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Xilinx at Work in Set-Top Boxes

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Summary

This White Paper gives an overview of different set-top box technologies and how Xilinx high volume programmable devices can be used to implement complex system level glue in a variety of set-top box designs. It concentrates on set-top box technology used to receive television over satellite, cable and terrestrial channels. The Xilinx device families targeted at these high volume applications include XC9500™ and Coolrunner™ CPLDs and Spartan™ FPGAs.

Introduction

The flow of this document will start with an overview of the various technologies behind the digital set-top box revolution. We will next examine the major functional blocks of a set-top box and give an overview of the Application Specific Standard Products (ASSPs) that are used in each functional block. We will then illustrate the system level glue functions that are needed in several different set-top box configurations.

Many first-generation digital set-top box designs are in the process of cost reduction and chip consolidation. The chipsets currently used will, in-effect, be merged together within System-On-a-Chip (SOC) devices with ever increasing capacity. This consolidation is seen as a way to drive down board costs as unit volumes ramp up to the multi-million units required to meet the world demand over the next decade. It is highly likely that due to the pressures to meet short development time goals, that there will be a requirement for some sort of "patch" capability should the SOC device not be fully working. Low cost PLDs such as the Spartan family provide the types of features and gate densities which will be ideally suited should this scenario arise.

While there is undoubted pressure to reduce the overall system cost in first generation digital set-top boxes, there have also been demands to provide more functionality within the set-top box. Such increased functionality will begin to unlock the true potential of set-top box technology both in terms of viewing experience and commercial services provided. The use of Xilinx programmable logic allows set-top box manufacturers to quickly incorporate new devices and functionality into their product line, without having to wait for large ASSP devices to be developed.

The pace of innovation within the set-top box market has started to increase, driven on by the demands of broadcasters for better functionality and improved services. Many industry analysts believe that the ultimate outcome will be that set-top boxes evolve into products that bring computing, Internet technology and high-bandwidth media broadcasting together in one appliance.

Market Overview

The set-top box market is experiencing rapid growth. Market projections show unit shipments for set-top boxes are set to increase to quantities of tens of millions of units per annum by 2002. The market is divided into three main systems, depending on the type of network being used to broadcast the television and multimedia channels. These are satellite, cable and terrestrial. Satellite is currently the biggest market. Cable growth is particularly strong in the USA, and is picking up in Europe. Many European countries have achieved good growth in digital terrestrial TV where signals are received via the old analog aerial. Some countries such as the U.K. have set timetables to stop analog broadcast transmissions by 2010 at the latest. This will allow the respective governments to auction off the radio frequency spectrum for various uses, including

adding extra television channels or providing more spectrum capacity for other services such as mobile systems. Such a change will of course require every household that has an analog T.V to be updated with a suitable set-top box, or to buy a TV with an integrated decoder. As a consequence, a huge market will be created not only for terrestrial TV but also for the satellite and cable companies. See Table 1.

Table 1: **Estimated Worldwide Digital Set-Top Box Shipments**

	Unit Shipments	Sales
Cable:		
1998	11.4 Million	$1.9 Billion
2000	14.6 Million	$2.4 Billion
2002	17.6 Million	$2.5 Billion
Direct Broadcast Satellite:		
1998	10.4 Million	$2.8 Billion
2000	17.3 Million	$4.3 Billion
2002	21.2 Million	$4.1 Billion
Terrestrial TV:		
1998	335,000	$845 Million
2000	945,000	$2.4 Billion
2002	5.4 Million	$10.3 Billion

Source: Cahners In-Stat Group

In the mid 1990s an industry association was formed to help develop compression techniques suitable for video transmission. This association was the Motion Picture Experts Group (MPEG). The MPEG-2 specification for video compression forms the heart of all digital broadcast systems. It has been designed to accommodate all types of video media formats and includes standards for High Definition Television (HDTV) compression. MPEG-2 video is a family of systems, each having an arranged degree of commonality and compatibility. It allows for four source formats, or "levels", ranging from Limited Definition (about VCR quality) to full HDTV.

Many professional broadcast equipment manufacturers use large Xilinx FPGAs, typically Virtex devices, to perform some of the key compression stages. The way the image is manipulated and interpreted is a vital differentiater for MPEG encoder equipment manufacturers. The function of the decoder within the set-top box is to decompress and reconstruct the original picture. This is performed within the set-top box by an ASSP device.

