NTSC Modulation Standard

The Impressionistic Era of TV.
It's **N**ever **T**he **S**ame **C**olor!

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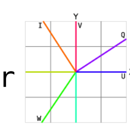
The first analog Color TV system realized which is backward compatible with the existing **B & W** signal. To combine a **Chroma** signal with the existing **Luma**(**Y**) signal a quadrature sub-carrier **Chroma** signal is used. On the Cartesian grid the **x & y** axes are defined with **B−Y** & **R−Y** respectively. When transmitted along with the **Luma**(**Y**) **G−Y** signal can be recovered from the **B−Y** & **R−Y** signals.

Matrixing

```
Let:

R = Red     \
G = Green    Each range from 0 to 1.
B = Blue    /

Y = Matrixed B & W     Luma sub-channel.
U = Matrixed Blue   Chroma sub-channel.   U #2900FC 249.76°   -U #D3FC00  69.76°
V = Matrixed Red    Chroma sub-channel.   V #FF0056 339.76°   -V #00FFA9 159.76°
W = Matrixed Green  Chroma sub-channel.   W #1BFA00 113.52°   -W #DF00FA 293.52°
                                                    HSV                  HSV
Enhanced channels:                                  Hue                  Hue
I = Matrixed  Skin  Chroma sub-channel.   I #FC6600  24.29°   -I #0096FC 204.29°
Q = Matrixed Purple Chroma sub-channel.   Q #8900FE 272.36°   -Q #75FE00  92.36°

We have:
    Y =  0.299 × R + 0.587 × G + 0.114 × B
B − Y = −0.299 × R − 0.587 × G + 0.886 × B
R − Y =  0.701 × R − 0.587 × G − 0.114 × B

G − Y = −0.299 × R + 0.413 × G − 0.114 × B
      = −0.194208 × (B − Y) −0.509370 × (R − Y)          (−0.1942078377, −0.5093696834)
Encode:
If:   U[x] = 0.492111 × ( B − Y ) ×   0° ┐ Quadrature                 (0.4921110411)
      V[y] = 0.877283 × ( R − Y ) ×  90° ┘ Sub-Carrier                (0.8772832199)
Then: W    = 1.424415 × ( G − Y ) @ 235.796°
Chroma Vector   = √ U² + V²
Chroma Hue   θ = aTan2(V,U) [Radians]
          If θ < 0 then add 2π.[360°]
Decode:              SyncDet
U: B − Y = -┼- @    0.000° ÷ 0.492111
V: R − Y = -┼- @   90.000° ÷ 0.877283
W: G − Y = -┼- @  235.796° ÷ 1.424415                   (1.4244145537, 235.79647610°)
 or
   G − Y = −0.394642 × (B − Y) − 0.580622 × (R − Y)     (−0.3946423068, −0.5806217020)
```

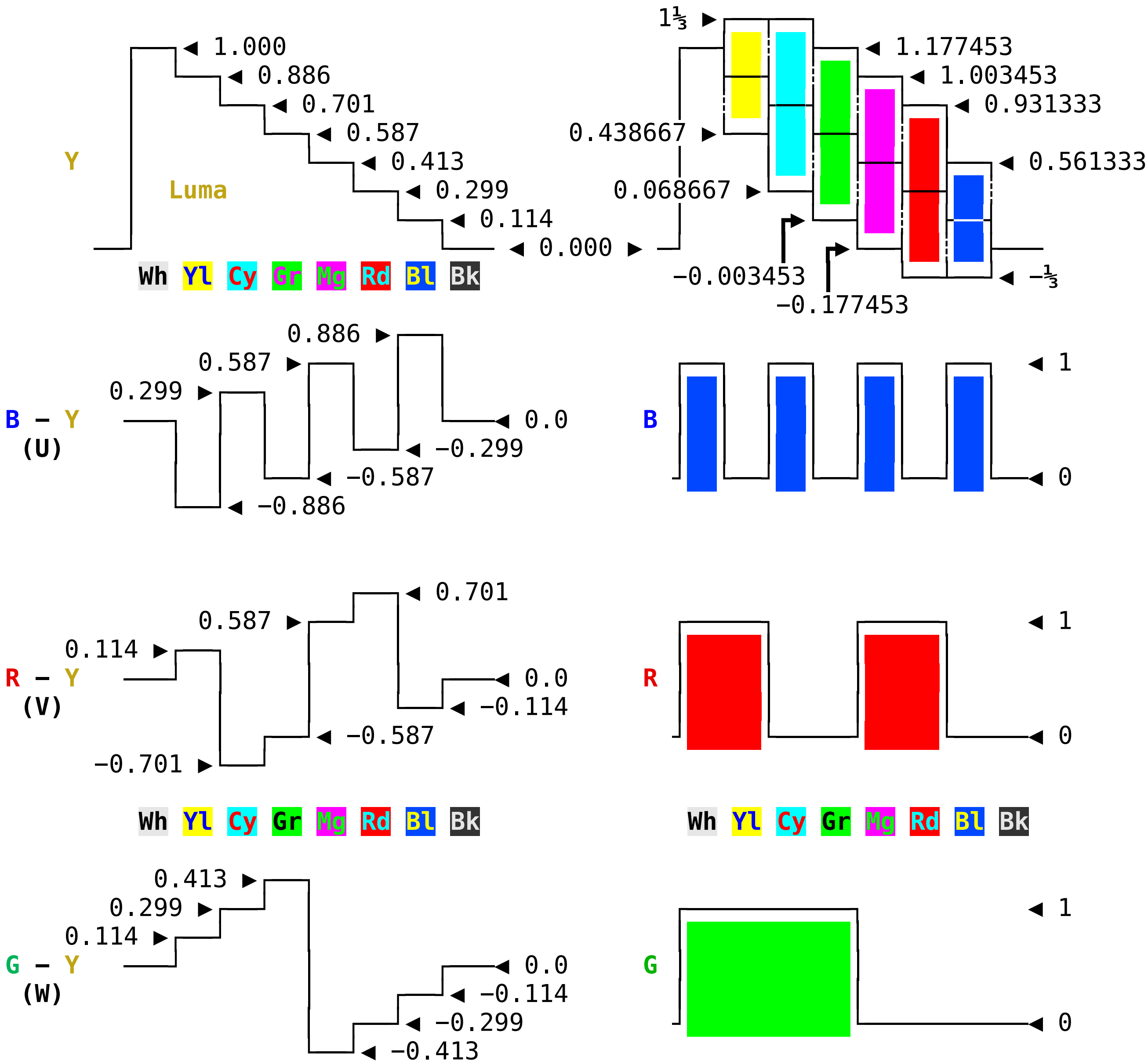


These scaling factors are for the quadrature **Chroma** signal before the **0.492111 & 0.877283** unscaling factors are applied to the **B−Y** & **R−Y** axes respectively.

100% Color Bars

Composite Luma & Chroma

0.492111×(B−Y) & 0.877283×(R−Y)



Color Bar	Luma Level	Chroma 0.492111×U	Levels 0.877283×V	Chroma Hue θ	Chroma Peak Level
White	100.0%	N/A	N/A	N/A	N/A
Yellow	88.6%	−0.436010	+0.100010	167.08°	0.447333
Cyan	70.1%	+0.147141	−0.614976	283.46°	0.632333
Green	58.7%	−0.288869	−0.514965	240.71°	0.590453
Magenta	41.3%	+0.288869	+0.514965	60.71°	0.590453
Red	29.9%	−0.147141	+0.614976	103.46°	0.632333
Blue	11.4%	+0.436010	−0.100010	347.08°	0.447333
Black	0.0%	N/A	N/A	N/A	N/A

The **Chroma** scaling for the colors with full saturation produces a minimum peak level of **0.4473** for the **Yellow−Blue** axis and a maximum peak level of **0.6323** for the **Cyan−Red** axis while the **Green−Magenta** axis is in the middle with **0.5904**. When modulated the p-p levels are **0.8947, 1.2647, & 1.1809** respectively. When combined with **Luma** the **Luma** + **Chroma** peak for **Yellow** & **Cyan** is at **+133⅓%** and **Red** & **Blue** is at **-33⅓%**.

After scaling the degree of separation between the MRYGCB color axes and their amplitudes is made even more unequal as shown in the vector image on page 4.

When the **B–Y** axis portion is added to the **Luma** the **Yellow** positive peak produced peak levels exceeding maximum signal levels and the negative peak levels for **Blue** exceeded sync levels thus interfering with syncing so this axis has been reduced by a factor of **0.492111**. This greater level of reduction compared to **R–Y** is needed due to a value of only **0.114** of the **Blue** signal used to create the **Luma** signal. This has a double impact in that the **Blue** percentage only subtracts **0.114** from the **Luma** level of **1** placing the **Luma** level at **0.886** for the **Yellow** portion of the **Chroma** sub-carrier to be biased with and for the **Blue** portion only adds **0.114** to the black level to be biased with. Also when **B–Y** is generated the low percentage of **Blue** within the **Luma** does not reduce **Y** by much for **Yellow & Blue** peak modulations thus making it larger in amplitude compared to **R–Y**.

The same holds true for the **Cyan–Red** axis but to a lesser extent. For **Cyan** **0.299** is subtracted from the **Luma** and for **Red** **0.701** is subtracted leaving **Luma** signal levels for **Cyan & Red** at **0.701 & 0.299** respectively for biasing requiring only a **0.877283** reduction for **R–Y**. This puts the **Cyan–Red** axis peak levels at the same peak levels as the **Yellow–Blue** axis in the composite signal as seen in the composite image.

After the **B–Y & R–Y** axes scaling the **Green–Magenta** axis levels produced within the quadrature **Chroma** sub-carrier are somewhere in between the **Yellow–Blue** and **Cyan–Red** axes levels. The **Luma** levels for **Green & Magenta** are centered around **50%** of the **Luma** at **0.587 & 0.413** respectively for biasing and does not produce any peak levels exceeding maximum signal level modulation so no adjustment is needed.

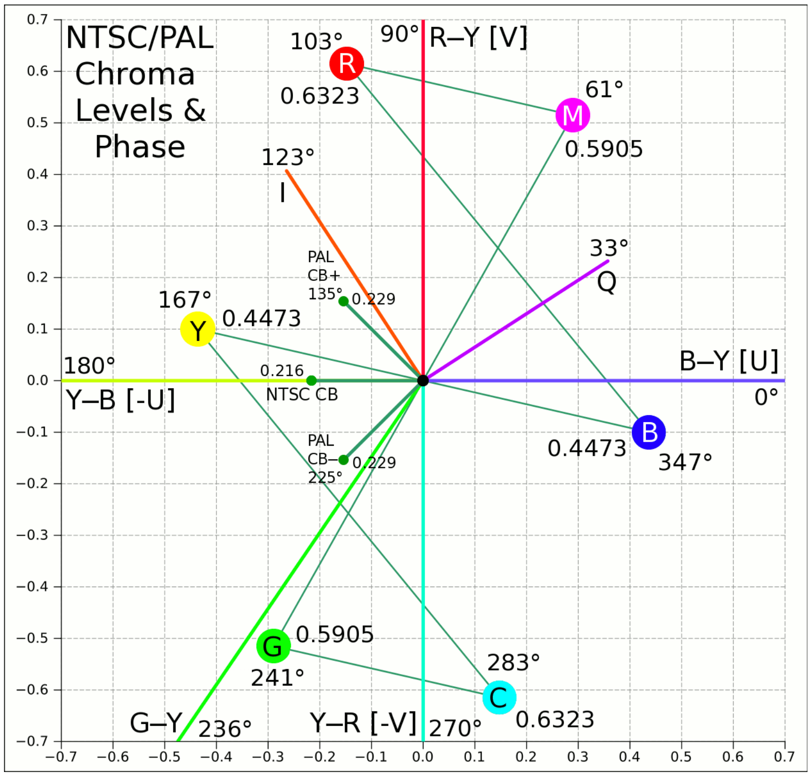
Since NTSC is required to be compatible with the existing **B & W** receivers and fit within the **6** mHz channel allocation this did not leave much bandwidth available for the **Chroma** signal so maximizing signal quality is greatly needed. It was discovered that vision of the eye is less sensitive to color changes than it is to brightness changes thus allowing a lower fidelity color signal transmitted in relation to the B & W signal without being noticed. The **B & W** portion would have a maximum bandwidth of **4.2** MHz while the highest color fidelity would be **35%** of that at **1½** MHz. The eye is also more sensitive to the flesh tones than to the other colors so the **I & Q** method, In phase and Quadrature alignment, was devised where the **I** channel would carry the oranges where the flesh tones are and would have a higher bandwidth for the lower sideband at **1.5** MHz and the upper sideband would be vestigial with a **500** kHz bandwidth. The **Q** channel where the purples are would have both its upper and lower sidebands limited to a **500** kHz bandwidth. The total bandwidth of the **Chroma** signal is **2** MHz. The **I & Q** channels are usually matrixed directly from the **Red, Green & Blue** signals for transmission and band limited to **1½** MHz & **500** kHz respectively before being sent to the quadrature modulators. A **ColorBurst** signal is added that is **57°** away from the **I** channel at **180°**. **I & Q** can also be obtained from the **U & V** signals which represent the **B–Y & R–Y** signals respectively with the following formulas:

Skin	(I)	123°	(U × Cos(123°) + V × Sin(123°))
Purple	(Q)	33°	(U × Cos(33°) + V × Sin(33°))

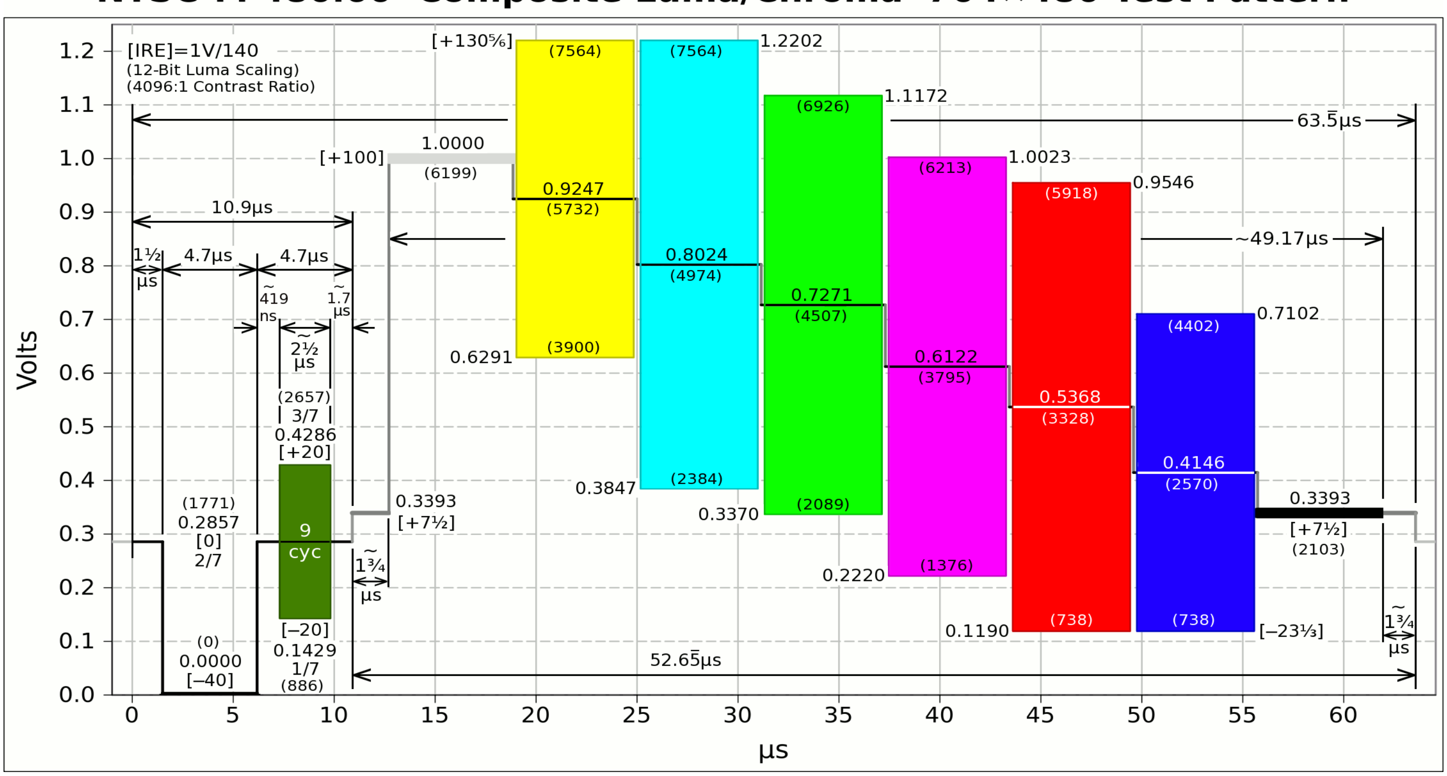
To derive **I & Q** directly from **Red, Green, Blue,** and since **Y = 0.299×R + 0.587×G + 0.114×B** , substituting **Y** with the scaled **Red, Green, Blue,** values into **0.492111×(B–Y) & 0.877283×(R–Y)** and substituting these into the equations above and solving for **Red, Green, Blue,** will give the scaling factors for each color.

```
U =  0.492111 × (B − Y) 'x'
  =  0.492111 × [−0.299 −0.587 +0.886]

V =  0.877283 × (R − Y) 'y'
  =  0.877283 × [+0.701 −0.587 −0.114]

I =  0.492111 × Cos(123°) × (B − Y)
    +0.877283 × Sin(123°) × (R − Y)

Q =  0.492111 × Cos(33°) × (B − Y)
    +0.877283 × Sin(33°) × (R − Y)

I = −0.268023 × [−0.299 −0.587 +0.886] 'Uₓ'
    +0.735751 × [+0.701 −0.587 −0.114] 'Vᵧ'

Q =  0.412719 × [−0.299 −0.587 +0.886] 'Uₓ'
    +0.477803 × [+0.701 −0.587 −0.114] 'Vᵧ'

   (0.5959007249   −0.2745567667    −0.3213439582)
I = 0.595901×Rd −0.274557×Gr −0.321344×Bl

   (0.2115366883   −0.5227362571     0.3111995688)
Q = 0.211537×Rd −0.522736×Gr +0.311200×Bl
```

