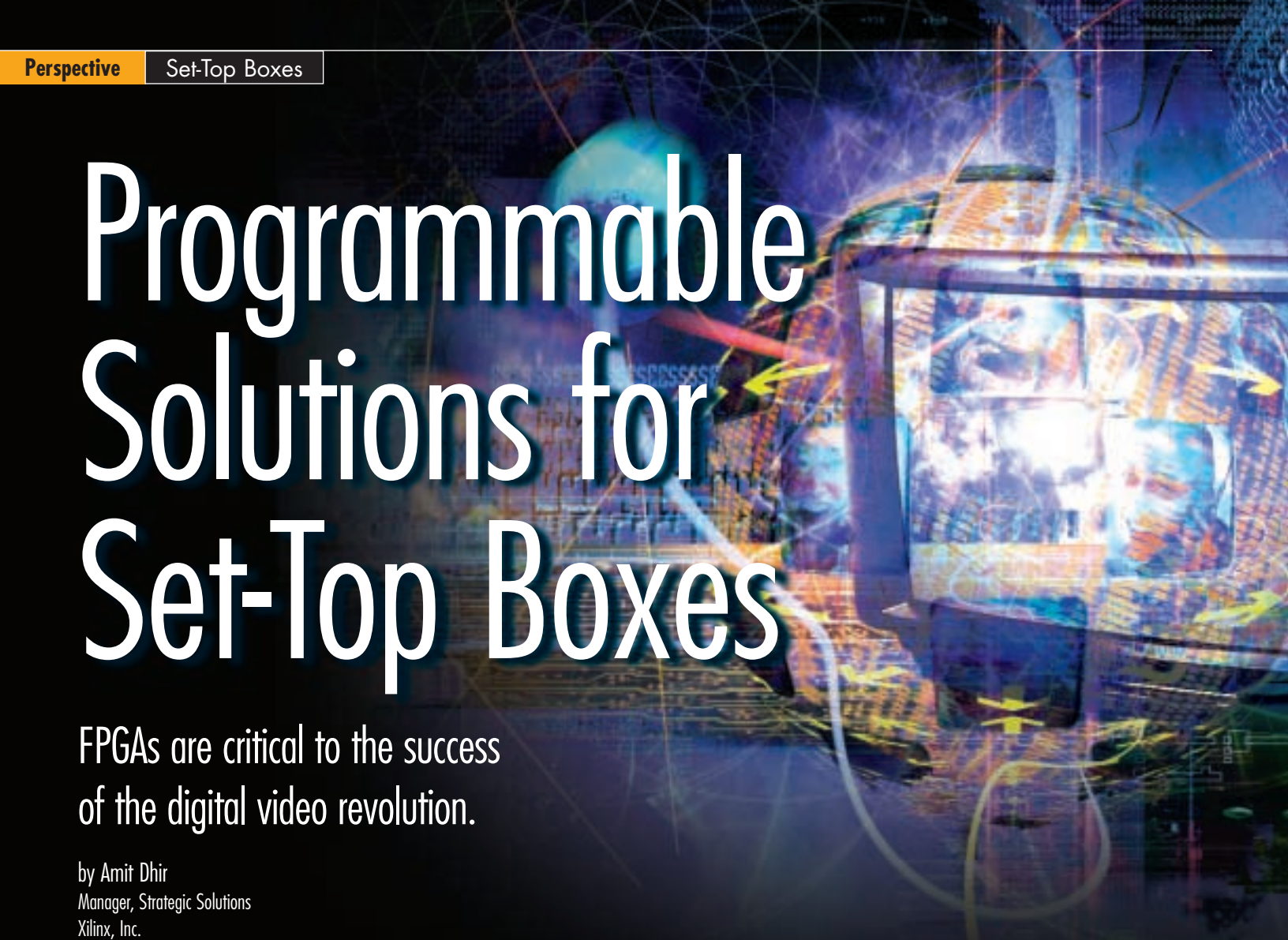

Programmable Solutions for Set-Top Boxes

FPGAs are critical to the success of the digital video revolution.

