Development of Button Electrodes for SuperKEKB Rings

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Abstract

Button-type beam position monitors for SuperKEKB rings have been designed. The RF characteristics such as beam response, trapped modes or wake functions have been simulated using 3-D E-M codes such as GdfidL and HFSS. The estimated instability threshold from the trapped modes was much higher than the radiation damping time. The prototype units have been tested in the prototype-antechambers installed in KEKB rings. The mechanical reliability and the beam responses are also reported.

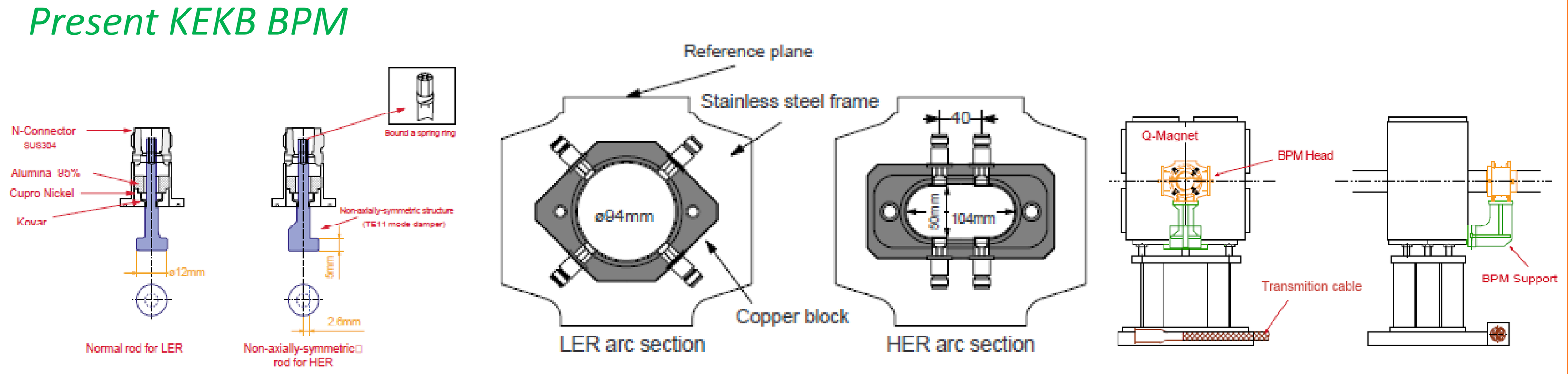
Introduction

SuperKEKB rings

- HER (7GeV, e-) LER (4GeV, e+) Damping Ring(1GeV, e+)
- Almost double the beam current, number of the bunches
- Reduce beam emittance down to 1/10
- Squeeze betatron function at IP
- New antechamber with TiN coating

x40 luminosity
8x10^{35} cm^{-2}s^{-1}

Present KEKB BPM

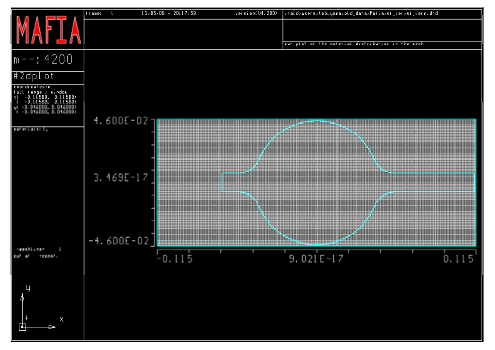


- All blazed structure: not easy to establish the final procedure
- Difficulty in repair, check the function
- HOM in low frequency (~5GHz), with larger coupling impedance

New BPM electrode with a vacuum flange-connection
Special BPM for IR nearest
- Estimation of coupling impedance with HFSS and GdfidL
- Beam test

	LER (positron)	HER (electron)	DR (positron)
Energy	4.0 GeV	7.0 GeV	1.05 GeV
Circumference	3016 m		135 m
RF frequency	508.886 MHz		
Beam current	3.6 A	2.6 A	0.08 A
Bunch number	2500		4
Bunch length	6 mm	5 mm	5 mm
No. of BPM	~450	~450	84
Horizontal emittance	3.2 nm rad	5.1 nm rad	13 nm rad
Coupling	0.27 %	0.25 %	10 %

