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# DESIGN AND SIMULATION OF THE WAVEGUIDE COUPLER FOR THE CAVITY BEAM MONITOR*

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*Abstract*

The waveguide coupling is an important way to extract the signals of the specific eigenmodes required. The design of the waveguide coupler, including the waveguide-to-coaxial adapter behind it for the cavity bunch length monitor is presented. The influence of the dimension parameters is analyzed, which offers the theoretical support for the design and application of cavity bunch length monitor or cavity beam position monitor (CBPM). A series simulation based on CST is performed to verify the feasibility, and the simulation results show good performance.

## INTRODUCTION

Beam monitors based on the RF resonant cavities have great potential especially for high quality beam sources because of many advantages, such as simple structure, wide application rage, and high signal to noise ratio. The fields of the eigenmodes within the cavities should be coupled out by some means and the beam parameters could be calculated according to the output signals. In a general way, there are two types of couplers used in the cavity beam monitor. One is antenna coupler, the other is aperture coupler. One common application of aperture coupling is in waveguide coupler, where power from one cavity is coupled to the waveguide through small apertures in a common wall. Due to the cut-off frequency of waveguide, the output signals of waveguide coupler are relatively pure without low frequency interference. In this paper, we will introduce the design and simulation of the waveguide coupler, including the waveguide-to-coaxial adapter behind it for a cavity bunch length measurement system which will be installed in the National Synchrotron Radiation Laboratory infrared FEL (FELiChEM).

## THEORETICAL BASIS

The schematic of the cavity for bunch length measurement is shown in Fig. 1. When a series of bunches pass through the beam drift tube on the axis of the cavity, some eigenmodes are excited, such as TM0n0 modes, which are related to bunch length. We are able to determine the bunch length according to the signals of the TM0n0 modes coupled out from the cavity. In order to enhance the resolution capability of the bunch length monitor, we desire to extract the signal of TM050 mode which is resonating at 17.136 GHz from the cavity in practice. The frequency is so high that the signals need to be coupled by the waveguide, because a waveguide with the cut-off frequency is usually regarded as the high-pass filter, and the output signal is relatively pure without low frequency interference. As shown in Fig. 1, a small aperture is in the common wall of the cavity and the waveguide. The field in the cavity is coupled into the waveguide where the TM050 mode changes to TE10 mode. Then it enters into the coaxial probe through the waveguide-to-coaxial adapter with the TE10 mode turning to TEM mode. Finally, this information will be extracted from the feedthrough to the post-processing circuit.

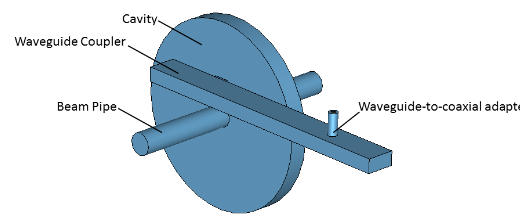


Figure 1: The schematic of the cavity monitor.

The magnetic field of TM050 mode within the cylindrical cavity is vortical field around on the cavity axis. The TE10 mode within the square waveguide has an electric field maximum on the centerline of the longest side (a/2). The process of mode conversion during the coupling is presented in Fig. 2.

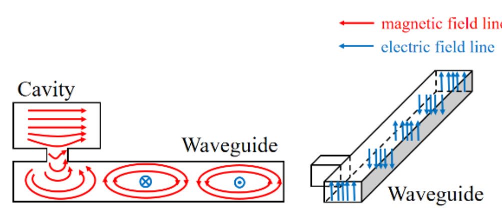


Figure 2: The electromagnetic field within cavity and waveguide coupler.

