A HIGH SENSITIVITY FARADAY CUP FOR ULTRASHORT ELECTRON BUNCHES

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Abstract

The UED (Ultrafast Electron Diffraction) beamline of KAERI (Korea Atomic Energy Research Institute) WCI (World Class Institute) Center has been successfully commissioned. A S-band co-axial RF photogun with 1.5 cylindrically symmetric cells was used to remove multiple modes of the electric filed inside the cavity. It is designed to generate sub-picosecond electron bunches with energy up to 3.3 MeV. We have developed a system consists of an in-air Faraday cup (FC) and a preamplifier for charge measurement. Tests performed utilizing 3.3 MeV electrons show the system were able to measure ultrashort bunches with tens of femtosecond pulse duration at 10 fC sensitivity. In this paper, we shall present the design, calibration and test results of this system.

INTRODUCTION

The RF photogun of KAERI WCI Center is designed to generate sub-picosecond electron bunches with energy up to 3.3 MeV. The gun is a S-band co-axial RF photogun and has 1.5 cylindrically symmetric cells to remove multiple modes of the electric filed inside the cavity. The electrical beam from the gun can be delivered to UED experiments or can be further accelerated up to 20-30 MeV by the main accelerating cavity for X-ray/THz pump and probe experiments as shown in the Fig. 1. The UED section of the beamline, shown the Fig. 2, supplies electron bunches with 0.1 ps bunch length, few pC to tens of pC charge, and 3 MeV nominal energy by utilizing an achromatic bend via velocity bunching [1]. For ultrashort beams, one has to match the impedance between the FC and test network to minimize signal loss [2].

We have measured electron beam parameters of the UED beamline. Bunch charge was measured using the FC located at the end of the 45° beamline as shown in the Fig. 2. Beam energy was estimated by using dipole d1. Beam emittance was measured using quad q6 and screen s5 with quad scan technique.

FARADAY CUP

The FC geometry, as shown in the Fig. 3, was optimized using G4beamline [3] for 3.3 MeV electron beam. The aluminum stopper were able to stop more than 99.8% of the electrons. The stopper was grounded via a 10 MΩ resistor and connected to BNC output via a 20 kΩ resistor.

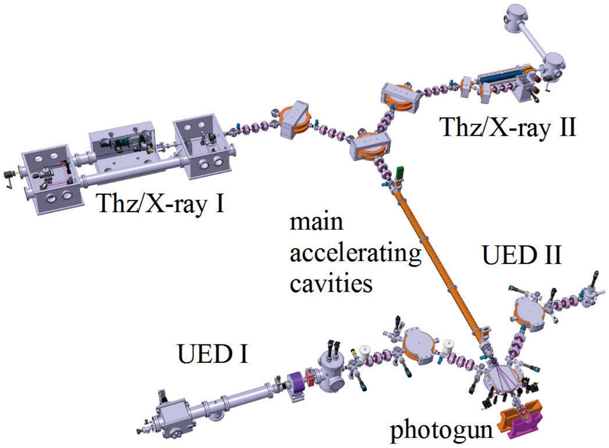

Figure 1: KAERI WCI center electron beamline layout.

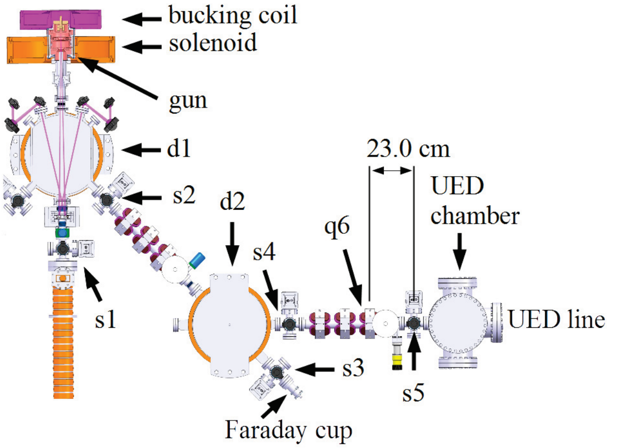

Figure 2: KAERI WCI center electron beamline UED section.

PREAMPLIFIER

Our UED beamline delivers 100 fs electron bunches with 100 A peak current which corresponds frequency of tens of THz. To eliminate signal loss due to impedance mismatch, we used a charge-sensitive preamplifier near the FC to integrate, amplify, and convert the current signal to a voltage signal. We have fabricated, calibrated, and tested this preamplifier using ultrashort electron beam and were able to achieve 10 fC sensitivity. The amplified signal has long rise time (few μs) and decay time (hundreds of μs) compared to the original pulse. So, the amplified signal frequency is about 1 kHz. Therefore, the loss by impedance

