CEC-enabled HDMI system design for multi-vendor compatibility

A look at the CEC spec, and tips for maximizing interoperability with other brands in the current environment.

By Del Jones and Hisaki Fujiwara,
Analog Devices

Video Imaging DesignLine
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When anyone in our family wants to watch a movie on our new HDTV, I usually have to help them operate the five remote controls that reside on our coffee table. If this scenario sounds familiar, there is some good news headed your way. A new feature of the HDMI (High Definition Multimedia Interface) link known as CEC (Consumer Electronic Control) is intended to make the home entertainment system useable by all family members. This article will define what CEC is and what it is not, explain the key features of interest to consumers of home entertainment products, describe details of the physical interface, and address some important system level hardware and software considerations. Design engineers embarking on a CEC-enabled design project should, of course, start with a diligent study of the latest HDMI specification.

While the general public may not be familiar with the term CEC, they may have heard of some of the leading consumer electronics industry makers' brand names for it. Among them are Sony's "Bravia Link," Panasonic's "Viera Link," and Sharp's "Aquos Link." The names may differ, but all support the CEC functionality described in the HDMI standard.

CEC basics

CEC is a single-wire, bidirectional interface intended to facilitate the control of any device on an HDMI network, as typified in *Figure 1*, with the remote control unit or on-device control buttons of any other device connected to the network. Defined as an optional feature in the HDMI specification, it is based on the AV Link function defined in the European SCART (Syndicat des Constructeurs d'Appareils Radiorcepteurs et Tlviseurs) specification. *Table 1* describes some typical end-user CEC features.

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Figure 1: Typical All-HDMI Home Theatre

Feature	Description
One-Touch Play	Pushing the "play" button commands a source to play and become the active video source for the TV.
Stand-By	Pushing the "power down" button of any active device commands all devices on the HDMI network to shut down.
One-Touch Record	Pushing the "record" button commands a recording device to power up and record the content currently displayed on the TV.

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Table 1: Some useful "End-User" CEC Features

Many of these end-user features require sending multiple messages over the CEC bus such as "Active Source," and "Routing Change," which support the CEC feature "Routing Control." This feature allows a device to play and become the active source by switching the TV's source input. If the TV is displaying another source at the time this command is used, it may place the other source into "stand-by" mode, depending on the implementation.

Those who have lost the DVD player's remote are in luck. Just pop in the DVD and push play on the front panel of the player. With a single push of the button, the following happens: the DVD player drawer closes, the TV and audio/video receiver (AVR) power-up, each device selects the correct HDMI port and the proper video and audio modes, and the DVD starts playing. Pretty cool.

There are some misconceptions about the current offerings of CEC-enabled products. In most current implementations, CEC commands only work with one brand; so unless the entire system is from the same manufacturer, it is impossible to simply pick up the TV remote and control the entire system without

performing some programming of the TV remote. Fortunately, current industry trends are leading in this direction, and equipment vendors are beginning to cooperate with developers to share some of their proprietary commands. The CEC specification allows for customization and vendors have been using this to encourage the end user to purchase full systems of their own brand's equipment.

CEC physical interface

The CEC interface consists of a single-wire bus that connects all devices in an HDMI enabled system. *Figure 2* illustrates a typical application. Any device in a CEC-enabled system can initiate a CEC command. The initiator sends the message structure and data on the common wire. Each device on the network must set the acknowledge bits when they receive a CEC message.

