DEVELOPMENT OF A FEEDTHROUGH WITH SMALL REFLECTION FOR THE TPS BPM

I. T. Huang#, H. P. Hsueh, C. L. Chen, C. C. Chang, G. Y. Hsiung, NSRRC, Hsinchu, Taiwan
J. R. Chen, NSRRC and NTHU, Hsinchu, Taiwan

Abstract

The TPS BPM feedthrough is a coaxial cable with a structure of a kind for which power loss occurs readily at places at which exists an impedance mismatch. With an impedance equation for a simple coaxial cable combined with a multi-dielectric modification, a model feedthrough with small reflection has been designed. With careful setting of brazing conditions and precise control of the dimensions of devices, a TPS prototypical BPM feedthrough having a reflection coefficient less than 0.05 was manufactured. The eccentricity was constrained within 0.03 mm, and the deviation of measured capacitance of button electrodes was less than 7 %.

INTRODUCTION

The characteristic impedance is an important parameter of a transmission line that is governed by the structure, shape and dielectric material of a device. A signal is transmitted by a transmission line, and any discontinuity existing in the transmission line would result in an attenuated amplitude of the signal. Impedance matching is hence an important design concept of a transmission line. From this core concept, the feedthrough used in a beam-position monitor (BPM) is divided into several sections, of which each can be considered as a coaxial transmission line. The final objective is for each section to have nearly the same characteristic impedance, 50 Ω, so that any reflection at each discontinuity becomes eliminated.

The reflection coefficient was measured with a time-domain reflectometer, TDR. A pulse was sent through a test section and a reflected pulse was returned. The voltage ratio of reflected and traveling waves represents the degree of the mismatch. The greater is the mismatch, the greater is the reflection [1].

COAXIAL TRANSMISSION LINE

A coaxial transmission line is a transmission line of a particular kind, which is constructed with two conductors between which is an inner dielectric layer. Figure 1 illustrates the structure of a coaxial transmission line.

The equations describing the inductance, capacitance and impedance of a coaxial transmission-line structure are derived from electromagnetic theory. [2] The characteristic impedance of a coaxial transmission line is determined by its inner radius, outer radius and the relative permittivity (see Eq.1a-1d.)

#huang.it@nsrrc.org.tw

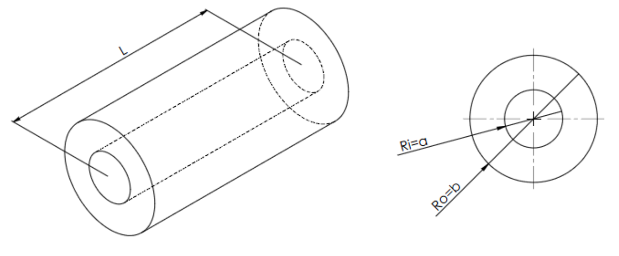


Figure 1: Structure of a common coaxial transmission line with a single dielectric medium.

$$C = \frac{2\pi\varepsilon L}{\ln\frac{b}{a}} \qquad (1a)$$

$$L_I = \frac{\mu_0 L}{2\pi}\ln\frac{b}{a} \qquad (1b)$$

$$Z_C = \sqrt{\frac{L_I}{C}} \qquad (1c)$$

For a simple coaxial transmission line, Z_C becomes expressed as

$$Z_C = \frac{1}{2\pi}\sqrt{\frac{\mu_0}{\varepsilon}}\ln\frac{b}{a} \qquad (1d)$$

According to equation 1d, with a particular geometry and relative permittivity ε of a coaxial transmission line, Z_C is determined automatically.

A multi-dielectric layer coaxial transmission line can be regarded as several coaxial structures in series. The contributed capacitance thus arises from all capacitors in series, and the contributed inductance arises from all inductors in series. With the contributed capacitance and inductance, the contributed characteristic impedance is also defined (see Figure 2 and Eq. 2a.-2c.)

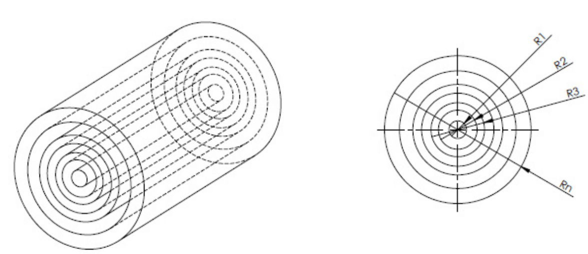


Figure 2: Structure of a common coaxial transmission line with multi-dielectric medium.

