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Preliminary Investigation of ISAC-I RF/Temperature Correlations and General Performance

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Abstract

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Prague/FTM Energy comparison

A preliminary investigation into the agreement between the Prague/Harp and ISAC-II flight time monitor (FTM) system was carried out, using $20Ne^{5+}$. Beam was then drifted through the cold linac and measured using the three ISAC-II FTMs.

Prague [MeV/u]	SCRF-FTM [MeV/u]	Discrepancy [%]
1.431±0.003	1.450±0.006	1.328
1.528±0.003	1.553±0.004	1.636

Table 1: Comparison of measured Energies for $20Ne^{5+}$.

The error assumption for the Prague energy is of 0.1% dE/E between two consecutive harp wires. It was found that the average discrepancy between both systems was roughly 1.5%. As the FTM relies on drift time of flight and subnanosecond gating electronics, its readback is considered more reliable.

The Prague on the other hand, relies on a Hall probe, which returns a position dependent magnetic field. Should its position shift over time (due to vibration, material fatigue or thermal effects), the field readback will change slightly, which will affect the calculated energy. Due to time constraints, further measurements were not possible. However, these preliminary results suggest further investigation should take place.

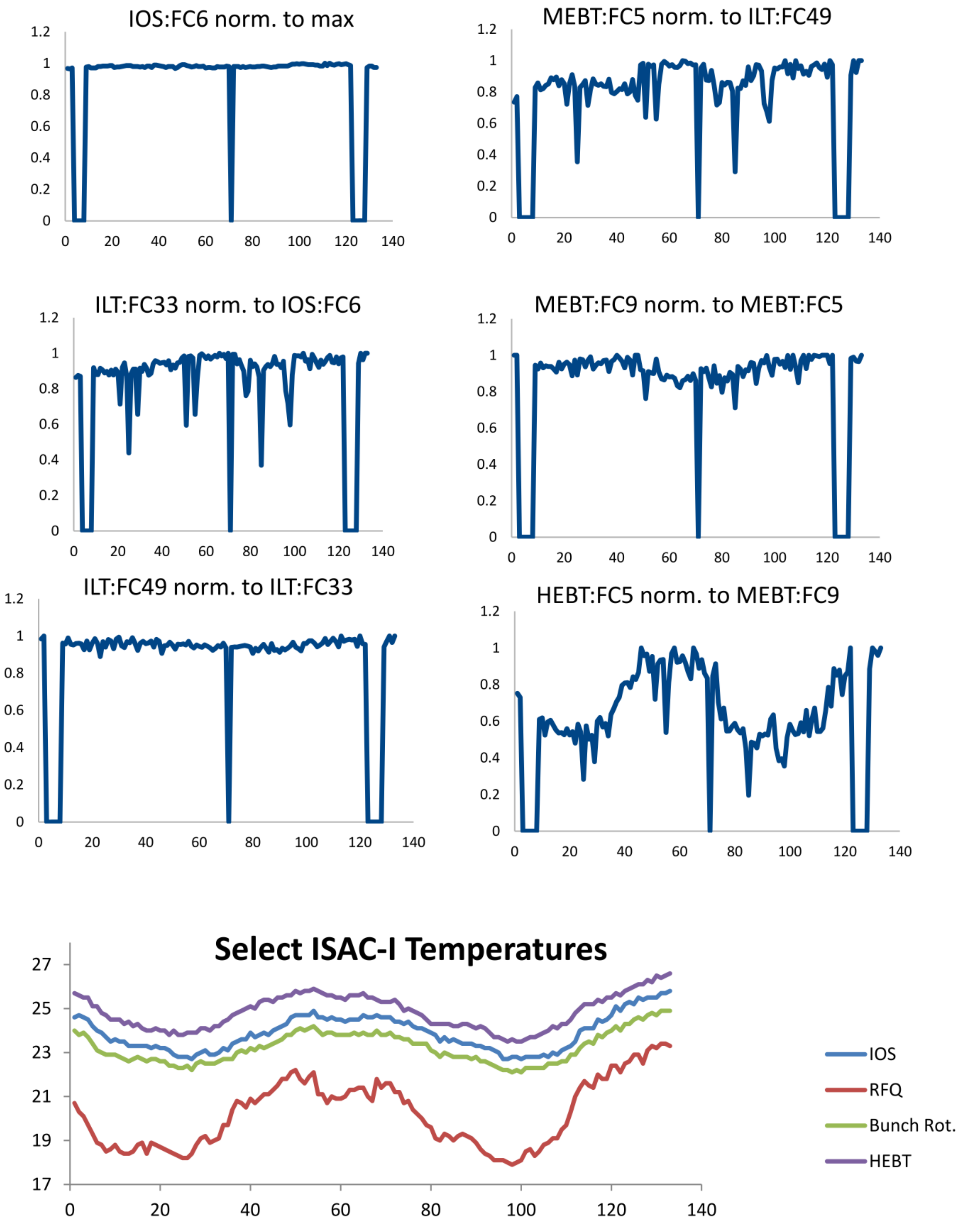

Figure 1: Various faraday cup currents, measured in 20 minute intervals, normalized to the previous FC reading. IOS:FC6 is normalized to the maximum value in the sample. Temperatures through the ISAC hall are shown at the bottom for comparison.

Temperature Dependency of ISAC-I Transport/Transmission

Following the installation and commissioning of the ISAC-I thermocouple network, in which a series of temperature probes were installed at various strategic locations along the transport lines and accelerators, it was possible to perform an analysis regarding the covariance of transport transmission and temperature in the hall.