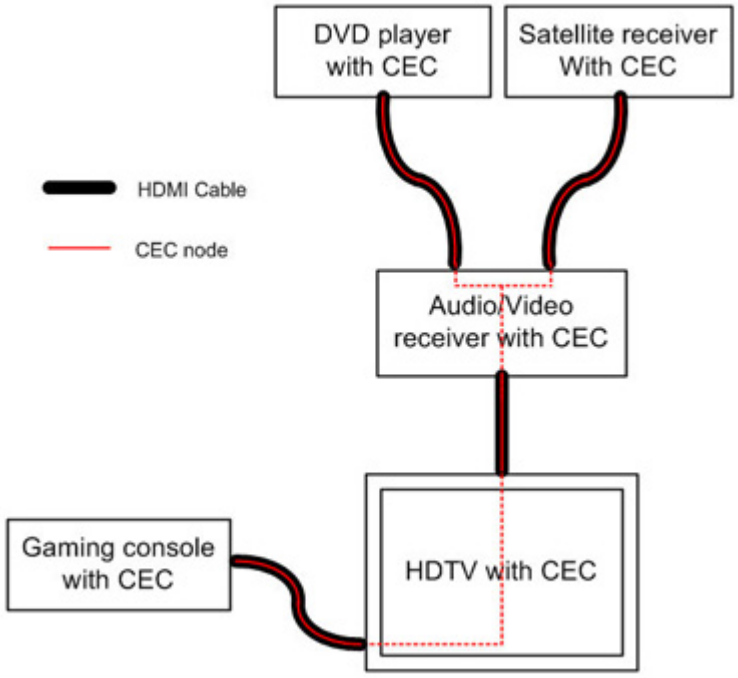

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Figure 2: Typical HDMI system block diagram

CEC messages are sent in frames that include a start bit and data bits. Data bits can be informational (logical addresses and CEC commands for example), or they can be control bits (end-of-message [EOM] or acknowledge [ACK]).

A high-to-low transition followed by a low-to-high transition that adheres to the timing shown in *Figure 3* indicates a start condition.

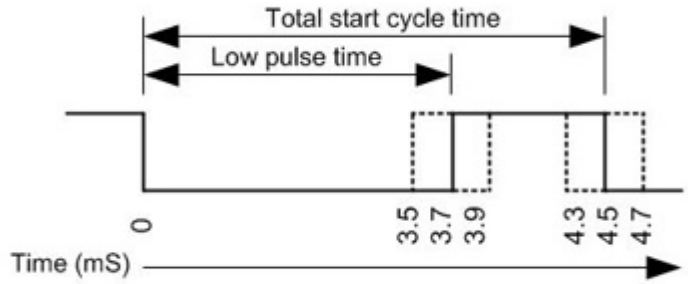

Figure 3: CEC start bit timing

The data that follows the start condition must adhere to the timing requirements for a logic '0' and logic '1' shown in *Figure 4*.

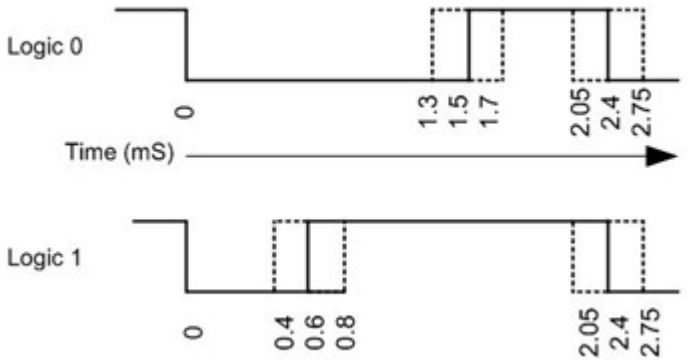

Figure 4: CEC logical state timing diagram

CEC frames are made of data blocks that consist of 10 bits each. Eight bits carry information, while the last two are the EOM bit and ACK bit. In the header block, the information bits contain the initiator's logical address (4 MSBs) and the destination logical address (4 LSBs), as illustrated in *Figure 5*. A logic '0' in the EOM bit position indicates more data is to follow. A logic '1' indicates the end of the message.

