Colorspaces and HDMI

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Color Transformations

CIE XYZ → Linear RGB → Nonlinear R'G'B' → Nonlinear Y'CbCr

3x3 matrix
(based on
chromaticities)

transfer function

3x3 matrix

Quantized R'G'B'

Quantized Y'CbCr

quantization range
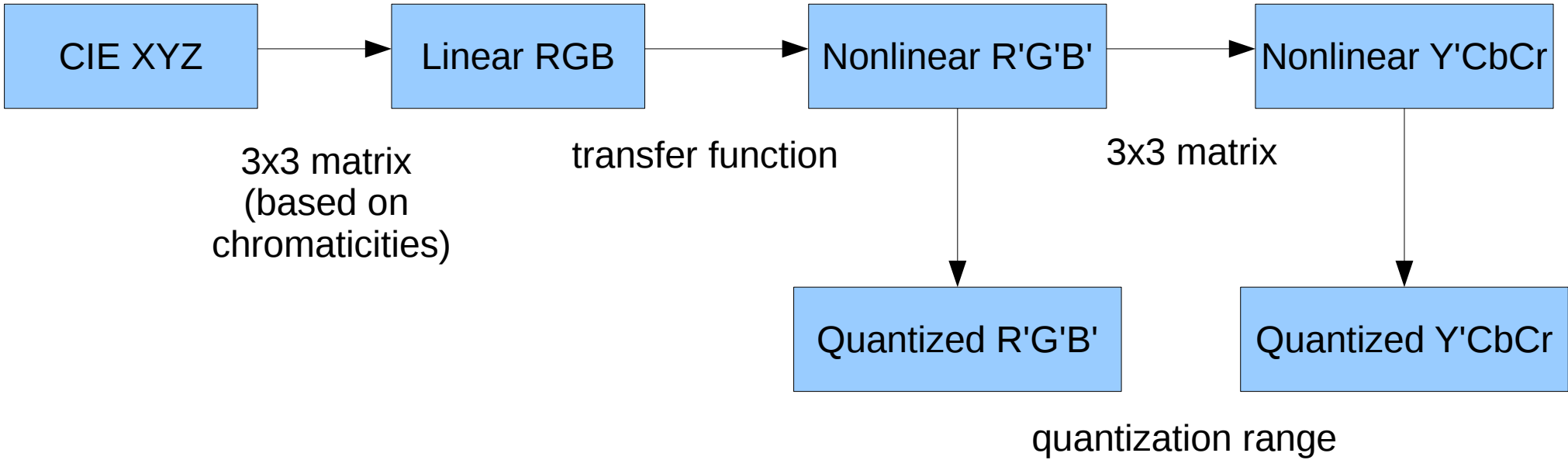
Standards

- sRGB: used for computer graphics. Standard: IEC 61966-2-1:1999.

- SMPTE 170M: defines the SDTV colorspace.

- Rec. 709: HDTV colorspace. Standard: Rec. ITU-R BT.709-5.

- Future: BT.2020 for deep-color (>= 10 bits) UHDTV.

|	Chromaticities	Xfer Func	Y'CbCr Enc
sRGB	Rec. 709	sRGB	Bt.601
SMPTE 170M	SMPTE 170M	Rec. 709	Bt.601
Rec. 709	Rec. 709	Rec. 709	Rec. 709
Bt.2020	Bt.2020	Rec. 709	Bt.2020

Limited and Full Range

- Typically 8-bit R', G' and B' values are quantized to the range [0-255]. This is full range quantization. Note: BT.2020 R'G'B' always uses limited range encoding.

- Typically 8-bit Y' values are quantized to the range [16-235] and Cb and Cr values to the range [16-240]. This is limited range quantization.

- But limited range R'G'B' (values in the range [16-235]) and full range Y'CbCr variants exist as well. HDMI can signal both variants.

Common Mistakes

- Using the wrong chromaticities: e.g. SMPTE 170M instead of Rec. 709. Harmless mistake since these are almost identical and the difference is almost impossible to detect.

- Using the wrong transfer function: e.g. sRGB instead of Rec. 709. Easy to see the difference when seen next to one another, but the average end-user will not detect the difference. An expert on color might, though.

- Using the wrong Y'CbCr encoding: e.g. BT.601 instead of Rec. 709. Easy to see the difference, and savvy end-users will detect such problems.

