A White Paper on

ASTB, IDTV & HDTV Display Interoperability In the Year 2000 and Beyond

September 7, 2000

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Introduction

This white paper presents an architectural analysis of modern, consumer-friendly interconnection systems to be used with Advanced Set Top Boxes (ASTBs, such as those specified by the OpenCable process), Integrated Digital Television receivers (IDTVs, such as those designed for the ATSC emission standard), and display devices (such as HDTV projection systems, plasma panels and cathode ray tube (CRT)).

Executive Summary

While IEEE 1394 (sometimes called *FireWire* or *iLINK*) is an impressive digital interface standard for the interconnection of certain types of consumer electronics equipment (such as a VCR or camera to a set top box (STB)), it is by no means a panacea. Specifically, although 1394 is an excellent consumer electronics interconnection scheme for *compressed* DTV signals, it has important shortcomings as a standardized DTV display interface with respect to high-bandwidth applications such as HDTV. Moreover, even in cases where the 1394 interface may provide an adequate solution, it is by no means the only such interface available. For example, new versions of the Universal Serial Bus (USB) interface will soon meet or exceed the capacity of the 1394 interface.[1] Therefore, making the assumption that standardization on 1394-based interconnects will remove all remaining obstacles to consumer acceptance of DTV could actually *hinder* the transition to digital television.

The interconnection requirements for advanced digital television products and services are diverse. Furthermore, a set of recommendations for solving the interconnection and labeling issues cannot be made in the absence of consideration of the services, software applications, consumer receiver architectures and content types that will run across these interfaces, both today and in the future.
To assure a rich, cost-effective and competitive DTV marketplace, flexibility in these interfaces (and in the corresponding industry labels for DTV equipment) will be required. This implies that such an environment must enable interconnection options other than (or in addition to) 1394 for interactive DTV services. Those options must include a type of interconnection system -- such as *Digital Visual Interface* (DVI) using *High-bandwidth Digital Copy Protection* (HDCP) -- that allows *uncompressed*, high-bandwidth protected digital video to be sent directly to HDTV display devices.

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[1] "NEC, In-System to Develop USB 2.0 Chip," *Electronic News Online*, September 1, 2000. http://www.electronicnews.com/enews/news/4530-245NewsDetail.asp

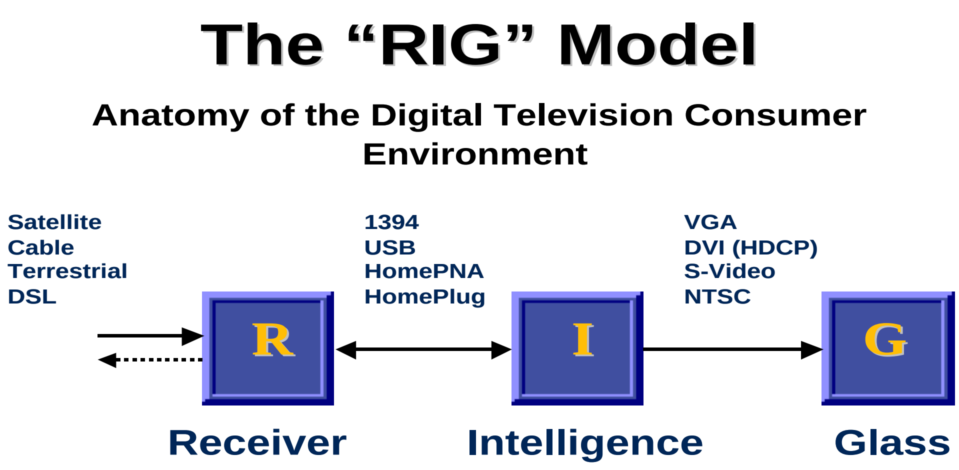
Definition of Terms: What is a "Digital Television Appliance"?

ASTBs and IDTVs are examples of digital television appliances. They contrast with analog NTSC television devices in their ability to receive television signals in digital form via terrestrial transmission, cable or satellite. Attributes common to all digital television appliances include: 1) the reception of program streams in a compressed digital form and 2) the processing power and intelligence[2] required to navigate and decode the digital stream. Additional intelligence may be required for interactive services such as shopping, personal video recording functionality, gaming, chat, e-mail and web access.

The type of digital television appliance(s) that a consumer acquires will depend on many factors, including the target location in the home and the consumer's disposable income level. In place of the current analog set top box attached to the traditional NTSC television in the living room, examples of consumer configurations likely to evolve include:

1. A large-screen HDTV system for the living room that is able to deliver a wide range of entertainment.
2. A PC in the den that can receive TV in a small window while performing productivity and communications tasks.
3. A small-screen DTV for the bedroom with gaming and other applications.
4. A flat-screen DTV in the kitchen with recipe, calendar and messaging capabilities.

