DEVELOPMENT OF 1.5 kW RF DRIVER FOR COMPACT CYCLOTRON*

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Abstract

The 1.5 kW RF driver was designed and manufactured with the resonance of frequency of 83.2 MHz. 3CX1500A7 / 8877 triode vacuum tube was used for RF power amplification, and grounded-grid amplifier (G.G. Amp.) type was adopted for this RF driver since the circuit design and manufacturing process is simple [1]. Anode, and cathode voltage of RF driver is approximately 3500 V, and 5 V respectively. In this paper, impedance matching process of RF driver is described. Variable capacitor and variable inductor is utilized to implement the impedance matching for cathode and anode. In addition, RF power output characteristics compare with RF input is shown.

INTRODUCTION

The 9 MeV compact cyclotron was designed and manufactured for getting F-18 at medium-small PET facilities. 1.5 kW, 83.2 MHz RF driver plays a role for providing RF power to RF cavity through 20 kW RF amplifier. RF driver employs 3CX1500A7 / 8877 triode, which has a high amplification factor of 200. This triode is grounded–grid, and cathode-driven amplifier. This amplifier has several advantages; first, this amplifier is a zero bias. Second, grid is grounded, so circuit configuration is simple compared with tetrode, and pentode. Third, this type of amplifier prevents from positive feedback. It can be operated in high frequency. Last, drive output is obtained by drive input plus output power. Figure 1 shows signal flow diagram of 1.5 kW RF driver. This RF amplifier can produce power of 1.5 kW at the maximum, however, since maximum power of final RF amplifier which transmits power to RF cavity was designed for 10 kW, RF driver provides about 1 kW. RF power is cathode-driven by 50 W pre-amplifier. It is a solid-state broadband amplifier, and operating frequency is from 20–500 MHz [2]. Anode voltage of this RF driver is provided by full-wave bridge regulator circuit. The circuit includes high voltage transformer, and capacitor. Transformer boosts voltage from 3-phase 380 V to 3500 V, and then capacitor regulates to DC. Automatic variable regulator is used to provide constant cathode voltage of 5 V even if there is a small signal fluctuation. Table 1 demonstrates main specification of RF driver for 9 MeV compact cyclotron.

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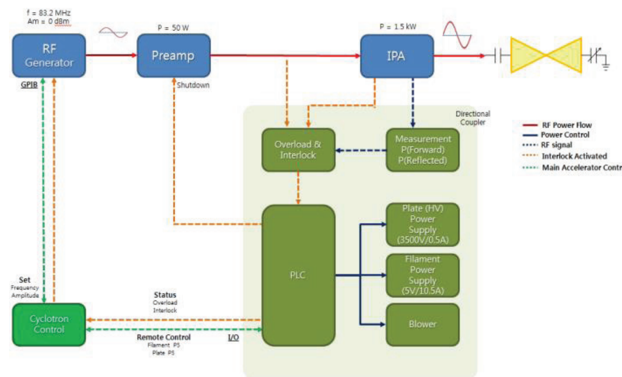

Figure 1: Signal flow diagram of 1.5 kW RF driver.

RF DRIVER DESIGN

For RF driver circuit design, we have composed pi matching network for both cathode and anode. Pi network is normally used when matching between high impedance source and 50 ohm load [3]. For fine tuning, two variable capacitors were used for RF matching in cathode, and two variable inductors were utilized in anode. Q value of RF driver affects circulating current, and bandwidth. In our case, we designed Q value below 5 in order to prevent from damage of RF component especially in anode with high circulation current.

