Application Report
SNLA095B–April 2007–Revised April 2013

AN-1613 Extending HDMI Cable Reach Using TI's DS16EV5110A, DS22EV5110 and DS34RT5110 Equalizers

ABSTRACT

The DS16EV5110A, DS22EV5110, and DS34RT5110 provide signal conditioning features to greatly extend the reach of the cable in HDMI or DVI applications. Understanding the interconnect parameters that has been selected will provide the necessary information to set the correct signal conditioning settings and then yield the maximum reach with the lowest jitter. The DS34RT5110 is unique in that it can be used in multiple hop applications.

Contents

List of Figures

List of Tables

1 Theory and Purpose

DVI and HDMI are originally intended to deliver video and data over shorter distances, where the effects of cable losses would have little to negligible effect. However, there are many applications requiring longer cable lengths, such as sending computer graphics to remote displays and routing video throughout home theaters and entertainment venues. Display resolutions, refresh rates and color depths continue to increase and so do the required data rates, at 1.65 Gbps for DVI 1.0 and upto 3.4 Gbps for HDMI 1.3a. Unfortunately, the cables that facilitate this high bandwidth data transfer also cause signal degradation in the form of attenuation, jitter, skew, and crosstalk, which limit the reach between source and display and creates screen flicker, noise sparkles, and audio distortion.

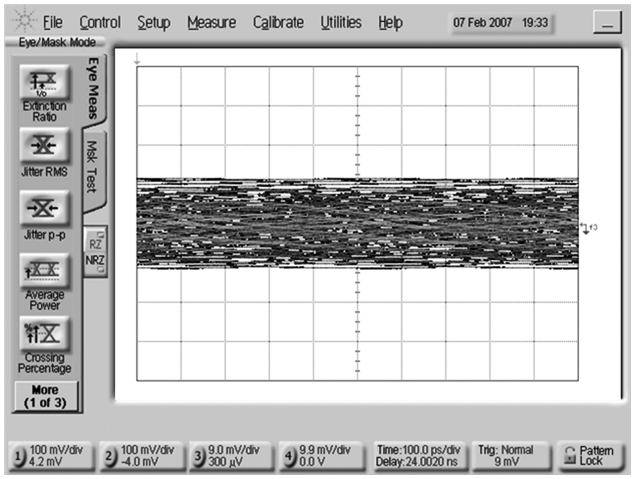

Figure 1. Eye Diagram After 25m 28 AWG DVI Cable (1.65 Gbps)

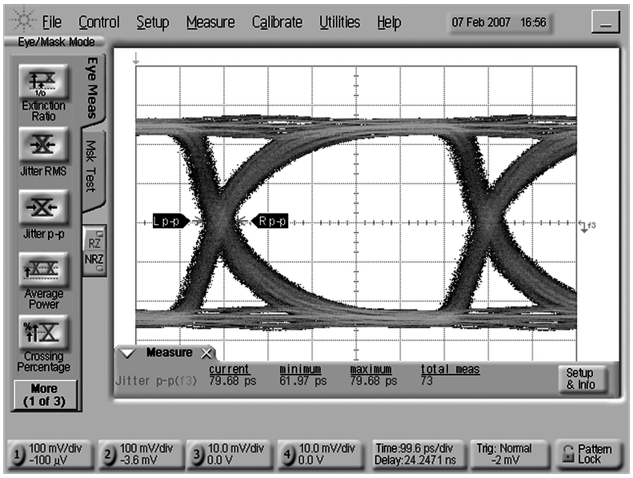

Figure 2. Output Eye Diagram of DS16EV5110A w/ 25m 28 AWG DVI Cable (1.65 Gbps)

2 Cable Attenuation Theory

Cable equalizers are used to offset the signal degradation caused by frequency dispersion and skin effect losses in the cables by equalization. These losses are highly dependent on the quality of the cable construction and worsen with the use of thinner wires, mismatched wire lengths or twist ratios, poor dielectric insulation or spacing, and poor shielding. In addition to other negative effects such as crosstalk, skew, and jitter, these cables create attenuation that reduces the amplitude of the signal, decreases the slope of the edges, and separates or disperses the high frequency signal into its individual components. The result is a closing of the “eye” of the differential signal, decreasing video quality, and increasing bit error rate resolutions, refresh rates and color depths continue to increase and so do the required data rates, at 1.65 Gbps for DVI 1.0 and upto 3.4 Gbps for HDMI 1.3a. Unfortunately, the cables that facilitate this high bandwidth data transfer also cause signal degradation in the form of attenuation, jitter, skew, and crosstalk, which limit the reach between source and display and creates screen flicker, noise sparkles, and audio distortion.

Total jitter (Tj) is comprised of both deterministic jitter (Dj) and random jitter (Rj). The gain curves of the DS16EV5110A, DS22EV5110 and DS34RT5110 are designed to match the inverse of the cable’s transmission losses over frequency (Figure 5 and Figure 17), counteracting deterministic jitter (Dj). Since random jitter is also very important, these equalizers are designed with the right gain, bandwidth, and noise generation combination to provide best-in-class random jitter (3ps rms) for optimum total performance.

