Topics in Digital TV: DTV Basics

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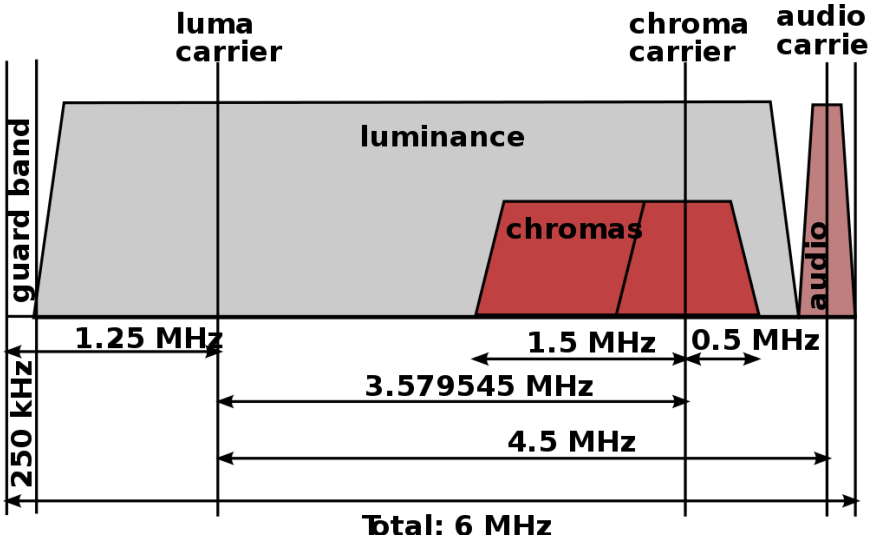
Agenda

- **ATV Review**
- DTV Overview
- Transport Basics
- Television Stuff – A & V
- Metadata – PSI & PSIP
- Amateur DTV

Analog Television (US)

- NTSC Monochrome (1941)
  - 4:3 aspect ratio, 525 lines (486 visible), 30 fps sent as 60 interlaced fields per second
  - 15750Hz line frequency
  - VSB luminance (Y), FM audio (monaural)
  - 6MHz channel bandwidth
- NTSC Color (1953)
  - CIE 1931 colorimetry
  - QAM chrominance (I/Q) at ~3.58MHz (suppressed carrier)
  - 29.97 (30/1.001) fps as 59.94 interlaced fields per second
  - 15734.26Hz (15750/1.001) line frequency

NTSC Channel Spectrum



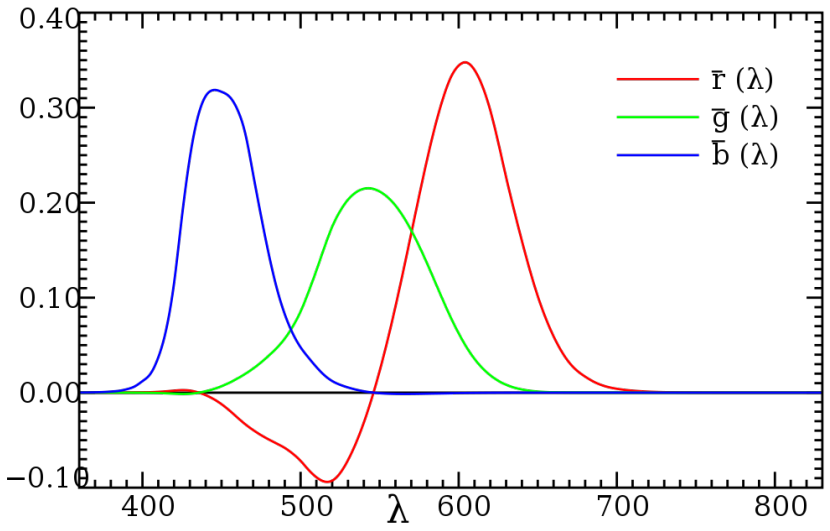
Human Vision

- Cones
  - function at medium to high intensity
  - ~4.5 million cones in retina
  - 3 types: S (420-440), M (534-545), L (564-580)
- Rods
  - function at low intensity
  - ~90 million in retina
  - peak at 498nm
- Experiments of David Wright and John Guild (1920s)
  - using monochromatic test color
  - observer adjusts brightness of three primaries for match color