LER antechamber



mode	Arc part (with NEG slot)	Wiggler part (w/o NEG slot)
1	989.17MHz	904.98MHz
2	1.7748GHz	1.1036GHz
3	1.9701GHz	1.9701GHz

Cu (HER) or Aluminum (or Cu) (LER)
Need to use 508.886MHz component for detection

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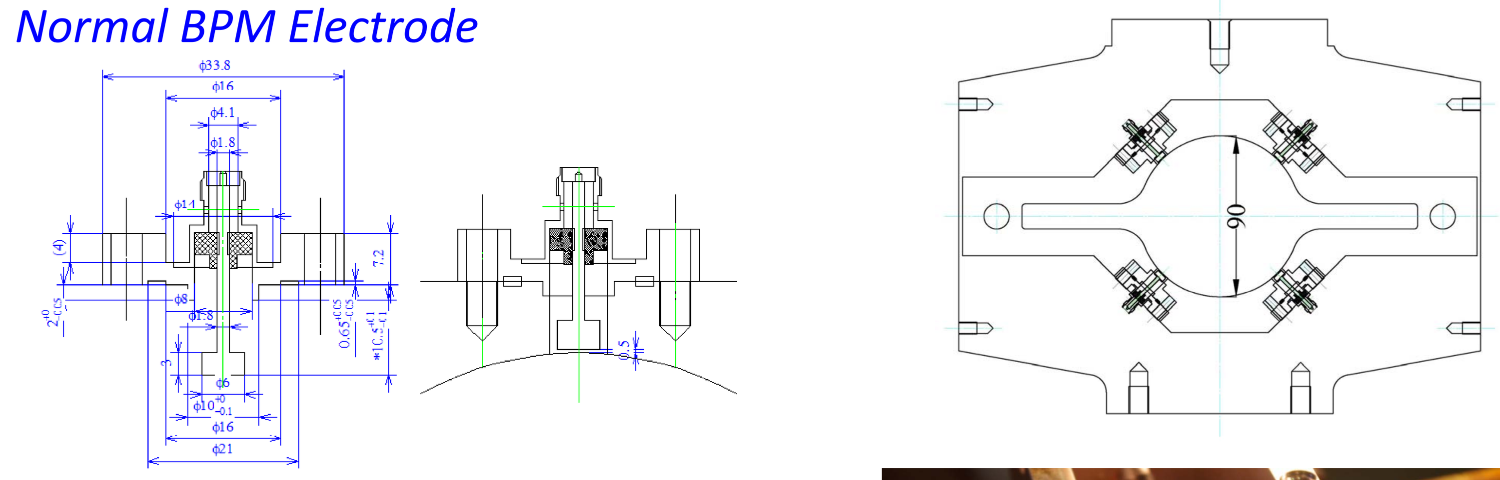
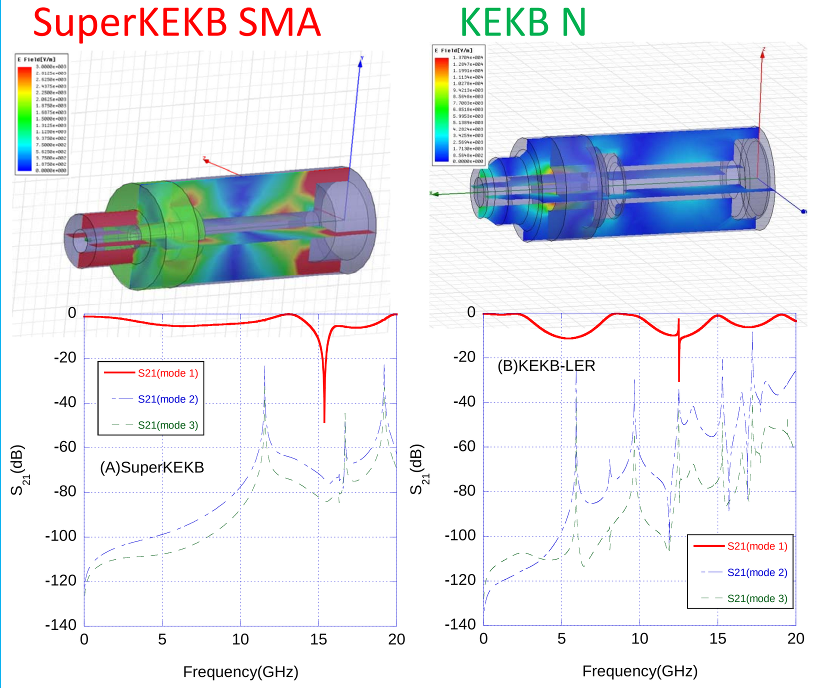
Normal BPM Electrode