Table 1: Main Specification of RF Driver for 9 MeV Compact Cyclotron

Parameters	Values
RF driver vacuum tube	3CX1500A7
Resonant frequency	83.2 MHz
Anode voltage / current	3500 V / 0.5 A
Cathode voltage / current	5 V / 10.5 A
Rated maximum power	1 kW / 1.5 kW
Characteristic impedance	50 Ω
Main Power source	380 V / 92 A - 3rd Phase

RF Matching Circuit

3CX1500A7/8877 triode has input capacitance, and resistance of 38.5 pF and 58 ohm respectively. In addition, this has output capacitance and resistance of 10.2 pF and 1800 ohm. Equivalent circuit of RF driver cathode and anode is seen on Fig. 2. The circuit design was implemented by ORCAD version 16.3 [4]. The basic formula of impedance is as follows:

$$Z_{total} = \frac{1}{R} + \frac{1}{jwC} \quad (1)$$

After calculating based on the formula, we can obtain the input impedance of vacuum tube as 24.61-j28.67 Ω, and the output impedance 19.42-185.96 Ω. In order to calculate the impedance, we put resonance frequency as 83.2 MHz. Capacitance of tune and load variable capacitor is ranging from 9-36 pF, and 15-154 pF respectively. In addition, variable inductor inductance is approximately ranging from 40–120 nH. Copper plane thickness is as thin as 0.5 mm and the width is more than 3cm in order to reduce inductance and transmit RF power.

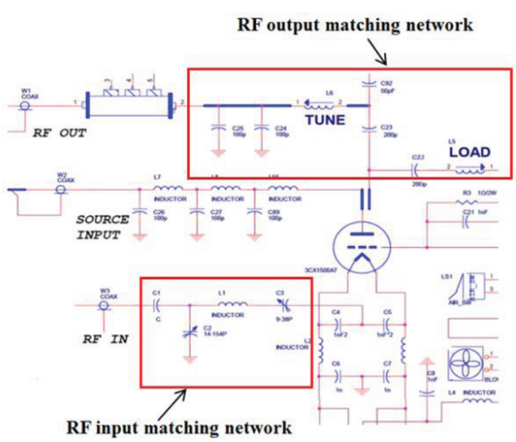

Figure 2: Schematic design of RF driver.

Rack Design and RF Driver Manufacturing

After the design of RF driver is finished, we manufactured RF driver rack based on the CAD design in order to assemble RF components [5]. The cathode and anode part of RF driver is shown in Fig. 3, and Fig. 4. Length, height, and height of the rack are 518 mm, 394 mm, and 550 mm respectively. On top case, and back case the hole has been made in order to assemble fan. Especially on the back case, we put 2 fans in stack for increasing air pressure. This enhances cooling efficiency. The thickness of copper coil for providing anode voltage is 2 mm. It can resist a current of 5 A, which is above the maximum current of vacuum tube.

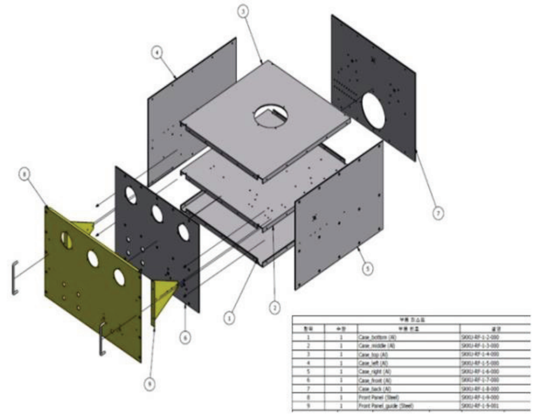

Figure 3: Design of RF driver rack.

