Transient Microphonic Effects In Superconducting Cavities

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Background

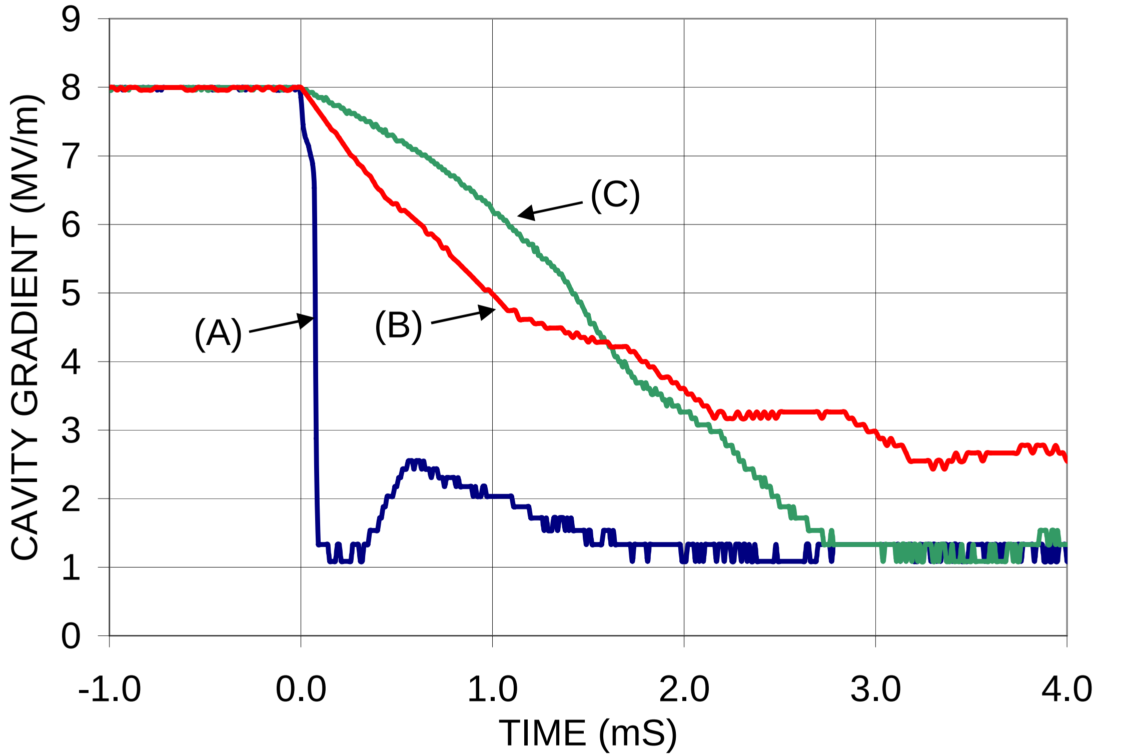
- Arcs in the vicinity of the cold RF waveguide window cause occasional cavity trips.
- On cavities that arc, the trip rate increases with gradient once the field emission onset gradient has been exceeded.
- The cumulative effect of these trips in 338 SRF cavities reduces CEBAF performance especially at beam energies 30% to 50% over the design value.
- Presently, beam recovery following a trip takes approximately 30 seconds. The first ten seconds is to restore gradient.
- The cryotargets used by physics require beam restoration within a few hundred milliseconds to remain at thermal equilibrium.
- The waveguide vacuum signal decays in about 2 seconds.
- Question. With a temporary mask on the vacuum interlock, how quickly could a "fast recovery" algorithm restore a cavity to service following an arc trip?

Types of Arc Events

1. Waveguide Arc
   - Occur in the vacuum space between warm and cold windows
   - Gradient decay time ~1 – 2 msec

2. "Electronic Quench"
   - Occur in vacuum space on the cavity side of the cold window
   - Gradient decay time < 200 μsec

