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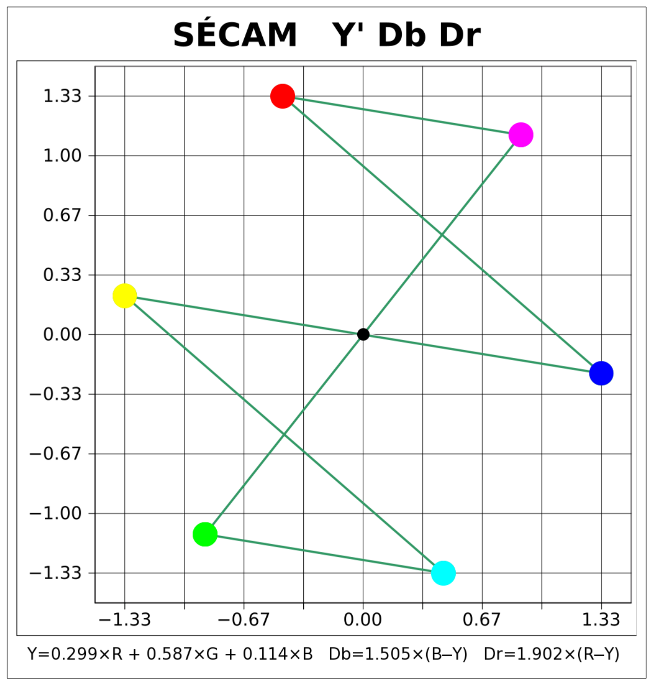
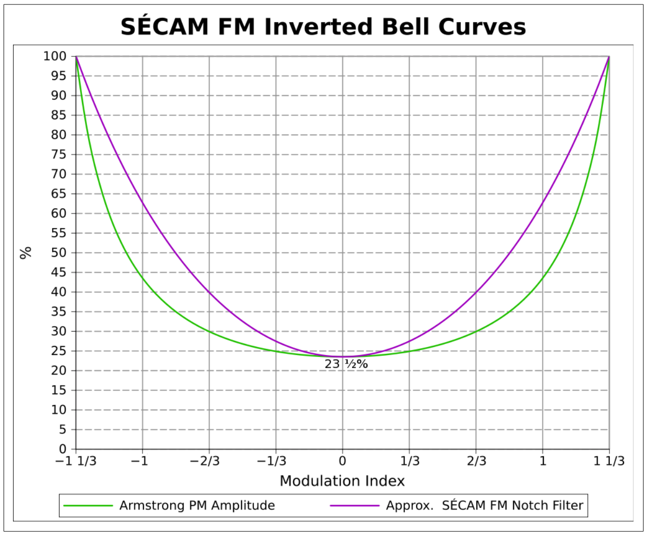
A Look At SÉCAM III

SÉCAM (Séquentiel Couleur Avec Mémoire) is a color TV system developed in France. This was a joint project with the USSR as Soviet technicians worked alongside French engineers to produce what was to become SÉCAM III along with some additional improvements later to be known as the 'A' and 'B' suffixes. The Soviets later came up with another version called SÉCAM IV that was incompatible with SÉCAM III but more on that later. Instead of using QAM to transmit the two channel color information for every scan line as it is done in NTSC and PAL the two color signals are transmitted on alternate lines. To recover the non-current line of color information a delay line of 1H is used to recover the other color from the previous line, hence the part 'Avec Mémoire' or 'With Memory'. The delay line is used after the detected signal so critical delay timing is not an issue as it is for NTSC or PAL delay lines. The **R G B** weighting for the Luminance is the same as **Y I Q** in NTSC and **Y U V** in PAL but the color matrix uses different scaling factors called **Y' D_B D_R**. Since each color channel is transmitted separately the **B**—**Y** and **R**—**Y** signals are scaled so they both peak at ±1⅓ to maximize modulation for both channels. If displayed on a vector scope the hexagon is more uniform in shape compared to NTSC's or PAL's tall and narrow pattern. It is rumored but unconfirmed that this scaling might be used for PAL-N which could provide better automatic hue correction on marginal signals although increased **U** levels could cause over modulation issues if not properly addressed.