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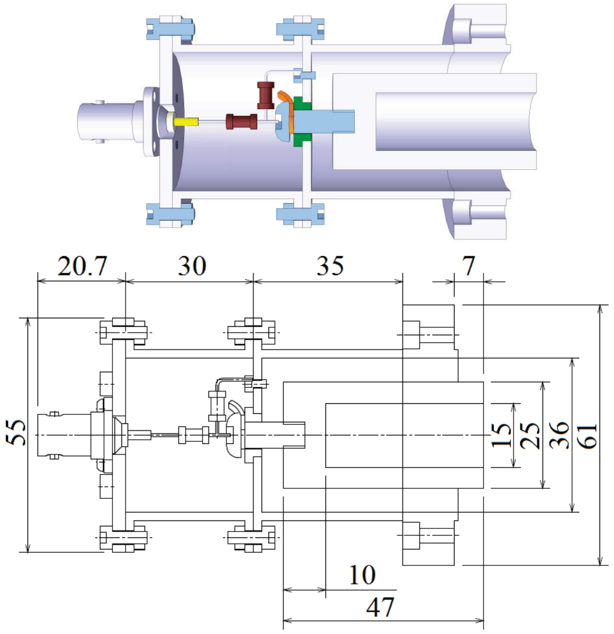


Figure 3: Low Energy Faraday cup. Dimensions are in mm unit.

mismatch is ignorable. The amplified signal are measured via an oscilloscope or ADC at remote locations.

The preamplifier is placed inside aluminum box to shield it from external noises. For powering the preamplifier, we use four 8-volt batteries placed inside the aluminum box. This can eliminate the noises that could leak in when external power supply is used.

Preamplifier Circuit Simulation

The preamplifier peak output voltage V_o is linearly dependent on the charge deposited q_{in} in the FC. This relation can be estimated using circuit simulation tool NL5 [4] and measured experimentally. Thus, the bunch charge can be obtained by directly measuring V_o.

The charge measurement system circuit diagram is shown in the Fig. 4. The capacitor C1 represents the capacitance between the FC stopper and external grounded shield. C1 is estimated to be around 10 pF. The BNC cable X1 has capacitance around 20 pF and is about 20 cm long.

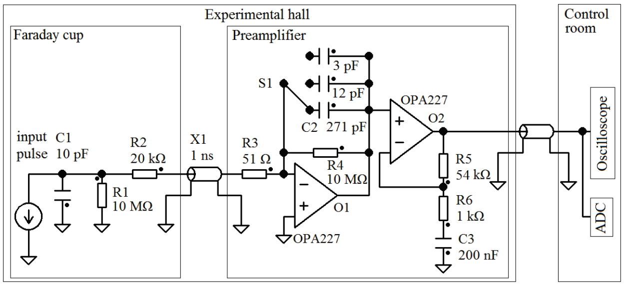


Figure 4: Charge measurement system circuit diagram.

The NL5 simulation result is shown in the Fig. 5 when 0.1 pC charge deposited to C1 while C2=271 pF. The output voltage signal decays to zero within 1 ms. The peak voltage to deposited charge ratio V_o/q_{in} and decay time are determined by C2, R4, R5, and R6 values. The maximum charge a preamplifier can measure before saturation is maximum charge limit of the preamplifier q_{max}. The simulated/calibrated V_o/q_{in} and q_{max} of the preamplifier for different C2 are given in Table. 1. As can be seen, q_{max} is proportional to C2, while V_o/q_{in} is inversely proportional.

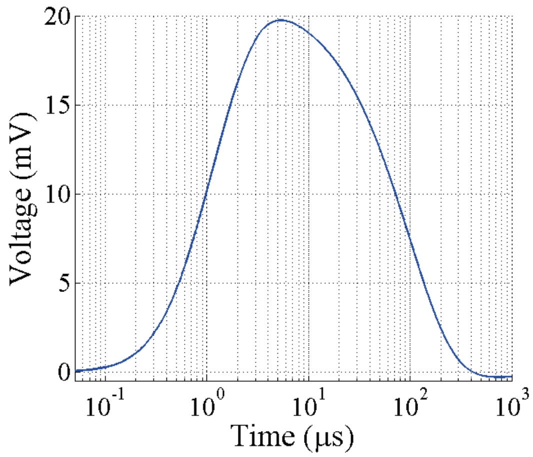


Figure 5: NL5 simulation result of the charge measurement system: output response of the preamplifier when 0.1 pC charge deposited to C1 (i.e. FC).

Preamplifier Calibration

Preamplifier was calibrated by depositing charges to FC and measuring the preamplifier output via an oscilloscope. A pulse generator, a voltage divider, and a capacitor were setup as shown in the Fig. 6 to deposit charges ranging from tens of fC to tens of pC. The voltages from pulse generator V_p were reduced by several orders of magnitude by the voltage divider. This reduced pulses (ranges from few μV to mV) can deposit fC scale charges to the capacitor C_0 and consequently same amount of charges are deposited to the FC.

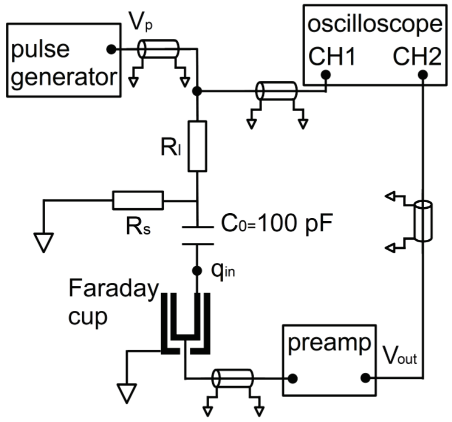


Figure 6: Preamplifier calibration setup.

