CYCLOTRONS
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DEVELOPMENT OF RF SYSTEM FOR K500 SUPERCONDUCTING CYCLOTRON AT VECC, KOLKATA

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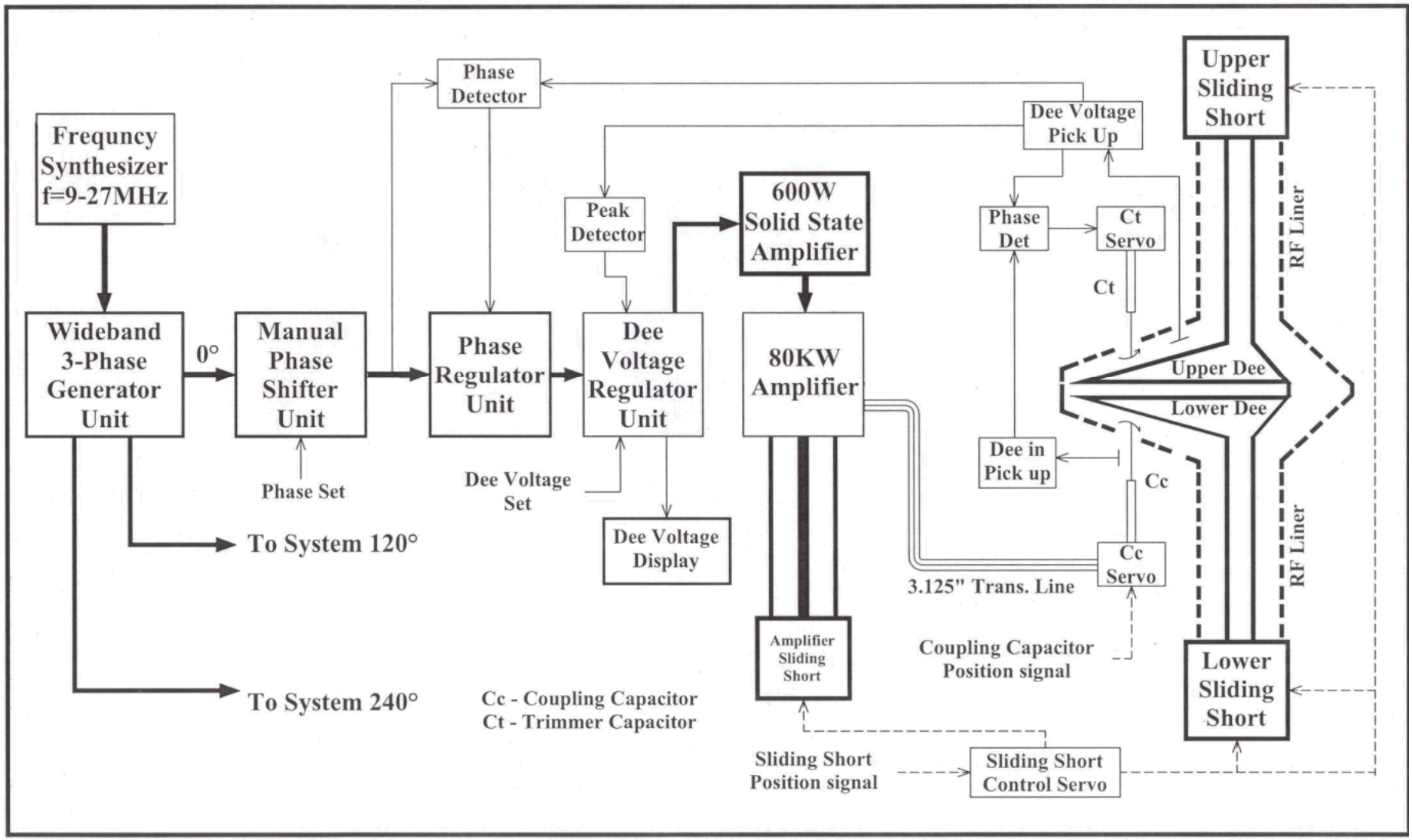
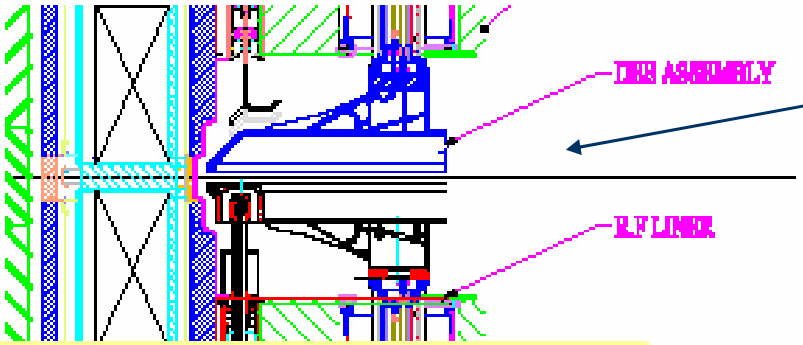
RF SYSTEM SPECIFICATION

- **Frequency range:** 9 to 27 MHz
- **Harmonic Modes:** 1,2,3,4,5,7
- **Peak Dee Voltage:** 100 kV
- **Frequency Stability:** 1×10^{-7}
- **Amplitude Stability:** 1×10^{-4}
- **Phase Stability:** $\pm 0.5^{o}$

