# Pegasus Set-top Terminal

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*Abstract*

*The Pegasus set-top terminal has many new features and functions. It is the first cable set-top converter that is built on open standards. These standards help to create a platform that can be used to enable many new services. This paper will discuss these new features and how standards will be employed to enable future digital services.*

## THE PEGASUS STRATEGY

On March 6, 1996 Time Warner Cable released an RFP for the Pegasus Program [1]. The Pegasus set-top terminal is the foundation of Time Warner Cable's strategy for providing advanced analog and digital services to our subscribers. The Pegasus Program itself is the culmination of several years of experience creating and operating the Orlando Full Service Network™ [2,3,4,5].

### Phased Implementation

It is clear that we cannot envision today all of the services that could potentially be provided over a Hybrid Fiber/Coax (HFC) network. Some services, such as Video-on-Demand (VOD) may not be cost effective today, due to server and switching costs. Consequently, the Pegasus set-top terminal must provide a platform that allows new services to be added to the system as they are created and become cost effective.

The Pegasus Program is a phased approach to deployment of services. The initial Phase 1.0 implementation provides analog and digital broadcast services, including Impulse Pay-Per-View, Interactive Program Guide, and Digital Music Service. Phase 2.0 represents the deployment of streaming video services, such as Video-on-Demand. Between Phases 1.0 and 2.0 is a continuum of applications that rely on connectionless IP based communications, such as Internet TV, Interactive Shopping, Interactive Games, etc. This phased approach allows for incremental investment in infrastructure and subsequent recovery of this investment through new revenue streams.

### Address Competitive Digital Offerings

In its initial phase, the Pegasus set-top terminal is intended to address the competitive offerings of the DBS and MMDS providers. Currently, DBS service providers are promoting more channels and higher audio/video quality provided by digital broadcast. In order to address this competitive threat it is necessary that cable operators provide superior services. The greatest advantage cable operators have at their disposal is a dedicated, high-bandwidth, two-way connection to the home. The Pegasus set-top terminal is capable of supporting all of the services currently available on DBS platforms and more.

### Open Standards

The Pegasus set-top terminal must be competitive on the cost side as well. A integral part of the Pegasus Program is the requirement for multiple vendors providing compatible products. In order to achieve this goal it is necessary to adopt open, standard interfaces at logical points throughout the system. The specific standards that were selected are described in subsequent sections.

### Superior User Interface

The acceptance of the Pegasus technology by our subscribers will be directly affected by the quality of the User Interface (UI). If the UI is unappealing or difficult to use, the acceptance of this product will be poor as well. The graphics capabilities of the Pegasus set-top terminal, as described later in this paper, provide for a rich user interface. It is also possible to download a new UI into Flash ROM, as improvements are made in the UI over time.

### Real-time Two-way Communications

One of the most critical features of the Pegasus set-top terminal is its real-time two-

way communications capability. Real-time two-way communications are required in order to support interactive applications such as Internet Television and Video-on-Demand. The Pegasus set-top terminal makes use of an out-of-band channel supporting TCP/IP and UDP/IP communications protocols.

Application Platform

Finally, the Pegasus Program is ultimately a software strategy. The Pegasus System, and the Pegasus set-top terminal in particular, represent an application platform. The creation and deployment of new applications is facilitated by the Pegasus system. One aspect of this strategy is an attempt to eliminate applications that are dependent on specific hardware components, such as Sega Channel and Digital Music Service. The use of standards facilitates this effort.

## PEGASUS HARDWARE ARCHITECTURE

Figure 1 is a block diagram of the Pegasus set-top terminal.