CIE 1931

- Commission internationale de l'éclairage
  - aka International Commission on Illumination
  - Established 1913 as successor to Commission internationale de photométrie
  - based in Vienna, Austria
- 8th Congress (1931)
  - Standard observer based on prior work, including that of Wright and Guild (1920s)
  - CIE RGB and XYZ Color Spaces
    - Red (700)
    - Green (546.1)
    - Blue (435.8)

CIE Standard Observer



CIE RGB Color Space

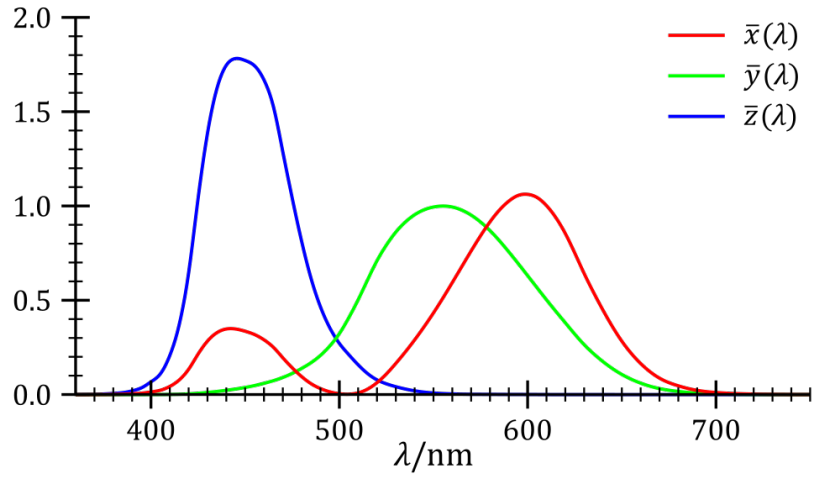
$$R = \int_0^\infty I(\lambda)\,\bar{r}(\lambda)\,d\lambda$$

$$G = \int_0^\infty I(\lambda)\,\bar{g}(\lambda)\,d\lambda$$

$$B = \int_0^\infty I(\lambda)\,\bar{b}(\lambda)\,d\lambda$$

$$I(\lambda) \stackrel{\text{def}}{=} \frac{\partial^2 \Phi}{\partial A \partial \lambda} \approx \frac{\Phi}{A \Delta \lambda}$$

CIE XYZ Matching Functions



CIE XYZ Color Space

$$X = \int_0^\infty I(\lambda)\,\bar{x}(\lambda)\,d\lambda$$

$$Y = \int_0^\infty I(\lambda)\,\bar{y}(\lambda)\,d\lambda$$

$$Z = \int_0^\infty I(\lambda)\,\bar{z}(\lambda)\,d\lambda$$

$$I(\lambda) \stackrel{\text{def}}{=} \frac{\partial^2 \boldsymbol{\Phi}}{\partial A \partial \lambda} \approx \frac{\boldsymbol{\Phi}}{A \Delta \lambda}$$

