IBIC 2021
International Beam Instrumentation Conference

国家同步辐射实验室
NATIONAL SYNCHROTRON RADIATION LABORATORY

# DESIGN AND SIMULATION OF THE COUPLING STRUCTURE FOR SINGLE RESONANT CAVITY BUNCH LENGTH MONITOR

Huanxiang Tuo, Qing Luo, Fangfang Wu, Tianyu Zhou, Ping Lu, Baogen Sun†
National Synchrotron Radiation Laboratory (NSRL), University of Science and Technology of China (USTC)

## INTRODUCTION

FELiChEM is a large-scale experimental device built by the National Synchrotron Radiation Laboratory of the University of Science and Technology of China. The device has high pulse intensity, continuously adjustable wavelength, and the bunch length is on the order of ps. The bunch length monitor based on the resonant cavity is a non-intercepting measurement and has little effect on beam. Therefore, this measurement method is suitable for measuring the bunch length of FELiChEM. When the beam moves from the beam tube through the resonant cavity, several characteristic modes will be excited in the cavity. We extract the desired electromagnetic field, and then process it electronically to get the bunch length information. Compared to conventional double-cavity bunch length monitor, the single-cavity bunch length monitor more compact. In this paper, we designed a single-cavity beam bunch length monitor and its coupling structure based on the beam current parameters of FELiChEM.

## MODEL CONSTRUCTION

### Coaxial low-pass filter design:

The structure diagram of the filter is shown in Fig. 1. High-impedance lines are used to simulate series inductance, and low-impedance lines are used to simulate parallel capacitors. Several high and low-impedance lines are alternatelycascaded to form a low-pass filter.

### Diaphragm Loaded Waveguide Bandpass Filter Design:

The three-dimensional structure of the waveguide bandpass filter is shown in Fig. 3.

### rectangular waveguide:

The designed filter should be able to conduct and output signal at 8.568 GHz, so the rectangular waveguide model R84 is selected whose main mode frequency range is from 6.57 GHz to 9.99 GHz, and size is a=28.499 mm and b=12.624 mm.

### diaphragm:

The waveguide section is used as a series resonator, and the parallel inductance formed by the diaphragm is used as the coupling structure between the resonators .

### Single Resonant Cavity Bunch Length Monitor Design:

The structure of the finally optimized design of the bunch length monitor is shown in Fig. 5.

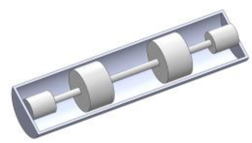

**Fig. 1.** Structure of low pass filter

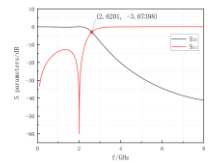

**Fig. 2.** S parameters of low pass filter

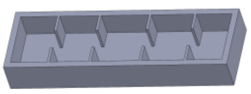

**Fig. 3.** 3D model of band pass filter

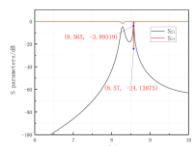

**Fig. 4.** S parameters of band pass filter

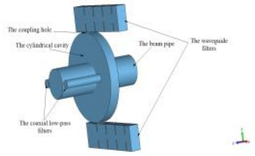


**Fig**. 5. structure of bunch length monitor

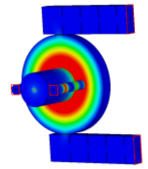

**Fig. 6.** electric field distribution of $TM010$ mode

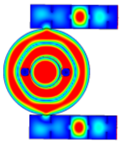

**Fig. 7.** electric field distribution of $TM030$ mode

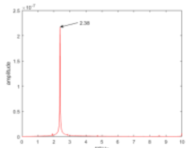

**Fig. 8.** output signal of low pass filter

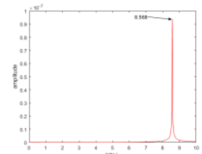

**Fig. 9.** output signal of band pass filter

## THEORETICAL ANALYSIS

### The beam current parameters of FELiChEM are shown in Table 1.

Table 1: Electron beam parameters of FELiChEM

| Parameter | Specification |
|---|---|
| Energy | 60 MeV |
| Energy spread | <240 KeV |
| Bunch charge | 1.0 nC |
| Bunch length | 5 ps |
| Micro-pulse repetition rate | 0.476 GHz |

### Derivation of the formula for solving bunch length:

for the Gaussian distributed beam, the n-th harmonic amplitude

$$I_n = 2I_0 \exp\left(-\frac{n^2\omega_0^2\sigma_\tau^2}{2}\right)$$

the harmonic voltage

$$\begin{cases} V_1 = I_1 \times Z_1 = 2I_0 \exp\left(-\frac{\omega_1^2\sigma_\tau^2}{2}\right) \times Z_1 & \omega_1 = n_1\omega_0 \\ V_2 = I_2 \times Z_2 = 2I_0 \exp\left(-\frac{\omega_2^2\sigma_\tau^2}{2}\right) \times Z_2 & \omega_2 = n_2\omega_0 \end{cases}$$

the bunch length

$$\exp\left[\frac{(\omega_2^2-\omega_1^2)\,\sigma_\tau^2}{2}\right] = K\frac{V_1}{V_2}$$

$$\sigma_\tau = \sqrt{\frac{2}{(\omega_2^2-\omega_1^2)}\ln\left(K\frac{V_1}{V_2}\right)}$$

## Simulation results

In the CST particle studiothe beam is loaded and the beam length is changed multiple times. The simulation results are shown in Table 2.

Table 2: Parameters of band pass filter

| Bunch length/(ps) | $\frac{V_{TM010}}{V_{TM030}}$ | Measurements of bunch length/(ps) | Relative error/(%) |
|---|---|---|---|
| 2 | 2.251 | 2.03 | 1.50 |
| 3 | 2.266 | 2.99 | 0.33 |
| 4 | 2.287 | 3.97 | 0.75 |
| 5 | 2.313 | 4.91 | 1.80 |
| 10 | 2.557 | 9.93 | 0.70 |
| 15 | 3.024 | 14.94 | 0.40 |
| 20 | 3.828 | 19.97 | 0.15 |

## CONCLUSION

We combines the filters with a single cavity based on the bunch length measurement theory and the filter design principle. By simulation with CST Microwave Studio and Particle Studio, bunch length monitor is designed that can couple output $TM010$ and $TM030$ modes at the same time. The simulation results show that the measurement error of the single-cavity bunch length monitor from 2 to 20 ps is less than 2%, which meet the measurement requirements of FELiChEM bunch length. Compared with a single cavity directly coupled with a probe, the signal interference of the output coupled with the filter is significantly reduced.