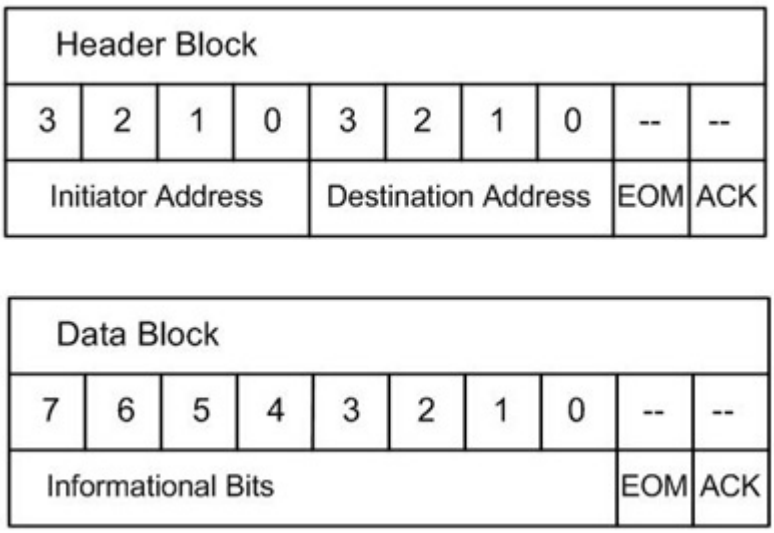

Figure 5: CEC header and data block

The logical meaning of the ACK bit position depends on the type of message. For a message that is sent to a specific follower, a logic '0' from the targeted follower indicates that it has received the message. A logic '1' indicates a "no-ACK" or "do-nothing" status. All other devices on the CEC link respond with a logic '1'. If the initiator is sending a broadcast message to all devices on the CEC link, each device will acknowledge the message by sending a logic '1' onto the link. This allows a single follower to reject the message by pulling the line down to a logic '0'.

CEC messages

A single CEC message is made of a Start Command, a CEC header, and one or more data blocks. A CEC feature is constructed from multiple CEC messages. *Figure 6* illustrates this.

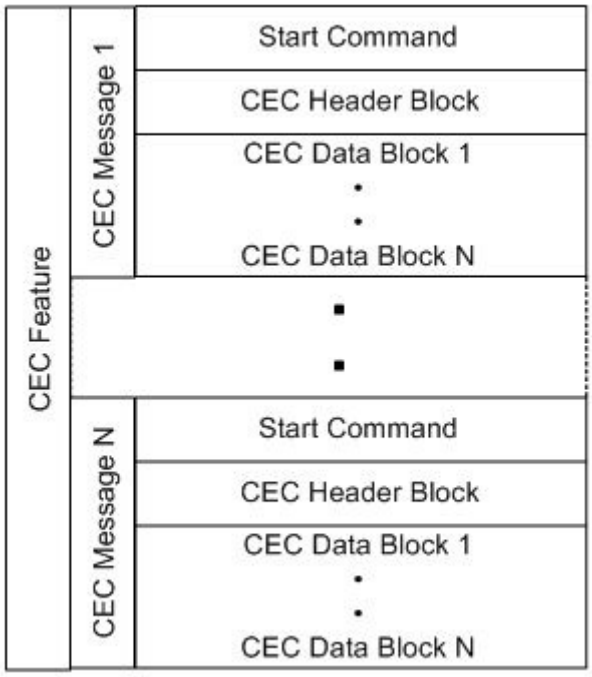

Figure 6: CEC command structure

CEC compatibility

CEC interoperability is a concern that should be at the forefront of any system designer's mind from the beginning of the design project to the end. Three levels of testing can help ensure compatibility with other CEC-enabled devices.

HDMI compliance testing is the first type of testing that needs to be completed. The HDMI Compliance Test Specification (CTS) is a supplement to the HDMI specification that provides detailed procedures for tests a device must pass before becoming HDMI certified. Several CTS tests are dedicated to the testing of CEC. Any device that supports CEC must pass these tests as part of the HDMI compliance test in order to be HDMI certified.

The second type of testing made available to CEC-enabled devices is the CEA 861/HDCP PlugFest. Held twice a year, Consumer Electronics Association (CEA) and Digital Content Protection (DCP) co-sponsor PlugFest, a forum where HDMI equipment manufacturers can perform interoperability testing in a cooperative environment. Every six months, manufacturers with CEC-enabled devices participate in this event. Manufacturers of CEC-enabled devices should participate in this event as a part of their development-cycle testing.

For thorough interoperability testing, CE equipment designers can supplement the first two levels of testing of CEC-enabled devices by using the resources of their CEC solution provider. For instance, Analog Devices (ADI) offers users of its HDMI Rx and Tx products HDMI pre-certification testing with the latest HDMI 1.3 test equipment, and multi-brand interoperability testing with over 100 HDMI sources and sinks, many of which are CEC enabled. These services are invaluable for detecting and debugging critical HDMI and CEC compatibility issues. It is highly recommended that the CE equipment maker develop his own process for completing this type of testing, in conjunction with the CEC solution vendor or independently.

