Experimental determination of impedance and delay time of the 100 Ω meander transmission line for the SPIRAL2 Single Bunch Selector

M. Di Giacomo, P. Balleyguier, Ac. Caruso, F. Consoli

EXPERIMENTAL DETERMINATION OF IMPEDANCE AND DELAY TIME OF THE 100 OHM MEANDER TRANSMISSION LINE FOR THE SPIRAL2 SINGLE BUNCH SELECTOR*

M. Di Giacomo#, GANIL/Spiral2, Caen, France
P. Balleyguier, CEA/DAM/DIF, F-91297, Arpajon, France
F. Consoli†, A. Caruso, A. Longhitano, INFN-LNS, Catania, Italy

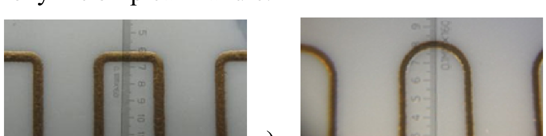
Abstract

A 100 Ohm meander line is used in the single bunch selector of the SPIRAL2 driver medium energy line. The non standard characteristic impedance helps to reduce the pulser power but introduces the problem of calibrated measurements. The paper describes the different methods used to measure the impedance and the delay of the electrodes.

INTRODUCTION

To reduce the required power, the single bunch selector [1] of the SPIRAL2 driver accelerator uses a static magnetic field deflecting the beam towards a beam dump, and two short pulses of opposite sign travelling along high impedance (100 Ω) meander electrodes, selecting the bunch to be accelerated. The characteristic impedance Z_c and the delay τ of the electrodes are then critical issues of the device, located along the in a beta (β=v/c)= 0.04 beam transport line.

The first set of electrodes that have been manufactured was measured with an impedance-meter and an oscilloscope and gave Z_c=94 Ω, β=0.044, as described in detail in [2]. Power tests with a continuous current were also performed and a manufacturing problem appeared on the meander u-bends, limiting the maximal current density the strip can handle.



a) b)

Figure 1a : former (a) and present (b) u-bend

According to the conclusion of [2], a second set was manufactured with modified shape as shown in Fig. 1 and with different dimensions as reported in table 1. The number of meanders was modified due to a reduction in the available space along the accelerator.

Table 1: difference in meander parameters

Parameter	Set 1	Set 2
Meander length (mm)	46	50
Al203 thickness (mm)	3	4.3
Meander number	45	39

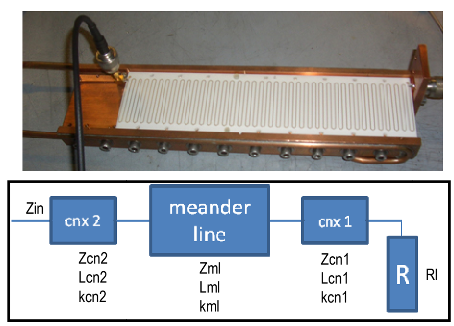
*Work supported by EU commission 7th framework project n. 212692.
#digiacomo@ganil.fr
†New affiliation: Associazione Euratom/ENEA sulla Fusione, CP 65-00044 Frascati, Rome, Italy

Several techniques were used to measure the characteristic parameters Zc and β of the new set of electrodes with a network analyser without the introduction of matching network, not easy to calibrate. The methods and the results are reported in the following chapters.

MEASUREMENT METHODS

Reflection Measurements

To measure reflection at the input of the meander plate a matching resistor (R_l) and connexions (cnx) at the beginning and at the end of the meander line are required as shown in Fig. 2.



a) b)

Figure 2: the electrode measurement assembly (a) and the equivalent circuit for simulation model (b).

Zin can be calculated by applying iteratively the well known transformation equation [3]:

$$Z = Z_{ci} \frac{Z_{li}+Z_{ci}\tanh\gamma_i L_i}{Z_{ci}+Z_{li}\tanh\gamma_i L_i} \qquad (1)$$

where Z_{ci} and Z_{li} are the characteristic and the load impedances of each section, $\gamma_i = \alpha_i + ik_i$ are the propagation constants, and Li is the related lengths. The reflection coefficient and the S11 parameter can be obtained from:

$$\rho = \frac{Z_{in}-Z_{p1}}{Z_{in}+Z_{p1}} \qquad (2)$$

S11 is measured with the network analyser and Z_{p1} is the characteristic impedance of the analyzer port, equal to 50 Ω. The model parameters of the connecting devices have to be measured aside or are already known for standard 50 Ω adapters and connectors. The longitudinal meander involved in the beta of the line, is L_{ml} = ~273 mm. Z_{ml} and k_{ml} have to be determined. We are interested in having R_l=50 Ω to use either calibrated coaxial loads or the second port of the network analyser.