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In the early 1970s, the only piece of equipment needed for watching TV was a standard television. In the 1980s, this simple model began to change. Cable and satellite TV providers required consumers to connect their TVs to dedicated networks. Also, operators decided to scramble TV signals, requiring a special box to de-scramble the signals at the consumers home. Today, digital television requires a set-top box to receive and decode digital transmissions.

The main function of a set-top box is to receive additional digital transmissions (cable, satellite and/or terrestrial channels) and to decode into a form suitable for display on analog television sets. It's a complex electronics device comprised of a myriad of hardware and software components, usually connected to the TV set and the cable connection on the wall. They are installed and configured by the local cable, terrestrial or satellite service provider.

The home audio-video landscape is quickly transitioning from analog to digital, now providing several hundred channels of 24-hour coverage, Internet access, and other services. The convergence of functions provided by the television and the PC requires a platform to provide these services. With the arrival of several services, the set-top box is growing beyond its traditional function of enabling digital video. Future generations of set-top boxes will provide more services such as the ability to pause, record, store and replay live video; provide video on demand (VoD); provide Internet access; and control other consumer devices. Providing these services will require the relatively simple set-top box to add components such as flash memory, hard-disk drives, security chips, home networking chipsets, and so on. Programmable logic solutions will enable the integration of these services and components in future generations of set-top boxes.

The Set-Top Box Today

Digital TV set-top boxes are sometimes called receivers. A set-top box is necessary to television viewers who wish to use their current analog television sets to receive digital broadcasts. Typical functions implemented in a set-top box include:

- Decoding the incoming digital signal
- Verifying security levels as well as content access rights
- Separating the audio and video data from the decoded signal
- Decoding the separated audio and video data
- Presenting video to the display device
- Presenting audio to the audio outputs
- Processing and rendering Internet content and other interactive services
- Providing electronic program guide and remote control features.

Figure 1 shows the block diagram of a generic current generation set-top box.

According to Dataquest, sales of digital set-top boxes reached 25.1 million units in 2000, worth an estimated $6.3 billion, and will exceed 92 million units and revenues of $11 billion by 2005. It is estimated that 35 million U.S. homes will use digital set-top boxes by the end of 2006, the estimated year ending the transition to DTV.

Digital set-top boxes are used for satellite, cable, and terrestrial digital TV services. They are especially important for terrestrial services because they guarantee viewers free television broadcasting. A set-top box price ranges from $100 for basic features to over $1,000 for a more sophisticated box. It is often leased as part of signing up for a service. Leading set-top box manufacturers are looking to increase revenues by winning consumers that would like to use the TV set not only to watch television programs but also to browse websites, send e-mail, and shop for goods and services through the Internet.

Set-top boxes in the future will provide more channels and increased choices through specialist channels, which can provide immediate feedback to broadcasters. The set-top box will provide new services such as improved pay-as-you view, online shopping, interactive TV, video-on-demand, and hard-drive storage.

Providing Digital Video Processing

In the digital TV realm, a typical digital set-top box contains one or more microprocessors for running the operating system (possibly Linux or Windows), and for parsing the MPEG transport stream. A set-top box also includes RAM, an MPEG decoder chip, and more chips for audio decoding and processing.

The contents of a set-top box depend on the digital TV standard used. European DVB-compliant set-top boxes contain parts to decode COFDM transmissions while ATSC-compliant set-top boxes contain parts to decode VSB transmissions. The set-top box provides improved quality, support for HDTV transmission, prevents "ghosting or interference effects, and allows broadcasters to provide flexibility in terms of bandwidth vs. quality.

