NEW CALIBRATION METHOD FOR RADIAL LINE EXPERIMENT

Xiaowei Wu, Hao Zha, Jiaru Shi, Huaibi Chen,
Department of Engineering Physics, Tsinghua University, Beijing, 100084, P.R.China and
Key Laboratory of Particle&Radiation Imaging, Ministry of Education, Beijing, 100084, P.R.China

Abstract

A radial line experiment is proposed to test the SiC load disks of the choke-mode structure. However, the general calibration cannot work out in this situation due to lack of matched load. A new calibration method named multi-offset short calibration is proposed. The principles of the method and the calibration steps involved are presented and the results of actual experimentation are used to validate the method. The results show multi-offset short calibration is a feasible method and that this method can provide a viable calibration scheme for radial line measurements.

INTRODUCTION

The Compact Linear Collider (CLIC) is the next generation electron-positron collider proposed by European Organisation for Nuclear Research (CERN). CLIC uses a room temperature main accelerator that works at X-band frequencies which in turn causes the wakefield inside to reach a critical state. The transverse wakefield must be adequately damped in order to preserve the luminosity of the colliding beams [1][2]. A variety of damping schemes are presented to achieve wakefield suppression. As a promising CLIC main accelerating structure, choke-mode structure can suppress the wakefield effectively without affecting the accelerating mode. The choke-mode accelerating structure was first proposed by Tsumoru Shintake [3], as shown in Fig. 1. As the matched load lays in the outer

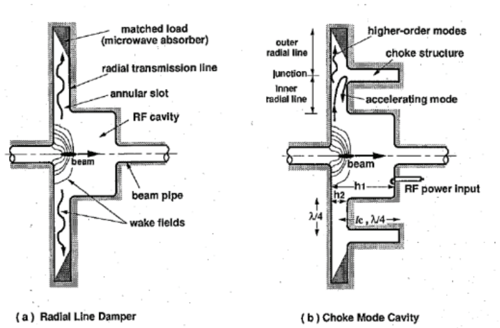

Figure 1: The choke-mode cavity [3].

radial line of the choke-mode cavity, we need to carry out radial line experiments to test the reflection of this load. However, we cannot measure the radial line directly in the actual experiment. As such we must use a conversion structure which is shown in Fig. 2 to convert the radial line into a coaxial line. This leads to reflection occurring in the transition area of the structure, which will need to be calibrated. However, without a matched load for the radial line we are unable to simply use general calibration theory in this situation.

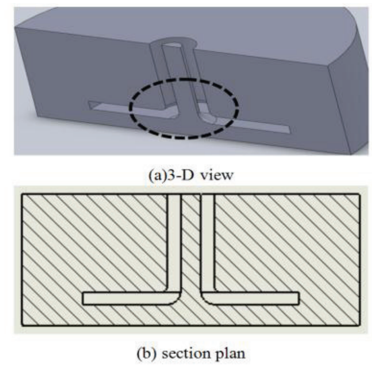

Figure 2: The conversion structure for radial experiment.

In order to carry out the radial line experiment which will allow us to test the properties of the load and to solve the problem of not being able to calibrate without a matched load, a new calibration method called multi-offset short calibration is proposed. This report introduces the principles of the method and the calibration steps involved, then uses the results of our simulation and actual experimentation to validate the method. We also make quantitative analysis of the factors that affect the calibration results. The results show multi-offset short calibration is a feasible method and that this method can provide a viable calibration scheme for radial line measurements.

PRINCIPLES OF MULTI-OFFSET SHORT CALIBRATION

General Calibration for Two-port Network

The incident wave and reflect wave of the two–port network shown in Fig.3 can be expressed as follows:

$$\begin{pmatrix} b1 \\ b2 \end{pmatrix} = \begin{pmatrix} s11 & s12 \\ s21 & s22 \end{pmatrix} \begin{pmatrix} a1 \\ a2 \end{pmatrix}. \quad (1)$$

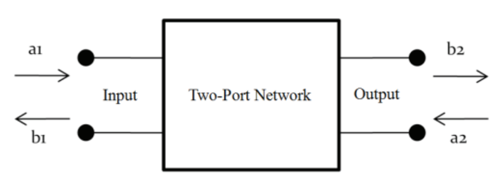

Figure 3: Two-Port Network. a1 and b1 are incident wave and reflect wave in the input port. a2 and b2 are incident wave and reflect wave in the output port.

