LOI status report

LOI-2

September 24, 2005

SUMMARY

Experiments with cavity-bias sweep have been performed in the MICE Hall during August 15-26, 2005 to produce the RF voltage which will be required for the beam test in the ISIS synchrotron. The frequency ranges from 2.6MHz to 6.2MHz at the repetition rate of 50Hz.The vacuum tubes in the driver and final stages are operated both in class A, and the grid switching systems are applied to avoid unnecessary plate dissipations during a non-accelerating period. RF generation was very stable, and a peak voltage of 12.6KV peak per gap was obtained at 2.76MHz (Fig.1). Closed loop controls for cavity tuning and RF voltage level were not used in this experiment.

Although the waveform of cavity voltage is smooth, those of driver-stage voltage and the cavity input current are distorted containing a second subharmonic and higher harmonics. Shunt impedance of the cavity is another problem: the impedance obtained from the harmonic analysis shows 1.5~5.8 times lower than those which have been assumed for the system design.

On the last day of experiments, spark discharges occurred frequently, probably somewhere in the cavity, and the experiment was stopped. Further RF test with closed loop controls will be continued in the next stage aiming more than 10KV peak at the mid acceleration cycle.

In the following sections are presented, experimental setup in section 1, parameters and various waveforms in section 2, and harmonic analysis in section 3.

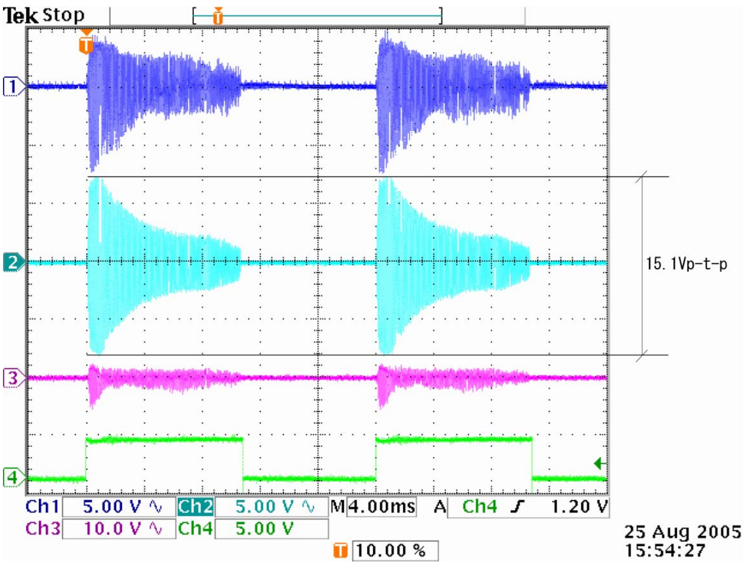


Fig.1 RF envelopes and 50Hz gate pulse. From top trace, ch.1 driver stage voltage (120×), ch.2 cavity gap voltage (1,666×), ch.3 cavity input current (20A/V) and ch.4 50Hz gate pulse. 15.1V peak-to-peak at ch.2 corresponds to 12.6KV peak per gap.

1. Experimental setup

Figure 2 shows the LOI high power drive system and locations of the probe points. In the final triode (EEV BW1643J2) and the driver tetrode (BURLE 4648), grid switching scheme is applied (fig. 3). The heater filaments are fed from the 1ϕ AC 200V, and the ripples on the tetrode anode current are big. The 50/100Hz ripple compensation is then introduced (fig. 4). Ripples on the triode, however, are not observed. Is it because the triode supply is equipped with sufficient rectifier capacitors and/or is controlled by PWM with 10KHz?: tetrode supply is comprised of 12-pulse rectifier.

Closed loop controls for cavity tuning and RF voltage level were not used in this experiment. However, manual correction was applied for the cavity tuning by minimizing the cavity input current (fig. 5). The value of liquid resistor showed 4.15KΩ when the RF data in fig.1 was rtaken. Table 1 summarizes the experimental conditions.

Table 1 Experimental conditions

repetition rate	50Hz
class of operation	class A for final triode and driver tetrode
grid switching	ON: -0.4msec ~ 10.4msec, with ring-magnet field minimum at t = 0.0msec OFF: other period than above
duty factor	54%
RF frequency	2.6 MHz (t = 0msec)~ 6.2 MHz (t = 10msec)

2. Parameters and waveforms

Parameters of the LOI operations and various waveforms are given in Table 2. The anode currents of triode and tetrode are nearly the same with RF ON and OFF, which means the operation is performed almost in class A. By comparing the waveforms of the tetrode anode current in the jpg-1 and -2, it is seen that the waveform is changing. The rate of change seems a beat frequency of the ISIS 50Hz and the mains 50Hz. A qualitative explanation of this change is in the following (fig.6). Assuming some vibrations of the heater filament at 50Hz which synchronizes with one of the mains three phases, the tetrode current will be enhanced when the distance between grid and heater is short, and will be suppressed when the distance is long. Since a time slot with 10msec duration for the grid ON time is moving at a beat frequency, the tetrode current will be changed accordingly. Table 3 shows the AC input currents to the anode supplies with 54% duty operations. Variations of three phase currents for the tetrode supply may be explained in a similar way.

Table 2 Parameters of the LOI operations. Numbers are due to meter reading at the chassis panel.

