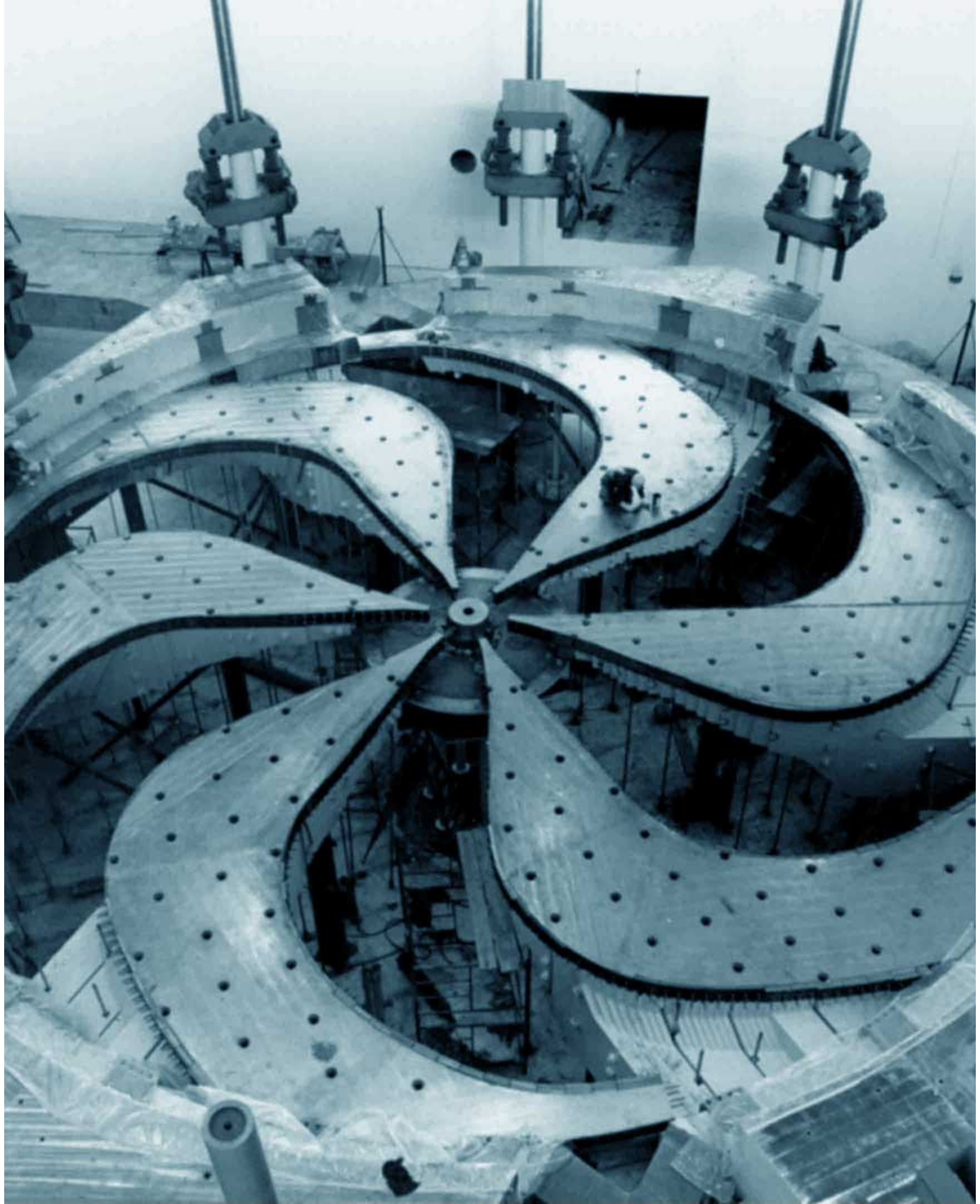
TRIUMF

TRIUMF ISAC RF System Development and Operational Experiences



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Discovery, accelerated

Outline

- Review of the ISAC accelerator and RF systems
- ISAC-I RF power coupler ceramic windows protection
- DTL frequency tuner improvement for reliable operation
- Sliding mode extremum seeking LLRF control implementation
- Upgrade of ISAC-II superconducting RF systems from triode tube to Solid State amplifiers
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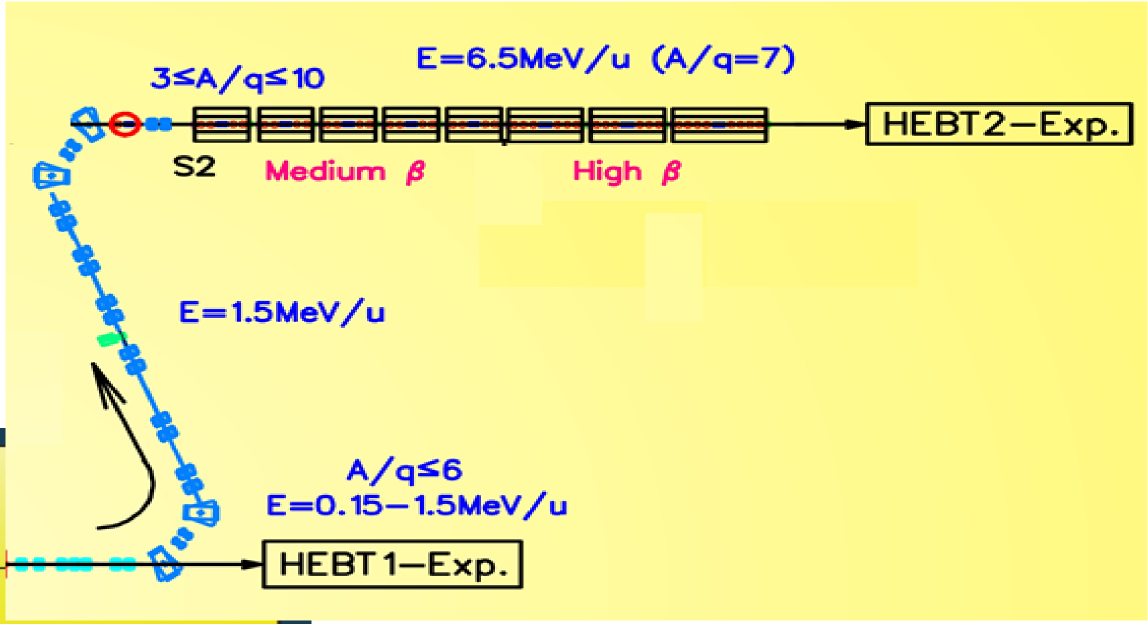
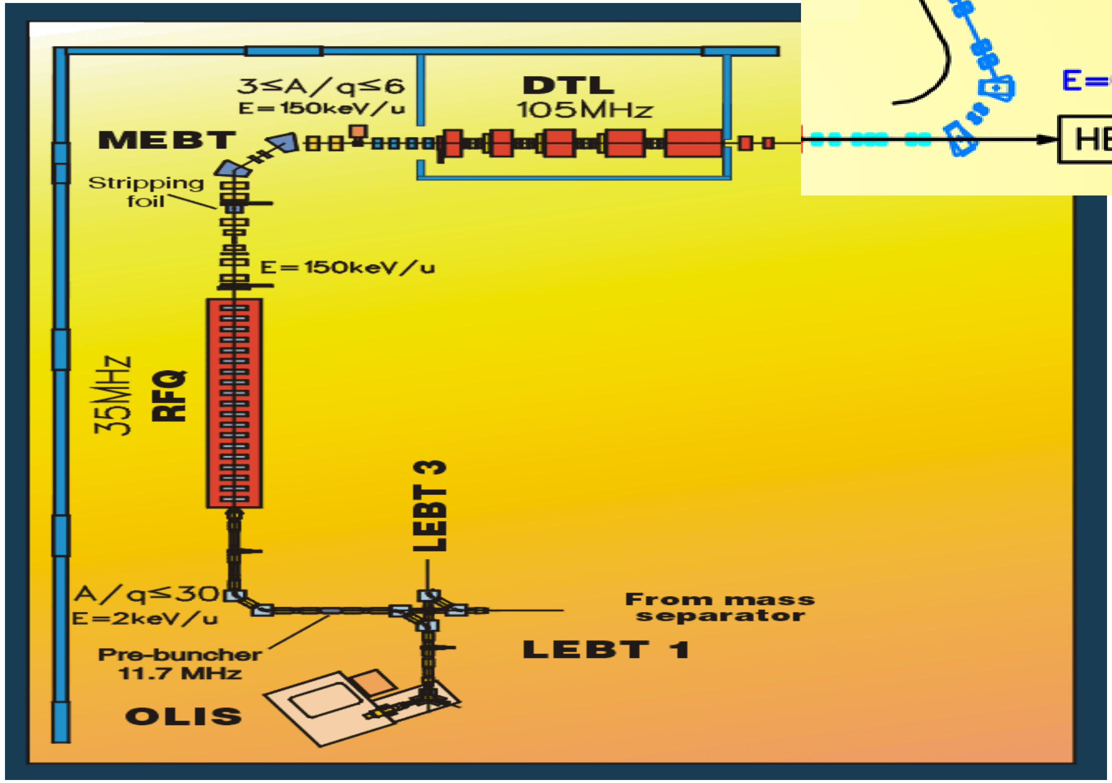
Introduction to ISAC Linac

- ISAC-I: Room temperature linac
  - ❖ RFQ: 153 KeV/u (1≤ A/Q ≤ 30)
  - ❖ DTL, 5 independent Interdigital H -Type structure tanks
  - ❖ Variable energy DTL 1.53 MeV/u (3 ≤ A/Q ≤ 6)
  - ❖ 18 RF systems





ISAC-II: superconducting linac,

QWR (40 cavities)

- ❖Variable energy
- ❖6.5 MeV/u (3 ≤ A/Q ≤ 7)
- ❖20 SCB at 106 MHz
- ❖20 SCC at 141 MHz

