디지털 방송 이론심화 과정 - 네 번째 시간

< Analog & Digital Basic >

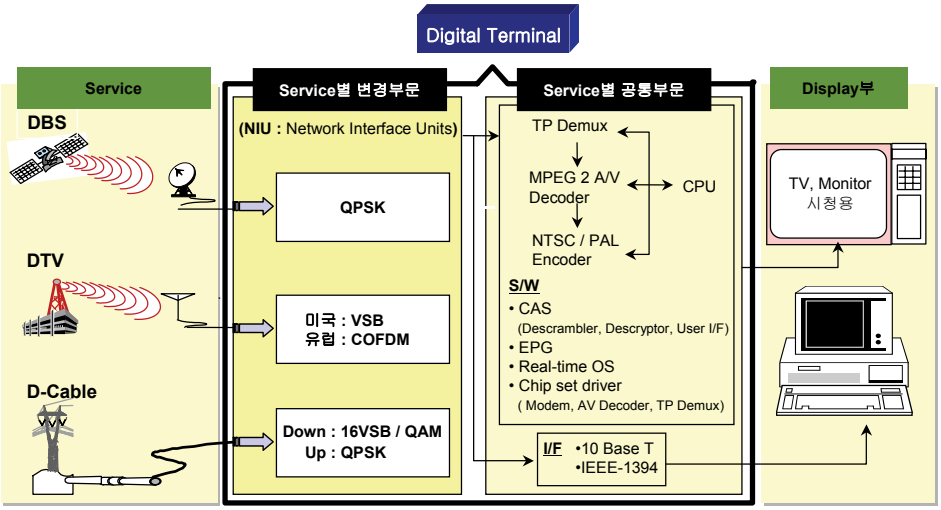
권 태 석

한국 텍트로닉스 차장

Analog & Digital Video Basic

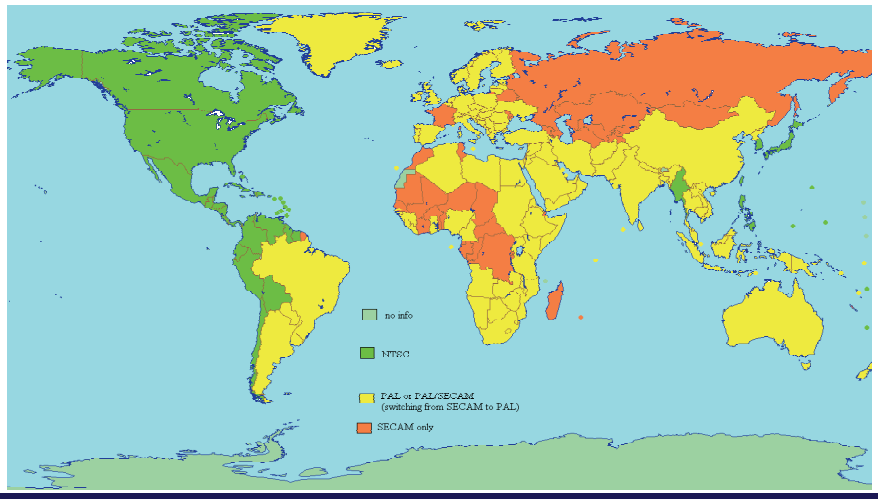
한국 텍트로닉스㈜

디지털 수신 시스템



Broadcast Standards

- World Use of the Composite Analog Signal

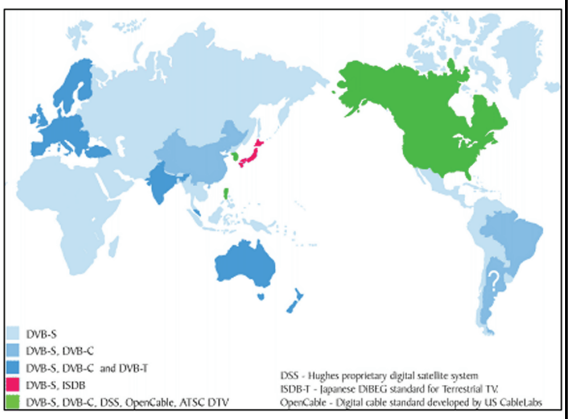


Broadcast Standards

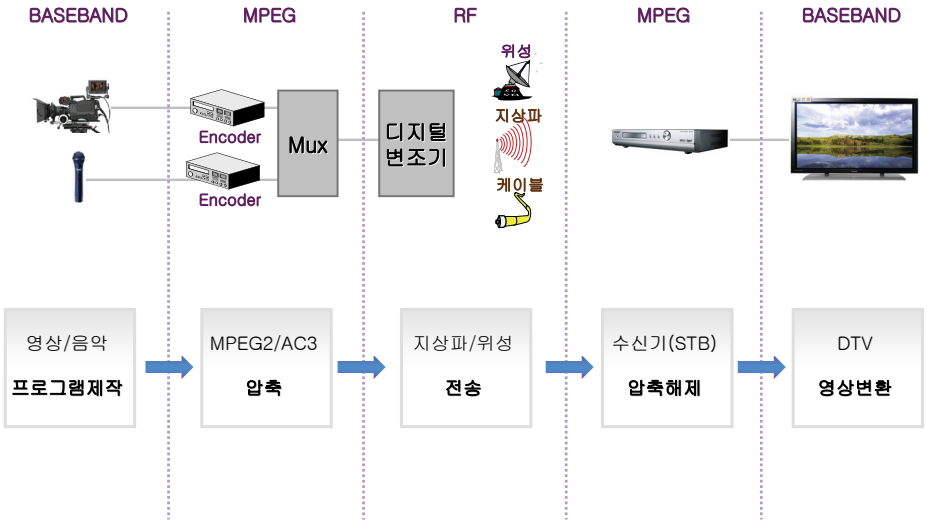
Name	Frame/Field Rate	Stds Org	Encoding System	Scan Lines	Subcarrier Frequency	Aspect Ratio
NTSC	29.97/59.94	EIA	NTSC	525	3.58MHz	4:3
PAL-M	29.97/59.94	EIA	PAL	525	3.58MHz	4:3
SECAM-M	29.97/59.94	EIA	SECAM	525	?.??MHz	4:3
PAL	25/50	ITU	PAL	625	4.43MHz	4:3
SECAM	25/50	ITU	SECAM	625	4.25MHz 4.40MHz	4:3
PALplus	25/50	ITU	PAL	625	4.43MHz	4:3

Digital TV Standards

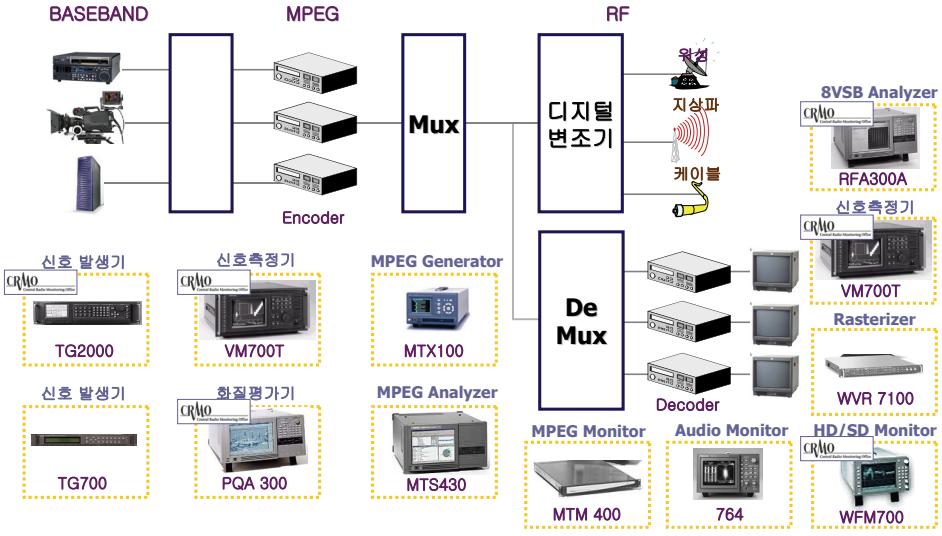
- Competing DTV Standards
  - Europe and Most of the World – DVB
  - North America and Limited Countries – ATSC
  - Japan – ISDB
  - China – Developing own standard



Digital Broadcasting

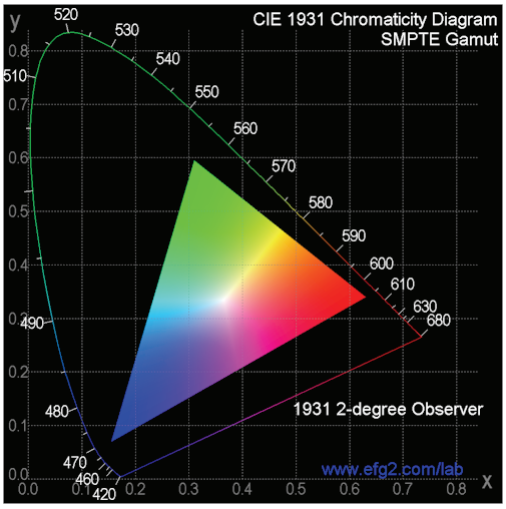


Digital Broadcasting



Chromaticity

- **Formats limit color range**
- **Care has to be taken when converting between formats**



Conversion: Colorimetry equations

- SMPTE240M

  Y’ = 0.701G’ + 0.087B’ + 0.212R’

  Pb = (B’-Y’)/1.826

  Pr = (R’-Y’)/1.576

- SMPTE 274M & 296M

  Y’ = 0.7152G’ + 0.0722B’ + 0.2126R’

  Pb = [0.5/(1- 0.0722)](B’-Y’)

  Pr = [0.5/1- 0.2126)](R’-Y’)

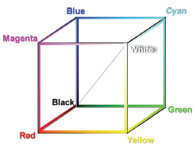
- ITU-R BT.601

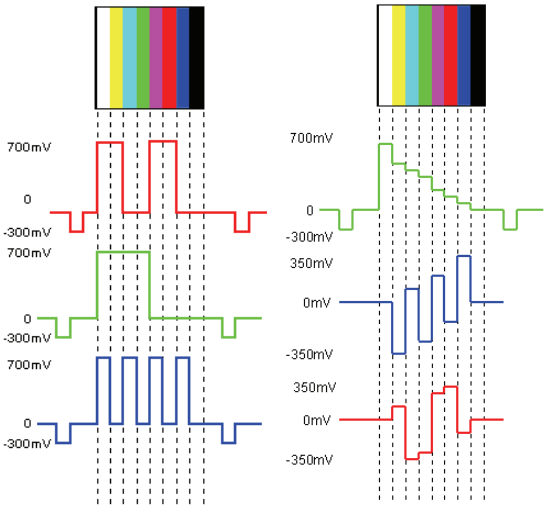
  Y’ = 0.587G’ + 0.114B’ + 0.299R’

