

LOI PROGRESS REPORT

— *Demonstration of a double-peak bunch structure at the injection* —

Experiment period: Wednesday, August 28, 2013 ~ Thursday, September 12, 2013

1. Introduction

By means of the digital master oscillator and the swept bandpass filter, signals with very low sub-harmonic and harmonic contents became available for triode input and phase detection of the cavity tuning. It then enabled producing higher gap voltage in a later acceleration cycle with the same buck regulator output current. It is also confirmed that the LOI give a significant effect upon the bunch formation at the RF trapping stage. The bunch shape showed a clear double-peak structure at -0.3ms, when the LOI voltage was slightly increased at the beam injection (fig. 1). Beam loading effect upon the waveform distortions of the grid voltage and cavity input current were observed with two different LOI voltage-demands: one with lower and the other with higher voltages at a later cycle.

In the following sections are described, experimental setup in section 2, experimental results in section 3, faults in section 4, and discussions & conclusions in section 5.

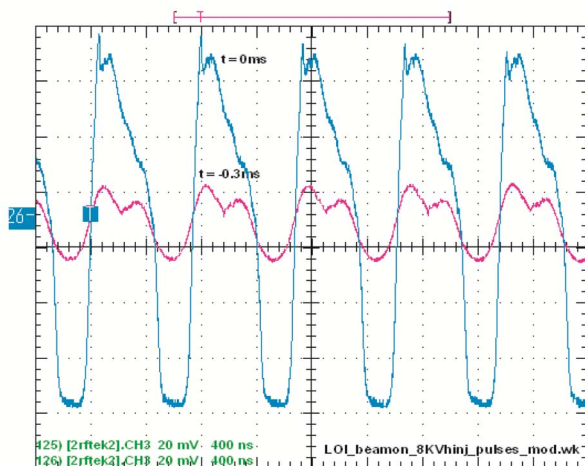


Figure 1: Bunch shapes at $t = -0.3\text{ms}$ and 0ms before the field minimum. Double peak structure can clearly be seen at -0.3ms .

2. Experimental setup

The analogue master oscillator (VCO) and the frequency doubler were replaced with the digital master oscillator (PXI platform) as shown in fig. 2. However, the analogue master oscillator was used in some beam experiment because of a “delay” problem of the digital master oscillator (MO). Although the digital MO with low harmonic contents is essential for

reducing the waveform distortions, there still remains the distortions by the higher harmonics generated in the subsequent amplifier chains, and by the sub- and higher harmonics contained in the beam [1]. The swept bandpass filter (SBPF) [2] was then used throughout this experiment to eliminate these components in the cavity tuning.

In order to measure the tetrode input voltage, 50Ω terminator of the all-pass network was removed, and a 50Ω coaxial cable was laid in place. The signal is fed to the MCR through the D21 receptacle at the 2RF6 breakout box in order to measure the thru gain in section 3-1.

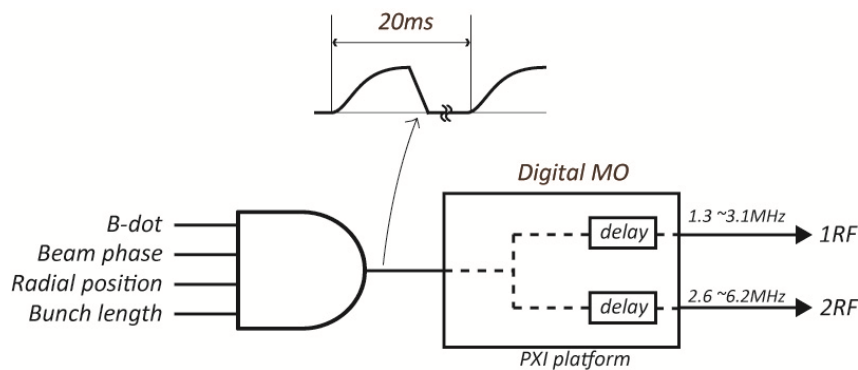


Figure 2: New master oscillator system.