Many other possibilities arise, particularly when the choice of screen (the "glass") is independent of the device that provides it with the video signal and navigation or control capabilities (the "intelligence"). When considering digital television appliances, it therefore may be useful to apply the so-called *RIG* model: A consumer digital television system consists of three functional parts – Receiver, Intelligence and Glass.



[2] In this context, the term *intelligence* refers to computational hardware, applications and algorithms.

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- The **Receiver** module tunes the desired frequency (channel), demodulates the signal, handles the conditional access and outputs an MPEG2 video stream, compressed digital audio streams and related data streams. There may be more than one type of Receiver in the home. The Receiver can either be integrated with the Intelligence module (see below) or it can be separate.[3]

  The Receiver can also authorize a connection between the digital content provider and the home; it contains everything that is necessary for identification and conditional access. In the context of cable, this interface module has traditionally been provided and controlled by the cable company to which the consumer subscribes. With the recent emergence of OpenCable-compliant ASTBs and removable security modules (i.e., "PODs"), we will begin to find situations where consumers make their own choice of ASTB and connect it to the cable system themselves. The network-specific POD module, however, will continue to be supplied by the respective cable operator.

  Receiver modules (sometimes referred to as "Residential Gateway Modules") will connect to the Intelligence via standardized consumer interconnects. When integrated into a single box, this interconnect could be a PCI or other computer bus. Many Receiver modules will be separate set top boxes and it's likely that they'll connect using 1394 or USB. There may be multiple Receiver modules (i.e., multiple tuners) fitted to a system in order to provide multiple video windows (e.g., for picture-in-picture), or multiple video providers (e.g., cable, satellite, terrestrial). A common dual-Receiver configuration example is a satellite Receiver that is also capable of terrestrial DTV reception.[4]

  When interactive services are provided, the connection between Receiver and Intelligence should support bi-directional communications. This is because the user interface and local rendering of interactive elements will be generated by the Intelligence component, while return transmissions of interactive commands from the user to the service provider (the so-called *back-channel*) will likely be handled by the Receiver module. 1394, USB and IP networks are well-suited for this type of interconnect.

- At a minimum, the **Intelligence** component handles MPEG video and AC-3 audio decoding. On more advanced devices, this component also serves as the platform for the generation and rendering of graphics for the system's user interface, electronic program guide (EPG) and other value-added and interactive services. This could include a platform for any downloadable applications, and the management of any local content storage capability. Such functionality could take the form of an OpenCable or ATSC-DASE STB, a DTV-PC, an advanced DTV home theatre console system with integrated personal video recorder (PVR), any of a number of proprietary STB platforms or just a simple 8-bit processor and MPEG decoder in an integrated DTV receiver.

  It is important to provide very fast pixel rates for the decoded video when linking the Intelligence to the Glass. Note that 1394 and "Vestigial Sideband (VSB) over coax" interfaces are not contenders for viable Intelligence-to-Glass interfaces because the MPEG stream has already been decoded (i.e., uncompressed) in the Intelligence component. Neither of these

[3] http://www.ce.org/newsroom/newsloader.asp?newsfile=6731
[4] The RCA DTC-100 is an example of this type of device. See http://www.rca.com/product/viewdetail/0,,PI640,00.html.

interfaces can handle the required resolution and speeds of the uncompressed program stream without significant additions to the cost and complexity of the Intelligence module. (This issue is described further below.) This is especially true of 1394 links using "5C" copy protection, because the required encryption overhead may reduce the net payload of the basic 1394 transport even further, given the typical cost constraints of consumer electronics equipment.

There is usually no need for bi-directional communication between the Intelligence and Glass. However, if it is provided, it can enable features such as adaptive remote setup and calibration of the display.

- The **Glass** provides the image display for the user. (The RIG model assumes that the speakers or audio reproduction system are at the "Glass end" of the diagram. They may or may not be included or attached to the display device itself.)

  This component can take the form of an (H)DTV projection system, a CRT, a plasma flat panel, an LCD or even an NTSC analog TV. Note that with an installed base of some 250+ million NTSC televisions in the U.S., it will be quite common for many years to see U.S. consumers connecting their "intelligent" DTV appliances (especially cable and satellite ASTBs) to their NTSC television sets. Subsequently, it is expected that these consumers will replace their NTSC displays with enhanced definition television (EDTV) or HDTV displays and connect to their existing DTV set top box interfaces.