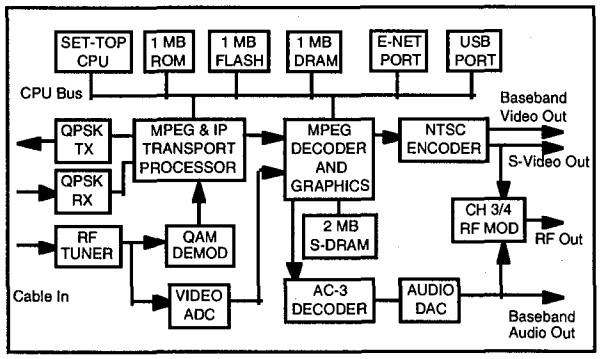


**Figure 1 - Pegasus Set-top Terminal**

The Pegasus set-top terminal uses QPSK modulation for out-of-band communications and a combination analog and QAM channel for video delivery. An MPEG and IP transport processor off loads much of the network protocol processing from the set-top CPU. The transport processor performs the task of MPEG transport demultiplexing and Packet Identifier (PID) filtering. The selected video and audio PIDs are passed on to the MPEG decoder and graphics processor. IP traffic from the out-of-band channel and potentially carried in MPEG private data are passed over the set-top CPU bus using Direct Memory Access (DMA) into DRAM memory.

Analog video is digitized through a video analog to digital converter (ADC) and passed to the graphics processor. Consequently, both the digital and analog video are processed in the same way. Graphics can be overlaid and blended with both the analog and digital video. The graphics processor also has the ability to scale the resulting digitized video.

The output of the MPEG decoder is passed to an NTSC encoder for baseband, S-Video, and RF modulated outputs. The output of the AC-3 decoder is passed to baseband stereo and RF modulated outputs.

The set-top CPU is interconnected with the set-top memory, MPEG decode/graphics, and two peripheral ports, a Universal Serial Bus (USB) port and 10BASE-T Ethernet port. These ports can be used to connect the set-top to other peripheral devices, such as keyboards, joy sticks, game players, and PCs.

Network Interfaces

The Pegasus set-top terminal is intended for use in an HFC network. Figure 2 shows the spectrum allocation for the Pegasus set-top terminal over the HFC network.

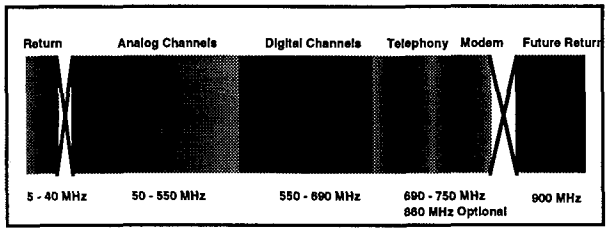


**Figure 2 - Spectrum Allocation**

The return path uses the range from 5 - 40 MHz. Analog broadcast is generally allocated to the 50 - 550 MHz range. A 140 MHz range is allocated for digital entertainment services and 30 MHz each is allocated to cable modem and telephony services. Future return capacity is available in the spectrum above 900 MHz. This spectrum allocation is not absolute and may vary based on programming choices and traffic requirements on individual headends.

The Pegasus set-top terminal has a single tuner for tuning both analog and digital services. Multiple tuners are possible, but it must also be possible to implement the set-top with only a single turner. Analog services use traditional broadcast NTSC signals. Digital services are implemented over a number of data channels:

- Forward Application Transport Channel (FAT)
- Forward Data Channel (FDC)
- Reverse Data Channel (RDC)
- Vertical Blanking Interval (VBI)

The Forward Application Transport Channel delivers MPEG-2 Transport Streams [6] to the Pegasus set-top terminal. The MPEG System Information Tables are defined by the ATSC standard[7]. The FAT Channel supports both 64 and 256 Quadrature Amplitude Modulation (QAM), using the ITU-T, Annex B QAM standard [8] as updated by SCTE-DVS [9]. This channel provides 26.97 Mbits/Sec with 64 QAM and 38.81 Mbits/Sec with 256 QAM in 6 MHz.