Case 1 : 50 Ω Load.

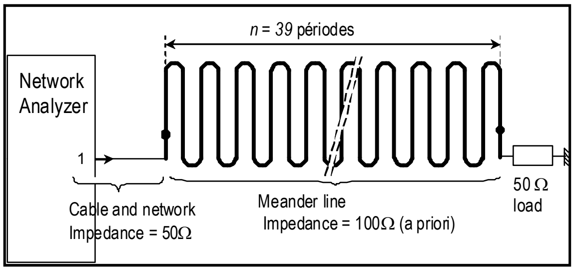


Figure 3: reflection measurements principle with unmatched ending load.

The network port measures the load impedance transformed by the meander line. Due to the effect of the transformation, points of minimum and maximum of Z_{in} are repeated periodically as shown in Fig. 4, where the magnitude of S_{11} and the polar plot of the reflection coefficient are represented.

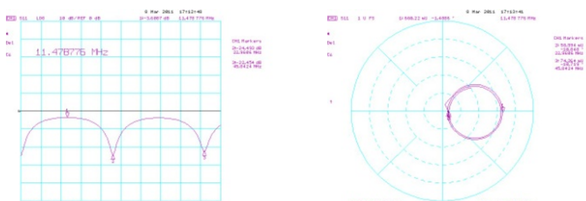


Figure 4: reflection measurement patterns with non matched ending load: S_{11} and normalised Z.

From the measured plots and considering the lowest frequency values to minimize parasitic effect we obtain:

- $S_{11\ max}$ = -3.61 dB or Z_{max}= 246.4 Ω at 11.48 MHz
- $S_{11\ min}$ = -24.49 dB or Z_{min}= 55.5 Ω
- Δf = 22.96 MHz

Zml can be calculated from two formulas:

$$Z_{max}=Z_{ml}^2/Z_{min} \quad (3)$$

$$|S_{11\,max}| \approx \frac{\left(\frac{Z_{ml}}{50}-\frac{50}{Z_{ml}}\right)}{\left(\frac{Z_{ml}}{50}+\frac{50}{Z_{ml}}\right)} \quad (4)$$

In the last case only the Z_{max} value is used.

Values of 116.8 Ω and 109 Ω have been obtained from the two methods, while 112 Ω is the value for which the analytical model fits better the measured results.

The frequency difference Δf between two minima is the frequency at which the meander length L_{ml} is equivalent to λ/2. The electrode β can then be calculated from:

$$\beta = 2L_{ml}\,\Delta f\,/c \quad (5)$$

Case 2: Open and Short Circuit

Another classic method consists to end the unknown line with a short and open circuit and to measure the corresponding reflection patterns ρ_{open} and ρ_{short} shown in Fig. 5.

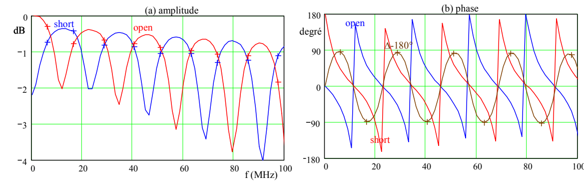


Figure 5: Reflection measurements pattern with closed and open circuits.

The phase difference of the two signals gives a quasi sinusoidal curve (Fig. 5b) whose extremes correspond to frequencies for which the length of the line is equal to λ/8. The first value is 5.7 MHz, corresponding to $\beta = 0.0415$.

In this case, Zc is given by the formula [4] :

$$Z_c = \sqrt{Z_{open}Z_{short}} \quad (6)$$

We used open and short circuits from a 50 Ω calibration kit, and the effect of the adapter is probably not negligible. The calculated impedance appears like in Fig. 6, and an average value around 115 Ω can be estimated at low frequency.

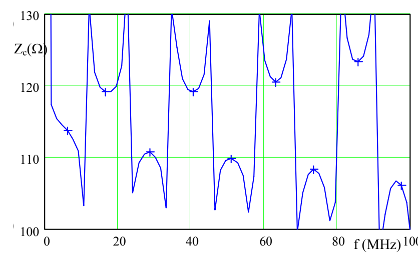


Figure 6: Estimation of Zc from the open/short method.

Case 3: Matched Line

If a variable termination is used in the scheme of Fig. 3, it is possible to reduce the circle to a quasi single point, centred at the value of the meander impedance as shown in Fig. 7a. Looking in detail, a small oscillation is still present (Fig. 7b) due to the reactive component of the trimmer. The measure of the trimmer resistance indicates 112 Ω but this value appears to be somehow smaller than the position of the circle centre on the diagram, situated around 115 Ω.