System Response to Arc Events

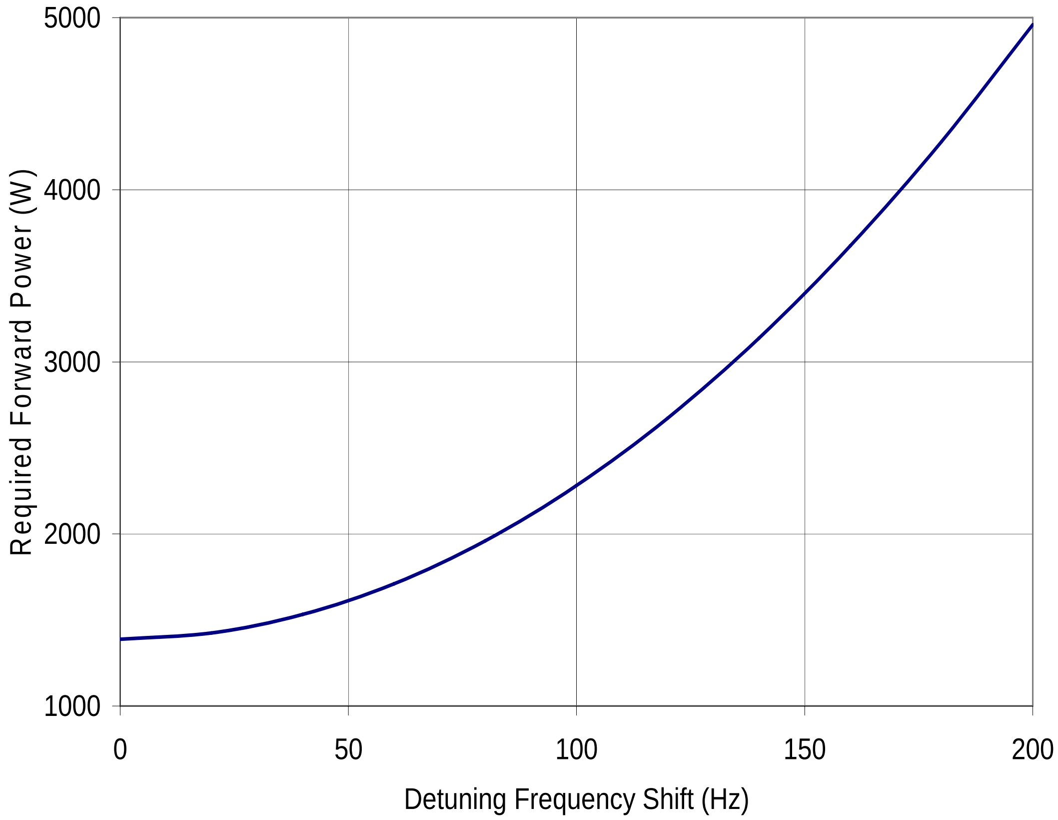


A. “Electronic Quench”
B. Waveguide Arc
C. Normal Response

RF Dynamic Power Requirements

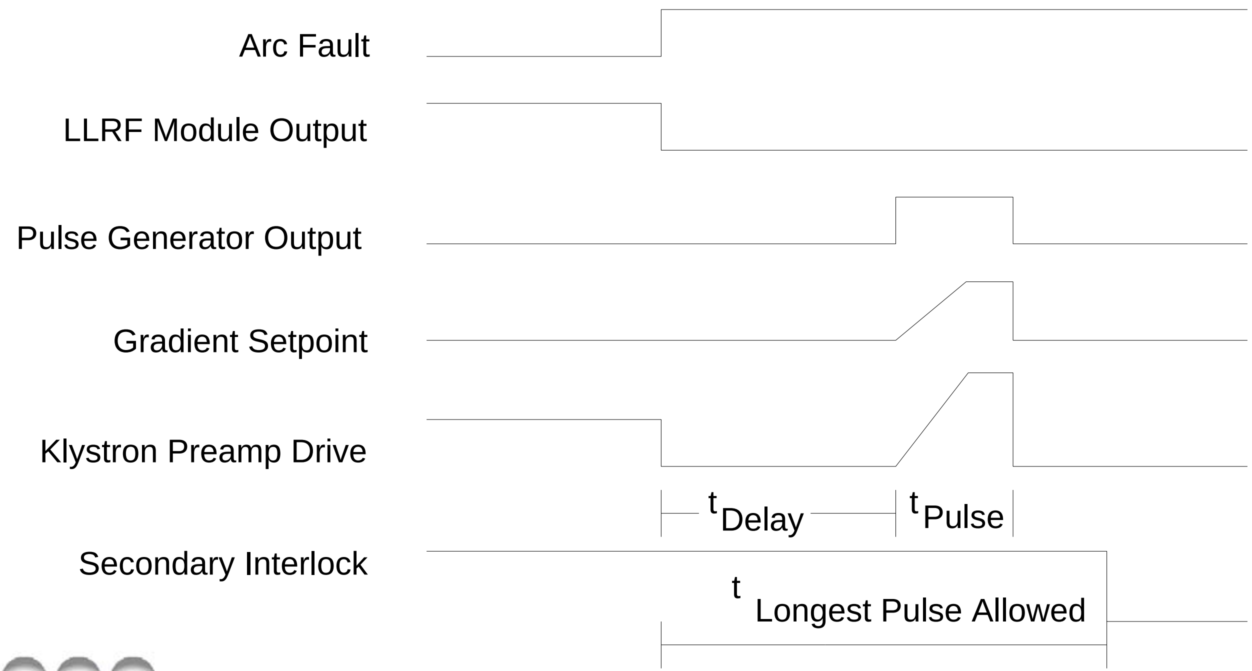
- **During normal operation, the power margin in order to avoid 5kW klystron saturation including microphonics effects is 300 to 700 Watts.**

- **Figure is the calculated power required as a function of detuning for a five-cell cavity with:**
  - **Bandwidth = 250 Hz,**
  - **Gradient = 8 MV/m,**
  - **No beam loading.**
- **For a cavity with these characteristics, 300 Watts of detuning is approximately 55 Hz.**