The Forward Data Channel delivers IP messages to the Pegasus set-top terminal. The FDC uses QPSK modulation providing 1.5 Mbits/Sec in 1 MHz bandwidth. The FDC is located in 70 to 130 MHz region and is frequency agile. The FDC is used to transmit commands and IP Messages. The advantage of the FDC is that it has 100 % availability, unlike the FAT which may be tuned to a different digital or analog channel. A second tuner could potentially make available a dedicated QAM channel for data transmission.

The Reverse Data Channel transmits IP messages from the Pegasus set-top terminal. The RDC uses QPSK modulation providing 1.5 Mbits/sec in 1 MHz bandwidth. The RDC is located in the 5 to 50 MHz region and is frequency agile.

The FDC and RDC communication channels conform to the DAVIC 1.1 standard [10] for the lower layer protocols. Higher level signaling, messaging, and download functions are performed using the Digital Storage Media Command and Control (DSM-CC) protocols [11].

A limited bandwidth channel is available through the use of the Vertical Blanking Interval (VBI) in analog channels. The use of the NABTS [12] standard for carrying data permits applications to receive data while tuned to an analog channel. This is particularly useful for augmenting analog broadcast video with program synchronous information, such as enhanced advertisement, sports, or weather information.

Unified Memory Architecture

One of the critical aspects of the Pegasus set-top terminal is its flexible memory architecture based on a unified memory address space. The MPEG decode memory is accessible to both the set-top terminal CPU as well as the MPEG decompression engine. This permits the MPEG decode memory to be used for application data or code when it is not being used for MPEG decompression. Larger, more graphically rich applications can run on the set-top by trading off video resolution with application size. This flexibility would not be possible in a split memory architecture. The net result is a lower cost set-top.

The memory space is made up of the following components:

- 1 Mbyte Mask ROM
- 1 Mbyte FLASH ROM
- 1 MB DRAM dedicated to set-top CPU
- 2 Mbytes DRAM shared between CPU and MPEG decoder

This memory architecture has the advantages of being downloadable, less DRAM required, and more application memory when the MPEG video resolution is low.

The set-top CPU includes a memory management unit (MMU) to prevent applications from corrupting the memory of other applications or the set-top operating system. This MMU is not intended to support a demand page swapping mechanism typical of general purpose computer systems.

Figure 3 shows the memory layout of the Pegasus set-top terminal.

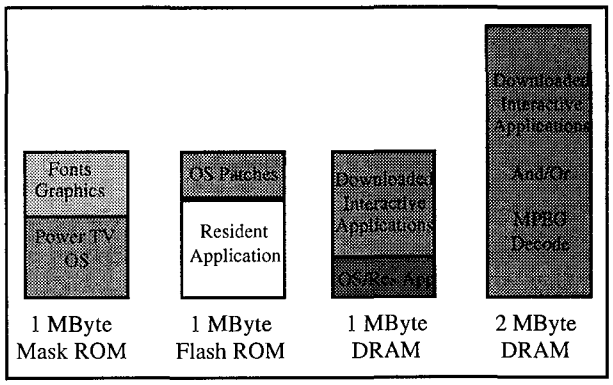


**Figure 3 - Pegasus Memory Layout**

The Mask ROM is used to hold the set-top operating system as well as many of the fonts and graphics used by the Resident Application. The Flash ROM contains the Resident Application itself and any OS patches that may be required. The Flash ROM is downloadable over the network and permits bug fixing and updates the User Interface over time. The DRAM dedicated to the set-top CPU is used for OS and Resident Application runtime variables and any transient applications that are downloaded to the set-top over the network. The DRAM associated with the MPEG Decoder and Graphics processor provides MPEG decode space and/or additional space for downloaded applications.

Video Processing

The Pegasus set-top terminal supports both analog and digital video. In the digital form it supports MPEG II Main Level / Main Profile [13]. This includes display resolutions of:

- 704 X 480
- 352 X 480
- 544 X 480

Supported aspect ratios are:

- 4:3
- 16:9

The supported MPEG data rates range from 1.5 to 15 Mbits/Sec.

