Screens: Flicker measurement and health impacts

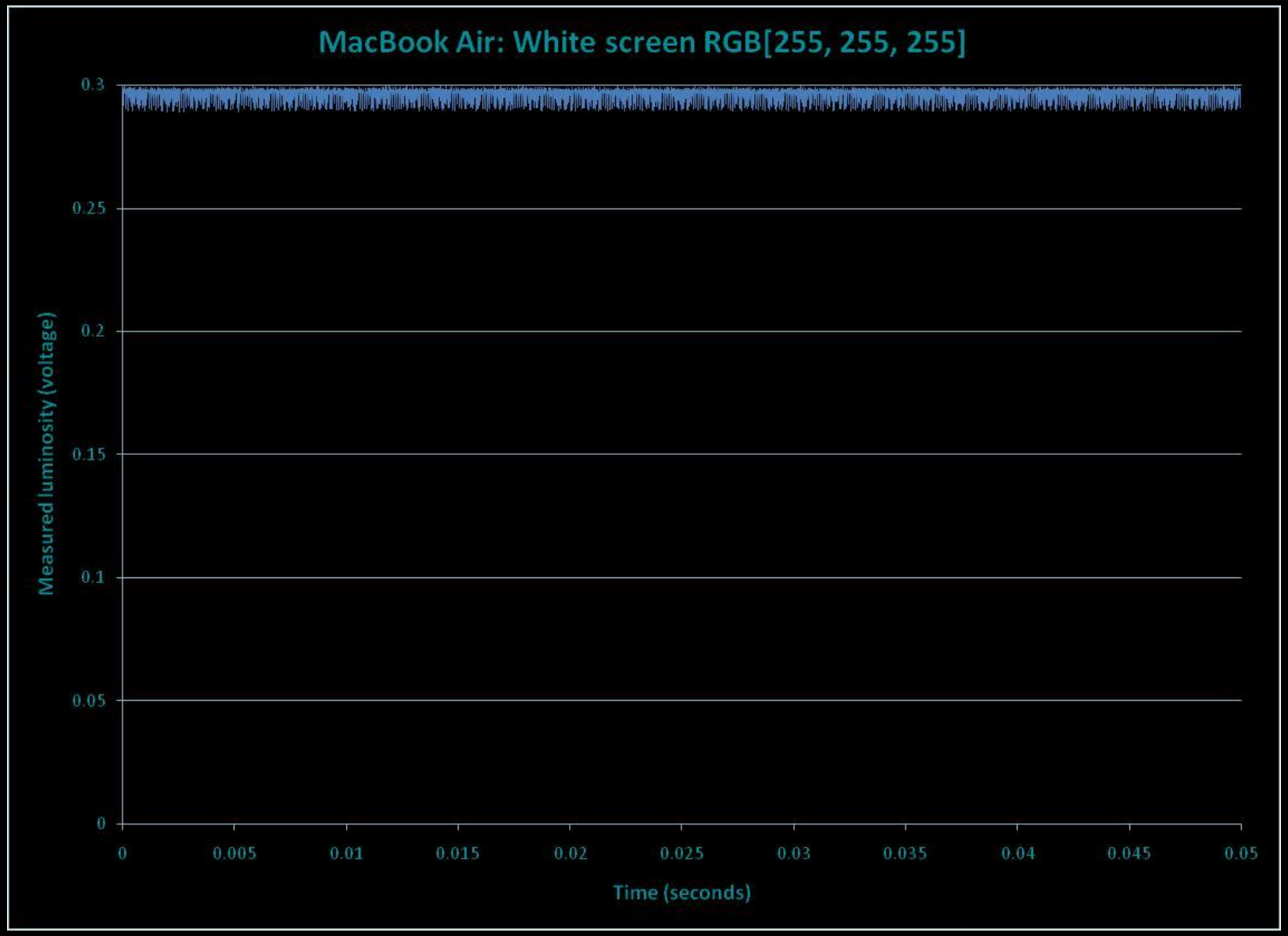
Part 2: MacBook Air 13”
(current work laptop)

13” MacBook Air: Flicker in an “overlapping feather” pattern that creates periodic patterns at multiple frequencies; 9663 jagged peaks per second

MacBook Air with 13.3” LCD LED screen, Model A1466, early 2015, Mohave OS 10.14.6, 1.6 GHz Intel Core i5 processor, Intel HD Graphics 6000 1536 MB; sRGB IEC61966-2.1 color display profile; Nightshift off (unless indicated).

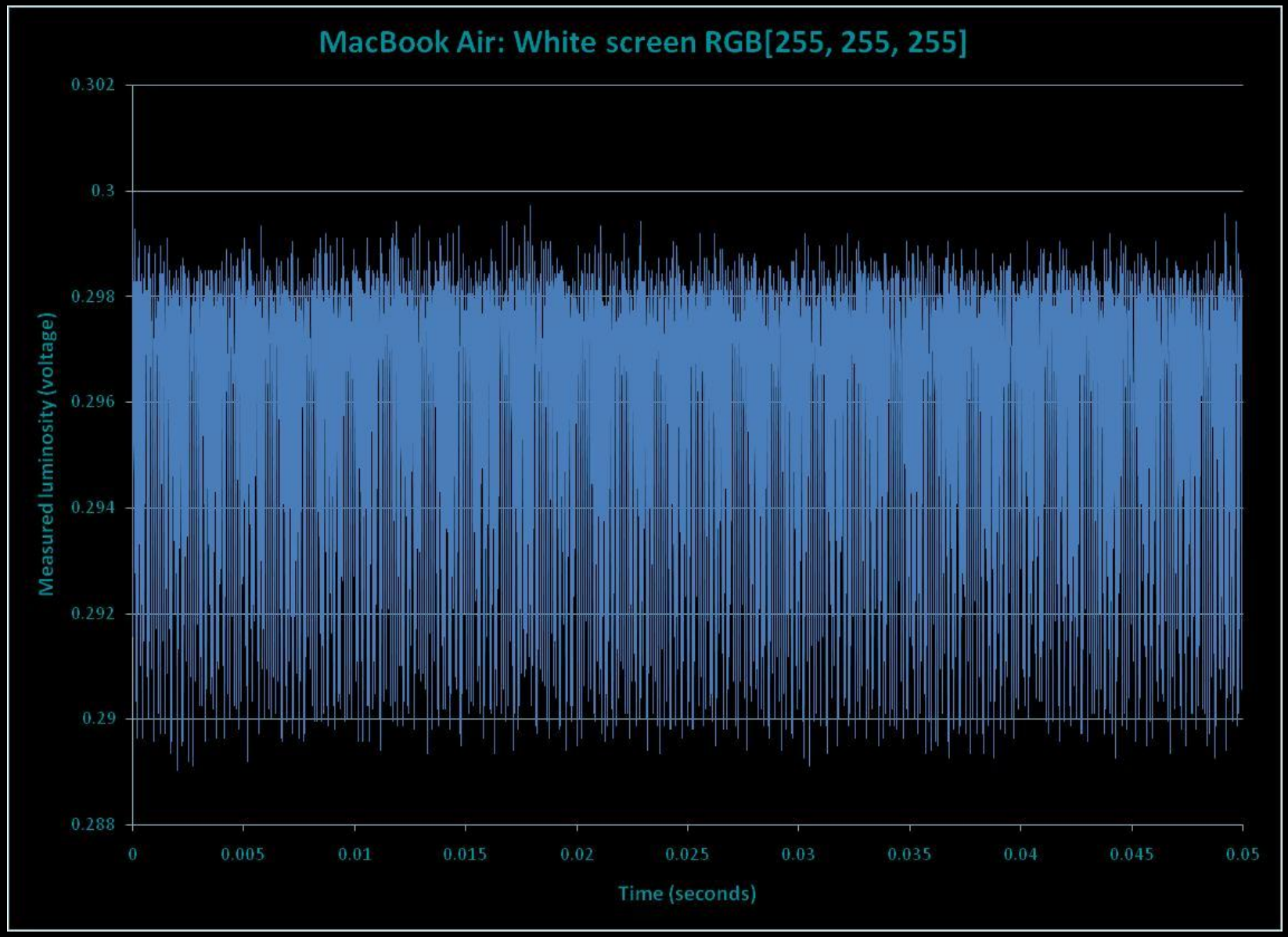
Data in folder “MacBookAir13”

MacBook Air (0.05s), 1.88% flicker



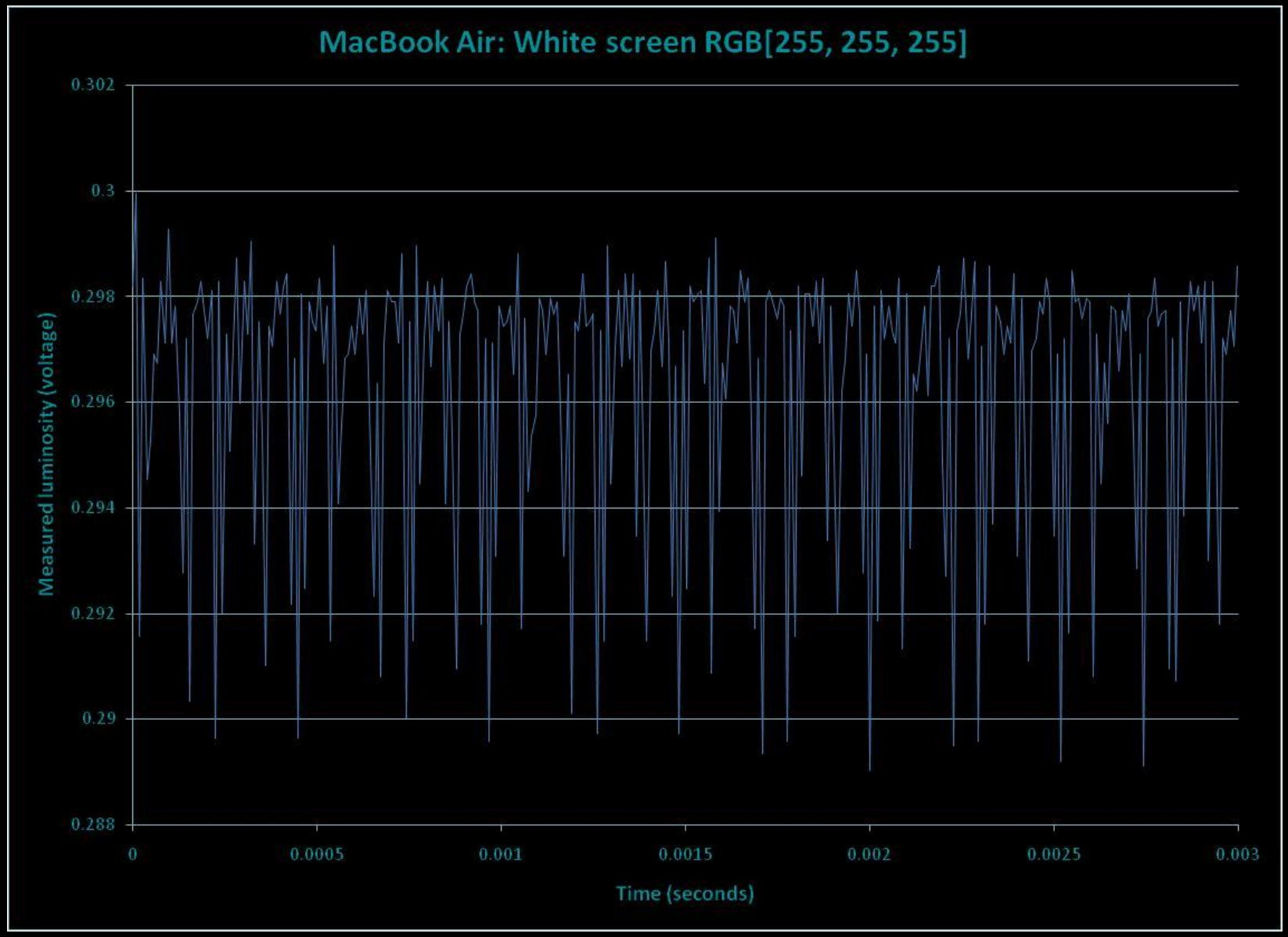
MacBookAirMonitor_100Bright_255_255_255c

MacBook Air (0.05s, zoomed y-axis)



MacBookAirMonitor_100Bright_255_255_255c

MacBook Air (0.003s, zoomed y-axis)



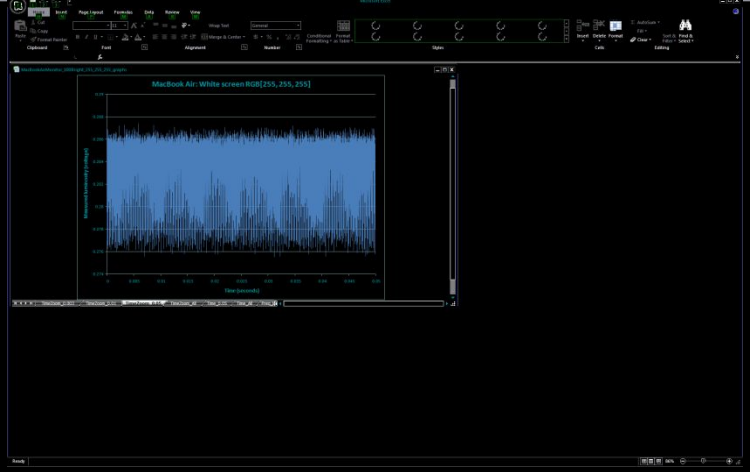
MacBookAirMonitor_100Bright_255_255_255c

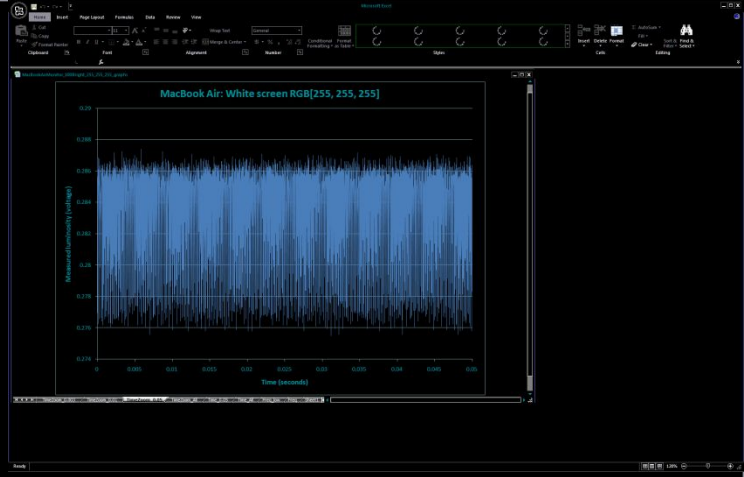
MacBook Air: Flicker in an “overlapping feather” pattern that creates periodic patterns at multiple frequencies; 9663 jagged peaks per second

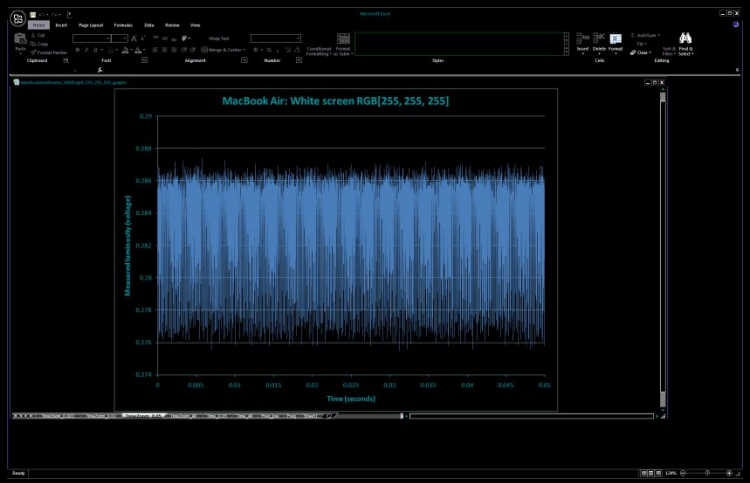
Apparent frequency of the “banding” pattern in the flicker waveform depends on the size of the graph image

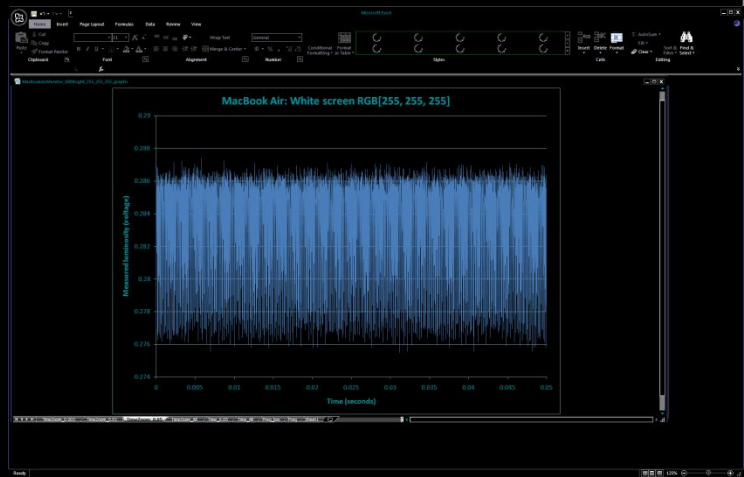
- Apparent frequency of the “banding” pattern in the flicker waveform depends on the size of the graph image:
- Screenshots from Excel, 0.05s zoomed y-axis, varying chart window size.

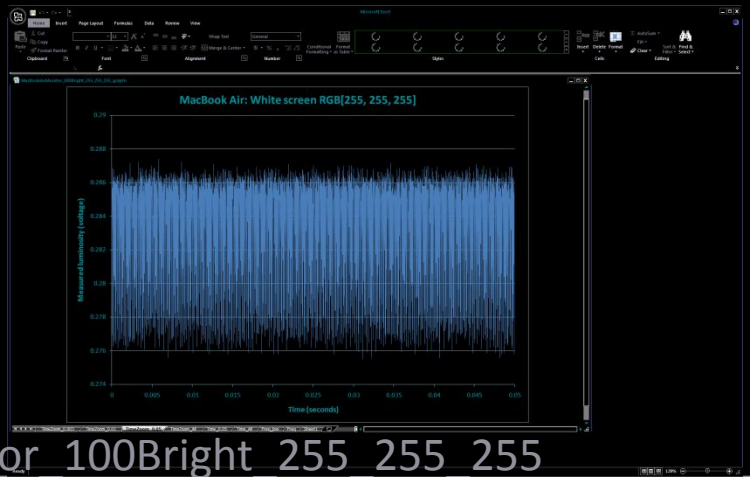
- Note: pasting graphs as jpegs from Excel in other slides seems to create a uniform scale regardless of the size of the pasted images

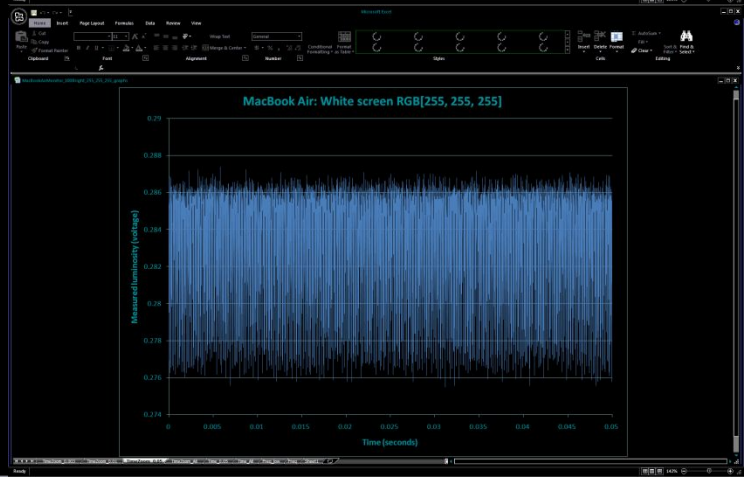












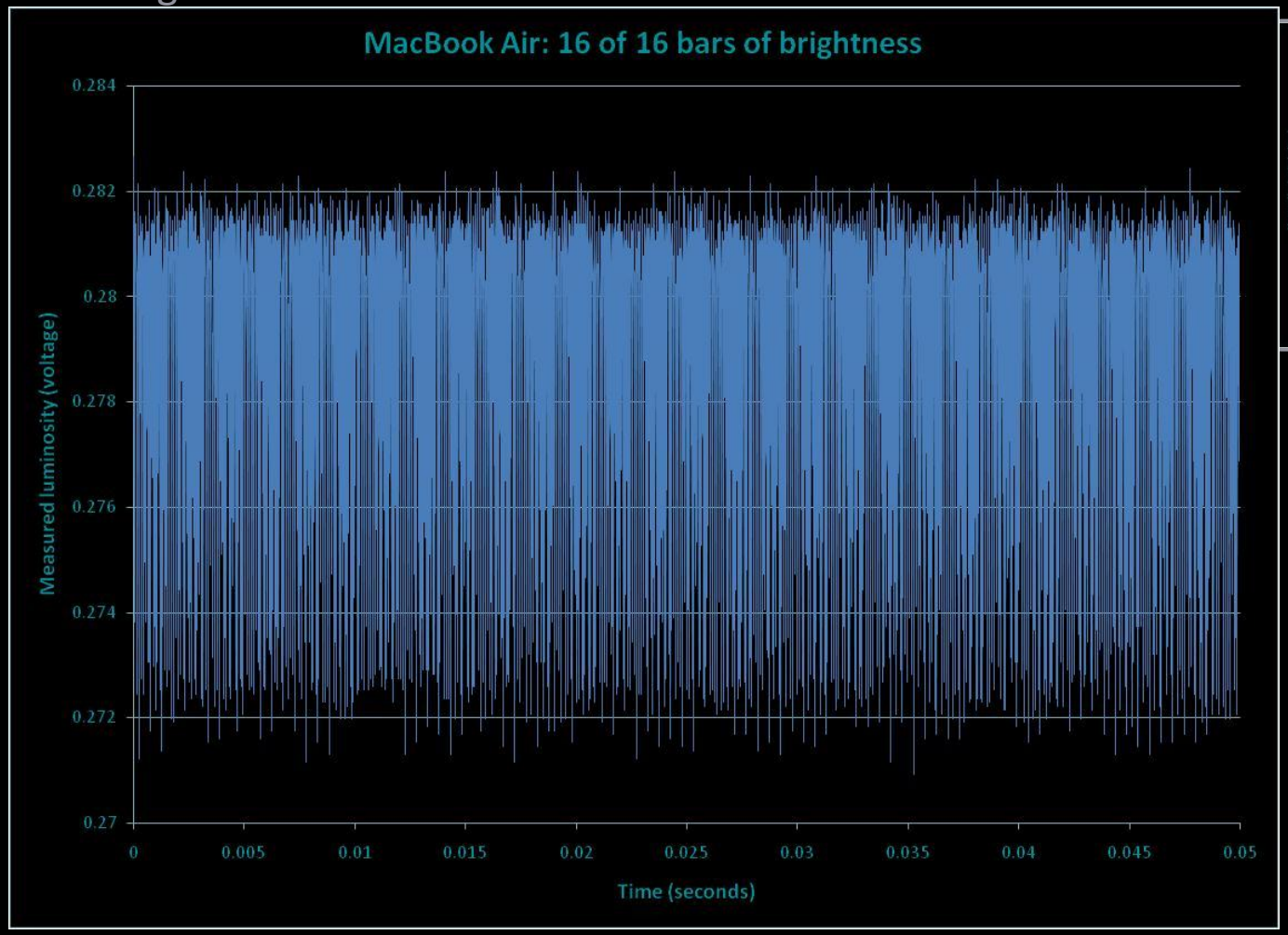
MacBookAirMonitor_100Bright_255_255_255

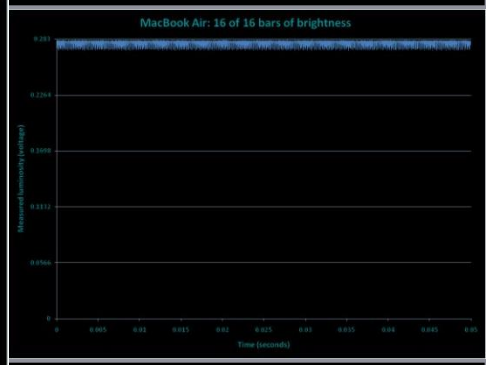
Dimming the backlight on the MacBook Air is worse for causing symptoms than without dimming

Increased flicker with dimming: MacBook Air

100% brightness

0.05s, zoomed y-axis





Same y-axis scale*; starts at y=0

Brightness 16
2.12% flicker

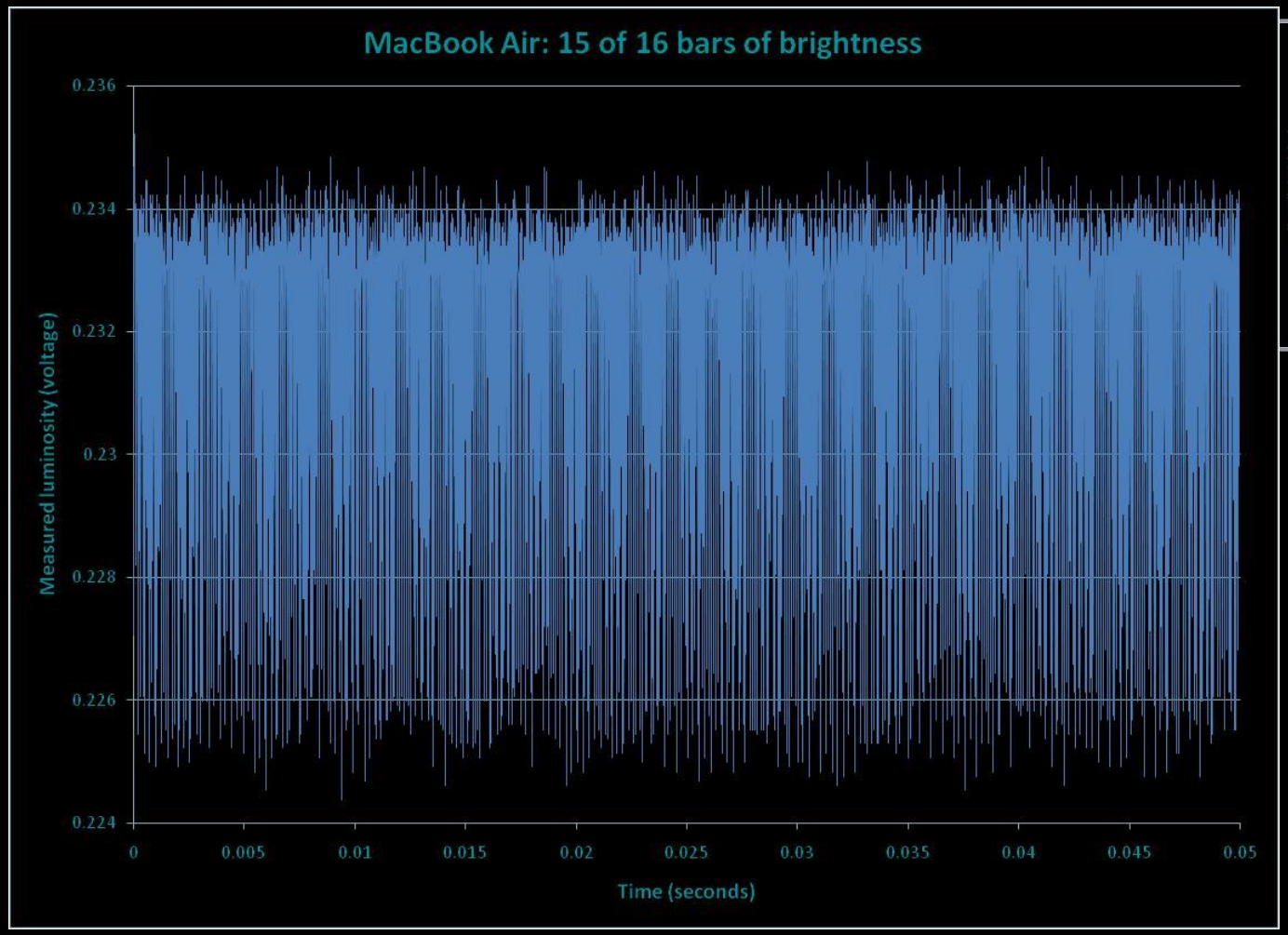
*15 and 16 measured at gain=3 to prevent overexposure;
1-14 measured at gain=4

White screen [255, 255, 255]

File: MacBookAirMonitor_16BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis



Same y-axis scale*; starts at y=0

Brightness 15
2.36% flicker

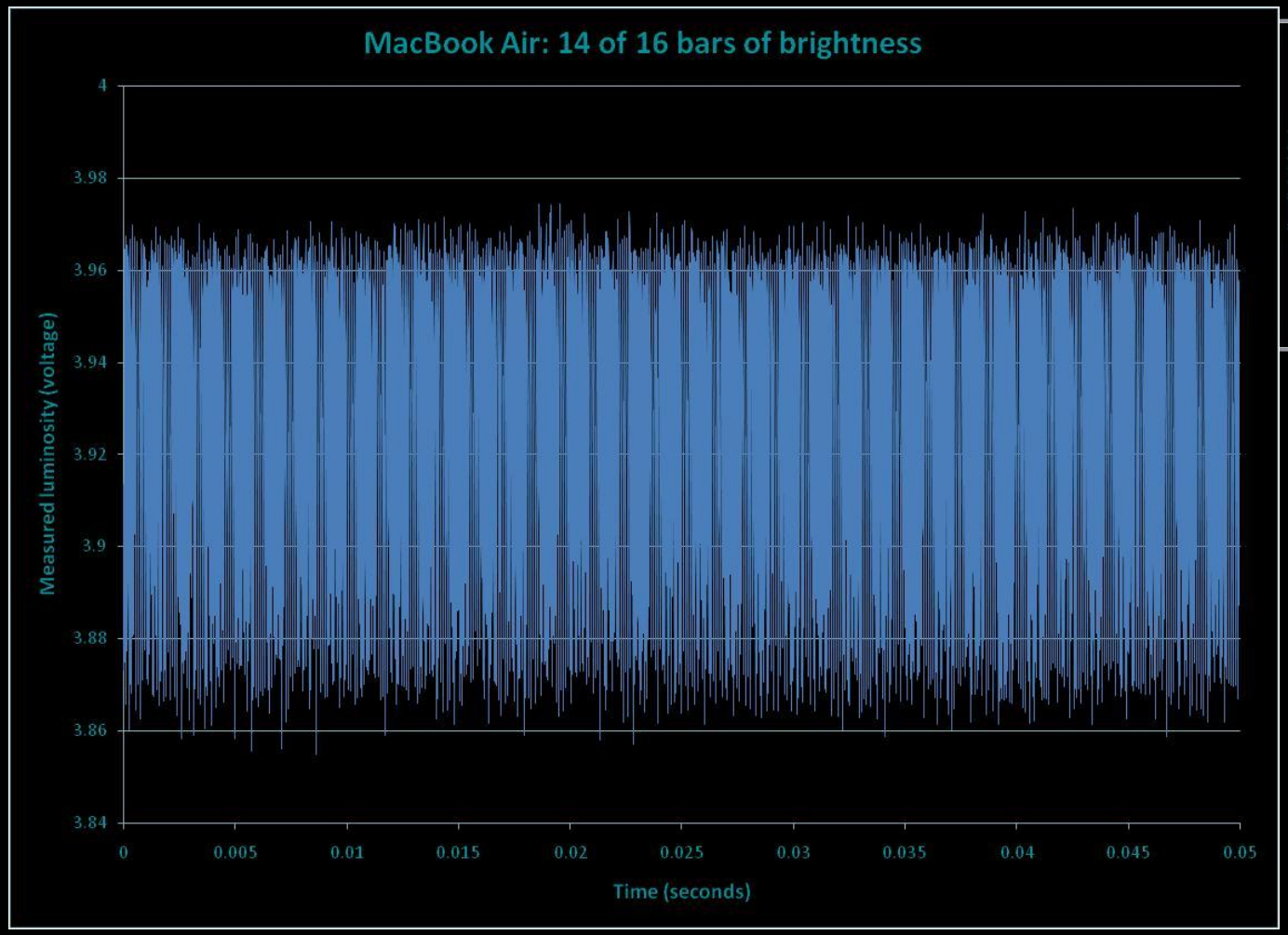
*15 and 16 measured at gain=3 to prevent overexposure;
1-14 measured at gain=4

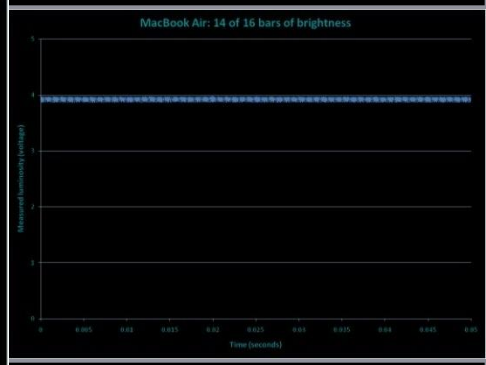
White screen [255, 255, 255]

File: MacBookAirMonitor_15BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis