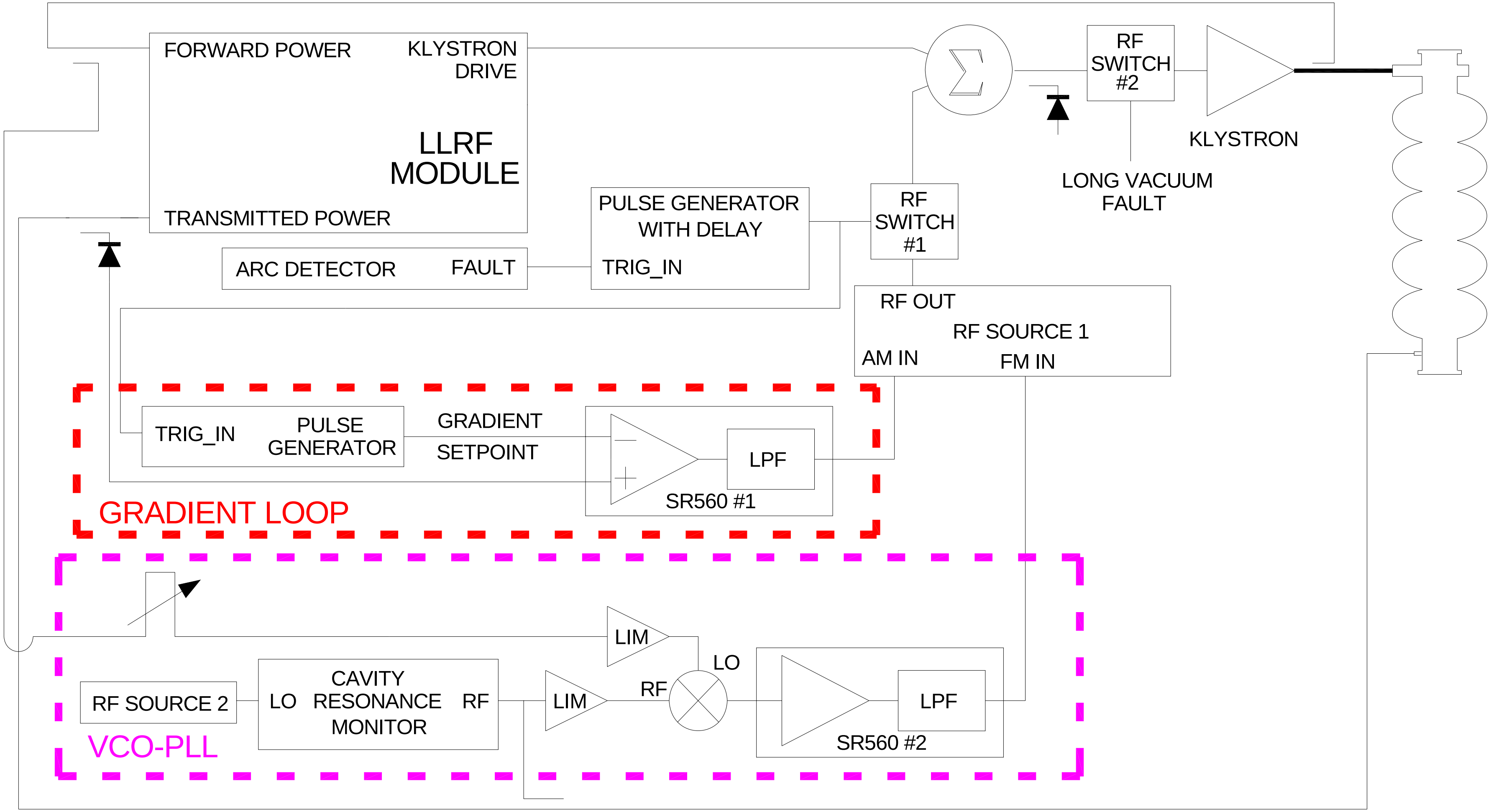


Experimental Overview

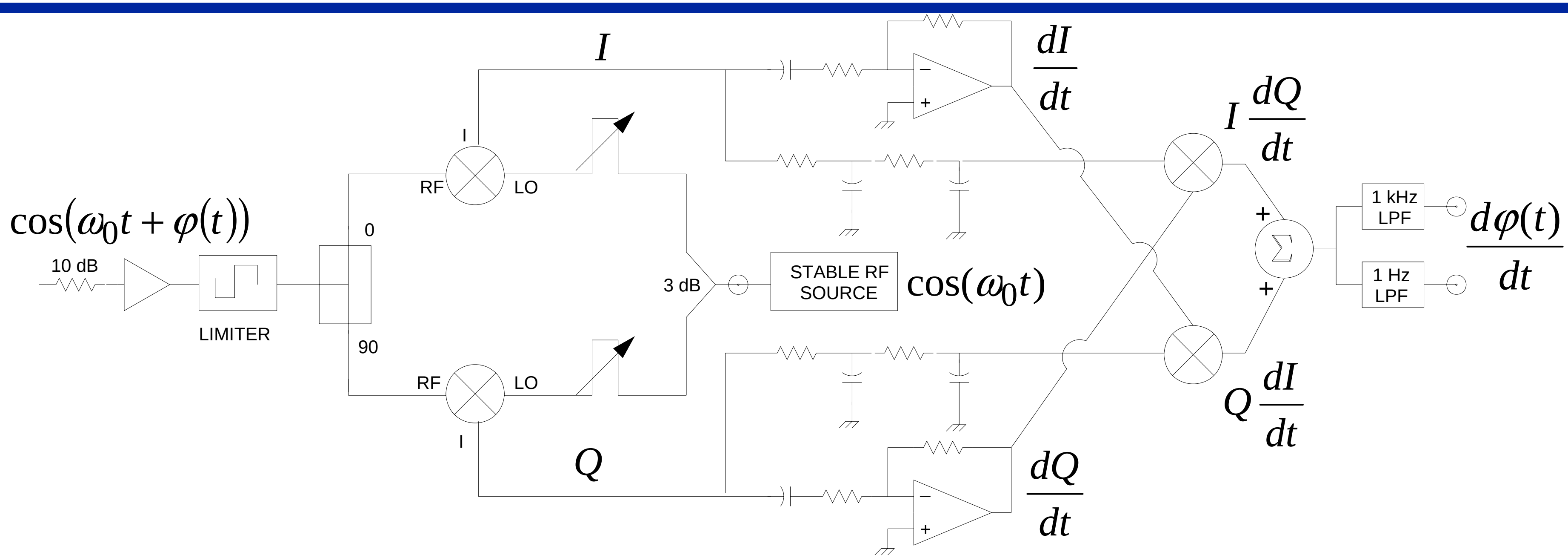
- **Induce arc events using the existing LLRF system**
- **Apply a secondary RF pulse following a delay**
- **Measure system response**
- **Vary delay and ramp-up time of secondary RF pulse**
- **Maintain machine protection via hardware interlocks**



Experimental Setup

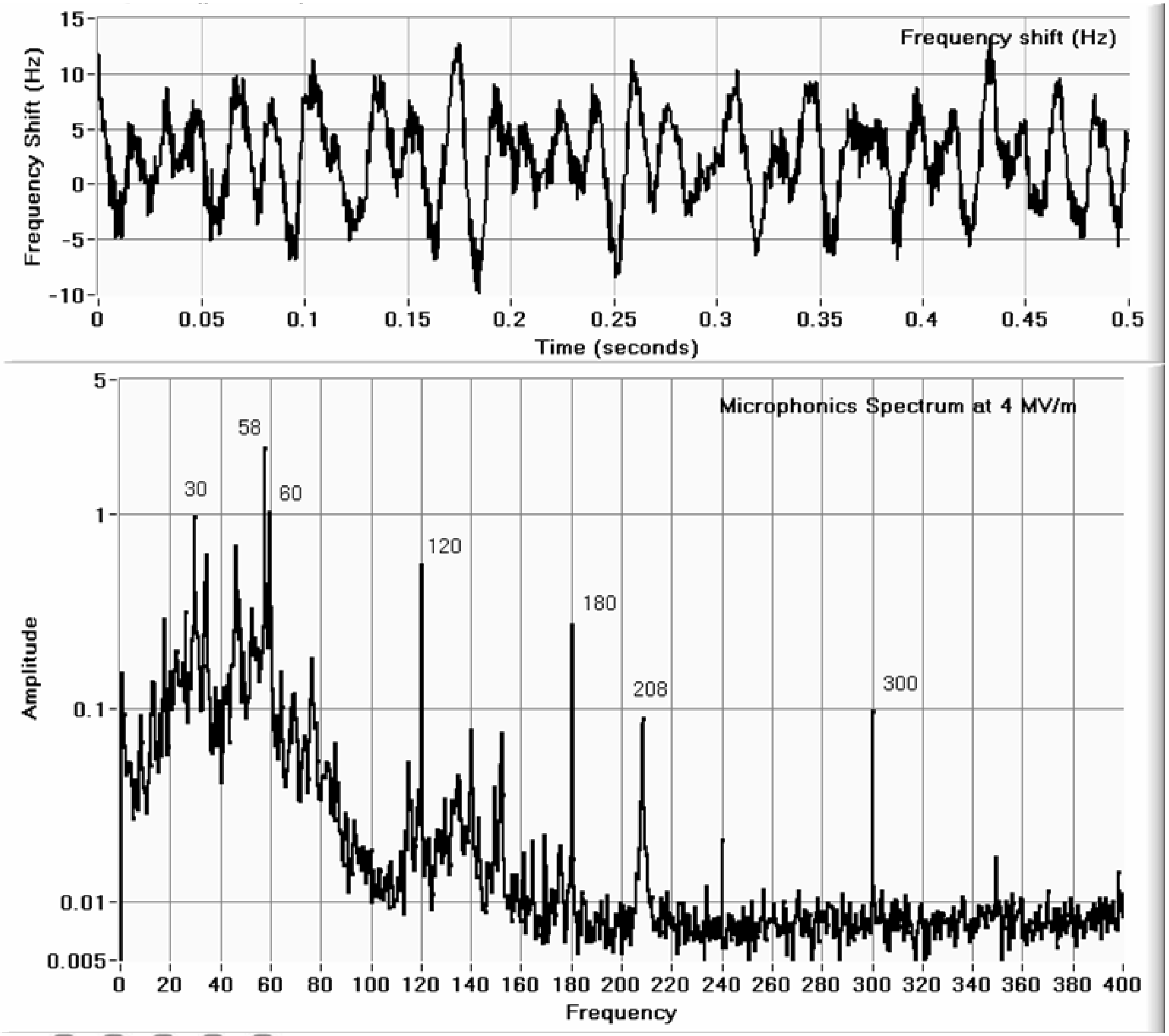


CAVITY RESONANCE MONITOR



- **A cavity resonance monitor is a system which provides an output signal which is proportional to the difference in frequency between the input signal and a reference source.**
- **They are useful for making accurate microphonic measurements in time domain.**
- **The front end circuitry requires careful tuning to ensure precise I/Q demodulation.**
- **The limiting amplifier is used to stabilize the gain in the system. Without it a separate power measurement would have to be made in order to calibrate the output signals.**

BACKGROUND MICROPHONICS MEASUREMENT



Time domain and frequency domain plots of the background microphonics for a 5-cell CEBAF cavity located in the CEBAF accelerator.