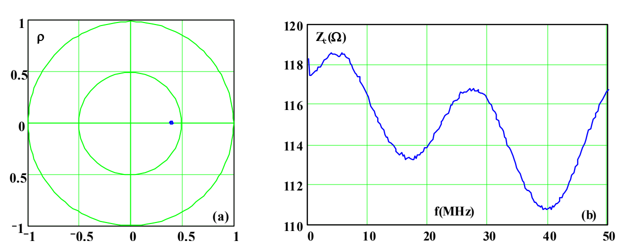


Figure 7: Reflection measurements pattern with rather matched ending load and corrected delay.

Transmission Measurements (S_{21})

The meander is loaded with a matching resistor and the S_{21} parameter is measured twice, for different positions of port 2 (28 meanders) as shown in Fig. 8.

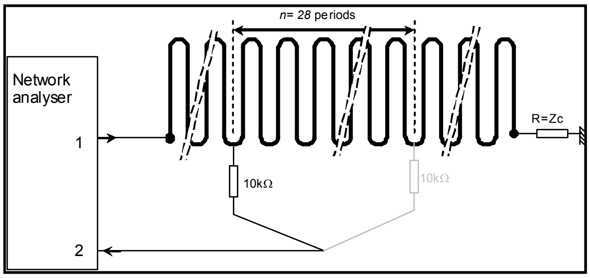


Figure 8: Measurement of beta by phase difference.

A 10 kΩ resistor is used to reduce the perturbation of the line impedance, nevertheless we observed that the matching resistor, placed at the end of the meander line, had to be changed slightly (6-7 Ω) between the two positions of port 2. From the difference between the phase delays (S_{21}) at both positions, one can calculate the delay of the considered number of meanders and the relative propagation speed (beta) of the electrodes:

$$\tau(\omega)=(\varphi_2-\varphi_1)/\omega; \qquad \beta = L_{ml}/(c\,\tau) \qquad (7)$$

Errors dues to port connections cancel with this method, while those due to impedance perturbation stay. We couldn't cancel the residual ripple visible in Fig. 9 and due to residual mismatching between the line and the ending load.

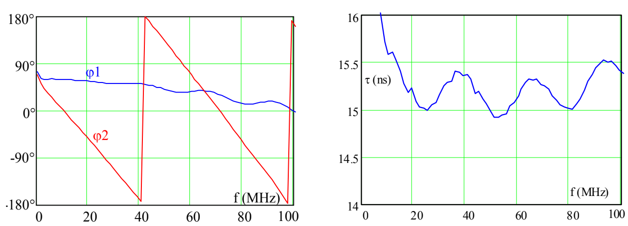


Figure 9: examples of phase measurement and calculated delay.

MEASUREMENT RESULTS

Results from the different method are summarised in Table 2 where S_{11} and S_{12} indicate a reflection or transmission measurement.

Table 2 : results with different methods

Method	Zc	Beta
S_{11} - 50 Ω load	117	0.0417
S_{11} - meas/model fitting	112	0.042
S_{11} - 50 Ω NA port2	109	0.042
S_{11} - open/short	115	0.0415
S_{11} - minimum reflection	114	
S_{12} – phase difference		0.043

Expected figures were Zc=100 Ω and β=0.04. Measured values are higher than expected (10 to 15% for Zc, a factor 2 less for the *β*) and their spread is not negligible. A parameter that could explain the difference is the relative permittivity of the Alumina which should be around 8.4 instead of 9.9. First measurements seem to confirm this hypothesis.

Concerning the spread, a more detailed analysis is in progress to take off the effect of the connections and to identify key points in the measurement procedure.

Other Measurements

We have also measured the spread among different plates and the sensitivity to the screw tightening. The four units show very similar results, confirming the reproducibility when built all together. Concerning the screws, it's paramount to tighten those at the extremities and in the middle of the plate at least, as shown in Fig.10.

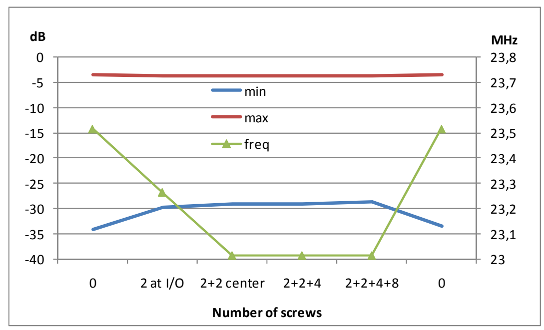


Figure 10: Sensitivity of the amplitude (dB) of the maximum and the minimum of the S_{11} curve of Fig.4a and of the frequency (MHz) of the minimum.

CONCLUSION

Several methods have been tested to determine the electrical parameters of non standard, high impedance travelling wave electrodes. Results still present some spread but clearly indicate higher Zc and delay than expected from the Mafia and CST Microwave Studio simulations. The difference could come from the permittivity of the Alumina.

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