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Beam Physics Note
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ISAC-II Phase Shifter Calibrations

Spencer Kiy

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Abstract: This note briefly summarizes measurements taken to calibrate effects of the phase shifters (EPICS phase setpoint) for the ISAC-II global phase, DSB buncher, SCB/SCC global phases, and all 40 SCRF cavities. Additional phase vs temperature measurements were collected for DTL cavities at RF console 3. Measurements were collected from September 30th to November 16, 2020.

4004 Wesbrook Mall, Vancouver, B.C. Canada V6T 2A3 Tel: 604 222-1047 www.triumf.ca

Phase Shifter vs EPICS Setpoint Measurements

Based on past discussions with beam physicists and low-level RF (LLRF) experts and the nature of the circuits that convert a digital signal (setting in the control system) into an analog reference signal driving each cavity, it was known that the behaviour is not perfectly linear, nor well investigated.

There are fourty four phase shifters in the ISAC-II linac, and the behaviour of these was calibrated using a Hewlett Packard 8508A Vector Voltmeter (VVM). The calibration procedure was as follows:

1. Connect the vector voltmeter to two signals:
   - Reference signal arriving at the local RF console
   - Signal coming out of phase shifter board for each cavity
2. Setup the voltmeter to output the phase difference between the two signals
3. Step the EPICS/LLRF setpoint from -220 to +220 in steps of 10, recording the voltmeter measurement at each step.
4. Repeat for each desired phase shifter.
5. Implement script to convert between control system setpoint and actual degrees in model.

Shown in the figures to follow, the phase error is the disagreement between a step in EPICS, $\Delta\phi_{epics}$, and the measured resulting step in the voltmeter, $\Delta\phi_{vm}$. The top plot shows the error for each individual 10 degree step, while the bottom plot shows the cumulative error in stepping from -220 degrees in the control system to the other measured phases.

$$Error = \Delta\phi_{epics} - \Delta\phi_{vm} \tag{1}$$

DTL RF Pickup phase vs temperature measurements

There were also suspicions of drifting phases in the ISAC-I room temperature accelerators, specifically in the DTL. To test this, a similar test was done with the Hewlett Packard 8508A Vector Voltmeter as follows:

1. Connect the vector voltmeter to two signals:
   - Reference signal arriving at the local RF console from a directional coupler
   - Signal arriving back at the RF console from the RF cavity pickup (located at the bottom of RF console 3 near the ground)
2. Setup the voltmeter to output the phase difference between the two signals
3. Record the voltmeter readings and ambient air temperatures over approximately 48 hours.

Results

The resulting observations are as follows:

For Phase Shifters

1. The relationship between the control system setpoint and the actual effect varies between different cavities.
2. The effect is not linear, the error changes depending on the range the setpoint is moving over.
3. The setpoint range over which the actual phase completes a full cycle ranges between around 374 and 384 degrees.
4. The ISAC-II global phase appears to adjust the phase relative to the reference signal in the opposite direction of all other phase shifters.

For Phase-Temperature Correlations

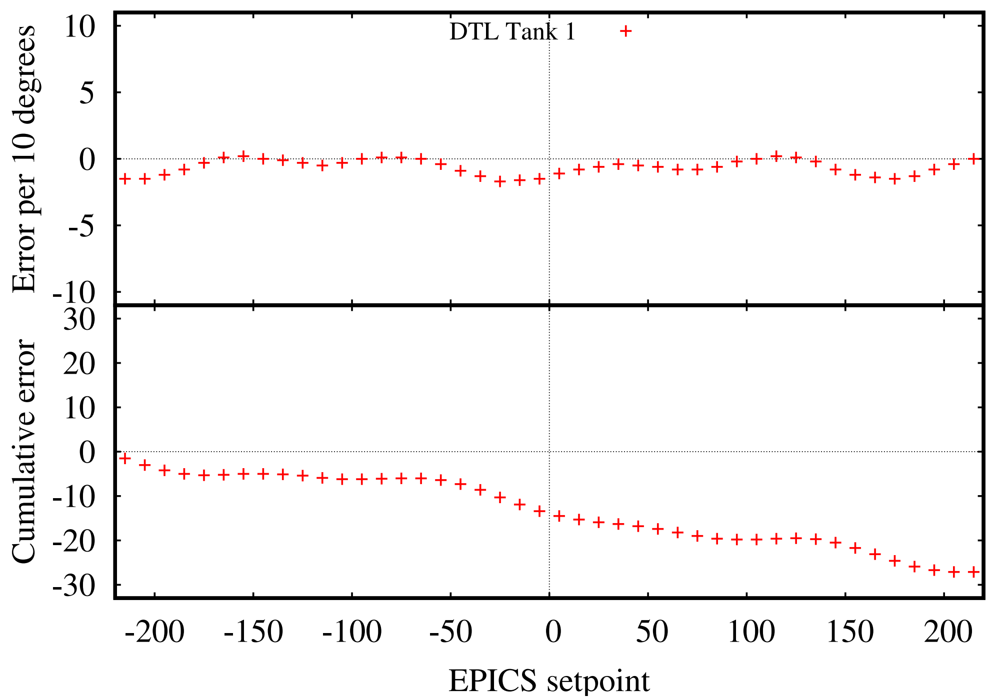
1. The phase arriving back at the VVM from the cavity pickups varies on the order of 1 RF degree (at 106 MHz) per degree Celcius.
2. Phase drifts in the same direction for all cavities that were measured.
3. There is some discrepency in the size of the drift per degree Celcius from one cavity to the next.