Analog video is digitized and can be combined with graphics in the same way as digital video. This provides a consistent user interface across analog and digital video services. This consistency is important particularly when interactive applications could be performed in conjunction with both analog and digital video. The video can also be scaled by the graphics processor.

The Pegasus set-top terminal has the following video output ports:

- Baseband Video Output
- RF Modulated Channel 3/4 Output
- S-Video Output

An optional RF bypass module is available to enable direct bypass of the set-top to the RF Modulated output. With this option, a VCR can record the output of the set-top terminal while a TV can either display the output of the set-top terminal or tune to any clear (unscrambled) analog channels. This is the most basic form that allows recording on one channel while watching another. The Pegasus set-top is also capable of Master/Slave operation permitting two set-top terminals to be linked permitting VCR recording from one set-top and TV viewing from another.

The Pegasus set-top terminal can receive Closed Caption material, when present in the MPEG data stream on a selected digital channel, and insert it onto line 21 of the vertical blanking interval prior to routing the signal to the baseband, RF, and S-video outputs. On analog channels VBI line 21 is passed through to the video outputs.

Audio Processing

The Pegasus set-top terminal supports a variety of audio formats for both analog and digital services. The audio formats supported for analog services are,

- Monaural
- BTSC Stereo
- Secondary Audio Program (SAP)

The audio formats supported for digital services are:

- Dolby™ AC-3
- Set-top synthesized PCM audio

The synthesized audio can be mixed with either the analog or digital audio. For both the BTSC and AC-3 audio 5.1 channel AC-3 encoded audio can be multiplexed into 2-channel Dolby Pro Logic™ encoded audio. Audio encoded in Dolby Pro Logic™ surround sound is not processed by the set-top and is passed transparent through the set-top terminal. An external Dolby Pro Logic™ surround sound processor is required. Stereo output is available through the baseband left and right outputs. The RF channel 3/4 output modulator always outputs monaural audio.

The Pegasus set-top terminal is also capable of synthesis of audio within the set-top. This locally generated audio can be used for sound clips, alarms, and alerts. The synthesized audio is mixed with the audio associated with the analog or digital video content.

Secondary Audio Program (SAP) can be selected for analog and digital services when available from the program source. Analog services support only a single secondary audio track, while digital could potentially support multiple audio tracks.

Graphics

The Pegasus set-top terminal has a powerful graphics processor that is integrated with the MPEG Video Decoder. This graphic processor is capable of graphic overlay onto both analog and digital video. The graphics can be combined onto the analog or digital video using opaque, transparent, and translucent graphics (translucency and alpha blending). The graphics processor provides a hardware blitter with alpha blending and chroma key applied on blit operations. The graphics processor supports 8, 16, and 24-bit color depths selected from a full color palette of 16 million colors. These color depths permit rendering of shaded objects as well as realistic images. As a result the UI presented by applications can be very rich.

The graphics processor is also capable of video scaling by decimation and can use arbitrary vertical and horizontal scale factors. Frames of the video can be captured to memory from either digital or analog video. The captured video can then be manipulated by the set-top CPU.

To overcome limitations of interlaced NTSC display the MPEG decoder/graphics processor incorporates an anti-flutter and horizontal smoothing filter. To improve the appearance of text on the screen anti-aliased font support is provided. The hardware blitter can also be synchronized with the vertical sync pulse to enable smooth scrolling of display and other animation effects.

Additional Peripheral Ports

In addition to the above mentioned video and audio output ports the Pegasus set-top terminal has two additional output ports:

- Universal Serial Bus (USB) [14] port
- 10BASE-T Ethernet [15] port

These ports are used for connecting the set-top terminal to a variety of peripheral devices. The type of devices that can be connected to the set-top via the USB port include:

- IR transmitter for VCR control
- Keyboard for textual input
- Joysticks and other pointing devices for game play or Web browsing
- Printer for hardcopy output

By using the USB standard interface additional devices can be created and integrated into the Pegasus system. There is no need for specific hardware implementations to support new devices.