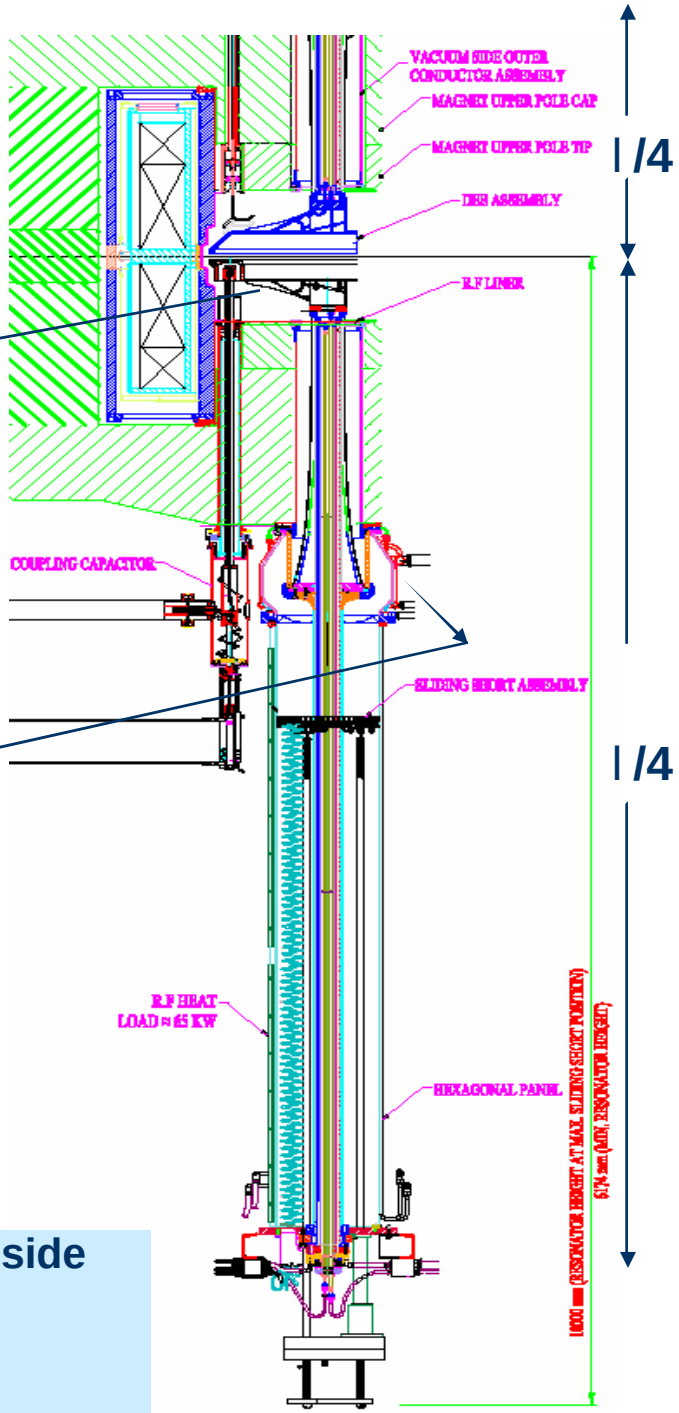
BLOCK DIAGRAM OF K-500 RF SYSTEM



MAIN DEE CAVITY WITH DEE STEM

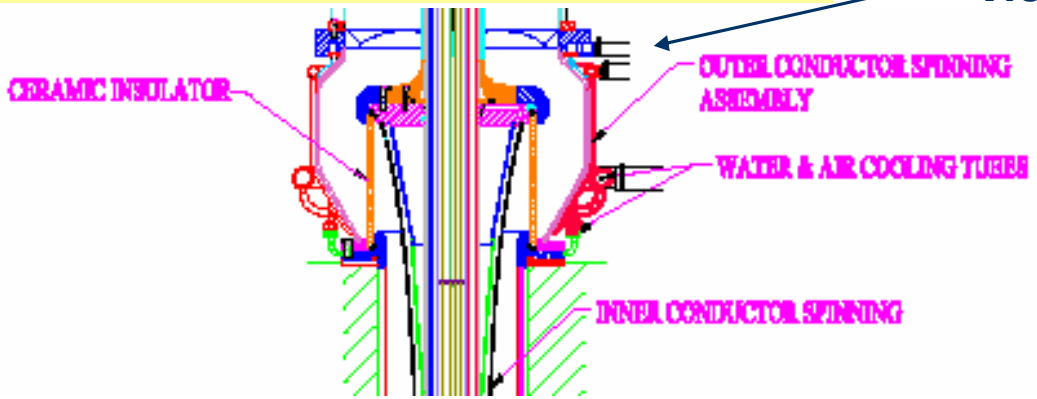


Close view



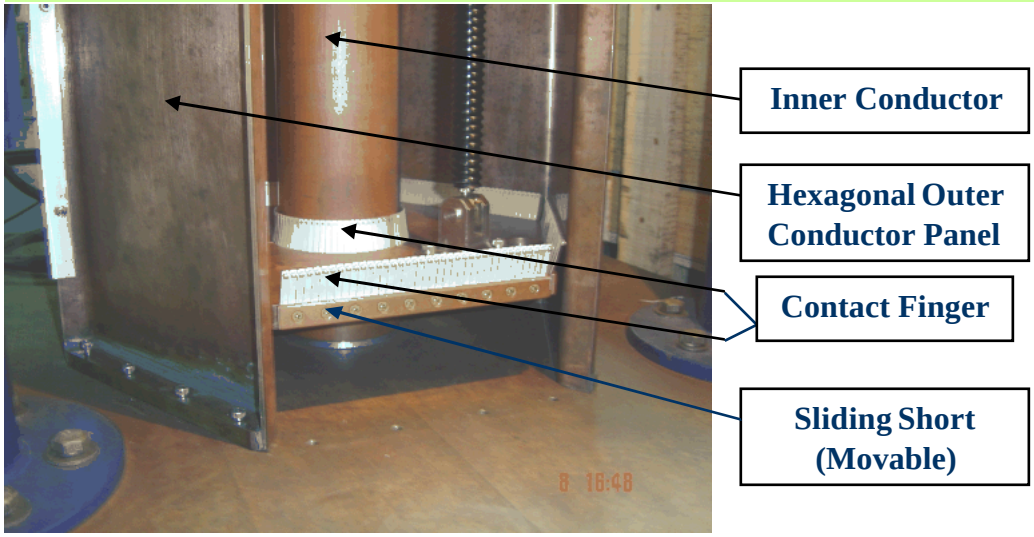
- Alumina (ceramic) insulator (99.5% purity)
- tanδ = 0.0004, Dielectric Const. ^{3} 9.6
- Tensile strength ^{3} 3.5 N/mm^2
- 285.75 mm. OD x 266.7 mm. ID x 228.6 mm. L

Close view



- Hexagonal Outer Conductor (in air): 201.65±0.05 mm each side
- Cylindrical Outer Conductor (in vacuum)
- Cylindrical Inner conductor (in air): 58.42±0.05 mm. OD.
- Tapered Inner Conductor (in vacuum)

SLIDING SHORT ASSEMBLY FOR CAVITY



- Sliding short plate electrically connected to inner & outer conductors of coaxial cavity by Be-Cu contact finger with silver-graphite (99%Ag +1%C) ball at the tip.
- Contact resistance ~ 0.7 mW per finger.
- Contact finger can carry current up to 4A/mm.
- Each finger can withstand force ~ 0.35 kg.

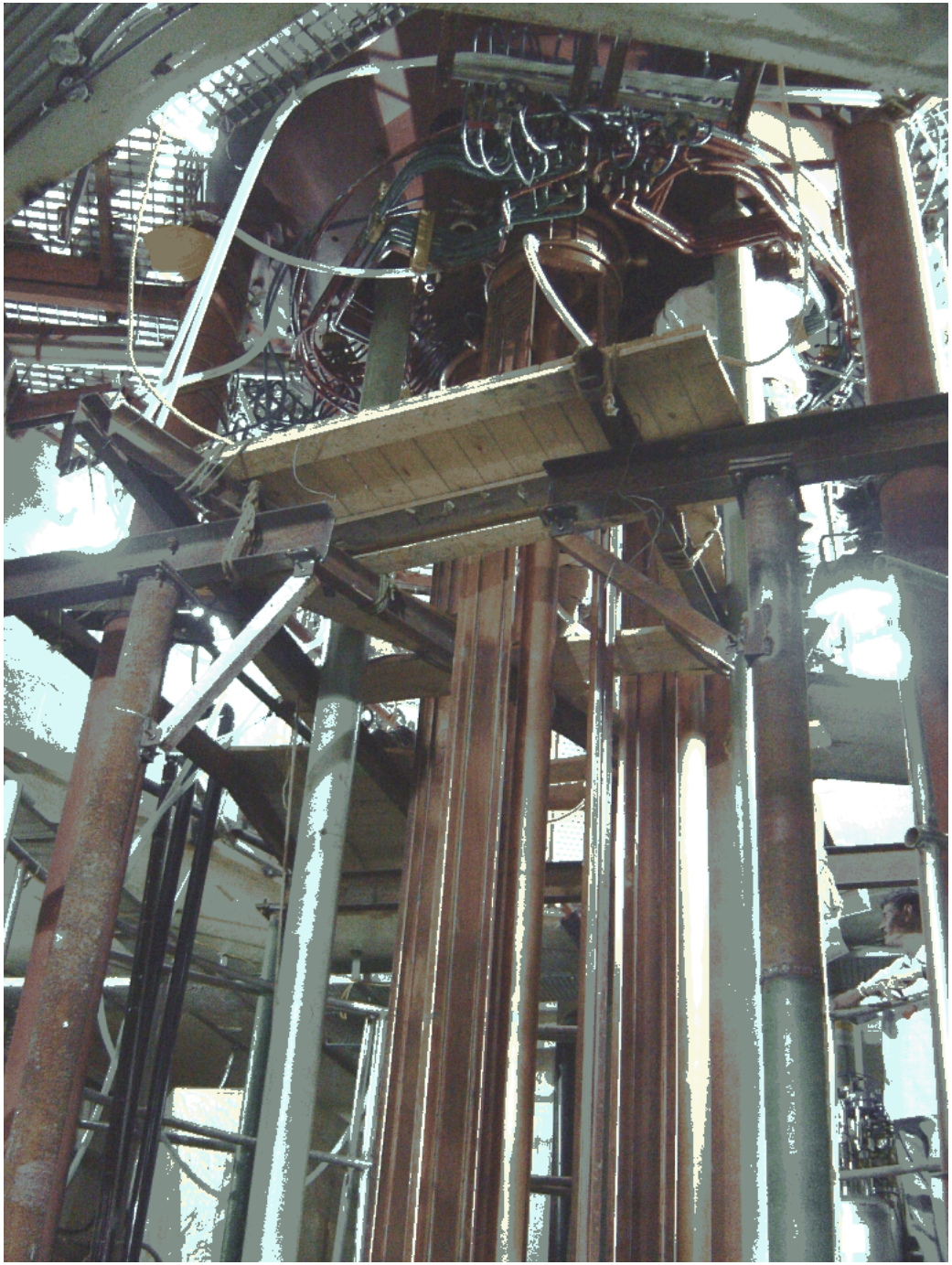
- Inner & outer conductor aligned concentric within ±0.25 mm., because large assymetry may give rise to uneven stress on the contact finger.
- Less contact pressure Þ higher probability of arcing.
- Higher contact pressure Þ more load on stepper motor.
- Coarse frequency tuning of the cavity is accomplished the precise movement of sliding short.
- Sliding short travel ~ 4370 mm. (max.) from lowest to highest frequency.