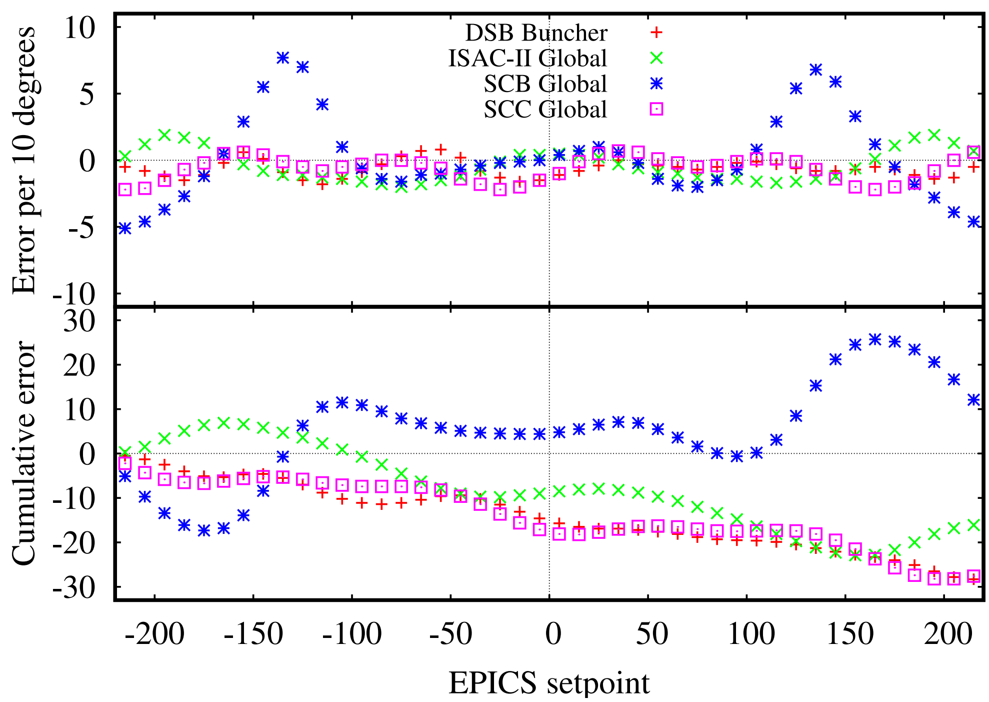
The measured phase shifter data has been input into a python package[1], which allows conversion between the uncorrected control system phase and the correct control system phase. Currently the python package does a simple linear interpolation between the collected data points.

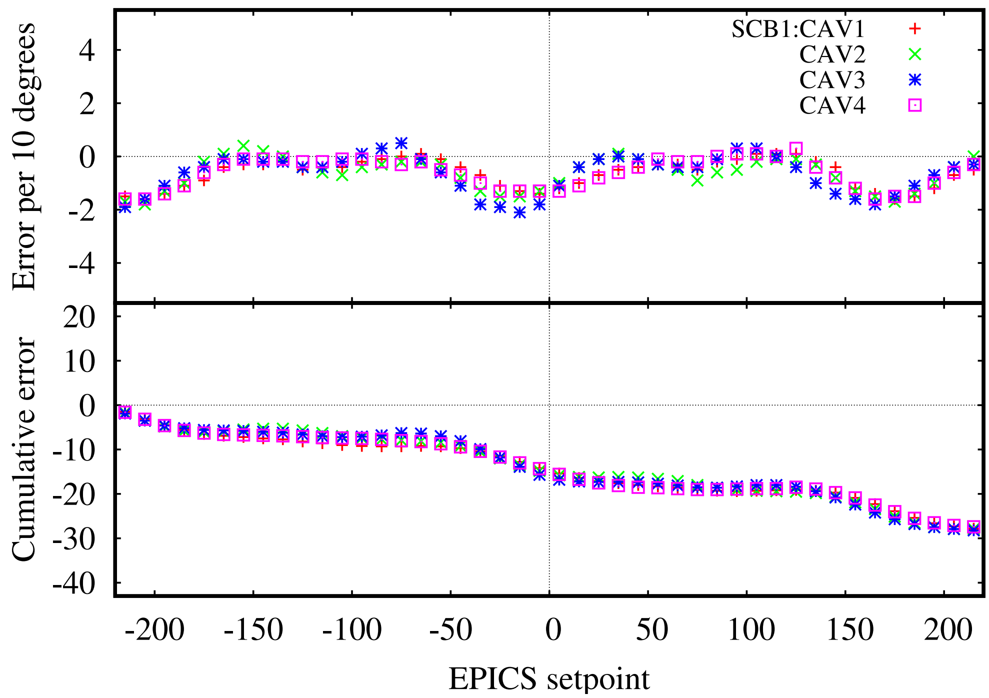
Acknowledgments

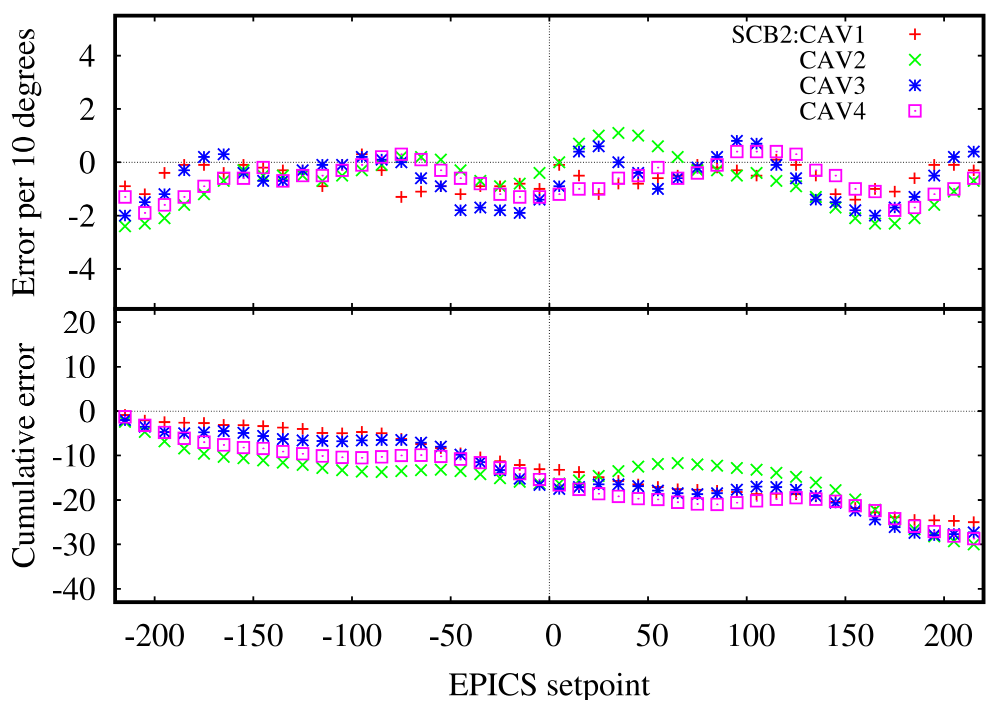
Thanks to the RF group at TRIUMF for discussions on the topic and help setting up for the measurements, specifically Ramona Leewe, Thomas Au, Qiwen Zheng, and Ken Fong.

