Layout Guidelines for adding ESD Protection in HDMI Receiver Applications

The High Definition Multimedia Interface (HDMI) video signals are transmitted on very high speed differential pairs. These lines are susceptible to electrostatic discharge (ESD) either directly from a user or from plugging a charged cable into the port. In order to ensure the functionality of this port, consumer electronics manufacturers require that HDMI ports be ESD hardened, often to the IEC61000-4-2 ESD standard. A level 4 discharge would require withstanding a ±15kV air and ±8kV contact discharge. In order to meet this stringent standard, external protection devices at the port entrance are required.

Semtech offers very low capacitance protection devices for high speed applications. However, adding even a small amount of capacitance across the differential pair can cause the impedance of the differential pair to drop as much as 40Ω depending on the measurement method. This is not desirable because HDMI sink (receiver) ports are required to maintain a differential impedance of 100Ω ±15% on each of the four differential pairs, per the HDMI Compliance Test Specification (CTS). Some compensation becomes necessary to remain within the HDMI CTS impedance requirement for a sink device. Sink ports include applications such as LCD-TV, PTV and HDTV. Source (transmit) ports include applications like Set-top-box and DVD players and are not subject to the HDMI CTS impedance requirement.

In addition to protection, filtering for EMI suppression is often needed. Taking advantage of the cancellation effect of the EMI filter inductance and/or by using some board layout techniques to increase the impedance of the differential pairs, compensation of the TVS capacitance can be done. This application note will outline these methods that will essentially cancel the effects of the added capacitance and inductance of the ESD/EMI protection components. Examples will be provided based on the uses of Semtech RClamp0502B® and RClamp0544M®ESD protection devices.

The HDMI CTS specifies that the impedance of the receiver HDMI port be measured using a Time Domain Reflectometry (TDR) method that utilizes a pulse with a risetime of <=200ps. Imperfections (added capacitance) on the lines will have a larger affect on the impedance of the line with a faster TDR measurement pulse risetime. If a protection device with a typical differential capacitance value of 1.5pF was added to the 100Ω differential transmission lines without any compensation, the differential impedance of the lines may decrease by 55Ω or more at the position of the protection device depending on the risetime of the test pulse. The measurements in this application note are made at a 200ps risetime.

The idea behind compensating for the added C_J is best described by Dr. Howard Johnson's "Potholes" analogy. The idea is to reduce the effect of the pothole by filling it with a rock that is approximately the size of a pothole. The results may not completely negate the effect but it can be reduced to a tolerable amount. Figure 1 shows a transmission line with the added capacitance of the protection device labeled as $C_{(TVS)}$. Equations 1 and 2 can be used as a good means of determining if it is even possible to compensate for the additional capacitance presented by the added protection component. The equations are for common mode impedance while the HDMI application specifies the differential impedance of a transmission line pair. It is common, for example, to design Z_0 to be 50Ω in order to achieve the 100Ω differential impedance HDMI requirement. However, this is not necessarily true especially as high speed differential traces are tightly coupled for good common mode reject. To determine the actual dimensions of traces, dielectrics thickness, trace spacing, etc., the PCB layout software will need to include a controlled impedance calculator add-on option. Layout software like Mentor Graphic's "Expedition" or Cadence's "Allegro" come equipped with an impedance calculator. However, a designer should still defer to the PCB manufacturer's software and calculation, because they have their own design rules, tolerances and constraints. Many PCB manufacturers use "Polar" as their controlled impedance calculator because of its accuracy.

To use the following method, a designer may start by making a board with 50Ω common mode traces that should result in a differential impedance of approximately 100Ω. The designer can then measure the amount of drop caused by the addition of the imperfection (added protection device and filtering on the lines). Z_1 will then need to be this measured impedance added to Z_0. Since the HDMI impedance