In the vector image below it can be seen that the **B–Y** axis is compressed in amplitude and expanded in **Hue** layout compared to the **R–Y** axis which is compressed in **Hue** layout and expanded in amplitude because **B–Y** axis has been reduced to **56.1%** of the the **R–Y** axis level creating a tall hexagon using the **MRYGCB** points that has been squashed on each side. This means the **Yellow–Blue** axis is affected more by noise in regards to saturation level and less to **Hue** changes but the opposite is true for the **Cyan–Red** axis and to a lesser extent the **Green–Magenta** axis since it is about half the distance away from the **R–Y** axis as it is from the **B–Y** axis. For transmission and reception this does not have a big detrimental effect and may be a benefit since the eye is less sensitive to amplitude and phase variations to the colors centered around the **Yellow–Blue** axis very near to the **B–Y** axis compared to the colors centered around the **Cyan–Red** & **Green–Magenta** axes which are closer to the **R–Y** axis.



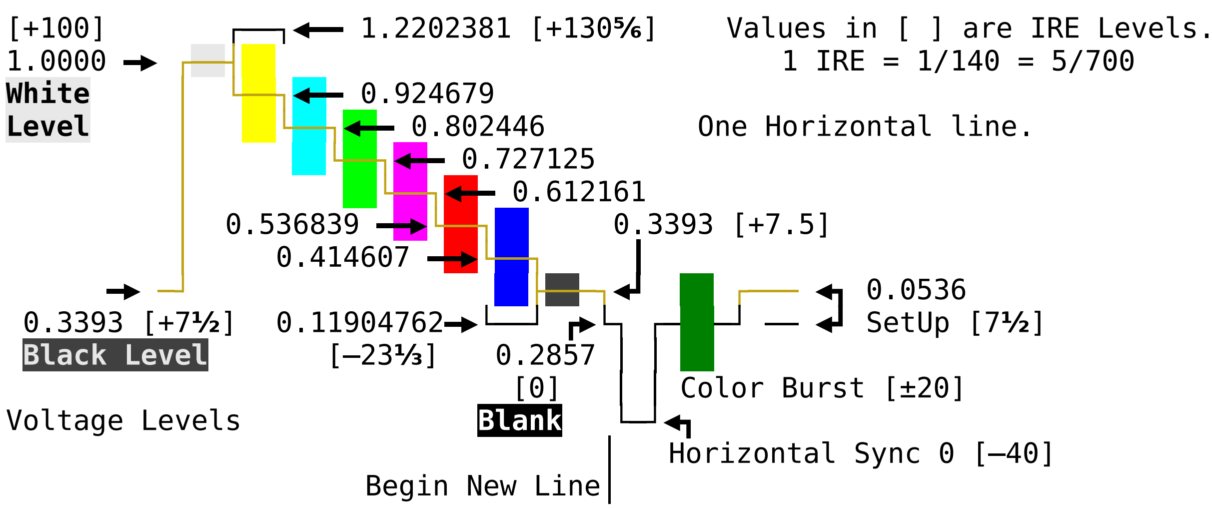
NTSC-M 480i60 Composite Luma/Chroma 704×480 Test Pattern



NOTE: In the vector image above it also shows the **ColorBurst** for PAL, the German adaptation of NTSC where the **R−Y** axis is phase inverted on every other line but the scaling for **R−Y & B−Y** is the same. In Europe channel spacing is **8** MHz, the field refresh rate is **50** Hz vs. **60** Hz for NTSC allowing higher resolution and the **Chroma** sub-carrier is at **4.43** MHz instead of **3.58** MHz for NTSC. There are several variations of PAL and PAL-M used in Brasil is basically U.S. NTSC with **6** MHz channel spacing but **R−Y** is phase inverted every other line. They would have used NTSC since they were already on the U.S. **B & W** standard but Philips and Telefunken persuaded them to **P**ay **A**nother **L**icense.

Any vector noise added to the **Chroma** signal for colors centered around the **B−Y** axis will have more of an effect on amplitude than phase since peak levels are lower and the **Hue** layout is expanded. For colors near the **R−Y** axis the opposite is true but the signal is stronger for peak levels and noise does not change saturation much nor does it affect the **Hue** much either.

However it is a different story for VCR recordings where phase jitter can be a problem with the **Chroma** signal regardless of the amplitude. The colors where the **Hue** layout is compressed around the **R−Y** axis the detrimental effects are greater and can be objectionable but the colors near the **B−Y** axis where the **Hue** layout is expanded phase jitter has less of an effect and the eye is less sensitive to **Hue** and amplitude changes for these colors. VHS and probably other formats use the color under method where the **Chroma** signal is hetrodyned down to around a **650** kHz carrier since phase jitter is less of an issue in the lower frequencies of the recording medium. The unequal shape of the **Chroma** hexagon also does not optimize peak tape saturation levels for colors near the **B−Y** axis.



Composite = (**Luma** + **Chroma**) × 0.66071429 + 0.33928571 (Sync + SetUp [47½])
[92.5]

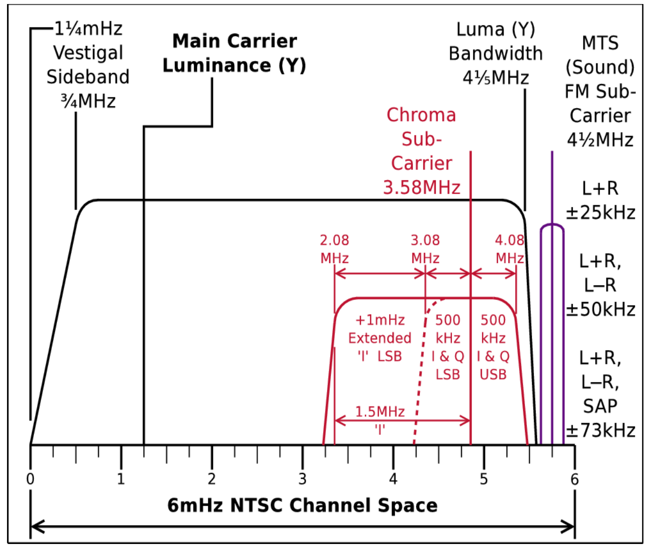
For a **1**Vp-p **B & W** video signal with sync **0.6607** composite scaling is used with **Chroma** levels of **0.5911**Vp-p minimum peak and **0.8356**Vp-p maximum peak depending on the color. Blanking level is exactly **2/7** V [**-40**]. **ColorBurst** is **±1/7** V [**±20**], centered on blanking level, **1/7** V [**-20**] to **3/7** V [**+20**].

Anatomy of a Vertical Sync Pulse

has been moved to page 29 with timing annotations added.

Specifications for a 6MHz Channel Space

To the right is the spectrum layout within the **6**MHz channel space. The bandwidth of a double sideband signal would waste spectrum so a vestigial sideband signal is used. As long as the lower frequencies of the signal are represented by both sidebands the higher frequencies can be represented by only one sideband without any detrimental effects. This is also used for the **I** channel of the **Chroma** signal. Since quadrature modulation requires both sidebands to carry **2** channels the **Q** channel bandwidth is limited to **±500**kHz modulation but the **I** channel has an extra **+1**MHz added to the **LSB** to extend the **500**kHz within the quadrature sub-carrier for a **1½**MHz bandwidth which is the channel that handles flesh tones. The sound is on a **4½**MHz sub-carrier that can handle **3** separate channels of audio, **L+R**, **L−R**, and **SAP**.

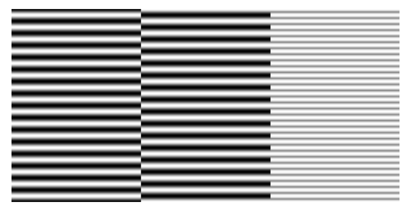


For vestigial sideband modulation method see **NTSC-DVD**

```
General:
      Aspect Ratio                      4:3   = 1⅓            Usable Aspect Ratio 16:9
      Total Picture Pixels  (Digital)  640×480 ; 307200 Pixels              NTSC 4.43
      Analog Resolution (Kell Factor)  452×340 ; 153600 Pixels (Studio)
      Broadcast (½ Contrast)           344×340 ; 116817 Avg. ; 413×340, 140181 Max.
Vertical:                                                         Pixel Aspect 1.315:1
      Frames Per Second                 29.97Hz  (PsF)                 3:2 DVD 1.191:1
      Frame Period                      33.3667ms                   16:9  4.43 1.210:1
      Total Lines Per Frame            525
      Picture Lines Per Frame          480
      Field Sweep                       59.94Hz
      Field Period                      16.68335ms
      Total Lines Per Field            262½
      Picture Lines Per Field          240
      Lines Per Blank                   22½
      Blank                              1.43ms
      Sync                             190.6μs ; 3 Lines           599 ; 1.009
Horizontal:                               499 427½                 513 ; 0.992
      Resolution ; Pixel Aspect        Avg:  344⅙  ; 1.315   Max: 413 ; 1.096 (@-9dB)
      Line Sweep                       15.734264kHz (563) ; 52.6055μs (466)
      Line (HP) ; Picture Period       63.55556μs   (455) ; 52.6254μs (376¾)
      Picture BW Pixels               368⅜≈1⅔×YBW×(HP−HB) ; (344⅙+24⅕)≈6⅔% OverScan, 3½μs
      Blank (HB) ; Active Picture      10.930μs (78¼) 10.922 (96¾)     (2×352=704) 49.168μs
      Front Porch                        1.502μs (10¾)  1.496 (13¼)     (2×360=720) 50.287μs
      Sync                               4.714μs (33¾)  4.713 (41¾)     (2×442=884) 49.896μs
      Back  Porch                        4.714μs (33¾)  4.713 (41¾)
Luma & Chroma:                                     ↑Chroma ½Cycles
      Luma (Y) BandWidth            6  51 4⅕MHz  Luma/Chroma BW Ratio 5⅗:2:⅔     Gamma 2.2
      Chroma:                         28.63636048 (8×)                Y  I Q
            Sub-Carrier                3.57954506MHz     4.429195316 (4.43)
            ½H Odd Harmonic            455 (227½)         563 (281½)
            I Bandwidth             1½ 1½MHz (120)
            Q Bandwidth             1½  ½MHz ( 40)                 Chroma Cycles
            Color Burst          2.709 2.794μs ; 10 Cycles ; 2×{1½+10+5⅜}=33¾ ←Fully optimized
            Baseband Guard          2½ 2MHz       12          2×{2  +12+6⅞}=41¾ ←  within specs.
MTS Sound: pg.18                                                 Brzwy+Snc+Snc2Blnk
      Carrier                          4.4999995MHz   FM ±25kHz, ±50kHz,    ±73kHz
      H Harmonic                       286                (L+R)    add(L−R)  add(SAP)
      L+R Equalization                 75μs Pre-Emphasis
      L−R Sub-Carrier   2×H            31.468528kHz AM DSB Suppressed Carrier
      Encoding/Compression             Zenith-dbx (THAT Corp.)
```

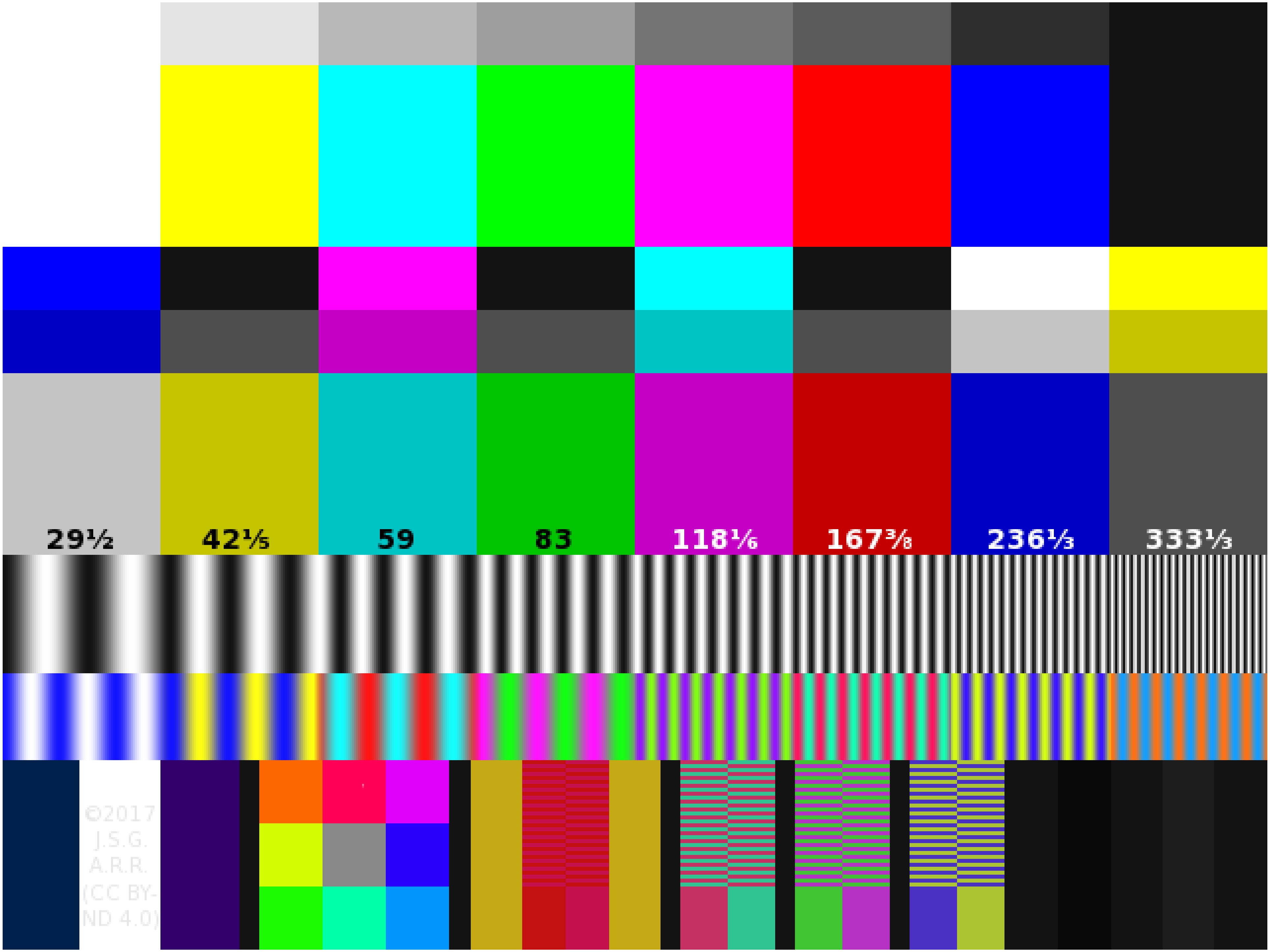
Ideal Size

20″×15″⇒25″
W H Diag
794μm Line Pitch
32 Lines/Inch



To extract test patterns from document click to highlight and copy, open image program and paste from clipboard.