Same y-axis scale;
starts at y=0

Brightness 14
1.60% flicker

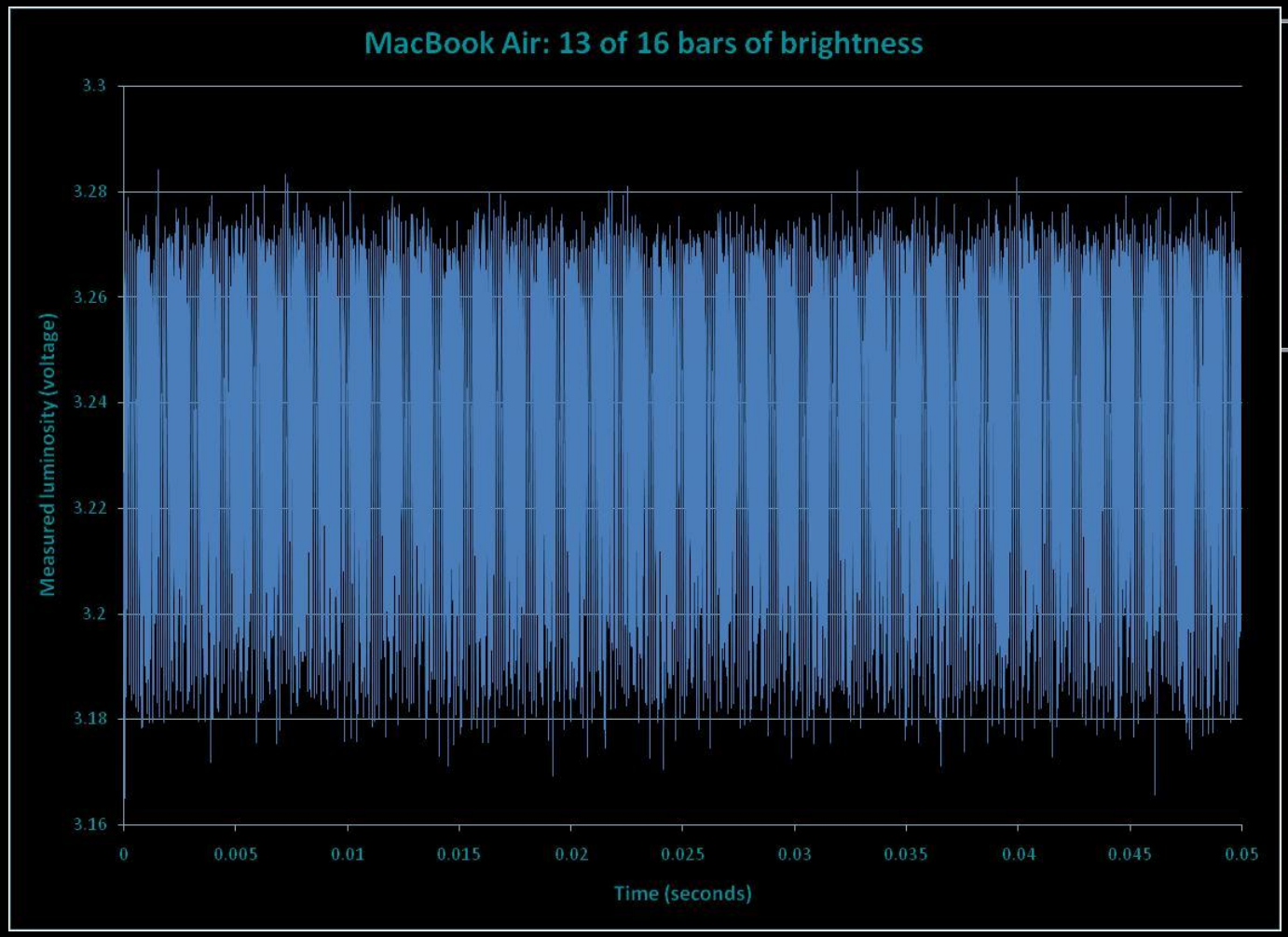
*15 and 16 measured at gain=3
to prevent overexposure;
1-14 measured at gain=4

White screen [255, 255, 255]

File: MacBookAirMonitor_14BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis



Same y-axis scale;
starts at y=0

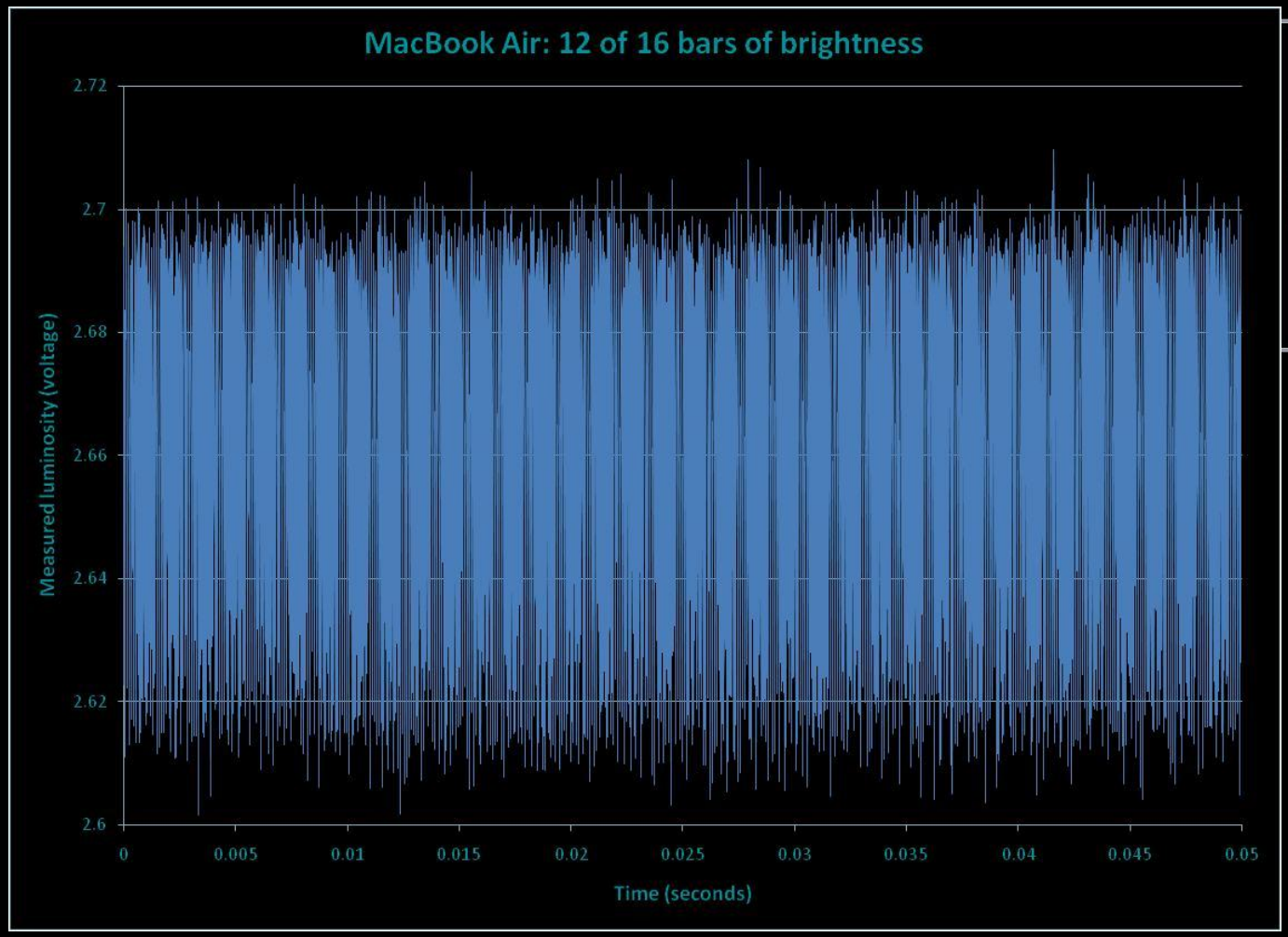
Brightness 13
1.89% flicker

White screen [255, 255, 255]

File: MacBookAirMonitor_13BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis



Same y-axis scale;
starts at y=0

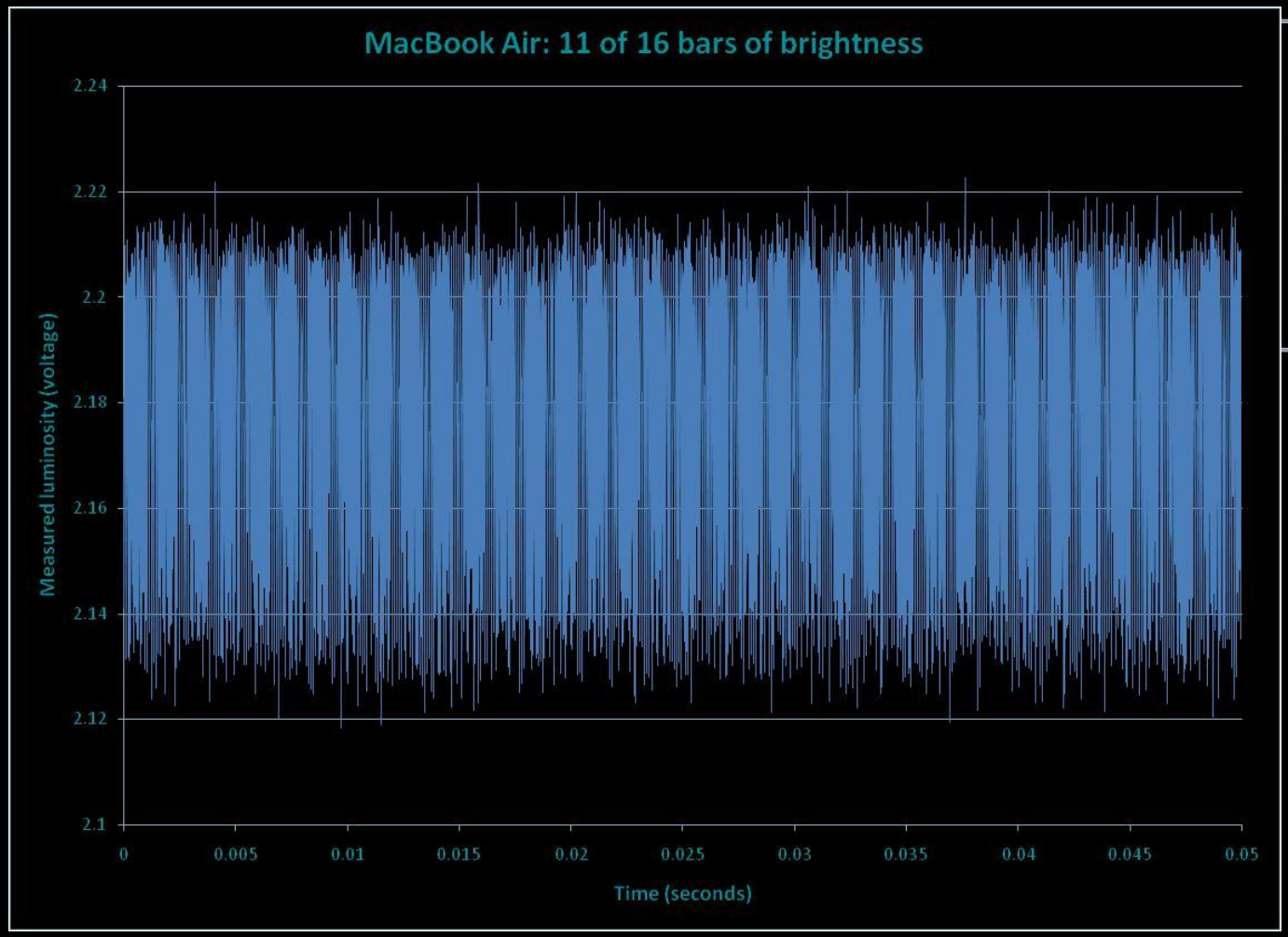
Brightness 12
2.06% flicker

White screen [255, 255, 255]

File: MacBookAirMonitor_12BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis



Same y-axis scale;
starts at y=0

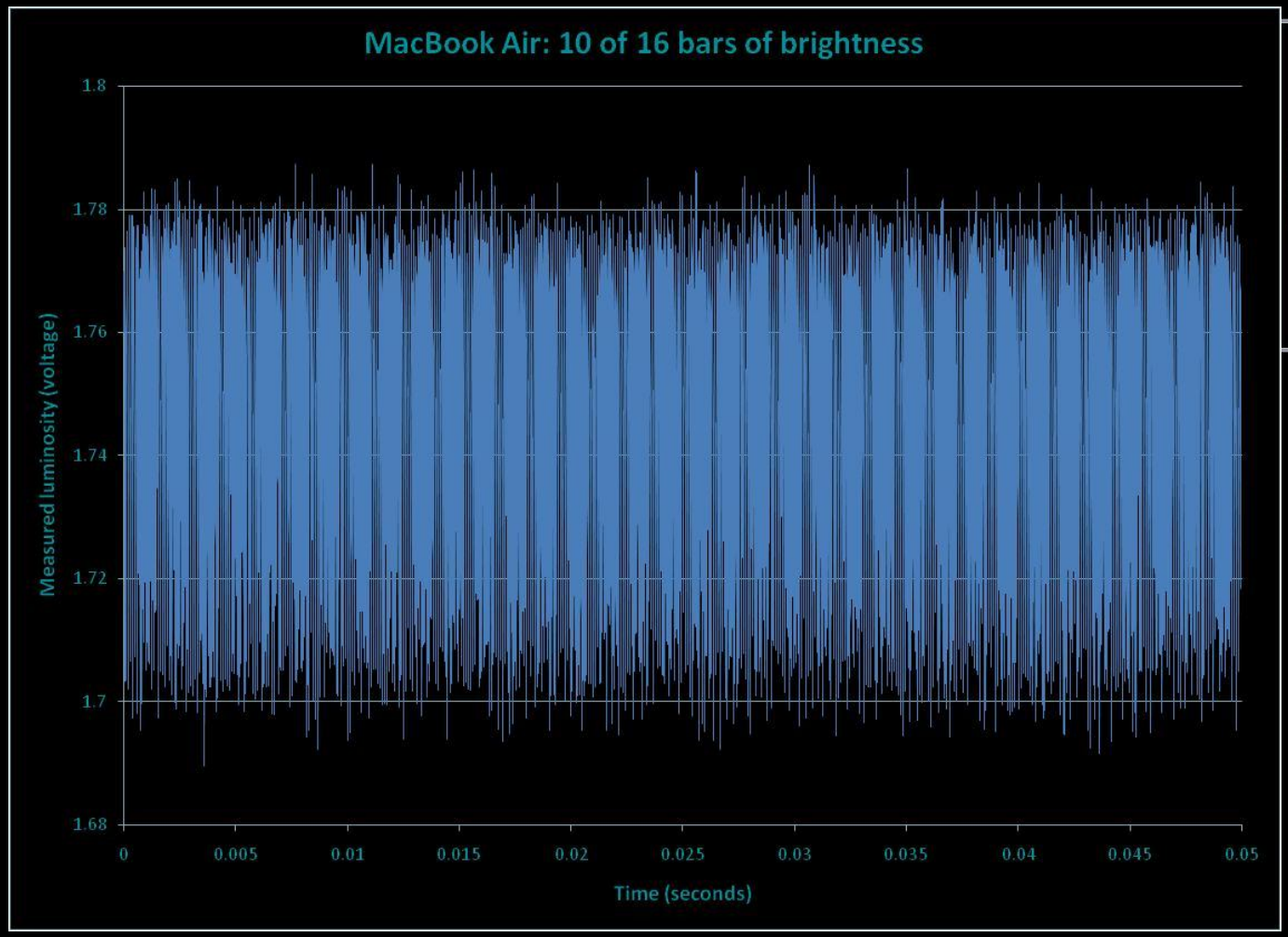
Brightness 11
2.46% flicker

White screen [255, 255, 255]

File: MacBookAirMonitor_11BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis



Same y-axis scale;
starts at y=0

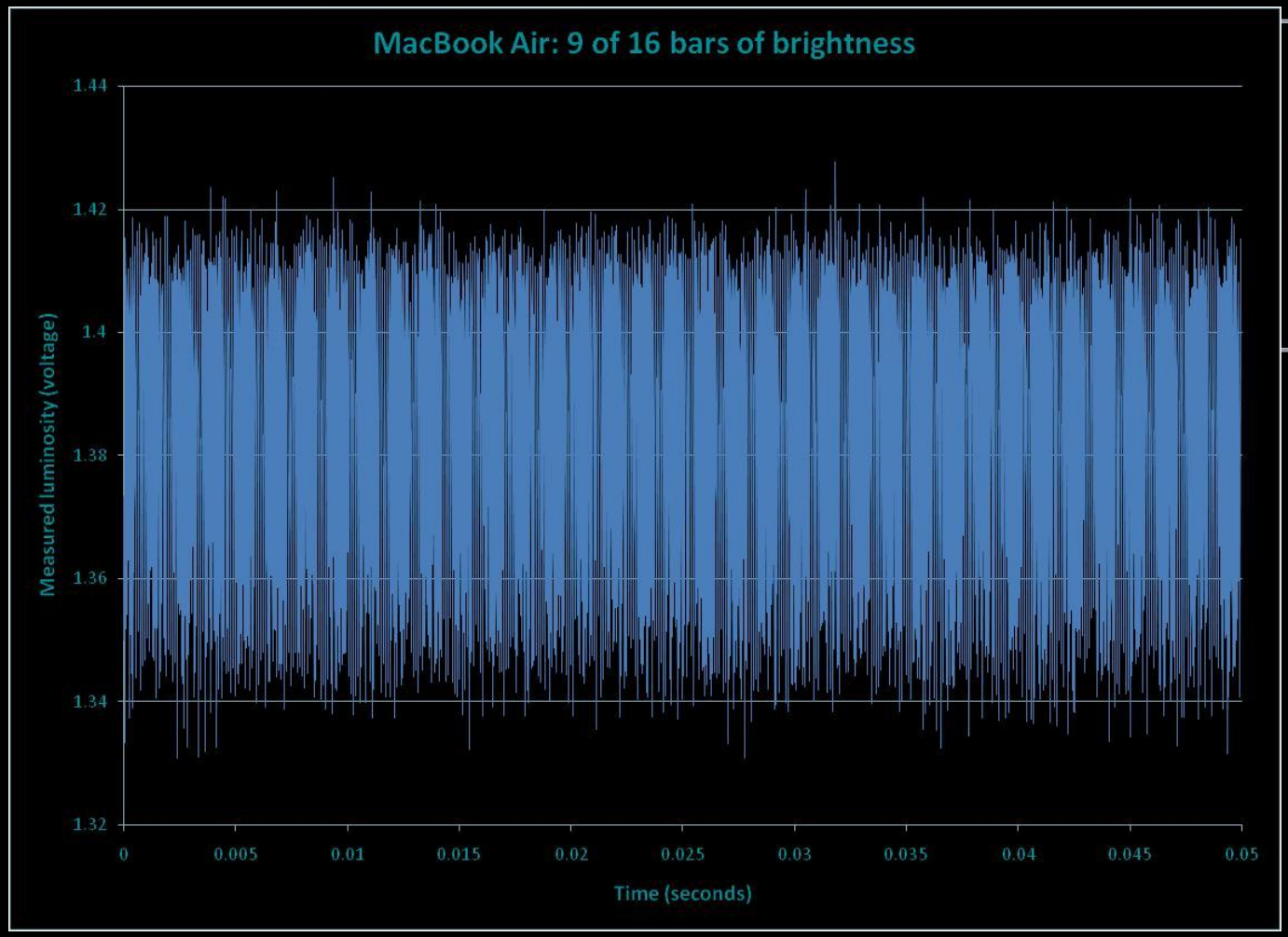
Brightness 10
3.1% flicker

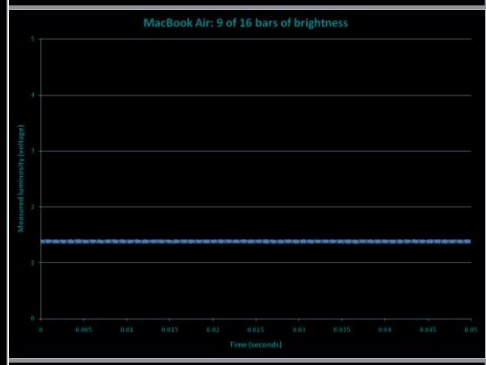
White screen [255, 255, 255]

File: MacBookAirMonitor_10BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, zoomed y-axis





Same y-axis scale;
starts at y=0

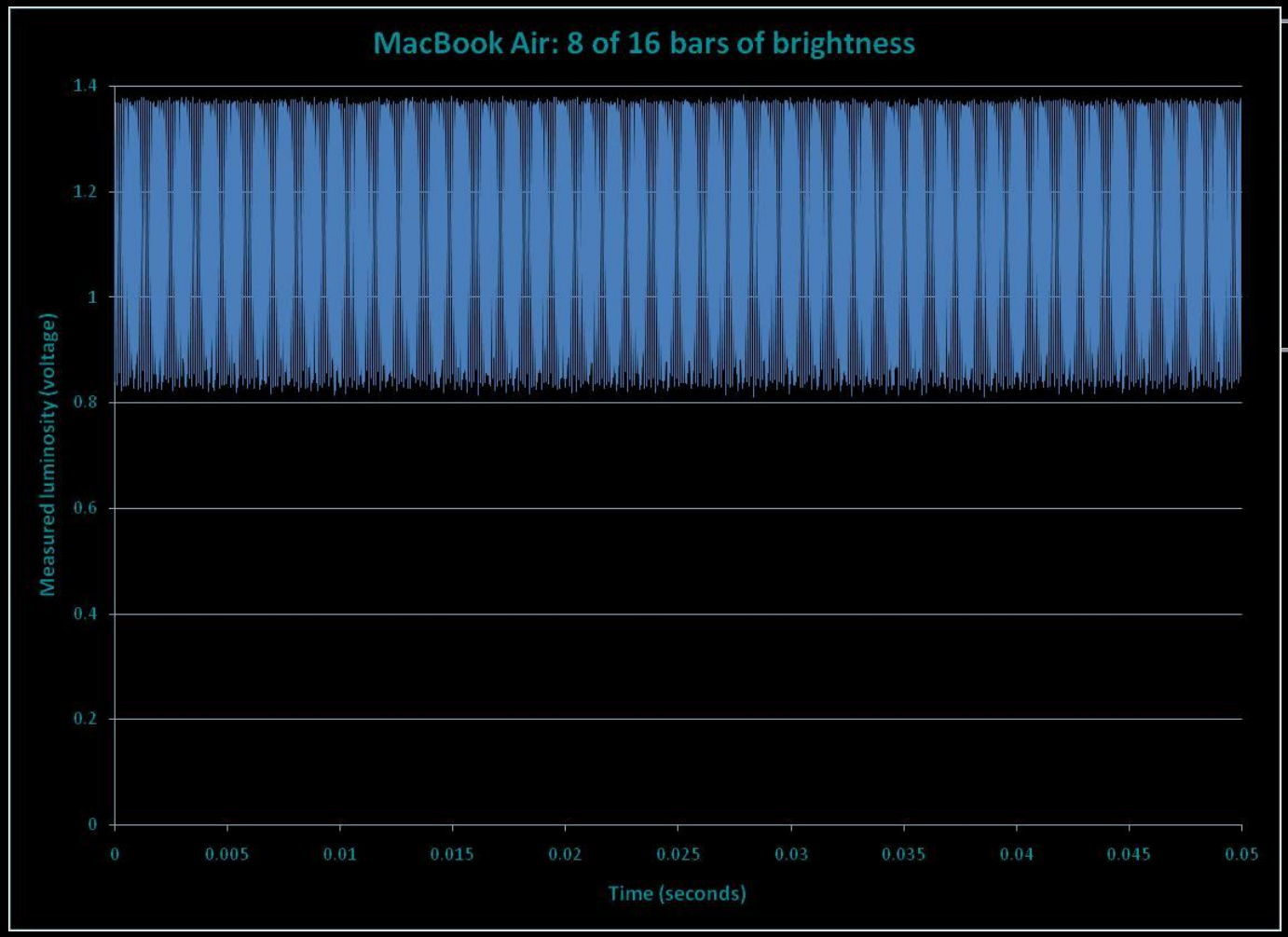
Brightness 9
3.6% flicker

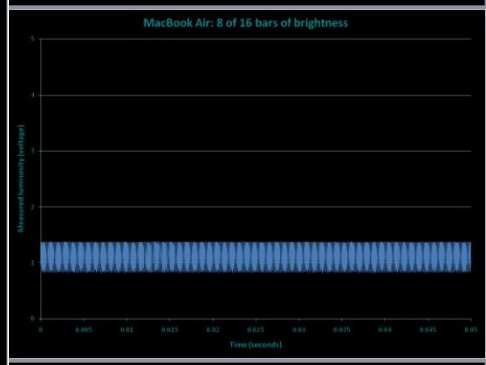
White screen [255, 255, 255]

File: MacBookAirMonitor_09BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

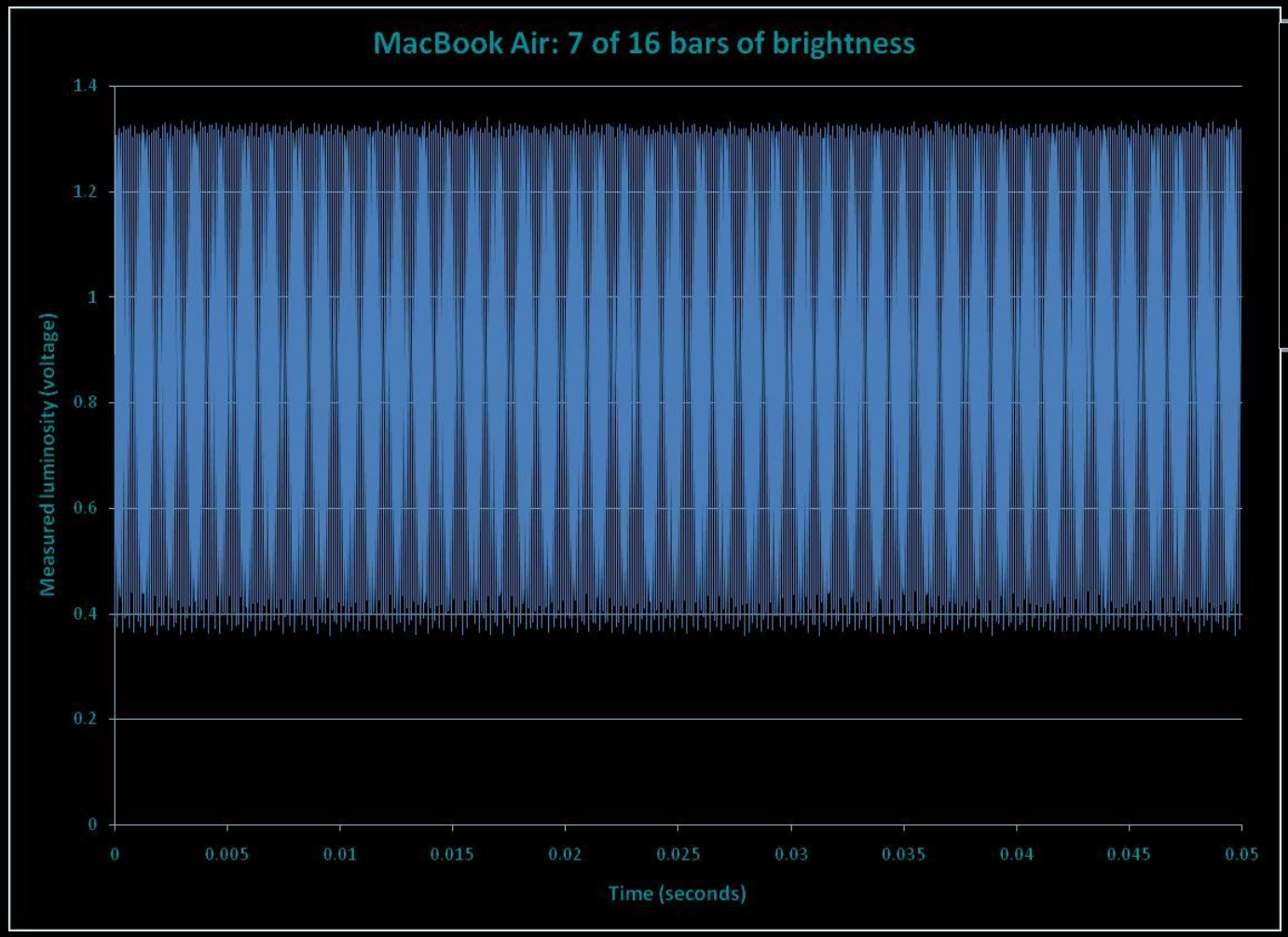
Brightness 8
26% flicker

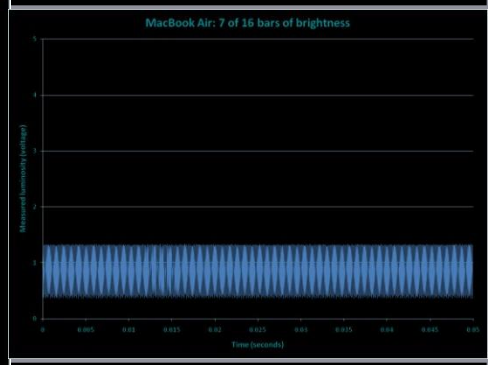
White screen [255, 255, 255]

File: MacBookAirMonitor_08BarsBriight_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

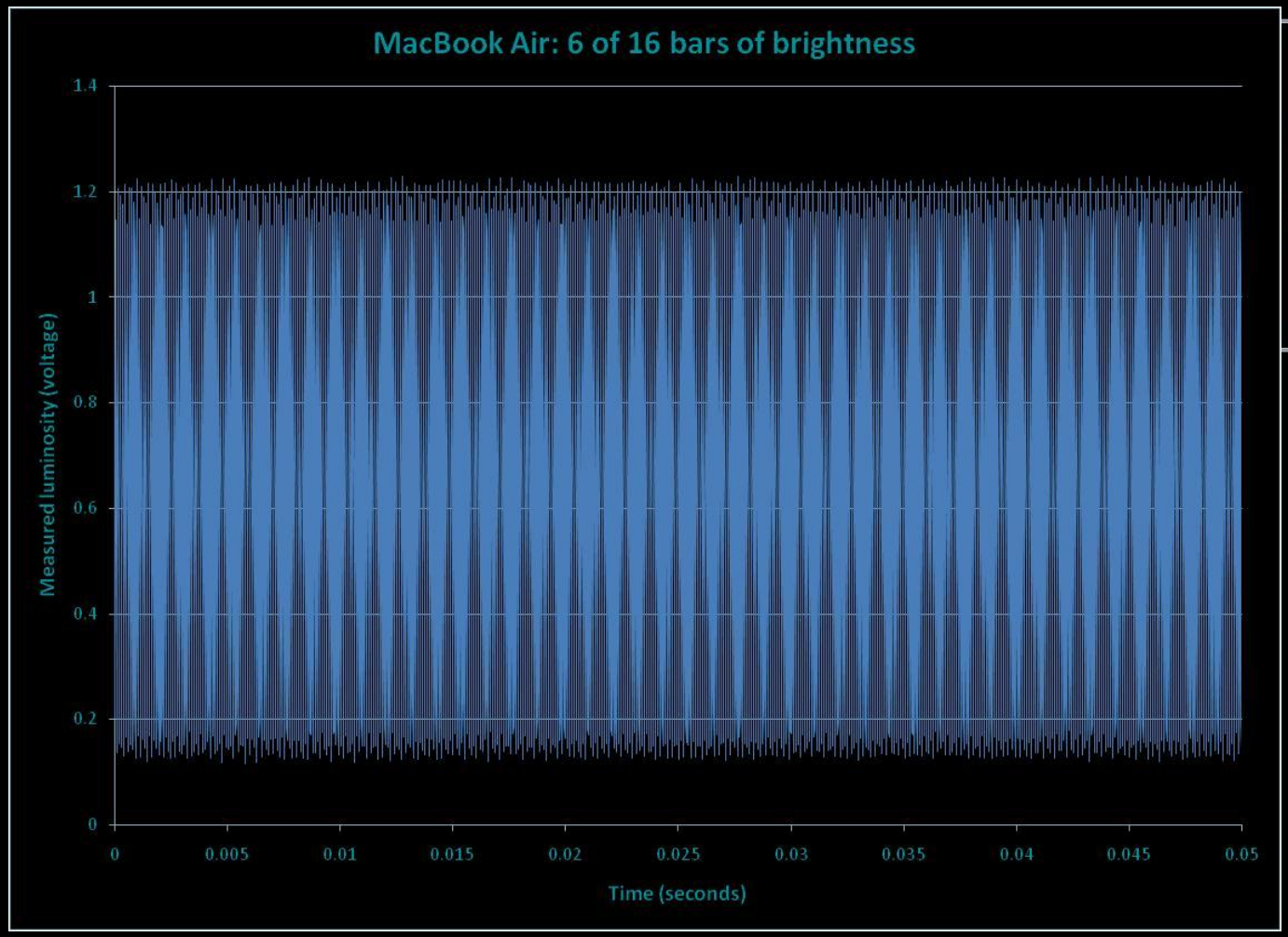
Brightness 7
58% flicker

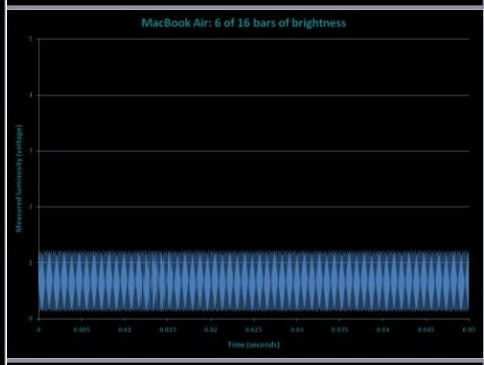
White screen [255, 255, 255]

File: MacBookAirMonitor_07BarsBriight_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

