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Ramped Bunch Train (RBT) Experiment on 13.625 GHz DLA Structure

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I. INTRODUCTION

In general, the wakefield transformer ratio, by definition of the maximum energy gain behind the drive bunch to maximum energy loss inside the drive bunch, is less than 2 [1]. However, in a few cases, by using asymmetric charge distribution, i.e., ramped bunch or bunch train, theoretically we can obtain much higher transformer ratio [2-4]. In this article, we present the preliminary results of our first wakefield transformer ratio enhancement experiment carried on the AWA facility on December 2005.

Device Under Test The DLA structure built for this experiment has been described in [5]. Here, we just simply repeat its major parameters.

Geometric and accelerating parameters	*value*
ID of dielectric tube	10mm
OD of dielectric tube	12.68mm
Dielectric constant	16
Loss tangent	1.1×10^{-4}
Length of dielectric tubes	100×4mm
Group velocity	0.1c
Shunt impedance *r*	13.7MΩ/m
Q	2315
r/Q	5921Ω/m
Power Attn	5dB/m

We should point out that the RBT experiment is designed to implement in a traveling wave structure. But for the simplicity of the fabrication, instead of rf couples, we put two short cutoff copper tubes at the both ends of the structure. Due to the proper location of the field probe (82mm away from the upstream end), the detected wakefield signal is still a traveling wave within a few nanoseconds.

Experiment Setup Wakefield measurement of the dielectric-loaded accelerator has been successfully demonstrated by using the witness beam technique at the Argonne Wakefield Accelerator (AWA) facility [6]. In that case, the longitudinal wakefield from a driving bunch is probed by measuring the energy gain of the following witness bunch with different spacing. However, the requirement of two electric guns limits the scope of this technique. One optional way to detect the wakefield signal is using a field probe to transform the varying electric field behind the moving electron bunches into RF signal that can be transmitted and analyzed by available instruments.

Limited by the availability of the 15GHz oscilloscope, we cannot observe the high frequency wakefield signal in time domain directly. Therefore, the basic idea of the wakefield RF measurement technique is to down-covert the high frequency wakefield to a certain low frequency then restore it by the data processing. The block diagram of the experiment configuration is shown in Figure 1. The hardware enclosed in the left box consists of 1) a probe antenna which is located in the coupling slot of the 13.625GHz DLA structure under test with a coupling coefficient of ~ -60dB; 2) a broadband mixer to down convert the wakefield signal, which has a major frequency component of 13.6GHz, to 5.3GHz; 3) a local oscillator circuit provides 8.3GHz RF signal; 4) a loss pass filter with cutoff frequency of 5.3GHz to block the high frequency interference; 5) a Lecory 6GHz oscilloscope operated at the sampling rate of 20Gs/s. The down-converted wakefield signal is sampled by the digital scope and export to the software post-processor enclosed in the right box in the Figure 1 which has an inverse function of the hardware subsystem to restore the real 13.6GHz wakefield signal. The signal flow in the post-processor is shown as follows: the digitized down-converted wakefield signal is firstly interpolated to raise the sampling rate up to 80Gs/s that is to match the sampling rate of the 8.3GHz digital local oscillator; then these two signals are mixed up in a multiplicator; the final step is to use a digital high pass filter to block the low frequency interference from the signal multiplication. All data processing is finished in MATLAB® environment. Picture of the experimental setup is shown in figure 2.

