LOW-OUTPUT-IMPEDANCE RF SYSTEM FOR THE ISIS SECOND HARMONIC CAVITY

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Abstract

A wideband low-output-impedance RF system for the second harmonic cavities in the ISIS synchrotron has been developed by collaboration between Argonne National Laboratory (US), KEK (Japan) and Rutherford Appleton Laboratory (UK). The system has less than 30 Ω of output impedance over the frequency range of 2.7 – 6.2 MHz. Precise control of the second harmonic voltage can then be realized without considering beam loading effects. A beam test with this system is planned at the ISIS synchrotron in 2009.

INTRODUCTION

Precise phase control of the second harmonic cavity to the fundamental one is essential to maximise the stable phase space area. In the high power synchrotron, the low-output-impedance RF system (LOI) is thus investigated, which is free from heavy beam loading and enables such precise control. The LOI is realized by the feedback from plate to grid of the final triode amplifier. The output impedance over the wide frequency range of interest is less than 30 Ω, and the voltage gain of the final triode more than 20. In [1], comparisons of measurements with calculations are discussed in detail. However, input impedance seen from the driver output looking into the grid input also becomes lower, e.g. 10 Ω, because it sees the reduced triode plate resistance, $r_p/(\mu+1)$, through the feedback circuit, where μ = amplification factor of the triode. The cathode follower is known as another low impedance scheme, the voltage gain of which is less than unity, but it provides much higher input impedance: 360 Ω at 6 MHz for the present triode.

LOI HIGH POWER DRIVE

Figure 1 shows the layout of the LOI high power drive (HPD). The vacuum tubes in the driver and final stages are the Burle 4648 tetrode and the EEV BW1643J2 triode, respectively, and are both operated in class A. A grid bias switching system is used on each tube to avoid unnecessary plate dissipation during the non-acceleration portion of the cycle. Closed loop controls for cavity tuning and RF voltage level have not been implemented in this experiment. The bias supply current was, however, controlled manually at each frequency so as to minimize the cavity input current. A Model 310 Pearson current transformer was used to monitor the cavity input current. The tube filaments are fed by a mains AC line at 50 Hz. This frequency is somewhat different from the ISIS 50 Hz

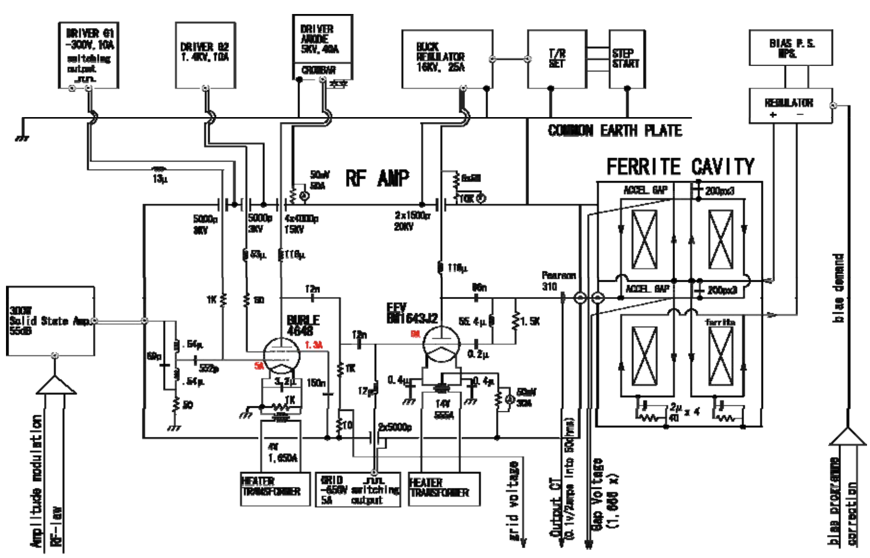

Figure 1: Layout of LOI high power drive.

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clock. Variations in the output current of the tetrode supply were observed at a beat frequency of these two 50 Hz's. Such variations, however, were not observed for a triode anode current (see table 1).