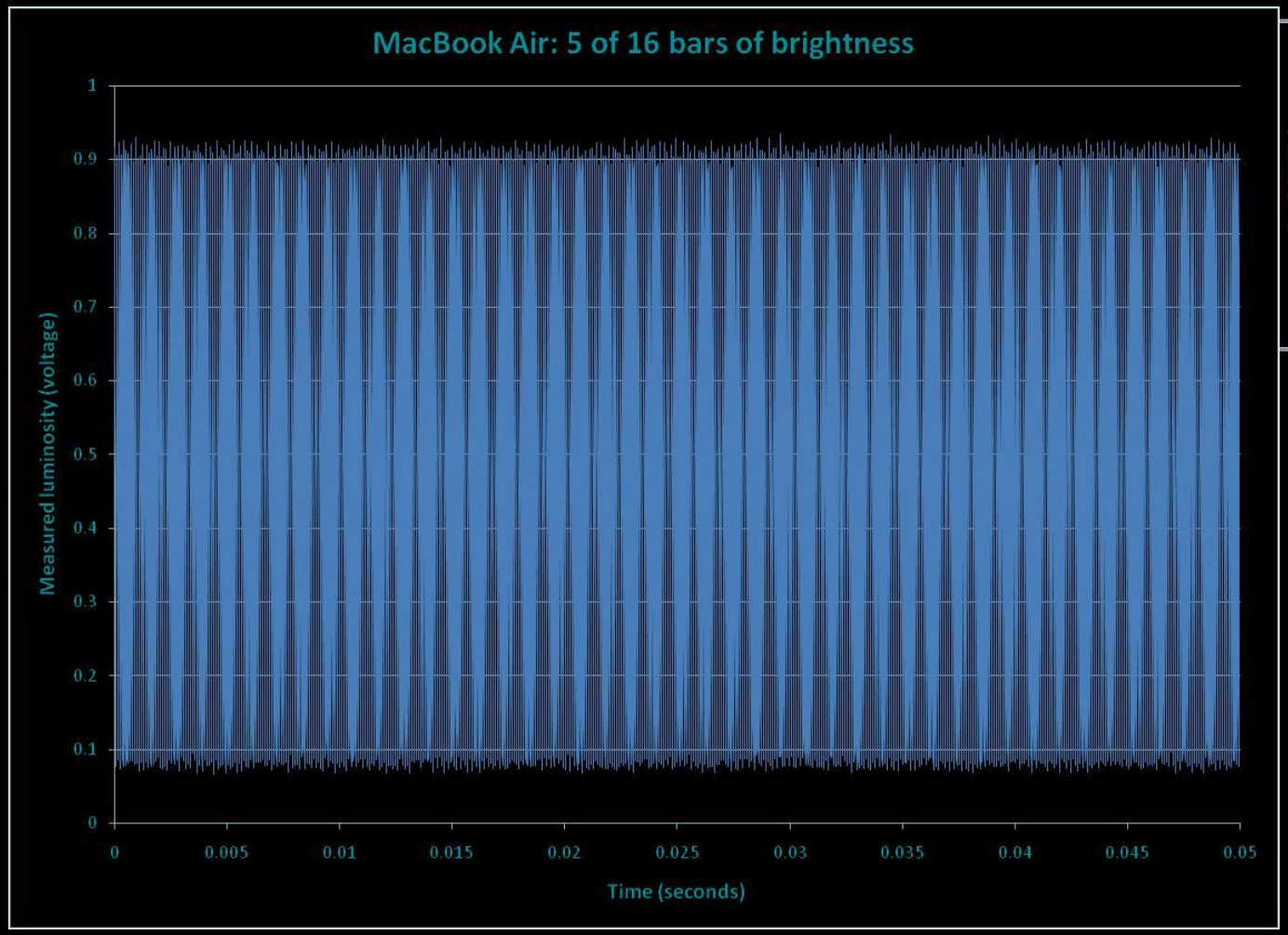
Brightness 6
83% flicker

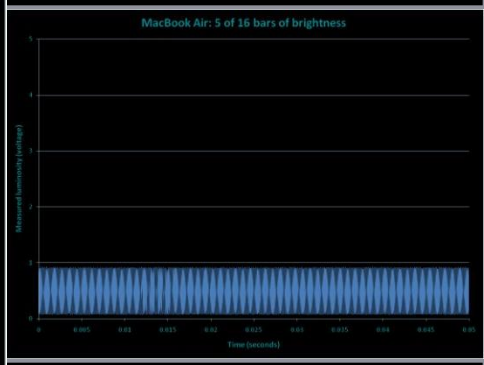
White screen [255, 255, 255]

File: MacBookAirMonitor_06BarsBriight_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

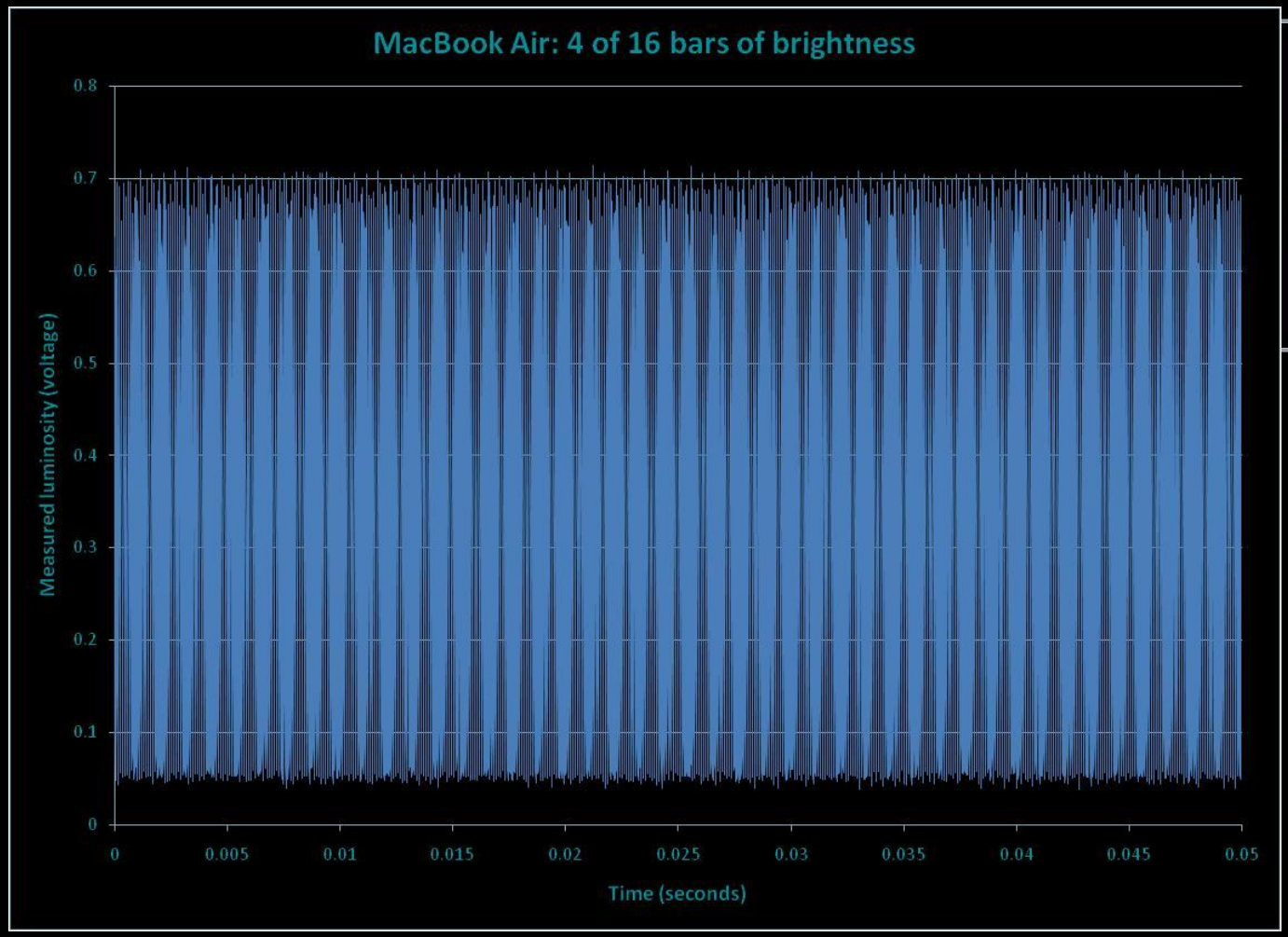
Brightness 5
87% flicker

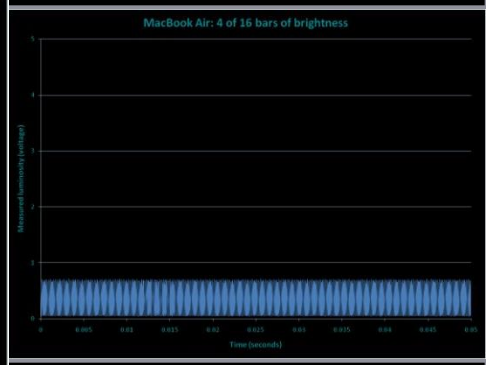
White screen [255, 255, 255]

File: MacBookAirMonitor_05BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

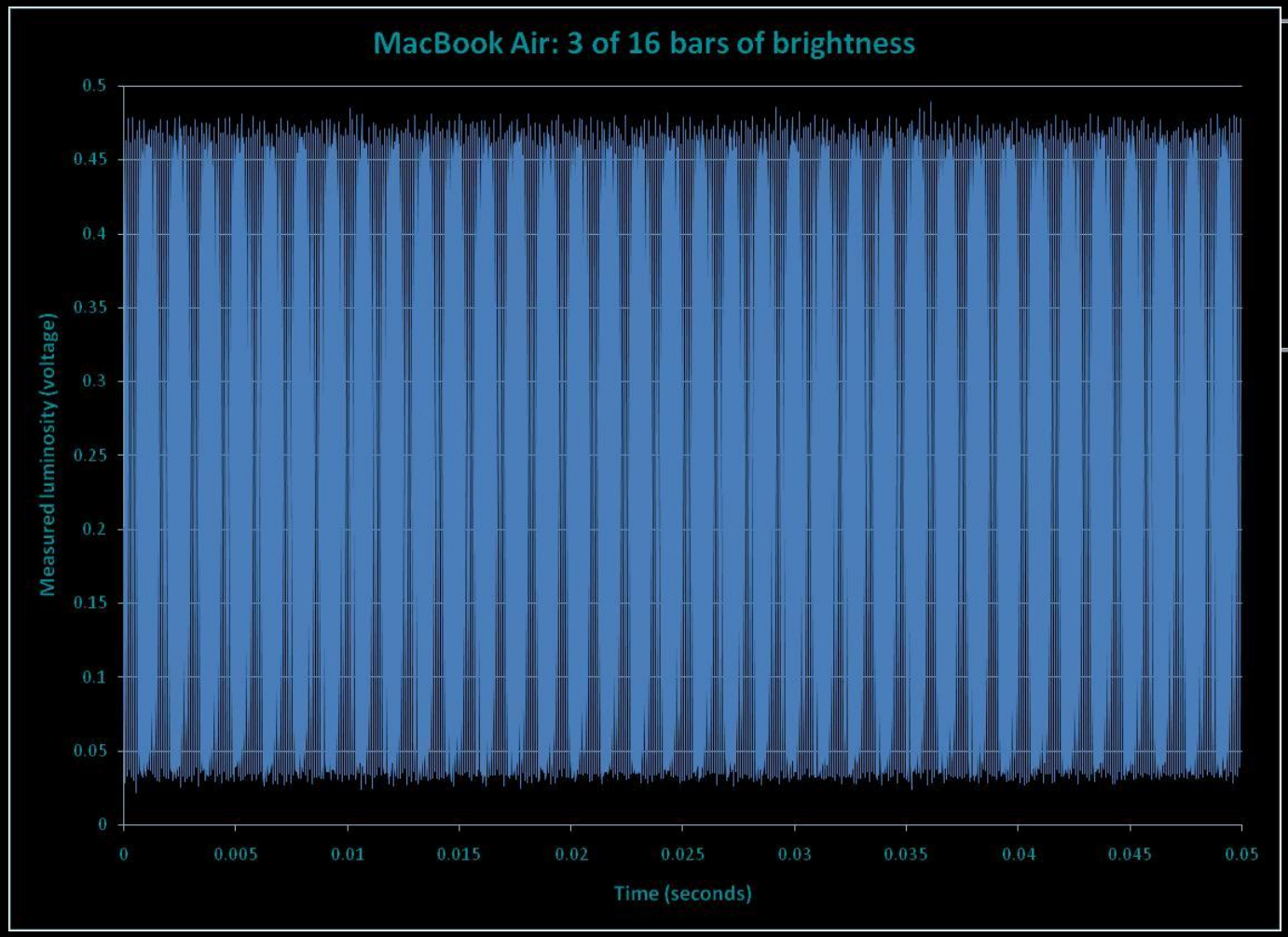
Brightness 4
90% flicker

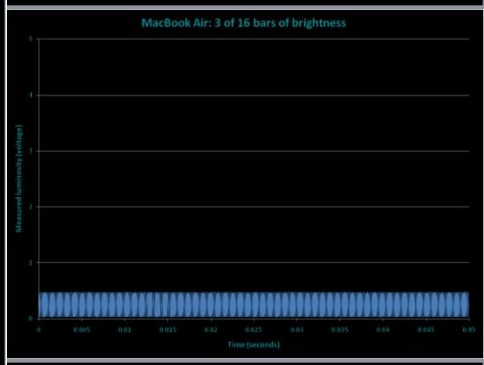
White screen [255, 255, 255]

File: MacBookAirMonitor_04BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

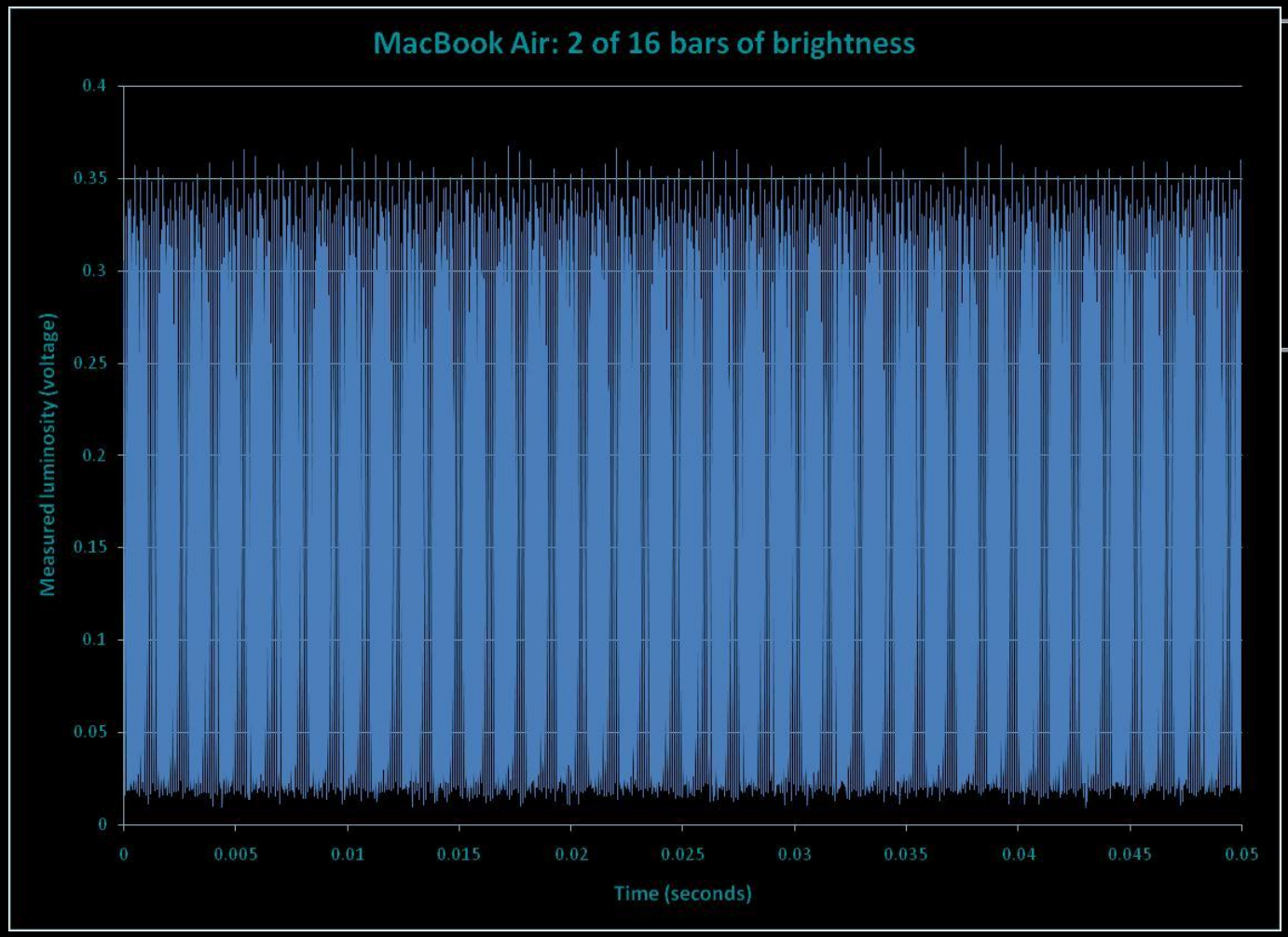
Brightness 3
92% flicker

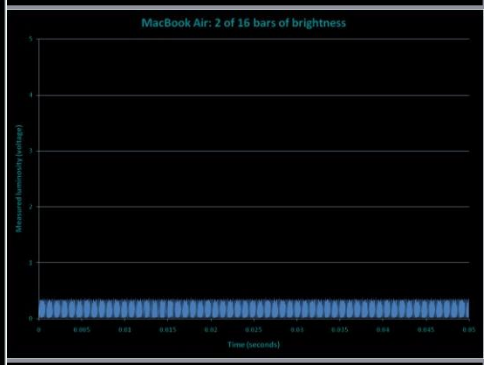
White screen [255, 255, 255]

File: MacBookAirMonitor_03BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





Same y-axis scale;
starts at y=0

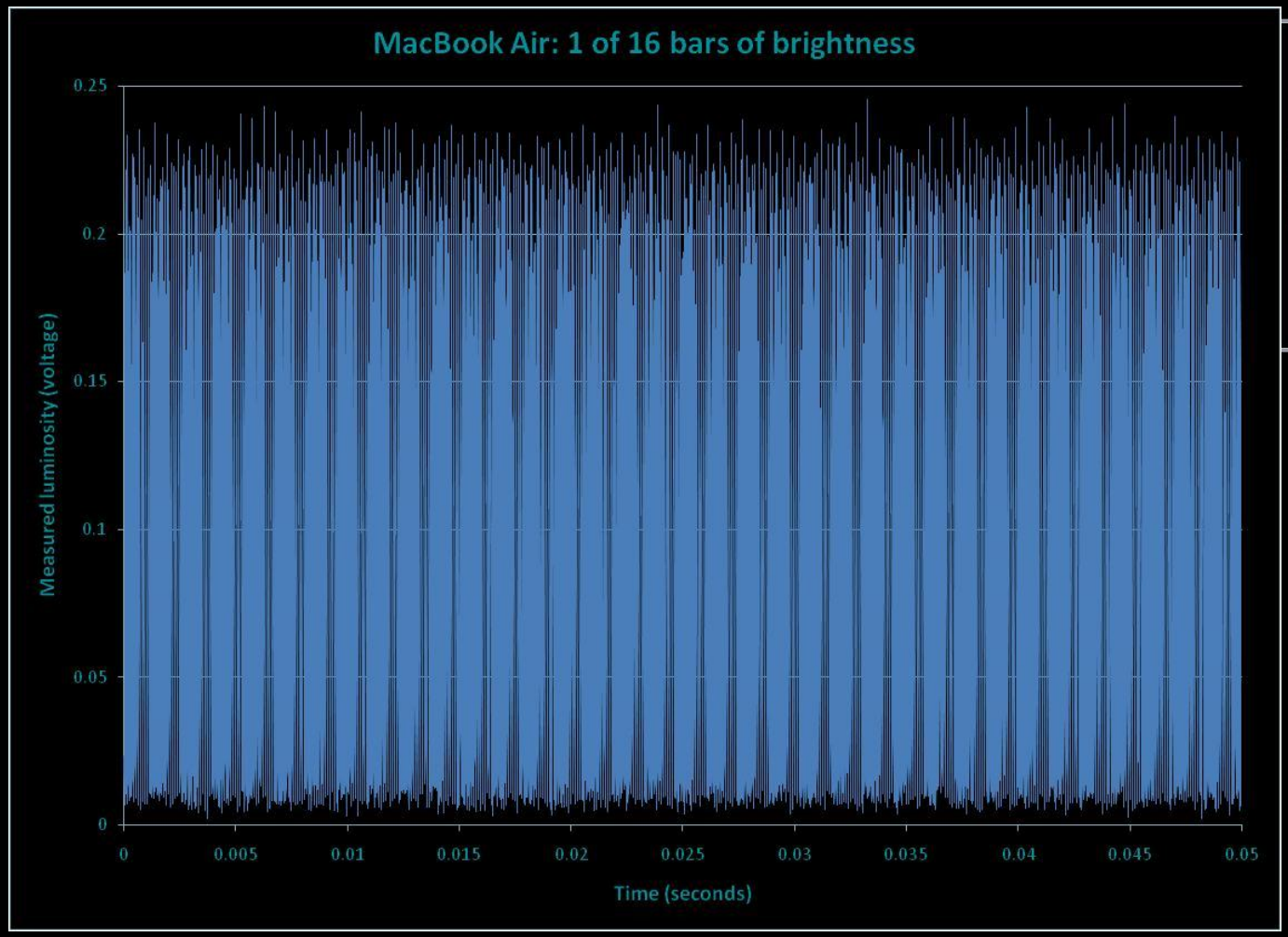
Brightness 2
95% flicker

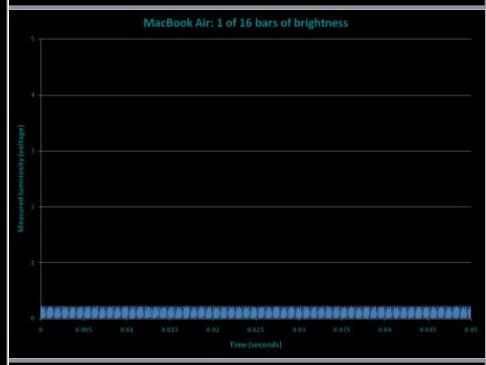
White screen [255, 255, 255]

File: MacBookAirMonitor_02BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

0.05s, y-axis NOT zoomed





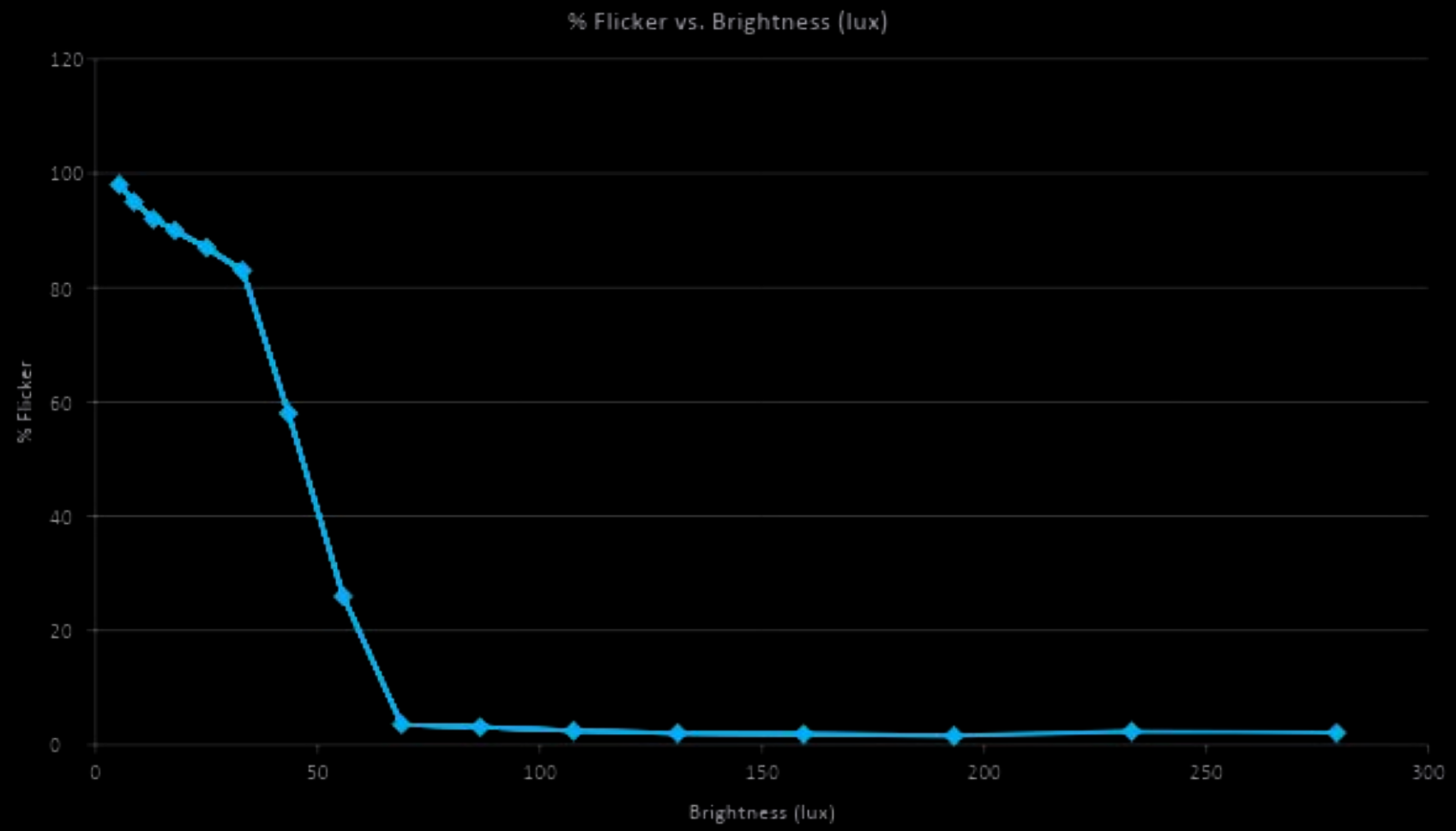
Same y-axis scale;
starts at y=0

Brightness 1
98% flicker

White screen [255, 255, 255]

File: MacBookAirMonitor_01BarsBright_255_255_255

Increased flicker with dimming: MacBook Air

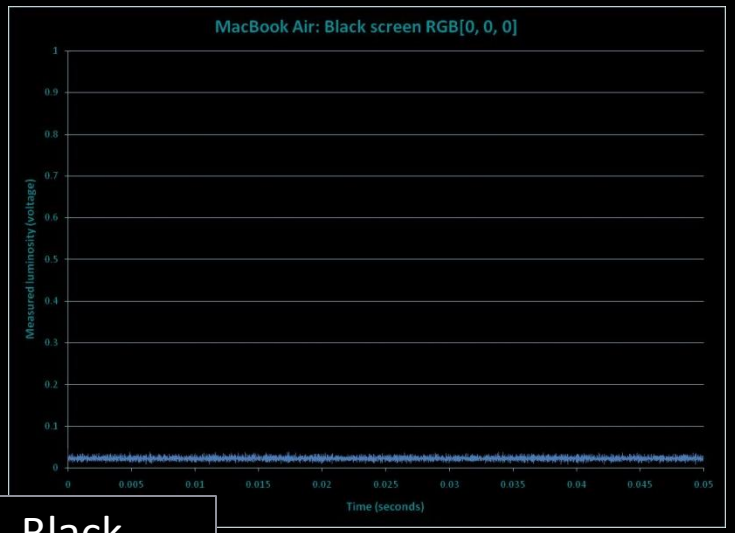


File: MacBookAirMonitor_DimmingFlicker

MacBook Air:
Flicker depends on color

"RGB" colors give numbers between 0 and 255 for each color channel in the form [red, green, blue]

MacBook Air: Black has the least regular pattern of flicker (or flicker pattern is below the level of detection due to insufficient brightness)



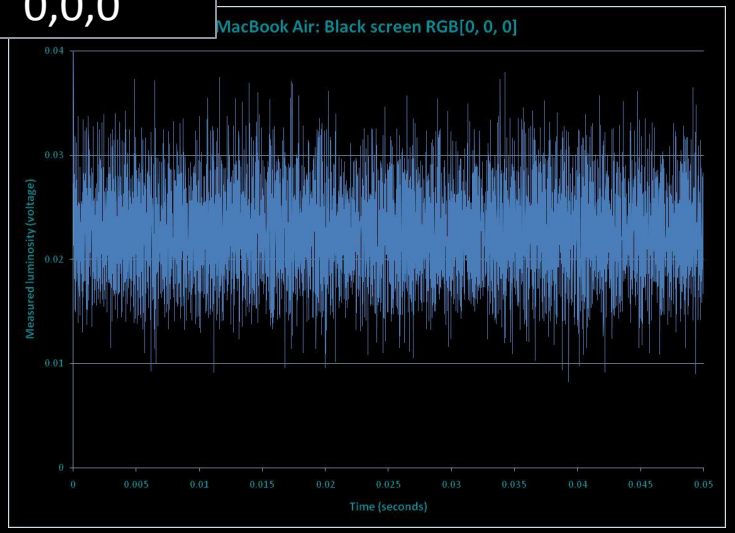
Approximately standardized y-axes

Black 0,0,0

68.9%

2.17%

White 255,255,255

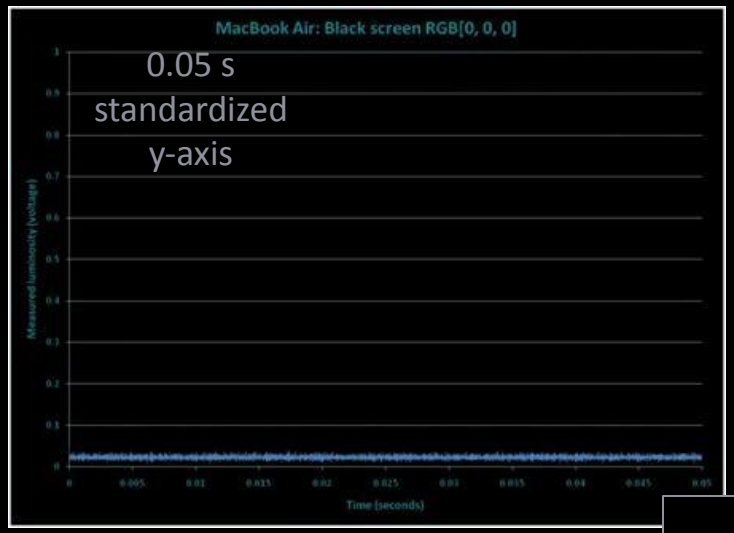


Zoomed y-axes

MacBookAirMonitor_100Bright_0_0_0.xls

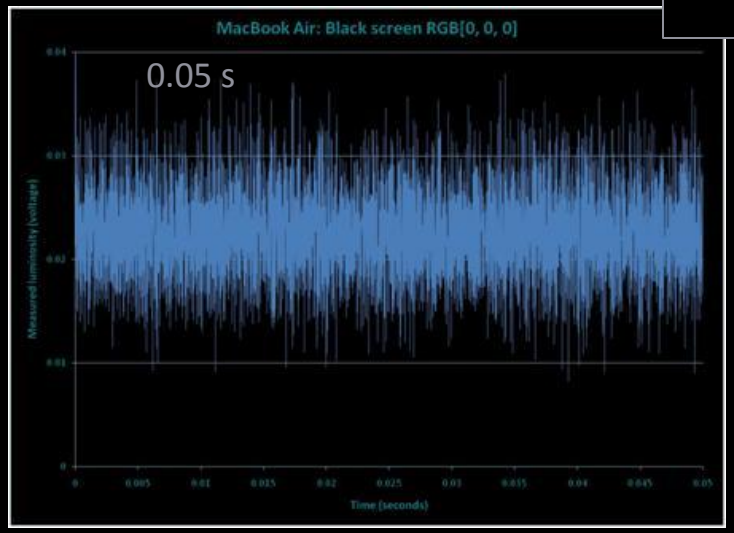
MacBookAirMonitor_100Bright_255_255_255

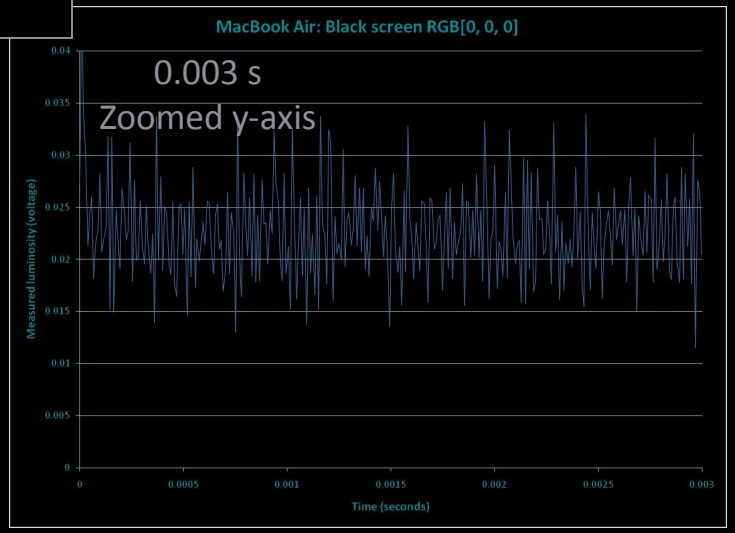
MacBook Air: Black has the least regular pattern of flicker (or flicker pattern is below the level of detection due to insufficient brightness)



