Designing CEC into your next HDMI Product

There is a little-known one-wire bus snaking its way through your HDMI products. The bus, known as the consumer electronics control (CEC) bus, is the basis for a new level of automatic control in HDMI-interfaced systems. With the recent release of a CEC compliance test specification and commercial CEC test equipment, consumer electronic companies are now poised to implement CEC in their products. In fact, new CEC-enabled products are expected to begin shipping in April 2006.

The CEC bus allows all products in the system to potentially discover and communicate with each other

The basic technology of the CEC bus originated in Europe, on the SCART interface, where it's been used with great success for many years. HDMI borrows and improves on the basic SCART technology, allowing AV products to discover and communicate with one another across a system. CEC makes possible global controls, which build on existing point-to-point E-DDC-based "plug & play" automation to minimize the number of IR remotes and key-presses required for basic operation of a system.

CEC enables global simplified (single remote) system control in HDMI-interfaced systems

CEC assumes that all AV source products in a system are directly or indirectly connected to a "root" display. HDMI connections form an up-side-down tree, with a display as the "root", switches as "branches", and various source products as "leaf" nodes. For example, CEC allows users to connect a mix of AV products as shown in Figure 1, place a DVD into the player, press PLAY, and let CEC handle the rest.
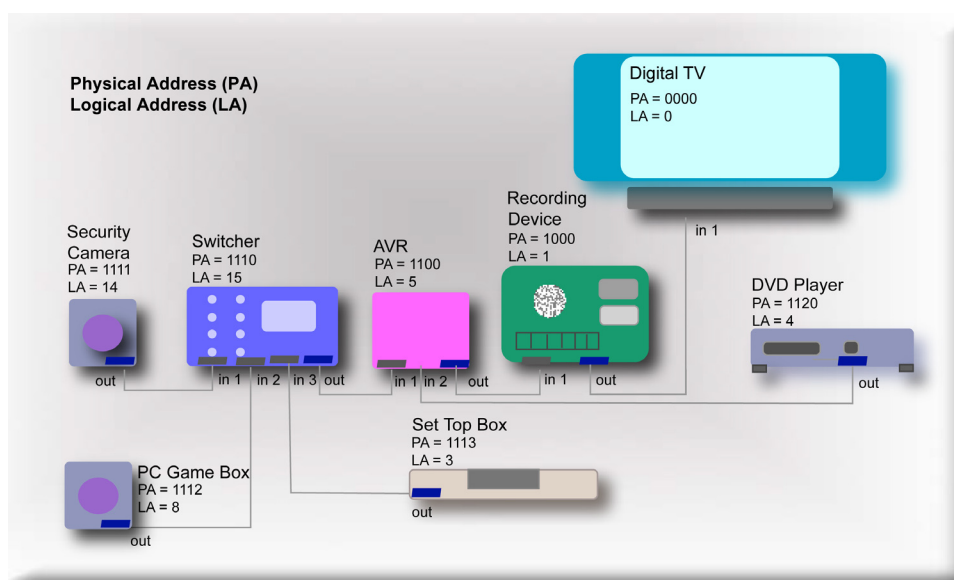

Figure 1 – HDMI CEC System

CEC will automatically power-on the appropriate products, route the DVD player's audio

output through the AVR to attached speakers, and route the player's motion picture to the Digital TV. Likewise, selecting a channel on the set-top-box will cause television audio to replace movie audio on the speakers and a television picture to replace the motion picture on the Digital TV. Further, pressing the RECORD button on the recording device will cause the television program on the "root" to be automatically routed to and recorded on that device. In short, CEC enables automatic equip-ment discovery and simple "one touch" operation in HDMI-interfaced systems.