The MPEG-2 encoder, at the heart of every set-top box, is composed of a number of discrete algorithmic sections:

- **Temporal processing** – It seeks out and removes temporal redundancy. This involves storing several successive images and performing motion estimation, compensation, and simple algorithmic processing to derive a pixel-by-pixel difference signal.
- **Spatial Processing** – It uses DCT (Discrete Cosine Transform) to remove the high frequencies not discernable by the human eye.

Statistical or variable length encoding (VLC) is used to remove redundancy in the output from the DCT. The MPEG-2 algorithm makes use of the DCT/IDCT algorithm. DCT returns the discrete cosine transform of "video/audio input" (referred to as the even part of the Fourier series) and converts an image or audio block into its equivalent frequency coefficients. IDCT (or inverse DCT) reconstructs a sequence from its DCT coefficients. Compression allows increased throughput through the transmission medium. Video and audio compression makes multimedia systems very efficient by increasing CPU bandwidth, providing higher video frame rates and better audio quality, and enabling multimedia interactivity.

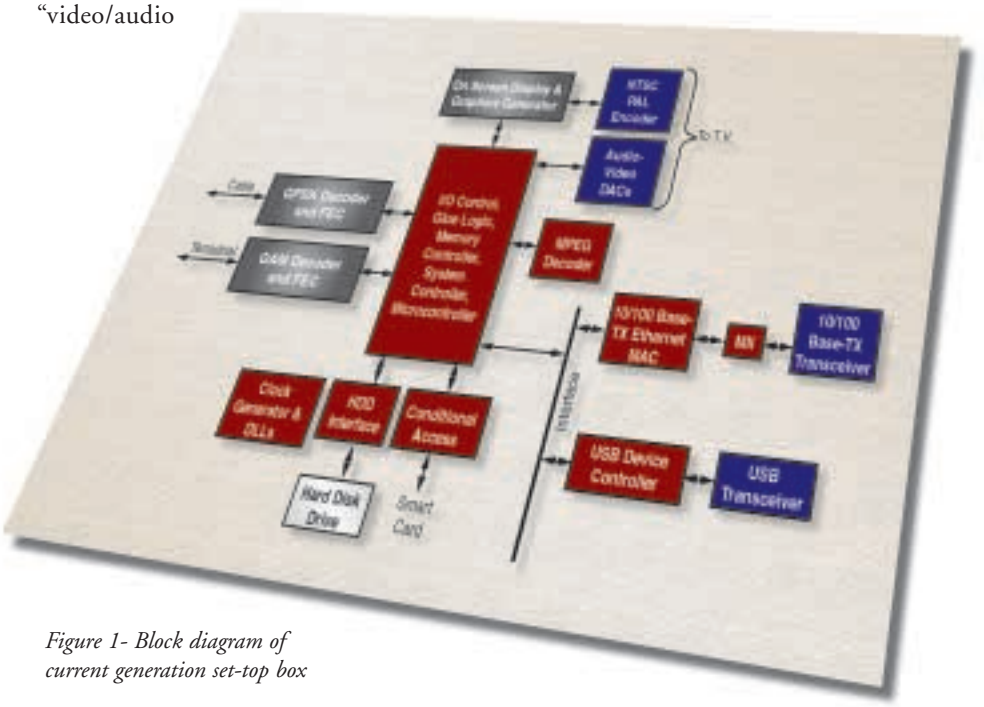

Figure 1- Block diagram of current generation set-top box

While MPEG-2 is the most common compression scheme used in set-top boxes, MPEG-4 compression technology is gathering acceptance. It is earning keen interest from set-top-box vendors and semiconductor companies hungry to add features (such as picture-in-picture) to current designs, and from service providers eyeing it for home networking and for set-tops integrated with digital video recorders (DVRs).

The MPEG-4 initiative is led by satellite providers exploring ways to reduce the bit rates of their broadcast streams and by cable operators looking to add object-based interactive features to their programming. Using the MPEG-4 Advanced Coding Efficiency profile, satellite broadcast streams – currently delivered at bit rates of 2.5 to 3 Mbps – can be trimmed to 1.6 Mbps while maintaining good-quality video. Meanwhile, some service operators are also considering MPEG-4 as a way of saving hard-disk-drive space in set-top boxes equipped with DVRs.