3. Experimental results

3-1 Higher gap voltage at a later acceleration cycle

Waveforms of triode grid input and gap voltages were seriously distorted at a later acceleration cycle. Such a grid input causes an excessive increase of the buck regulator output current, while only a fundamental harmonic component produces a gap voltage. Also, phase detector output signal for cavity tuning becomes very noisy, and the stable tuning condition cannot be attained. This fact has made it difficult to increase the LOI gap voltage at the later stage due to the limit of the buck regulator output current. However, higher voltage could be achieved in this experiment by applying the digital MO and SBPF.

Fig. 3 shows the comparison of the gap voltage envelopes between the cases with an analogue MO and with a digital MO, where the gap voltage demand “LOIISISgapV.dat” was used for both cases. Owing to the SBPF, phase detector output is clear for two cases. Also, it is conspicuous that the voltage sag at a later cycle is improved with the latter case, while buck regulator output current was the same for both cases, i.e. ~14.3Amps (587mVrms): the

maximum current rating is 16Amps [3]. It can be thought the buck regulator output current is efficiently used for cavity excitation.

— The gain of the intermediate amplifier (AR) was not the same in the two photos of the fig. 3. Data with the digital MO at the AR gain 35% was taken actually. But, it was overwritten erroneously with the case at AR gain 50% during data acquisition.

The voltage sag may be improved if the AR gain is raised to be higher than 50%. However, beyond this gain, spikes appeared in the envelope at 0.5ms. So, we did not pursue this problem anymore. Thru gain from the tetrode input to the gap voltage is compared in fig. 4 for the measurements and the SPICE simulation, where the cavity shunt impedance is assumed to be constant, 538Ω [4]. Similar sag is seen in the measurements. While the cause of the sag is not known, it may be due to the fact shunt impedance is not constant, to change of another parameter such as valve gain, or to both.

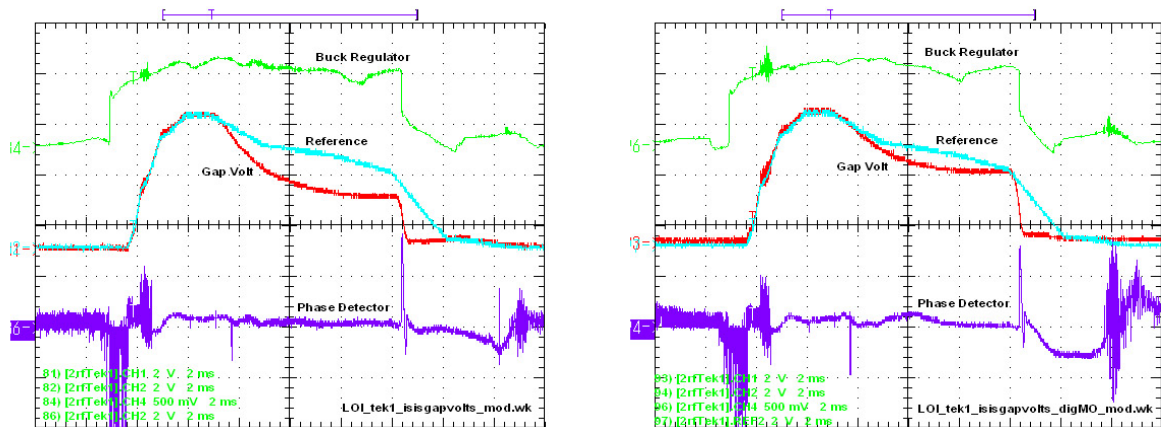


Figure 3: Operations with analogue MO (left) and digital MO (right). From top in each frame, buck regulator current, gap volt, reference gap volt (2RF4) and PD output ($20^\circ/\text{div}$). Peak gap voltage is 6.7kVpk . Gain of the intermediate amplifier was 35% and 50%, respectively.