Open Loop Test Results at 7.7 MV/m

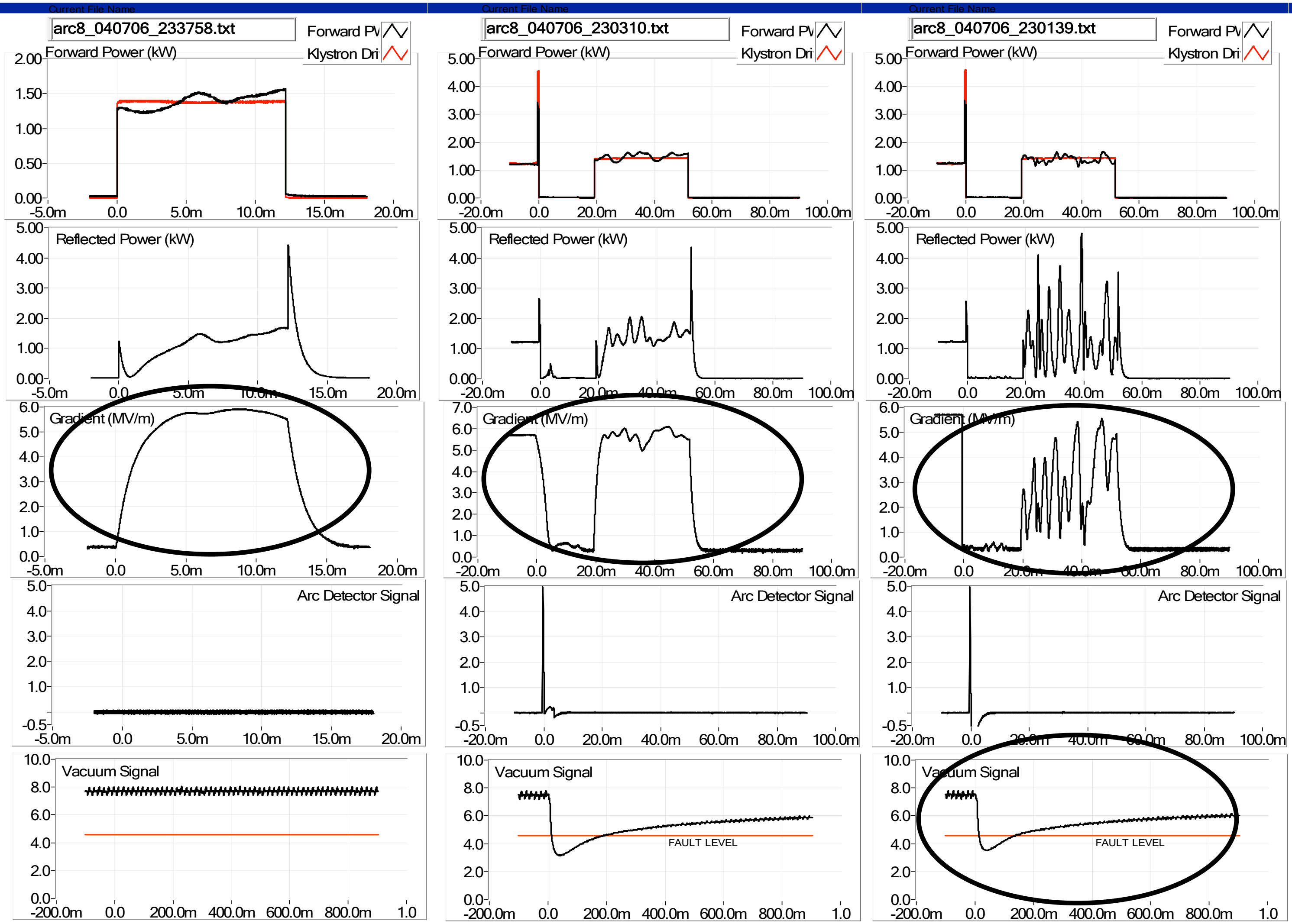
Forward Power

Reflected Power

Gradient

Arc Detector

Vacuum



Normal Pulse (no event)

Pulse following Waveguide Arc

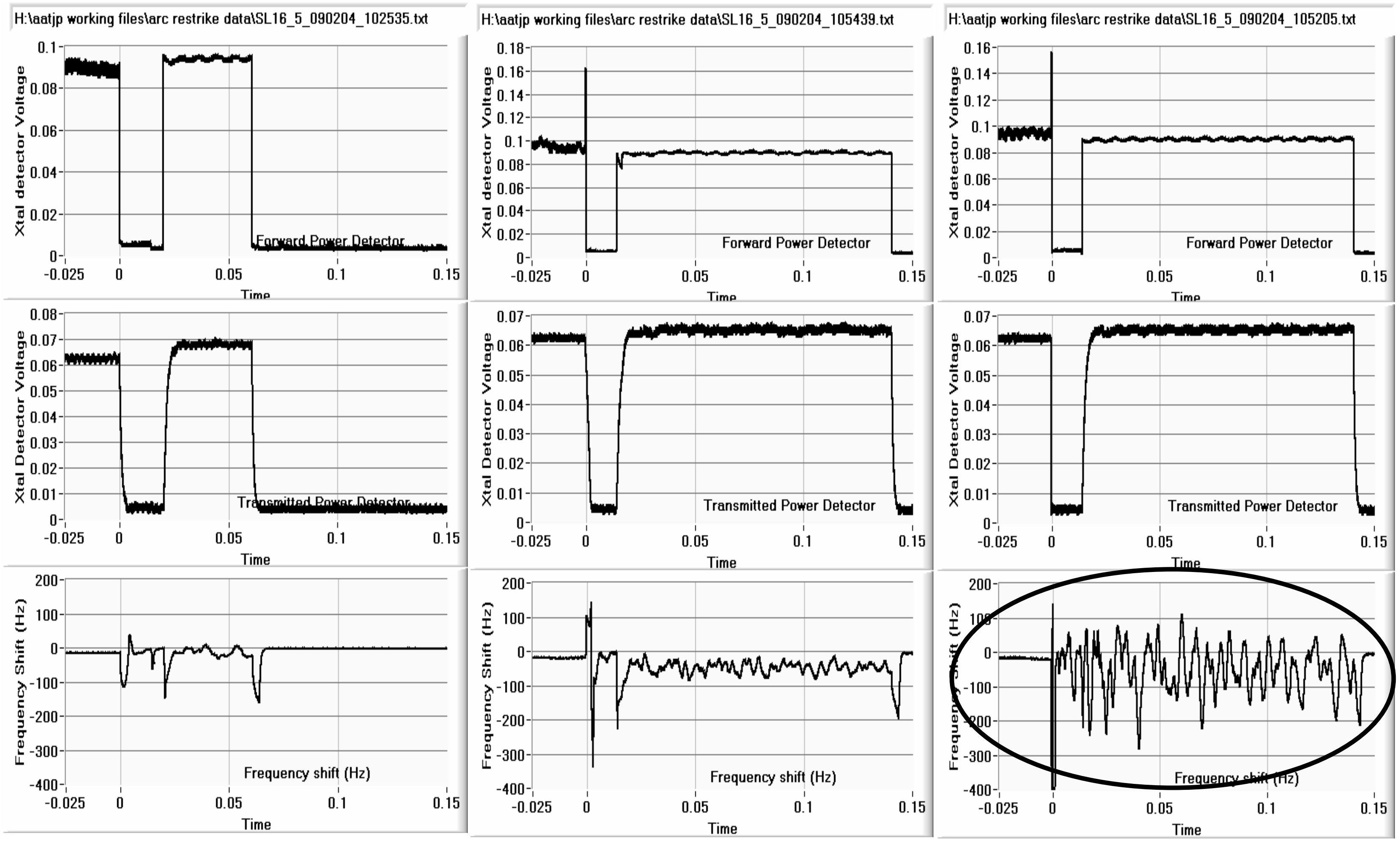
Pulse following “Electronic Quench”