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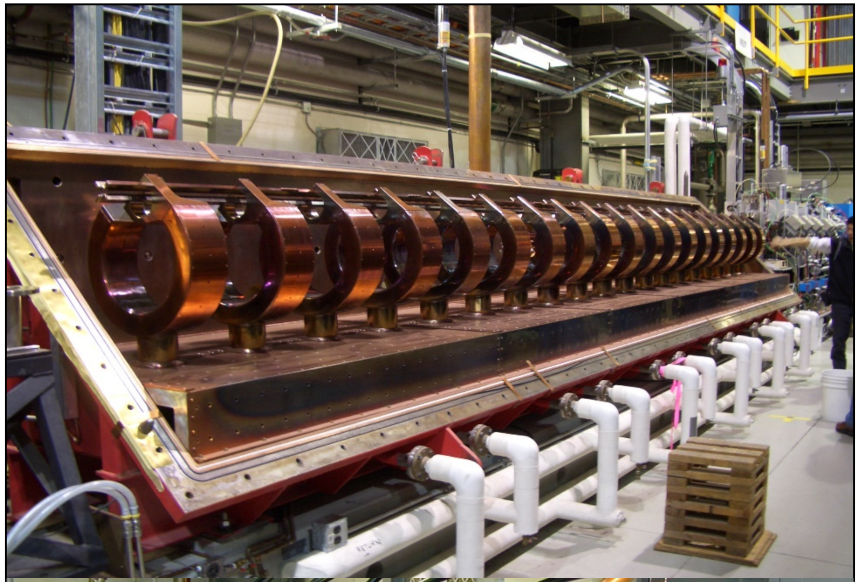
ISAC – I RF System

- ISAC-I room temperature RF system parameters

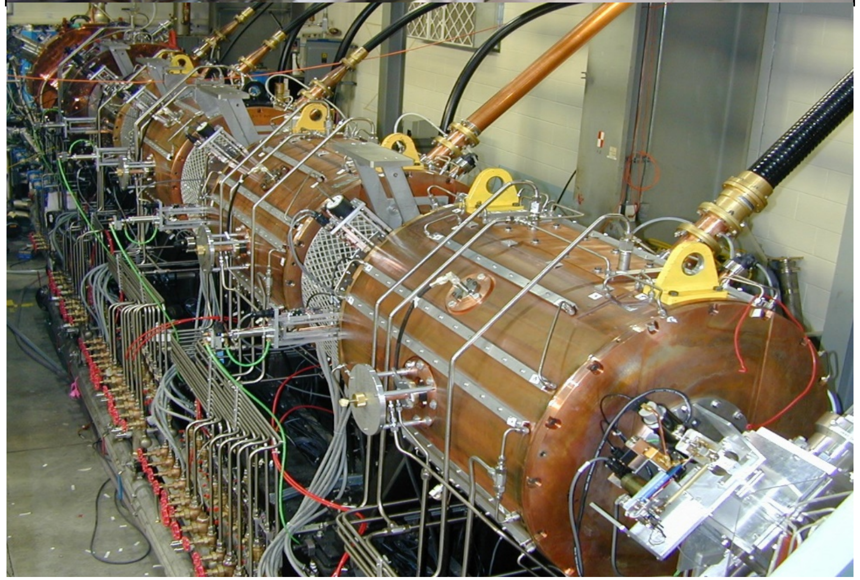
System	Frequency	V_eff.	RF Power
Name	(MHz)	(KV)	(KW)
Pre-Buncher	**11/23/35**	**400 V**	**1**
ISAC Booster	**11.78**	**16**	**300 W**
RFQ	**35.36**	**74**	**85**
Buncher Rotator	**106.08**	**35**	**3**
Chopper 1	**5.89**	**5.5**	**70 W**
Chopper 2	**11.78**	**7.4**	**150 W**
Rebuncher	**35.36**	**30**	**1.9**
DTL Tank 1 - 5	**106.08**	**47 - 110**	**4 - 21**
DTL Buncher 1-3	**106.08**	**55 - 91**	**10 - 12**
HEBT Buncher 1	**11.78**	**30**	**1.8**
HEBT Buncher 2	**35.36**	**170**	**15**
DSB Buncher	**35.36**	**170**	**15**

ISAC – I Room Temperature RF Structure

- RFQ (35.36MHz) , 2 KeV/u → 153 KeV/u
  - 4.4 MV (8m long, 0.55 MV/m)
  - 4-rod split ring structure,19 rings
  - 74 KV inter-vane voltage
  - Tetrode 150 KW tube amplifier

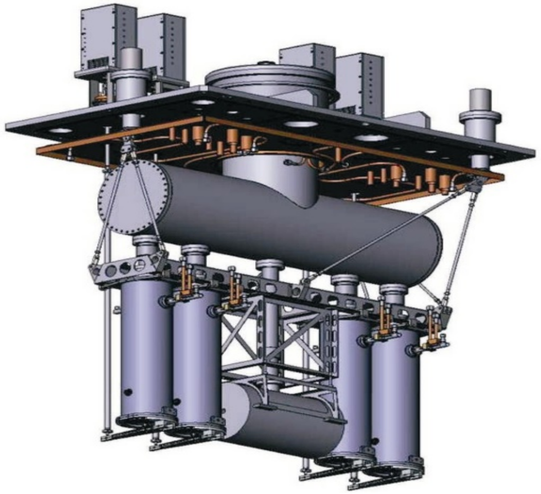


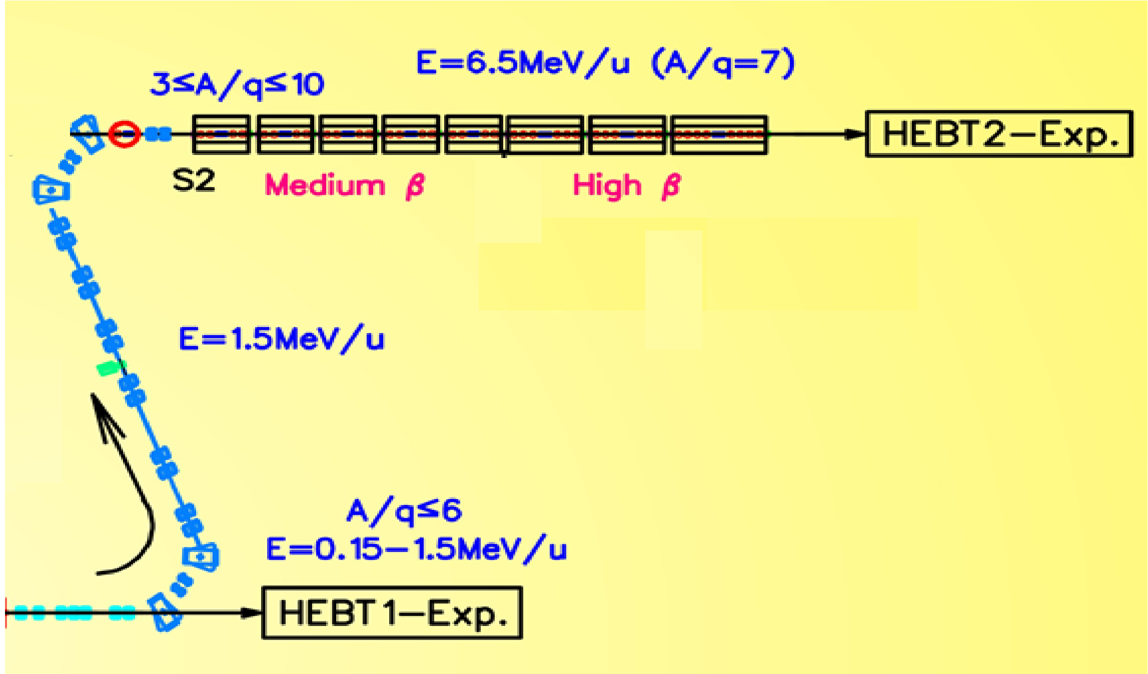
- DTL (Drift Tube Linac), 106.08 MHz
  - 5 DTL tanks and 3 bunchers
  - 8m long, 2MV/m, 8.1 MV(V_{eff})
  - Loop RF power couplers
  - Coarse & fine tuners employed
  - 500 W SSA driver
  - 4CW25,000, 25 KW finally PA



ISAC – II Linac

- ISAC-II superconducting RF structure (QWR)
  - 20 + 20 SRF cavities in 8 cryostats
  - 6 MV/m, 40 MV (**V**_eff)
  - 20 SCB 550 W SSA (original triode tube PA), at 106.08MHz
  - 20 SCC 500 W SSA, at 141 MHz





