Development of 100kW RF Amplifier for the RIKEN Charge State Multiplier

Yoshinobu MURAKAMI, Yukio KUMATA, Yutaka TOUCHI, Toshiyuki OCHI,
Osamu KAMIGAITO*, Masatake HENMI*, Shigeo KOHARA*, Eiji IKEZAWA*
Takashi FUJISAWA**, Shohei HAYAKAWA**, Takayuki MORISHIMA** and Hiroyuki KAI**
Sumitomo Heavy Industries Co., Ltd. (SHI)
5-2 Soubiraki-cho Niihama Ehime 792-8588, Japan
*The Institute of Physical and Chemical Research (RIKEN)
2-1 Hirosawa Wako Saitama, 351-01, Japan
**Denki Kogyo Co., Ltd. (DKK)
4052-1, Nakatsu-Sakuradai Aikawa Aikou Kanagawa, 243-0303, Japan

Abstract

We have developed 100kW RF amplifier systems to feed RF power to the RIKEN Charge State Multiplier (CSM). It has following specifications with the power grid tube RS2058CJ (SIEMENS)

Frequency: from 36 to 76.4 MHz
Maximum power: 100kW C.W.
Voltage Stability: $\pm 0.1\%$
Phase stability: $\pm 0.1^{\circ}$

In order to change RF frequency continuously, it has a 1/4 λ stub type output circuit and a newly developed 1/2 λ input circuit. Adopting the configuration of the input/output circuit and 5kW solid state driver, the amplifier system has only three moving components. Thus simple adjustment of frequency and impedance were achieved.

It has been tested and operated with 50Ω dummy load. During the test, instabilities caused by parasitic oscillation and resonance of 4th harmonics component were observed. To solve these problems, ferrite absorbers and dumping resistors were installed. Finally, it achieved the design specifications, stable operation at 15dB gain and 100kW output in required frequency band.

1. Introduction

The CSM is a system that multiples charge state of heavy ions like uranium from the RIKEN Linear Accelerator (RILAC)[1]. It is going to be located between the RILAC and RIKEN Ring Cyclotron (RRC) to enable the acceleration of heavy ions in the RRC. The low-energy part of the CSM consists of two acceleration resonators, a charge-stripper and a deceleration resonator.

All the resonators are based on the same structure of 1/4 λ -coaxial type with drift tubes. In order to generate operating voltage of 450kV,RF power of 100kW is necessary over the frequency range of 36 to 76.4MHz. The configuration of the amplifier system is shown in Fig.1. The standard signal is fed to a amplifier chain through a phase shifter and a amplitude modulator. The amplifier chain has two stages of a 5kW solid state wide band amplifier and a 100kW tuned amplifier. The 100kW amplifier has a tetrode based on a grounded grid configuration.

Designs and test results of the amplifier system are described in this paper.