↓640×480↓ ↓↓ **Chroma LoR**/Freq: **49½**/503kHz, **123⅘**/1.259MHz for [**640**|**704**|**720**]×**480**


29½
42⅕
59
83
118⅙
167⅜
236⅓
333⅓
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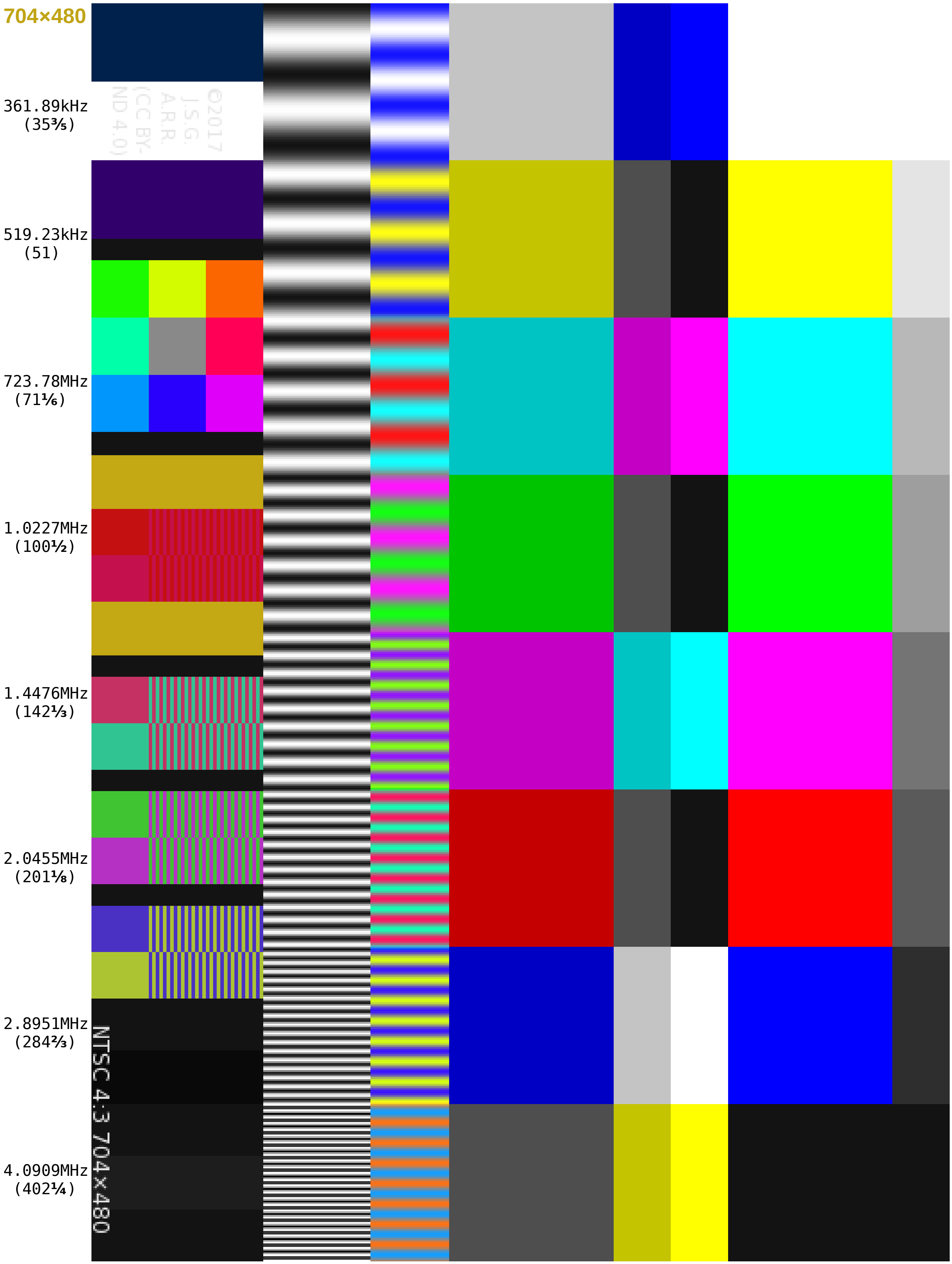
(CC BY-
ND 4.0)


704×480
361.89kHz
(35⅗)
519.23kHz
(51)
723.78MHz
(71⅙)
1.0227MHz
(100½)
1.4476MHz
(142⅓)
2.0455MHz
(201⅛)
2.8951MHz
(284⅔)
4.0909MHz
(402¼)
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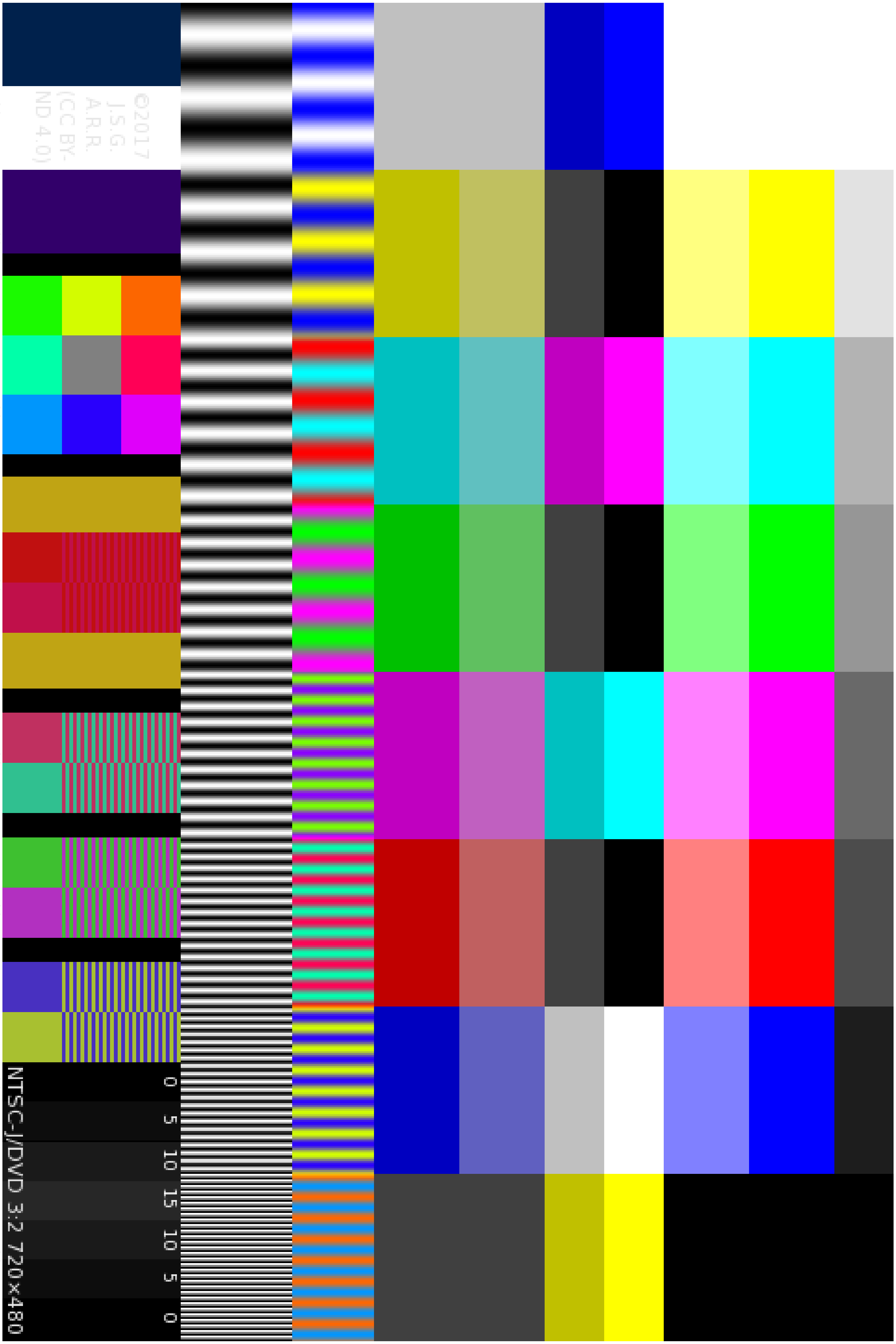
NTSC 4:3 704×480

720×480



314.865kHz
(47¾)

597.902kHz
(60⅛)

849.650kHz
(85½)

1.19580MHz
(120¼)

1.68357MHz
(169⅓)

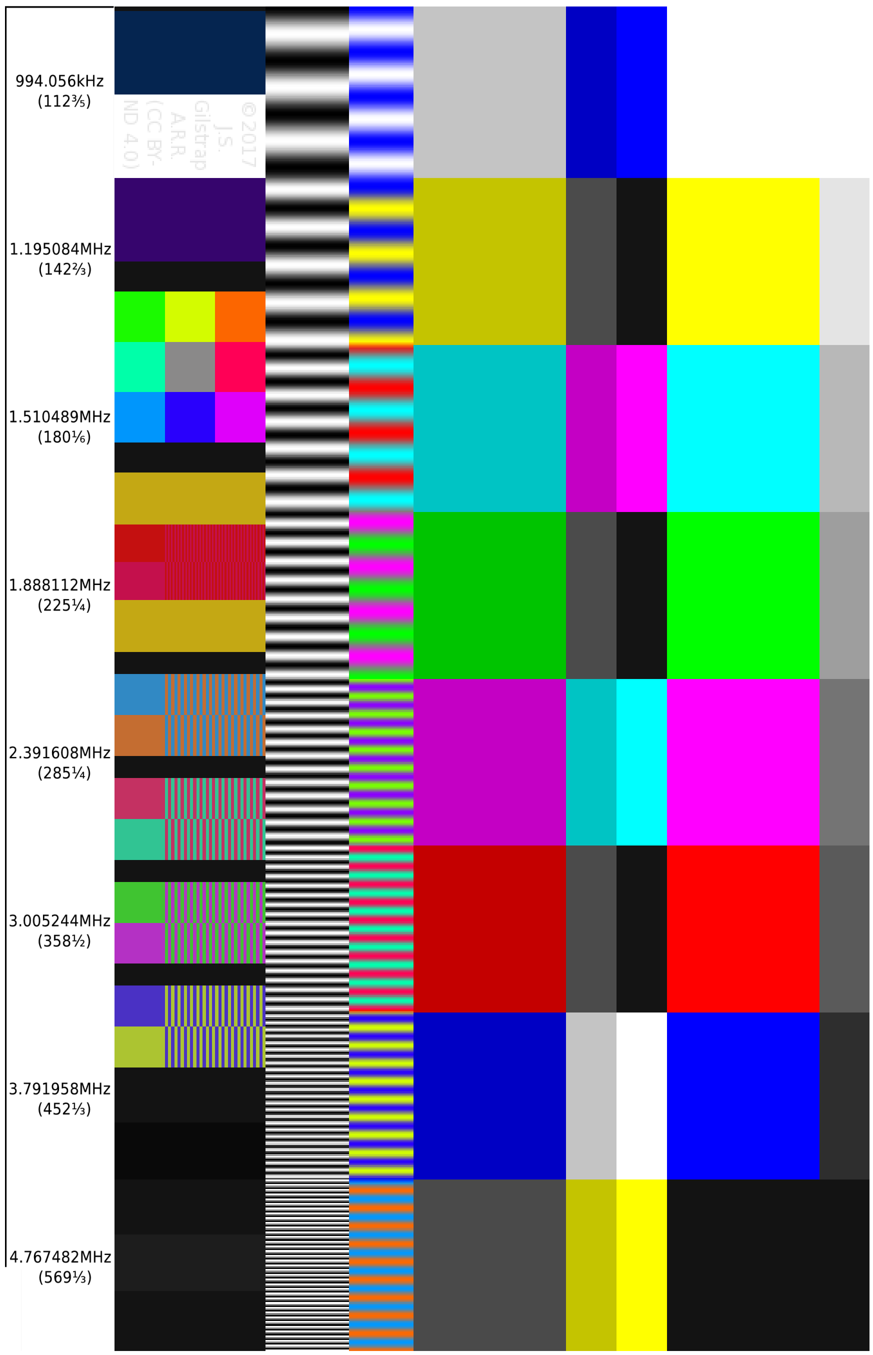
2.39161MHz
(240½)

3.36713MHz
(338⅝)

4.77273MHz
(480)

NTSC Chrominance Locked Test Patterns

The test patterns on page 13 & 14 are **704** & **720** pixels wide even though the displayed aspect ratio is nominally 4:3 (640×480). This also corresponds to the 4× sample rate of the Chroma sub-carrier, **4**×3.579545MHz=14.31818MHz. It is necessary to have the sample rate of the Luma signal at a multiple of the Chroma sub-carrier frequency and at 4f it is Chrominance locked so that the Chroma signal within the composite video signal is sampled every 90°. This 4f frequency period is 69.84ns in length and represents the width of the 1 pixel sample. The horizontal period is ~$63.\overline{5}$µs=**1/15.734**kHz and the horizontal blank is ~10.9µs leaving 52.66µs for the active picture area. Allowing for the standard 6.6% overscan, 3½µs (6.632%), this leaves 49.1683µs for the actual image, so 49.1683µs÷69.84ns=**704** pixels, 176 Chroma cycles. For standard TV broadcast using the standard 6.6% overscan and sampling the horizontal line at **704** pixels allows the Chroma signal, sampled at the 90° incremented ±**I** & ±**Q** marks, to be seamlessly merged with the Luma to create the composite video signal. If not using the ±**I**,1½MHz / ±**Q**,½MHz dual bandwidth setup then the 90° sample points would be at ±**U** & ±**V**. Having the master clock at 14.31818MHz allows the development of the quadrature oscillator for Chroma signal generation. For digital encoding in the studio all timing components of the composite signal are synchronized to the master clock and for digital decoding in the receiver the 14.31818MHz 4f Chroma oscillator is PLL locked to the incoming Colorburst signal on the horizontal back porch. The 6.6% overscan defined in the early days of NTSC was needed to allow for the limitation of older transmitter/receiver technology and drifting so they would function properly. As technology has advanced a smaller amount of overscan can be used and reducing it to 4½%, 2⅜µs, allows for **720** chrominance locked Luma samples, 180 Chroma cycles @ 50.286µs, to be used for a horizontal line to support the **720×480** DVD format.