Others see MPEG-4 as effective in reducing the bandwidth required for real-time video for home-networking applications.

There is a need for MPEG-4 in picture-in-picture applications – while a national game broadcast occupies the screen, for example, a local game compressed in MPEG-4 could be broadcast simultaneously so that it appears as a picture within the picture. Further, Internet-streaming content – compressed in MPEG-4 or Windows Media – could also be displayed on screen in a picture-in-picture format.

Most set-top box manufacturers are not looking to replace MPEG-2 with MPEG-4, but to equip a set-top box to transcode MPEG-2 streams into MPEG-4. Clearly, the versatility of the MPEG-4 standard is playing to its advantage as MPEG-4 finds its way into different set-top uses.

Integrating DVR, VoD, and NetTV Functions

The last few years has seen the introduction of the digital video recorder (DVR), also known as digital VCR and personal video recorder (PVR). The DVR uses local storage (such as a hard-disk drive) to enable the user-controlled storage and playback of live digital video streams. The functionality includes the ability to simultaneously record and playback separate video streams or different portions of the same stream in real-time.

With a built-in modem, the DVR device dials a service provider and downloads the programming guide and other software updates. While high unit growth is being predicted for these DVRs, most set-top box manufacturers are looking to incorporate a hard-disk drive and DVR functionality within the set-top box. This will provide the capability to store real-time TV broadcasts in high digital quality, instant access to the recorded data, proactive and quick TV management, and the simultaneous use of multiple data streams. It will also allow the ability to download software and other applications provided by a digital TV service provider.

Apart from providing real-time TV broadcast recording capability, set-top boxes will provide the consumer with video-on-demand capability. The consumer will be able to order a movie instantly. It provides the ability to pause, fast forward, and rewind the movies as often as the consumer desires.

The NetTV is a TV-centric consumer appliance that provides Internet access while using the TV as the primary display. In its most basic offering a NetTV provides limited interactive electronic programming guides or customized information tickers. Advanced NetTVs provide full graphical Web browsing and video email. While the consumer is very interested in services such as access to the Internet, cost remains a big inhibitor for the success of the NetTV appliance. Set-top box manufacturers are looking to integrate the functionality of the NetTV in next generation set-top boxes. In the Internet realm, a set-top box is really a specialized computer that can "talk to" the Internet – that is, it contains a Web browser (which is really a Hypertext Transfer Protocol (HTTP) client) and the Internet's main program, TCP/IP. The service to which the set-top box is attached may be through a telephone line or through a cable TV company.