ACCELERATING ELECTRODE (DEE)

Accelerating electrode (DEE)

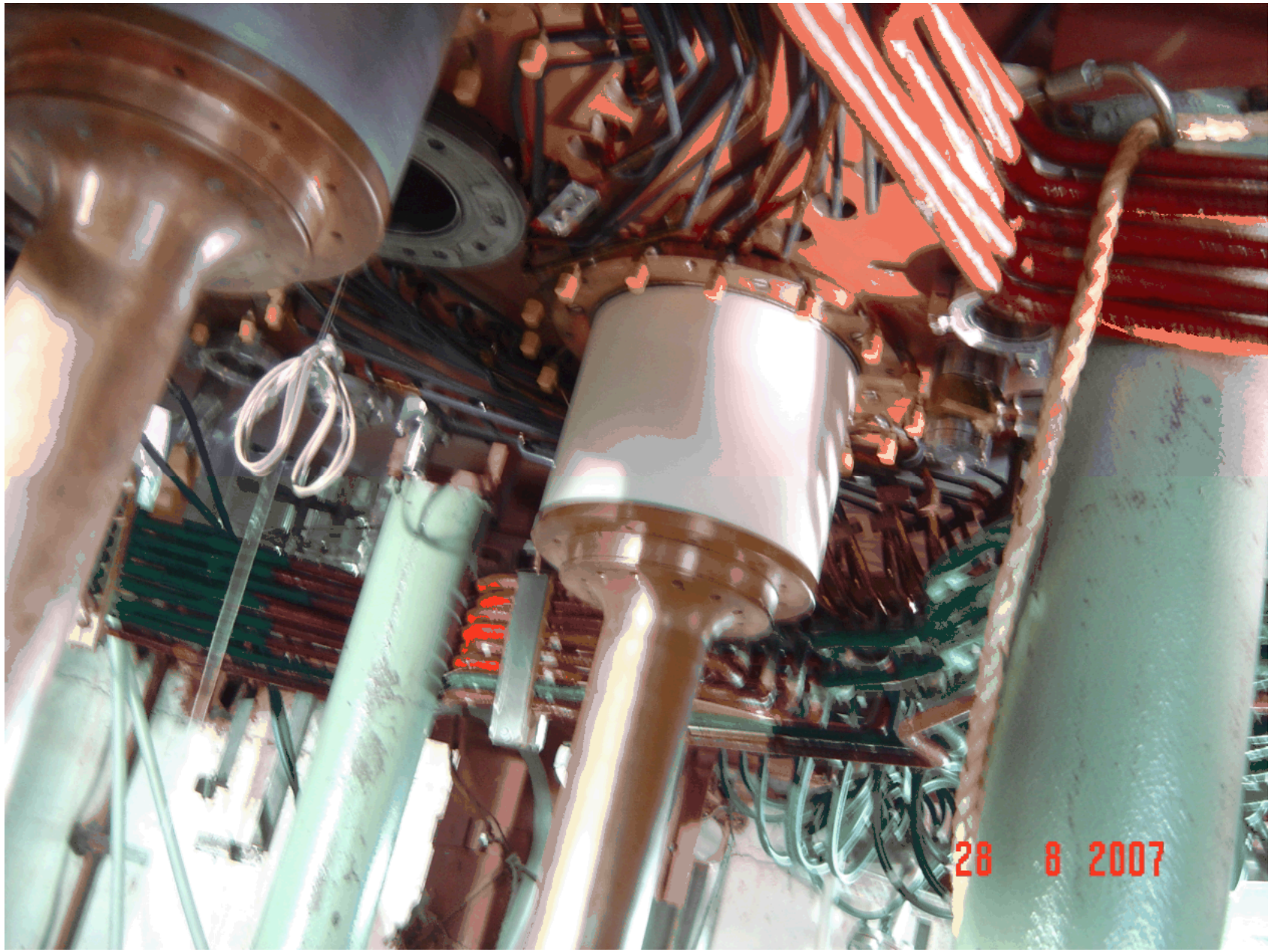
- Spiral shaped
- Dee angle ~ 53^{o}
- No. of Dees : 3 lower + 3 upper
- Made of OFHC copper
- Kept in vacuum (~ 1 x 10^{-7} torr.)
- Lower Dee housed with cryopanel
- Water-cooled
- Max. Dee Voltage ~ 100 kV
- RF power coupled to lower Dee through Coupling Capacitor
- Trimmer capacitor (fine Tuner) formed with upper Dee.

"DEE" assembly during inspection



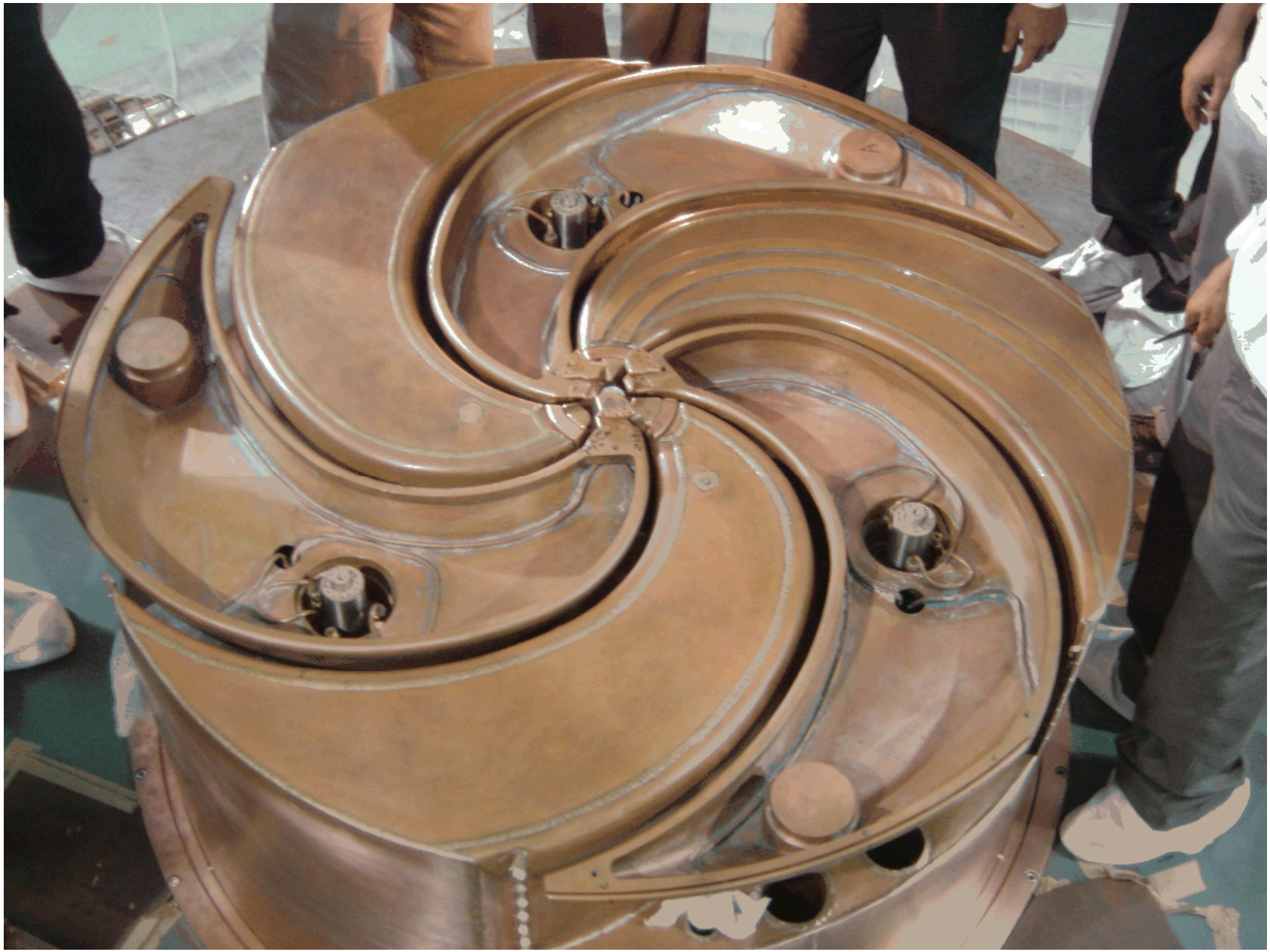
3 NOS. OF LOWER RF CAVITY ASSEMBLY IS IN PROGRESS

