

STRETCHED WIRE CALIBRATION FOR BEAM POSITION MONITORS WITH 2X THRU DE-EMBEDDING

T. Toyama*, High Energy Accelerator Research Organization, Tsukuba, Japan

Abstract

Calibration with stretched wire on a test bench is widely used for beam position monitors. Addressing impedance mismatches at both ends of the system is difficult, especially at high frequencies exceeding 100 MHz. Tapered pipes are sometimes utilized for better impedance matches which is difficult for applying to the BPMs, because the wire position moves in horizontal and vertical directions. To eliminate mismatch effects more efficiently in this system, we propose applying 2x Thru de-embedding and demonstrate its effectiveness through electromagnetic simulation using CST Studio Suite.

INTRODUCTION

Stretched wire calibration on a test bench is important in quality verification of manufactured devices, and in determining the actual beam position sensitivity coefficient. Conventional methods make it difficult to address the effects of impedance mismatches between the cables from/to a network analyzer and the wire. This problem can be solved by the 2x Thru de-embedding method using the proposed configuration. We explain this problem with the stretched wire calibration bench for the J-PARC MR BPMs. Next, the 2x Thru de-embedding method is introduced for a 4-port system having two wire input/output ports and two signal pickup ports. The method is simulated using the electromagnetic simulator CST studio suite, with a rectangular diagonal-cut BPM and a rectangular beam pipe. The position responses in the frequency domain were obtained, demonstrating favorable behavior at lower frequencies and degraded behavior at higher frequencies.

STRETCHED WIRE CALIBRATION TEST BENCH FOR J-PARC MR

As an example of stretched wire calibration test bench, we explain the system for J-PARC MR (Fig. 1) [1, 2].

In Fig. 2 the configuration of measurement and the responses from the wire input to the signal output (S parameters) are plotted, in the case with outer matching loads. Frequencies below 100 MHz seem usable.

In Fig. 3 the configuration of measurement and the responses from the wire input to the signal output (S parameters) are plotted, in the case with series matching loads at the wire. This matching method was proposed by F. Caspers [3]. The RF finger contacts are installed at the pipe ends to contact the end-plates, allowing the DUT to slide on the end-plates. Frequencies below 100 MHz seem usable. This ap-

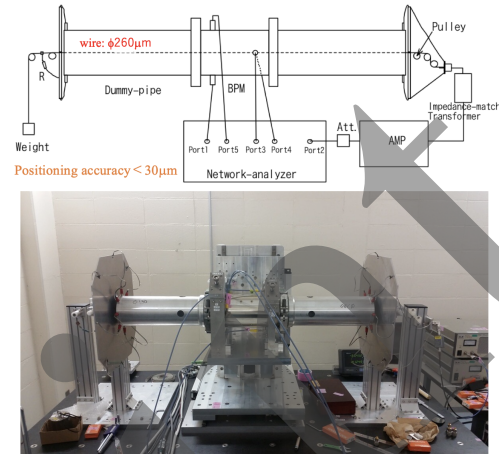


Figure 1: Stretched wire calibration system for J-PARC MR.

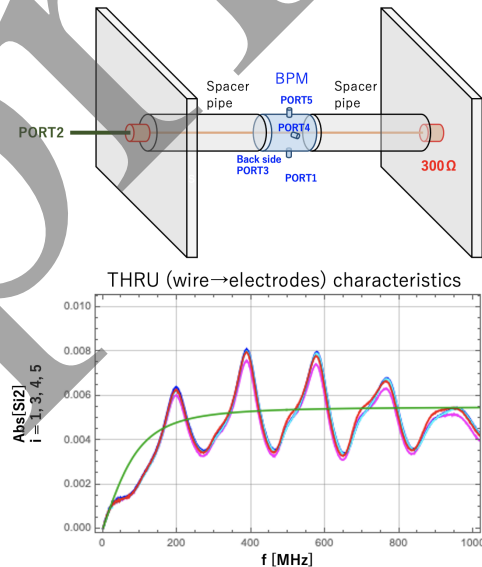


Figure 2: Frequency response with outer matching loads.

proach was successfully applied to the BPMs for the RIKEN superconducting LINAC [4].

To access frequencies higher than those mentioned above, further solutions are required. The 2x Thru de-embedding method appears to be a promising candidate.

2X THRU DE-EMBEDDING METHOD FOR BPMs

The 2x Thru de-embedding method evaluates the S-parameters of each adapter by measuring the S-parameters of two adapters connected in series, and removes those effects from the full S-parameters of the DUT [5, 6].