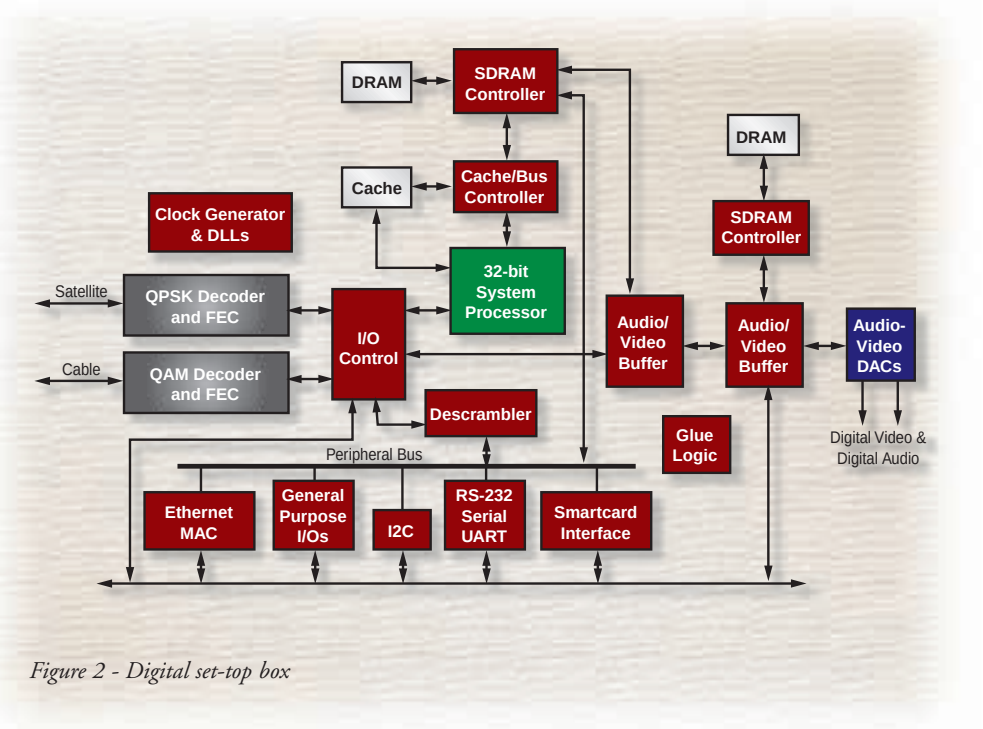

Figure 2 - Digital set-top box

Enabling Broadband Access and Home Networking

The arrival of digital media such as data, voice, video and communications (Internet) through appliances such as digital cameras, MP3 players, cellular phones, and Web pads, is bringing a need for networking consumer devices and PCs. All these consumer devices are demanding high-speed access to the Internet. A house however will have a single broadband access point and the digital media will be shared not only between friends and family across the Internet but also between appliances in the house.

The set-top box of the future will provide high-speed Internet access from satellite, cable, DSL, fixed wireless, and terrestrial access technologies. While one box may support a single access technology, combinations of broadband access technologies will exist within one set-top box. Set-top boxes will also provide interconnectivity between consumer devices through a number of home networking technologies, such as:

- **No new wires** – Phonelines, powerlines
- **New wires** – IEEE 1394, IEEE 1355, Ethernet, USB 1.1/2.0, Optic Fiber, RS-232, IEEE 1284 Parallel Port
- **Wireless** – HomeRF, Infrared, Bluetooth, DECT, IEEE 802.11b, IEEE 802.11a, HiperLAN2

As home networking gains popularity, the set-top box will grow from enabling digital TV and broadband access in the house, to a residential gateway that manages and controls other information appliances in the home.

Categories and Evolution to Home/Residential Gateway

This huge installed base of set-top boxes can be broadly classified into the following categories:

- Analog set-top boxes perform the function of receiving, tuning, and de-scrambling incoming television signals. These receivers have changed very little over the past twenty years.
- Dial-up set-top boxes allow subscribers to access the Internet from the comfort of their living room through the television.
- Entry-level digital set-top boxes are capable of receiving broadcast digital television that is complemented with a pay-per-view system and a very basic navigation tool. They have no return channel, and therefore do not interact with computer servers. Characteristics of this type of low-cost box include limited quantities of memory, interface ports and processing power. Figure 2 shows a digital set-top box.
- Mid-range digital set-top boxes include a return (back) channel, which provides communication with a server located. These set-top boxes provide e-commerce, Internet browsing, and multimedia services. The return channel further allows for customized broadcasts to the local viewing population. These types of boxes have higher processing power and storage capabilities of entry-level boxes.
- Advanced digital set-top boxes are like multimedia desktop computers, containing much higher processing power than other set-top boxes. Enhanced capabilities in conjunction with a high-speed return path can be used to access a variety of advanced services such as video teleconferencing, home networking, IP telephony, VoD, and high-speed Internet TV services. Additionally, it has enhanced graphical capabilities to receive high definition TV signals and can store video on a hard disk drive, while providing the capability to record and view video simultaneously. Such receivers have a range of high-speed interface ports, and resemble residential gateways. For cable, terrestrial, and satellite companies, set-top boxes that support advanced technologies are an opportunity to increase revenue streams through providing services.