CEC Technical Overview

The HDMI-CEC bus connects up to 10 HDMI AV devices

The CEC bus is a one-wire, "party line" that connects up to ten (10) AV devices through standard HDMI cabling. The CEC protocol includes automatic mechanisms for physical address (topology) discovery, (product type based) logical addressing, arbitration, retrans-mission, broadcasting, and routing control. Message opcodes support both device specific (e.g. set-top-box, DTV, and player) and general features (e.g. for power, signal routing, remote control pass-through, and on-screen display).

Electrical Characteristics

When idle, pull-ups within CEC devices lift the CEC bus voltage to between 2.5 and 3.63 volts. CEC devices assert bits by pulling the bus down to between 0 and 0.6 volts. All devices monitor the logical state of the bus by comparing bus voltage with a state-dependent threshold, which provides approximately 400 millivolts of hysteresis. Rise and fall times may be purposely slowed to avoid ringing. Signal rise and fall times only need to be less than 250 and 50 microseconds, respectively. Maximum leakage current is limited to 1.8 microamps to prevent devices from affecting the CEC bus, when they are disconnected from the power company. Since the CEC bus can include ten 100pF devices and nine 700pF cables, the maximum bus capacitance is 7200pF.

Bit-level Protocol

CEC enables one-wire "party-line" communications between all devices

Communication is always between an initiator and one (or more) follower(s). Both initiator and follower(s) can assert bits. Initiator-asserted bits provide data, while follower-initiated bits provide acknowledgment. Bit-level communication is very slow by modern bus standards - with bit rates of less than 500 bits/second. Messages begin with one long start bit and are immediately followed by a number of shorter data bits. Start bits last 4.5 milliseconds and have a low period of 3.7 milliseconds (Figure 2a).
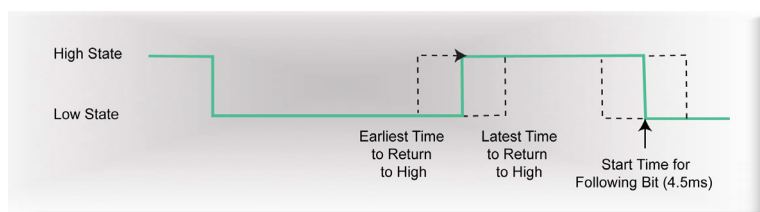
Figure 2a – HDMI-CEC Start Bit Timing

Data bits only last for 2.4 milliseconds and have a low period that depends on the logical data value being communicated. Here, logical zero bits have a longer low state than logical one bits (see Figure 2b).
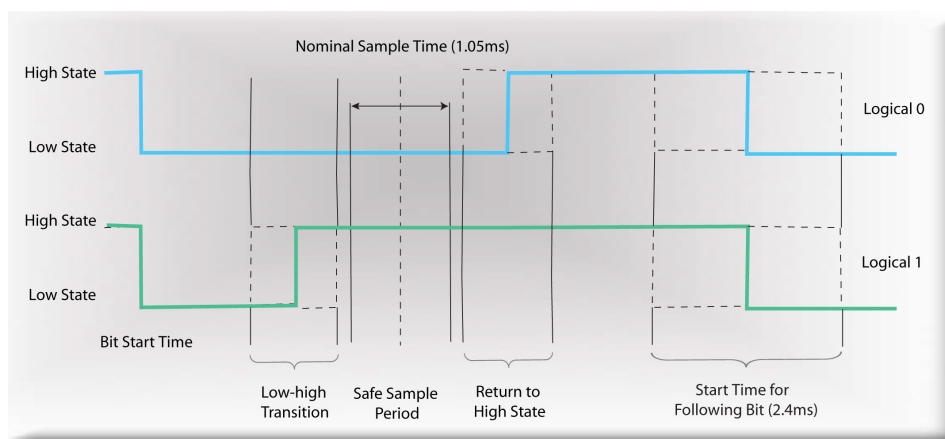

Figure 2b – HDMI-CEC Data Bit Timing

Block-level Protocol

Bits are grouped into 10-bit header and data blocks. Both header and data blocks include 8-bits of data along with EOM and ACK bits. The EOM bit signals the final block in a message. A '0' indicates that one or more blocks follow and a '1' indicates the message is complete. When a single follower provides an ACK to an initiator, it does so by "overriding" the output from the initiator (i.e. by pulling the bus to a logical '0' while the Initiator sends a "passive" logical '1'). Broadcast messages have special rules for handling simultaneous ACKs from multiple devices. Here, the logic is reversed and a group of followers ACK by not "overriding" the initiator (i.e. by allowing the Initiator to send a "passive" logical '1').

