

# A COMPACT 70 KW POWER AMPLIFIER AT 100 MHZ

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## Abstract

A compact 70 kW power amplifier (using a RS2058CJ tube) has been designed and installed as an intermediate power amplifier of a new 1.4 MW test amplifier system for Alvarez tanks (100 MHz) at the NIRS-HIMAC injector. This system will be used for testing RS2074SK tubes at the final stage and for developing some techniques to suppress any parasitic oscillations under a power region of 1.4 MW. This compact 70 kW power amplifier employs the  $\lambda/4$  type for both the cathode and anode tuning circuits, of which the size is greatly reduced compared to the existing  $3\lambda/4$  type. Preliminary tests showed that the characteristics are quite satisfactory; particularly, there is no significant resonance lower than 100 MHz, because of using the  $\lambda/4$  type. This paper describes the details of the design parameters and calculations with preliminary results.

## 1 INTRODUCTION

Since 1994 at HIMAC, the injector (RFQ and Alvarez) linacs have been used for the acceleration of various heavy ions (H~Xe) with energies from 8.0 keV/n to 6.0 MeV/n [1]. After stripping with a carbon foil at 6.0 MeV/n, these ions are injected into two synchrotron rings, and accelerated up to 100-800 MeV/n for cancer therapy and basic research. The maximum radio- frequency (RF) power for Alvarez tanks (100 MHz) is 1.4 MW with a duty factor of 0.3%, which allows the acceleration of heavy ions having a charge-to-mass ratio ( $q/m$ ) of 1/7 at minimum; the peak RF power is roughly proportional to  $(q/m)^{-2}$ .

With recent progress in research projects using various ion species at HIMAC, several groups require metallic ions (Fe) or heavy elements, such as Xe. Regarding the capability in heavy-ion sources, the higher intensity generally follows the lower  $q/m$  values; a high RF power is thus necessary for high intensity. So far, the parasitic oscillation, or higher harmonics modes, at the anode tuning circuit of the final tube (RS2074SK of SIEMENS) has sometimes disturbed stable operation, particularly under a power region higher than 1.2 MW ( $q/m \leq 1/6.5$ ). In daily maintenance, tests for both the newly supplied tubes (from SIEMENS) and the used ones for a long time are also important for judging whether they are really usable or not.

The maximum output power of the test amplifier was 20 kW in CW or 140 kW in pulsed operation with a duty

factor of 0.1%, due to both the limitation of the DC power supply and there being no intermediate amplifier. Thus, a new 1.4 MW test power amplifier has been proposed and designed, in which an intermediate 70 kW power amplifier (using RS2058CJ tube) has been newly designed. This report mainly describes the design parameters and preliminary performance.

## 2 DESIGN OF A 70KW POWER AMPLIFIER

### 2.1 amplifier

We selected a RS2058CJ tube (SIEMENS) for a new 70 kW (intermediate) power amplifier. This tube is the same as the existing one. Considering the application of this tube at 100 MHz, a  $\lambda/4$ -type anode circuit seems to be possible, and has been tried in order to make the size compact and to eliminate any resonance at a frequency lower than 100 MHz. The existing intermediate amplifier for DTL employs a  $3\lambda/4$  type anode tuning circuit, in which the unwanted oscillation was actually observed at around 30 MHz; this would be because the length of the anode circuit is close to  $\lambda/4$  of 30 MHz.

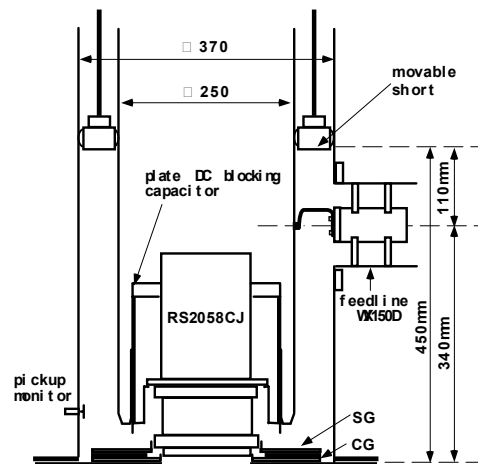


Figure 1: Anode tuning circuit.

To simplify the output circuit, the coupling scheme was modified to a direct type from a capacitive type; the coaxial cable is connected to the position where the anode

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load resistance becomes  $790 \Omega$ . The anode load resistance was estimated to be  $790 \Omega$  from the operation curve of the tube under an output power of 70 kW. Figure 1 shows the anode tuning circuit. The cross-sectional shapes of the inner and outer conductor are quadrangular. Preliminary calculated results are as follows: under the tuning condition at 100 MHz, the position of the movable short is 450 mm away from the CG socket; under the impedance-matching condition, the position of the output RF coupling is 110 mm from the movable short. Thus, the calculated results showed that the above-mentioned idea would be basically possible.