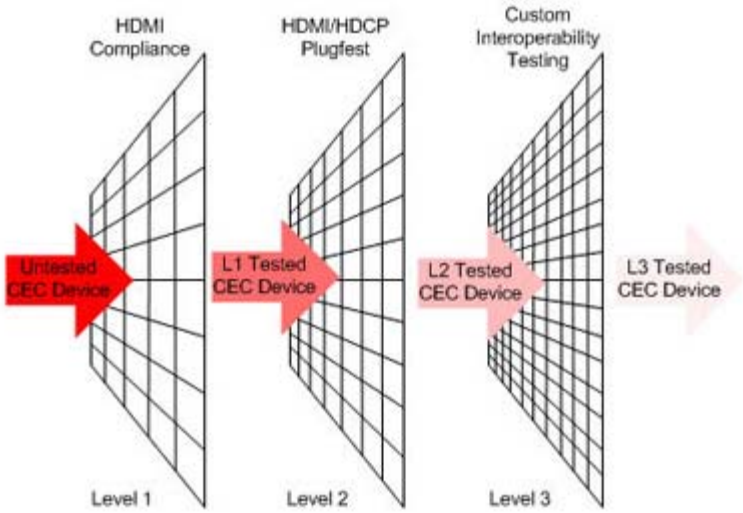

Figure 7: "Catch" more potential issues with thorough compatibility testing

Interoperability testing with multiple brands, models, and equipment types is essential for diligent testing of a CEC solution. Since most of the major CE equipment makers use multiple HDMI solutions, making multiple models for multiple regions, it is important to have access to as many permutations of each brand's products as possible. *Figure 8* illustrates the number of permutations for just one type of CEC-enabled device. AVRs must be tested with both HDMI sources and sinks, further increasing the variety of testing that must be done.

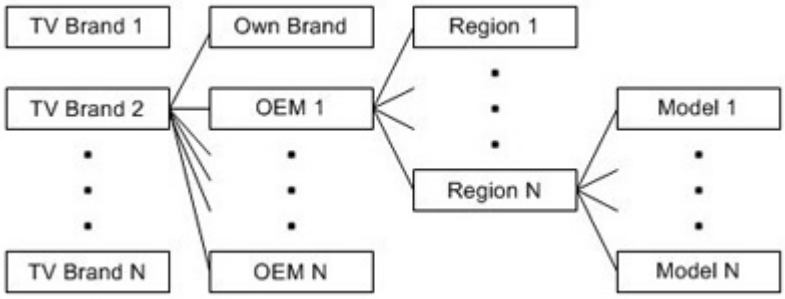

Figure 8: Possible permutations for a single CE device type (such as a TV)

Using this three-level approach to testing CEC-enabled devices provides the system designer with the most comprehensive process for finding problems that could otherwise lead to incompatibility with other CEC-enabled devices.

Causes of CEC compatibility problems
The adoption rate of CEC is ramping up, and so are concerns about CEC interoperability. The main issues behind CEC compatibility problems are the use of proprietary commands and differing interpretations of the CEC specification.

While the definition of many basic CEC features is clear, flexibility that allows custom CEC features and messages is part of the spec. Each vendor defines their own vendor specific messages; these messages are valid only when the same vendor produces both the message sender and the receiver. This leads to interoperability problems, since these messages are typically proprietary. The current prevailing attitude is that proprietary commands are effective for "closed" systems such as the "home theatre in a box" solutions that many vendors sell. Proprietary commands are not recommended, however, for makers of off-the-shelf system components that desire multi-brand compatibility.

Despite the clarity of the CEC specification and CEC CTS, it is still possible to encounter interoperability problems, even if vendor-specific messages are not used, due to differences in the interpretation, or even manipulation, of these specifications.

The feature "One touch play" is an example. The CEC specification defines that the TV shall be brought out of Standby (turned on) when the appropriate messages are received from a CEC initiator (a video source in most cases) as a part of the "One touch play" operation. To ensure this is done according to the CEC specification, the CEC CTS defines test 11.1.1-3 for this operation. This sounds simple enough but the CEC CTS item is valid and applied only when the system designer claims in their Capabilities Declaration Form (CDF) that their TV can be brought out of Standby when the appropriate CEC message ("Image View On") is received. The note in this test states: "Test only applies if DUT can be brought out of Standby. See CDF."

Of course, most CEC enabled TVs on the market can be powered on from Standby by using their remote control. Unless the manufacturer claims it can be done by CEC, however, they don't need to pass this item of CEC CTS. Despite this, they would still be considered compliant to the CEC specification.

If they want to support their own "One touch play like" function -- working only within their own brand of equipment -- they can do so using their own combination of CEC messages or using vendor-specific messages. Unfortunately, this is common practice.