There is no intrinsic grouping of these three functional parts or prescribed method for their integration. The consumer electronics association (CEA) has recently put forth new definitions that allow many different configurations.[5] Substantial latitude exists for product differentiation and added value to the consumer in this respect. With the amount of flux that exists in today's DTV environment, most vendors find it sensible to implement DTV systems in at least two separate boxes. This is primarily due to the separate paths upon which display and Receiver/Intelligence technologies are independently evolving.

Moreover, consumers may want to purchase different parts at different times. The choice of display is often dictated by aesthetics or physical constraints and room layout, the latter of which do not often change. Because the display can also be quite costly and typically has a long life expectancy, it is less frequently updated or replaced. This implies that the consumer transition to DTV may occur faster if low-cost set top boxes are available, and the cost of more expensive new displays can be deferred. In addition, such proliferation of inexpensive ASTBs and their associated services will eventually accelerate consumer demand for new displays (thereby providing earlier cost reductions for all of these products due to economies of scale).[6]

Consider also that all players in the DTV industry are motivated to provide as much added value as possible in order to attract consumers to their respective offerings. Consumers will be the ultimate beneficiaries, but only if their equipment environment allows easy integration of such offerings. Any

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[5] http://www.ce.org/newsroom/newsloader.asp?newsfile=6731

[6] This trend has already been demonstrated by the early adoption of "HDTV ready" displays driven by reasonably priced and widely available digital video sources such as DVD and high-definition satellite services, even in the current absence of digital terrestrial receivers. It can only be expected to expand if other DTV sources (i.e., terrestrial and cable DTV) come to market at similar price points and availability.

interface limitation to such consumer equipment presents a range of problems that will only increase in complexity as the industry moves toward intelligent, feature-rich devices.

Providing such an environment will pay additional dividends for industry as well. Cable and satellite network operators have undertaken billion-dollar network build-outs to provide intelligence-based services to their customers. If, for example, these services cannot be easily presented to HDTV displays in a secure and cost-effective manner, then these service providers will be reluctant to deliver HDTV content to the 80% of the U.S. population that they serve.

Start With the "Glass" and Work Backwards

As the era of digital television dawns, much of the enthusiasm among consumers is generated by the large screen displays coming to market. The larger screen is a key enabler for HDTV because HDTV's quality is only fully appreciated at such display size.

Current products targeting early adopters place little or no inherent Intelligence in these display devices. This implies that all of the Receiver and Intelligence functions noted in the RIG model above are upstream of the Glass. The type of interconnection between display systems and upstream Intelligence is therefore critical to the operation of existing and future products.

In today's consumer environment, such interconnections are well established, with a large base of NTSC, composite video and S-Video equipment currently in use. These interconnect types are generally unsuitable for DTV because they will not accommodate its higher-resolution video formats. Without an industry-standardized video interface that can sustain EDTV and HDTV signals, mainstream consumer acceptance of large screen DTV displays will face an insurmountable obstacle.

Because such large screen, HDTV-ready display products typically have no intrinsic signal-decoding capabilities, they are incapable of dealing with a compressed video stream. This implies that the new industry display interconnect – whatever form it may take -- must be capable of handling HDTV streams in high-speed *uncompressed* form. Such uncompressed HDTV signals may be transported in either analog or digital form. Both are examined below.

Analog Consumer Interconnects

Options for analog interconnect schemes, of which S-Video is a common example in today's consumer space, become quite limited if they are required to accommodate HDTV signals. Few, if any, of the existing standards are suitable in their current form. S-Video is incapable of supporting the resolution required, and there is simply no HDTV equivalent for composite analog video.

Component analog video is a contender, and VGA stands as an example in today's consumer environment. But because an analog signal is easily diverted, split and copied, the issue of copy protection immediately arises. This is particularly critical in the case of an HDTV signal's high resolution, which can deliver near-theatrical quality program content. Use of HDTV component analog interconnects is a stumbling block because there are no existing industry standards for copy protection of these signals. While some consumer electronics (CE) manufacturers have nevertheless produced designs with unprotected HDTV component-analog outputs, this does not meet the needs of the content industry, and could prevent the broadcast of high-resolution premium content, such as movies. Although HDTV component analog signals are not recordable with any of today's standard consumer electronics products, they are quite easily recordable with professional and industrial equipment. Premium HDTV programming shipped "in the clear" over component analog interconnects can therefore be easily pirated. Even if a copy protection scheme existed (such as an HDTV version of Macrovision[7]), encrypted component analog signals would be easily decoded by anyone with moderately sophisticated skills. Subsequent evolution and deployment of new encryption standards in this area would likely render the current generation of consumer HDTV products obsolete and incapable of displaying an image.