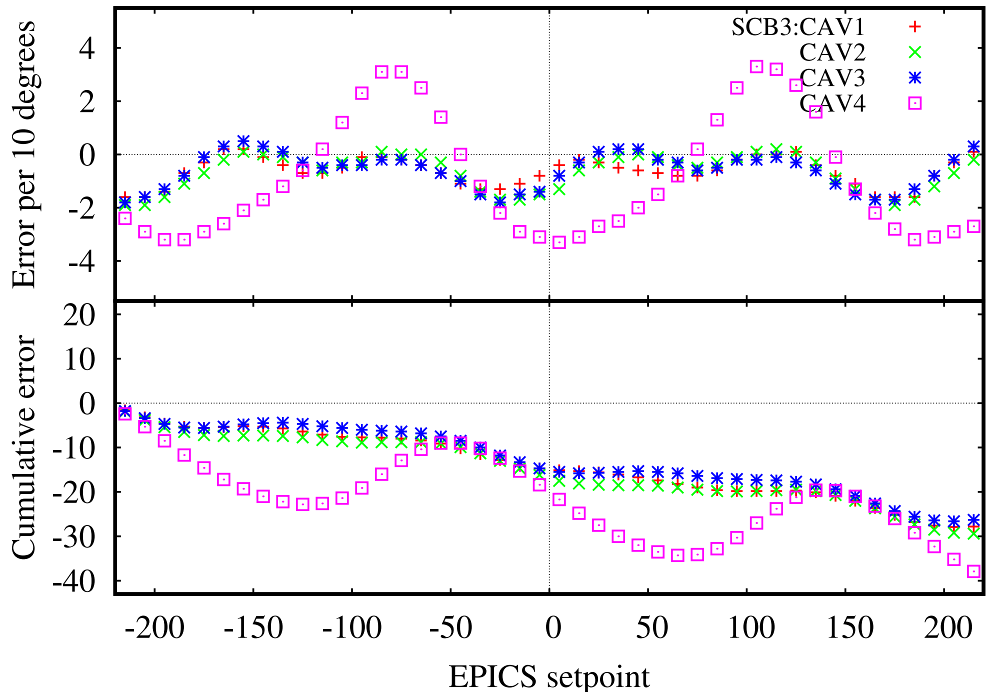
[1] https://gitlab.triumf.ca/hla/acc-utilities/phase_shifter

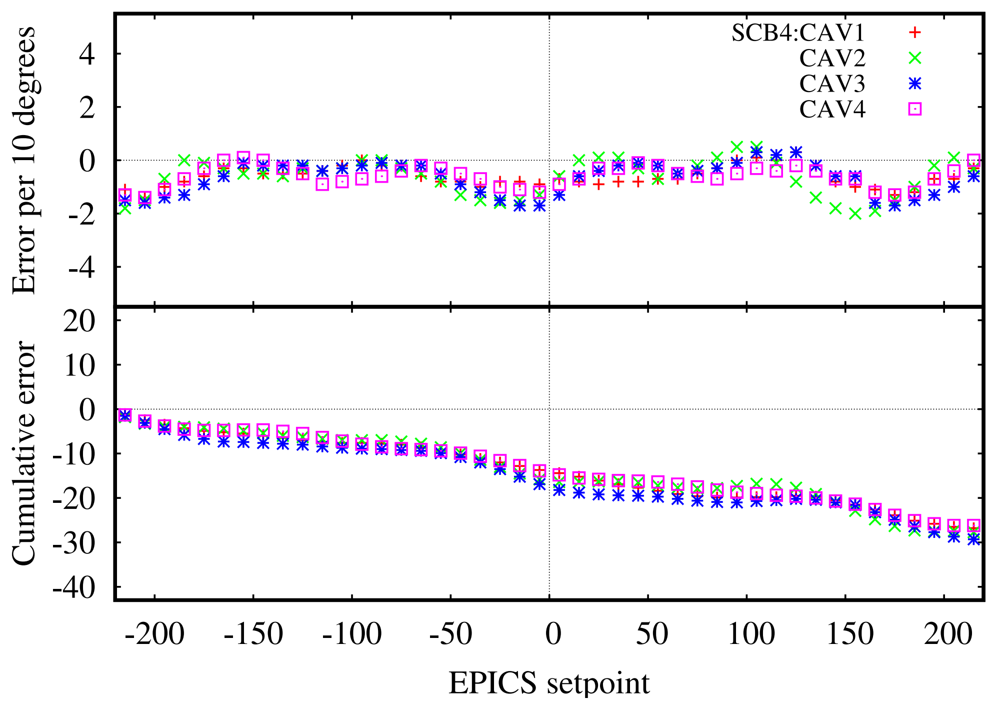

DTL Tank 1
Error per 10 degrees
Cumulative error
EPICS setpoint
10
5
0
-5
-10
30
20
10
0
-10
-20
-30
-200
-150
-100
-50
0
50
100
150
200

