CONSTRUCTION OF THE NEW AMPLIFIERS FOR THE RIKEN-LINAC

K. Suda, E. Ikezawa, O. Kamigaito, N. Sakamoto, K. Yamada
RIKEN Nishina Center for Accelerator-Based Science, Wako, Saitama 351-0198, Japan
Y. Touchi, Sumitomo Heavy Industries, Ltd., Niihama, Ehime, 792-8588, Japan

Abstract

New tetrode based amplifiers have been constructed for the RIKEN heavy-ion linac, so called RILAC, replacing 36-year-old amplifiers to improve their reliability as a main injector for the RIBF accelerator complex. The RILAC is a DC machine and their frequency are tunable between 18 to 40 MHz so as to be capable of accelerating heavy ions with mass-to-charge (m/q) ratios up to 28. The new rf amplifier is based on a tetrode THALES/SIEMENS RS2042SK coupled with a tetrode THALES/SIEMENS RS2012CJ with a grounded grid circuit. The maximum output power is 150 kW with a frequency ranging from 18 to 40 MHz. The amplifier was originally designed for RIKEN Ring Cyclotron. Since we have many experiences with this type of amplifier, some modification to avoid exciting the parasitic modes which might damage the cavity and/or the amplifier itself. Their construction started in April 2013 and installation was performed in January 2014. After the installation their commissioning has been successfully made. Beam services started in March 2014, and the new amplifiers were operated without any troubles.

RIKEN HEAVY-ION LINAC (RILAC)

The RIKEN heavy-ion linac, RILAC [1], consists of six variable frequency cavities (tanks) constructed in 1978 (Fig. 1). It accelerates various kinds of ions up to 4 MeV/u by varying RF frequency from 18 to 40 MHz. Beam service started since 1981. Since 2002, by adding six booster cavities, intense beams up to 6 MeV/u are provided for experiments such as super heavy element (SHE) synthesis. RILAC is also used as an injector for RI Beam Factory (RIBF) since 2006.

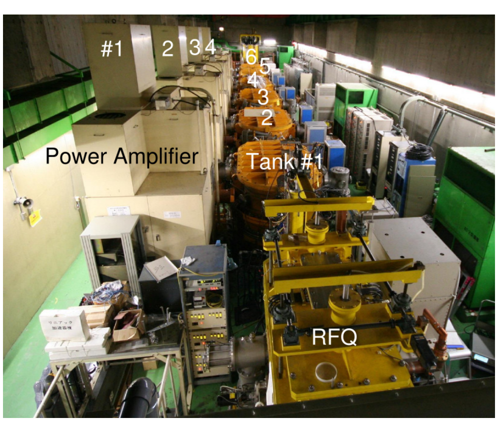

Figure 1: RILAC tanks and power amplifies.

POWER AMPLIFIER FOR RILAC

There are six power amplifiers for RILAC tanks. The prototype of amplifier was constructed in 1977, prior to the construction of tanks, and the amplifier was used for tank #1. Other five amplifiers were constructed in 1978. The #5 and #6 amplifiers were upgraded in 1999 for SHE experiments. Three final-stage plate DC power supply were upgraded at the same time; one power supply is used for two amplifiers. In recent years, several troubles occurred, such as water leaks from a pin hole on cooling pipe, and damage of socket for tetrode caused by a insufficient contact between socket and tetrode. The contact is shallow and a careful alignment is necessary. Such troubles deteriorated the reliability of the RF systems. Therefore, in FY 2013, amplifiers for #1 and #2 were upgraded (Fig. 2). The upgrade project started in April 2013. Installation of two amplifiers started in January 2014, and dummy load and power tests were performed in February 2014. Beam service using the new amplifier started in March 10 th, 2014 on schedule.

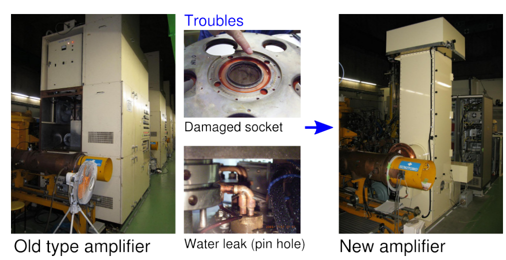

Figure 2: Old power amplifier, its troubles, and a new amplifier constructed in FY2013.