ASSEMBLY OF ALUMINA INSULATOR IN MAIN DEE CAVITY



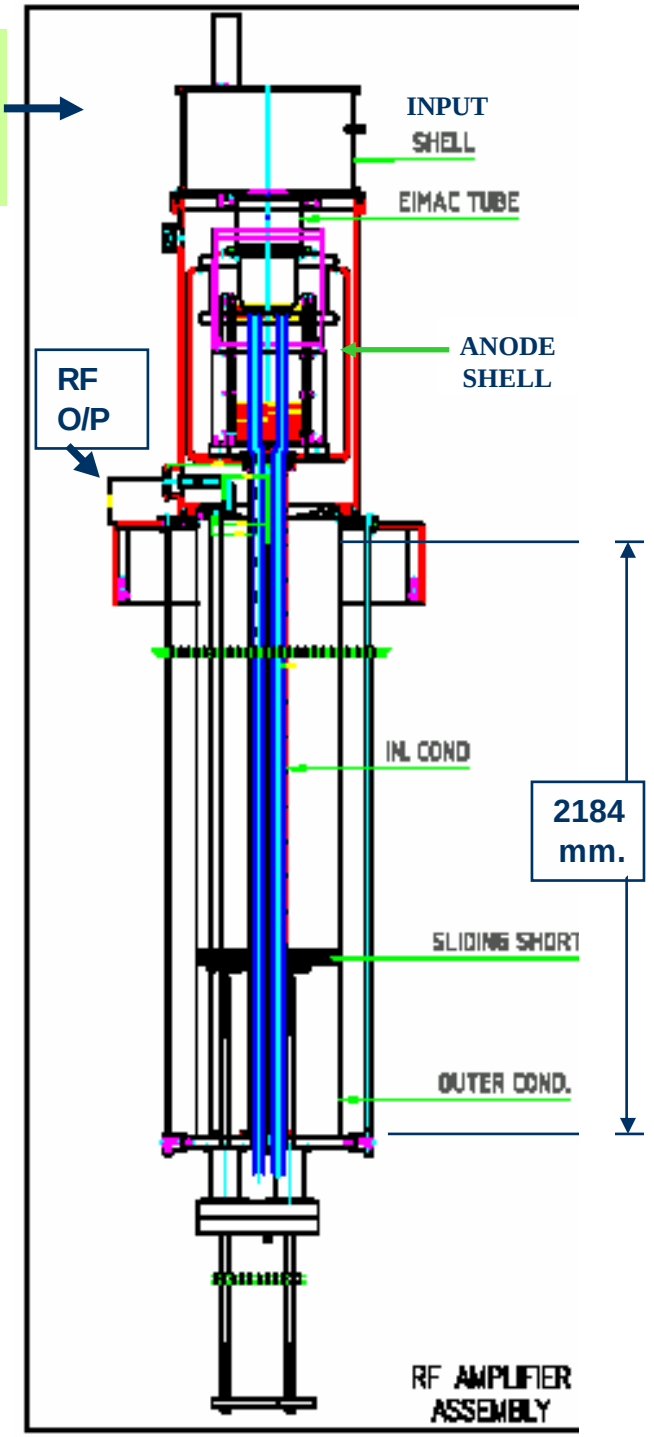
ASSEMBLY OF INNER CONDUCTORS OF MAIN DEE CAVITIES

ASSEMBLY OF LOWER DEES OF SUPERCONDUCTING CYCLOTRON

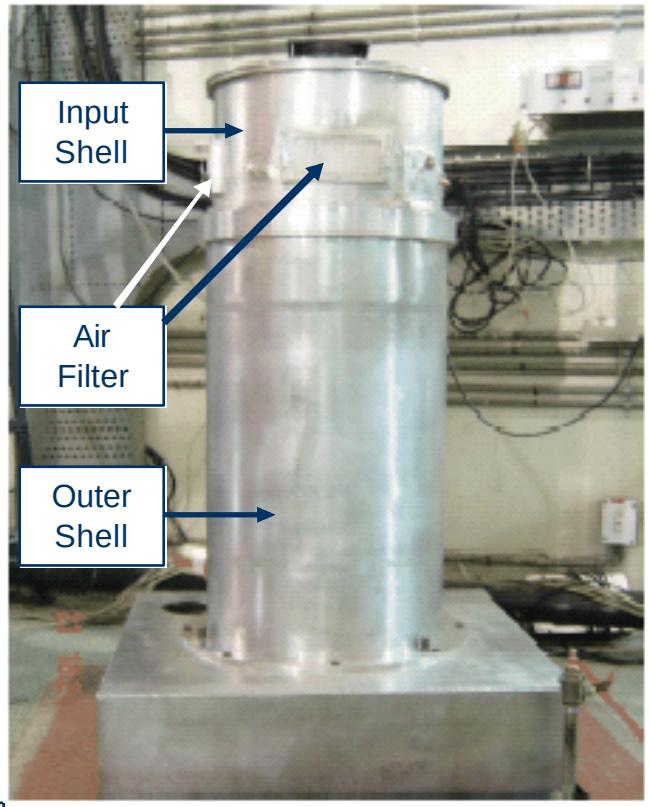


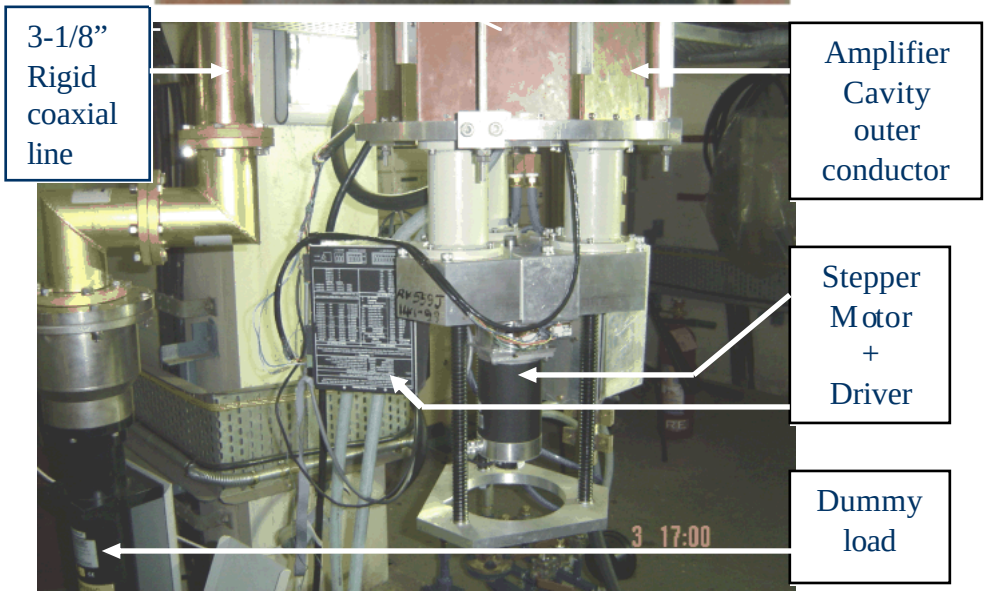
CROSS-SECTIONAL VIEW OF RF POWER AMPLIFIER

- Eimac 4CW 150000E Tetrode based power amplifier
- Output Power: 100 kW max. at 50 Ohm
- Power gain ~ 22 dB
- Input Power: 600 W at 50 Ohm
- Mode of operation: Class AB
- l/4 Resonant cavity similar to main Dee-cavity
- Tunable from 9 MHz to 27 MHz by movable Sliding short
- Sliding short travel ~ 2184 mm. max.
- Precise movement of sliding short (with resolution ~ 50 mm.)