## PHYSICAL DESIGN AND SIMULATION

The output power is related to the position of the aperture because aperture coupling is the magnetic coupling. If we would like to obtain the higher power, the coupling aperture should be slotted at the place where the magnetic field of TM050 mode is larger. The magnetic field intensity distribution curves along the radial direction of TM050 mode are given in Fig. 3. It can be seen that the magnetic field intensity of TM050 mode reaches the local maximal value when r is equal to about 13.50 mm. It is difficult to install the waveguide coupler near the beam pipe, so we do not select 5 mm as the position of the ap-

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erture. The size we need to consider is shown in Fig. 4. and Table 1. In the following sections, each dimension parameter is analyzed with the 3D electromagnetic field simulation software CST.

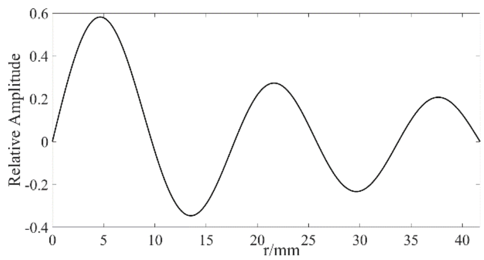


Figure 3: The magnetic field intensity distribution curves along the radial direction of TM050 mode.

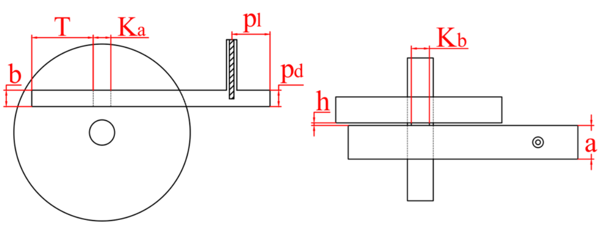


Figure 4: Engineering drawing and dimension parameter. The front view (left) and the top view (right).

Table 1: The Key Dimension Parameter

| Parameter | Explanation |
|---|---|
| a | Square Waveguide Broad Side |
| b | Square Waveguide Narrow Side |
| $K_a$ | Broad Side of Square Aperture |
| $K_b$ | Narrow Side of Square Aperture |
| h | Thickness of Square Aperture |
| T | Distance from Aperture to Left End Face |
| $p_l$ | Distance from Probe to Right End Face |
| $p_d$ | Insertion Depth of Coaxial Probe |

## *The Selection of Waveguide Type*

The frequency of the transmission signal is 17.136GHz, so the waveguide R180 is suitable. The main performance parameters of R180 are shown in Table 2.

Table 2: Performance Parameters of Waveguide R180

| Frequency Range of Fundamental Mode (GHz) | Cut-off Frequency (GHz) | Broad Side (mm) | Narrow Side (mm) |
|---|---|---|---|
| 14.5~22.0 | 11.571 | 12.945 | 6.477 |

It can be seen that a is equal to 12.945 mm, b is equal to 6.477 mm. In order to avoid the reflection within the aperture due to discontinuity, $K_b$ is set as 6.477 mm.

## *The Influence of Aperture Thickness h*

All the parameters except h are fixed and h is swept in CST. The influence of aperture thickness h on the TM050 mode frequency and the output amplitude can be obtained, which is shown in Fig. 5. It can be seen from the illustration that h has little impact on the TM050 mode frequency with the cavity. But the output power will decrease with increasing h. So we would like to minish the value of h. In practice, h depends on the thicknesses of the waveguide wall and the cavity wall. We make it equal to 1 mm in simulation.

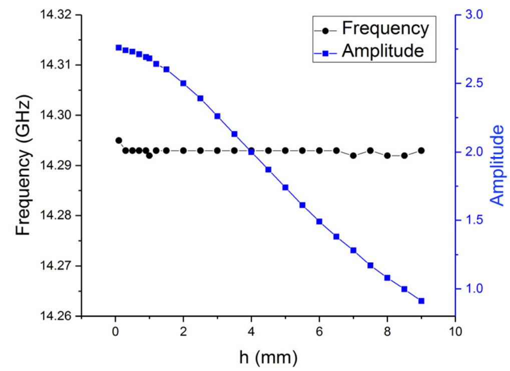


Figure 5: The influence of aperture thickness h on the TM050 mode frequency and the output amplitude.