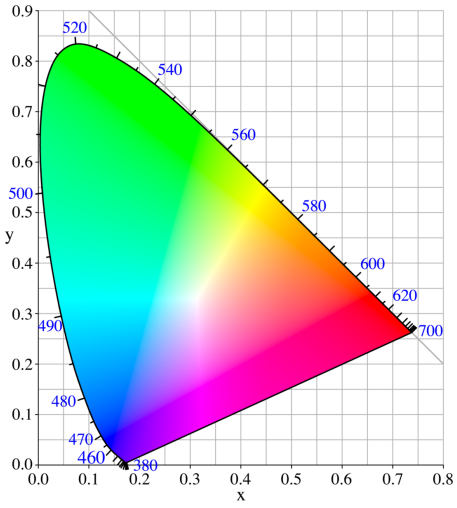
CIE xyY Color Space

$$x = \frac{X}{X+Y+Z} \qquad X = \frac{Y}{y}x$$

$$y = \frac{Y}{X+Y+Z} \qquad Y = Y$$

$$z = \frac{Z}{X+Y+Z} = 1-x-y \qquad Z = \frac{Y}{y}(1-x-y)$$

CIE Chromaticity Diagram



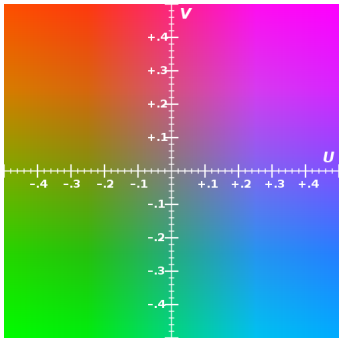
YUV Color Space

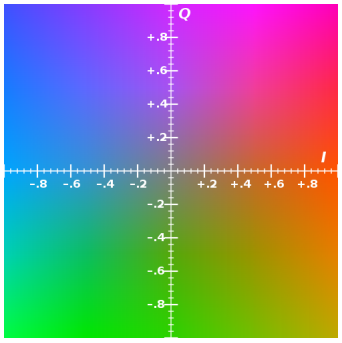
$$W_R = 0.299$$
$$W_B = 0.114$$
$$W_G = 1 - W_R - W_B = 0.587$$

$$U_{Max} = 0.436$$
$$V_{Max} = 0.615$$

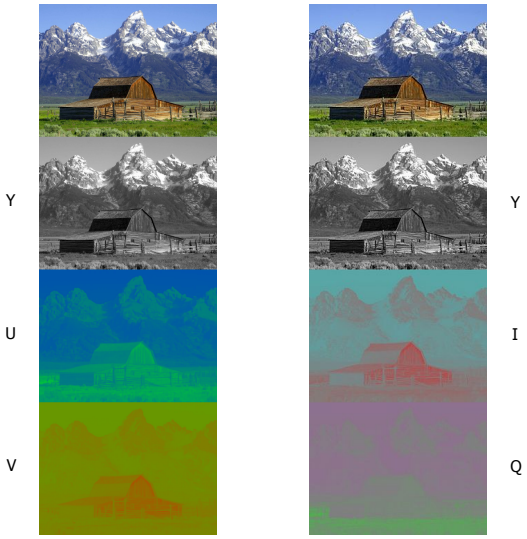
$$Y = W_R R + W_G G + W_B B \quad \in [\,0,1\,]$$
$$U = U_{Max} \frac{B - Y}{1 - W_B} \quad \in [\,-U_{Max}, U_{Max}\,]$$
$$V = V_{Max} \frac{R - Y}{1 - W_R} \quad \in [\,-V_{Max}, V_{Max}\,]$$

YUV vs YIQ Color Space





YUV vs YIQ – Sample Separation



YIQ Color Space

$$\begin{bmatrix} I \\ Q \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \cos 33 & \sin 33 \\ -\sin 33 & \cos 33 \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix}$$

$$Y = 0.299\,R + 0.587\,G + 0.114\,B \qquad \in [\,0,1\,]$$
$$I = 0.736\,(R - Y) - 0.268\,(B - Y) \qquad \in [\,-0.596\,,\,0.596\,]$$
$$Q = 0.478\,(R - Y) + 0.413\,(B - Y) \qquad \in [\,-0.523\,,\,0.523\,]$$

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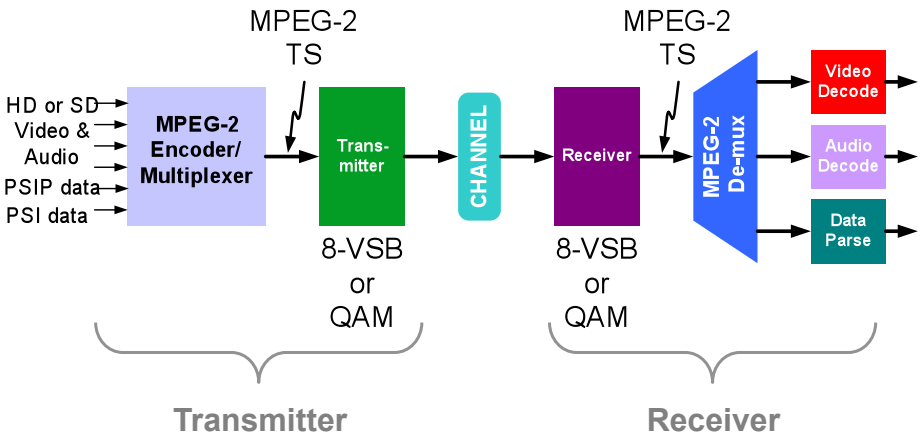
System Block Diagram