Frequency Shift Measurements at 7.7 MV/m

Forward Power

Transmitted Power (Gradient)

Frequency Shift

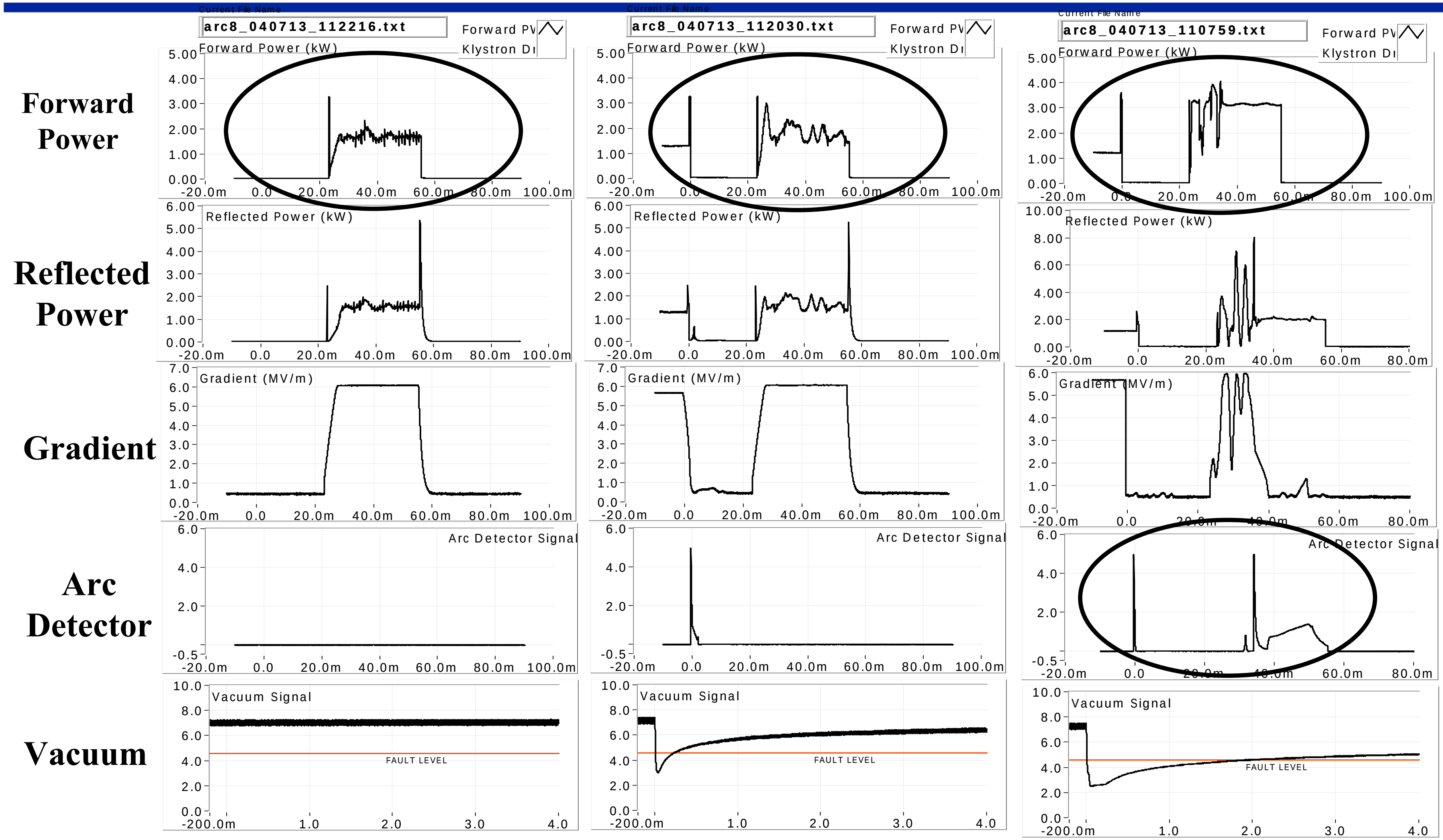


Normal Pulse (no event)

Pulse following Waveguide Arc

Pulse following "Electronic Quench"