## *The Determination of $p_l$ and $p_d$*

Both $p_l$ and $p_d$ are the crucial parameters, since they decide the reflection of the waveguide-to-coaxial adapter. Li Xiang [1] has studied the influences of $p_l$ and $p_d$ in a certain extent. In this section, more detailed data is presented. The model created in CST is shown in Fig. 6. Port 2 is the input end, while Port 1 is the output end. The transmission factors S12 are obtained with different $p_l$ and $p_d$. The simulation results are shown in Fig. 7.

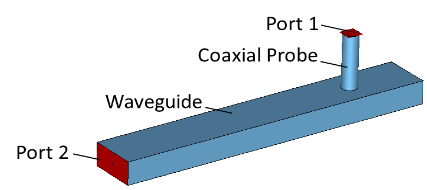


Figure 6: The waveguide model.

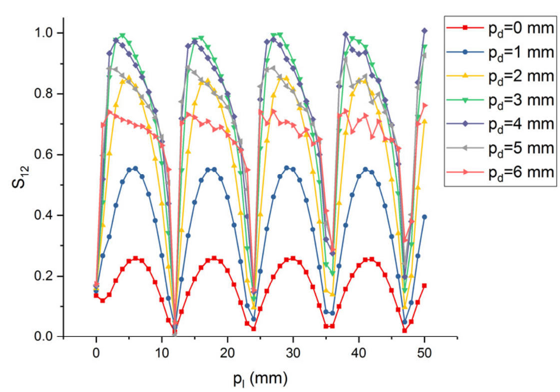


Figure 7: S12 in different $p_l$ and $p_d$.

The S12 closed to 1 is preferred, which means the signal transmits without reflection. From the Fig. 7, it can be seen that there is a great deal of variation in transmission preference when the probe inserts in different depths. For the same $p_l$, with the increase of $p_d$, S12 increases first and then decreases. There is a specific $p_d$ which makes S12 approximately equal to 1. After fine scanning, it is found that S12 may reach 1 when $p_d$ is equal to 3.4 mm.

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What's more, for the same $p_d$, S12 varies periodically with the increase of $p_l$, since the standing wave is formed between the two end faces. The output power reaches the maximum when the probe penetrates at the antinode. The period which is equal to half of the guide wavelength can be calculated in theory. For a TEmn mode in square waveguide, the guide wavelength is [2]

$$\lambda_g = \frac{2\pi}{\sqrt{(\frac{2\pi f}{c})^2 - (\frac{m\pi}{a})^2 - (\frac{n\pi}{b})^2}} \tag{1}$$

Where $f$ is the frequency of the TEmn mode. In this case, the guide wavelength of TE10 mode at 17.136 GHz is 23.76 mm. The period is 11.88 mm, which agrees with the simulation. From the Eq. (1), we can infer that TE10 mode with different frequency has different guide wavelength. Therefore, high order interference modes could be removed using this principle. For instance, the TM060 mode at about 19.992 GHz exists in the cavity and may be coupled out with TM050 mode as an interference signal. They have different guide wavelength, so a proper $p_l$ could avoid the interference. Figure 8 is S12 of the TM060 mode at 19.992 GHz and TM050 mode at 17.136 GHz versus $p_l$ when the $p_d$ is equal to 3.4 mm. It can be seen that S12 of 17.136GHz is nearly 1 while S12 of 19.992 GHz is very small when $p_l$ is 27.59 mm.

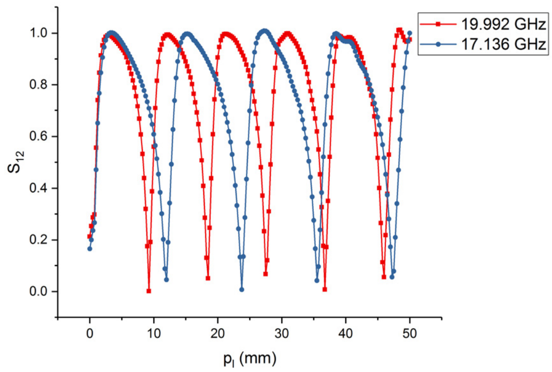


Figure 8: S12 of TM050 mode and TM060 mode.