Solutions to compatibility problems
Due to backlash from the distribution channel and end users, there is increasing pressure on CEC equipment vendors to resolve these interoperability issues. System designers should take the following steps to minimize these issues:

Designing and testing against the CEC Compliance Test Specification. This should always be the first place for all CEC enabled equipment makers to start before claiming to be HDMI compliant with their CEC enabled system.

Rigorous interoperability testing with multiple brands and models of CEC enabled equipment (including participation in "Plugfest"). Designers and CEC solutions suppliers can use this testing not only to improve the CEC enabled devices, but also can help improve the system's ability to tolerate the variances in "real world" environments.

As mentioned earlier, due to this increasing pressure, many of the current CE equipment makers are now willing to share the definitions of some of their proprietary CEC messages once a Non-Disclosure Agreement (NDA) has been signed. It is highly recommended to work with these vendors to create the highest level of interoperability possible.

CEC Design Tips
Here are some tips for designing CEC into consumer electronics equipment:

System and Software Considerations
Most systems incorporating HDMI already have a system controller in place. To determine if the controller is adequate for adding CEC system software to its workload, the system designer needs to consider these minimum requirements.

- An available I^2C master
- An available interrupt input pin
- A timer function
- A "high-end" 8-bit or standard 16-bit controller

For an integrated CEC solution, the controller used for HDMI functions such as EDID reading/parsing and HDCP control is easily capable of handling the CEC system functions as well. As a general guideline, a controller with faster response time is preferred over one that has a lot of computing power. If the current controller is too slow, or if does not have enough available interrupt inputs, it may be possible to upgrade with a pin- and software-compatible version.

Since CEC messaging is asynchronous to the system timing, it is a good idea to use a controller that is able to implement a timing function. This function is required to pass CEC messages between the two time domains without bogging down the system controller. A real-time operating system (RTOS) or a system with an internal timer is recommended for this purpose, especially when using an HDMI device with integrated CEC controller. The system's vertical synchronization (Vsync) signal can be used to trigger the function calls to the CEC software, when not using a RTOS system or timer. This method is adequate but not as easy to implement as when the RTOS or other timing function is used.

Using a system's main controller to handle the CEC messaging is not recommended. The CEC's timing is slow (400 Hz), asynchronous to the system, and requires constant monitoring. This sort of function would be too cumbersome for the system controller and would limit its effectiveness to control and monitor the rest of the system. A small, inexpensive controller can handle the CEC signaling and timing. This controller and associated software is then slaved to the system controller and handles the CEC messaging and synchronization. *Figure 9* illustrates this configuration:

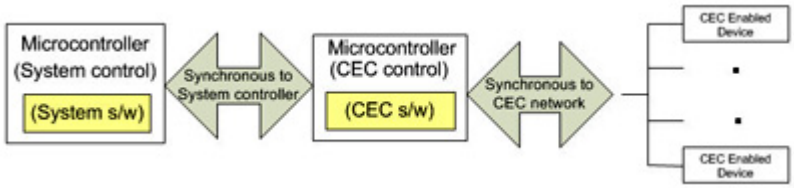

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Figure 9: System with "master" controller and "slave" controller for CEC.

In this configuration, the slave CEC controller and associated software are responsible for:

- All basic electrical operations, bit timings, etc.
- Handling transmission errors and schedules re-transmission of faulty frames.

The system controller and software are responsible for:

- Media Access Control (MAC) layer functions
- "Command to action" translation

- Logical address generation.

There are many reasons to consider a solution that has the CEC controller and software integrated with the HDMI hardware and software.

- Fewer components → Lower cost
- Uses less space
- Lowers the barrier to entry, especially when software is included
- Since there is a natural "fit" between the HDMI related software and CEC-related software, development time is reduced

The memory required for running the CEC application software is approximately the same as that required for a software driver or stack. A safe estimate for the CEC stack is about 20K bytes of ROM and 1K bytes of RAM. An optimized solution would require much less memory that this.

Hardware considerations

The physical connection to the HDMI network is straightforward. Per the CEC specification, the CEC pin of the HDMI connector should be pulled up to a 3.3V supply via 27K ohm resistor. However, the pull-up should be disconnected when the device (CE equipment) is powered off. The circuit in *Figure 10* shows how this can be accomplished. In order to reduce the I-R drop across the resistor-diode network, a low leakage diode is recommended.