- Using the wrong quantization range: e.g. full range when it should be limited range. Easy to see the difference, especially in grayscale ramps.
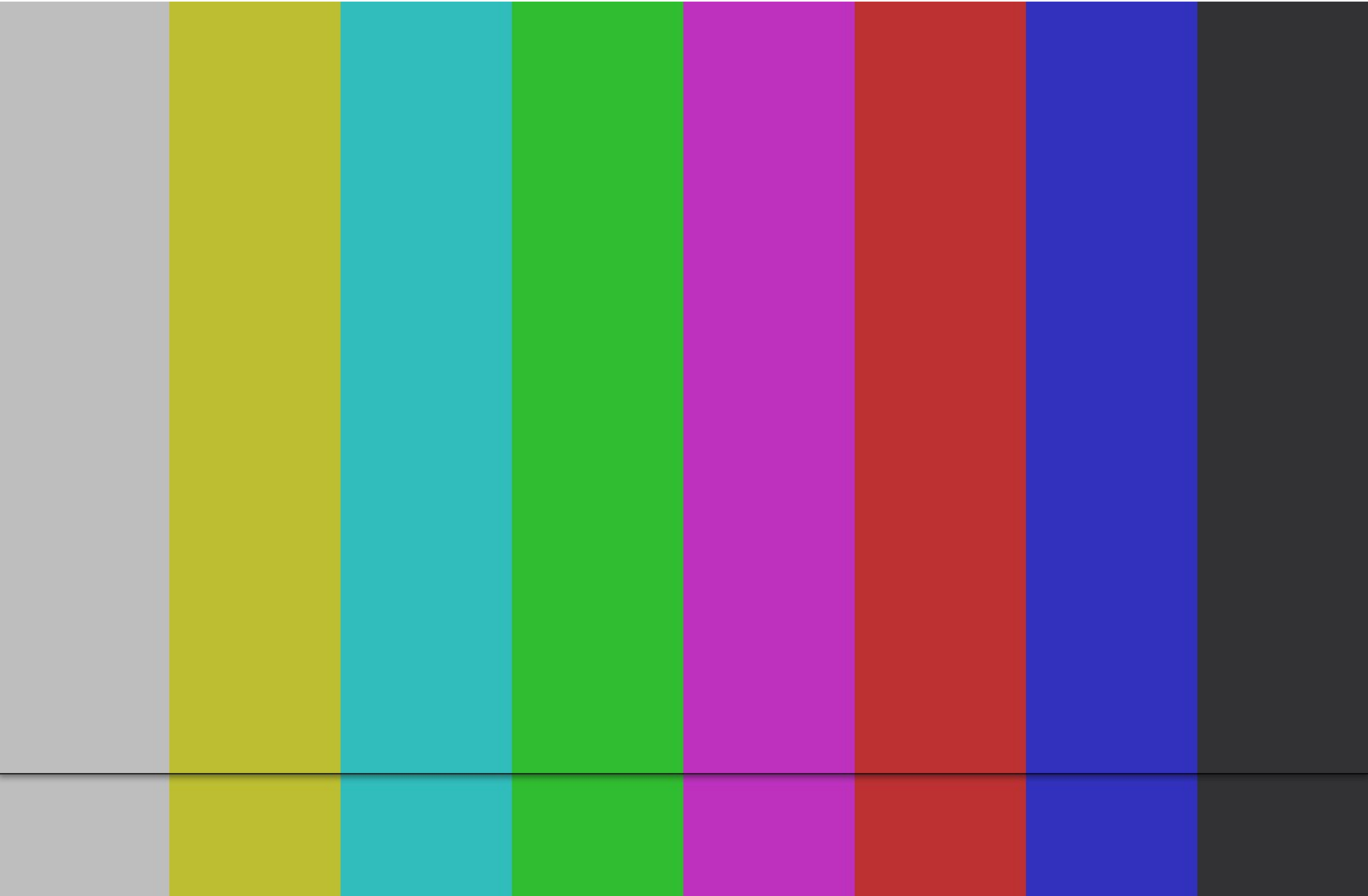
SMPTE-170M vs Rec. 709
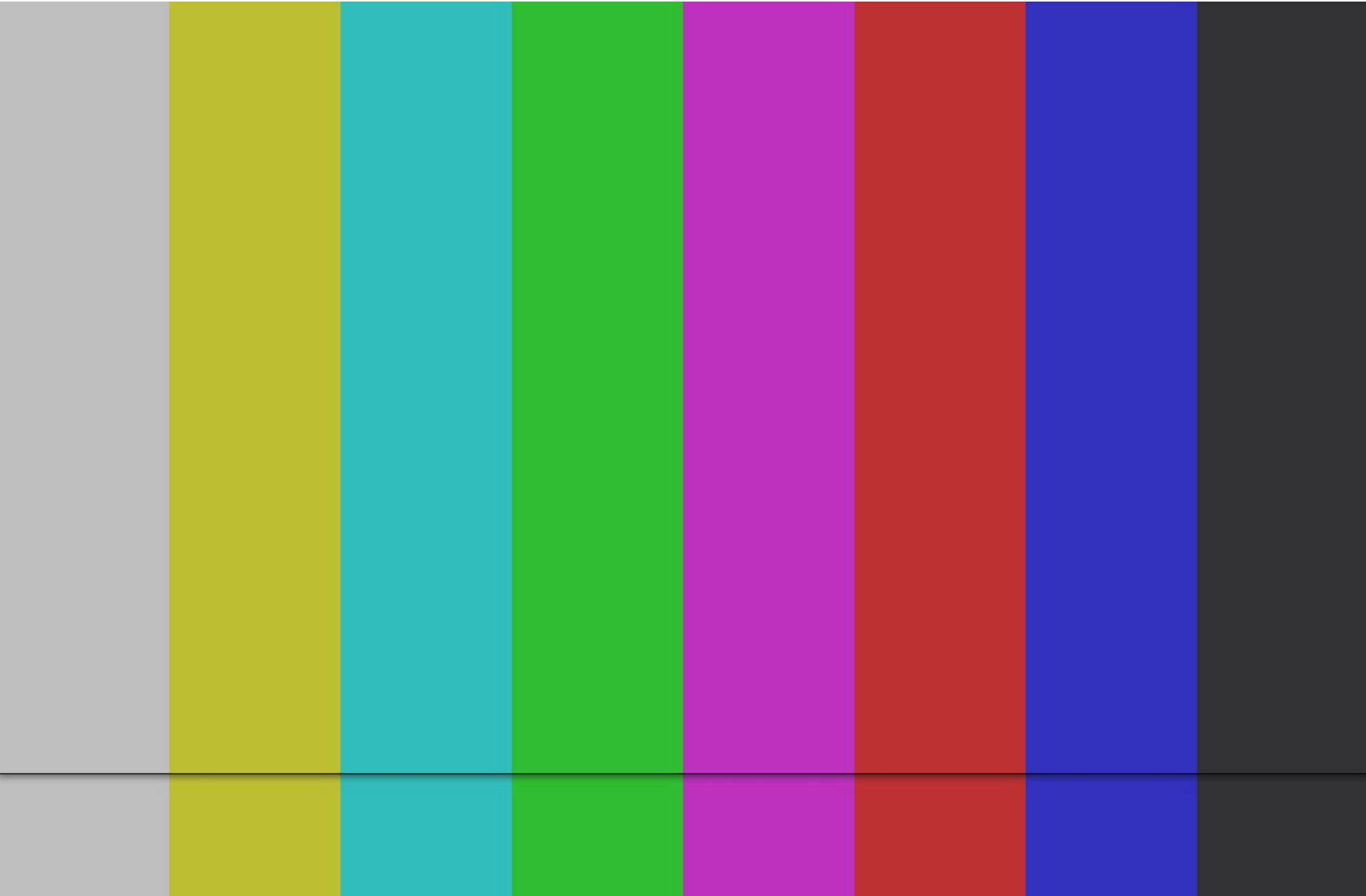