### *The Determination of $K_a$ and T*

Both $K_a$ and T are related to the output power. The output amplitude in different T and different $K_a$ is calculated in CST. The simulation results are shown in Fig. 9. The working frequencies of TM050 mode in the cavity under different $K_a$ and different T are shown in Fig. 10. It can be seen that for the same $K_a$, the amplitude varies periodically with the increase of T+$K_a$/2 which is the distance from the end face to the centreline of the aperture. We can clearly find out the best T to maximize the output power. Moreover, for the same T, with the increase of $K_a$, the output amplitude will not increase constantly. Furthermore, the overlarge $K_a$ may have serious effect on the TM050 working frequency. Ultimately, T is set as 24.4 mm, while $K_a$ is set as 7 mm.

Using the method discussed above, a=12.945 mm, b=6.477 mm, $K_a$=7.00 mm, $K_b$=6.477 mm, h=1.00 mm, T=24.40 mm, $p_l$=27.59 mm and $p_d$=3.40 mm are finally determined.

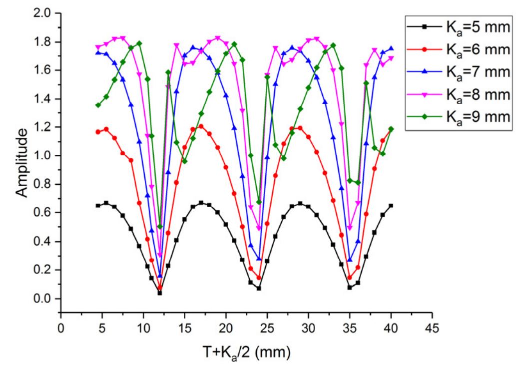


Figure 9: Relative Amplitude versus T+$K_a$/2 in different $K_a$.

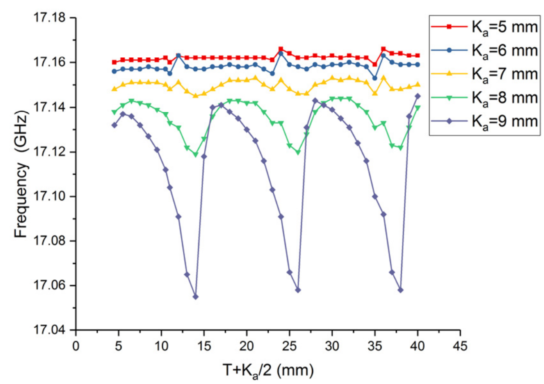


Figure 10: The frequency of TM050 mode within the cavity versus T+$K_a$/2 in different $K_a$.

## RESULTS AND CONCLUSION

To analyze the performance of the waveguide coupler, the whole cavity with coupler was modeled in CST. S parameter, external quality factor and resonant frequency are shown in Table 3.

Table 3: Simulation Results

| Performance Parameter | Value |
|---|---|
| Transmission Coefficient (S12) | 0.998 |
| TM050 Mode Frequency in Cavity without Waveguide Coupler | 17.134 GHz |
| TM050 Mode Frequency in Cavity with Waveguide Coupler | 17.136 GHz |
| External Quality Factor (Qext) | 1859.407 |

S parameter is approximately equal to 1 and the external quality factor is very small, which means the information required is coupled out completely with large amplitude. The resonant frequency is almost unchanged before and after the installation of the waveguide coupler. This phenomenon suggests that the coupler has little effect on the original electromagnetic field within the cavity. According to the results obtained from the CST, this waveguide coupler shows good performance in the process of the information transmission.

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