Experimental Results

High power tests were carried out with the ISIS second harmonic cavity as a load. The ferrite bias current was swept at 50 Hz repetition rate to tune the cavity at resonance. The RF generation was stable, and 12.6 kV peak per cavity gap was obtained as shown in figure 2. Parameters during operation are given in table 1.

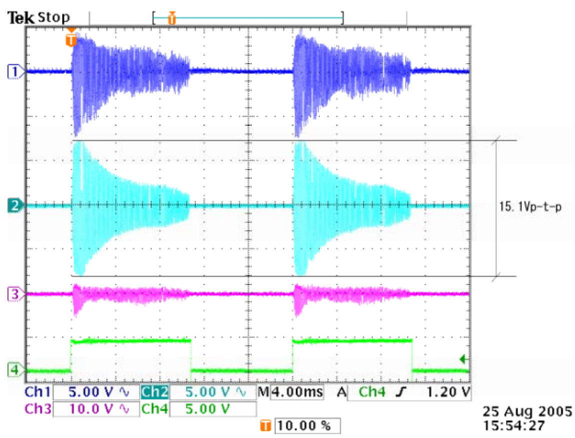

Figure 2: RF envelopes and 50 Hz gate pulse. From top trace, ch.1 driver stage voltage (120×), ch.2 cavity gap voltage (1,666×), ch.3 cavity input current (20A/V) and ch.4 50 Hz gate pulse. 15.1V peak-to-peak at ch.2 corresponds to 12.6 kV peak per gap.

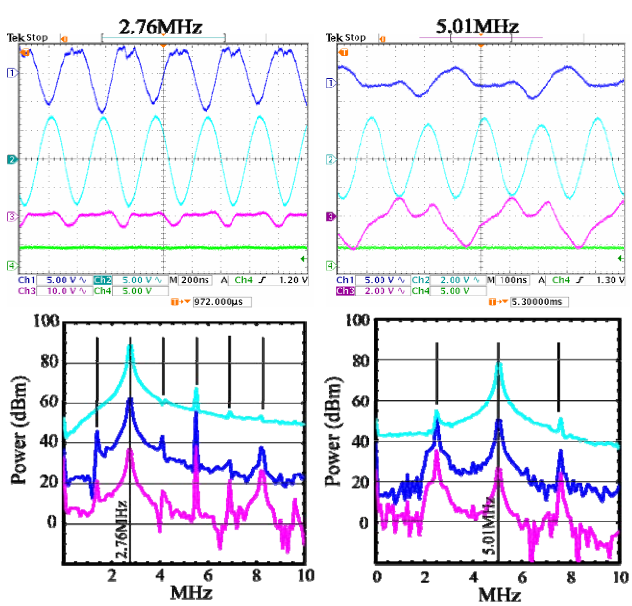

Figure 3: Waveforms and their frequency spectra at 2.76 and 5.01 MHz operations. Traces in upper figures are in same order with Fig. 2. Vertical bars in lower figures indicate the locations of a second sub-harmonic and its multiples.

Waveform analysis

Figure 3 shows the detailed waveforms. FFT analysis was applied to these waveforms, and the voltage gain and shunt impedance of the cavity were derived from the fundamental components. The voltage gain is defined as cavity gap voltage divided by driver stage voltage, and the cavity shunt impedance as cavity gap voltage divided by cavity input current. The results are summarized in table 2. The shunt impedance seems ~1.5 – 5.8 times lower than the design values [2]. As for voltage gain, measurements and calculations agree reasonably. Another remarkable feature is the appearance of a second sub-harmonic and its multiples. The reasons are yet to be investigated.

For further studies on the discrepancy of the cavity impedance and sub-harmonic issue, a dummy load has been installed in place of the cavity (see figure 4). The load comprises a solution of $CuSO_4$.

Figure 4: Dummy load in place of the cavity, which is seen at the left-hand side.

Table 1: Parameters of LOI operations.