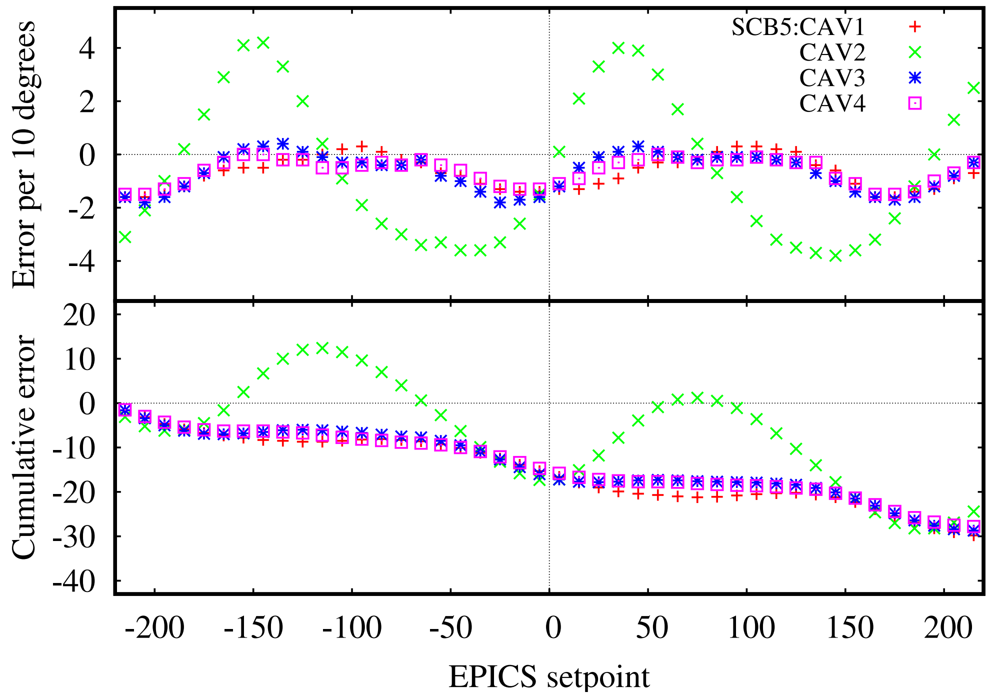

DSB Buncher
ISAC-II Global
SCB Global
SCC Global
Error per 10 degrees
Cumulative error
EPICS setpoint
10
5
0
-5
-10
30
20
10
0
-10
-20
-30
-200
-150
-100
-50
0
50
100
150
200

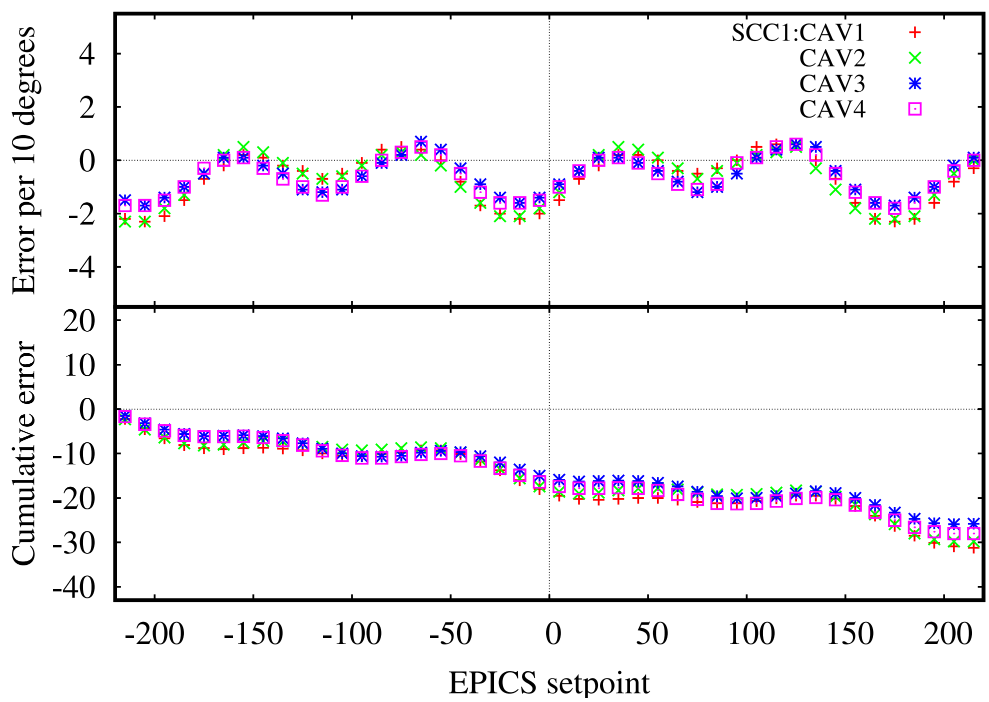

SCB1:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint
4
2
0
-2
-4
20
10
0
-10
-20
-30
-40
-200
-150
-100
-50
0
50
100
150
200

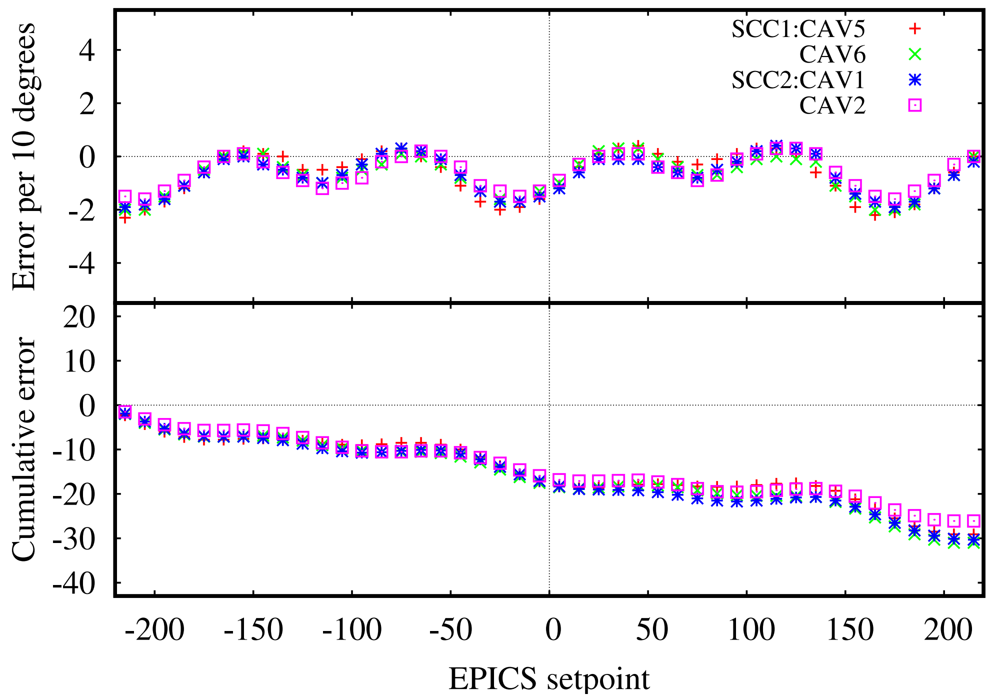

SCB2:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint
4
2
0
-2
-4
20
10
0
-10
-20
-30
-40
-200
-150
-100
-50
0
50
100
150
200