$$\frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n} \qquad (2a)$$

$$L_{series} = L_1 + L_2 + L_3 + ... + L_n \quad (2b)$$

$$Z_{C_{series}} = \sqrt{\frac{L_{series}}{C_{series}}} \quad (2c)$$

TIME-DOMAIN REFLECTOMETER

A time-domain reflectrometer was used to measure the reflection coefficient, which is related to the characteristic impedance (Z_L) of a device under test and the characteristic impedance (Z_0) of the original transmission line (see Eq.3).

$$\rho = \frac{V_{reflect}}{V_{incident}} = \frac{R_L - R_0}{R_L + R_0} \quad (3)$$

Figure 3 shows a circuit for a TDR measurement; a pulse is sent through Z_{Load}, and $V_{reflect}$ is then received; the ratio of $V_{reflect}$ and $V_{incident}$ is calculated to yield the reflection coefficient; once ρ is known, R_L is easily resolved.

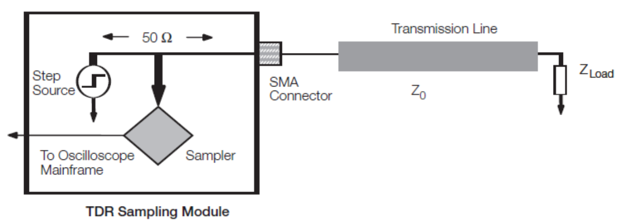


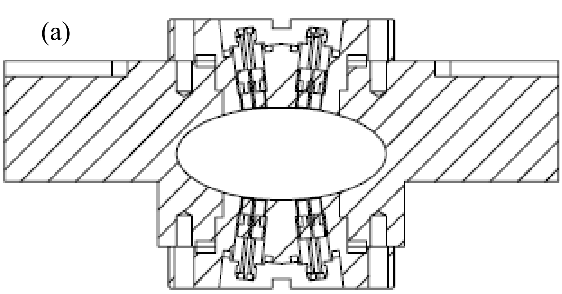
Figure 3: Block diagram of a TDR measurement circuit

DEVELOPMENT OF THE TPS BPM FEEDTHROUGH

Decision of a TPS BPM Feedthrough Structure

Using Eq.3 and setting Z_0=50 Ω, carefully choosing the inner diameter, outer diameter and dielectric material of the TPS BPM feedthrough, a coaxial transmission line with a small reflection coefficient, as a TPS BPM feedthrough, is advanced [3,4]. Figures 4a-4c show a TPS BPM set drawing; table 1 lists the corresponding characteristic impedance of every section of the TPS BPM feedthrough.

(a)



(b)

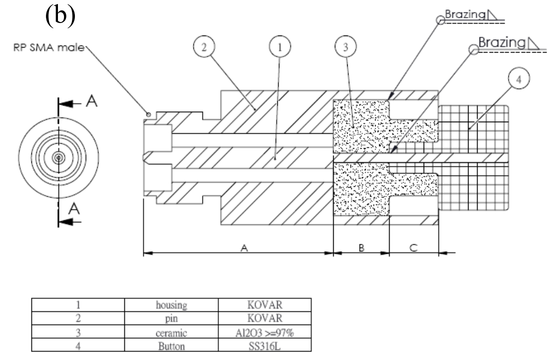


Figure 4: (a) Cross section of TPS beam position monitor. (b) Cross section of a feedthrough with small reflection.

Table 1: Impedance of every section of a TPS BPM feedthrough

Section	Dielectric material	impedance	ρ
A	Air (ε =1)	49.95 Ω	-0.0005
B	Alumina (ε =9.7)	48.04 Ω	-0.01949
C	Alumina & air	49.56 Ω	0.01557

TDR Measurement Spectrum

Figure 5 shows a typical TDR spectrum of a button-type BPM feedthrough; the time scale is on the horizontal axis and the reflection coefficient is on the vertical axis. When a traveling pulse meets a discontinuity, it takes $t = \frac{2L}{v}$ to return to the TDR machine. Because the pulse goes and returns along the same loop, the length is $2L$, not L. From this TDR measurement spectrum, as the time needed to travel trough the device is seen by the TDR, and the velocity of travel is known $(v = \frac{c}{\sqrt{\varepsilon \mu_0}})$, the location at which a pulse meets a discontinuity can be deduced.

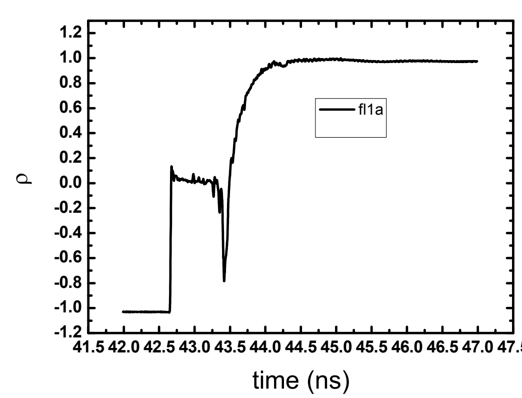


Figure 5: TDR spectrum of a TPS BPM feedthrough

Capacitance Fitting of the BPM TDR Spectrum

Figure 6 illustrates capacitor and inductor behaviors from TDR measurements. Using charging and discharging equations for a capacitor, the capacitance becomes fitted (Eq.4a-4b).