CEC devices have both physical and logical addresses. Normally, upon each hot-plug, each CEC source obtains a physical address by reading the EDID of the sink it is attached to. The physical address of each CEC device is expressed as four numbers and indicates where it is relative to the "root" display, whose address is always fixed at 0.0.0.0. For

example, a source attached to input #1 of the "root" display, will have a physical address of 1.0.0.0 (see Figure 1). Each CEC device also obtains a logical address - reflecting its product type - by

negotiating with other CEC devices in the system. For example, the first STB in the system is always given the logical address 3.

Header blocks contain the 4-bit logical address of the Initiator and 4-bit logical address of the Destination in their data bit field as shown in Fig. 3a.
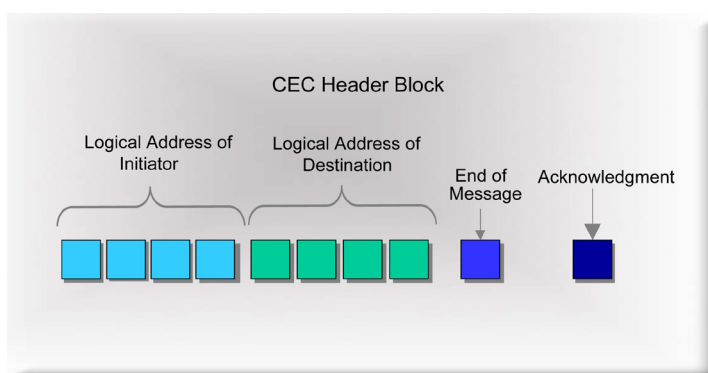

Figure 3a – HDMI CEC Header Block

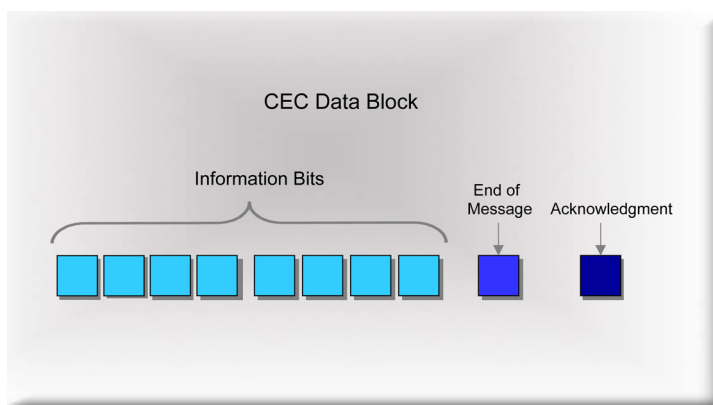Data blocks contain 8-bits of arbitrary data as shown in see Figure 3b.

Figure 3b – HDMI CEC Data Block

Frame-level Protocol

HDMI CEC messages are sent using frames. Each CEC frame consists of a start bit, a header block and possibly data blocks as shown in Figure 3c.
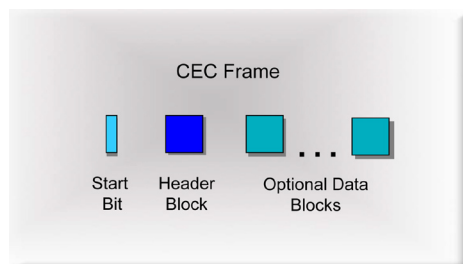
Figure 3c – HDMI CEC Frame