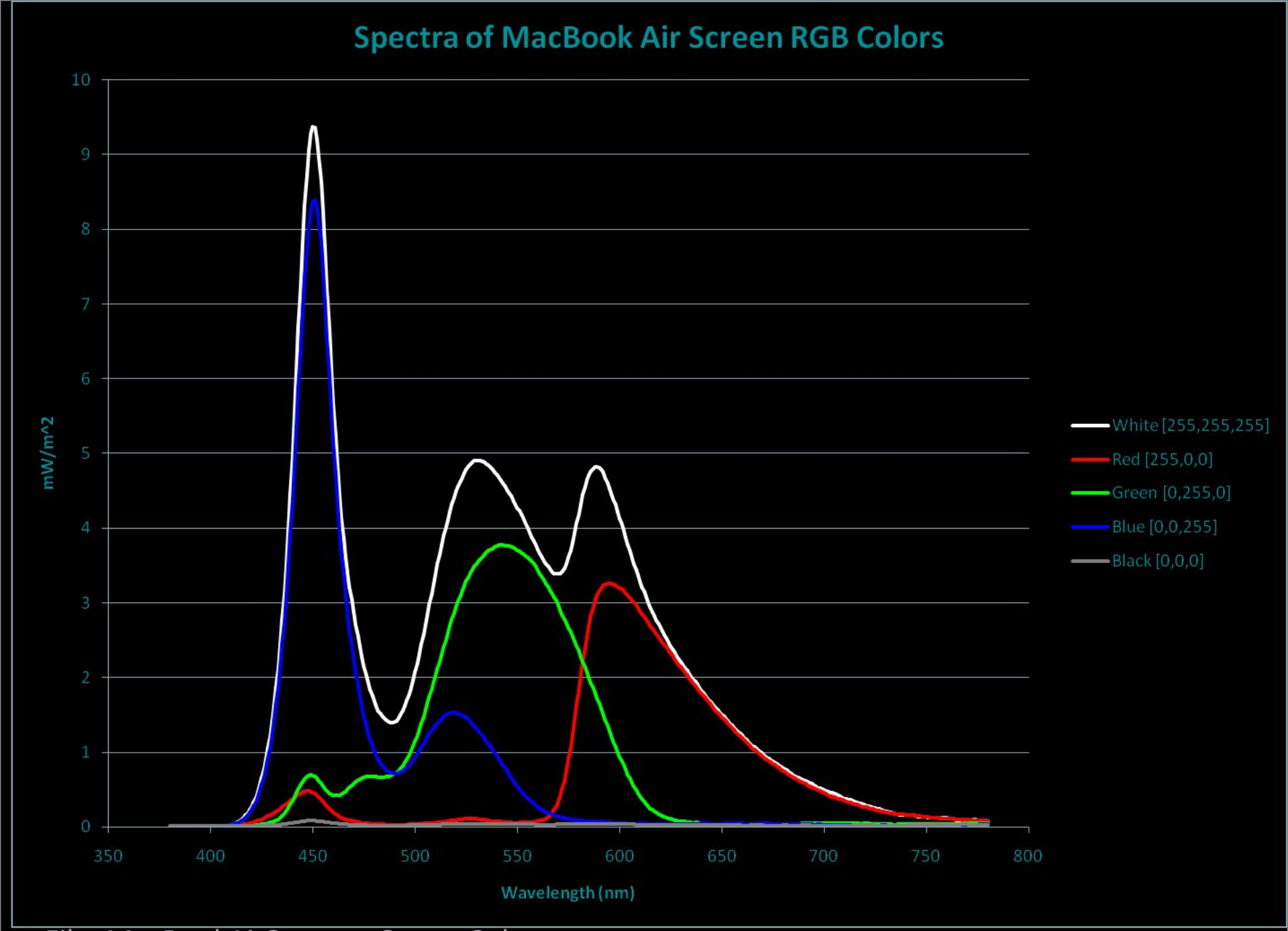
68.9%

Black
0,0,0

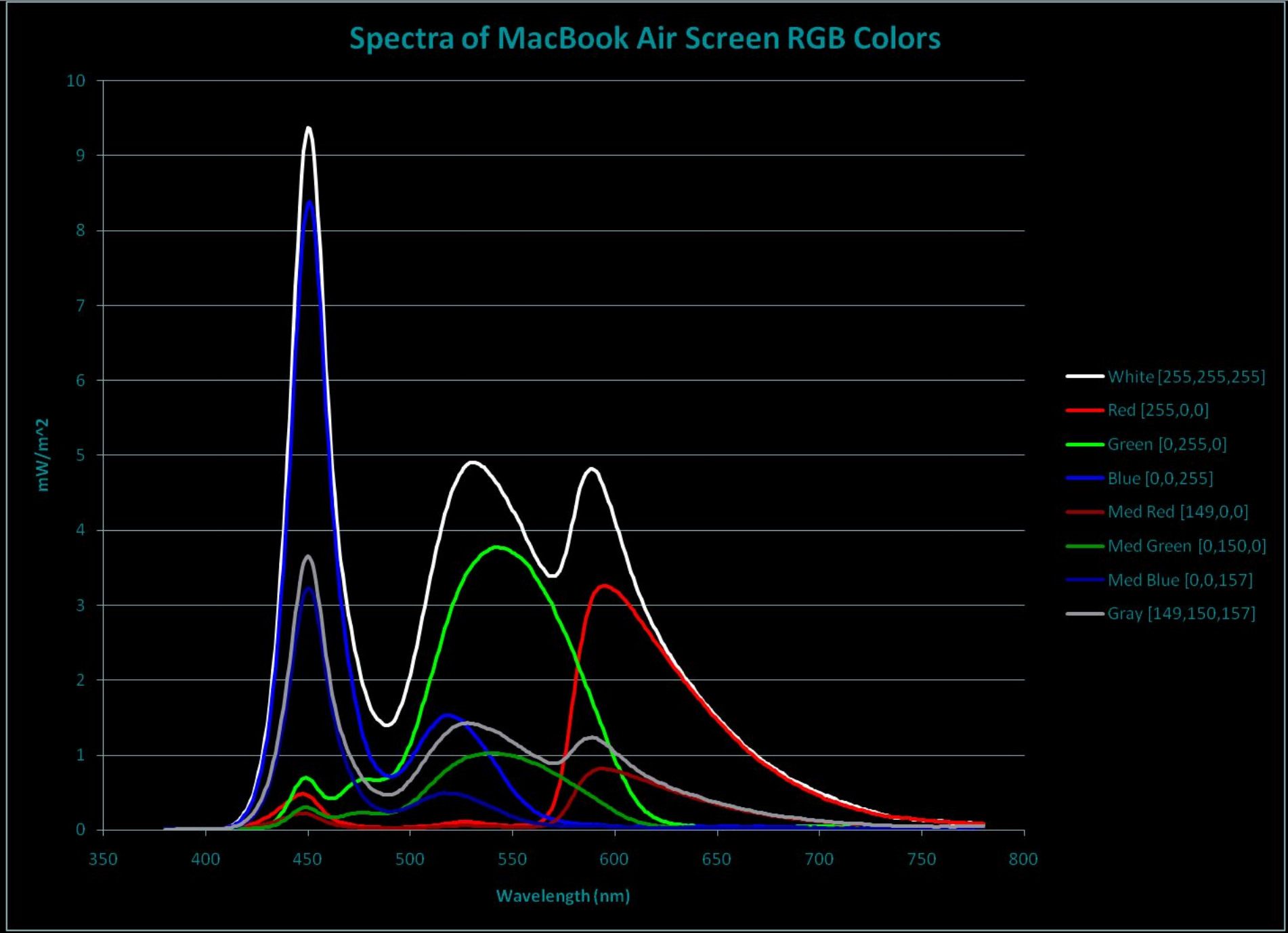




MacBookAirMonitor_100Bright_0_0_0.xls

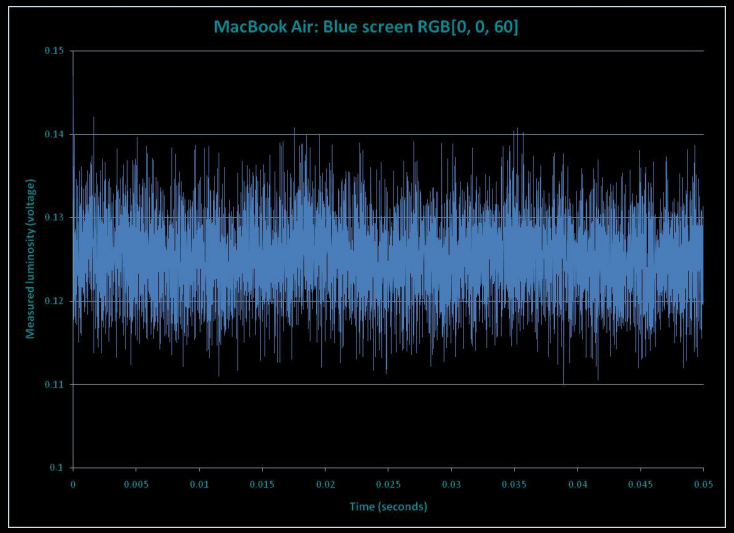


File: MacBookAirSpectra_ScreenColors

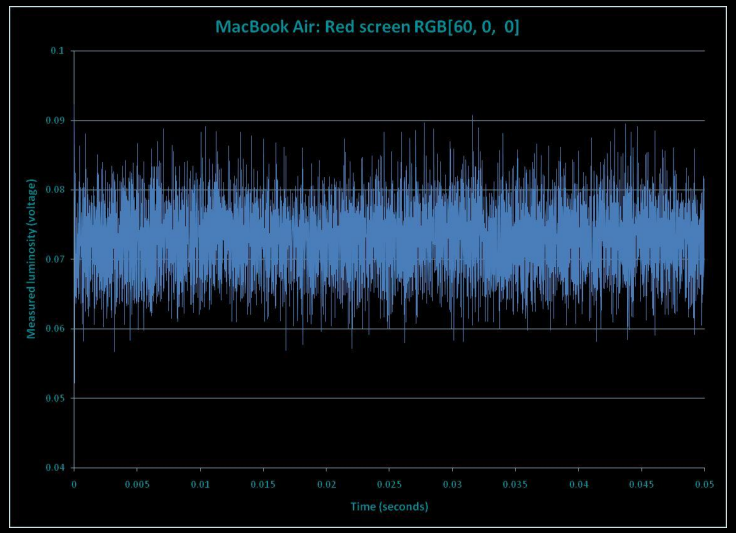


File: MacBookAirSpectra_ScreenColors

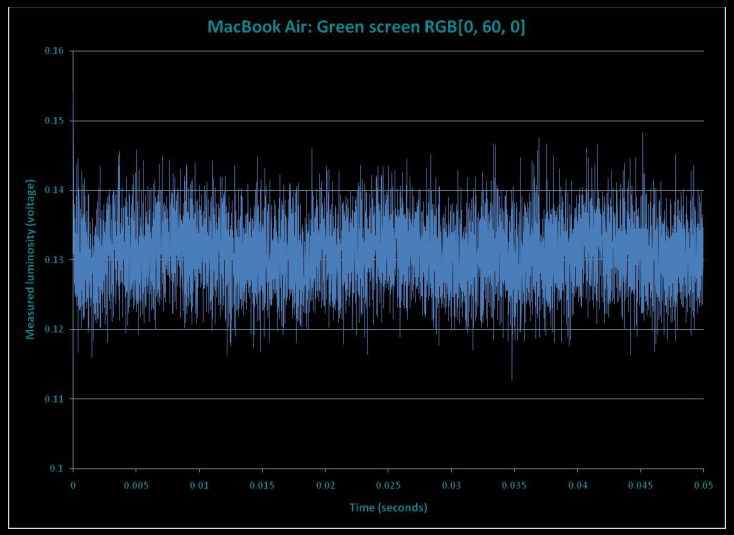
MacBookAir: Flicker pattern changes with color brightness



0,0,60



60,0,0

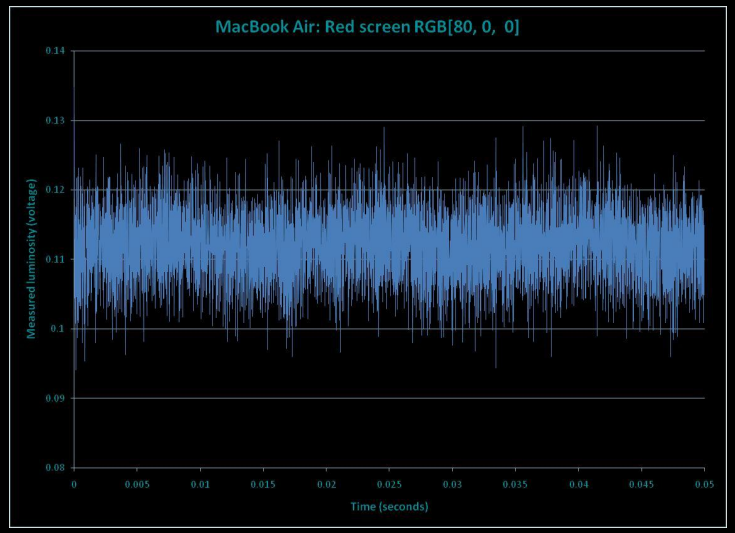


0,60,0

0.05s, zoomed y-axis

MacBookAir: Flicker pattern changes with color brightness

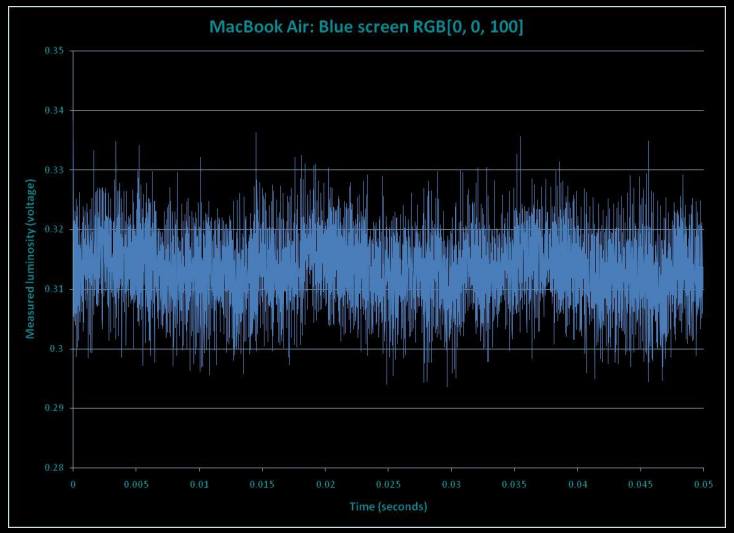
0,0,80



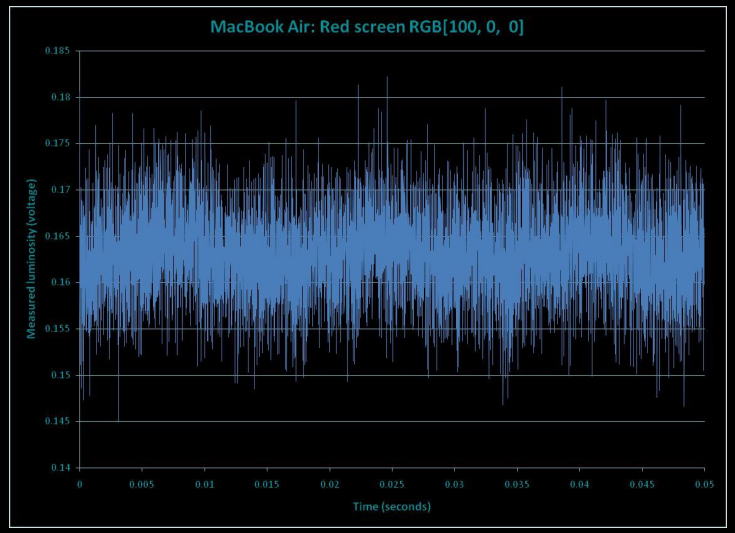
80,0,0

0,80,0

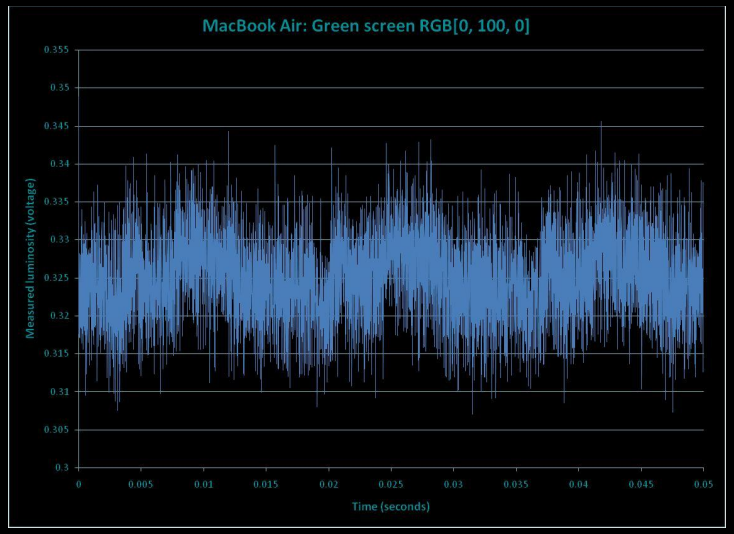
MacBookAir: Flicker pattern changes with color brightness



0,0,100

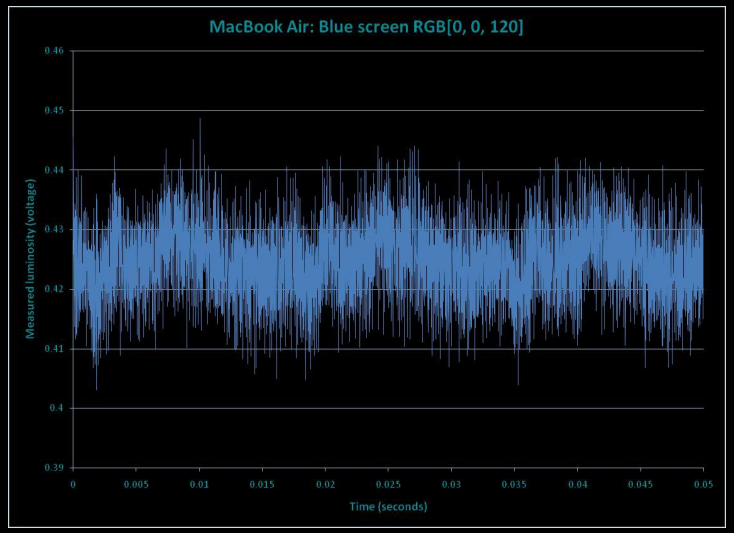


100,0,0

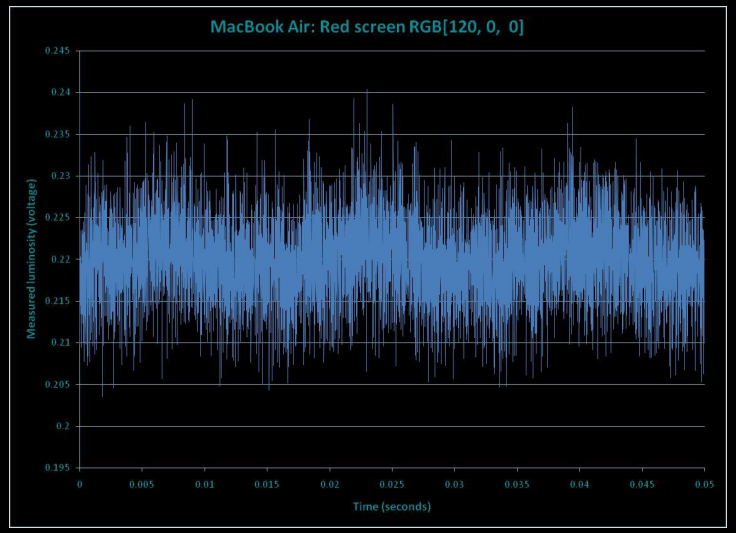


0,100,0

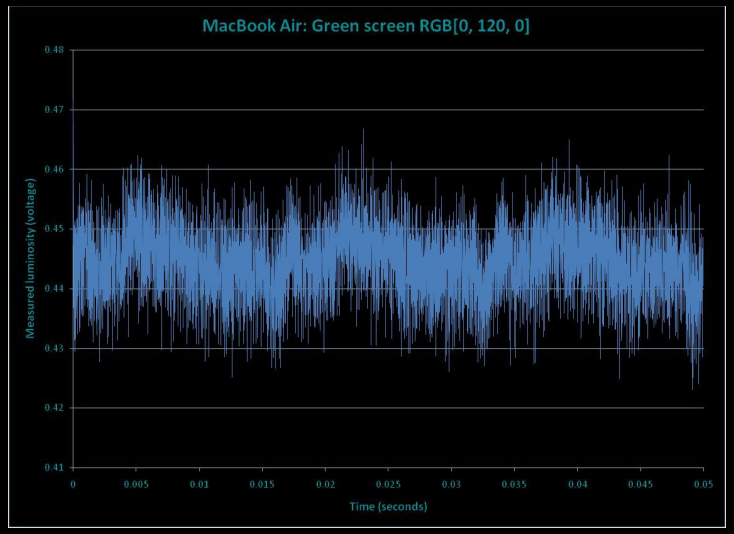
MacBookAir: Flicker pattern changes with color brightness



0,0,120

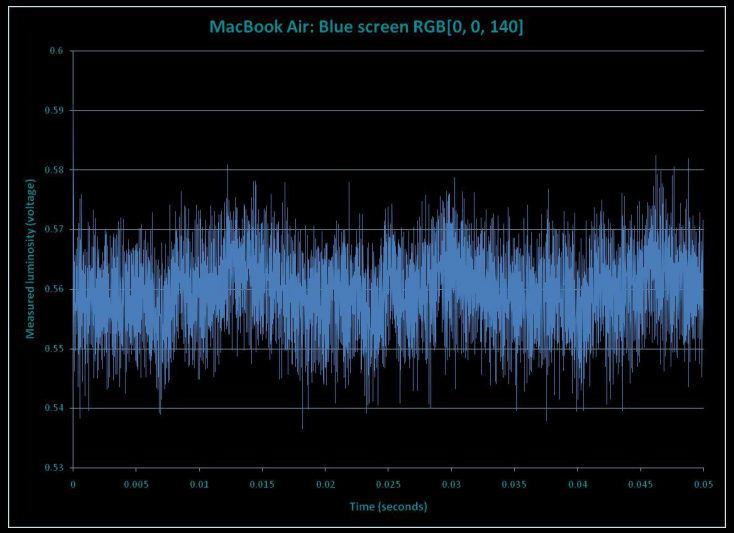


120,0,0

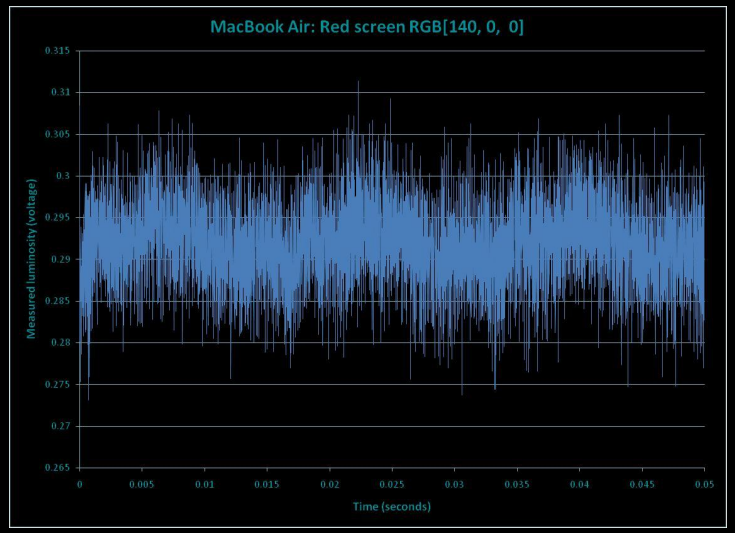


0,120,0

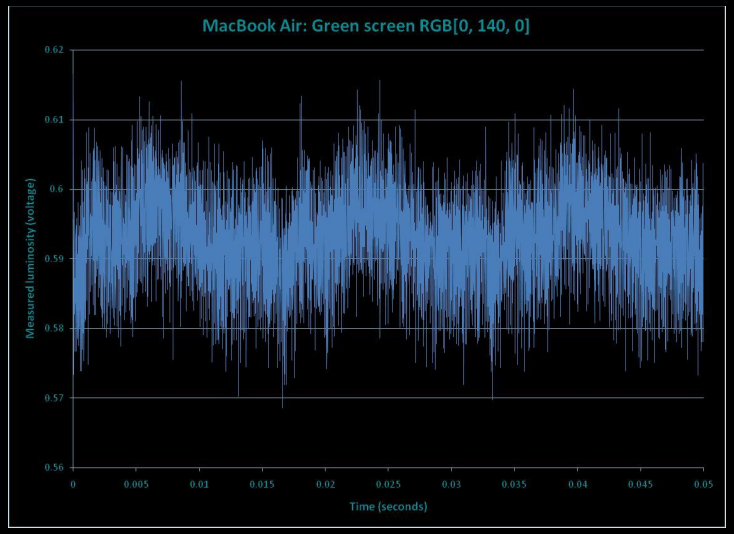
MacBookAir: Flicker pattern changes with color brightness



0,0,140

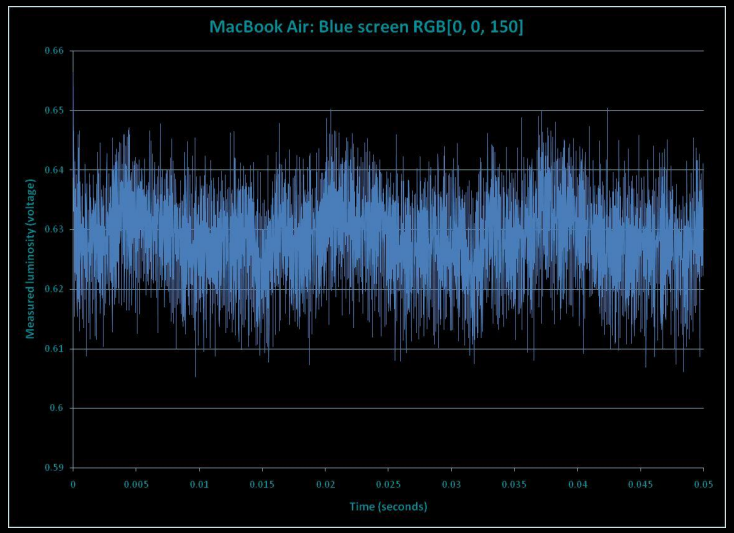


140,0,0

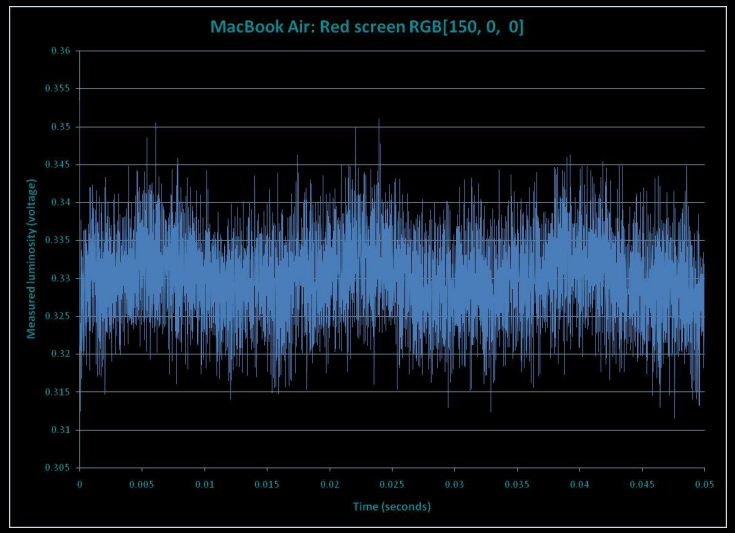


0,140,0

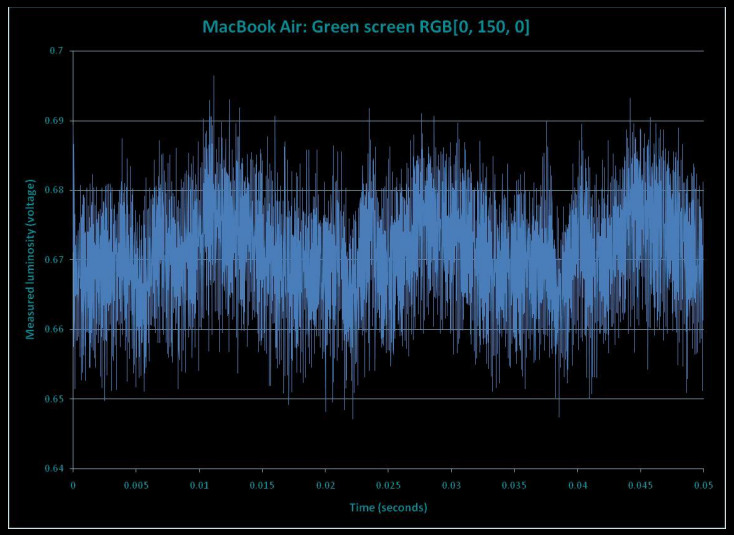
MacBookAir: Flicker pattern changes with color brightness



0,0,150



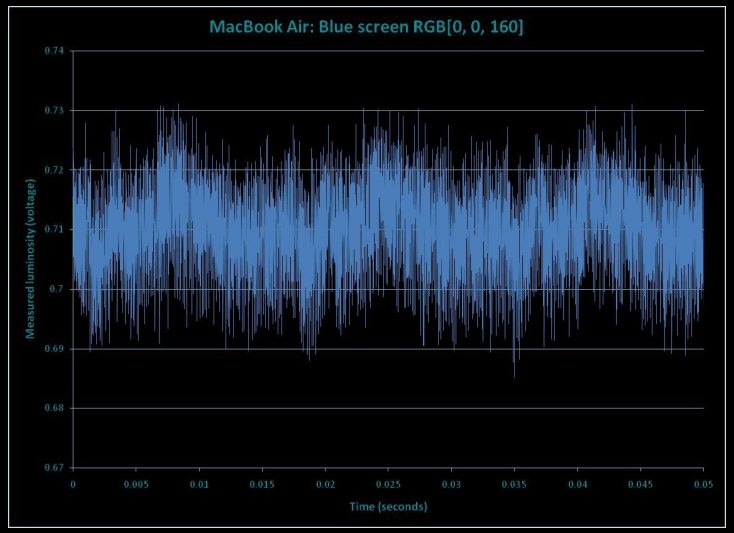
150,0,0



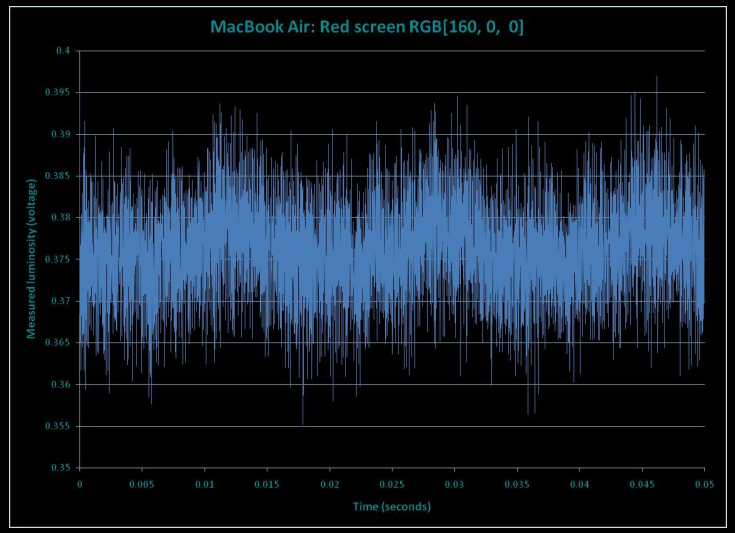
0,150,0

60 Hz zigzag clearest

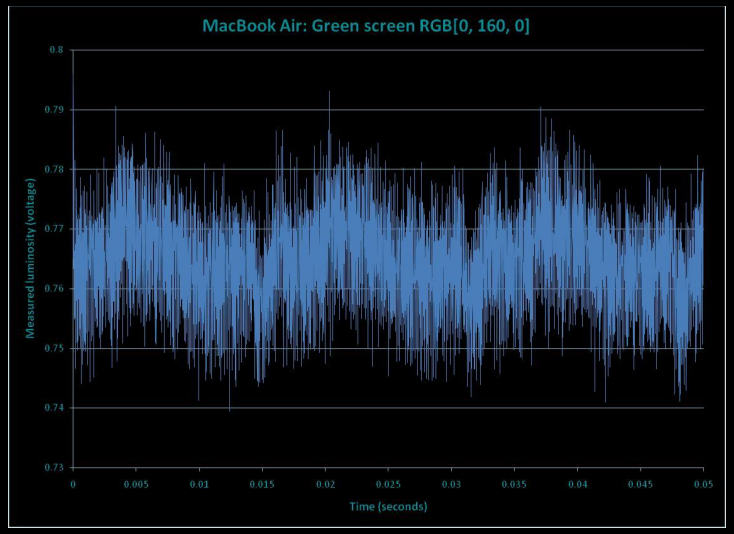
MacBookAir: Flicker pattern changes with color brightness



0,0,160

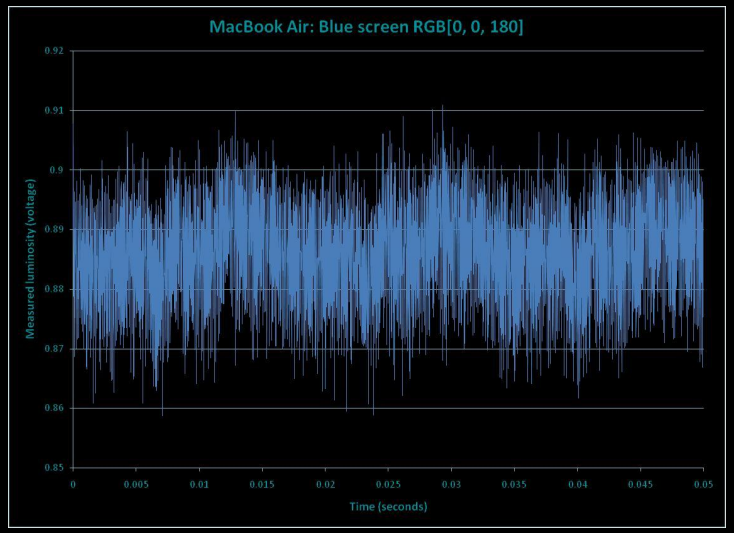


160,0,0

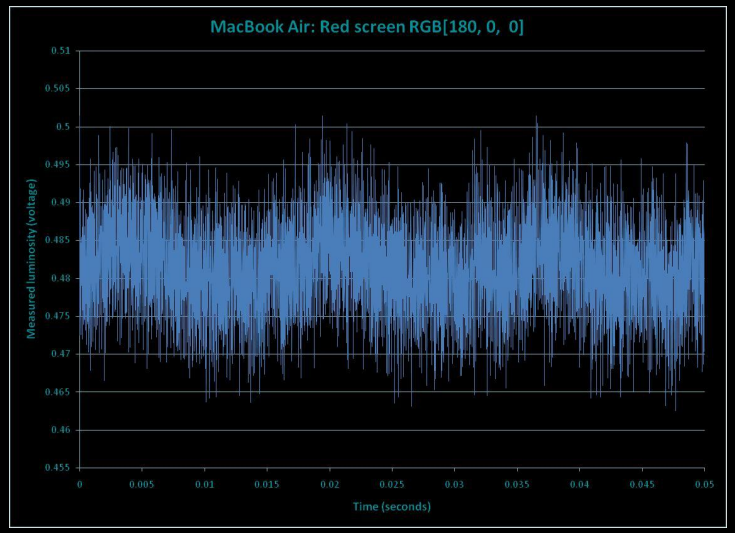


0,160,0

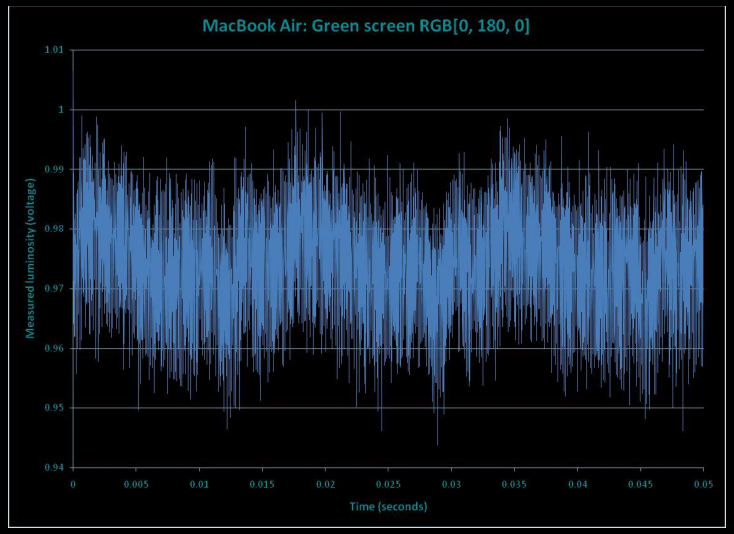
MacBookAir: Flicker pattern changes with color brightness