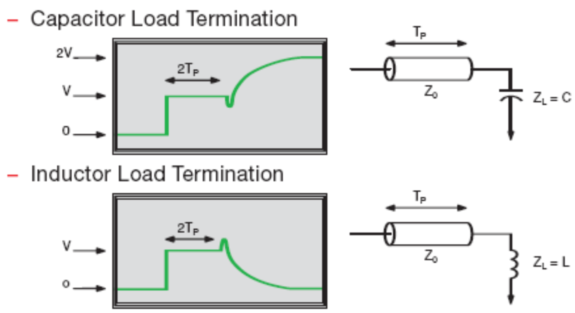


Figure 6: Capacitive and inductive load terminations

$$Q = Q_0 e^{-t/RC} \qquad (4a)$$

$$Q = Q_0 (1 - e^{-t/RC}) \qquad (4b)$$

When a pulse meets a capacitor, in this case at time t = 43.45 ns, the capacitor begins to charge; when this capacitor is saturated, it becomes an open circuit, and in the TDR spectrum, the reflection coefficient tends to 1. Equation 5 is thus used to simulate the charging behavior of a capacitor in the TDR spectrum (see Eq. 5 and fig. 7).

$$y = y_0 + A_1 \times \exp(-\frac{x - x_0}{t_1})$$

$$y_0 \approx 1 \qquad (5)$$

$$A_1 \approx 1 - \rho$$

$$t_1 = (50 + R)C$$

x_0 : time taken to meet a capacitor

R: resistance of an imperfect capacitor

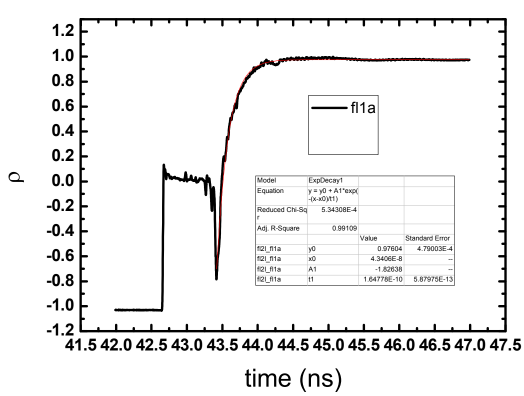


Figure 7: Fit of capacitance of a TPS BPM feedthrough

The reflection coefficient of the capacitance is -0.83, and the corresponding R_c is 4.75 Ω. Taking R_C into eq. 5，the value of the capacitance is solved, about 3.01 pF. Compared with the theoretically calculated value from eq. 1a, C_{theory} = 2.71 pF, the measured value is larger than the theoretically calculated value, because that the capacitance comes mainly from the button-type electrode; other coaxial structure sections connected with the button electrode might contribute some capacitance, although these sources are minor.

CONCLUSION

A feedthrough of small reflectance was designed with guidance from equations for a transmission line and the reflection coefficient. From measurements with a reflectometer in the time domain, the locations of impedance mismatch were directly discovered and the capacitance of a button electrode was also fitted. Based on these disciplines mentioned above, a feedthrough with small reflection has been manufactured. Figure 8 shows the improvement of reflection of a TPS BPM feedthrough after adjustment of the device geometry to maintain characteristic impedance 50 Ω along the entire transmission line. Using capacitance fitting described in eq.5, the capacitance difference of each button-type electrode is within 7 % (from 2.91 pF to 3.06 pF).

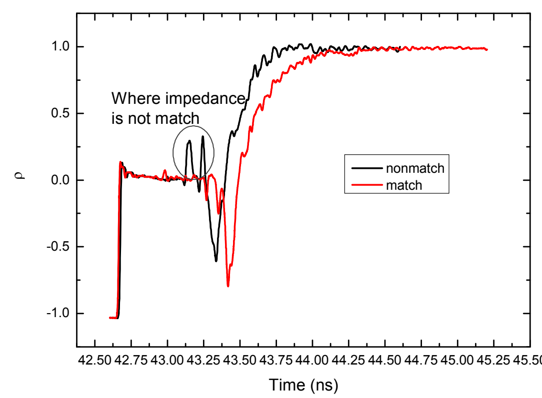


Figure 8: TDR spectra of impedance-matched and non-matched BPM feedthroughs

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