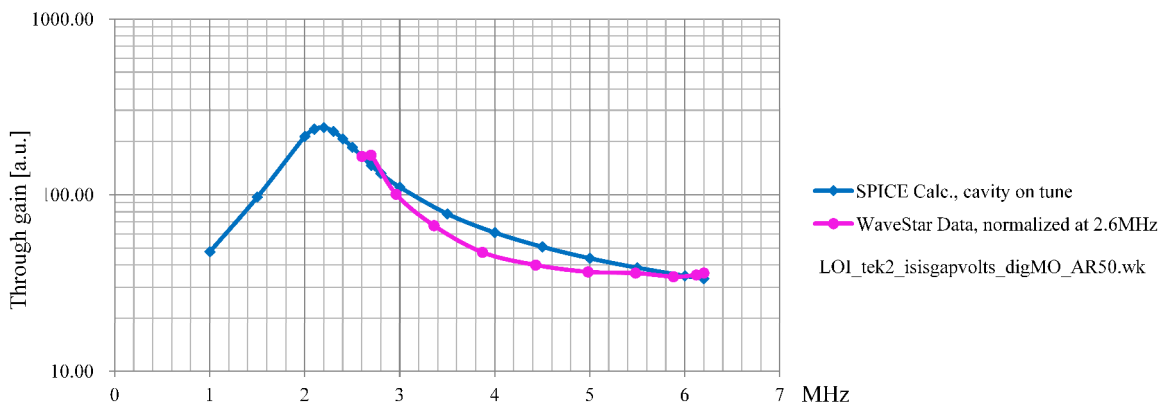


Figure 4: Comparison of thru gain from tetrode input to gap voltage. SPICE calculations (blue) assume the cavity is a pure resistor of 538Ω , and the measurements (pink) are normalized to the calculation at 2.6MHz.

3-2 Beam bunch shape at an RF trapping stage

The LOI has an advantage to change the gap voltage almost independent of the beam loading. The beam bunch shape was measured under the two voltage demands as shown in fig. 5. The one is to follow the “LOIsep13low”, where the gap voltage has almost the same pattern with the other 2RF systems up to 2.5ms, but decreases much faster afterwards. The other, which follows the “LOIhighinj”, has a slightly higher voltage at beam injection: 690V at injection start ($t = -0.4\text{ms}$) and 1.91kV at injection end ($t = -0.2\text{ms}$). The analogue MO was used in this experiment.

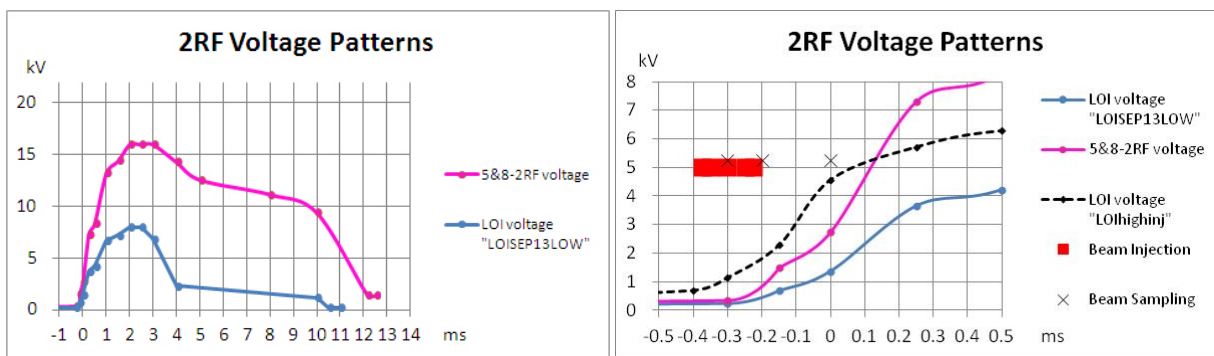


Figure 5: (Left) Typical voltage patterns for sum voltage of 2RF5 and 2RF8, and LOI voltage with demand, “LOIsep13low”. (Right) For the bunch shape observations, LOI voltage was slightly increased at injection with demand, “LOIhighinj”. See in the text.

The bunch shapes with these two voltage demands are compared in figs. 6 and 7. The beam intensity was 2.50×10^{13} ppp injected and 2.26×10^{13} ppp accelerated. In fig. 6, the bunch shapes were taken at -0.2ms and 0ms , while in fig. 7 these were taken at -0.3ms and 0ms . Difference in bunch shapes at -0.2ms and -0.3ms is conspicuous.

