MATCHING BPM STRIPLINE ELECTRODES TO CABLES AND ELECTRONICS*

C. Deibele, ORNL, Oak Ridge, TN 37831, U.S.A.
S. Kurennoy, LANL, Los Alamos, NM 87545, U.S.A.

Abstract

The Spallation Neutron Source (SNS) is an accelerator-based neutron source being built at Oak Ridge National Laboratory. The 805-MHz coupled-cavity linac (CCL) accelerates an H⁻ beam from 86 to 186 MeV, while the 805 MHz superconducting-cavity linac (SCL) accelerates the beam to its final energy of 1 GeV. The SNS beam position monitors (BPMs) which are used to measure both position and phase of the beam relative to the master oscillator, have the dual-planed design with four one-end-shorted stripline electrodes. We argue that the BPMs are optimally broadband matched to the cabling and electronics when the geometrical mean of the sum-mode and quadrupole-mode impedances is equal to the dipole-mode impedance, and both are equal to the external-line impedance, 50 Ohms. The analytical results, MAFIA and HFSS simulations, wire measurements, and beam measurements that support this statement are presented.

OVERVIEW

Consider a four-electrode BPM depicted in Fig. 1. This topology supports four independent TEM eigenmodes of operation. These modes can be chosen as a sum mode ($V_1=V_2=V_3=V_4$), two dipole modes ($V_1=V_2=-V_3=-V_4$ and $V_1=-V_2=V_3=-V_4$), and a quadrupole mode ($V_1=-V_2=-V_3=V_4$). Each of these eigenmodes has characteristic impedance that can be easily calculated with electrostatic 2-D solvers. In this paper, we assume that the structure is axially symmetric, and therefore the characteristic impedances of the two dipole modes are identical.
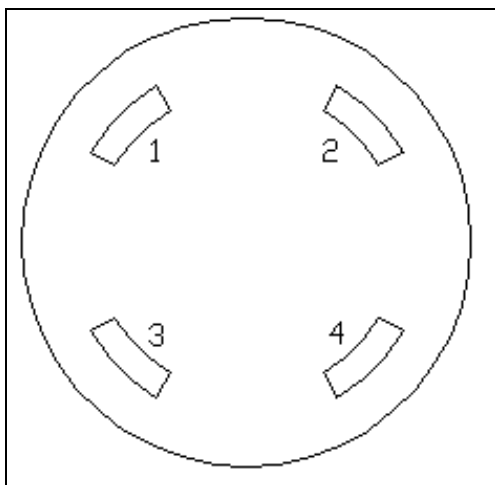

Figure 1: Schematic of four-electrode BPM.

We seek to match the electrodes to either cables or electronics such that a broadband match is observed. The goal is to use the BPM electrodes for other purposes, namely for bunch length measurements or bunch shape measurements and minimize deconvolution calculations in the measurements. Schematically, a beam measurement appears as in Fig. 2.
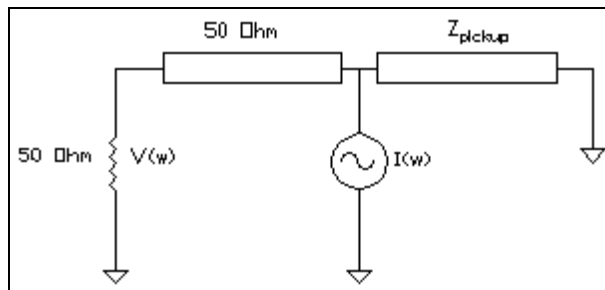

Figure 2: Schematic of a typical beam measurement.

In Fig. 2, the beam, $I(\omega)$, excites an electrode. In this particular example, the electrode is shorted on one end to the beam-pipe wall, and the other electrode is connected to a transmission line having the impedance R_0=50 Ohm. A voltage is measured at the end of the transmission line across a 50-Ohm resistor. Calculations show that when the following two conditions are satisfied:

$$\sqrt{Z_{sum}Z_{quad}} = Z_{dipole} = R_0, \qquad (1)$$

the electrode is matched.

