

The Roadmap of Digital TV System in USA

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The Digital Television (DTV) display low noise and very clear (crystal) picture with wide screen (16:9 in stead NTSC 4:3 ratio). The colors of video keep the high fidelity. The audio systems provide surround sound with less noise. The DTV systems use the channel band width more efficiently. The digital transmitter requires less power for equal coverage, resulting in reduced interference. In the original 6 MHz bandwidth of radio frequency, it can carry more than 4 programs of SDTV simultaneously. The SDTV is higher quality than NTSC that can carry only 1 program. The DTV will create more revenue for TV stations and more tax for US government to license the radio spectrum! US Congress has been pushing the DTV transition very hard, so do other countries.

Based on the history and status of the Digital TV system development in USA, this paper describes the future development of the Digital TV.

1. Introduction

Electronics Industries and Information Technologies (IT) change our life daily -- the most significant one is the TV (Television). TV systems utilized and integrated most the electronic and information technologies when they were invented. The TV systems, including the transmitters and receivers, occupy wider spectrum that covered from low frequency (several Hertz) to very high frequencies (GHz). Modern Digital TV systems require high speed digital data processing capabilities for video and audio compression and decompression, in additional, encryption and decryption. No doubt, the status of Digital TV indicates the level of Electronics Industrial and Information Technologies (IT) of a country.

2. History of Analog and Digital TV.

The black/white TV was invented in the middle of 1930s. In 1941, the United States adopted 525-line National Television System Committee (NTSC) black/white TV standard. The NTSC color TV system was adopted in 1953. This standard, well known as analog TV, has been used for more than 50 years!

The analog TV standard was the result of these early developments and reflected the technological limitation of that time.

Digital video was a dream without very high speed processing hardware and software. Information technology got breakthrough in 1980s. The digital image processing and compression theory and technology made good progresses. The VLSI (Very Large Scale Integrated) circuit chip advanced rapidly. The digital video became a hot R&D area.

In 1987, US broadcasters, approved by Federal Communication Commission (FCC), started to investigate the feasibility of terrestrial broadcast standards for ATV (advanced TV) system. By the end of 1988, a total of 23 ATV proposals were submitted and started testing.

At the beginning of 1991, four all-digital ATV systems and two analog systems were proposed for testing. After two years of testing, no single satisfactory system could be selected. It was decided to retain all-digital technology and to improve their performance.

In May 1993, the Digital HDTV Grand Alliance (GA) formed to create the "Best of Best" system. The GA selected the MPEG video compression, Dolby AC-3 audio compression and MPEG transport protocol. In 1994, GA selected the VSB as transmission system.

In 1995, GA completed the lab test and field test of the Digital TV. ATSC completed the DTV standard documentation and submitted to FCC.

In 1996, FCC adopted the ATSC DTV standard for USA. It planned to complete the transition of Analog TV to Digital from 1997 to 2006. Government wanted the broadcaster to return the NTSC channel for auction in 2006.

In January 1998, the International Consumer Electronics Show in Las Vegas demonstrated the HDTV of Space Shuttle launch with life time transmission from Eastern coast using the MPEG encoder and decoders made by Mitsubishi.

Almost at the same time, Japan adopted the ATV analog system, called Hi-vision. The Hi-vision system broadcasted few years, some Hi-vision TVs were sold in market. The analog Hi-vision system could not compete with Digital System. Japan finally gave-up the Hi-vision system and moved to Digital System later.

The analog NTSC TV is going to be replaced by Digital TV system based on the Advanced Television System Committee (ATSC) Standard. The transition from NTSC to ATSC has been delayed and could not shut down by the end of 2006. In 2005, US Congress finally decided to shutdown the NTSC broadcast by Feb. 17 2009. After that time, analog NTSC TV broadcasting will cease and enter the history. People will concern how about the Analog TV set in their home. Consumer can buy a DTV to Analog converter to view the DTV program in the conventional TV set. Two types of DTV receivers are available in marketplace:

- High Definition TV (HDTV): the resolution 1920x1080 at 60 fields (two fields = one frame) per second and 1280x720 at 60 frames per second. The data rate is 1 million pixels per frame.
- Standard Definition TV (SDTV): the resolution 720x480 at 60 frames per second or below.

3. Foundation of Digital TV (DTV) System.

Information Theory and Electronic Technologies are the foundation of Digital TV system. The communication (voice, telex etc) required the development of Information Theory. The digital TV systems require much higher data rate than telephone. What is shown in the DTV screen? In the HDTV screen displays the picture with 1 million pixels / 1 frame at 30 frames per second. Each pixel needs 24 bits for RGB three colors. In additional the digital audio and data service, roughly, it needs to process 1000 million bits per second (bps) – a huge data. How can the DTV system transfer this huge data from source (TV station) to the TV receiver in you home? It is hard to describe the details in a short paper. The paper presents two key technologies in DTV system: Video Compression and Transmission.