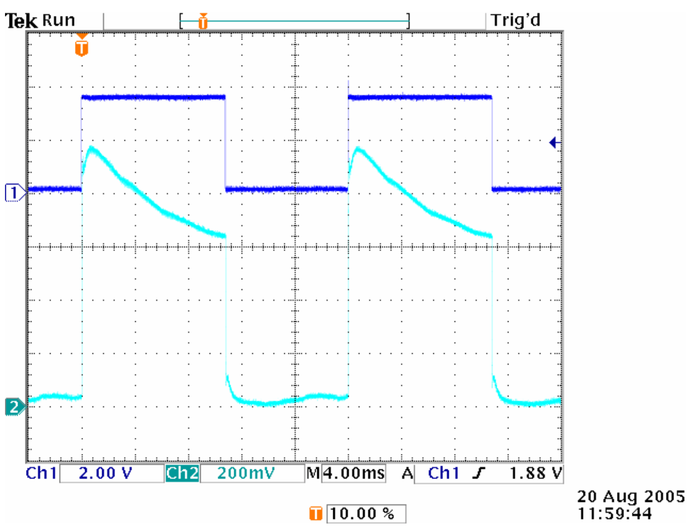
	RF OFF	RF ON
Triode Supply anode voltage, KV	 16.6	 15.2

anode current, A anode current waveform grid voltage	12.1 (see figure #1.6) switching at 50Hz: -340V(conduction), -500V(cutoff)	14.2 (see figure #2.3)
Tetrode Supply anode voltage, KV anode current, A anode current waveform G1 control grid voltage waveform G2 screen grid voltage, KV G2 screen grid current, A*)	 6.6 ~ 6.7 14 ~ 17 (see figure jpg.1) (see figure #1.4) 1.4 2.9	 6.6 ~ 6.7 13 ~ 16.2 (see figure jpg.2) (see figure #3.3) 1.4 3.
ENI A-300 output, Vrms		25.

*) Shunt resistor of 700Ohms is attached across the output terminal of the screen grid supply. Then, 2Amps out of 2.9~3.0Amps in the right columns come from the current flowing through this resistor.

Table 3 AC input currents to the anode supplies with 54% duty operations. Values are due to portable current-meter reading for the triode supply, and meter reading at the chassis panel of the tetrode supply. AC voltage is 415V.

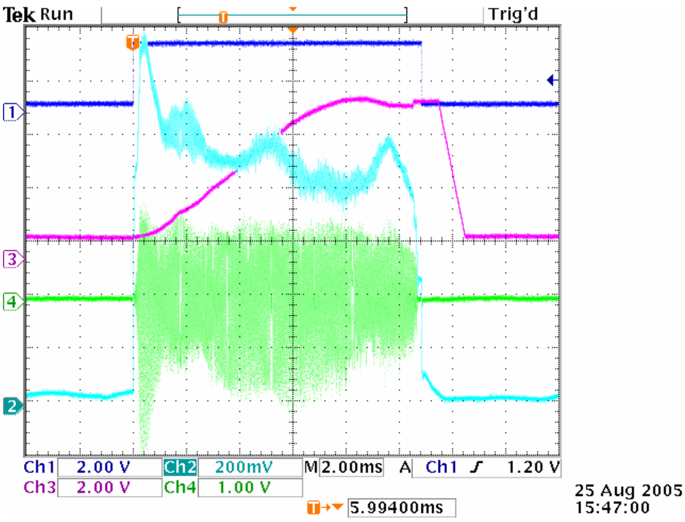
Triode Supply φ_A φ_B φ_C	 361A 352A 384A
Tetrode Supply phase R phase S phase T	 135~350A, varies in several seconds 90 ~ 360A 110~370A



#1.6

ch.1 TTL trigger to triode grid switcher

ch.2 triode anode supply current at J3 in fig.2, 35A/V.



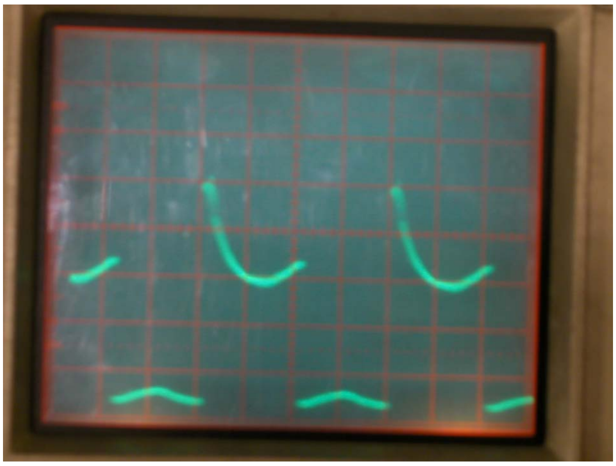
#2.3

ch.1 50Hz gate pulse

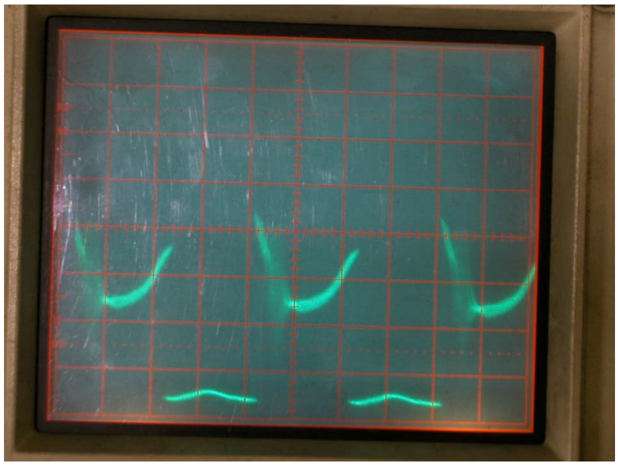
ch.2 triode anode supply current at 'J3' in fig.2, 35A/V.

ch.3 bias demand to bias regulator

ch.4 cavity input current at 'Output CT' in fig.2, 20A/V.