854×480 (~50µs) ⇒

PAL

(Der SystemBruch)

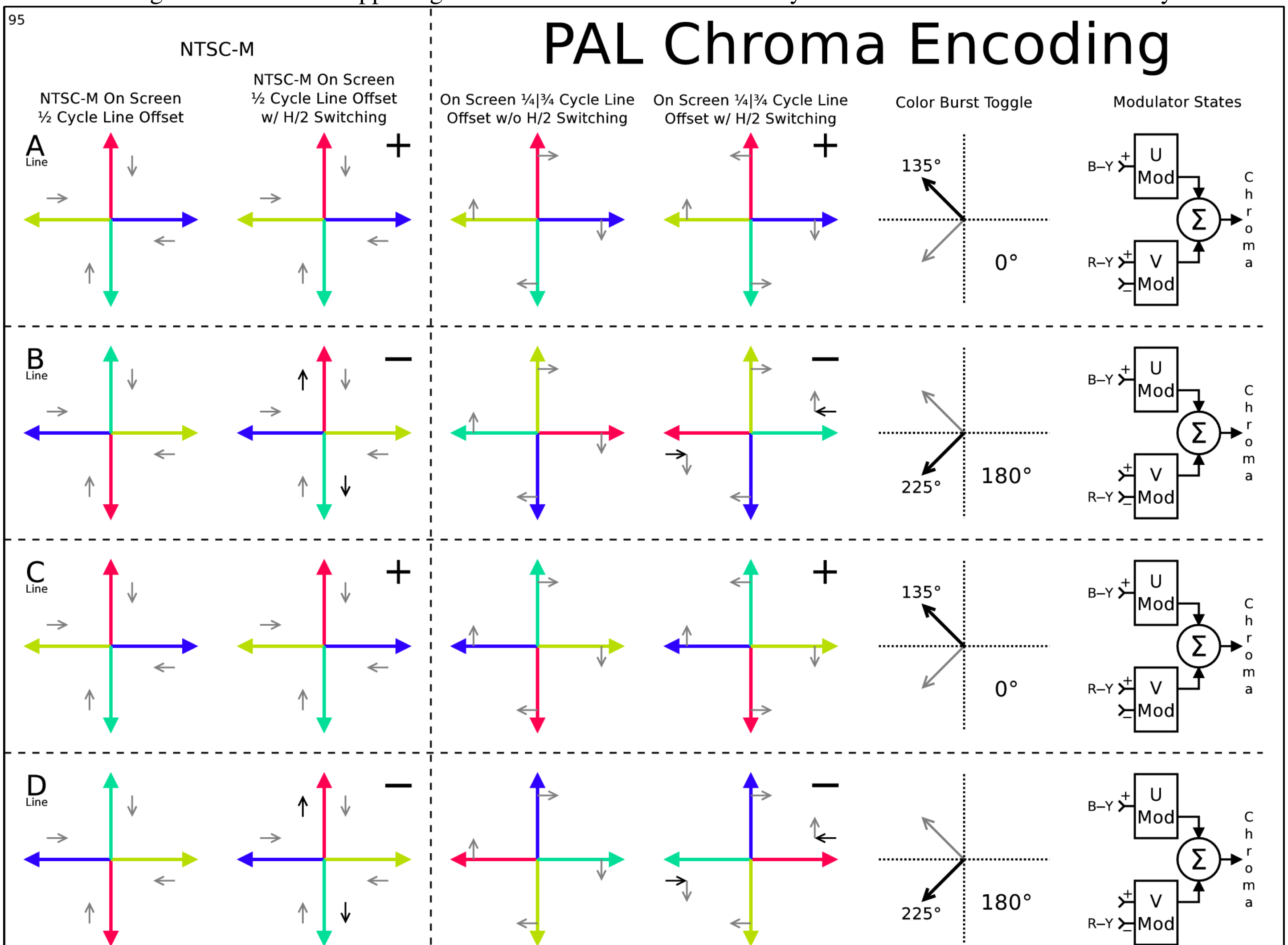
PAL is a modified form of NTSC. It addresses the drifting **Hue** issues that are present in NTSC giving inaccurate colors when the phase tracking of the **Chroma** decoder is in error. This is accomplished by inverting the phase of the **R−Y** channel on every other horizontal line hence the name **P**hase **A**lternation **L**ine. Any decoding phase errors will cancel out visually on the screen in the PAL Simple decoding mode. PAL Simple mode also has the effect of creating what is called Hanover Bars where under severe phase decoding errors two scan lines of a full frame will have its **Hue** shifted in one direction and the next two will have its **Hue** shifted in an equal but opposite direction. The visual addition of the two sets will produce the near perfect **Hue** as the eye's color resolution is less than what it is for the **B & W** **Luma** portion of the image. Depending on how severe the phase error is and the viewing distance from the screen they may or may not be noticeable. The greater the error the greater the viewing distance is needed to have the eye blend them together and not be noticed. A more advanced decoder uses a delay line of **1H** or **1/F_H** to electronically blend two lines together before being put on screen eliminating Hannover Bars. The enhanced version of this controls the delay time by a chrominance lock of so many cycles for the perfect and most accurate delay. Both methods reduce color saturation levels when phase decoding errors occur and the greater the error the greater the saturation reduction. This is more acceptable to the viewer than the wrong **Hue**.

In NTSC each horizontal line ends with **½** **Chroma** cycle which causes the clusters of **Chroma** energy to fall in between the clusters of **Luma** energy. In PAL the phase inversion of every other line of **R−Y** by **H/2** effectively modulates it with a square wave smearing its spectrum and creating sidebands of **±H/2** causing **R−Y** energy clusters to fall directly on top of the **Luma** culsters causing interference. The solution to this is to adjust the **Chroma** sub-carrier frequency so that each horizontal line ends with either **¼** or **¾** of a cycle of the **Chroma**. Having the sub-carrier frequency end with **¼** or **¾** of a cycle and not **½** of a cycle does not cause interference with the **Luma** even on the fine mesh level for **B−Y**. When **R−Y** is phase inverted at the **H/2** rate its modulated sidebands are fall on the **¾** cycle marks when the line ends with **¼** cycle of the **Chroma** sub-carrier and when the sub-carrier ends with **¾** of a cycle the **R−Y** modulated sidebands fall on the **¼** cycle marks.

The downside to not ending the line with **½** cycle of the carrier breaks the dot pattern system of NTSC when the **Chroma** signal is super-imposed onto the **Luma** which is designed to average out the **Luma** brightness for each spot on screen both vertically and temporally. The vertical inversion breaks up the vertical stripes which is realized by the lines ending in **½** cycle and the temporal inversion is created by having an odd number of lines per frame. Ending the lines with **¼** or **¾** of a **Chroma** cycle creates a very noticeable dot pattern motion. In NTSC this pattern repeats over two frames inverting on every frame and is unnoticeable to the eye when viewed at a distance. In PAL this pattern repeats over **8** fields or **4** frames and produces a visible slanted vertical line pattern that can move either to the left or right. To counteract this visible dot pattern motion the number of fame cycles per second is added to the **Chroma** frequency to cause the **Chroma** phase to invert 180° at the beginning of every field from its normal repeat pattern to simulate a similar effect as NTSC. This maintains a **4** frame repeat pattern and a motion that is not visible. Adding the frame rate to the **Chroma** frequency creates phase creep ; 4 × the Number of Frame Scan Lines is the number of unique **Luma**/**Chroma** scan line combinations, a digital coding nightmare where NTSC has only, **Two**. For PAL[-N] this 180° inversion can also be realized by using 621 scan lines without creating phase creep producing only **Four** line combinations. The **R−Y** switching has a **4** line repeat pattern and adding the frame rate to the **Chroma** frequency aligns with the repeat rate of **8** fields or **4** frames, 41⅔% the speed of NTSC. Therefore NTSC with its higher frame and dot repeat rate handles fast motion better and allows a picture 5 times as bright before flicker is noticed.

NTSC-M variant PAL-M used in Brasil is one example. In Brasil before Color TV was introduced they were on the U.S. 525 lines 30 frames per second '**M**' **B & W** system using a **6**MHz channel spacing. Facing the same compatibility issues as the U.S. and being a large country with many **B & W** sets in service it was only logical that they use NTSC-M or a variant thereof and thus PAL-M was spawned. The two systems are so alike that it is very easy to convert from one format to the other. PAL-M uses a slightly lower Chroma sub-carrier frequency of **3.5756115**MHz so a horizontal line will end with **¼** of a cycle where NTSC-M uses **3.57954506**MHz for the chroma and **15.734264**kHz horizontal scan which is **1/227½** of the Chroma. For PAL-M the frequencies are: **15.734264**kHz **× 227¼ = 3.5756115**MHz. The horizontal, vertical, and sound frequencies are identical and only the Chroma sub-carrier frequency was reduced enough to create the **¼** cycle per line offset but does not need the frame rate cycle increase. Both systems are B&W and stereo sound compatible with each other.

The next image shows what is happening on screen where NTSC uses **½** cycle offset and PAL uses **¼** or **¾** cycle offset.



The colored vectors, R–Y & B–Y, are their actual colors where they are placed on the color wheel and the color pointing in the opposite direction is its complementary color. The small gray arrows are the natural phase changes that are produced on screen when the chroma sub-carrier does not end a horizontal line with a full cycle. In NTSC they are parallel to the colored vectors representing a full 180° rotation on screen caused by the chroma sub-carrier ending a line with ½ cycle. In PAL they are perpendicular representing a 90° rotation caused by the chroma-subcarrier ending a line with ¼ or ¾ of a cycle producing +90° or –90° rotations on screen. The small black arrows parallel to the colored vectors represent the H/2 switching. If applied to NTSC with its ½ cycle offset it appears to reverse the on screen 180° rotation for the R–Y axis leaving it at +90° on screen always. In the frequency spectrum the opposite is happening with the B–Y axis harmonicly unaffected but the R–Y axis with the H/2 switching shifts its spectrum off by ±H/2 of the line frequency with its energy clusters sitting directly on top of the luminance clusters causing interference. The ¼ or ¾ offset with the H/2 switching will offset the chroma clusters to sit at the ¼ and ¾ spacings but this creates an on screen visible stationary dot pattern. To eleviate this and simulate the dot inversion pattern of NTSC the number of cycles per frame rate is added/subtracted to/from the chroma frequency to break up the standing dot patterns. Ironicly even at the fine mesh level of interleaving this does not produce interference since the harmonics are shifted over one whole slot, the fine mesh level of the frame rate spacing.

Why Brasil chose PAL over NTSC in the early 1970's when solid state Chroma decoders were coming on the scene having much greater phase accuracy, greatly reduced the Hue issues that NTSC posed during the vacuum tube days leaves one pondering. When IC decoders arrived in the mid 1970's in Japanese sets it was rare to require any Hue adjustment once it was set. By the late 1970's and early 1980's all U.S. brands were using IC decoders also. In the end NTSC with its simpler dot pattern and **½** cycle/line ending Chroma 3-Line and 3-D Comb Filters provided an almost complete Chroma/Luma separation whereas PAL Chroma with its **¼** cycle and frame cycle offset and the spectrum smearing **H/2** switching make separation a much more complicated an incomplete process. Here is a GIF animation of **PAL On Screen Vector Rotation and V Switch** (CC BY-SA 4.0).

Repairing the Brokenness of PAL

The big mistake in PAL's design is adding the frame rate to the chroma frequency to re-arrange the on screen chroma dots into a non-objectionable pattern. Unfortunately this creates an unlocked relationship between the horizontal and Chroma frequencies, as they are locked in NTSC. This unlocked condition makes digital coding impossible to do efficiently. This pattern varies in relation to the number of scan lines and the 4 phase states of PAL color. It just so happens that 625 lines cause the 2 fields within a frame to pair lines with the same chroma dot position on screen. The next pair of lines within a frame will be shifted to the left or right 90°. The results produced are diagonal lines moving to the left or right in a 4 frame step repeat pattern. The pattern is not fast enough to blur the motion so it must be altered. When adding the frame rate the 1st line in the next field will be inverted 180° from its original phase. This same inverted order on a scan line in a field is 2 lines away (4 lines in a frame). Adding or subtracting 4 frame lines from the total number of lines in a frame will also break up this pattern. It then becomes unnecessary to add the frame rate to the chroma frequency thus keeping the horizontal and Chroma frequencies locked. Conventional PAL[-N] sets should be able to handle the 4 line adjustment as this is a <1% change in the lines per frame. Here are some new specs. for 625 line PAL formats.

PAL-EU

621	Lines/Frame		
310½	Lines/Field		
50Hz	Vertical	49.97013256	–0.05973%
1.33ms	V. Blank		
15.525kHz	Horizontal	15.515726	
6MHz	Luma		
4.43626875MHz	Chroma	4.43361875	
285¾	Factor		
17.745075MHz	4 x Chroma	17.34475	
1143	Factor		
2½MHz	LSB		
1½MHz	USB		
6.504975MHz	Sound (419)	6.5010892	

PAL-N

621	Lines/Frame		
310½	Lines/Field		
50Hz	Vertical	49.99528946	–0.00942%
1.33ms	V. Blank		
15.525kHz	Horizontal	15.523537	
4⅕MHz	Luma		
3.57463125MHz	Chroma	3.58205625	
230¾	Factor		
14.298525MHz	4 x Chroma	14.328225	
923	Factor		
1¾MHz	LSB		
⅝MHz	USB		
4.50225MHz	Sound (290)	4.5018258	

Determining the Need for Frame Rate Increase of Chroma Frequency

Depending on the number of scan lines in combination with the 4 phase states of PAL Color the Chroma dot arrangement may create an on screen objectionable pattern.

There must be an odd number of scan lines in a frame for a 2:1 interlace. Divide the total number of scan lines by 4. If the quotient is even with a ¼ remainder or if the quotient is odd with a ¾ remainder then add the frame rate to the Chroma frequency. If the quotient is odd with a ¼ remainder or if the quotient is even with a ¾ remainder then it is not necessary to modify the Chroma frequency. This is the ideal situation as there will be only 4 unique Luma/Chroma line combinations making it easy to digitally process.

PAL-M (The Frame Rate is NOT added to the Chroma Frequency! Easy to DSP.)

```
         B&W 'M' Standard
            525  Lines/Frame
           262½ Lines/Field    NTSC-M & PAL-M Vert.
            60Hz Vertical       59.94Hz –0.1%
          1.43ms V. Blank       NTSC-M & PAL-M Horiz.
        15.75kHz Horizontal     15,734.264±0.044Hz         NTSC Frequencies
           4⅕MHz Luma
     3.5791875MHz Chroma         3.575611494MHz              3579545.06±10Hz
           227¼ Factor          PAL-M Adjusted Chroma          227½
      14.31675MHz 4 x Chroma    14.30244598MHz             14318180.24±40Hz
             909 Factor                                        910
          1¾MHz LSB  (2⅓)
           ⅝MHz USB  ( ⅚)        NTSC-M & PAL-M Sound
          4.5MHz Sound    (286) 4.499999504MHz
```

An Alternate NTSC-M & PAL-M Frequency Arrangement

Looking at the commonality of the frequencies between NTSC-M & PAL-M an alternative to keeping the Horizontal line Vertical refresh frequencies the same and changing the Chroma frequency is to use the same Chroma frequency and slightly alter the Horizontal and Vertical frequencies. For PAL-M it turns out that this keeps the Horizontal and Vertical frequencies the same as they are for a Type-M B & W signal, making TV sets that are dual NTSC-M & PAL-M simple to manufacture. A set would automatically switch between the two systems depending on whether the colorburst has a static phase for NTSC-M or a swinging gate for PAL-M, controlling the **R–Y V** Switch phase. This would apply to VCRs as well. The color under system would have to properly preserve the Horizontal, Vertical and Chroma frequency relationships since 1 scan stripe of the tape is one field and this would differ slightly between the two systems. The only side effect would be if a show was in NTSC-M the frame rate would be 0.11% slower than a PAL-M show or faster vice-versa. The RC timing circuits for the Horizontal and Vertical sections will operate well within these tolerances whereas the Chroma crystal oscillator would stay exactly the same.