* takeshi.toyama@kek.jp

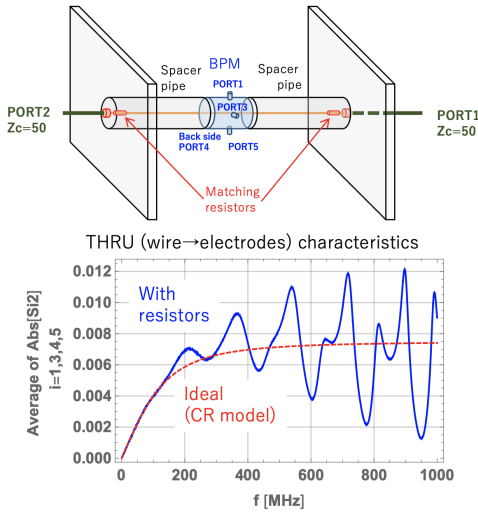


Figure 3: Frequency response with series matching loads at the wire.

This method is implemented in devices from various manufacturers [7, 8], while the calculation procedure is detailed, for example, in [5].

We formulate 2x Thru de-embedding procedure for a 4-port system. As shown in Fig. 4, this system consists of two wire input/output ports (a'_1, b'_1 and a'_2, b'_2), and two signal pickup ports (a_3, b_3 and a_4, b_4).

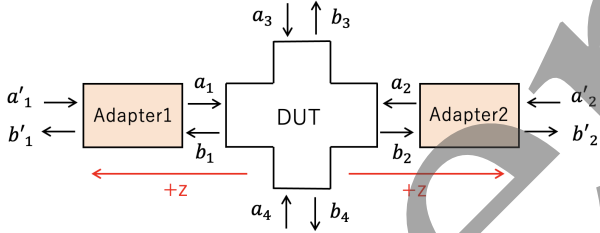


Figure 4: Block diagram of DUT and two adapters.

Writing signal transfers at the adapter1 and adapter2 as

$$\begin{pmatrix} a_1 \\ b_1 \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} a'_1 \\ b'_1 \end{pmatrix}, \quad (1)$$

and

$$\begin{pmatrix} a_2 \\ b_2 \end{pmatrix} = \begin{pmatrix} U_{11} & U_{12} \\ U_{21} & U_{22} \end{pmatrix} \begin{pmatrix} a'_2 \\ b'_2 \end{pmatrix}, \quad (2)$$

the S parameter of the DUT, \mathbf{S} , can be derived from full S parameter, \mathbf{S}' ,

$$\mathbf{S} = (\tau_{22}\mathbf{S}' + \tau_{21})(\tau_{12}\mathbf{S}' + \tau_{11})^{-1}, \quad (3)$$

using matrices,

$$\tau_{ij} = \begin{pmatrix} T_{ij} & 0 & 0 & 0 \\ 0 & U_{ij} & 0 & 0 \\ 0 & 0 & \delta_{ij} & 0 \\ 0 & 0 & 0 & \delta_{ij} \end{pmatrix}, \quad (4)$$

where δ_{ij} is the Kronecker delta, and $i, j = 1, 2$. T_{ij} and U_{ij} are obtained from 2x Thru measurement.

As indicated by the equation, no direct coupling is assumed between the adapters and the signal pickup ports. In other words, the adapter must be long enough to ensure that the HOM is sufficiently attenuated.

SIMULATION WITH CST STUDIO SUITE

To verify the effectiveness of this method, we developed the following computational model using CST Studio Suite [9]. The BPM with a total length of 100 mm and the beam pipes, a square cross-section with sides of 140 mm, connected upstream and downstream of it, and the BPM employs a diagonal-cut design similar to that used in the J-PARC MR (Fig. 5(a) and (b)). A 50- Ω port was installed at both the input and output ends of the wire. For the 2x Thru de-embedding, we used the geometry shown in Fig. 5(c).