The detailed design of the input circuit is shown in Figure 2(a) and its schematic drawing of the electrical elements in Figure 2(b), in which the  $\lambda/4$  type is also employed. Impedance matching can be made by adjusting both the position of the stub and vacuum-type variable capacitor. The stub is a single-ended coaxial line, which should act as an inductive element to the input characteristics; this length is far shorter than  $\lambda/4$  at 100 MHz.

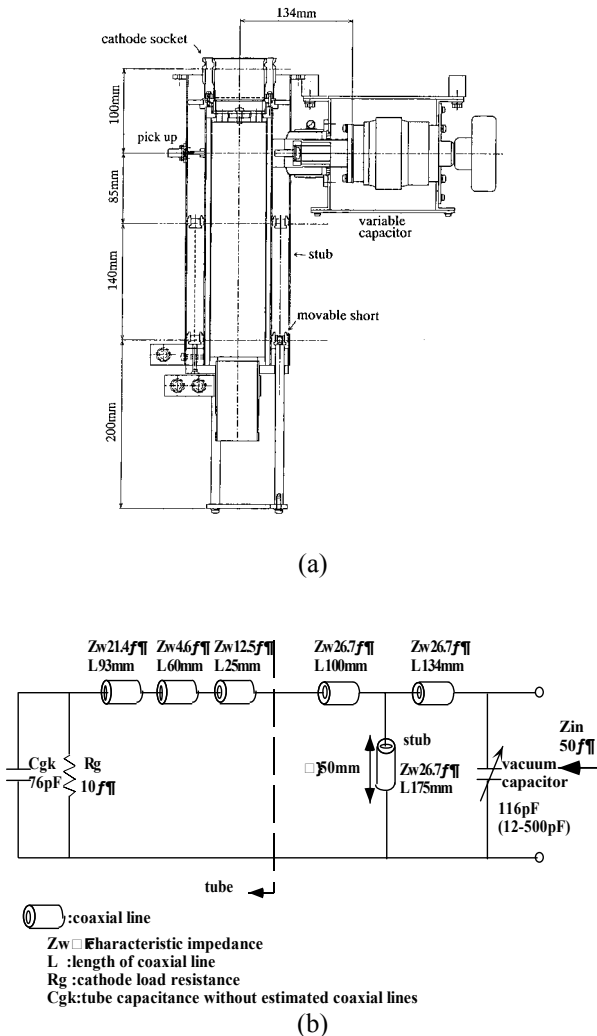


Figure 2: Detail design of the input circuit (a) and its schematic drawing of the elements in the input circuit (b).

Figure 3 shows the calculated impedance curve of the input circuit, assuming that  $R_g$  is 10  $\Omega$ . Although this  $R_g$  should become large under the actual power of 70 kW, it is possible to well meet such a situation ( $R_g = 10\text{--}40 \Omega$ ) by adjusting both the stub and the variable capacitor.

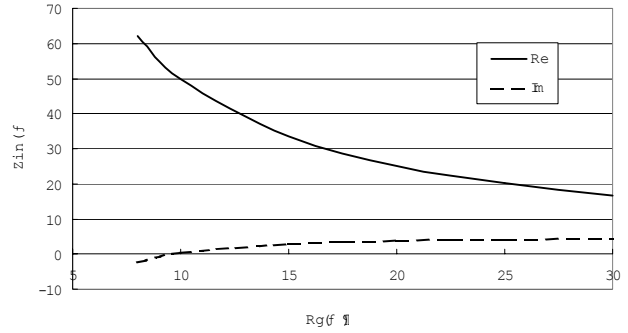


Figure 3: Matching characteristics of the input circuit.

The socket for the tube was also modified so as to have pickup monitors at the control grid (CG) and screen grid (SG), which are a direct and capacitive coupling type. Each bias (DC) power supply can be directly connected to the socket.

## 2.2 DC power supplies

Previously, the DC power supply for the final power amplifier was used for 20 kW under the CW operation. This was modified to meet a pulsed peak power of 1.4 MW. To stabilize the plate voltage (20 kV, 100 A) to better than 10%, the capacitor was increased up to 60  $\mu$ F. The crowbar circuit was eliminated and a series resistor (15  $\Omega$ , 540 W) was added in the output port to satisfy a limit condition of the product of current and time (900A $\times$ 2s) for the safety of the RS2074SK tube.

## 3 RESULTS AND DISCUSSION

The characteristics of the 70 kW power amplifier were measured under low power, and the results were compared with those of calculations. A resonance curve of the output circuit was measured using a network analyzer (HP4195A). The length of the output tuning circuit was 440 mm, which agreed well with that of a calculation (450 mm). Although two significantly large resonance points can be seen at 282 and 373 MHz, these may cause no problems, because they are far from the higher harmonics of 100 MHz (300 and 400 MHz).

The most appropriate load resistance of RS2058CJ is 790  $\Omega$  for the output power of 70 kW. The load resistance is estimated by measuring the impedance at the monitor position (Figure 1) when the feeder line is terminated by 50  $\Omega$ . The calculated result showed that this resistance at the monitor position should be 370  $\Omega$  when the anode load resistance is 790  $\Omega$ . The matching position was measured to be 105 mm from the movable short, which agrees well with the calculated value (110 mm).