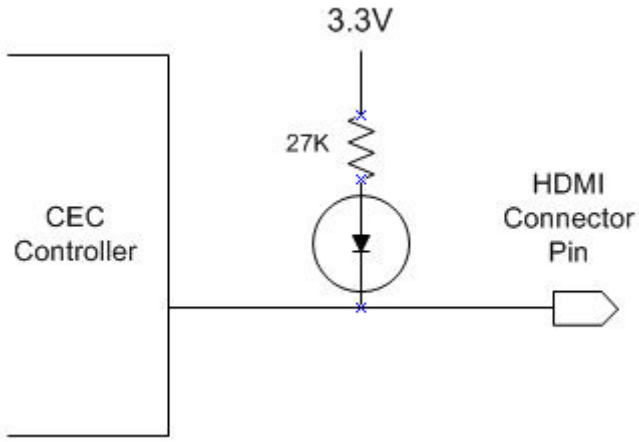

Figure 10: Pull-up circuit for CEC line

The recommendation for the PCB layout is to keep the distance between the HDMI and CEC components and the HDMI connector to a minimum. It is also recommended that the routing of noise-emitting digital circuitry and the signal routing to the HDMI connector be separated. Also remember that the differential HDMI signals should be 100 ohms differential impedance ± 15 ohms. A layout example is shown in *Figure 11*. Analog Devices' ADV7520NK HDMI transmitter (U6) with integrated CEC is shown as an example. The package is a 6 mm x 6 mm ball grid array package (BGA). The CEC net is in pink and the CEC_CLK net is red. R2 and D13 form the diode/resistor network for CEC. D2"D12 are ultra-low-capacitance ESD diodes for the HDMI interface. U1 is a 12 MHz oscillator that provides the CEC clock. J2 is the small profile "Type C" HDMI connector for portable devices.

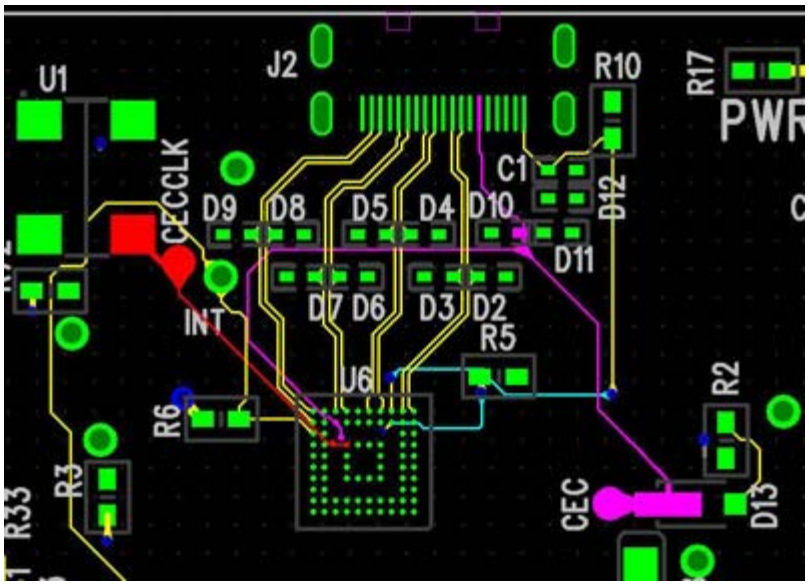

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Figure 11: HDMI transmitter with integrated CEC layout example

In systems that have multiple HDMI ports (inputs and/or outputs), the CEC bus connects all of the ports together on a single net.

An Integrated CEC solution
An HDMI device with an integrated CEC controller, such as Analog Devices' ADV7520NK,, reduces the barrier to entry for the system designer. *Figure 12* illustrates the CEC subsystem with an external controller vs. one with an internal controller.

Enhanced PHY
The enhanced physical interface (PHY) used in ADI's CEC hardware automatically generates the required low-to-high and high-to-low signal timing that is required to send CEC messages and measures the low pulse time and high pulse time to receive CEC messages. This automated bit signaling function eliminates the real-time response requirement and allows a system microprocessor to operate CEC in a polling mode vs. an interrupt driven mode eliminating the need for a dedicated CEC microcontroller.