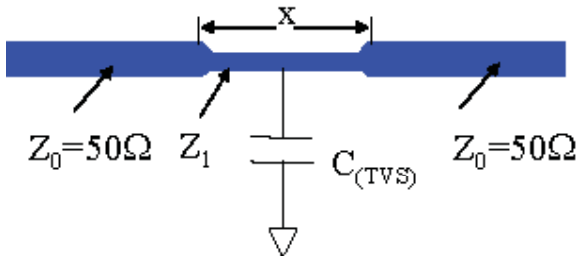


Figure 1 - Compensation of $C_{(TVS)}$ with trace length

Equation 1:

$$x = \left(\frac{Z_0 C_{TVS}}{\tau}\right)\left(\frac{k}{k^2+1}\right)$$

Equation 2:

$$k = \frac{Z_1}{Z_0}$$

- Z_0 is the surrounding transmission line.
- k defines the unloaded impedance of the the adjusted segment
- Z_1 is the impedance needed to compensate for the add $C_{(TVS)}$
- τ is the effective delay of the adjusted segment which is 180ps FR4.
- x is the length of the adjusted segment and will be given in inches if is given in ps and $C_{(TVS)}$ in pF.

measurement is made differentially, Z_1 must be the amount of measured impedance drop divided by two plus the Z_0. Knowing how much Z_1 is needed to compensate for the added capacitance of the line, k and x can be found. A designer should give this Z_1 impedance requirement to the PCB manufacturer to determine if the layout parameters needed to achieve this impedance can be reliably produced.

In order to perform an empirical evaluation of these methods, Semtech has designed several boards of varying layouts and measured the results. The boards were designed specifically for the RClamp0504M, the RClamp0502B, and the RClamp0514M protection devices. The results of these evaluations are given in the following section.

Evaluation Board Results of the RClamp0502B

The RClamp0502B is a low capacitance protection device that protects one high speed differential pair. The typical differential capacitance of the RClamp0502B is 0.6pF. Due to this low differential capacitance, it was determined that the RClamp0502B on the HDMI signals can still remain within the HDMI CTS impedance requirement when minor layout compensation are made. If a common mode choke is normally used in the HDMI design, some considerations need to be made to ensure that the impedance on the high side does not exceed the HDMI CTS impedance requirement or a more capacitive device should be used (RClamp0504M). The capacitance of the RClamp0502B is so low that it may not necessarily cancel the added inductance of the common mode choke.

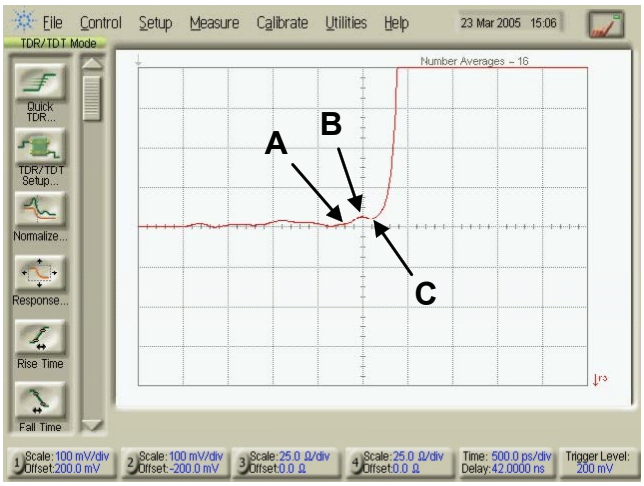
Four Layer Evaluation Board Results of the RClamp0502B

The "SC-75 HDMI EVAL Rev D" evaluation board was designed with minor impedance adjustments to compensate for the RClamp0502B low capacitive loading to keep the differential impedance of the HDMI signal traces within the 100Ω ± 15% HDMI CTS requirement. Table 1 shows the summary of the board and trace parameters. The TDR test results in Figure 2 shows were well within the HDMI CTS impedance

HDMI SC-75 Rev D Evaluation Board RClamp0502BM with layout and board compensation	
Number layers	4
Copper thickness	1.5 oz finished thickness
Board thickness	0.062"
Dielectric thickness between layer 1 and Gnd	0.010"
Trace pitch	(1.0mm) or 0.0393"
Trace thickness	0.004" for 0.080" before and after the RClamp0402B
Trace thickness to achieve 50 Ω nominally	0.013"

Table 1 - RClamp0502B four layer evaluation board layout parameters

requirements. On the high side, the impedance measured at 106.1Ω and on the low side, the impedance measured at 101.6Ω. Figure 3 shows the impedance design guidelines a PCB board designer may use in accordance with their board layout and design parameters.