The calculated input impedance becomes  $50\ \Omega$  when the cathode load resistance is  $10\ \Omega$  under 70 kW; the measurement was made under low power, when this resistance was assumed to be infinite. The variable capacitor ( $C_V$ ) and the stub length ( $L_V$ ) were determined so that the measured impedance (Figure 4) can agree with the calculated value (Figure 5). The obtained values were 93.2 pF and 215 mm, which are slightly different from those of calculations (116 pF and 175 mm). These differences would be due because the real value of  $C_V$  at 100 MHz is different from that measured at 1 kHz. It is basically possible to improve these differences to be small, because both the  $L_V$  and  $C_V$  values are widely adjustable.

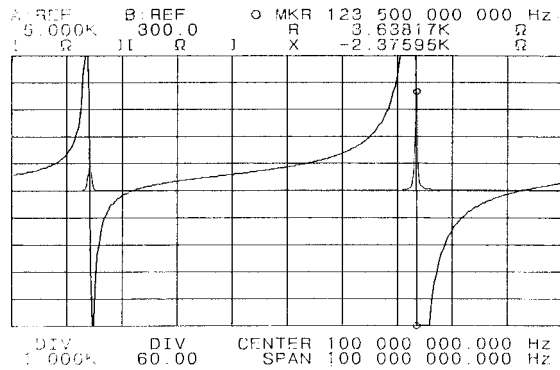


Figure 4: Impedance characteristics of the input circuit obtained by low-power test.

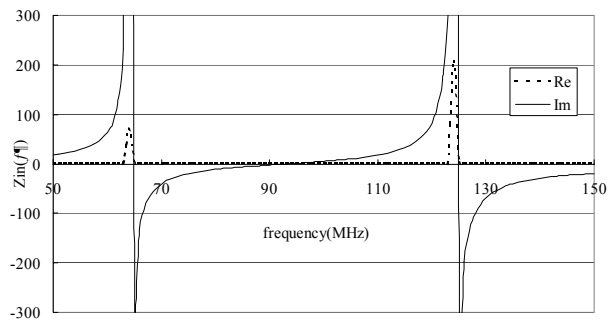


Figure 5: Calculated input impedance of the input circuit assuming  $R_g = \infty$ .

The CG-SG circuit of the DTL high-power amplifier has a clear resonance at around 23 MHz, causing a large oscillation. In order to verify whether such a resonance exists in the new 70 kW amplifier or not, we measured the resonance frequency of the CG-SG. It was measured to be 174 MHz (the calculated 161 MHz), though it may cause no problems, because it is far from the higher harmonics, and not lower than 100 MHz.

Finally, the overall transmissions between the input and output circuits were measured (Figure 6). The purpose was to know whether an unexpected resonance would occur or not. The results showed there was one resonance

at 65 MHz. Our calculations also suggested a similar resonance due to the variable capacitor and stub. However, this resonance should disappear under full-power operation. Figure 7 shows the input impedance, which was calculated with  $R_g$  of  $10\ \Omega$ ; there can be seen no resonance, except at 100 MHz.

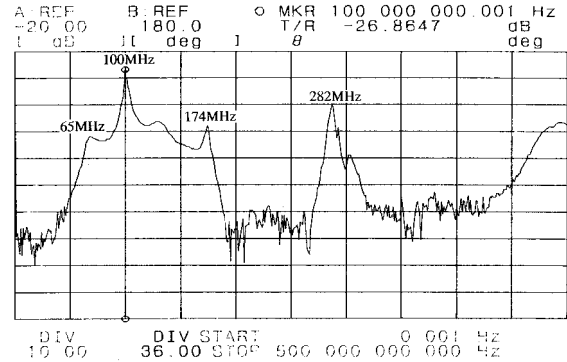


Figure 6: Transmission between the input and output terminals under the low-power test.

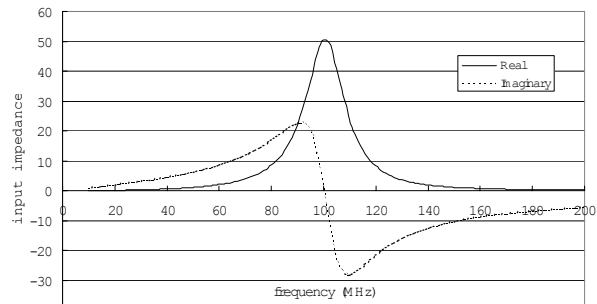


Figure 7 : The calculated input impedance with  $R_g = 10\ \Omega$ .

## 4 CONCLUSION

We measured the characteristics of a newly designed 70 kW power amplifier. The results were quite consistent with our calculations. There was no significant resonance, even at a frequency lower than 100 MHz. This is attributed mainly to the use of  $\lambda/4$ -type tuning circuits for both the input and output.

## 5 ACKNOWLEDGMENT

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## 6 REFERENCES

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