CIRCUIT DIAGRAM OF AMPLIFIER

The new amplifier for RILAC #1 and #2, as well as for #5 and #6 is based on a tetrode RS2042SK coupled with a tetrode RS2012CJ from THALES/SIEMENS with a grounded grid circuit, which was originally designed for RIKEN Ring Cyclotron (RRC) [2]. The maximum RF input power of 0.01 W(10 dBm) is amplified by a pre-, driver- and, final-stage amplifiers up to 1, 15, and 150 kW, respectively. A frequency range is from 18 to 40 MHz. The circuit diagram of the amplifier is shown in Fig. 3. In 14 years operation of the amplifier for RILAC #5 and #6, we have experienced several parasitic modes, which might damage the tank and/or the amplifier itself. One is caused by a coupled oscillation between the 99-MHz G1-G2 resonance of RS2042SK and the output circuit including a feeder line to the tank. The other example is the 7th harmonic mode observed in RILAC #5 shown in Fig. 4. In order to avoid such parasitic modes, we have installed a 50 kW dummy load at plate STUB.

ISBN 978-3-95450-142-7

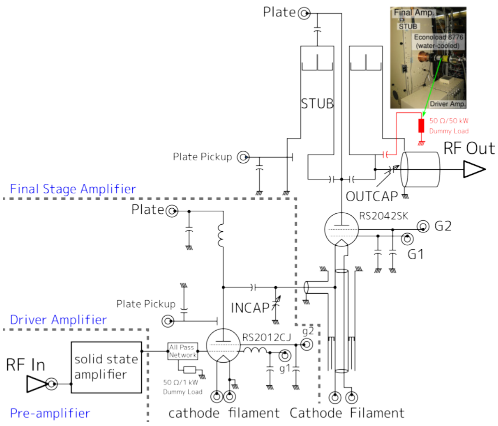

Figure 3: Circuit diagram of a new amplifier.

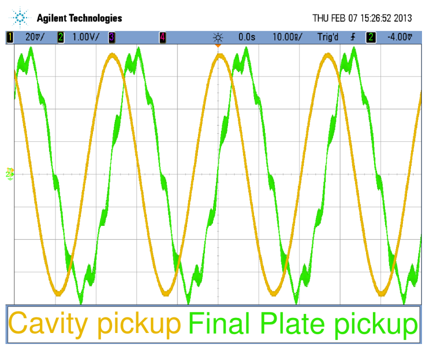

Figure 4: Parasitic mode observed in RILAC #5. A yellow line shows a signals from a cavity pickup, and a green line shows that from a plate pickup at the final plate.

LOW POWER TEST

Before installation, matching conditions for input and output circuits of driver- and final-stage amplifiers were measured and/or tuned.

(a) The input circuit for a driver amplifier is called "All Pass Network" (Fig. 5). A major purpose of this circuit is to cancel an imaginary part of a load (a capacitance $C_g^{RS2012CJ}$ between a cathode and a control grid of RS2012CJ). The Voltage Standing Wave Ratio (VSWR) seen from an input should be less than two, which corresponds to the condition that the return loss ($|S_{11}|$) to be less than −10 dB. The measured values were less than 1.6 in the frequency range. The input and output voltages, V_{in} and V_{tube} were also measured, and the voltage ratio (V_{tube}/V_{in}) was confirmed to be higher than 0.5 (Fig. 6).

(b) An input circuit for the final amplifier was tuned by a vacuum variable capacitor, INCAP (15 – 450 pF) and a movable shorting stub at a cathode input of the final amplifier (Fig. 7). A dummy tetrode with a capacitance $C_g^{RS2042SK}$ between a cathode and a control grid of 360 pF, and a resistance of 13 or 20 Ω was used, instead of using an actual tetrode, so that the expensive tetrode may not be damaged during a transportation to a factory. The desired input impedance is in a range from 700 to 2000 Ω. After tuning a position of the cathode stub, the value can be tuned within 1000 – 1800 Ω (Fig. 8).