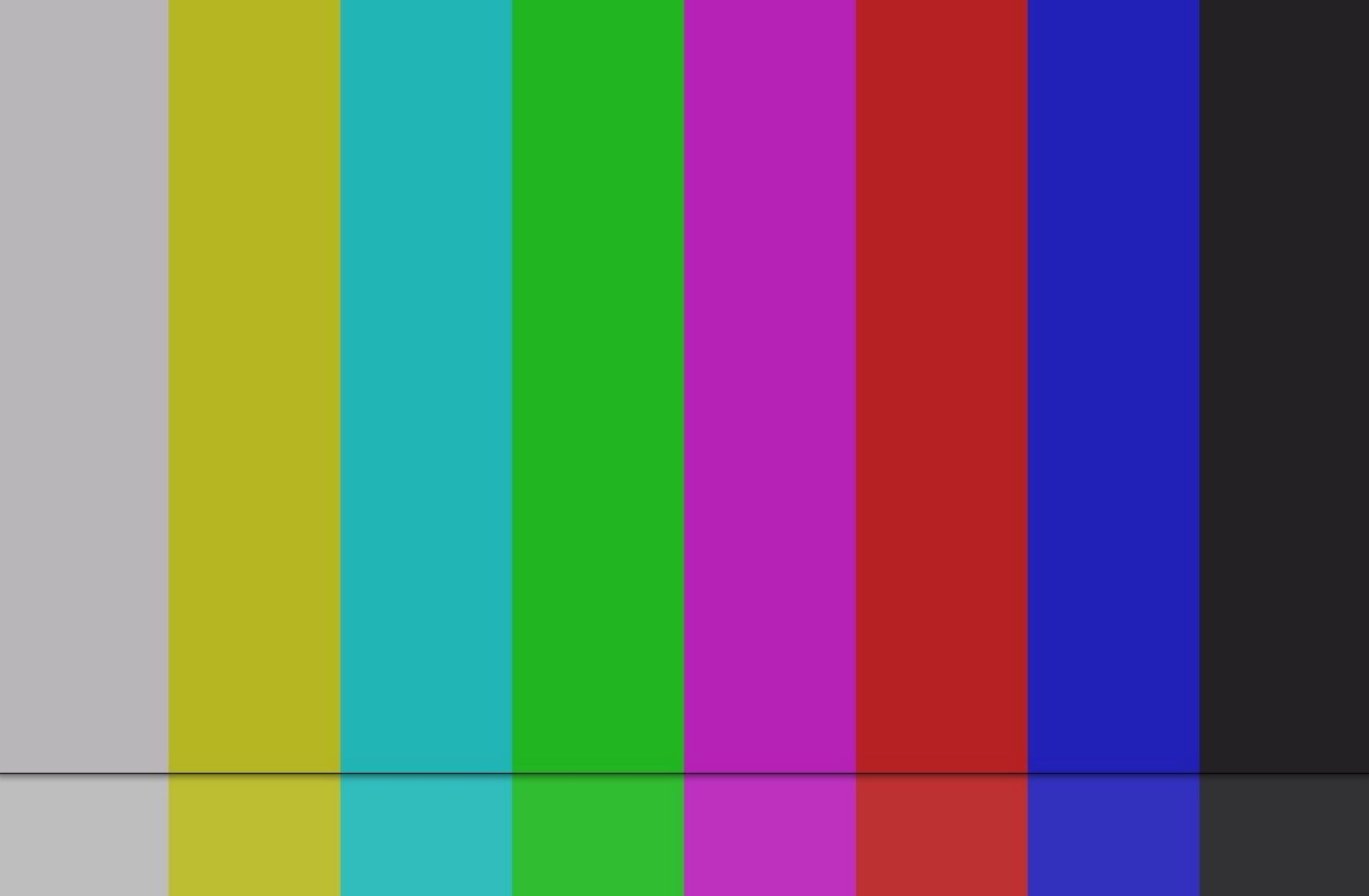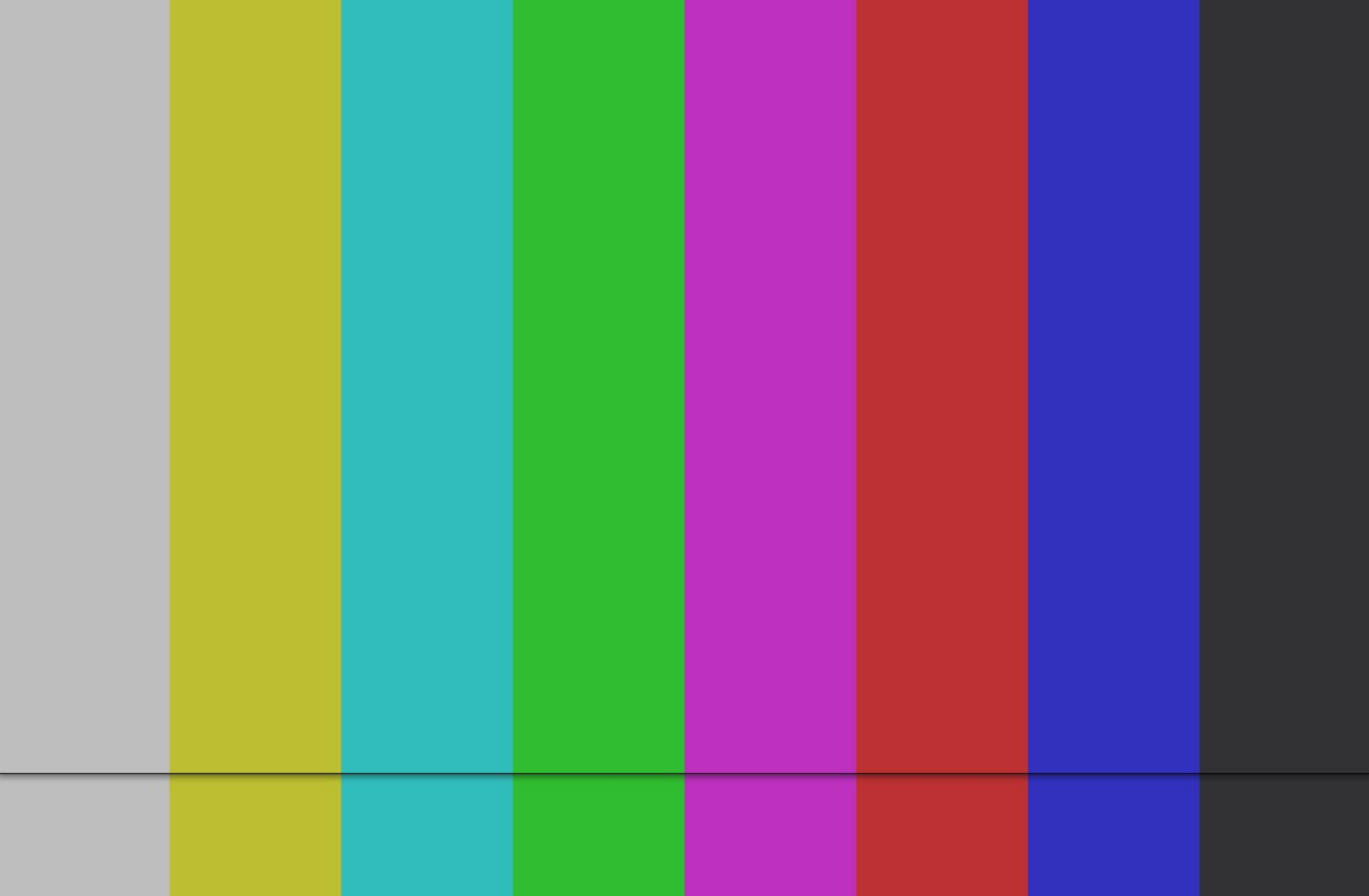# SMPTE-170M vs Rec. 709