	A	B	C	
X-axis	1.816	1.95	2.15	nsec
Y-axis	108	102	108	Ω

Figure 2 - RClamp0502B TDR test results on four layer evaluation board

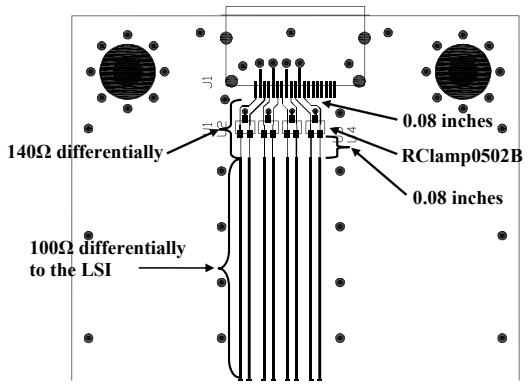


Figure 3 - HDMI SC-75 Rev D Evaluation Board Design Guideline for RClamp0502B

Evaluation board results of the RClamp0544M

The RClamp0544M has a flow through pacakge design to help reduce discontinuities on high speed signal lines. The typical differential capacitance of the RClamp0544M is 0.7pF. Like the RClamp0502B, the RClamp0544M also has a very low differential capacitance. This allows it to be designed with minor layout compensation onto HDMI signals to remain within the HDMI CTS impedance requirement. Results for a two, four and six layer board is presented in the following.

RClamp0544M Four Layer Board Evaluation

The "HDMI MSOP-10L Rev E" board is a four layer board designed with minor trace compensation to keep the impedance of the differential pairs within the HDMI CTS impedance specification. A higher trace impedance of 140 Ω is placed 0.1575 inches before and after the RClamp0544M to compensate for added capacitance. This design guideline is shown in Figure 4. The board and trace parameters of the evaluation made to these design guidelines are summarized in Table 2.

HDMI MSOP-10L Rev E Evaluation Board RClamp0544M with layout and board compensation	
Number layers	4
Copper thickness	1.5 oz finished thickness
Board thickness	0.062"
Dielectric thickness between layer 1 and Gnd	0.010"
Trace pitch	(0.500 mm) or 0.0197"
Trace thickness	0.004" for 0.1575" before and after the RClamp0544M
Trace thickness to achieve 50 Ω nominally	0.010"

Table 2 - RClamp0544M four layer Evaluation board layout parameters

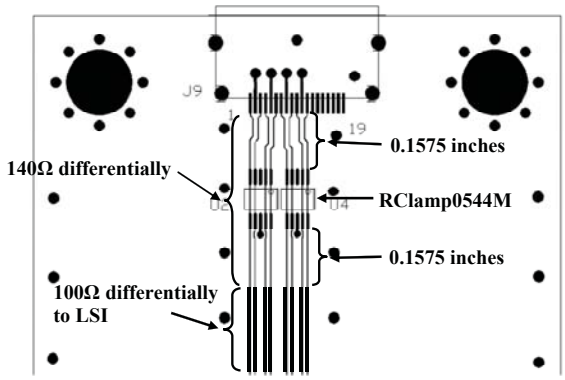
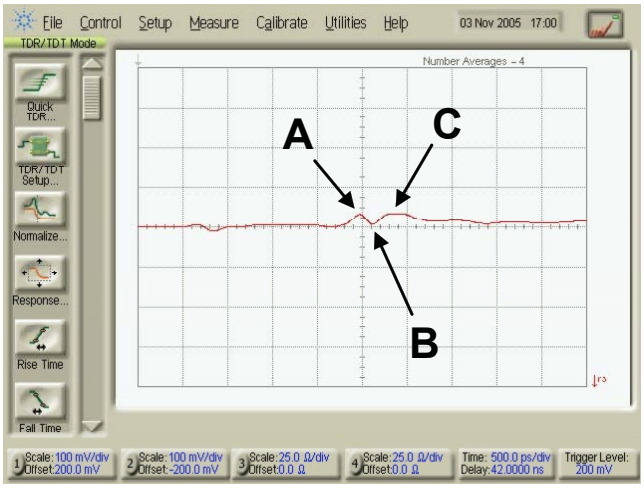


Figure 4 - RClamp0544M Four Layer Design Guideline (HDMI MSOP-10L Rev E)

Two Layer Evaluation Board Results of the RClamp0544M

In the pursuit of saving manufacturing cost, many designers are try to convert their design to two layers. This may not alway be possible as a design number of trace connections increase. As more functions are provided in each design, it may become very difficult if not impossible to route all the required traces using only two layers. The "HDMI MSOP-10L Rev G" board is a two layer board designed with minor trace compensation to keep the impedance of the differential pairs within the HDMI CTS impednace requirement. The two layer board design guideline shown in Figure 6 provides the means to use the RClamp0544M on the HDMI high speed signal while keeping the differnential impedance of the signal traces within the HDMI CTS impedance requriement. Table 3 summarizes the trace parameters for the two layer evaluation board that was made (HDMI MSOP-10L Rev G). The TDR result is shown in Figure 7. As shown, the impedance of the differential pair is well within the HDMI CTS spec of 100 Ω ± 15%.