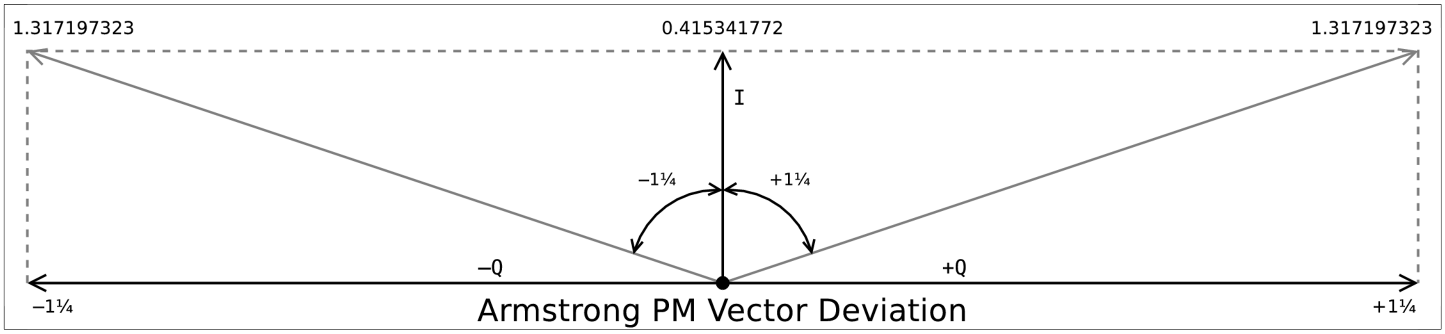
The color signal is also modulated on an FM sub-carrier instead of AM and offers distinct advantages but some disadvantages too. FM by its very nature has better noise immunity than AM and the limiting process eliminates any AM noise. If the FM detector operates above the limiting knee then full quieting is achieved as the signal has captured the detector. Good design must go into the detector in order to produce a good capture ratio. Below the limiting knee when the detector is not fully captured a not-beautiful '**SÉCAM Fire**' will flair up and spread across the whole scene. In NTSC or PAL the BFO signal is provided by a PLL crystal oscillator so the reference signal is always there unlike an FM detector seeing a signal below the limiting knee threshold level. Under these conditions the detector will act erratic and produce a false signal. Both NTSC and PAL have color killer circuits when the PLL is not locked so an improperly detected color signal is not available. Higher end SÉCAM sets probably have something similar but momentary loss of a captured detector from noise in the middle of a picture will produce saturated color streaks on the screen as will text inserted from VCR/DVD menus as this squashes the FM sub-carrier. If improper detection of line switching order and/or phase occurs then the whole color palate can flip and colors can become completely different. The FM sub-carriers are always present unlike QAM-SC used in NTSC and PAL. In B & W areas the two sub-carriers are reduced to 23% of their levels during full color saturation. This is done through the use of an inverted **Bell Curve** notch filter that has maximum attenuation when the sub-carriers have no color modulation. As the frequency of the sub-carriers shift they move out from under the center of the notch filter introducing amplitude modulation. While the unmodulated FM sub-carriers are a multiple of the line frequency maintaining them in exact sync with the rest of the signal is nearly impossible. This and along with the character of FM prevents any composite mixing of two or more signals or fading from one to the next.



SÉCAM IV developed by the Soviets at NIR had some different characteristics. It was non-linear, assuming in its deviation be it frequency or phase. It was incompatible with SÉCAM III. There were two versions, one with and one without gamma correction. Prior to their venture into SÉCAM they experimented with what would seem to be a version of NTSC Chroma using the European 625 line B & W D/K system called 'Simultaneous System with Quadrature Modulation'. Supposedly there were even TV sets manufactured using this system listed in the goods catalog. From working with this system and being familiar with QAM it wouldn't be surprising if one of these sets became a SÉCAM IV conversion. The envelope of both the sub-carriers is $\sqrt{Db^2+Dr^2}$ +10%pep, carriers on even[odd] lines within a field are phase modulated with aTan[D_B/D_R] while the odd[even] lines are unmodulated. A very accurate 1H delay line is used to supply the two carriers to a product detector. Recovering both signals might depend on the phase offset of the BFO, 0° or 90°, applied to the detectors. This is overly complex, inherently flawed and probably why it was rejected. Using plain Armstrong PM would be a much simpler approach and an easier conversion. Use only one of the QAM detectors output, add a delay line, a line switching detector with switch, and that should do it. For transmission replacing one of the QAM color signals with a DC level for the carrier which would be in quadrature to the DSB-SC AM modulated signal would produce non-linear Armstrong Phase Modulation. This single modulated signal would switch between D_B & D_R on alternate lines. If the modulation index peaked at ±1⅓, which are the D_B D_R peak values, then this would produce a non-linear phase deviation and apply a gamma. It would also introduce inverse **Bell Curve** amplitude modulation to the signal that would be 23½% at zero crossing in relation to its peak ±1⅓ modulation index. What a coincidence, SÉCAM III is spect. at 23%. If proper equalization and gamma correction were applied then this would produce an FM compatible signal with a linear frequency deviation that FM discriminators could properly detect. If the carrier was an odd multiple of ½ the horizontal line frequency then the clusters and fine mesh harmonics would interleave just like NTSC and the dot crawl pattern would be identical when no color modulation was present. The dot pattern could also have a two frame repeat rate depending on the line switching scheme. Since the color sub-carriers would stay synchronized with the horizontal frequency two or more signals could be mixed together or faded from one to another, although adding gamma correction for a linear deviation would negate this feature for **Chroma** signal modulations above 40% of peak producing inaccurate color mixing, hue and saturation changes. Since the majority of most **Chroma** modulation levels are <50% of peak this should be a minor issue. For all practical purposes it is NTSC with one of the color signals replaced with a DC level for the quadrature carrier.

It is believed that PM has a natural pre-emphasis compared to FM and this is true for frequency deviation but it is FM that has a natural de-emphasis with PM having a flat response for sideband energy. The modulation index, which determines the number of sideband harmonics generated, of FM is not constant across the modulating frequency band but varies according to its relationship to the frequency of deviation according to the formula 'Frequency of Deviation' ÷ 'Modulating Frequency'. As a result for the same amount of frequency deviation sideband energy decreases 6dB/oct. along with the same decrease in S/N ratio as the modulation frequency increases creating a triangular noise spectrum whereas PM has a rectangular noise spectrum. It is for this reason that pre-emphasis is almost always used with FM. A couple of octaves above the corner frequency and the rise in gain becomes 6dB/oct. making the sideband energy resemble that of PM so why not just use PM instead. In the frequencies below the pre-emphasis point the modulation index increases along with the S/N as frequency decreases. This direction of gain in S/N is contrary to the balance of the overall modulated signal integrity. It is better to have a greater S/N ratio in the higher frequencies than the lower frequencies. FM, especially without pre-emphasis, produces just the opposite. PM is all around a better approach to generate an angular modulated signal. It is also much easier to control the center frequency of a phase modulator than a frequency modulator and in practice as with FM Stereo indirect FM generation is often used. The modulating signal is first integrated before being sent to the phase modulator.