3.1. Video compression technologies

Without video data compression, it can not transmit the video in 6-MHz bandwidth constraint for terrestrial TV broadcasting. For example, the 1920x1080@60I format requires the bit rate: ~1000 Mbps. The nominal ATSC video channel bandwidth is 19 Mbps, so the compression of the video needs about 1:53.

The ATSC is based on the MPEG-2 compression, a Main Profile (MP) implemented from Main Level (ML) to High Level (HL). It uses a motion-compensated Discrete Cosine Transform (DCT) algorithm.

Video compressions are a combination of various processing techniques to reduce the bit rate. Many “loss” and “lossless” data reduction techniques have been developed; only few are suitable for video application.

Lossless video compressions are:

- Variable-length coding (VLC), or called Huffman coding and entropy coding. It assigns a short code to the values with the highest probability of occurrence and long code to the others.
- Run-length coding (RLC). This method relies on the repetition of the same data samples value to generate special codes that indicate the start and end of a repeated value.
- Blanking data removal reduces the original bit to active picture area content.
- DCT coding. The pixel data of blocks are converted to the coefficients of frequency by the Discrete Cosine Transform (DCT).

Loss compression:

- Sample sub-sampling. It used in chrominance as the 4:2:0 format, while 4:2:0 format s used in MPEG.
- Differential pulse coding modulation (DPCM). This is a predicative encoding that transmits the sample-to-samples difference rather the full samples value.
- Quantization of DCT coefficients.

3.2 Video Compression standard in ATSC – MPEG-2:

The video compression standards are defined to achieve two main goals:

1. Exploit the signal redundancy and the video system tolerance to reduce the original picture data ate.
2. Represent the compressed picture data stream in a format that can manipulated in production and transmission. A video data hierarchy made up of six layers is used in MPEG:

- Block of 8x8 pixels of luminance and chrominance are defined to be used for DCT compression.

- Macroblock. A macroblock is a group of DCT blocks which correspond to the information of a window of 16x16 pixels. The header of macroblock contains information about its type (Y or Cr or Cb) and motion vectors.
- Slice. A slice is formed of one or more contiguous macroblock.
- Picture. The picture layer tells the decoder about the type of frame, synchronization, resolution, and range of the motion vectors.
- Group of pictures. A group of picture (GOP) is a combination of various frames such as I-, P- and B-frames.
- Video sequence. The sequence layer includes a header, more GOPs and end code. The header of sequence contained the horizontal and vertical sync of each picture, the bit rate, picture rate and minimum decoder buffer. The video sequence and header information constitute the encoder bit stream called video elementary stream.

3.3 DTV Transmission technology used in ATSC

The Vestigial Sideband (VSB) digital system was adopted as US DTV transmission/reception standard for terrestrial broadcasting. The transmission and reception blocks are shown in the diagram.