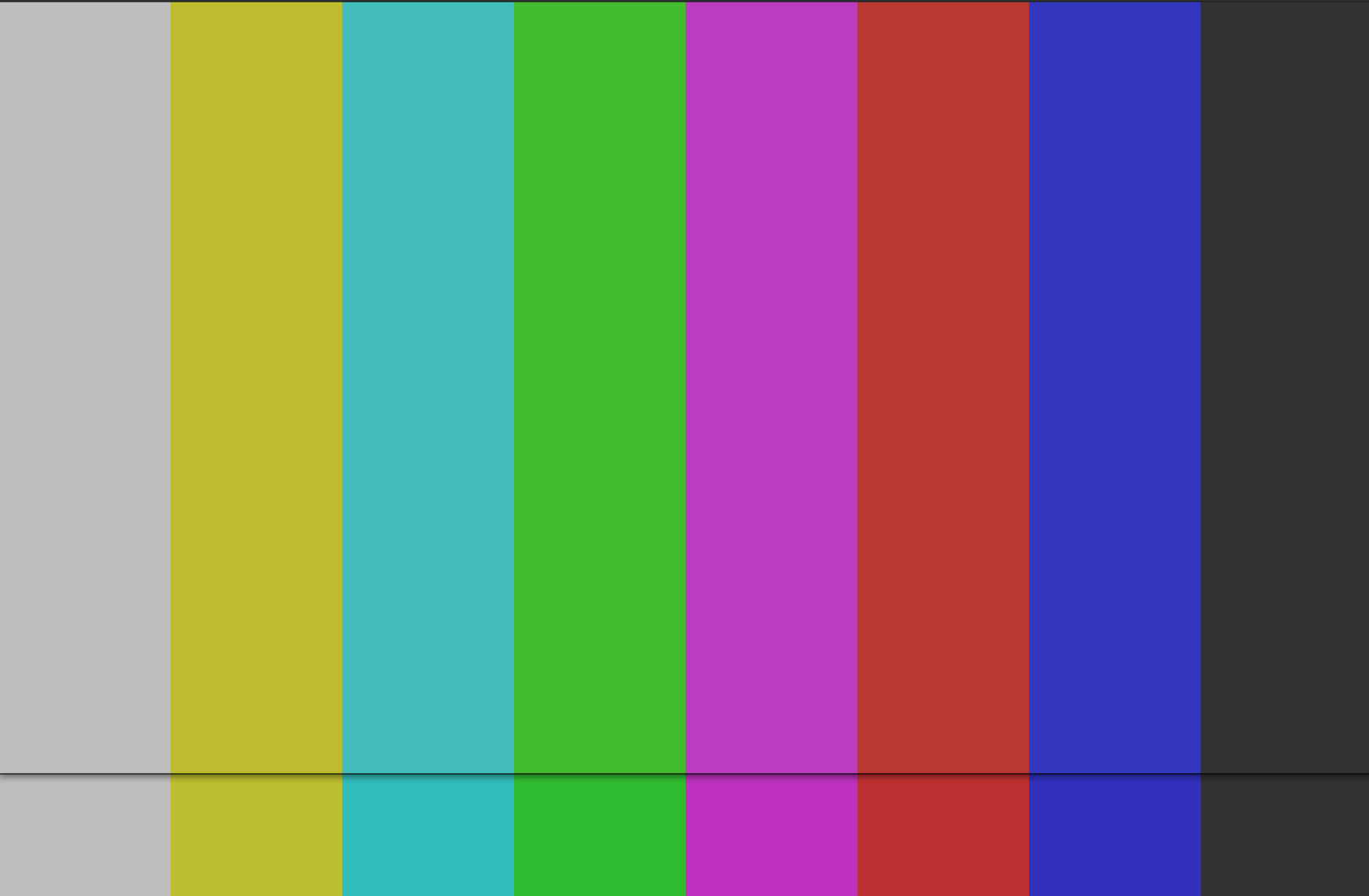
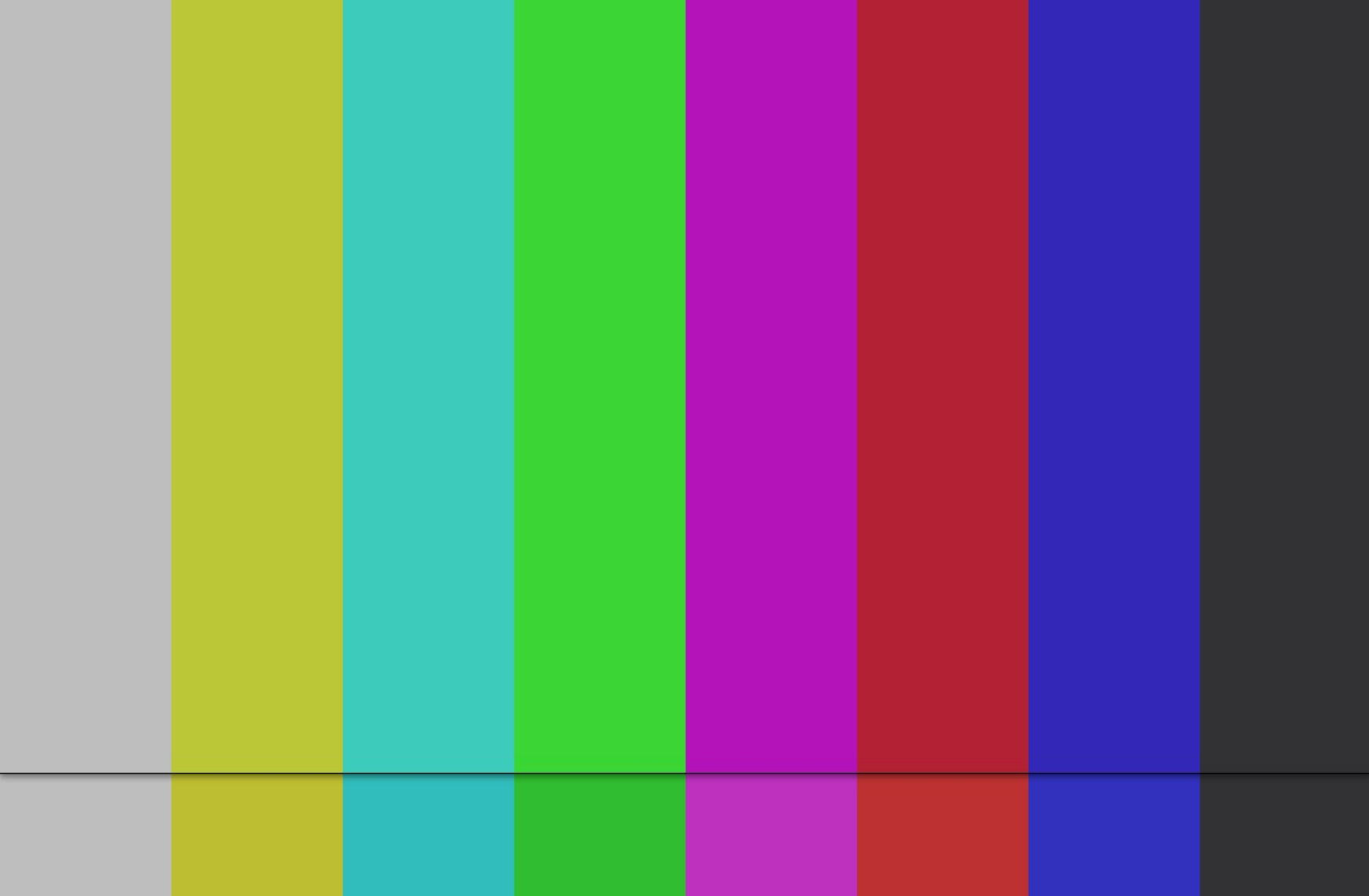# Rec. 709 vs sRGB Transfer Function