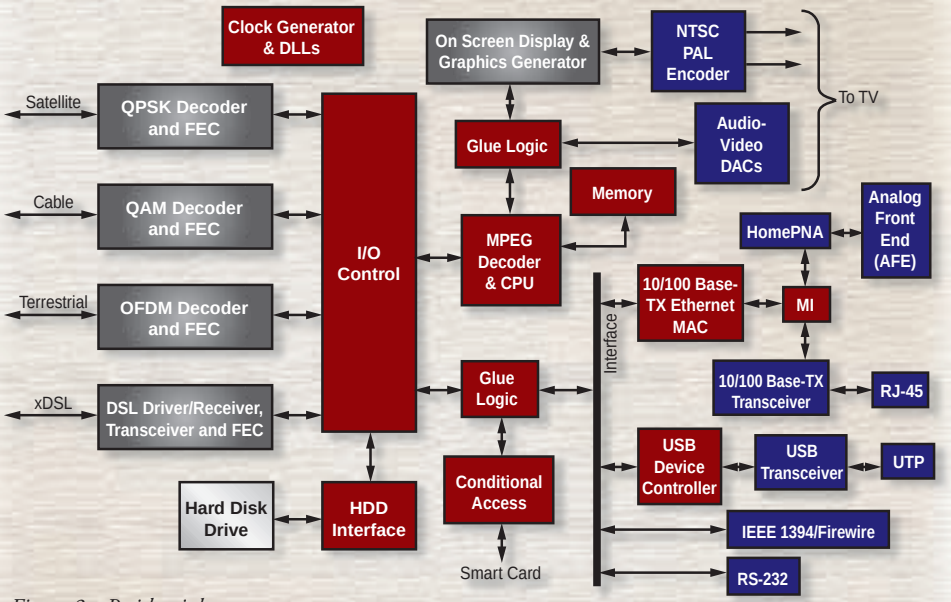

Figure 3 - Residential gateway

The residential gateway is a platform to bring broadband into the house and connect or bridge to home networking technologies. It enables communication between networked appliances in the home and across the Internet. The evolution of new data broadcasting services has created the need for a device to pass digital content between the Internet and the home network. Future gateways will provide integrated services such as remote management, home automation, and home security.

Mass deployment of gateways will come in three distinct phases. While the gateway is a new term, it already exists in many homes. Most of our homes have a set-top box for receiving television and a modem to connect to the Internet. Phase two includes advanced features such as broadband connectivity, home networking interfaces, and IP telephony in the residential gateway. The third phase will be deployment of powerful gateways, capable of delivering video, voice and data throughout the home and providing services such as home automation, energy management, security control, and so on.

Supporting multiple technologies makes the gateway less likely to become obsolete. Support for modularity will fuel the evolution of gateways into a type of application server that consumers will use to distribute broadband services throughout their homes. The gateway must have a reliable and robust hardware platform, and software that is not susceptible to errors. Unlike PC users, consumers will not stand rebooting their gateways. Supporting multiple services with complete security is essential. Functions such as e-commerce transactions, and remote home control and access from authorized service providers are critical. Providing quality of service to support multiple intelligent devices from different vendors is extremely important.

Figure 3 shows the block diagram of a residential gateway. The gateway provides a unified platform to satisfy the needs of most consumers, providing infotainment, conveniences, and communication. The success of the set-top box, and hesitation by a large population to own a PC, allows for the set-top box to grow into a successful residential gateway. Set-top boxes will evolve into multimedia servers, forming the hub of the

home network for primary access to the Internet, such as the residential gateway.