There is a mathematical relationship between FM and PM. One is the integral or derivative of the other. An FM compatible signal can be generated using PM by integrating the modulating signal first, called indirect FM. Likewise a PM compatible signal can be generated using FM by modulating the derivative of the signal, called indirect PM. For PM signal detection a frequency discriminator is used by integrating the detected signal. For FM detection a phase discriminator used with the derivative of the detected output. This offers unique opportunities in **de**modulation of FM using PM.
Armstrong PM based on QAM has the following characteristics. With QAM there are **I** & **Q** channels. In Armstrong PM the **I** channel has a constant level representing the carrier and the **Q** channel is a DSB-SC AM signal. This naturally produces a phase modulated

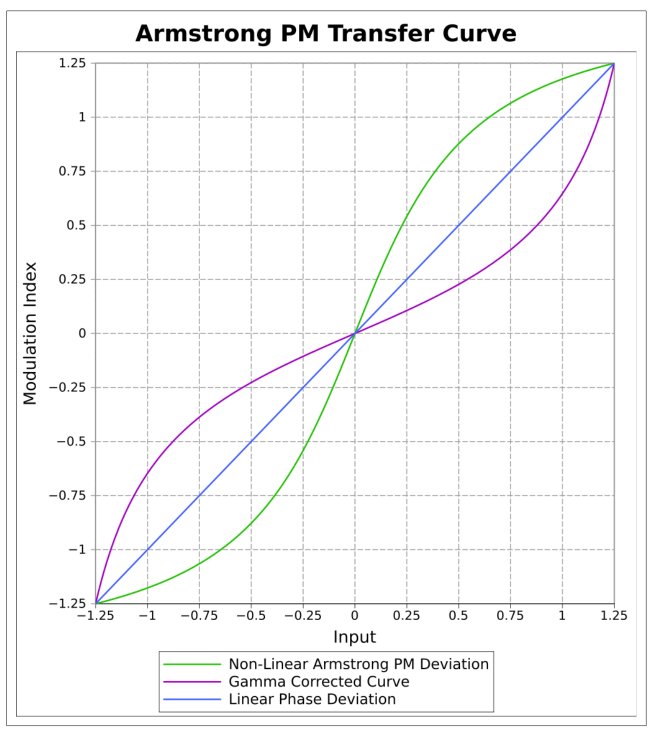


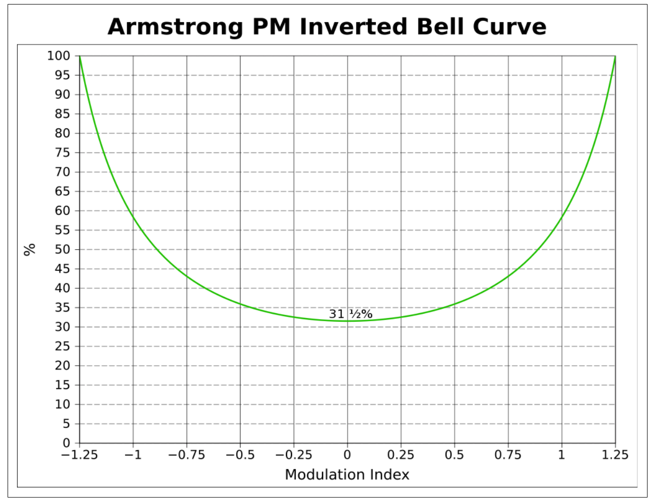
term and as long as the modulation index does not exceed ±⅓ a fairly linear phase deviation is produced along with some AM envelope components. If left unlimited the bandwidth resembles that of an AM signal, and if limited higher ordered harmonics are produced that increase as the modulation index increases. This apples to Motorola® C-QUAM® AM Stereo as well which is a modified QAM / **I** & **Q** system. The FCC limits peak phase deviation for the L─R channel, absent of any L+R modulation, to ±0.7854 (±45°). Since C-QUAM is QAM×Cosθ with the carrier at 0°, when there is no modulation in the **I** (1+L+R) channel, and with the envelope unmodulated, Env×Cosθ, this is Armstrong PM that has been limited. The FCC is specifying one of the modulation limits as pure Armstrong PM. You could say that Armstrong was C-QUAMing long before Motorola ever thought of it. The other FCC limit is for L or R single channel modulation to 75% of Mono L+R modulation. On downward (─) modulation where **Q** is increasing and **I** decreasing, at this limit **I** is ⅓ of **Q** producing a peak modulation index of ±1¼ (±71⅗°) which makes Cosθ peak at $\sqrt{0.1}$, the amount of gain reduction applied to force the QAM envelope to carry 1+L+R. Upon decoding to restore the original envelope to the QAM signal when applying the 1/Cosθ (Secθ) factor its gain peaks out at $\sqrt{10}$.

For practical applications when using Armstrong PM exceeding a modulation index of ±1¼ starts to increase this gain factor rapidly so keeping the **Q:I** ratio limit around 3× is desired. The proper transfer function for Armstrong PM decoding is a Tanθ detector. This explains why keeping peak **M**odulation **I**ndex within ±1¼ is important. Exceeding this can cause the Secθ correction factor *to go off on a Tangent* and start expanding the noise.

