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Modelling, Measurement and Construction of the Stripline Kickers for the Tevatron Transverse Dampers

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ABSTRACT: In this paper, we will describe the modelling, measurement and construction of the stripline kickers for the Tevatron transverse dampers. We will show that the odd/even impedances calculated using Poisson gave very good results when compared to the measured odd/even impedances of a stripline prototype. Using the prototype, we will show how we had adjusted the launch impedance so that the reflection coefficient $s_{11} < -35$ dB between 0 to 100 MHz. We will also show the final design of the kickers and point out the deficiencies of this design.

INTRODUCTION

In this paper, we will describe the modelling, measurement and construction of the stripline kickers for the Tevatron transverse dampers. Figure 1 shows the conceptual design of the striplines which basically consists of an outer tube with and two copper strips. Using this conceptual design, we divided the problem into the following three parts:

(*i*) A Poisson model which allowed us to calculate the size and position of the copper strips with the constraint that the odd impedance of the structure be at 50Ω. We require the odd impedance to be at 50Ω because the kicker will be driven differentially.

(*ii*) Construction of a stripline prototype. The prototype allowed us to measure the odd and even impedances of each stripline which in effect, checked our Poisson model. More importantly, it allowed us to adjust the launch impedance so that it is also 50Ω.

(*iii*) Produce a final design which can be built and installed in the Tevatron. Many problems were encountered at this stage and we will point out the deficiencies in the present design.

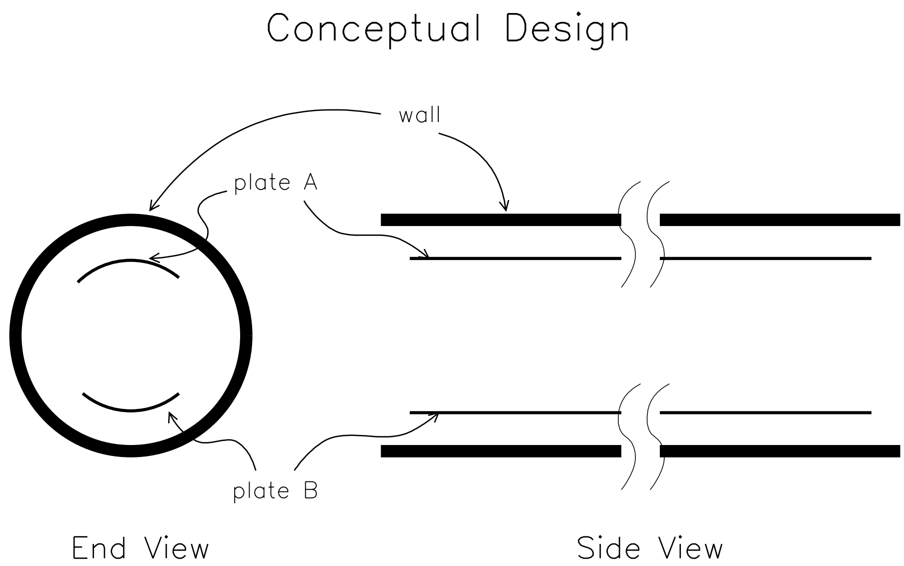

Figure 1 This figure shows the conceptual design of the stripline kickers. The design consists of an outer wall which is held at ground and two curved plates A and B held at some potential difference w.r.t. the wall.

POISSON MODEL

In order to calculate the odd impedance Z_{odd} of stripline A[†] which is when plate A is at $+V$ and plate B is at $-V$ w.r.t. wall, we notice that the equipotential lines in the stripline are the same when we replace the plane of symmetry by a perfectly conducting wall. See Figure 2. Thus Z_{odd} can be easily calculated using the structure in Figure 2 by the following method:

We know that

$$\left.\begin{aligned} E_{\text{odd}} &= \frac{1}{2}CV^2 \\ c &= \frac{1}{\sqrt{LC}} \\ Z_{\text{odd}} &= \sqrt{\frac{L}{C}} \end{aligned}\right\} \tag{1}$$

