

PROTECTION PRODUCTS**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 $\pm 15\text{kV}$ air and $\pm 8\text{kV}$ 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 $100\Omega \pm 15\%$ 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. Compensation of the TVS capacitance can be done by either 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. 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 RClamp0504M, RClamp0502B, RClamp0514M 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 $\leq 200\text{ps}$. Imperfections (added capacitance or inductance) on the lines will have a larger effect 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. For a 200ps risetime pulse, the 1.5pF differential capacitance of the protection device will look like a 55Ω differential impedance drop.

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 $C_{(TVS)}$. Equation 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. Note that 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. 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.

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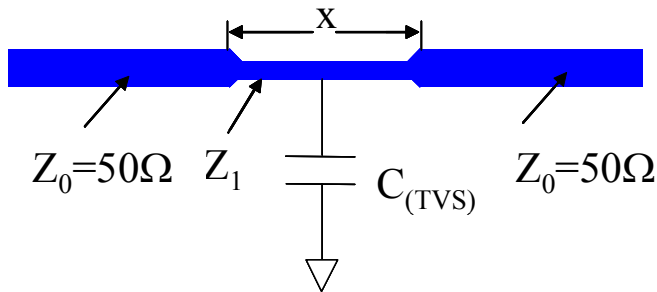


Figure 1 - Compensation of $C_{(TVS)}$ with trace length

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 τ is given in ps and $C_{(TVS)}$ in pF.

To use the above 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 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.

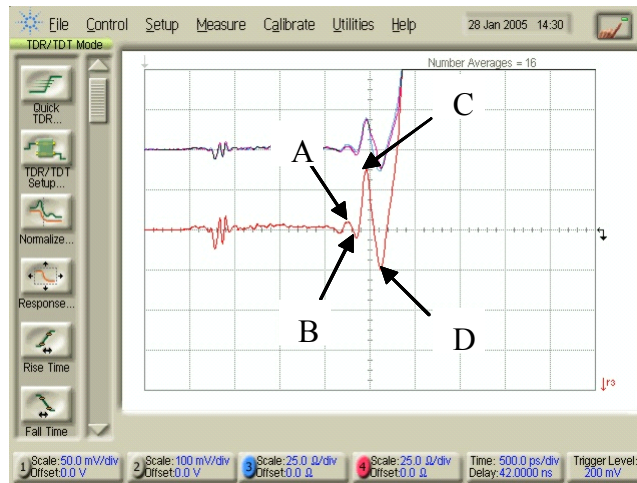
In order to perform an empirical evaluation of these methods, Semtech has designed several boards of varying layouts and measured the results. The boards were designed specifically for the RClamp0504M, the RClamp0502B, and the RClamp0514M protection devices. The results of these evaluations are given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

Evaluation board results of the RClamp0504M

The RClamp0504M has a flow through package design that helps reduce discontinuities on high speed signal lines. The typical differential capacitance of the RClamp0504M is 1.5pF. The initial goal was to see if the capacitance of the RClamp0504M could be compensated purely by adjustment of the board and layout parameters. It was determined that this was not possible using reliably producible trace widths to increase the impedance of the lines. This evaluation was done on the “HDMI MSOP-10L Rev B” evaluation board. Table 1 summarized the parameters of the board and traces. The test results are shown in Figure 2. The impedance at the low end was at 75Ω which is still outside of the 100Ω ±15% goal. It is possible to reduce the width of each trace to less than 0.004 inches in order to increase the inductance of the line. However, trace widths of less than 0.004 inches become increasingly more difficult for PCB manufacturers to reliably achieve.

HDMI MSOP-10L Rev B Evaluation Board RClamp0504M with layout and board compensation	
Number layers	4
Copper thickness	1.5 oz finished thickness
Board thickness	0.062 inches
Dielectric thickness between layer 1 and Gnd	0.010 inches
Trace pitch	(0.500mm) or 0.0197 inches

Table 1 - HDMI MSOP10-L Rev B evaluation board layout parameters



	A	B	C	D	
X-axis	1.5248	1.6322	1.7494	1.9008	(nsec)
Y-axis	105.7	95.6	139.6	75.9	(Ohm)

Figure 2 - RClamp0504M mounted on the HDMI MSOP-10L Rev B evaluation board test results