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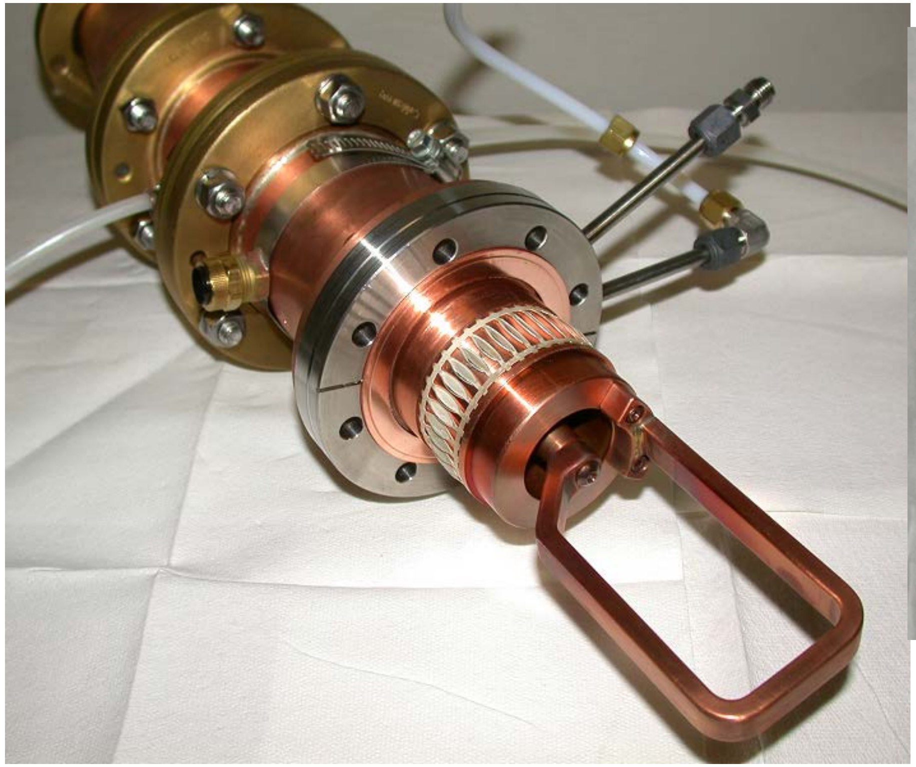
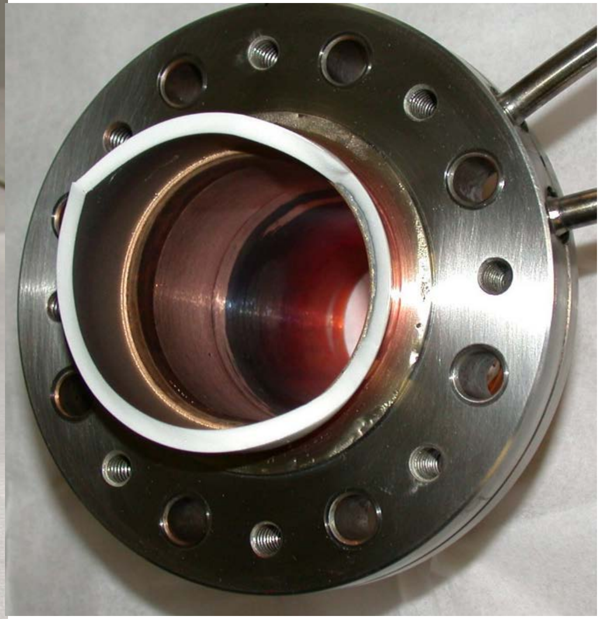
RF Power Coupler Protections

- Effective protections against overheat, overdrive and reverse power should be applied in RF high power couplers
  - ❖ No protection employed for higher reflected RF power during commission
  - ❖ Temperature of RF power coupler ceramic windows was not monitored
  - ❖ Less experience to condition cavities
  - ❖ The RF levels from pulse to CW mode should be limited to a safe level, to prevent overheating





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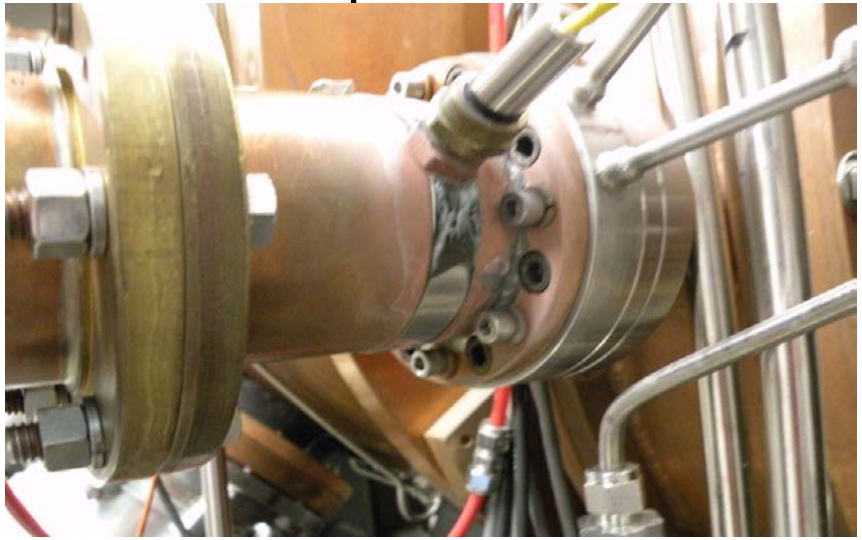
RF Power Coupler Protection

- Reliable protections applied in the RF power couplers
  - ✓ infrared sensor on the ceramic window to monitor the temperature (RF trip off @ ≥ 40 ºC)
    - ✓ Monitor and Archive the temperature data to analyze RF window status; if it's coated or broken
  - ✓ Trip RF while higher reflected power via LLRF control
  - ✓ Limit the RF drive levels from pulse to CW mode
- RFQ ceramic window was coated, repaired with the help of the archive data

Infrared Thermocouple OS36 to monitor the T. of ceramic window



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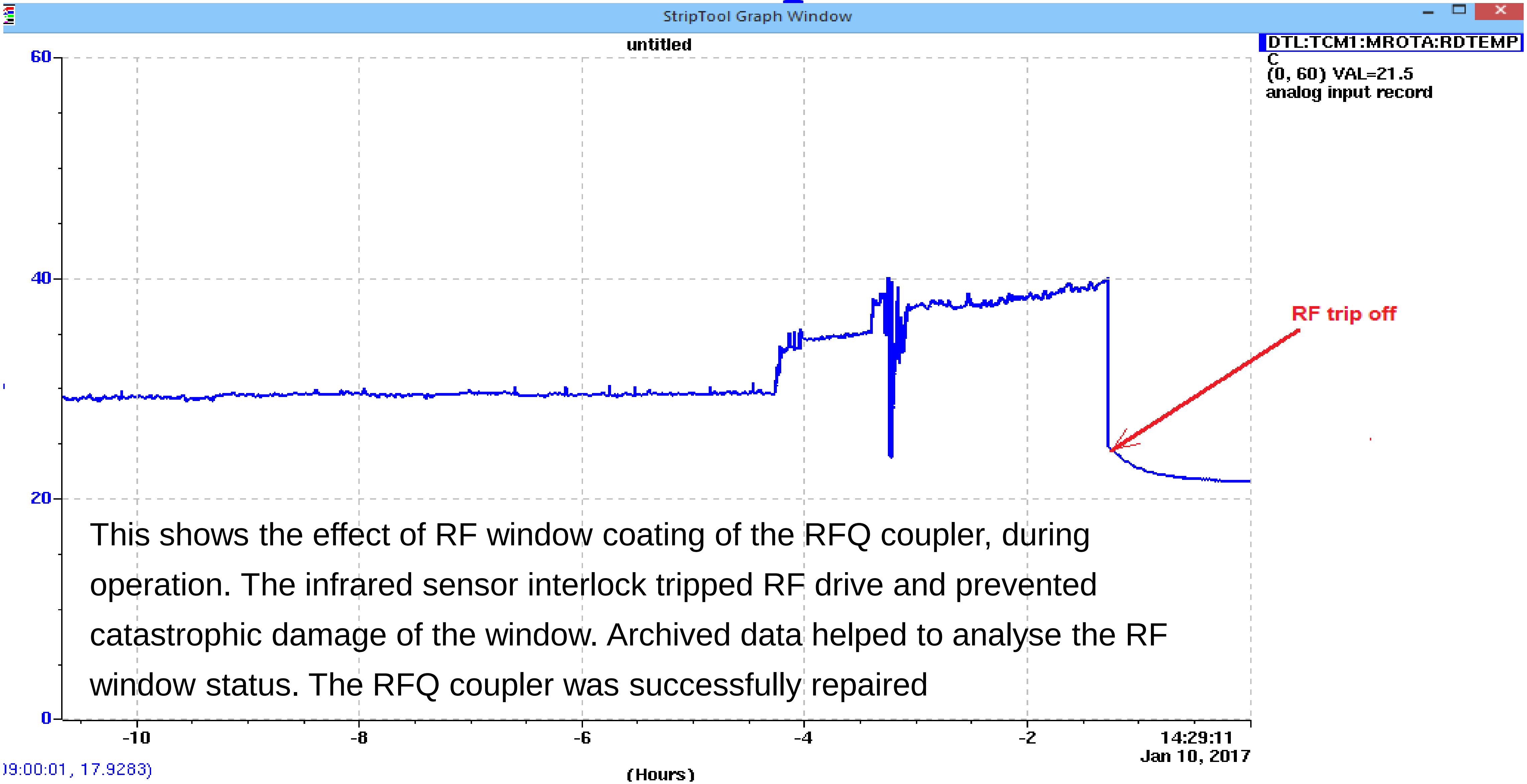
RF Power Coupler Protection



This shows the effect of RF window coating of the RFQ coupler, during operation. The infrared sensor interlock tripped RF drive and prevented catastrophic damage of the window. Archived data helped to analyse the RF window status. The RFQ coupler was successfully repaired