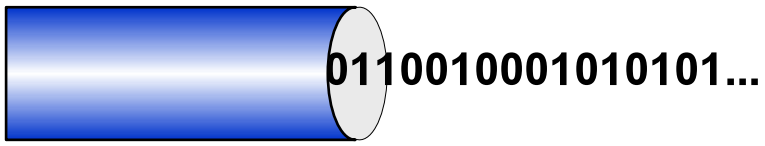


DTV = VIDEO + AUDIO + DATA + Metdata

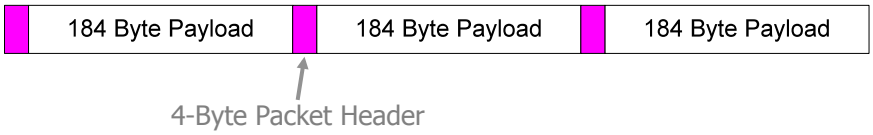
MPEG-2 Transport Streams carrying multiplexed:

- **Service Information (ATSC PSIP + MPEG-2 PSI)**
- **Audio, video and *data elementary streams***

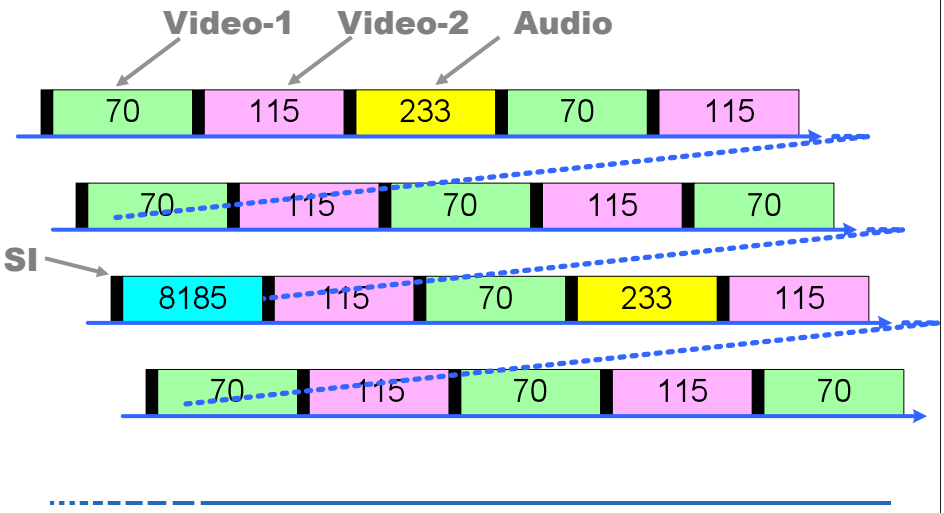
The Digital Pipe

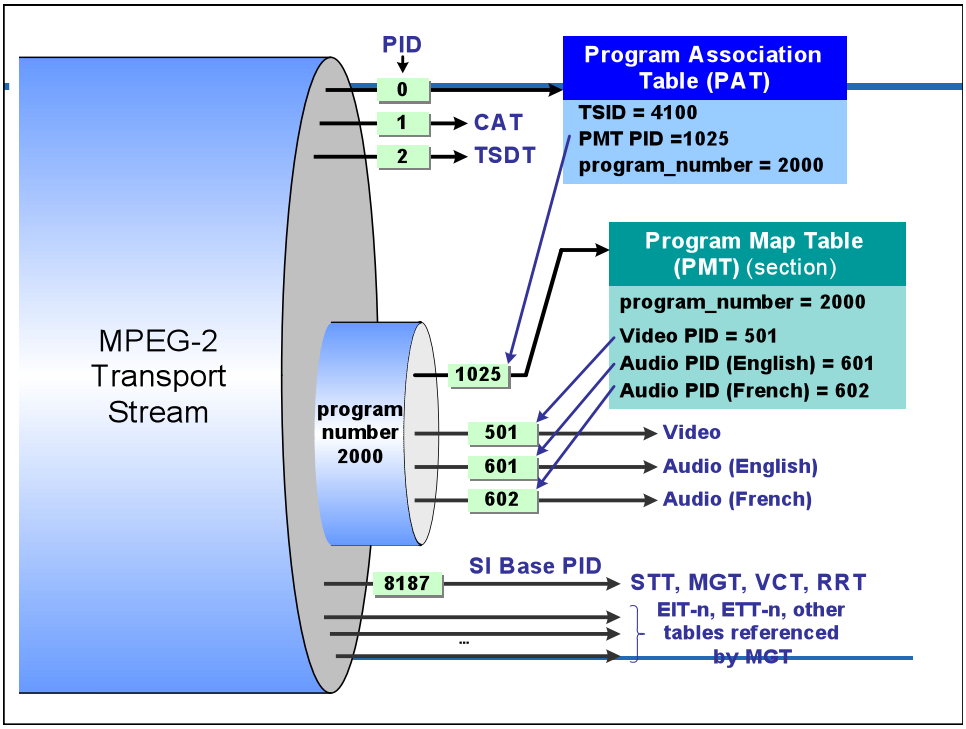


- MPEG-2 Transport Stream

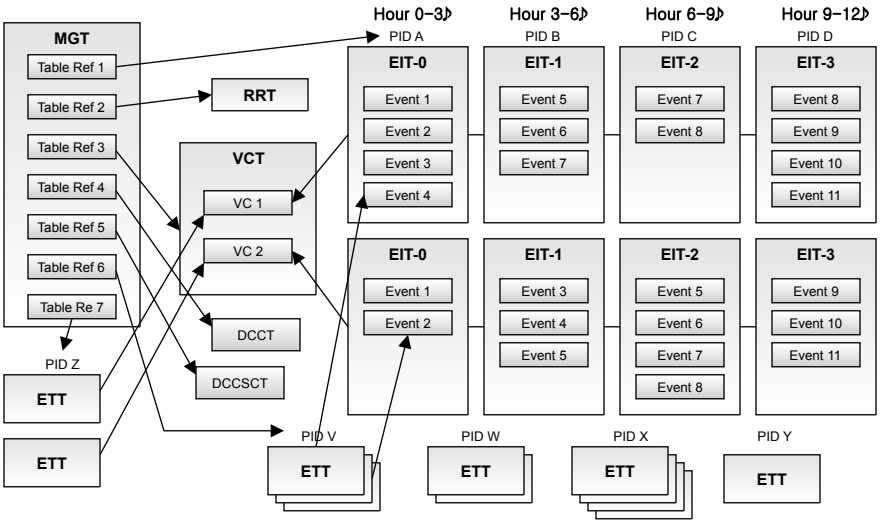


MPEG-2 Transport Stream

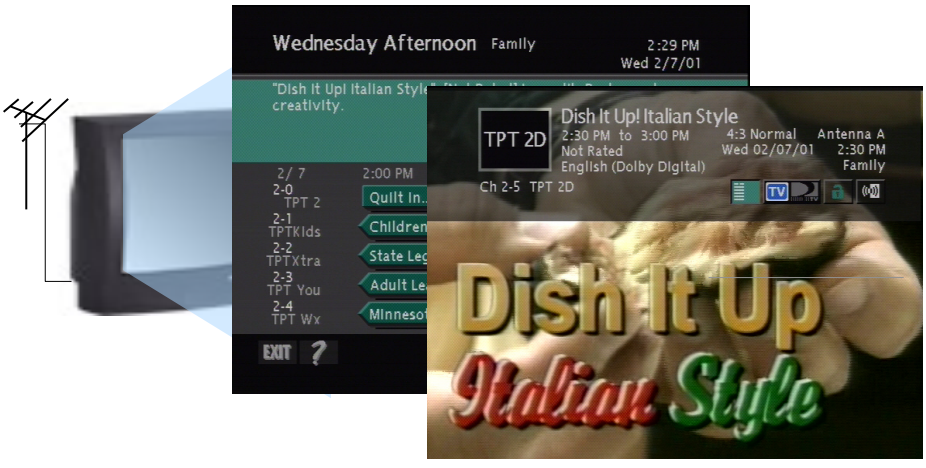




PSIP Tables: The Big Picture



End Result - Television



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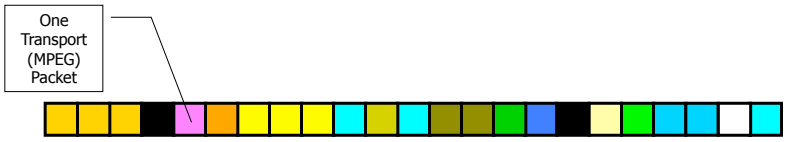
DTV Broadcast Stream

- Special case of ***MPEG-2 transport stream***
- May contain multiple ***virtual channels***
  - Video channels
    - A video stream
    - One or more audio streams