Temperature values for 13 separate locations were logged at intervals of 20 minutes, with a precision of 0.1^{O}C. A 20Ne5+ beam was tuned from the OLIS microwave source and accelerated to 816keV/u. The DSB section was used as a post DTL mass selection filter, with beam dumped on SCB1:FC0. Automated scripting took Faraday cup readings every 20 minutes for 3 consecutive days. Five samples were taken at 2 second intervals on each cup, and averaged, to reduce noise sensitivity. During the acquisition period, instructions were left not to tune, optimize, or otherwise alter the tune.

Normalized cup readings and temperatures over 2720 minutes (1.88 days) are shown in Figure 1. Temperatures over the same period at 4 locations (IOS,RFQ,MEBT Bunch rotator & HEBT-1) are displayed at the bottom for reference.

Inspection of Figure 1 reveals a weak correlation between transport transmission and temperature variation for all cups except ILT:FC49 to MEBT:FC5 (ISAC-I RFQ) and more strikingly, MEBT:FC9 to HEBT:FC5 (ISAC-I DTL), where the transmission is seen to fluctuate by more than 50% over a ~2 day period. Both the relative invariance of drift section transmissions and the hints of a diurnal cycle in RF accelerator transmission suggest clear temperature dependency in the performance of ISAC-I RF.

Calculating the product correlation coefficient, defined as:

$$\rho_{X,X'} = \frac{E[(X-\mu_X)(X'-\mu_{X'})]}{\sigma_X \sigma_{X'}}$$

where E is the expectation value, μ is the set X mean and σ is the standard deviation. $\rho_{X,X'}$ is defined from [-1,1], where ±1 indicates a perfect positive (negative) correlation, and 0 indicates no correlation. Correlation coefficients between transmission and indicated temperature are shown in Table 2.

Faraday cup	Ref. Temperature	$\rho_{X,X'}$
IOS:FC6	IOS Ambient	-0.26
ILT:FC33	Prebuncher	0.28
ILT:FC49	Prebuncher	0.21
MEBT:FC5	RFQ	0.26
MEBT:FC9	Bunch Rotator	-0.13
HEBT:FC5	DTL	0.49

Table 2: Correlation coefficients between Faraday cup currents and ambient temperatures.

The correlation coefficients for non RF transport segments average at 0.22 absolute value (positive or negative). MEBT:FC5 shows a similar level of correlation at 0.26. The DTL (HEBT:FC5), shows the strongest correlation level of all.