- 6mm diameter button electrode
- Alumina ceramics εr=9.7
- Reverse SMA connector
- Mechanical precision <0.1mm

Frequency-domain simulation(HFSS)

SuperKEKB SMA   KEKB N

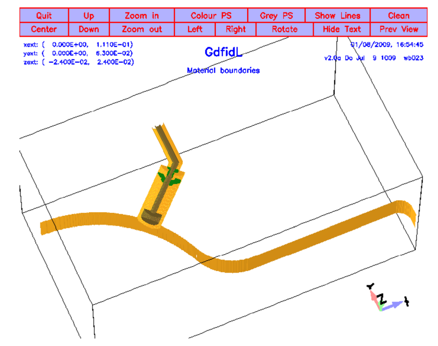


- Flat response up to 10GHz
- TE mode around button head at 12.5 GHz
- Trapped mode in ceramics around 16 GHz

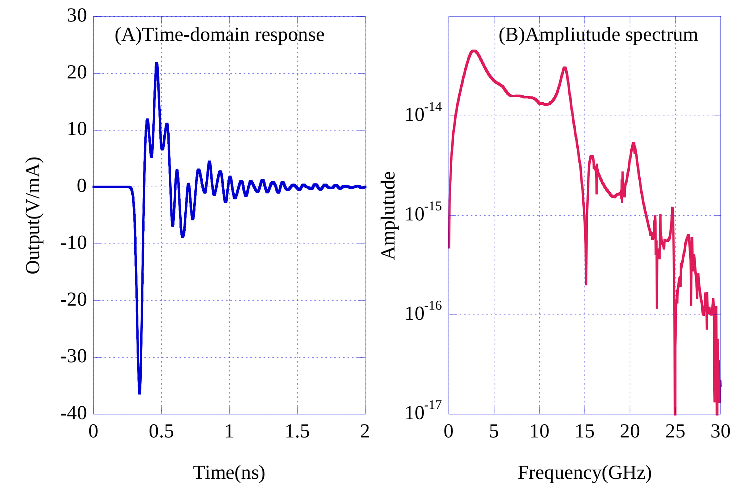
- Not so flat from 3GHz
- TE mode around 6GHz
- Trapped mode in ceramics around 12 GHz

Bunch length~6mm: frequency >15GHz will not be so important.

Time-domain simulation(GdfidL)

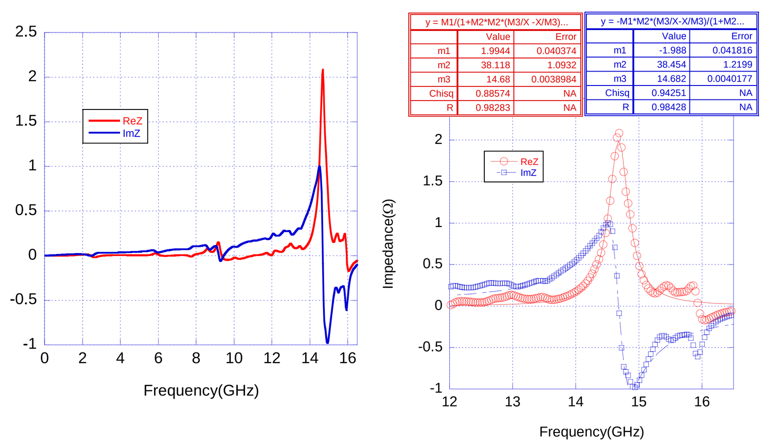


- 111x119x50mm
- 0.2mm mesh size
- 6mm bunch
- 5h30min CPU time for 5m wake under 32 cores of Opteron



