國立交通大學

電機學院與資訊學院 資訊學程

碩 士 論 文

數位機頂盒的影像品質研究：
維持品質指標下改進測試生產力

Video Quality in Set-Top Box：
Improving Test Productivity
While Retaining Quality Index

研 究 生：劉百振

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摘　　　要

在數位家庭與多媒體產品中，數位機頂盒扮演著極為重要的溝通橋樑，其中讓使用者能直接感受到產品性能優劣的第一印象，莫過於影像與聲音的品質。然而一般影像測試時，需要使用各種不同的測試圖形，所以我們依據影像品質指標，提出一種組合式圖形測試方法：把二十四種個別單一的圖形，構成一種組合式圖形。另外，在數位機頂盒系統品質測試中，需要測試影音訊號輸出品質、數位壓縮的相容性與傳輸網路所造成的影響，若要全部測試則高達 329,726,592 項，故我們使用一台電腦控制了影音訊號源、數位壓縮設備、傳輸網路、影像聲音品質分析儀，實作了自動化測試系統，此一系統可以大大地縮短測試時間。綜觀上述之研究其優點：降低測試複雜性、縮短測試週期、提高產品競爭力進而大幅提升測試生產力。

關鍵字：機頂盒，機上盒，影像，品質，自動化，測試，多媒體，數位電視，量測，測試方法，數位家庭

Video Quality in Set-Top Box：Improving Test Productivity While Retaining Quality Index

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ABSTRACT

Among many multimedia products, digital set-top box plays a key role as consumer promise equipment. The key performance index for a set-top box appears to be its video and audio quality. The video quality is benchmarked by many different types of video patterns. In this thesis, we propose a Video Combination Technique (VCT) to integrate twenty-four video sources into a single one. Thus, the benefits of VCT include lower test complexity, lower test cycles and cost saving. From the system quality point of view, there are testing network transmission layer, compression layer and video/audio output signal layer. All the tests are sum up to be 329,726,592 items. Therefore, we implement an automated test measurement system (ATMS) to save the test cycles and time. So set-top box manufacturing cost is lower and productivity is improved.

Keyword：set-top box, STB, video, quality, automated test, test, multimedia, digital TV, measurement, test methodology, digital home

誌　　謝

組合式圖形的靈感來自孩子們的樂高積木，看著他們將一堆分散的積木，經由他們的巧手它可以變成老鷹、城堡、汽車、直昇機、蝴蝶、翼手龍…甚至更多我們想像不到的創意。這些立體造型不禁讓我聯想到工作上影像測試所使用的二十四種單一圖形，如果可以整合成一張圖形將可獲得事半功倍的效果，經過不斷地實驗，終於獲得成果展現並取得專利權。而在數位電視產業多年工作經驗中，都是使用人工來量測眾多的測試項目以驗證系統品質，因此衍生一套自動化量測系統，用來控制影像聲音的測試、數位壓縮設備，大大提昇工作上的效率，感謝目前任職的鴻海精密工業股份有限公司新竹園區分公司提供實驗中所有設備。

承蒙太太鄭梅芬女士的支持與孩子們濬磊、羿欣、玟欣的體諒，讓我能夠充分利用上班之餘，進入嚮往已久的交通大學，尋求新知增進見識；更感謝林盈達教授與蔡文錦教授的傾囊相授大力指導，讓我能在專業的領域裡更上層樓。

最後，再次感謝所有幫助過我的人!

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Chapter 1. Introduction

Digital Set-top Box (STB) presents new opportunities for network service providers to deliver revenue-generating home entertainment services. Users can enjoy video and music, browsing over Internet, playing games, and using e-mail services—all through a single interface to a television provided by an STB. Set-top boxes can receive signals through the cable, terrestrial or satellite. The bi-directional IP infrastructure enables inherent support for a broader range of applications and interactive services.[1]

Everyone knows what the video is – it is another definition for the television. Televisions have been around in our homes; it is an integral part of modern life.[24] What is the key performance index (KPI) of a digital home product? It appears to be its video quality.[4] The quality index contains amplitude, timing, linear distortion, nonlinear distortion and noise. The quality index covers all test items and the measurement. This thesis discusses the test methodology of video quality. Since the video quality is benchmarked by many different types of video test patterns, how to simplify these complicated video sources will be an issue. We propose a Video Combination Technique (VCT) to simplify the video test pattern. The VCT combines twenty-four video sources into one. The VCT is now in patent pending. The benefits of VCT include lower test complexity, lower test cycles and cost saving. Thus, it improves the test productivity while retaining quality index.

There are many test cases for system quality of STBs. For example, the numbers of video and audio codecs are 716 and 371, respectively. So we implement the automated test measurement system (ATMS) to save the test cycles and time. The ATMS consists of the video source, audio source, encoder, transmission network, video analyzer and audio analyzer. The ATMS can be applied to all STB products.

The rest of this thesis is organized as follows. Chapter 2 describes the background knowledge. The problem statement is presented in Chapter 3. In Chapter 4, the operation model is explained. Chapter 5 gives the details of implementation. And finally, we evaluate VCT in chapter 6 and Chapter 7 concludes this work.

Chapter 2.   Background

Before the problem statement, there are some background knowledge to be introduced first. The first one is STB connection overview, and leads all kinds of STB categories. The second one will have a system overview. Due to the data rate difference, digital broadcasting system has two types like single program transport stream (SPTS) and multiple program transport stream (MPTS). There is a system model discussing from signal layer, compression layer and transmission layer. Finally, it will talk about video methodology and their quality index.

2.1 Set-Top Box Category Overview

There are some kinds of STB categories as shown in Figure 2-1. The STB receives the triple-play digital multimedia contents from kinds of transmission media then decodes to sorts of services and networking. The transmission media can be different types like cable, terrestrial, satellite and Ethernet. The worldwide digital TV standards include DVB-C, DVB-T, DVB-S, ISDB and ATSC.

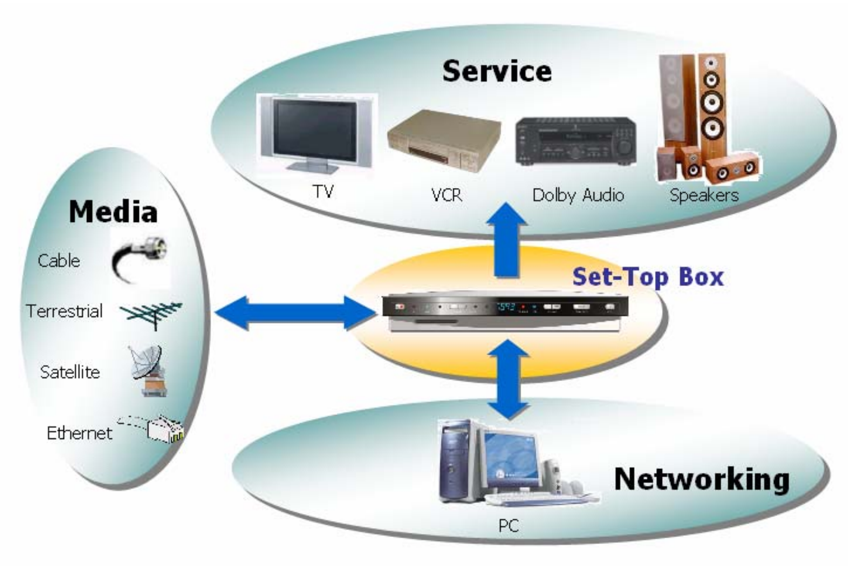


Figure 2-1 Set-Top Box Category

2.2 Set-Top Box System Topology

In order to convert an analog television to a digital one, the analog television signal inputs into an encoder and comes out a digital stream. One type of encoding that is dominant right now is called MPEG2, and the encoded digital streams are called MPEG2 Transport streams. Transport streams can be either single or multiple. A single program transport stream (SPTS) refers to Figure 2-2, like those coming out of an encoder contains only one program channel of information. For example, if you play the movie "Gone With The Wind" into an encoder, a single program transport stream (SPTS) of digital bits would come out of the encoder. This stream can go into a decoder, in order to convert the digital stream back into pictures that can be seen on a normal television.[2]

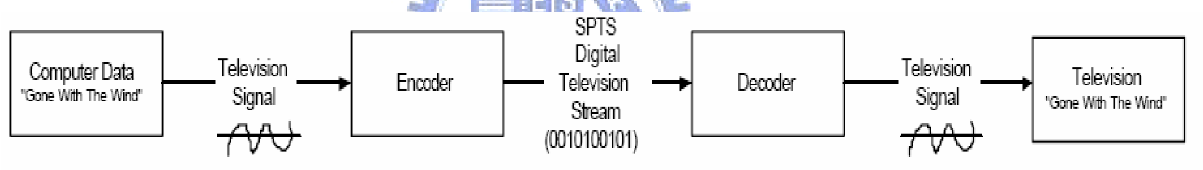


Figure 2-2 SPTS Topology

Figure 2-3 illustrates the topology that explains the benefit of digital television with many of these SPTS combined together into one multiple program transport stream (MPTS). This combining process is done by a multiplexer. The input to a multiplexer is several SPTS. The output of a multiplexer is one MPTS. For example, if the movies like "Gone With The Wind", "Wizard of Oz", "The Terminator", and "Star Wars" are all encoded and multiplexed together, one MPTS would carry all four of the digital television programs. This stream goes into a decoder to convert any one of the programs back to television pictures.[2]

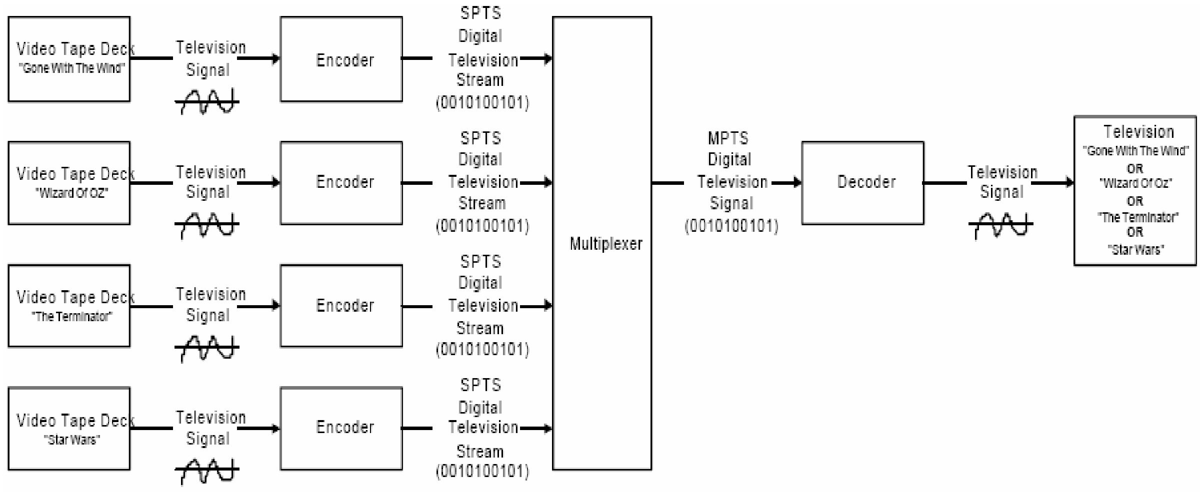


Figure 2-3 MPTS Topology

As the video production and broadcast industry makes the transition from analog to digital video, the facilities will contain a mixture of both analog and digital video equipment. In order to verify video performance in a mixed analog and digital video transmission link, the system should account for the following categories. [3]

As STB is a home user product, it requires a digital headend to distribute multimedia contents over the transmission media to home users. For the system topology, we divide them into four panels like data, network and transmission, control and test Panels.

The IP STB system of topology can divide into four panels in Figure 2-4.

Data Panel:

Member: Satellite IRD, Terrestrial IRD, Video Server, DVD + Encoder

Objective: Acquire digital contents or encoding analog A/V source to MPEG-2 transport stream

Control Panel:

Member: Middleware Server, Web Server, TFTP Server, DHCP server

Objective: STB user interface, EPG, Database, Subscriber Management System, Billing System

Test Panel:

Member: Video Source Generator, Audio Source Generator, Video Analyzer, Audio Analyzer

Objective: Video/Audio Quality Measurement

Networking and Transmission Panel:

Member: TS/IP Gateway, Ethernet Switch, Ethernet Router, DSLAM

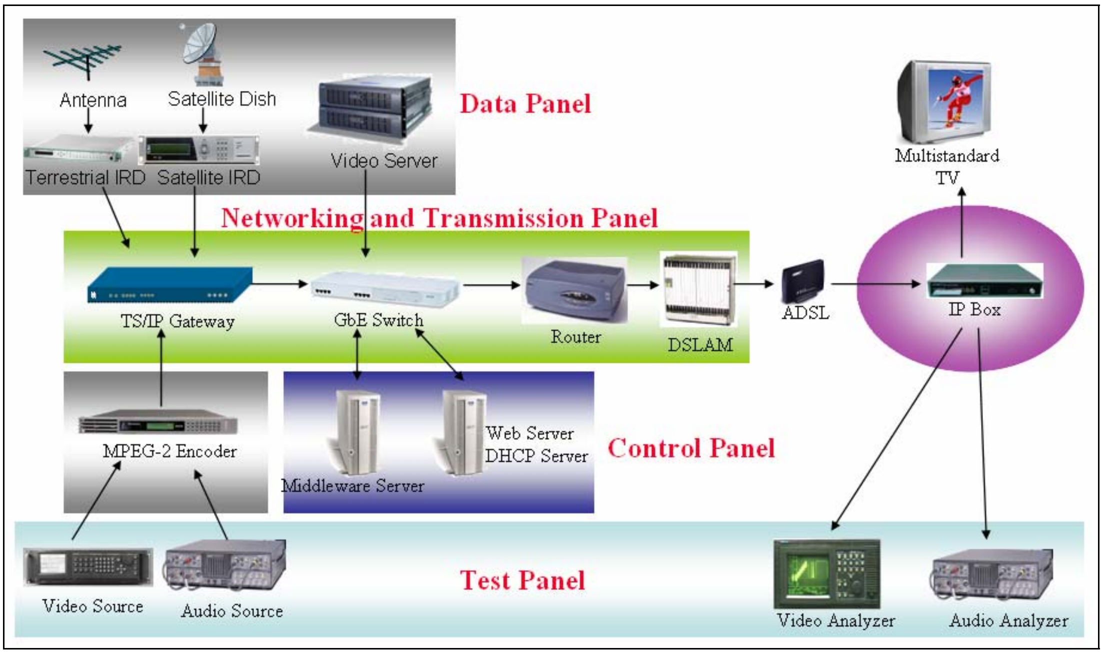


Figure 2-4 IP Set-Top Box System Topology

2.3 Layers of Test Item

Three key testing layers can be defined as the modern television system as shown in Figure 2-5.[4] The layers simply separate the standard into three consecutive blocks that have defined interfaces. This does not only make it easier to understand the standard, but provides means for interoperability with other standard that may have equivalent layers. In broadcasting, the layers are traversed top-down, and in a receiver that is processed bottom-up.

