DEVELOPMENT OF 350 MHZ, 3 KW (CW AND PULSED) RADIO FREQUENCY (RF) AMPLIFIER

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Abstract

A 350 MHz, 3 kW RF amplifier has been developed as new driver for a 350 MHz, 60 kW RF system that is being developed for 400 KeV deuterium RFQ accelerator. This paper describes and discusses the design details, developmental issues and test results obtained.

RF System Description

The RF amplifier system consist of tetrode tube, its cavity, various bias supplies, interlock & protection circuit, a signal generator, a 100 Watt driver stage, directional couplers for power monitoring both at input and output, a 1-5/8 transmission line and a 50 ohm resistive load. High capacity blowers are used for air cooling of the tube and cavity assembly.

The system is modular in configuration with each sub-system independent and can be easily dismantled for troubleshooting or repairs. All the DC supplies have their own switching and protection signals that are used for interlocking and protection. RF sub-systems and most of the bias supplies are housed in a single aluminium rack except anode power supply which is located separately. Figure 1 shows the photograph of the complete system.

System Setup

The RF driver uses Thales make Tetrode TH393[1] in grounded cathode configuration along with its cavity[2] which is tuned to frequency 350 MHz

The first stage of the amplifier is a signal generator that determines the signal frequency, signal level and mode (CW or Pulse) of operation. The signal generator provides a maximum output of 20 mW and in turn drives the pre-driver. The pre-driver is a wide band amplifier and can generate an output up to maximum 100 W. The driver stage is coupled to the cavity via an 'N'-type input port.

The RF cavity is a coaxial type with its input and output structure resonating at 350 MHz. The DC bias supplies for control grid (G1) and screen grid (G2) are connected to the tube via BNC connection provided on the RF cavity. The RF output from cavity is available on 1-5/8", 50 ohm port and is connected to 50 ohm RF load via 1-5/8" rigid coaxial line.

Interlock and protection

An interlock circuit is designed for proper sequencing of the various bias supplies. The circuit ensures that in the event one of the stages fails to operate or reach a pre-determined level, the next stage will not be turn on.

A slow ramping circuit (1.75V/min) is designed to power the filament of the tube. A slow ramp up/ ramp down ensures that the surge current[3] due filament voltage applied to the filament of the tube is within safe limits. All DC bias power supplies have their own protections against short circuit, over-load. These signals are interlocked to trip RF drive, screen and anode appropriately.

Matching

The RF cavity houses the tetrode, its neutralization circuit and its input-output resonant circuit. The input resonant circuit consists of 3λ/4 (three quarter wavelength) type resonant line and the input is fed via a 50 Ω coaxial line with movable short for tuning.

The output line is a λ/4 (quarter wavelength) resonant line coupled to the output load via a movable coupling. The output line is 1-5/8" 50 ohm type transmission line.

Figure 1: Photograph of RF Amplifier System

Low power testing

Initially the RF system was tested on a Vector Network Analyser (VNA) for its input and output curves. Tuning of the input was carried out for maximum transmission and minimum reflection at centre frequency and then the output was tuned for minimum reflection.

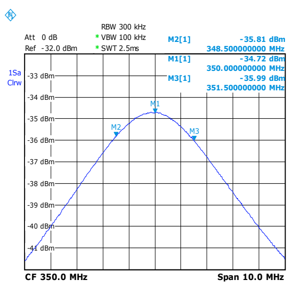


Figure- 2
Transmission curve

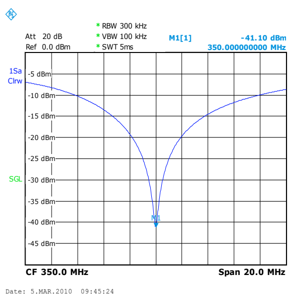


Figure- 3
Reflection curve

The response obtained is shown in figure 2 & figure 3 respectively. The process was repeated until best transmission curves were obtained.

High Power Testing:

After optimising the tube performance in low power testing, it was tested at high power gradually. Various RF and DC bias parameters were adjusted for achieving a maximum of 3 kW of output power. The test result is shown in figure 4.