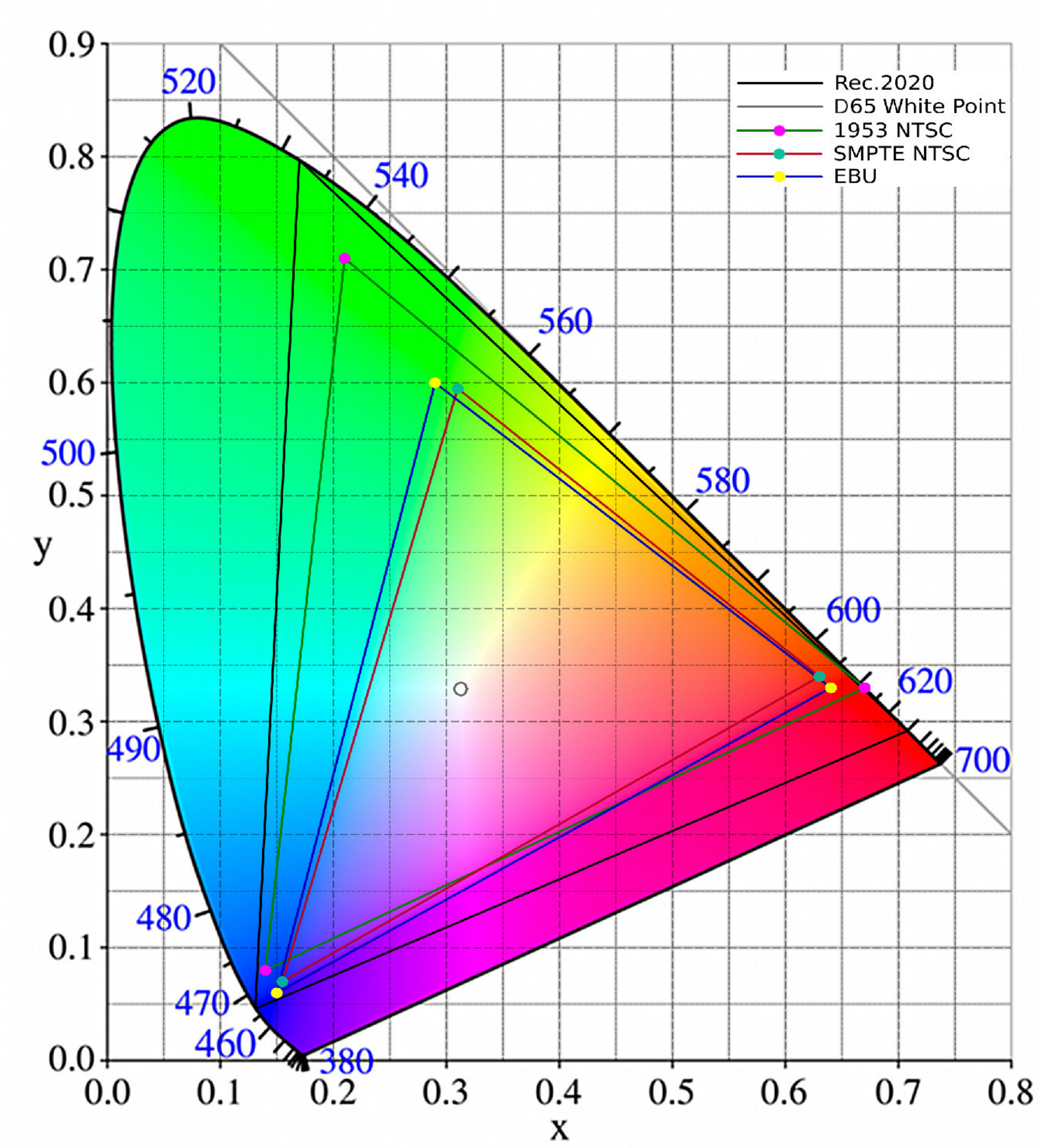
```
            PAL-M                    NTSC
            525  Lines/Frame
            262½ Lines/Field
            60Hz Vertical          59.934Hz –0.11%
          1.43ms V. Blank
        15.75kHz Horizontal        15.732692kHz
           4⅕MHz Luma
     3.5791875MHz Chroma            3.5791875MHz
           227¼ Factor                   227½
      14.31675MHz 4 x Chroma       14.31675MHz
             909 Factor                   910
           1¾MHz LSB  (2⅓)
            ⅝MHz USB  ( ⅚)
      4.5045MHz Sound (286)         4.49955MHz
```

Was OSKM really NTSC-D/K?   8/4.43/15625/625/50/25

Early in 1960, before adopting SÉCAM 7 years later, the USSR experimented with a 625 line 50Hz system on an 8MHz channel space for about 3 years. The **Chroma** system was basically NTSC with a full DSB-SC ±1½MHz BW at 4.43MHz. “Simultaneous System with Quadrature Modulation” (Одновременная Система с Квадратурной Модуляцией). Since the quadrature modulation did not have a vestigial sideband it was not necessary to use the dual bandwidth **I** **&** **Q** system but used the European **B−Y** **&** **R−Y** / **U** **&** **V** matrixing that PAL and SÉCAM adopted later. The use of an NTSC style **Chroma** (an adaptation of NTSC for the current European scan and field/frame rate at the time) and given the rules in selecting frequencies, syncs, and bandwidths for analog TV systems, this is maybe a fair description of the specification. The potential resolution is not bad at all. If they would have stayed with this system with the hue drifting issues becoming a minor issue with the advent of transistor/IC **Chroma** decoders, the benefits of a simpler on screen **Chroma** dot pattern with the use of 3 line and digital 3D comb filters would have provided superior **Luma** / **Chroma** separation and image enhancement that NTSC greatly benefited from. SÉCAM (**S**ystème **E**xtrêmement **C**ontraire à la **A**méricaine **M**éthode) or PAL (Bild Immer Schön) never achieved this level of separation. It would have had the best picture out of all the systems in use.

General:	
Aspect Ratio	4:3 = 1⅓
Total Picture Pixels (Digital)	768×576 ; 442368 Pixels
Analog Resolution (Kell Factor)	543×407 ; 221184 Pixels (Studio)
Broadcast	498×407 ; 202742 Avg. 597×407 ; 243154 Max.
Vertical:	
Frames Per Second	25 Hz
Frame Period	40 ms
Total Lines Per Frame	625
Picture Lines Per Frame	576
Field Sweep	50 Hz
Field Period	20 ms
Total Lines Per Field	312½
Picture Lines Per Field	288
Lines Per Blank	24½
Blank	1.568 ms
Sync	192 µs ; 3 Lines
Horizontal:	
Resolution ; Pixel Aspect	Avg: 497¾ ; 1.091 Max: 597 ; 0.91 (@−9dB)
Line Sweep	15.625 kHz
Line (H_P) ; Picture Period	64 µs (567) ; 53.277 µs (472)
Picture BW Pixels	532¾≈1⅔×$\mathbf{Y}_{BW}$×(H_P−H_B) ; (497¾+35)≈6⅗% OverScan
Blank (H_B)	10.723 µs (95) 49.$\overline{7}$µs (441)
Front Porch	1.467 µs (13)
Sync	4.515 µs (40)
Back Porch	4.741 µs (42)
Luma & Chroma:	
Luma (**Y**) Bandwidth	6 MHz ; Vestigial 1¼ MHz, Corner ¾ MHz
Chroma:	
Sub-Carrier	4.4296875 MHz
H/2 Odd Harmonic	567 (283½)
U Bandwidth	1½ MHz
V Bandwidth	1½ MHz
Color Burst	2.48 µs ; 11 Cycles ; 2×{5+11+5}=42
Baseband Guard	2⅞MHz
Sound:	
Carrier	6.5 MHz
H Harmonic	416

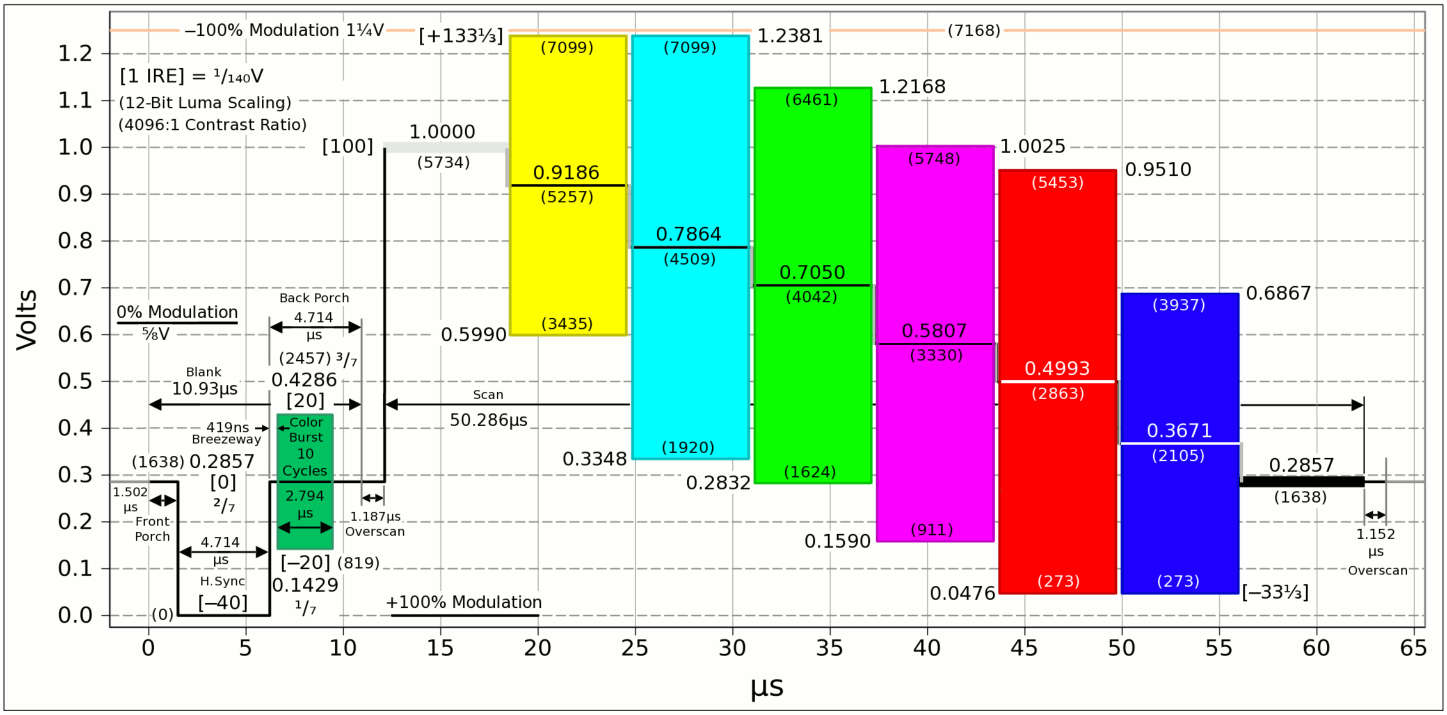
Color Gamuts



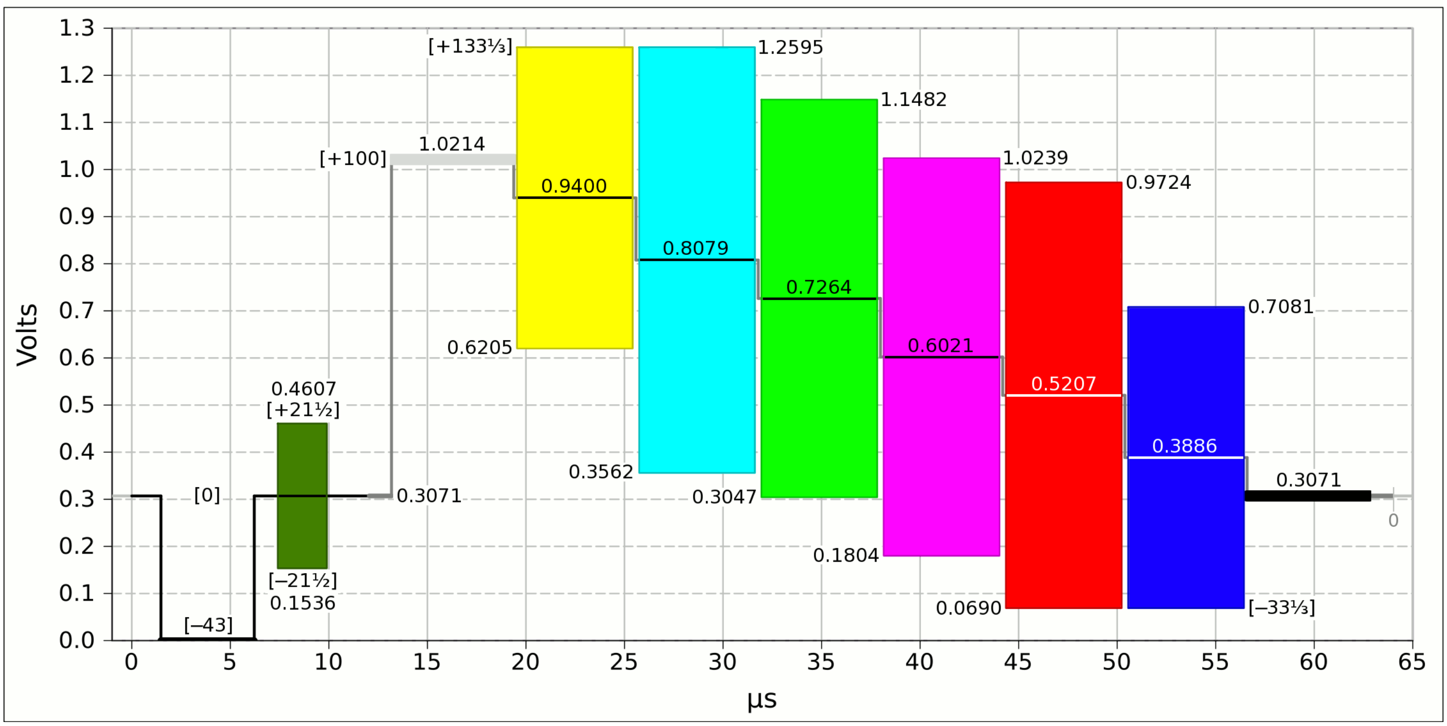
	RED	GREEN	BLUE
Rec.2020	(0.708, 0.292)	(0.170, 0.797)	(0.131, 0.046)
1953 NTSC	(0.670, 0.330)	(0.210, 0.710)	(0.140, 0.080)
SMPTE NTSC	(0.630, 0.340)	(0.310, 0.595)	(0.155, 0.070)
EBU	(0.640, 0.330)	(0.290, 0.600)	(0.150, 0.060)

6504°K White Point (0.3127, 0.3290)

NTSC-J/DVD 720×480i60 Composite Luma/Chroma 3:2 Test Pattern



PAL 576i50 Composite Luma/Chroma



Alternative Horizontal Blank Timings and Levels, a Blend of NTSC-M, NTSC-J & PAL-B/G Specifications, Producing Increased Composite, Colorburst & Sync Levels with 0 SetUp for 720×480 Resolution

Timings **Timings are within NTSC-M specifications. IRE Levels are an average mix of the three.**

Active Picture	50.286µs	(360)	+
Overscan Lead In	1.362µs	(9¾)	+ = (455)
Overscan Lead Out	1.397µs	(10)	+
Blank (HB)	10.511µs	(75¼)	+
Front Porch	1.292µs	(9¼)	(½Chroma
Sync	4.470µs	(32)	Cycles)
Breezeway	384ns	(2¾)	
ColorBurst (11cyc)	3.073µs	{1⅜+11+4⅝}×2=(34)	
Back Porch	4.749µs	(34)	

Gain: Sync & ColorBurst +5%, Luma/Chroma +5.95%

Levels		[1 IRE]	$^{1}/_{140}$V
Setup:	0 V	[0/140]	
Video:	700mV	[98/140]	$^{7}/_{10}$V
Sync:	300mV	[42/140]	$^{3}/_{10}$V
Burst:	±150mV	[±21/140]	±$^{3}/_{20}$V
Peak:	450mV	[63/140]	$^{9}/_{20}$V
Bias:	300mV	[42/140]	$^{3}/_{10}$V
Trough:	150mV	[21/140]	$^{3}/_{20}$V

TRANSMISSION STANDARDS

Television Stereophonic Sound Standards

Television broadcast stations may transmit stereophonic sound by employing a subcarrier on the aural carrier. The main channel modulating signal shall be the stereophonic sum modulating signal; the subcarrier modulation shall be the stereophonic difference encoded signal.

The subcarrier shall be the second harmonic of a pilot signal which is transmitted at a frequency equal to the horizontal line rate. Note: if the station is engaged in stereophonic sound transmission accompanied by monochrome picture transmission the horizontal scanning frequency shall be 15,734 Hz ±2Hz.