RESULTS

A transmission-line analysis that supports the general result (1) was presented in [1]. For the case of a single-plane BPM, with two electrodes, the condition similar to (1) would be usual $\sqrt{Z_{even}Z_{odd}} = R_0$. From a physical viewpoint, such a condition corresponds to matching for each independent mode simultaneously. It is desirable, therefore, to examine this result and check it with numerical calculations. The specific example of the SNS CCL BPMs is examined. These BPMs were designed originally using the traditional sum-mode matching and wide electrodes to maximize the beam signals [2]. While such a matching is adequate for single-frequency measurements, the desire to use the BPMs also for broadband measurements, e.g. of a bunch length, motivated the design modifications [1]. To keep the design changes minimal, it was decided to adjust just one parameter – the electrode subtended angle – to satisfy the matching conditions (1), at least approximately. It is interesting to compare results between the sum-mode

matching and the matching to conditions (1) that this paper proposes. The mechanical parameters of BPMs are compared in Tab. 1.

Table 1: Comparison of mechanical parameters

Beam-pipe (electrode inner) radius	15 mm
Electrode enclosure box inner radius	19.2 mm
Electrode thickness	1.0 mm
Electrode length	26.8 mm
Electrode angle for Z_{sum}=50 Ohms	60 degrees
Electrode angle for matching (1)	45 degrees

Coax with a characteristic impedance of 50 Ohms feeds each electrode. The impedances of the independent modes calculated by the MAFIA [3] electrostatic solver are summarized in Tab. 2. The value of $\sqrt{Z_{sum}Z_{quad}}$ is 52.5 Ohm for the 45-degree design, so that the first of the two conditions (1) is satisfied only approximately.

Table 2: Impedances for 60- and 45-degree electrodes

Impedance	60-degree electrode	45-degree electrode
Sum Mode	50.0	58.4
Dipole Modes	41.1	50.3
Quadrupole Mode	37.4	47.2

The BPM structure was simulated using HFSS [4]. Since HFSS can only simulate individual ports, a small center wire was inserted along the geometric and electrical axis of the beam pipe. A screen snapshot of the simulation is shown in Fig. 3.
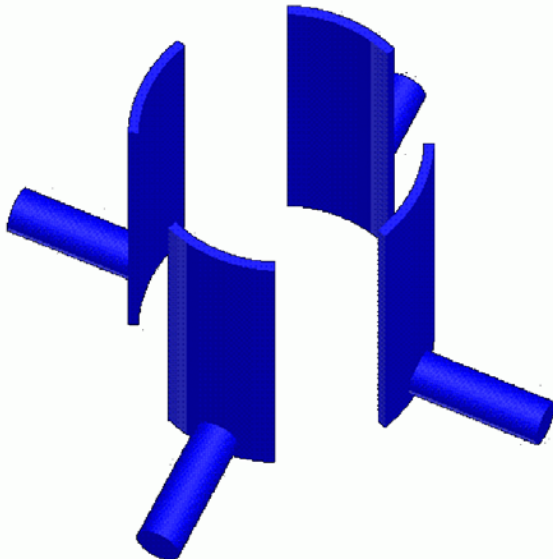

Figure 3: Picture of 45-degree electrodes in HFSS simulation model. Center wire is not shown.