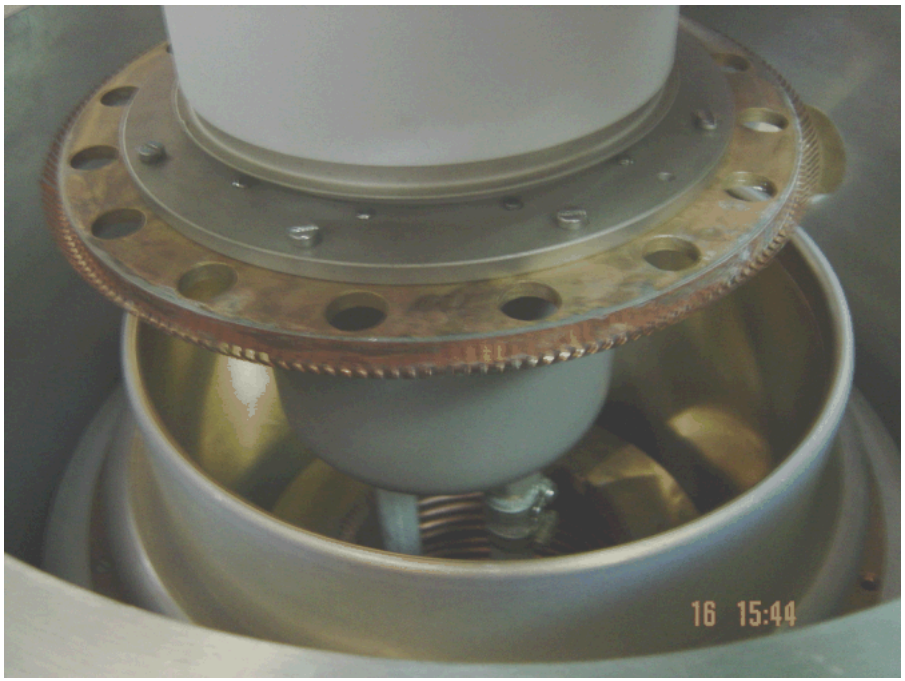
RF AMPLIFIER: PC-based Stepper motor controlled drive system for sliding shorts





- High power RF Amplifier installed at vault/basement of SCC building
- Top portion of RF Amplifier consisting of Input matching circuitry, Blocking capacitor, Screen by-pass capacitors, tetrode etc. (inside the shell) are located at vault
- Bottom portion of RF Amplifier consisting of Coaxial cavity with movable sliding short, stepper motor/Driver, Output rigid coaxial line etc. are located at the basement (below vault floor)

RF AMPLIFIER: ASSEMBLY OF TETRODE

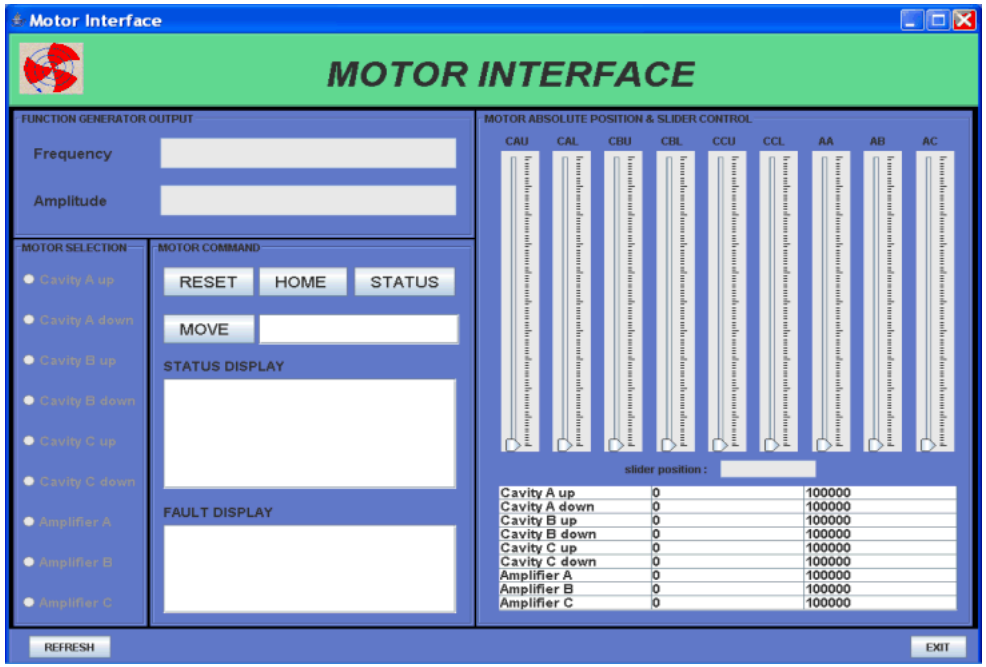


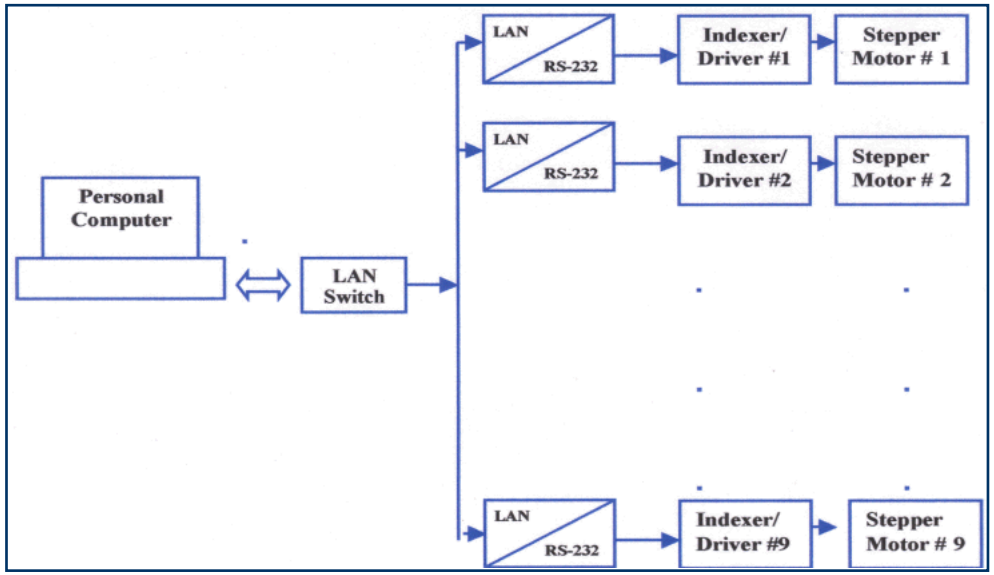
Eimac 4CW 150,000E Tetrode assembled with Blocking Capacitor

- Assembly of Screen by-pass capacitors
- 16 nos. x 10000 pF/2.5kVDC, MICA capacitors from Jahre, Germany.