The reflectance of the network is shown below:

$$\Gamma_{in} = \frac{b1}{a1} = y, \Gamma_L = \frac{a2}{b2} = x \cdot \quad (2)$$

Γ_{in} is the reflection coefficient of the input port and Γ_L is the reflection coefficient of the output port. With (1) and (2):

$$y - s22 \cdot x \cdot y + D \cdot x - s11 = 0 \cdot \quad (3)$$

Here $D = s11 \cdot s22 - s21 \cdot s12$ [4].

To calibrate two-port network is to calculate $s11$, $s22$ and D. General calibration theory uses short load, open load and matched load to calculate those three parameters.

However, there is no ideal matched load for radial line. We cannot simply use general calibration theory in radial line experiment. In order to calibrate the coaxial-radial line conversion system shown in Fig. 2, a new calibration method called multi-offset short calibration is proposed.

Multi-offset Short Calibration

In the situation lacking of ideal matched load, use another short load with a length of transmission line to replace matched load to calibrate. With short load, open load and the short load with transmission line, network parameters can be solved by general calibration theory. In order to decrease the error, more such short loads can be used to calibrate the system. Then use least squares method to calculate $s11$, $s22$ and D. Based on all above, a new calibration method named multi-offset short calibration is proposed. Multi-offset short calibration uses a series of short loads with transmission lines of different lengths instead of using short load, open load and matched load to calibrate.

The experimental setup for multi-offset short calibration is shown in Fig. 4. There are four radial loads with different radius of radial line in Fig. 4. The end of each radial loads are short loads and the radial line plays the role of transmission line for multi-offset short calibration method. From left to right, the radius of the radial line becomes larger. The key to achieving multi-offset short calibration is the changes of the radial line radius.

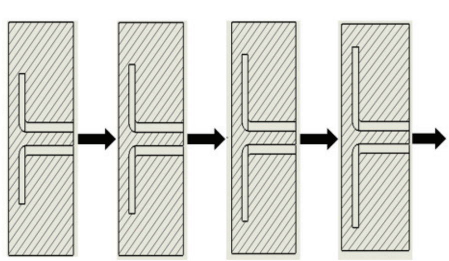

Figure 4: Experimental setup for multi-offset short calibration.

The following will explain the solution process of the reflection coefficient of the output port in detail. Suppose we use n radial line loads with different radius and the radius is a, r_1, r_2, r_3, …, r_{n-1}. Choose the radial load of radius a as a reference and set its location as the reference plane A. Use ref plane A to define a two-port network which is shown in Fig. 5.

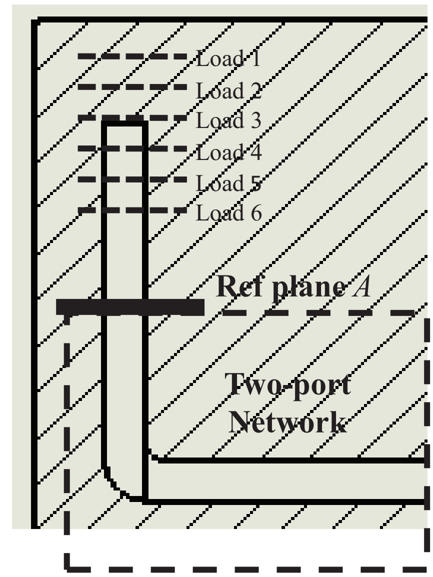

Figure 5: Two-port network for radial experiment.

For the radial load of radius r_1, E field at the short plane is 0.

$$E_{r_1} = J_0(kr_1) + \alpha N_0(kr_1) = 0 \cdot \quad (4)$$

Here $k = \frac{2\pi f}{c}$ and $\alpha = -\frac{J_0(kr_1)}{N_0(kr_1)}$. The E field at reference plane A is shown as follow:

$$E_z = J_0(ka) + \alpha N_0(ka) = AH_0^{(1)}(ka) + BH_0^{(2)}(ka) \quad (5)$$

Here $H_0^{(1)}$ spreads along $-r$ direction and $H_0^{(2)}$ spreads along $+r$ direction. The reflection coefficient of the output port (Γ_L) is shown below:

$$\Gamma_L = \frac{AH_0^{(1)}(ka)}{BH_0^{(2)}(ka)} = \frac{1 - j \cdot \alpha}{1 + j \cdot \alpha} \cdot \frac{J_0(ka) + j \cdot N_0(ka)}{J_0(ka) - j \cdot N_0(ka)} = x \quad (6)$$

By taking advantage of Bessel function, the reflection coefficient of the output port (x) can be exactly solved. The reflection coefficient of the input port (y) is measured in the experiment. With a series of x and y, the network parameters can be calculated by using least squares method.