Thus, the top layer is "Video Source" for headend site and "Video Output" for receiver respectively. What we measure this layer is "Video Quality".

The second layer, compression, performs audio and video compression in transmission for encoder and decompression at the STB. This layer of the standard defines the usage of video and audio compression techniques. They are based on MPEG-2, MPEG-4, VC1 for video and MPEG-1 Layer 2, Dolby AC3 for audio.

In the final layer, transmission, the composite data stream containing video, audio, and possibly other data are modulated into a carrier suitable for distribution by terrestrial broadcasting, satellite, cable, or Ethernet. The test item here is channel analysis.[24]

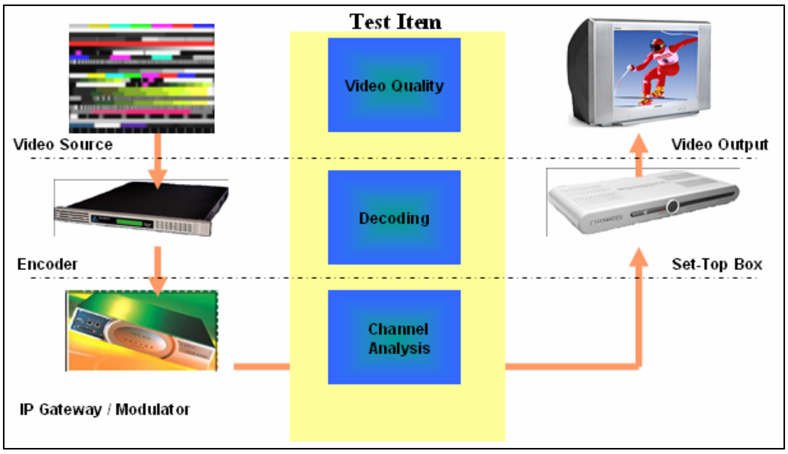


Figure 2-5 Signal vs. Test Item

2.4 Video Quality Index

The overall of video quality is influenced at a number of index: amplitude, timing, linear distortion, nonlinear distortion and noise in Table 2-1.

Index	Description	Influence	How to measure
Amplitude	NTSC defines peak-to-peak amplitude 1 volt (140 IRE)	Too light or too dark	100 IRE white level
Timing	Horizontal and vertical synchronization pulse widths fall within specified limits	Picture breakup	Any composite signal
Linear Distortion	Caused by imperfect transfer characteristics in the signal path	Incorrect color saturation, color smearing, fuzzy vertical edges, brightness variation, flicker	12.5T sine-squared pulse with 3.58 MHz modulation, T rise time white bar, 18 us 100 IRE bar, window or field square wave
Nonlinear Distortion	Crosstalk and intermodulation effects between luminance and chrominance	High brightness areas colors not reproduced,	Modulated staircase, unmodulated 5 step staircase, modulated pedestal
Noise	Noise random or coherent from natural and man-made sources	Snowy, grainy, sparkles	Any line with constant level

Table 2-1 Video Quality Index

Amplitude

Video amplitudes are most frequently measured in order to verify the conformity to nominal values. Measurement of the peak-to-peak amplitude is 1 voltage for NTSC systems. 1 IRE is defined into an absolute unit equal to 1/140 of 1 voltage. Signal amplitude can be measured with a waveform monitor. The amplitude of gain errors causes the picture to appear too light or too dark.[22]

Timing

Both RS-170A and the FCC provide the recommended limits for these timing parameters. However, the two standards have different definitions for various time intervals. FCC specifies sync width between the 90% points of the two transitions as shown in Figure 2-6. RS-170A specifies sync width between the 50% points as shown in Figure 2-5. The RS-170A requirements are generally more stringent.[22]

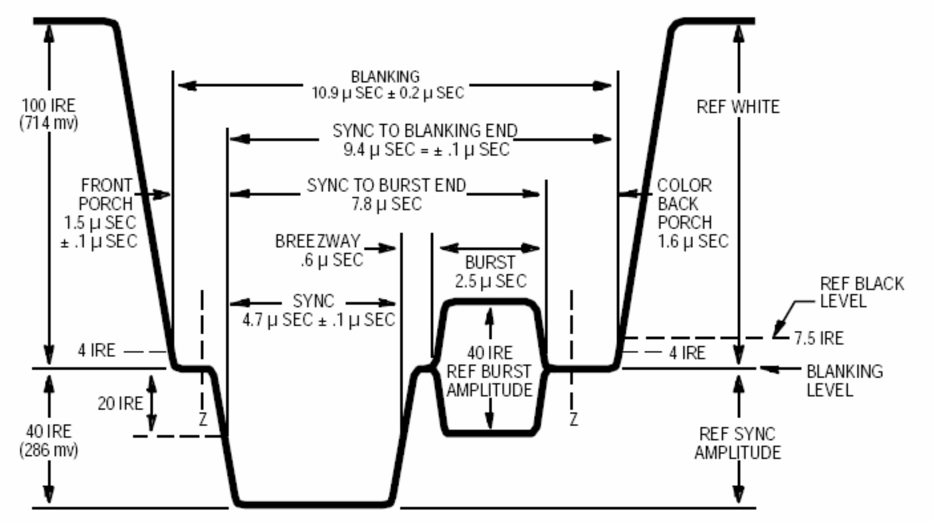


Figure 2-6 RS-170A Defined Timing Standard

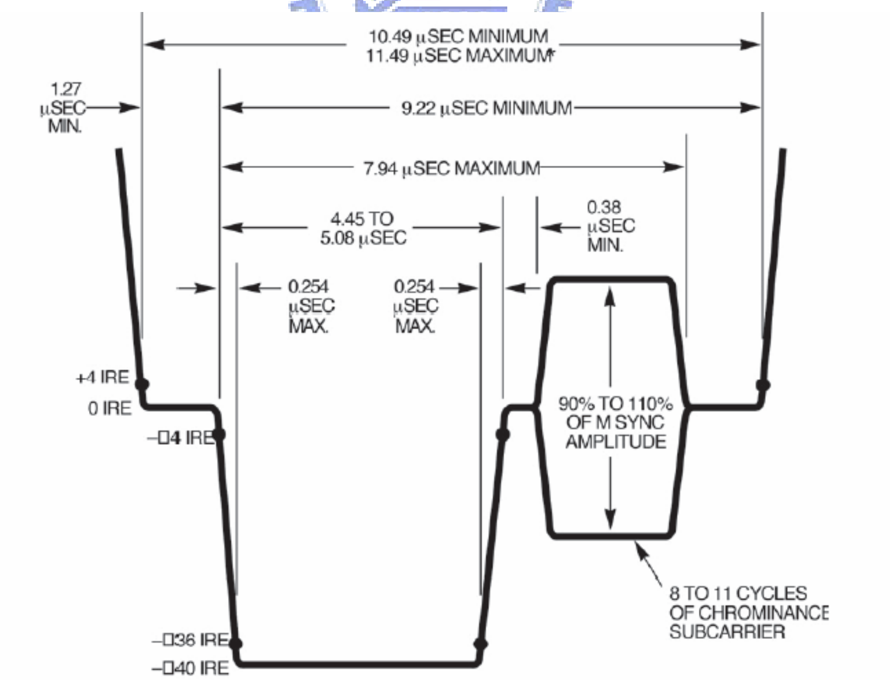


Figure 2-7 FCC Defined Timing Standard

Linear Distortions

All systems require a specific bandwidth to transmit all significant luminance and chrominance information. Table 2-2 summarizes significant linear distortions and gives a short description of the test concept.[8]

Parameter	Definition	Test signal	Test method
Gain versus frequency response	Gain variation over band from 500kHz to maximum frequency	Multiburst or sweep	Measure signal level at selected frequencies in dB wrt level at 500kHz
Long-time distortion	Damped signal-level oscillations resulting from sudden picture-level changes	Any test signal allowing a controlled change in average picture level	Measure overshoot peak as % of peak luminance level
Field-time distortion	Change in shape of a field-time square wave	Field-rate square wave	Measure peak-to-peak tilt of top of bar in % wrt centerer of bar excluding first and last 250 μs
Line-time distortion	Change in shape of a Line-time square wave	Line-rate square wave	Measure peak-to-peak tilt of top of bar in % wrt centerer of bar excluding first and last 1 μs
K factor	Quantified subjective impairment rating	2*T* sine-squared pulse	Read *K* rating in % on Special graticule
Chrominance to luminance gain	Change in ratio of chrominance versus luminance amplitude	Modulated sine-squared pulse	Measure amplitude of chrominance component in % wrt the luminance component
Chrominance to luminance delay	Change in timing of chrominance versus luminance	Modulated sine-squared pulse	Measure delay of chrominance component in ns wrt to the luminance component

Table 2-2 Summary of Linear Distortions and Test Methods

Nonlinear Distortions

Table 2-3 summaries and defines the nonlinear distortions and gives a short description of the measurement concept.[5] The most common measurable nonlinear distortions are luminance nonlinearity, differential gain and differential phase.[8]

Parameter	Definition	Test signal	Test method
Luminance nonlinearity	Output/input amplitude proportionality change of a small unitstep function as the step level is shifted from blanking level to white lecel. The average picture level is kept constant.	Luminance staircase	Measure % of largest step amplitude variation
Chrominance gain nonlinearity	Output/input Chrominance subcarrier amplitude proportionality change as the subcarrier amplitude is varied from a minimum to a maximum specified value. Luminance and average picture levels are kept constant.	Modulated pedestal	Measure % of steps 3 and 1 chrominance amplitude change with reference to step 2
Chrominance phase nonlinearity	Chrominance subcarrier phase variation when the subcarrier amplitude is varied from a minimum to a maximum specified value. Luminance and average picture levels are kept constant.	Modulated pedestal	Measure largest phase difference(in degrees) of steps 3 or 2 with reference to step 1
Chrominance to luminance intermodula-tion	Variation of luminance signal amplitude resulting from the superimposition of a specified amplitude chrominance signal. The average picture level is kept constant.	Modulated pedestal	Measure % of largest luminance level change due to chrominance level
Differential gain	Amplitude change of a constant small-amplitude chrominance subcarrier superimposed on a luminance signal level that changes from blanking to white. The average picture level is kept constant.	Modulated ramp or staircase	Measure % of largest chrominance subcarrier level change with reference to burst amplitude

Differential phase	Change in phase of a constant small-amplitude chrominance subcarrier without phase modulation superimposed on a luminance signal level that changes from blanking to white. The average picture level is kept constant.	Modulated staircase or ramp	Measure largest chroma phase change in degrees with reference to burst phase

Table 2-3 Summary of Nonlinear Distortions and Test Methods

Noise

Table 2-4 summaries the types of noise encountered in studio environment and gives a short description of the test method.[23] The test signal for the measurement of noise is a flat field at the black level.[8]

Parameter	Definition	Test signal	Test method
Continuous random noise	Ratio, expressed in dB, of the nominal amplitude of the luminance signal (714.3 or 700 mV) to the RMS amplitude of the noise in a frequency band extending from 10 kHz to the upper frequency of the video band (4.2,5,5.5 or 6 MHz).	Flat field	Feed test signal to input of equipment under test and measure SNR at output with specialized RMS-reading instrument. Alternately, use an oscilloscope preceded by a band-limiting filter and synchronized to display single line.
Hum	Ratio, expressed in dB, of the nominal amplitude of the luminance signal (714.3 or 700 mV) to the peak-to-peak amplitude of the noise after band-limiting to 10 kHz.	Flat field	Feed signal to input of equipment under test and measure SNR at output with specialized peak-to-peak reading instrument. Alternately, use an oscilloscope synchronized to display a single field and measure peak-to-peak hum amplitude.
Other	Ratio, expressed in dB, of the	Flat field	Feed test signal to equipment

periodic noise	nominal amplitude of the luminance signal(714.3 or 700 mV) to the peak-to-peak amplitude of the noise in a frequency band extending from 1 kHz to the upper frequency of the video band(4.2,5,5.5, or 6 MHz).		under test and use an oscilloscope to isolate, identify, and measure peak-to-peak amplitude of interfering single in the specified frequency band.
Crosstalk	Ratio, expressed in dB, of the nominal amplitude of the luminance signal (714.3 or 700 mV) to the peak-to-peak amplitude of the interfering signal.	Sweep signal and flat field	Feed sweep to unwanted channel and flat field to wanted channel. Normalize gains and measure the peak-to-peak value of the interfering signal at the wanted channel output.