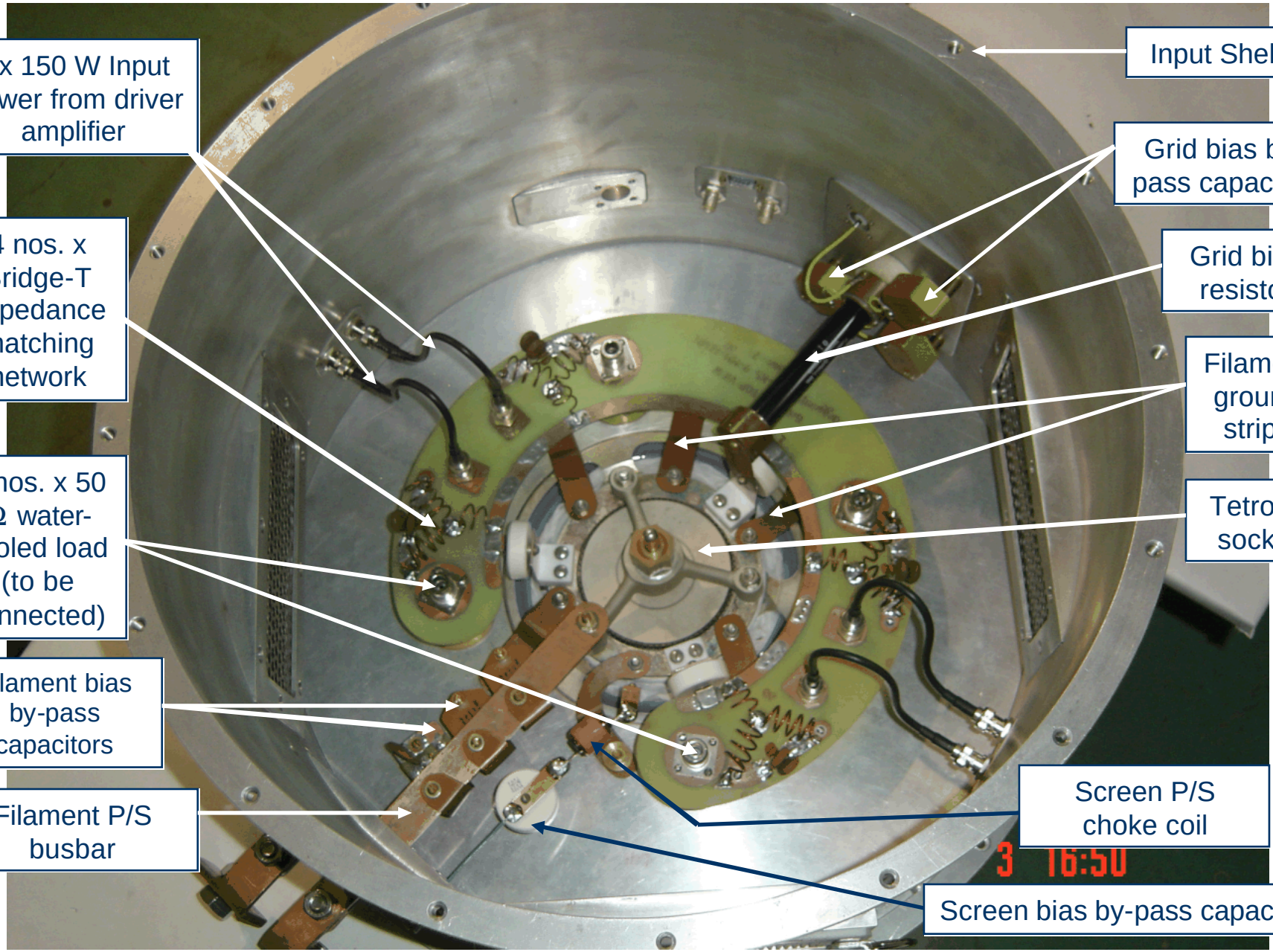
STEPPER MOTOR CONNECTION SCHEME & PC WINDOW

- Motor Interface window on a PC Screen for the precise movement of sliding shorts for
  - Amplifier cavities (3 nos.)
  - Main Dee cavities (6 nos.)
- Positioning of the stepper motor is controlled through LAN from remote computer terminal located at RF Local Control Room.
- Indexer/Driver of the stepper motor has RS-232 interface. A RS-232 to LAN converter is used for remote operation.
- RS-232 to LAN converter and Indexer/Driver are programmed.
- The program is done using JAVA and MySQL.

