Quench Antenna Development Status

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Quench antenna instrumentation allows for better understanding of coil design/fabrication issues

The quench antennas being developed are inductive pick-up loops (etched onto flex circuitry that could be placed around and between coils) developed primarily for characterizing quenches (location, velocity, etc.).

Goals include:

- Complete coverage of magnet
- Robust, low cost, low-risk implementation in magnets
- Azimuthal and axial localization of quench origin
- Possibility of detecting outer layer quenches
- Detection of quenches for magnet protection in HTS (?)
- Detecting other transient magnetic events

LDRD (Lab Directed R&D) award granted for this work at FNAL.

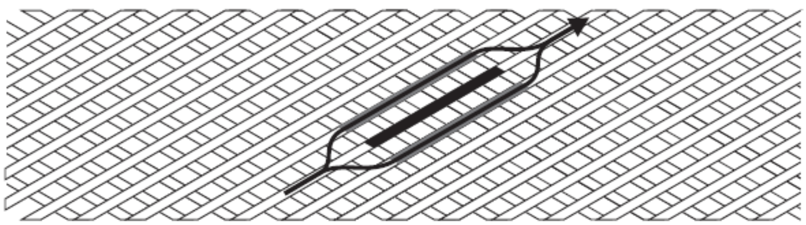
Quench antenna advantages/challenges

- Inductive pick-up flex circuit quench antennas are fairly mature technology and have been used successfully.
- Work is primarily in extending technology to covering full magnet with a high number of channels and eventually incorporating the antennas in fabrication between magnet layers.
- Scaling has its challenges - large flex PCB circuits may be fairly expensive ($20k+) or hard to produce with large sensitivity. Infrastructure of high speed, high resolution, data acq at $0.5k-$1k/channel
- Resolution is limited by practicality of large number of channels ➔ implementation of analysis treating signals from the multiple antennas as an array can improve this.

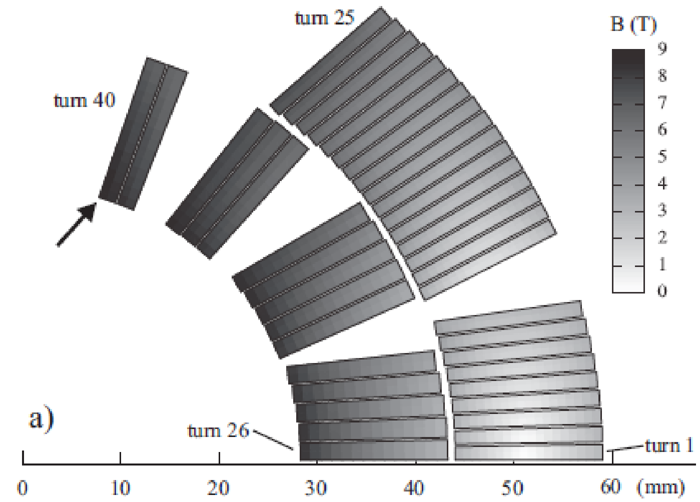
Developing simulation of quench antenna response

Current redistribution in quenching strand

Gerard Willering "STABILITY OF SUPERCONDUCTING RUTHERFORD CABLES FOR ACCELERATOR MAGNETS", Ph.D. thesis, University of Twente

