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MEASUREMENTS AND LABORATORY TESTS ON A PROTOTYPE STRIPLINE KICKER FOR THE CLIC DAMPING RINGS*

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Abstract

The Pre-Damping Rings (PDRs) and Damping Rings (DRs) of CLIC are required to reduce the beam emittances to the small values required for the main linacs. The injection and extraction, from the PDRs and DRs, are performed by kicker systems. To achieve both low beam coupling impedance and reasonable broadband impedance matching to the electrical circuit, striplines have been chosen for the kicker elements. Prototype striplines have been built: tests and measurements of these striplines have started. The goal of these tests is to characterize, without beam, the electromagnetic response of the striplines. The tests have been carried out at CERN. To study the signal transmission through the striplines, the measured S-parameters have been compared with simulations. In addition, measurements of longitudinal beam coupling impedance, using the coaxial wire method, are reported and compared with simulations.

S-PARAMETER MEASUREMENTS

The striplines require a total of four coaxial feedthroughs, type 15kV-F-UHV [1] are used, to transfer power from the inductive adders to the two electrodes and from the electrodes to two 50 Ω terminating resistors. Initial high voltage (HV) tests on a prototype inductive adder [2], for powering the striplines, use resistors from Diconex [3] for the 50 Ω termination: these resistors have also been used for some of the measurements reported in this paper.

The following sources of impedance mismatch, for the striplines, have previously been identified:

- the feedthroughs are coaxial outside of the beam pipe but the connection from each feedthrough to an electrode is not coaxial: hence the characteristic impedance of the connection between the electrode and feedthrough is not constant.
- during kicker operation (odd mode), the characteristic impedance of the electrodes is lower than 50 Ω [4].
- simulations have shown that the presence of electrode supports increase the reflections [5].

In addition to the above, the terminating resistors are not ideal: their value is frequency dependent. In order to take this into account measurements have been carried out on the Diconex 50 Ω termination resistors.

The S-parameter measurements have been done using an Agilent E5071C 2-port Network Analyzer (NA): the ports on the E5071C have N-type connectors. In order to carry out the measurements a total of six low-loss HTC-50-7-2 coaxial cables [6] were required with connectors: (1) four cables with N-type connectors on one end and RG213-521 plugs [7] on the other end, and (2) two cables with the mentioned plugs on both ends.

A number of measurements were carried out to compare simulations with measurements. The simulations shown in this paper are for an updated version of the model shown in [5]. Initially "high quality" (HQ) 50 Ω resistors were used, and subsequently more representative HV resistors were used.

HQ Terminating Resistors

The HQ terminating resistors used are the resistors from the calibration kit of the NA, with a "constant" 50 Ω characteristic impedance. To compare measurements with CST [8] simulations of the reflection parameter S_{11}, each electrode was terminated with these HQ resistors. An hybrid splitter has been used in order to drive both electrodes in either odd or even mode, and the NA has been calibrated at the output of the hybrid. For this measurement the four cables with N-type connectors on one end and RG213-521 plugs on the other end were required.

Results comparing both simulations and measurements are shown in Fig. 1.

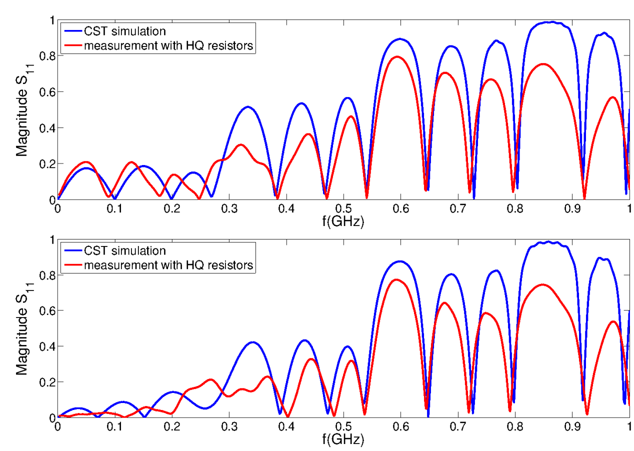

Figure 1: S_{11} parameter measured when driving the electrodes in the odd (top) or even (bottom) mode configuration, when output is terminated with the HQ terminating resistors, compared with CST simulations.

The reflections during odd mode operation of the striplines (kicker ON), shown in Fig. 1 (top), may increase the driving pulse ripple. However, significant content of

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the driving pulse from the inductive adder will extend up to ≈ 0.01 GHz, for a pulse rise time of 50 ns. Hence, the reflections shown in Fig. 1 (top) are not expected to significantly influence the ripple of the pulse field.

