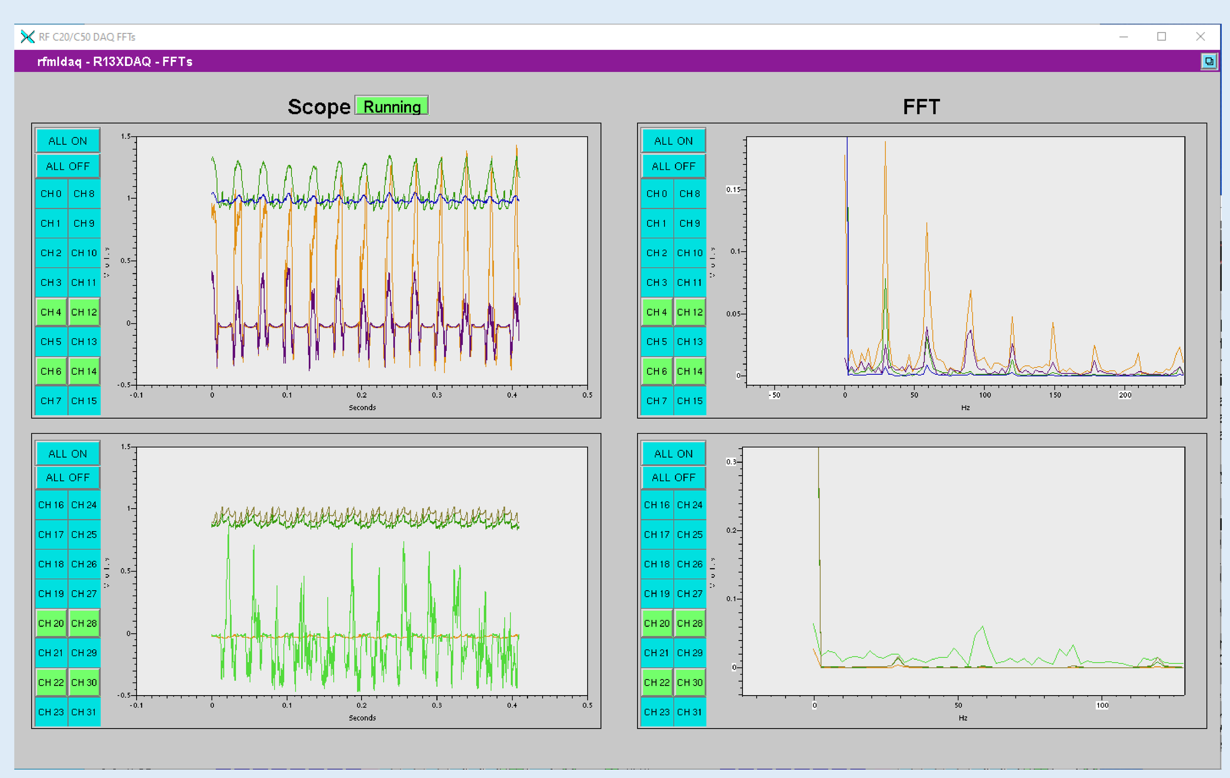
The Data Acquisition (DAQ) Chassis was developed to take in up to 32 channels of differential analog signals (+/- 12 VDC range) over 4 identical ADC boards. It was a design decision to choose PCB to PCB connections in place of ribbon cable connections. This increases the robustness of the design while making the design very compact. Additionally there is one fiber trigger board which take a 5 MHZ Fast Shutdown Signal (FSD). This FSD is held low when beam is lost, triggering a freeze in the data collection. This archived data is the raw form of the training data used for some of the machine learning projects at Jefferson Lab. The FPGA carrier for this is a Digilent Nexys Video board which has installed a Xilinx Artix 7 FPGA. This FPGA has more than enough internal BRAM to store all 32 of the 8k waveforms that are frozen when a trip occurs.