Table 2-4 Summary of Noise and Test Methods

2.5 Composite Video

The most television systems communicate by means of composite signal, which is a special format that contains all the information needed to convey a picture like brightness, color and synchronization on a single cable. [24]

Luminance (Y) signal is derived by adding from red, green and blue together, but in a sum which is weighted by the relative response of the eye.[21] Thus :

$$Y = 0.299R + 0.587G + 0.114B$$

The UV and IQ vector diagram is shown in Figure 2-8. To transmit color information, U and V or I and Q "color difference" signals are used:

$$\mathrm{U} = 0.492(\mathrm{B} - \mathrm{Y})$$
$$\mathrm{V} = 0.877(\mathrm{R} - \mathrm{Y})$$

Or

$$\mathrm{I} = 0.596R - 0.275G - 0.321B = V\cos 33^{\circ} - U\sin 33^{\circ}$$
$$Q = 0.212R - 0.532G + 0.311B = V\sin 33^{\circ} + U\cos 33^{\circ}$$

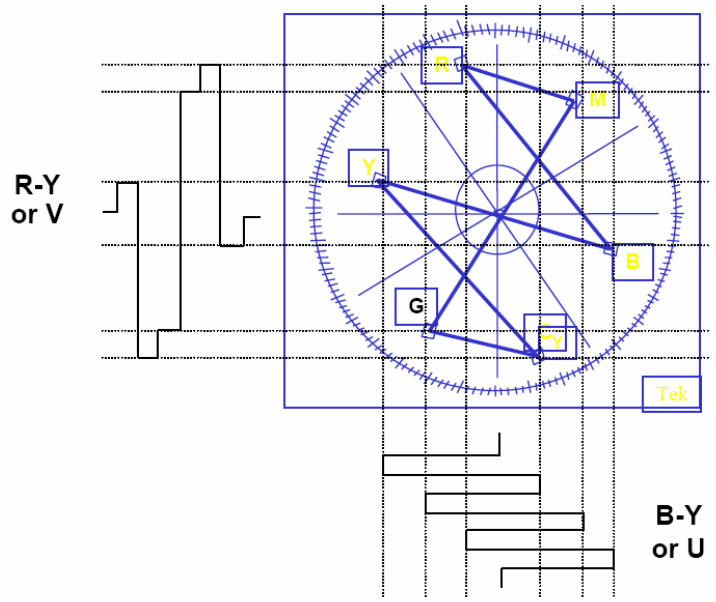


Figure 2-8 UV and IQ Vector Diagram for 75% Color Bars

I and Q (or U and V) are used to modulate a 3.58MHz color subcarrier using two balanced modulators operated in phase quadrature: one modulator is driven by the subcarrier at sine phase, the other is driven by the subcarrier at cosine phase. The outputs of the modulators are added together to form the modulated chrominance signal:

$$C = Q\sin(wt + 33^{\circ}) + I\cos(wt + 33^{\circ})$$

$$where \quad w = 2\pi Fsc; \quad Fsc = 3.579545MHz$$

$$C = U\sin wt + V\cos wt$$

With respect to Figure 2-8, a good video quality of color vector must locate on square for each vertex. We will adopt the color vector diagram to be our pass/fail criteria in Table 5-3.

The modulated chrominance is added to the luminance information along with appropriate horizontal and vertical sync signals, blanking information, and color burst information, to generate the composite color video waveform shown in Figure 2-9.

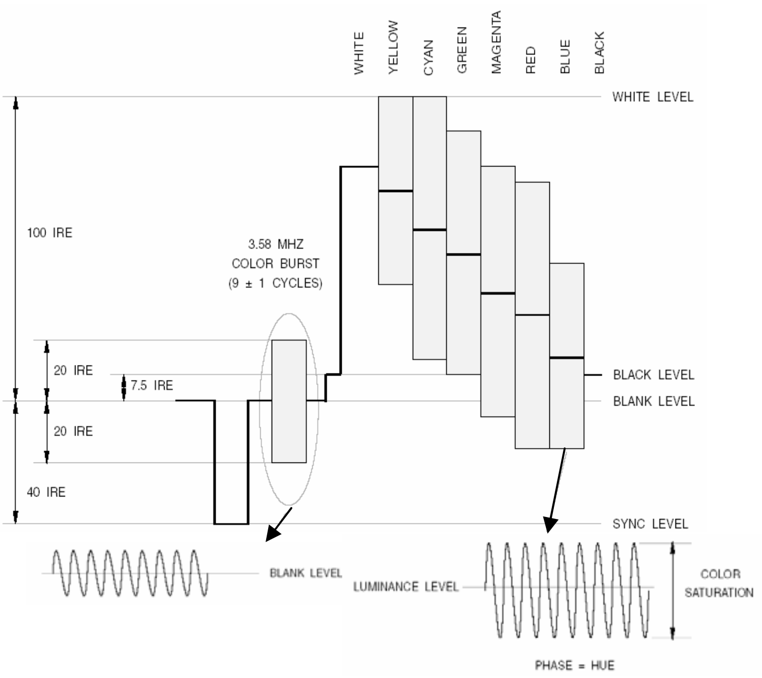


Figure 2-9 Composite Video Signal for 75% Color Bars

Table 2.5 lists the details of the color bar signal luminance and chrominance values as well as the phase angles of the six colors.

Color	Luminance, IRE/mV	Chrominance, IRE/mV	Angle, degrees
White	100/714.3	0/0	- - -
Gray	76.9/549.29	0/0	- - -
Yellow	69/492.86	62.1/443.58	167.1
Cyan	56.1/400.72	87.7/626.44	283.5
Green	48.2/344.29	81.9/585.01	240.7
Magenta	36.2/258.57	81.9/585.01	60.7
Red	28.2/201.43	87.7/626.44	103.5
Blue	15.4/110	62.1/443.58	347.1
Black	7.5/53.57	0/0	- - -
Burst	0/0	40/285.72	180

Table 2-5 NTSC 75% Color Bars Signal Waveform Characteristics

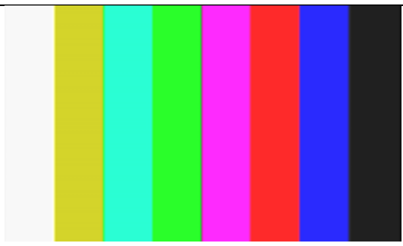
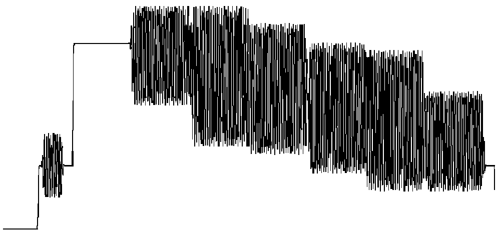
Chapter 3.　Problem Statement

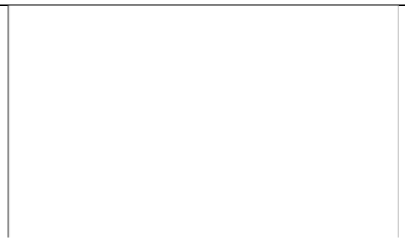
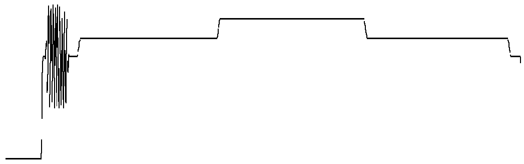
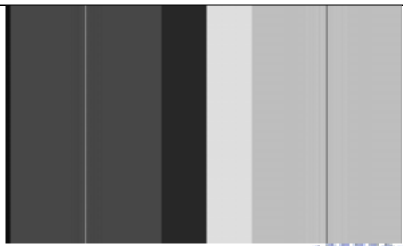
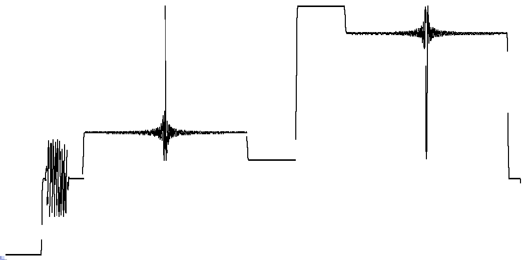
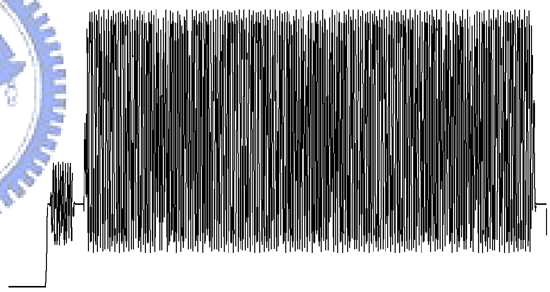
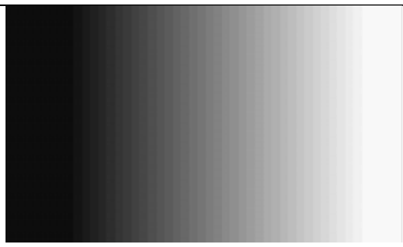
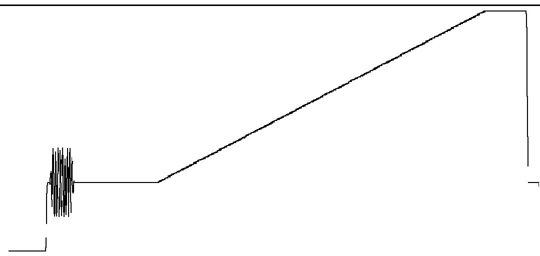
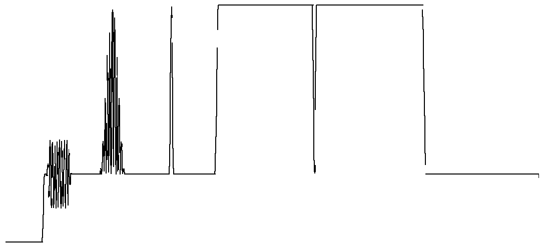
While benchmarking the video quality of STB, we normally use different kinds of test patterns to measure the performance from video output. Depends on the specification's requirement, you should change the pattern source, and then measure the performance. For the video broadcasting system, the source is encoded by compression standard. We use MPEG compression as example to describe the problem. Finally, we summarize the test cases.

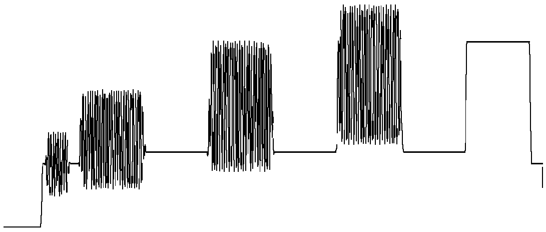
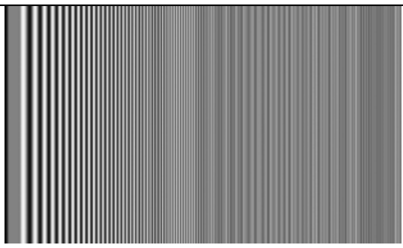
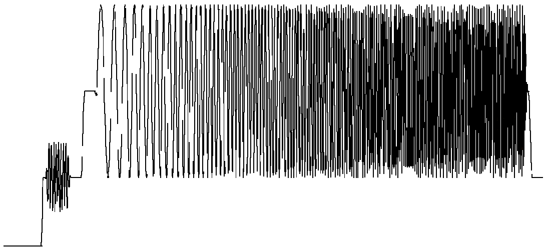
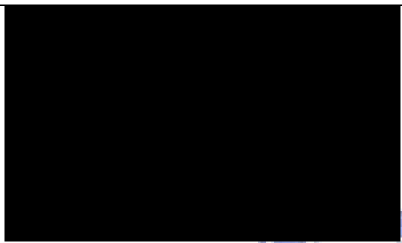
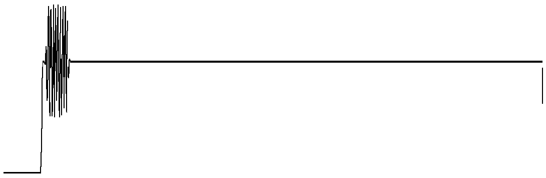
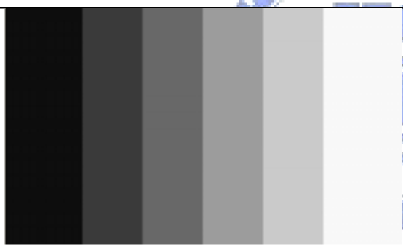
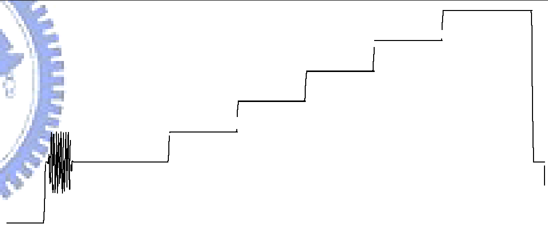
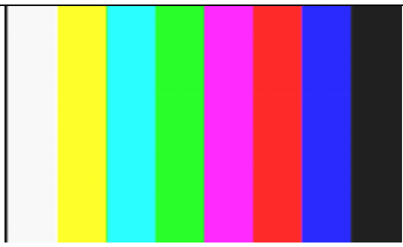
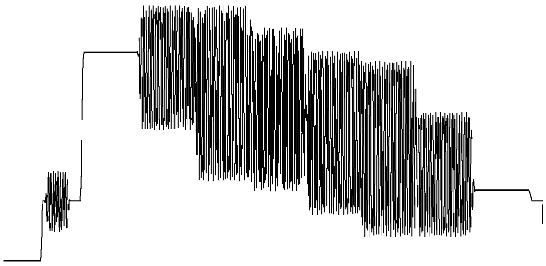
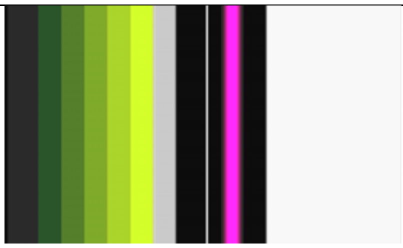
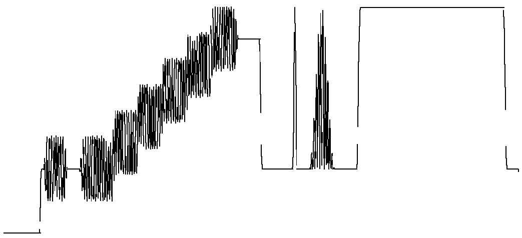
3.1 Complex Video Patterns