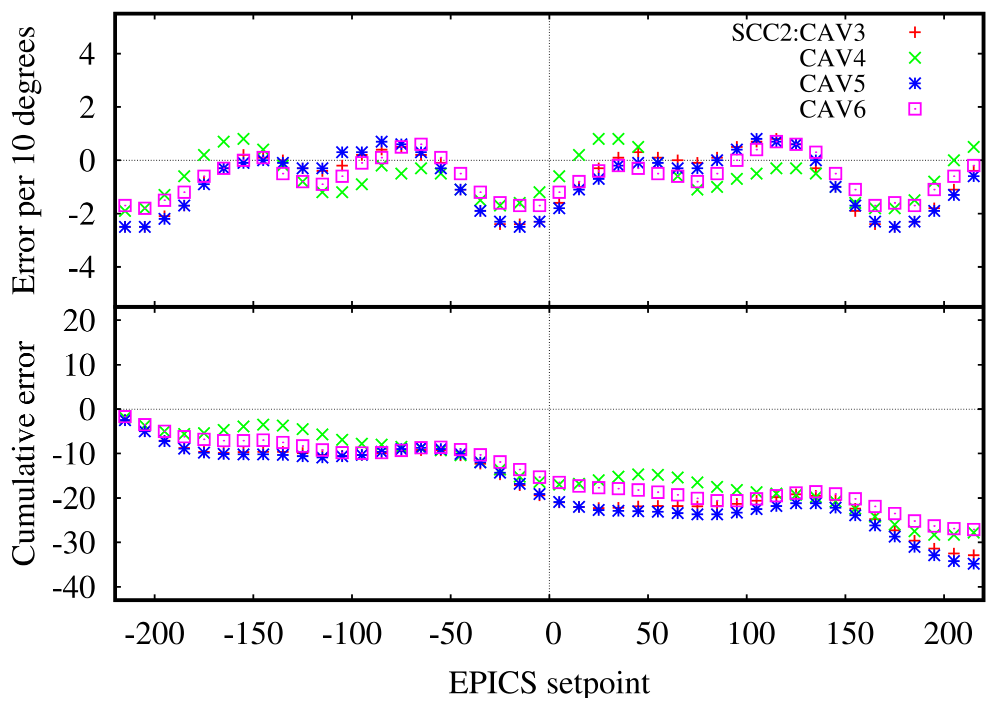

SCB3:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint

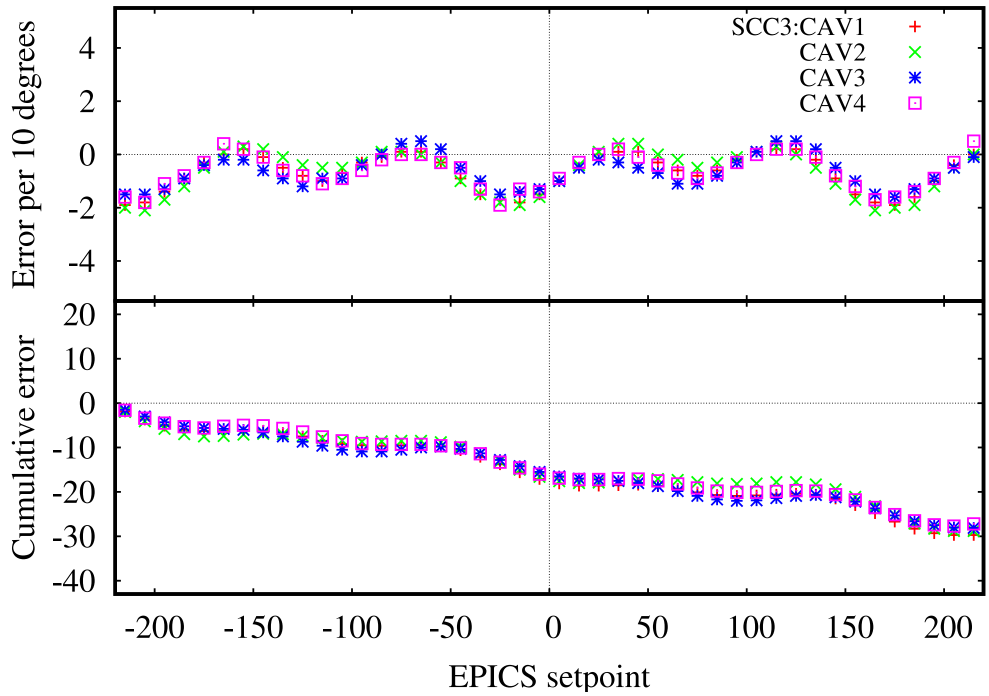

SCB4:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint

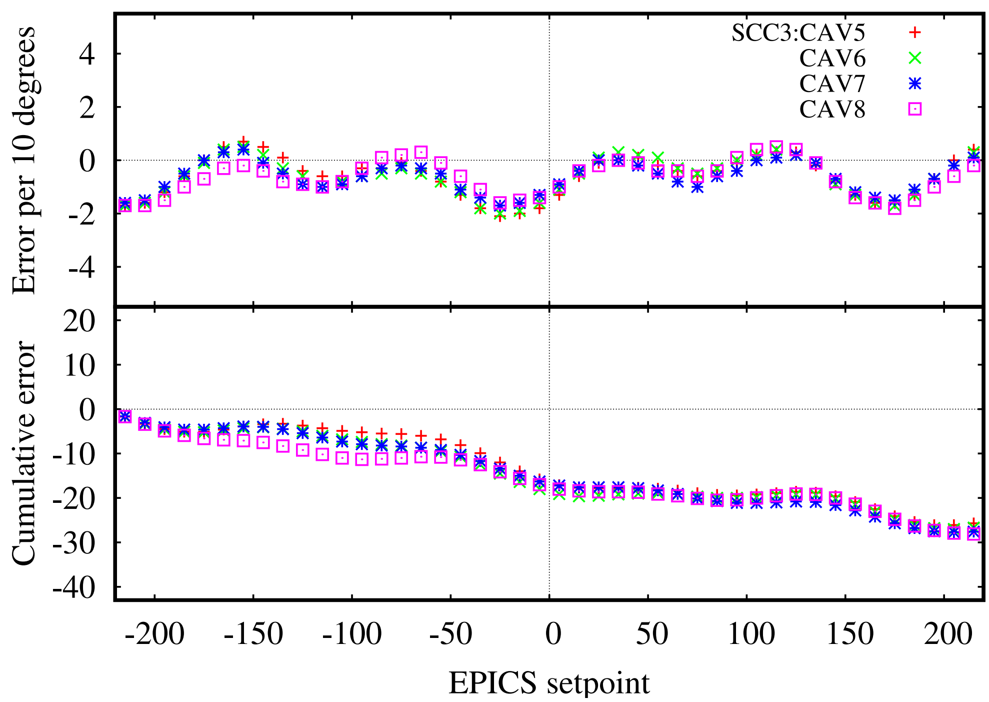

SCB5:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint
4
2
0
-2
-4
20
10
0
-10
-20
-30
-40
-200
-150
-100
-50
0
50
100
150
200


SCC1:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint
4
2
0
-2
-4
20
10
0
-10
-20
-30
-40
-200
-150
-100
-50
0
50
100
150
200


Error per 10 degrees
Cumulative error
EPICS setpoint
SCC1:CAV5
CAV6
SCC2:CAV1
CAV2


Error per 10 degrees
Cumulative error
EPICS setpoint
SCC2:CAV3
CAV4
CAV5
CAV6


SCC3:CAV1
CAV2
CAV3
CAV4
Error per 10 degrees
Cumulative error
EPICS setpoint
4
2
0
-2
-4
20
10
0
-10
-20
-30
-40
-200
-150
-100
-50
0
50
100
150
200


SCC3:CAV5
CAV6
CAV7
CAV8
Error per 10 degrees
Cumulative error
EPICS setpoint
4
2
0
-2
-4
20
10
0
-10
-20
-30
-40
-200
-150
-100
-50
0
50
100
150
200