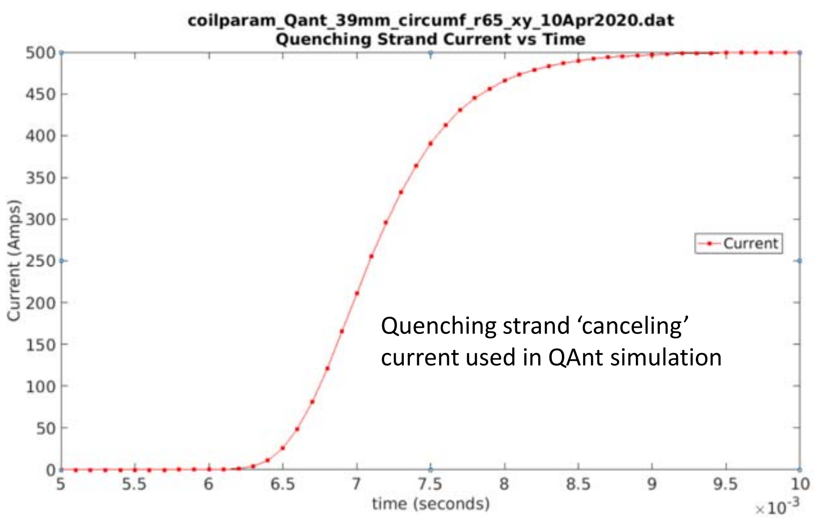


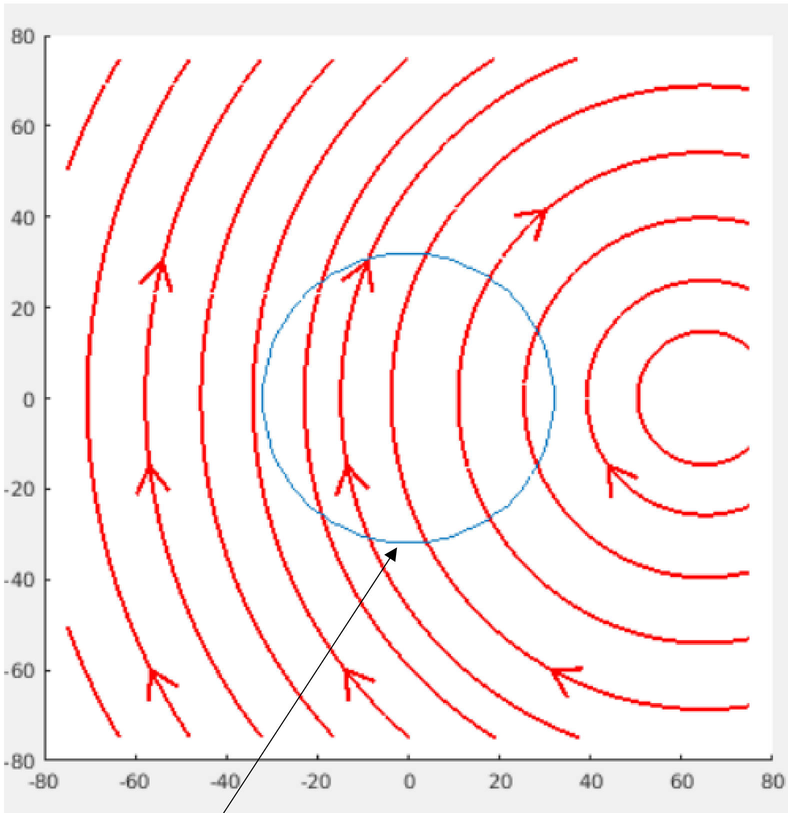
Current redistribution from a quenching strand



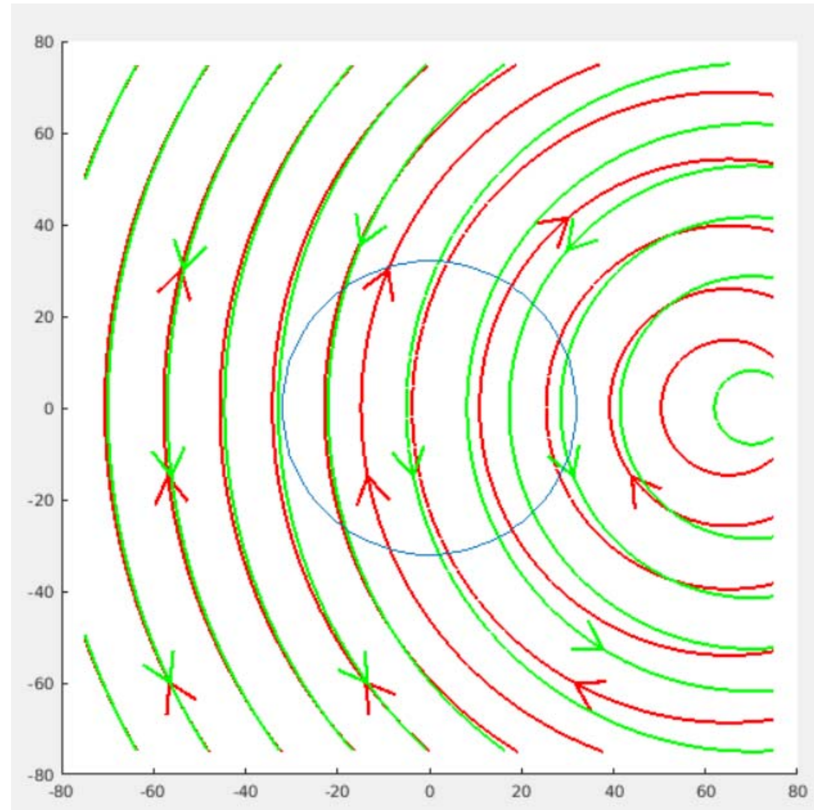
LHC magnet cross-section

Model quench stranding as effectively negative current line appearing which cancels current in strand, and an additional current line in a neighboring location. If assume this occurs at an edge, then the distribution is radially outward.