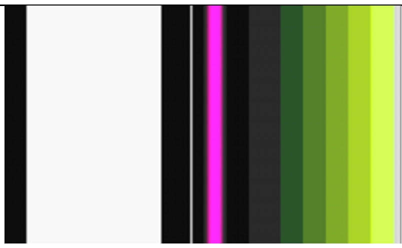
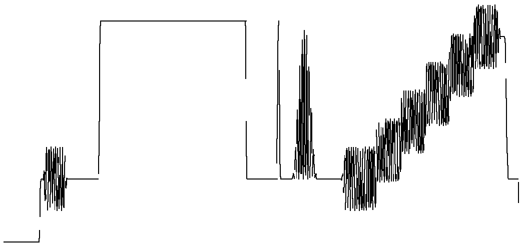
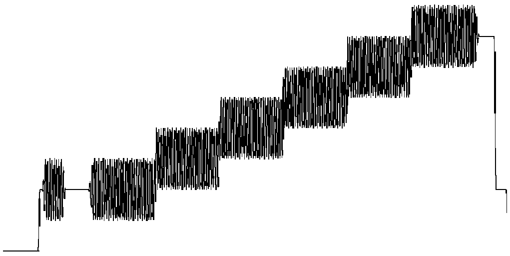
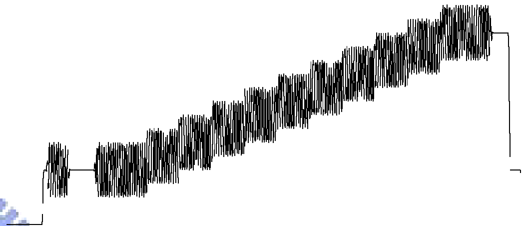
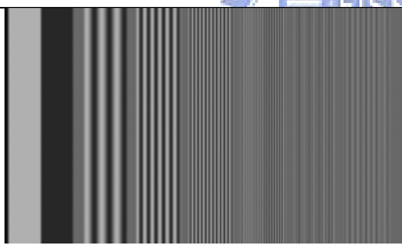
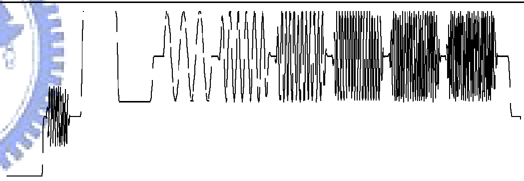
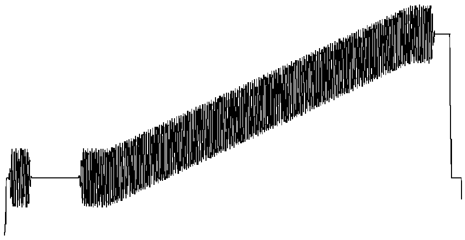
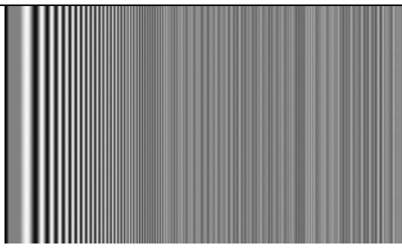
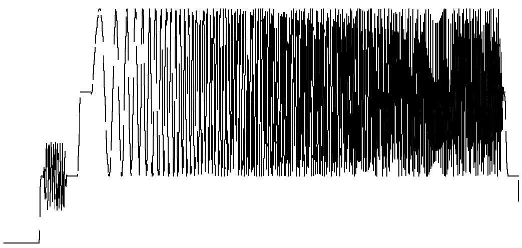
Broadcasters traditionally rely on test patterns and images to check the signal quality throughout the signal path. These various formats produce different signal degradation and so naturally require different test material.[6]

To measure these parameters, a series of video test signals are injected into the video transmission system. Then measure the response from the output of the transmission system with a video waveform monitor and a video chrominance vector scope.[3] Table 3-1 illustrates generic video source patterns. There are twenty-four patterns. Each video pattern on television is full screen. Each pattern is designed by their physical methodology to benchmark video performance. In Table 3-1, it shows the picture outlook and waveform.

Name	Picture Outlook	Waveform
Color Bar 75%		

IRE100		
GreyWind		
Sin(x/x)		
RED100		
Ramp		
PulseBar		

RBB		
6MHzSweep		
IRE0		
5 Step		
ColorBar 100%		
FCC Composite		

N7 Composite		
Mod 5 Step		
Mod 10 Step		
Multi-burst		
Mod Ramp		
8MHz Sweep		

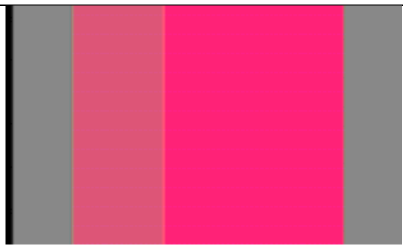
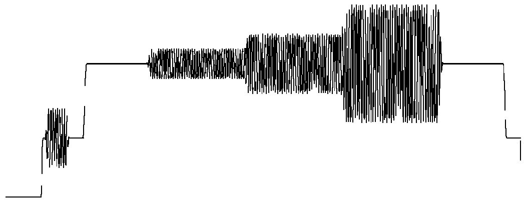
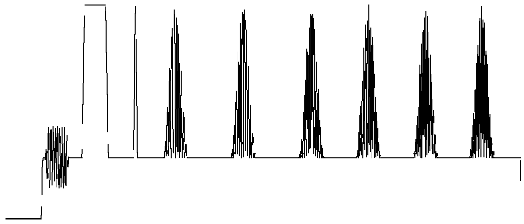
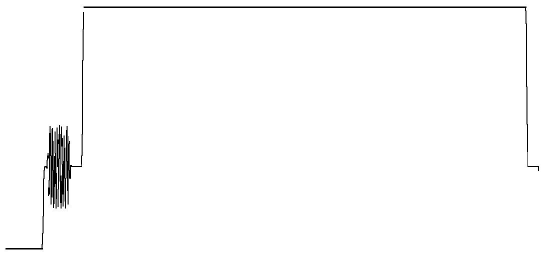
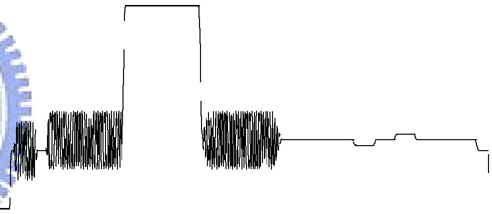
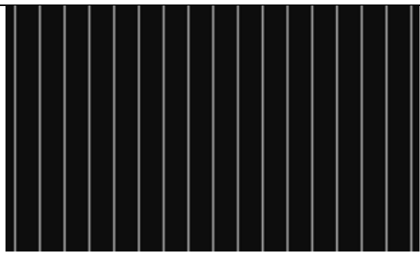
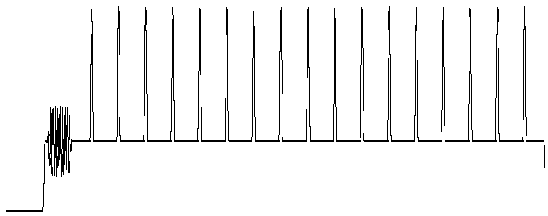
Mod Ped		
Multi-pulse		
Horzline		
IWQ		
Vertline		

Table 3-1 Video Sources Outlook and Waveform

3.2 MPEG Side Effect

The starting point of the MPEG compression process is color space conversion and chroma sampling as shown in Figure 3-2 Perceptual redundancy is removed from the compressed video signal as a result of 4:2:0 chroma sampling. 4:2:0 chroma sampling is used by most MPEG encoders. By down-sampling from 4:4:4 (RGB) to 4:2:0 in YUV color space, 50% of the original RGB signal is lost but with minimal impact to the human eyes. The human eyes are very sensitive to the changes in luminance (Y), for this reason the luminance component is preserved at full resolution. The human eyes are much less sensitive to color changes that allow for the half-resolution color difference signals (U and V). Macro block formatting is the next stage in the compression process. Each macro block represents a 16x16 pixel area. This area is comprised of four 8x8 luminance blocks (Y) and two 8x8 chrominance blocks (U and V). The block served as the primary tool is used in removing temporal redundancy. When video is tested on a frame by frame basis, very little changes between adjacent frames. MPEG uses three frames types to remove temporal redundancy. These frames types are I, P, and B. Converting from the spatial domain to the frequency domain is performed by discrete cosine transformation (DCT). The 8x8 block of pixels is represented in the frequency domain by an 8x8 matrix of frequency coefficients. Quantization is the process of removing high frequency information. While the DCT process is completely reversible without loss, the quantization process is lossy. High frequencies are removed by applying a scale factor to the DCT coefficients. The final stage of the compression process involves run length encoding (RLE) and entropy encoding. The output of the compression process is a packetized elementary stream. The raw compressed data emerged from the RLE and entropy encoding stage is packed with MPEG header information. This information includes time stamps, start codes, quantization tables, and other information needed to generate a syntactically correct MPEG bit stream.[20]

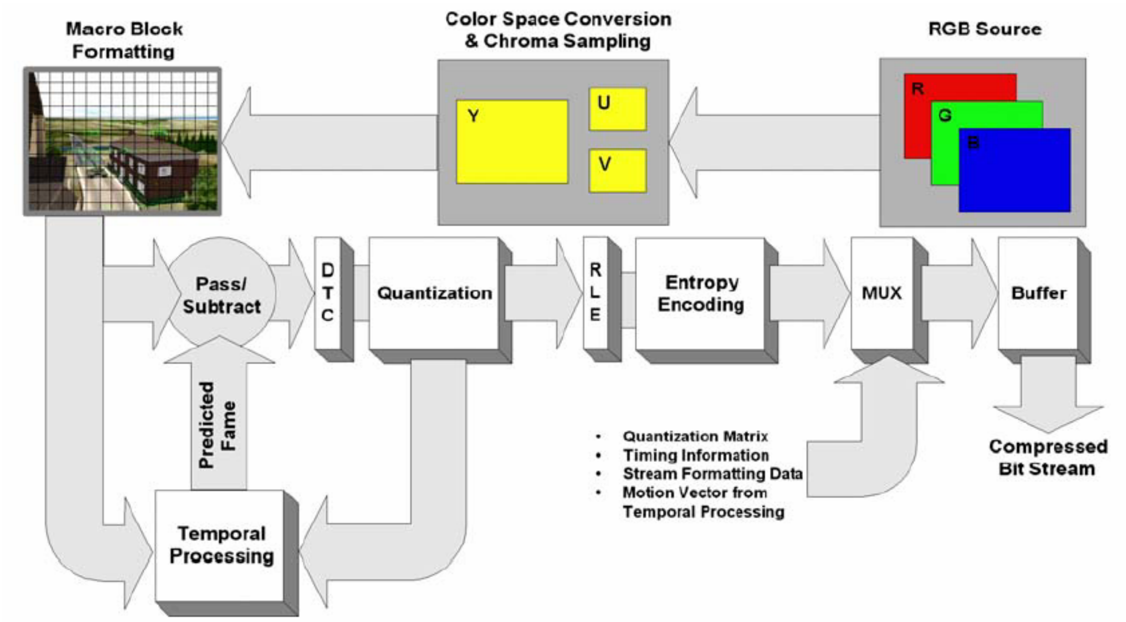


Figure 3-1 MPEG Encoding Process

The side effect of MPEG encoding is the macro block formatting. While STB is decoding the bit stream and recovering to analog video output. The television has blocking effect. So we measure the video quality from the composite output signal that should consider the television scanning line with guard video.

3.3 A Large Number of Test Cases

A robust STB should decode any kinds of compression parameters to meet customers' requirements. The following Figure 3-3, 3-4, 3-5 represent Encoder's video and audio parameters. The video setting contains video standard, compression codec, chroma format, data rate, resolution and aspect ratio. The total test cases are 716.

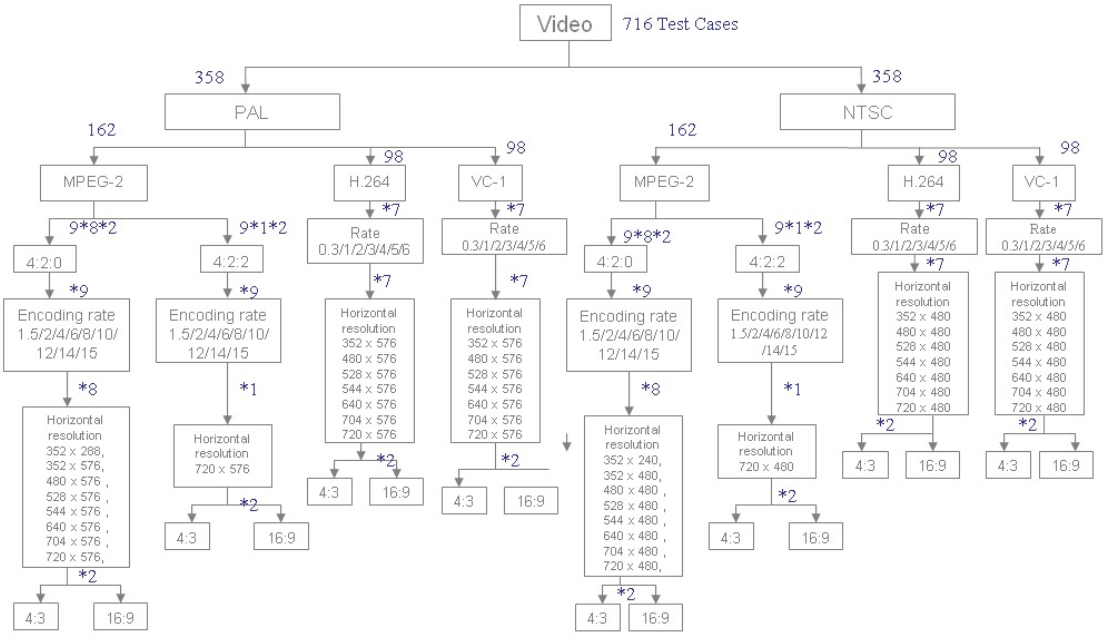


Figure 3-2 Video Codec Test Cases

The audio settings of Encoder are compression codec, sound track, sample frequency and data rate. The total test cases are 533.