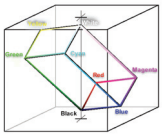
  Pb = 0.564(B’-Y’)

  Pr = 0.713(R’-Y’)

R’G’B’ to Y’P’bP’r format conversion







Cameras

Monitors

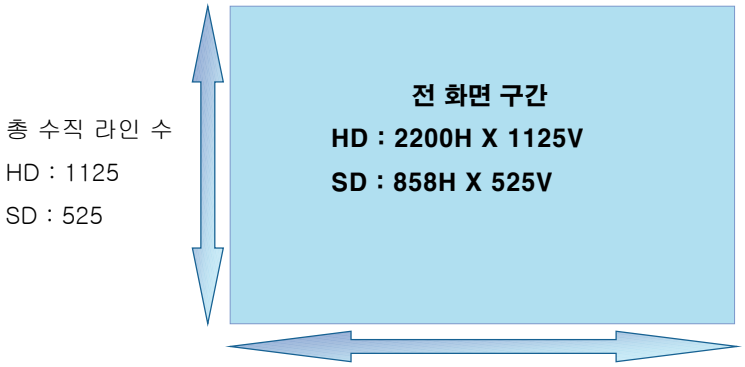
Editing equipment

Routers

Switchers

Storage equipment

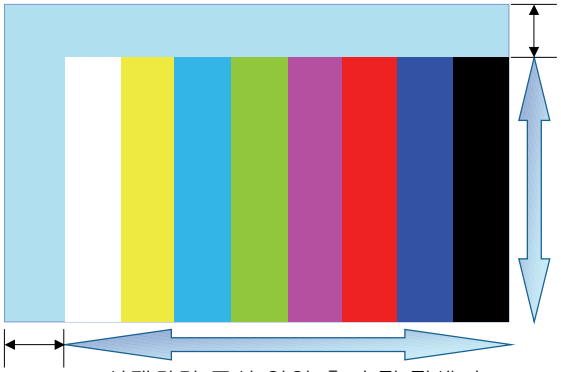
전 화면 구간



총 수직 라인 수
HD : 1125
SD : 525

총 수평 픽셀 수
HD : 2200
SD : 858

실제화면 표시영역(Active Picture Area)



Horizontal Blanking

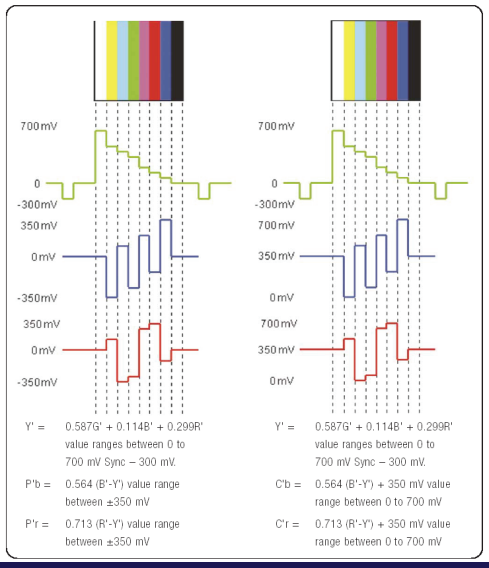
실제화면 표시 영역
총 수직 라인 수
HD : 1080
SD : 480

Vertical Blanking

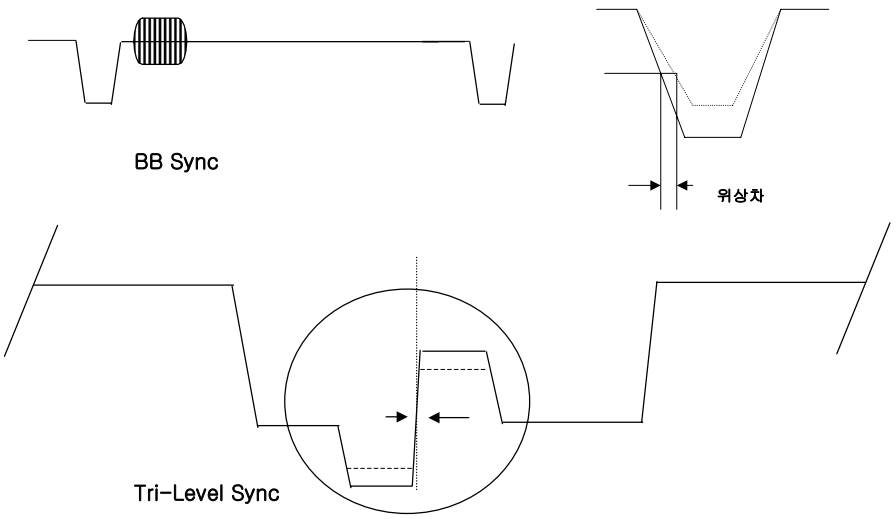
실제화면 표시 영역 총 수평 픽셀 수
HD : 1920
SD : 720

Component Color Difference

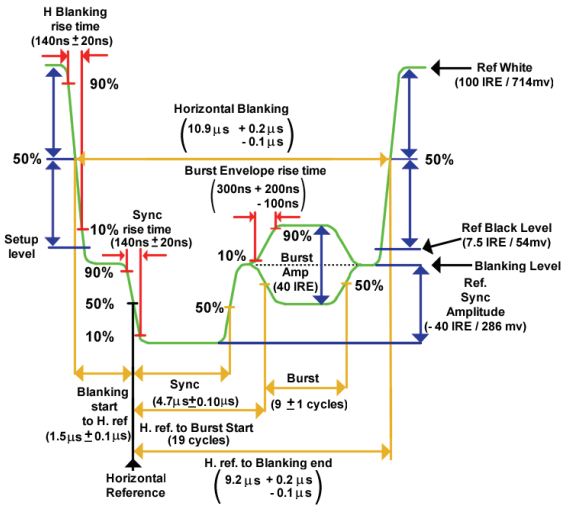
- Y, Cb, Cr
  - Pb and Pr values moved to 0mV-700mV
  - This signal is digitized.



Analog B.B & HD Tri-Level Sync

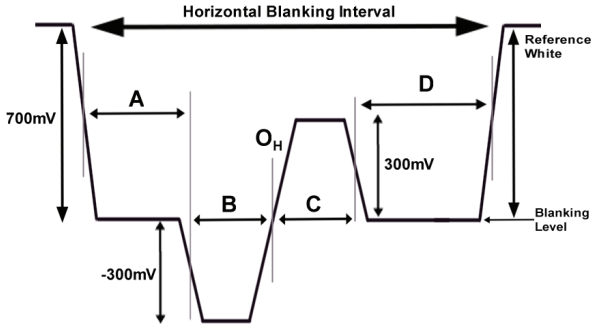


NTSC Horizontal Blanking

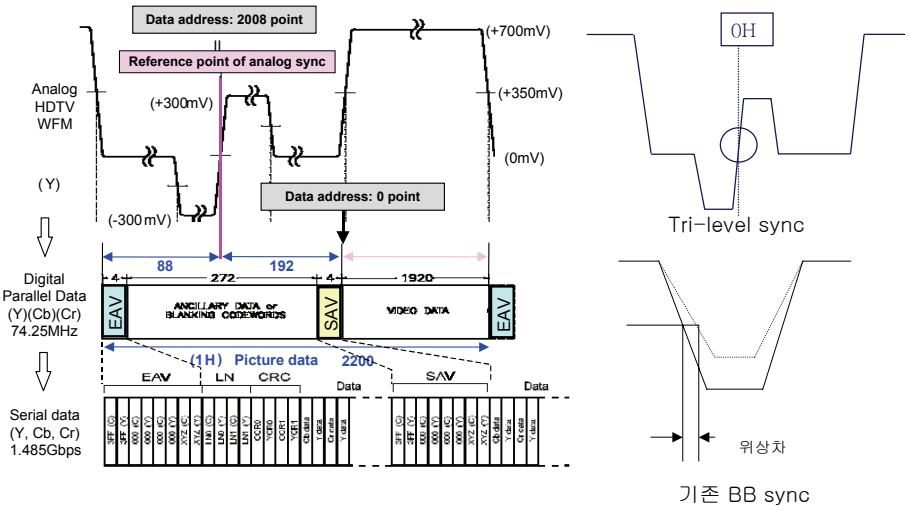


HD Analog Horizontal Timing

- HD Tri-Level Sync Signal
  - Fast rise times provide accurate timing edges
  - Tri-level period much shorter than analog BB



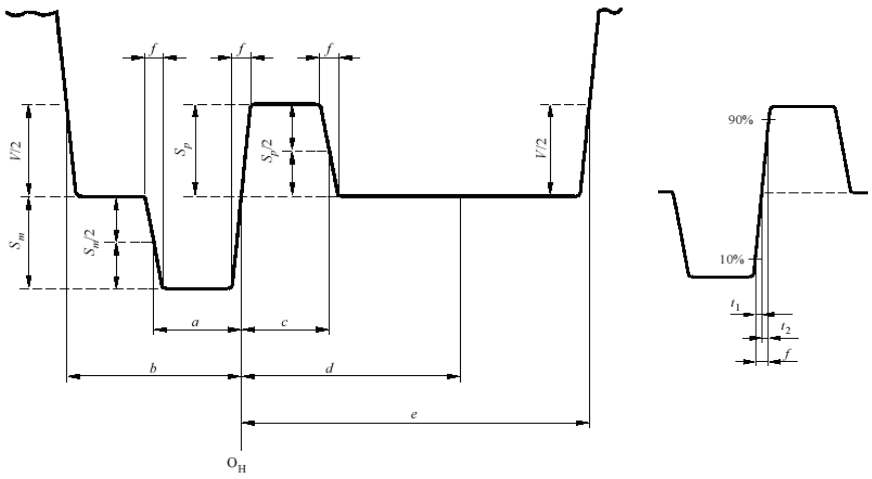
HD Analog Tri-level sync



HD Line Timing in Sampling Cycles

Format	Sampling Frequency (MHz) (1/T)	A	B	C	D	E
1920x1080 60 1:1	148.5	44T	148T	280T	1920T	2200T
1920x1080 59.94 1:1	148.5/1.001	44T	148T	280T	1920T	2200T
1920x1080 60 2:1	74.25	44T	148T	280T	1920T	2200T
1920x1080 59.94 2:1	74.25/1.001	44T	148T	280T	1920T	2200T
1920x1080 30 1:1	74.25	44T	148T	280T	1920T	2200T
1920x1080 29.97 1:1	74.25/1.001	44T	148T	280T	1920T	2200T
1920x1080 50 1:1	148.5	484T	148T	720T	1920T	2640T
1920x1080 50 2:1	74.25	484T	148T	720T	1920T	2640T
1920x1080 25 1:1	74.25	484T	148T	720T	1920T	2640T
1920x1080 24 1:1	74.25	594T	148T	830T	1920T	2750T
1920x1080 23.98 1:1	74.25/1.001	594T	148T	830T	1920T	2750T
1280x720 60 1:1	74.25	70T	212T	370T	1280T	1650T
1280x720 59.94 1:1	74.25/1.001	70T	212T	370T	1280T	1650T
1280x720 50 1:1	74.25	400T	212T	700T	1280T	1980T
1280x720 30 1:1	74.25	1720T	212T	2020T	1280T	3300
1280x720 29.97 1:1	74.25/1.001	1720T	212T	2020T	1280T	3300
1280x720 25 1:1	74.25	2380T	212T	2680	1280T	3960
1280x720 24 1:1	74.25	2545T	212T	2845	1280T	4125
1280x720 23.98	74.25/1.001	2545T	212T	2845	1280T	4125