The type of devices that can be connected to the set-top via the Ethernet port include:

- Video Game Players

- Personal Computers

The Ethernet interface makes an ideal interface to video game players. A single standard interface can support a variety of game players without custom modification to the devices or the set-top. Games could be interactively downloaded to a particular game player and the Ethernet port enables interactive network games.

Since the Pegasus set-top uses IP as its data transport for the out-of-band communications channel, the Ethernet interface to a computer is a logical extension to the set-top terminal. In this configuration, the set-top terminal can function as a symmetric cable modem and a normal set-top terminal at the same time. Because the bandwidth is limited on the FDC this is not a replacement for cable modem, but can give people a taste of the capabilities offered by a cable model.

Security

The Pegasus set-top has a slot for a smart card and a built in secure-micro for support of security services. This includes key management for decryption of digital services and local authorization of IPPV purchases.

## PEGASUS SOFTWARE ARCHITECTURE

Figure 4 is a diagram of the set-top software architecture.

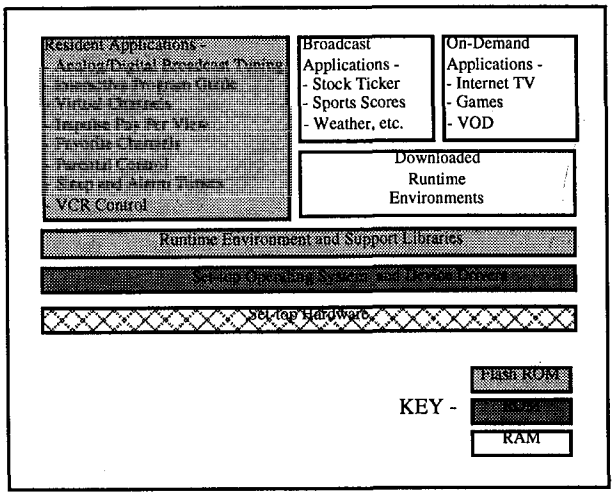


**Figure 4 - Software Architecture**

At the lowest level in this diagram is the set-top terminal hardware described in the previous sections. The next level is the set-top operating system and device drivers. Above the set-top operating system are the applications. The diagram also shows how these software components are mapped into the set-top memory architecture.

Set-top Operating System

The set-top operating system provides the interface layer between the applications and the set-top hardware. The Pegasus set-top terminal uses the PowerTV™ [16] operating system. This operating system kernel provides the following features:

- Priority-based, preemptive task scheduling, supporting multi-threaded applications
- Unified events system
- Dynamic linking and dispatching of functions and modules
- Interprocess communication facilities
- Interrupt and exception handling services
- Efficient dynamic memory management

In addition to these features, the operating system provides a set of support modules appropriate for set-top applications.

Resident Application

The Pegasus set-top terminal supports the resident application in Flash ROM. The resident applicant provides basic navigation and those additional features that must be immediately available when the set-top is turned on. In Phase 1.0 the Resident Application provides:

- Analog and Digital Broadcast Tuning, Channel Up/Down, Volume Up/Down, and Mute
- Reservation and Impulse Pay-Per-View (IPPV)
- Interactive Program Guide (IPG)
- Digital Music Service
- Parental Guidance Control
- Favorite Channels

- Sleep and Reminder Timers
- Messaging (including Emergency Alert System)
- Set-top settings (including AC outlet control,
- VCR Control through an IR link

After Phase 1.0 the Resident Application must also permit the download of interactive applications that provide other interesting services. These interactive applications fall into one of two broad categories, Broadcast Applications and On-Demand Applications.

Broadcast Applications

Broadcast Applications typically are program synchronous, i.e. they relate to the video content along with which they are broadcast. Examples of Broadcast Applications include:

- Enhanced advertisement
- Stock tickers
- Sports information
- Weather information

These applications are also typically broadcast in-band, either in the VBI channel for analog services or in MPEG private data for digital services.