0,0,180

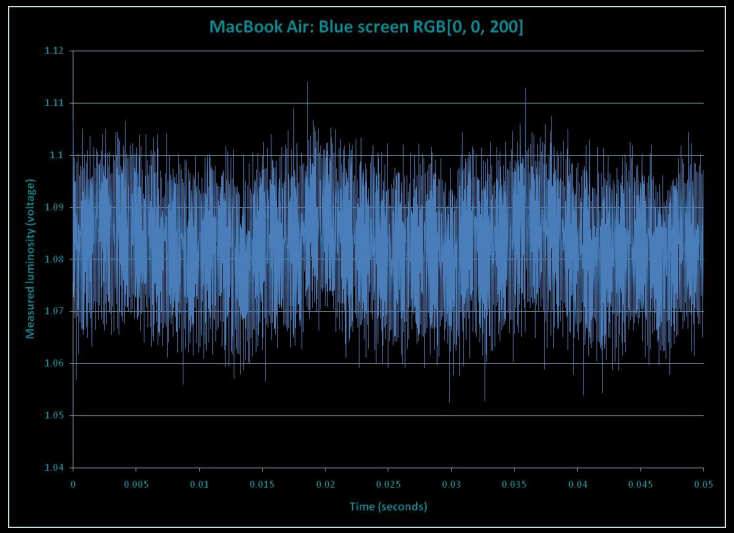


180,0,0

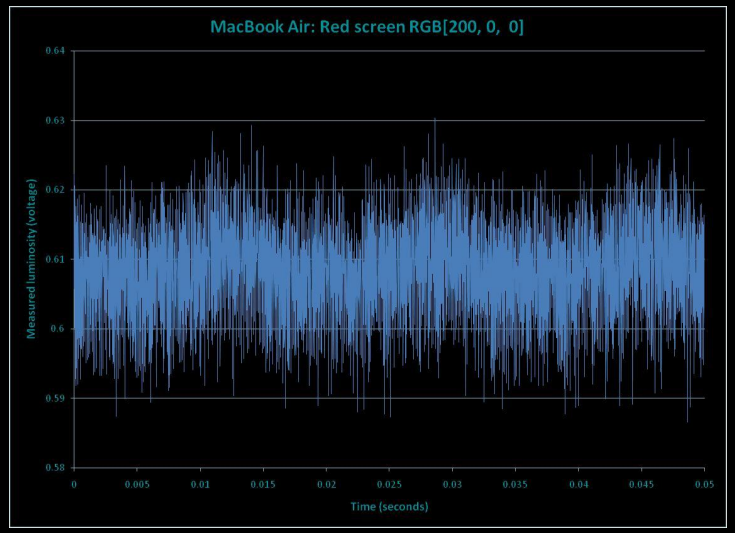


0,180,0

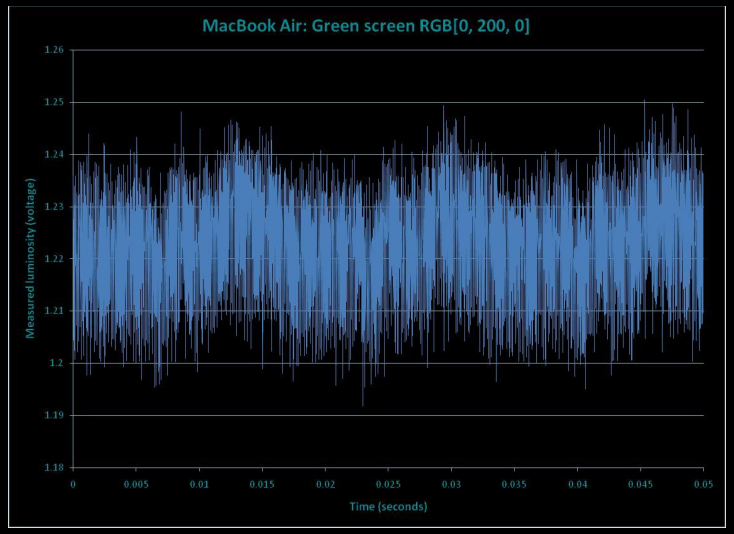
MacBookAir: Flicker pattern changes with color brightness



0,0,200

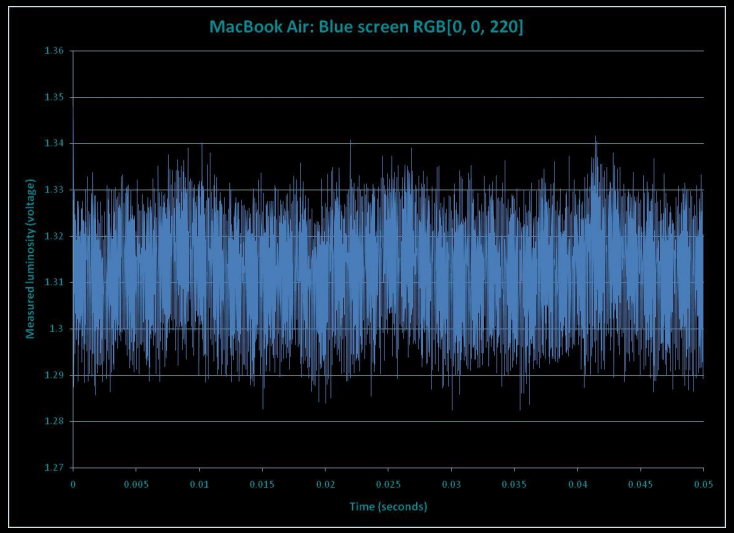


200,0,0

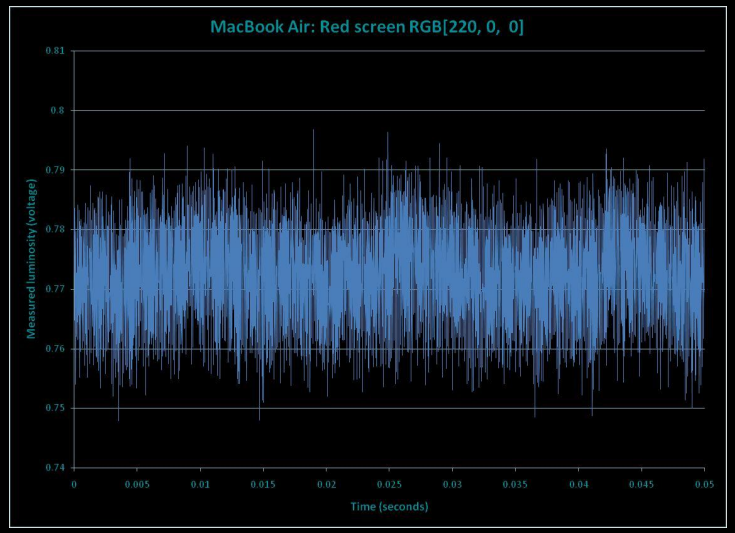


0,200,0

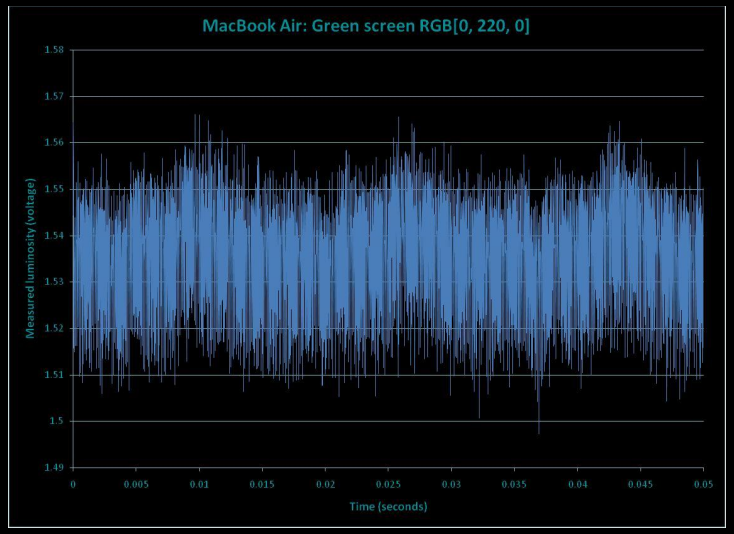
MacBookAir: Flicker pattern changes with color brightness



0,0,220

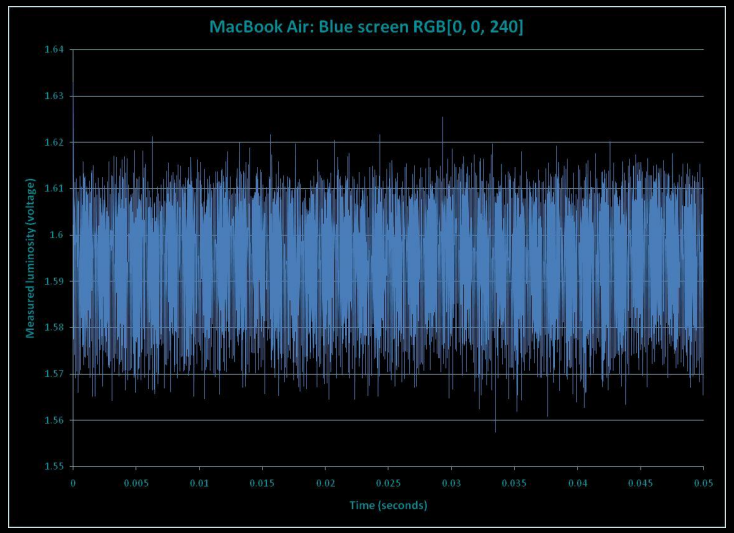


220,0,0

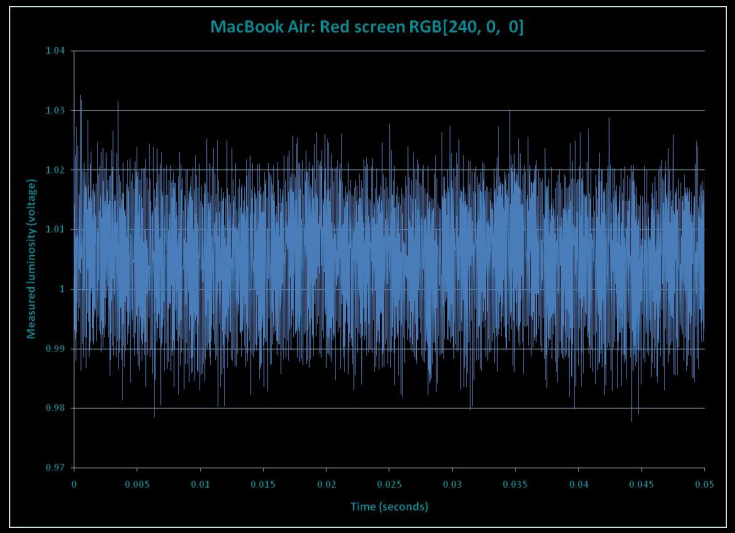


0,220,0

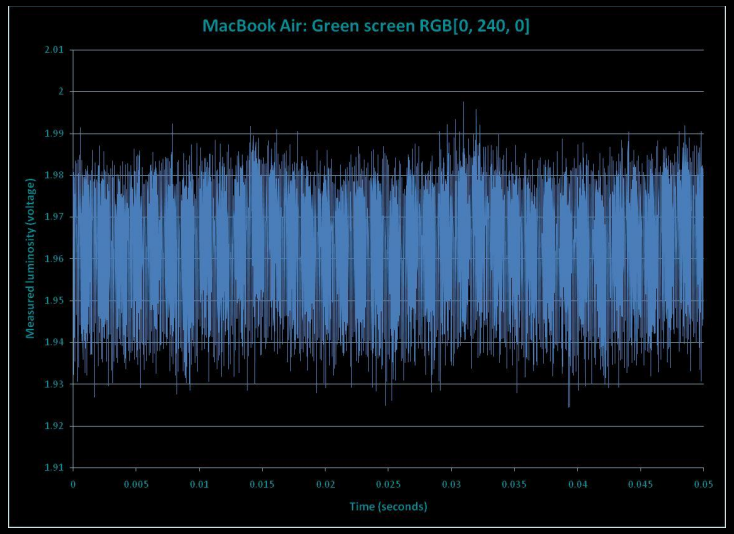
MacBookAir: Flicker pattern changes with color brightness



0,0,240

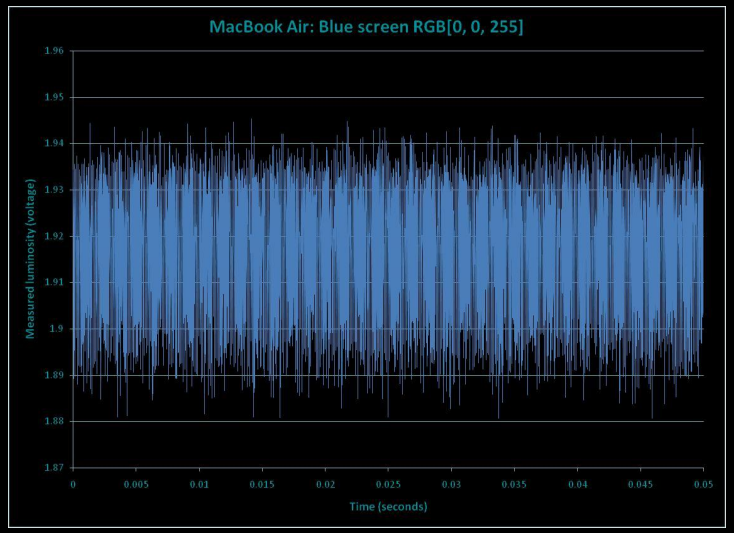


240,0,0

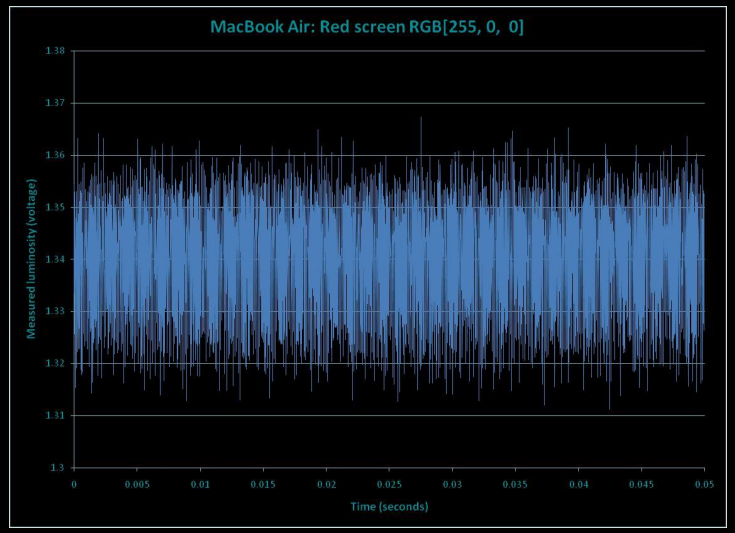


0,240,0

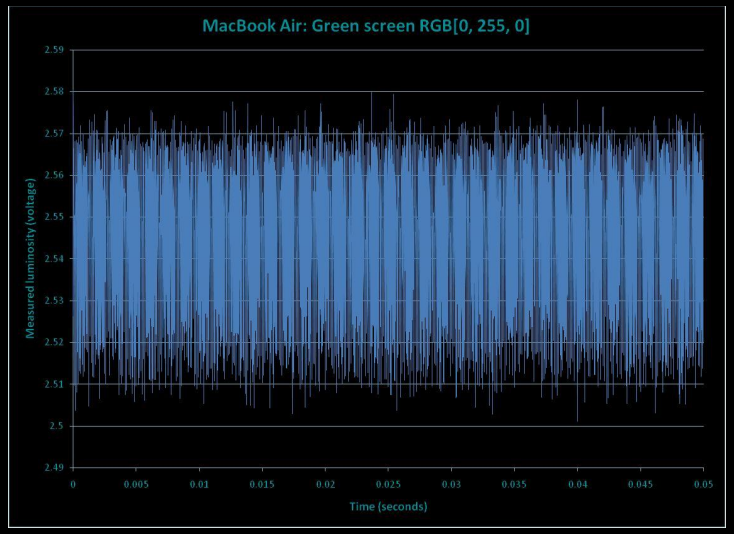
MacBookAir: Flicker pattern changes with color brightness



0,0,255



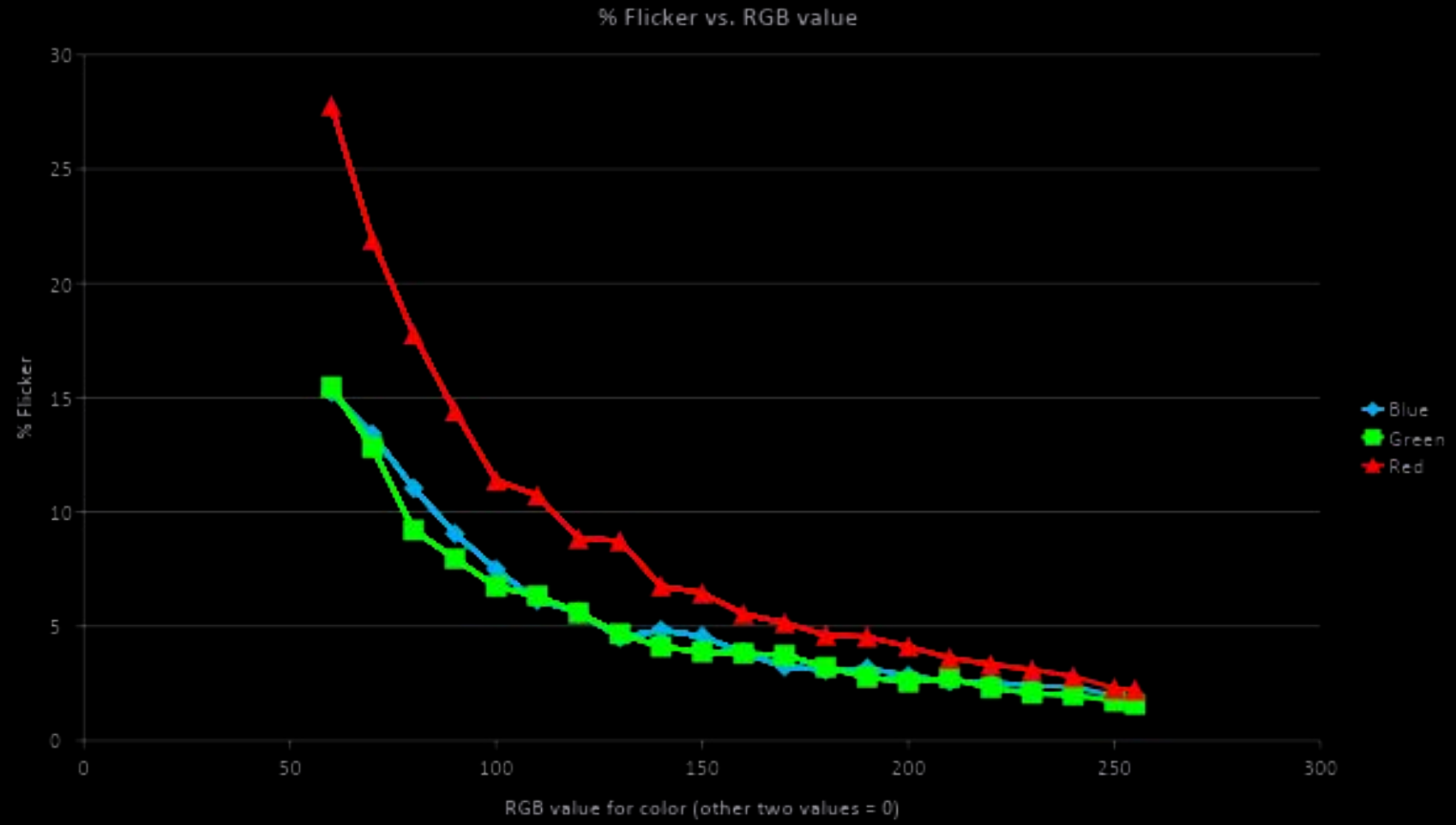
255,0,0



0,255,0

"Banding" from "overlapping feather" pattern clear; little 60 Hz flicker

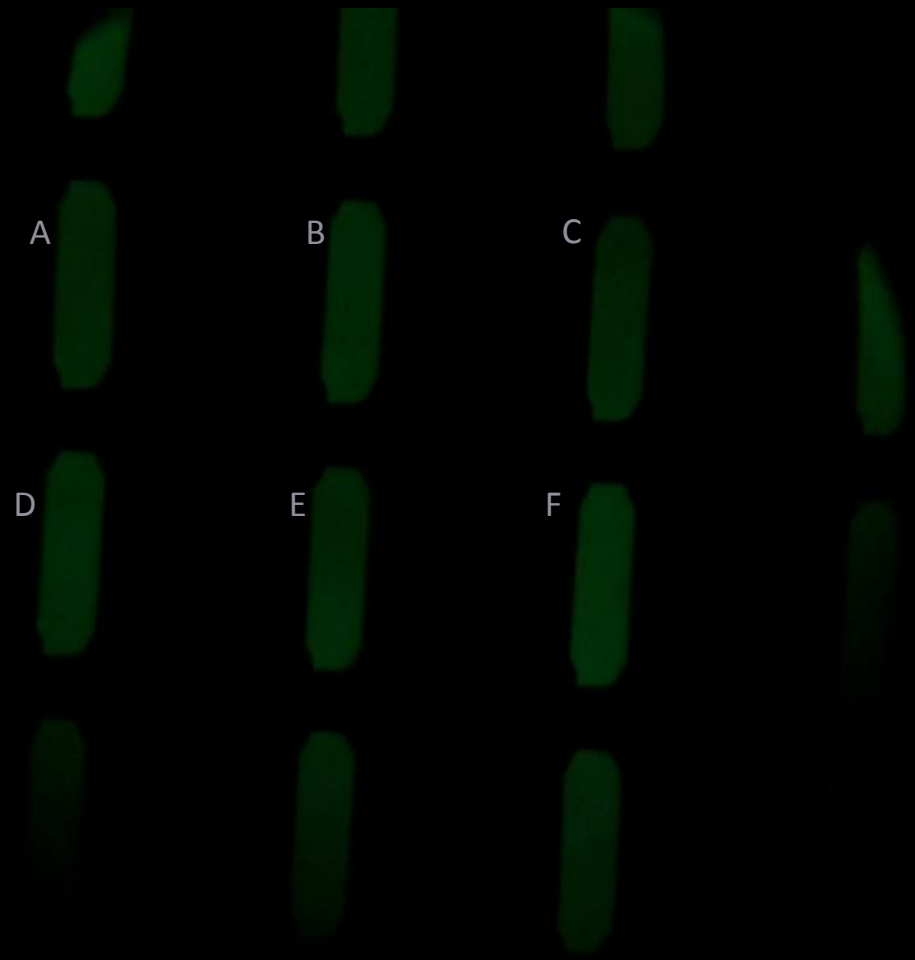
% Flicker (or measurement noise) decreases as RGB value increases



MacBook Air:
30 Hz subpixel flicker

Microscope and slow-motion video analysis

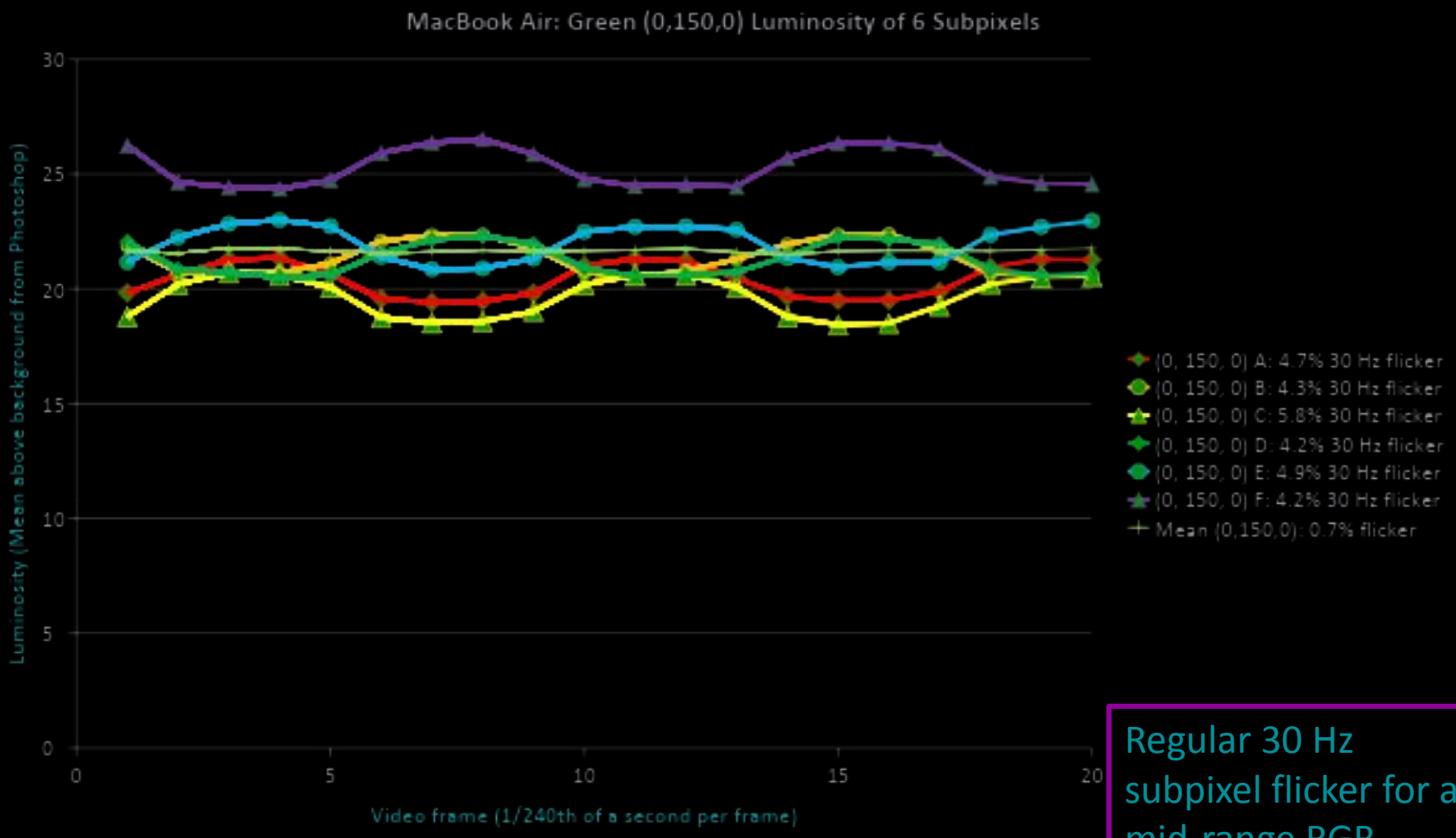
MacBook Air, Green (0,150,0): Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames



MMNT_20230916_113814811_MacBookAir_0_150_0

250X magnification

MacBook Air, Green (0,150,0): Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames

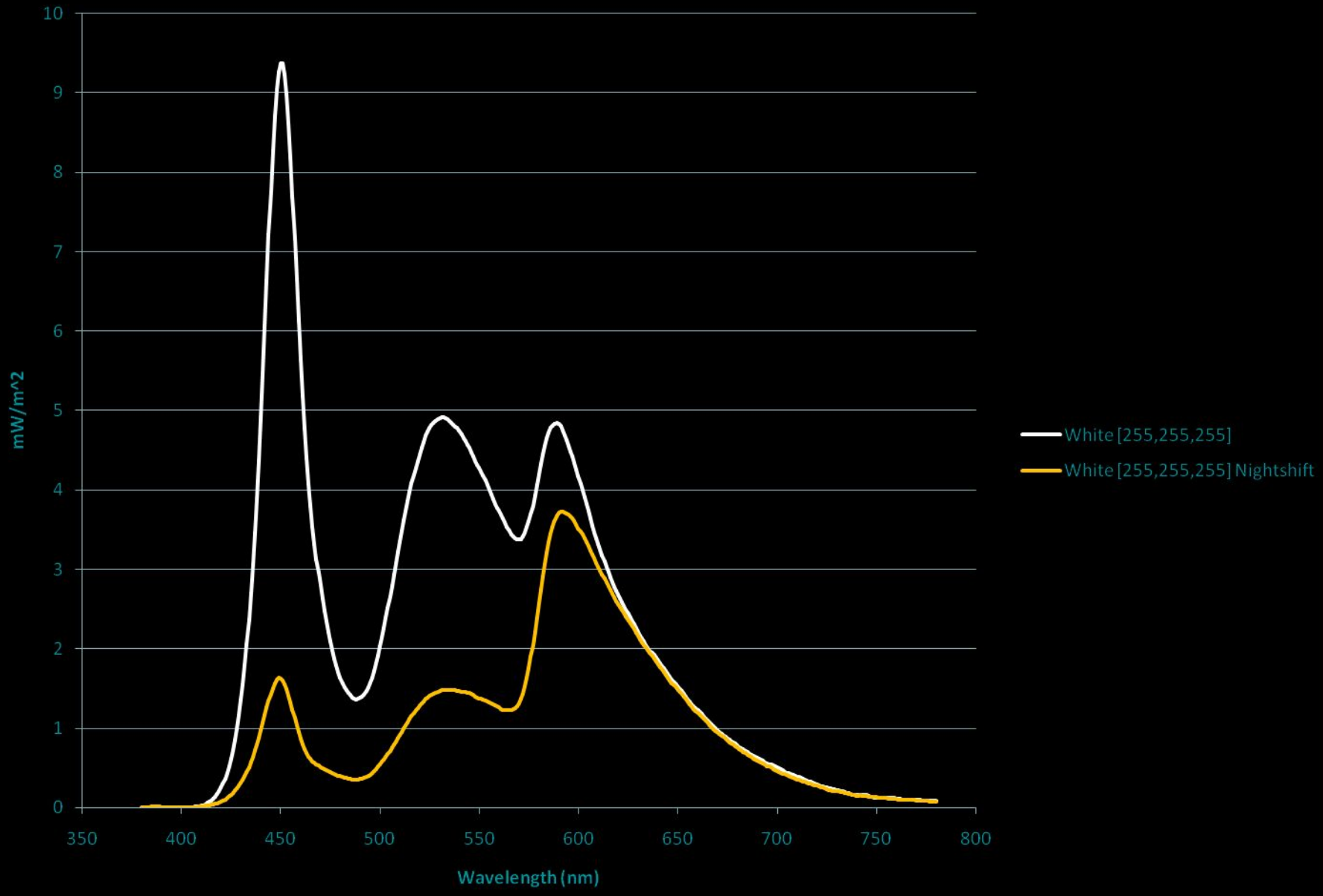


Regular 30 Hz subpixel flicker for a mid-range RGB setting; variable subpixel brightness

Pixel_Flicker_MacBookAir13_240fps

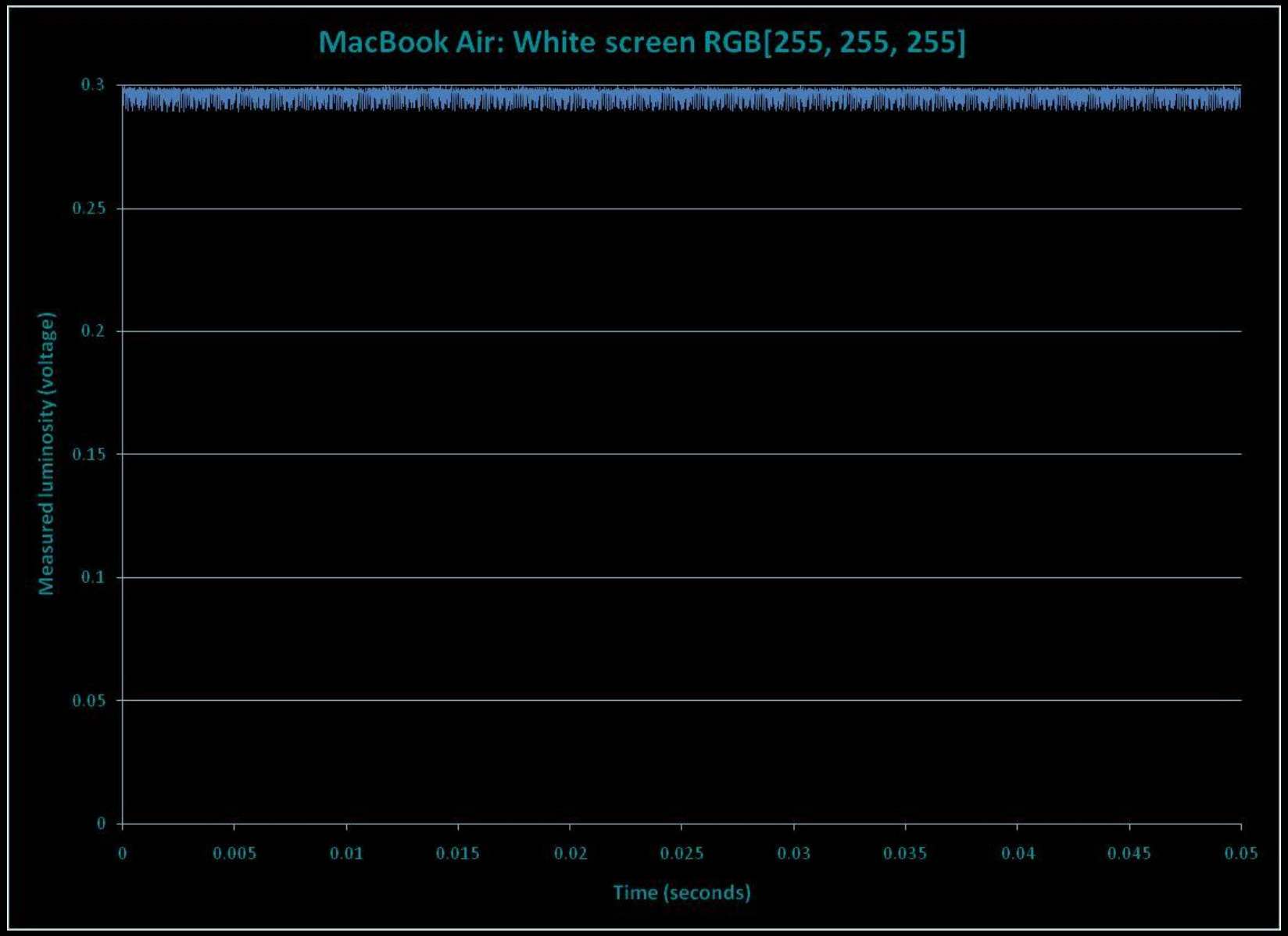
Nightshift on the MacBook Air is worse for causing symptoms than without Nightshift