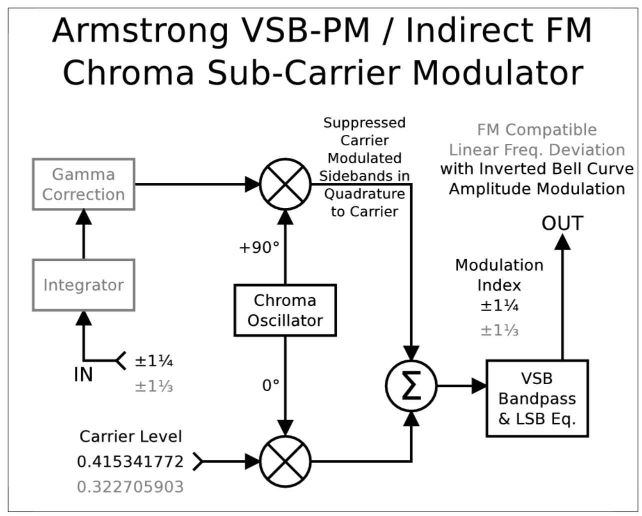
I = 1¼ ÷ Tan(1¼) **;** **MI** = aTan(**Input** ÷ **I**)
Gamma Correction □ **Input** = **I** × Tan(Input)

In the graph to the right are the Armstrong PM transfer curves. The **Green** is the non-linear output, the **Purple** is the gamma corrected input that will produce the linear phase output in **Blue**.

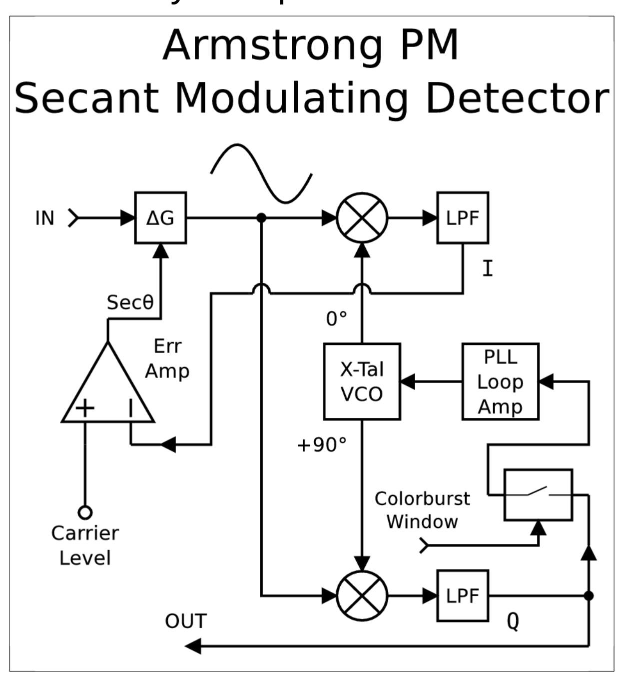




To the right is the Armstrong PM inverted **Bell Curve** for a modulation index of ±1¼. It dips to 31½%, but not quite as much as an index of ±1⅓ at 23½%. This is a trade off to keep Tanθ from exceeding 3 and making any detectors excessively prone to distortion caused by noise. In keeping the amplitude of the unmodulated carrier level the same as an index of ±1⅓ the peak level with an index of ±1¼ would be 74⅗ %. This is a >2½dB loss in peak levels but it is made up by the non-linear gamma response offering an average +6dB gain for indices ≤|±¾|, 60% of peak linear phase deviation for input levels ≤|±⅜| .



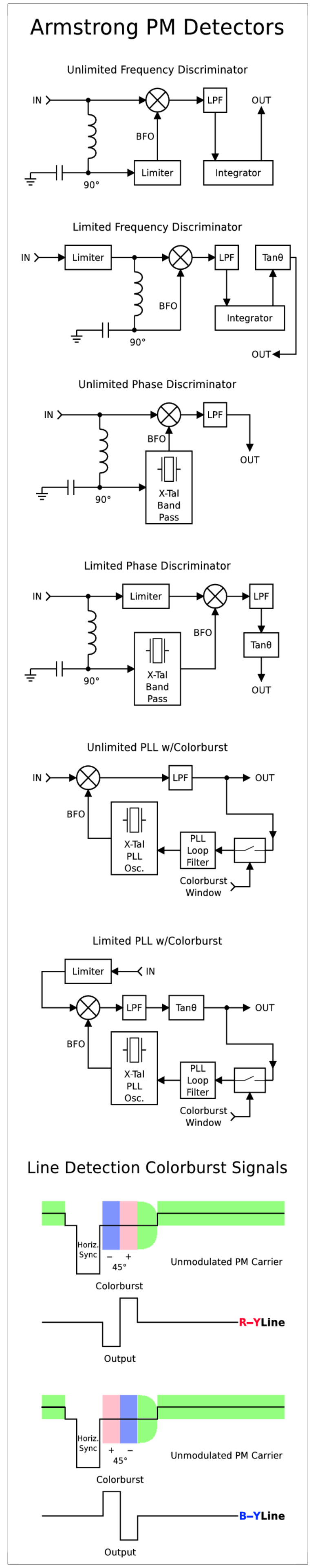
To the right is an Armstrong VSB-PM modulator. It is for both linear and non-linear deviations. For a linear deviation that would be compatible with existing SÉCAM IIIB TV sets the values in gray are used, pre-emphasis not shown. For non-linear Armstrong PM all the values are in black with the gray ones omitted. As with VSB-AM used for the main carrier for the luminance signal omitting the higher frequencies in one of the sidebands saves bandwidth. Since Armstrong PM is generated using DSB-SC AM the sideband structure is identical to the luminance carrier and truncating one of the sidebands higher frequencies is possible without causing issues. The non-truncated extended sideband will have to do double duty to replace the loss of the VSB truncation. All energy past the VSB corner frequency will require a 6dB boost. This applies to both the **Luma**[**Y**] (VSB-AM) and **Chroma**[**C**] (VSB-PM) signals. The only difference between the two is the carrier phase in relation to the sidebands. With VSB-AM the carrier is in phase (**I**@0°) with the sidebands and can be inserted by applying a DC bias (1+**Y**) to the modulator input. For VSB-PM the sidebands (**Q**@90°) are offset 90° from carrier (**I**@0°) and requires a second modulator.