On Demand Applications

On Demand Applications are typically downloaded to the set-top terminal at the time the subscriber requests the service. They are also typically session based or use client/server interaction. Since the Pegasus set-top terminal integrates real-time, two-way communications, interactive applications will be supported without hardware modification in subsequent Phases. The types of on demand interactive applications that are envisioned for future phases include:

- Internet TV
- Interactive Shopping
- Community Based Information Services
- Interactive and Networked Games
- Video-On-Demand (VOD)

The Pegasus set-top terminal will support true Video-On-Demand (VOD) as the capital investment becomes cost effective. The cost of video servers, headend switching and modulation equipment

## SUMMARY

The Pegasus set-top represents more than just a digital set-top, it represents a strategy for moving forward into the competitive age of digital entertainment services. The key points of the Pegasus strategy are:

- Phased Implementation - deploy services as it makes sense
- Address Competitive Digital Offerings - meet and exceed the digital services provided by DBS and MMDS providers
- Open Standards - standards permit interoperability and multi-vendor suppliers
- Superior User Interface - a powerful graphics processor provides a rich user interface and Flash ROM provides the ability to update the UI over time
- Real-time Two-way Communications - essential for on-demand interactive applications, such as Internet TV and VOD
- Application Platform - to succeed in bringing new services to market, the Pegasus set-top provides an open application platform

## REFERENCES

1. *Time Warner Cable - Pegasus Program Request For Proposal and Functional Requirements*, Time Warner Cable - Engineering & Technology, March 6, 1996.

2. Michael Adams, *Real Time MPEG Asset Delivery over ATM*, Proceedings National Cable Television Association - Cable '95 Conference, Dallas, TX, May 1995, pp. 315-326.

3. Louis D. Williamson, *Conditional Access and Security Considerations of Transactional Broadcast Digital Systems*, Proceedings National Cable Television Association - Cable

'95 Conference, Dallas, TX, May 1995, pp. 207-212.

4. Michael Adams, *Fault Tolerance in the Orlando Full Service Network*, Proceedings National Cable Television Association - Cable '95 Conference, Dallas, TX, May 1995, pp. 279-286.

5. Ralph W. Brown and J. Callahan, *Software Architecture for Broadband CATV Interactive Systems*, Proceedings National Cable Television Association - Cable '95 Conference, Dallas, TX, May 1995, pp. 270-278.

6. ISO/IEC 13818-1 (1994), Information Technology — Generic Coding of Moving Pictures and Associated Audio: Systems.

7. System Information for Digital Television, ATSC Standard, Document A/56, January 3,1996.

8. ITU-T Recommendation J.83 Annex B (1995), Digital Multi-Programme Systems for Television Sound and Data Services for Cable Distribution.

9. *Digital Video Transmission Standard for Cable Television*, SCTE DVS-031, Society of Cable Television Engineers - Digital Video Standards, October 15, 1996.

10. Digital Audio Visual Council (1996), DAVIC 1.1 Specification Part 8: Lower Layer Protocols and Physical Interfaces (draft as of September, 1996).

11. ISO/IEC 13818-6 (1995), Information Technology — Generic Coding of Moving Pictures and Associated Audio: Extension for DSM-CC.

12. Joint EIA/CVCC Recommended Practice for Teletext: North American Basic Teletext Specification (NABTS) (ANSI/EIA-516-88) (May, 1988).

13. ISO/IEC 13818-2 (1994), Information Technology — Generic Coding of Moving Pictures and Associated Audio: Video.

14. Universal Serial Bus Specification, Version 1.0, Compaq, DEC, IBM, Intel, Microsoft, NEC, Northern Telecom, January 19, 1996.

15. IEEE Std 802.3i-1992, Type 10BASE-T Medium Attachment Unit (MAU) Protocol Implementation Conformance Statement (PICS).

16. Information on the PowerTV™ operating system can be found on the World-Wide-Web at: `http://www.powertv.com`.