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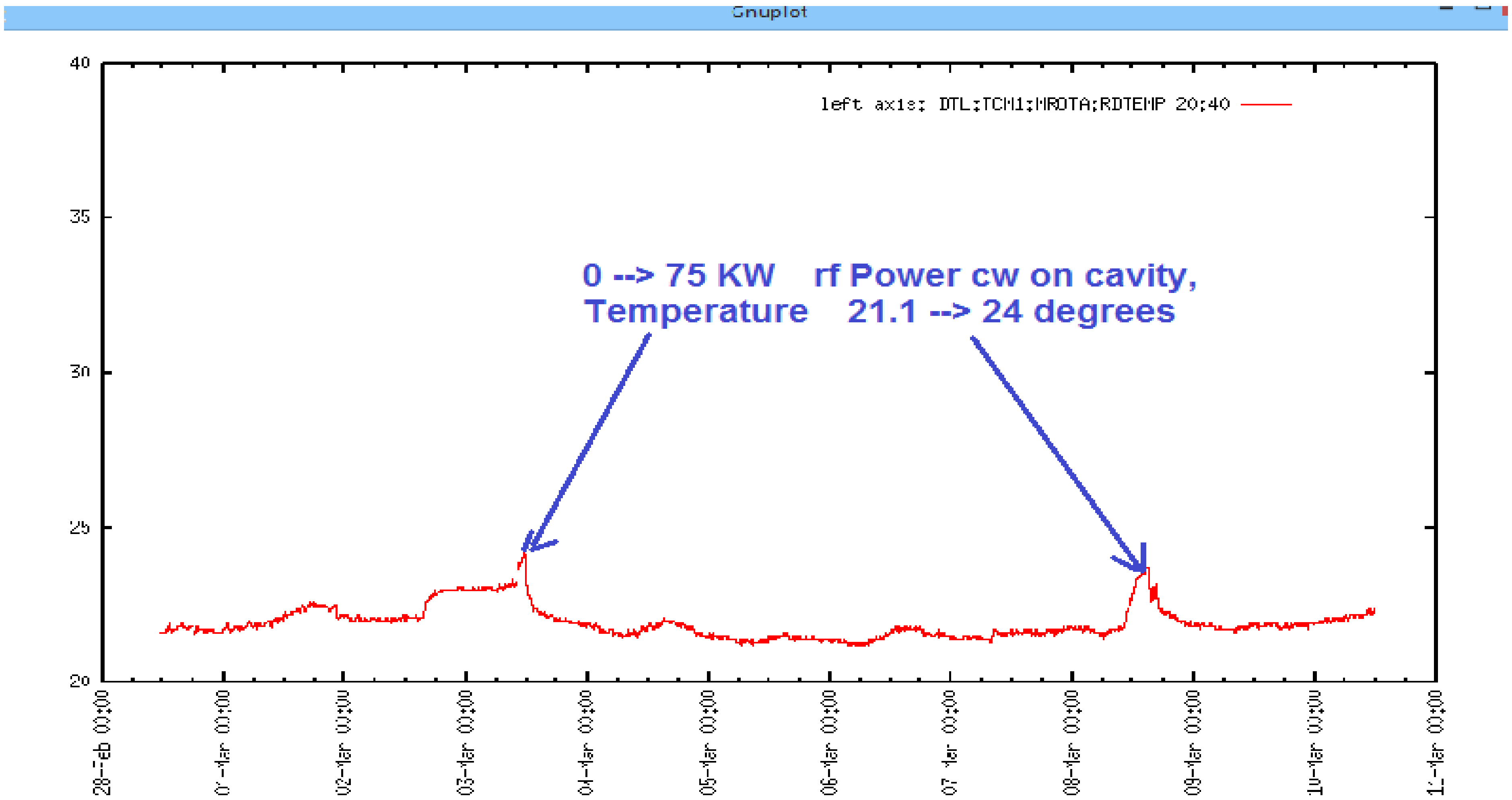
RF Power Coupler Protection

- RFQ ceramic window was coated and replaced; repaired for spare

RF Power Coupler Protections

- Failed RFQ ceramic RF window was replaced

- The temperature records shown how good the new RF window works



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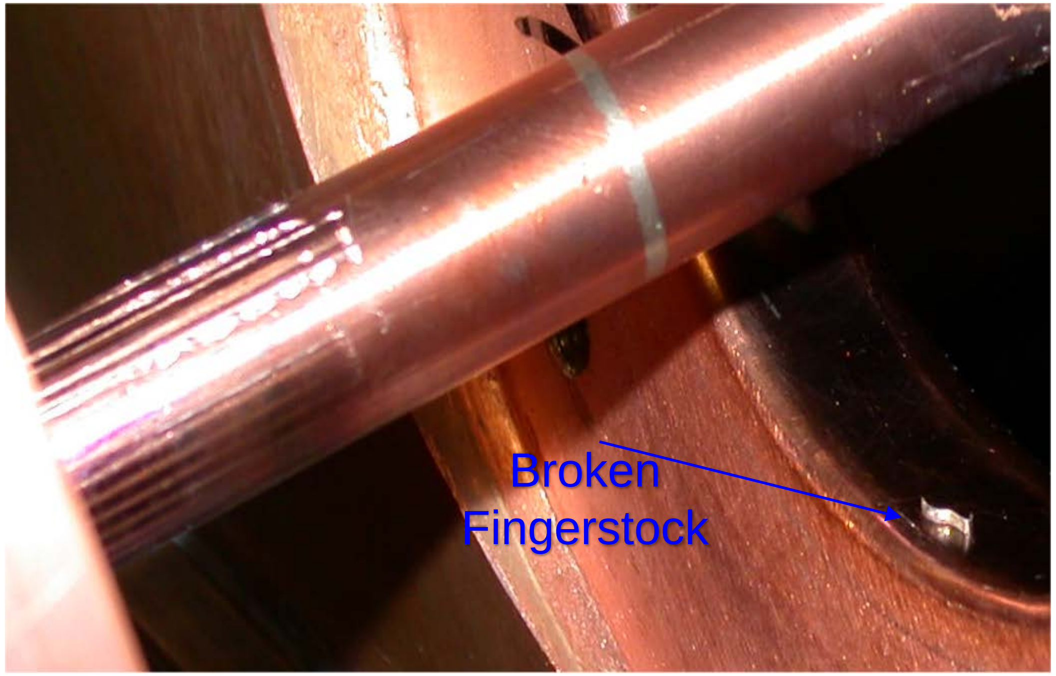
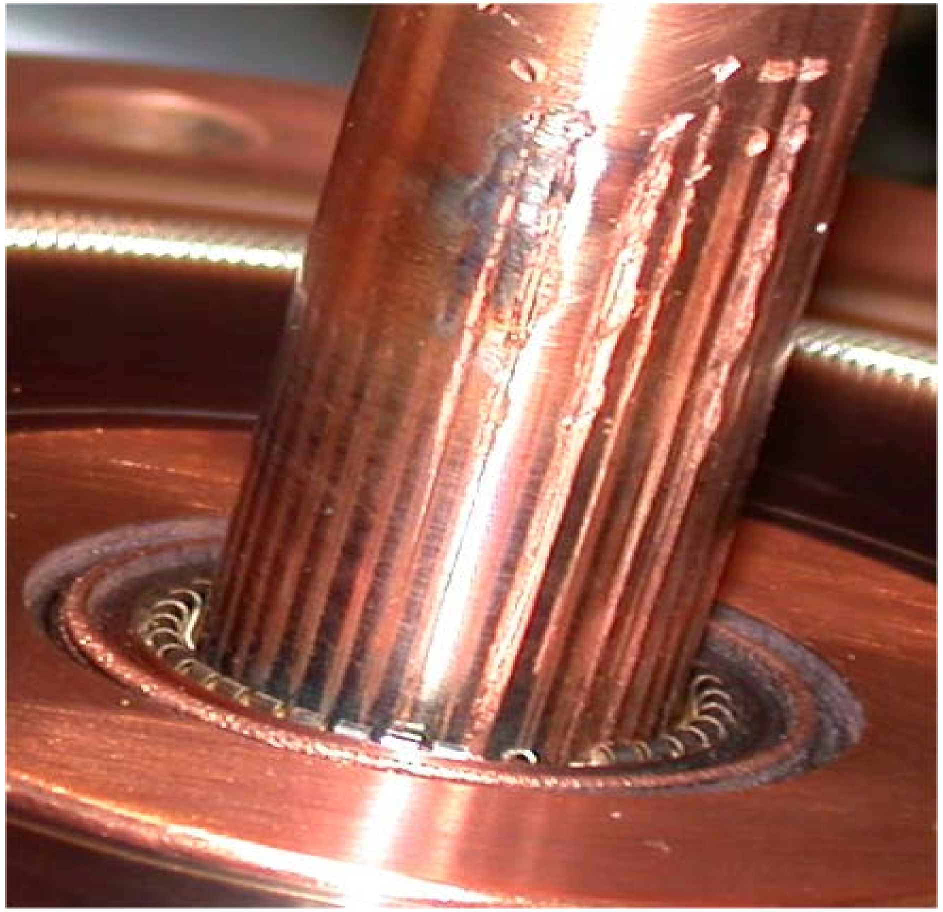
Frequency tuner problem & improvement

- The tuner copper shafts were scratched severe after years of operation
  - Tuner shaft moves horizontally, and tilted due to the weight load of tuner’s plate
  - The different hardness of the materials between tuner shaft & fingerstock
- LLRF control failed, can't close loop
  - The tuner can’t moves smoothly; bad regulation
  - Larger reflected RF power tripped RF