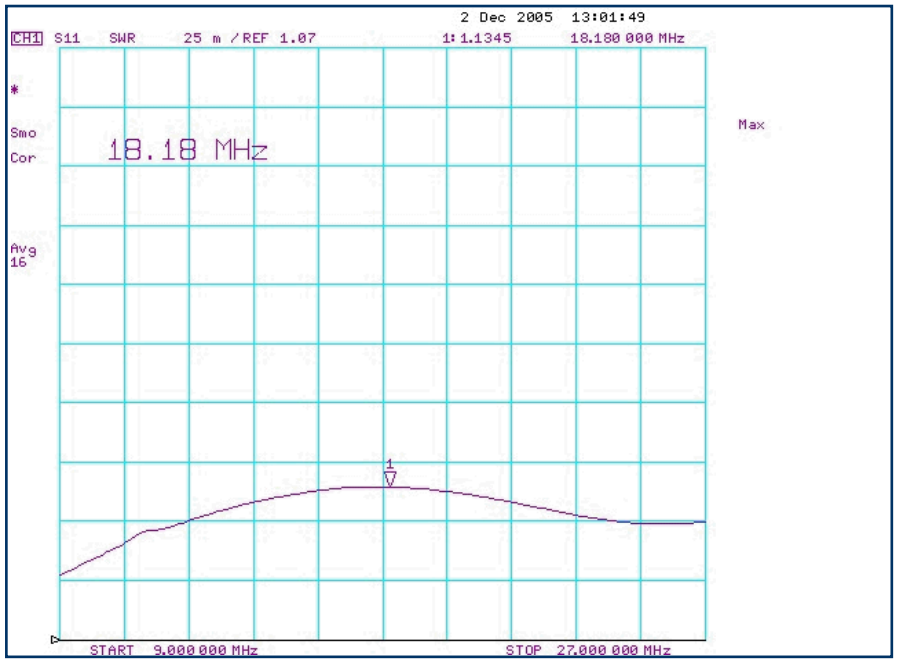




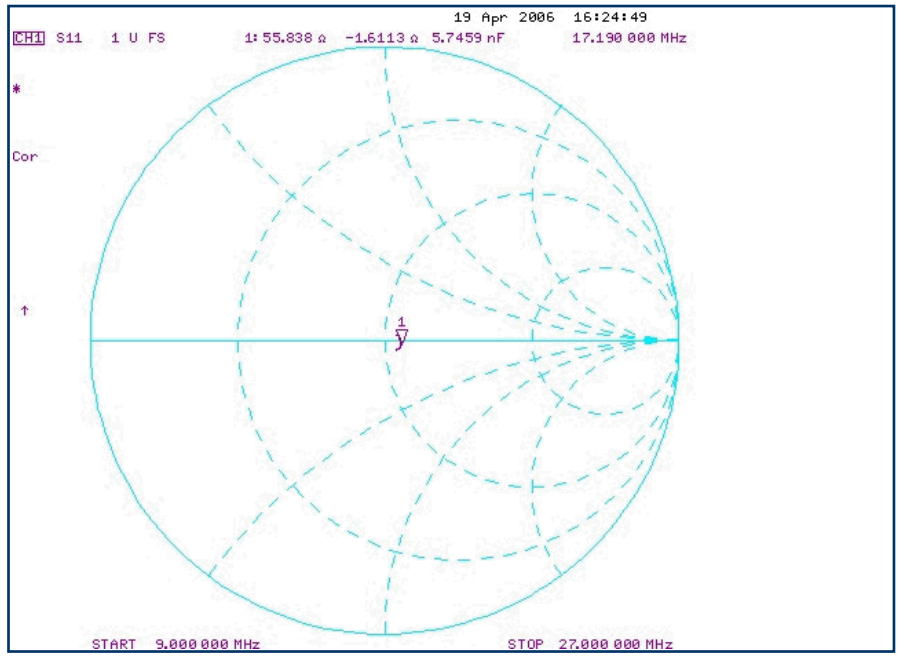
INPUT CIRCUIT FOR RF AMPLIFIER



INPUT VSWR MEASUREMENT USING VNA



SWR format



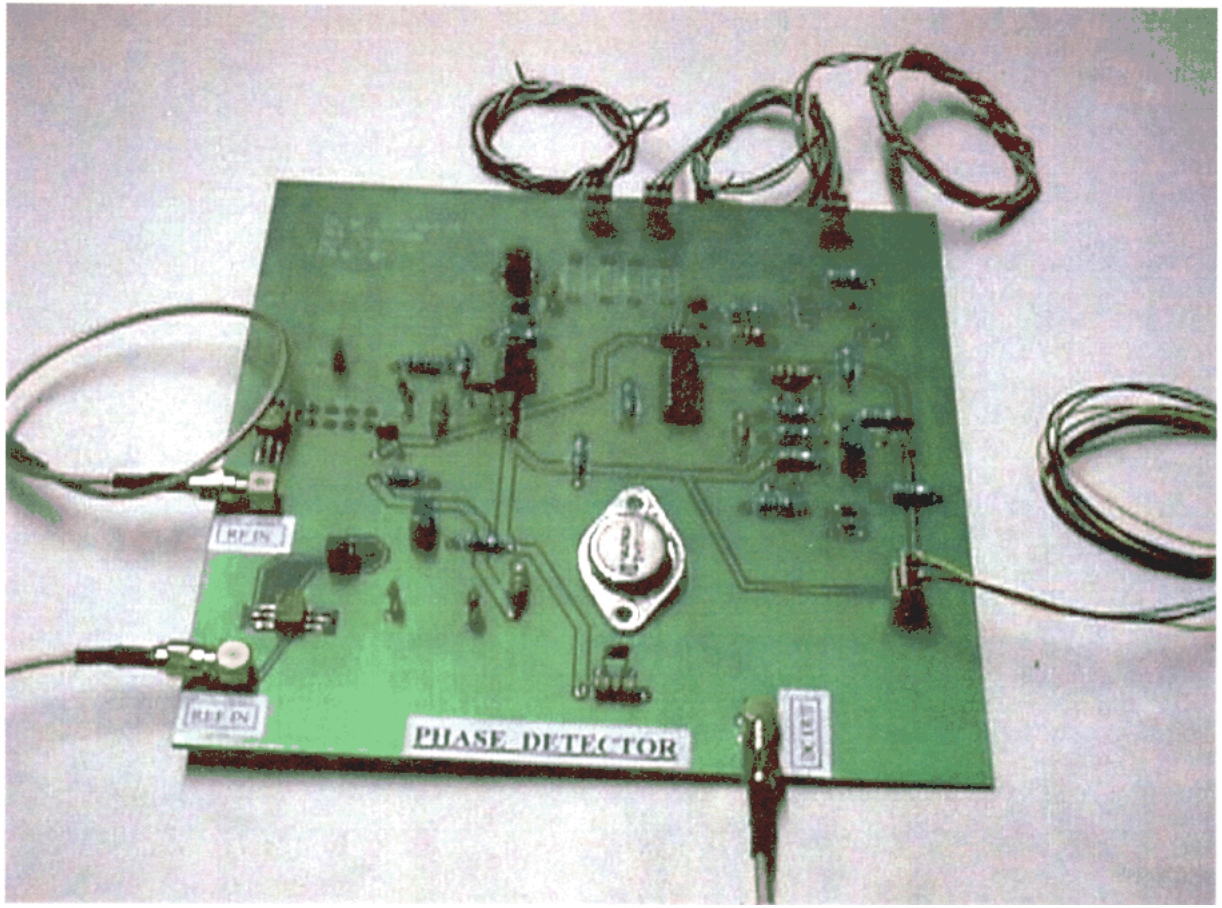
Smith-chart format

- **VSWR (Voltage standing wave ratio) is measured within 9 to 27 MHz.**
- **Max. VSWR is 1.1345 at 18.18 MHz.**
- **Input impedance is (55.838-j1.6113)Ω at 17.19 MHz**

DEE VOLTAGE REGULATOR UNIT

- Based on AD834JN RF Modulator
- It modulates RF drive signal according to the error signal between highly stable dc reference and the feedback sample obtained from Dee pick-up signal
- Dee voltage stability: 1×10^{-4}

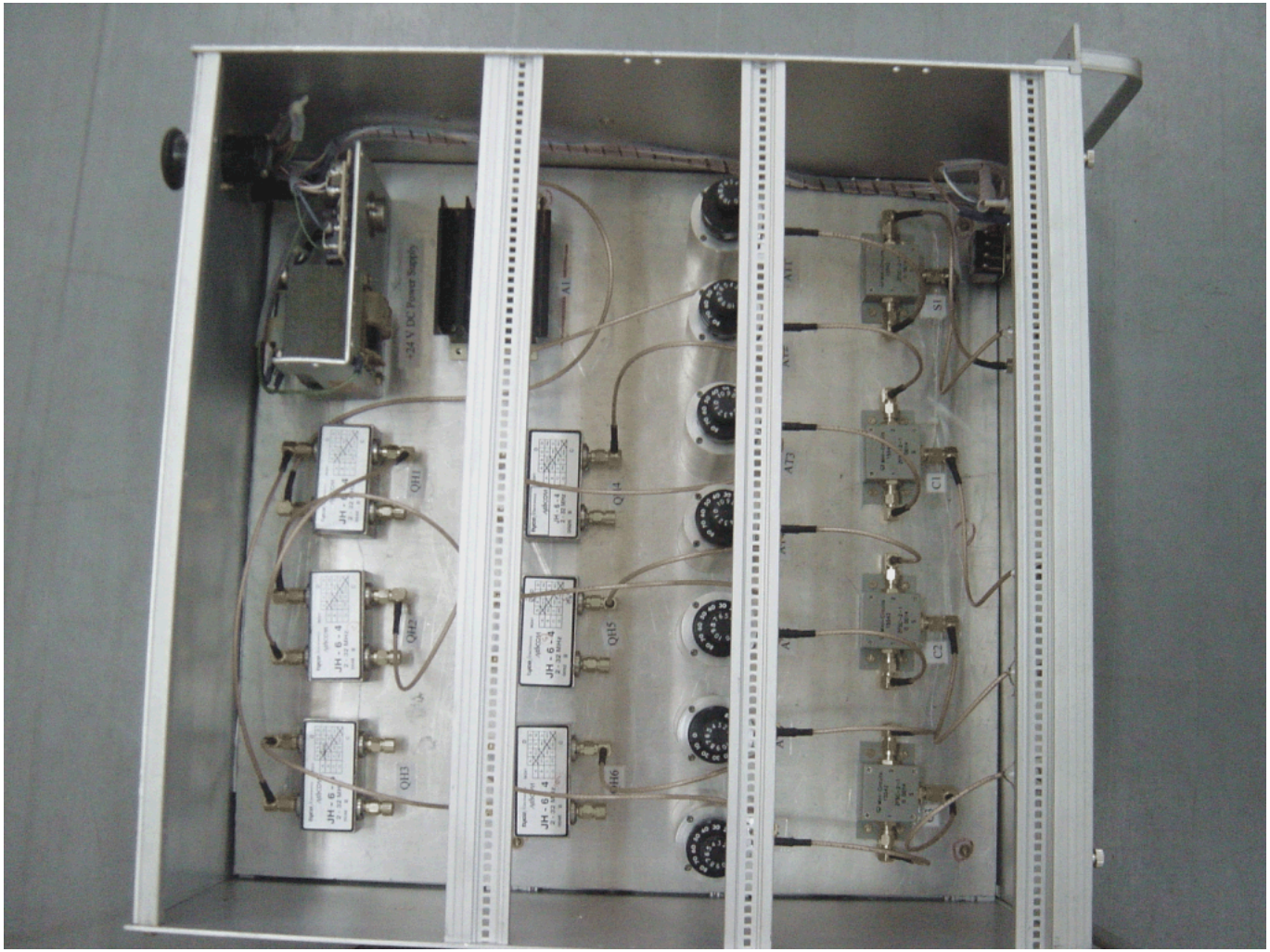
PHASE DETECTOR CARD



Phase Detector card (assembled)

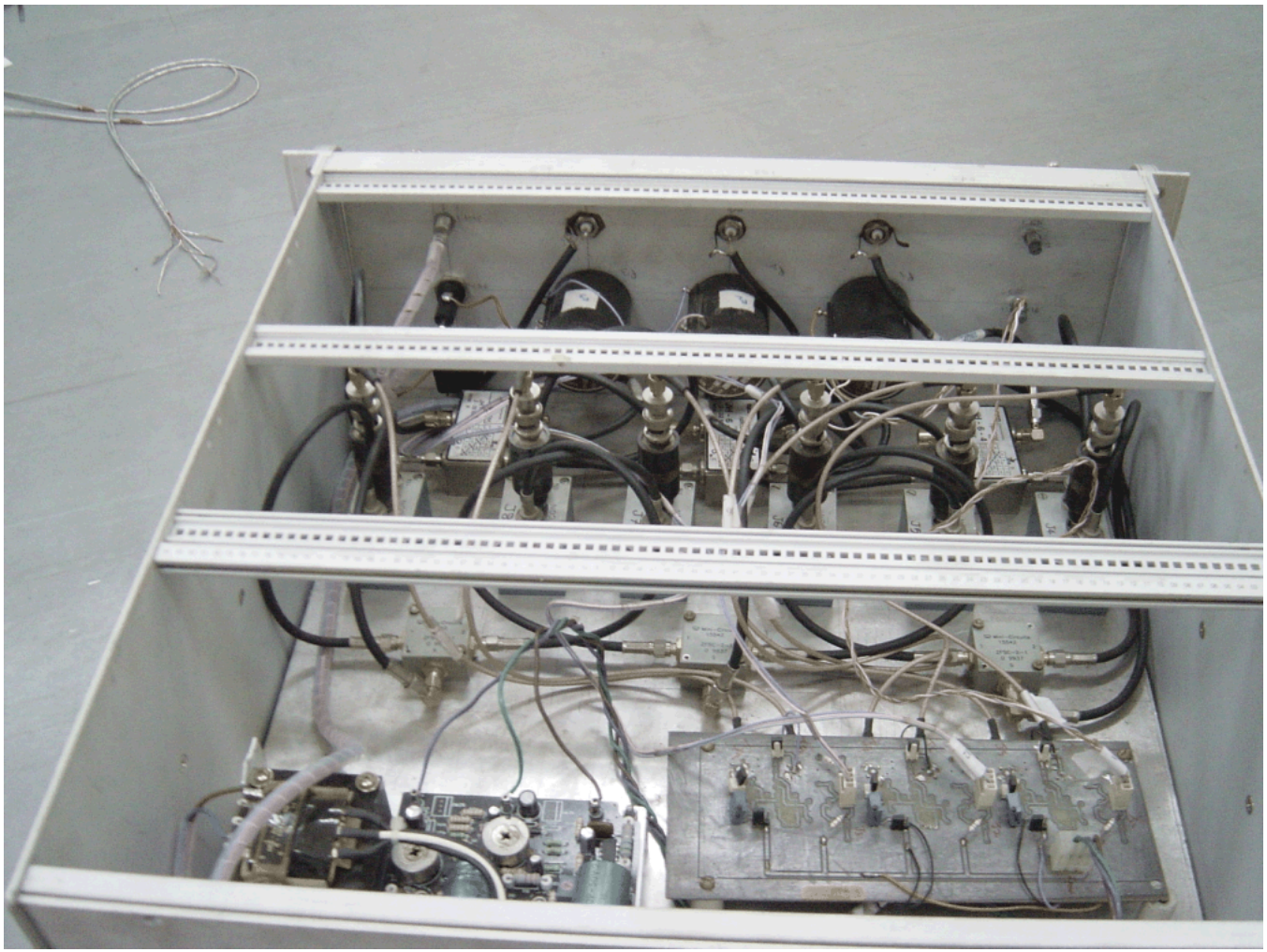
- Any deviation from sample phase from the reference phase is detected by the phase detector that produces dc error signal
- Based on double balanced mixer (used Mini Circuits# MCL-RPD-1)
- Response: 8mV/degree in +8dBm saturated mode