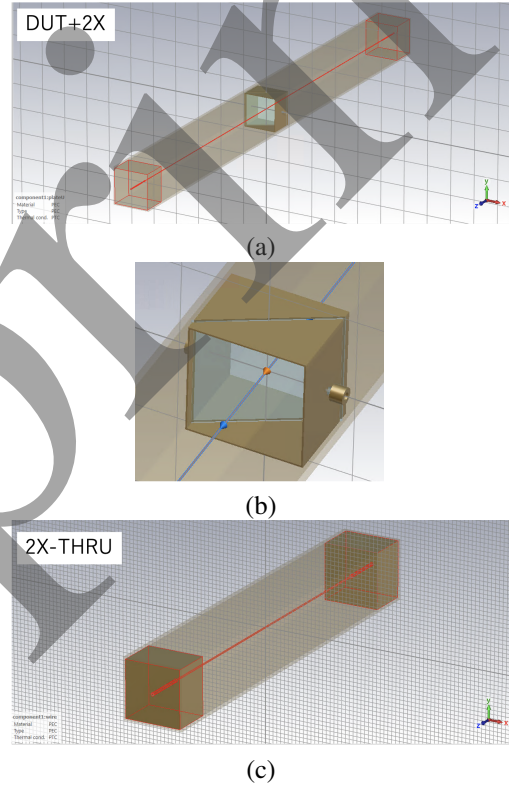


Figure 5: CST simulation models: (a) DUT+2x. The total length is 2 m. (b) Diagonal-cut BPM is displayed in enlarged view. (c) 2x-Thru. The total length is 1 m.

The simulation results are shown in Fig. 6: (a) presents the S-parameter magnitudes for the 2x Thru, (b) shows the full S-parameters for the DUT and 2x Thru, and (c) displays the results for the de-embedded DUT.

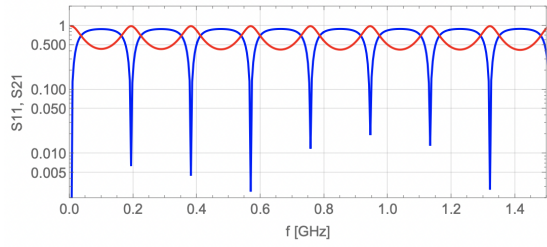
Calculating

$$\Delta/\Sigma = (1 - |S_{41}|/|S_{31}|)(1 + |S_{41}|/|S_{31}|), \quad (5)$$

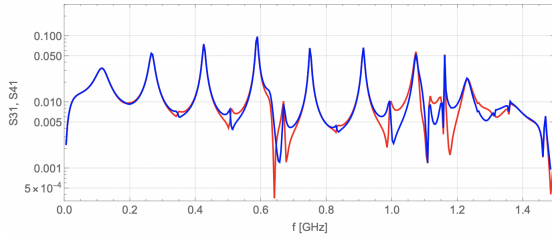
for the wire or beam at 0, ± 10 , ± 20 mm, frequency domain responses, Fig. 7, Fig. 8, and Fig. 9 are obtained.

The position sensitivity κ in the frequency domain is obtained by calculating the linear coefficient

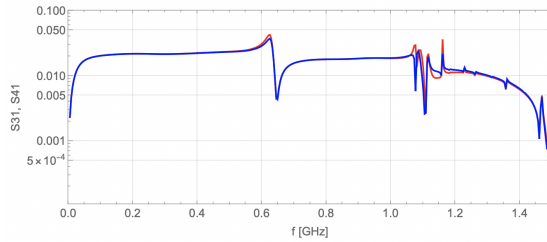
$$\kappa x = \Delta/\Sigma, \quad (6)$$



(a)



(b)



(c)

Figure 6: S-parameter amplitudes for the 2x Thru (a), pickup responses without 2x Thru de-embedding (b), and pickup responses with 2x Thru de-embedding (c), all for a centered wire. In (b) and (c), the red and blue lines correspond to $|S_{31}|$ and $|S_{41}|$, respectively.

from a third-order polynomial fit at each frequency; these results are presented in Fig. 10.

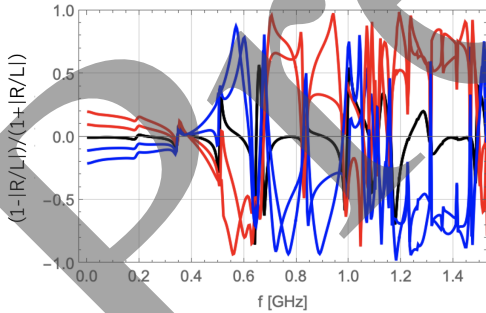


Figure 7: Calculated pickup responses (raw S-parameters) for wire positions at 0 mm (black line), ± 10 and ± 20 mm (red lines for positive and blue lines for negative offsets).