    - Possibly one or more data streams
  - Audio channels
    - One or more audio streams
    - Possibly one or more data streams
  - Data-only channels
    - One or more data streams

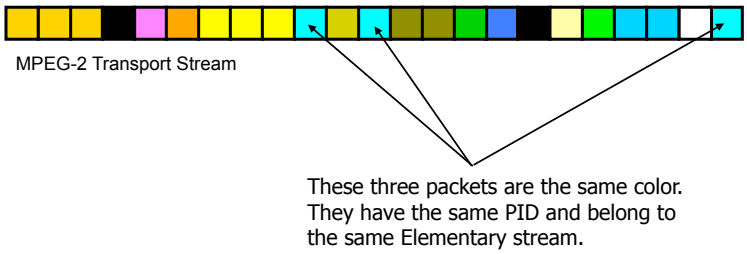
MPEG-2 Transport Stream

- Made up of 188-byte ***transport packets***, each with 4 byte header & 184 byte payload
- Each packet contains any ONE kind of information– audio, video, data, PSI, …



MPEG-2 Transport Stream (Contd.)

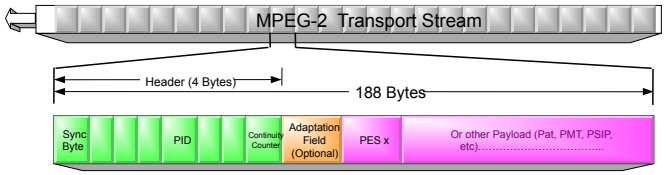
- We say transport packets have multiple interleaved ***elementary streams*** -- audio, video, data, PSI, ...
- Packets belonging to the same elementary stream are identified by ***packet id*** (PID) in packet header (same color in our illustrations).



MPEG-2 Transport Stream – Header Fields

Noteworthy fields:

1) Sync Byte – Find packet boundary
2) PID – Used while demultiplexing stream
3) Continuity Counter – Identify packet loss
4) PCR stamp in adaptation field – Clock sync



MPEG Header Fields: Sync Byte

- When a decoder first tunes, all it sees are a stream of 0's and 1's
- The decoder must first identify the beginning of packets before it can interpret the stream
- The decoder uses the Sync Byte field to do this

01010001111010010101101010001100011110010111000

MPEG Data Prior to Packet Sync

MPEG Header Fields: Sync Byte (Contd.)

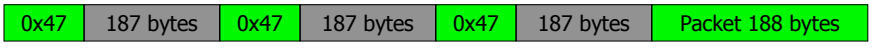
- The Sync Byte of a packet is always 0x47 (Hexadecimal) or 01000111 binary
- The decoder looks for strings of zeros and ones which match the pattern of the sync byte (see red below)

01010001111010010101101010001100011110010111000

MPEG Header Fields: Sync Byte (Contd.)