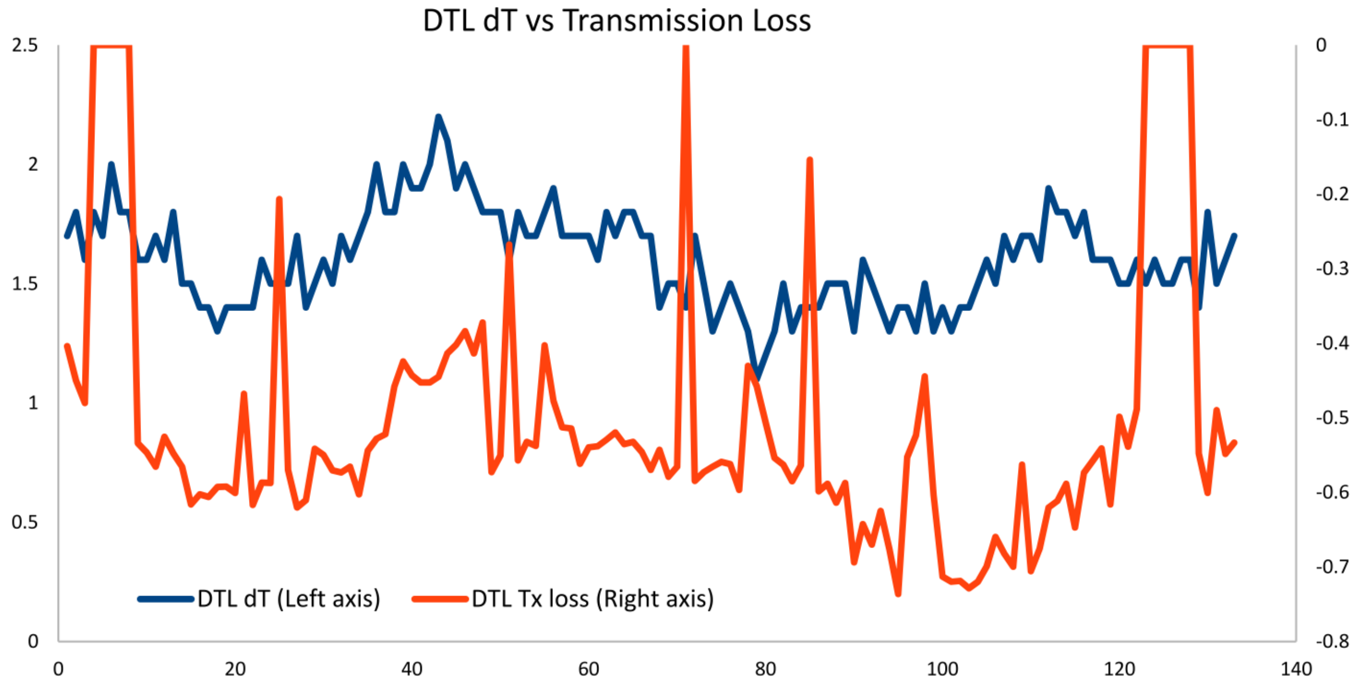

Figure 2: Comparison of DTL temperature variation (L axis) & transmission loss (R axis).

Qualitative inspection of Figure 1 also reveals a clear correlation between DTL transmission and temperature variation. Looking at the DTL transmission, defined as the normalized current difference between HEBT:FC5 and MEBT:FC9, and comparing the DTL temperature difference, defined as the temperature difference between HEBT & MEBT thermocouples, it is possible to further see the strong temperature dependence of DTL performance. This is shown in Figure 2. One notes the appearance of an apparent phase lag, in which transmission trends follow temperature trends by approximately 100 minutes (five separate 20 minute snapshots apart).

Investigation of RF phase vs DTL Transmission and Temperature

With the above results hinting at temperature dependence in the ISAC-I RF, an attempt was made to identify correlations between RF performance and temperature, while keeping an eye on beam transmission. The working hypothesis was that temperature variations caused changes in the performance of the RF transmission lines, causing a slight phase shift, on the order of a few tenths of a degree per cavity.

It was decided that measuring the output RF would be of little value, as this would merely confirm the internal stability of the RF generation electronics on the ISAC-I mezzanine. Instead, the reflected RF was monitored, seeing as it travels through the coaxial transmission line and interacts with the cavity. The EPICS compliant oscilloscope in the HEBT section was used to accomplish this goal. A 50’ BNC connector was strung between the oscilloscope on the ground level, and was teed off the connector on the mezzanine RF electronics console (DTL console #1). A sample reflected RF sine from DTL buncher 1 is shown in Figure 3.