Programmable Logic Solutions Enable Future Set-Top Boxes

For residential gateways to be successful, programmable solutions will have to be at the heart of the system. Programmable logic devices address the fundamental disconnect between ASSPs and provide the interface and protocol translation between different broadband and home-networking chipsets. They provide significant time-to-market advantages and the ability to upgrade quickly, which is imperative for a successful product. This gives you the cutting edge to bring products first to market, while having the ability to remotely add features to the set-top box already deployed in the home.

The set-top box will combine components such as digital modem chipsets, home networking chipsets, processors, memory, and software. Digital modem chipsets provide connectivity to different broadband networks, and home networking chipsets provide interconnectivity technologies between appliances. Other ASSPs/ASICs handle and process digital video and audio services. These ASSPs communicate with each other via buses on the system board. The processor is responsible for coordinating the different components. With additional features, set-top boxes will require higher performance processors to keep pace with increased data throughput. However, all these standards and ASSPs promote differing interfaces making glueless connectivity impossible between the different ASSPs, memories, and processors.

There are three types of set-top box software: operating systems, middleware, and applications. The operating system operates the set-top box parts. The middleware is a layer of software programs that operates between the interactive TV applications and the operating system. Viewers use application software to watch TV and use interactive features. The middleware also enables the smooth interoperation of information appliances and services within the home, to eliminate the complexity, distribution, and technical disparity of the system elements.

For video processing conventional DSPs (digital signal processors) provide a fixed data width and inflexible architecture. They typically have 1-4 MAC units and require serial processing, which limits data throughput. This causes a need for high clock frequency DSPs, which creates system challenges. Hence, multiple DSPs are needed to meet bandwidth requirements, thus causing power and board space issues. Programmable logic devices have a flexible architecture with distributed DSP resources and embedded multipliers. These devices can support any level of parallelism or serial processing through an optimal performance/cost tradeoff. This parallel processing maximizes the data throughput. Hence, programmable logic solutions exceed DSP requirements of the video market – providing both flexibility and performance. FPGAs are off-the-shelf devices, which provide fast time-to-market, rapid adoption of standards, optimal bit widths, and real-time prototyping along with support for high data rates. With a whole suite of DSP algorithms/cores and tools created for programmable logic devices, development time can be reduced by weeks while increasing the performance of the system. For example, the implementation of the DCT/IDCT core in a programmable logic device can off-load the system processor performing MPEG encoding/decoding with a 50X to 200X performance gain.

Programmable solutions also provide the ability to interface to different hard-disk drive types as well as NAND and NOR flash memory types (depending on availability). They also provide content protection capabilities using DES, triple DES, AES, and even proprietary encryption schemes. They also provide system interface functions such as PCI, USB, and so on, in the set-top box and residential gateway. In addition, the presence of the FPGA in the system provides the capability to remotely upgrade features through the Internet when the box has been shipped to the customer, hence providing a significant cost savings.

Summary

The set-top box is driving the digital revolution right into your living room. Your fingertips now command a wealth of high-quality digital information and digital entertainment, right from your favorite armchair. The set-top box revolutionizes home entertainment by providing vibrant television images with crystal clear sound, along with e-mail, Web surfing, and customized information such as stock quotes, weather and traffic updates, on-line shopping, and video-on-demand – right through a traditional television.

The set-top box will evolve into home multimedia centers, possibly forming the hub of the home network system and the primary access for consumers to connect to the Internet. There will be a convergence of technology with equipment connected to the television, such as adding hard drives for television program storage and instant replay. As the set-top box evolves, it will also provide home networking capabilities and value-added services, while becoming the residential gateway of the future.

Programmable logic solutions are necessary for the success of set-top boxes and residential gateways as they provide time-to-market and time-in-market advantages in interfacing disparate technologies, components and system interfaces. They also provide a significant performance advantage over digital video processors. What is clear is that the set-top box market is growing at a very dramatic rate, and when markets are so dynamic and the future is very unpredictable, decreased time-to-market and the ability to upgrade very quickly is imperative for a successful product.