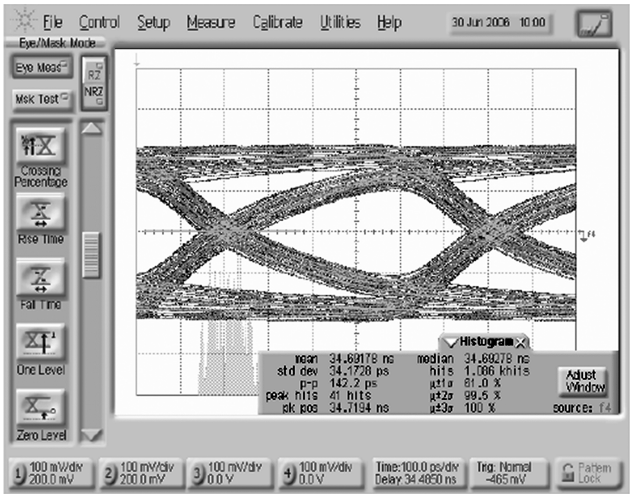

Figure 3. Eye Diagram After 5m 28 AWG DVI Cable (1.65Gbps)

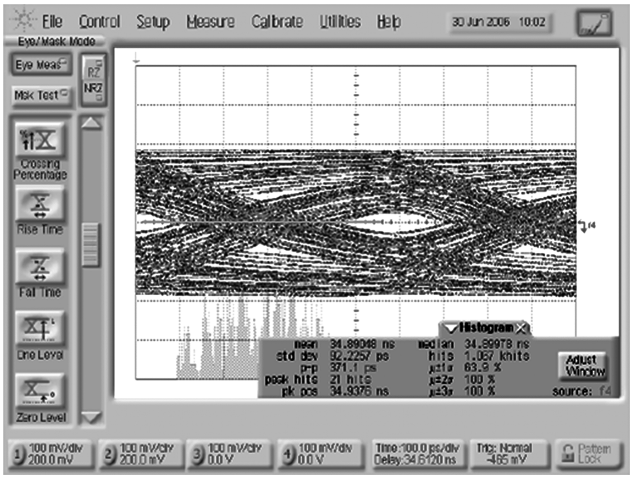

Figure 4. Eye Diagram After 10m 28 AWG DVI Cable (1.65Gbps)

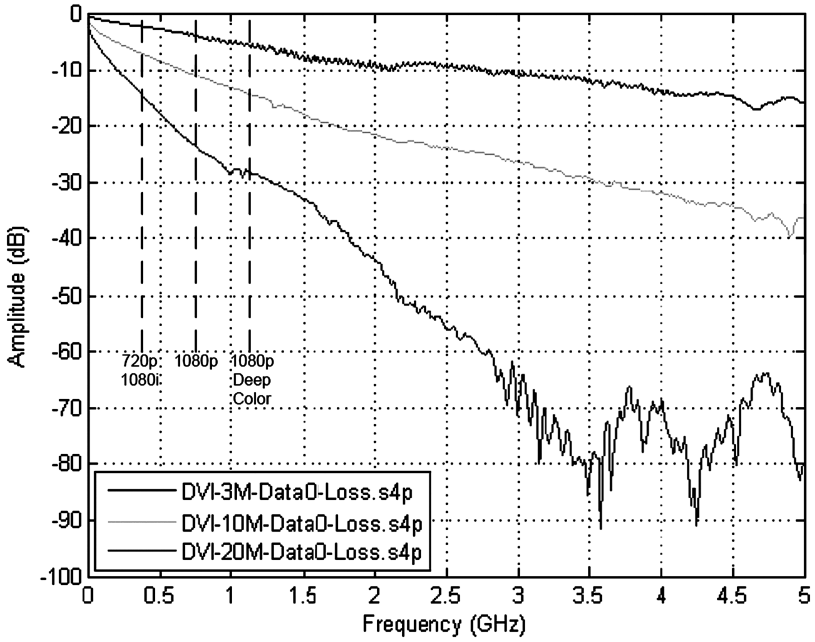

Figure 5. Transmission Loss of 3-, 10- and 20-Meter DVI Cables (28 AWG). Vertical lines drawn at 720p/1080i, 1080p60, and Deep Color 1080p60.

3 Cable Equalization and Reclocking

TIs DS16EV5110A, DS22EV5110 and DS34RT5110 HDMI equalizers are designed to counter many of the negative effects caused by using longer length cables for video transmission (Figure 1 and Figure 8). In effect, the equalizer of the devices re-opens the eye of the differential signal (Figure 2 and Figure 9) by applying a high-pass filter and gain curve inversely proportional to the cable's attenuation curve, which is primarily comprised of skin effect and dielectric losses. The DS16EV5110A, DS22EV5110 and DS34RT5110 can equalize greater than 40 meters of 24 AWG DVI or HDMI cable at the full 1.65 Gbps and over 25 meters using the low cost 28 AWG version of these cables. On the high end of the resolution range, the DS16EV5110A, DS22EV5110 and DS34RT5110 can support greater than 30 meters of deep color depth HDMI (12 bits per color, 36 bits per pixel) at 2.25 Gbps using 24 AWG cable. Greater than 20 meters of standard CAT5-based cabling can also be used, which is becoming more popular for video distribution due to its low cost, large existing installation base, and ease of new cable routing through conduits.

In addition to the equalization feature, the DS22EV5110 and DS34RT5110 also offer reclocking and output de-emphasis features. The reclocker consists of a PLL for the TMDS clock channel, and three clock and data recovery (CDR) circuits for the TMDS data channels. The PLL regenerates a low jitter sampling clock for the TMDS clock channel and also for the CDR units in the TMDS data channels. Each CDR aligns the sampling clock edges by digitally interpolating the clock from PLL of the TMDS clock channel. Thus, the output total jitter is extremely low over the supported data rates (Figure 10). With the de-emphasis driver (Figure 11), additional lengths of cables or FR4 traces can be driven by the output (Figure 12).

The DS34RT5110 reclocking equalizer supports the total throughput of 10.2 Gbps (3 x 3.4 Gbps), enabling 48-bit deep color depth or higher resolution / higher refresh rate; and is optimized for DVI / HDMI repeater and multi-hop applications. A total of 30 meters of 28 AWG HDMI cable can be reached at 10.2 Gbps; or 100 meters of CAT6 cable can be achieved at 1.5 Gbps (1080p 8-bit color) with multi-hop application (Figure 13). The multi-hop application is widely used for home theater and professional studio systems. The DS34RT5110 is also idea to equalize the long cable reach requirement, and clean the system jitter due to the complexity of PCB routing for the complex security system with large matrix HDMI switches as shown in Figure 14.