SUMMARY AND OUTLOOK

In this paper, we demonstrate the effectiveness of the 2x Thru de-embedding method for calibrating BPMs with stretched wires via EM simulation. The full S-parameters are de-embedded using the 2x Thru of each corresponding wire position. This process eliminates the effects of position-dependent characteristic impedance as well as impedance

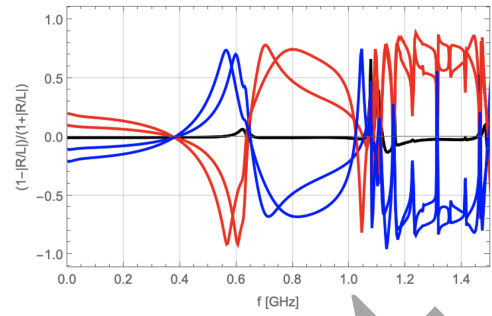


Figure 8: Calculated pickup responses (S-parameters with 2x Thru de-embedding) for wire positions at 0 mm (black line), ± 10 mm, and ± 20 mm (red lines for positive and blue lines for negative positions).

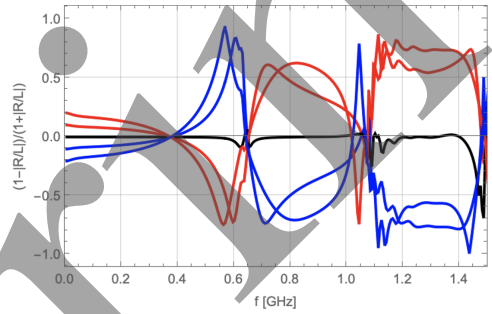


Figure 9: Calculated pickup responses for beam positions at 0, ± 10 , and ± 20 mm (black line for 0 mm, and red and blue lines for positive and negative positions, respectively).

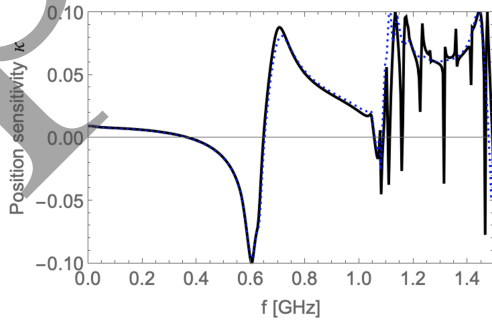


Figure 10: Position sensitivity κ in Eq. (6) of the pickup in the frequency domain. The wire and beam results are shown by the solid black and dotted blue lines, respectively.

mismatches at the wire input/output ends. The results for the wire method agree well with those for the beam at frequencies up to approximately half of the cut-off frequency.

As a precaution, direct coupling must not exist between the adapters and the signal pickup ports. Specifically, the adapters should be sufficiently long to ensure sufficient attenuation of HOMs; alternatively, electromagnetic absorbers may be used.

The next steps include a precise evaluation of errors, the application of this method to BPMs with step-in/step-out beam pipes, and testing with practical devices.

REFERENCES

- [1] K. Hanamura *et al.*, “Development of Calibration System for BPM at J-PARC 50 GeV Synchrotron”, in *Proc. PASJ3-LAM31*, Sendai, Japan, Aug. 2006, pp. 466–468.
- [2] T. Miura *et al.*, “Calibration of Beam Position Monitor for J-PARC Main Ring Synchrotron”, in *Proc. PASJ3-LAM31*, Sendai, Japan, Aug. 2006, pp. 469–471.
- [3] T. Kroyer *et al.*, “Longitudinal and Transverse Wire Measurements for the Evaluation of Impedance Reduction Measures on the MKE Extraction Kickers”, CERN, Geneva, Switzerland, Rep. AB-Note-2007-028, 2007.
- [4] T. Watanabe *et al.*, “Calibration for Beam Energy Position Monitor System for Riken Superconducting Acceleration Cavity”, in *Proc. IBIC’19*, Malmö, Sweden, Sep. 2019, pp. 526–529. doi:10.18429/JACoW-IBIC2019-WEPP007
- [5] J. Ellison, S. B. Smith, S. Agili, “Using a 2x-thru standard to achieve accurate de-embedding of measurements”, *Microw. Opt. Technol. Lett.*, vol. 62, pp. 675–682, 2020. doi:10.1002/mop.32098
- [6] T. Toyama *et al.*, “Update of beam coupling impedance evaluation by the stretched-wire method”, presented at IPAC’22, Bangkok, Thailand, May 2022, unpublished. doi:10.48550/arXiv.2208.09217
- [7] Keysight Technologies, Inc., “S96007B Automatic Fixture Removal”, www.keysight.com/us/en/product/S96007B/s96007b-automatic-fixture-removal.html
- [8] Accurate test fixture characterization and de-embedding, cdn.rohde-schwarz.com/cn/pws/dl_downloads/dl_application/application_notes/1sl367/1SL367_0e_Test_Fixture_Characterization_and_De-embedding.pdf
- [9] CST Studio Suite, Electromagnetic Field Simulation Software, www.3ds.com/products/simulia/cst-studio-suite