The subcarrier shall be double sideband amplitude modulated with suppressed carrier and shall be capable of accepting a stereophonic difference encoded signal over a range of 50 – 15,000 Hz.

The total modulation of the aural carrier, including that caused by all subcarriers, shall comply with the requirements of § 73.1570 of the FCC Rules and Regulations.

Television Second Audio Program Standards

Television broadcast stations may transmit a subcarrier carrying a second audio program.

The subcarrier frequency shall nominally be equal to the fifth harmonic of the horizontal line rate.

The second program encoded signal shall frequency modulate the subcarrier to a peak deviation of ±10 kHz.

The second audio program subchannel shall be capable of accepting second program encoded signals over a range of 50 – 10,000 Hz.

The modulation of the aural carrier by the second audio program subcarrier shall comply with § (D) (a) (1) (iv) of this bulletin (±15kHz deviation).

Television Sound Encoding Standards (dbx, now THAT Corp.)

The stereophonic difference audio signal and the second program audio signal shall be encoded prior to modulating their respective subcarriers. A diagram of one method of obtaining this encoding is shown as Fig. 8–1.

This encoding shall have the following characteristics where *f* is represented in kilohertz (kHz).

(i) Fixed pre-emphasis F(*f*) whose transfer function is as follows:

$$F(f) = \left[\frac{1+j2.451f}{1+jf/5.23}\right] \times \left[\frac{1+jf/2.19}{1+jf/62.5}\right]$$

(ii) Wideband amplitude compression wherein:

(a) The decibel gain (or loss) applied to the audio signal during encoding is equal to minus one times the decibel ERMS value of the encoded signal (the result of the encoding process), weighted by a transfer function P(*f*) as follows:

$$P(f) = \frac{jf/0.0354}{[1+jf/0.0354]\times[1+jf/2.09]}$$

(b) The exponential time weighting period **T_1** of the ERMS detector referred to above in (a) is 34.7ms

(c) The zero decibel reference ERMS value for the encoded signal referred to above in (a) is 8.99% modulation of the subcarrier at 300 Hz.

(iii) Spectral compression wherein:

(a) The transfer function S(*f*,b) applied to the audio signal during encoding is:

$$S(f,b) = \frac{1+j(f/F)\times(b+51)\div(b+1)}{1+j(f/F)\times(1+51b)\div(b+1)}$$

F=20.1kHz; D=decibel rms value and b is the decibel ERMS value of the encoded signal (the result of the encoding process) weighted according to a frequency transfer function Q(*f*) as follows:

$$Q(f) = \frac{j(f/5.86)^3}{[1+j(f/7.66)^2+jf/7.31]\times[1+jf/26.9]\times[1+jf/3.92]}$$

(b) The exponential time weighting period **T_2** of the ERMS detector referred to above in (iii-a) is 11.4ms.

(c) The ERMS zero decibel reference for the encoded signal referred to above in (iii-a) in 5.16% modulation of the subcarrier at 8kHz.

Note: This reference results in a +18.4dB gain throughout the encoding process at 32.0% modulation using an 8kHz tone, when the output bandlimiting filter (see (iv) and (v) following) gain is +18.4dB at 8kHz.

(iv) Overmodulation protection which functionally follows the functions i, ii, & iii above.

(v) Bandlimiting to appropriately restrict bandwidth which functionally functions i, ii, & iii above.

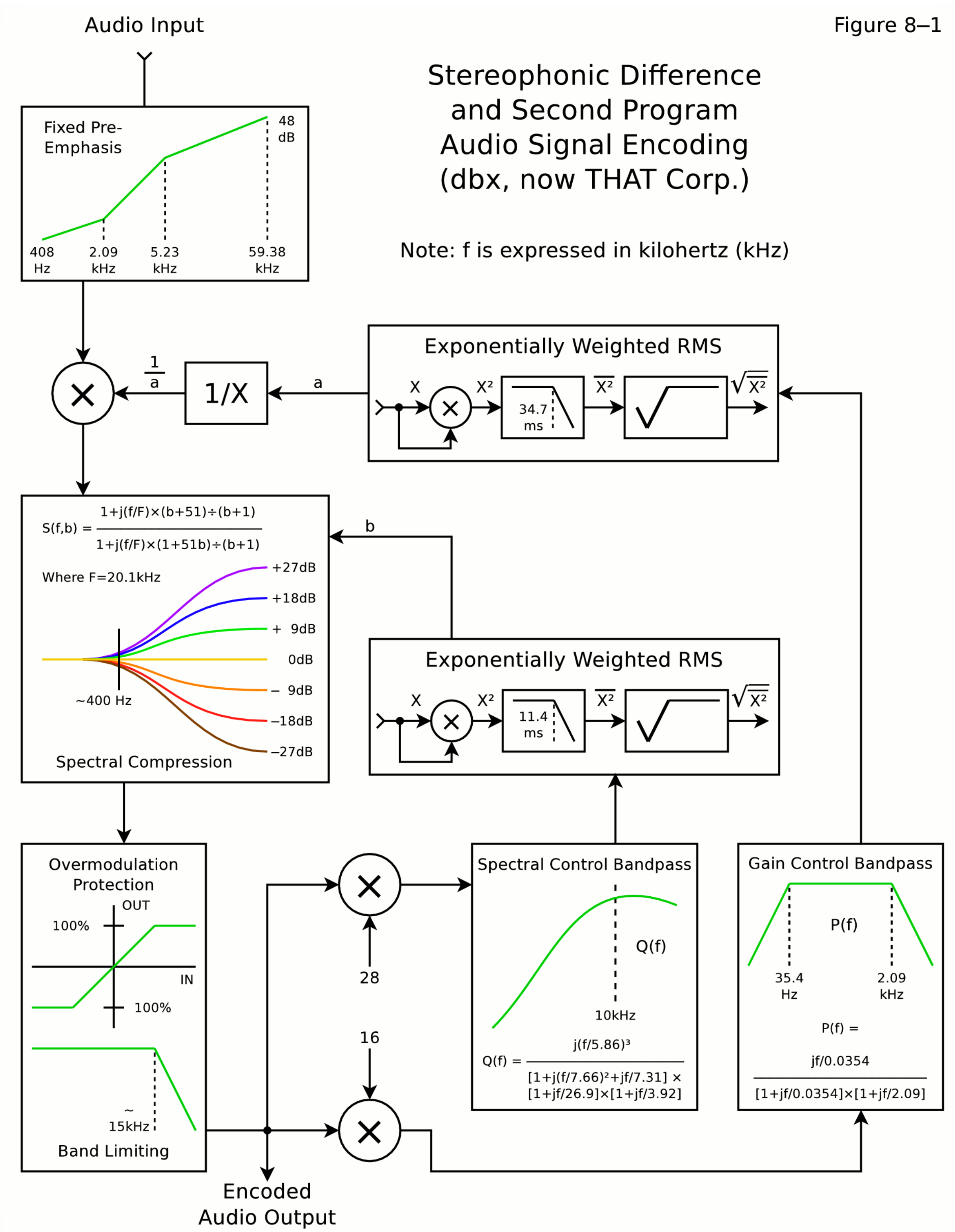
Television non-program related aural subcarrier standards.

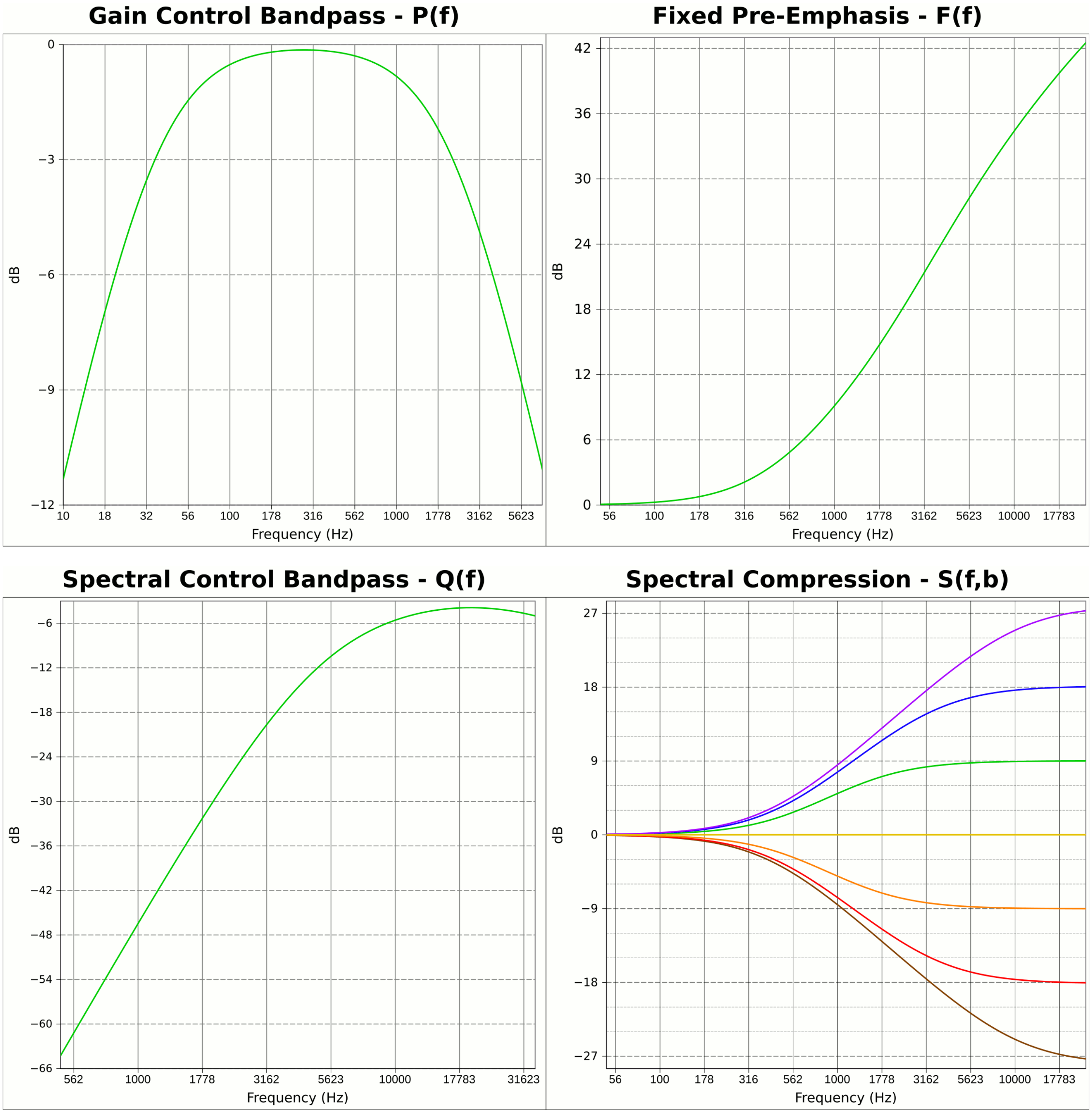
Multiplexing of the aural carrier is subject to the requirements of § 73.682 (c) of the FCC Rules and Regulations: provided, however, that when the stereophonic and/or second audio program subchannels are transmitted, multiplexing, of the aural carrier by non-program related subchannels is subject to the following changes:

(i) The maximum modulation of the aural carrier by the non-program related subcarrier shall comply with the requirements of § (D) (a) (1) (iv) of this bulletin.

(ii) When the stereophonic and second program subcarriers are transmitted, the instantaneous frequency of the non-program related subcarriers shall have the average value of six and one half times the horizontal scanning frequency with a tolerance of ±500Hz.

(iii) When only the stereophonic subcarrier is transmitted, the instantaneous frequency of the non-program related subcarrier shall lie between 47 and 120kHz with a tolerance of ±500Hz.





TRANSMISSION SYSTEM REQUIREMENTS /MULTICHANNEL SOUND REQUIREMENTS

Electrical Performance Standards for Stereophonic Operation

The aural transmitter must operate satisfactorily with a frequency deviation of ±73kHz.
It is recommended that the transmitter operate satisfactorily with a frequency of ±100kHz.

The pilot subcarrier shall be frequency locked to the horizontal scanning frequency of the transmitted video signal.

The requirements of § 73.687 (b) (2) of the FCC Rules and Regulations shall be compiled for both (L+R) main channel and (L–R) subchannel, except for pre-emphasis as specified in § (B) (c) of this bulletin, with the additional requirement that the aural transmitter shall be capable of transmitting a band of frequencies from 50 to 120,000 Hz.

Unless otherwise specified, the transmission system requirements are defined for 75µs pre-emphasis (which is matched to that in the main channel in the case of stereophonic transmission) substituted for encoding. Measurements are made over the band of 50 to 15,000 Hz and employ 75µs de-emphasis in the measuring equipment.

The stereophonic subcarrier, being the second harmonic of the pilot signal, shall cross the time axis with a positive slope simultaneously with each crossing of the time axis by the pilot subcarrier. The pilot subcarrier shall cross the time axis at points locked within ±3° (approximately ±530ns) of the zero crossings of the stereophonic subcarrier.

The unmodulated stereophonic subcarrier shall be suppressed to a level less than 250 Hz deviation of the main carrier.

The combined audio frequency harmonics measured at the output of the transmitting system (including the sound encoder), as defined in § 73.687 (b) (3) of the FCC Rules and Regulations, at any audio frequency from 50 – 15,000 Hz and at modulating percentages of 25, 50 and 100%, 75µs equivalent modulation shall not exceed the rms values in the following table:

50 to 100 Hz	3.5%
100 to 7,500 Hz	2.5%
7,500 to 15,000 Hz	3.0%

Harmonics shall be included to 30kHz.

The ratio of peak main channel deviation to the peak stereophonic subchannel deviation when only a steady state Left (or Right) signal exists shall nominally be one half of all levels of this signal and for frequencies 50 – 15,000 Hz.

The phase and amplitude characteristics of the stereophonic sum modulating signal and the stereophonic difference encoded signal shall be such that the minimum equivalent input at 10%, 75µs equivalent modulation is as follows:

(i) 30dB separation from 100 Hz to 8 kHz.

(ii) Smoothly decreasing separation below 100 Hz, from 30 dB to 26dB at 50 Hz.
(iii) Smoothly decreasing separation above 8 kHz, from 30 dB to 20 dB at 15kHz.

Note: it is recommended that the transmission system excluding encoding, shall meet a 40 dB separation requirement when 75µs pre-emphasis in substituted for sound encoding.

Crosstalk into the main channel caused by a signal in the stereophonic subchannel shall be at least 40 dB below 24 kHz main carrier deviation.

Crosstalk into the main channel caused by a non-stereophonic multiplex signal shall be at least 60 dB below 25 kHz aural carrier deviation.

Crosstalk into the stereophonic subchannel caused by signal in the main channel shall be at least 40 dB below 50 kHz aural carrier deviation.

Crosstalk into the stereophonic subchannel caused by another multiplex signal shall be at least 60 dB below 50 kHz aural carrier deviation.

The aural transmitting system output frequency modulation noise level in the band of 50 – 15,000 Hz (with de-emphasis) must be at least 58 dB below the audio level representing a frequency deviation of ±25 kHz. The frequency modulation noise level in the stereophonic subchannel, after demodulation in the band of 50 – 15,000 Hz (with de-emphasis) must be at least 55 dB below the audio level representing a frequency deviation of ±50 kHz.

The pilot subcrrier to interference ratio, over a bandwidth of 1 kHz centered at the pilot subcarrier, shall be at least 40 dB.

Electrical Performance Standards for Second Program Operation

The aural transmitter frequency deviation capability must comply with the requirement of § (C) (a) (1) of this bulletin.

The aural transmitter modulation bandwidth capability shall comply with the requirement of § (C) (a) (1) of this bulletin.

The unmodulated subcarrier shall be frequency locked to the fifth harmonic of the horizontal line rate. When modulated, the center frequency shall nominally be that of the fifth harmonic of the horizontal line scanning frequency with a tolerance of ±500 Hz.

Frequency modulation of the subcarrier shall be used.