While there have been efforts to standardize the architecture of the set-top box, currently most set-top boxes are designed to a detailed specification defined by an individual broadcast network. The specification can include the requirement for a specific chip-set to be used at the heart of the set-top box architecture. Broadcasters see control of the set-top box architecture to be vital to their corporate interest. The chips used within a set-top box are tightly coupled to the firmware and higher software levels, all of which ultimately govern the "viewer experience."

Within the satellite, cable and terrestrial system market segments, set-top boxes are also tiered in terms of functionality. These can be defined as low-end, mid-range, and high-end.

- Low-end set-top boxes decode the audio and video and display the output to either an analog TV or a digital display.
- Mid-range boxes add in limited interactivity, and may incorporate interactive advertising, and program schedulers etc.
- High-end set-top boxes offer a high degree of interactivity, with advanced features such as web-browsing and hard-disk video storage.

Xilinx devices tend to address the newer, more advanced systems. They allow set-top box designers to bring the functionality desired by the network operators to market in a short time scale.

The number of companies providing solutions to the set-top box market is continually increasing. Many see it as the biggest opportunity for growth since the dawn of the PC. This has lead to an enormous pressure to be first to market with a chip-set that incorporates the latest features. Xilinx devices are sometimes used as "patches" should some parts of the chipset not work. They allow manufacturers to deliver products to the market within their window-of-opportunity even if the chip-sets needs to be corrected.

What Is a Set-Top Box?

A set-top box is a piece of equipment which can receive digital transmissions via the conduit it was designed to interface to, and then process the data in order that both the video and audio information can be sent to an external display and amplifier for the viewer to experience. There are also other interfaces to the set-top box both as inputs and outputs, although these are supplemental to the main data flow.

Much of the functionality at the heart of a set-top box is similar, whichever of the three broadcast systems it is designed to work with. The functions form a receiver-to-display bit-stream path. Set-top box chip-sets partition the system up differently in accordance with the way the manufacturers believe best suits their overall design objectives. It is common for a manufacturer to balance the chip-sets in terms of the amount of on-chip memory or number of available I/O, for instance. This allows them to provide maximum silicon efficiency, even though such a partitioning may not seem obvious in terms of how the functional blocks interchange data.

Satellite Systems

Satellite-based systems deliver programs and multimedia content from broadcasters, who use a number of geostationary satellites to relay their signals to customers back on Earth. Customers must be within the "footprint" of a given satellite in order to receive the transmission.

The set-top boxes designed for receiving broadcasts from satellite-based systems were the first to be deployed. Broadcasters such as DirecTV, JSAT, Canal+ and BSkyB were eager to deliver a system which would both improve reception quality and allow them to bring in services which could would not be possible with conventional TV systems.

A set-top box decodes the incoming data from the satellite transponder. Each manufacturer has specified the requirements for their own particular system, and to a large extent this has governed the choice of ASSP used in the set-top designed for their system.

Cable Systems

In cable systems, broadcasts are sent to the home via coaxial or optical fibre based cable. In the near future, xDSL systems will also be able to deliver these services over normal twisted-pair telephone wire.

Cable-based systems are beginning to ramp up significantly in volume. The rapid deployment of satellite systems is seen as an obvious threat by the cable companies. They are meeting the challenge, and are also looking to the future to how their set-top boxes may evolve into the primary means for accessing the Internet. This will open up the market and allow them to compete in areas normally associated with the PC systems.

In the long run some industry analysts predict that cable based set-top boxes could become the hub of a media-centric system, connecting systems and appliances within the home to their own network and acting as a bridge to the Internet.

Terrestrial Systems

In a terrestrial system, digital broadcast signals are transmitted via ground based transmitters in exactly the same way as analog television signals are transmitted. In fact, in the majority of cases exactly the same aerial can be used.

Systems designed for terrestrial systems are limited in terms of the number of channels they can offer compared to both satellite and cable based systems. The modulation scheme required is more complex than that required for cable or satellite. In this system the data is spread over a number of frequency channels. There are two formats which can be used. One allows for 1705 carriers (usually known as "2K"), the other utilizes 6817 carriers ("8K"). A concatenated error correction system is used, and other techniques such as the use of "guard intervals" are also employed in order to ensure as robust a scheme as is practical. The system needs to be practical in order to overcome the effects of multi-path echo and noise effects which occur when the signals transmitted by a terrestrial system are reflected around objects.