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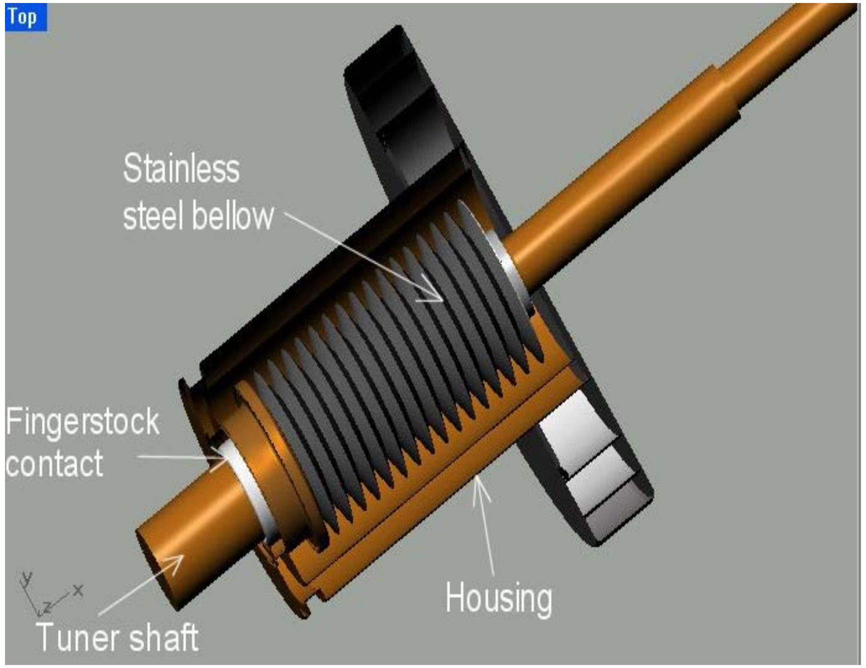
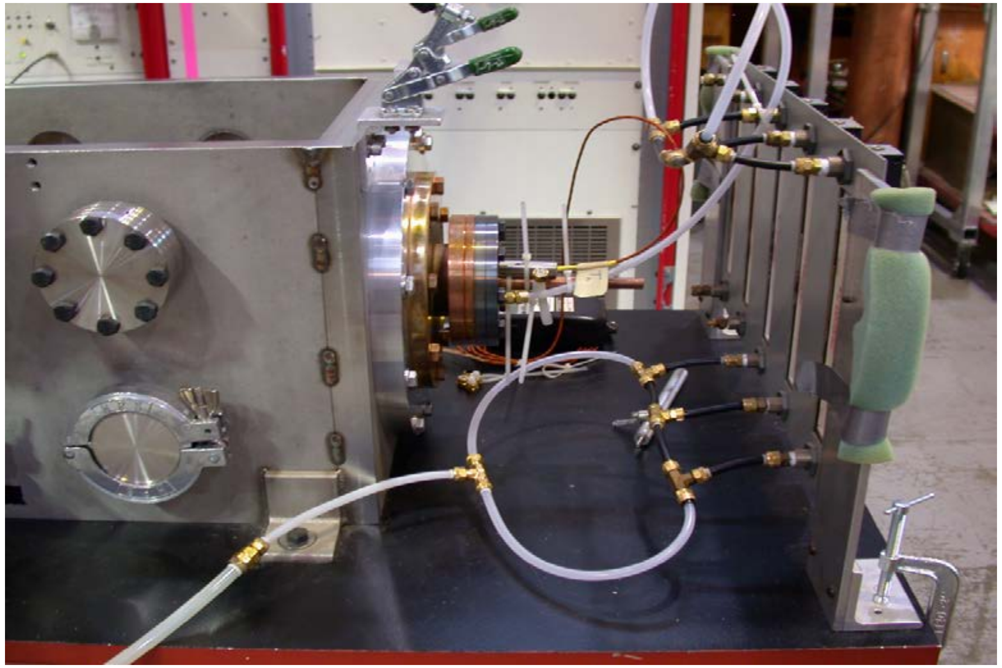
Frequency tuner problem & improvement

- Bench tests after removing the RF fingerstocks
  - 25 W dissipation power, cause bellow 100 ºC rise without cooling
  - 100 W dissipation power, cause bellow 40 ºC rise with air cooling
- Full RF power on DTL Tank#5 cavity after removing the fingerstocks
  - Q measurement comparison with/without fingerstocks of Tank#5 - no difference
  - Continue run RF at 20KW on cavity, temperature rise ~ 10 degree C without cooling
- The fingerstocks in all fine tuners of DTL & buncher were removed





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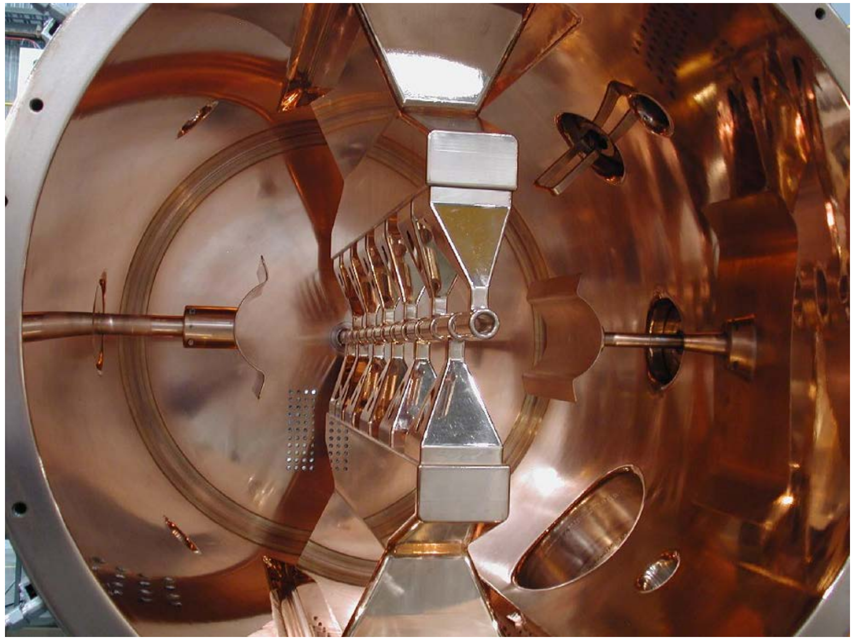
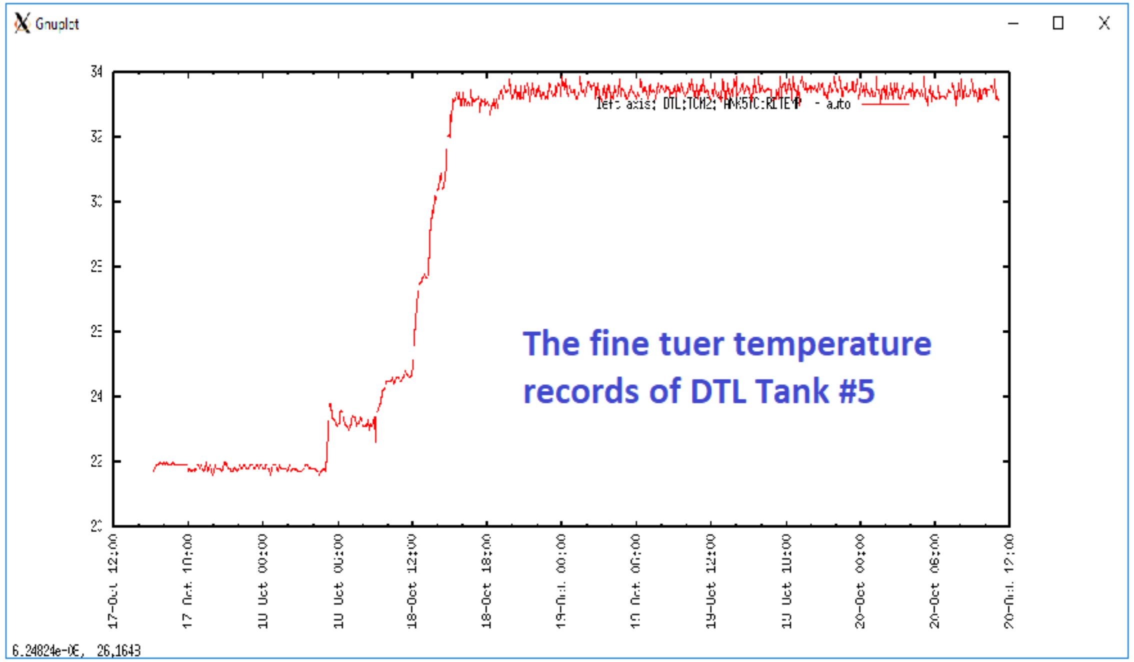
Frequency tuner problem & improvement

- Thermocouples were installed in all the fine tuners for ISAC – I RF system
- Set up interlock of the sensors for routine operations
- All the tuners have been working very stable since removing the fingerstocks in the RF systems
- Archive records help to monitor temperature and troubleshoot RF systems