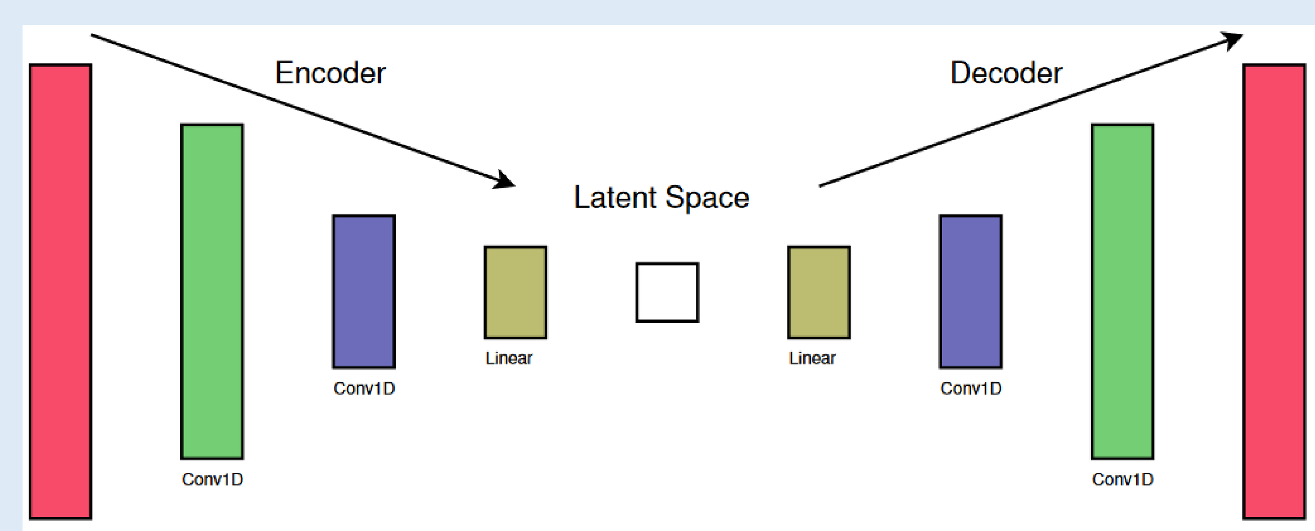
## System Level Block Diagram

The DAQ samples key control signals used to control the C20 which is an 8 cavity Cryomodule. There are 4 control signals looked at per cavity which pertain to the gradient and phase. All signals are continuously sampled and saved onto a circular buffer. Whenever a beam is lost, the buffers are frozen which allows EPICS (a software based control system) to save all of the fault data on external hard drives. This is done for all zones which have the DAQ installed.

The fault data is used by RF experts to assess if a particular cavity may have caused the loss of beam and it is also given to Machine Learning tools which attempt to identify statistical variants from normal operation and flag them so that they can be looked at by an operator.




## ADC Board

An 8-channel analog-to-digital converter (ADC) board with onboard filtering and circular buffers is a powerful tool for data acquisition and analysis. It can be used to sample and digitize eight analog signals and then store the data in circular buffers for further processing. The analog Sallen-Key filtering can be used to remove noise and interference from the signals before they are digitized, which can improve the accuracy and reliability of the data. The circular buffers are a type of data structure that allows for continuous data acquisition. The data is stored in a ring buffer, and as new data is acquired, the oldest data is overwritten. This allows the FPGA to have access to the most recent sample. When the FPGA wants to read the data, the circular buffer is frozen, allowing the contents to be read and displayed on EPICS waveforms and saved on external hard drives for post processing

## Tuner Waveform Viewer

The DAQ allows for real time monitoring of cavity performance. The above shows a display of the waveform viewer. In addition to machine learning research, these tools are used to help debug cavities in real time.

The increased sample rate of the DAQ chassis has helped RF experts in identifying and detecting cavity instability in NL03 (shown above). Shown here is 30 Hz noise source (and its harmonics). These would have been invisible given the legacy cavity controls. Machine learning researches at Jefferson Lab are designing ML based tools that use these waveforms to predict cavity instability.

## Auto encoder Model

When beam is lost, it is not always evident which cavity may have caused the trip. For example an ARC event on one cavity may be caused by an upstream instability on another cavity. Being able to identify the source of the instability is paramount for low trip rates. One of the machine learning tools used to identify cavity instability was an auto encoder model [1]. This tool has been shown to help identify cavities which are behaving differently than others by activating on features correlated with any label (encoding phase) and then correlating these filtered features with a specific classified label (decoding phase).

Other models using PCA (a purse statistics approach of machine learning) are also being actively investigated [2].

## Future Work

There are nearly 300 legacy CAMAC controlled cavities at Jefferson Lab. Though these legacy zones are actively being replaced with newer LLRF control systems, developing tools to diagnose and identify issues with the C20 cavities is essential to operations. The DAQ tools will help technicians and operators to run the CAMAC zones. It is the hope that these DAQ chassis accelerated by machine learning tools will make it easier to identify which of the +300 cavities may be causing an instability.

Future work is to finish outfitting all zones with the DAQ tools and to refine machine learning models and develop new ones as needed.

## Summary

In summary, the DAQ has shown to be useful in troubleshooting some of the legacy zones. The DAQ has hopes to serve as triage to help focus efforts on cavities that are causing instabilities. However this triage only needs to hold fast until newer Cryomodules and new LLRF control system can be deployed. In the meantime, state of the art stochastic modeling (machine learning) will be used to help the legacy zones usefully be operated until these much needed upgrades can be funded and implemented.

## References

[1] D. Turner et al., “SRF CAVITY INSTABILITY DETECTION WITH MACHINE LEARNING AT CEBAF” in Proceeding of 5th North American Particle Accel. Conf., Albuquerque, NM, USA, 2015.
[2] H. Ferguson. “CAVITY INSTABILITY DETECTION FOR THE CONTINUOUS ELECTRON BEAM ACCELERATOR FACILITY” Tech note, Jefferson Lab.
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[5] Clyde Mounts, private communications and expert suggestions.

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