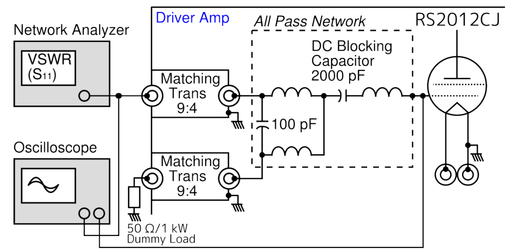

Figure 5: Input circuit for a driver amplifier (all pass network).

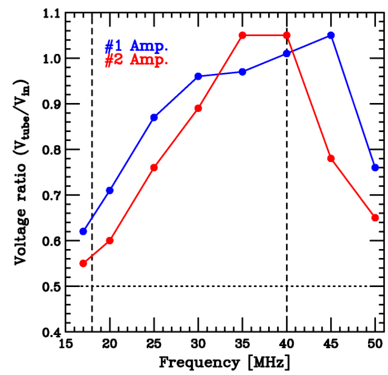

Figure 6: Voltage ratio (V_{tube}/V_{in}) of the all pass network.

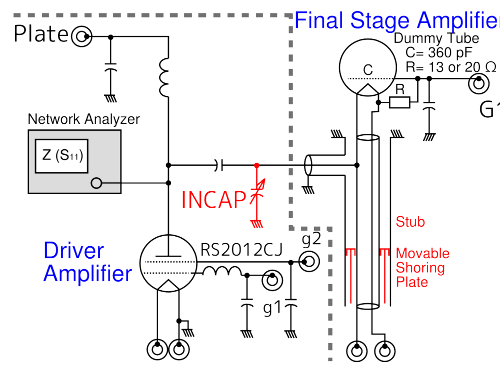

Figure 7: Input circuit for a final-stage amplifier.

(c) An output impedance of the final amplifier was matched by changing a plate STUB and OUTCAP (10 – 250 pF) (Fig. 9). An inductance (plate STUB) is used to cancel the imaginary part of the impedance, whereas a capacitance to set the real part of the impedance to be 59 Ω, which corresponds to a characteristic impedance of a feeder line to the tank. The preliminary measurement was performed in a factory, and the final measurement was performed when a control system became available after an installation of the amplifier. A measured relation between OUTCAP (matching capacitance) and a position of STUB is shown in Fig. 10, as well as a dependence of a load impedance Z_{load} against a matching capacitance, where Z_{load} is defined as an amplitude of voltage divided by a peak current at a plate. Typical values of Z_{load} were calculated to be 200 Ω for an output power of 100 kW, and 200 Ω for 300 kW, respectively at a plate voltage of 14 kV.

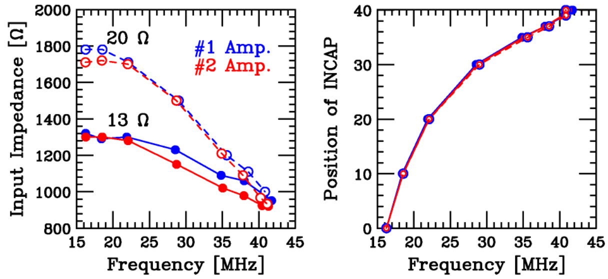

Figure 8: Measured input impedance for a final-stage amplifier (left panel), and a relation between frequency and a position of INCAP (right panel).

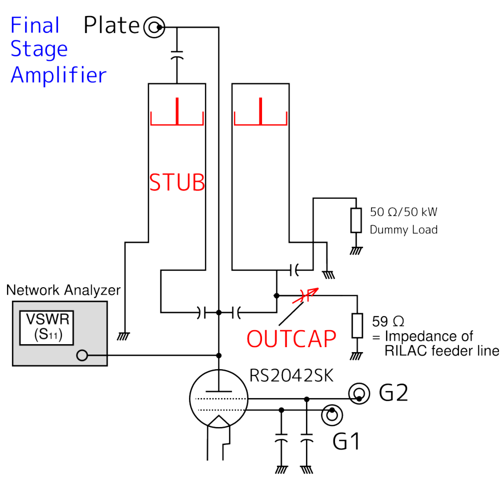

Figure 9: Output circuit for a final-stage amplifier.

