DEVELOPEMENT OF TUBE BASED 2 KW, 97 MHZ RF AMPLIFIER

Rajesh Kumar, Raj Kumar, S.Venkataramanan, C.P.Safvan
Inter University Accelerator Centre, New Delhi-110067, India.

Abstract

A Triode vacuum tube based 2 kW RF amplifier has been developed for testing purposes of resonators of the superconducting LINAC and the room temperature drift tube LINAC prototypes at IUAC. It has been designed for operation at 97 MHz and is capable of operating in continuous wave and pulsed mode. A high amplification factor triode (3CX3000A7) is used in grounded grid class-A configuration. The required biasing power supplies (plate & filament) and control electronics consisting of metering circuits, overload circuits and safety interlocks were developed. All sub-assemblies were integrated in a 19" rack to make a stand-alone amplifier system. The unit has been tested and is being used successfully.

INTRODUCTION

A high current injector (HCI) for Superconducting LINAC is under development. The injector system consists of Drift Tube LINAC (DTL) and Radio Frequency Quadrupole (RFQ) LINAC, where high power RF amplifiers will be used. Initially a 2 kW tube based amplifier has been developed for low power testing of the cavities. This development also helped in understanding tube based RF amplifier configurations. This will help in future developments and maintenance of high power RF amplifiers required for the operation of room temperature accelerator cavities of the high current injector.

LAYOUT OF THE AMPLIFIER

Figure-1 shows the block diagram of the 2 kW RF amplifier. The amplifier mainly consists of four subassemblies:

- 200 W solid-state driver amplifier
- 2 kW tube assembly
- HV plate power supply
- Metering, Interlock and Control panel

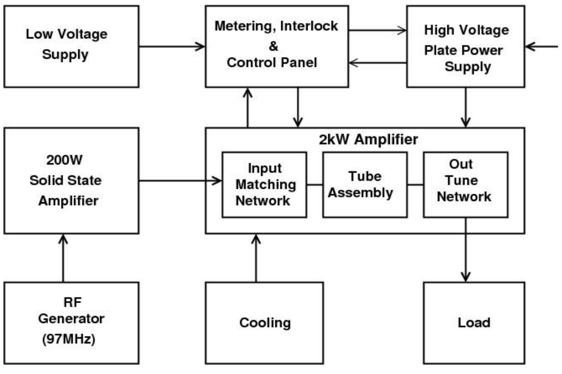

Figure 1: Block diagram of 2 kW RF Amplifier

To achieve 2 kW at 97 MHz, two stage amplification has been done. The RF signal from signal generator is fed to an indigenously developed 200 W solid-state RF amplifier [1] which drives the final 2 kW triode amplifier. The 2 kW triode amplifier is in grounded grid configuration and needs only a plate power supply for biasing. The high voltage anode/plate power supply is rated for 4 kV at 1.5 A. The control panel is housed in a 19" cabinet consists of metering, interlocking and on/off control circuits. The amplifier is forced air-cooled, the air is routed through bottom to top, ensures proper cooling.

ASSEMBLIES DESIGNED AND DEVELOPED

200 W solid-state driver amplifier

The driver amplifier is a stand-alone solid-state amplifier with built in power supply, metering and automatic gain control section housed in a 19”/3U cabinet. The required power gain is achieved in 3 stages, a pre-driver amplifier (2W), intermediate amplifier (25W) and final power amplifier to deliver 200W. The intermediate and final power stages are identical and consists of RF Power MOSFET (MRG151G) wired in class-AB configuration. The necessary power monitoring, safety interlocks are provided for trouble free operation.

Triode based 2 kW RF amplifier

The simplified schematic of tube amplifier is shown in figure-2. The amplifier assembly/housing consists of the triode tube, input impedance matching network and output impedance matching network. A high amplification factor power grid triode tube (3CX3000A7) of 4 kW plate dissipation is used in grounded grid configuration. In this amplifier configuration the grid is at ground potential and the input signal is applied to the cathode. At the same time, the cathode is kept at DC ground potential via the centre tape of the filament transformer. The bi-filler choke between the filament and transformer raise the filament above ground for RF, but permits it to remain at ground potential with respect to DC. Cathode is biased at -8 V using high current diodes between centre-tap of the filament transformer and ground to set the idling plate current of 225 mA at 4 kV plate voltage. When the signal is applied, maximum current will flow from cathode to plate during the negative half of the input cycle, and will reach its lowest level at the plate during positive half of the input cycle. This makes the input and output 180° out of phase and prevents coupling between output and input stages, thereby eliminating the possibility of self oscillation. The grounded grid configuration causes comparatively low input impedance, which is easy to match.