The DS22EV5110 Super Equalizer is a 6.75 Gbps (3 x 2.25 Gbps) extended reach equalizer with the reclocker and output de-emphasis. A total of 37 meters of 28 AWG HDMI cable can be supported at 6.75 Gbps (1080p 12-bit deep color).

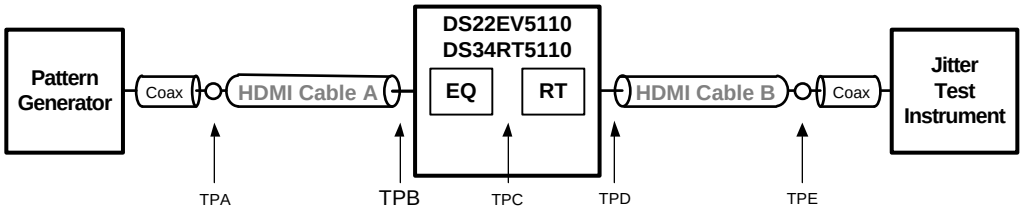

Figure 6. Simplified Test Setup as a Single Repeater

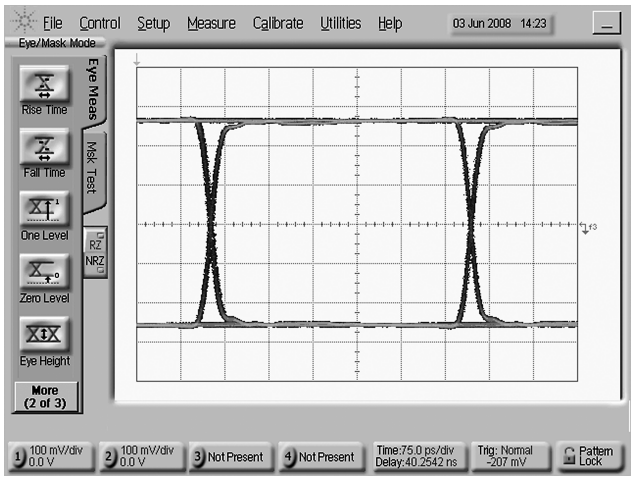

Figure 7. Eye Diagram at TPA (2.25 Gbps)

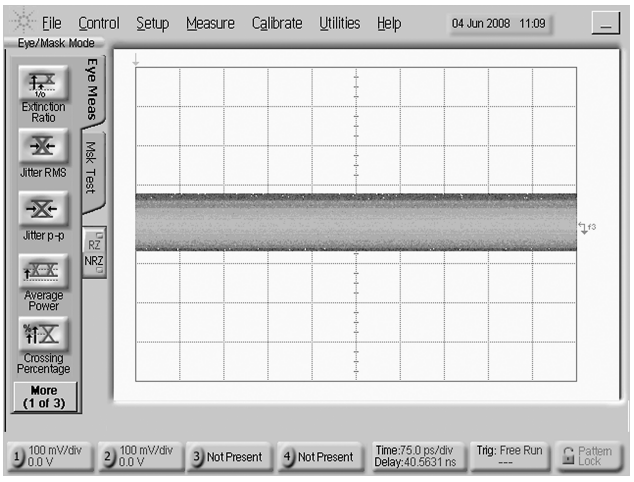

Figure 8. Eye Diagram at TPB (2.25 Gbps, Cable A = 25m 28 AWG HDMI)

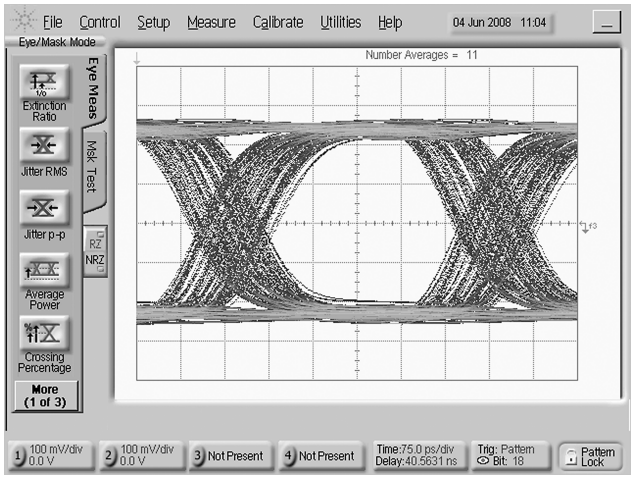

Figure 9. Eye Diagram at TPC w/ EQ Only (2.25 Gbps, Cable A = 25m 28 AWG HDMI)

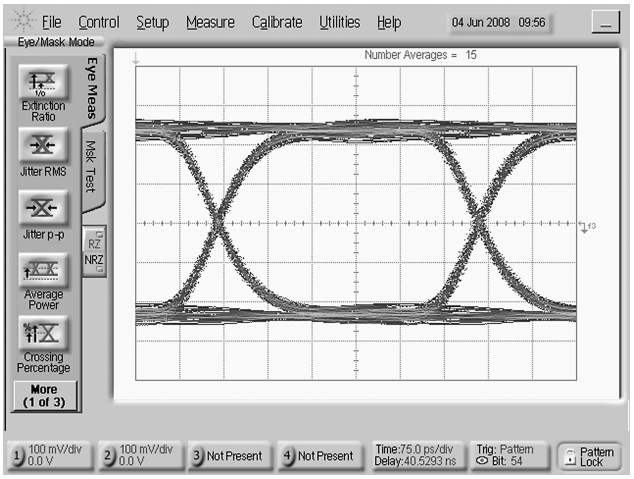

Figure 10. Eye Diagram at TPD (2.25 Gbps, Cable A = 25m 28 AWG HDMI)