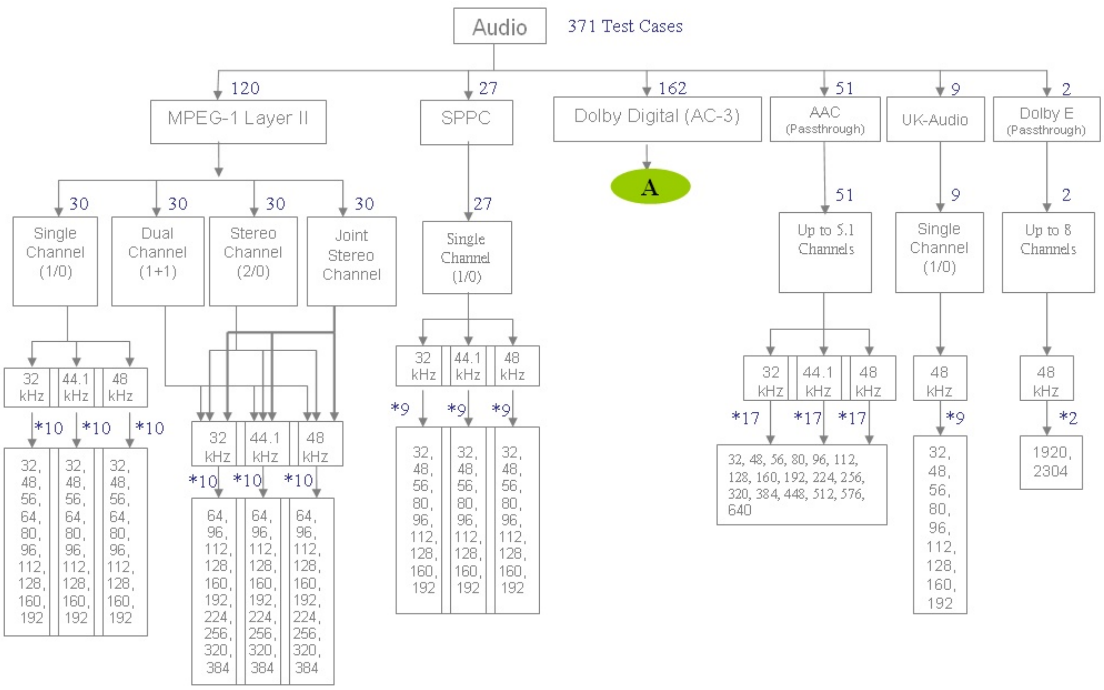


Figure 3-3 Audio Codec Test Cases

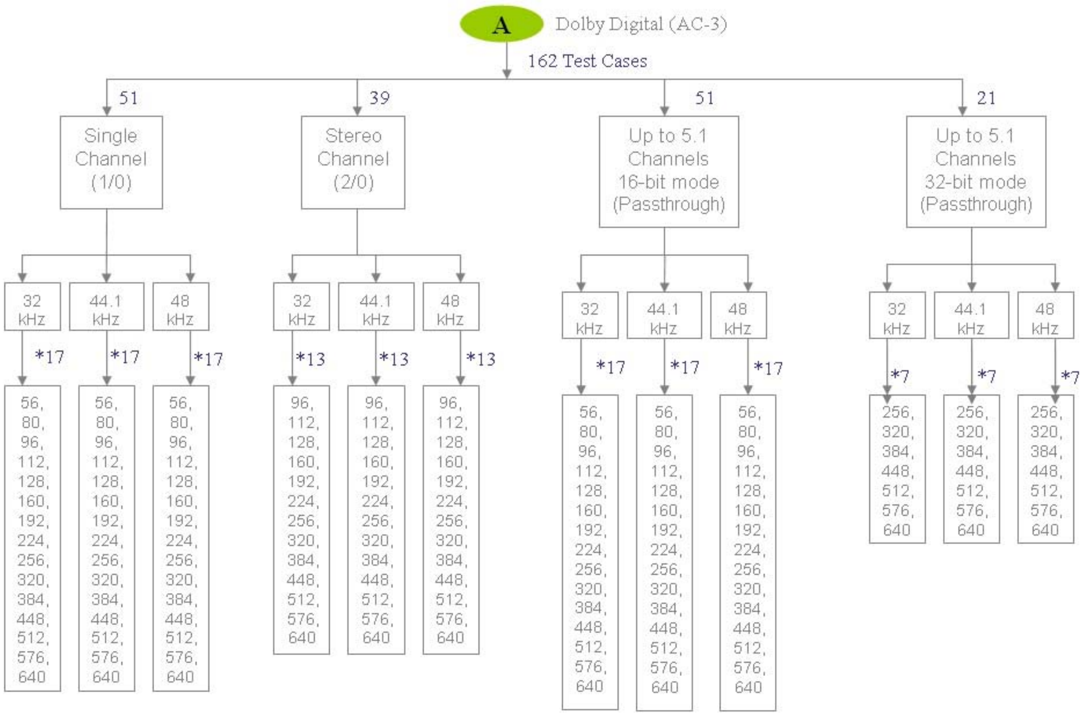


Figure 3-4 Audio Dolby Codec Test Cases

The above test cases are encoding parts. For the system test cases, it covers from signal layer, compression and transmission as Table 3-2.

Layer	Interface	Items	Total Test Cases
Signal	CVBS	NTSC/PAL Amplitude Timing Linear Distortion Nonlinear Distortion Noise	18
	Stereo	Output Voltage Frequency Response THD+Noise Channel Separation	6
Compression	Audio Codec	MPEG Dolby AAC	533
	Video Codec	MPEG-2 H264	716

		VC1	
Transmission	Ethernet	Packet delay Both fixed and variable jitter Packet reordering Packet loss Both random and congestion-dependent Packet duplication Bandwidth limitation	8

Table 3-2 Set-Top Box Test Cases Summary

If all of the test layers and test cases are considered as following Table 3-3. It will consume 329,726,592 test cases. Assume each test case takes 10 second duration. The time will be as long as 522.78 years. It is impossible to do the test, so the most important thing is to do the partial test and automation. The advantage of automation saves the test cycles and time for hundreds of years.

Layer	Total Test Cases	Test Duration	Time Consume
Signal	(CVBS Video) 18	10 sec	180 sec
	(Stereo Audio) 6	10 sec	60 sec
Compression	(Audio Codec) 533	10 sec	5,330 sec
	(Video Codec) 716	10 sec	7,160 sec
Transmission	8	10 sec	80 sec
Summary	329,726,592	-	16,486,329,600 sec (522.78 Years)

Table 3-3 Test Cases Consume 522.78 Years

Chapter 4. Operation Model

Both of the video combination technique and automation test measurement system are discussed in this chapter.

4.1 Video Combination Technique (VCT)

As there are so many video test patterns, the video combination technique is collecting 24 patterns into one video frame as shown in Figure 4-1.

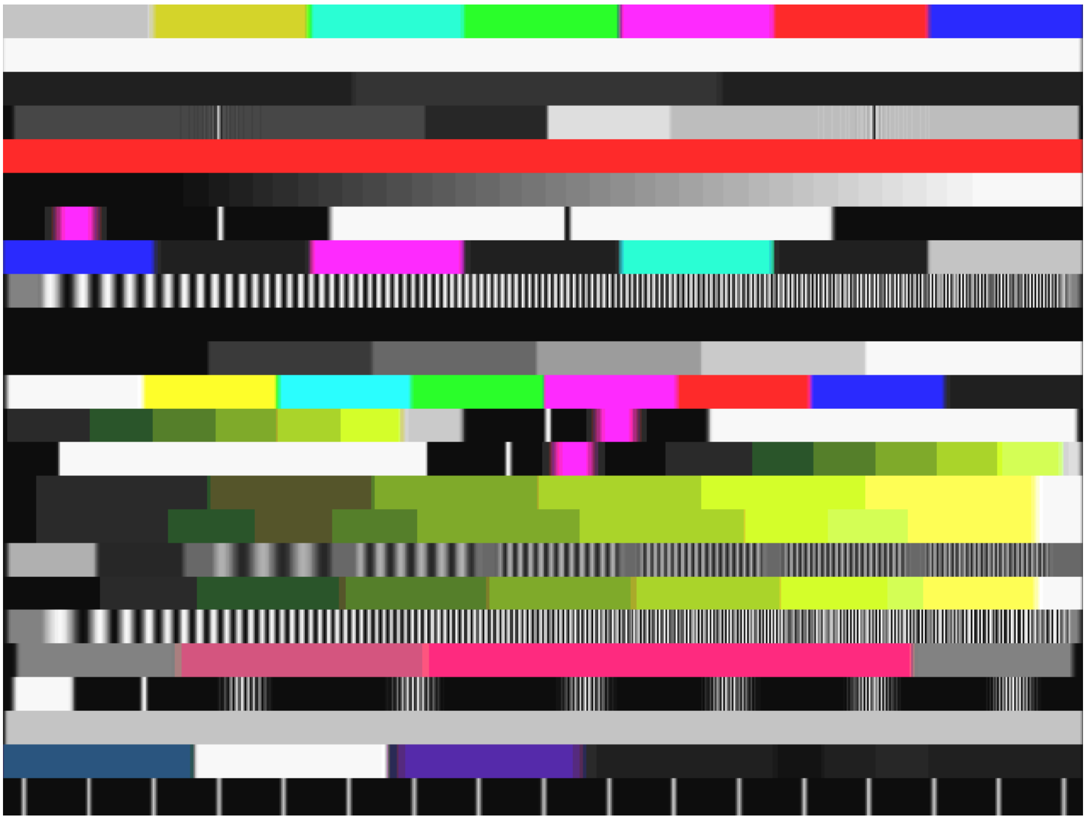


Figure 4-1 Video Combination Technique Pattern

The specific unique patterns are assigned as Table 4-1. Each unique video source has 10 scanning lines. There are 24 specific patterns totally. The 24 patterns can apply to all of the STB's video performance test requirements.

	Line @Field 1	Name
1	21 ~ 30	Bar 75
2	31 ~ 40	IRE 100
3	41 ~ 50	GreyWIND
4	51 ~ 60	Sin(x/x)
5	61 ~ 70	Red 100
6	71 ~ 80	Ramp
7	81 ~ 90	Pulse Bar
8	91 ~ 100	RBB
9	101 ~ 110	6MHz Sweep
10	111 ~ 120	IRE 0
11	121 ~ 130	5 Step
12	131 ~ 140	Bar 100
13	141 ~ 150	FCC Comp
14	151 ~ 160	N7 Comp
15	161 ~ 170	Mod 5 Step
16	171 ~ 180	Mod 10 Step
17	181 ~ 190	Multi Burst
18	191 ~ 200	Mod Ped
19	201 ~ 210	8MHz Sweep
20	211 ~ 220	Mod Red
21	221 ~ 230	Multi Pulse
22	231 ~ 240	Horizontal Line
23	241 ~ 250	IWQ
24	251 ~ 262	Vertical Line

Table 4-1 VCT Pattern Arrangement

4.2 Automation Test Measurement System (ATMS)

The generic digital broadcast system contains signal source, compression, transmission network and STB, so the Automation Test Measurement System (ATMS) also follows the generic rules. The sources must have standard video source and audio source. The real-time encoder plays with different kinds of codec, bit rate, resolution. After the encoder, signal is digital bit stream then connects to transmission network. Depends on the transmission network, STB receives the signal then decodes to baseband video and audio signal to television.

The controller PC is the key equipment. The controller PC connects to all equipment like Figure 4-2. The jobs of control PC are automatic changing video/audio source patterns, real-time encoder parameters, video analyzer and audio analyzer. With respect to equipment's interface, the control PC must have some interface like GPIB card, APIB card, Ethernet and infrared fixture.

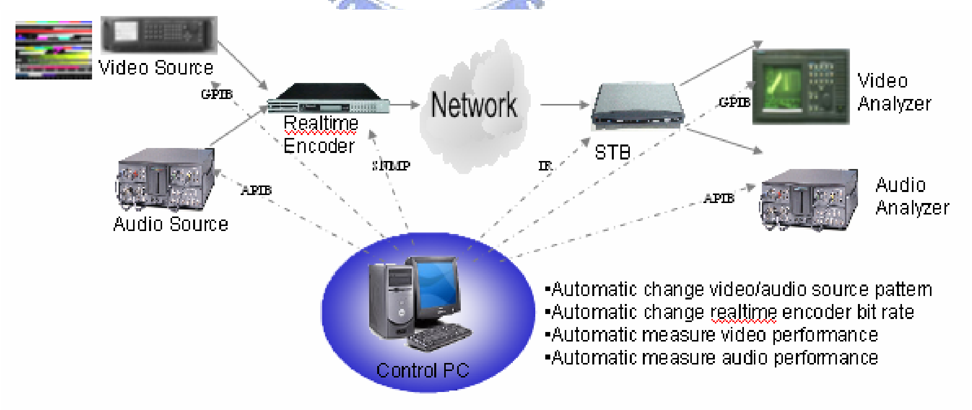


Figure 4-2 Automation Test System Topology

Chapter 5. Implementation

Here we implement two techniques. The first one is Video Combination Technique (VCT), and the other one is Automation Test Measurement System (ATMS). The VCT has 3 sections to describe video scanning line assignment, frame editing flow chart and guard video scanning line. Finally, ATMS implements a program to integrate all the test cases.

5.1 VCT

5.1.1 Video Scanning Line Assignment

As NTSC system has 525 scanning lines. Thus, each frame takes two vertical scans (fields), with the even and odd lines scanned on alternate fields as shown in Figure 5-1.[24]

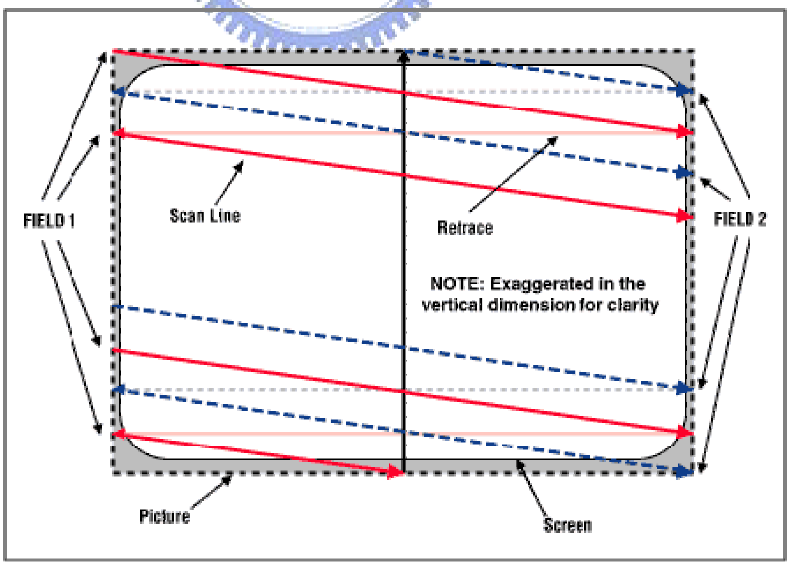


Figure 5-1 Television Interlaced Scanning

The first one to 20 scanning lines are vertical blanking interval (VBI). VBI is not displayed by televisions. Figure 5-2 illustrates the logical of NTSC scanning standard, hence, the useful scanning lines start from 21 to 262 for odd field as summarized in Table 5-1.