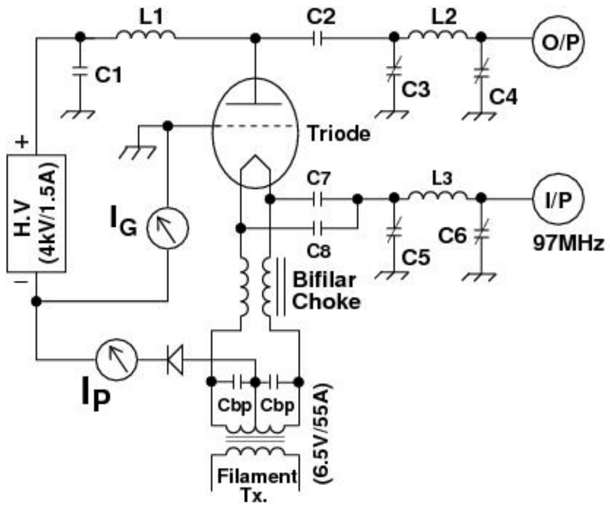

Figure 2: Simplified schematic of 2 kW RF Amplifier.

The input impedance matching network is Pi-type resonant circuit which transforms driver amplifier output impedance to tube amplifier input impedance. A Pi-type impedance matching network is used to transform the internal output (cathode to plate) impedance of the tube to the load impedance. The components of matching networks are made of silver plated copper to handle large power.

Plate and filament bias power supplies

A high voltage (4000 V/ 1.5 A) power supply has been developed to bias the tube plate. The unit incorporates a three phase transformer, three phase full bridge rectifier and LC smoothing circuit. The LC filter is used to have low ripple and better voltage regulation over a wide current range. The resonance of the LC filter (L = 1.5 H and C = 1 uF) is kept at 129 Hz which is well below and not a multiple of fundamental ripple frequency 300 Hz (from the three phase rectifier). The measured no-load high voltage was 4100 V (with bleeder). The high voltage dropped to 4000 V a 225 mA load, when the amplifier was turned on with no input drive. At a 1 A load (full power), the high voltage was 3940 V. The filter is damped using bleeder resistors to avoid over voltage conditions during warm up or no load. A single phase center-tap 6.5 V_{AC}, 75 A transformer has been used to power the tube filament/cathode.

Control and Metering Electronics

Various control parameters such as forward power, reflected power, plate current, plate voltage, filament voltage, filament current signals have been processed and scaled to 0-10 V and 0-100 μA for remote monitoring and for front panel analogue metering respectively. The scaled parameters are also compared with pre-set limits and are used to generate interlocks. These are utilized to shut-off anode/plate voltage in case of overload or fault conditions. The interlocks are latched on to the interlock board to monitor the type of interlock that occurred. On/off control powers the amplifier in steps. Turning on circuit breaker provides power to control electronics and filament. A soft-start delay was built to power the high voltage plate power supply using a timer with a contactor that shorts out large wire-wound start-up resistors. This avoids input current surge into a fully discharged filter capacitor. In case of interlock/overload condition the amplifier will come to standby state putting off HV supply. The amplifier will not come ON until the failure condition is not cleared and needs a reset to put it ON again.

Test results

Full power tests were conducted with a high power terminator and directional coupler (5 kW, 50 Ω). For 120W of input power from the driver amplifier, the tube amplifier produced 2 kW of output power. With best impedance matching, the tube amplifier produced nearly 17 times the input power with an efficiency of approximately 40%. Measurements of the incident and reflected power at various stages of the amplifier were consistent with the current delivered by the HV plate supply. Under full load, there is no significant difference in output power noticed when plate voltage was increased by 10%. With the higher plate voltage, the idling current is higher and slightly less drive is required for the same output power. Figure-3 shows the power transfer characteristics of the amplifier at 97 MHz.

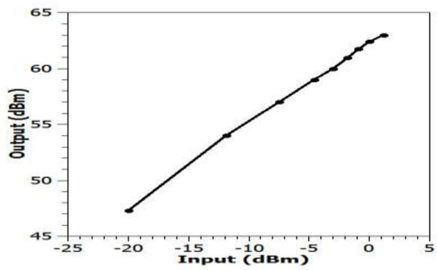

Figure 3: Power transfer characteristics

REFERENCE

[1] Technical Report on 200W RF Driver Power Amplifier [IUAC/TR/SV/2008-09/11]