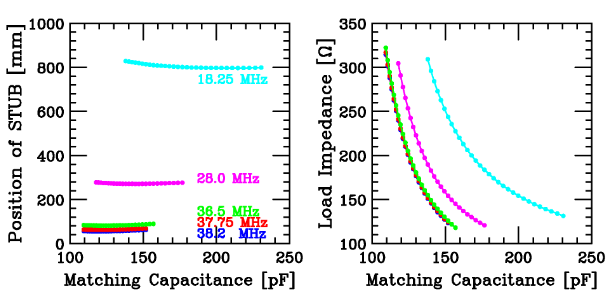

Figure 10: Measured relation between OUTCAP (matching capacitance) and a position of STUB (left panel), and a dependence of a load impedance Z_{load} against a matching capacitance (right panel).

DUMMY LOAD AND POWER TEST

Output tests using a dummy load were performed. A water-cooled 250 kW dummy load was connected to the output of the amplifier through a coaxial line of WX-203D. The plate voltages for a driver- and a final amplifiers were 6, and 10 kV, respectively. It succeeded to obtain an output power of 150 kW at frequencies of 37.75, 28.0, and 18.25 MHz (Fig. 11). Then, load tests were performed at 36.5 MHz. The required accelerating voltages of RILAC were successfully obtained for both the tanks of #1 and #2. The parameters for the load tests are shown in Table. 1.

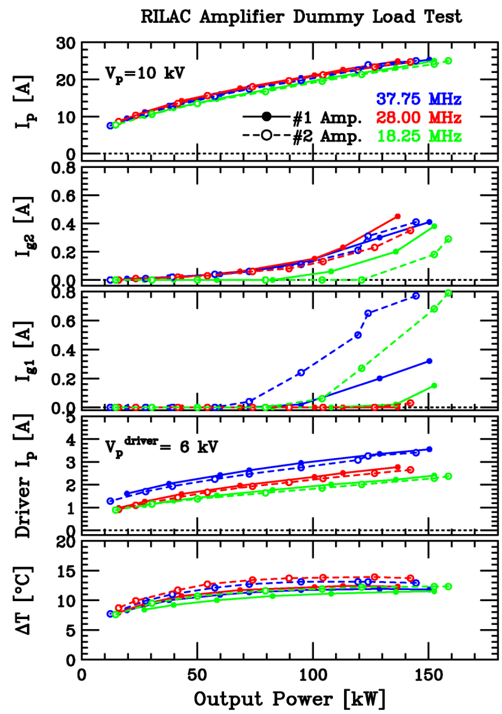

Figure 11: Result of dummy load tests. Currents of plate (I_p), screen (I_{g2}) and control grids (I_{g1}) for the final amplifier, and a plate current for the driver amplifier (Driver I_p) are shown as well as a change of temperature of the cooling water for the final amplifier (ΔT).

Table 1: Parameters for Load Tests at 36.5 MHz

Tank	INCAP	STUB	OUTCAP		Z_{load}
				[pF]	[Ω]
#1	1811	75.3	300	138.1	155
#2	1787	90.8	432	114.7	198

BEAM SERVICE

Beam service using the new amplifiers started on schedule in March 10th, 2014. They operated without any troubles so far at frequencies of 37.75, 36.5, and 28.0 MHz, for seven experiments with eight ions of ^{14}N, ^{15}N, ^{23}Na, ^{27}Al, ^{40}Ar, ^{70}Zn (for RIBF), ^{80}Kr, and ^{130}Xe.

REFERENCES

[1] M. Odera et al., Nucl. Instrum. and Methods, 227, 187 (1984).

[2] T. Fujisawa et al., Sci. Papers I.P.C.R. 80 (1985).

ISBN 978-3-95450-142-7