[†] Stripline B also has odd impedance Z_{odd} from the anti-symmetric way odd impedance is defined. Similarly, striplines A and B have the same even impedance.

where E_{odd} is the energy/length of the structure, C is the capacitance/length of the structure, L the inductance/length of the structure, V the potential difference between the plate and the wall, and c the speed of light in vacuum. Then it is easy to show that

$$Z_{\text{odd}} = (2cV^2 E_{\text{odd}})^{-1} \tag{2}$$

In particular, when the wall has a radius of 2 inches, the plate has a radius of 1.5 inches and an angular size of 79°, and $V = 1$ then $E_{\text{odd}} = 3.33 \times 10^{-13}$ Joules/cm when calculated using Poisson. When these numbers are substituted into (2), we see that $Z_{\text{odd}} = 50.0\Omega$.

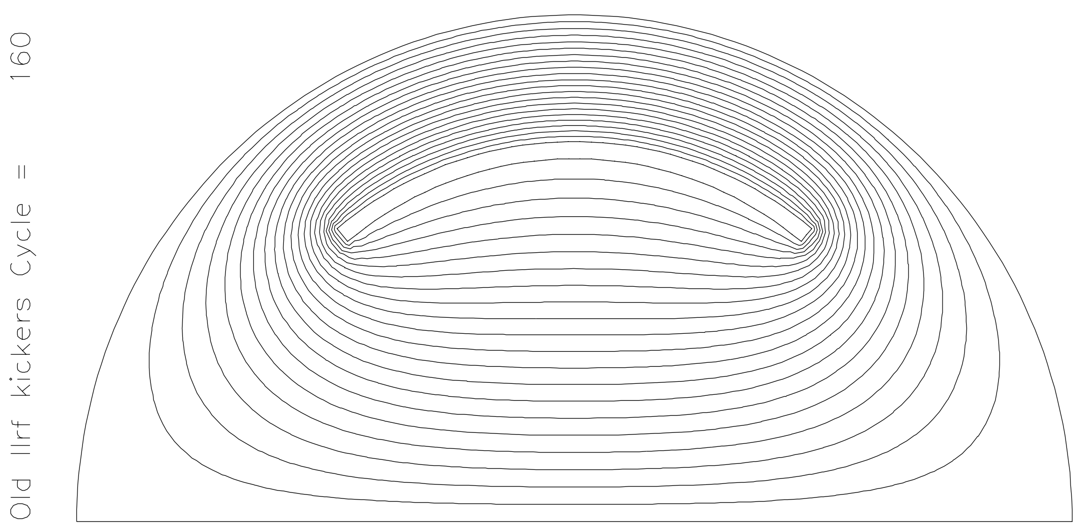

Figure 2 This figure shows the equipotential lines for half the structure when we have electric boundary conditions which means that the calculation is for Z_{odd}. The angular size of the curved plate is 79° and its radius is 1.5 inches. The wall has a radius of 2 inches.

A similar argument can be used for calculating the even impedance Z_{even} of stripline A which is when both the plates are at V w.r.t. the wall. E_{even} is calculated using Poisson when the plane of symmetry is a perfect magnetic wall and

$$Z_{\text{even}} = (2cV^2 E_{\text{even}})^{-1} \tag{3}$$

Again using the same structure shown Figure 2, we find from Poisson that $E_{\text{even}} = 2.96 \times 10^{-13}$ Joules/cm when $V = 1$ and thus $Z_{\text{even}} = 56.3\Omega$ from (3).

TDR MEASUREMENTS

In order to verify the impedances calculated in the previous section, we constructed a prototype of the stripline kicker with transverse dimensions discussed in the previous section. Its impedances Z_{odd} and Z_{even} were then measured using a TDR (time domain reflectometer). The results are shown in Figure 3 and 4.