	A	B	C	
X-axis	1.816	1.95	2.15	nsec
Y-axis	108	102	108	Ω

Figure 5 - RClamp0544M TDR test result on Four Layer Board

Two Layer Evaluation Board (HDMI MSOP-10L Rev G) RClamp0544M with layout and board compensation	
Number layers	2
Copper thickness	1.0 oz finished thickness
Board thickness	0.062"
Dielectric thickness between layer 1 and Gnd	0.010"
Trace pitch	(0.500 mm) or 0.0197"
Trace thickness	0.006" for 0.1575" before and after the RClamp0544M
Trace thickness to achieve 50 Ω nominally	0.010"

Table 3 - RClamp0544M two layer Evaluation board parameters

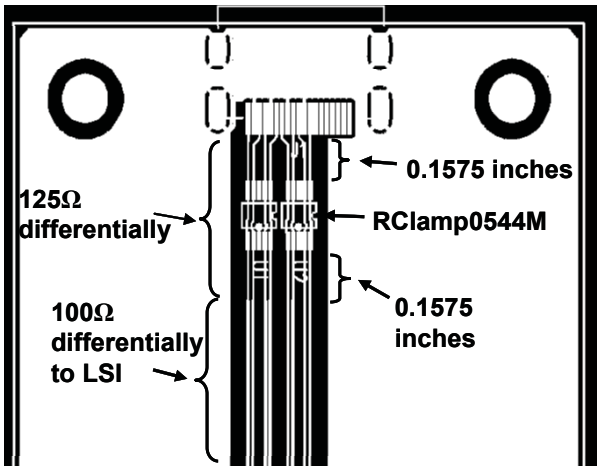
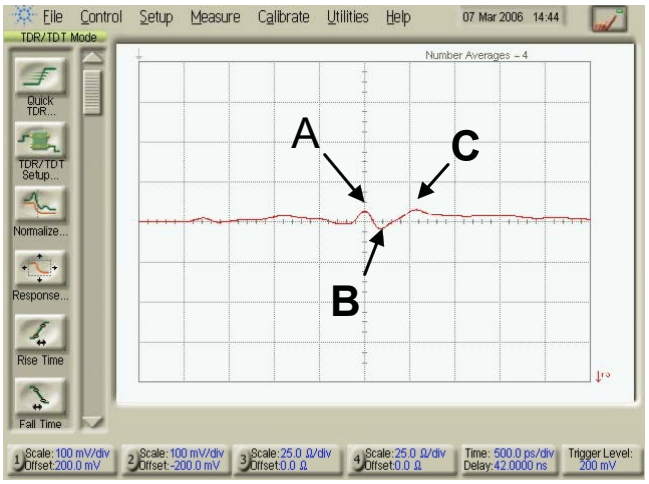


Figure 6 - RClamp0544M Two Layer Design Guideline (HDMI MSOP-10L Rev G Evaluation Board)



	A	B	C	
X-axis	1.794	1.98	2.356	nsec
Y-axis	107	95	108	Ω

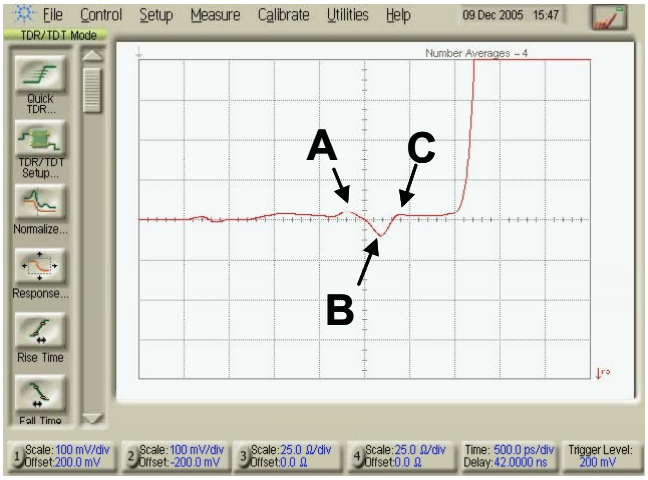
Figure 7- RClamp0544M TDR test results on two Layer Board