Closed Gradient Loop Test Results at 7.7 MV/m

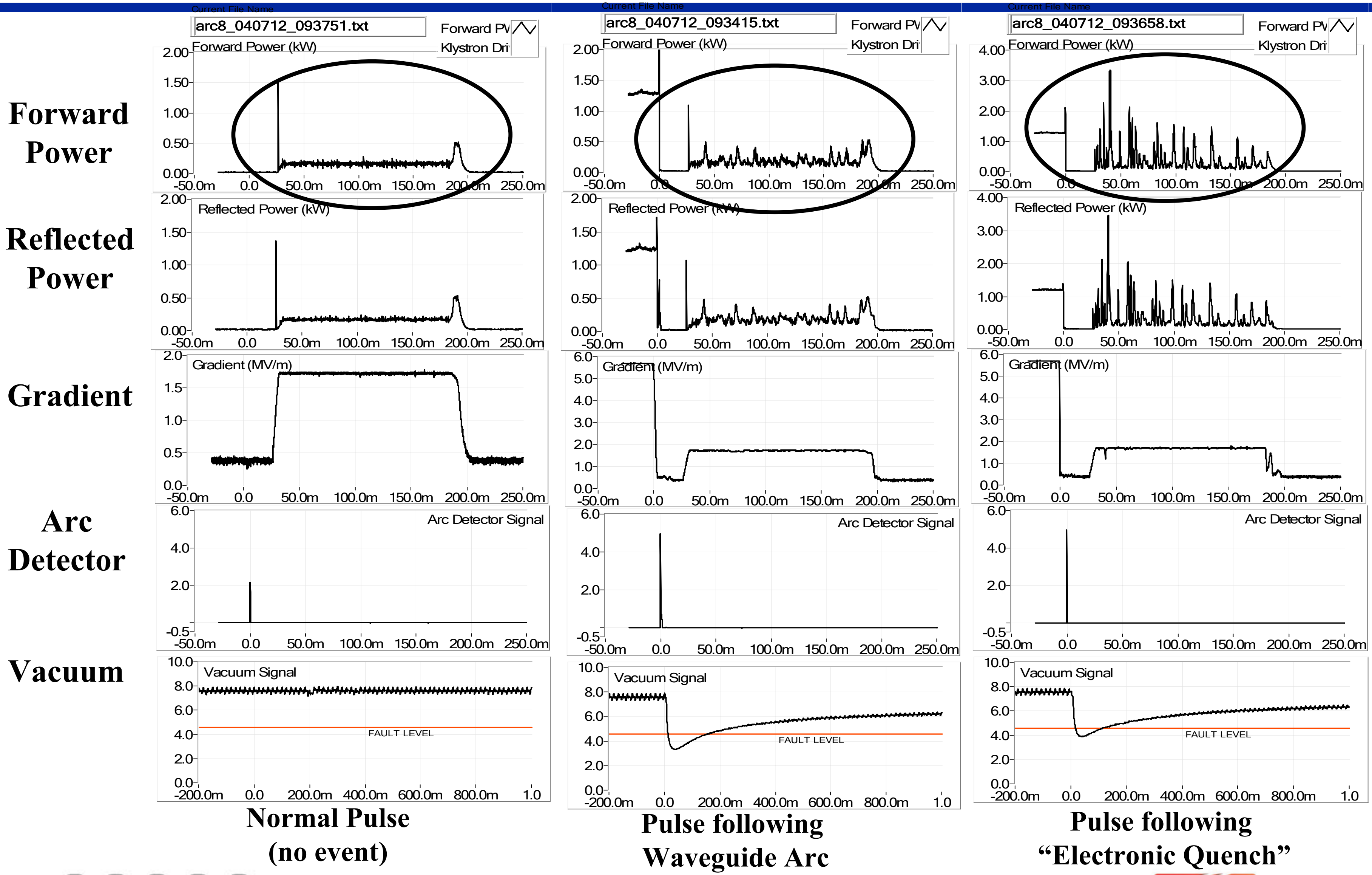


Normal Pulse (no event)

Pulse following Waveguide Arc

Pulse following "Electronic Quench"

Closed Gradient Loop Test Results at 2.3 MV/m



VCP-PLL Results, 100mS "Soft Start"