Rec. 709 vs sRGB Transfer Function

Rec. 709 vs BT.601 Y´CbCr Encoding

Rec. 709 vs BT.601 Y´CbCr Encoding

Limited vs Full Range Quantization
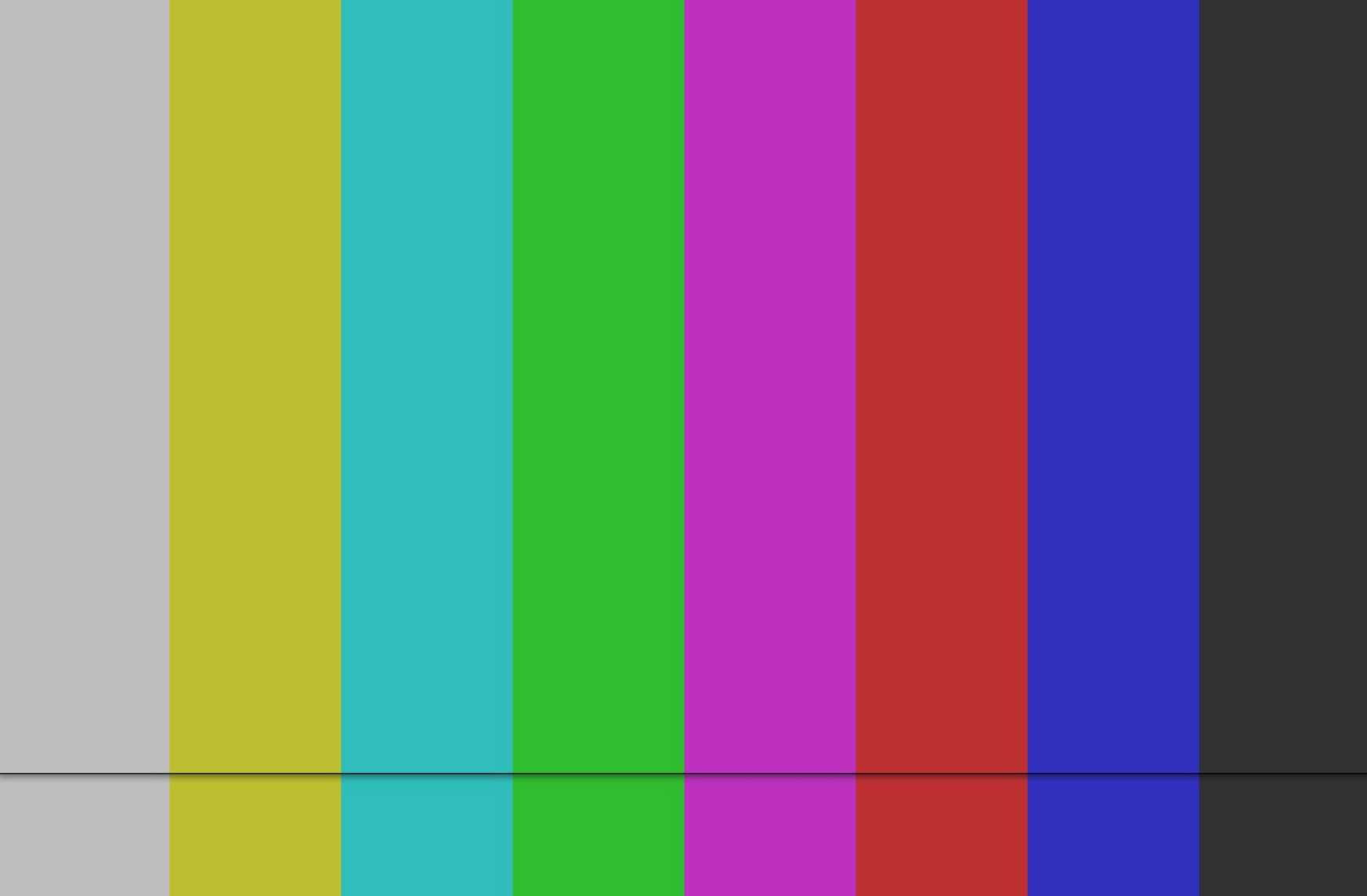
Limited vs Full Range Quantization
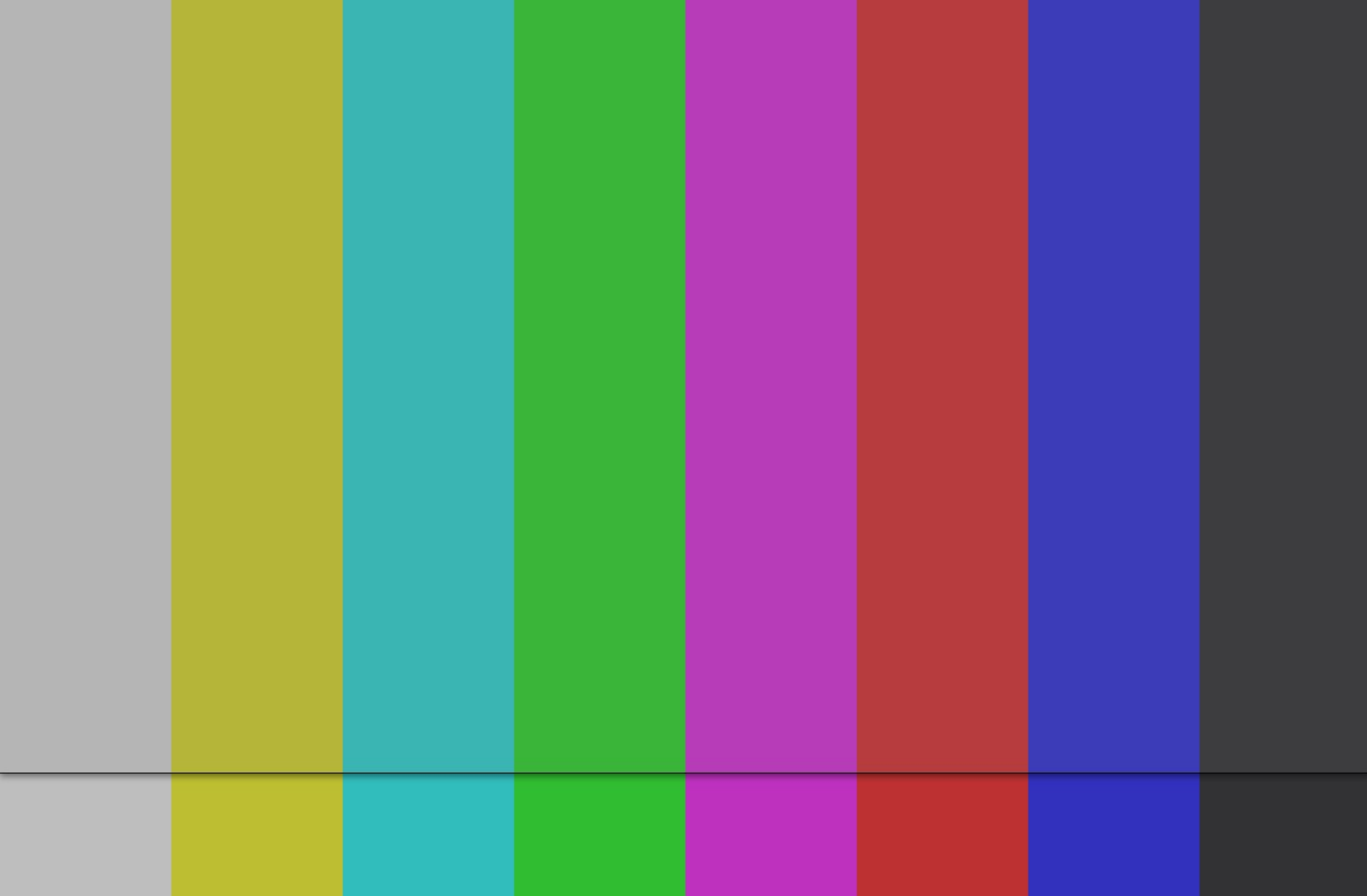
HDMI: Supported Colorspaces

1. sRGB R'G'B', limited and full range quantization

2. SMPTE 170M Y'CbCr, limited and full range quantization

3. Rec. 709 Y'CbCr, limited and full range quantization

4. xvYCC 709 Y'CbCr, full range (wide gamut Rec. 709)

5. xvYCC 601 Y'CbCr, full range (as xvYCC 709, but using BT.601 for Y'CbCr encoding)

6. sYCC, limited and full range (= sRGB but using BT.601 Y'CbCr encoding)

7. AdobeRGB, limited and full range

8. AdobeYCC, limited and full range

9. BT.2020 Y'cCbcCrc, limited range (constant luminance)

10. BT.2020 RGB, limited range

11. BT.2020 Y'CbCr, limited range

HDMI: Supported Colorspaces

- Y'CbCr available as 4:4:4, 4:2:2 and 4:2:0.