It was determined that it was not possible to compensate for the added RClamp0504M $C_{(TVS)}$ purely by adjusting layout parameters. The next step was to evaluate the possibility of using a CM choke to offset the adverse effect of the added capacitance. The CM choke was chosen because many designs already used it for CM noise reduction. Figure 3 shows the layout of the “HDMI MSOP-10L Rev D” evaluation board. Table 2 summarizes the parameters of the board and traces. The part number of the CM choke used is ACM2012D-900 and is manufacturer by TDK. The test result is shown in Figure 4. The impedance this time was within the $100\Omega \pm 15\%$ HDMI CTS for a sink device. On the low end, the impedance was at 92Ω while the high end was kept to 100Ω . This showed that by using the inductance of the CM choke to offset the capacitance of the RClamp0504M along with some layout adjustments to increase the impedance of the line, the differential trace impedance of the lines stay within the HDMI CTS impedance requirement. Since each board will have a

different layout and design parameters, Figure 5 provides some impedance design guidelines that a PCB board designer can use to size their traces based on their board constraints.

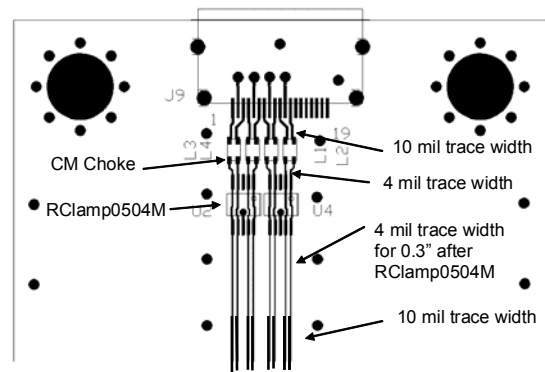
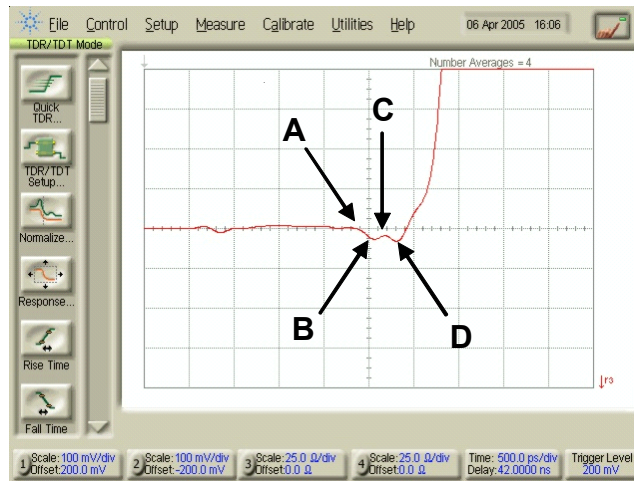


Figure 3 - HDMI MSOP-10L Rev D Evaluation Board Layout



	A	B	C	D	
X-axis	1.639	1.868	1.985	2.122	(nsec)
Y-axis	100	93	95	92	(Ohm)

Figure 4 - RClamp0504M and CM choke mounted on HDMI MSOP-10L Rev D evaluation board test results

HDMI MSOP-10L Rev D Evaluation Board RClamp0504M and CM Choke with layout and board compensation	
Number of layers	4
Copper thickness	1.5 oz finished thickness
Board thickness	0.062 inches
Dielectric thickness between layer 1 and Gnd	0.010 inches
Trace pitch	(0.500mm) or 0.0197 inches

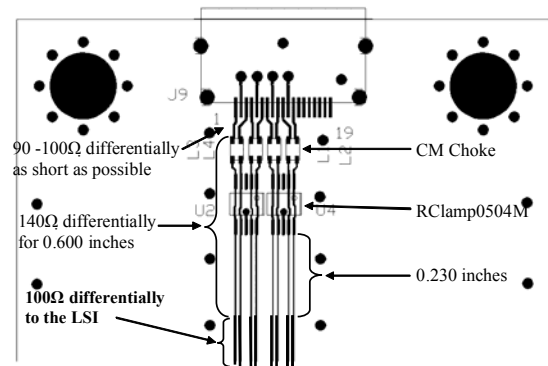


Figure 5 - HDMI MSOP-10L Rev D Impedance Design Guideline

Table 2 - HDMI MSOP10-L Rev D evaluation board layout parameters

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Evaluation Board Results of the RClamp0502B