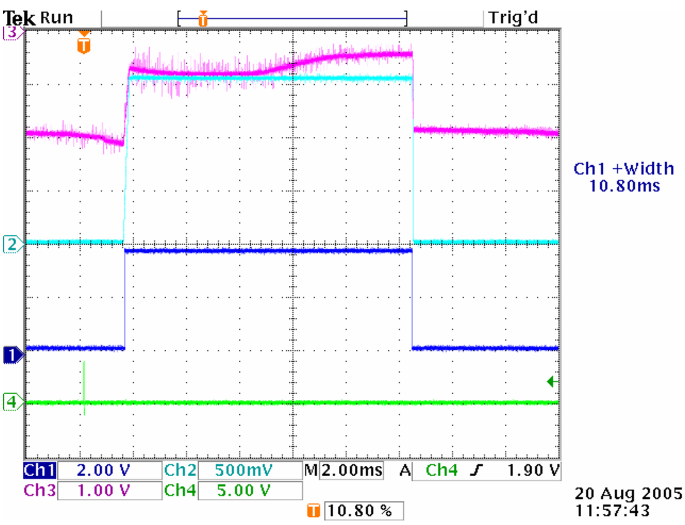


jpg.1



jpg.2

Anode current waveforms of the tetrode supply without RF (jpg.1), and with RF (jpg.2). Probe point is 'Current Monitor A6303+AM503' in fig.2, and the horizontal and vertical scales are 5msec/div and 10A/div., respectively. The current waveform is changing with period of several seconds.



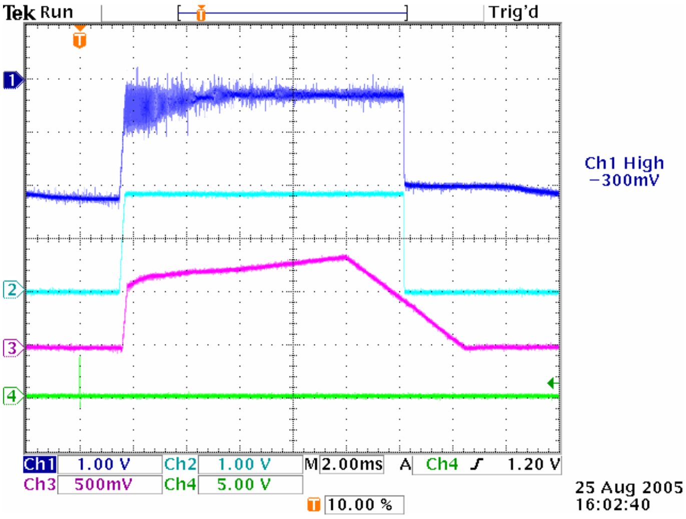
#1.4

ch.1 TTL trigger to triode grid switcher

ch.2 input to tetrode G1 supply

ch.3 output of tetrode G1 supply (100×) at 'G1 Monitor Output' in fig.2

ch.4 ISIS 50Hz timing pulse



#3.3

ch.1 output of tetrode G1 supply (100×) at 'G1 Monitor Output' in fig.2

ch.2 input to tetrode G1 supply

ch.3 amplitude modulation to RF envelope

ch.4 ISIS 50Hz timing pulse

3. Harmonic analysis

Figure 7 shows the waveforms in details of fig.1 at the fundamental frequencies of 2.76, 4.04, 5.01 and 6.20MHz. The fft results of these waveforms are given in figs.8 and 9 with frequency range of 0~10MHz and 0~50MHz, respectively. The remarkable features of these waveforms are the appearance of a second subharmonic for all waveforms, and the enhanced higher harmonics between 20 and 30MHz for driver stage voltage and cavity input current, especially at 6.20MHz. Thanks to the high Q value of the ferrite cavity (unloaded Q), effects of these subharmonic and higher harmonics are not significant in the cavity gap voltage. As for the output of the solid state amplifier (ENI A-300), higher harmonic components are measured with 50-ohm dummy load with the fundamental frequency range of 2.6~6.2MHz. The 2nd and 3rd harmonics are less than 50dB.

From the fundamental components thus obtained, voltage gain and cavity shunt impedance are derived. 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 shown in Table 4. As for voltage gain, measurements and calculations reasonably agree. However, the shunt impedance is 1.5~5.8 times lower than the reference values, which have been assumed for the system design of LOI HPD.

The problems on the subharmonic and higher harmonics, and the shunt impedance of cavity are to be investigated in the next stage. More precise cavity tuning system may be required.

Table 4 Voltage gain and cavity shunt impedance for fundamental harmonic

Frequency (MHz)	Voltage Gain		Cavity Shunt Impedance (ohms)	
	this analysis	calculated*)	this analysis	reference**)
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.

*)calculated by transfer function of the final stage assuming the cavity shunt impedance obtained here.