— *The trigger timing should, however, be the same for an exact comparison. Unfortunately, it was set at a different timing by mistake!*

The bunch shape was then retaken in a user cycle in October by A. Seville using 2RF4, 2RF5 and 2RF8 (fig. 8). The beam intensity was slightly higher than this experiment: 2.82×10^{13} ppp injected and 2.65×10^{13} ppp accelerated. The difference in bunch shapes at -0.3ms is clearly seen between those in figs. 7 and 8. Double-peaked bunch shape in fig. 7 is a typical feature for the 2nd harmonic system. Beam tracking simulation will be envisaged to explain these shapes quantitatively.

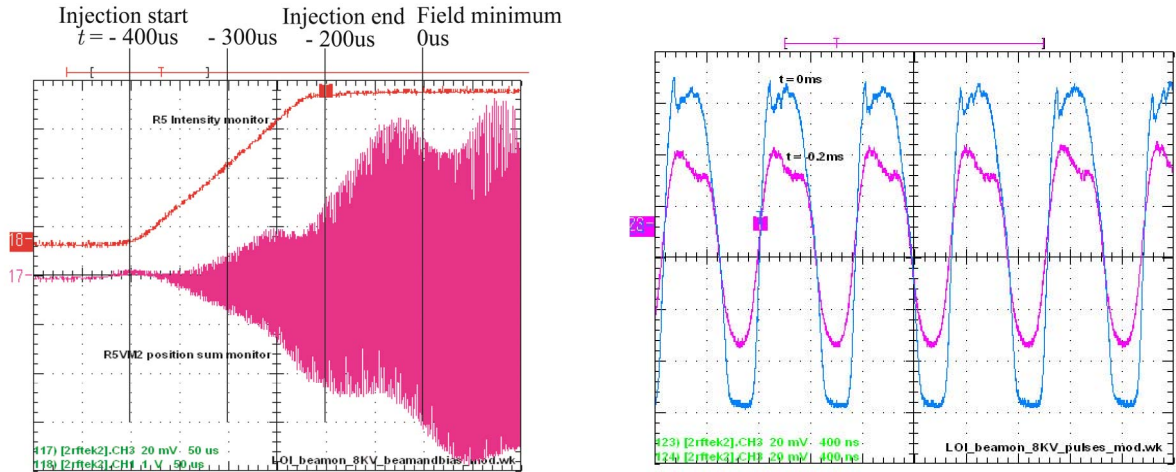


Figure 6: (Left) beam intensity (R5 intensity monitor) and beam envelope (R5VM2 vertical position sum signal) at injection for typical voltage pattern with “LOIsep13low”. (Right) bunch shapes at -0.2ms and 0ms.