- BT.2020 only available for 10 or 12 bits per component formats (deep color).

- R'G'B' quantization setting: ambiguous if this applies to BT.2020 R'G'B' which is supposed to be limited range.

- Y'CbCr quantization setting: ambiguous if this applies to xvYCC which is supposed to be full range or BT.2020 Y'CbCr since that is supposed to be limited range.

- Note that HDMI doesn't support SMPTE 170M or Rec. 709 R'G'B' formats! These are only available as Y'CbCr formats.

HDMI Receiver/Transmitter

```
┌──────────┐      ┌──────────┐      ┌─────────────────┐
│   HDMI   │─────▶│ ADV7842  │─────▶│ Memory R'G'B'   │
└──────────┘      └────┬─────┘      └─────────────────┘
                       │
                       │            ┌─────────────────┐
                       └───────────▶│ Memory Y'CbCr   │
                                    └─────────────────┘


┌─────────────────┐      ┌──────────┐      ┌──────────┐
│ Memory R'G'B'   │─────▶│ ADV7511  │─────▶│   HDMI   │
└─────────────────┘      └────▲─────┘      └──────────┘
                              │
┌─────────────────┐          │
│ Memory Y'CbCr   │──────────┘
└─────────────────┘
```

Color Transformations

```
┌─────────┐         ┌────────────┐         ┌──────────────────┐         ┌──────────────────┐
│ CIE XYZ │ ──────▶ │ Linear RGB │ ──────▶ │ Nonlinear R'G'B' │ ──────▶ │ Nonlinear Y'CbCr │
└─────────┘         └────────────┘         └──────────────────┘         └──────────────────┘
```

3x3 matrix
(based on
chromaticities)

transfer function

3x3 matrix +
offset vector

Quantized R'G'B'

Quantized Y'CbCr
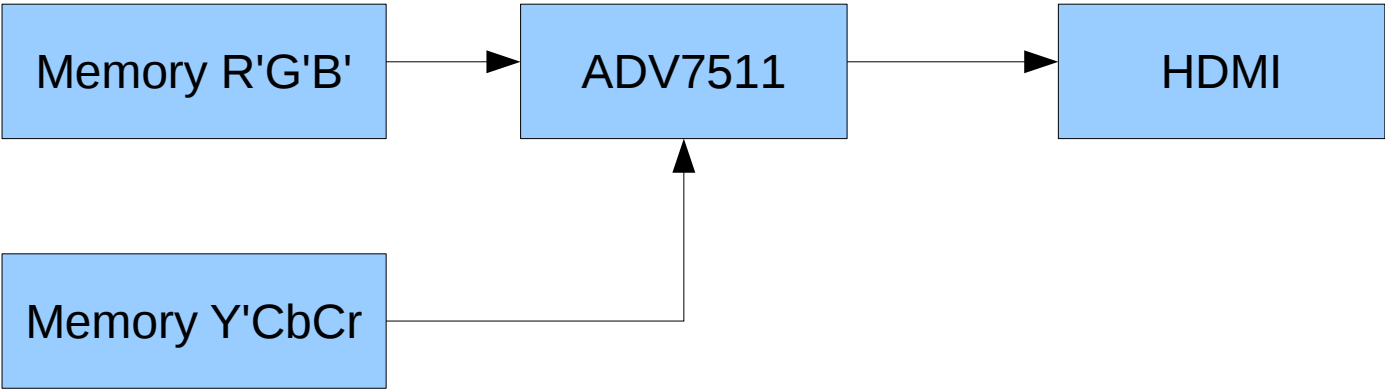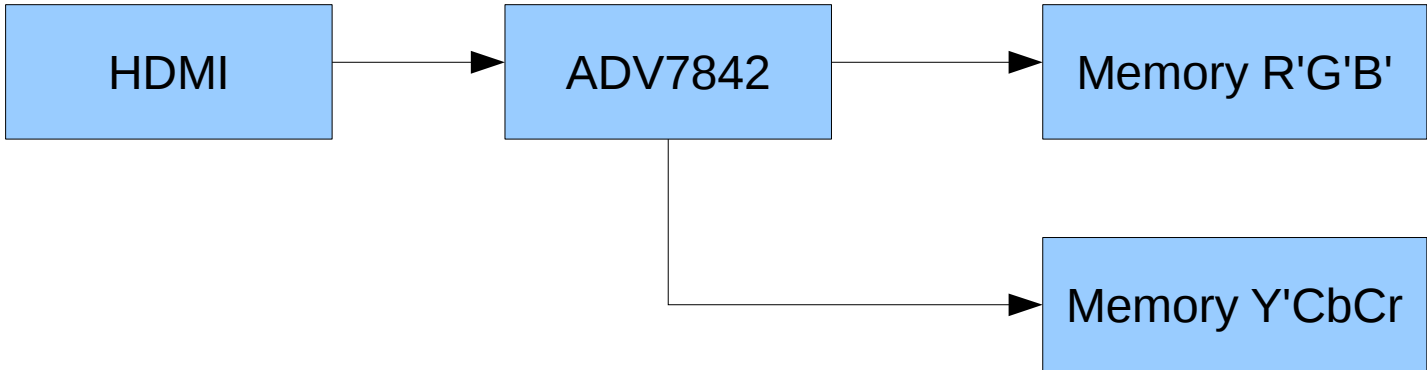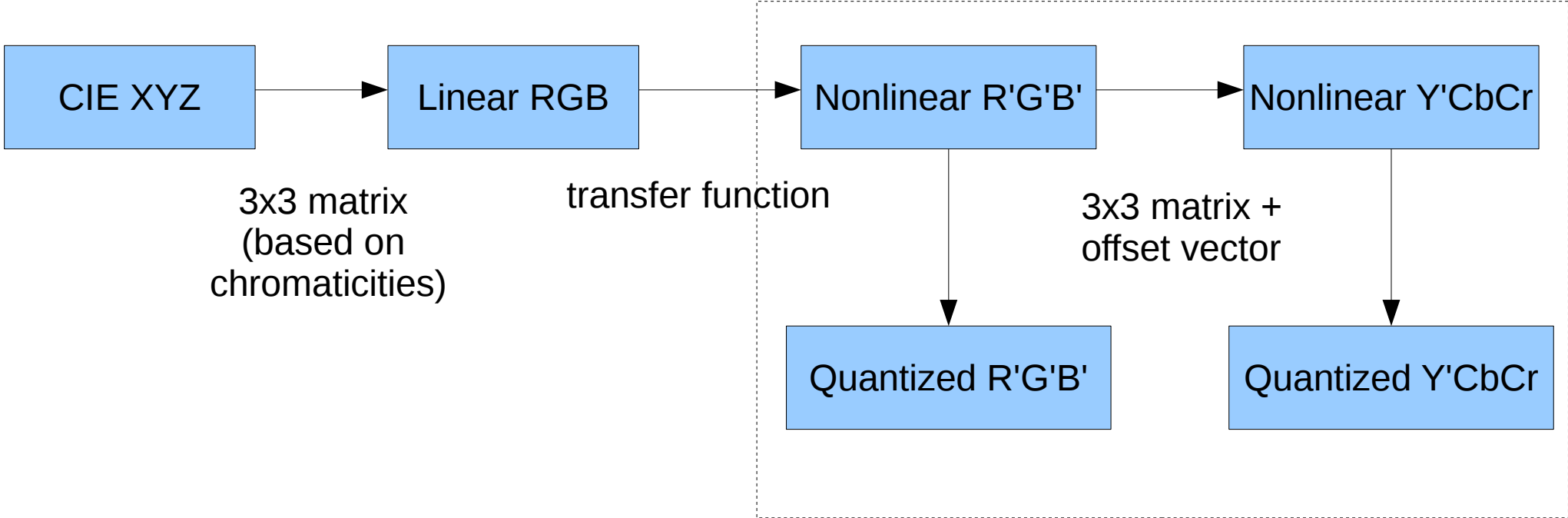
HDMI (CEA-861-F): Choosing the Colorspace