**) R Bendall, ISIS/DHRF/P2/97.

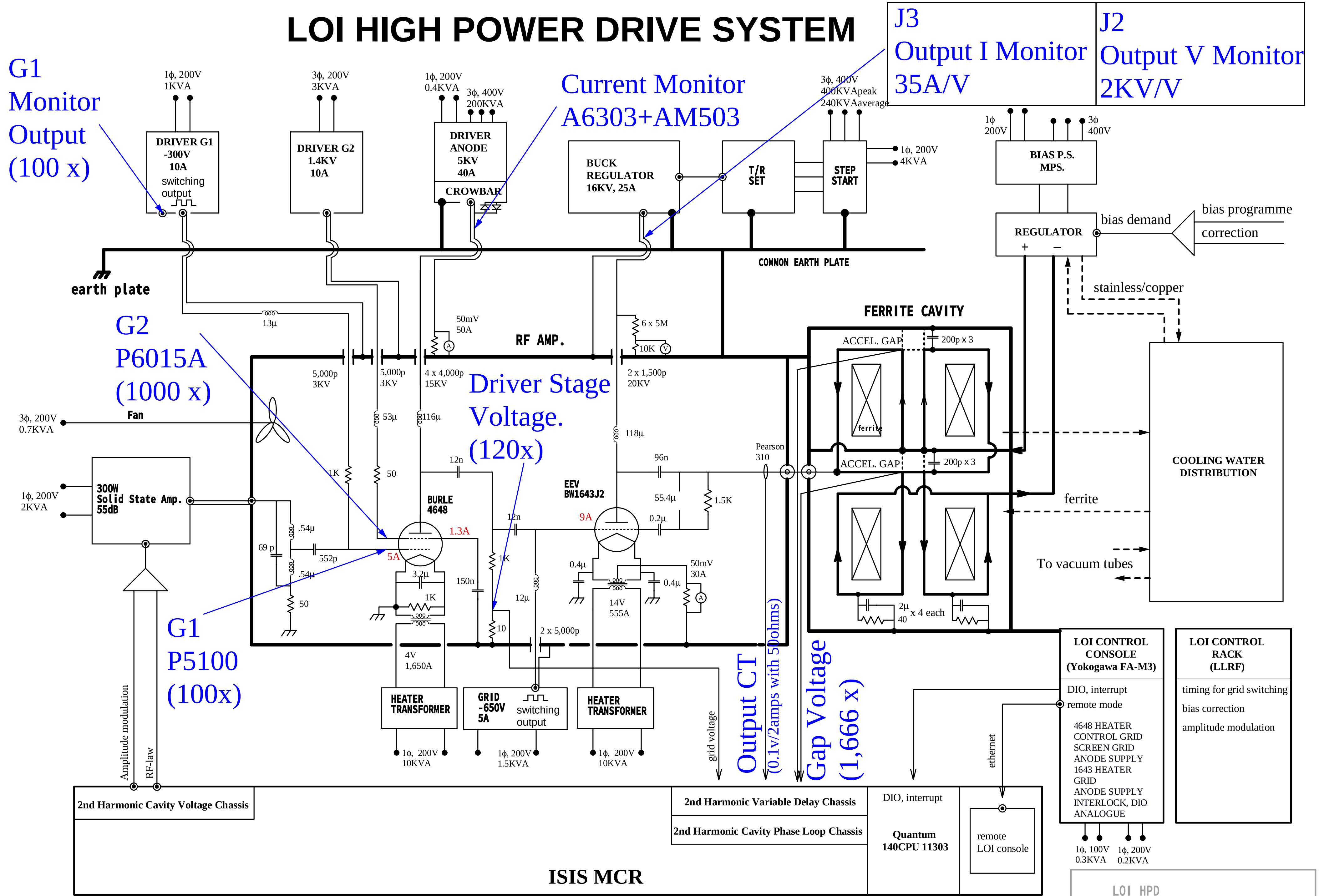


Fig.2 Probe Points for LOI HPD

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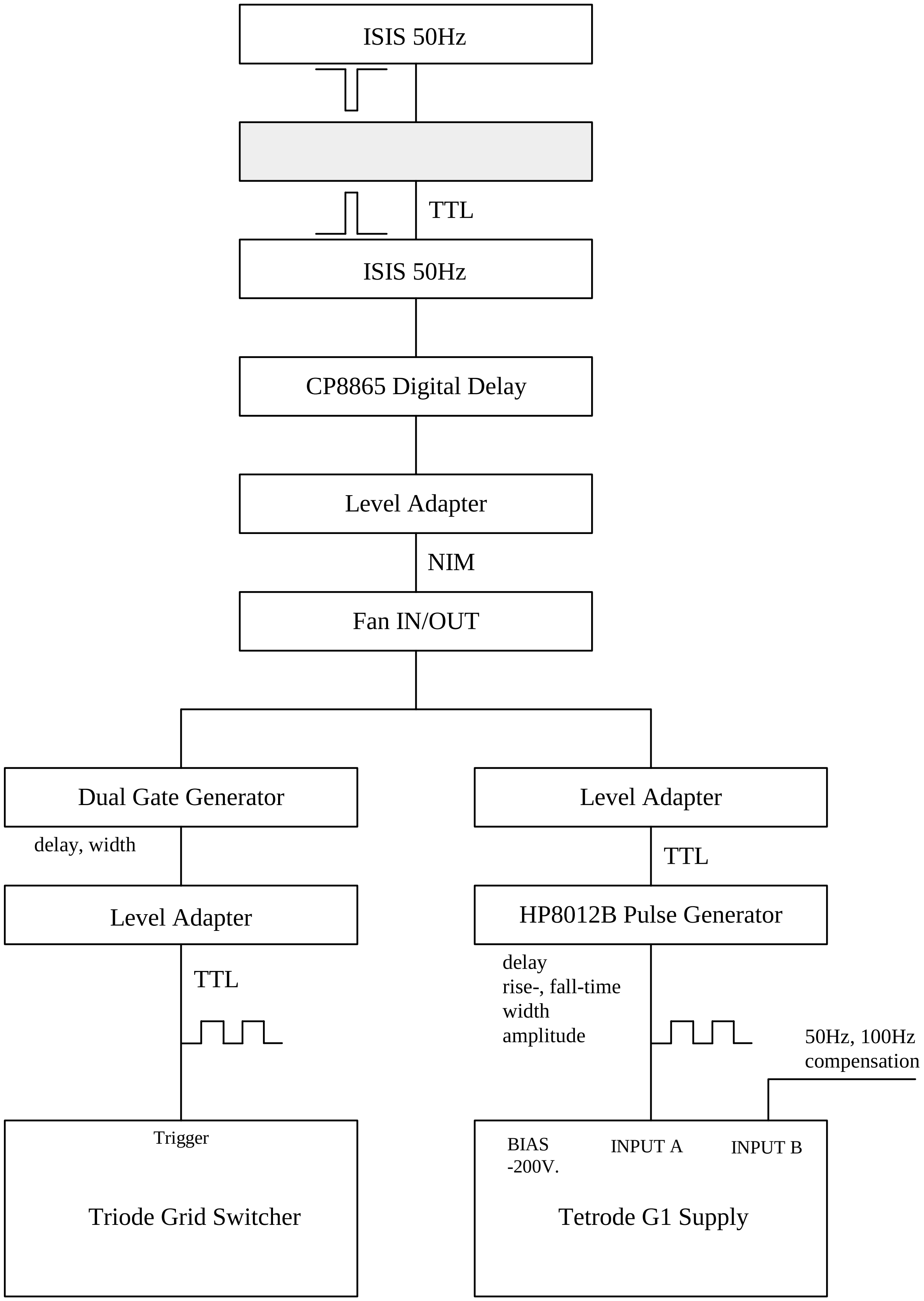