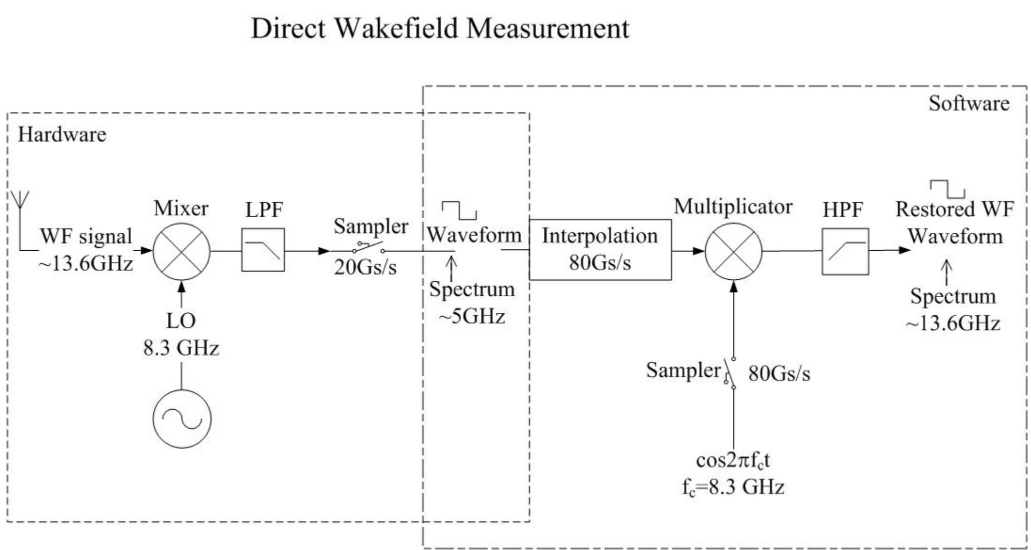


Figure 1 Block diagram of wakefield RF measurement technique.

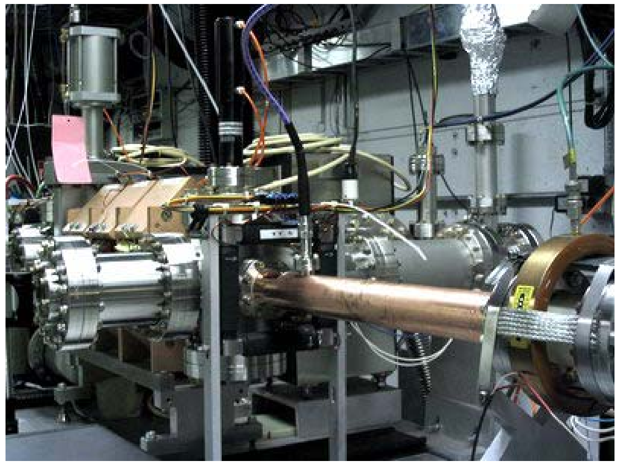
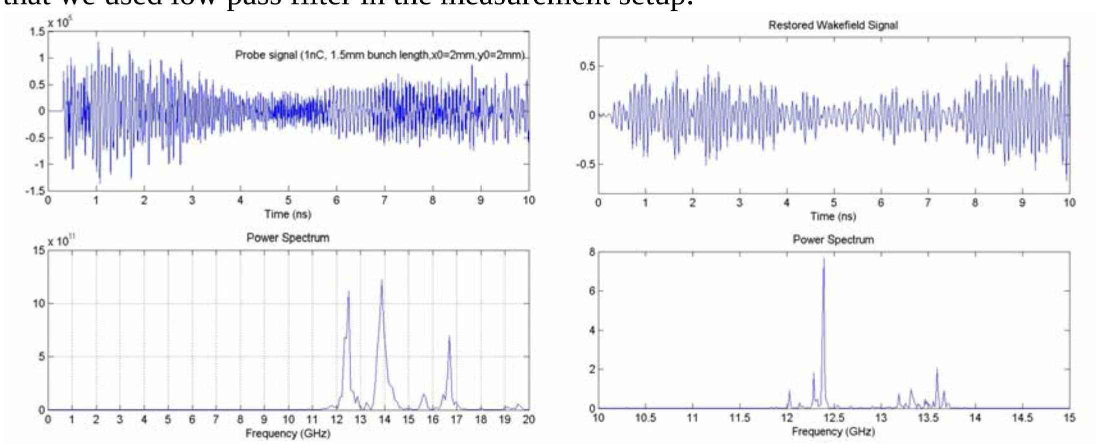


Figure 2 picture of RBT experiment setup.