Analog interconnects also impose certain quality constraints and may severely limit the length of the cables that consumers could reliably use. Potential signal distortion and noise pickup could greatly reduce the quality of the HDTV viewing experience. Finally, as the industry moves toward display technologies such as digital light processing (DLP),[8] grating light value (GLV),[9] liquid crystal display (LCD)[10] and other inherently digital HDTV display systems, the disadvantages of using an analog interconnect will become increasingly obvious. For reasons of quality, convenience, content security and cost, a standardized digital interconnect between the DTV appliance and the display is therefore required – and expected – by the industry.

Digital Consumer Interconnects

Common HDTV image formats such as 1920 by 1080 pixels at 30 frames per second interlaced (commonly referred to as "1080i"), or 1280 by 720 pixels at 60 frames per second progressive (commonly referred to as "720p") have data rates on the order of 1.4 gigabits per second (Gb/s) in their uncompressed component form. To put this in perspective, this is almost 25,000 times faster than a common dial-up computer modem connection. More importantly, these HDTV speeds are seven times faster than the absolute maximum speed of today's IEEE 1394, implementations for consumer electronics equipment. While future versions of 1394 may eventually reach speeds in the 1.4 Gb/s range, the 1394 interface was not designed to carry sustained HDTV data rates without interruption as required by continuous television viewing. Industry insiders and observers generally agree that use of 1394 content-protected, baseband uncompressed DTV video will not be feasible in the consumer environment for quite some time to come. Further, the extension of the 5C content protection proposed for use with 1394 is also not currently extensible to such speeds. In short, 1394 has important shortcomings as a standardized DTV display interface format with respect to high-bandwidth applications.

On the other hand, 1394 is an excellent consumer interconnection scheme for *compressed* DTV signals. An example of this would be its use for transport of a 19.39 Mb/s ATSC stream. Even the slowest (200Mb/s) version of 1394 is easily capable of transporting such compressed signals. But with no Intelligence at the Glass, the display is not capable of rendering a picture from such a compressed signal. ATSC and other compressed stream types must be decoded into viewable signals by DTV appliances upstream of the display. Therefore, given the characteristics of today's television content and the capabilities of consumer electronics components, HDTV-capable display devices[11] are simply not compatible with the use of 1394 as an interconnect technology.[12]

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7 http://www.macrovision.com/vcp.html
8 http://www.ti.com/dlp/products/, http://www.dlp.com/dlp/resources/tech_dmd.asp
9 http://www.siliconlight.com/htmlpgs/homeset/homeframeset.html
10 http://www.sharp.net.au/product_sales/digital_tv/lcr60hd.htm
11 "CEA Expands Definitions for Digital Television Products" (Press Release), Consumer Electronics Association, Arlington, VA, August 31, 2000. http://www.ce.org/newsroom/newsloader.asp?newsfile=6731
12 http://www.eetimes.com/story/OEG20000714S0037

A potential solution to this problem exists, however. A high bit-rate digital video display interconnection standard has been proposed for use with consumer DTV displays. It is called the *Digital Visual Interface* (DVI) and includes an extension known as *High-bandwidth Digital Copy Protection* (HDCP).[13] DVI technology already has been widely deployed in high-resolution computer displays and adapted for consumer applications with HDCP for protection of digital video content.[14] Its features and advantages have stimulated a rapid growth in its popularity for interconnecting DTV appliances with their respective display systems. A substantial and growing number of computer and consumer electronics companies have announced their intent to deploy products that support this interconnect standard. The companies include Fujitsu,[15] NEC,[16] Echostar,[17] Silicon Image,[18] JVC,[19] Sony,[20] Samsung[21] and Intel.[22] The Video Electronics Standards Association (VESA) has also embraced this standard, and it is now also under study by CableLabs for possible inclusion in the OpenCable specifications.[23]

Key features of DVI are its low cost, resolution independence and potential for supporting advanced copy protection suitable for feature film content. It is capable of handling the bit rates associated with all existing and proposed EDTV and HDTV formats. Note also that while 1394 is a bi-directional link, suitable for connecting communicating devices such as cameras or recorders to STBs, DVI is optimized for one-way, high-speed connections to display devices.[24]

High bandwidth Digital Copy Protection (HDCP) on the DVI link

Security for premium content is of vital importance. If digital copying of premium content such as early release-window movies were allowed to occur, the revenue structure of the film industry could be threatened.

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[13] *High-bandwidth Digital Content Protection* (White Paper). Silicon Image, Sunnyvale, CA. February 2000. *See* next section for a more detailed explanation of HDCP.