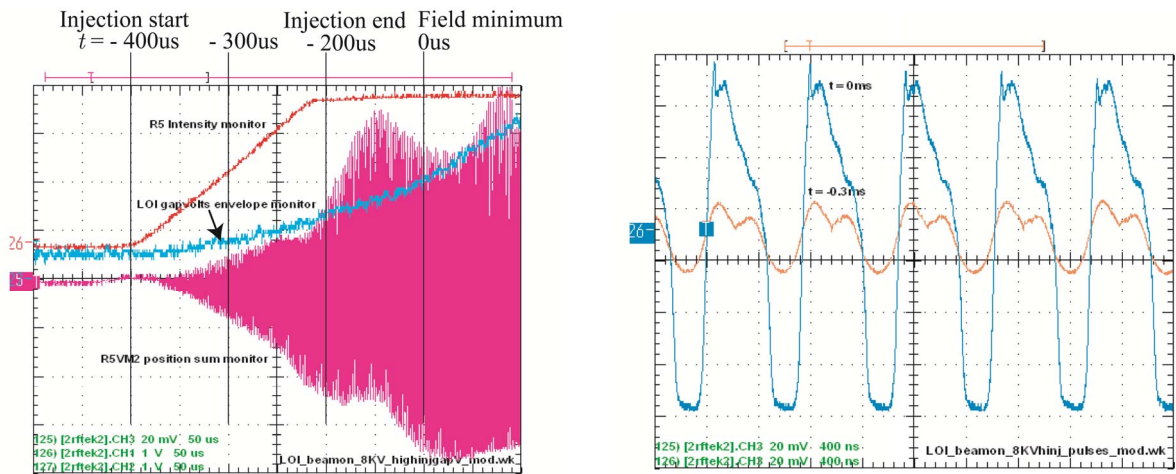


Figure 7: (Left) beam intensity (R5 intensity monitor) and beam envelope (R5VM2 vertical position sum signal) at injection for higher LOI voltage pattern with “LOIhighinj”. (Right) bunch shapes at -0.3ms and 0ms.

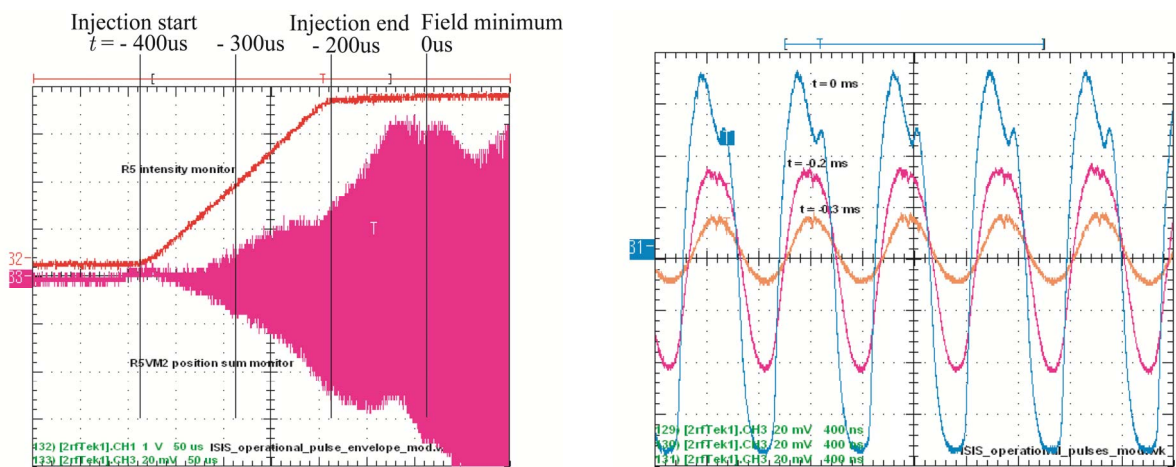


Figure 8: (Left) beam intensity (R5 intensity monitor) and beam envelope (R5VM2 vertical position sum signal) at injection for user cycle using 2RF4, 2RF5 and 2RF8. (Right) bunch shapes at -0.3ms, -0.2ms and 0ms. These figures were taken by A. Seville in October, 2013 after the LOI experiments in September.

3-3 Beam loading effect upon the waveform distortions

Beam loading effect upon the waveform distortions in the grid voltage and cavity input current were observed at 3ms and 7ms with two different voltage patterns (fig. 9). The one is to follow the above mentioned “LOIsep13low”, and the other to follow the demand “LOIISISGAPV”, which is similar to that of the 2RF5 and 8, but falls off quickly after 10ms. Beam intensity was 2.50×10^{13} ppp injected, and 2.27×10^{13} ppp accelerated. The results are shown in fig. 10. Although statistics is not good, it seems cavity input current is more affected with the sub-harmonic component by the beam. It is needed to acquire data in an average mode next time.