Fig.3 Grid switching schematic

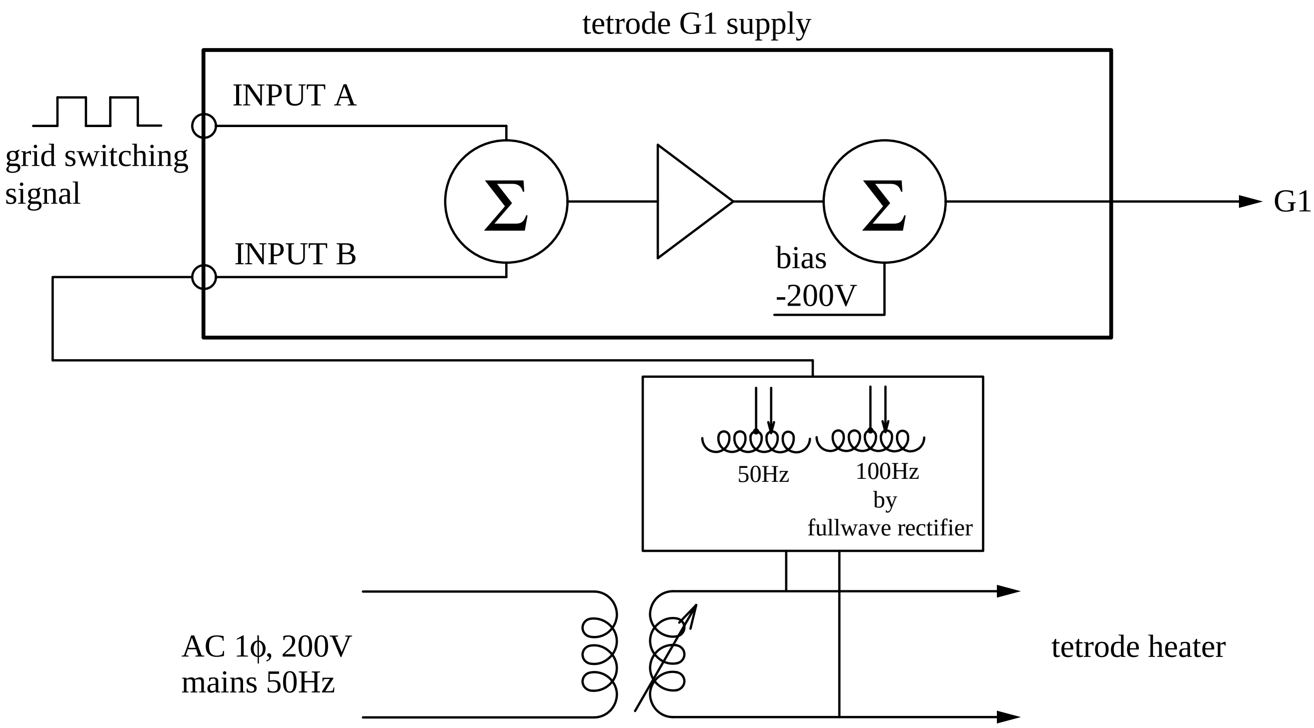

Fig.4 50/100Hz compensation for tetrode G1 supply

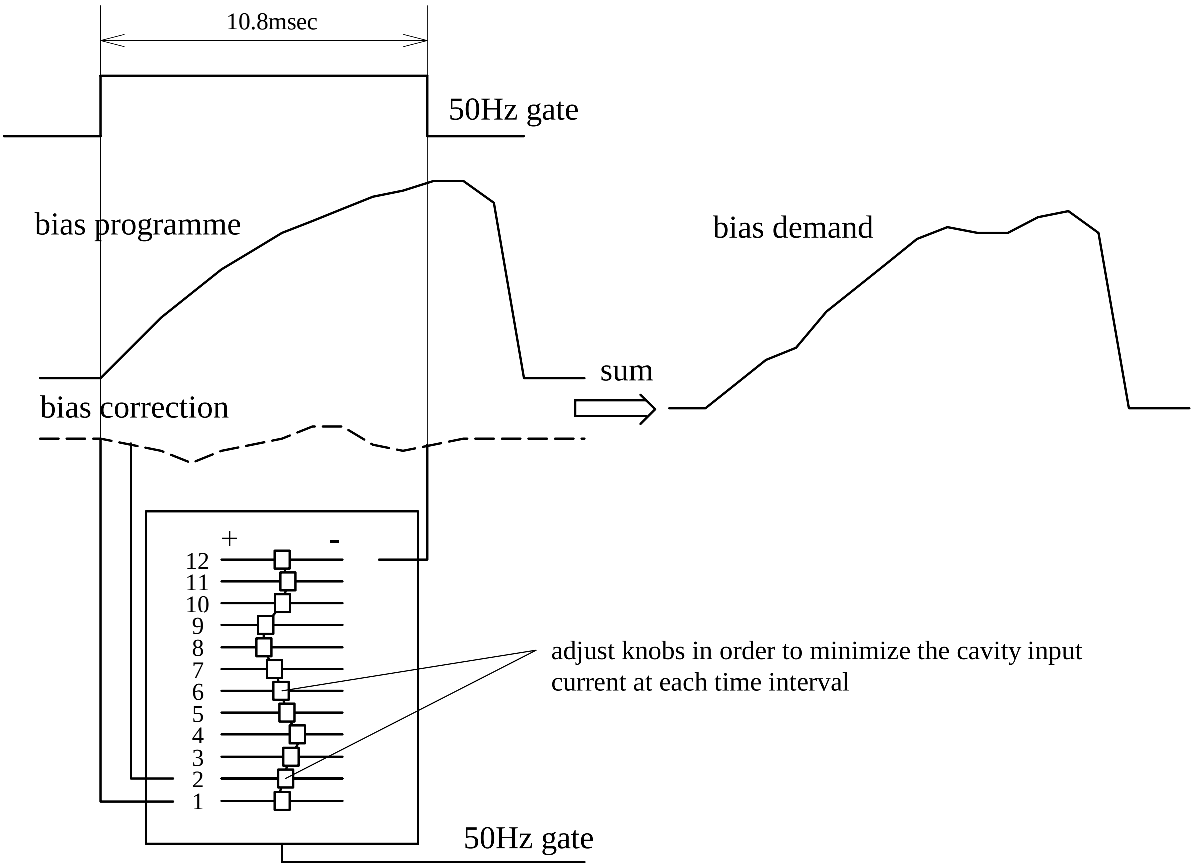

Fig.5 Cavity bias correction

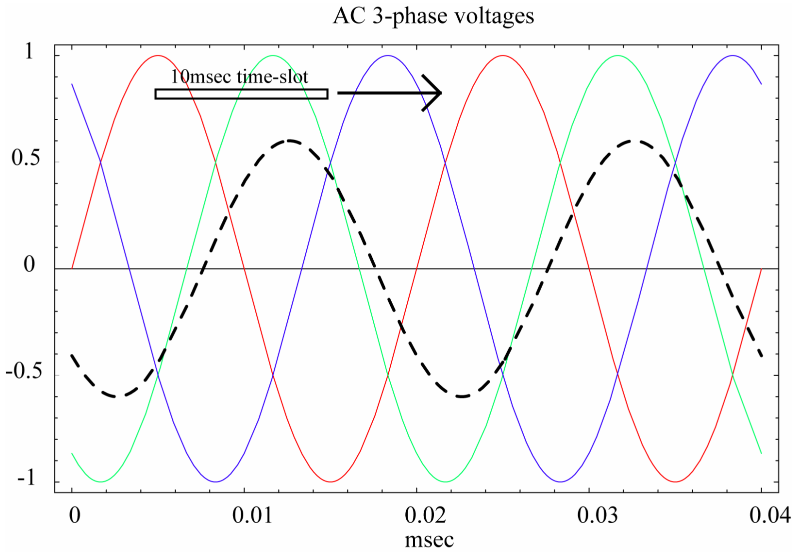

Fig.6 3ϕ voltage input (solid) of the tetrode supply and 50Hz pattern (dotted) showing some vibrations of the heater filament synchronizing with one of the three phases. Time slot with 10msec duration moves at a beat frequency.