Six Layer Evaluation Board Results of the RClamp0544M

As HDMI design gets more complicated, a four layer board may not provide enough room to make the necessary connections. When this happens, designers will use a six layer board. The six layer board design guideline shown in Figure 8 provides the means to use the RClamp0544M on the HDMI high speed signal while keeping the differnential impedance of the signal traces within the HDMI CTS impedance requirement. Table 4 summarizes the trace parameters for the six layer evaluation board. The TDR result is shown in Figure 9. As shown, the impedance of the differential is well within the HDMI CTS spec of 100 Ω ± 15%.

Six Layer HDMI Evaluation Board RClamp0544M with layout and board compensation	
Number layers	6
Copper thickness	1.5 oz finished thickness
Board thickness	0.062”
Dielectric thickness between layer 1 and Gnd	0.0047”
Trace pitch	(0.500 mm) or 0.0197”
Trace thickness	0.005” for 0.220” before and after the RClamp0544M
Trace thickness to achieve 50 Ω nominally	0.010”

Table 4 - RClamp0544M Six layer Evaluation board parameters



	A	B	C	
X-axis	1.68	1.993	2.134	nsec
Y-axis	104	90	100	Ω

Figure 8- RClamp0544M TDR test results on six Layer Board

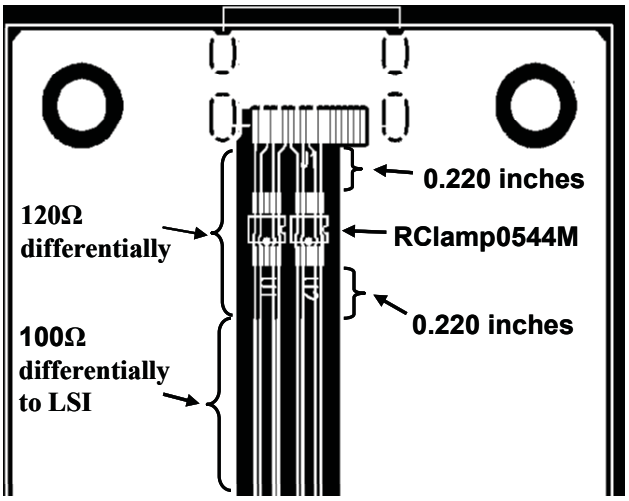


Figure 9 - RClamp0544M Six Layer Design Guideline (HDMI MSOP-10L Rev G)

Conclusion

This application note discussed two protection solutions to meet the IEC61000-4-2 ESD standard; the RClamp0502B and the RClamp0544M. Unfortunately, the protection solution is inherently capacitive. Both the RClamp0502B and RClamp0544M were designed to be very low in capacitance for high speed signals. Although the capacitive loading of these devices are very low, they can still cause the differential impedance of the signal trace go outside of the HDMI CTS impedance requirement. This application note provided design guidelines to provide trace compensation around the protection device in order to keep the impedance within the HDMI CTS. Design guidelines were provided using the RClamp0502B on a two layer board and the RClamp0544M in a two, four and six layer board. Table 5 summarizes the TDR test results of all four test configurations. In all cases, the TDR of the trace stayed well within the HDMI CTS.

	Spec Max (W)	Spec Min (W)	Actual Max (W)	Actual Min (W)
Four Layer Evaluation Board (RClamp0502B)	115	85	108	102
Two Layer Evaluation Board (RClamp0544M)	115	85	108	95
Four Layer Evaluation Board (RClamp0544M)	115	85	106.1	95
Six Layer Evaluation Board (RClamp0544M)	115	85	104	90

Table 5 - Summary of TDR Test Results

References:

- Johnson, Dr. Howard "*Potholes", EDN Magazine Nov 1999 and www.sigcon.com*
- Johnson, Dr. Howard, " High Speed Signal Propagation- Advance Black Magic"
- Geske, Hani and Yoshima, Satoko, "HDMI Compliant ESD/CDE Protection for Real World Video Circuit." June 9, 2006.