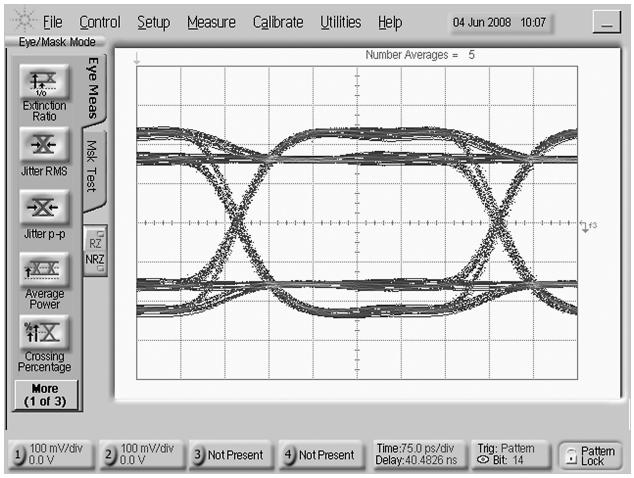

Figure 11. Eye Diagram at TPD w/ DE on (2.25 Gbps, Cable A = 25m 28 AWG HDMI)

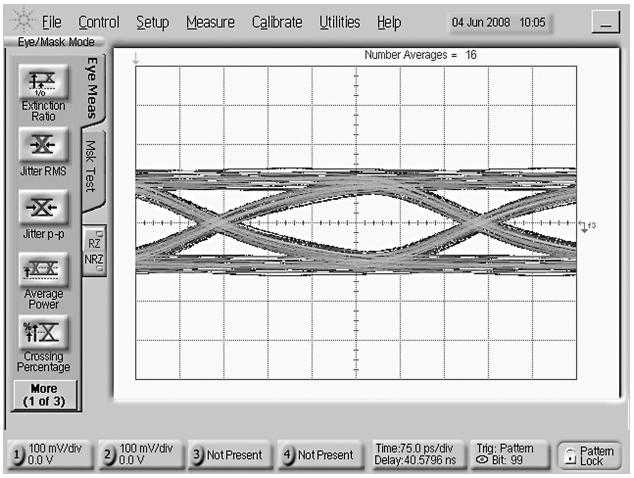

Figure 12. Eye Diagram at TPE w/ DE on (2.25 Gbps, Cable A = 25m, and Cable B = 7.5m 28 AWG HDMI)

Table 1. Cable Reach at Different Data Rates and Video Formats

Video Format	Data Rate (Per Channel)	DS16EV5110A			DS22EV5110 / DS34RT5110		
		HDMI Cable A (28 AWG)	HDMI Cable B (28 AWG)	Total Cable Length (28 AWG)	HDMI Cable A (28 AWG)	HDMI Cable B (28 AWG)	Total Cable Length (28 AWG)
1080i / 720p	750 Mbps	> 50m	—	> 50m	> 60m	> 15m	> 75m
1080p 8-bit Color	1.65 Gbps	> 25m	—	> 25m	> 40m	> 10m	> 50m
1080p 12-bit Color	2.25 Gbps	> 20m	—	> 20m	> 30m	> 7m	> 37m
> 1080p 16-bit Color	3.4 Gbps (DS34RT5110 Only)	—	—	—	> 25m	> 5m	> 30m

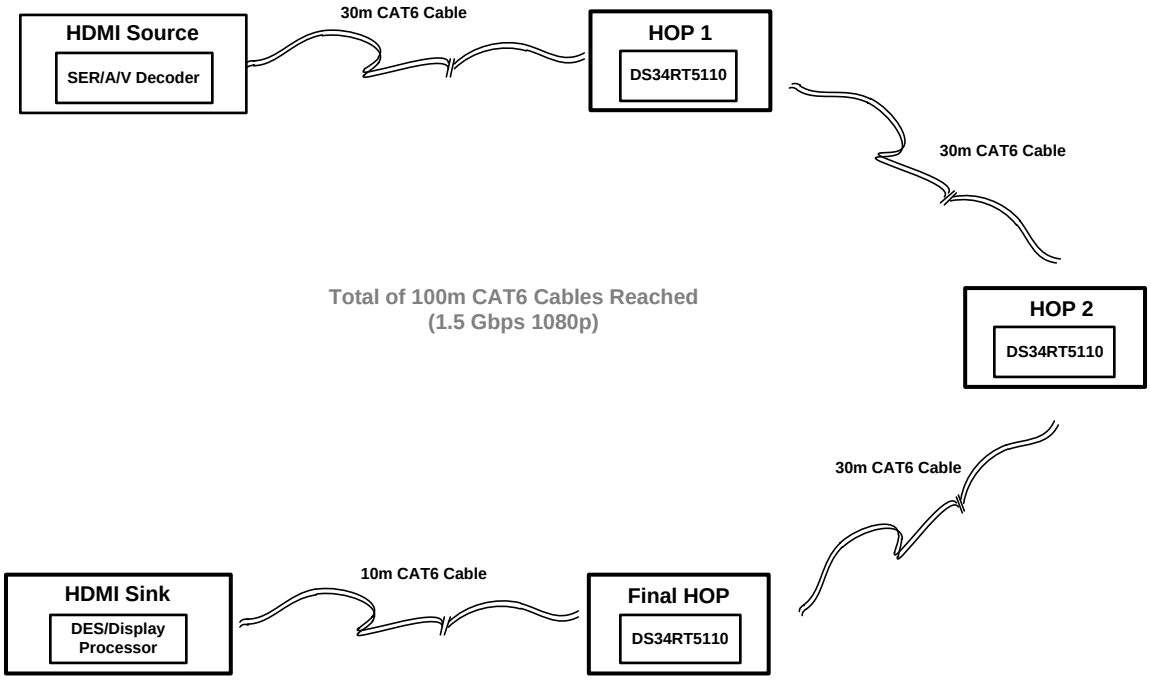

Figure 13. Multi-hop System (1.5 Gbps — 1080p, Total Cable Reach = 100m CAT6)