For the even mode (kicker OFF), the simulated reflections shown in Fig. 1 (bottom) above ≈ 0.3 GHz, are generally stronger than those measured. Reflections in the even mode configuration are lower than in the odd mode configuration, with greater difference at low frequencies: this is due to the fact that the striplines even mode characteristic impedance is better matched to 50 Ω than in the case for the odd mode characteristic impedance: in the odd mode the characteristic impedance of the striplines is ≈ 41 Ω [4].

Diconex Terminating Resistors Measurement

Diconex 50 Ω resistors are presently being used for high voltage testing of the inductive adder [2]. To evaluate the potential of this type of resistor for terminating the electrodes with 50 Ω when the striplines are installed in an accelerator test facility, their impedance has been measured with the NA.

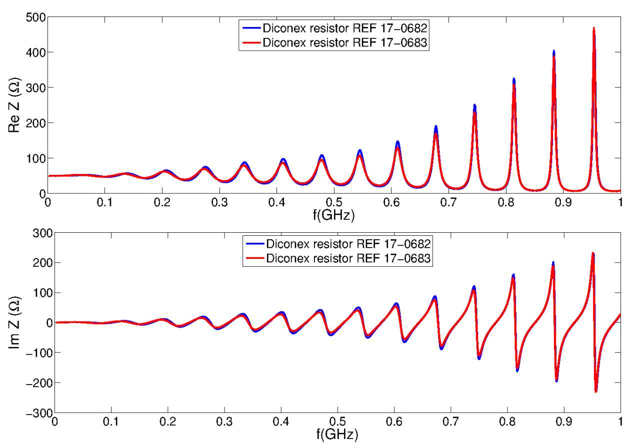

Figure 2: Real impedance (top) and imaginary impedance (bottom) calculated from the S_{11} parameters measured with the NA, for two Diconex terminating resistors.

Figure 2 shows the measured impedance, real part (top) and imaginary part (bottom), of the Diconex terminating resistor as a function of frequency. Up to ≈ 0.1 GHz the impedance variation is ±5% of its nominal value (50 Ω), The frequency content of the driving pulse extends to only ≈ 0.01 GHz, which corresponds to a resistor impedance variation of ±0.2%. Therefore, the impedance of the Diconex resistor is expected to be acceptable for the inductive adder.

Figure 3 shows a measurement of the S_{11} parameter when the remote end of each electrode is connected to a Diconex terminating resistor using the two cables with RG213-521 plugs on both ends, and the electrodes are driven in the even mode. For comparison the measurement of the S_{11} parameter when the remote end of the electrodes is connected to the HQ resistors are also shown in Fig. 3. The results show that there are more resonances, when the striplines are terminated with the Diconex resistors, at frequencies above ≈ 0.2 GHz, and they are therefore expected to influence the beam coupling impedance.

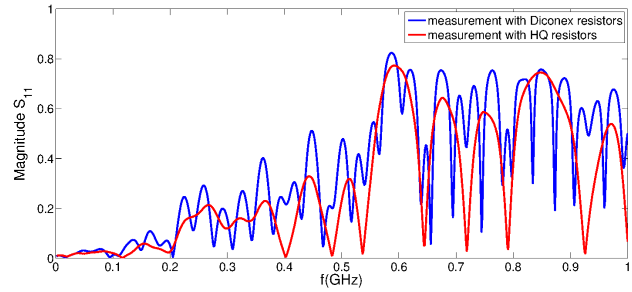

Figure 3: S_{11} parameter measured when driving the electrodes in the even mode configuration, and terminating both electrodes (i) with the Diconex resistors and (ii) HQ resistors.

LONGITUDINAL BEAM COUPLING IMPEDANCE MEASUREMENT

Wire measurements rely on the fact that the electromagnetic field distribution of an ultrarelativistic beam is very similar to that of a Transverse Electromagnetic (TEM) line [9]. The diameter of the wire used for the measurement should be as small as possible to obtain a high line impedance, which best reflects the fact that the beam acts as an ideal current source. For our measurements, a wire of 0.5 mm diameter has been used. The wire is made up of Cu/Ag_{20}, not enamelled, with a ≈ 2.1 μm thick coating of silver. Soft copper is used when measuring elements which are longer than approximately 1 m, where the effect of sag may play a significant role [9].

Single Wire Transmission Method

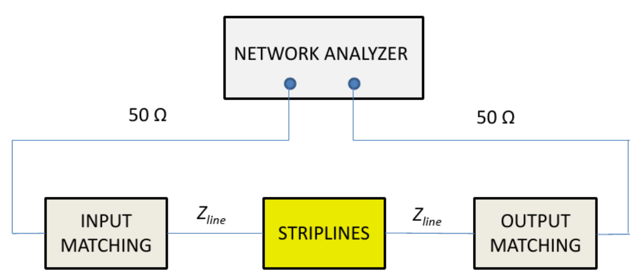

Figure 4: The setup for a longitudinal impedance measurement. The box named "striplines" comprises both the striplines and the inserted wire.