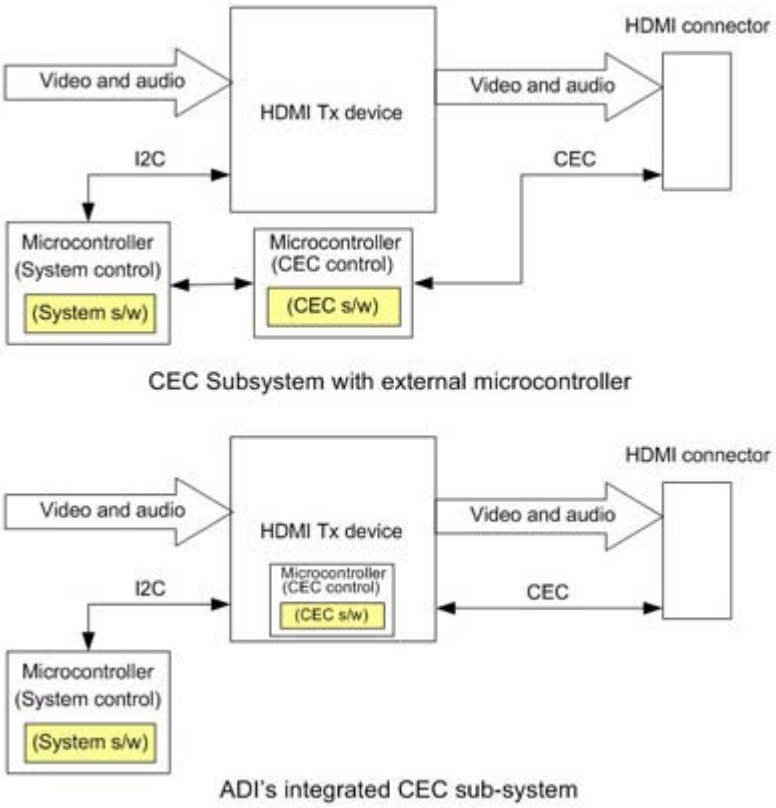

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Figure 12: CEC block diagram comparison

Implementation differences in a board or system can lead to various timing delays and capacitive loading conditions that can affect the timing of the CEC interface. An integrated CEC interface must have the ability to adjust the minimum and maximum pulse time to accommodate a variety of board and system designs. This flexibility provides a high level of tolerance to CEC-enabled products that may not be perfectly compliant to the HDMI specification.

Automated message retransmission
The integrated CEC interface should also include an automated message retransmission mode. This allows the system designer to set the number of times the CEC hardware will try to retransmit each outbound message.

If the CEC hardware detects an unexpected condition while sending a message, it should automatically terminate the session and restart the same message from the beginning. If the condition persists, the CEC hardware will continue retransmission up to the limit set by the designer. This retransmission system should be automated and not require the intervention of the system's microcontroller.

Low power
Rising concerns about energy conservation and an increase in the prevalence of battery-powered video devices are driving increasing focus on low power usage. A smartly designed integrated CEC solution can help to reduce system power consumption through a multi-level power down mode.

Even if the CEC hardware is integrated into the HDMI hardware, having a separate power down mode allows it to be powered independently. In order to receive or send messages, the CEC subsystem has to remain "awake" even while the rest of the system is in sleep mode. This separate power down mode allows the system to shut down the rest of the HDMI device when the equipment (e.g. TV, DVD player, etc) is in standby mode. This feature minimizes system standby power consumption while allowing the CEC hardware to stay "alert" to receive any incoming CEC messages. *Figure 13* illustrates this.