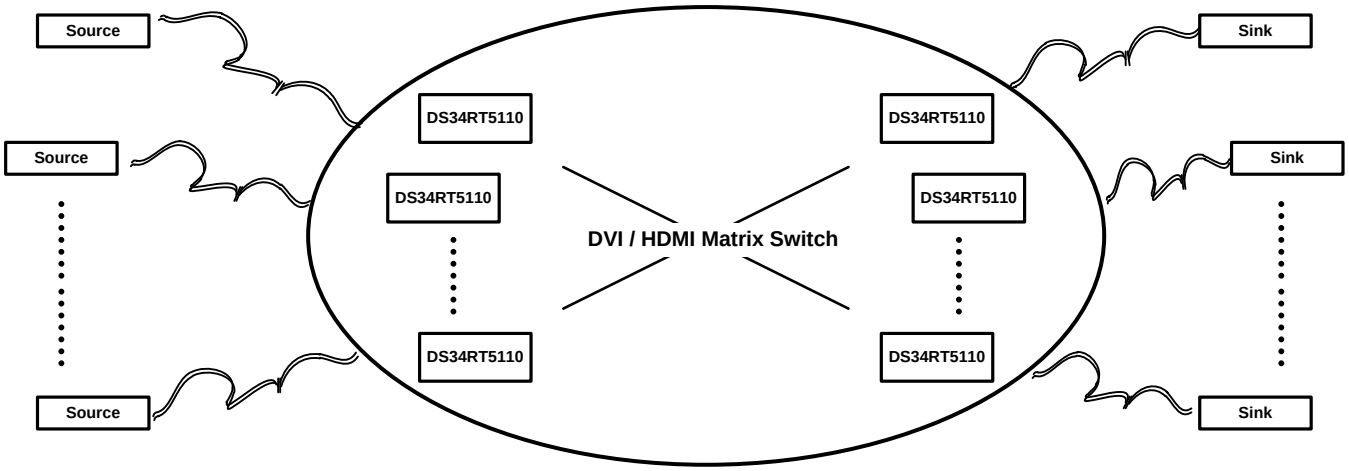

Figure 14. Complex HDMI Matrix Switch System

4 HDMI Equalizer Features

Some of the other features of the TI's HDMI Equalizers include programmability configuration through SMBus interface (DS16EV5110A only), settable equalization or de-emphasis control for optimized cable reach, robust ESD protection, and the ability to parallel two equalizers (Figure 15 and Figure 16) for DVI dual link applications. For detailed information, see Table 2.

Table 2. Feature List

Description	DS16EV5110A	DS22EV5110	DS34RT5110
	HDMI Equalizer	**HDMI Super Equalizer**	**HDMI Reclocking Equalizer**
Applications	Sink	Source, Sink, Repeater	Source, Sink, Multi-hop Repeater
DVI Applications	Single / Dual Link	Single Link	Single / Dual Link
Max Data Rate Per Channel (Video Format)	2.25 Gbps (1080p 12-bit Color)	2.25 Gbps (1080p 12-bit Color)	3.4 Gbps (1080p 16-bit Color)
Standard Support	HDMI v1.3a / DVI 1.0	HDMI v1.3a / DVI 1.0	HDMI v1.3a / DVI 1.0
Max Cable Reach	Long	Very Long	Extremely Long w/ Multi-hop
Configuration	Pin, SMBus	Pin	Pin
Equalization	8-level Settable	8-level Settable	8-level Settable
De-Emphasis	—	4-level Settable	4-level Settable
Retiming	—	PLL / CDR	PLL / CDR
VOD	1000 mVpp	1000 mVpp – 2000 mVpp	1000 mVpp – 2000 mVpp
Output Status	Signal Detect	Signal Detect / Lock	Signal Detect / Lock
ESD Protection	> 6 kV HBM	> 8 kV HBM	> 8 kV HBM

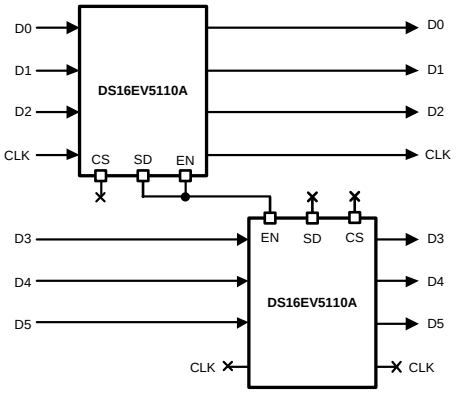

Figure 15. 2 DS16EV5110A in a DVI Dual Link Application

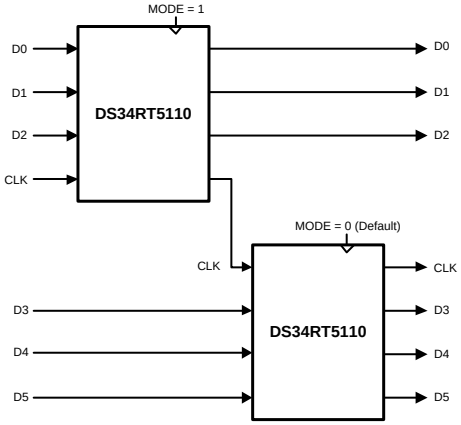

Figure 16. 2 DS34RT511 in a DVI Dual Link Application

5 Optimizing the Performance of the Equalizer

The gain setting can be configured using the SMBus interface (DS16EV5110A only) or the three external pins provided. Two of these pins can be permanently strapped if you wish to use a simple high or low setting that captures the majority of the equalizer's gain curve, binary b'100' for < 20 meters and b'110' for > 20 meters (Table 4). Our evaluation boards use a dial version of a 3-bit dip switch with eight settings for easy manual adjustment and visual tuning of equalizer gain.