The subcarrier shall be shut off when the second audio program subchannel is not in use.

The combined audio frequency harmonics measured at the output of the transmitting system (including the encoder) at any audio frequency from 50 – 15,000 Hz and at modulating percentages of 25, 50 and 100% 75µs equivalent modulation shall not exceed the rms values in the following table.

50 to 100	Hz	3.5%
100 to 7,500	Hz	4.0%
7,500 to 15,000	Hz	3.0%

Harmonics shall be included to 20 kHz.

Cross-talk into the SAP subchannel caused by a signal in the main channel and/or in the stereophonic shall be at least 50 dB below level representing full modulation of the SAP subcarrier (±10 kHz deviation).

The aural transmitting system output frequency modulation noise level after subcarrier demodulation be at least 50 dB below the level representing full modulation of the SAP subcarrier (±10 kHz deviation).

The aural transmitting system output frequency modulation noise level in the band of 63 – 94 kHz shall be at least 50 db below the level representing 100% amplitude modulation.

Electrical Performance Standards for Video Operation

The requirement of § 73.687 (a) (1) and (2) of the FCC Rules and Regulations shall be complied with provided, that when the station is engaged in stereophonic sound transmission, or when the station transmits stereophonic sound and/or second audio program, subparagraphs (1) and (2) apply, except except as modified by the following: A sine of 4.5 kHz introduced at the terminals of the transmitter which are normally fed the composite color picture signal shall produce a radiated signal having the amplitude (as measured with a diode on the RF transmission line supplying power to the antenna after the combination of visual and aural power) which is down at least 30 dB with respect to the signal produced by a sine wave of 200 kHz.

In the situation where stereophonic sound and/or second audio program is transmitted, the following requirements shall be met: the incidental phase modulation of the visual carrier by video signals in the frequency band of 1 and 92 kHz shall be less than 3° for carrier amplitude below ¾ of the voltage at synchronizing peaks and less than 5° for carrier amplitudes exceeding ¾ of the voltage at synchronizing peaks.

Electrical Performance Standards for Sound Encoding

The equivalent input noise of the sound encoder, measured over a 15 kHz bandwidth, shall be more than 70 dB below the 100 Hz, 100% 75µs equivalent modulation level.

The tracking characteristics of the sound encoder shall be such that the minimum equivalent input separation a modulation percentages from 1 to 100% 75µs equivalent modulation is 26 dB from 100 Hz to 8 kHz.

Modulation Levels

When only a monophonic audio signal is transmitted, the modulation of the aural carrier shall not exceed 25 kHz deviation on peaks of frequent recurrence, unless some other peak modulation level is specified.

For stations transmitting more than one audio program channel the maximum modulation levels must be meet the following limitations"

(1) TV stations stereophonic sound signals must limit the modulation of the aural carrier by the stereophonic sum modulating signal to 25 kHz deviation on peaks of frequent recurrence.

(2) TV stations stereophonic sound signals must limit the modulation of the aural carrier by the sum of stereophonic sum modulating signal and stereophonic difference encoded signal to to 50 kHz deviation on peaks of frequent recurrence.

(3) The modulation of the aural carrier by the stereophonic pilot signal shall be 5 kHz deviation wit a tolerance of ±500 Hz.

(4) TV stations transmitting a second audio program must limit the modulation of the aural carrier by the SAP subcarrier to 15 kHz deviation.

(5) TV stations transmitting multiplex signals on the aural carrier for non-program related purposes must limit the modulation of the aural carrier by the arithmetic sum of all subcarriers, other than the stereophonic and second audio program to 3 kHz deviation.

(6) The total modulation of the aural carrier by multichannel sound shall not exceed 73 kHz.

Definitions

Decibel ERMS Value: The exponentially time-weighted root mean square (ERMS) value converted to dB as follows:

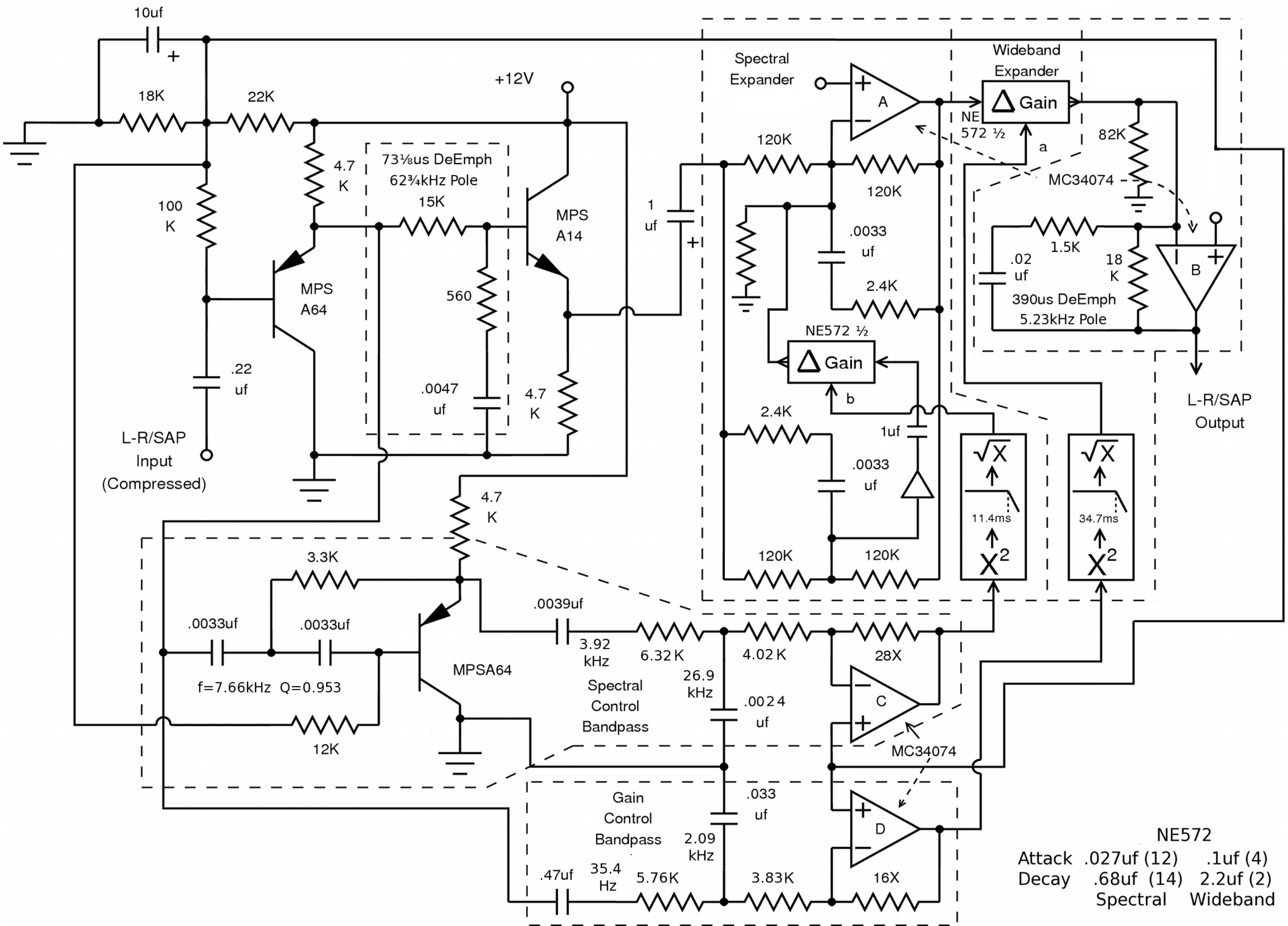
$$\text{decibel ERMS Value} = 20 \log \left[\frac{\text{ERMS Value}}{\text{Reference}} \right]$$

Where Reference is the 0dB ERMS value.

Exponentially Time-Weighted Root Mean Square (ERMS) Value: The ERMS value of a waveform is obtained from the following formula:

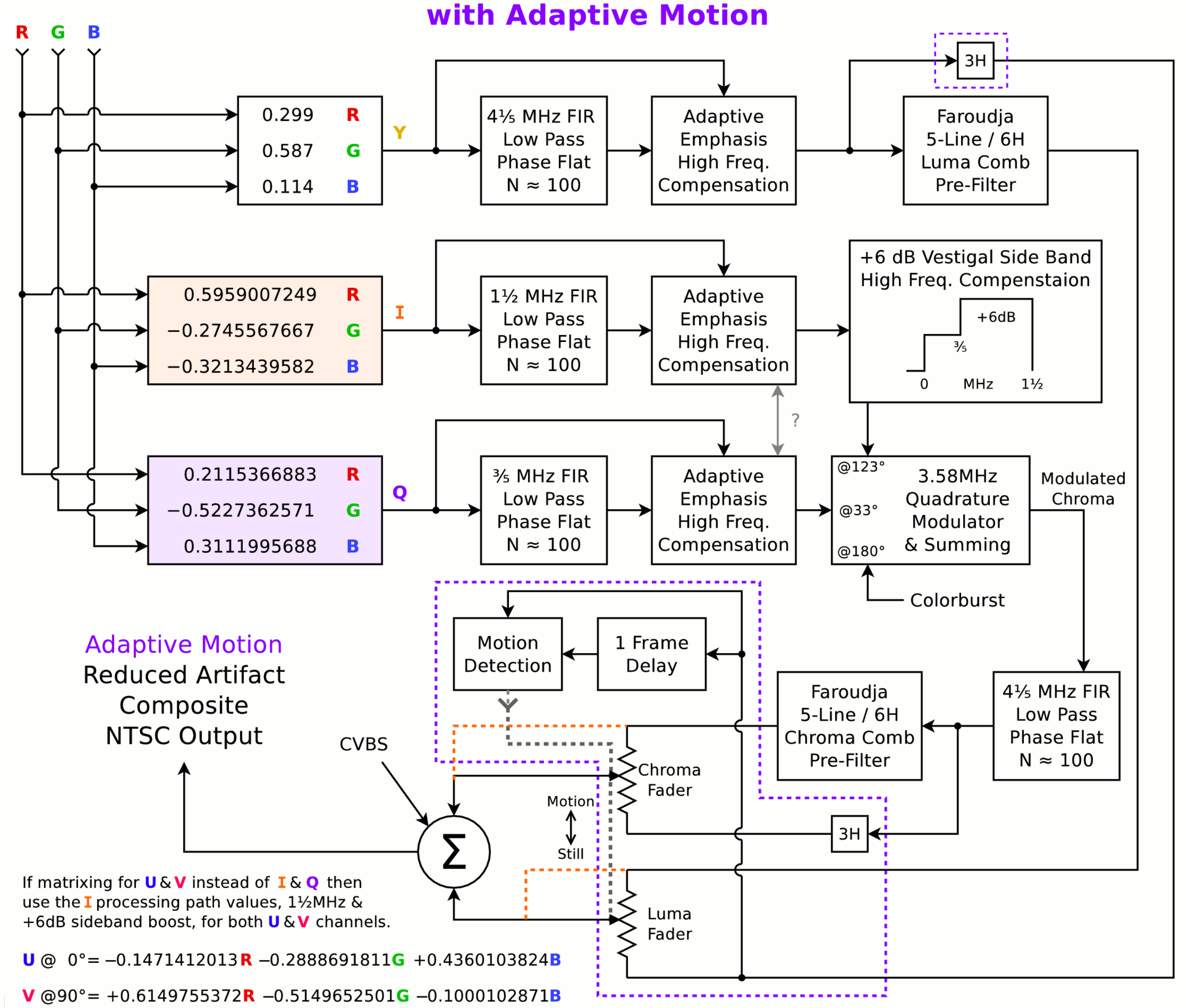
$$\text{ERMS value} = \sqrt{\frac{1}{T} \int_{-\infty}^{t} S^2(u) e^{-(t-u)/T} \, du}$$

Example Spectral & Wideband Expander



Enhanced Encoding NTSC Signal Generation

with Adaptive Motion

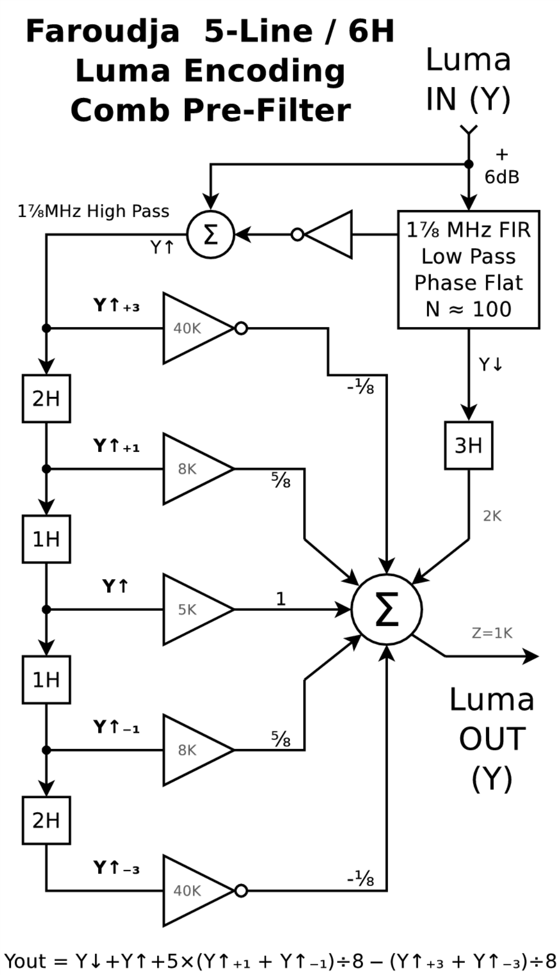


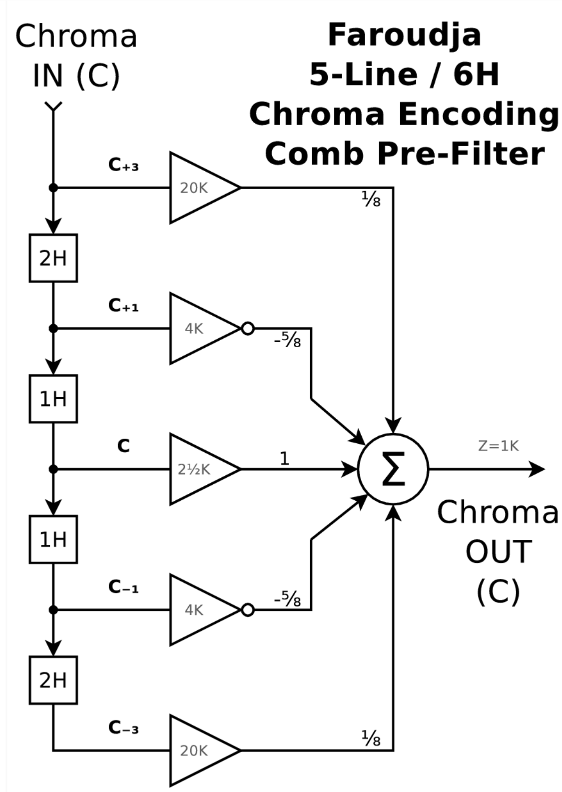
Above is a block flow chart of NTSC advanced encoding. After matrixing into Y, I & Q they are then low pass filtered at 4⅕, 1½ & ⅗ MHz respectively.

Adaptive Emphasis High Frequency Compensation[1] – This circuit boosts signal levels of higher frequencies that lack the harmonics necessary to produce sharp edges. A square wave contains the fundamental and odd harmonics to produce sharp image edges. A filtered square wave with all harmonics removed contains a sine wave that is only 63⅔% of peak. This will boost the sine wave peak to the same level of the square wave. It does not increase sharpness but it does restore peak contrast and if circuits in the receiver square it up it will return the signal close to its original form.

Vestigial Sideband on I Channel – When eliminating one sideband there is a 6dB loss in envelope modulation for frequencies above the cutoff frequency. To compensate those frequencies above the cutoff will need a 6dB boost to restore a flat response.