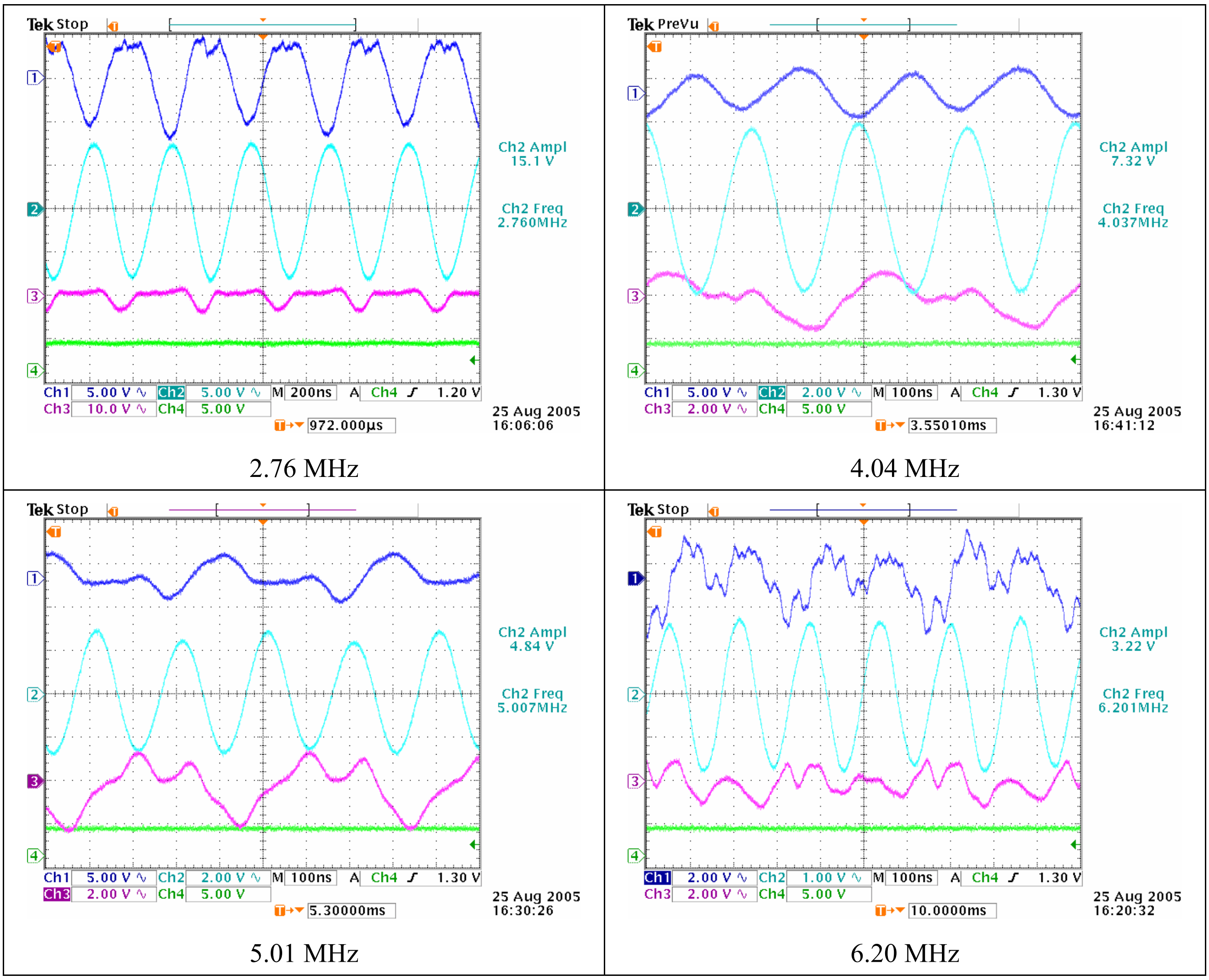

Fig.7 Waveforms in a magnified scale at 2.76, 4.04, 5.01 and 6.20MHz. From top trace, ch.1 driver stage voltage (120×), ch.2 cavity gap voltage (1,666×) ch.3 cavity input current (20A/V) and ch.4 50Hz gate pulse.