The RClamp0502B is a low capacitance protection device that protects two high-speed signal lines. The maximum differential capacitance of the RClamp0502B is 0.9pF. Since the HDMI CTS impedance is specified as a differential impedance, the maximum capacitance loading due to the RClamp0502B on the differential pair is only 0.9pF. Due to this low differential capacitance, the RClamp0502B was determined to be capable of meeting the HDMI CTS impedance requirement by making minor adjustments to the board layout parameter. The inductance compensation of a common mode choke is not necessary. If a common mode choke is used normally in the application, some considerations need to be made to ensure that the impedance on the high end does not exceed the HDMI CTS impedance requirement. If it does, a higher capacitance device like the RClamp0504M should be considered. The “SC-75 HDMI EVAL Rev D” evaluation board was designed specifically to compensate for the low capacitive loading of the RClamp0502B protection device yet keeping within the HDMI CTS impedance requirement. Table 3 shows the summary of the board and trace parameters. The TDR test results in Figure 7 shows that the differential impedance measurements were well within the HDMI CTS impedance requirements. On the high side, the impedance measured at 106.1Ω and on the low side, the impedance measured at 101.6Ω. Figure 6 shows the impedance design guidelines a PCB board designer may use in accordance with their board layout and design parameters.

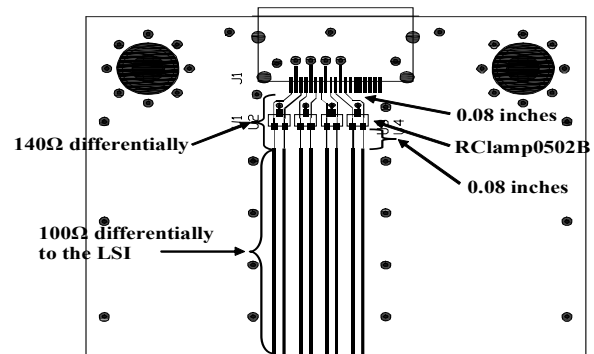
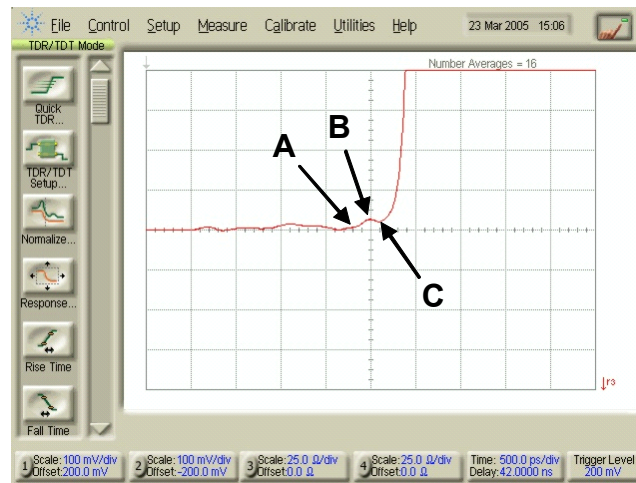


Figure 6 - HDMI SC-75 Rev D Impedance Design Guideline

HDMI SC-75 Rev D Evaluation Board RClamp0502B with layout and board compensation	
Number of layers	4
Copper thickness	1.5 oz finished thickness
Board thickness	0.062 inches
Dielectric thickness between layer 1 and Gnd	0.010 inches
Trace pitch	(1.0mm) or 0.0393 inches

Table 3 - HDMI SC-75 Rev D evaluation board layout parameters



	A	B	C	
X-axis	1.655	1.801	1.938	(nsec)
Y-axis	101.6	106.1	105.1	(Ohm)

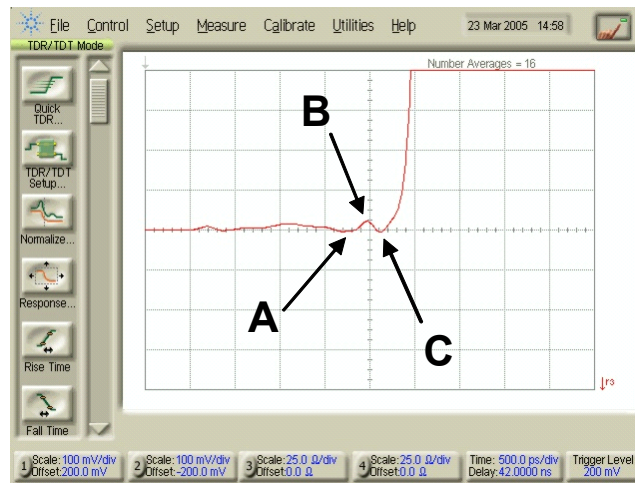
Figure 7 - RClamp0502B mounted on HDMI SC-75 Rev D evaluation board test results