HD Timing (1125/60Hz 2:1)

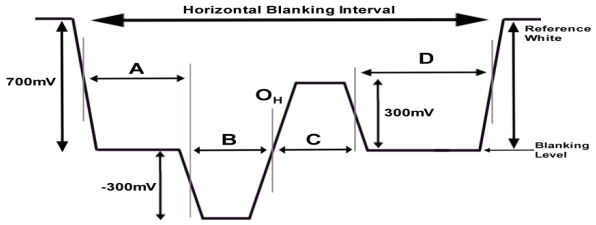


HD Timing (1125/60Hz 2:1)

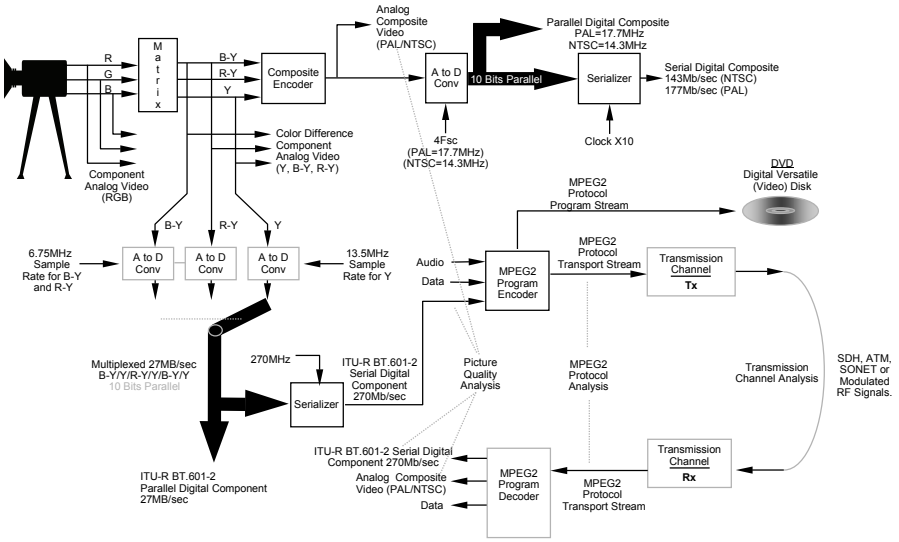
Symbol	Parameter	Nominal value	Reference clock intervals	Tolerance
a	Negative line sync width	0.593 µs	44	±0.040 µs
b	End of active video	1.185 µs	88	+0.080 µs/−0 µs
c	Positive line sync width	0.593 µs	44	±0.040 µs
d	Clamp period	1.778 µs	132	±0.040 µs
e	Start of active video	2.586 µs	192	+0.080 µs/−0 µs
f	Rise/fall time	0.054 µs	4	±0.020 µs
$t_2 - t_1$	Symmetry of rising edge	–	–	±0.002 µs
S_m	Amplitude of negative pulse	300 mV	–	±6 mV
S_p	Amplitude of positive pulse	300 mV	–	±6 mV
V	Amplitude of video signal	700 mV	–	–
–	Field-blanking interval	45 *H*/field	99 000	–

Tri-Level Sync

- 아날로그 HDTV는 컴포넌트 인터페이스로 Burst 없음
- HDTV 개발 초기에 Tri—Level Sync가 제안됨
- 3개의 레벨로 구성되며, 각각의 크기는 300mV로 전체 600mV임
- 0 Time Point : 3개 레벨의 50% 점
- Tri—Level Sync 펄스 폭 : 44Sample (HDTV의 모든 포맷 동일)
  - 1080i 60Hz : A, B, C = 44T, D = 148T



Standard Definition 비디오 포맷



디지털관련 용어

- Sampling
- Quantization
- Quantizing Error
- Nyquist Principle
- Aliasing
- Anti Aliasing Filter
- Dither
- Over-Sampling
- Aperture Effect

디지털 신호의 규격

- Video 규격
  - SMPTE 125M(SD)
    - Component Video Signal 4:2:2 – Bit-Parallel Digital Interface
  - SMPTE 274M(HD)
    - 1920X1080 Scanning And Interface
- Interface 규격
  - SMPTE 259M(SD)
    - 10-Bit 4:2:2 Component And 4fs Composite Digital Signal – Serial Digital Interface
  - SMPTE 292M(HD)
    - Bit-Serial Digital Interface For High-Definition Television Systems
- Embedded Audio
  - SMPTE 272M(SD)
    - Formatting AES/EBU Audio and Auxiliary Data into Digital Video Ancillary Data Space
  - SMPTE 292M(HD)
    - 24-Bit Digital Audio Format for HTV Bit-Serial Interface

Component Digital Video

SDTV

SDI Speed

- 13.5MHz x 2 x 10 = 270Mbps
- Y channel
  - Sampling frequencies : 13.5MHz
  - Quantized bits : 10 bits
- Pb/Pr channel
  - Sampling frequencies : 13.5MHz（6.75MHz x 2）
    - Pb CH(6.75MHz）+ Pr CH(6.75MHz）
  - Quantized bits : 10 bits

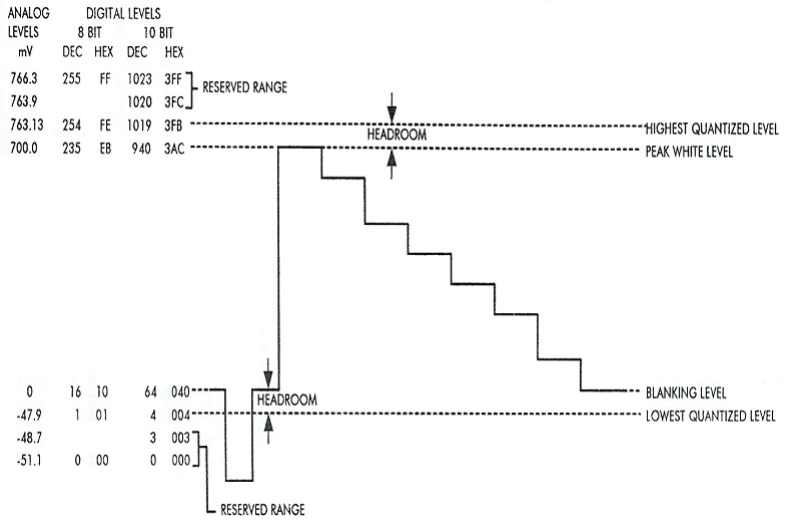
Sampling Rate

- ITU-R BT.601 Recommendation
  - 아날로그에서 디지털로 전환 시 미국과 유럽의 표준화 노력 결과
  - NTSC와 PAL 방식에 공통으로 적용되는 디지털 컴포넌트 비디오 포맷에 관한 표준
  - 샘플링 주파수 : 13.5MHz(양 방식의 최소공배수 2.25MHz의 정수배)

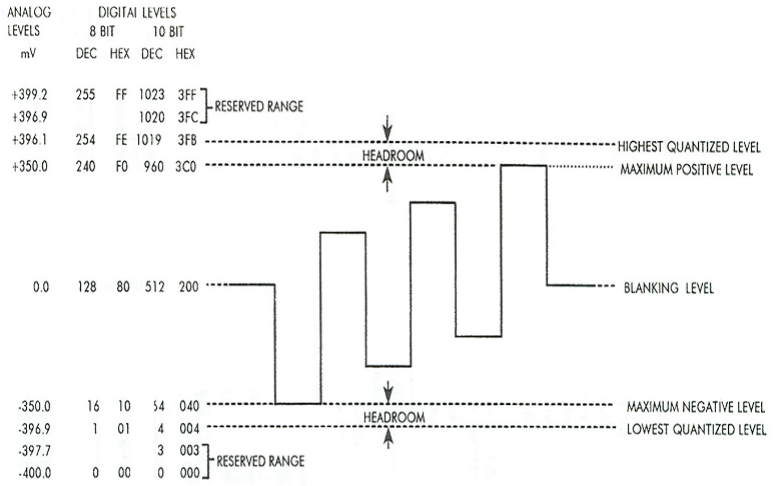
- 샘플링 분류
  - 4:1:1 샘플링 : 휘도신호는 13.5MHz, 두 개의 색차신호는 3.375MHz
  - 4:2:2 샘플링 : 휘도신호는 13.5MHz, 두 개의 색차신호는 6.75MHz
  - 4:4:4 샘플링 : 휘도신호, 두 개의 색차신호 모두 13.5MHz로 샘플링