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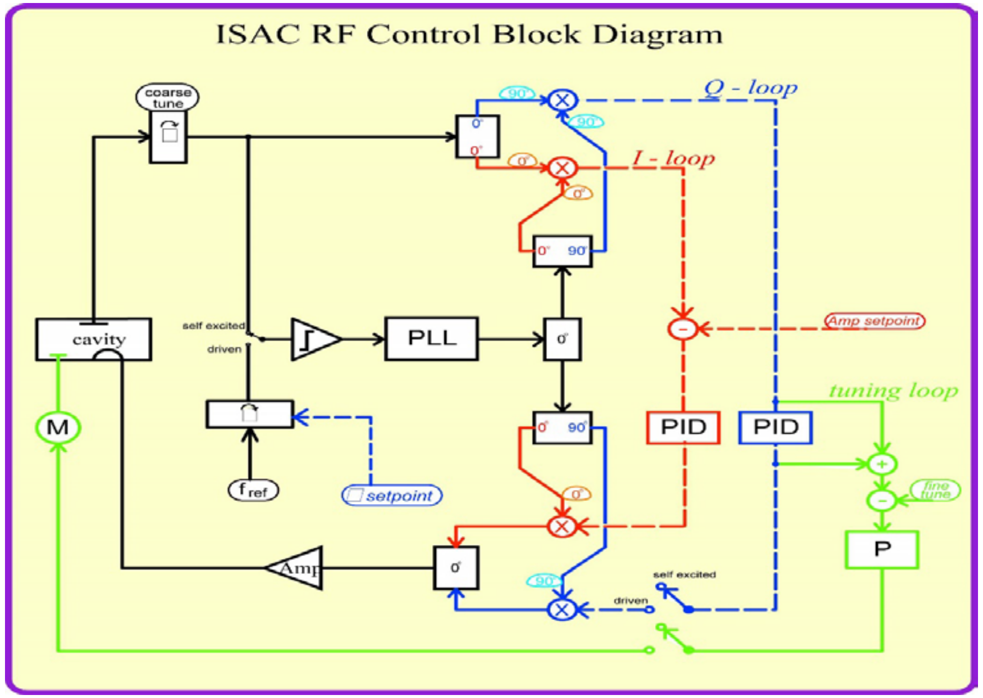
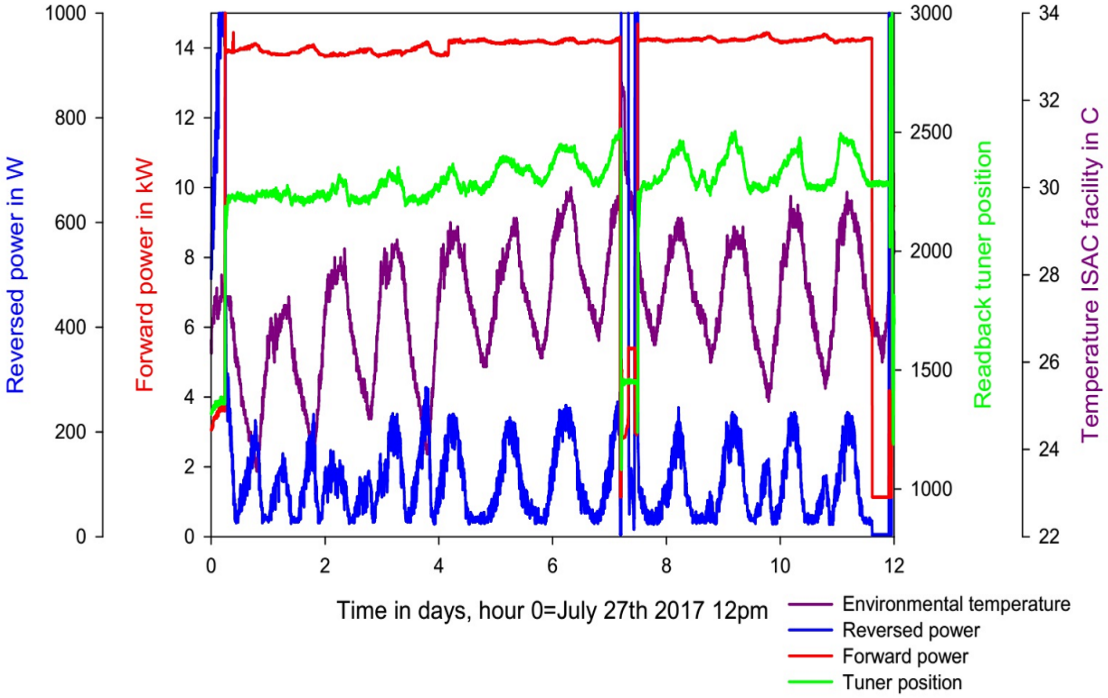
LLRF Control Upgrades

- The problems of LLRF control via phase comparisons technique
  - The long cables of LLRF phase reference are not temperature controlled
  - Big phase errors induced by the environment & facilities temperature variables (Temperature of building > 30 degrees C)
  - Replace PS, caused larger phase changes in loop, LLRF control won't work





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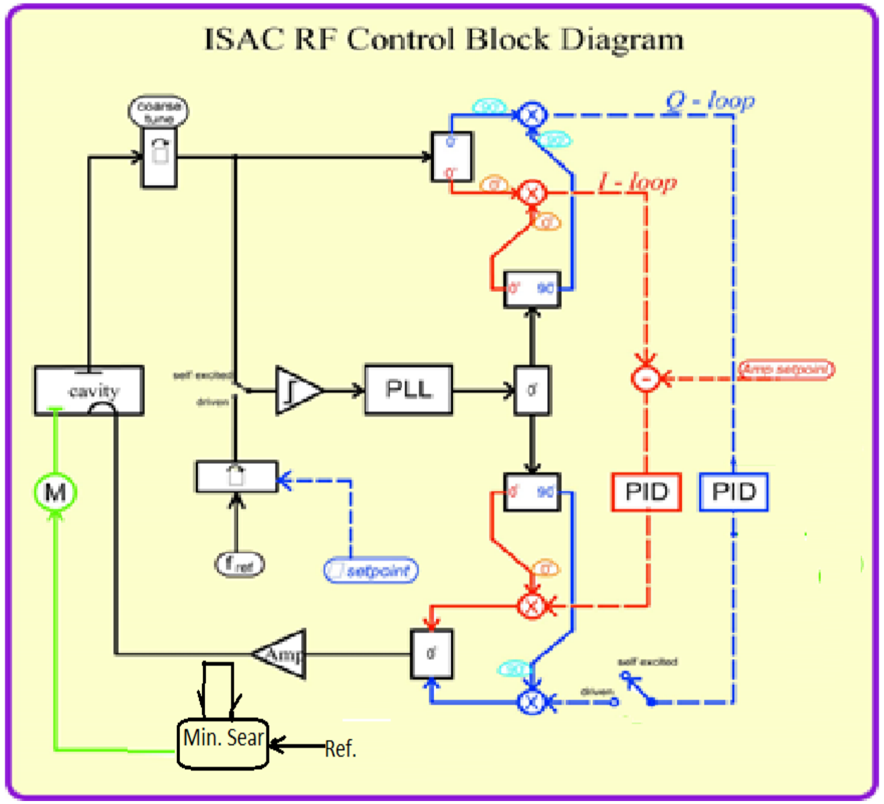
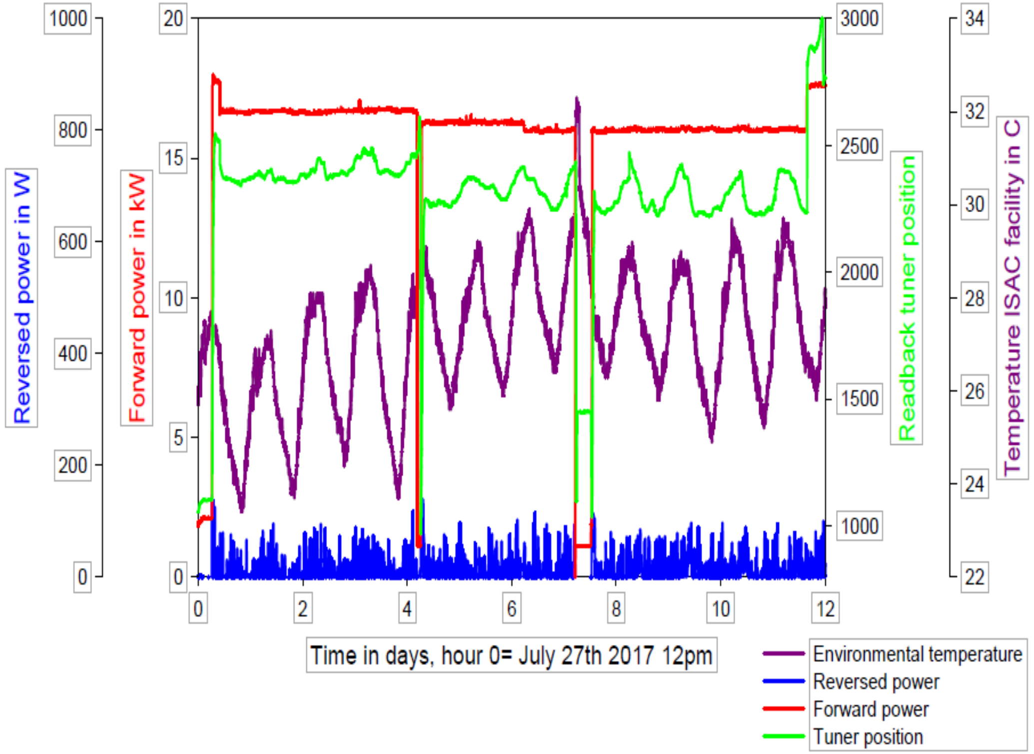
LLRF Control Upgrades

- The sliding mode extremum seeking control(minimize reflections)
  - Minimize the reflected RF power by moving the tuner
  - Big phase change induced by temperature in LLRF loop are ignored
  - The tuners have more idle time while smaller reflection





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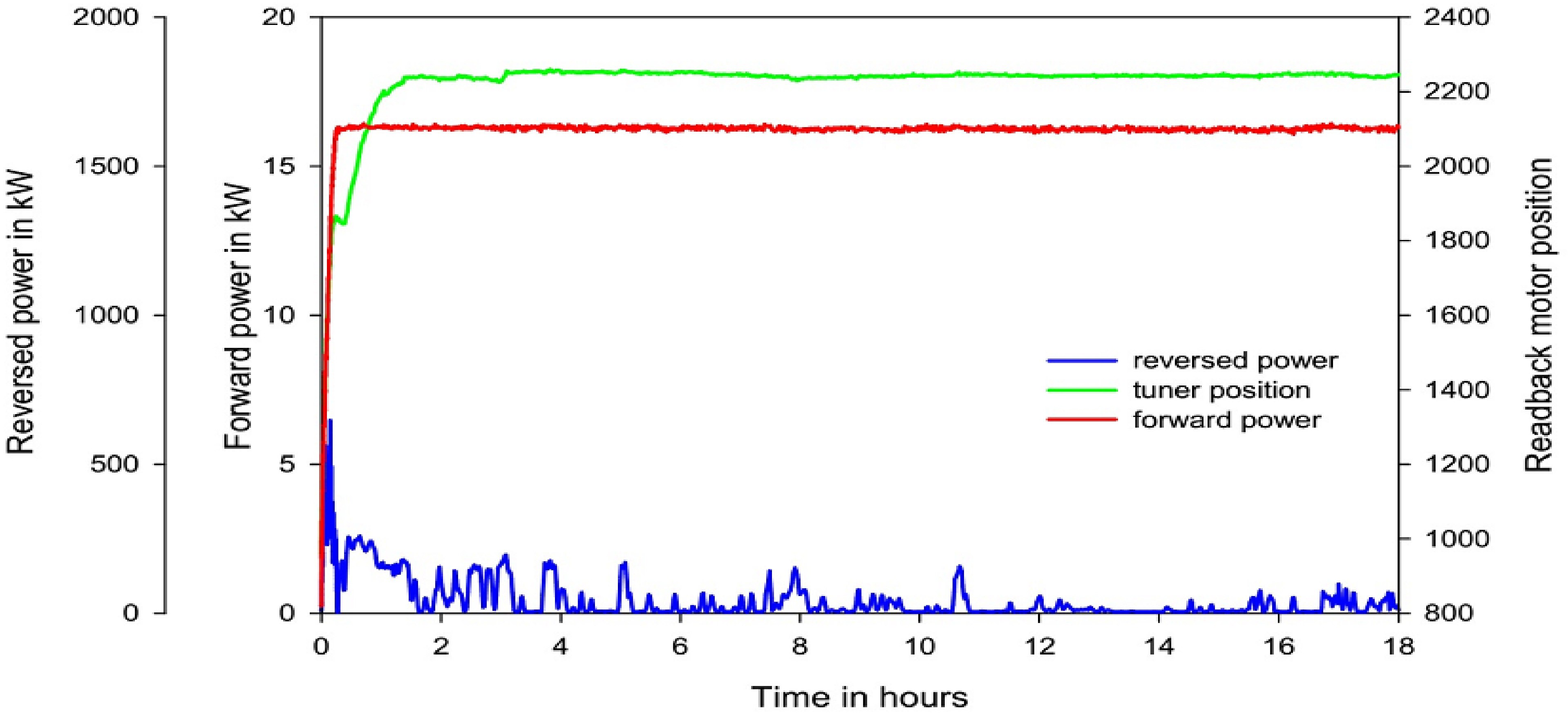
LLRF Control Upgrades