HFSS is a frequency-domain package. Since it is desirable to observe time-domain results, frequency-

domain data should be Fourier transformed. The structure was simulated to 6 GHz and a cosine-squared weighting function was used on the Fourier transformed frequency domain data. The calculated transmission from the center wire to an electrode is shown in Fig. 4.
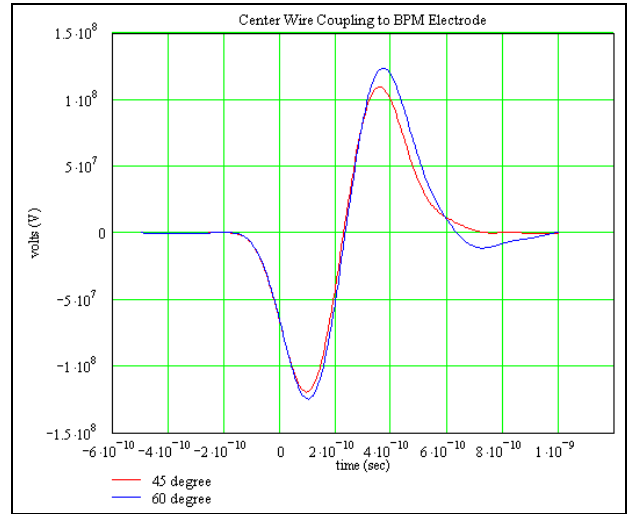

Figure 4: Fourier-transformed calculation of center wire coupling to electrode.

In Fig. 4, as expected, each method of electrode design results in a classical doublet shaped response. One observes a small ringing in the case of the electrode that is matched to the sum mode that is not observed in the other electrode. Note also that the signal magnitudes do not differ by more than a few percent. One effect that must be considered, in addition to the ideal general analysis, is that waveguide modes exist in the beam pipe. It changes the results slightly.

Measurements

Measurements using a synthetic pulse using an 8753ES network analyzer are shown in Figs. 5 and 6.
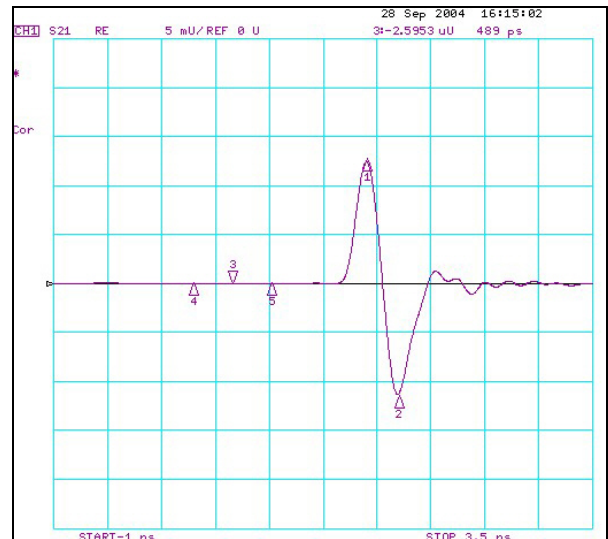

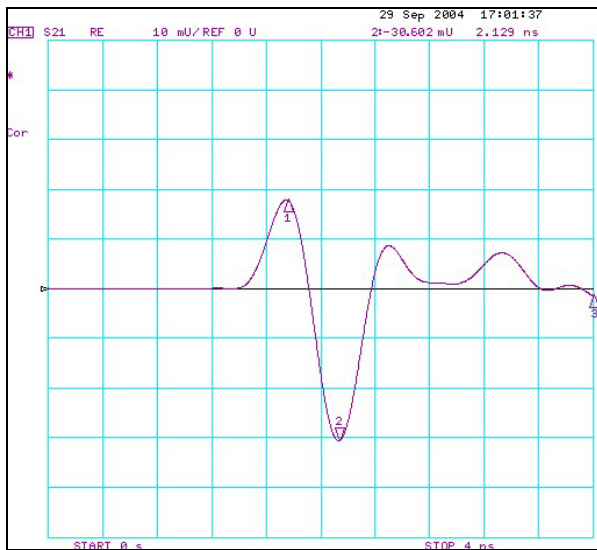Figure 5: Stretched wire measurement through 45-degree electrode.

2608

Figure 6: Stretched wire measurement through 60-degree electrode.