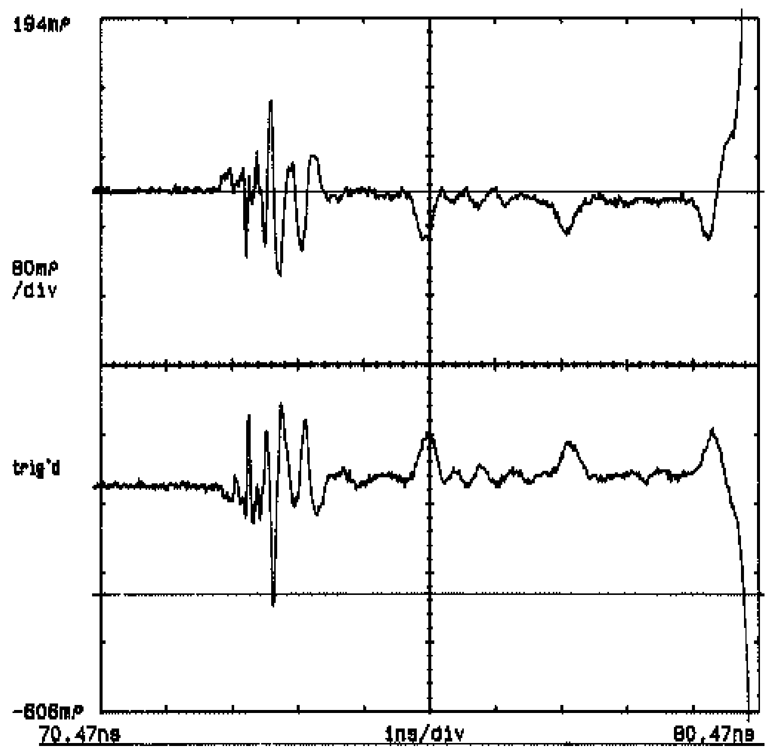

Figure 3 Z_{odd} of input A and input B measured by a TDR. Notice the anti-symmetry between input A and input B. The average impedance of the inputs is 49.4Ω which is only 1.2% error from the theoretical value of 50Ω.

We can see that the error between calculation and measurement is $\sim 1\%$ for Z_{odd} and 3.5% for Z_{even}. The bumps seen in the figures are from the ceramic standoffs which hold the plates to the wall.

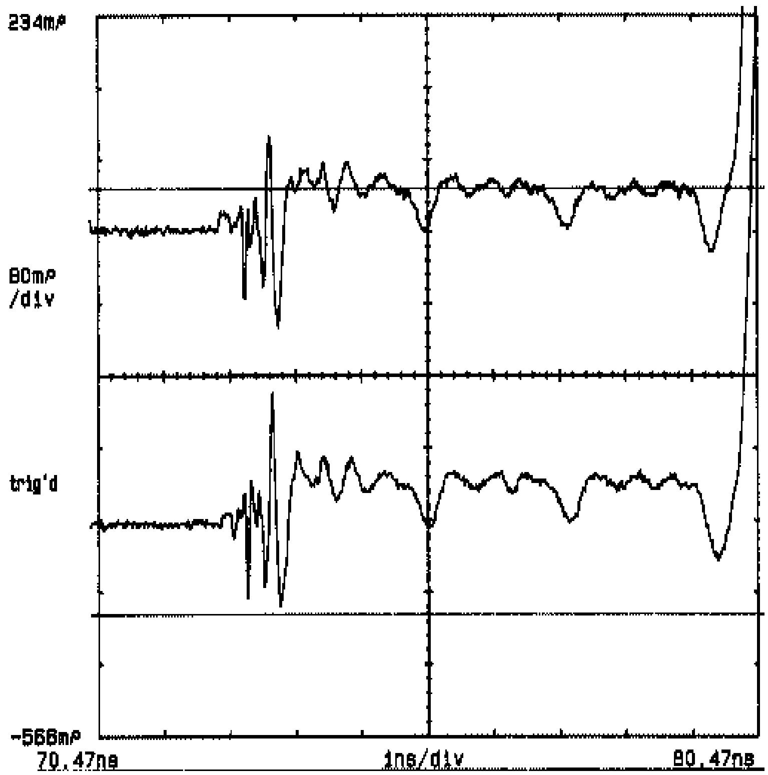

Figure 4 Z_{even} of input A and input B measured by a TDR. Notice the exact symmetry between input A and input B. The average impedance of the inputs is 54.4Ω which is only 3.5% error from the theoretical value of 56Ω.