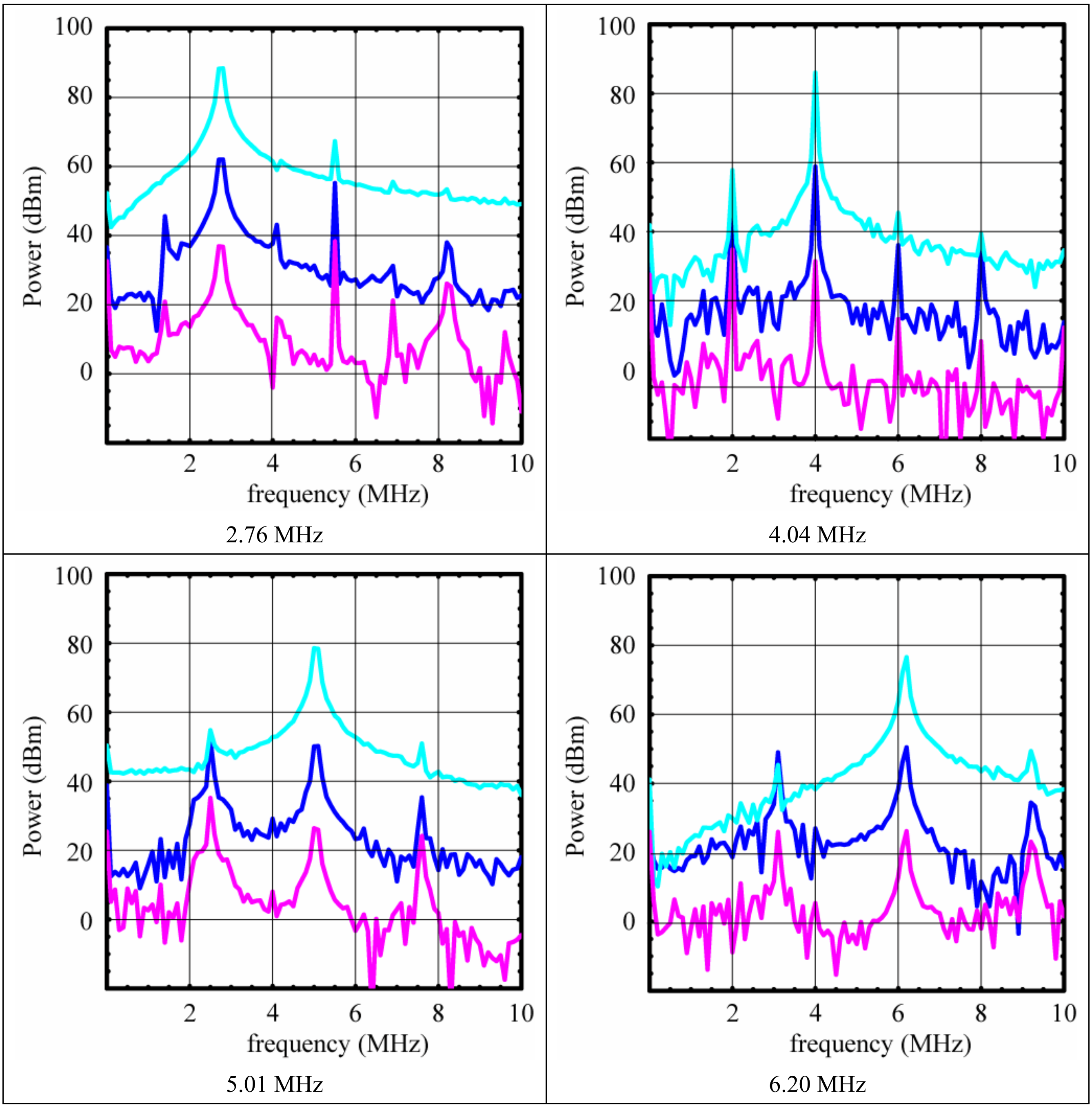

Fig.8 FFT results of the waveforms in fig.7 in the frequency range of 0~10MHz. From top trace, cavity gap voltage (light blue), driver stage voltage (blue) and cavity input current (red).

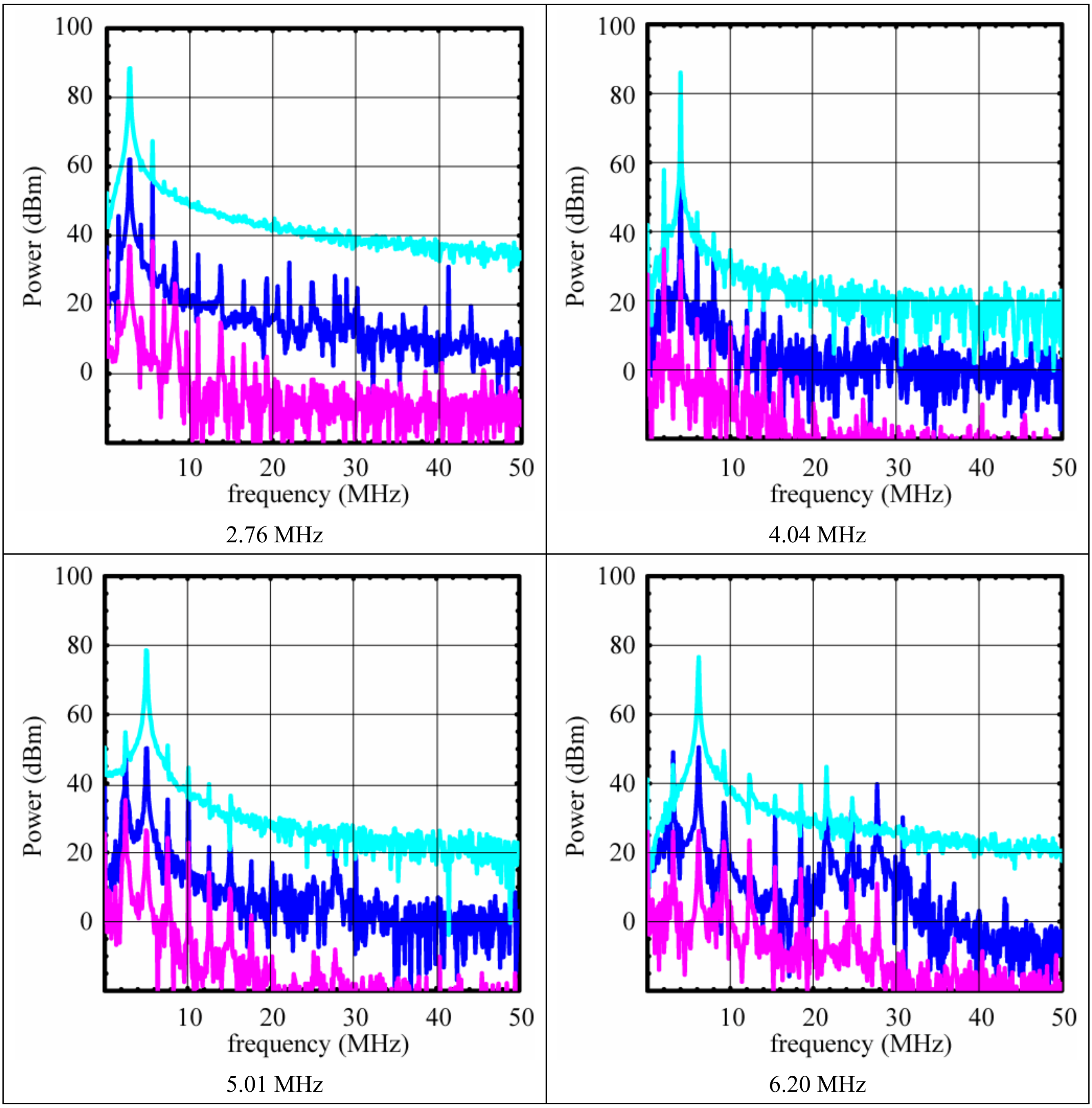

Fig.9 FFT results of the waveforms in fig.7 in the frequency range of 0~50MHz. From top trace, cavity gap voltage (light blue), driver stage voltage (blue) and cavity input current (red).

(Y Irie)