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Summary of the New Calibration

1. Use radial loads of different radius radial line to measure a series of reflection coefficient of the input port (y) by experiment.
2. Calculate reflection coefficient of the output port (x) by the experimental setup parameters such as r and f and Bessel function.
3. Use least squares method and a series of x and y to calculate the network parameters.

RADIAL LINE EXPERIMENT

Experimental Setup

The model number of vector network analyser used in the experiment is Agilent E8364B. Its bandwidth is from 10MHz to 50GHz. The coaxial-radial line converting structure is shown in Fig. 6. We design and process one

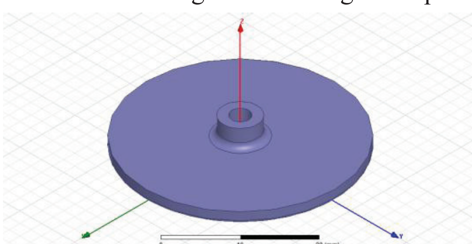
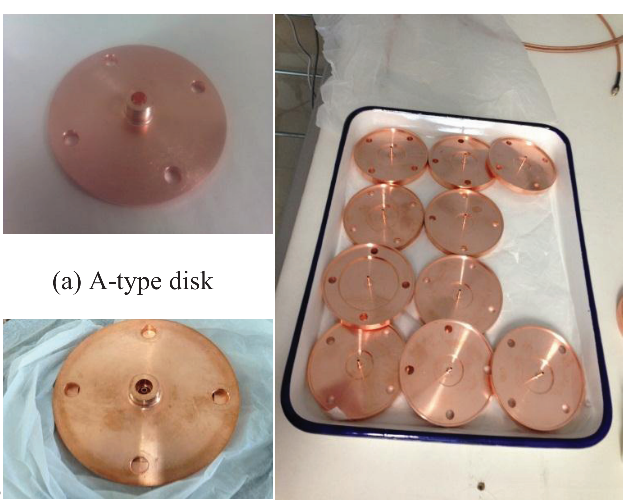


Figure 6: Coaxial-radial line converting structure.

A-type disk and ten B-type disks which is shown in Fig. 7 for the radial line experiment. The ten B-type disks have different radius of the radial loads. The radius is respectively 12mm, 13mm, 14mm, 15mm, 16mm, 17mm, 18mm, 19mm, 20mm and 32mm. When A-type disk is put upside on B-type disk which is shown in Fig.7(c), the space inside the two disks is same as the space shown in Fig. 6. Connect the disks to the VNA to measure a series of reflection coefficient of the input port (y).



(a) A-type disk

(c) A and B-type disks (b) B-type disks

Figure 7: A-type disk and B-type disks.

Experiment Data and Analysis

The results of the radial line experiment for testing and verifying multi-offset short calibration is shown in Fig. 8.

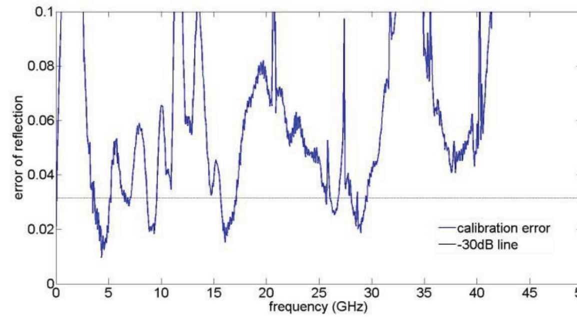


Figure 8: Error of reflection.

The error of the reflection is the difference between output port reflection coefficient (x) which is calculated by multi-offset short calibration and the ideal reflection coefficient. The smaller the error is, the more precise the new calibration method is. The error is almost below 0.05 in Fig. 8 and it means the precision of multi-offset short calibration is about -26dB. In some frequency band such as 15GHz~18GHz and 25GHz~30GHz, the new calibration method has a precision of -30dB. The results show that multi-offset short calibration is a feasible method and can be applied in radial line experiment.

CONCLUSION

In this work, a new calibration method named multi-offset short calibration is proposed to calibrate radial line system in the situation which is lacking of ideal matched load for radial line. Radial line experiments have been done to test and verify multi-offset short calibration. The results show multi-offset short calibration is a feasible method and that this method can provide a viable calibration scheme for radial line measurements.

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