- ITU-R BT.709 Recommendation
  - HDTV의 디지털 컴포넌트 비디오 포맷에 관한 표준

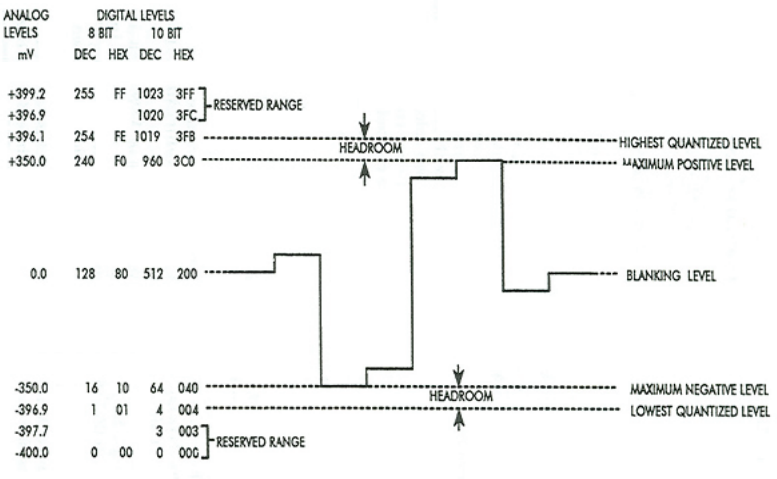
Y신호와 8/10비트 샘플값



Cb신호와 8/10비트 샘플값



Cr신호와 8/10비트 샘플값



데이터의 시분할 다중화

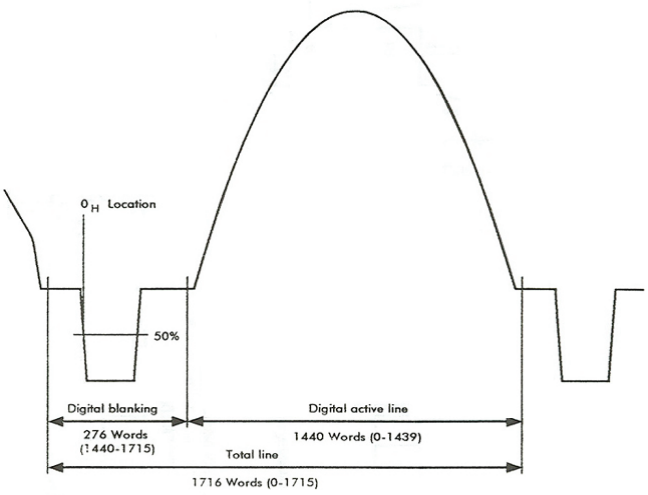
- 샘플수
  - 샘플링주파수(fs)/수평주사주파수(fh)
- SDTV 샘플수(4:2:2)
  - 샘플링주파수(fs) = 13.5MHz, 수평주사주파수(fh) = 15.734kHz
  - Y 샘플수 : fs/fh = 13.5MHz/15.734kHz = 858샘플
  - Cb 샘플수 : 6.75MHz/ 15.734kHz = 429샘플
  - Cr 샘플수 : 6.75MHz/ 15.734kHz = 429샘플
- Line 당 Total Sample 수 = 858+429+429 = 1,716샘플
- Parallel Data 전송
  - 패러럴 비디오 데이터 워드는 27Mwords/s로 전송
  - 패러럴 데이터의 전송순서
    - Cb, Y, Cr, Y, Cb, Y, Cr,.....

SD Video Bit Rate

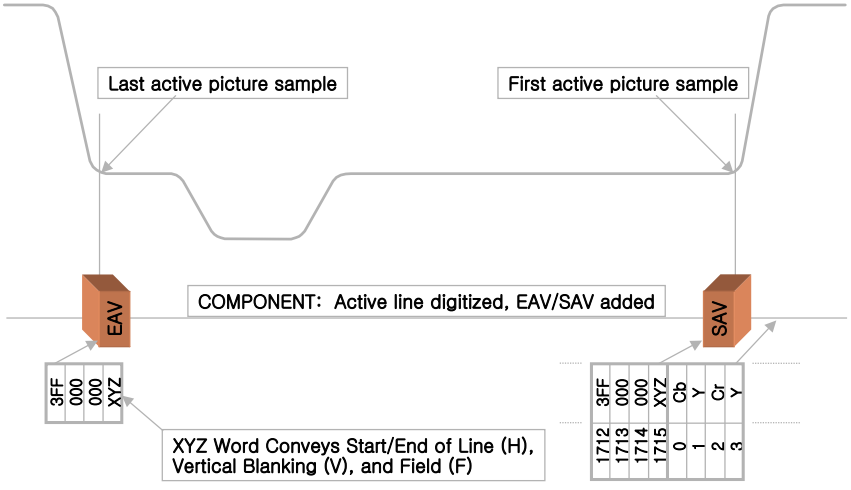
* 525 Line / 60 Hz

- Luminance(Y) : 858 samples/line X 525 lines/frame X 30frames/sec X 10bits/sample = 135Mbit/sec
- R-Y(Cr) : 429 samples/line X 525 lines/frame X 30frames/sec X 10bits/sample = 68Mbit/sec
- B-Y(Br) : 429 samples/line X 525 lines/frame X 30frames/sec X 10bits/sample = 68Mbit/sec
- Total Bit Rate
  - Y + Cr + Cb = 270 Mbit/sec

Line당 Word 수



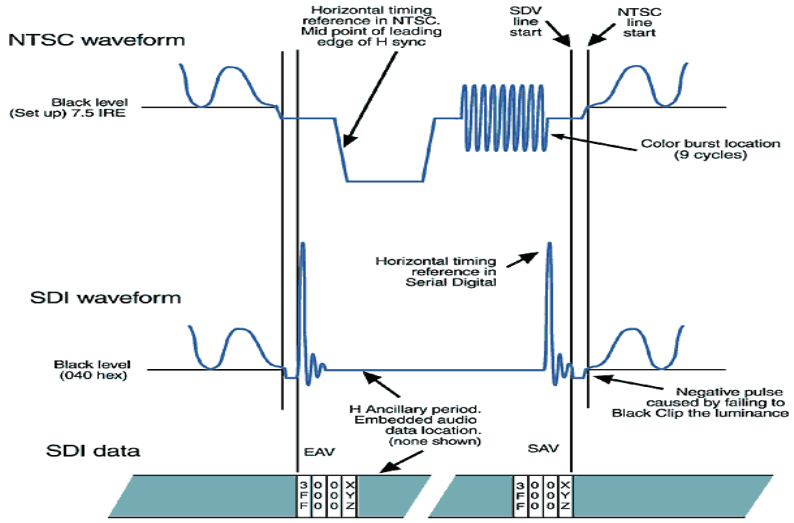
SD Horizontal Line



TRS의 X, Y, Z 구성

- 필드의 식별
  - F = 0 → 필드 1
  - F = 1 → 필드 2
- 수직블랭킹
  - V = 0 → 유효영상기간
  - V = 1 → 수직블랭킹기간
- 수평블랭킹
  - H = 0 → SAV
  - H = 1 → EAV
- 기타
  - Bit 0 & 1 = 0, Bit 9 = 1, P0,P1,P2,P3 = 에러정정
- 수평.수직 블랭킹 기간에 부가데이터가 없을 때
  - 휘도 샘플에 해당되는 워드 : 040h 삽입
  - Cb, CR 샘플에 해당되는 워드 : 200h 삽입

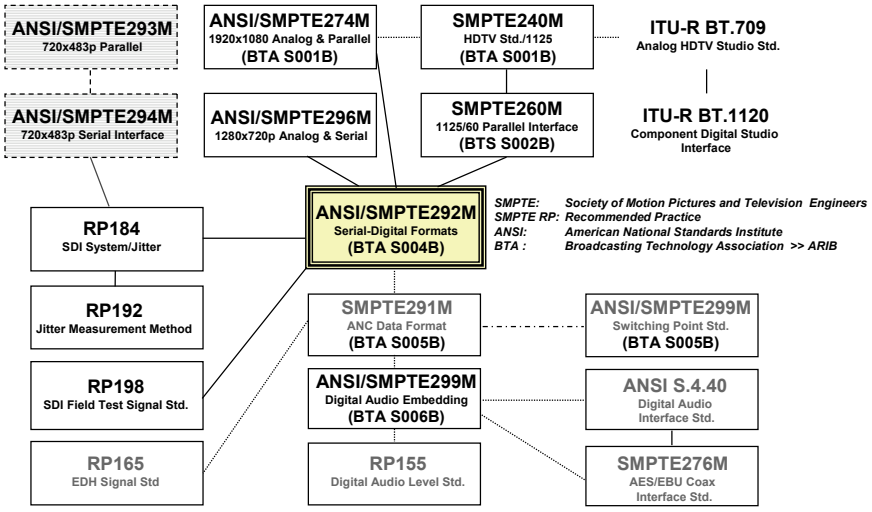
Digital Horizontal Timing



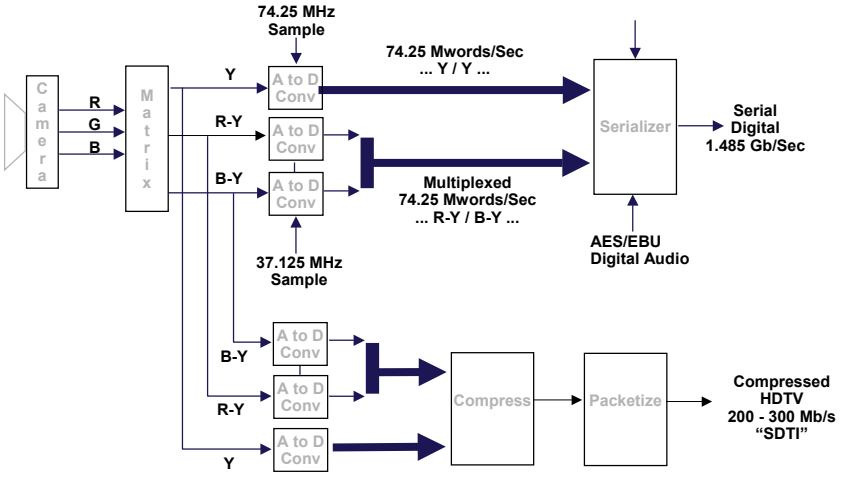
Component Digital Video

HDTV

HDTV Standard



HD Video Diagram



HDTV(1080i) 샘플 수

- SDTV의 샘플 수(4:2:2)
  - Y 샘플 수 : 858샘플, Cb/Cr 각 샘플 수 : 429 샘플
  - Line 당 Total Sample 수 = 858+429+429 = 1,716 샘플
- HDTV의 샘플 수
  - Fs = 74.25MHz, fh = 33.750kHz
  - Y 샘플 수 : 74.25MHz/33.750kHz = 2,200 샘플
  - Cb & Cr 각 샘플 수 : 1,100 샘플
  - Line 당 Total Sample 수 = 2,200+1,100+1,100 = 4,400 샘플
- 유효화소수
  - SDTV
    - Y 신호 : 720 샘플 X 480 line = 345,600 화소
    - Y+Cb+Cr = 691,200 화소
  - HDTV
    - Y 신호 : 1,920 샘플 X 1,080 line = 2,073,600 화소
    - Y+Cb+Cr = 4,147,200 화소

HD-SDI Speed

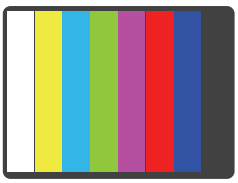
- 74.25MHz x 2 x 10 = 1.485Gbps
  - 74.25/1.001MHz X 2 X 10 = 1.485/1.001GHz
- Y channel
  - Sampling frequencies : 74.25MHz
  - Quantized bits : 10 bits
- Pb/Pr channel
  - Sampling frequencies : 74.25MHz(37.125 x 2)
  - Pb CH(37.125MHz) + Pr CH(37.125MHz)
  - Quantized bits : 10 bits