Ringing ~12GHz, as anticipated
No dangerous behavior

Beam coupling impedance(MR)

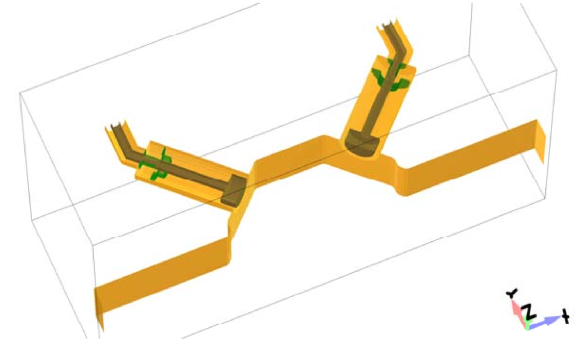


- Longitudinal loss factor: -0.16mV/pC/monitor
- Rsh~2Ω, Q~38 CF 14.8GHz
- KEKB-N: Rsh~10Ω, Q~48 at 7.3GHz

$$\tau_\mu^{-1} = \frac{eI_0\alpha}{2E_0T_0\omega_s}\sum_{p=1}^{\infty}\left(\omega_p^{\mu+}\rho(\omega_p^{\mu+})\mathrm{Re}(Z(\omega_p^{\mu+})) - \omega_p^{\mu-}\rho(\omega_p^{\mu-})\mathrm{Re}(Z(\omega_p^{\mu-}))\right)$$
$$\omega_p^{\mu+} = ((p-1)M+\mu)\omega_0+\omega_s$$
$$\omega_p^{\mu-} = (pM-\mu)\omega_0-\omega_s$$
$$\mu = 0,1,2,\cdots,M-1$$
$$\mathrm{Re}(Z(\omega)) = \frac{R_S}{1+Q^2\left(\frac{\omega_R}{\omega}-\frac{\omega}{\omega_R}\right)^2}$$
$$\rho(\omega) = e^{-\omega^2(\sigma_z/c)^2/2}$$

Growth time of longitudinal -inst. in the worst case ~ 120ms
<->7ms(KEKB-N)

Beam coupling impedance (DR)