LAUNCH IMPEDANCE

The launch impedance is defined as the impedance at the point of transition between the type N connector and the copper strip shown in Figure 8. There is an impedance change here because geometrically, the current flowing from the centre conductor of the type N connector must make a 90° turn to flow into the copper strip. Furthermore, there is also a physical transition between a round conductor to a wide conductor.

We can see the result of this transition using a TDR as before. Figure 5 shows the large impedance oscillations at the launch. In order to remove one of the large inductive impedances, we made a copper block and attached it to the centre conduction of the type N connector and affixed it to the copper strip. The final assembly drawing Figure 8 shows where the launch corrector is placed. The size of the copper block is adjusted so that the capacitor formed between the copper block and the wall would just cancel one of the oscillations. Clearly this method is not perfect because cancellation only occurs in some finite bandwidth. Figure 6 shows the result after the copper block is affixed and we can see that one of the inductance oscillations is in fact reduced using this method.

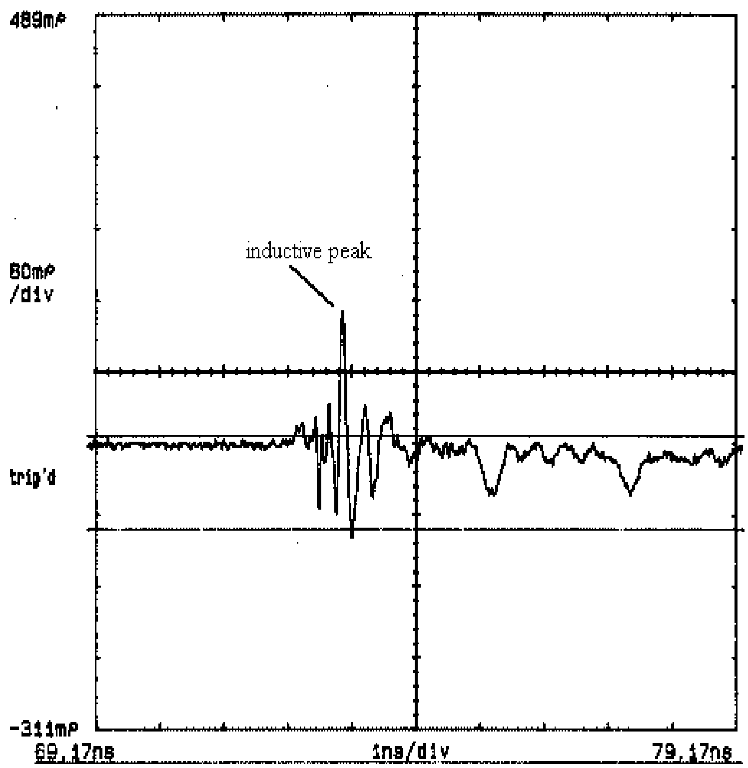

Figure 5 This figure shows the large impedance oscillations at the launch before correction. The large spike indicated in the figure shows that there is too much inductance at that point.

Figure 7 shows the reflection coefficient s_{11} from 0 to 200 MHz and we see that within this bandwidth $s_{11} < -30$ dB. Thus our efforts in matching the impedances to 50Ω have been successful because the carrier frequency of the kicker generator is 53 MHz.