HD Video Bit Rate

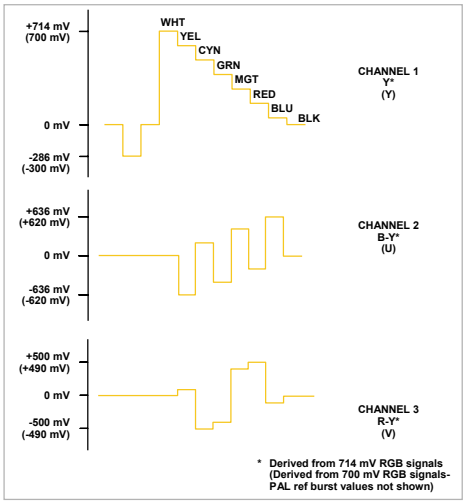
* 1080i at 60Hz(1125 Total Lines)

- Luminance(Y) : 2,200samples/line X 1,125lines/frame X 30frames/sec X 10bits/sample = 742.5Mbit/sec
- R-Y(Cr) : 1,100samples/line X 1,125lines/frame X 30frames/sec X 10bits/sample = 371.25Mbit/sec
- B-Y(Br) : 1,100samples/line X 1,125lines/frame X 30frames/sec X 10bits/sample = 371.25Mbit/sec
- Total Bit Rate
  - Y + Cr + Cb = 1.485Gbit/sec

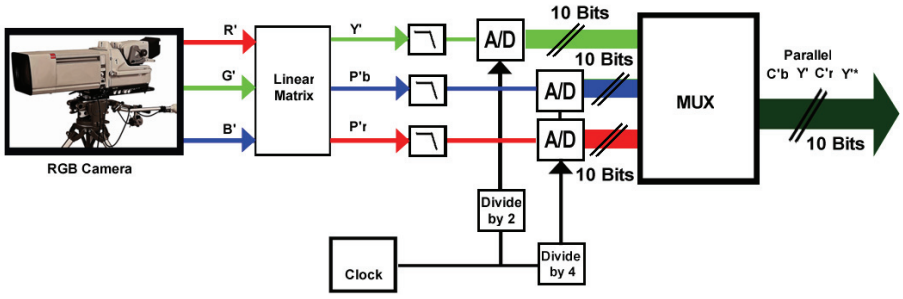
Y, B-Y, R-Y Color Bars



- Y - Luminance
- B-Y (U)
- R-Y (V)



Analog to Digital Conversion

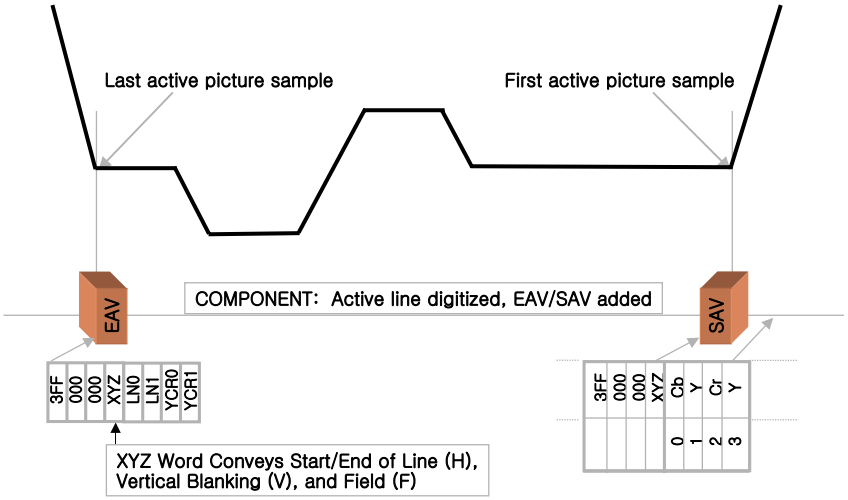


< Sampling 주파수 >
- 13.5 MHz : Component
- 4 X Fsc : Composite
- 74.25MHz : HDTV

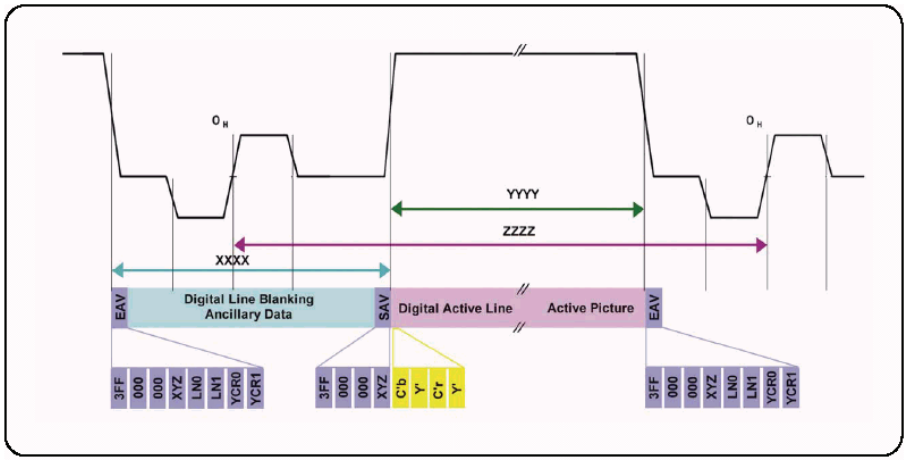
Standard Definition Clock 27MHz

High Definition Clock
148.5 MHz even rates
(148.5/1.001) = 1.4835 MHz odd rates

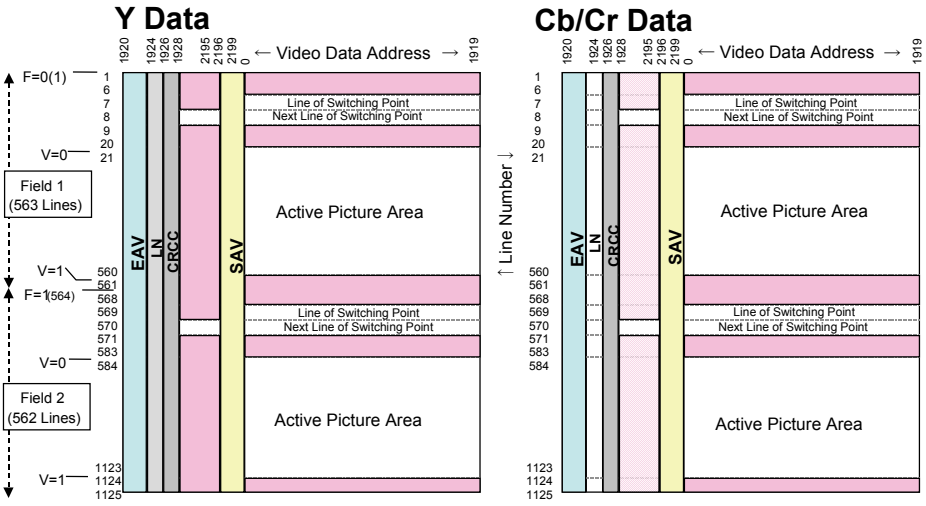
HD Horizontal Line(Y신호)



High Definition
Digital Horizontal Line

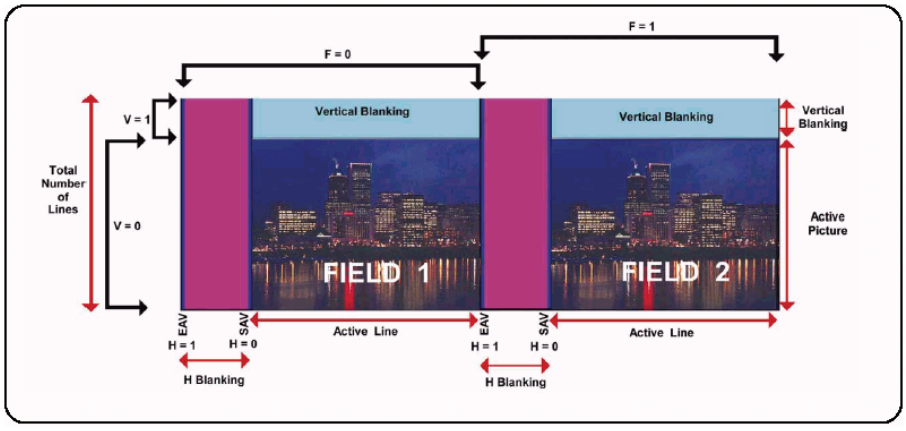


Blanking & Ancillary Data



LN: Line Number CRCC: Cyclic Redundancy Check Code

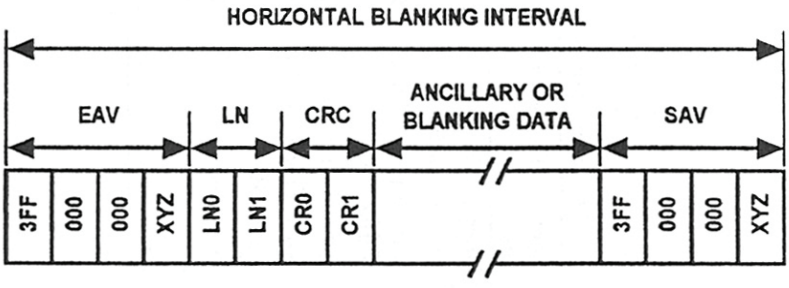
Ancillary Data(부가데이터)