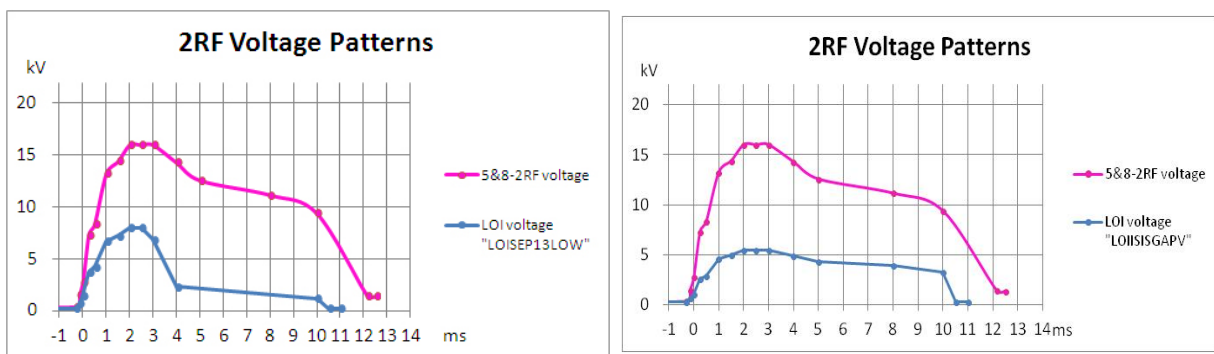


Figure 9: (Left) Typical voltage patterns for sum voltage of 2RF5 and 2RF8, and LOI voltage with demand, “LOIsep13low”. (Right) For testing beam loading effect, LOI voltage was increased at a later half-cycle with voltage demand, “LOIISISGAPV”.

4. Faults

In September 4, two of the 3 ϕ AC input lines, 415V, were found to be burnt at the contactor of the buck regulator step-start control box (fig. 11). Fuses of the AC input lines were, however, intact. The cause is not well known, but it may be due to loose connections of the cable termination. The burnt cable lags were replaced tightly next day.

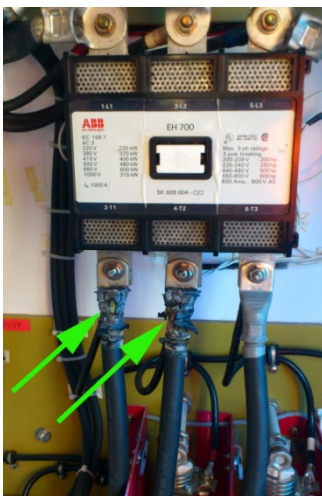


Figure 11: Cable lags at the buck regulator control box were burnt (arrows).