Single bunch experiment The electron bunch launched in the experiment is around 3nC. Figure 3 shows the comparison of the simulated and measured probe signal and their frequency components. The simulation is finished by MAFIA with launching one 1nC, σz=1.5mm off center electron bunch (x0=y0=2mm). The measurement result is the restored probe signal (unconverted to 13.6GHz). In figure 3(a), there are three major frequency components: the first 12.5 GHz signal represents the major dipole mode (HEM11 mode) excited by off-axis electrons; the second peak is the major monopole mode (TM01 mode); the third one is higher order mode. In comparison, there are two major frequency spikes shown in figure 3(b): the first 12.4GHz signal is corresponding to the first dipole mode in the simulation; the second 13.6 GHz is corresponding to the TM01 mode. The difference of the frequency value between the simulation and measurement is due to the short simulation time (10ns is only to have 100MHz resolution bandwidth). The measured signal has 200nS duration which means 5MHz resolution bandwidth, and we just zoom in the first 10 nS in figure 3 for comparison. The third frequency component in the simulation does not show up in the measurement because that we used low pass filter in the measurement setup.



(a) simulation (b) measurement

Figure 3 simulated and measured probe signal

Two-bunch experiment -- equal charge case: in this experiment, we used a bunch train consisted of 2 equal charge bunches (1nC each) with time interval near one rf cycle of 1.3GHz. Figure 4 shows the detailed experiment results and the simulation as a comparison. The signal addition is obtained when we adjust the time interval of the two bunches to be 733ps, which means the wakefields excited by two electron bunches is in phase. In contrast, the signal subtraction shows up when they are out phase (180 degree difference from the addition case).