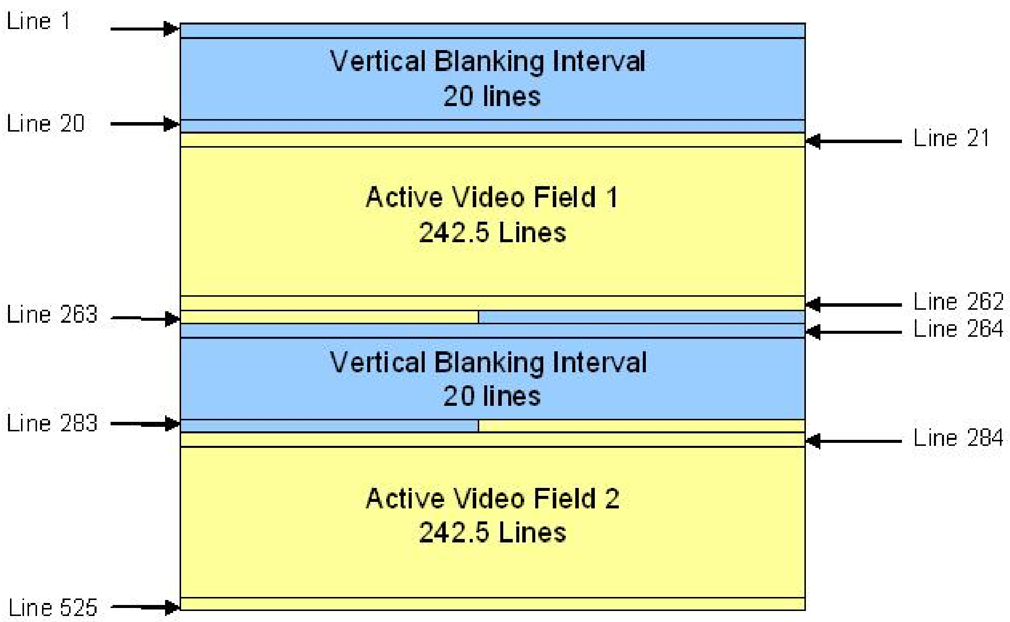


Figure 5-2 Details of NTSC Scanning Standard

There are twenty-four video sources to be implemented by video combination technique. Therefore, each specific pattern requires 10 scanning lines.

Each pattern scanning line = (262-21) / 24 = 10

	Lines	Useful Lines
Field 1 (Odd)	1 ~ 262	21 ~ 262
Field 2 (Even)	263 ~ 525	284 ~ 525

Table 5-1 NTSC System VCT Assignment

5.1.2 Frame Editing Flow Chart

First of all, each video source must follow their equations as illustrated in Figure 5-3. Each scanning lines contain three parts: sync, color burst and white Level. Each of specific patterns then combines to a video frame as Table 4-1. While the combination frame is done then compiles the unique frame, we must assign the pattern's directory to be fetched out. Finally, download the file to video source generator. Operate the video source and play the video combination pattern.

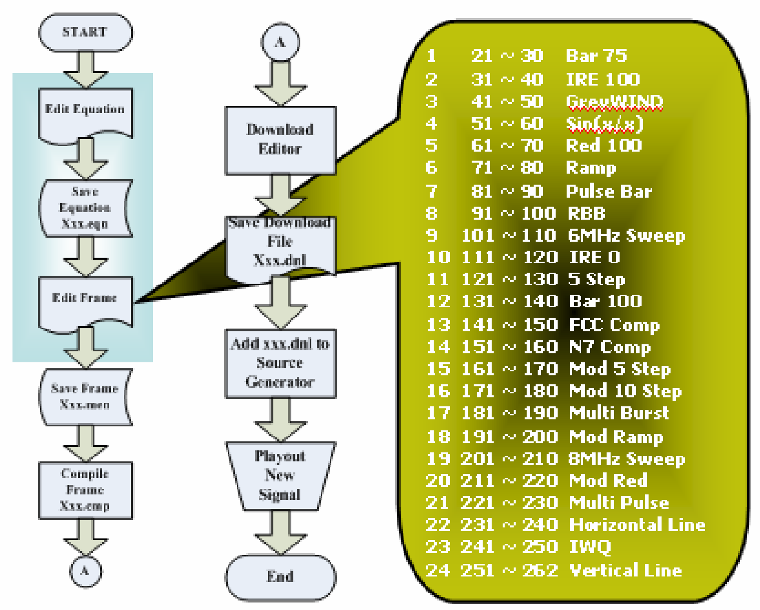


Figure 5-3 Frame Editing Flow Chart

5.1.3 Guard Video Scanning Line

According to chapter 5.1.1, each video contains 10 scanning lines logically. But the physically, we design a unique pattern as shown in Figure 5-3 to evaluate how many scanning lines are available. We do an evaluation pattern that only has IRE0 and color bar 75%. The scanning lines with color bar are from 1 to 9 group and step with 20 lines as shown in Table 5-2. The pattern passes through the digital broadcasting system as shown in Figure 2-4. We normally use color bar pattern to evaluate the picture quality as discussed in Chapter 2.5. Using video analyzer analysis the video quality then comes out the color vector result as shown in Table 8.

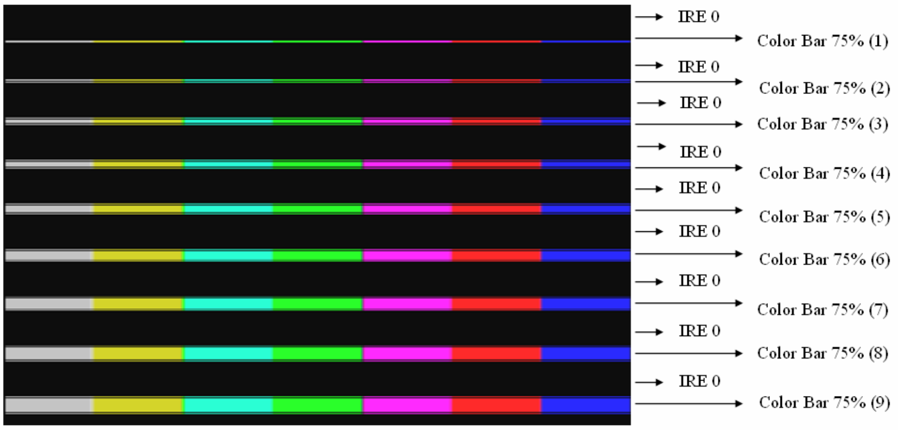


Figure 5-4 Guard Video Scanning Pattern

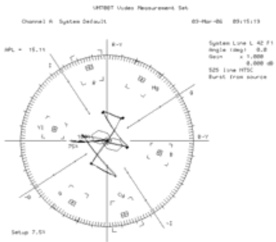
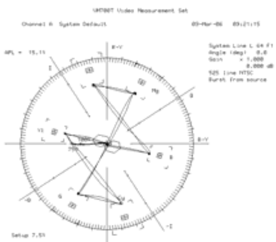
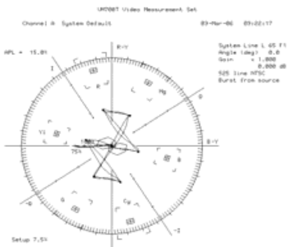
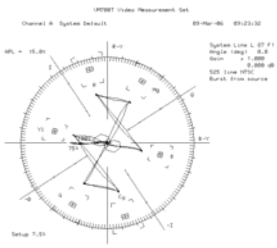
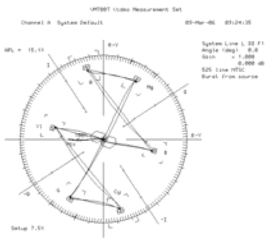
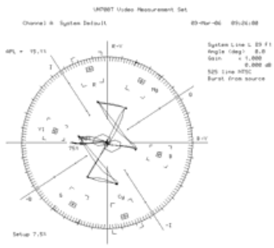
In Table 5-2, we define the guard video scanning lines. Due to the line limitation, we test to group nine.

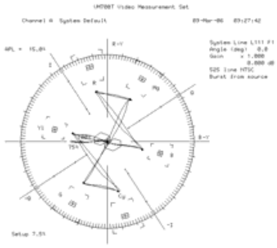
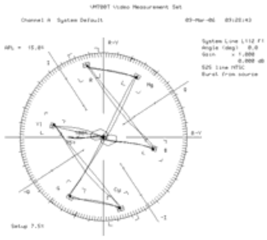
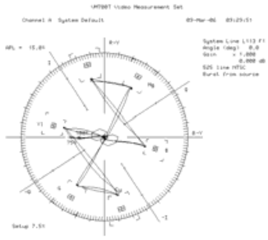
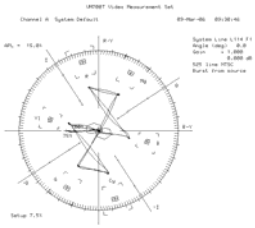
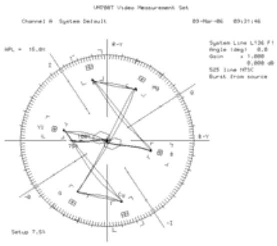
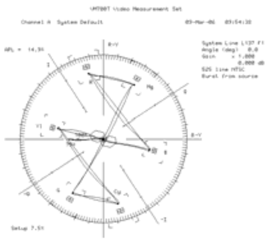
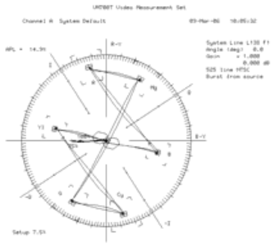
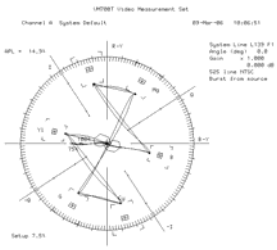
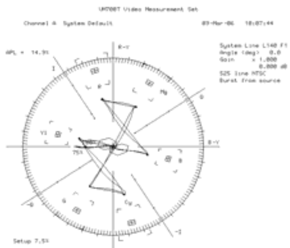
Name	Line @Odd Field	Line @Even Field	Total Lines
IRE0	21 ~ 41	284 ~ 304	20
Color Bar 75%	42 ~ 42	305 ~ 305	1
IRE0	43 ~ 63	306 ~ 326	20
Color Bar 75%	64 ~ 65	327 ~ 328	2
IRE0	66 ~ 86	329 ~ 349	20
Color Bar 75%	87 ~ 89	350 ~ 352	3
IRE0	90 ~ 110	353 ~ 373	20
Color Bar 75%	111 ~ 114	374 ~ 377	4
IRE0	115 ~ 135	378 ~ 398	20
Color Bar 75%	136 ~ 140	399 ~ 403	5
IRE0	141 ~ 161	404 ~ 424	20
Color Bar 75%	162 ~ 167	425 ~ 430	6
IRE0	168 ~ 188	431 ~ 451	20
Color Bar 75%	189 ~ 195	452 ~ 458	7
IRE0	196 ~ 216	459 ~ 479	20
Color Bar 75%	217 ~ 224	480 ~ 487	8
IRE0	225 ~ 245	488 ~ 508	20
Color Bar 75%	246 ~ 254	509 ~ 517	9
IRE0	255 ~ 262	518 ~ 525	7

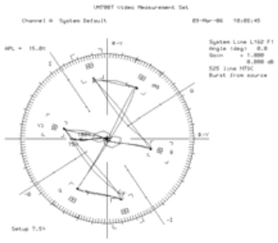
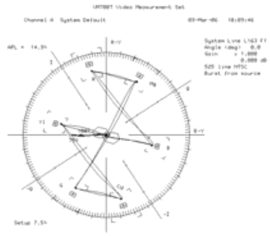
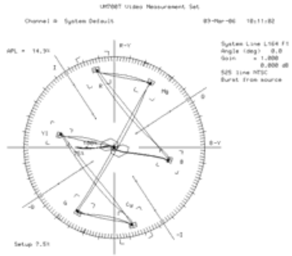
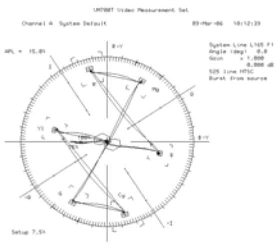
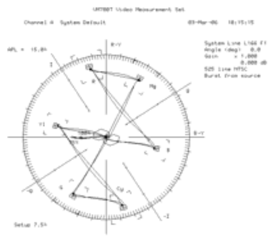
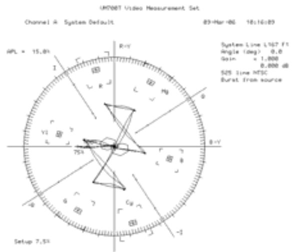
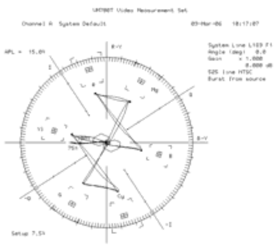
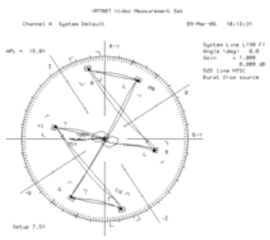
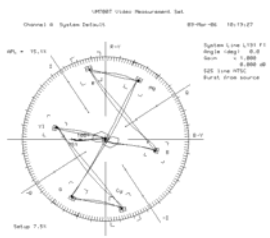
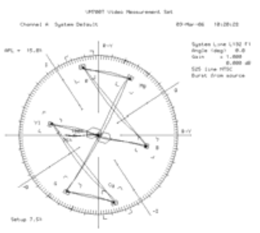
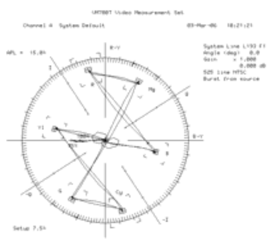
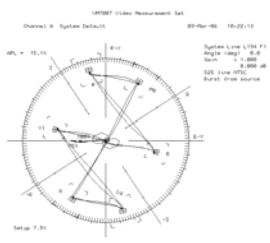
Table 5-2 Guard Video Scanning Pattern Lines Arrangement