As an example, a message from a source device to a TV might display a text message on screen (On Screen Display – OSD). Such a message begins with a start bit, followed by a header block (with proper initiator /destination addresses), followed by data blocks containing an opcode 0x64 <set OSD string> and parameters to control the duration time and the text to be displayed. Each 10-bit block (except the last one) will have the EOM set to '0', while the last block will have it set to '1'. Each block sent by an Initiator must have its ACK bit "overridden" by the destination device. If the destination is address 15, the message is deemed a "broadcast" and all devices may ACK by not overriding the Initiator's '1'.

Reliable communication is provided via frame retransmissions. If any block in a frame is not acknowledged - or other bus errors exist - initiators will sense the condition and may retransmit up to five (5) times. When destination devices withhold their ACKs, initiators retransmit.

Since the CEC bus is a single wire, bus arbitration is very important. The CEC specification calls for a signal free time before sending. To allow other devices a chance to send, the time for a current initiator to send another frame is longer than that of a new initiator that wants to send a frame, and signal-free times for retransmissions are the shortest. If multiple devices try to send a message at the same time, a priority scheme is used to give a single initiator precedence.

CEC Device Architecture
As extensive as the HDMI-CEC specification is, it makes no recommendation regarding architecture for implementing a CEC device in a product. To some extent your architecture will depend on what, if any, off-the-shelf intellectual property is available. The corollary to this is how willing you are to develop your own components. But setting that aside, it is important to identify the layers in the architecture and how they will interface with one another. Figure 4 illustrates a typical layered archi-tecture, with options.

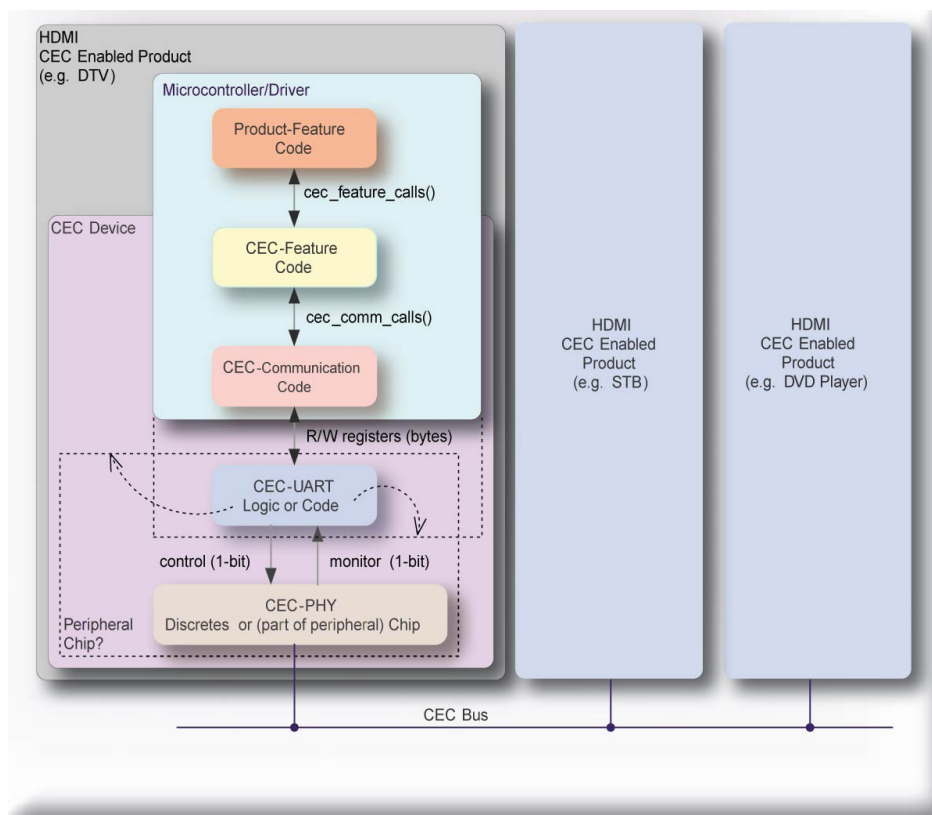You may want to use a layered CEC device architecture – it's up to you