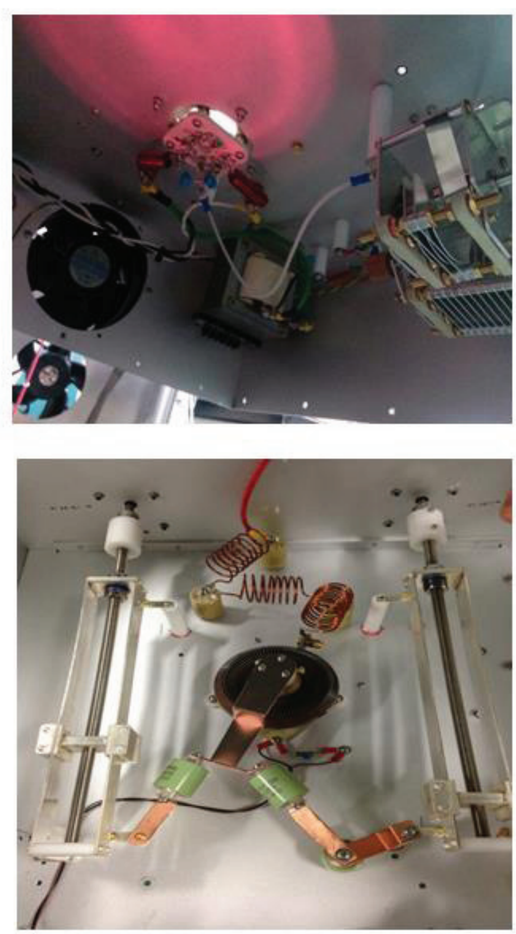

Figure 4: RF driver cathode (above), and anode (below).

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RESULT

Cold Test

We have conducted cold test by using Agilent 8753C network analyser in order to check 50 ohm matching [6]. Figure 5 and Figure 6 show reflection coefficient (S11), and smith chart of cathode and anode respectively. Reflection coefficient is measured around -30 dB at 83.2 MHz. In addition, smith chart shows the RF signal is impedance matched with 50 ohm.

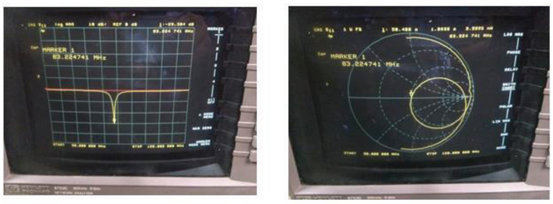

Figure 5: Measurement data of network analyzer (cathode).

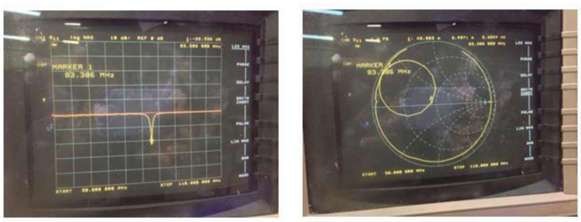

Figure 6: Measurement data of network analyzer (Anode).

RF Test

RF power test was performed with both 5kW oil type dummy load and RF cavity. Input power versus output power is seen on Fig. 7. The power source is generated from signal generator with 83.2 MHz frequency. The ratio of output power/input power is approximately 20. Operating time of RF driver lasted more than 2 hours. As seen on the Fig. 8, the value of SWR is below 1.15, which means reflected power is less than 0.5% out of total forward power.

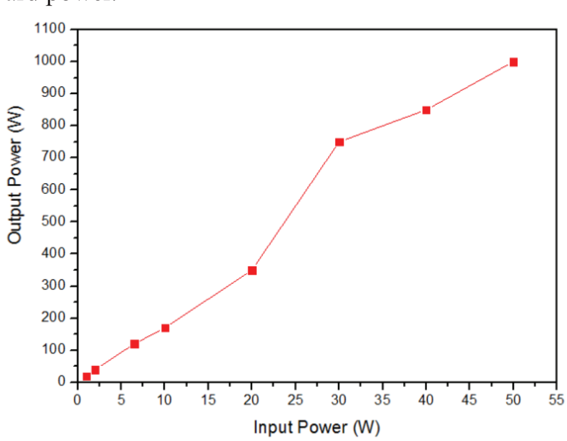

Figure 7: Measurement data of RF driver power.

Output power depends upon anode voltage and current. In our RF driver, we can select Y-Y connection (low mode) or Δ-Y connection (high mode). The first choice produces anode voltage of 2400 V, and second one generates 3500 V. Low mode produces 1 kW, whereas, high mode generates 1.5 kW of maximum output.

Figure 8: RF driver output power.

SUMMARY

We have observed some key features of 1.5 kW RF driver for compact cyclotron. RF Amplifier circuit matching was done by LC circuit. Fine tuning was accomplished with variable inductor and capacitor. In addition, power test was done with both 50 ohm dummy load and RF amplifier. Recently, we have designed and manufactured solid-state 1.5 kW RF driver prototype. We have to deal with difficulties for unexpected reflected power. This can be done by low-level RF control system.

ACKNOWLEDGMENT

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