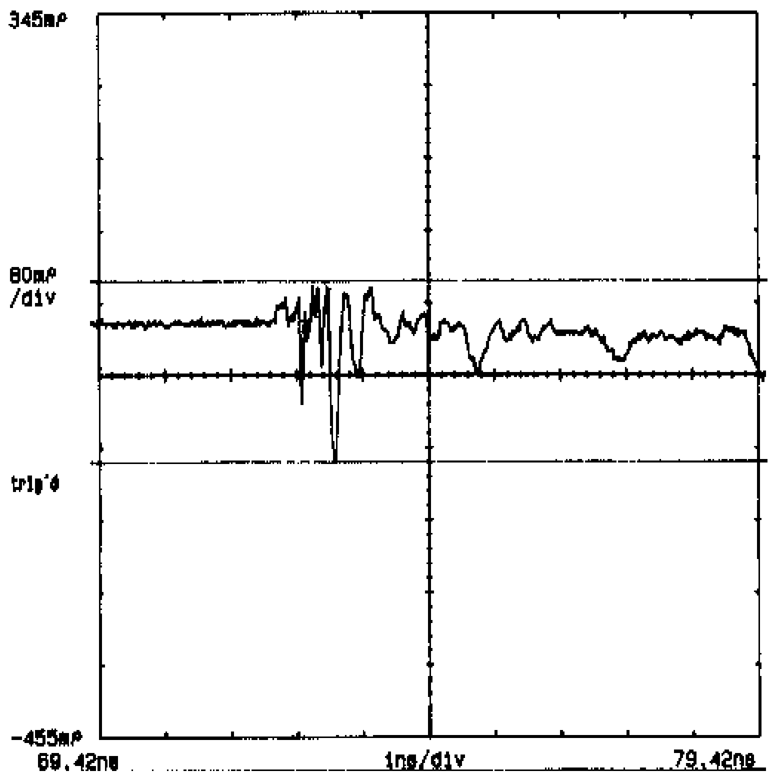

Figure 6 After inserting a $(0.6 \times 0.5 \times 0.375)$ inch^3 copper block at the launch that increases capacitance at that point, we can reduce the effect of the inductance.

DESIGN

The final design is shown in Figure 8. The overall length of the kicker is about 1 m and like the prototype, each copper plate subtends an angle of 79° and has a radius of 1.5 inches. The wall is made of stainless steel and has an inner diameter of 4 inches.

Unfortunately, although this design has performed to its electrical design, here are many drawbacks to its mechanical design:

(i) Attachment of the copper plates to the wall requires the holes on the wall to align with the holes of the ceramic standoffs. Any misalignment can cause the standoffs to crack when the screws are tightened.

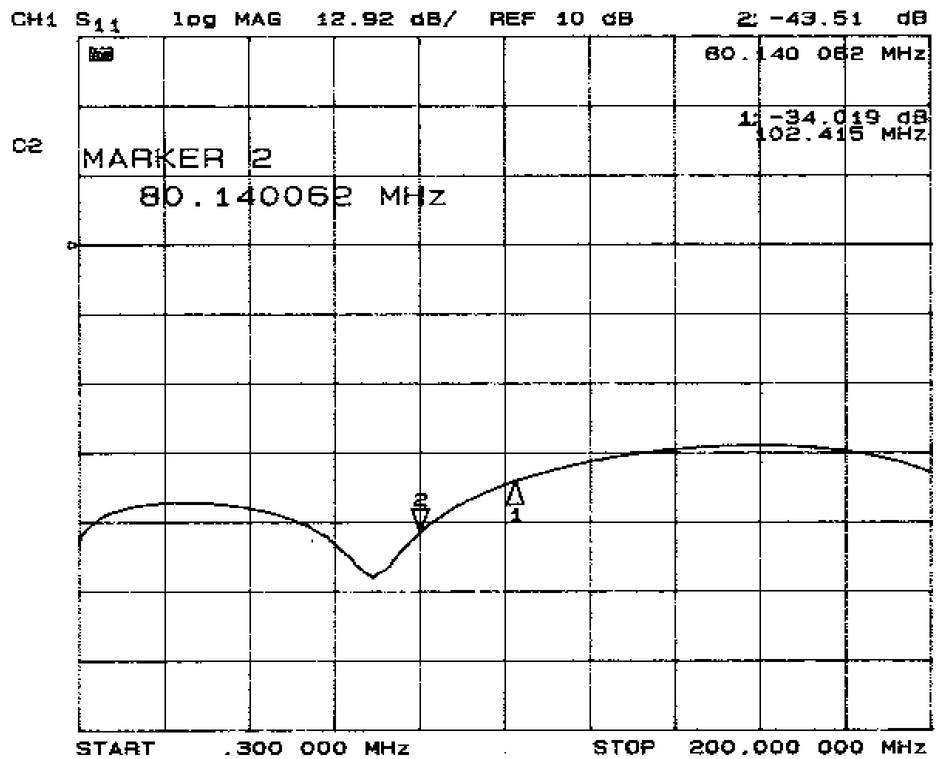

Figure 7 This is the s_{11} measurement and shows that the reflection coefficient is at < -30 dB within the bandwidth of 200 MHz from DC and < -35 dB within 100 MHz from DC.