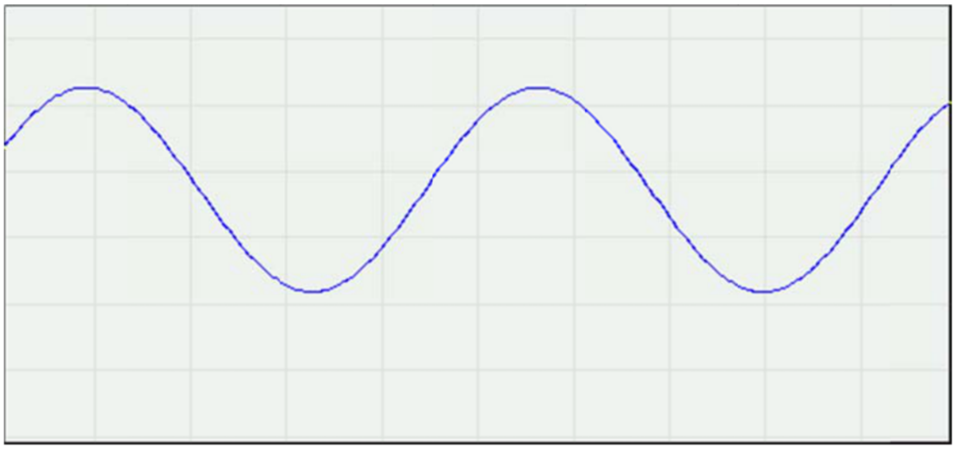

Figure 3: sample 106MHz reflected sine wave from DTL Buncher1, sampled at 2ns/div.

The reflected RF waveform was recorded through the scope every 5 minutes for 4 days. A sine wave was fit to the collected data, using the standard form:

$$V = Asin(kt + \phi)$$

with amplitude A, wavenumber k and phase offset ϕ being extracted by linear regression. Figure 4 shows the time-evolution of the extracted phase shift versus time, compared to both current on SCB1:FC0 and temperature at both the ISAC-I mezzanine (near the DTL RF console) and at the DTL proper.

Visual inspection of Figure 4 reveals a clear correlation between the reflected buncher phase and temperature drift. A maximum reflected phase variation of ~0.45^{O} is apparent over a ~2 day period. It is also evident that transmission is inversely correlated (for this specific case) to RF phase drift. Of course, correlation does not imply causation. However, this data does suggest that further investigation into the relationship between the DTL RF (which is not temperature stabilized) and DTL transmission/performance is warranted.