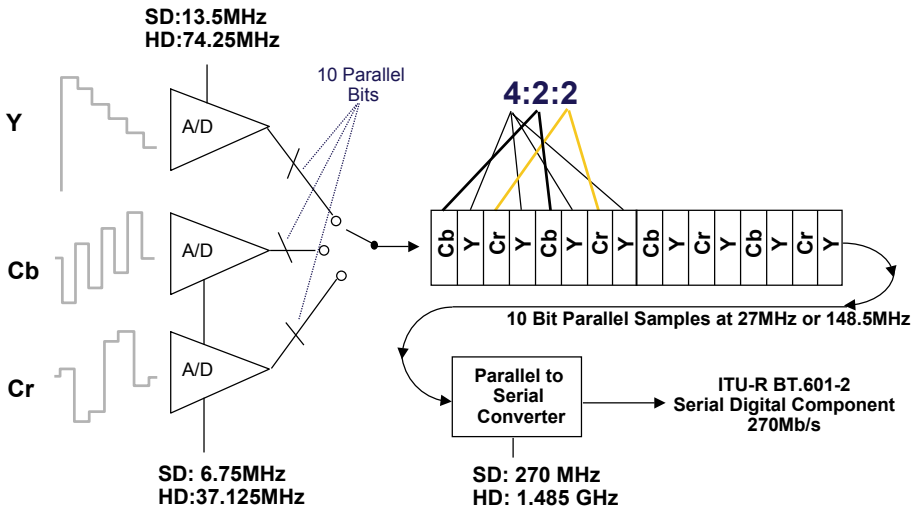
SMPTE 292 HD Formats

SMPTE Standard	260M	260M	295M	274M	274M	274M	274M	274M	274M	274M	274M	296M	296M
Format	A	B	C	D	E	F	G	H	I	J	K	L	M
Lines Per Frame	1125	1125	1250	1125	1125	1125	1125	1125	1125	1125	1125	750	750
Words per active line	1920	1920	1920	1920	1920	1920	1920	1920	1920	1920	1920	1280	1280
Total Active Lines	1035	1035	1080	1080	1080	1080	1080	1080	1080	1080	1080	720	720
Words Per total line	2200	2200	2376	2200	2200	2640	2200	2200	2640	2750	2750	1650	1650
Frame Rate	30	29.97	25	30	29.97	25	30	29.97	25	24	23.97	60	59.94
Fields per Frame	2	2	2	2	2	2	2	2	2	2	2	1	1

HD-SDI Horizontal Blanking(Y Only)



SD 4:2:2 Sampling Serialized

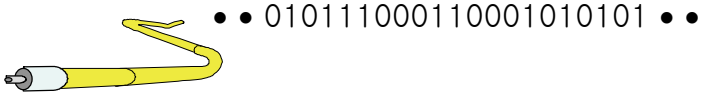


Digital Baseband Signal Measurement

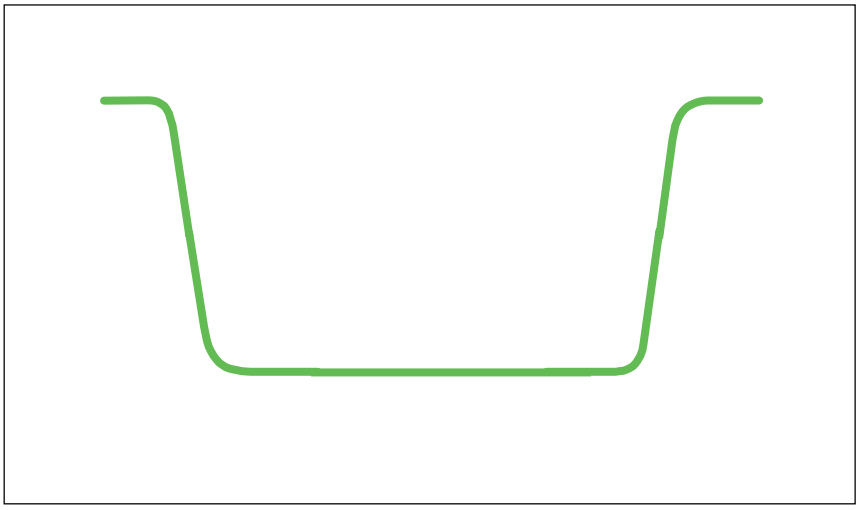
Analog & Digital

Analog

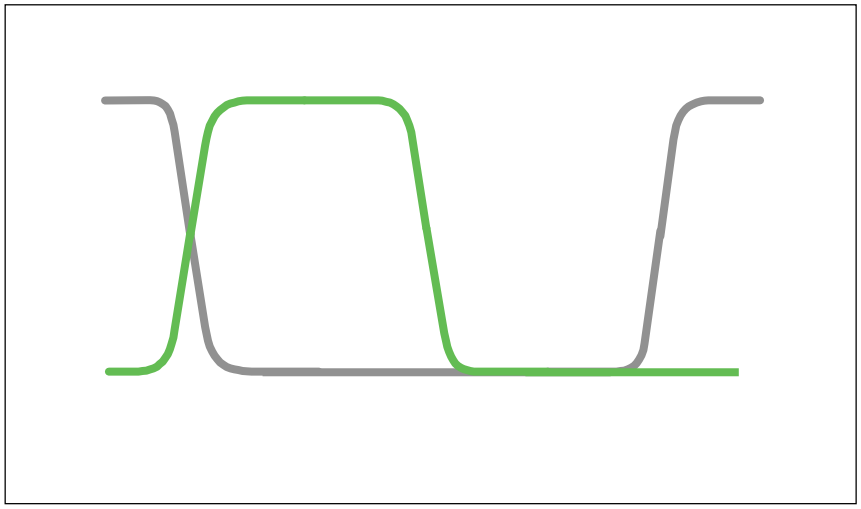
Digital



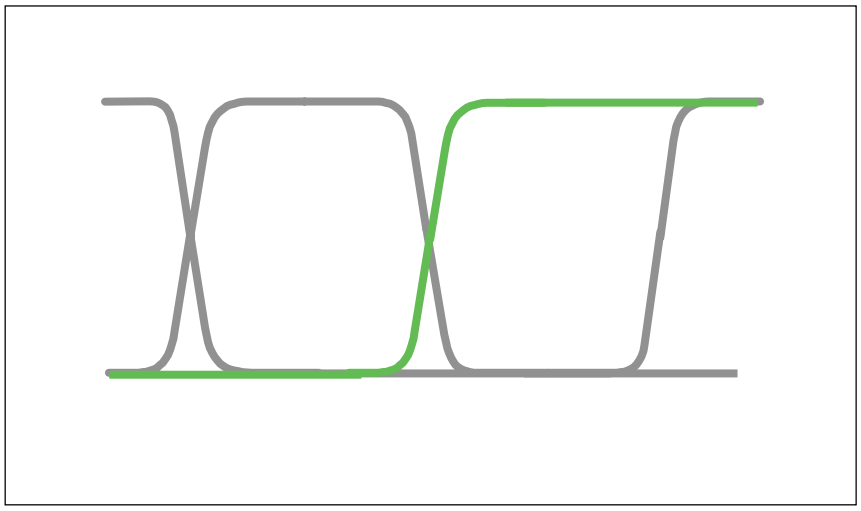
Construction of Eye Diagram



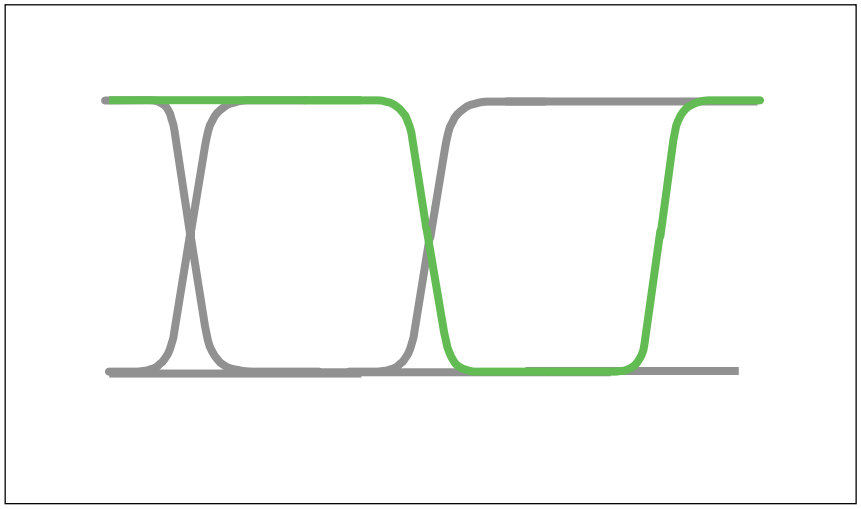
Construction of Eye Diagram



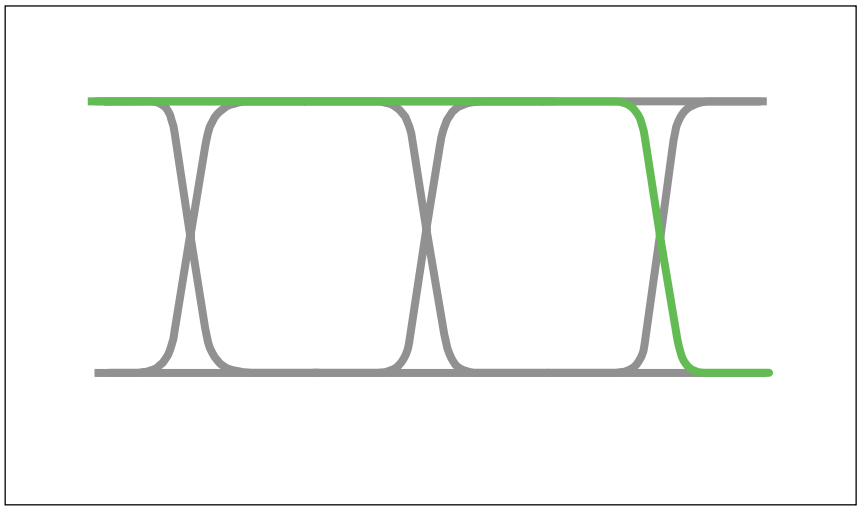
Construction of Eye Diagram



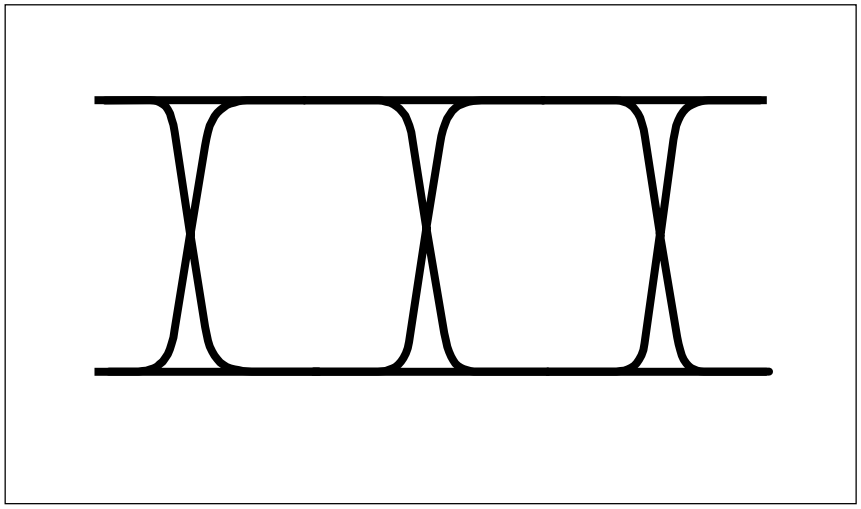
Construction of Eye Diagram



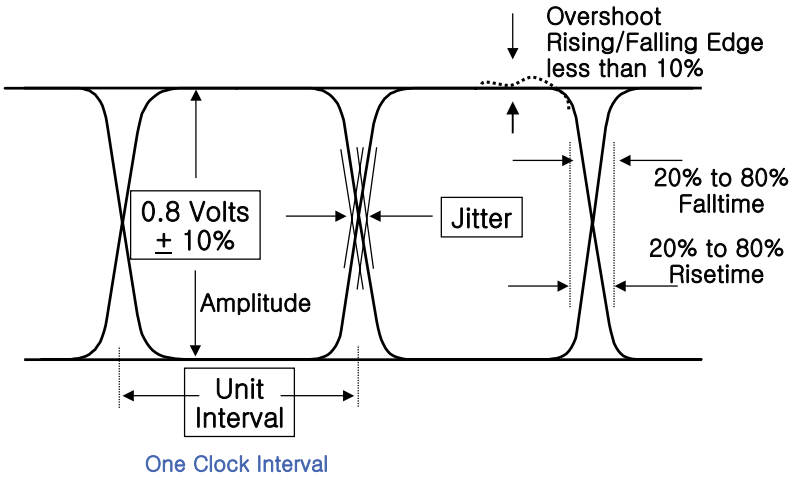
Construction of Eye Diagram



The Eye Pattern



Eye Pattern 측정 파라미터



One Clock Interval

Unit Interval(UI)