Repetition rate	50 Hz	
Class of operations	class A for triode and tetrode	
Duty factor	54% by grid switching	
RF frequency	2.6 MHz (t=0msec) ~ 6.2 MHz (t=10msec)	
	RF OFF	RF ON
Triode Supply: anode voltage average anode current grid voltage at conduction grid voltage at cutoff	 16.6 kV 12.1A	 15.2 kV 14.2A -340V -500V
Tetrode Supply: anode voltage average anode current G1 voltage at conduction G1 voltage at cutoff G2 screen grid voltage	 6.6 – 6.7 kV 14 – 17A 1.4 kV	 6.6 – 6.7 kV 13 – 16.2A -60V -200V 1.4 kV
ENI A-300 output		25Vrms

Table 2: Voltage gain and cavity shunt impedance for fundamental harmonic. *Calculation by transfer function of the final stage assuming the cavity shunt impedance obtained here. ** R G Bendall, ISIS/DHRF/P2/97.

Frequency (MHz)	Voltage Gain		Cavity Shunt Impedance (Ω)	
	this analysis	calculation*	this analysis	design value**
2.76	20.9	18.6	384.	2215.
4.04	22.8	18.7	538.	809.
5.01	26.4	17.2	404.	1000.
6.20	20.2	16.3	330.	1700.

BEAM TEST SCENARIO

A second harmonic cavity is required to increase bunching factor, thus improving the RF trapping efficiency and mitigating the space charge detuning as well. The RF voltage with a second harmonic component is written as,

$$V(\phi) = V_0[\sin(\phi) - \delta \sin(2\phi + \theta)], \qquad (1)$$

where the parameters, V_0, δ and θ, are given in [3] for the acceleration of 3.7×10^{13} protons per pulse, 295μA average on the ISIS synchrotron. The allowable range of θ for low loss operation is quite limited, especially at the initial acceleration stage. A very precise control of θ is then essential. Since the RF voltage is low in this stage, the beam loading is severe. Figure 5 shows the relative beam loading throughout the acceleration cycle, which is defined as the ratio of the beam current, $2I_b$, to the generator current required to produce the same gap voltage without beam load and with the cavity tuned at resonance. A factor 2 in the beam current comes from the fact that the ISIS cavity has two accelerating gaps. It is seen that the loading parameter exceeds a threshold value of 2.5 [4] during a period between 0 and ~0.4 msec. However, when the LOI with 30 Ω output-impedance is employed, the loading parameter lies well under the threshold, and the RF system will be stabilized. The LOI can then realize a precise control of θ regardless of the beam loading effect.

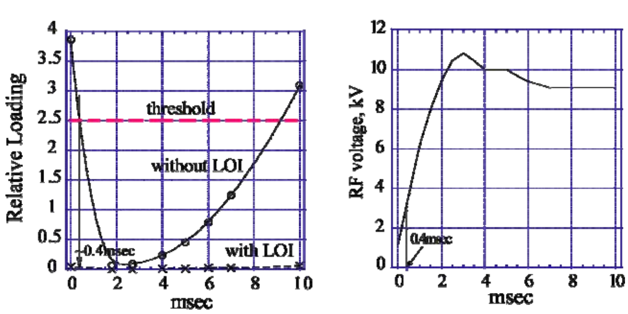

Figure 5: Relative beam loading of a second harmonic cavity with and without LOI (left). Required second harmonic voltage per cavity gap (right).

Four second harmonic cavity systems have been installed on the ISIS synchrotron, each of which is equipped with a beam feed-forward system to compensate for the beam loading. The required RF voltage per cavity gap [3] is also shown in Fig. 5. The maximum voltage between 0 and ~0.4 ms amounts to 3.2 kV, i.e. 25.6 kV per ring. The LOI is capable of generating the maximum voltage, so then one of the beam feed-forward systems can be replaced by the LOI for a beam test. Simulation shows that outer particles in the longitudinal phase space undergo ~1.6 turns of synchrotron motion during this period. Therefore, it is possible to observe the bunch evolutions under precisely controlled second-harmonic voltages. Results will be compared with those from the existing beam feed-forward system.

CONCLUSIONS

A wideband low-output-impedance RF system for the second harmonic cavity in the ISIS synchrotron has been developed. High power tests at 50 Hz repetition rate were carried out successfully. However, some problems were revealed, such as appearance of a second sub-harmonic and lower cavity shunt impedance, which are to be solved before the beam tests scheduled in 2009.

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