- Once the decoder finds a 0x47 in the stream, it looks 187 bytes down the stream, and looks for another 0x47
- If it finds three Sync Bytes in a row, then the Decoder has Found Sync and assumes packet boundaries from then on
- Each packet is tested for 0x47 as soon as it arrives. If a packet arrives with an incorrect sync byte, the decoder starts over. This is called SYNC LOSS

Found Sync



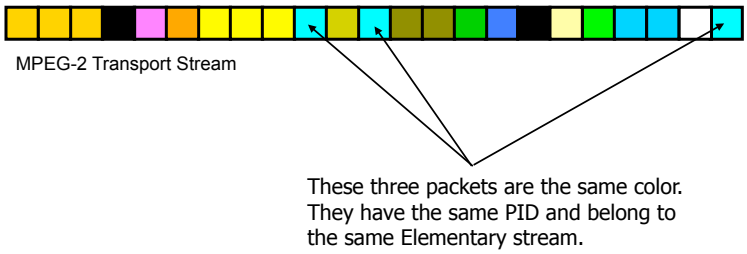
Sync Lost

MPEG Header Fields: Sync Byte (Contd.)

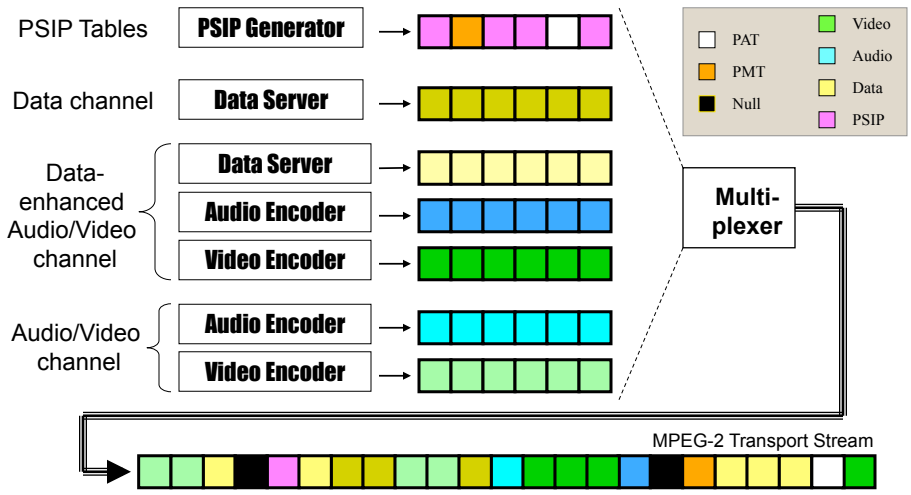
- If you don't have Packet Sync, the decoder cannot find packet boundaries. You will not be able to decode at all
- Packet Sync problems typically occur in hardware at packet boundaries during format converters, edge devices, demodulators etc:
  - ASI to Gig-E
  - ASI to Microwave or QAM
  - Satellite to ASI

PIDs Defined

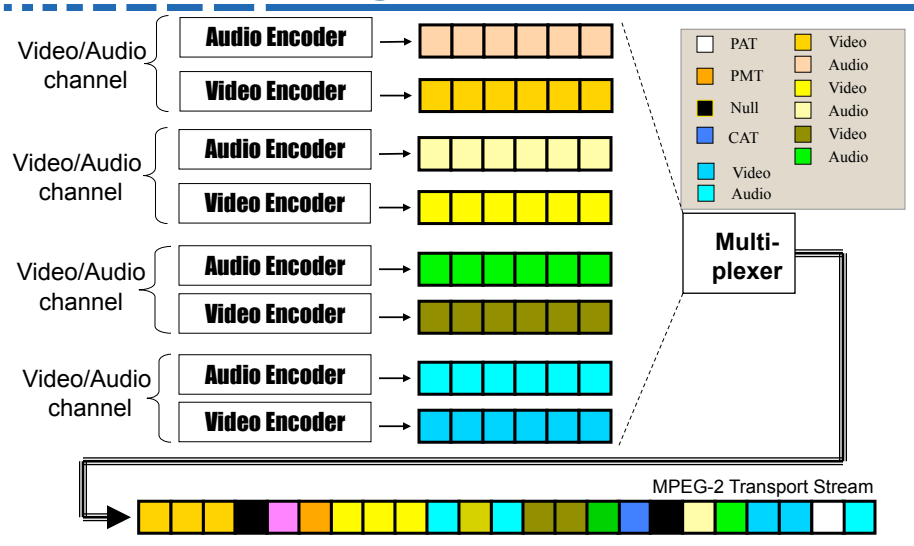
- PID stands for Packet ID
- Each Packet has a PID (indicated by color). Packets belonging to the same source of information have the same PID (same color).