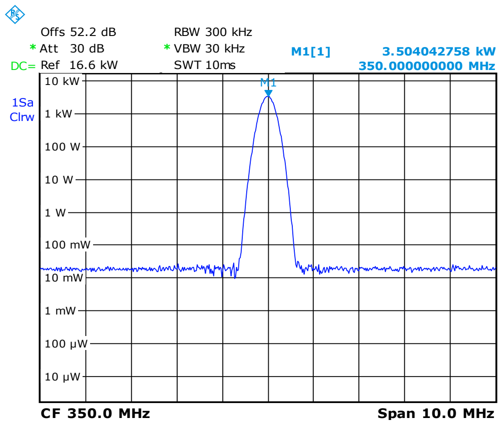
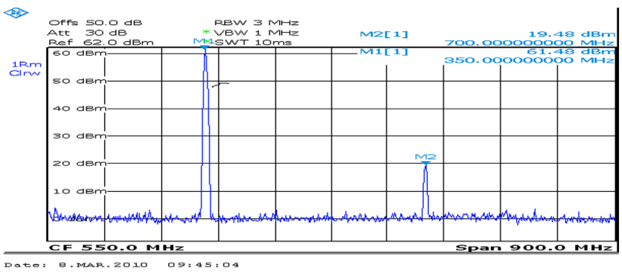


Figure- 4 – Output power waveform

The RF amplifier has been tested upto a power of 3 kW+ with gain of 16 dB and efficiency of 60%. Presently, the tube operates in Class-A mode. It is planned to operate in class C mode to achieve higher power with higher overall efficiency thereby reducing the thermal dissipation across the RF tube.

Harmonics Distortions

The 2nd and 3rd harmonics measured at 700 MHz and 1.05 GHz are 40.76 db and 42.13 db below the centre frequency as shown in figure 5



1st Harmonic Frequency				Total Harmonic Distortion (THD)			
349.99792480 MHz					0.02 %		-75.26 dB
No	Frequency	RBW	Power	No	Frequency	RBW	Power
1	350.00 MHz	300 kHz	1.55 kW	6	2.10 GHz	3 MHz	-46.23 dBc
2	700.00 MHz	1 MHz	-40.76 dBc	7	2.45 GHz	3 MHz	-46.42 dBc
3	1.05 GHz	1 MHz	-42.13 dBc	8	2.80 GHz	3 MHz	-44.57 dBc
4	1.40 GHz	3 MHz	-47.23 dBc	9	---	---	----
5	1.75 GHz	3 MHz	-48.11 dBc	10	---	---	----

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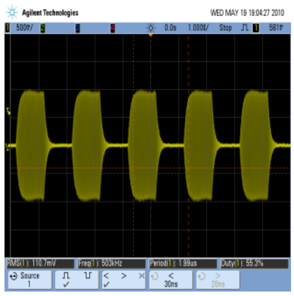
Figure- 5 – Harmonic measurements

Pulse Operation:

The system has been tested in pulsed mode with a pulse rate of 1 mS and PRR of 100 Hz at a peak power of 4kW. The figure 6 and figure 7 below shows the wave forms in pulse mode.



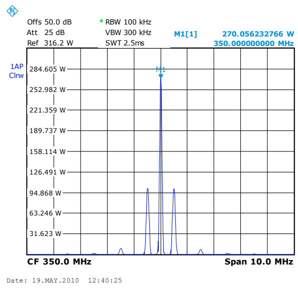


Figure- 6 Figure- 7

CONCLUSION

The RF driver has been successfully tested for 3 kW+ power levels with good efficiency and power gain. Initially the system will be utilised to test the RFQ in both pulse and CW mode at 3 kW power level. Then, it will be integrated with 60 kW amplifier.

The maximum power dissipation and operating voltage has enough margin for the amplifier to provide higher output. Hence the power level can be enhanced beyond the 3 kW by optimizing various bias parameters and input drive. Presently the system uses linear DC supplies. Use of SMPS based supplies that may reduce the space requirement in the future.

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REFERENCES

[1] Data sheet of Tetrode TH 393 - Thales

[2] Data sheet of Thales cavity TH 18665F - Thales

[3] Care and Feeding of vacuum tube - Eimac

[4] Radio Laboratory Handbook – Vol 1