Figure 4 – Example HDMI-CEC System Architecture

At the bottom is a physical layer (PHY), which simultaneously drives and monitors the CEC bus. The PHY has a 1-bit control input and 1-bit monitor output. The control input tells the PHY when to pull the bus low, while the monitor output indicates the current logical state of the CEC bus.

The dividing line between software and hardware depends on your microcontroller's speed

Above the PHY is a bit-level protocol layer, which is similar to a serial UART. The UART layer serializes and deserializes bit streams, while buffering transmit and receive byte strings. Here you have some options. If the speed of the product's microcontroller is sufficiently fast (e.g. with less than 100 microsecond uncertainty), the UART might be implemented in code - as part of the microcontrollers firmware. If not, hardware logic may be required. In this case, UART logic might reside in a specialized peripheral IC – along with the PHY.

Above the UART is a driver layer, which composes and interprets the standardized CEC messages defined by the HDMI standard. Above that is the main body of embedded product feature code, which implements the unique overall behavior of the product.

Verifying Your Implementation

Verifying a CEC implementation requires both general purpose and highly specialized test equipment.

Test Point Adapters allow you to attach precision loads, bias voltages, and specialized test equipment to the test target when needed

Quiescent electrical performance is normally measured with a multimeter, while dynamic electrical performance is measured with an oscilloscope. Test Point Adapters (TPAs) are needed to connect these general-purpose instruments to the HDMI port of the device being tested. TPAs also attach precision loads, bias voltages, and specialized test equipment when needed. Dynamic electrical tests require a specialized product-emulating test instrument to coax messages from the device under test (see Figs. 5 & 6).
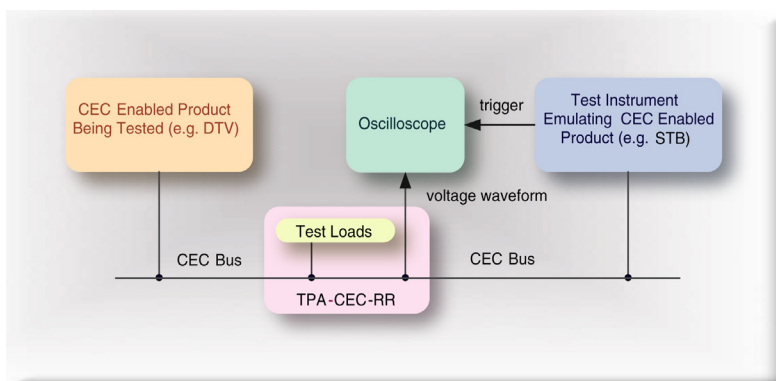

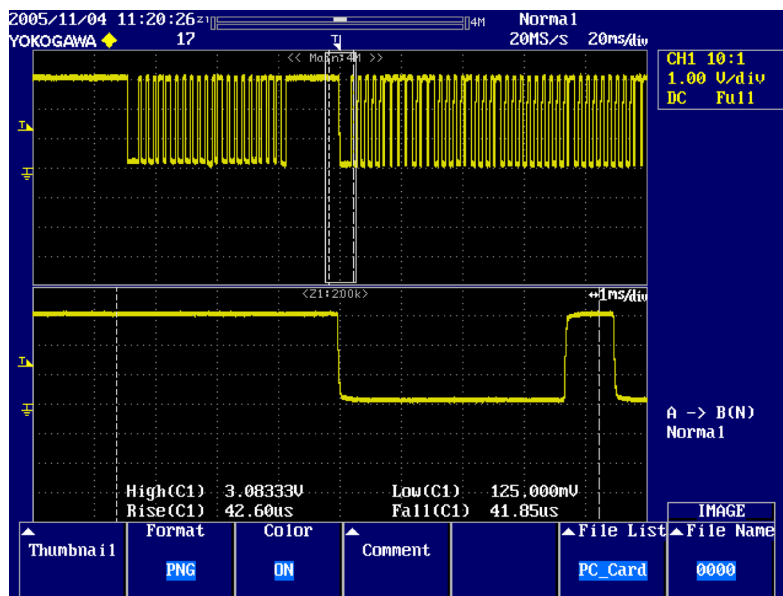**Figure 5 – Dynamic PHY Electrical Test Point Adapter**