Spectra of MacBook Air Screen RGB Colors without and with Nightshift



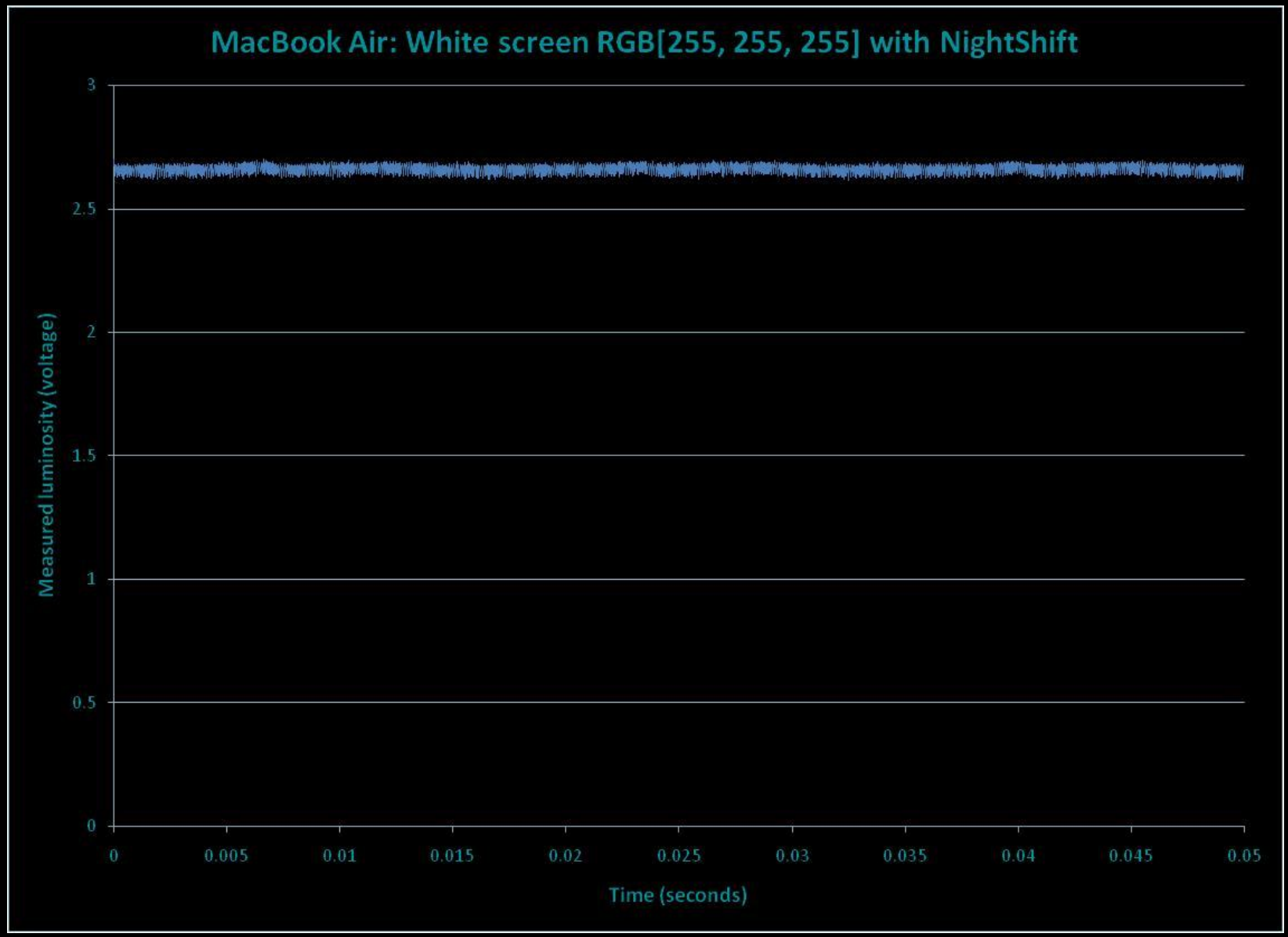
File: MacBookAirSpectra_ScreenColors

MacBook Air (0.05s), 1.88% flicker



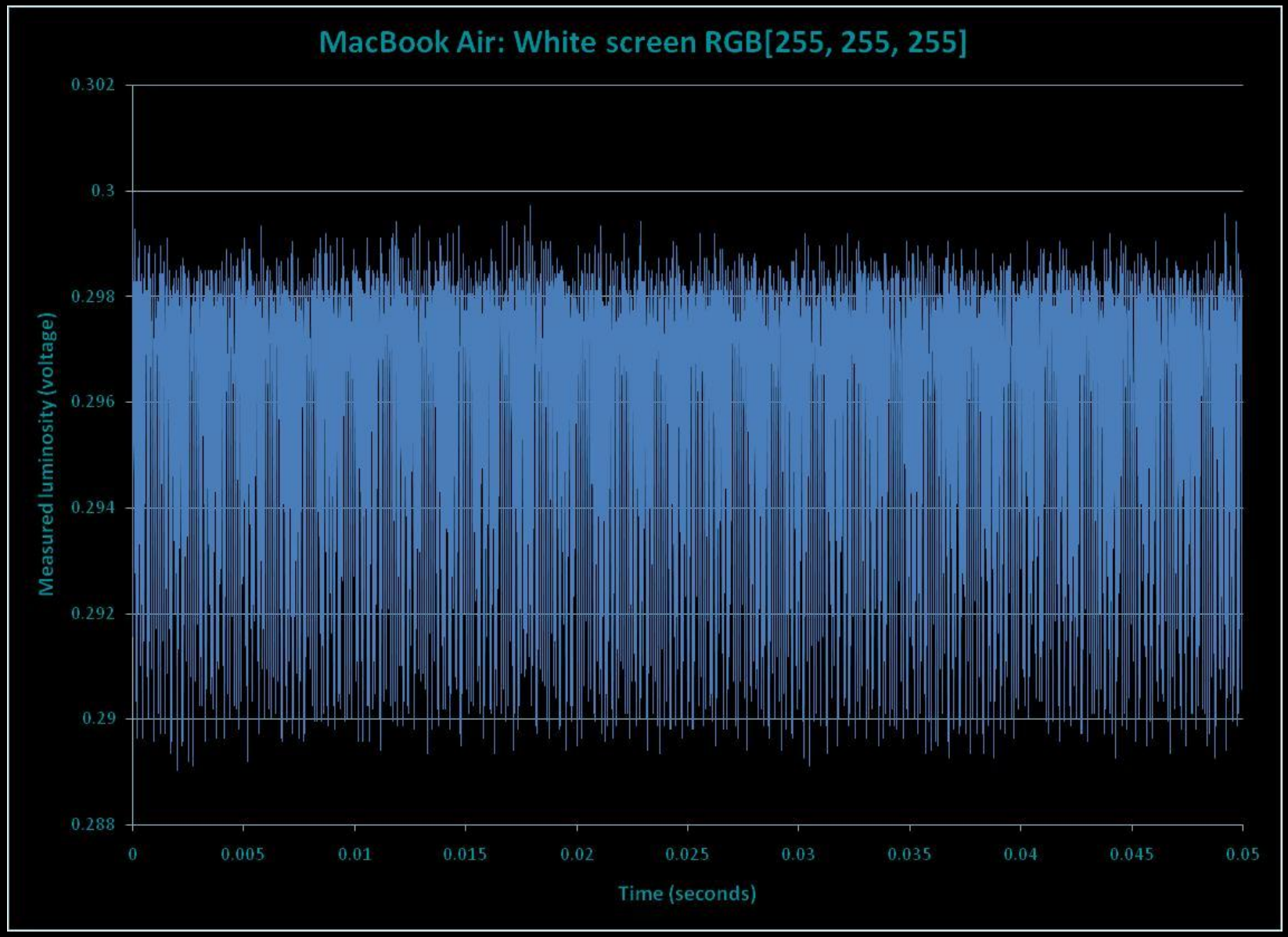
MacBookAirMonitor_100Bright_255_255_255c

MacBook Air with Nightshift (0.05s), 1.61%



MacBookAirMonitor_100bright_255_255_255c_NtShft

MacBook Air (0.05s, zoomed y-axis)

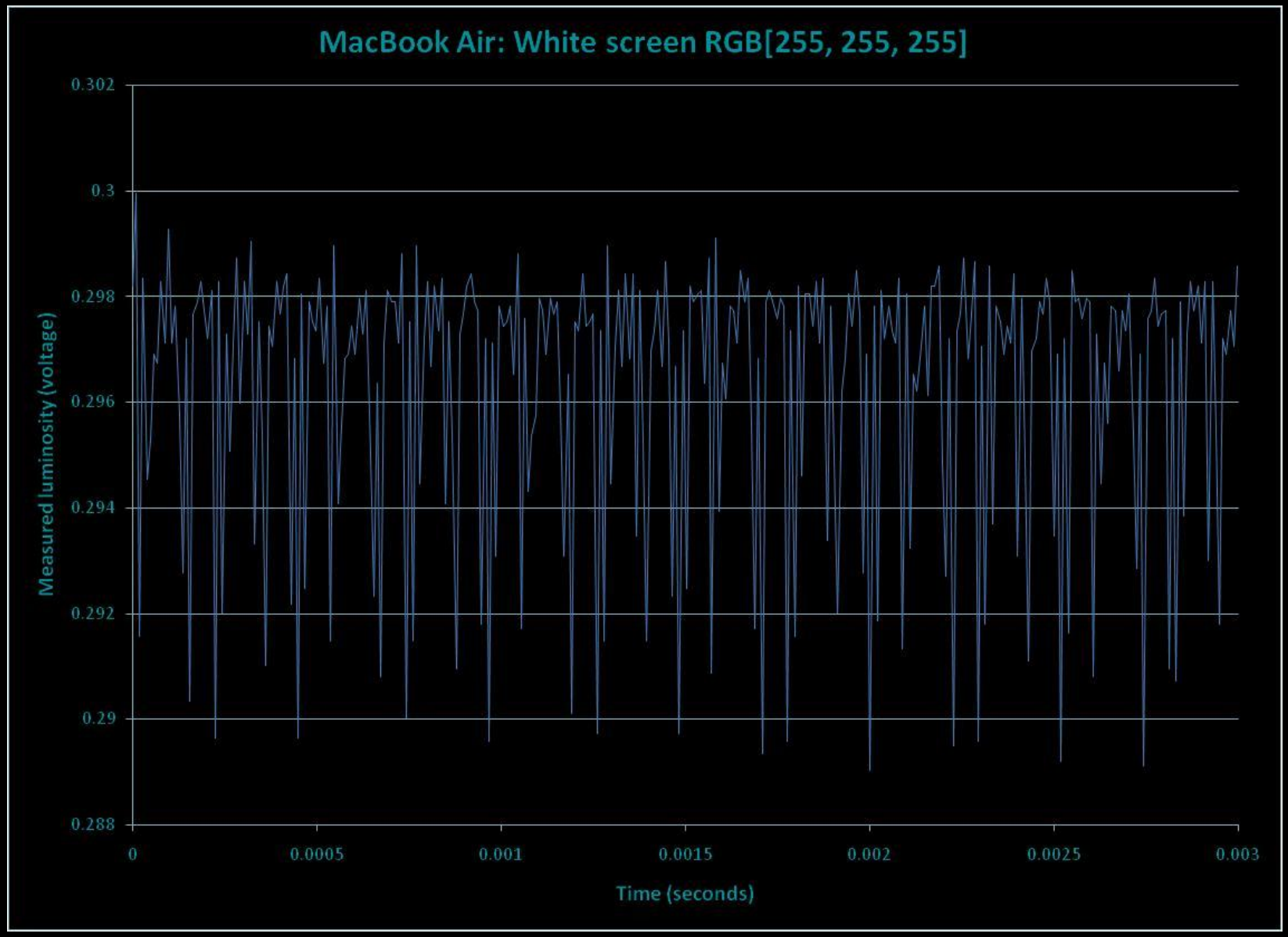


MacBookAirMonitor_100Bright_255_255_255c

MacBook Air with Nightshift (0.05s, zoomed y-axis)

MacBookAirMonitor_100bright_255_255_255c_NtShft

MacBook Air (0.003s, zoomed y-axis)



MacBookAirMonitor_100Bright_255_255_255c

MacBook Air with Nightshift (0.003s, zoomed y-axis)

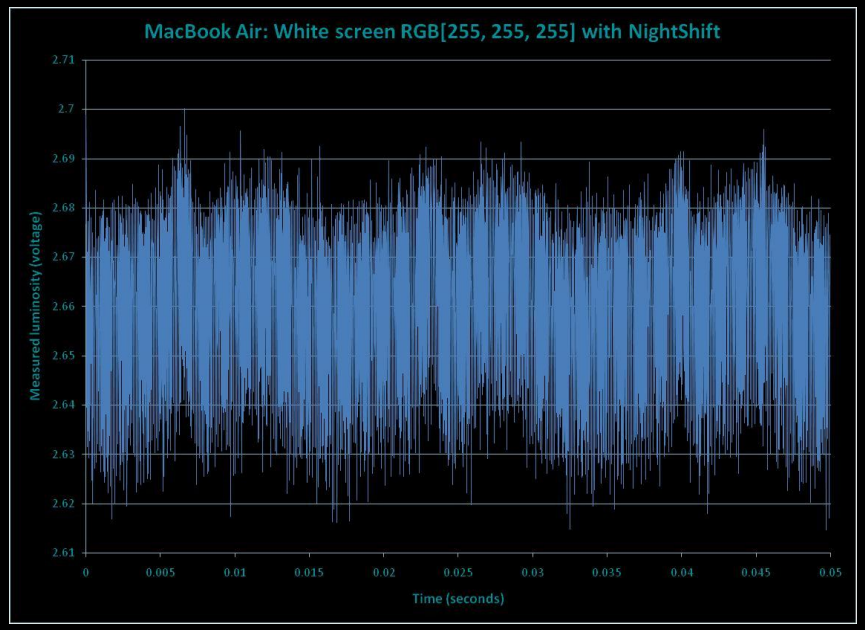
MacBookAirMonitor_100bright_255_255_255c_NtShft

MacBook Air white [255,255,255] screen without and with Nightshift (0.05s, zoomed y-axis)

Without Nightshift, 1.88%

MacBookAirMonitor_100Bright_255_255_255c

With Nightshift, 1.61%



MacBookAirMonitor_100bright_255_255_255c_NtShft

Extra 60 Hz pattern
"Banding" pattern frequency changed

Using color-separating camera filters to approximately mimic differences in absorbance by human cones (Note: what role, if any, specific light receptors play in health effects of LED flicker is unknown)

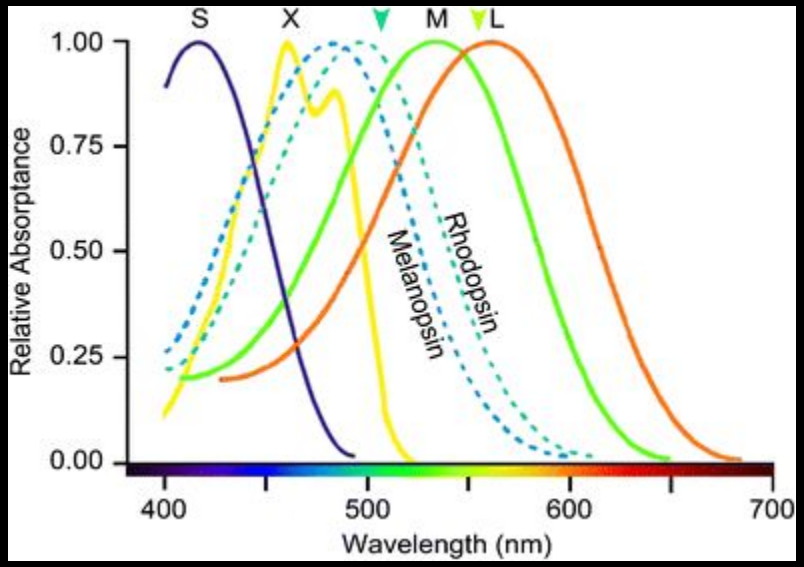
Absorbance of light in the human eye: Blue (S), green (M), and red (L) cone max:

S: 420 nm

M: 534 nm

L: 564 nm

https://www.researchgate.net/figure/Spectral-sensitivity-of-human-vision-The-maximum-spectral-sensitivity-of-the-human-eye_fig2_283210525



rods: 498 nm

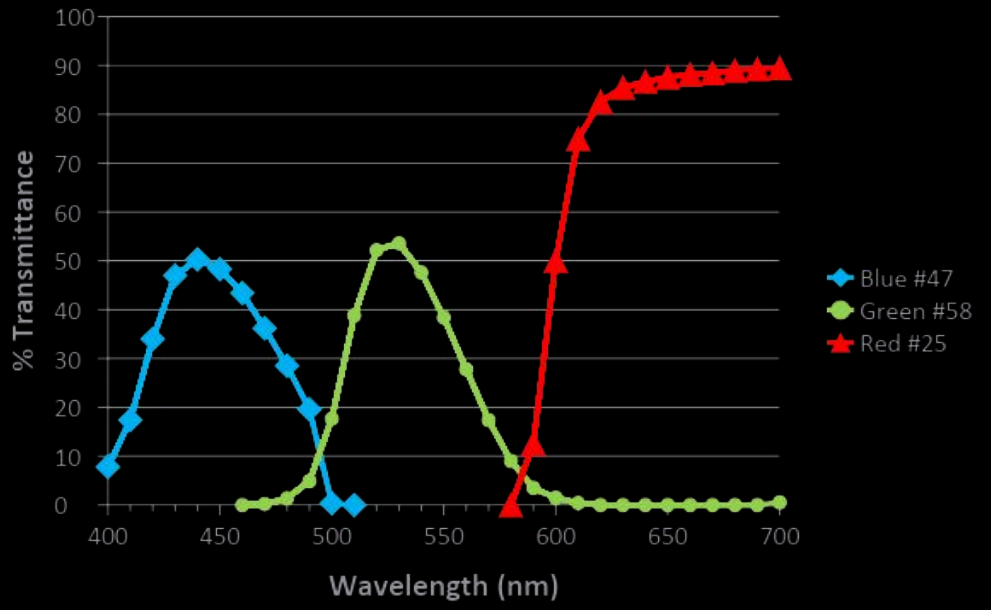
ipRCG types 1&2: 459 and 457 nm

ipRCG type 3: 447-560 nm

Kodak Color-Separating Wratten Filters (Blue 47, Green 58, Red 25)

Transmission of Wratten Filters, Allie C. Peed, Jr., The Eastman Kodak Company

http://www.astrosurf.com/luxorion/Documents/transmission-wratten-filters.pdf

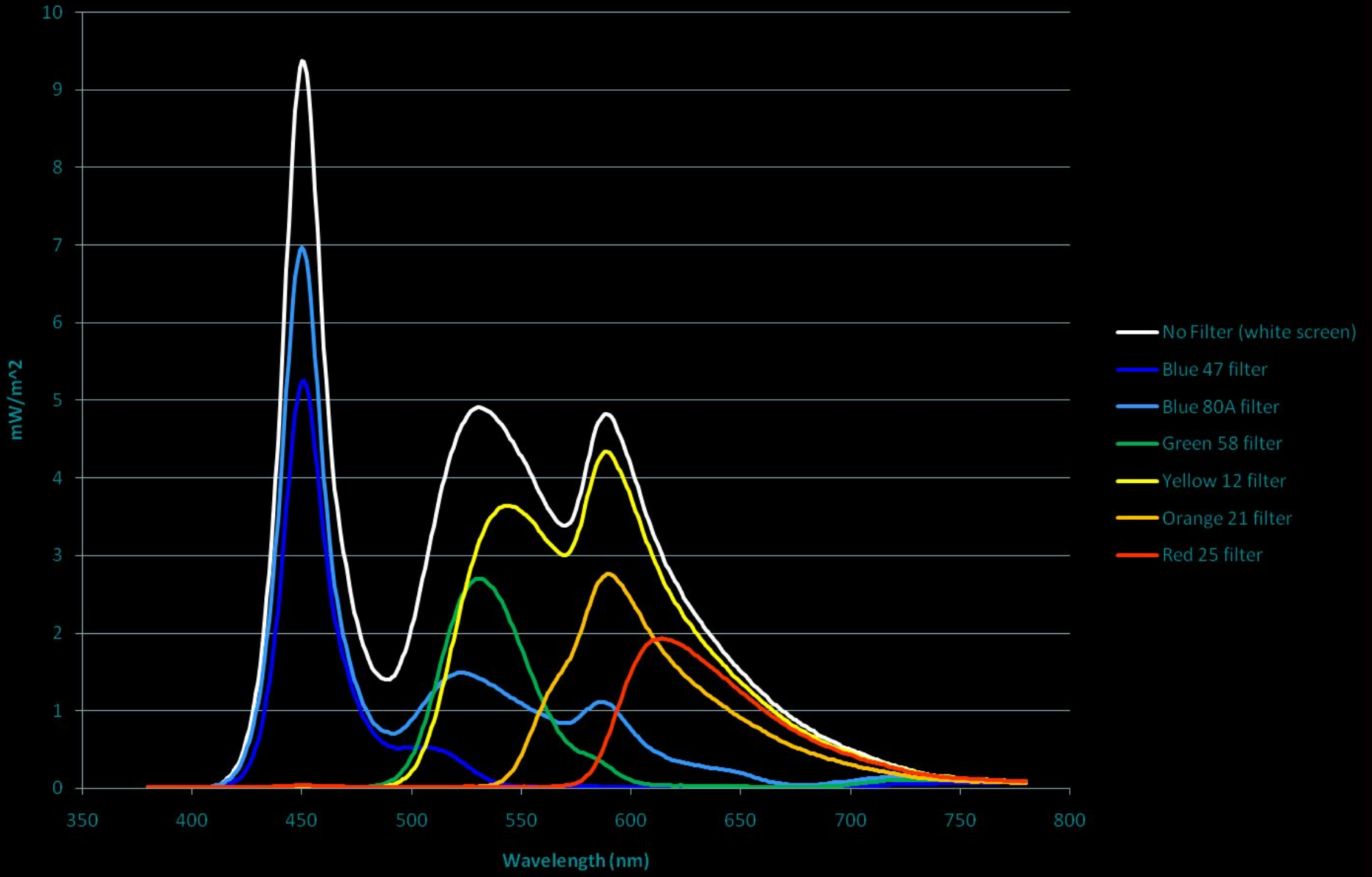


Filters tested

- Tiffen 58mm camera lens glass filters (Wratten numbers given)
  - RGB color separating: Blue 47, Green 58, Red 25
  - Low red/green, high blue trans. (peak 471.7nm): Blue 80A
  - Minus blue: Yellow 12,
  - Minus blue-blue/green: Orange 21
  - Deep Red: Red 29
- “Green_L” greenfilter.com 58mm camera lens glass filter
  - Near-IR: IR680

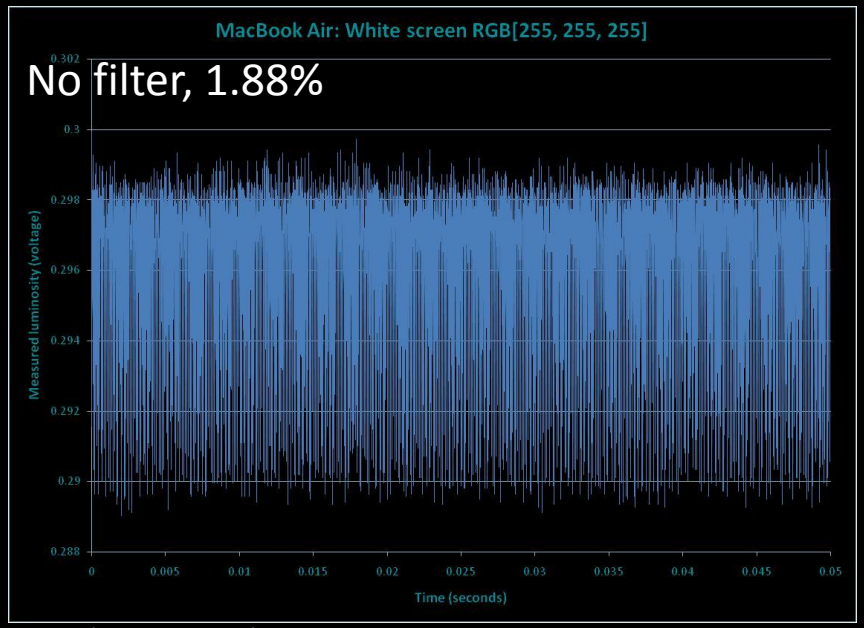
http://www.astrosurf.com/luxorion/Documents/transmission-wratten-filters.pdf

Spectra of MacBook Air white [255,255,255] screen with glass color filters over spectrophotometer sensor

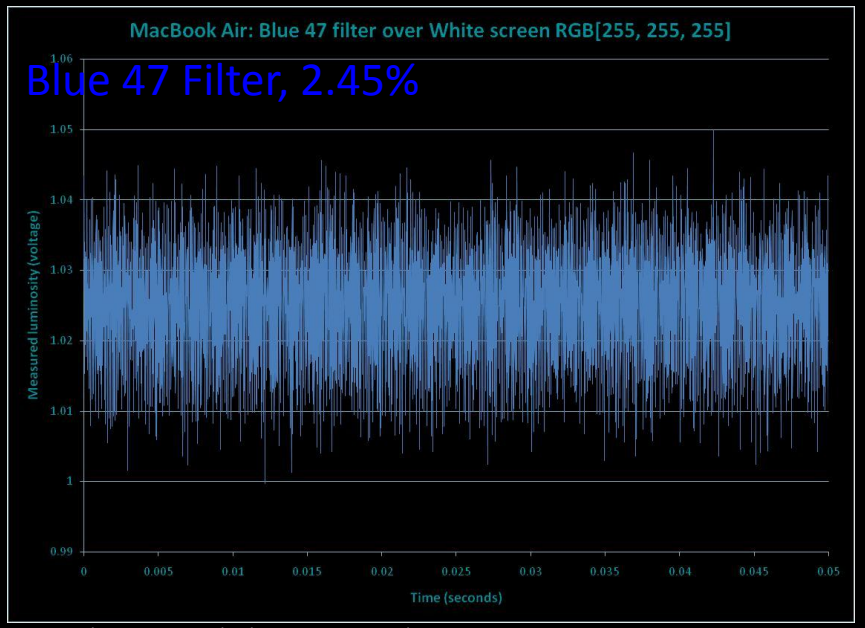


File: MacBookAirSpectra_Filters

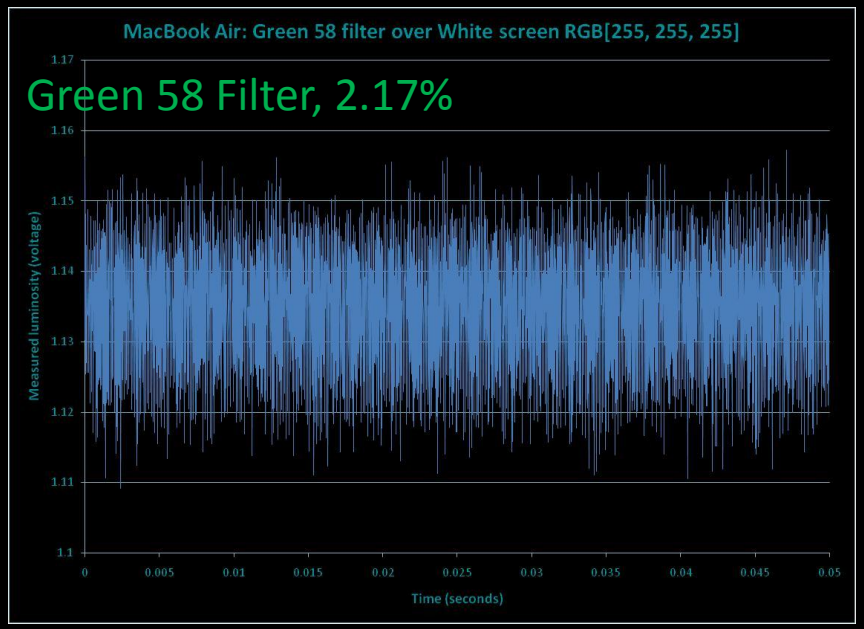
MacBook Air without Nightshift (0.05s, zoomed y-axis)



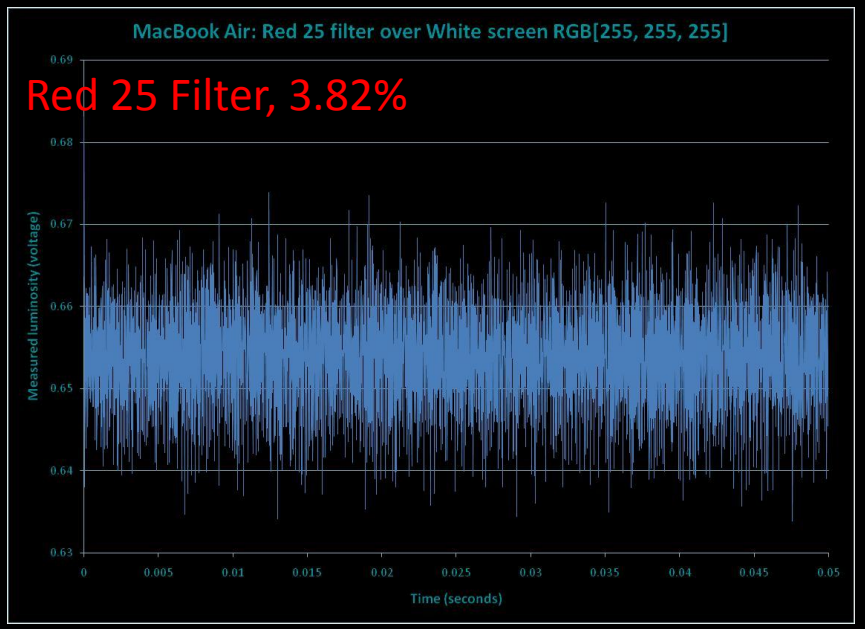
MacBookAirMonitor_100Bright_255_255_255c



MacBookAirMonitor_100bright_255_255_255c_Blue47

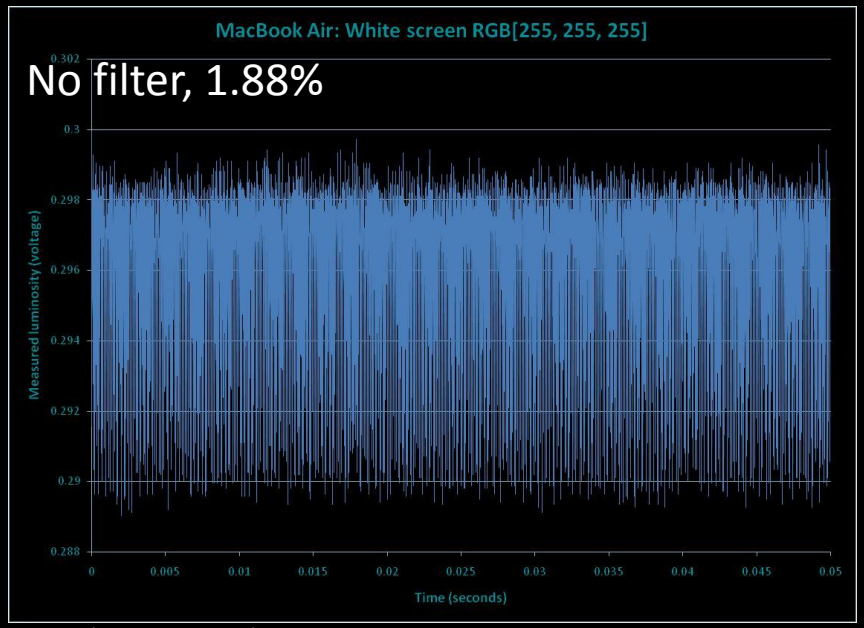


MacBookAirMonitor_100bright_255_255_255c_Green58

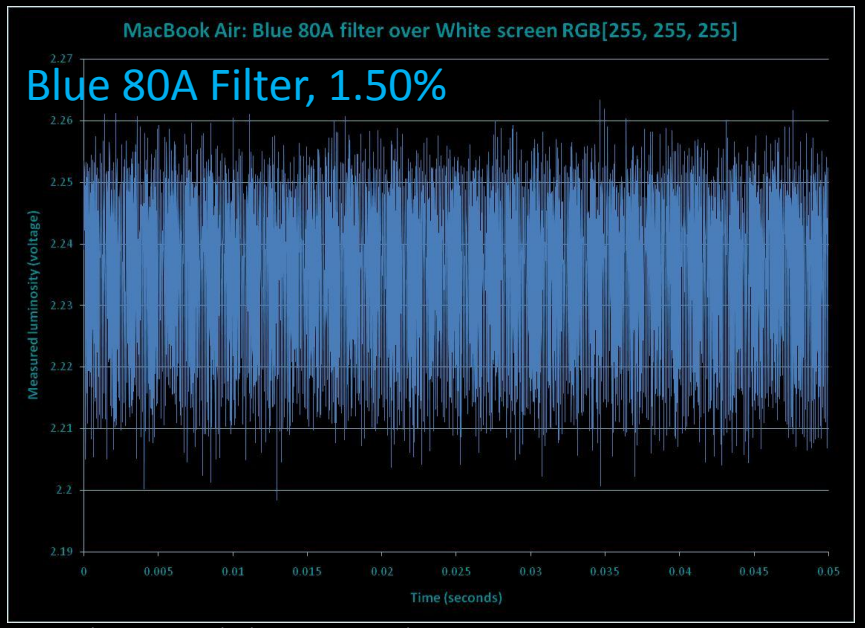


MacBookAirMonitor_100bright_255_255_255c_Red25

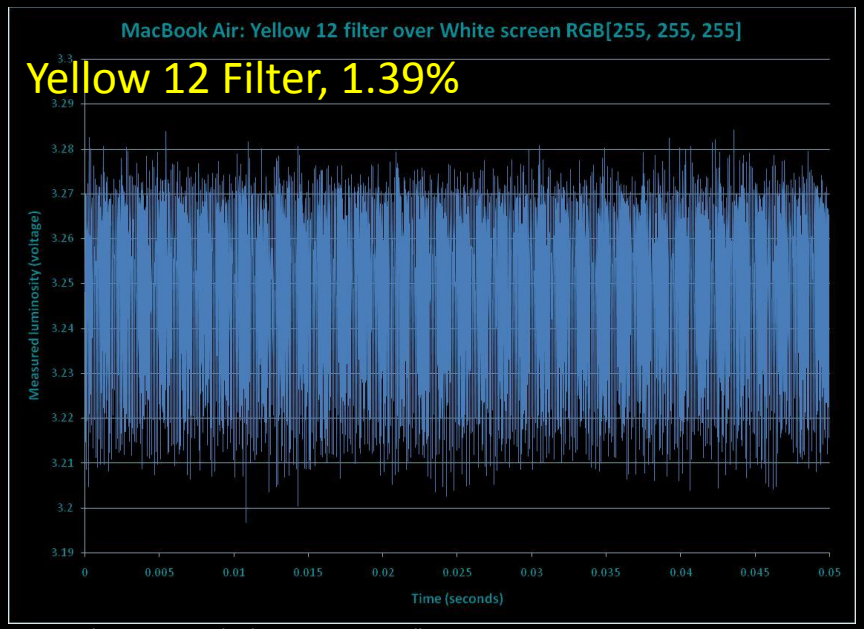
MacBook Air without Nightshift (0.05s, zoomed y-axis)