Example of a Set-Top Box Architecture

The functional blocks that make up the system are (see Figure 1):

- A connection to either a satellite receiver or a cable modem receiver.
- A terrestrial receiver or an xDSL modem with subsequent demodulation to a digital stream.
- A Conditional Access system, used to decrypt and enable further MPEG-2 decoding.
- A central processor, such as ARM, MIPs, PowerPC or X86 processor architectures, which is often embedded with other functions.
- An MPEG-2 decoder with video and audio outputs.
- Interfaces to external standards such as RS232, USB.
- A low data rate modem for connection to a dial-up site controlled by the broadcaster.

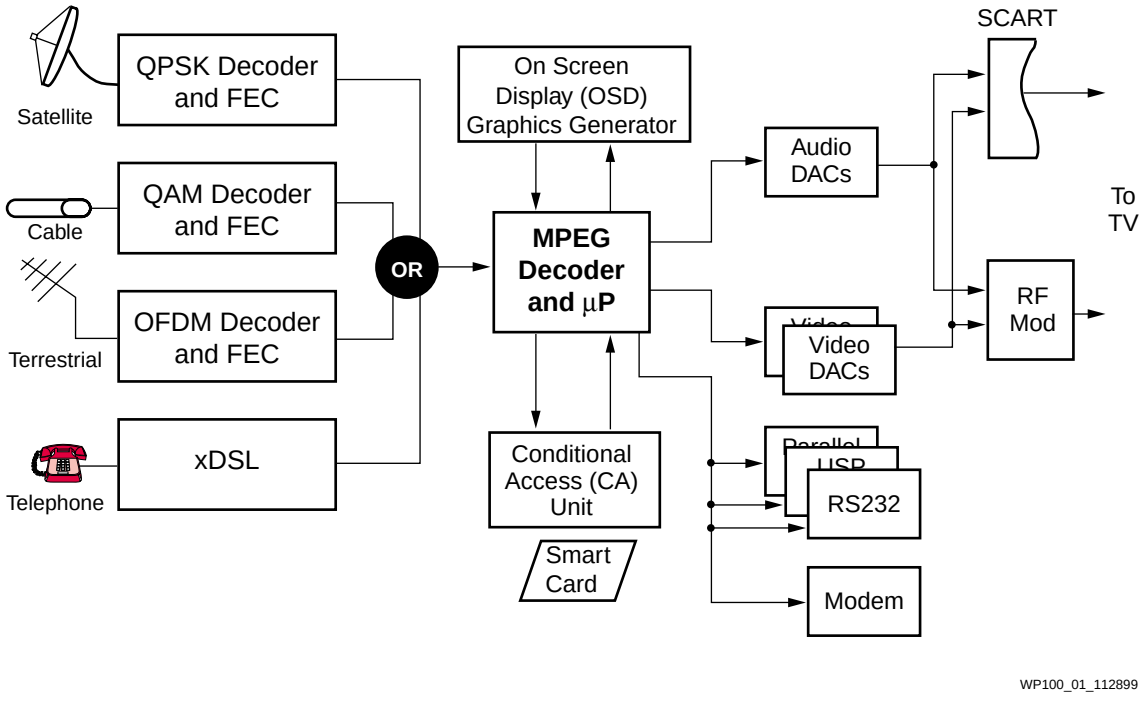

Figure 1: **Example of a Current Set-Top Box Architecture**

Data bit-streams must flow through each of the functions that make up a set-top box in turn. The video/multimedia datastream begins at the front-end interface. This is a tuner in the case of a satellite or terrestrial system, and a network interface unit in the case of a cable system. It is the front-end interfaces that provide the greatest differences between set-top boxes manufactured for satellite, cable, or terrestrial systems. This is because each system uses a different modulation scheme, most suited to their requirements. Satellite systems use Quadrature Phase-Shift Keying (QPSK), cable systems use Quadrature Amplitude Modulation (QAM), and terrestrial systems utilize Orthogonal Frequency Division Multiplexing (OFDM). After the data stream has been recovered, the rest of the functionality is virtually the same.