Quench is modeled as current line at some distance and angle to the antenna (left), or as a current line doublet (right) – the doublet models the fact that current decrease in one part of the cable, causes redistribution to a nearby part.



64 mm Qant diameter is used

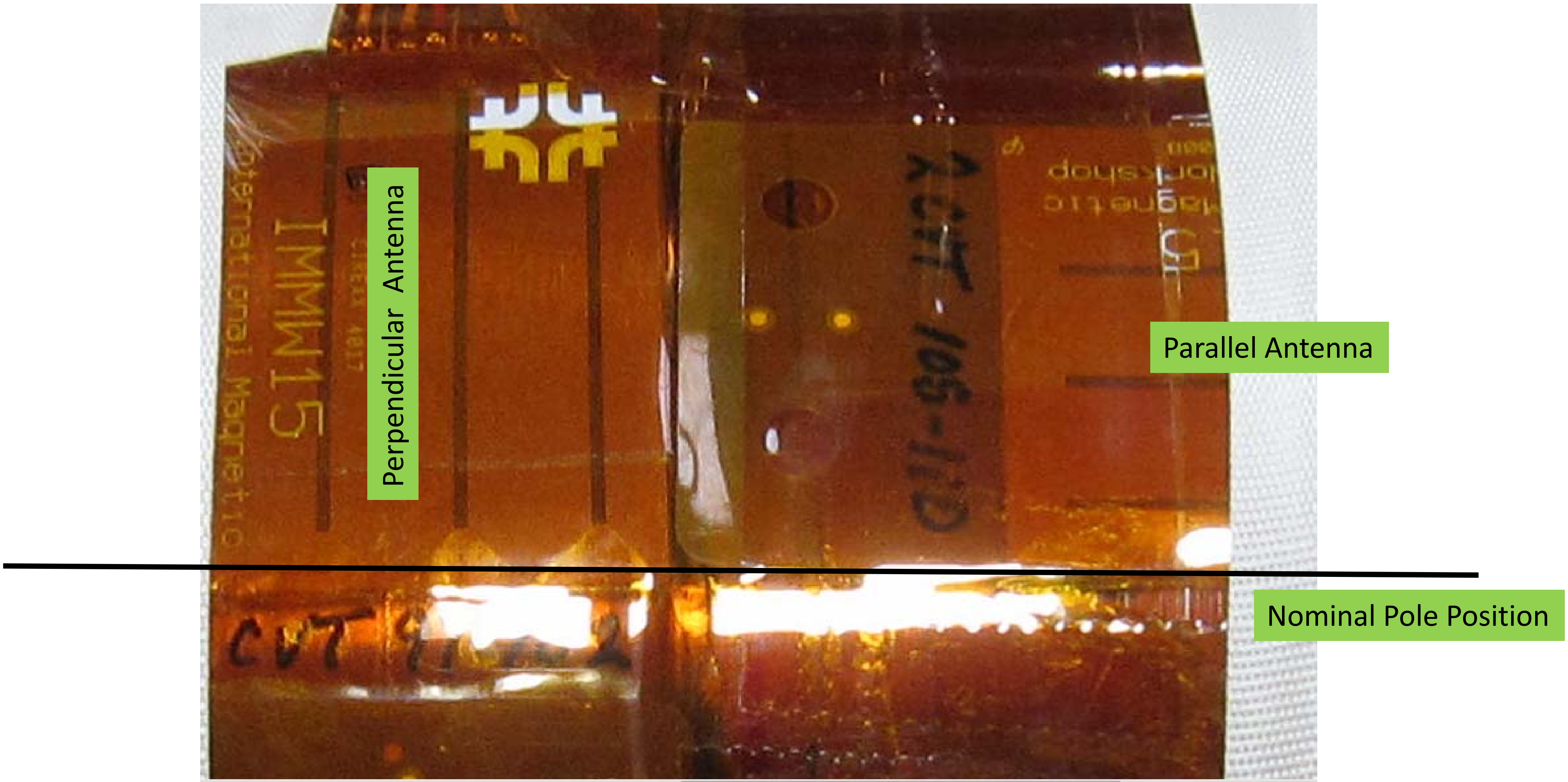
Can adjust parameters for

- Quench distance to antenna
- # of neighbors that current redistributes to
- the distance between quenching and redistributed strand