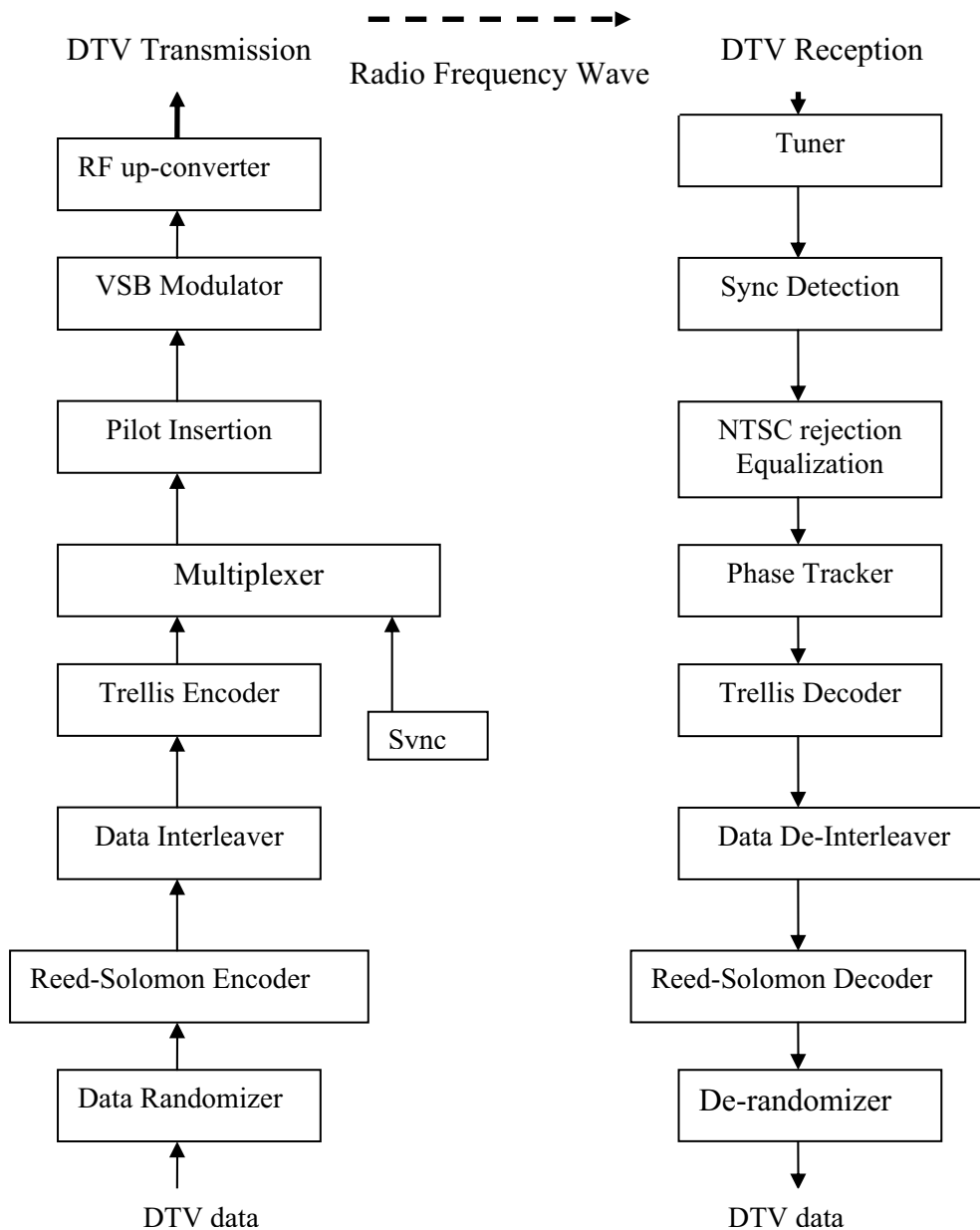


Figure 1. ATSC DTV Transmission and Reception Block Diagrams

The Digital VSB can send the HDTA signal over 6 MHz bandwidth used in analog TV. The advantages of Digital VSB:

- Perfect picture & Sound quality
- Robust Synchronization
- Powerful forward error correction
- Very efficient use of bandwidth and Power.

The cable DTV adopted the quadrature amplitude modulation (QAM), a digital modulation method in which the value of a symbol consisting of multiple bits is represented by amplitude and phase state of carrier.

The practice of ATSC DTV broadcasting has been successful. The 1st DTV model station WHD-TV established in the suburb of Washington DC and as pioneer to experiment test ten years ago. The author visited it. The picture showed the broadcasting equipment in WHD-TV. Most of TV stations built the DTV broadcast facilities. The DTV signal covered most US territory. The DTV receiver can display video reliably with high quality. It is expected that the analog TV will cease in 2009. However, the development of digital TV will not cease at current level. The Digital Revolution opens the door for evolution of DTV in wider and deeper advancement.

4. Perspective of Digital TV System.

Digital TV is not just a TV any more. Digital TV is the combination of achievements in the digital revolution. In reaction, Digital TV is driving the digital revolution forward. At least, not at last, the following arenas are very active in the digital TV:

4.1 Advanced Display Technologies:

Digital Revolution generates lots of display devices. More and more Display devices show high resolution and color fidelity.