For the setup in the Fig. 6, the deposited charge in FC is given by

$$q_{in} = C_0 \frac{R_s}{R_s + R_l} V_p \qquad (1)$$

Where R_s/R_l is the resistor with smaller/larger resistance. The calibration results (i.e. V_o/q_{in} and q_{max}) when C2=3, 12, and 271 pF are shown in the Fig. 7 and Table 1. The preamplifier is linear up to 15 V and saturated beyond it.

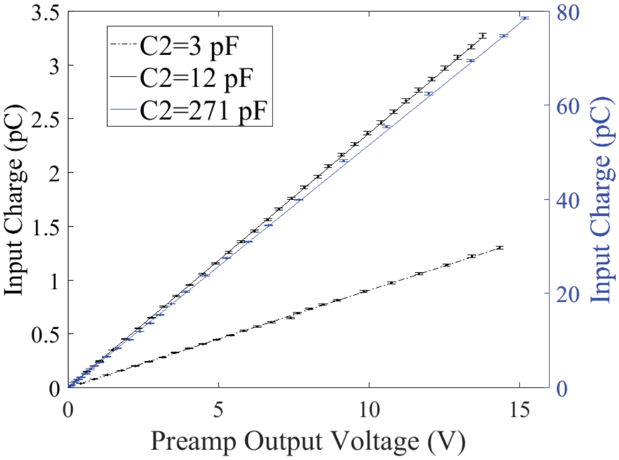


Figure 7: Preamplifier calibration results.

Table 1: Peak Output Voltage to Input Charge Ratio (V_o/q_{in}) and Maximum Charge Limit (q_{max}) of the Preamplifier.

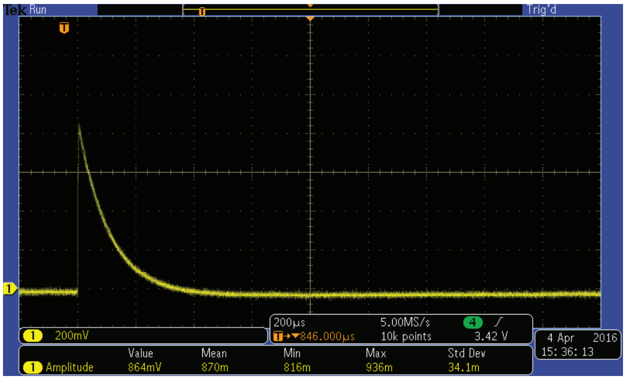
C2	**V_o/q_{in}**	**q_{max}**	**V_o/q_{in}**	**q_{max}**
	(simulated value)		**(measured value)**	
(pF)	(V/pC)	(pC)	(V/pC)	(pC)
3	16.04	1.0	11.02 ± 0.004	1.3
12	4.23	3.7	4.422 ± 0.006	3.2
50	1.06	15		
100	0.534	30		
271	0.198	81	0.192 ± 0.001	80
500	0.107	150		
1000	0.054	296		

CHARGE MEASUREMENT

Charge was measured at the end of 45° beamline using an oscilloscope. The dipole d2 was turned off and quads upstream were tuned to maximize charge transmission to the FC. The output signal measured using the oscilloscope is shown in the Fig. 8. The peak voltage 0.870 ± 0.034 V corresponds to 4.53 ± 0.18 pC charge, when C2 = 271 pF. The output voltage returns to zero in 1 ms (as predicted in simulation), which allows preamplifier to operate at 1 kHz repetition rate.

While predicted preamplifier sensitivity can be 0.01 pC (or better depending on the background noise level), the output voltage fluctuated in the experiment. The main source of this fluctuation is beam instability. We observed the beam image on the screen s3 (located right before FC) shifted pulse to pulse horizontally. Therefore, the amount of charge deposited to the FC varied pulse to pulse as well. We speculate this horizontal fluctuation is caused by the energy fluctuation, which is caused by the temperature fluctuation in the RF gun. Further tests will be performed with improved gun temperature control.

The charge measured above includes charge generated by laser beam incident on cathode and dark current. The dark current was measured to be 1.71 ± 0.04 pC by blocking the laser while RF is on. Thus, the electron bunch charge generated by laser is 2.82 ± 0.18 pC.



	Value	Mean	Min	Max	Std Dev
1 Amplitude	864mV	870m	816m	936m	34.1m

Figure 8: Preamplifier output measured using oscilloscope.

CONCLUSIONS

We have developed a novel charge measurement system to measure the bunch charge of ultrashort electron beam. We used G4beamline and NL5 simulations to study and optimize our system. The measurement results agreed with simulation predictions. The measured average bunch charge is 2.82 ± 0.18 pC and the beam energy was 3.26 MeV.

ACKNOWLEDGMENT

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