THREE PHASE GENERATOR UNIT



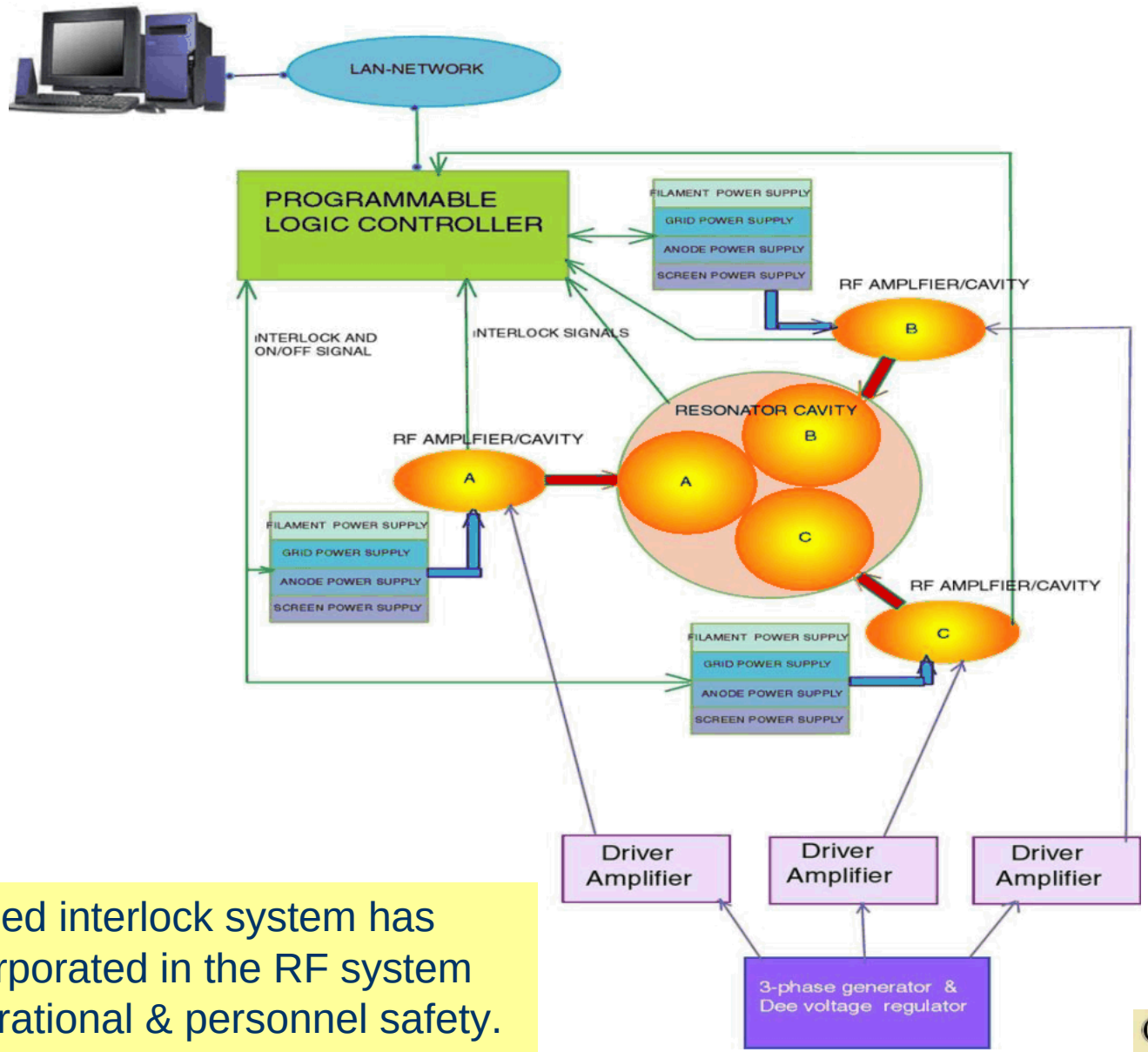
- **Phase shifting of 120^{o} is done by double mixing and auxiliary transmission line based technique, thereby making insensitive to frequency change**
- **Phase imbalance between 3 channels is <±1^{o} and amplitude unbalance is <±0.2 dB with harmonic content < -40dBc.**

MANUAL PHASE SHIFTER UNIT



- Based on classical I&Q modulator
- Used Quadrature Hybrid (M/A COM# QH-6-4), Electronic attenuator (Minicircuits# MCL-ZAS-3) & Splitter (Minicircuits# MCL-ZFSC-2-1)
- In normal operation $\pm 15^{o}$ phase variation is sufficient and output signal balance is << ±0.05 dB with harmonic content less than -38 dBc

PLC-BASED INTERLOCK SYSTEM



• PLC-based interlock system has been incorporated in the RF system for its operational & personnel safety.

RF CONTROL CONSOLE

FILAMENT POWER SUPPLY

- 3 Nos. of Filament P/S.
- Rating: 15.5 V±0.75 @ 215A DC P/S.
- Motorized Variac regulated in Primary side of 3f main power transformer.
- Slow-start feature incorporated.

CONTROL GRID POWER SUPPLY

- 3 Nos. of Control Grid P/S.
- Rating: -200V to -500V @ 100mA DC P/S
- Regulation: 100ppm & Ripple ~10mVp-p
- Regulation achieved by using IGBT (1200V, 20A) in emitter follower configuration.

ANODE POWER SUPPLY

- 1 No. of 20 kV @ 22.5A DC P/S with 3 Nos. of decoupled O/P to the anodes of 3 RF Amplifiers.
- Regulation: 6.8% with ripple ~ 50Vp-p
- Ignitron based fast Crow-bar Protection within 2㎳.

SCREEN GRID POWER SUPPLY

- 3 Nos. of P/S: 1.6 kV@0.5A,
- Regulation: 60ppm & Ripple ~160mVp-p
- Fast Crow-bar protection

PRESENT STATUS

- **Installation of all three High Power RF amplifiers have been completed.**
- **LLRF (Low-level RF) Electronic control units for the Superconducting Cyclotron have been completed.**
- **PC-based Stepper Motor Controlled (Sliding-Short movement) system for amplifier cavities and main Dee cavities has been completed.**
- **PLC-based interlock system for the operational and personnel safety of the rf system has been installed.**
- **DC Power supplies for High power rf amplifiers have been installed.**
- **Mechanical assembly of the lower-half of three main Dee cavities have been completed and assembly of the upper-half of main Dee cavities are in progress.**

Thank you for your attention.