The setup for a single wire measurement is shown schematically in Fig. 4. The NA and the connecting coaxial cables have 50 Ω characteristic impedance, while the TEM line is composed of the wire and the striplines: these have impedance Z_{line}. For a wire between two parallel plates the line impedance is given approximately by [9]:

$$Z_{line}(\Omega) = 60\, ln\left(1.27\,\frac{D}{d}\right) = 235.7\Omega \qquad (1)$$

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where $D = 20\,mm$ is the distance between the electrodes, i.e. the aperture, and $d = 0.5\,mm$ is the wire diameter. One-way matching of the characteristic impedance of the line Z_{line} to the system impedance Z_0 can be carried out by means of a single series resistor at both ends of the wire. In this case we have connected two low-inductance carbon resistors of $R_s = Z_{line} - Z_0 \approx 185\,\Omega$, as shown in Fig. 5.

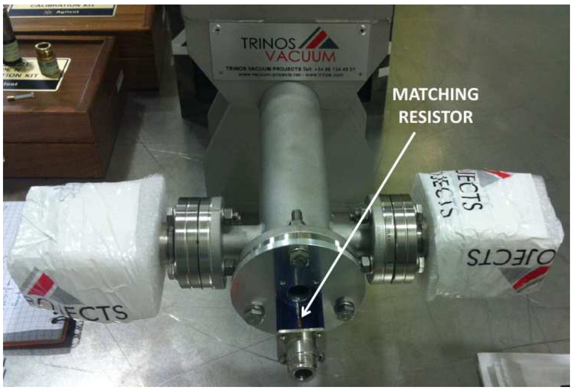

Figure 5: Resistor connected at both ends of the wire, in order to obtain one-way matching of the characteristic impedance of the line Z_{line} to the system impedance Z_0.

For the calculation of the longitudinal impedance $Z_{\|}$, from the measured S_{21} parameter, the log formula can be used [9]:

$$Z_{\|} = -2Z_{line} ln S_{21} \qquad (2)$$

From the measured S_{21} parameter, the longitudinal beam coupling impedance $Z_{\|}$ is calculated, when the remote end of the striplines is matched to 50 Ω by using the hybrid. Results for both measurements and CST simulations are shown in Fig. 6. There is a good agreement between the calculated and predicted longitudinal beam coupling impedance up to ≈ 0.25 GHz: at higher frequencies the simulations and measurements are not in good agreement, probably because of the non-ideal properties of the matching resistors and cables.

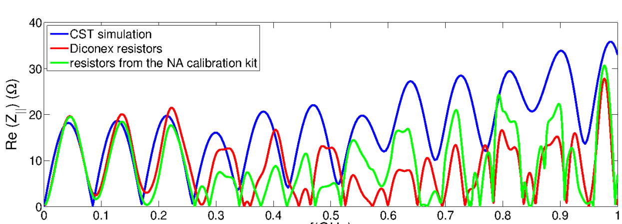

Figure 6: Calculated $Z_{\|}$ from the measured S_{21} parameter, compared with CST simulations.

The classical coaxial wire measurement technique gives good frequency resolution, however any residual mismatch in the characteristic impedance between the measurement network and the device under test (DUT) results in reflections in the system. These reflections can be removed by an appropriate time domain gated measurement but there can be a large DC offset, caused by the loss of transmitted energy by the gating of the signal. The resistively matched measurements generally gives good results below a few hundred MHz but the residual mismatch in the system can cause large oscillations which mask the true impedance [10]. It is planned to repeat the beam coupling impedance measurements using the resonant method: in order to give reasonable frequency resolution the length of the striplines will be artificially extended.

CONCLUSIONS

The laboratory tests of the CLIC DR extraction kicker have started, without beam, in order to characterize the electromagnetic response of the striplines. The measurements carried out have been: (1) the S_{11} parameter and (2) the longitudinal beam coupling impedance. The electrodes have been driven in either odd or even mode, and have been terminated with either a HQ 50 Ω from the NA calibration kit or with the Diconex HV resistors, which have a frequency-dependent impedance. A good agreement has been found between the laboratory tests and the CST simulations up to 0.25 GHz. Further tests will be carried out in order to finish the characterization of the striplines, including the resonant method to measure the longitudinal beam coupling impedance, transverse beam coupling impedance studies and HV tests.

ACKNOWLEDGMENTS

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