Figure 6 – Dynamic PHY Electrical Waveform

Debug utilities are essential for verifying the CEC timing parameters and protocol rules	Debug utilities that enable you to simulate a real-world environment are an essential part of any development system. There are several types of utilities that are useful for verifying the protocol layer. Debug utilities that can simulate timing errors, corrupt bits, invalid frames and blocks, and that can force errors to check for boundary conditions are particularly useful. Since the CEC bus is a shared bus, a utility for simulating arbitration errors and verifying proper operation would be useful as well.
CEC bus monitors can help pinpoint timing and protocol errors	An important complement to error simulation is the ability to monitor the CEC bus and log bus transactions. A CEC bus monitor enables you to pinpoint bit timing problems and protocol errors such as acknowledge-ments and end of message placement. A CEC monitor that displays bus traffic, decodes individual frames, and shows bit timing is invaluable.
Multiple CEC device emulators are required to verify that the test target is a "good CEC bus citizen"	While a device under test is being developed, multiple CEC devices are needed to verify that logical address allocation, bus arbitration, and broadcast message handling work correctly, along with other "good citizen" type testing. A wide variety of CEC compatible equipment is required to test networks that represent typical bus configurations. Another alternative is to use test equipment that can emulate multiple devices with different characteristics.

A device emulator that can withhold ACKs, inject bit errors, or cause protocol violations by inserting extra EOM bits is required to verify correct operation.

To verify an implementation, a CEC device emulator that can change timing and win arbitration is needed. Testing can be accomplished by either creating special test drivers to vary bit timing to the device under test, or using commercially available test equipment that provides emulated CEC devices with the ability to change bit timing to determine if the device under test meets the specification.

CEC Compliance Testing

As you complete the implementation of your CEC device, your focus will shift to compliance testing. CEC compliance testing is governed by the HDMI LLC, which has published a CEC compliance test specification. There are now CEC certification test centers that certify proper CEC operation.

An application that can simulate a compliance lab environment helps you avoid costly engineering and testing time	The compliance process itself starts with a declaration of what features your device supports. Although this task is not difficult, assessing which specific tests in the CEC compliance test specification apply is not straightforward. An application that simulates the compliance test environment and can map high level supported features to the specific tests in the CEC

compliance test specification would be useful both at the early stages of development and just prior to compliance testing during internal prequalification.

By knowing which specific tests apply prior to compliance testing, you can avoid failures of tests you did not anticipate. Alternatively you may have over engineered your product and added support for functions that really do not apply. Having access to a utility that compiles compliance tests based on product capabilities in the early engineering phase can reduce the risk of failure in the compliance lab and the additional cost incurred by designing in features that do not apply.

Typically about 10% of products submitted to the ATC pass on the initial test

Only about 10% of products submitted to HDMI compliance labs for testing gain compliance on the initial test series (according to an HDMI ATC representative). Delays for resubmission and retesting often extend time to market. To avoid costly resubmissions and delays that impact product launch, consider running all of the CEC tests in the HDMI Compliance Test Specification v1.2a before submitting. That can be a daunting task since the tests include dynamic and quiescent electrical tests and an extensive series of protocol tests. Interpreting the specification and building the required test jigs can be very time consuming and error prone.