Luma & Chroma Adaptive Pre-Combing[1] – In order to reduce cross color and hanging dots during comb mesh failure or for receivers with poor Luma & Chroma separation pre-combing will reduce those spectral components to a tolerable level that will make them minimally visual. The choice of using this only for areas of motion is to optimize it for larger screen receivers that also use adaptive motion (purple dotted line). Combing can reduce resolution and for still areas this is noticeable on larger screens. Using adaptive motion provides the best performance for larger screens but for smaller screens that may or may not use a 3-line comb filter the artifacts can be noticeable in still areas. Full non-adaptive combing (orange dotted line) will reduce artifacts for all screen sizes but but dose not offer the best performance for larger screens. Since this advanced processing is mostly beneficial for larger screens and of limited benefit to existing smaller screens implementing adaptive motion seems to be the prudent choice. For still areas a field comb of 1 frame delay in the receiver will provide complete artifact free **Luma**/**Chroma** separation. Not using pre-combing for still areas offers the sharpest images for larger screens.

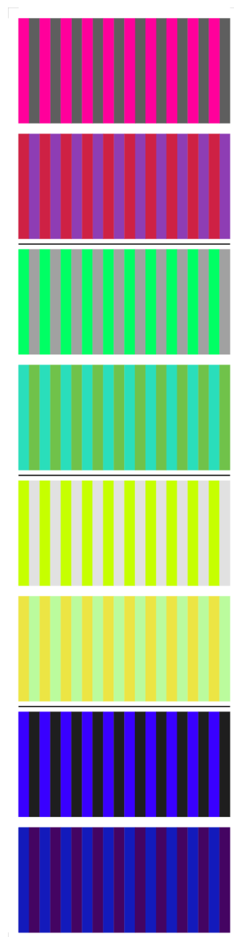




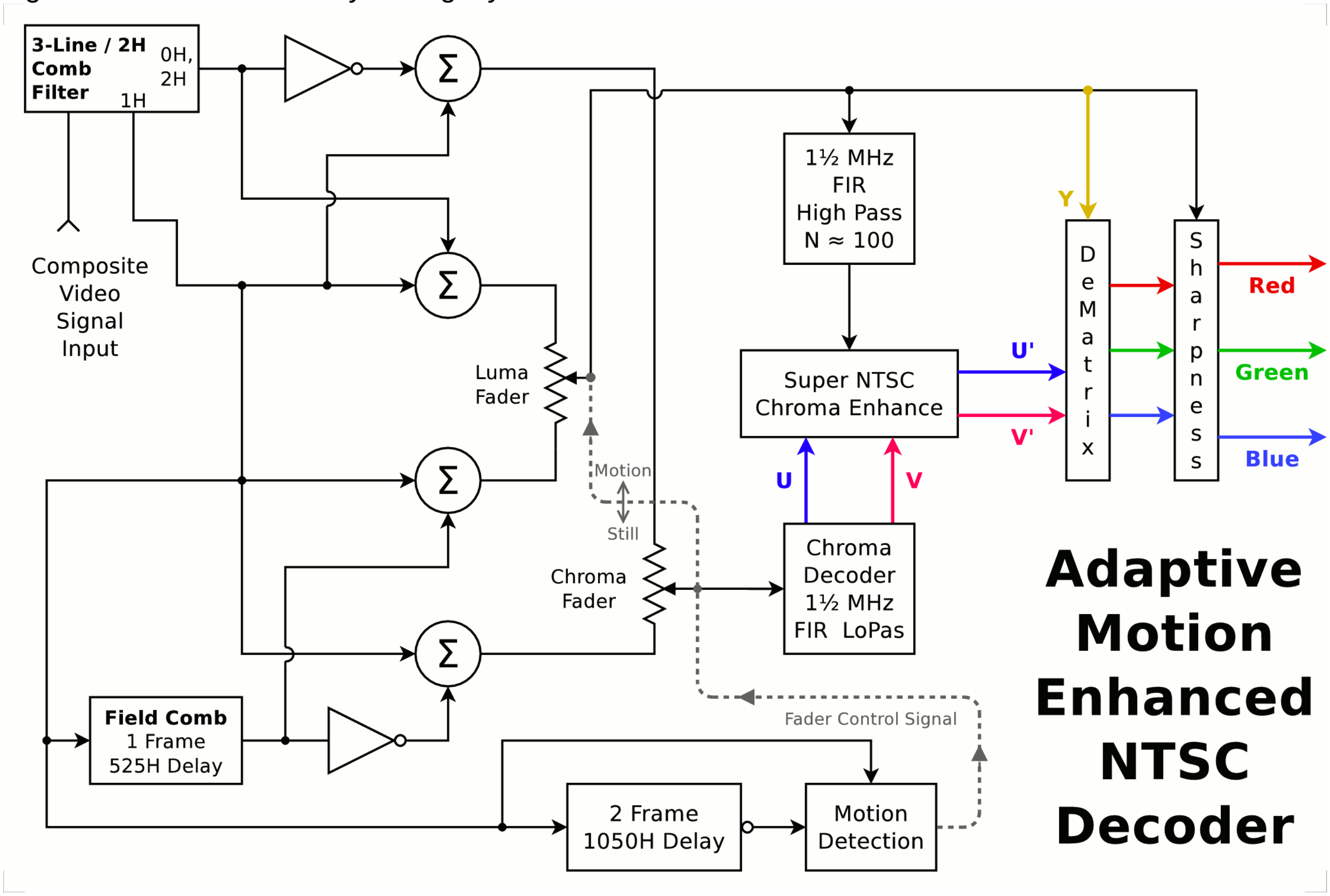
$$\text{Cout} = C - 5\times(C_{+1} + C_{-1})\div 8 + (C_{+3} + C_{-3})\div 8$$

For both Luma & Chroma filters the mixing ratios were based on the equation in the original Luma drawing however the drawing has descrepencies with the equation itself, namely a sign error for the ±3H lines, and switching the sign aligns the two. Since the Luma filter only combs video above 1⅞MHz the signal below is then mixed with the combed signal to form the composite. The Chroma filter is derived from the Luma filter mix by inverting the ±1H & ±3H lines.

NTSC was designed to use **I** & **Q** chroma channels under the belief that a QAM signal could only properly carry the higher frequencies of only one of the channels so it was chosen to assign the wider bandwidth channel to flesh tones. However this was a mistake that produces improper colors for signals from ½ to 1½MHz falling 45° between the **I** & **Q** channels. For signals that fall on either **I** or **Q** the hue will be correct but as hues approach the 45° mark the hue error increases to its maximum. The reason for this is that the **I** channel portion will contain modulation that the **Q** channel does not. With a 50/50 duty cycle the filtered **Q** channel output will be an average 50% of the peak modulation. The resulting modulated hue output will bounce between two hues on either side of the original hue, hence the earned moniker **N**ever **T**he **S**ame **C**olor. To the right are four sets of patterns that represent the four vectors that are 45° to the **I** & **Q** axes in a before and after arrangement. The input, above, is fully saturated and at full brightness that alternates between its **Luma** equivalent with no color. The output is just below. From top to bottom the 45° vector order is: **I** & **Q**, –**I** & –**Q**, **I** & –**Q**, –**I** & **Q**.



For a higher bandwidth **Chroma** using vestigial sideband QAM modulation for both **U** & **V** channels is the better option. The two **Chroma** channels are usually thought of as being separate but in reality they are a Cartesian representation of a polar signal, **R** being saturation and **θ** being hue. With this in mind the QAM signal should be able to carry the higher frequencies well of both channels, [2]pg29. This has probably been employed on PAL-B/G that uses a 7MHz channel space where the **Luma** has been reduced to 5MHz and thus the **Chroma** USB has been reduced to ⅗MHz. Take for instance a **Green**–**Magenta** color bar pattern. The vestigial sideband **Chroma** signal generated has 0° phase shift and resembles a suppressed carrier signal from a single modulator similar to the **Luma** signal. It is off axis to the **U** & **V** channels which represent its Cartesian co-ordinates. Upon de-matrixing into **RGB** sharper transitions are produced compared to what is seen on the NTSC test pattern. It should be safe to assume that the non vestigial sideband portion should do a good job on chroma modulation that contains hue changes. This dual band filtering of **I** & **Q** which produces improper colors should be abandoned in favor of the **U** & **V** scheme. A dual **I** / **Q** bandwidth receiver will still produce hue errors on a wideband **U** & **V** signal but the outcome may be slightly different. On sets that use ⅗MHz **Chroma** this is a non-issue.



Above is a block flow diagram of advanced receiver decoding. Adaptive processing switches between a field comb for still image areas to a 3-line comb for motion which is controlled by comparing a two frame delay signal to the current to detect motion which then drives the fader controls. The faders are necessary to transition the wipe over several pixels to avoid sharp transitions that would be noticeable. The **Chroma** output is Super[1]NTSC processed to square up the signal by using the higher **Luma** frequencies above the **Chroma** cutoff frequency. This requires proper amplitude and phase adjustments to the high frequencies before being added to the **Chroma** signals.

Advanced reading:

1. NTSC and Beyond – Yves Faroudja – IEEE Transactions on Consumer Electronics, Vol.34#1 2/88
2. The Engineer's Guide to Decoding & Encoding – John Watkinson – Snell & Wilcox Handbook Series
3. A Handbook for the Digital Engineer – Keith Jack – Newnes Elsevier
4. Improved Television Systems: NTSC & Beyond – William F. Schreiber
5. Design of FIR Filters – Elena Punskaya

Horizontal & Vertical Blank & Sync Timings & Structure

Regarding the horizontal blank & sync components, front porch, sync, back porch and colorburst the dot clock optimized timings are:

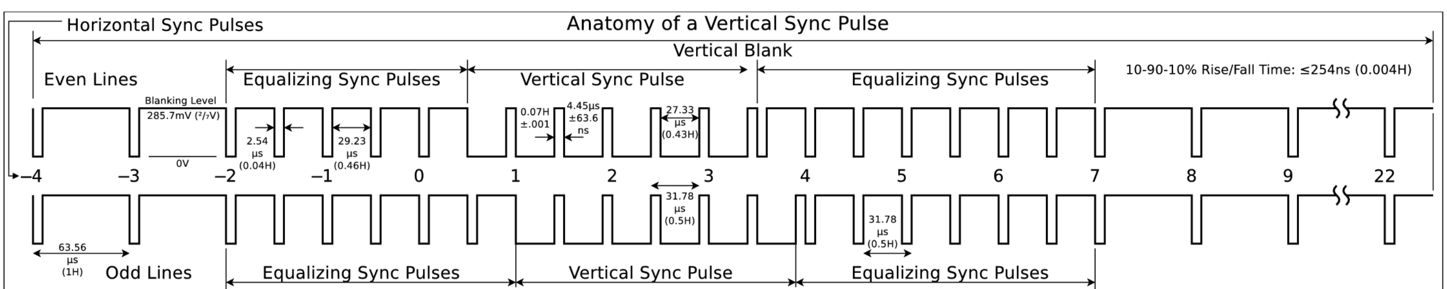
Horizontal Blank: 10.9µs
Front Porch: 1½µs
Sync: 4.7µs
Back Porch: 4.7µs
Colorburst: 2⅘µs, 10 cycles

Horizontal Blank Structure available in Composite Video Scope Image on page 4.

The timings on page 6 reflect these within the tolerances that the dot clock, the chroma 8× oscillator, can produce. When generating the signal these values should be adhearded to. For better compliance with PAL-M, and instead of centering the colorburst on the back porch, the minimum breezeway betweem sync and burst is 381ns, the average space after centering is ~1µs, so this space can be reduced to the mimimum allowing for greater time for the **V** switch to complete its operation. Using 419ns (1½ cycles) with a 10 cycle colorburst leaves 1½µs of time for the **V** switch to complete its opertaion within the blank.

However specification tolerances are a bit looser and any decoding must accommidate these ranges.

Horizontal Blank: 10.487µs (0.165H) min
Front Porch: 1.271µs (0.020H) min
Sync: 4.449µs (0.070H) min
5.08$\overline{4}$µs (0.080H) max
Breezeway Spacing: 381ns (0.006H) min
Sync Start to Burst End: 7.9$\overline{4}$ µs (0.125H) max
Sync Start to Blank End: 9.21$\overline{5}$µs (0.145H) min
Colorburst: 2.234µs (0.035H) min (8cycles)
3.073µs (0.048H) max (11cycles)
Back Porch: 4.131µs (0.065H) min



In order to interlace the 2 fields into 1 frame there needs to be a 1/2 line offset of the vertical sync pulse between the fields of odd and even lines. By adding equalization pulses before and after the vertical sync pulse at a rate of 2H this will allow the vertical sync pulse to start in the middle of a horizontal line for one of the fields. This shifts the lines of one field vertically by one half line in order to fit between the lines of the other field. It is also necessary for each field to start or end with a half of a horizintal line and a full frame will have an odd number of lines. For NTSC-M there are 525 lines per frame, divide by 2 and each field will have 262.5 lines. Since the horizontal sync oscillator is synced to the regular horizontal sync pulses it ignores the extra equalization pulses while it is in the middle of a sweep.

For information on vestigial sideband modulation as it pertains to NTSC-M broadcast transmission see **NTSC-DVD** on pages 7 & 8.

Enhanced NTSC Timings

In the goal of squeezing every last bit of performance out of the NTSC signal space it is probably possible to modify the specs within limitations that most older sets shouldn't have an issue with. With this in mind here are a set of parameters that may work. It offers a ~10¼% increase in detail improvement.

		Chroma	Chroma	
Aspect Ratio	4:3 = 1⅓	½Cyc	½Cyc	3:2 = 1½
H.Freq	15,734.264Hz			
H.Period	63.555µs	455 (227½)	423 (211½)	
H.Blank	7.543µs	55	52½	7.888µs
F.Porch	0.768µs	5½	5	0.751µs
H.Sync	3.492µs	25	23½	3.531µs
B.Porch	3.422µs	24½	24	3.606µs
Space	0.419µs	3	3	0.451µs
Burst	2.235µs	16	16	2.404µs
Space	0.768µs	5½	5	0.751µs
Pixels	55.873µs	400	370½	55.667µs
Active Pixels	54.197µs	388 (776)	360 (720)	54.090µs
Overscan	1.676µs	12 3.1%	10½ 2⅚%	1.578µs
Chroma	3.57954506MHz			3.327796836MHz
Chroma BW	1½MHz			
Luma BW	4⅕MHz			
Ratio	2⅘:1:1			
Luma Lines	A:379/455 D:536/644 Avg/Max			
Pxl.Asp.	1.193:1			1.345:1

	IRE=1V/140	
Luma (Y) Level:	98	700mV
Sync:	–42	300mV
ColorBurst:	±21	±150mV
Max (**Yl** & **Cy**)	130⅔	1.2$\overline{3}$V
Min (**Rd** & **Bl**)	–32⅔	66⅔mV

Rec.709 sRGB Gamut	**1931 CIE x**	**y**	**nm**
Red	0.64	0.33	~**607**
Green	0.30	0.60	~**556**
Blue	0.15	0.06	~**467**
White Point	0.3127	0.329	6504°K
Contrast 2^{12}:1	Gamma 2.4		

While the 720×480 **DVD** aspect is 3:2 at 4:3 the analog pixel aspect is already at 1.193:1 and stretching it to 3:2 would increase this to an acceptable 1.342:1. With the goal of keeping the vertical edges sharp using typical sharpness circuits 4:3 is probably best. Increasing it even more to 854×480 16:9 (1.592:1 pixel aspect) would make those edges fuzzy. Advanced circuitry can square up these edges and increase contrast without overshoot but actual detail can never go above 455 lines because of luminance bandwidth limitations, 227½ cycles of a 4⅕MHz sine wave within 54.197µs. This would set the pixel aspect for 3:2 at 1.119:1 which is very good and 1.327:1 for 16:9 which is acceptable. This advanced circuitry is great for 4:3 providing a pixel aspect 0.99:1, which is perfect and almost studio quality (500). Using this circuitry this is good enough to make the default resolution 720×480 but in order to have 180 chroma cycles that would align to the 720 samples within ~54µs the chroma would need to be lowered to 211½×15,734.264kHz=3.327796836MHz and this would also increase the USB chroma to ⅞MHz.