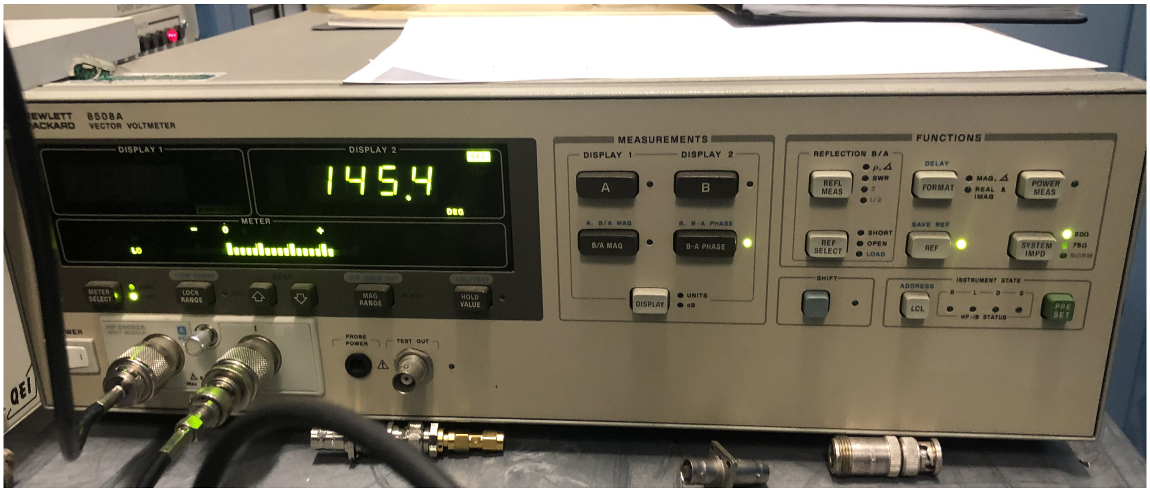


Figure 1: Picture of the vector voltmeter during measurements

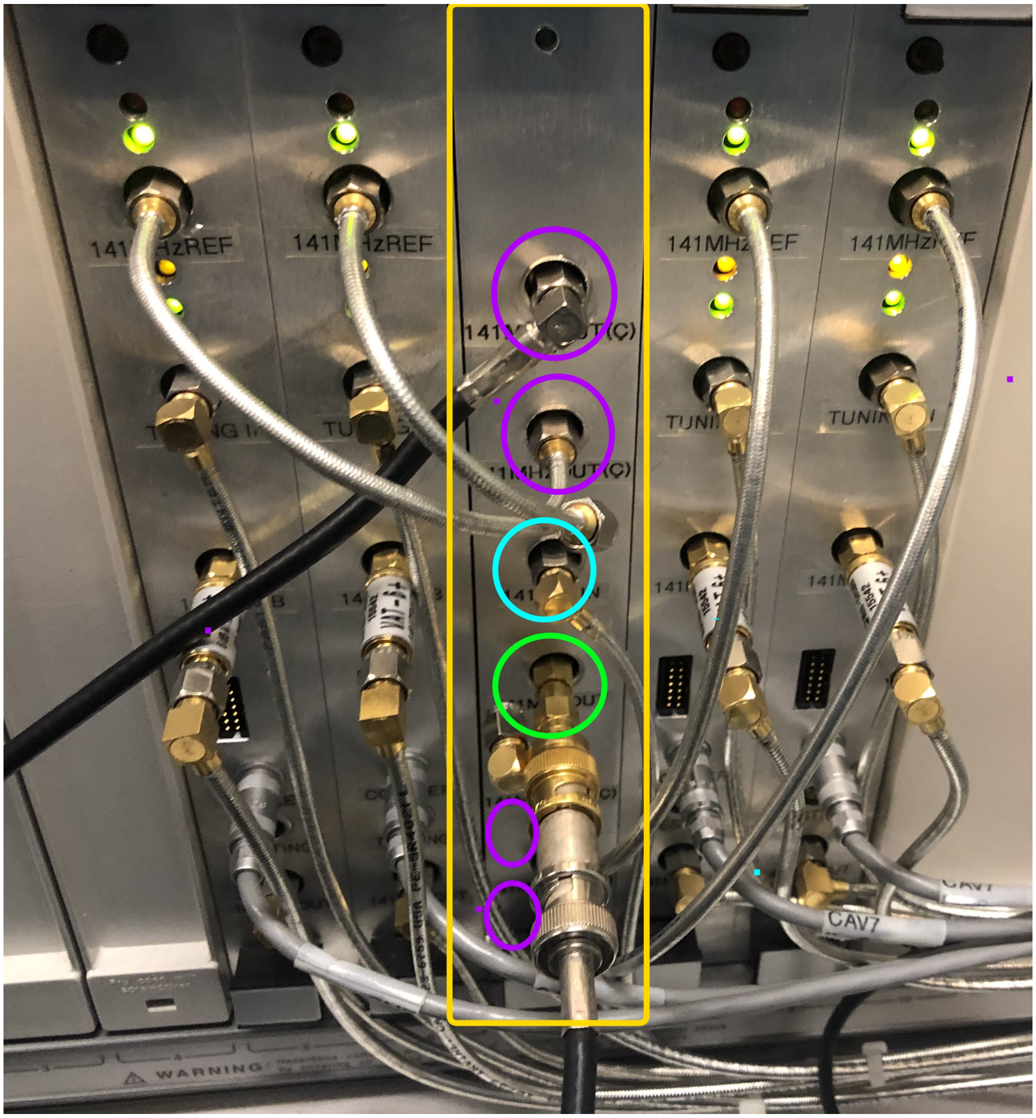


Figure 2: Picture of a phase shifter board (yellow rectangle), showing where connections were made. The 141 MHz reference signal arriving at the board is circled in blue, the 141 MHz signal (unshifted) leaving the board is circled in green, and the four phase