Quantum Data Tools

Quantum Data has recently released an HDMI-CEC Development and Compliance Suite that includes all the essential utilities, applications and test point adapters for designing a CEC device into an HDMI product. The components of this test suite are listed below and referenced in the accompanying photograph (Figure 7).

1. HDMI-CEC core emulation. The 882CA contains three CEC cores that can emulate two HDMI-CEC source devices and one sink device.

2. Interactive Troubleshooting Environment (ITE) is a debug utility used for simulating CEC timing and protocol errors. The ITE offers both a command line and graphical user interface application.

3. Auxiliary Channel Analyzer (ACA) with CEC bus monitor is a graphical application that logs and displays CEC bus transactions in real time. Figure 8 shows a screen shot of this application while logging CEC bus activity.

4. Test Management Environment (TME) is a graphical application used by the HDMI organization ATC lab for testing HDMI-CEC products for compliance. It is therefore an ideal application for running pre-compliance tests prior to submission to the ATC for compliance. The TME provides expert system-like functions for compiling the detailed test suite from the Capabilities Declaration Form (CDF) as well as executing the test suite. Figure 9 shows a screen shot of this application during a CEC electrical compliance test.

5. Test Point Adapters (TPAs) are test fixtures used during compliance testing or development. They allow test instruments to be attached to the unit under test and apply calibrated loads as set forth in the HDMI-CEC specification. Figure 5 (above) shows a block diagram of a TPA.
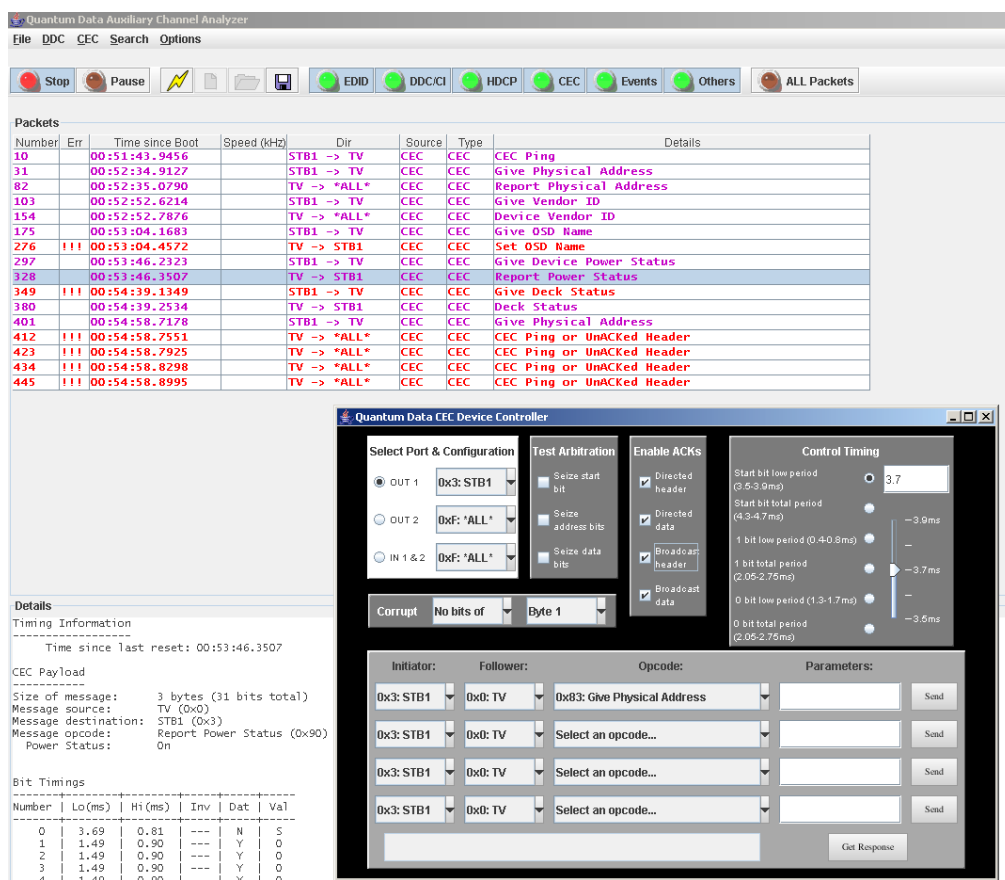