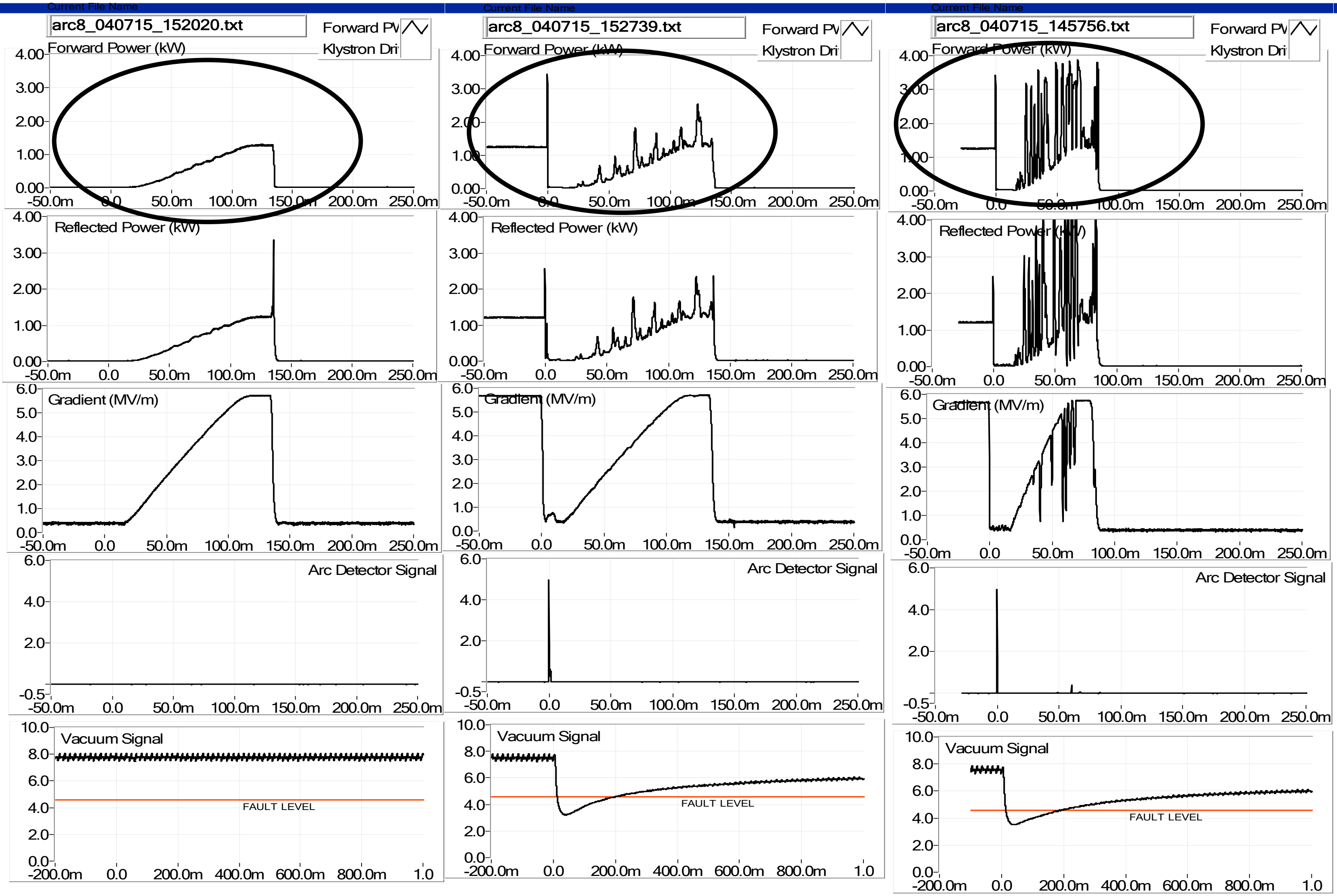
Forward Power

Reflected Power

Gradient

Arc Detector

Vacuum

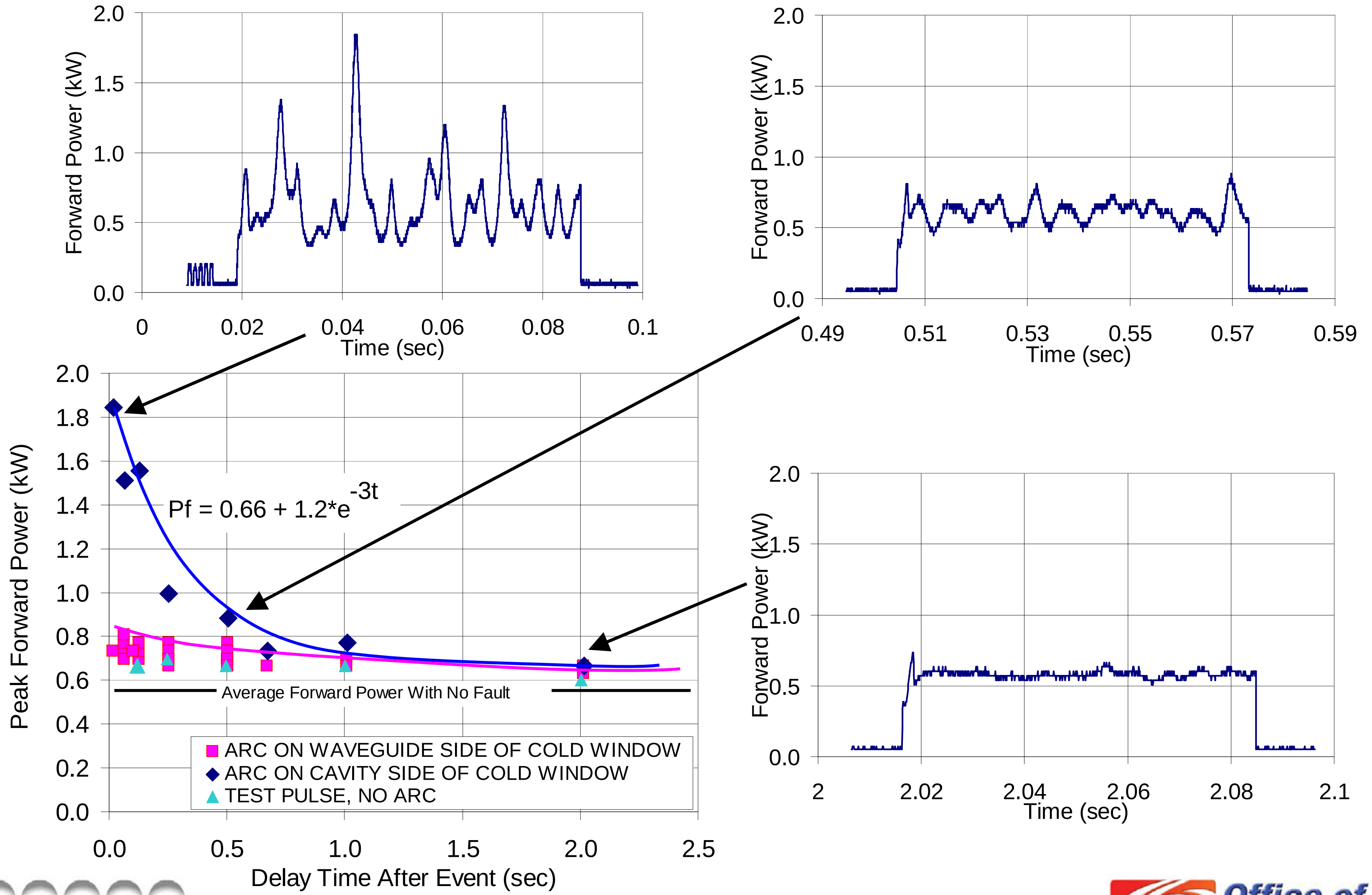


Normal Pulse (no event)

Pulse following Waveguide Arc

Pulse following "Electronic Quench"

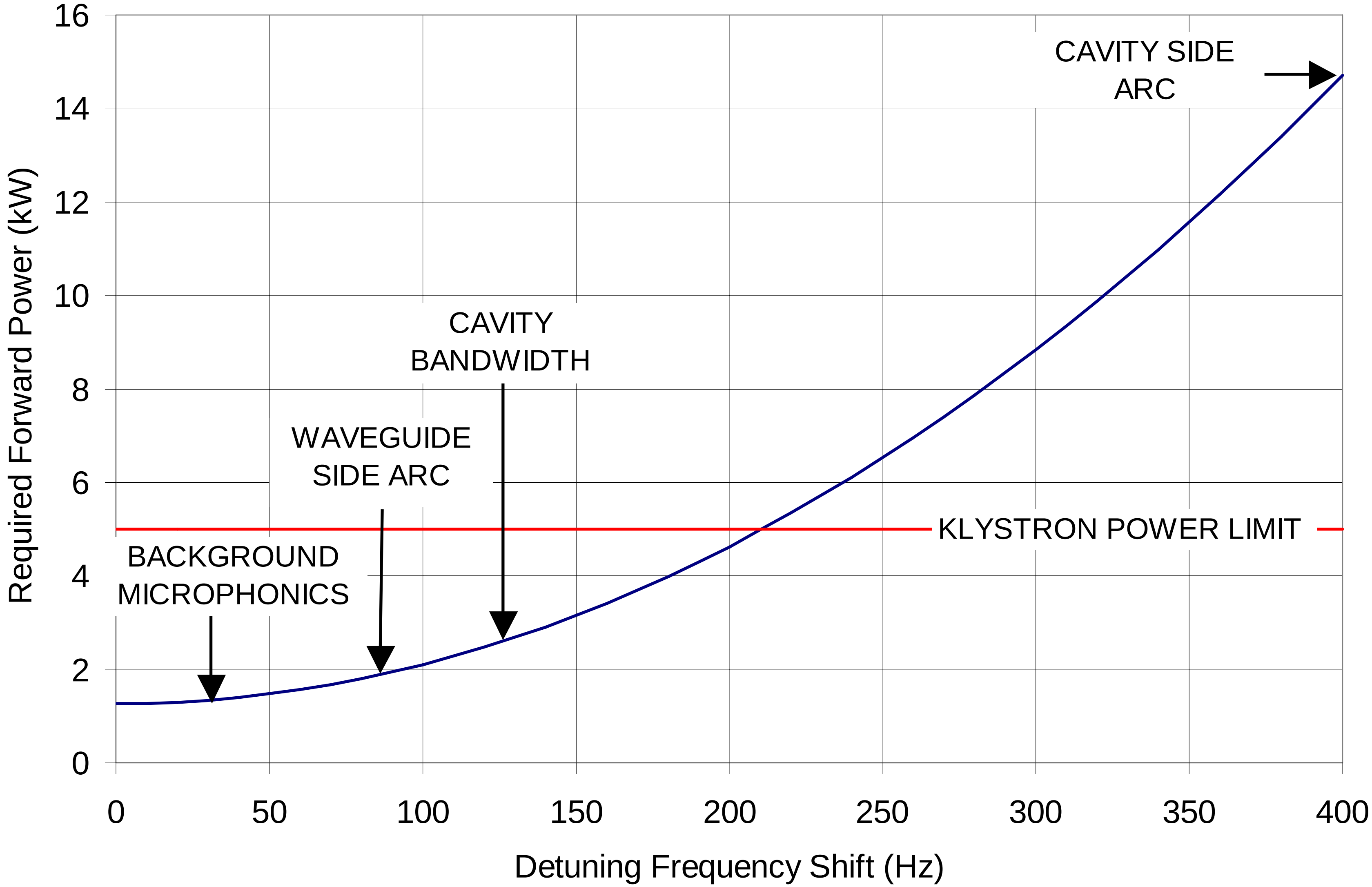
Response vs. Time Delay



Summary of Results

Event Type	Gradient Decay Time	Gradient Fill Time	Peak to Peak Frequency Shift
Background Microphonics	NA	NA	30 Hz
Arc Detector Test Pulse	5 ms	3 ms	45 Hz
Waveguide Vacuum Fault	2.5 ms	3 ms	75 Hz
Electronic Quench Fault	80 μs	3 ms	400 Hz