[14] http://www.ti.com/sc/docs/news/2000/00034b.htm, http://www.eetimes.com/story/OEG20000525S0020

[15] http://www.ddwg.org/releases/fujitsu_aug99.html

[16] http://www.eetimes.com/story/OEG20000710S0106

[17] http://www.eetimes.com/story/OEG20000714S0037

[18] http://www.ddwg.org/releases/silicon_image.html

[19] http://www.users.freenetname.co.uk/~mcfc/100042.htm, http://www.jvc-victor.co.jp/english/products/vcr/D-security.html

[20] http://www.world.sony.com/News/Press/200002/00-0218/, http://www.bellmicro.com/Semi/NewsBrief_Archive/February00/0218_Intel_Sonyteam.htm

[21] http://www.stanfordresources.com/news/articles/et_120099.html

[22] "Intel is convinced that DVI represents the next major shift in interfacing for computer displays. With the availability of our own content protection specification, HDCP, this technology now has the opportunity to provide high-bandwidth interface solutions with robust content protection for both computing and consumer digital displays, offering interoperability between a wide range of PC and CE devices." Mark Waring, DVI Strategic Initiative Manager, Intel Corporation.

[23] "An imminent decision by satellite-TV operator Echostar Communications Corp. to incorporate the Digital Visual Interface (DVI) in its next-generation set-top box could have major implications in the balance of power over the interface for consumer appliances that hook up to digital television sets…. CableLabs, the R&D lab for U.S. cable operators, is also investigating DVI and a few other digital interfaces, not as a competing interface but as complementary to IEEE 1394." David Broberg, Director of OpenCable Requirements, quoted in *EE Times*, "Echostar Taps DVI for Set-tops, Sparks Interface Debate," July 14, 2000. http://www.eetimes.com/story/OEG20000714S0037

[24] "IEEE 1394 is a different interface designed for different applications. It's for a two-way communication link, perfect for connecting a VCR or a camera to a set-top. DVI is designed for a one-way connection for uncompressed signals. Both interface standards will coexist." Rich Nelson, Director of Marketing, Broadcom, quoted in *EE Times*, "Broadcom Makes Pivotal Bid for DVI, Bluetooth Technologies," May 25, 2000. http://www.eetimes.com/story/OEG20000525S0020

For this reason, it is critical that every link in the DTV chain be secure. There is no point in protecting some of the links if others are left open to attack. Each stage in the chain needs to verify that it is passing premium content to a downstream stage that can be trusted as secure. A copy-protection scheme known as *DTCP* (Digital Transmission Content Protection),[25] typically referred to as "5C,"[26] can be used on any one of a number of interconnection types (1394, IP transport, etc.) to determine that the link from the Receiver to the Intelligence is secure, or else the Receiver will not pass on the content. Likewise the link from the Intelligence to the Glass needs to be secure, or the Intelligence device will not pass on the content to the display.

The methods used to provide security within the Intelligence component vary, depending on the openness of the device's architecture. A "sealed" STB can do without security inside the box because it is difficult to open the box and design snooping devices that could extract premium data from the internal video paths. Yet protection within the box is in vain if the box's output to the display is not protected, hence the need for a copy protection scheme on the wire that goes to the display.

Various attempts were made to try to find a copy protection scheme for analog component interconnection (usually called RGB in the consumer video environment, or VGA in the PC industry). No approach could be identified that provided the required level of protection without detracting from picture quality. Ultimately it became apparent that the only way to provide the level of protection sought by the content industry was to move from an analog component to a digital component interconnection approach. The result of this work was the DVI interface standard noted earlier and the associated copy protection system developed for it, HDCP. The HDCP specification provides a robust, cost-effective and transparent method for securely transmitting premium digital entertainment content to certified DVI-compliant digital displays.

The HDCP system was designed by the same engineers who developed most of the 5C system. Because the high data rate of DVI exceeded the capability of the 5C system, 5C could not be directly applied to DVI. Thus, these engineers developed HDCP to accommodate the requisite faster scrambling scheme for DVI. The authentication process of HDCP (which happens before the content data starts flowing and determines if the equipment downstream is a trusted device) retains much in common with the 5C system.

This authentication process is a critical step. It is important that it not be possible for a device to report that it is a display when it is actually a recording device. To prevent this possibility, display manufacturers must obtain securely encrypted electronic certificates from the HDCP licensing authority for their displays. These certificates are stored within the display devices.