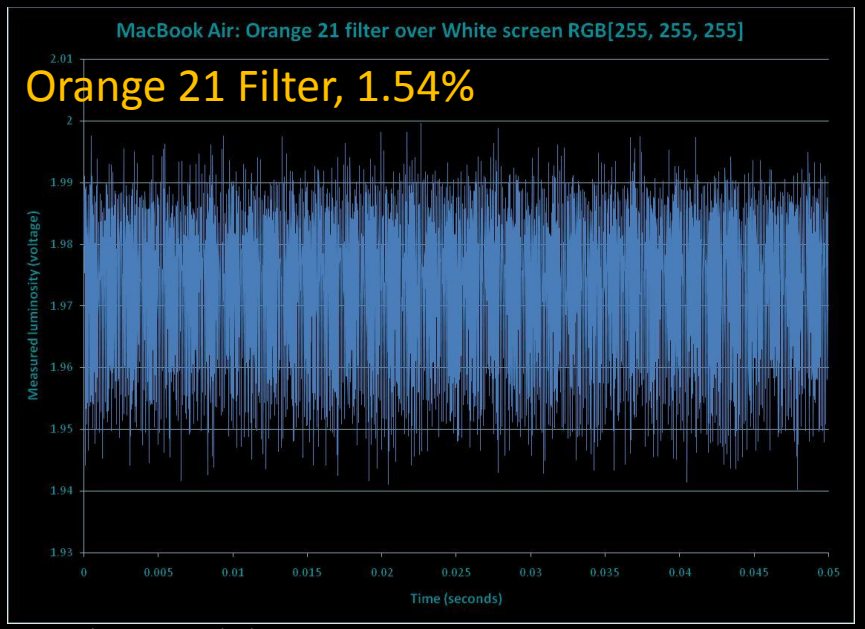
MacBookAirMonitor_100Bright_255_255_255c



MacBookAirMonitor_100bright_255_255_255c_Blue80A

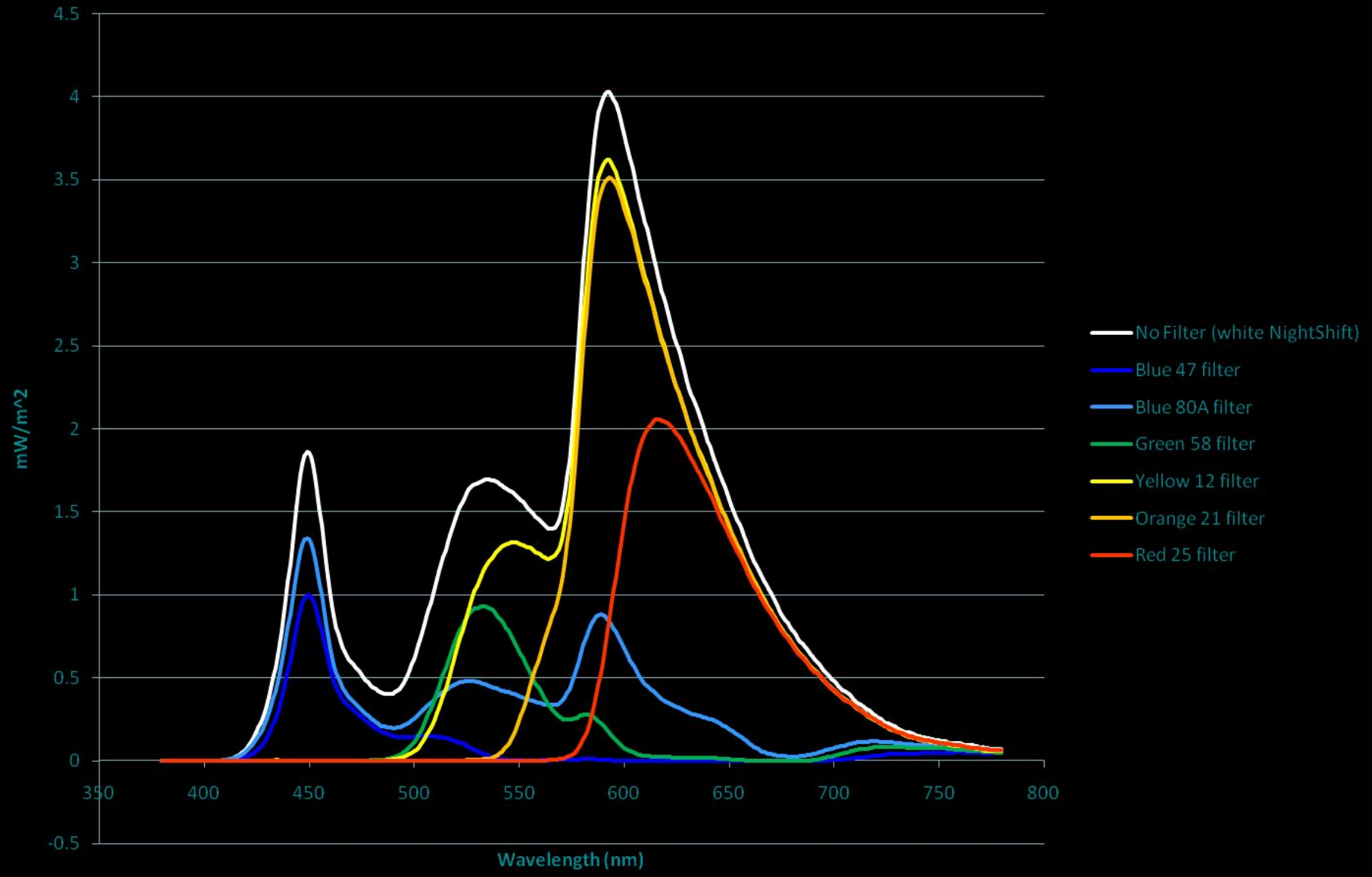


MacBookAirMonitor_100bright_255_255_255c_Yellow12



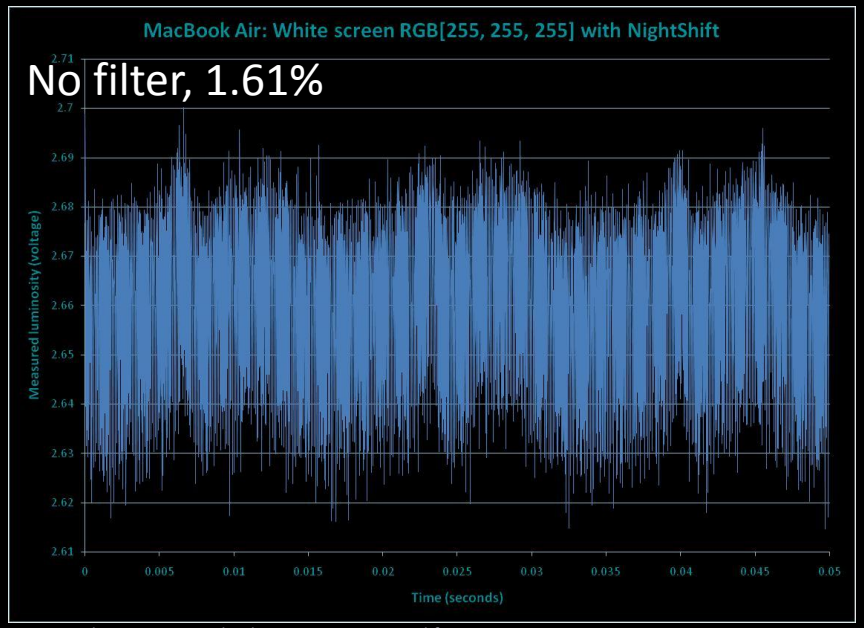
MacBookAirMonitor_100bright_255_255_255c_Orange21

Spectra of MacBook Air white [255,255,255] Nightshift screen with glass color filters over spectrophotometer sensor

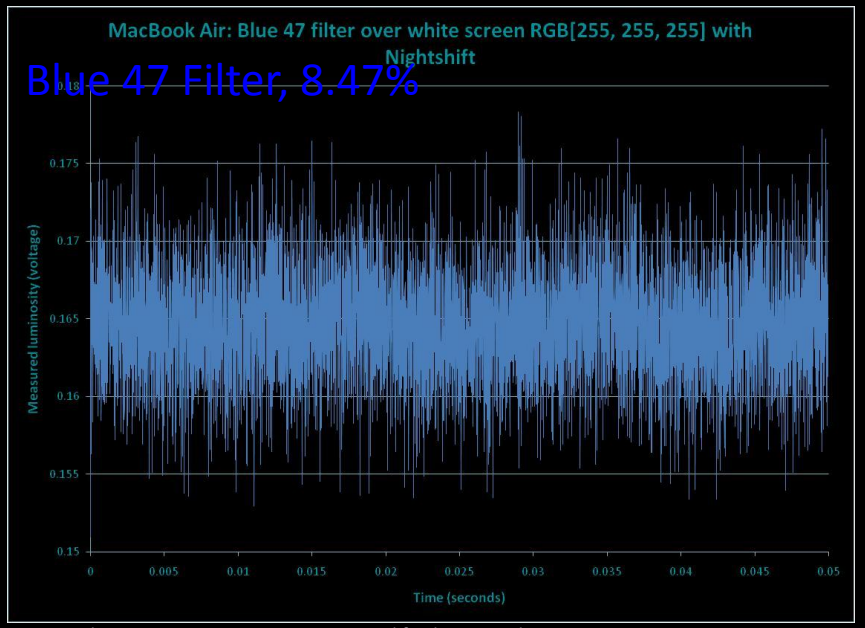


File: MacBookAirSpectra_Nightshift_Filters

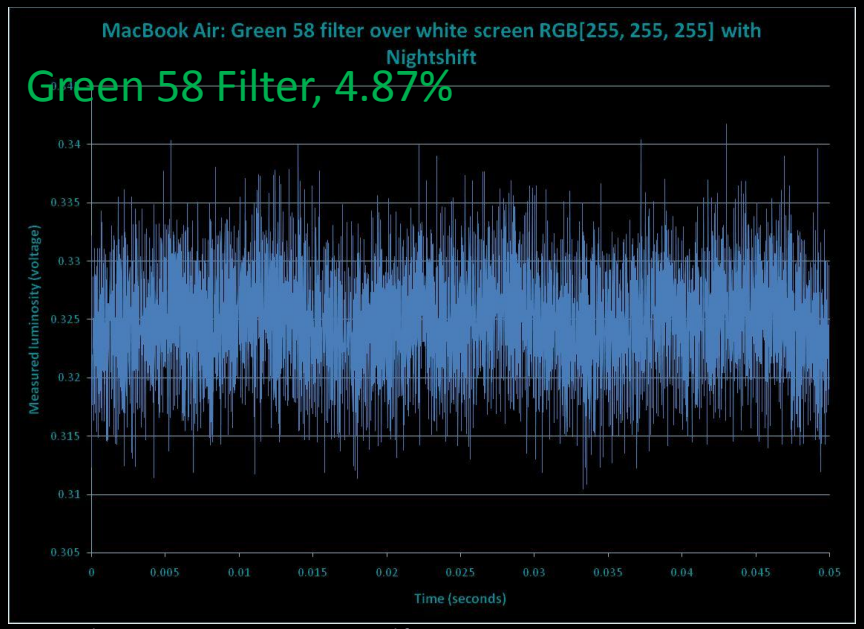
MacBook Air with Nightshift (0.05s, zoomed y-axis)



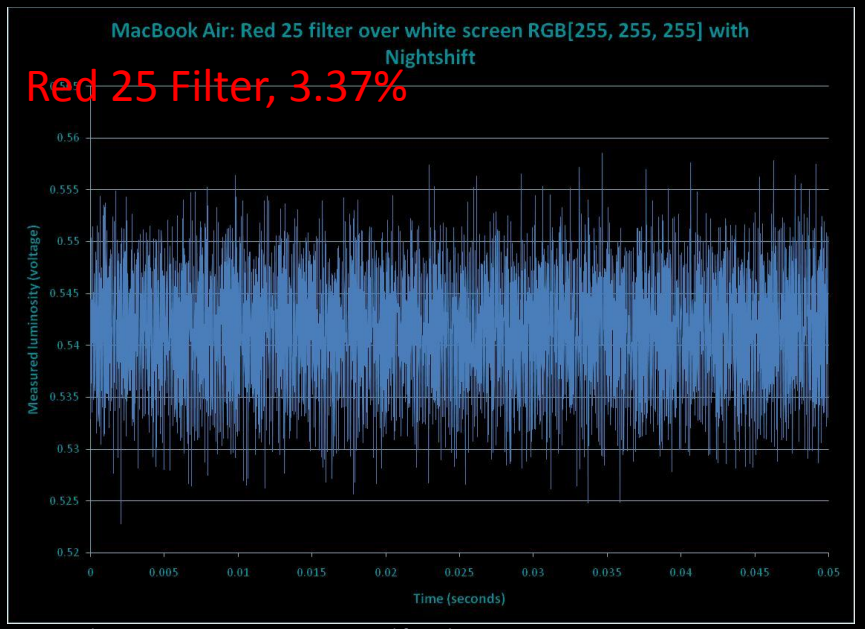
MacBookAirMonitor_100bright_255_255_255c_NtShft



MacBookAirMonitor_100Brt_255_255_255_NtShft_Blue47_graphs

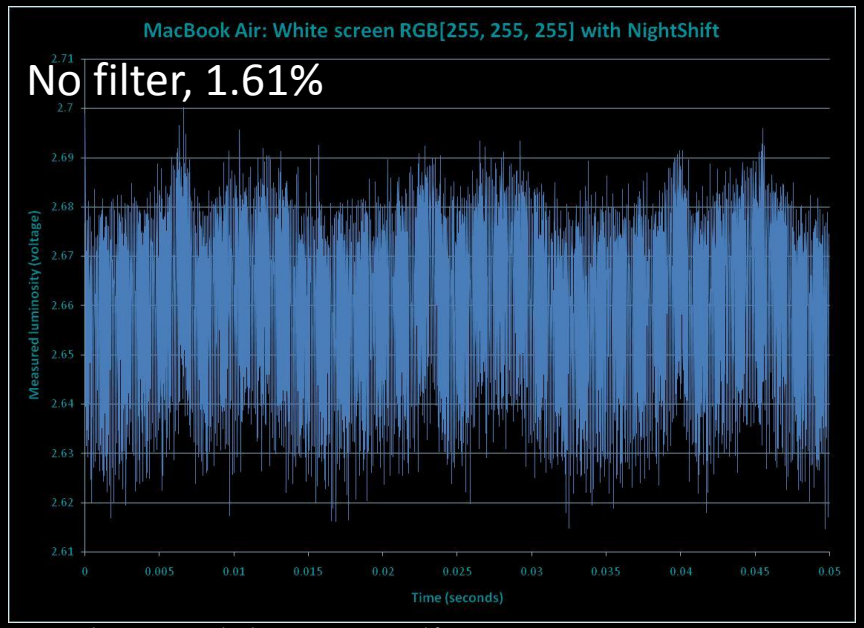


MacBookAirMonitor_100Brt_255_255_255_NtShft_Green58

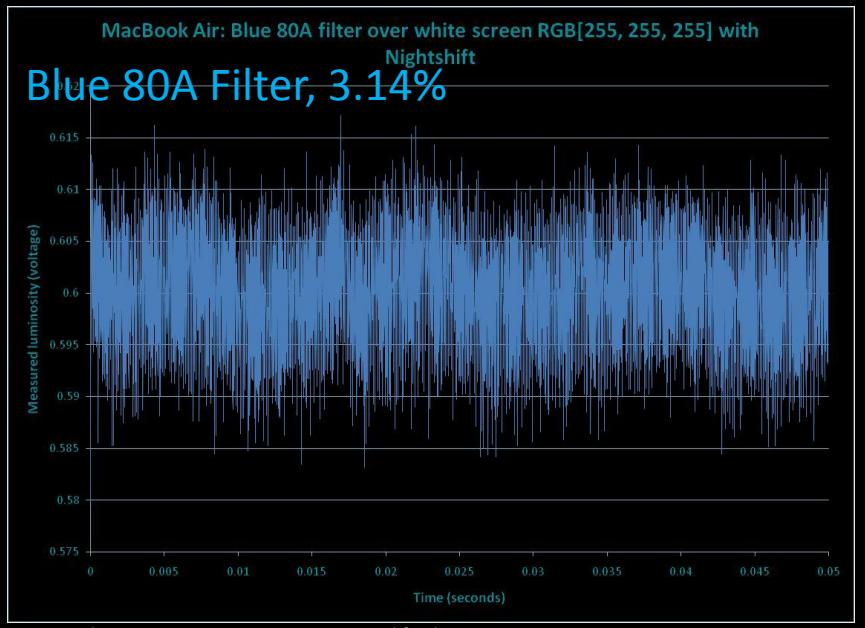


MacBookAirMonitor_100Brt_255_255_255_NtShft_Red25

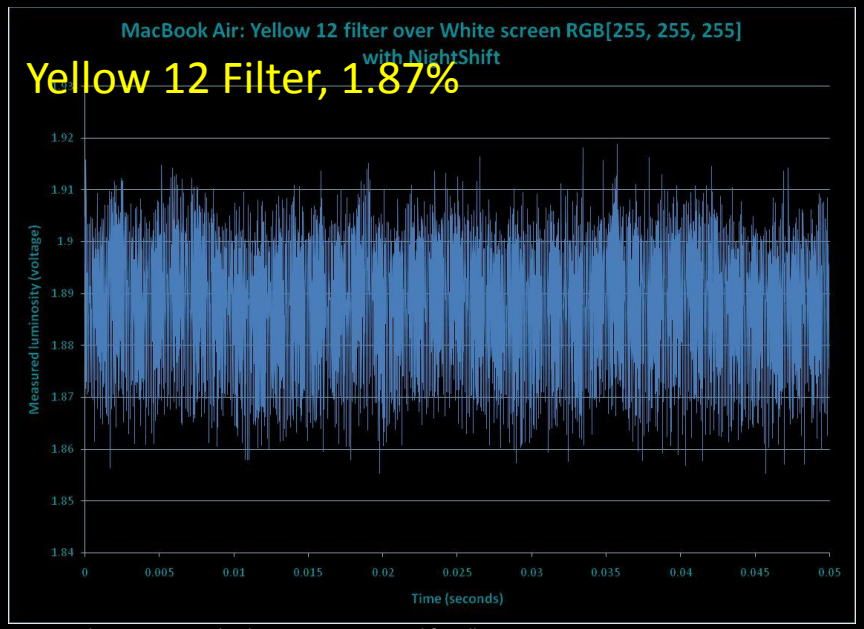
MacBook Air with Nightshift (0.05s, zoomed y-axis)



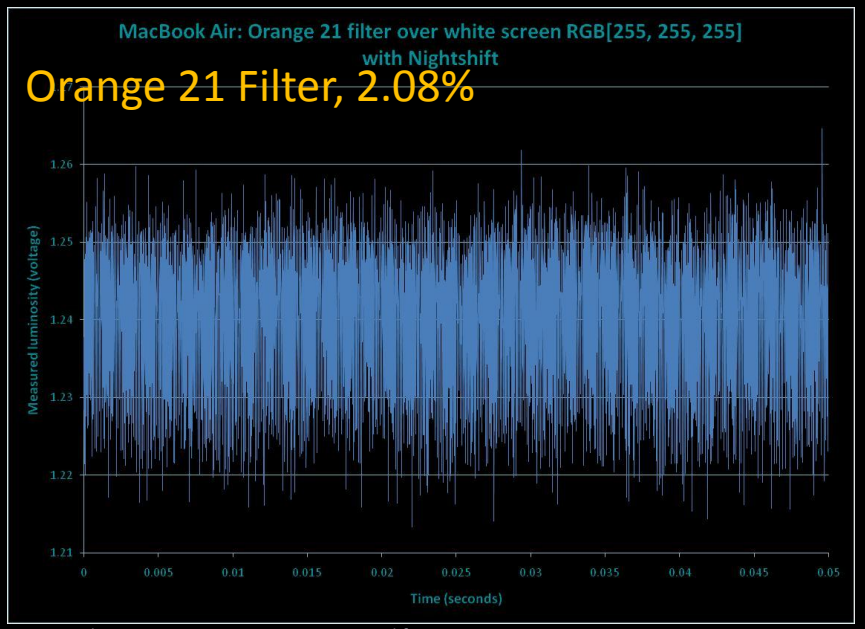
MacBookAirMonitor_100bright_255_255_255c_NtShft



MacBookAirMonitor_100Brt_255_255_255_NtShft_Blue80A



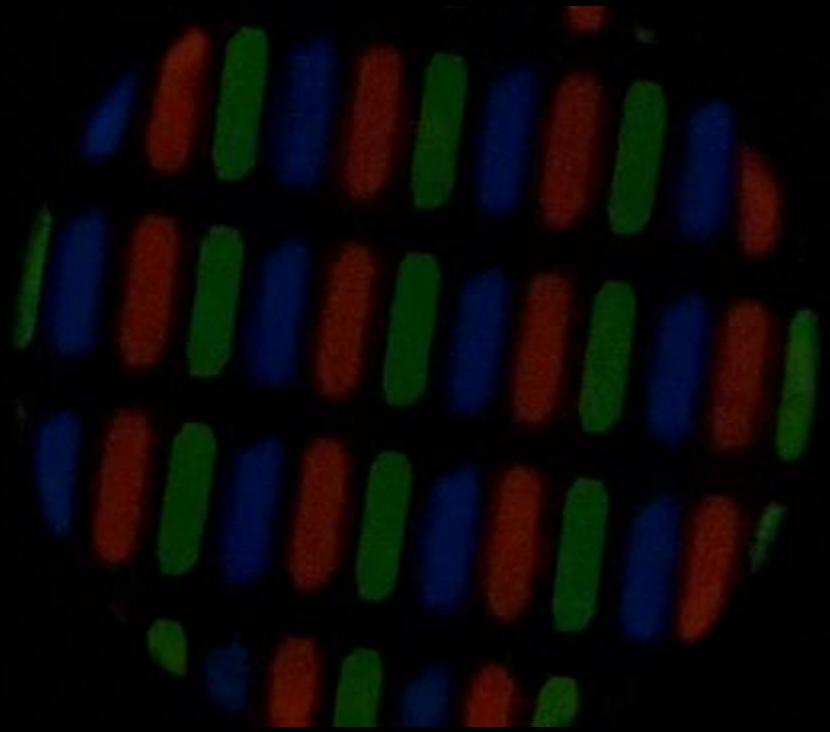
MacBookAirMonitor_100bright_255_255_255c_NtShft_Yellow12



MacBookAirMonitor_100Brt_255_255_255_NtShft_Orange21

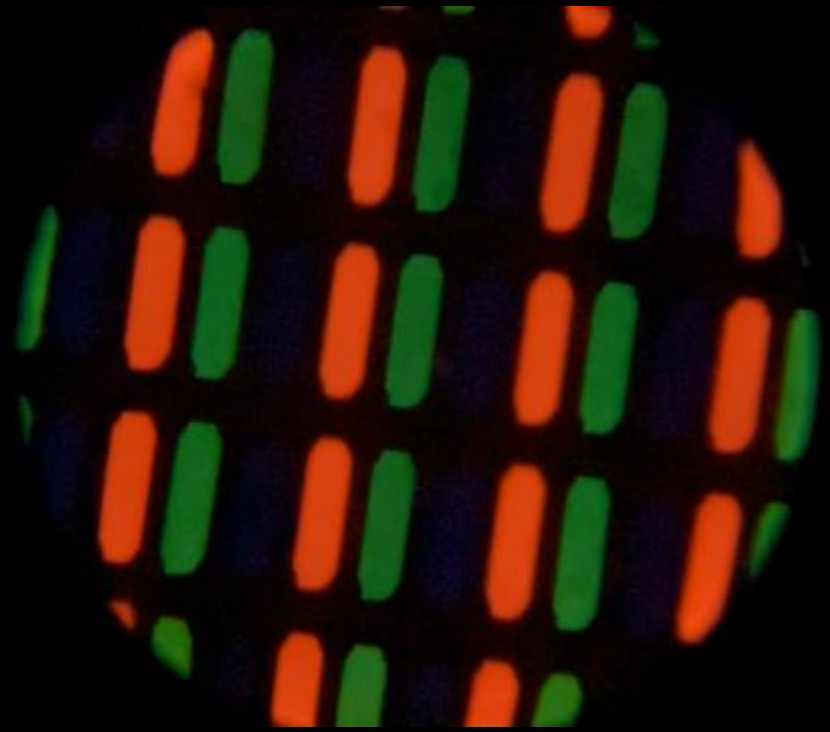
MacBook Air, White (255,255,255): Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames

Without Nightshift



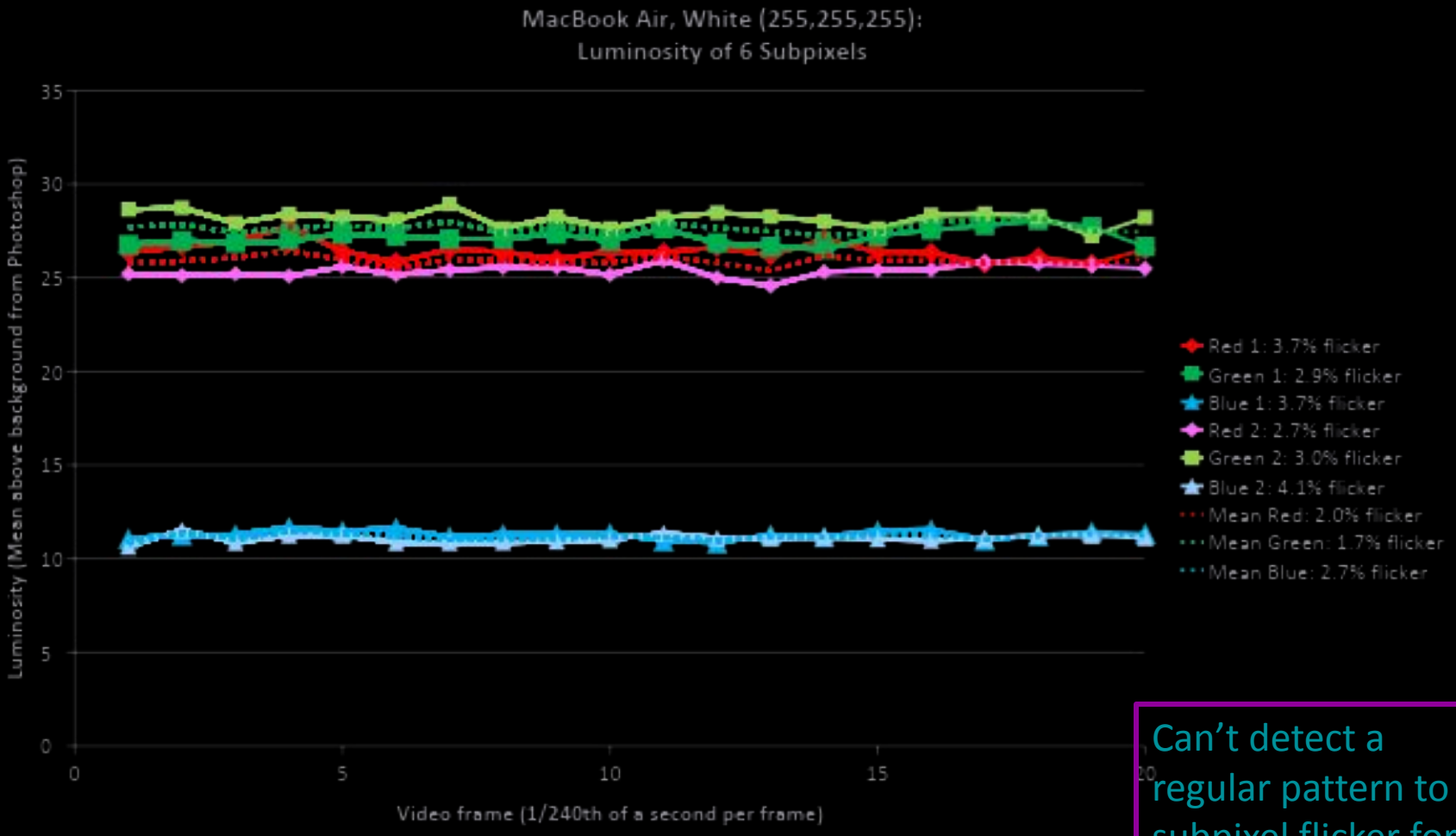
MMNT_20230915_233310961_MacBookAir_255_255_255

With Nightshift



MMNT_20230915_233212289_MacBookAir_255_255_255_NtSft

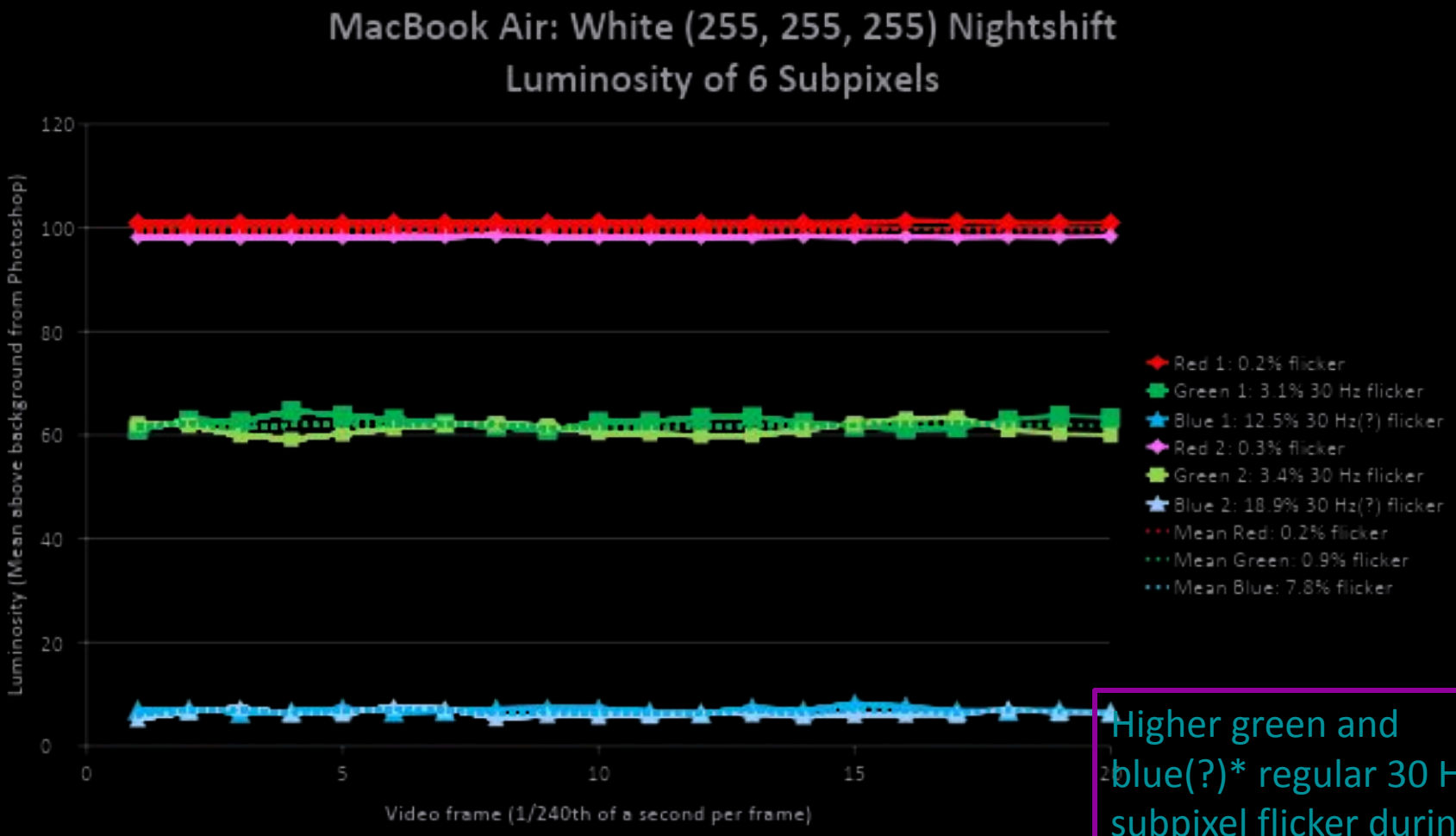
MacBook Air, White (255,255,255): Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames



Can't detect a regular pattern to subpixel flicker for a white screen without Nightshift

Pixel_Flicker_MacBookAir13_240fps

MacBook Air, White (255,255,255) Nightshift : Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames



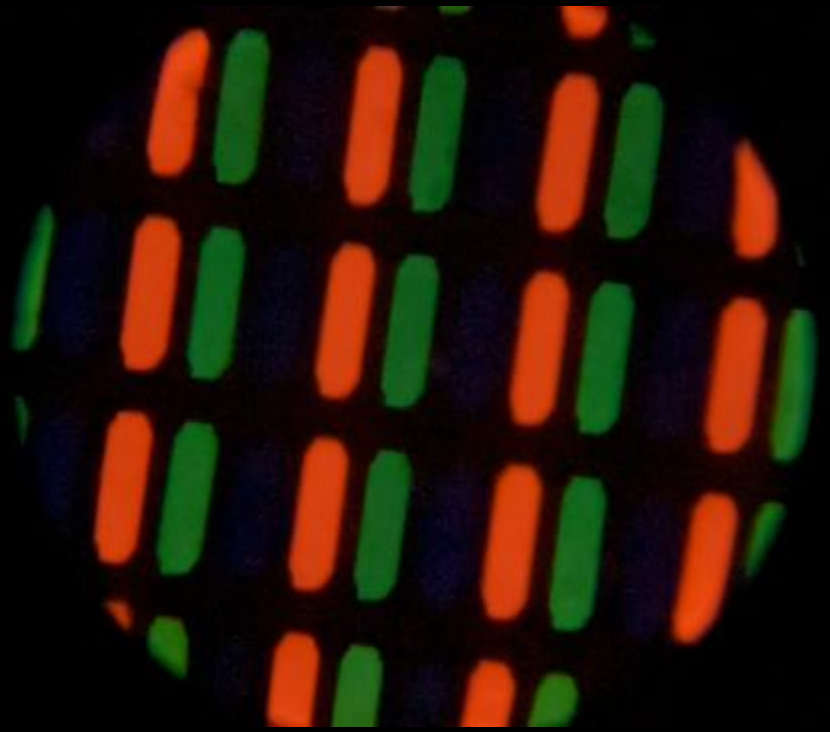
Higher green and blue(?)* regular 30 Hz subpixel flicker during Nightshift