- Unit Interval = $\frac{1}{ClockFrequency}$

- Composite Digital
  - 1UI = 1/143MHz = 6.99ns
- Component Digital(SD)
  - 1UI = 1/270MHz = 3.70ns
- Component Digital(HD-SDI)
  - 1UI = 1/1.485GHz = 0.67ns
- AES/EBU Digital Audio
  - 1UI = 1/6.144MHz = 163ns

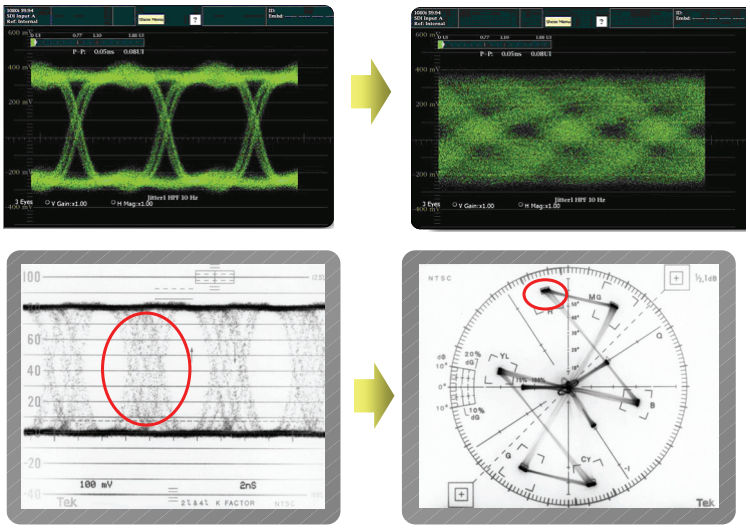
SDI 측정 항목

측정 항목	정의	비고
Eye Pattern Analysis	시리얼 데이터 스트림의 다수의 비트들을 하나의 그림으로 표시하는 것으로 시리얼 데이터 신호의 전기적 특성을 관찰하고 확인할 수 있다	SMPTE259M SMPTE292M
진폭 특성	신호의 크기를 p_p로 측정한 값으로 800mV±10% 이내로 규정하고 있다. [mVolt]	SMPTE259M SMPTE292M
Rise 특성	신호의 진폭이 20%에서 80%에 도달하는 시간으로 정의하며 SD급은 0.4nsec~1.5nsec로, HD급은 100psec ~ 270psec로 규정하고 있다.	SMPTE259M SMPTE292M
Fall 특성	신호의 진폭이 80%에서 20%에 도달하는 시간으로 정의하며 SD급은 0.4nsec~1.5nsec로, HD급은 100psec ~ 270psec로 규정하고 있다.	SMPTE259M SMPTE292M
Rise/Fall Time Difference 특성	Rise/Fall Time의 시간 차이는 0.5nsec 이내로 규정하고 있다. (p or n sec]	SMPTE259M SMPTE292M
Rise Overshoot 특성	파형의 Rising edge의 overshoot 크기로 정의하며 진폭의 10% 이내로 규정하고 있다. [%]	SMPTE259M SMPTE292M
DC Offset	신호크기의 중간지점으로 정의하며 0V±0.5V로 규정하고 있다. [V]	SMPTE259M SMPTE292M
jitter Analysis	디지털 신호가 신호의 이상적인 위치에서 이동한 변화량으로 정의한다. SDI Jitter를 통해 신호의 P_P timing과 alignment timing을 측정함으로써 SDI 전송계의 전기적 특성을 알 수 있다. 0.2UI이내	SMPTE259M SMPTE292M

Eye Pattern Measurement Spec 비교

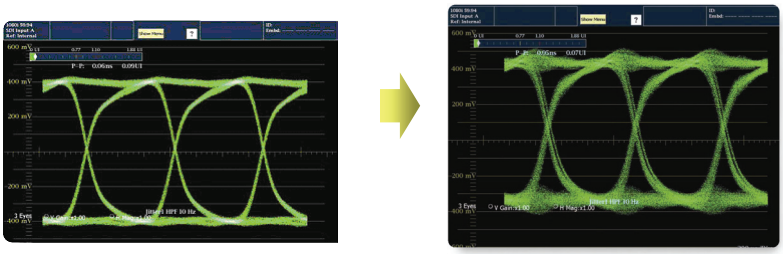
항 목	SD	HD
Amplitude	800mV ±10%	800mV ±10%
Rise/Fall Time	0.4ns ~ 1.5ns	< 270ps
Rise/Fall Time Difference	< 0.5ns	< 100ps
Rise/Fall Overshoot	< Amplitude*10%	< Amplitude*10%
DC Offset	0V ±0.5V	0V ±0.5V
Timing Jitter	< 0.2UI	< 1UI
Alignment Jitter	< 0.2UI	< 0.2UI
Return Loss	> 15dB(5MHz~Clock Freq)	> 15dB(5MHz~Clock Freq)

Jitter



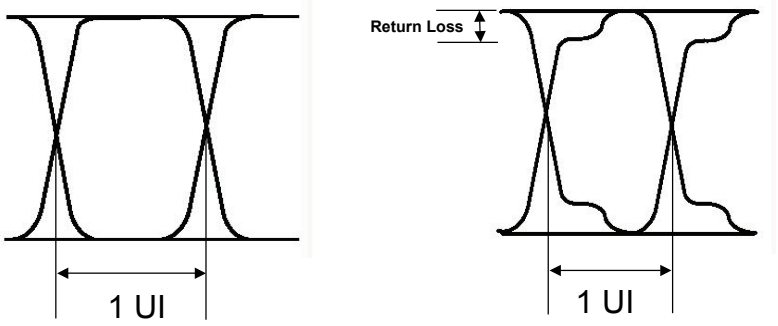
SDTV – Eye Diagram, Jitter and Wander

- Eye Pattern
  - Effects of improper termination - Reflection



SDTV – Eye Diagram, Jitter and Wander

- Return Loss on Eye Diagram



Jitter Spec

- SDTV

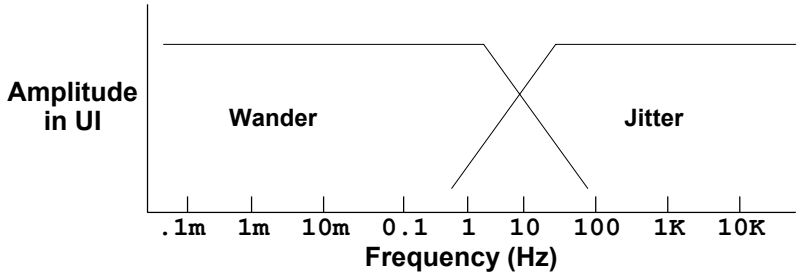
Timing Jitter Lower Band Edge	**10Hz**	**f1**
Alignment Jitter Lower Band Edge	**1kHz**	**f3**
Upper Band Edge	**>1/10 Clock Rate**	**f4**

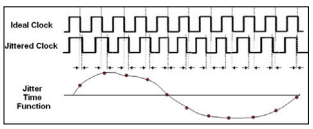
- HDTV

Timing Jitter Lower Band Edge	**10Hz**	**f1**
Alignment Jitter Lower Band Edge	**1kHz**	**f3**
Upper Band Edge	**>1/10 Clock Rate**	**f4**

SDTV – Eye Diagram, Jitter and Wander

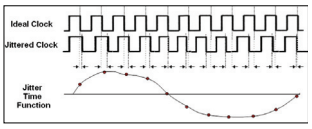
- Jitter and Wander
  - Jitter > 10Hz (difficult for receiver to adjust to so can be a problem)
  - Wander <= 10Hz (receiver can adjust to so *normally* not a problem)

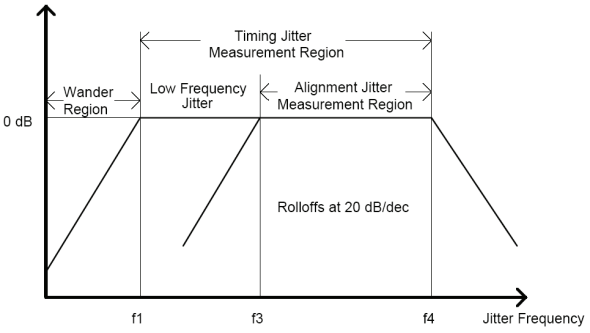




SDTV – Eye Diagram, Jitter and Wander

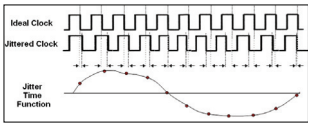
- Timing Jitter
  - The variation in time of the significant instants of a digital signal relative to a clock with no jitter above 10Hz
  - Measurement based on very stable clock in test device
  - Used to determine general health of system
  - f1=10Hz, f3=1KHz for SDTV
  - f4=PLL Upper limit

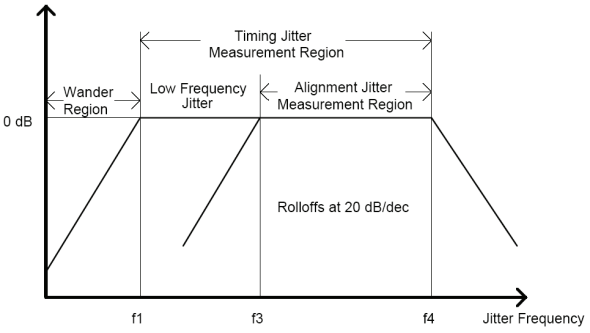




SDTV – Eye Diagram, Jitter and Wander

- Alignment Jitter : (0.2UI)
  - Jitter the receiver PLL cannot track
  - Measured based on clock recovered from the signal itself
  - Indicates jitter that can cause system problems