- **Large screen TV:** For examples, the Digital Light Processor (DLP) and Liquid Crystal Device (LCD) demonstrate good performance in Projection TV with reasonable price. The Liquid Crystal on Silicon (LCoS) Device can be used in high quality in large screen TV. For example, the 82" LCoS PTV is the largest TV with the resolution 1920x1080 at 60 frames per second.
- **Flat panel TV:** Not like the CRT (Cathode Ray Tube) TV with thick depth, the flat panel TV with less than 8 inches depth can hang up in wall. The PDP (Plasma Display Panel) has shown in Horizon first, however, the Liquid Crystal Device (LCD) panel is catching up. The LCD operated with lower voltage with longer life time looks more attractive than PDP.
- **Three dimension TV without wearing special glass.** This is not realized yet. However, it is feasible in the display technology. Normally, it is necessary to wear a polarization glass to view a 3D Picture. The cell of LCD panel can be blocked for one eye and viewed by another eye to create the 3D effect. Although the 3D video creation, compression, transmission, decoding and display are very challenging, I believe that the 3D TV will become one portion of our entertainment.
- **Wider color range TV.** Current digital display devices already are richer color than NTSC analog color TV. The future digital TV will display wider color range. A new color standard has been defined as xvYCC – Color management -- Extended-gamut YCC color space for video application (IEC61966-2-4). People can watch richer color of motion object and details such as text of flowers and grass. New light sources will be introduced in order to display the extended color space, such as LED and laser beams. The digital processing makes user can control color easier, called color management.

4.2 Mobile TV. The Digital TV transmission system is more efficient and reliable than Analog TV system. The smart data coding and error correct function enhance the reception in the multi-path and adjacent channel interference. The moving reception becomes possible. Further more, some DTV standard to deploy the multi-frequencies carrier modulation for mobile reception. The DTV receiver will be highly integrated and consume mini

power. Connecting it with the very thin LCD monitor, the handheld TV will become popular. DTV everywhere is not a dream to watch the world cup game in future.

4.3 DTV Centered Home Networking:

Digital TV will become most important platform of entertainment in future. The DTV will build strong CPU and peripheral ports, such as USB and IEEE1394 wires. The DTV will not only display the video, but also can record the video, send the programs to other Audio/Video (A/V) devices in other rooms, It can control other A/V or electric equipments (such as air condition, microwave etc). Connecting with cameras The DTV can monitor doors and windows as surveillance system. Our life will be more comfortable, convenient and secure to establish the DTV centered home networking. The DTV centered Home Networking under developing are:

1. The following new wired Networks are stable and secure, but a little bit expensive:
 - IEEE1394 bus
 - Ethernet
 - USB
2. Use existing wires as network infrastructure:
 - HomePNA -- Use existing phone line.
 - Home Cable Network Alliance -- Use existing coaxial TV cable.
 - Power line networks --Use existing power line, multiple outlets in almost every room (HomePlug 1.0 PLC standard).
3. The wireless A/V network is free to move around. The most popular wireless technology is: IEEE 802.11b with data rate 11Mbps or IEEE 802.11n with data rate 54Mbps.
Actual Home Networking may be the combination of those technologies.

4.4 The Advanced Compression Theory and Technology.

Video compression is the core portion of digital TV. The requirement of higher compression rate and lower video error require improving the compression technology. H.264/AVC is a recently completed video compression standard. The coding structure of this standard is similar to that of all prior major digital video standards, but the video transform is remarkably simple when compared to an ordinary 8x8 IDCT in MPEG-2. The standard promises much higher compression than that of earlier standards. It allows coding of non-interlaced and interlaced video efficiently and provides more acceptable visual quality than MPEG-2.

Further, the standard supports flexibilities in coding and can increase resilience to errors or losses. It is possible that the H264/AVC will be the next generation compression method of DTV. The compression method will not stop at earlier level.

If the advanced compression method with more efficient and error resilience is developed, ATSC may adopt that new compression method as new generation standard.

4.5 The Advanced Transmission Theory and Technology

The method of RF modulation directly is related to the reception performances. Although ATSC adopted the VSB as the transmission standard for terrestrial broadcasting, it does not mean VSB is the best one. The US cable industry decided the QAM as the modulation standard. The targets of cable transmission are to maximize information carry capacity, minimize bandwidth and minimize power requirement. The signal condition in cable is different from Terrestrial broadcasting.

Some countries are selecting other RF modulation methods instead of VSB. For example, OFDM (Orthogonal Frequency Division Multiplexing) is potential one. The incoming data is broken into a number of individual data streams, each of which is then QAM modulated onto its own carrier. The carriers are spaced just for enough apart to prevent the adjacent channel interference. Each carrier has modulated sidebands around it. The carrier may be moved closer together if the timing of bits on adjacent carriers is carefully controlled. By dividing the spectrum sub-bands, a single band of high-speed data is replaced by a large number of bands of lower-speed data. Since demodulation is done over a narrow band, the effects of impulse noise and group delay are reduced, and the effective carrier-to-noise ration is improved in each channel by narrowing of the pass-band.

OFDM has better performance than VSB under the moving multi-path interference and is suitable for mobile TV. Several countries adopted the OFDM as RF transmission standard. The researches of transmission continue to provide the better technologies for the future.