- **Much stable operation have been approached when we implemented the sliding mode extremum seeking LLRF control (the minimize reflected power, the systems are much stable and more reliable)**



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SCB 106 MHz amplifier upgrade

- The disadvantages of the small triode tube amplifiers
  - The degradation of the tube amplifiers is very fast (~10k ~ 12k hours only)
  - Matching & frequency tuning was not stable enough; retune PA were required from time to time
  - Investigate failures of system is intricate.
  - Costs to replace the failure/aged tubes are higher for operations.
  - Time of replacing a failed amplifier, pre-amplifier or DC PS is not negligible for operation downtime
- The advantages of commercial Solid State Amplifier (SSA)
  - Reasonable price
  - Long lifetime and stable operation
  - Easy for troubleshoot, less operation downtime

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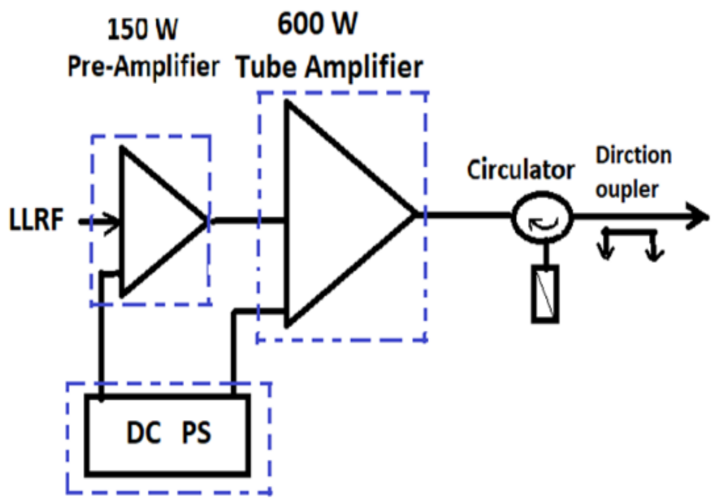
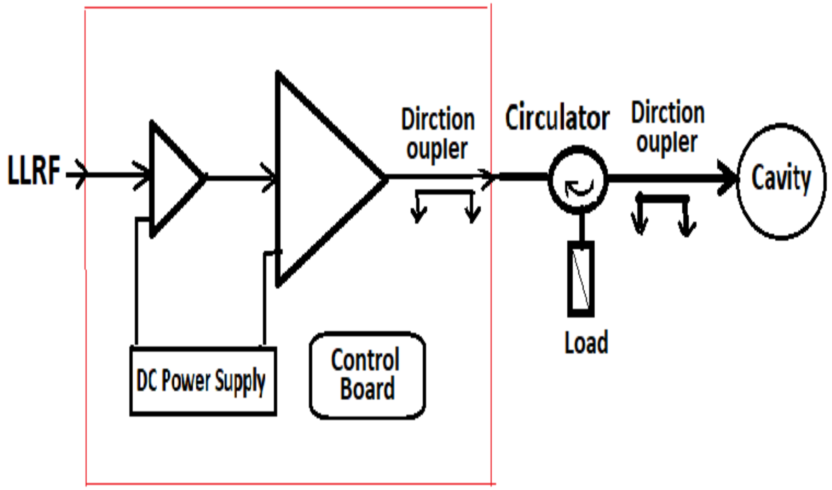
SCB 106 MHz amplifier upgrade

- The 20 Triode tube amplifiers were replaced to SSA in 2018
- The maintenance and troubleshooting is simple, downtime drops dramatically
  - ❑ Good stabilities of the amplitude and phase
- Long term cost for the 20 RF SSA will be much less compared to the tube PA



106 MHz, 600W Tube Amplifier Block Diagram



106 MHz, 560 W Solid State Amplifier

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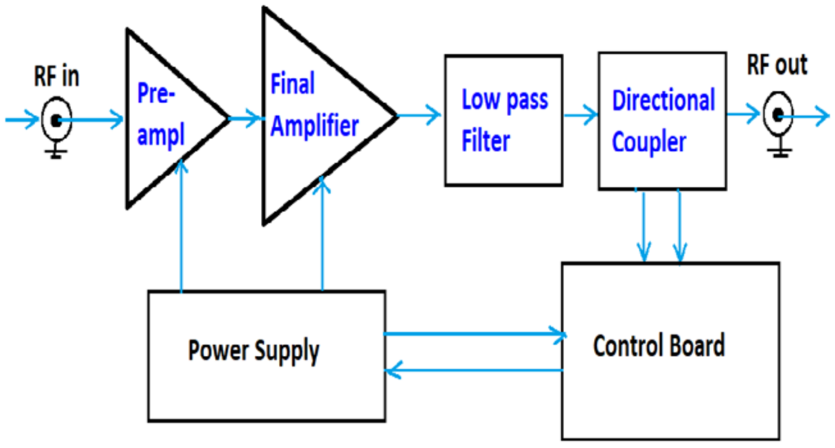
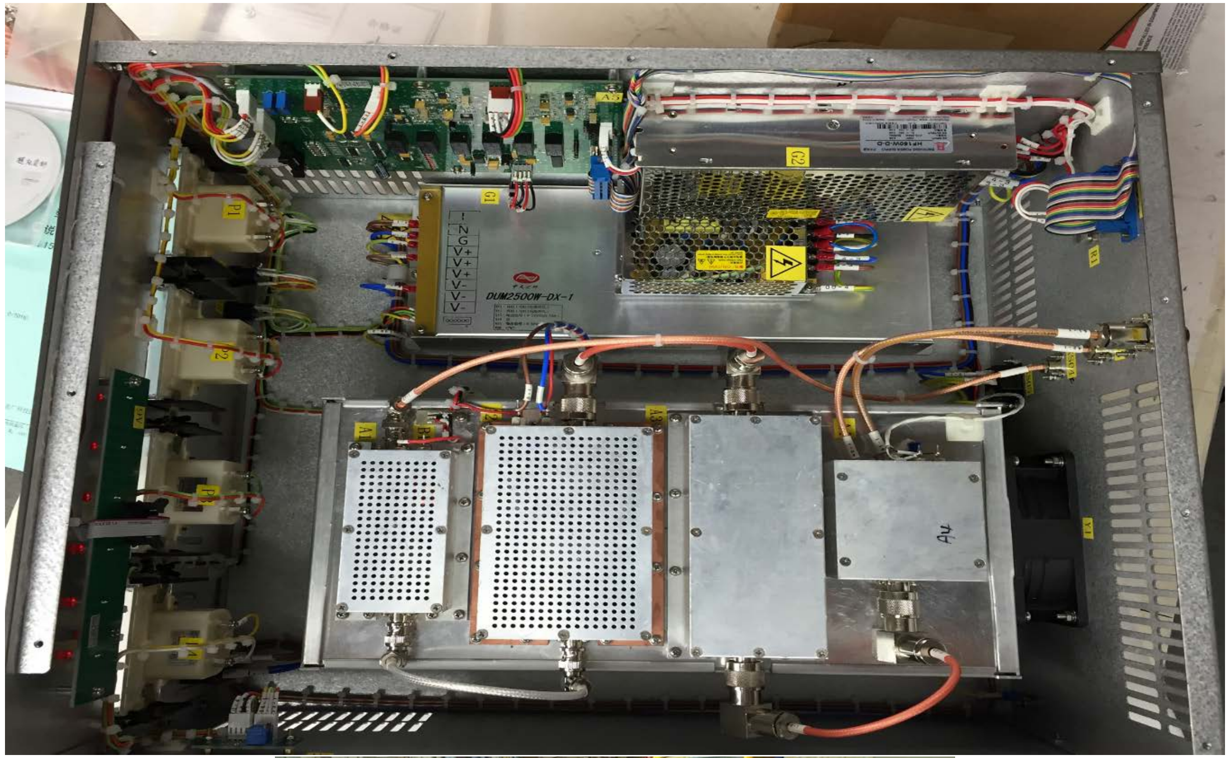
SCB 106 MHz amplifier upgrade

- The prototype of new ISAC-II SCB 560W SS Amplifier
  - ❑ Modular design
  - ❑ Meet our specification