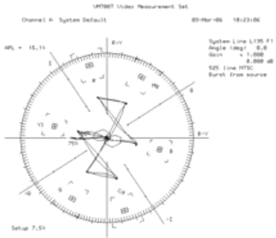
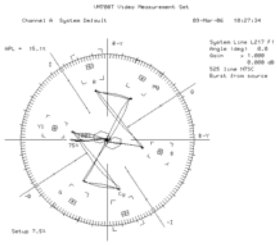
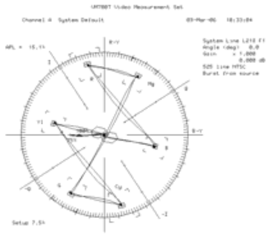
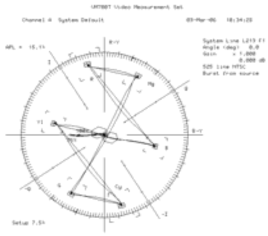
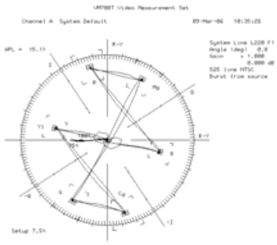
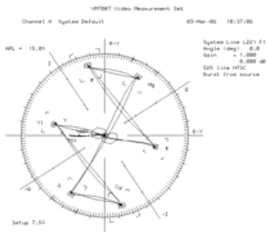
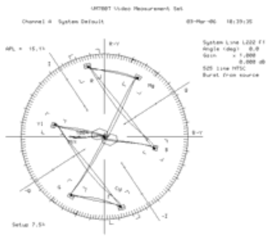
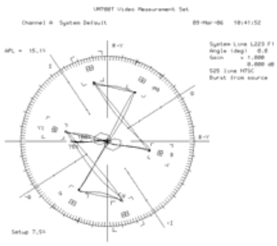
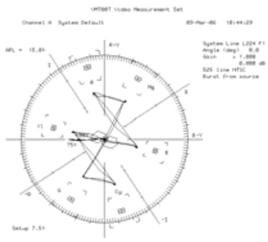
Table 5-3 describes the guard video scanning line result from group 1 to 9. We come out our observation. The background knowledge of color vector is discussed in Chapter 2.5. A good video quality of color vector must locate on square for each vertex.

We conclude the test result while groups are below 3 then the video fails. All of top and bottom video are worse. After Group 7, the scanning line has 5 good quality of video. The “Guard Video Scanning Line” should have two scanning line spaces for each top and bottom video source. The video quality is good besides “Guard Video Scanning Line”.

Scanning Line	Color Vector Measurement Result		
Line 42 (Group 1)	Line 42  Fail		
Line64 ~ 65 (Group 2)	Line 64  Fail	Line 65  Fail	
Line 87 ~ 89 (Group 3)	Line 87  Fail	Line 88  Pass	Line 89  Fail

Line 111 ~ 114 (Group 4)	Line 111  Fail	Line 112  Pass	Line 113  Fail
	Line 114  Fail		
Line 136 ~ 140 (Group 5)	Line 136  Fail	Line 137  Fail	Line 138  Pass
	Line 139  Fail	Line 140  Fail	

Line 162 ~ 167 (Group 6)	Line 162  Fail	Line 163  Fail	Line 164  Pass
	Line 165  Pass	Line 166  Pass	Line 167  Fail
Line 189 ~ 195 (Group 7)	Line 189  Fail	Line 190  Pass	Line 191  Pass
	Line 192  Pass	Line 193  Pass	Line 194  Pass

	Line 195  Fail		
Line 217 ~ 224 (Group 8)	Line 217  Fail	Line 218  Pass	Line 219  Pass
	Line 220  Pass	Line 221  Pass	Line 222  Pass
	Line 223  Fail	Line 224  Fail	

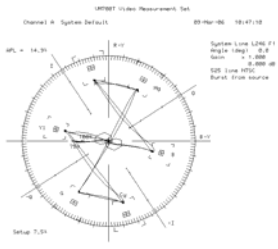
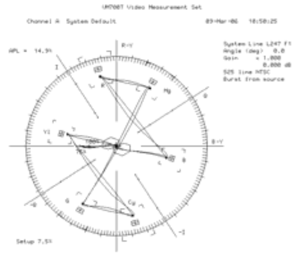
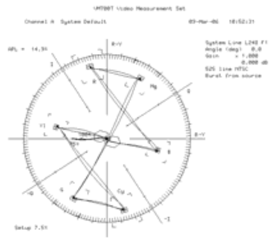
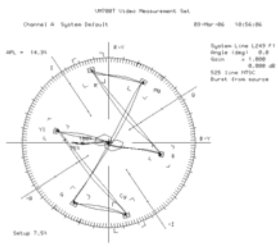
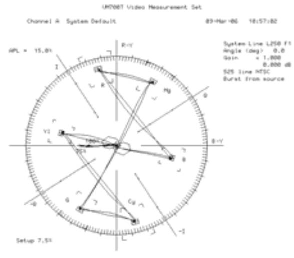
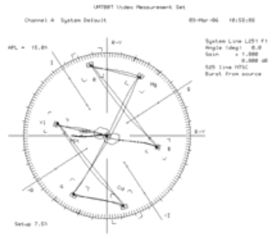
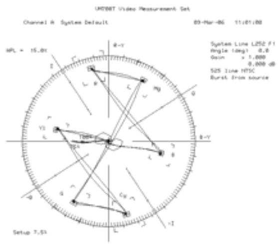
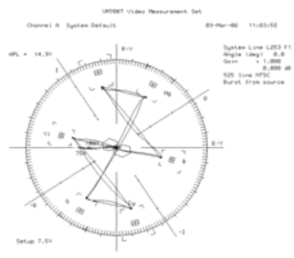
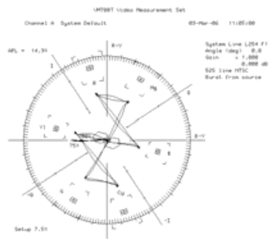
Line 246 ~ 254 (Group 9)	Line 246  Fail	Line 247  Fail	Line 248  Pass
	Line 249  Pass	Line 250  Pass	Line 251  Pass
	Line 252  Pass	Line 253  Fail	Line 254  Fail

Table 5-3 Guard Video Scanning Line Color Vector Performance

5.2 ATMS

While STB has so many test cases, it is essential to implement the Automation Test Measurement System (ATMS). All components of the measurement systems allow for a remote control operation.[25] The controller PC will be the control center for all equipment. According to test cases and specification, the test engineer can define the criteria and limitation. Then everything is automatic. ATMS improves the test productivity to hundreds of year as shown in Table 3-3.

5.2.1 Controller PC Working Flow Chart

ATMS connects video source, video analyzer, audio source, audio analyzer, encoder and device under test unit as shown in Figure 5-4. First of all, ATMS must communicate with these equipments. The next step will be parameter setting. The settings depend on customer's requirements, run the program, and then generate the test report.

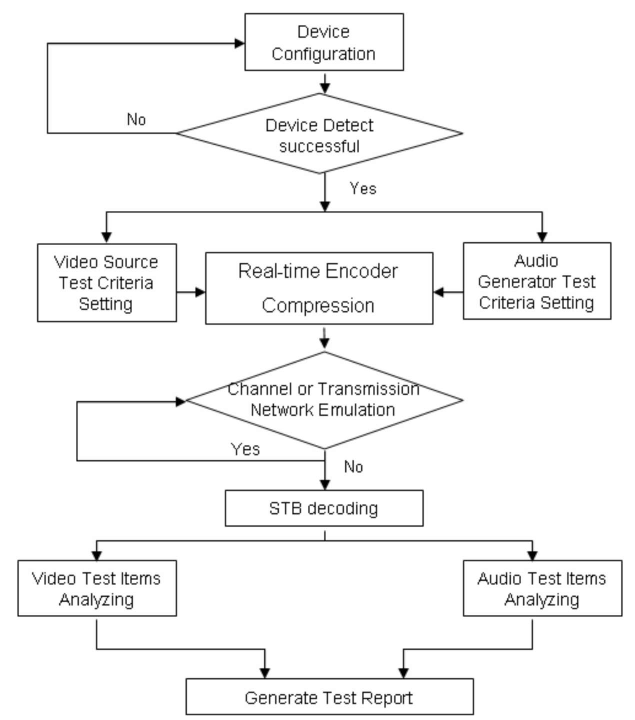


Figure 5-5 Controller PC Working Flow

5.2.2 Menu Tree of ATMS

The ATMS of menu hierarchy is as Figure 5-5. In the beginning, we must check the device setup, and then set the test items. Finally, ATMS will record the test results. Device Setup menu will configure the TG2000, AP2700, MV100 and VM700. So the program should make sure every thing connected.

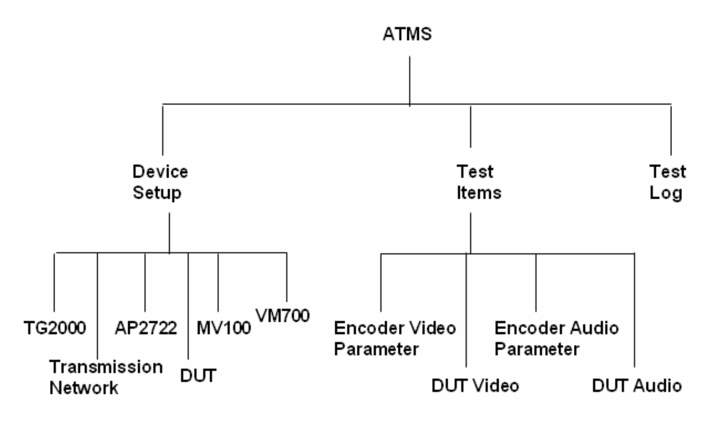


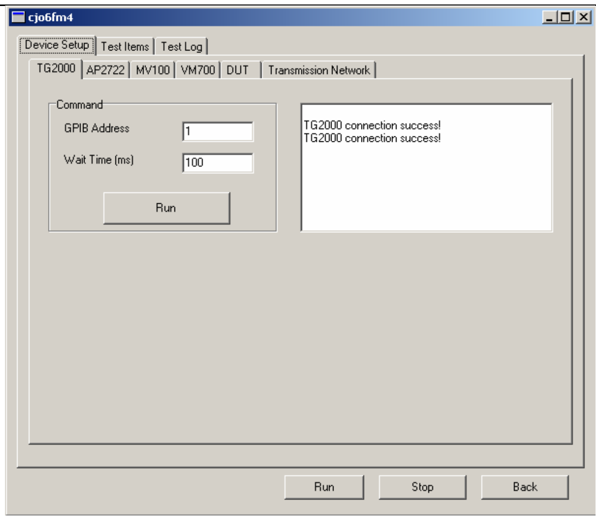
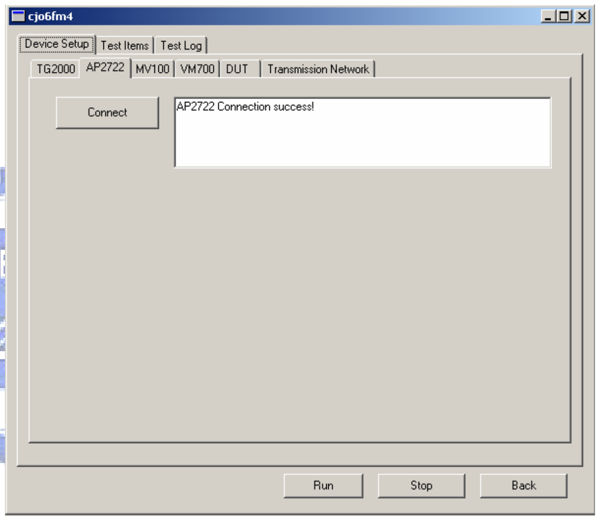
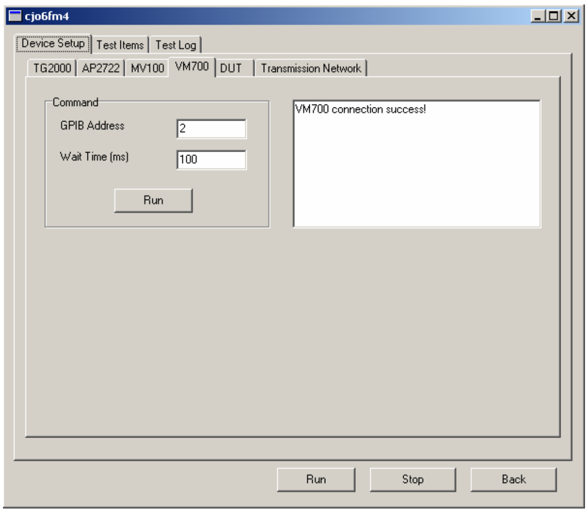
Figure 5-6 Menu Tree of ATMS

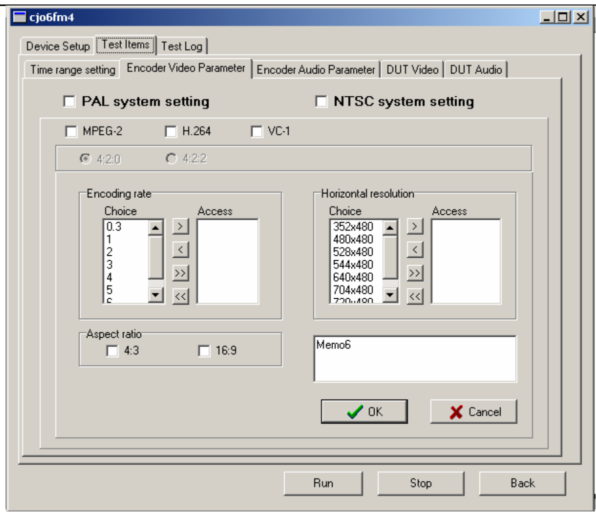
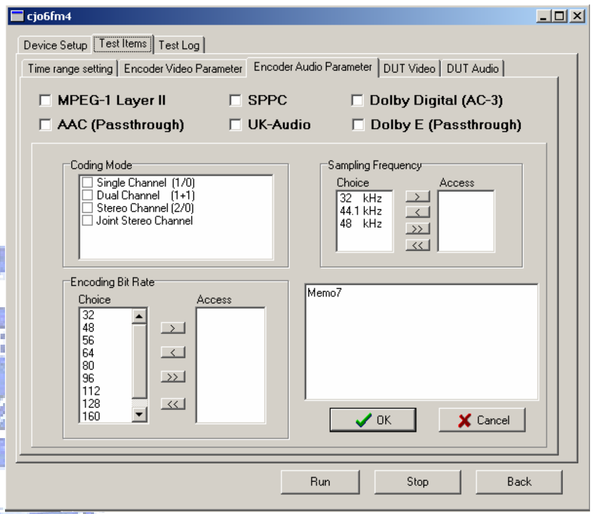
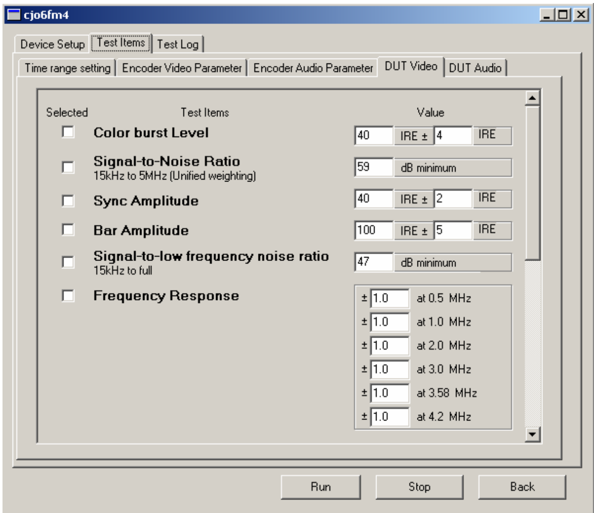
5.2.3 System Implementation

While implementing the ATMS, it requires many professional equipment like Table 5-4. Depends on equipment interface, the controller PC is also required to setup the same interface as well. We use Borland C++ Builder for programming. The functionality of program is Table 5-5 for details.