Since cable attenuation increases with frequency, the equalizers' gain should be set at your highest supported resolution (Figure 5 and Figure 17). Table 3 lists some common resolutions and the associated frequency of interest for equalization. Notice that this frequency is half the speed of the data rate, which is created by a worst case 1010 data pattern. Table 4 shows the equalizers' gain for three key frequencies and illustrates how the gain curves of these equalizers are sloped to automatically provide less gain for the lower resolutions using the same cable. Since the equalizers will handle the lower resolutions automatically, you will not need to change gain settings once you've established the correct gain setting for your cable. Therefore, this procedure needs to be done only once for any given cable installation.

For example, if your attenuation is 30dB based on 40 meters of 24 AWG DVI cable and a bit rate of 1.65Gbps, then the boost setting should be set close to the maximum of 30dB (b'111'). However, if you change the cable to a 20 meter length and the attenuation drops to 21dB, you should change your boost setting to reflect this with an equalization setting closer to 21dB (b'011'). Although your new 20 meter cable length will still be supported by the same 30dB setting that was used for the 40 meter length cable, the lower 21dB setting is preferred as it will limit some of the gain at the higher frequencies, which will improve jitter and help reduce noise and crosstalk.

Deterministic jitter is minimized when the skin effect and dielectric losses of the cable are neither under-equalized nor over-equalized by the equalizers. The most accurate method for determining the proper setting is to use a communication analyzer which separates the deterministic jitter and random jitter to specified Bit Error Rate (BER), and find a setting which minimizes the deterministic jitter. Another method is to use the histogram function on a high bandwidth oscilloscope, and find a setting which minimizes the total jitter. Since many labs are not outfitted with this test equipment, a simple visual test using some demanding resolutions like those from HD-DVD Players, computers and PS3 game consoles can often be adequate.

Table 3. Common Resolutions With TMDS Data Rates and Frequencies for Equalization

Standard	Resolution	TMDS data rate	Frequency to Equalize
VGA	640 x 480	252 Mbps	126 MHz
SVGA	800 x 600	400 Mbps	200 MHz
XGA	1024 x 768	650 Mbps	325 MHz
720p 60fps HDTV	1280 x 720	742.5 Mbps	371.25 MHz
1080i 30fps HDTV	1920 x 1080	742.5 Mbps	371.25 MHz
SXGA	1280 x 1024	1080 Mbps	540 MHz
1080p 60fps HDTV	1920 x 1080	1485 Mbps	742.5 MHz
UXGA	1600 x 1200	1620 Mbps	810 MHz
DVI1.0/HDMI 1.2a Max	—	1650 Mbps	825 MHz
12-bit Deep Color 1080p 60fps HDTV	1920 x 1080	2250 Mbps	1125 MHz
16-bit Deep Color 1080p 60fps HDTV	1920 x 1080	3000 Mbps	1500 MHz
HDMI 1.3a Max	—	3400 Mbps	1700 MHz

Table 4. EQ Gain Control Table

BST[2:0] / EQ [2:0] b'xxx'	Equalizing at 375 MHz / 750 Mbps (DS16EV5110A)	Equalizing at 825 MHz / 1.65Gbps (DS16EV5110A)	Equalizing at 1.125 GHz / 2.25Gbps (DS22EV5110 and DS34RT5110)	Equalizing at 1.7 GHz / 3.4 Gbps (DS34RT5110)
0 0 0 (Default)	5 dB	9 dB	0 dB	0 dB
0 0 1	7 dB	14 dB	12 dB	10 dB
0 1 0	10 dB	18 dB	18 dB	16 dB
0 1 1	12 dB	21 dB	21 dB	19 dB
1 0 0	14 dB	24 dB	24 dB	23 dB
1 0 1	16 dB	26 dB	26 dB	25 dB
1 1 0	18 dB	28 dB	28 dB	26 dB
1 1 1	19 dB	30 dB	30 dB	27 dB

6 Cable and Connector Selection

Signal degradation is the result of skin effect losses, noise injection from inadequate shielding, impedance mismatches, unequal wire distances, dielectric spacing, and composition. The DS16EV5110A, DS22EV5110 and DS34RT5110 are designed to improve the performance of systems that use longer distances of low cost cables. However, if you want to maximize overall signal quality and cable reach, we recommend using superior quality cables and connectors with thicker gauge wires (22 AWG is best, 28 AWG is most common), minimize excessive cabling by using the most direct path possible, and reduce

return loss due to impedance mismatches and reflections by reducing connectors, adapters, solder joints and couplers. Cables should be routed to avoid noisy grounds, heavy EMI environments, and bends or loops in the cables. The DS16EV5110A, DS22EV5110 and DS34RT5110 are designed to equalize deterministic jitter and attenuation and will not compensate for perturbations from noise injection and random spikes. This is especially important if using lower cost cabling such as unshielded CAT5 (Figure 17).

There really is no standard for extended reach DVI / HDMI cable, or CAT5/5e/6/6a/7 cable for DVI / HDMI application. Performance can vary dramatically since each manufacturer may be targeting different customers, ranging from lowest cost to highest performance. Each manufacturer designs their cables and connectors using cost versus performance tradeoffs such as wire thickness and composition, dielectric composition and spacing, skew/length accuracy between wires and pairs, shielding of pairs and cables, etc.

Unfortunately, some trade-offs can't be avoided. For example, in order to achieve tight skew tolerances, each wire and pair must be closely matched in length. DVI and Category 1 HDMI cables allow only 151 psec (0.25 Tbit) of intra-pair skew and 2.42 nsec (0.4 Tpixel) of inter-pair skew. Category 2 HDMI cables have even more stringent requirements with 111 psec of allowable intra-pair skew and only 1.78 nsec of allowable inter-pair skew. This necessitates matched twist ratios for each TMDS twisted pair, but matching twist ratios also increases capacitance between pairs and can increase crosstalk dramatically. DVI and HDMI cables combat this effect by using shielding around every twisted pair, and even more shielding around the entire cable to help reject noise from being injected into the cable. The tight tolerances, additional shielding, and intricate connectors result in a more expensive cable.