Evaluation board results of the RClamp0514M

The RClamp0514M is a favorable alternative to the RClamp0504M, where a CM choke is not needed for the application. Similar to the RClamp0504M, the RClamp0514M also has the flow through package design for ease of layout and for reducing discontinuities on the high speed signal lines. The RClamp0514M has a maximum differential capacitance value of 0.9pF. Since the HDMI TDR requirement is specified as a differential impedance, the RClamp0514M will be a <1pF load on the differential lines. The RClamp0514M low capacitive loading allows for it to sit on the HDMI high speed differential lines and yet remain with the HDMI TDR requirement with some board layout compensation. The “HDMI MSOP-10L Rev E” board was designed specifically to compensate for the small capacitive loading of the RClamp0514M in order to remain in the HDMI TDR requirement. The board and trace parameters are summarized in Table 4.

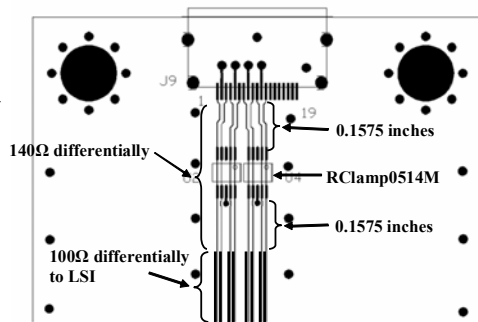
HDMI MSOP-10L Rev E Evaluation Board RClamp0514M with layout and board compensation	
Number of layers	4
Copper thickness	1.5 oz finished thickness
Board thickness	0.062 inches
Dielectric thickness between layer 1 and Gnd	0.010 inches
Trace pitch	(0.500mm) or 0.0197 inches

Table 4 - HDMI MSOP10-L Rev E evaluation board layout parameters



	A	B	C	
X-axis	1.640	1.796	1.953	(nsec)
Y-axis	99.3	105.3	98.7	(Ohm)

Figure 8 - RClamp0514M mounted on HDMI MSOP-10L Rev E evaluation board test results



As shown in the test results in Figure 8, the RClamp0514M has proven to meet the HDMI CTS impedance requirement through board and layout modifications only. On the high side, the impedance measured at 105.3Ω and on the low side, the impedance measured at 98.7Ω. Figure 9 shows the impedance design guidelines a PCB board designer may use in accordance with their board layout and design parameters.

Figure 9 - HDMI MSOP-10L Rev E Impedance Design Guideline

Summary of Test Results				
Evaluation Board	Specification Maximum	Specification Minimum	Actual Maximum	Actual Minimum
Units	(Ohm)	(Ohm)	(Ohm)	(Ohm)
HDMI MSOP-10L Rev D RClamp0504M and CM Choke	115	85	100	92
HDMI SC-75 Rev D RClamp0502B	115	85	106.1	101.6
HDMI MSOP-10L Rev E RClamp0514M	115	85	105.3	98.7

Table 5 - Summary of TDR Test Results

Conclusion

This application note discussed three protection solutions to meet the IEC61000-4-2 ESD standard while maintaining the impedance requirement of the HDMI CTS for sink devices. Since the protection solution is capacitive, adding protection to the HDMI sink devices require extra consideration in order to stay within the HDMI CTS impedance requirement. The first option was shown with the HDMI MSOP-10L Rev D evaluation board, which uses Semtech's RClamp0504M and TDK CM choke combination. The inductance of the CM choke along with board and trace adjustments were used to compensate for the capacitive loading of the RClamp0504M. In designs where integration of a CM choke is preferred, the RClamp0504M and CM choke combination may be used to meet the HDMI CTS impedance requirement. Two other options with test results within the HDMI CTS impedance requirement were shown using the RClamp0502B on the HDMI SC-75 Rev D board and the RClamp0514M on the HDMI MSOP-10L Rev E board. Since the differential impedance of both the RClamp0502B and RClamp0514M are less than 1pF, the inductance compensation of a common mode choke is not used or necessary. Minor board and trace adjustments were used to compensate for the low capacitive loading of the RClamp0502B or the RClamp0514M. This is especially beneficial for designs with limited board space and where CM choke filtering is not needed. Through the suggestions provided in this application note, the test results summarized in Table 5 may be obtained.

References:

- Johnson, Dr. Howard "Potholes", *EDN Magazine* Nov 1999 and www.sigcon.com
- Johnson, Dr. Howard, "High Speed Signal Propagation- Advance Black Magic"