shifter outputs that then go to the individual cavity LLRF boards are circled in purple. The comparison done was between the unshifted 141 MHz output signal and the phase shifter output for each different cavity.

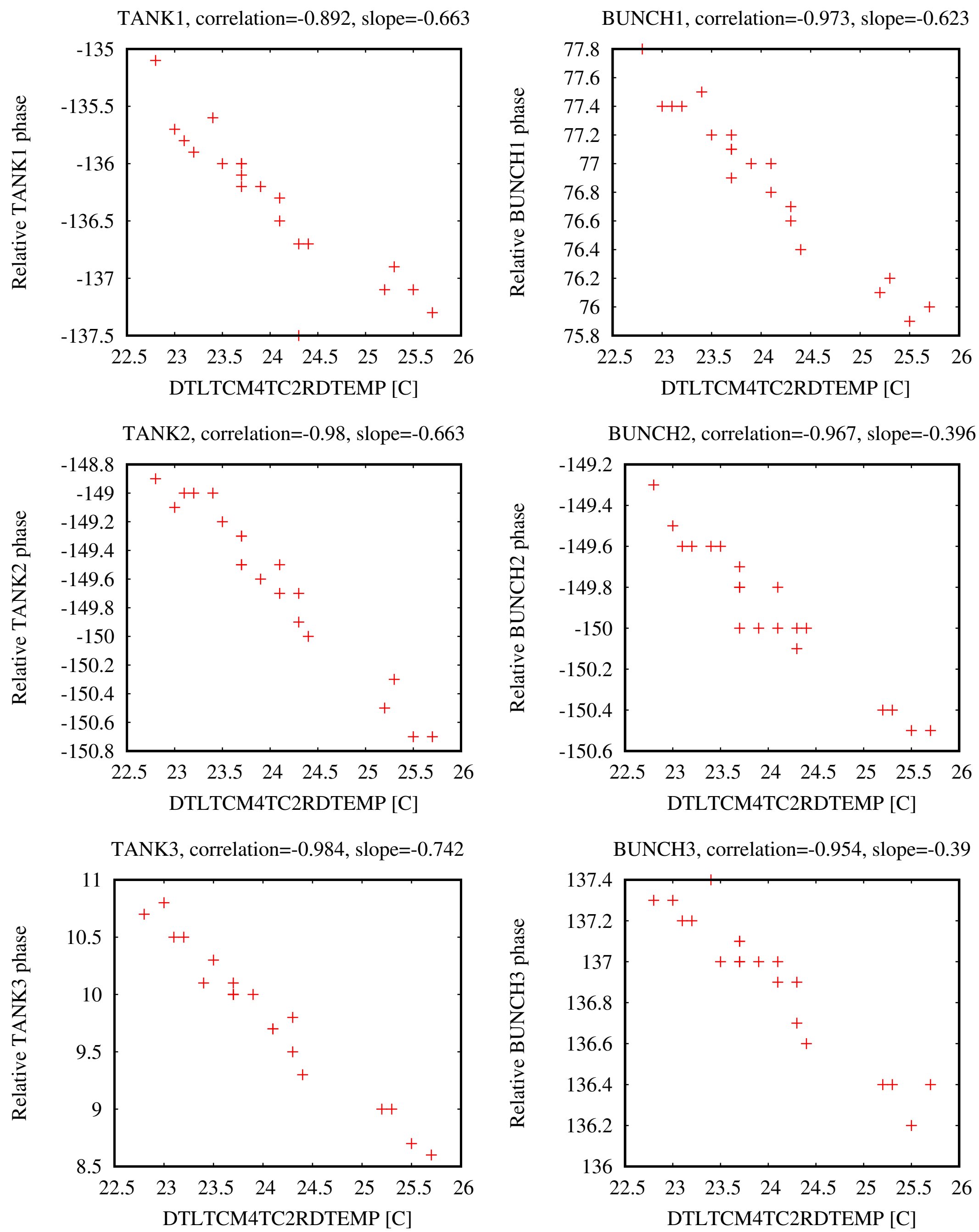


Figure 3: Collected relative phases of DTL tanks and buchers plotted against the ambient air temperature on the north mezzanine in ISAC near RF console 3.