1. If the sink cannot receive AVI InfoFrames then:

   – For IT (i.e. non-SDTV/HDTV) timings use full range sRGB.

   – For CE (i.e. SDTV/HDTV) timings use limited range sRGB. God knows why...

   – Actually, for IT timings a transmitter should read the Basic Display Parameters and Feature block of the EDID and use the specified chromaticities.

2. If the sink can receive AVI InfoFrames then:

   – Read supported formats and quantization ranges from EDID.

   – If the sink cannot receive Y'CbCr, then use sRGB. If the R'G'B' quantization range cannot be selected, then follow 1, else use the input R'G'B' quantization range.

   – For R'G'B' or Y'CbCr video using the sRGB colorspace: convert Y'CbCr to R'G'B'. The quantization range is full range if the sink can select the R'G'B' range, else follow 1.

   – For R'G'B' or Y'CbCr video using the SMPTE 170M or Rec. 709 colorspace: convert R'G'B' to Y'CbCr. The quantization range is kept if the sink can select the Y'CbCr quantization range, else use limited range.

HDMI (CEA-861-F): Choosing the Colorspace

3. For non-sRGB/SMPTE 170M/Rec. 709 colorspaces:

- Check if colorspace is supported by the sink (EDID Colorimetry Data Block).

- sYCC can be converted to sRGB if needed.

- xvYCC 601 and xvYCC 709 can be converted to Rec. 709 if needed.

- BT.2020 Y'CbCr can be converted to BT.2020 R'G'B' and vice versa.

- AdobeYCC can be converted to AdobeRGB and vice versa.

- sYCC and AdobeYCC should use as defaults limited range for CE formats and full range for IT formats. No mention of AdobeRGB, so I assume as default full range for both CE and IT formats.

Conversion Table

From \ To	sRGB/R'G'B'/lim	sRGB/R'G'B'/full	170M/601/lim	170M/601/full	709/709/lim	709/709/full
sRGB/R'G'B'/lim	OK	Convert				
sRGB/R'G'B'/full	Convert	OK				
sRGB/601/lim	Convert	Convert				
sRGB/601/full	Convert	Convert				
sRGB/709/lim	Convert	Convert				
sRGB/709/full	Convert	Convert				
170M/R'G'B'/lim			Convert	Convert	Convert	Convert
170M/R'G'B'/full			Convert	Convert	Convert	Convert
170M/601/lim			OK	Convert	Convert	Convert
170M/601/full			Convert	OK	Convert	Convert
170M/709/lim			Convert	Convert	OK	Convert
170M/709/full			Convert	Convert	Convert	OK
709/R'G'B'/lim			Convert	Convert	Convert	Convert
709/R'G'B'/full			Convert	Convert	Convert	Convert
709/601/lim			OK	Convert	Convert	Convert
709/601/full			Convert	OK	Convert	Convert
709/709/lim			Convert	Convert	OK	Convert
709/709/full			Convert	Convert	Convert	OK

Summary

- It's a mess!

- Poorly defined, especially when dealing with more obscure colorspaces.

- Limited vs Full Range quantization is hit-and-miss due to different default quantization range choices with IT format vs SDTV/HDTV formats.

- User must be able to override quantization range.

- R'G'B' cannot use SMPTE 170M or Rec. 709, that's only allowed for Y'CbCr.

- Passing video to the GPU: must take colorspaces into account, this can be different for different video sources.

- Due to the complexity of colorspace handling and poorly defined standards many vendors will implement it incorrectly. This makes color handling unpredictable.

Resources

- Color Imaging – Fundamentals and Applications, Erik Reinhard et. al.

- Digital Video and HDTV – Algorithms and Interfaces, Charles Poynton.

- http://www.brucelindbloom.com

- http://hverkuil.home.xs4all.nl/spec/media.html#colorspaces

- CEA-861-F: Consumer Electronics Association (http://www.ce.org). A DTV Profile for Uncompressed High Speed Digital Interfaces.

- HDMI 2.0a: HDMI Licensing LLC (http://www.hdmi.org). High-Definition Multimedia Interface. Specification Version 2.0a.

Questions?