To the right is an Armstrong PM detector. It is borrowed from a C-QUAM decoder. The only difference is that the Carrier Level replaces the envelope detected signal since the **I** channel in

Armstrong PM is unmodulated. This has unique benefits. Replacing the noisy envelope signal with a DC Carrier Level reference without noise serves to un-modulate any noise in the **I** channel thus having a limiting effect producing a similar response to full quieting from a ratio detector or a frequency discriminator operating on a limited signal. The Carrier Level can also be sourced from the AGC'd signal to maintain the proper **Luma**/**Chroma** mix. It also causes the **Q** detector to output Tanθ, proper detection for Armstrong PM. Now this circuit is easy to construct for C-QUAM AM Stereo decoding. At a 450kHz IF using full wave detection 60 samples per cycle of 15kHz are provided for the highest audio frequency. Two standard Gilbert Cells, Quadrature Oscillator, High Performance Audio Op-Amp, and an IF Gain Cell should work. This will produce very accurate decoding. As for using this type of detector for video a dedicated high speed IC would be needed. If built out of discrete components Gilbert Cells should be µPA101, HFA3101 or similar. As for the Op-Amp and Gain Cell discrete high speed transistors or specialized ICs should be used. The LPF for the **I** detector should be a 2f notch of the **Chroma** carrier frequency for minimum phase offset. Using a minimum number of samples needed (~6) for the highest **Chroma** frequency then with a **Chroma** sub-carrier of 5¼mHz this would limit the **Chroma** bandwidth to 1¾MHz. It may preform fair with only 4 samples per cycle for a 2½mHz bandwidth but that may be pushing it. It is only a theory that an economical circuit could be constructed and perform well.

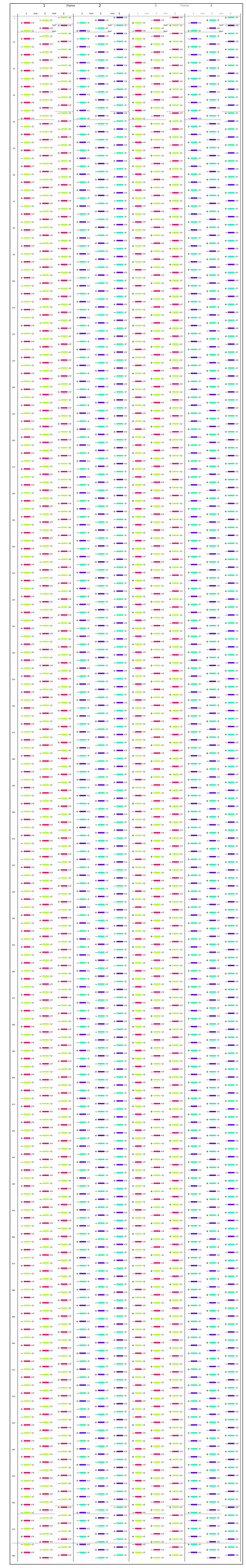
In the drawing to the right are several types of detectors for Armstrong PM. The 1st uses a frequency discriminator on an unlimited signal to preserve the Tanθ characteristic so proper integration is preformed. The BFO from the 90° shift will need to be limited or strong enough to fully switch the detector. This is the simplest approach but lacks the noise reduction obtained from limiting. The 2nd example uses full limiting to benefit from noise reduction but since the amplitude modulation is removed the Tanθ factor is lost. After integration wave shaping must be done to restore Tanθ. The 3rd example uses a quartz crystal as a narrow bandpass to remove the sidebands for the BFO. This now resembles a PLL BFO without the Loop Amp. It could even be a ringing oscillator not quite at critical feedback. If there is no signal then there is no output but its ringing capability can carry a BFO signal to the detector during a momentary signal loss minimizing '**SÉCAM Fires**'. It would operate on an un-limited signal so the Tanθ characteristics are preserved.



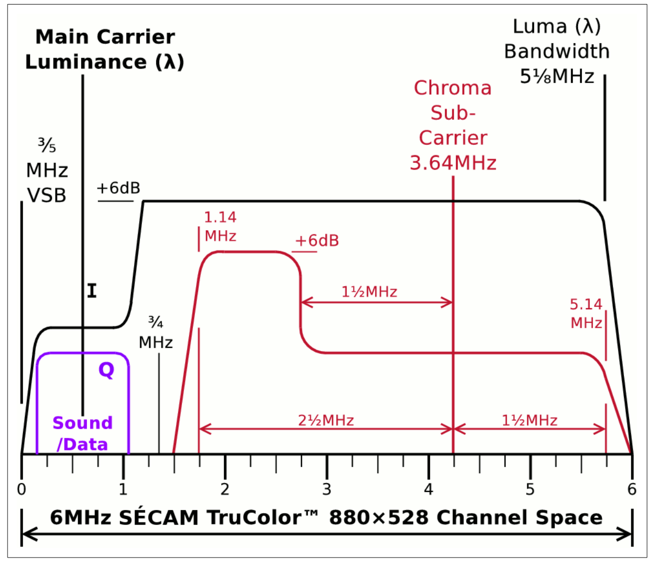
The 4th example is like the 3rd but operates on a fully limited signal for additional noise reduction but the Tanθ characteristic is lost. Wave shaping must be done to restore Tanθ. Examples 5 & 6 are like 3 & 4 respectfully except that the crystal ringing oscillator is replaced with a PLL version locked to a colorburst signal on the back porch of the horizontal sync.