Calculated Power vs. Detuning at 7.7 MV/m



Conclusions

- There are cavity vibration modes that, coupled with beam-loaded klystron power margins, limit the recovery of CEBAF cavities after an arc event.
- The most likely source of the vibration excitation is the dynamic Lorentz force detuning which occurs when the cavity gradient is rapidly reduced by an arc event. This effect is substantially worse for an arc which occurs on the cavity side of the cold window where the gradient decays in less than 100µs.
- Using the existing RF system, one would probably have to wait for at least 500 ms prior to applying RF and about 1.5 seconds prior to loading the system with beam.

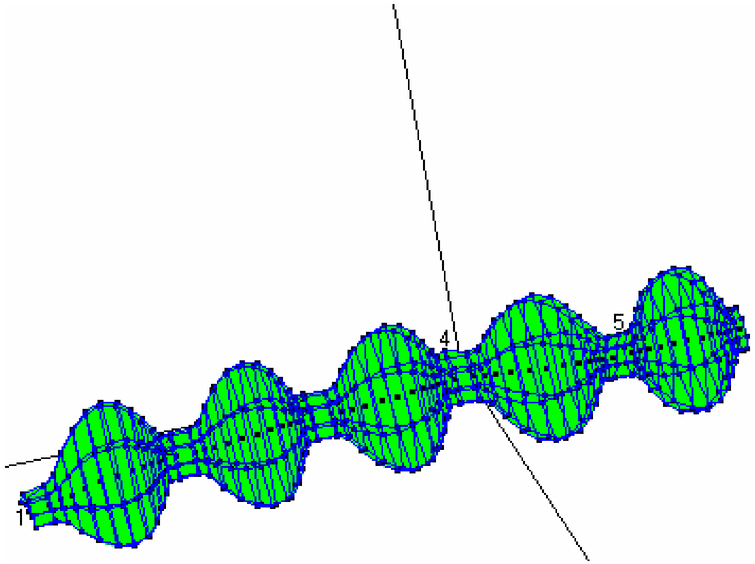
Conclusions

- **Power levels exceeding 10 times the nominal level (that is 3 times the CEBAF klystron capacity) would be required in order to maintain closed loop gradient control following an electronic quench.**
- **Vibration Modeling, testing, and control are important aspects of cryomodule design cycle for accelerators that are susceptible to microphonic effects.**

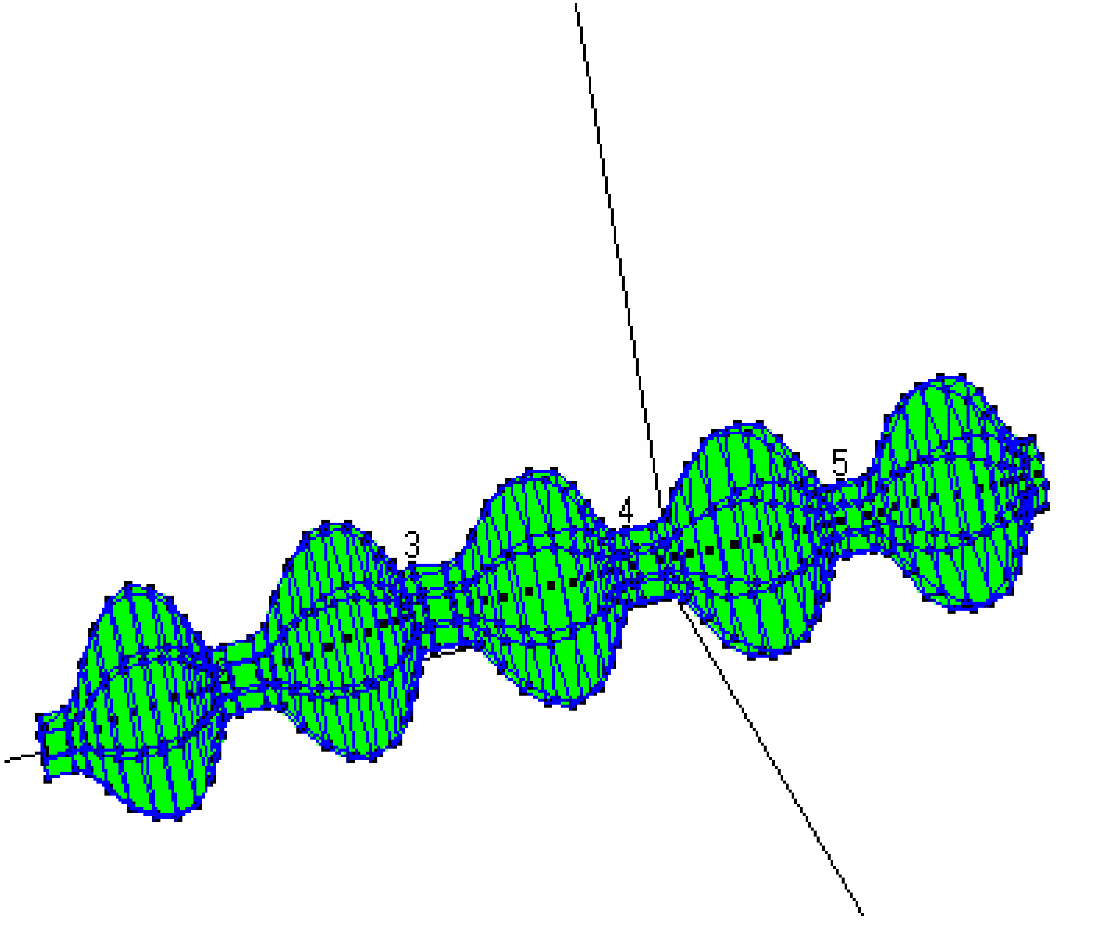
Ongoing Research, Vibration Modal Analysis

- **Modal Testing Using Accelerometers**
- **Warm Testing Performed**
- **Cold Testing Planned**

- **48 Hz Mode**



72 Hz Mode



166 Hz Mode