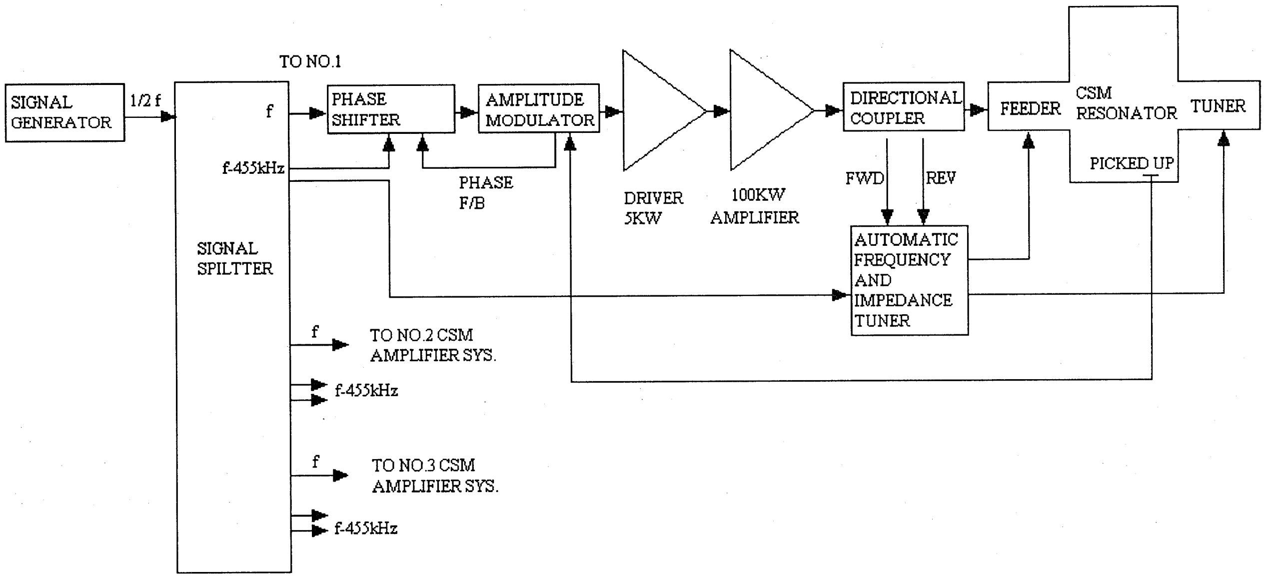

Fig.1 Block diagram of the CSM resonator and its RF feeding system

2. Circuit Analysis and Design

2.1. Analysis of Tube Performance

The power grid tube, SIEMENS RS2058CJ, was selected as a final stage to output 100kW. It is operated in the grounded-grid circuit to suppress the feedback power from the output circuit to input one. The performance of the tube was analysed [2)] by SHI and SIEMENS as shown in Table.1

Table.1 Performance of RS2058CJ in the grounded-grid circuit, class B operation.

Output power	107kW
Duty	100%
Frequency	36 – 76.4 MHz
Plate dissipation	46kW
Efficiency	72%
Drive power	3.2 kW
Input Impedance	14Ω
Output Impedance	532 Ω
Anode P.S.	12kV,12.75A
G2 P.S.	900V,0.46A
G1 P.S.	-240V,0.28A

2.2. Design of Input and Output Circuits

A 1/2 λ input circuit and a 1/4 λ stub output circuit contribute to feed and output over the wide frequency range. They consist of two variable capacitors and a movable short that adjust frequency and impedance as shown in Fig.2

The 1/2 λ input circuit consists of a 500pF variable capacitor and a pre-adjustable short. The capacitor tunes the resonance frequency from 36 to 76.4MHz. The short adjusts input impedance to 50 Ω. It is fixed at an optimised position. Because the input VSWR is almost independent of the frequency as shown in Fig.3 at maximum operating condition(Zin=13.6 Ω).

The 1/4 λ output stub circuit consists of a 60pF variable capacitor and a movable short. The capacitor adjusts output impedance at 50 Ω. The movable short, moving 800mm stroke, tunes resonance frequency from 36 to 76.4MHz.

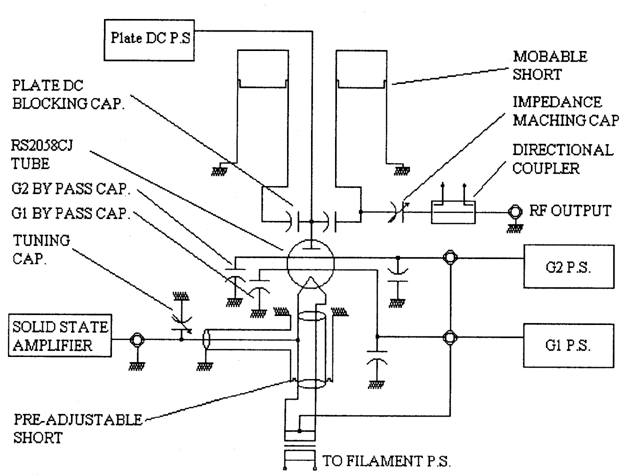

Fig.2. Schematic drawing of CSM amplifier

2.3. Design Method

The input and output circuits were analysed with the one dimensional distributed circuit model. Additionally electric fields in output circuit ware calculated with SUPERFISH code. The calculations contributed to determine the positions of the moving short over the frequency range of 36 to 76.4 MHz.

3. Performance Evaluations

Performances of the amplifier were evaluated by Low Power Test (LPT) and maximum output power test (PT). In the LPT, a dummy tube was used instead of RS2058CJ. In the PT, a 50Ω dummy load was utilised instead of the CSM resonator. In these tests, following items were measured.

LPT: VSWR, parameters of moving components in the input/output circuits

PT: parameters of moving components in the input/output circuits, forward and reverse power of the driver and the 100kW amplifier, current and voltage of power supplies (anode, G1and G2) and temperature of cooling water.

Then the amplifier achieved to output more than required

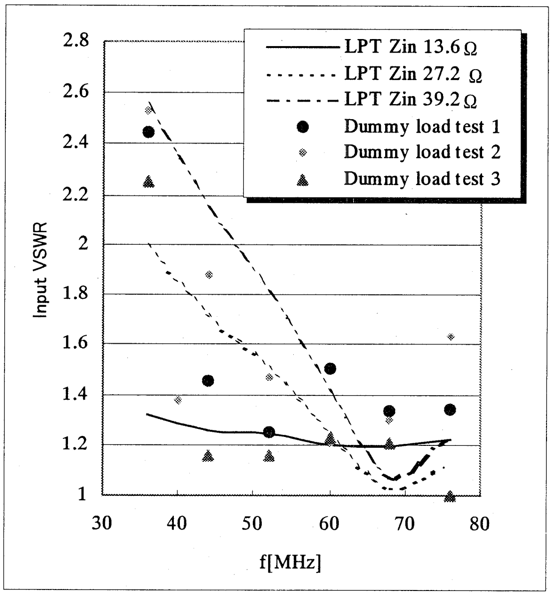

Fig.3 Input circuit's VSWR at 100kW output.