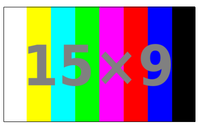
QAM arrangements for generating Armstrong PM have also been commonly used for PM or indirect FM generation as with FM Stereo. To increase the deviation level the signal is not heterodyned up to the transmit frequency but multiplied by 2×, 4×, 8×... which increases the deviation by the appropriate factor. With modulation indices >|±⅓| the phase modulated term becomes more compressed similar to the non-linear quantization used in µ-Law or A-Law digital telephony and for a TV **Chroma** signal a varying level of gamma is applied depending on the peak deviation used. When using a peak modulating index of ±1¼ a moderate amount of gamma is applied which can be beneficial to improve S/N ratio for color saturation of 50% or less offering an average 6dB gain in S/N ratio. If Armstrong PM is used with a modulation index >|±⅓| for a compatible FM signal distortion correction must be used to produce a linear deviation and for TV **Chroma** a gamma correction factor is needed for linear deviation as shown on page 5.

SÉCAM TruColor™ in 6MHz



For the vertical scan a **3:1** interlace is used at a field rate of **72** Hz to produce the **F**ilm standard **24** frames per second. For a ⅔ line offset having the last field arrive one line early in relation to the other two will properly align the chroma channels into an alternate switching pattern for both field and frame lines. To the right is the field line, sync and color channel arrangement. The **±** to the left of the colored stripes represent the peaks and troughs of the **Chroma** sub-carrier phase at the start of every line. Although not necessary swapping **Chroma** channels on a per line basis in the 2nd 2 frames from the 1st 2 frames temporally provides both color channels for every line in motionless areas doubling the vertical color resolution through **DSP** and maybe randomizing dot patterns more at the expense of doubling the **2** frame repeat to **4**. Using a **Chroma** frequency that is an odd harmonic of ½ the horizontal line frequency will create the same cross-hatch dot pattern as **NTSC** when no color modulation is present on a per frame basis and create a **2** frame dot repeat for brightness averaging. Modulation of the Color channels will cause the dots to move left or right. **+V** & **—U** switch lines so the dots will move in the same direction for the **I** (+135°) channel. For the **Q** (+45°) channel they will move in opposite directions and almost align vertically (~37°) depending on saturation but with the **2** frame repeat rate and the eye's lower sensitivity to details on the **Magenta Green** axis this should help mask any otherwise noticeable patterns. Using a **3:1** interlace the motion of the dots will be slightly different than the **NTSC 2:1** interlace pattern of moving up. The **3:1** interlace may display both up and down motion, one moving faster than the other. At **72** Hz using **192⅔** lines with a **3:1** interlace this allows the use of a lower horizontal scan rate providing increased definition of the **Luma** channel with an Aspect Ratio of **15:9**. The vestigial sideband of the main carrier has been reduced to **⅗**MHz and the Luma corner bandwidth increased to **5⅛**MHz with full cutoff at **5⅖**MHz to fit within a **6**MHz channel space. A **2½**MHz bandwidth **PM Chroma** sub-carrier will be used with a **VSB** of 1½MHz. With the sideband energy being strictly mono **AM** of will provide full bandwidth color of **2½**MHz. In the graph on page 10 the **TruColor™ λ' $T_B T_R$ Luma/Chroma** matrix is used. **U**&**V** levels are adjusted along with the **RGB** weighting of the luminance so an equilateral hexagon is created on the Cartesian grid, however **U** has been further reduced by ~3¾% in relation to **V** so both **U**&**V** peak at ±1⅜, to eliminate ~3.9% peak difference. The PM sound sub-carriers are on the **Q** channel of the main carrier.





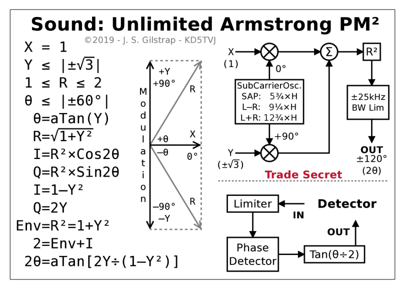
32″ diagonal, (27½″×16½″), 81⅝cm diagonal, (70 ×42 cm), 795µm line pitch.
26¼″ diagonal, (22½″×13½″), 66⅔cm diagonal, (57<u>15</u>×34<u>29</u>cm), 650µm line pitch.

General:

			Fair Contrast
Aspect Ratio	15:9	= 1⅔	365:264 = 1.3822
Total Picture Pixels (Digital)	880×528	; 464640 Pixels	730×528 ; 385440
Kell Factor (Analog Resolution)	622×373	; 232320 Pixels	516×373 ; 192720
Maximum Digital Equiv. @–8dB	876×528	; 462528 Pixels	619×373 ; 231264
			Pixel Aspect 1.206:1

Vertical:

Frames Per Second	24Hz
Total Lines Per Frame	578
Fields Per Second	72Hz
Total Lines Per Field	192⅔
Picture Lines	176
Lines Per Blank	16⅔
Blank	1.201ms
Sync	192µs ; 2⅔ Lines



