Development of Pre Pre-Driver Amplifier Stage for Generator of SST-1 ICRH System

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Abstract. The Ion Cyclotron Resonance Heating (ICRH) system for SST1 consists mainly of the cwrf power generator to deliver 1.5MW for 1000sec duration at the frequencies 22.8, 24.3 and 45.6±1MHz, the transmission line and the antenna. This is planned to develop a independent and dedicated cwrf generator that consists of a oscillator, buffer, rf switch, modulator, rf attenuator, directional coupler, three stage solid state low power amplifier and four stage triode & tetrode based high power amplifier with specific performance at 45.6±1MHz including frequencies 22.8 and 24.3±1MHz. The pre pre-driver high power amplifier stage is fabricated about triode 3CX3000A7. The tube has sufficient margin in terms of plate dissipation and grid dissipation that makes it suitable to withstand momentarily load mismatch and to upgrade the source in terms of output power later. This indigenously developed amplifier is integrated inside a radiation resistant rack with all required biasing power supplies, cooling blower, controls, monitors and interlocks for manual or remote control operation. This grounded grid mode amplifier will be operated at plate with 3.8KV/ 800mA in class AB for 1.8KW cwrf output power rating. The input circuit is broadband and the output circuit is tunable with slide variable inductor and a vacuum variable capacitor in the frequency range of 22.8 to 45.6MHz. It is designed for a gain of about 12dB, fabrication completed and undergoing cwrf power testing. This paper presents specifications, design criteria, circuit used, operating parameters, tests conducted and the results obtained.

1. Introduction
Development of an independent and dedicated cwrf power generator to deliver 1.5MW for 1000sec duration at the frequencies 22.8, 24.3 and 45.6±1MHz, for Ion Cyclotron Resonance Heating (ICRH) system of SST-1 is in progress. The generator consists of a oscillator, buffer, rf switch, modulator, rf attenuator, directional coupler, three stage solid state low power amplifier and four stage power grid based high power amplifier with specific performance at 45.6±1MHz including other frequencies like 22.8 and 24.3±1MHz etc. The pre pre-driver high power amplifier stage is designed and fabricated with Eimac make triode 3CX3000A7.

2. Amplifier Specifications
Triode 3CX30000A7 capable of delivering more than 5KW is used in class B, grounded grid mode of operation with the targeted efficiency of about 50% at full power output. The circuit is fabricated using lumped rf components. The amplifier stage will be operated at plate with 4KV and 1.0A for 1.8KW cwrf output power rating. 1.5kW is needed for the next stage i.e. pre-driver of the HPA and the remaining is kept as margin. The input circuit is fixed broadband.
The output circuit is tuneable with slide variable inductor and a vacuum variable capacitor in the frequency range of 22.8 to 45.6MHz. It is designed for a gain of about 12dB i.e. a drive of more than 120W is needed. The designing of rf solid state low power drive amplifier and the pre-driver of HPA is in progress.

This indigenously developed amplifier should be space optimized and integrated inside a radiation resistant rack with all required biasing power supplies, cooling blower, controls for manual or remote control operation, monitors and interlocks.

3. Operating Parameters of the Circuit
Using manufacturer’s data for the tube 3CX30000A7, the load line is drawn at the quiescent point 4KV and 400mA with cathode at 0V and following operating parameters are obtained.

| Parameter          | Value       | Parameter          | Value       |
|--------------------|-------------|--------------------|-------------|
| Plate operating voltage | 4kV         | Plate operating current | 1.0A        |
| Cathode voltage    | 0V          | Cathode current    | 1.2A        |
| Filament voltage   | 7.5V        | Filament current   | 51A         |
| Power output       | 2040W       | Power input        | 120W        |
| Plate dissipation  | 1580W       | Grid dissipation   | 28W         |
| Power Gain         | 12dB        | Efficiency         | 55%         |
| Load impedance     | 2200 Ohm    | Source impedance   | 75 Ohm      |
| Air cooling        | 80 CFM      | Pressure drop      | 40mm WG     |