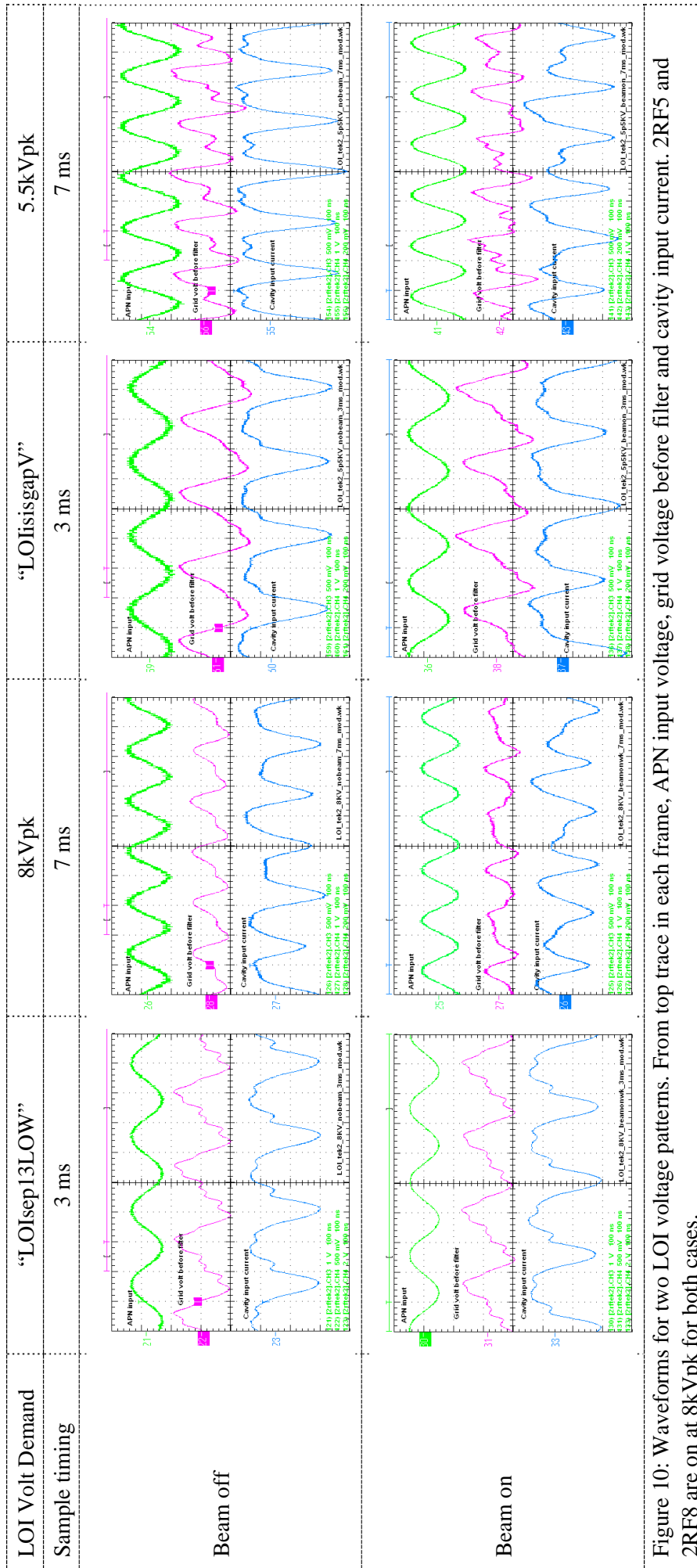


Figure 10: Waveforms for two LOI voltage patterns. From top trace in each frame, APN input voltage, grid voltage before filter and cavity input current. 2RF5 and 2RF8 are on at 8kVpk for both cases.

5. Discussion & conclusions

In these few years, main efforts have been devoted to the developments of the digital master oscillator (MO) and the swept bandpass filter (SBPF). In June 2011 (LOI-12), the SBPF was first tested on the LOI without beam. The SBPF could well improve the waveform distortions of the grid input voltage and cavity input current. In February 2012 (LOI-13), the digital MO with low harmonic contents was used to produce as high gap voltage as possible with a limited available current of the triode anode supply. It could achieve 8.4kVpk at ~1.6ms without using the SBPF. However, the digital MO was not used in the subsequent beam test because the output frequency had an offset of ~30kHz. In September 2012 (LOI-14), the SBPF was first applied to the phase detection of the cavity tuning system together with the delay equalizer to the cavity gap voltage. Although the analogue MO was then used, it could achieve 10kVpk. In September 2013 (this report), the digital MO together with the SBPF was first tested without beam to increase the gap voltage at a later acceleration cycle. It was successful, but further study with higher gain of the intermediate amplifier (AR) was not conducted because spikes on the gap voltage envelope appeared nearly at 0.5ms. The beam test on the bunch shape was expected with this system. However, due to the delay problem of the digital MO, which, *I heard but could not understand*, is associated with synchronization to the B-dot signal, the beam test was carried out using the analogue MO.

Since the digital MO and SBPF are fully developed and are now available, it will be the time to apply the LOI for the beam test with these technique. Interesting data may be acquired at the beam injection stage where we can take most advantage of the LOI with its low impedance characteristic. Beam tracking simulation is also necessary along with this study.

References:

- [1] LOI progress report LOI-13, June 4, 2012.
- [2] LOI progress report LOI-14, December 17, 2012.
- [3] D. Horan, "Summary of buck regulator current output upgrade work during LOI collaboration visit to ISIS", January 8-18, 2008.
[http://research.kek.jp/group/www-loi/12th.Doug.Mark.LOI Buck Regulator work summary Jan 08 Rev.1.pdf](http://research.kek.jp/group/www-loi/12th.Doug.Mark.LOI%20Buck%20Regulator%20work%20summary%20Jan%2008%20Rev.1.pdf)
- [4] LOI progress report LOI-2, September 24, 2005.