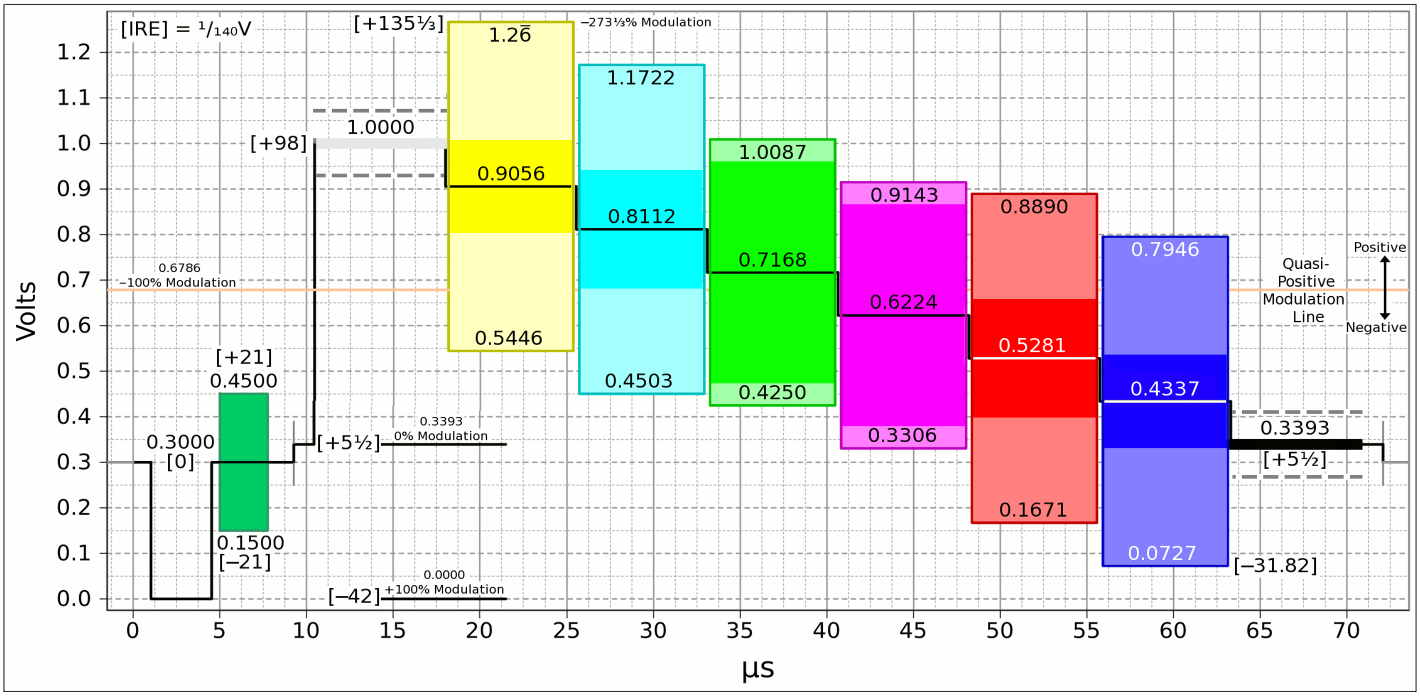
Horizontal:

	Resolution Fair:516 Max@–8dB:619	
Lines Per Second	13.872kHz	
Period (HP)	72.088µs (525)	
Picture	62.819µs (457½)	
Total Picture Pixels	536⅗ ≈ 1⅔ ×λBW×(HP–HB);(516+20⅗)≈3⅚%/2⅖µs OverScan	
Viewable Picture Pixels/Line	516 ; 60.416µs (440)	
Blank (HB)	9.268µs (67½)	
Front Porch	1.030µs (7½)	+16% Increase of EU B/G
Sync	3.501µs (25½)	*+65% Increase of NTSC-M*
Back Porch	4.737µs (34½)	*Broadcast Resolution*

Luma & Chroma:

Luma (λ) Bandwidth @-3dB	5⅛MHz FullCut 5⅖MHz, VSB ⅗MHz Corner ⅖MHz
Chroma:	Sub-Sampling 4:2:2
Sub-Carrier	3.6414MHz 8×⇒29.1312 (Armstrong PM, Non-Linear
½H Odd Harmonic	525;**262½**;175 Uncorrected Gamma)
Bandwidth	2½MHz (LSB –2½MHz & USB +1½MHz) Corner Frequencies
Modulation Index	±1¼, Tan(±1¼)=±3, 31½% **Bell** page 6, I=0.415341772
Swinging Color Burst	2.746µs ; 10 cycles 2×{1¾+10+5½}=(34½) ±45°
T_B T_R Line ID	See next page.

SÉCAM TruColor™ 880×528i72 Composite Luma/Chroma 15:9 Test Pattern



In order to optimize chroma modulation levels between the **Blue–Yellow** and **Red–Cyan** modulations, making them equal, **U** (**B–λ**) is reduced with ⅚ instead of √3/2 (Sin[60°]) in relation to **V** (**R–λ**), a ~3¾% greater reduction (from under the heading 'We have:' on pg11). This only slightly squeezes the equilateral hexagon, a minor distortion. For a **Luma** of 0–1 the scaling factors for **U** & **V** are ⅝ & ¾. To generate Armstrong phase modulation that produces a peak aTan[5] value of ±78.69° deviation (±1.373^{R} **M**odulation **I**ndex, ±87.43^{g}) **I** (@0°) needs to be 0.107143 when combined with either the scaled **U** or **V** on the 90° **Q** channel. After scaling the **Luma** to 92½ IRE the scaling factors will become 0.412946 & 0.495536 and 0.0709082 for **I**. For a **MI** of 1⅓^{R}, aTan[~4⅛], (76.39° deviation) **I** becomes 0.129659 & 0.0856673, before and after IRE reduction. As in PAL line identification is realized by the swinging phase of the colorburst signal, +45° for **U** and –45° for **V**, or as described on page 7.