Current doublet gives better correspondence with measurement data and is used in the following

Experimental validation

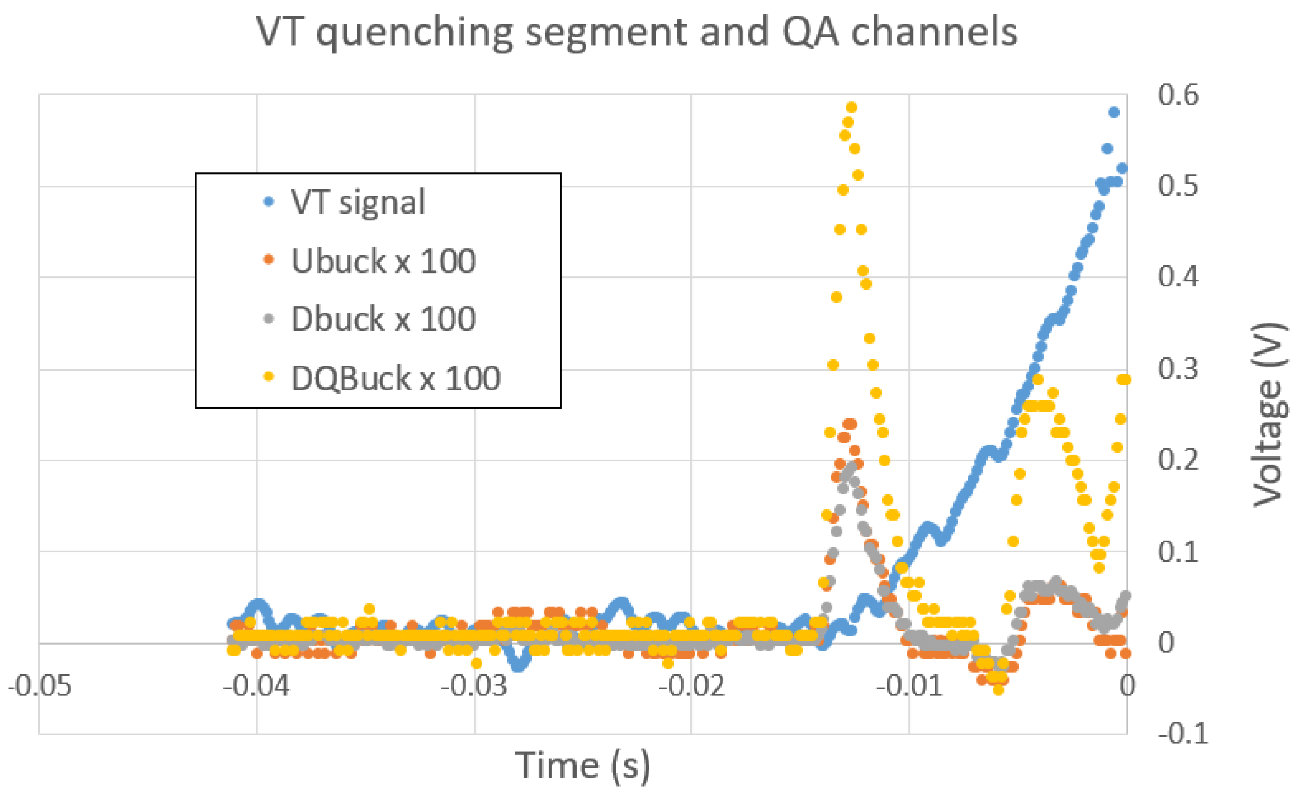
MQXFS1d/e short model quad had well known quench location – quench antennas were mounted nearby for testing



Parallel antenna signals had large clean signals which matched voltage tap response

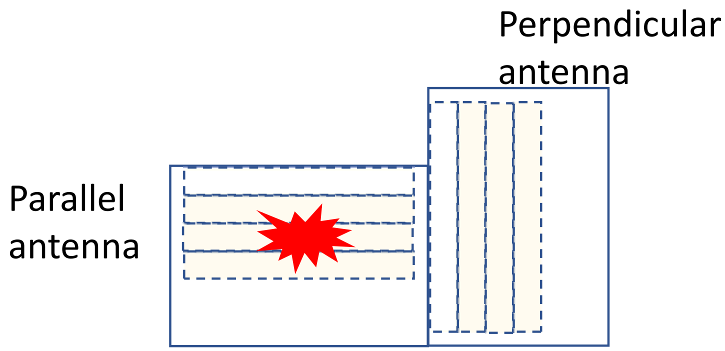
Actual Qant data (x100):