During the authentication process, the certificate is read by the upstream Intelligence box to verify that it is a valid display device (i.e., "trusted Glass"). As part of the process, the Intelligence component checks the certificate against an up-to-date revocation list to verify that no security breaches have been reported for that display model. HDCP uses a 56-bit key, with individual keys distributed to the various vendors. A violated key can be tracked down and revoked, and this revocation can be distributed to consumers' Intelligence devices via a TV broadcast network, for example.

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[25] http://www.dtcp.com

[26] The 5C specification of DTCP was developed by Hitachi, Intel, Matsushita, Sony and Toshiba. The name "5C" was coined in recognition of the five companies involved.

HDCP is an ideal solution for the consumer electronics industry to protect the link from an ASTB to any display device. It is also an ideal technology for DTV receivers to use as an alternative to low resolution analog S-video or composite video inputs.

Several major Hollywood studios have endorsed the HDCP technology.[27] Developers of HDCP have reported strong positive reactions from the content community.[28] Worldwide adoption of DVI with HDCP by multiple industries will have a strongly positive impact on the DTV industry, because content producers such as Hollywood studios will be able to release new, high-definition digital content with high confidence in its security.[29] While no encryption system is completely unbreakable, HDCP includes a certificate revocation method, which allows it to recover from the possibility of a successful hack.[30]

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[27] "Warner Bros. has a library of movies and television productions that look great in the new high-definition digital formats. We are pleased to see the work done by Silicon Image to develop the HDCP chip set and welcome the deployment of such technology. It is important for consumers to understand that systems which lack an effective technology to limit unauthorized copying of our most valuable and highest quality content will not be able to receive it." Silicon Image press release, March 14, 2000, http://www.siimage.com/press/03_14_00.asp (quoting Wendy Aylsworth, Vice President, Technology, Warner Bros.); *id.* (quoting Phil Lelyveld, director of Digital Industry Relations, The Walt Disney Company) ("Secure interconnections such as HDCP are important elements of an overall content delivery system, addressing a key need in the development of new channels for high quality digital content delivery.").

[28] *Id.* (quoting Steve Tirado, Executive Vice President of Marketing ("We are enabling the industry transition to new high-definition digital content. This latest demonstration reflects our ability to successfully execute on our DVI innovation strategy, lead the market we are pioneering and receive endorsement of this vital new technology from members of the Motion Picture Association (MPA).").

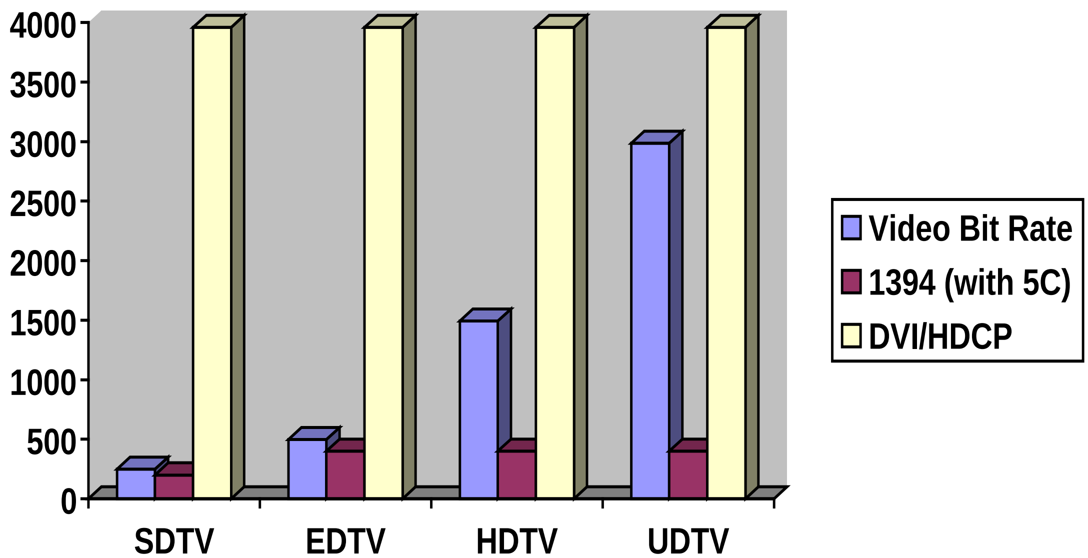
[29] "HDCP also answers a plea from the entertainment industry, particularly from the studios that provide much of today's premium content." *Electronic Design*, June 12, 2000. http://www.elecdesign.com/magazine/2000/jun1200/coverstory/cov1.shtml?ads=ne

[30] *High-bandwidth Digital Content Protection* (White Paper). Silicon Image, Sunnyvale, CA, February 2000.