(*ii*) The ceramic standoffs are extremely fragile and extreme care must be exercised when the screws holding the ceramic standoffs are welded to the wall.

(*iii*) The correction copper blocks have to align with the centre conductor of the type N connector and many times this has to be done with extreme prejudice.

(*iv*) The type N connectors have a vacuum failure rate of 10% when welded. Thus if after most of the kicker has been assembled and welded and a type N connector failure is detected, disassembly to fix the problem may prove to be impossible.

In conclusion although this particular kicker design (and an extremely similar pickup design) has been successfully installed and used in the Tevatron, it is advisable to redesign the mechanical assembly to take care of the above problems.

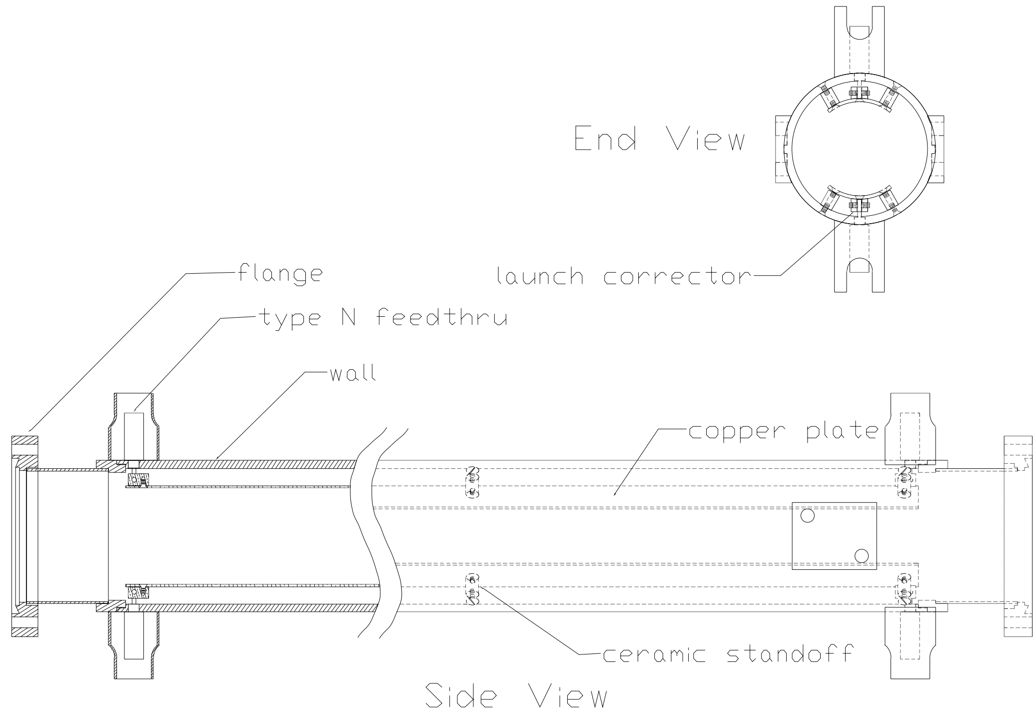

Figure 8 This figure shows the final assembly drawing of the stripline kickers.

CONCLUSION

We have shown how we have modelled the stripline kicker using Poisson and used its results to construct a kicker prototype. Using this prototype, we showed that Poisson's impedance results closely matched the measured values. In fact, we produced four kickers and eight similarly desinged pickups and all of them have similar s_{11} results. These are now currently used for the Tevatron transverse dampers system.

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