Primary of the filament supply transformer is provided with a set of resistance, timer, contactor based circuit for 1min preheating before the full voltage is applied. This ensures jerk free longer life and lesser cold in rush current to the tube filament. Integrated HVDC floating plate supply for ±10% overall effective change in final rf power output is fabricated and tested for the following specifications.

| Parameter          | Value       | Parameter          | Value       |
|--------------------|-------------|--------------------|-------------|
| DC plate voltage   | 5kV max.    | DC plate current   | 1.0A max.   |
| Variability at plate | 1 to 5kV   | Voltage set precision | < 100V    |
| Ripples at any voltage | ± 0.5%   | Load regulation at 100% load change | ± 1% max |
| Overshoot / Undershoot | ± 1.0% max. | Line regulation at ±10% mains change | ± 0.5% |
| Settling time      | < 10m sec   | Current rise time  | 1m sec      |
| Output drift       | 0.5% per Hr.| Fault turn off time | 6m sec     |
| Temperature sensitivity per degree C | < 0.02% | Protections | SC, OC and OV |

4. Circuit Description
Circuit diagram for the pre pre-driver high power amplifier stage is shown in figure 1. The required source impedance of 75 Ohm in the broadband of 22.8 to 45.6MHz would be provided by means of L-section, series inductor matching network with 50 Ohm output drive of the solid state low power amplifier. A tapped plate RFC with series coupling capacitor is matching the required resonant load impedance of 2200 Ohm to couple 50 Ohm load at output. Output resonant tank is made tuneable with 1mH slide variable inductor and a 10 to 250pf vacuum variable capacitor in the frequency range of 22.8 to 45.6MHz. Tunable 1mH slide variable rf inductor is designed, fabricated and indigenously developed within organization.

The circuit is simple and uses only plate supply, as cathode is not biased. All power supply cables and control connections are provided with rf feed through capacitors and L-section rf filters for smooth and reliable operation.
5. Performance Test and Results

Fabrication completed in an aluminium rack of final size 1800mmX800mmX600mm as shown in the photograph. Passive testing is performed and the input resistance found varying from 54 to 91 Ohm whereas plate resistance from 2.1 to 3.0k Ohm. This along with insulation testing at 5kV ensures the desired response. Test set up for rf power testing includes a Rohde & Swartz make synthesized rf source, ENI make 25W maximum low power solid state amplifier, Bird make through line power meter and 1500W rf dummy load. The pre pre-driver stage of HPA is tested with 4kV plate at some of the selected frequencies in the desired range and following is observed.

| Frequency | Plate Current | Output Power | Power Gain | Efficiency |
|-----------|---------------|--------------|------------|------------|
| 22.8MHz   | 550mA         | 440W         | 12.5dB     | 20.0%      |
| 25.0MHz   | 550mA         | 460W         | 12.6dB     | 20.9%      |
| 30.0MHz   | 500mA         | 450W         | 12.7dB     | 22.5%      |
| 35.0MHz   | 575mA         | 700W         | 14.5dB     | 30.4%      |
| 40.0MHz   | 525mA         | 800W         | 15.1dB     | 38.1%      |
| 45.6MHz   | 450mA         | 650W         | 14.2dB     | 36.1%      |

Small input signal testing of the amplifier due to available 25W drive is providing the expected output performance.

![Diagram of HPA Pre-Pre-Driver Stage](image)

**FIGURE 1. PRF PRF DRIVER STAGE OF HPA**
6. Photographs of the Pre Pre-Driver Stage of HPA

7. Conclusion
The pre pre-driver performance at low rf output is found satisfactory, ensuring the rated calculated desired output as soon as the drive is increased. Sign of overheating or parasitic oscillations are not seen during five minutes testing at each of the selected frequency. The self contained, integrated rf amplifier with optimized power density makes it a good commercial model. A space is left in this compact model to accommodate a solid state driver so that a complete integrated tunable rf source may be obtained. This circuit may be altered in frequency and increased in power with small modifications. The amplifier will soon be tested and expected to provide for rated output.