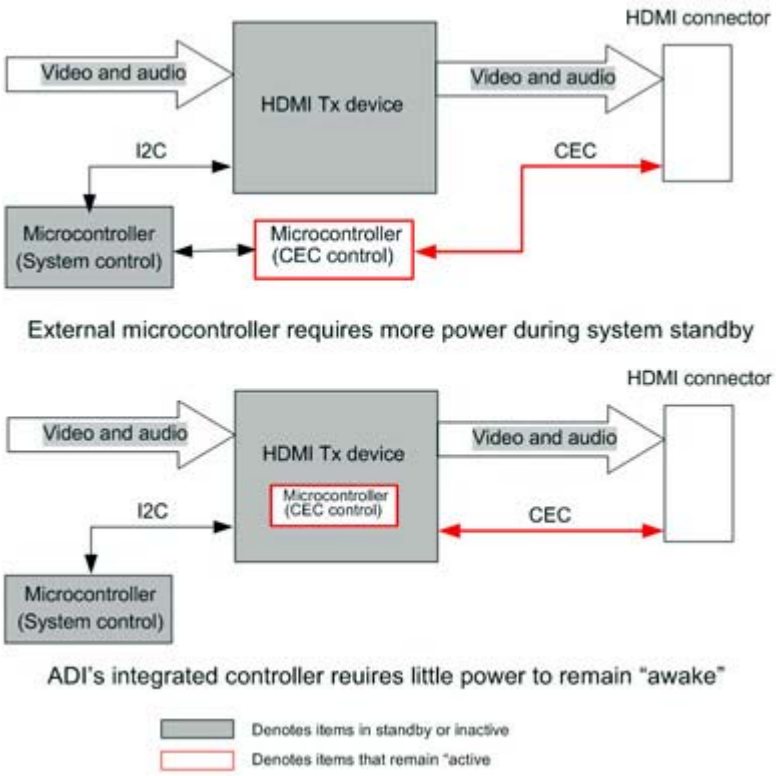

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Figure 13: CEC subsystem when system is in "standby" mode

To further reduce a system's stand-by power consumption, the CEC hardware can be programmed to automatically go into sleep mode when the Hot Plug Detect (HPD) signal is not present. This is possible if the system designer chooses not to receive CEC messages when HPD is not asserted.

The features listed above are few of the advantages of using a robust integrated CEC solution. Analog Devices' ADV7520NK is one device that meet these requirements.

An easy to integrate software driver

A complete integrated CEC solution should include a system software "driver" that is provided in "C" code or other portable format. Integration of structured functions into the system level code allows the use of any processor or compiler. The CEC software should also be agnostic regarding byte ordering (able to pass data in big-endian or little-endian format) and processor bus width (16, 32, and 64 bits are all acceptable). These features give the system designer flexibility in choosing the embedded microcontroller to use in the design.

The software ought to allow implementation in an RTOS or simple loop architecture environment. In an RTOS environment, the CEC software can run as one task without timing restrictions. For a software driver structured in this way, there are no special handling requirements for interrupt service routing (ISR).

All that is needed is a single application programming interface (API) inside the ISR. The API should be included as part of the CEC software package and not interfere with other functions of the system level software such as accessing hardware resources from ISR.

Command and Message Level APIs
The CEC software ought to have the flexibility provided by multiple level APIs. This allows system designers to choose the level of interface they prefer. If they choose the message level API, all of the transactions between the CEC software and the system software should consist of CEC messages. This allows system designers the flexibility to implement end-user features and supporting features the way that best suits their system.

However, some system designers may desire a higher-level interface to reduce their system software complexity. In this case, they can use a command-level API, which uses additional functions to implement end-user and supporting features as defined in the CEC specification. Therefore, instead of calling message level API multiple times that request specific messages, they can simply call a single API to request a particular CEC feature. For example, the CEC end-user feature "One touch play" requires two or three CEC messages by itself and may require two more, one of which depends on the follower's response, which depends on the TV's implementation. This one feature can become very complex. However, by using command-level API and calling only one API the CEC software and integrated hardware can handle the rest.

	Command Level API	Message Level API
Transaction Level	CEC Features (end-user and supporting features)	CEC messages
Complexity	basic, easy-to-use	more direct, not as easy to implement
Sequence Control	ADI's CEC software	System software
Customization	Supports all CEC features	Flexible structure allows "custom" features

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Table 2: Command Level versus Message Level API

Analog Devices line of HDMI devices with integrated CEC hardware includes a software driver structured in this manner. It is provided with technical support that includes tips to deal with these issues as well as suggestions for system software to improve interoperability based on ADI's CEC experience with HDMI receivers, transmitters, repeaters, and muxes.

Summary
All consumers of home entertainment systems desire simplicity when relaxing with their families. From programming their DVR (today's VCR), to searching for the right remote, they are eager to have home entertainment features that will make their life easier. CEC, if implemented smartly, can be the vehicle to provide this need. While it is not here yet, a day is coming when components from Sony, Yamaha, and Panasonic can all peacefully coexist on the same HDMI network. So, jump on the straight-talk express because change you can believe in is possible! Please excuse the election year hyperbole; I've been watching too much news because I can't find my remote!

About the authors
Del Jones *is an applications engineering manager in the Advanced TV Segment of Analog Devices He holds a BSEE from the University of Texas at Dallas. He can be reached at* del.jones@analog.com.

Hisaki Fujiwara *is a senior applications engineer in the Advanced TV Segment of Analog Devices. Hisaki holds a BSEE from Waseda University, Tokyo Japan. He can be reached at* hisaki.fujiwara@analog.com.