- DQB ~2.5x larger than UB
- UB slightly larger than DB
- Signs same on all signals

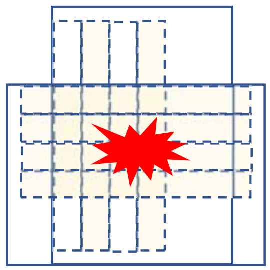


Note that get max voltage in ~1.2ms

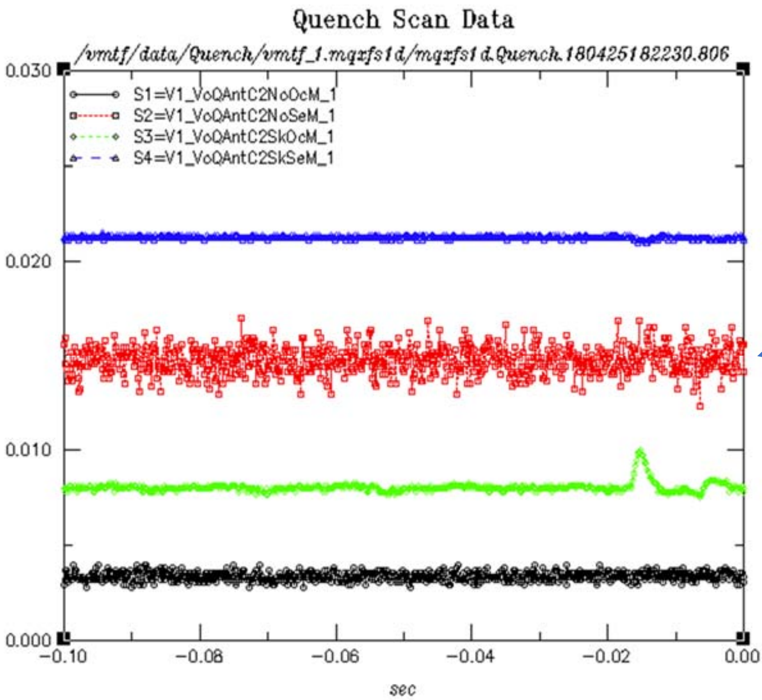
In the MQXFS1d Qant data, the perpendicular antenna data signals are in the noise, while the parallel antenna is always seen and has signal size of about 5mV. See if simulation matches these results:



Original (mqxfs1d) orientation

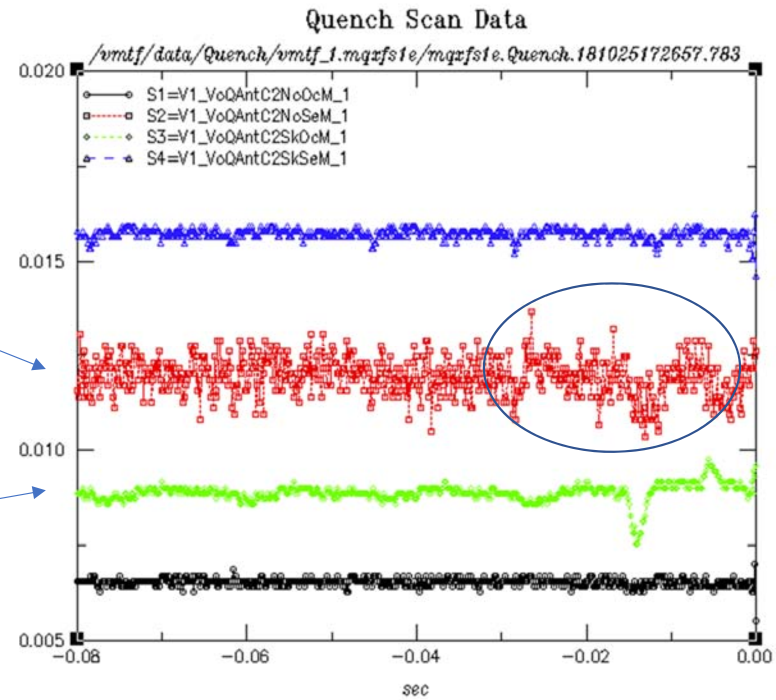


mqxfs1e orientation



Perpendicular antenna UB

Parallel antenna DQB



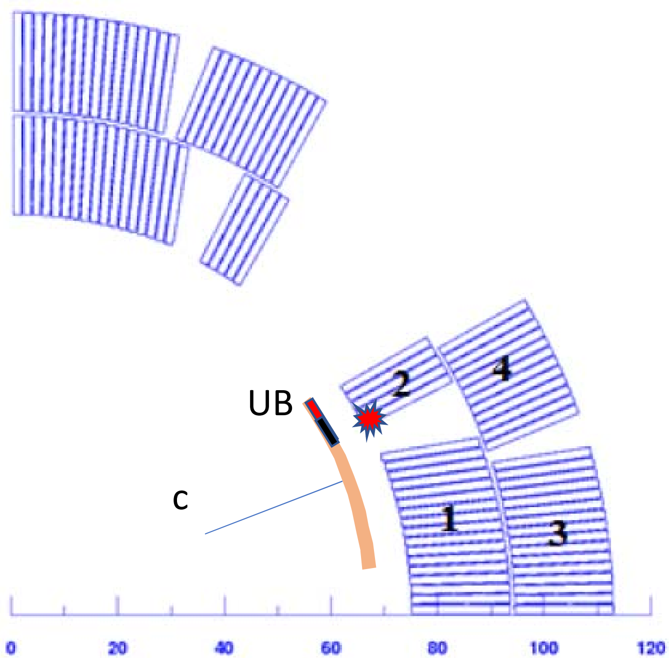
MQXFS1d

The perpendicular antenna has no real response

MQXFS1e

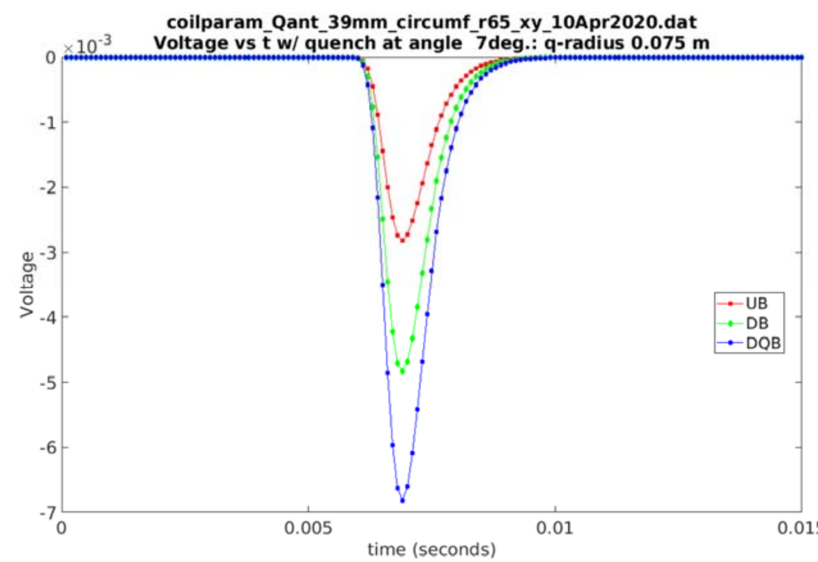
The perpendicular antenna now has some small response

Parallel antenna, quench_radius = 75mm



Using 1.8mm as cable thickness

Quench antenna is rotated 0 deg
from nominal daq position



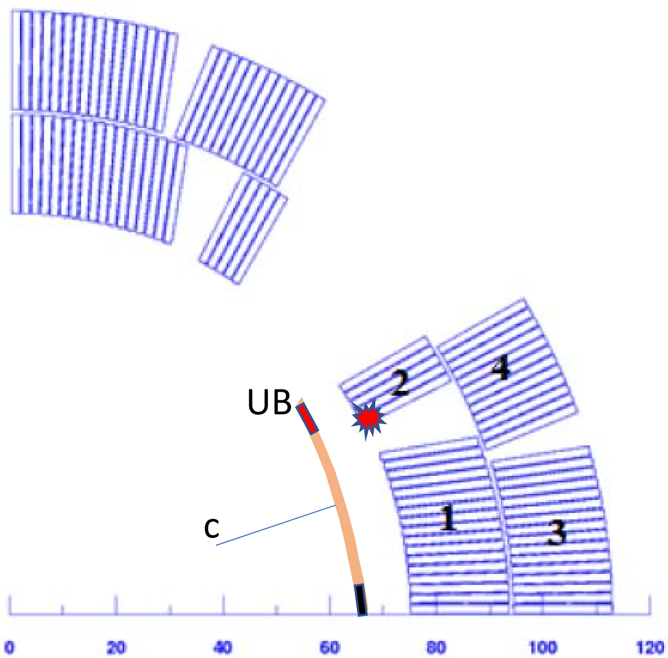
"parallel" Qant case: Quench is effectively at ~ +7 deg