Once the data stream has been demodulated, it is then decrypted. While decrypting standards such as those defined by DVB exist, most broadcasters employ their own encryption technology. In order to facilitate these different decryption standards while keeping the rest of the set-top box generic, a Common Interface has been defined to allow broadcasters to supply their own decryption circuitry on a PCMCIA style card that interfaces to the set-top box motherboard itself. However, many set-top boxes do not utilize this technology and are designed only to work with the broadcast network which commissioned the set-top box manufacturer to develop it.

After decryption, the data-stream moves into the heart of the processing functions, primarily the MPEG-2 video and audio decoder and system CPU, moving on to the graphics block and then finally to the output block.

Set-Top Box ASSP Providers

One of the major manufacturers of ASSPs targeting the set top market is ST Microelectronics. This was primarily because these devices were designed into the first digital set-top boxes for the DirecTV satellite service. ST Microelectronics also developed the highly successful ASSP, The Omega, which integrated MPEG-2 functions within a processor. DirecTV and Echostar Communications Corporation, both US satellite service providers, used the device in their end products. As a result, ST Microelectronics dominates the market for MPEG-2 chips used in set-top boxes, although they are increasingly under pressure from the likes of LSI Logic and other ASSP manufacturers. It has been estimated that ST Microelectronics had a 68% market share of the MPEG-2 decoder chips shipped in 1998. According to Dataquest, ST Microelectronics had 31% of all IC sales going into satellite set-top boxes, followed by LSI Logic with nearly 17%.

Table 2 shows a selection of some of the ASSP devices available today. New devices and companies seeking to gain a foothold in the set-top box market are producing devices all the time. However, it is clear to see how many companies have partitioned the system functions together, the main difference being whether a system CPU is integrated or not.

Table 2: **Set-Top Box ASSPs**

Supplier	Chipset Name	Components	Interface
ST Microelectronics	STi5510	Transport function, descrambler, 32-bit ST20 µP, MPEG video and audio decoder, NTSC encoder.	IEEE1284 IEEE1394 AC3 I2C
	STi 5505		
	Omega		
LSI	L64008	Transport demultiplexer, MIPs core	I2C, IEEE1284 parallel port, teletext, smart card i/f
	L64005	MPEG-2 audio/video decoding, graphics controller	SDRAM

Table 2: **Set-Top Box ASSPs (cont'd)**

Supplier	Chipset Name	Components	Interface
Philips / VLSI	VES2750	MPEG-2 demultiplexer and peripheral controller	
	VES6200	MPEG-2 decoder, AC3 audio, ARM7 CPU, graphics engine, DMA controller, NTSC/ PAL/SECAM video encoder.	
National Semiconductor	Geode		
Broadcom	BCM7010	MPEG-2 decoder, AC-3 decoder and audio DACs, NTSC/PAL Video encoder	
	BCM7014	Graphics engine, audio engine, DMA	Power-PC and MIPs
IBM	CD20/CD21 MPEG-2		
C-Cube	Avia-iNX		

Receiver ASSP Providers

There are a number of suppliers in the market for the front-end receiver chips used within many set-top box designs to date. The leading supplier is currently LSI Logic. (See Table 3.)

Table 3: **RF Demodulator and Error-Correction Function ASSPs**

Supplier	Chipset Name	Channel	Comments
LSI	L64704	Satellite	DBS satellite receiver with QPSK demod. and FEC
	L64768	Cable	Single chip cable receiver with QAM demod. and FEC
Broadcom	BCM3120	Cable	Cable set-top box transceiver
Philips	SD1228		
	TDA8044	Satellite	Single chip front-end satellite channel decoder
Motorola	MC92301 MC92300 MC92303 MC92305 MC92308 MC92307	Reed-Solomon Decoder Viterbi Decoder QPSK/BPSK demod QAM receiver and Reed Solomon decoder OFDM demodulator 2K samples FFT processor	
ST Microelectronics	STV0199 STV0299	Satellite	QPSK Demod and FEC
	STV0296 STV0297	Cable	QAM receiver DVB standard DAVIC standard
	STV0395 STV0396M STV0495	Cable	FEC DOCSIS standard
Mitel			

External Interfacing

Set-top boxes have a number of external interfaces, The exact number and type are defined by the requirements of the broadcaster. However, most set-top boxes have RS232, USB and parallel ports.

There is also a modem to allow the broadcaster to retrieve information about the customer's viewing habits, as well as offer facilities such as online voting and game-shows.