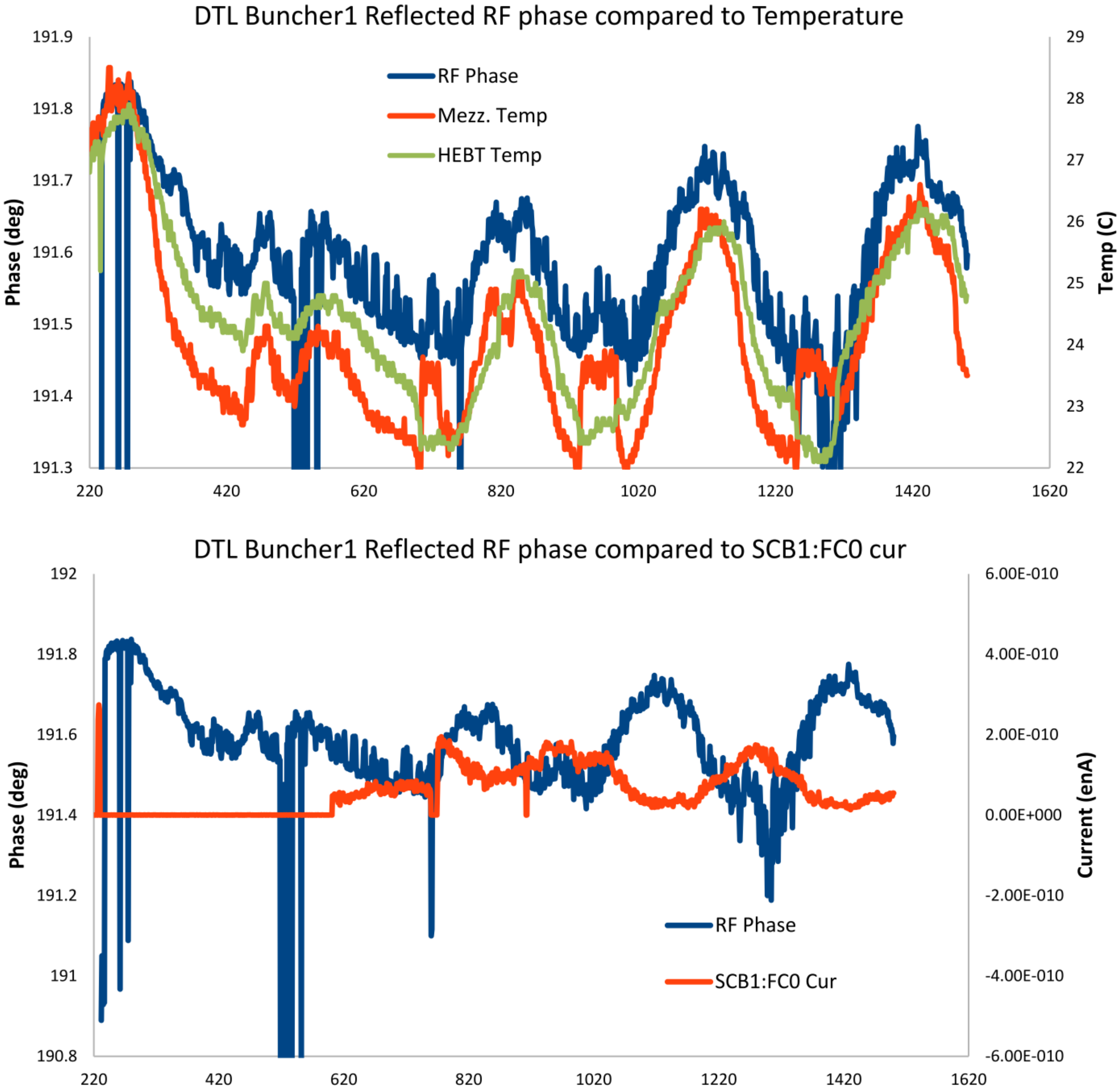

Figure 4: (T) – DTL Buncher1 RF phase vs time (in units of 5 minute intervals), compared to temperature on both the west ISAC-I mezzanine and HEBT. (B) – Buncher1 reflected RF phase versus current on SCB1:FC0. Note that prior to T ~ 620, drifting was such that no current successfully transmitted DSB. No tuning intervention took place to bring signal back.

Finally, the same procedure was repeated for DTL tank2, to gather evidence for tank drift behavior. Preliminary results are shown in Figure 5.