A comparison of digital interconnection proposals

The following table and graph summarize the considerations made above. They illustrate the requirements of various video signal resolutions and the capacities of various digital interconnection systems. The values shown are derived from currently published specifications.[31]

Uncompressed DTV Interface Bit Rates	1394 (with 5C)	DVI/HDCP[32]
UDTV[33] Tuner/Monitor: 2,986 Mb/s	200-400 Mb/s	3,960 Mb/s
HDTV Tuner/Monitor: 1,493 or 1,327 Mb/s	200-400 Mb/s	3,960 Mb/s
EDTV Tuner/Monitor: 498 Mb/s	200-400 Mb/s	3,960 Mb/s
SDTV Tuner/Monitor: 248 Mb/s	200-400 Mb/s	3,960 Mb/s



The above graph clearly indicates the inadequacy of the 1394 interface for certain applications and the capability of the DVI interface to handle current applications and beyond.

[31] *DVI 1.0 Specification*, April 2, 1999. http://www.ddwg.org/
[32] Per DVI 1.0 spec with 165 MHz maximum pixel clock rate and 24 bits per pixel. Dual link version extends this value to 7920 Mb/s.
[33] UDTV refers to 1920x1080x60Hz progressively scanned displays.

What DTV Equipment Will Consumers Buy?

Keeping in mind the RIG model discussed above, consider the following permutations for DTV equipment options in the consumer's home:

1) *Integrated Digital Television:* includes all "RIG" components in a single device.[34] No inter-component interfaces are required, unless external STBs are used for additional services.

2) *External Receiver:* STB Receiver serves as a tuner[35] (R) and sends a demodulated but not decoded signal (i.e., a compressed bit stream) across an interface to an integrated decoder/display (I+G, or "intelligent Glass").

3) *ExternalReceiver/Decoder:* STB demodulates and decodes all signals (R+I), and sends audio and video across appropriate interface(s) to display/reproduction devices (G).[36]

Since interactivity will be added in the digital environment, any Receiver/Intelligence interfaces that are used must also support bi-directional communication, for reasons explained earlier.

Finally, an ideal technical and regulatory environment will allow all of these options to coexist and interoperate, thus stimulating competition and maximizing flexibility. This in turn will optimize user choices and satisfy the widest range of consumer budgets.
Given these issues, consider the implications for the interfaces noted above. Option 1 essentially requires no Receiver/Intelligence interfaces, but is the least likely to be deployed. This type of integrated DTV product is virtually nonexistent in today's environment, and does not seem to be high on either consumers' or manufacturers' priority lists for new product development. This is partially due to the current uncertainty in formats and requirements for easy hardware upgrades. In addition, the prevalence of cable and satellite in this country dictates a separate set top box whose functionality and network-specific security features are typically not integrated with the digital television set. There is no sign of harmony across digital cable, digital satellite and ATSC platform standards, thus precluding any hope for integration of all interactive services into all receivers for the foreseeable future. While this situation may eventually change, it remains likely that the integrated DTV receiver model will apply primarily to non-interactive, integrated DTV sets used as secondary devices in the home. Therefore, Option 1 is not a critical factor in this discussion.

Option 2 presents a fairly simple technical interface, given that compressed incoming signals could be passed through a moderate-bandwidth interface (such as 1394, USB or HomePNA) to the decoder/display. But this implies that a standard signal format to the decoder exists, which is certainly not the case. Over-the-air terrestrial, digital cable and satellite television systems all use different formats, and this is unlikely to change, as established above. In particular, the interactive applications proposed for these systems are widely divergent, largely ruling out the possibility of any comprehensive solution in this case. Unless and until the full range of interactive and enhanced television services planned by cable, satellite, wireless and telecommunications companies can be

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[34] See *High Definition Television* (HDTV), *Enhanced Definition Television* (EDTV). "CEA Expands Definitions for Digital Television Products" (Press Release), Consumer Electronics Association, Arlington, VA, August 31, 2000. http://www.ce.org/newsroom/newsloader.asp?newsfile=6731

[35] See *High Definition Television (HDTV) Tuner*, *Enhanced Definition Television (EDTV) Tuner*, CEA press release, *ibid.*

[36] See *High Definition Television (HDTV) Monitor*, *Enhanced Definition Television (EDTV) Monitor*, CEA press release, *ibid.*

implemented in "intelligent Glass," and the necessary digital stream standards and physical interfaces are supported in such integrated displays, any decisions regarding the labeling of DTV appliances for Option 2 are premature. (This is not to say that flexible equipment labels are not appropriate for more mature configurations, such as those that fall under Option 3.) Further, the feasibility of any such solution for Option 2 is suspect, given that it is unclear whether it would be in the public interest to have a fixed level of enhanced/interactive TV functionality built by display manufacturers, or instead to continue to add new features and Intelligence in STBs to ensure that attractive new services will be available to consumers.