Figure 7 – Quantum Data HDMI-CEC Compliance Kit

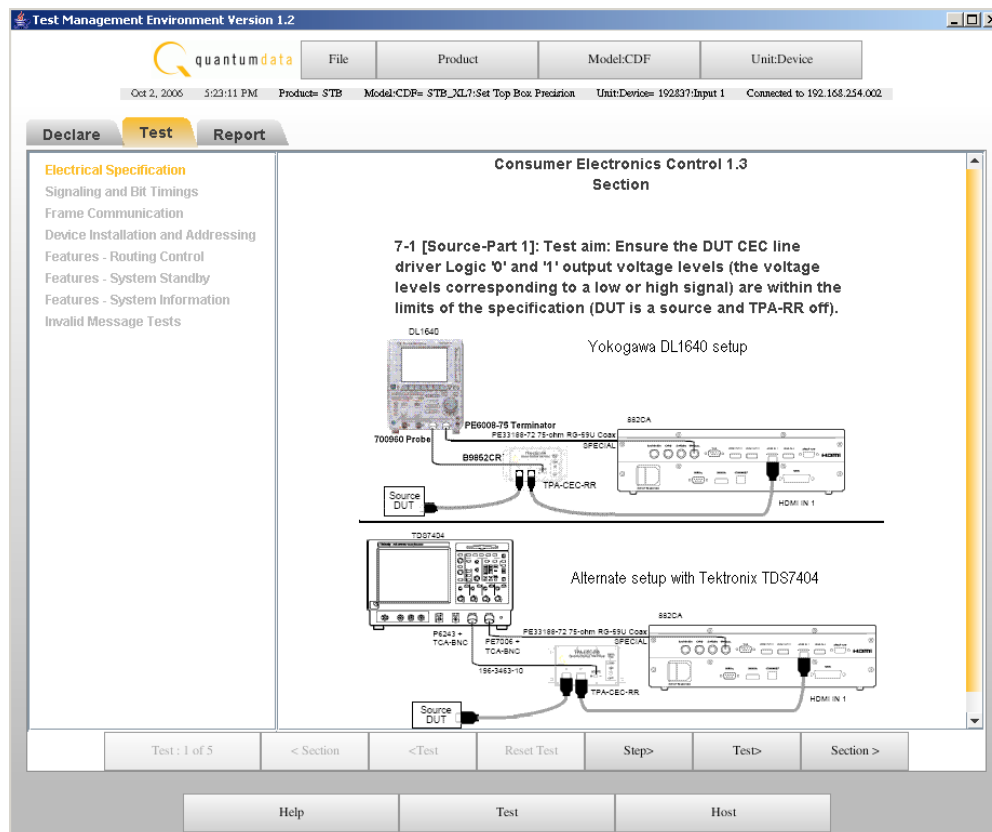**Figure 8 – Screen Capture of HDMI-CEC ACA Application with ITE GUI**

Figure 9 – Screen Capture of HDMI-CEC TME Application

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Quantum Data has been providing high quality test equipment for 27 years and has extensive expertise with CEC. Quantum Data equipment is recommended in the latest HDMI Compliance Test Specification and is used in the certification test labs. The tools provide help in all aspects of development and testing. Please give us a call if you need assistance in designing CEC into your next HDMI product.