The most prevalent negatives of DVI and HDMI cabling are related to their bulk and cost. In an effort to reduce cost and simplify cable routing, CAT5 and its variants are gaining in popularity. Like DVI and HDMI cabling, there is no standard performance for basic CAT5 cabling and performance can vary greatly. Unlike DVI and HDMI cabling, CAT5 contains no shielding to reduce crosstalk and noise (Figure 17) and is much more lenient when it comes to impedance variations and skew due to mismatched lengths and manufacturing tolerances. In Figure 17, the vertical lines are drawn at 720p/1080i, 1080p60, and Deep Color 1080p60; the intersection of the line and curve at the highest resolution used will identify the optimum equalizer gain setting. The lack of shielding on CAT5 cabling results in additional noise and crosstalk. Please note that the bottom trace is for the 28 AWG DVI Cable.

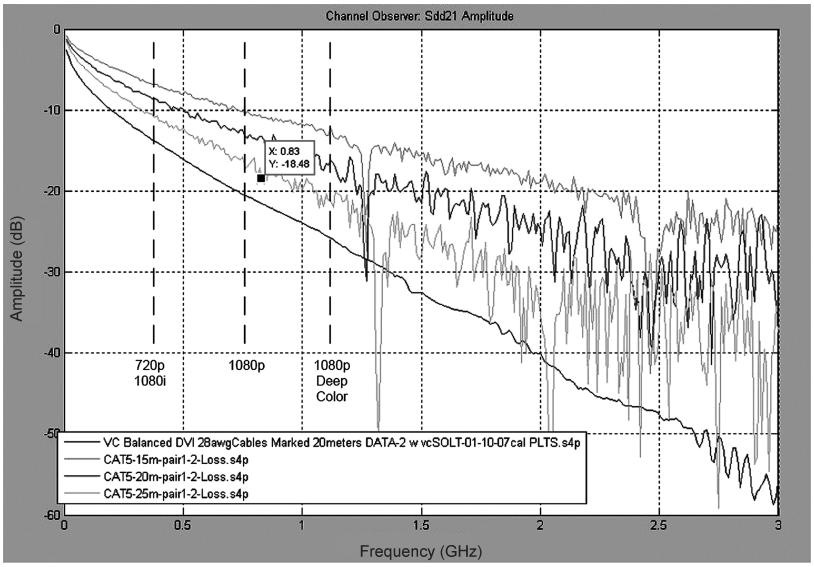

Figure 17. Transmission Loss of 20-Meter DVI Cable, 15-, 20- and 25-Meter CAT5 Cables

In general, the higher the category, the better the cable. As the category increases from CAT5 (100 MHz), CAT5e (100 MHz with far end inter-pair crosstalk specs), CAT6 (250 MHz), CAT6a (500 MHz with cable crosstalk specs), and CAT7 (600 MHz), the quality of the cables improve to reduce attenuation, crosstalk, return loss, and noise rejection. Thicker gauge wiring, tighter manufacturing specifications, and improved shielding improve cable performance - but these changes also increase the price of the cables. System performance and cost requirements will determine the appropriate cable type and performance for each application.

CAT7 is closest to DVI and HDMI cables since it is generally designed with shielding around each pair and around the entire cable to meet the very demanding requirements, but installation can be cumbersome and expensive. The shielded connectors used with CAT7 can be backwards compatible to the RJ45 and have additional pins for grounding the cable's shields.

CAT6a is the next best performer and is easier to field terminate than CAT7, with higher bandwidth requirements than CAT5e and CAT6 and limitations on alien (cable) crosstalk which almost guarantees the use of shielding. This is a good choice for running your high speed TMDS lines over standard CAT cabling. Keep in mind that the connectors you use must also be rated for the highest category of cable you use.

Some manufacturers, such as Belden, have CAT cabling designed for low skew with closely matched wire lengths and cables with bonded twisted pairs which ensure that the spacing in each twisted pair remains constant throughout the cable, even when bent during installation and routing. This can be very helpful in combating crosstalk, return loss and noise.

Regardless of whether it's CATx, DVI, or HDMI cabling, if the twisted pairs are identical in composition and tolerances for thickness, spacing, twists, and dielectric, then the attenuation curves and deterministic jitter will be similar and the DS16EV5110A, DS22EV5110 and DS34RT5110 will help correct either cable. However, lack of shielding and wide tolerances inherent in CAT5 cabling will show up as increased crosstalk, noise, return loss and random jitter that cannot be equalized out.

Lower speed CAT5 or CAT5e cabling can be used for the second cable containing the control signals such as DDC, hot plug detect, +5V, CEC, and ground.

7 Board Design

The DS16EV5110A, DS22EV5110 and DS34RT5110 are packaged to provide easy alignment and pass through for both DVI and HDMI connectors. Since impedance changes cause reflections, make sure to keep the high speed TMDS lines as close to the connectors as possible, allowing any reflections to settle out quickly. Care must also be taken to ensure that all the traces between the TMDS pins and the connectors are kept equal to reduce skew (Figure 18 and Figure 19).

The DS16EV5110A, DS22EV5110 and DS34RT5110 are packaged in the LLP-48 package, which has a large thermal pad on the underside and has excellent power dissipation properties. Operation is guaranteed with system ambient temperatures up to 70 °C. Several small vias can be used to connect this thermal pad to additional copper on the bottom side of the board for additional heat dissipation (Figure 18 and Figure 19). For additional information on the LLP package, see AN-1187.

Since noise rejection is very important in this application, using an LDO regulator with ceramic output capacitors is recommended for superior noise and load transient performance.