Option 3 is the most likely to be accepted by consumers for home theater and interactive systems, based on current trends and future product plans. It would allow a variety of services to coexist and interoperate with a given display. It would improve competition in the less expensive and more volatile Receiver/Intelligence market segment, while protecting consumers' investments in the more expensive display components. This allows consumers to upgrade or change services with relative ease and low cost, and without replacing expensive screens. This also keeps down the cost of display devices, by reducing their requirements for additional signal processing circuitry. Finally, it allows any number of competing interactive TV formats (either standard or proprietary) to interoperate with the consumer's choice of display. The consumer simply selects or purchases the appropriate STB for the service, and connects it to the service and to the display. Clearly this is a technically sound and simplified environment that benefits the consumer.

To allow Option 3 to work, however, a high-bandwidth interface is required. It must have the capability of carrying a baseband digital video signal -- approximately 1.5 Gb/s. To satisfy the content community, this high-quality signal interface must also incorporate copy protection. An example of such an interface is the DVI with HDCP described above. Although variations of the 1394 interface have been proposed for Option 3-type display interconnect applications, as noted, they remain inadequate for EDTV and HDTV display applications.

The model provided in Option 3 also allows the value added services of DTV service providers -- such as EPGs, branded graphical user interfaces (GUIs) and picture-in-picture (PIP) -- to be locally rendered in the STB with high quality and passed through to the display without difficulty, along with received video content. The same local rendering requirement applies for some interactive TV content, DVD, and game displays. Again, this is only possible with a high-bandwidth interface between the STB and the display. Otherwise, the locally rendered content could only be delivered with the video on an analog S-Video or NTSC interface, or it would have to be compressed along with the video in real-time after rendering. In either case, image quality could be substantially reduced. Any additional compression and decompression circuitry required would also add cost to both the STB and the display.

Finally, the Option 3 architecture model maximizes the flexibility and functionality of a local storage device (PVR), which is likely to become an extremely popular component of interactive DTV systems. For best results, this local storage should be integrated with the Receiver and Intelligence components of the system.

Extending DTV Architecture to the Home Network

It is expected that multiple digital television appliances eventually will proliferate in the consumer's home and it will not be uncommon to want premium services on many if not all of them. Desktop PCs can also serve as DTV appliances, and these too have begun to appear in multiple numbers within consumers' homes. These PCs will require access to television content, along with high-speed Internet connectivity provided by a cable modem or DSL connection.

Home networks will provide an efficient and intelligent method of transporting digital television content and services throughout the home, along with shared access to a high-speed Internet connection. This implies that the network must have sufficient bandwidth to carry multiple television programs simultaneously. To manage bandwidth efficiently, it is best to keep the content in compressed form until it reaches the individual display locations.

Relating back to the RIG model, home networks will therefore require that the Intelligence is split into two halves and separated by some kind of network. CEA has a number of efforts underway to establish standards in this area.[37] In parallel, a number of industry groups are also working on technologies and standards for this area, including the HomePNA,[38] HomePlug,[39] HomeRF[40] and IEEE.[41] Nevertheless, much work remains to be done in order to provide consumers with ubiquitous, flexible, low cost interconnect strategies.

Conclusions

The above discussion points out the critical role that signal interfaces will play in the success or failure of the DTV environment. If properly managed, these interfaces will benefit consumers by providing flexibility, compatibility and a broadly competitive marketplace. Without appropriate interfaces, however, the consumer DTV experience will become complex, cumbersome, frustrating and fail to achieve its potential economic maturity and cultural impact.

To maximize interoperability, the best approach to interface specifications will involve flexibility. This implies that multiple interfaces may be required, but that in all cases displays and any devices intended to feed them directly should include a copy-protected interface capable of handling uncompressed digital video, such as DVI with HDCP.

Finally, the commitment of the industry to create standardized DTV equipment labels is laudable, but labeling alone will not solve this problem. It is only a way to consistently identify certain functionality across the industry's products. If the required functionality is not implemented, no labeling conventions will solve the problem. Similarly, if the labels chosen are not flexible and do not evolve as technology evolves, but rather lock in a single interface standard, they will harm consumers by stifling the development and implementation of advanced interface standards that could facilitate the offering of more enhanced digital services.

The industry is at a pivotal point in determining the course of future DTV technology and practice. Good decisions made today will pay dividends well into the future. Conversely, inappropriate choices or non-decisions today may haunt the industry for decades to come.

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