Item	Name	Function	Control Interface
1	Video Source	Generate Video Patterns	GPIB
2	Audio Source	Generate Audio Patterns	APIB (GPIB like)
3	Encoder	MPEG-2 Realtime Encoder	MIB
4	IP Gateway	Transcode MPEG-2 To IP	MIB
5	Cable Modulator	Digital QAM Modulation	MIB
6	Satellite Modulator	Digital QPSK Modulation	MIB
7	Terrestrial Modulator	Digital COFDM Modulation	RS232
8	Video Analyzer	Analyze Video Performance	GPIB
9	Audio Analyzer	Analyze Audio Performance	APIB
10	PC	Control All Equipments	
11	Router	IP Multicast Router	Ethernet
12	NIST Net	WAN Emulator	

Table 5-4 ATMS Equipment List

Name	Objective	Menu
Device Setup TG2000	Connecting to video source generator	
Device Setup AP2700	Connecting to audio source generator	
Device Setup VM700T	Connecting to video analyzer	

Test Item Video Codec Test Cases Setting	Connecting to real-time encoder to setup video compression parameters	
Test Item Audio Codec Test Cases Setting	Connecting to real-time encoder to setup audio compression parameters	
Test Item Device Under Test Unit Video Output Performance Measurement	Measure set-top box CVBS output quality performance	

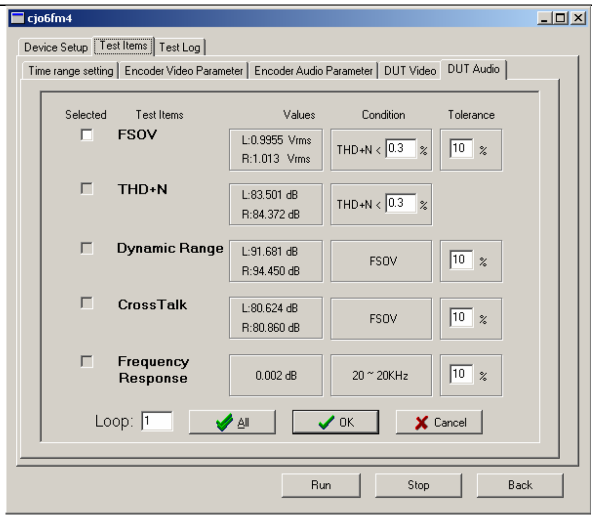
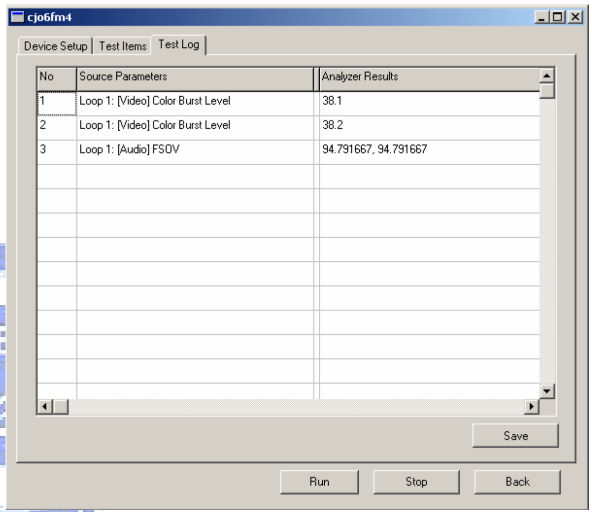
Test Item Device Under Test Unit Audio Output Performance Measurement	Measure STB stereo output quality performance	
Test Log	According test cases generating test report automatically	

Table 5-5 ATMS Implementation Menu

Chapter 6. Evaluation

With respect to Figure 6-1, we setup a VCT evaluation test environment. The video source is directly connecting to video analyzer without any encoding and decoding equipment. The video source plays generic video pattern and VCT pattern as shown in Table 3-1 and Figure 4-3 then we record the values as shown in Table 6-1.

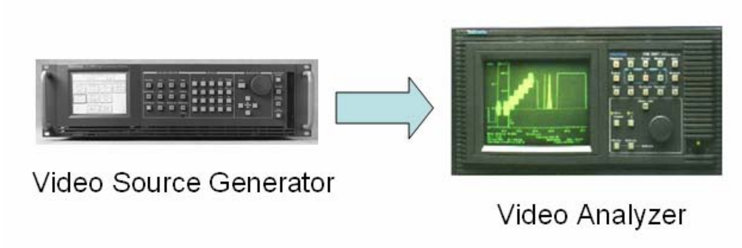


Figure 6-1 VCT Evaluation Test Topology

With respect to video quality index, we measure amplitude, timing, linear distortions, nonlinear distortions and noise. Each quality index defines their test items. The comparison table totally has 33 items are matching, and the other 1 items are in machine tolerance. So it proves the Video Combination Technique is reliable and robust in the video source.

No.	Video Quality Index	Measure Item	Video Analyzer Test Item	Unit	Scanning Line	Generic Pattern	VCT Pattern
1	Amplitude & Time	Time Measurement	Bar Line Time	Sync Level	F1L145	39.8 IRE	39.8 IRE
2			Bar Line Time	Sync/Bar Ratio	F1L145	99.80%	99.80%
3			H Timing (RS-170A)	Burst Cycles	F1L145	9.0 cycles	9.0 cycles
4			H Timing (RS-170A)	Burst Level	F1L145	39.1 IRE	39.1 IRE
5			H Timing (RS-170A)	Sync Cycles	F1L145	4.70 us	4.70 us
6			H Timing (FCC)	Burst Cycles	F1L145	9.0 cycles	9.0 cycles
7			H Timing (FCC)	Burst Level	F1L145	39.1 IRE	39.1 IRE
8			H Timing (FCC)	Sync Cycles	F1L145	4.84 us	4.84 us
9		SCH Phase	SCH_Phase	SCH Phase	F1L145	1.8 deg	1.8 deg

10	Linear Distrotions	Chrominance-to-Luminance Gain & Delay	Chrom/Lum Gain Delay	Chroma Gain	F1L145	97.80%	97.90%
11			Chrom/Lum Gain Delay	Chroma Delay	F1L145	1.0 ns	1.0 ns
12		Short Time Distortion	Short Time Distortion	Rising Edge	F1L155	0.4% SD	0.4% SD
13			Short Time Distortion	Rise Time	F1L155	128.9 ns	128.9 ns
14		Line Time Distortion	Bar Line Time	LineTime Dist.	F1L155	0.10%	0.10%
15			Bar Line Time	Bar tilt	F1L155	0.00%	0.00%
16			Bar Line Time	Bar Width	F1L155	18.0 us	18.0 us
17		Frequency Response	MultiBurst	0.5MHz	F1L185	-0.03 dB	-0.03
18			MultiBurst	1.0MHz	F1L185	-0.07 dB	-0.07
19			MultiBurst	2.0MHz	F1L185	-0.14 dB	-0.14
20			MultiBurst	3.0MHz	F1L185	-0.16 dB	-0.16
21			MultiBurst	3.58MHz	F1L185	-0.19 dB	-0.19
22			MultiBurst	4.2MHz	F1L185	-0.22 dB	-0.22
23			GroupDelay SinX_X	Amplitude at 0.20MHz	F1L55	-0.1 dB	-0.1
24			GroupDelay SinX_X	Group Delay at 0.20MHz	F1L55	-1 ns	-1 ns
25		Group Delay	GroupDelay SinX_X	Amplitude at 0.20MHz	F1L55	-0.1 dB	-0.1
26			GroupDelay SinX_X	Group Delay at 0.20MHz	F1L55	-1 ns	-1 ns
27		K Factor Ratings	K_Factor	K-2T	F1L145	0.3%	0.3%
28			K_Factor	K-PB	F1L145	-0.3%	-0.3%
29			K_Factor	PB Ratio	F1L145	98.8%	98.8%
30			K_Factor	HAD	F1L145	251.2 ns	251.2 ns
31	Nonlinear Distrotions	Differential Phase	DGDP	pk-pk	F1L155	0.09 deg	0.09 deg
32		Differential Gain	DGDP	pk-pk	F1L155	0.11 %	0.11
33		Luminance NonLinearity	Luminance NonLinearity	pk-pk	F1L125	0.3%	0.3%
34	Noise Measurement	Signal-to-Noise Ratio	Noise Spectrum	Noise Level @BW 15KHz to 5.0MHz	F1L35	-78.6 dBrms	-78.6 dBrms

Table 6-1 Generic Pattern and VCT Pattern Comparison

Chapter 7. Conclusions and Future Works

As the generic video test methodology is to display the source in turns. Our approach VCT shows the pattern one time and at least 24 patterns per frame. The benefit of VCT will save time for 24 times less than the one of traditional methodology. The operation complexity is also lower than generic one.

If we estimate the shipping quantity is one million per year and use six kinds of video sources for test cases, the operation costs two NT dollars per minute. Therefore, the generic method costs twelve million NT dollars. And the VCT approach costs two million NT dollars. As a result, the VCT approach could save up to ten million NT dollars per year.

The concept of guard video improves the accuracy of video measurement. Due to broadcasting system, it is essential to choose video compression standard. The side effect of MPEG compression downgrades the VCT performance between the adjacent patterns. While the pattern of VCT is over ten scanning lines, we choose the center scanning line of each pattern. The performance of video quality is reliable.

The VCT has been filed as a patent application in Taiwan, US, Europe and China. It also presents in Hon-Hai Precision 3rd R&D Technical Committee.

The Automation Test Measurement System (ATMS) can apply to all STB products. The ATMS reduces the human resources and test cycles. The benefits of ATMS are also time and cost saving.

In the modern STB and broadcasting network, high-definition contents are more popular. The decoder interface will build in digital video and component interface. Based on the quality index experience, we will do more research on this topic in the future.

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Appendix - Acronyms Definition

AAC	Advanced Audio Coding, developed by the MPEG group.
AC3	A way of compressing audio signals to produce Dolby Digital 5.1. surround sound. ie 5 Channels. It is sometimes refered to as a AC3 Codec.
APIB	Audio Precision Interface Bus
A/V	Audio and video
ATMS	Automated test measurement system
ATSC	Advanced Television Systems Committee
CVBS	A format designed to provide both video and synchronizing information in one signal.
CPE	Consumer promise equipment
DHCP	Dynamic Host Configuration Protocol
Dolby	Dolby Laboratories, well-known in consumer audio standard
DUT	Device under test unit
DVB	Digital video broadcasting
EPG	Electronic program guide
FCC	Federal Communications Commission
GPIB	General Purpose Interface Bus
H.264	H.264, MPEG-4 Part 10, or AVC, for Advanced Video Coding, is a digital video codec standard which is noted for achieving very high data compression. It was written by the ITU-T Video Coding Experts Group (VCEG) together with the ISO/IEC Moving Picture Experts Group (MPEG) as the product of a collective partnership effort known as the Joint Video Team (JVT). The ITU-T H.264 standard and the ISO/IEC MPEG-4 Part 10 standard (formally, ISO/IEC 14496-10) are technically identical.
HDTV	High Definition Television, this term describes several advanced standards proposals to allow high-resolution TV to be received in the home.
IR	Infrared
IRD	Integrated Receiver Decoder
IRE	Institute of Radio Engineers, a unit equal to 1/140 of the peak-to-peak amplitude of the video signal, which is typically one volt.
ISDB	Integrated Services Digital Broadcasting
KPI	Key performance index

MIB	Management Information Base
MPEG	Moving Picture Experts Group
MPTS	Multiple program transport stream
NIST	NIST Net is a network emulation package that runs on Linux.
NTSC	National Television Standards / Systems Committee, the color system used in the United States and North America. The field rate for NTSC is 60 Hz with 525 lines per screen and the subcarrier transmission method is a straight phase and amplitude modulation system for chroma using a subcarrier frequency of 3.58 MHz.
RS-170	the United States standard that was used for black-and-white TV (monochrome) , and defines voltage levels, blanking times, the width of the sync pulses, and so forth.
SNMP	Simple Network Management Protocol
SPTS	Single program transport stream
STB	Set-top box
TFTP	Trivial File Transfer Protocol
THD	Total Harmonic Distortion, Harmonic Distortion is a means for measuring Nonlinear Distortion .
TS	Transport stream
TS/IP	Transport stream over IP
VBI	Vertical blanking interval
VC1	Windows Media Video 9 Advanced Profile codec is Microsoft's implementation of the advanced profile of VC1, Microsoft submits into Society of Motion Picture and Television Engineers (SMPTE) to establish a new video codec specification.
VCT	Video combination technique