4.6 IP (Internet Protocol) TV

Internet Protocol TV (IPTV) is rapidly emerging as a source of rich content and innovative interactive services to the home. The backbone of telecommunication provides enough bandwidth to transmit high speed video data. In order to reduce the data rate, IPTV requires the advanced video compression tools. Recently, the advanced compression tools, such as H.264/AVC, are available and provide efficient tools for IPTV. Higher compressed ratio and higher bandwidth of optic fiber are the basic condition of the IPTV implementation. Usually, the IPTV will provide the services with SDTV or below to save the bandwidth and increase the service contents.

The IPTV standards are not completed yet. European, WE and several Asian countries are working on the IPTV standards. The basic operation scenarios can be expected:

- The IPTV have Ethernet ports and are connected to a home network (LAN).
- IPTV servers will deliver basic and premium content to the home via a private, IP-based service (access) network. IPTV STB will be capable of receiving and outputting multiple audio/video streams simultaneously.
- IPTV services will also include an interactive program guide (IPG).
- Multiple users in the home can watch different, live IPTV programs simultaneously.
- Users can browse and select content individually at each DTV. Control information is set back to the IPTV STB to “tune” to the desired content.

The basic block diagram is shown in the following figure:

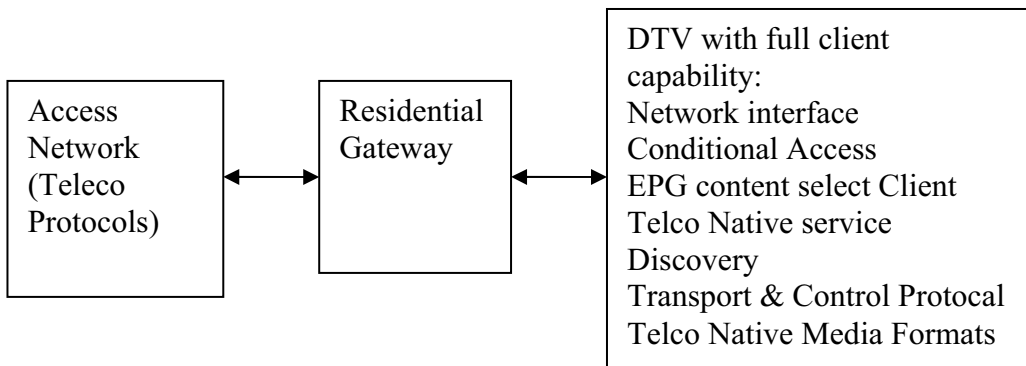


Figure 2 Scenario of Internet Protocol TV (IPTV)

5. End words: DTV just beginning

Digital Revolution is the most significant advancement since the Industry Revolution started from British. So many exciting products have been created in the digital revolution: Personal Computer, Internet Networking, VLSI (Very Large Scale Integrated Circuit), digital camera etc. Digital TV is one of most important achievement of Digital Revolution and will affect all our life.

This paper presented the roadmap of Digital TV in USA. Most major countries, such as European, China, Japan and Southern Korea are matching toward to Digital TV era. China is developing its own digital standard. Two modulation schemes compete each other: Qinghua’s time-domain synchronous orthogonal frequency-division multiplexing (OFDM) and Jiantong’s vestigial sideband (VSB) modulation. China planned to have 100 million DTV households to watch air HDTV content from the Summer Olympics by 2008. A 2015 deadline is in place to end analog broadcasts.

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1971年-1978年作为安徽地震局的首批地震工作者，楼望和探索应用地质力学来预报地震的方法。1976年7-8月实地考察唐山大地震一个月，调查天津唐山周边地区的灾情，拍摄大量的照片现存安徽地震局编辑整理的“唐山7.8级地震震害照片集”。

1981年-1984年中国科技大学从事科研工作，研制成高分辨高精度可控频率源，用于中国科技大学的同步辐射加速器。

1984年后，楼望和来美在康乃尔大学从事数字图像处理 and 计算机视觉研究，并取得博士学位。楼望和博士后来在美国三菱数字电子公司任电子研发部门经理。长期从事高解析度数字电视系统的研发，参与美国高解析度数字电视标准的制定和更新，领导研制成功一批高科技的数字产品，如：首批集成高分辨高解析度数字电视，特大屏幕高分辨数字 LCoS 显示系统(1920x1080p)等。楼望和博士是美国高解析度数字电视标准委员(ATSC)会投票权成员,EIA/CEA 电子视像标准委员会投票权成员，有线电视标准委员(SCTE)会投票权成员,国际电子电工工程师协会 IEEE/ICCE 分会论文评选委员会成员。