Interface ASSPs are still available, although increasingly this functionality is being absorbed into larger ASSPs together with other functions such as the MPEG-2 decoder. However, because these ASSPs are not always designed to communicate directly with each other, Xilinx programmable logic provides an ideal, highly flexible means of interfacing many of the devices found within a set-top box (see Table 4).

Table 4: **Interface ASSPs**

Supplier	Chipset Name	Features
Philips	SAA9730	PCI Video Ethernet USB UART Parallel Port
IBM	Set-top box peripheral chip	I2C IEEE1284 Smart card I/F UARTs 24-line GPIO 3 -channel PWMI/F SCP serial I/F

Set-Top Box Design Examples

We have already seen the basic architecture for a set-top box. This design forms the basis for most set-top box designs today. Xilinx devices are used to perform the interfacing functions between the main sections. Most of the interfacing can be considered a simple glue logic replacement. Figure 2 and Figure 3 show the main sections where Xilinx devices are to be found.

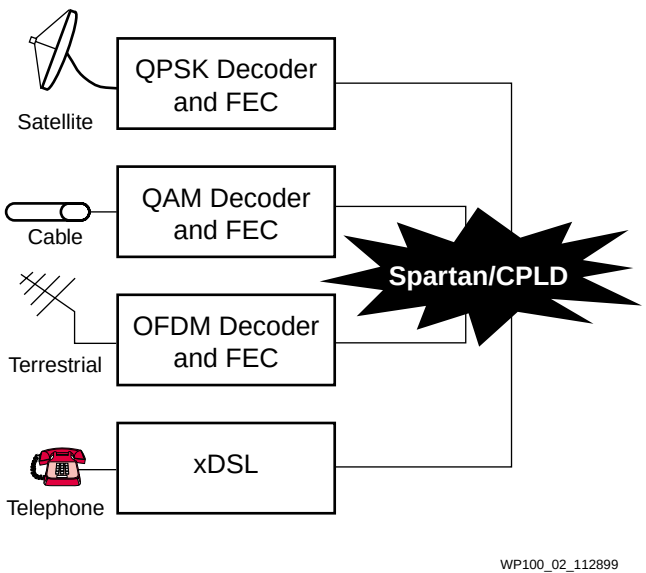

Figure 2: **The Interface Between the Receiver Section and the Main Processing Section**

It is too expensive to provide a multiple receiver solution for all the different types of system on the market. However, the main processing section of a set-top box can be made generic. Programmable logic can be used to provide the interface logic at this point in the data path.

Using programmable logic allows set-top box manufacturers to provide solutions which do not rely on a single chip-set supplier. Also, the choice of the chips to be used in the various sections found within a set-top box is normally influenced greatly by the facilities and features the broadcaster wants to have in their set-top box. Therefore, in many cases a single vendor's set-top box solution will not provide all that is needed. In this case solutions from different vendors have to be stitched together, with programmable logic providing the ideal mechanism for doing this.

Another important section where Xilinx programmable logic can be found is the Conditional Access (CA) system (see Figure 3). It is at this part in the system that the signal is decrypted. In order for the signal to be decrypted it has to be sent through an appropriate algorithm. The algorithm can be implemented in either software or hardware and is contained on a Smartcard. Attempts have been made to make the decryption process conform to a standard. However, most broadcasters specify their own decryption algorithm and consequently a number of different decryption methods are currently being used. Employing a programmable logic device in the Conditional Access system allows for a single, standard set-top box platform to be manufactured and then customized to the conform to broadcasters' unique encryption requirements late in the manufacturing flow. This approach provides for simplification of the product manufacturing process and allows for the benefits usually realized in large scales of economies in constructing a single, standard product.