Eye Pattern 외 측정항목

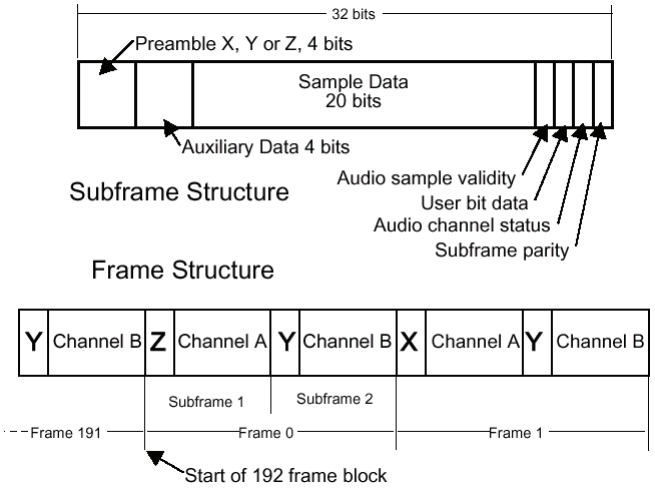
- 디지털 포맷 특성
- 타이밍 특성
- 오디오/비디오 지연(Lip sync) 특성
- 파형/벡터 특성
  - Lightning 디스플레이
  - Diamond 디스플레이
  - Arrowhead 디스플레이
  - Bowtie 디스플레이
- EDH 특성
- 임베디드 오디오 레벨, 주파수, THD 특성
- 부가 데이터 포맷 분석
- Wander 특성

Digital Audio

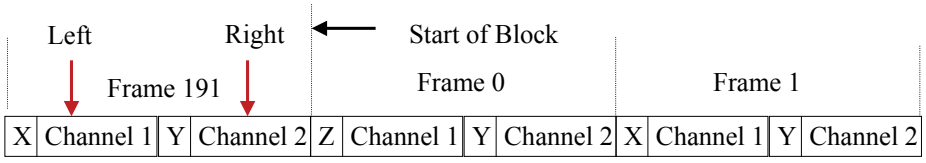
AES/EBU

SMPTE 272M

AES/EBU Audio Data Format



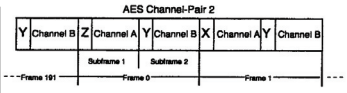
Block and Frame Format



- Frame repeat
  48kHz : 20.83μs, 44.1kHz : 22.67 μs
- Block repeat
  48kHz : 3999.36μs=4ms, 44.1kHz : 4352.64μs=4.352ms
- A Block = 192 Frames
- A Frame = 2 Subframes
- Preamble X identifies Channel 1 after Frame 0 at Start of Block
- Preamble Y identifies Channel 2
- Preamble Z identifies Channel 1 and the Start of Block

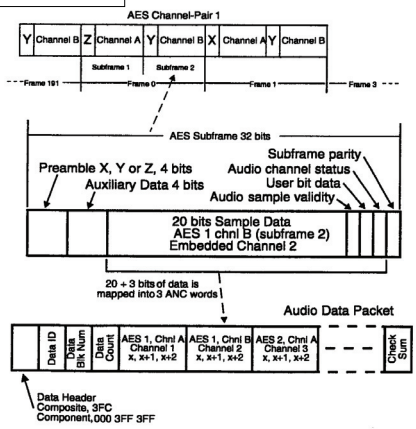
SDTV - AES/EBU Embedded Audio

- **One 32 bit audio sub-frame put in three 10 bit ANC video words.**

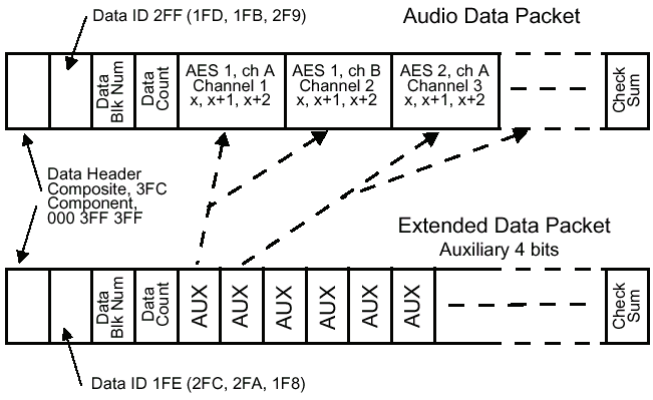


00 – AES1 CHA
01 – AES1 CHB
10 – AES2 CHA
11 – AES2 CHB

Bit	X	X+1	X+2
b9	not b8	not b8	not b8
b8	aud 5	aud 14	Parity
b7	aud 4	aud 13	C
b6	aud 3	aud 12	U
b5	aud 2	aud 11	V
b4	aud 1	aud 10	aud 19 (msb)
b3	aud 0	aud 9	aud 18
b2	ch bit-1	aud 8	aud 17
b1	ch bit-2	aud 7	aud 16
b0	Z-bit	aud 6	aud 15



Embedded Audio Format

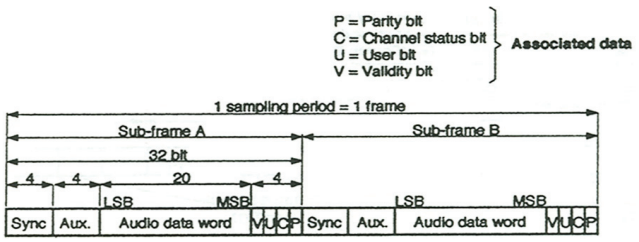


Embedded Audio Bit Distribution

3 data words (X, X+1, X+2) for each audio sample

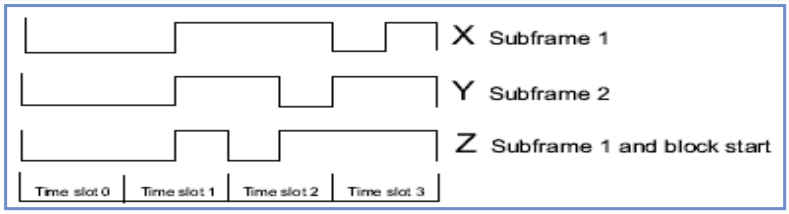
Bit	X	X + 1	X + 2
b9	not b8	not b8	not b8
b8	aud 5	aud 14	Parity
b7	aud 4	aud 13	C
b6	aud 3	aud 12	U
b5	aud 2	aud 11	V
b4	aud 1	aud 10	aud 19 (msb)
b3	aud 0	aud 9	aud 18
b2	ch bit-1	aud 8	aud 17
b1	ch bit-2	aud 7	aud 16
b0	Z-bit	aud 6	aud 15

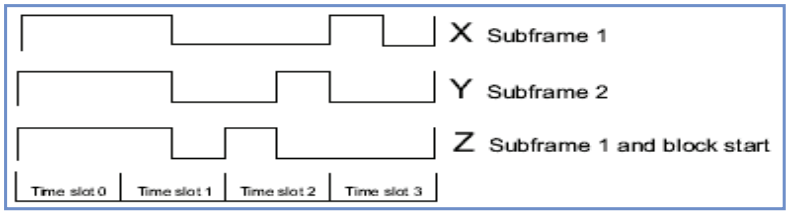
AES/EBU 디지털 오디오 프레임 구성



- 1프레임 : 2개의 서브프레임(A/B)으로 구성
- 각 서브프레임(32비트) = 오디오 데이터 20비트 + Aux 데이터 4비트 + Sync 데이터 4비트 + V,U,C,P 각 1비트
- 1프레임(64비트) = 서브프레임 A(32비트) + 서브프레임 B(32비트)
- 1 Audio Block = 192개 프레임으로 구성

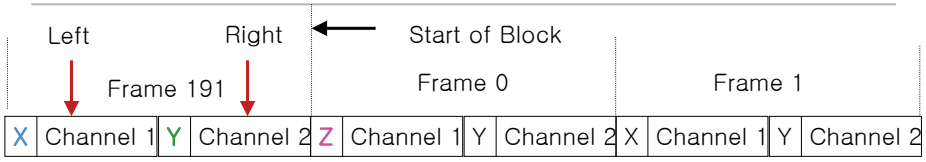
Sync Word X, Y, Z





"X"	11100010	00011101	Subframe 1
"Y"	11100100	00011011	Subframe 2
"Z"	11101000	00010111	Subframe 1 and block start

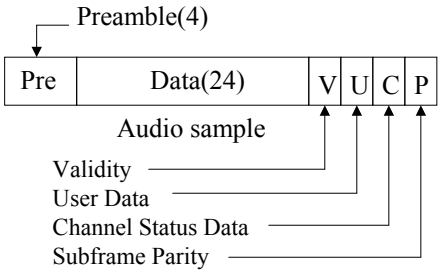
Block & Frame Format



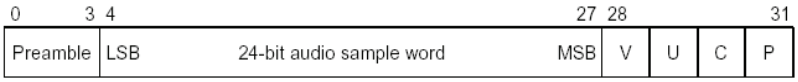
- Frame Repeat
  - 1 Frame : 1/48kHz = 20.83us (44.1kHz=22.67us)
- Block Repeat
  - 1 Block : 20.83us X 192frame = 4ms (44.1kHz=4.352ms)
- AES/EBU Interface Bit Rate
  - 48kHz X 2CH X 32Bit = 3.072Mbps
- After BPM Encoding
  - 3.072Mbps X 2 = 6.144Mbps

AES/EBU Frames & Subframes & Data rate

- 32 Bits/Subframe
- 4 Preamble Bits
- 24 Data Bits
- 1 Validity
- 1 User
- 1 Channel status
- 1 Parity(Even parity)
- Data rate
  48kHz : 32bits/10.415μs or 64bits/20.83 μs
  = 3.072Mb/s

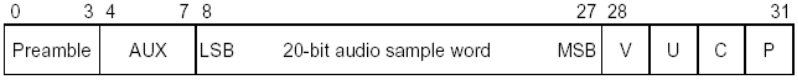


Subframe Format



(a)

V Validity bit
U User data bit
C Channel status bit
P Parity bit
AUX Auxiliary sample bits



(b)

그림(a) : 24-Bit Extended Format(HD)
그림(b) : 20-Bit Standard Format(SD)