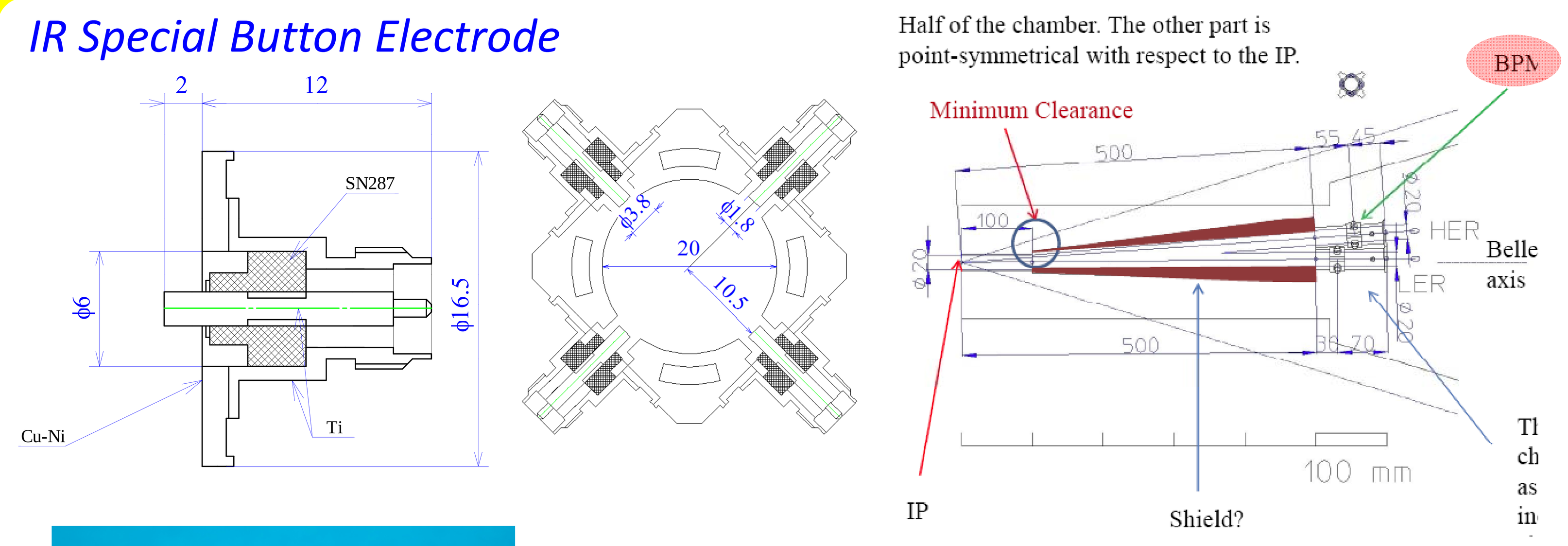


Much smaller duct size (34mm in diameter) on vacuum chamber (antechamber)

- Longitudinal loss factor:-2.6mV/pC/BPM
- Rsh=38Ω, Q~104 at 14.8 GHz

- Threshold beam current of the longitudinal instability >> maximum beam current.
- Transverse kick factor, wake function for ultra short bunch length are both negligibly smaller than other impedance sources.