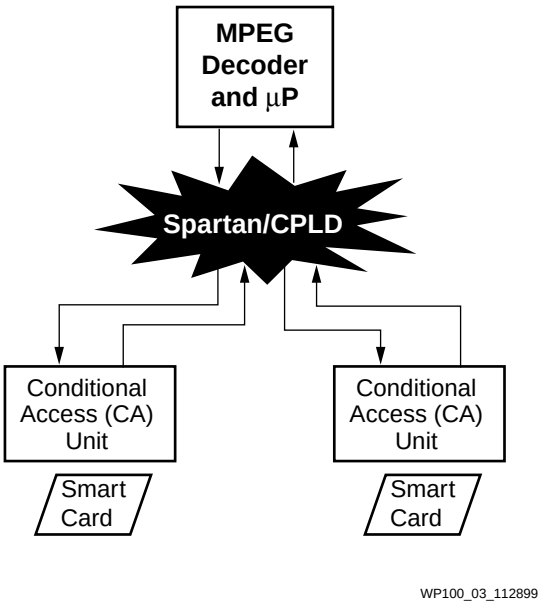

Figure 3: **Interfacing to Multiple Conditional Access Systems**

One attempt to bring the benefits of using one decryption system while allowing broadcasters to use their own preferred method, is called the "Common Interface". The Common Interface defines a standard for the way the main processing sections connect to the decryption circuit. It has been standardized under the auspices the European Committee for Electrotechnical Standardization (CENELEC). It has also been adopted by the Digital Audio Video Council (DAVIC) as its CA0 interface and is included in the DAVIC specifications. The interface also forms the basis of the specification of the NRSS (National Renewable Security Standard) committee in the USA.

It is envisaged that newer designs of set-top boxes will utilize the Common Interface. It allows set-top box designs to be built that can support multiple decryption standards in a simpler, more

cost-effective way. Both Xilinx Spartan and CPLD devices have been used in a variety of designs in order to implement a bridge between the set-top box and the encryption Smartcard.

Hard Disk Storage

While Xilinx devices have found a home in standard set-top box systems, especially in those areas outlined previously, their main use is in enabling the rapid development of new set-top box designs with radical and exciting features. Perhaps one of the most interesting developments has been that of hard disk storage, as championed by such companies as ReplayTV, NDS, and Pace Technologies.

Xilinx has been involved with a number of manufacturers who intend to deliver set-top boxes with hard disk storage capability. With hard disk costs down to less than $100 for 10GB, it has become a very realistic proposition. Being able to store movies on hard disk drives has a number of advantages over video storage. It allows the disk to be both read and written to at the same time. This allows consumers to time-shift their viewing.

It is impossible for a video to record an incoming program while playing what happened in the program (for example) 15 minutes earlier. This facility will allow viewers to answer a telephone or the door, and then return to viewing their program as though nothing had happened—although in reality they would be seeing events 15 minutes behind the actual time they were transmitted. It will also be possible for viewers to have their own "instant replay" and slow-motion facilities. It may also have a profound effect on advertisers. By watching a program with a 10-15 minute time shift, it will be possible for viewers to "fast forward" through the advertisements. Broadcasters are aware of this. One of the reasons that many set-top boxes have a return channel, usually using a relatively low data rate modem, is so that at night information on a customers viewing habits can be sent back to the broadcaster. This allows them to profile the customer, and in the future it will be possible to send advertising and services targeted at that particular customer's wants and needs.

The application of hard-disk technology has been developed quickly. While many ASSP chip-sets will undoubtedly be available in the future that incorporate a hard-disk controller, Xilinx Spartan devices offer a cheap and effective way of implementing this functionality today. With its on-chip RAM capability, it is a relatively simple task to construct the control circuitry and FIFOs required to buffer the data to and from the disk. Programmability also allows for set-top box manufacturers to optimize their design for different hard-disk manufacturers. This has obvious benefits in terms of allowing a set-top box manufacturer to support the latest technologies from a wide range of hard disk suppliers.

Western Digital, one of the worlds largest hard disk drive manufacturers, has recently launched a new range of hard drives specifically designed for the set-top box market. Other disk drive manufacturers are also releasing similar products. Unlike PCs, set-top boxes require very high reliability and quiet operation. Streaming video also makes different demands on a hard disk than a PC does. Western Digital has developed a command set called StreamWeaver which has been optimized for audio/visual performance. It also allows the data streams to be written and read simultaneously, which is a requirement for the types of services the set-top box manufacturers want to provide

In the future, it is envisaged that recordable DVD may also be utilized. Currently, they do not have the same capacity as standard hard disks. However, it certainly seems that it may not be too long before the humble VHS video becomes a relic of the past.

Internet and E-Commerce

It is predicted that set-top boxes will become perhaps one of the main ways in which consumers will use e-commerce to buy goods and services over the Internet. Some manufacturers are looking to incorporate additional Smart Card readers, so that the next generation of credit and charge cards that incorporate Smart Card chips can be used to securely order goods.