SS Amplifier Block Diagrams



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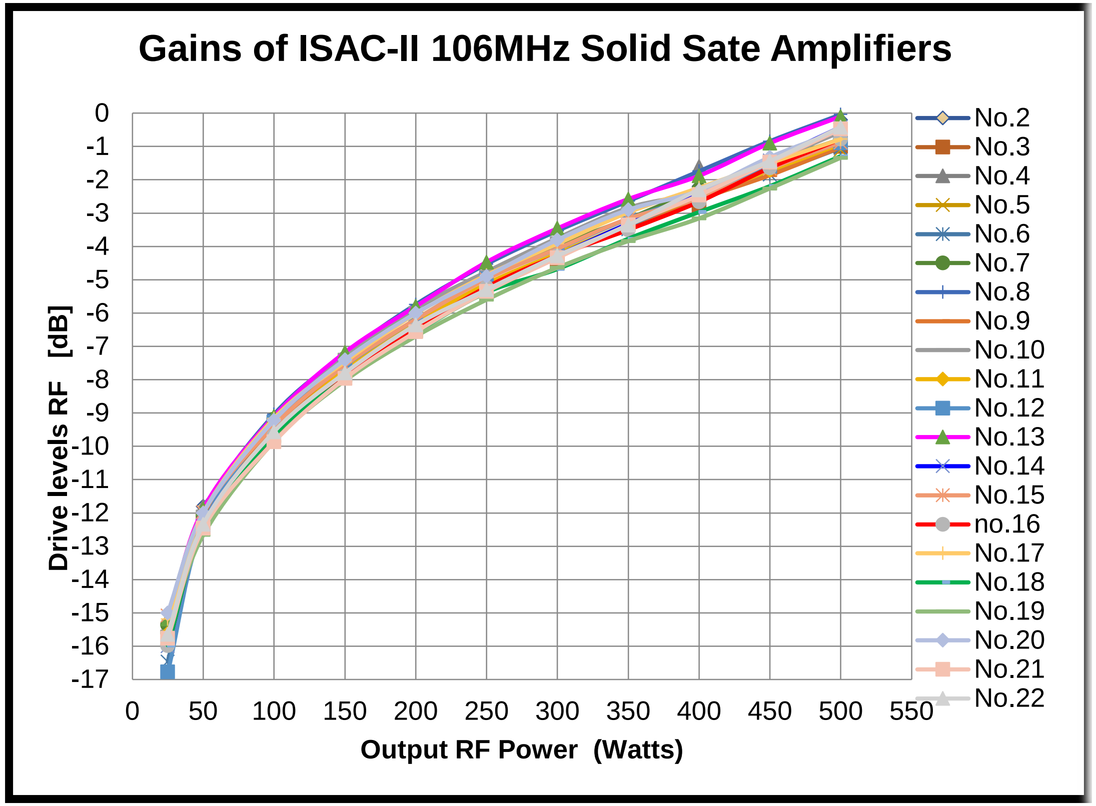
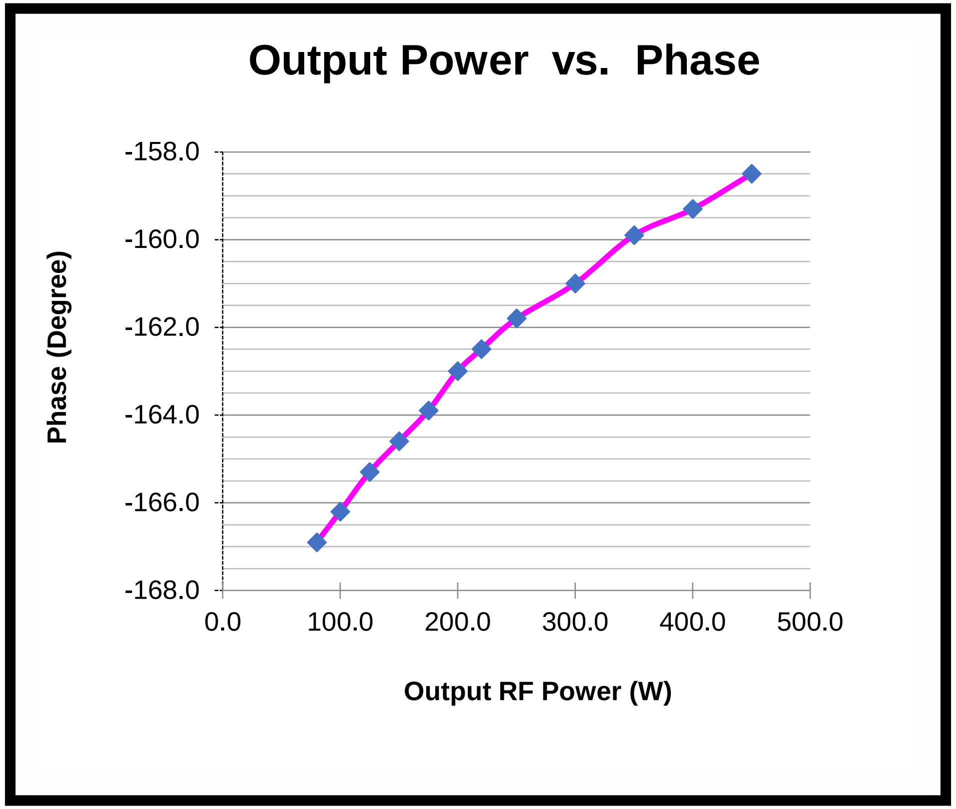
SCB 106 MHz amplifier upgrade

- **Phase stability** is less than one degree of phase change in 5 hours
- **Phase variable** is less than 10 degrees in power range 80 - 450 W
- **Gain differences** are approximately one dB among the 21 SSA





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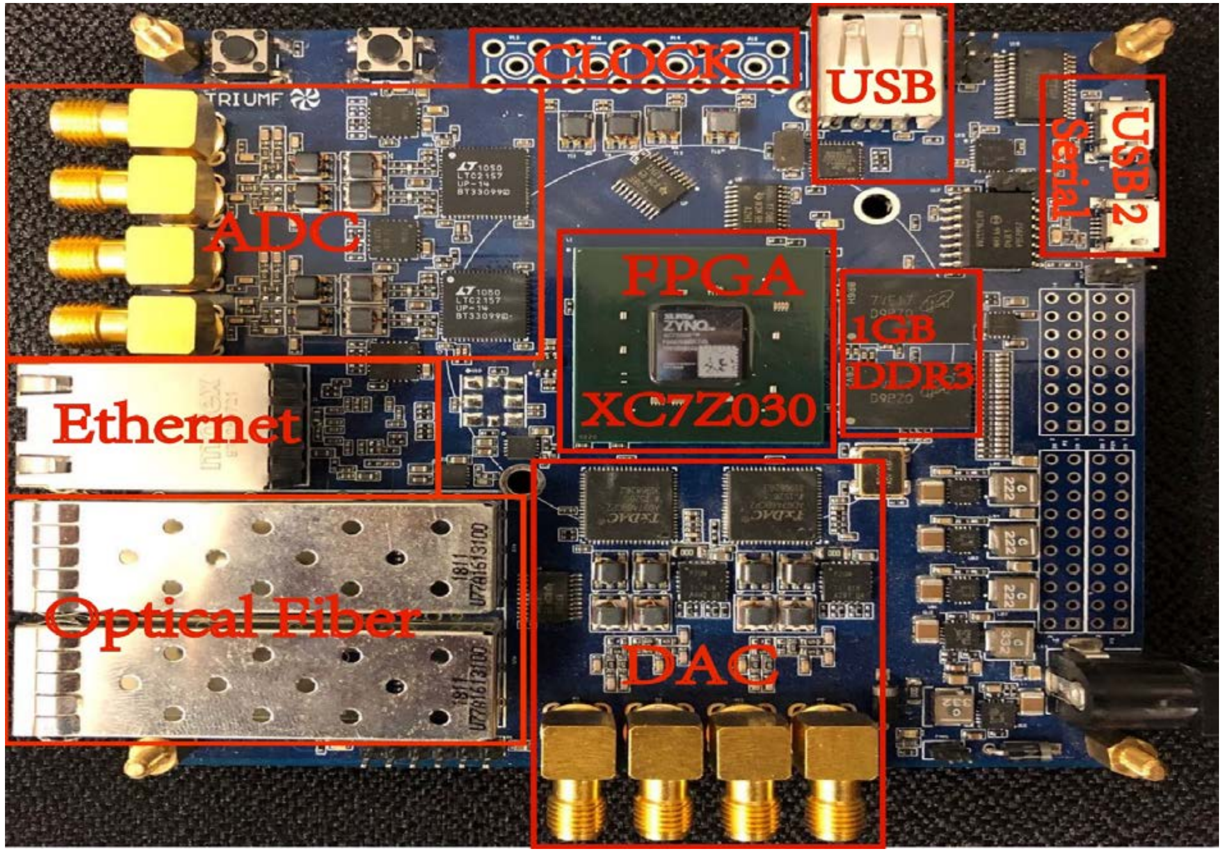
LLRF digital control board in operation

- 11/23/35 MHz broad band Pre-buncher first time has been controlled though the LLRF digital control system
- More RF systems will employ the LLRF digital control in near future

The first LLRF digital control board developed at TRIUMF and now in operation



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Summary

- **ISAC RF system developing in success**
  - ✓ Replacement of semi-rigid cables to rigid coaxial lines
  - ✓ RFQ HV soft-start circuit in use to protect RFQ tetrode, reduced crowbar during start of HV
  - ✓ Screen net flanges added for protections to vacuum turbos and resonators
  - ✓ Develop monitoring and data acquisition for ISAC-I RF system. Archive for status
  - ✓ Lifetime of RF power couplers increased after protection implementation
  - ✓ Frequency fine tuners modifications made them more reliable for operations
  - ✓ Sliding mode LLRF control implemented in DTL, increased the reliability of RF system operations
  - ✓ Upgrade of the tube to SSA in ISAC-II SCB has decreased downtime and maintenance time significantly
  - ✓ First digital LLRF control realized at TRIUMF, it has performed very stable
- **Availability of ISAC RF systems increased to > 98% up from < 90 %**

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Thank you
Merci

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