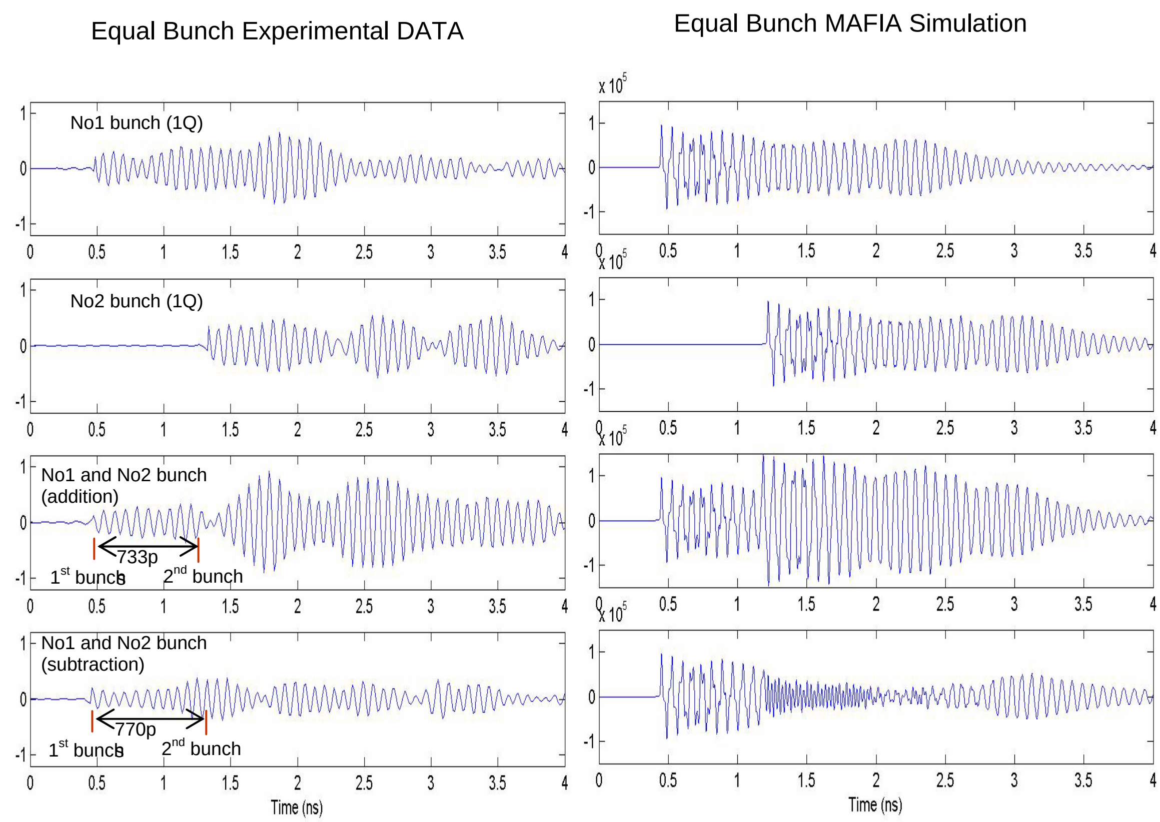
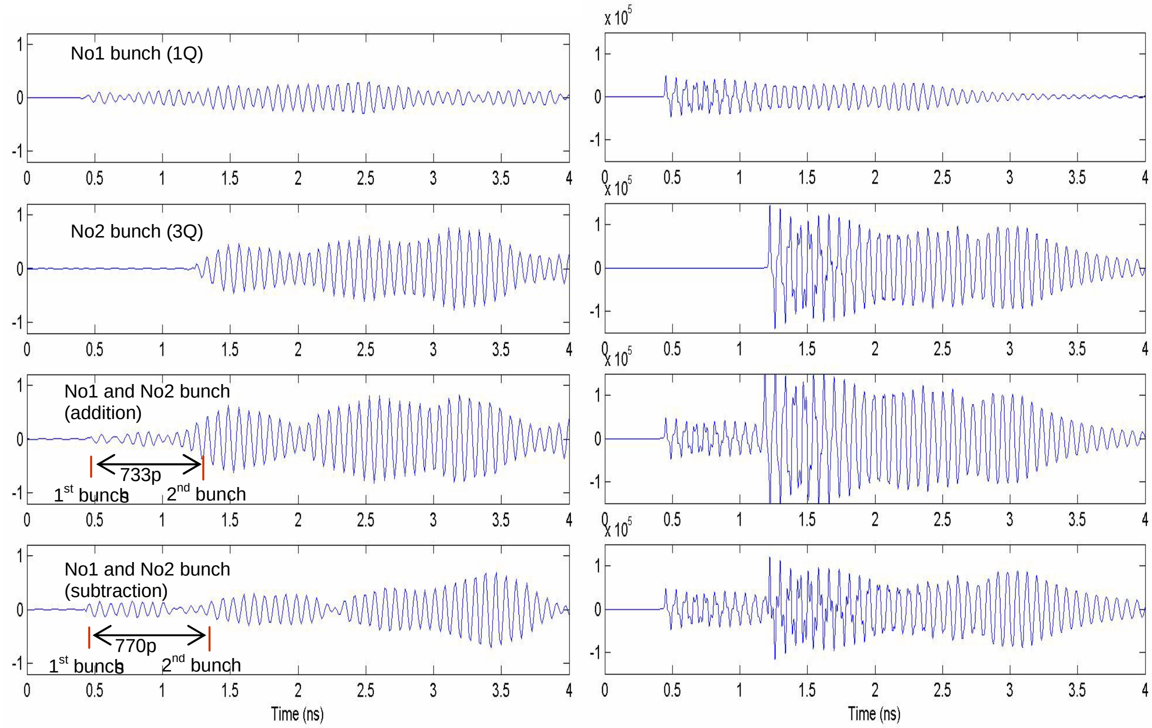


Figure 4 two equal bunches experiment—experiment and simulation

Two-bunch experiment -- ramped charge case: Instead of two equal charge bunches, in this case, we used a bunch train consisted of a leading 0.5nC bunch followed by the second 1.5nC bunch with the same time interval as the equal bunch case. The experimental results are shown in figure 5. Limited by the rising time of the mixer circuit, the experimental data do not show the sharp leading edge as that in the simulation. But the signature of signal superposition varying with the time delay appears very significant.

Ramped Bunch Experimental DATA Ramped Bunch MAFIA Simulation



Plan to the next run: Because we didn't have chance to use the spectra meter to monitor the bunch energy during the experiment, we cannot determine the wakefield transformer ratio directly. Therefore, the next running in near future is really expected.

Reference:

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