PIDs Defined - ATSC Bitstream

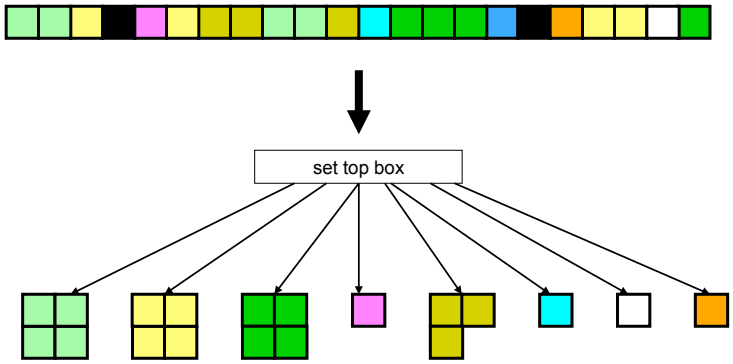


PIDs Defined - Digital Cable Bitstream



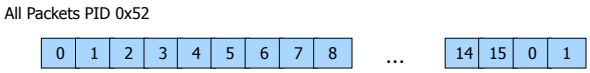
Transport Stream Demultiplexing

- When a set top box first receives a Transport Stream, it demultiplexes that stream based on PID.

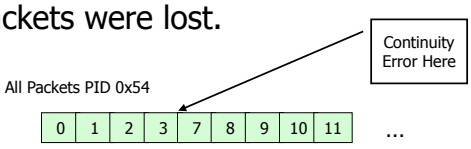


MPEG Header: Continuity Counter

- The continuity counter is a 4 bit field in the header which increments by 1 each time a packet comes out on a specific PID:



- When a PID 'skips' one value of the continuity Counter, we call it a 'Continuity Error.' This means one or more packets were lost.



MPEG Header: Continuity Counter (Contd.)

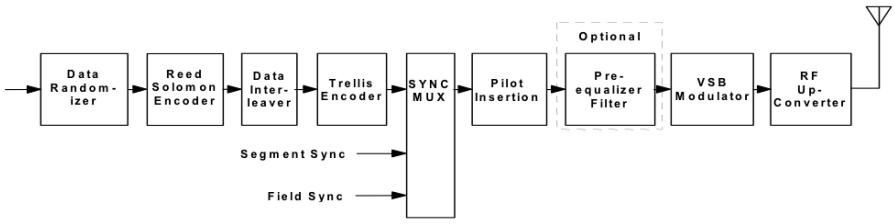
Identifies WHEN we lose
Packets, but not HOW MANY!

- Packet loss causes many other kinds of analysis to 'reset' or give bogus results.
- Any analysis based on an average over many packets will automatically reset when it encounters continuity problems.
- Since a continuity error mean 'some packets' have been lost, frequent continuity errors should be one of the FIRST things you look for when debugging.

Digital Television (US)

- ATSC Main Service (1997)
  - ITU-R BT.709 (sRGB) colorimetry
  - 16:9 aspect ratio, 720 or 1080 lines, 24 or 30fps, interleaved or progressive
  - MPEG-2 Video
  - Dolby AC-3 Audio
  - MPEG-2 Transport Stream (188 bytes/packet)
  - Randomizer
  - 208/188 Reed Solomon Outer Coding
  - 2/3 Trellis Inner Coding
  - 8VSB Modulation
  - 6MHz channel bandwidth

ATSC Main Service - Block Diagram



ATSC Channel Spectrum