Composite levels, Luma, Sync & Colorburst.

Luma (λ) Level:	92½	700mV
SetUp:	5½	39.29mV
Sync:	–42	300mV
ColorBurst:	±21	±150mV
Max (Yl)	135⅓	1.26̅V
Min (Bl)	–31.82	72.71mV
	IRE=1V/140	

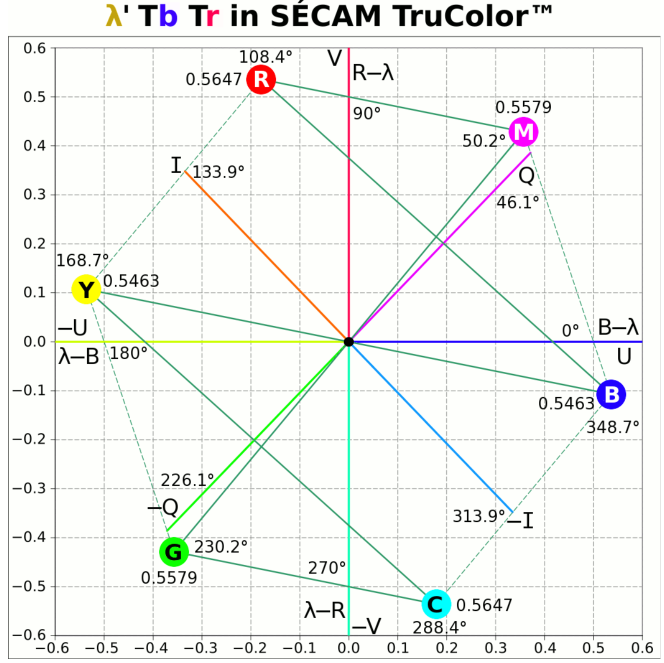
Horizontal Timings.

Period	72.088µs
Blank	9.268µs
Front Porch	1.030µs
Back Porch	4.737µs
Sync	3.501µs
Breezeway	481ns
Colorburst	2.746µs
Brst2BlnkEnd	1.510µs
OS Lead In	1.167µs
Picture	60.416µs
OS Lead Out	1.236µs

Graph Scaling

~3¾% **U** channel greater reduction applied.

λ' Tb Tr in SÉCAM TruColor™



The ΣHSλ to λUV TruColor™ Matrix

A method for converting **ΣHSλ** Color with a modified **Luma** (**λ**) to analog Color TV **λUV** to balance for better **Chroma** (**UV**) matrixing.

Where: **Σ** = **Chroma** level is a vector matrix sum/difference and not a saturation percentage factor.
H = Hue of the **Chroma** signal in θ°
derived from the quadrature matrix.
S = Saturation level (R) of the **Chroma** signal as quadrature summation of the **U** & **V** vectors.
λ = Brightness, or intensity factor of the **Luma** signal.

32-Bit – 12-Bit Luminance, 2×10-Bit Chrominance, **U** & **V** each.

Matrixing

Let:

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

```
                                                   HSV                         HSV
λ = Matrixed B & W     Luma channel.               Hue                         Hue
U = Matrixed B − λ   Chroma channel.   U #3300FF 252.00°   −U #CCFF00  72.00°
V = Matrixed R − λ   Chroma channel.   V #FF0055 340.00°   −V #00FFAA 160.00°
W = Matrixed G − λ   Chroma channel.   W #00FF33 132.00°   −W #FF00CC 312.00°
```

Enhanced channels:

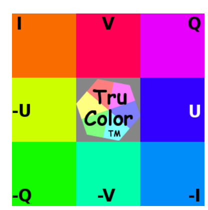
```
I = Matrixed  Skin  Chroma channel.   I #F96D00  26.27°   −I #008CF9 206.27°
Q = Matrixed Purple Chroma channel.   Q #E700FB 295.22°   −Q #14FB00 115.22°
```

We have:

```
    λ = +1/7 × B  +2/7 × R  +4/7 × G
B − λ = +6/7 × B  −2/7 × R  −4/7 × G
R − λ = −1/7 × B  +5/7 × R  −4/7 × G
G − λ = −1/7 × B  −2/7 × R  +3/7 × G
G − λ = −¼  × (B − λ) −½ × (R − λ)     [W, B−λ Scaled with √3/2]
```

Encode:

```
If:   U(x) = √3/2 × (B − λ) ×   0° ┐ Quadrature  _|_
      V(y) =        (R − λ) ×  90° ┘ Sub-Carrier  |
Then: W    = √3   × (G − λ) @ 240°
```




```
Chroma Vector    R = √ U² + V²
Chroma Hue       θ = [ aTan2(V,U) ; If θ < 0 Then θ + 2π ]
```

Decode:

```
                   SyncDet
U: B − λ = ─┼─ @    0° ÷ √3/2
V: R − λ = ─┼─ @   90°
W: G − λ = ─┼─ @  240° ÷ √3
```


↓↓ Chroma LoR/Freq: 121½/1MHz, 243⅛/2MHz

880×528
Expanded to
1760
2×HorizSample

430.032kHz
31×13872Hz
(50⅔ Lines)

610.368kHz
44×13872Hz
(70¾ Lines)

860.064MHz
62×13872Hz
(103º Lines)

1.220736MHz
88×13872Hz
(147½ Lines)

1.720128MHz
124×13872Hz
(207⅚ Lines)

2.427600MHz
175×13872Hz
(293⅓ Lines)

3.440256MHz
248×13872Hz
(415⅔ Lines)

4.855200MHz
350×13872Hz
(586⅔ Lines)