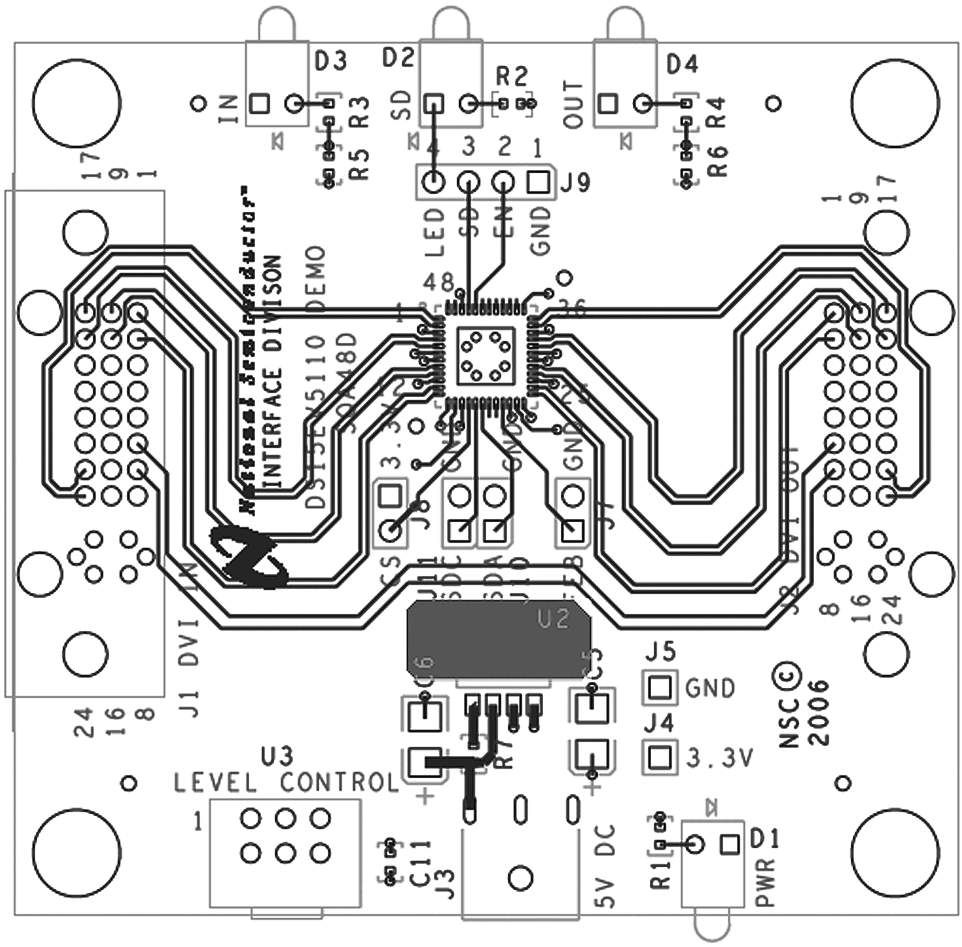

Figure 18. DS16EV5110A Evaluation Board Layout (with DVI Connectors) – top side

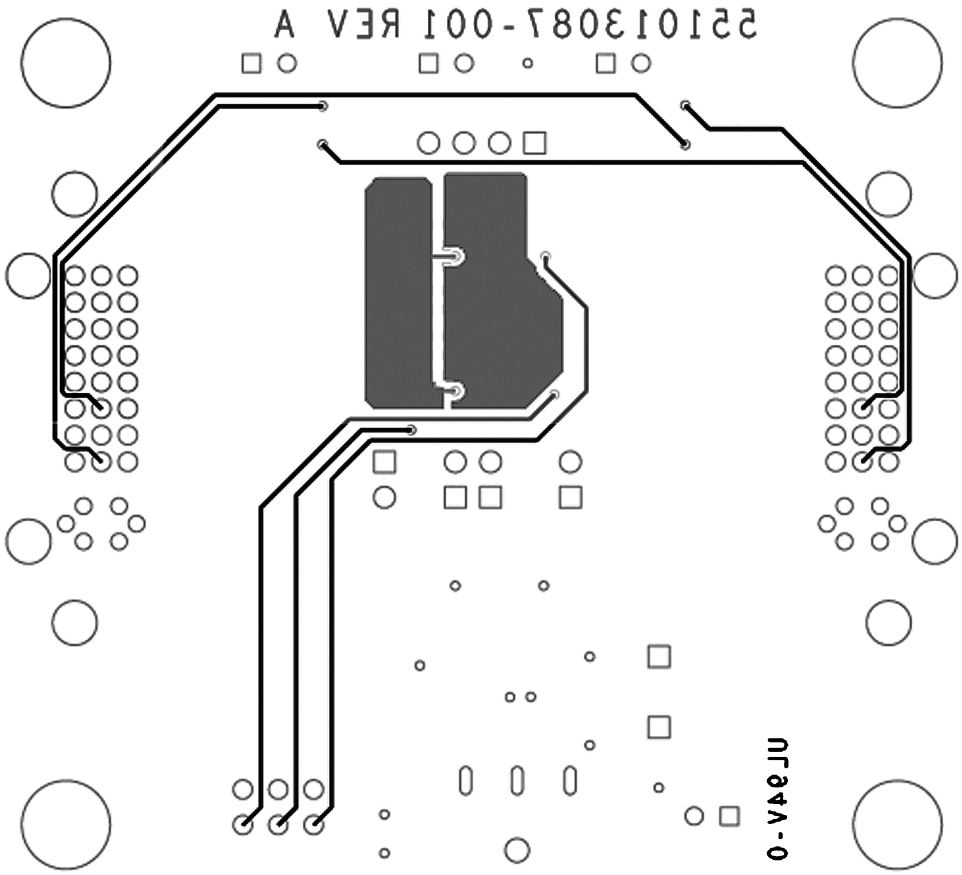

Figure 19. DS16EV5110A Evaluation Board Layout (with DVI Connectors) – Bottom Side

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