This has some repercussions for the PC industry. It is noticeable that many of the vendors involved in the PC industry are rapidly moving to gain a position in the set-top box market.

Currently, web access is limited. Many of the functions such as MP3 players and document readers are not support by the current generation of set-top boxes. This will change in the future. The competition by microprocessor vendors to get their devices on a board is intense. Programmable logic allows a set-top box vendor to easily interface a microprocessor into their set-top box system. While the move to consolidate functionality in the basic set-top boxes will continue, it is arguable that flexibility will be more of a key requirement in more advanced set-top boxes, at least at this stage in the development cycle. Xilinx XC9500 family and CoolRunner devices are widely used to interface microprocessors to system chips. As both families are in-system programmable (ISP), they can be modified at all stages of the development cycle, including once they have been deployed in the field. This would allow the designer sufficient flexibility to meet changing system specifications regarding any microprocessor to peripheral chip protocols and timing characteristics.

Video Games

Much of the circuitry is common between a set-top box and a video game console. The latest video game consoles also incorporate web access. The main difference is in the 3D graphics processing capability. It is certainly conceivable that this functionality will be incorporated into a set-top box chip-set in the future. ST Microelectronics plans to integrate Nvidia's RIVA-128 core to deliver high performance 3-D graphics. Such 3-D graphic processing is required to bring the sort of gaming capability that the public demand. It will also allow for more interesting graphics for electronic programme schedulers as well as increased graphic overlay capability.

There are already a number of satellite channels, such as Open in the U.K and Game One based in France, that provide a low data rate games service. There are also companies such as Two Way TV that are promoting a new concept termed "join-in-as-you-view". This facility gives the viewer the ability to take part in games based around standard TV broadcasts. For example, it may be possible for viewers to take part in games based around a team's football yardage, or the time a goal was scored in a soccer game. Currently, the games tend to take the form of the puzzle or quiz. Obviously, this is a far cry from the advanced graphics capability in most dedicated games consoles. The attraction for the broadcasters, however, is to get a part of the huge dollars spent on games software. In Europe alone the revenue from games software was $6.4 billion (source: European Leisure Software Publishing Association), which is far higher than the combined video rental and cinema sales in the same region.

It is doubtful that the specialist games consoles will disappear altogether; however, many industry analysts see some consolidation being inevitable.

High Definition Television (HDTV)

At the moment, virtually every set-top box design is designed to work with standard definition television, such as PAL, SECAM, and NTSC. In the future it is envisaged, especially in the USA, that there will be an upswing in the demand for HDTV services. Customers who wish to watch movies and sports programs with the best possible quality will primarily drive the uptake of HDTV.

The infrastructure has been designed to provide these services. It still remains for the market to show whether the demand for HDTV services outweighs the benefit of being able to provide more standard definition television channels in the same spectrum.

It is certain that the demand for HDTV will be much less than that for standard definition television for the foreseeable future. The extra processing requirements, more limited market demand and undefined market could be best served by utilizing programmable logic in order to give maximum flexibility for product development.

Conclusion

The set-top box market is a very dynamic, yet cost-sensitive market. New features are defined and then rapidly brought into the market in order for one broadcaster to offer features in advance of their competitors. Xilinx high-volume FPGA and CPLD devices provide system designers with cost effective solutions that retain the traditional PLD time to market advantage. While many functions ultimately become absorbed in ASSP devices, the pace of innovation

almost ensures a need to deliver features or functionality that are not available in a standard chip-set, or the use ASSPs that are not fully functional. Today, Xilinx programmable logic devices are employed by a large number of set-top box manufacturers who recognize the added flexibility and time to market benefits achievable through the use of programmable logic solutions.

In the future, it is expected that programmable logic technology will play a bigger role in the set-top box. This will come as a result of its ability to provide advanced network-centric features, such Xilinx Internet Reconfigurable Logic, IRL. By using IRL, the set-top box manufacturer can ship a product that can support feature fixes as well as introduce new features well after the set-top box has been deployed. Perhaps equally as important, these feature fixes and upgrades will not require the deployment of field service personnel, but instead can be accomplished directly across the conduit used to receive the data signals.

Revision History

The following table shows the revision history for this document.

Date	Version	Revision
3/28/00	1.0	Initial Xilinx release.