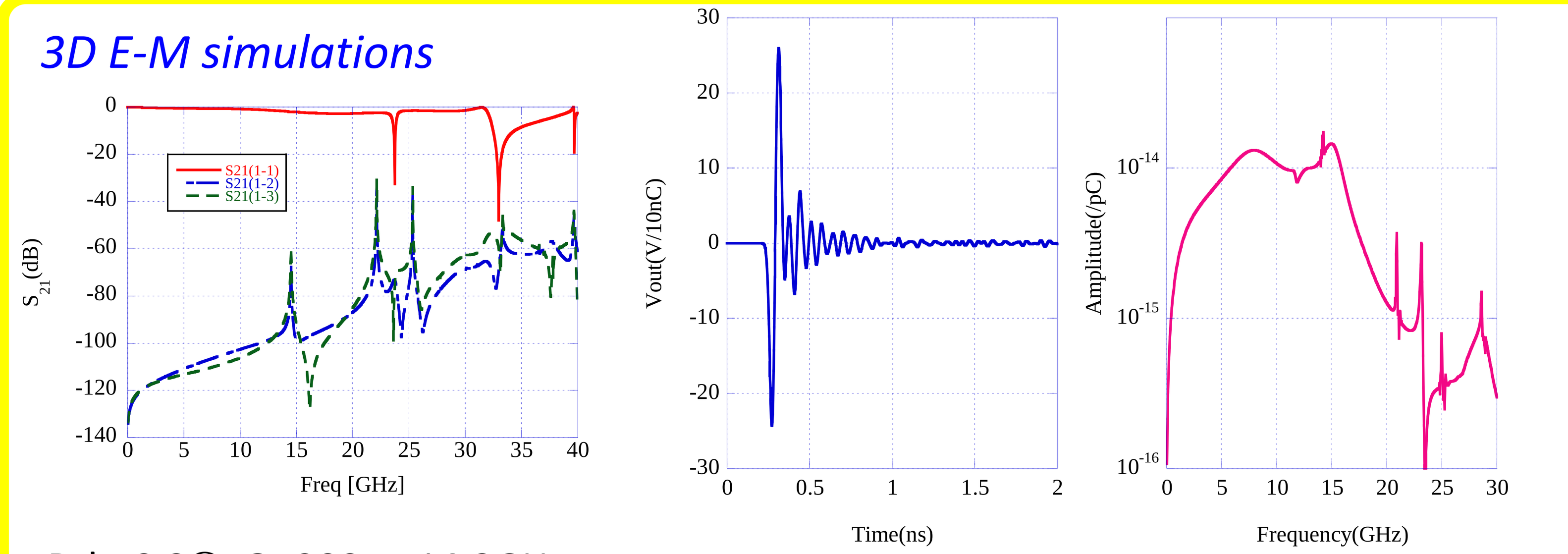
IR Special Button Electrode



Button head is simple rod of diameter of 1.8mm
Ti body and rod for strong magnetic field
Low loss ceramics (SiN) with εr~7.9
Cu-Ni flange to weld vacuum chamber made of Cu

Breaking strength of the center rod
☆Normal BPM (alumina ceramics) : 1kN
★IP special BPM (SiN) : 120N much weaker!

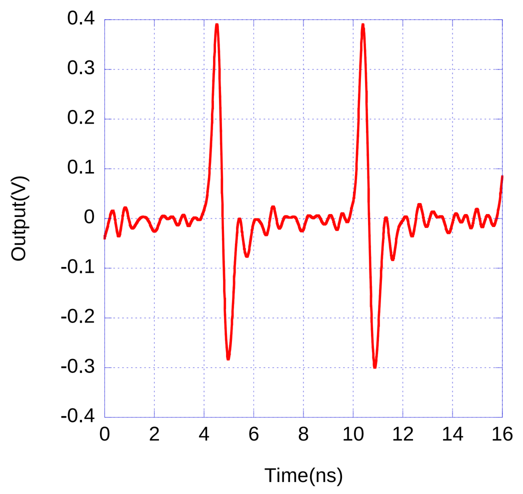
3D E-M simulations



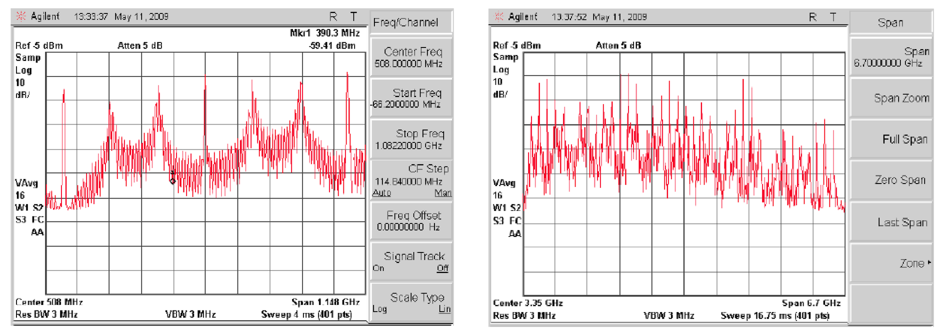
- Rsh~0.3Ω, Q~200 at 14.3GHz
- Total beam power passing through the FT~10W
- 508.886MHz componet~6dBm

Beam Response with the Real KEKB Beam

LER South ARC   LER Straight (Wiggler section)



Raw BPM signal observed with a 1.5GHz Oscilloscope passing 50m cable.



Beam spectrum around 508MHz and wideband

Summary

We have designed the BPM heads for SuperKEKB rings in normal section and the damping ring, and the special BPM for the IR nearest position monitor. The RF and beam coupled response such as frequency response and coupling impedance are estimated using 3D electromagnetic simulation codes such as HFSS or GdfidL. The impedance was low enough not to cause the coupled bunch instability. The broad band characteristics was also calculated using much shorter bunch and the broad band impedance was confirmed small enough. Simulated signal output showed enough level for detection frequency and safe level for total pass power of the feedthrough.

The prototype monitor chamber was installed in KEKB-LER and the beam response was observed. The response was as expected and no major difficulty was found up to now.

We will replace most of the BPM chamber with the new BPM unit on SuperKEKB. The new damping ring for positron beam will also use the same type of BPM.