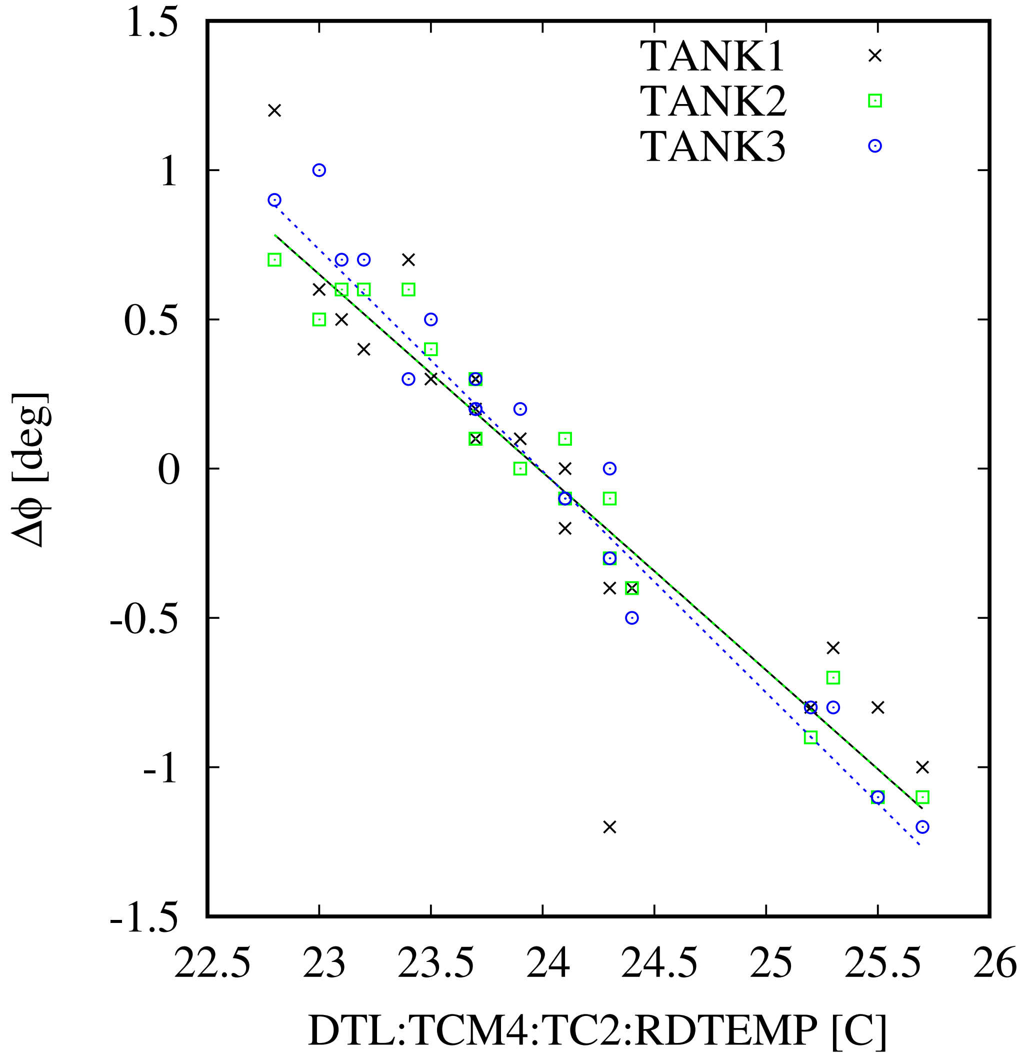


Figure 4: Phase vs temperature behaviour comparison between the three DTL tanks.

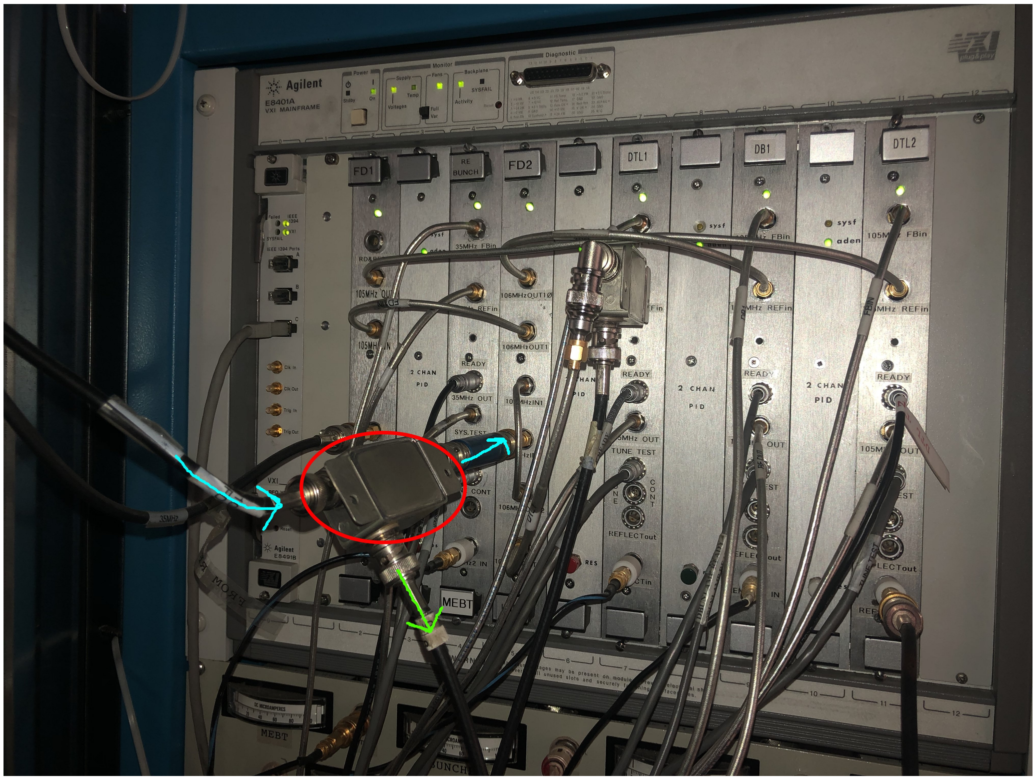


Figure 5: Picture of a the RF console 3 LLRF boards on the top VXI crate. The 106 MHz reference signal arriving at the console is in light blue, the directional coupler installed by LLRF personnel is in red, and the cable off the directional coupler used as one input into the vector voltmeter is in green