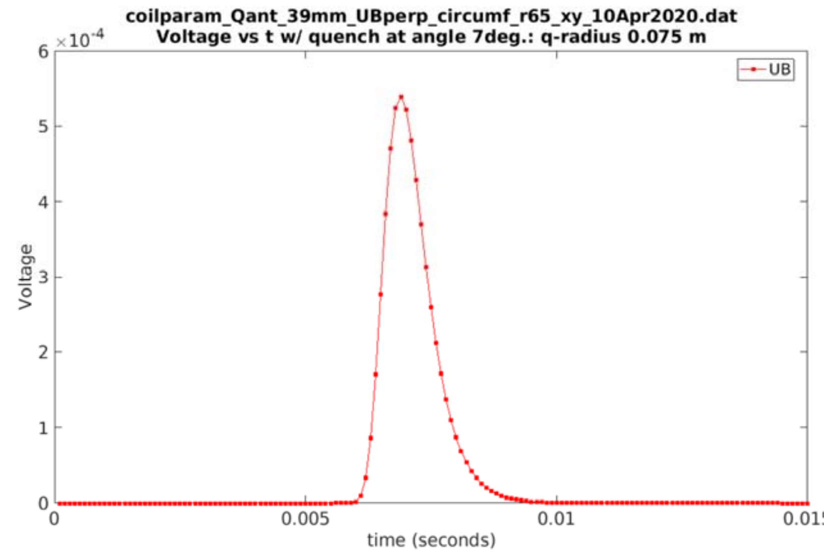
- ➔ DQB signal is near (negative) max at this angle (-6.7e-3) ✓
- ➔ DQB signal ~2.5x larger than UB ✓ (UB -2.6e-3, DQB about 2.6x)
- ➔ UB amplitude little larger than DB ✗ (DB ~-4.5, 1.7x larger than UB)
- ➔ Sign of UB and DB are same as DQB ✓

Perpendicular antenna, quench_radius = 75mm

Using 1.8mm as cable thickness

Quench antenna is rotated 0 deg from nominal daq position





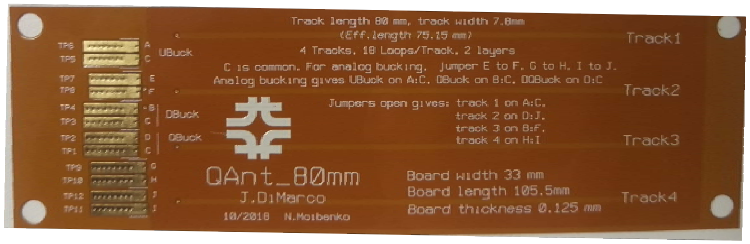
“perpendicular” Qant case: Quench is effectively at ~ 10 deg

➔ UB amplitude 5.3e-4 ✓ factor 10 smaller than parallel signals

Simulation model recreates fairly well the response (including magnitude) of the experimental quench antenna voltage signal data (both parallel and perpendicular) taken at known quench location on MQXFS1.

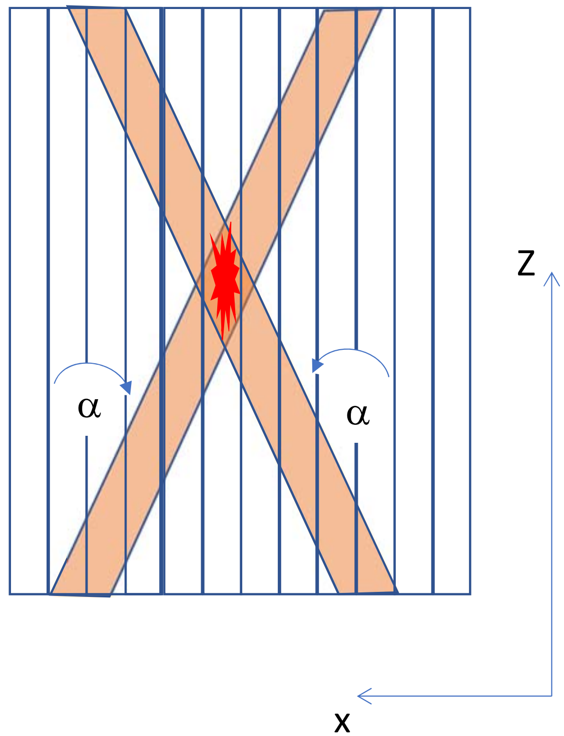
➔ Some confidence in going forward with new designs and analysis.