VSWR in Low Power Test (LPT), drawn with lines, were measured with network analyser in assumption that tube's input capacitance (Ckg1) and impedance (Zin) were as following values.

Ckg1:140pF ,Zin: 13.6,27.2 and 39.2Ω.

VSWR in dummy load test, drawn with points, were calculated from forward and reverse power of driver amplifiers.

power over the range of 36 to 76.4MHz.

3.1. Characteristics of Input & Output Circuits

The input circuit achieved as good matching as VSWR<1.5 at maximum operating condition(Zin=13.6Ω). The VSWR were obtained from the LPT and the PT. Both data had no contradiction except for a difference around 36MHz as shown in Fig.3. The difference is assumed to be caused by the driver amplifier's distortion at low frequency. The distortion may cause reverse power from the 100kW amplifier.

The output circuit achieved as perfect matching as VSWR=1.0 at maximum operating condition (Zout=540Ω). The VSWR were measured in the LPT.

3.2. Maximum Output Power and Efficiency

The required output power of 100kW was obtained over the required frequency range as shown in Fig.4. Power gain and efficiency were estimated with the results of the PT. The power gain was about 15dB. The efficiency increased as the frequency went up as shown in Fig.5. The characteristic is assumed to relate to instabilities by resonance of 4th harmonics component described in subsection *4.2.*

The output power was estimated with two methods. One is a measurement with directional coupler. The other is calorie metric method (CM). In the CM method, plate dissipation was calculated from the cooling water temperature. We adopted the CM method to determine output power because of less error caused by harmonics components.

4. Instabilities and their Measures

Since instabilities were observed during the PT, following counter measures were carried out.

4.1. Parasitic Oscillation of the Grid Tube

1.4GHz parasitic oscillation of the RS2058CJ was observed at 30kW output. Then 12 pieces of ferrite bars, about 30cm total length, were installed around G2 electrodes. They can absorb 1GHz RF as much as 6.5dB/cm. In the full power operation, their temperatures were increased up to 115℃ by absorbing 1.4GHz RF.

4.2. Resonance of the 4th Harmonics Component by the 3/4λ Stub Resonance Mode

In an operation at 40MHz, a resonance of 3/4λ mode was exited at 160MHz. This phenomenon may cause instability of amplifier. In order to dump 3/4λ resonance, some 50Ω resisters were installed on the voltage node points of the 3/4λ resonance mode. The node points were obtained from the SUPERFISH analysis. As a result, the 4th harmonics component was decreased to acceptable level.

5. Conclusion

The newly developed 100kW amplifier achieved its performance concerning required output power over the range of 36 to 76.4MHz. In the next step, its voltage and phase stability will be evaluated with feeding power to the CSM resonator.

Acknowledgement

We would like to appreciate to all members who concern RIKEN CSM Project.

References

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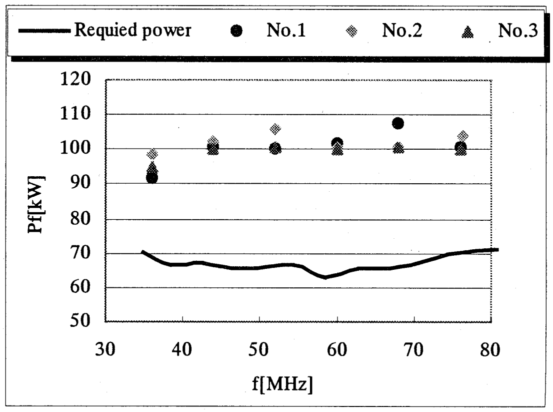

Fig.4. Maximum output power in PT and required power for CSM resonator to generate 450kV-electrode voltage. The required power was based on measurement of CSM resonator's shunt impedance..

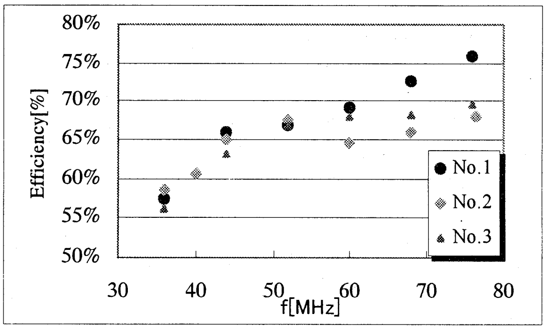

Fig.5 Efficiency at maximum output power in PT.