A clear difference exists between two stretched wire measurements, and care must be exercised when interpreting each plot. It is essential to understand that these measurements include waveguide modes, and it can be tricky to understand relative effects of waveguide and BPM modes. The two stretched wire measurements had a larger beampipe diameter (about 5 cm) than the original structure, but had the same matching conditions on each electrode. The salient difference is the magnitude of ringing in each structure.

The dramatic difference between two types of the BPM matching can be observed in the beam measurements, Figs. 7 and 8. These measurements were taken close together but with two different BPM geometries. In each of these pictures, the microbunch structure of the SNS beam is measured.
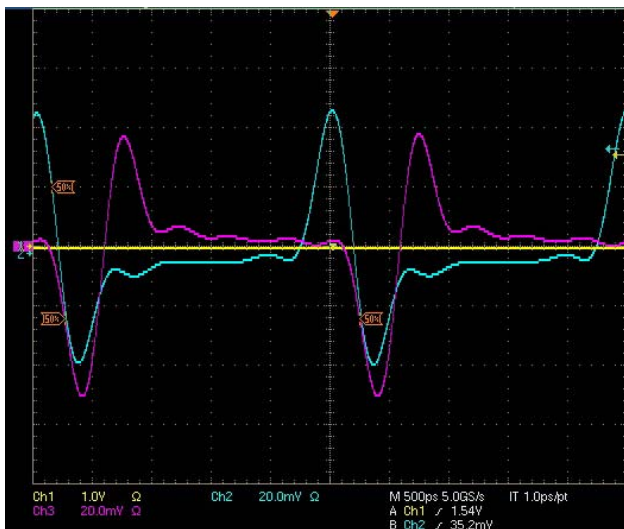

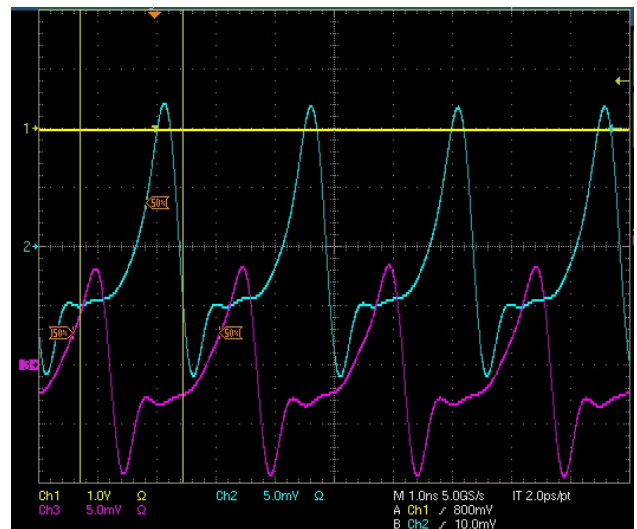Figure 7: BPM response to 45-degree electrode.

Figure 8: BPM response to 60-degree electrode.

In Fig. 7, BPM electrodes with the 45-degree included angle are used as a pickup, whereas in Fig. 8 we measure using the electrodes with the 60-degree included angle. The beam parameters had not changed during the measurement period.

In both Figs. 7 and 8, the measurement takes place deep within the macropulse, and therefore reflections on the electrode have time to develop. For the case of the 45-degree electrode, the reflections are small, and therefore the beam response to the electrode has a characteristic doublet structure, whereas the beam response to the 60-degree electrode in Fig. 7 does not share this luxury.

CONCLUSIONS

The results presented support our statement that four-electrode BPMs are optimally broadband matched to the cabling and electronics when the geometrical mean of the sum-mode and quadrupole-mode impedances is equal to the dipole-mode impedance, and both are equal to the external-line impedance.

It is worth mentioning that when the coupling between electrodes is very small, different kinds of matching lead to the same BPM geometry. In particular, this is the case when BPM electrodes are separated by longitudinal metal ridges placed in the gaps between the adjacent electrodes, as was discussed in [2]. Of course, such separators reduce the BPM beam signals.

REFERENCES

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