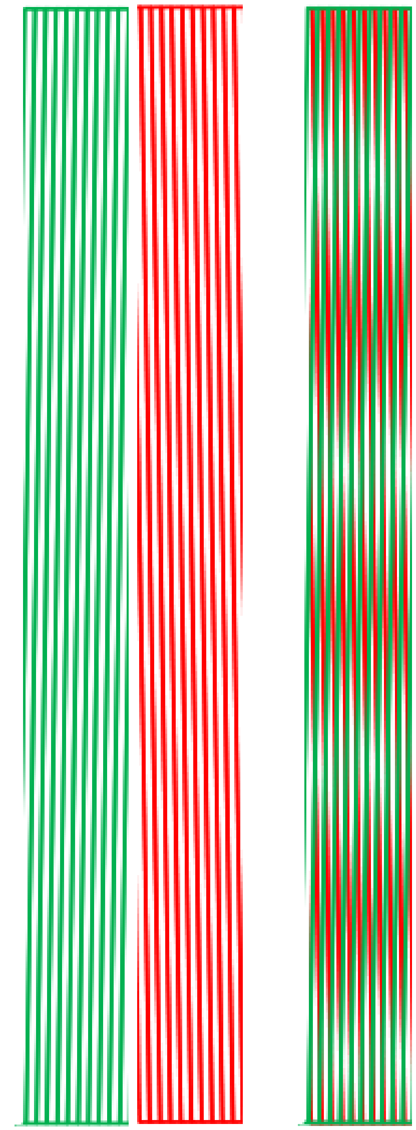
Short quench antenna from magnetic measurement probe design



MQXFA 5m quench antenna with axial and azimuthal antennas, Designed for 50mm z-resolution

Try to cover whole magnet with flex circuit panels which offer 'pixilated' quench origin localization





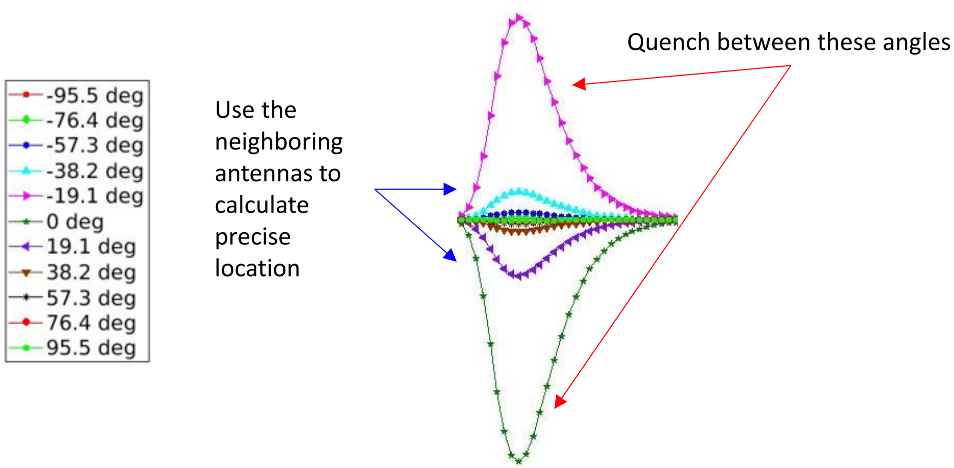
Example of 1m 20 channel full coverage design

An example of analysis which can improve nominal pixel resolution

Use the multiple loops as ensemble of probes - can interpolate (or apply other magnetic analysis) to increase angular resolution (and therefore z-resolution) beyond the simple pixel height

Turns out that for panel angle 1.5 degrees, the quench start can be determined from the two dominant signals weighted by their outside neighbors, and the resulting error/uncertainty is < 2 degree in theta, corresponding to about 20mm in z. (This is about a factor of 15 lower than if using the size of the loop intersection (pixel height)).

11 antennas cover ~180 degrees in this example (~19 deg per antenna)



e.g. weight the -19.1 degree antenna position by the amplitude of the -38.2 deg. antenna, and the 0 degree antenna position by the amplitude of the 19.2 deg. antenna ➔ find the quench angle of 3.3 degrees

Future plans:

Test 0.5m and 1m long quench panels with 10 degree and 1.5 degree angles for evaluation in mirror magnet (no bore, antenna panels cold in Lhe).

Test quench antennas for various radii for use in Warm Bore Tubes at FNAL VMTF (100mm diameter, 28mm diameter)

In these tests and others, optimize antenna design for signal size and resolution, cabling/amplifiers, length, number of turns, data acquisition, analysis, etc., and evaluate analysis to reduce larger natural pixel size.