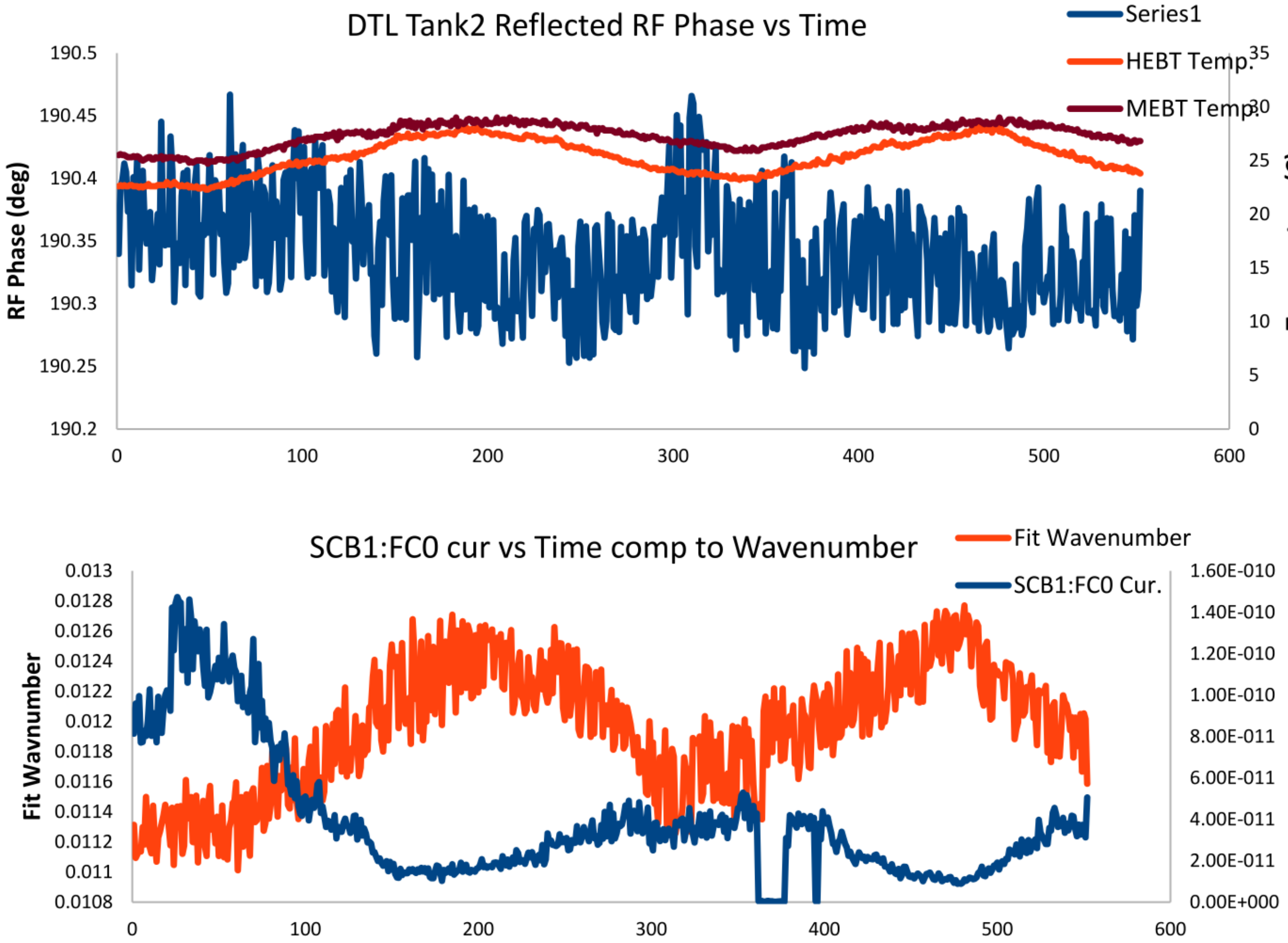

Figure 5: DTL Tank2 reflected RF fit phase (T) and wavenumber (B), compared to temperature (T) and SCB1:FC0 current (B).

Inspection of Figure 5 reveals that the wavenumber appears to be shifting, implying a variation of the frequency of the reflected RF. The maximum magnitude of the oscillation is 12%. A 12% variation in in a 106MHz linac would evidently result in a total loss of acceleration/transmission. The hypothesis on this (preliminary) data is that this variation is either due to i) an unstable reflected RF power causing discrepancies in the fit algorithm or ii) transients in the monitoring electronics causing an apparent change in wavenumber. Further investigation on this issue is warranted.

Inspection of the top graph in Figure 5 does nevertheless show a much weaker RF phase shift, totaling about 0.15^{O} in the entire 2760min/1.9day observation period.

Conclusion

The goal of these various measurements was to lay the foundation for further investigations, and improvements to the system where warranted. Consequently, no definitive statement can be made regarding the mechanisms that may have been observed.

However, there is now strong supporting evidence that:

I. There is a discrepancy between the Prague magnet energy measurement system and the SEBT FTM, on the order of 1.5%.

II. The ISAC-I RF system has a temperature dependency, which does correlate well with temperature variations in the ISAC-I hall.

III. The principal temperature effect is diurnal.

IV. There appears to be a temperature dependent phase shift in the ISAC-I RF, apparent at least in Buncher1 and Tank2. The order of this shift, when looking at reflected power, is a tenth to half a degree over several days.

In the event that a causal link is established between DTL RF phase and temperature, this would open up the possibility of writing software that would enforce PID regulation of the RF phase delivered to the cavity, by monitoring phase and possibly temperature. This would potentially eliminate the necessity for much online tuning that takes place while delivering beyond the DTL in general, and in ISAC-II in particular.