*Low signal/high noise for blue; need higher exposure video for blue

Pixel_Flicker_MacBookAir13_240fps

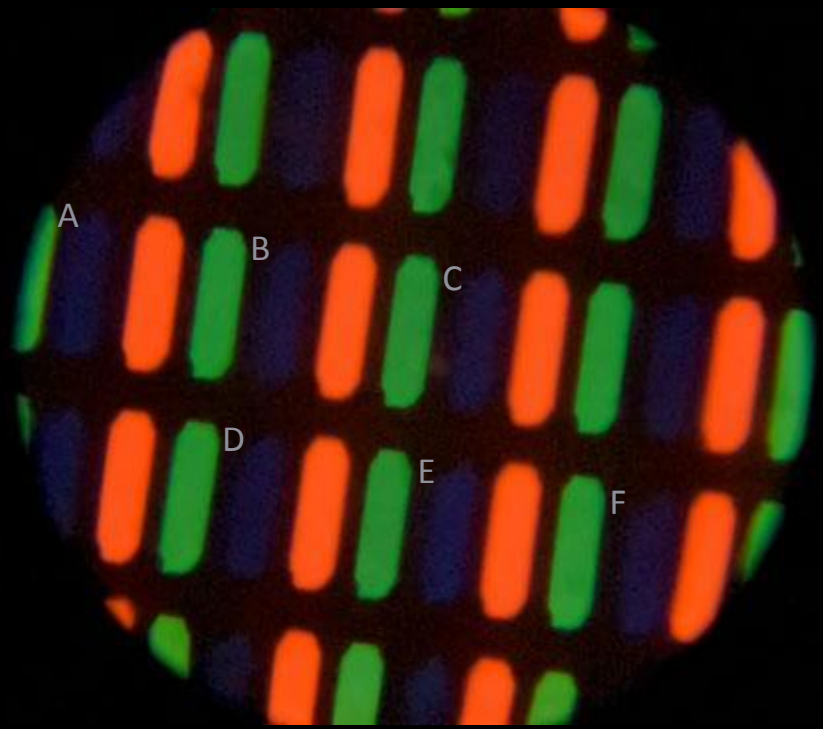
MacBook Air, White (255,255,255): Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames

With Nightshift (previous slide)



MMNT_20230915_233212289_MacBookAir_255_255_255_NtSft

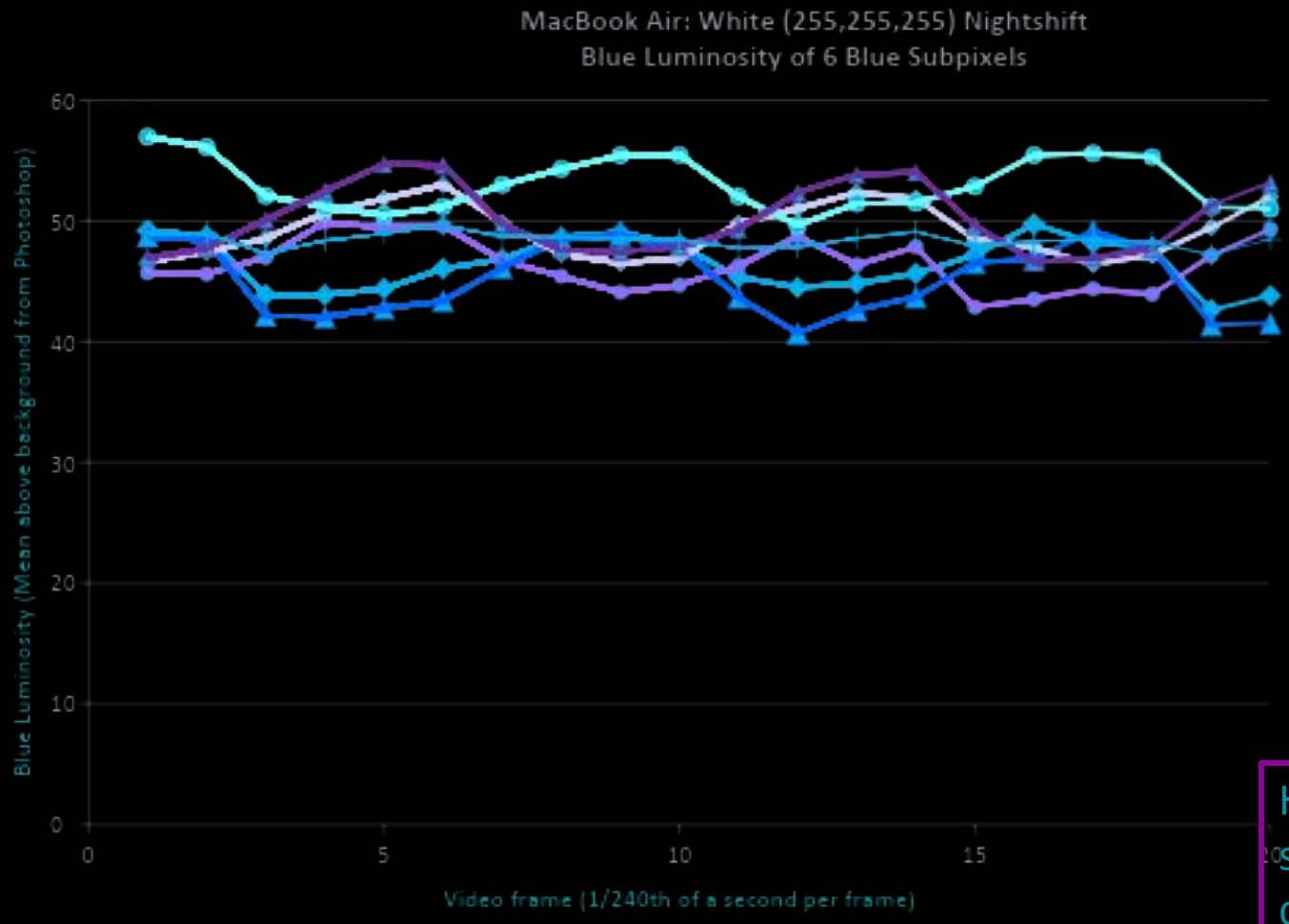
With Nightshift (next slide)



250X magnification

MMNT_20230915_233224665_MacBookAir_255_255_255_NtSft

MacBook Air, White (255,255,255) Nightshift : Photoshop quantification of blue subpixel blue* luminosity in consecutive 240 fps microscope video frames



*Blue histogram values measured instead of luminosity histogram values in Photoshop to minimize the influence of bleed from much brighter adjacent red and green subpixels

High blue 30 Hz subpixel flicker during Nightshift

Pixel_Flicker_MacBookAir13_240fps

Nightshift on the MacBook Air is worse for causing symptoms than without Nightshift

UPRTek meter:

- 60 Hz zigzag flicker predominately in blue/green during Nightshift.
  - Seems similar to low to mid-range G or B data in single color channel tests without Nightshift
- Banding, but little 60 Hz zigzag flicker in orange/red during Nightshift.
  - Seems similar to high (R, 0,0) data in single color channel tests without Nightshift

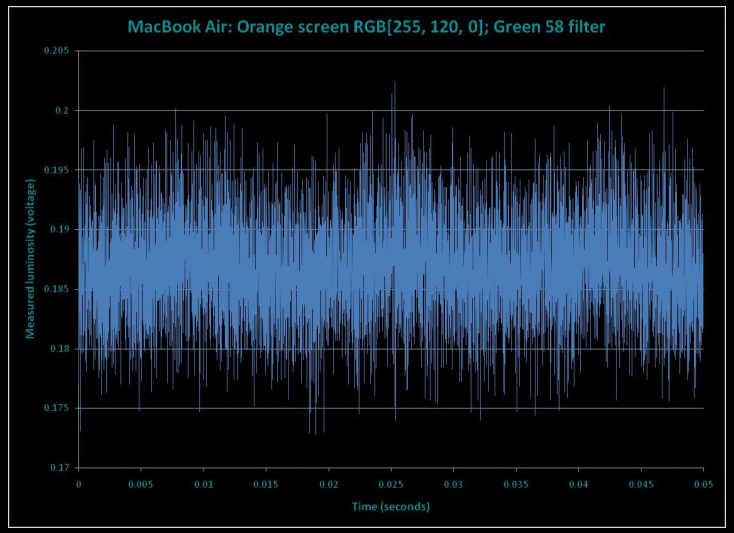
Microscope:

- 30 Hz zigzag flicker predominately in blue/green during Nightshift. Different subpixels flicker in opposite phases
  - Does the average of 30 Hz flicker create the 60 Hz flicker detected with the meter?
- Banding is too rapid to detect with the microscope/camera.
- Uneven pulsing of luminosity across the area of subpixels is visible in videos.

Nightshift on the MacBook Air is worse for causing symptoms than without Nightshift

- Does the increased 30 Hz subpixel flicker and/or increased 60 Hz flicker in blue/green compared to red channels contribute to why Nightshift is more inducing of concussion-like symptoms than without Nightshift?
  - Are the red and blue/green flicker more out-of-sync with each other, creating more color-to-color flicker with Nightshift?
  - To what extent does the increased brightness flicker in those color channels contribute to causing symptoms (independent of any color-to-color flicker effects)?

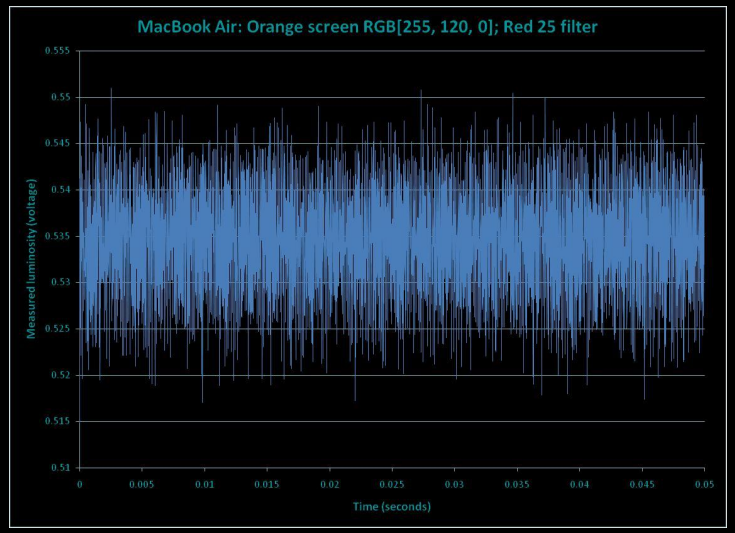
Example of different flicker in different color channels (nearly all colors are in this category)



7.95%

255, 120, 0

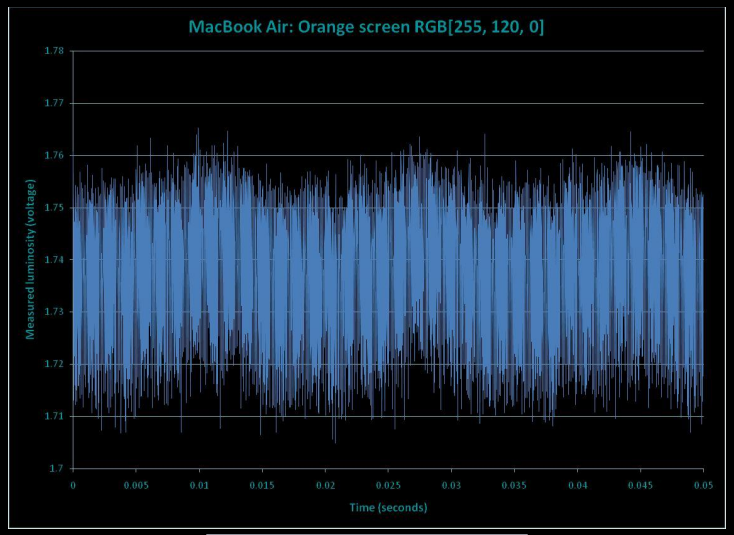
Green 58 Filter



3.60%

255, 120, 0

Red 25 Filter



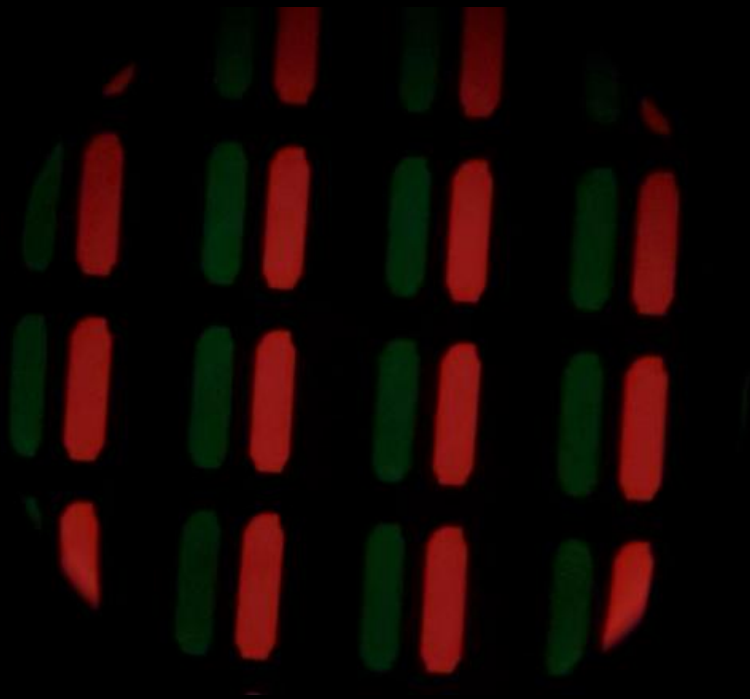
1.91%

255, 120, 0

No Filter

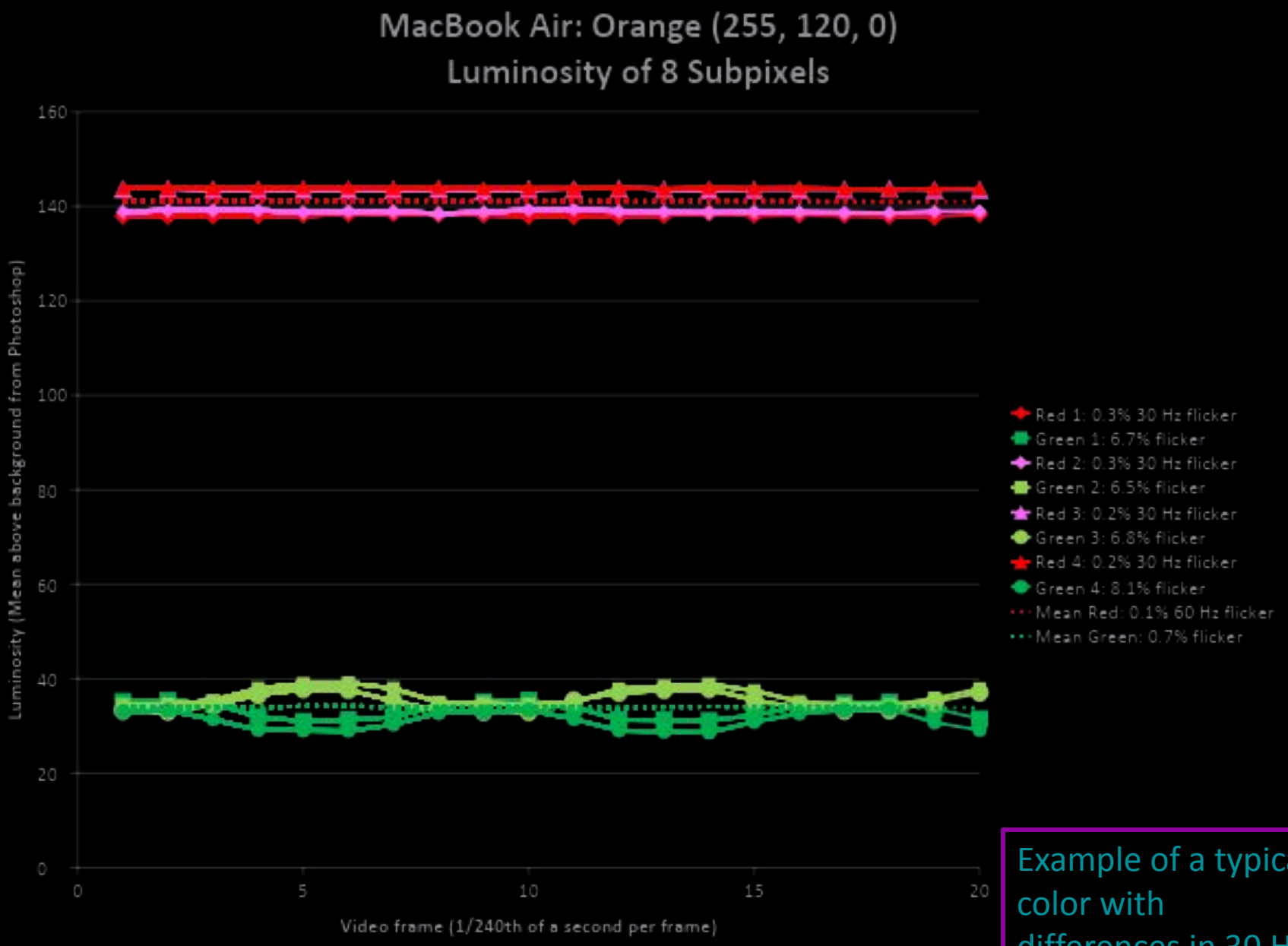
0.05s, zoomed y axis

MacBook Air, Orange (255, 120, 0): Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames



MMNT_20230924_225827186_255_120_0

250X magnification



Example of a typical color with differences in 30 Hz flicker for different color channels.

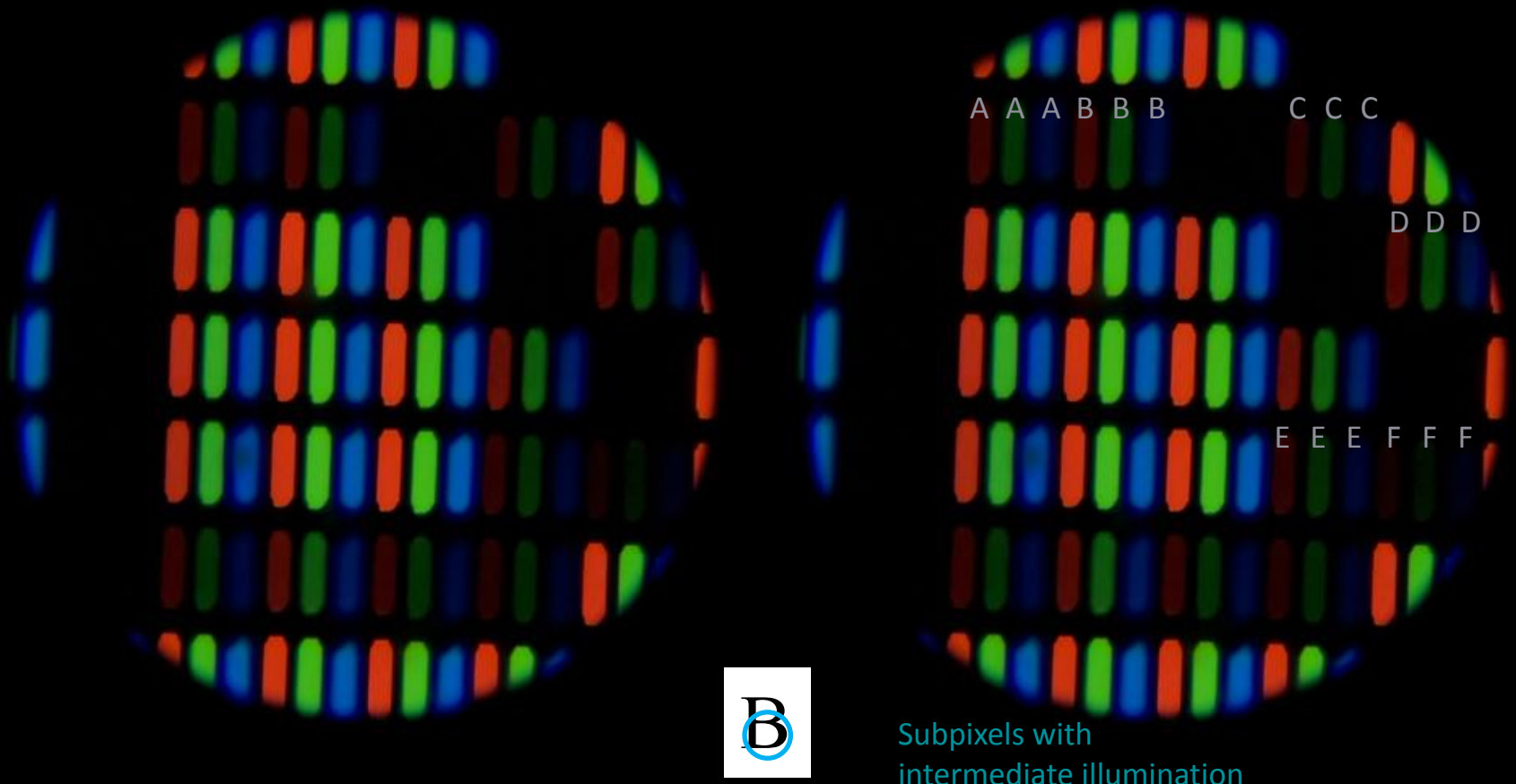
Pixel_Flicker_MacBookAir13_240fps

Flicker of mixed RBG colors

- Flicker patterns detected with color filters and the UPRTek meter differ with different color filters. Mid-range colors have 60 Hz flicker and saturated (255) colors show little 60 Hz flicker, but show the banding flicker pattern.
  - Such differences may result in color-to-color flicker.
- Based on microscope data, does having significant 30 Hz subpixel flicker lead to having a 60 Hz flicker pattern that can be detected with the meter?
- Is the noisiness in the 60 Hz flicker measurements for mid-range RGB values with the meter due to the variation in 30 Hz flicker in different subpixels?

MacBook Air: Font smoothing uses flicker

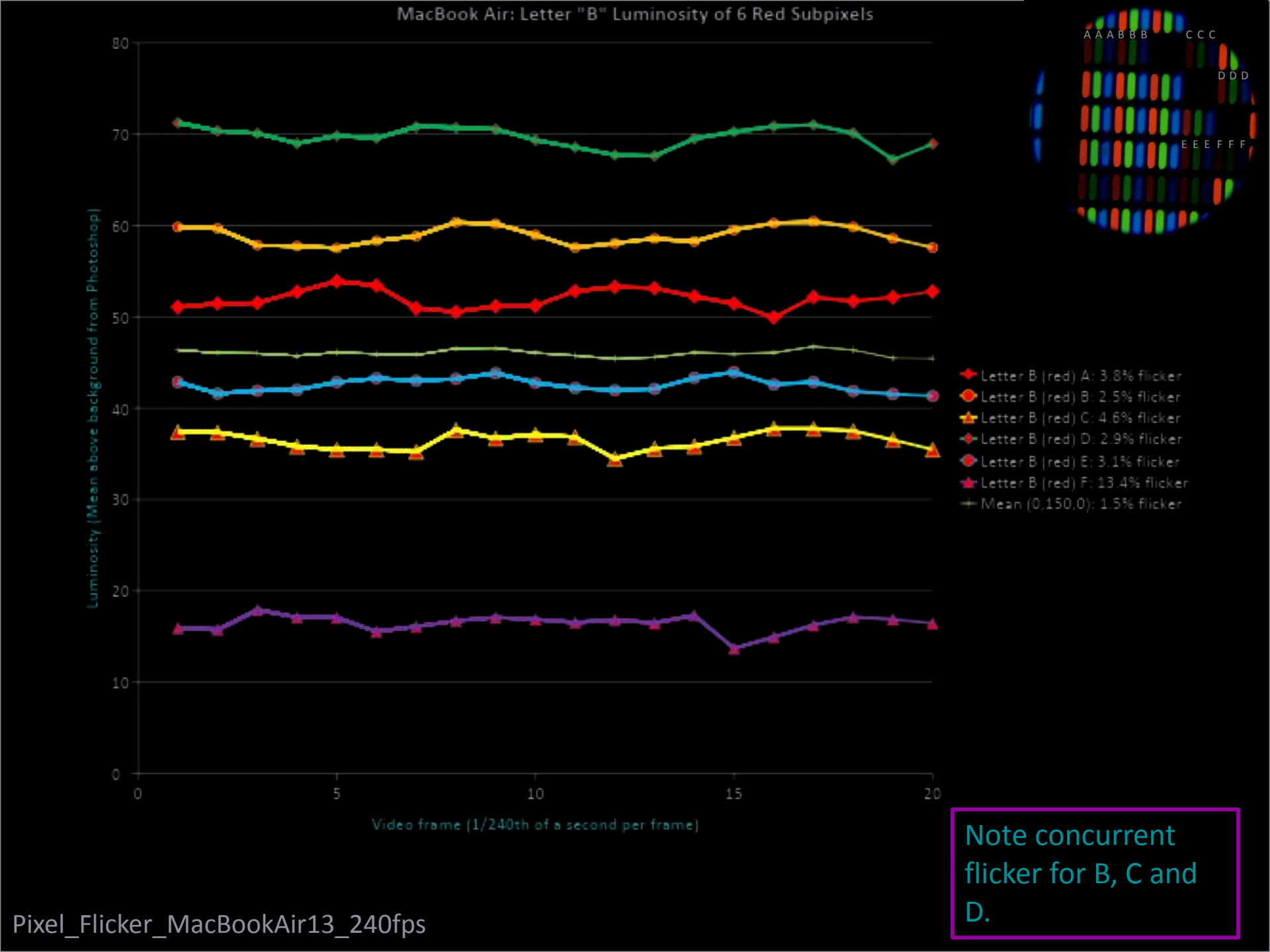
MacBook Air, Black Letter “B” on white in Microsoft Word, 12 pt Times New Roman, “use font smoothing” system setting off: Photoshop quantification of subpixel luminosity in consecutive 240 fps microscope video frames



Subpixels with intermediate illumination noticeably flicker in the video. Quantified subpixels labeled.

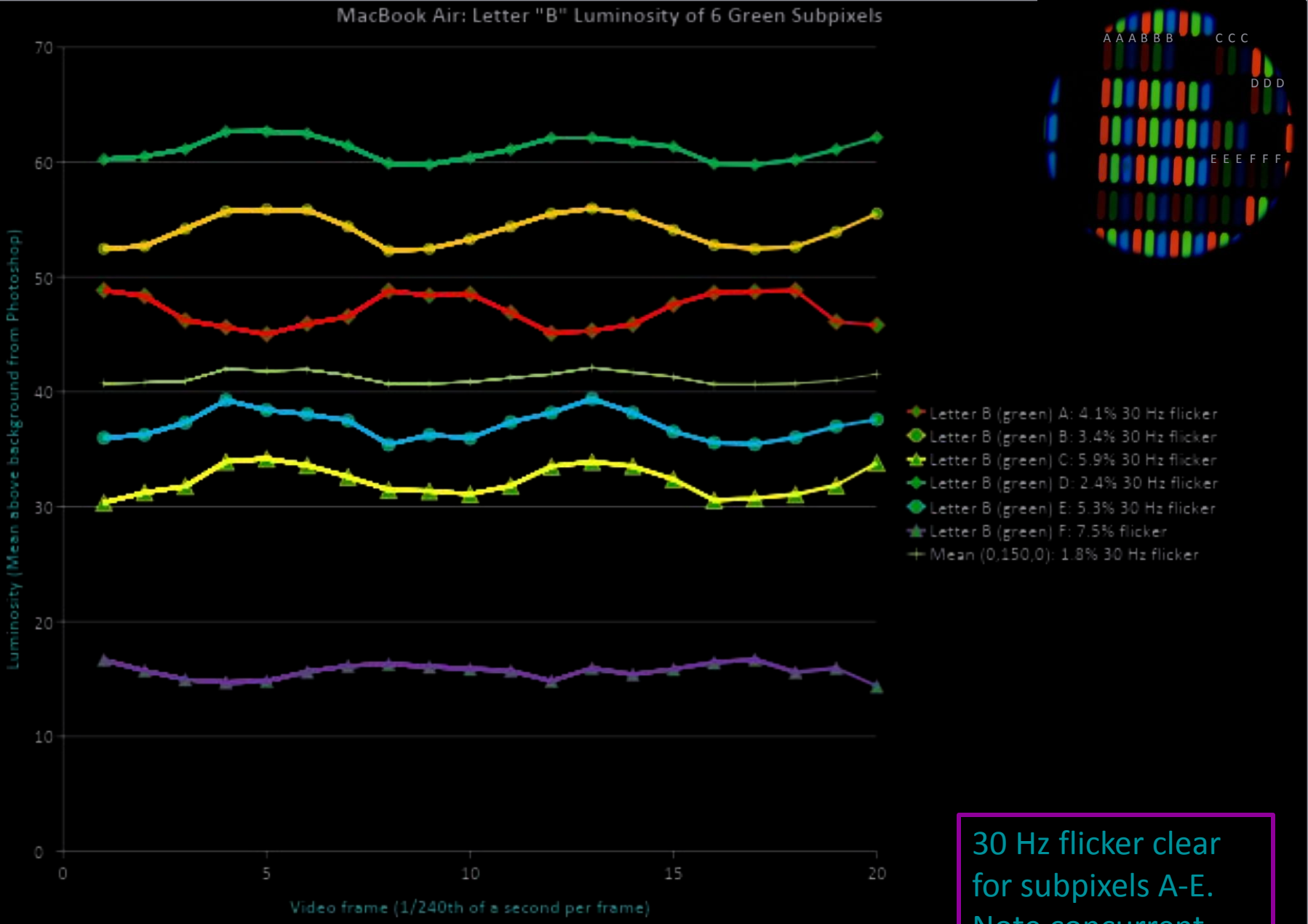
MMNT_20230930_215938212_LetterB

120X magnification



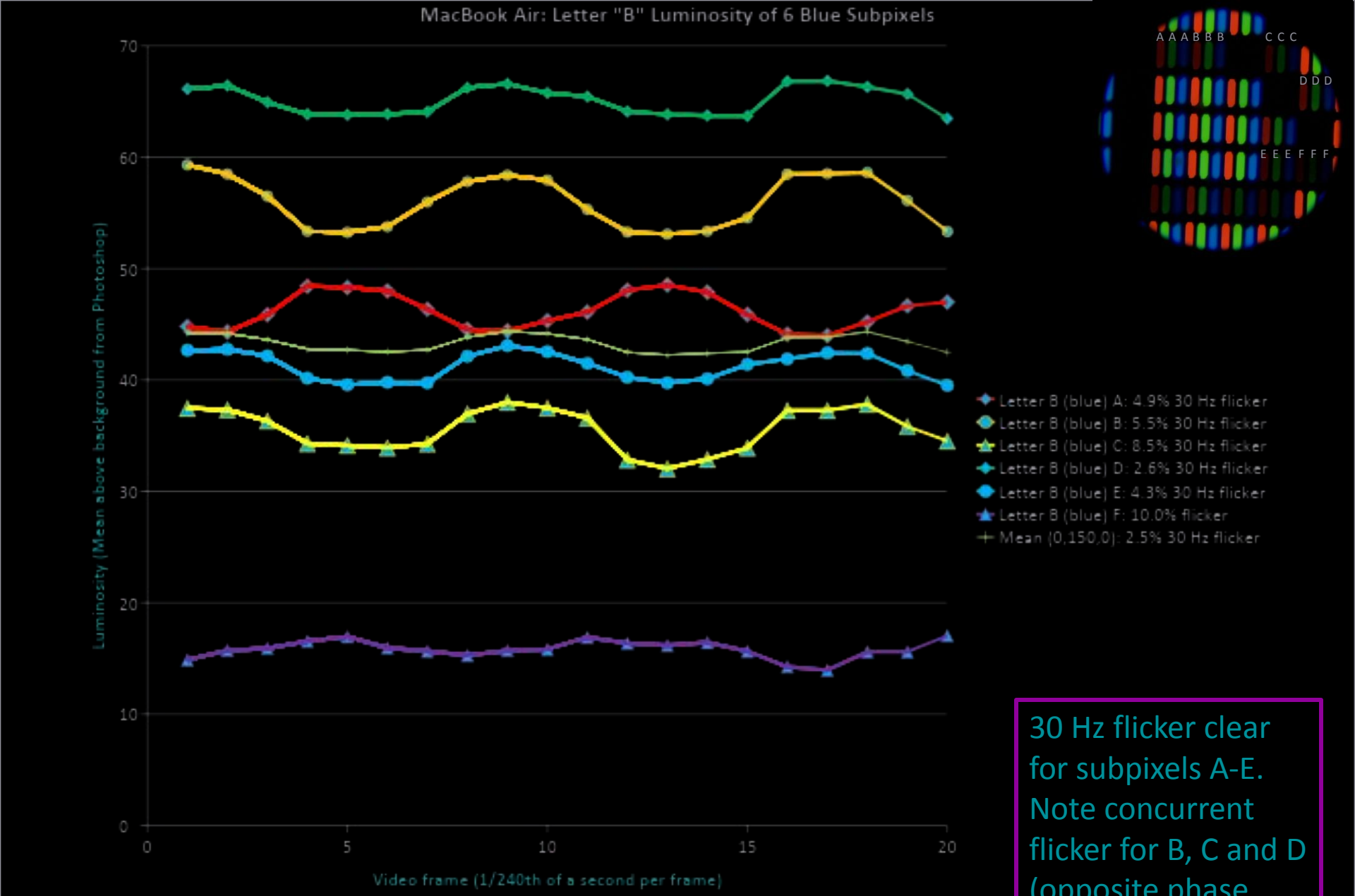
Note concurrent flicker for B, C and D.

Pixel_Flicker_MacBookAir13_240fps



30 Hz flicker clear for subpixels A-E. Note concurrent flicker for B, C and D.

Pixel_Flicker_MacBookAir13_240fps



30 Hz flicker clear for subpixels A-E. Note concurrent flicker for B, C and D (opposite phase compared to green).

Pixel_Flicker_MacBookAir13_240fps

Flicker of text

- The 30 Hz subpixel flicker used for font smoothing occurs in 2 alternating subpixel groups.
- The 2 subpixel groups occur in every other pixel.
- Smoothed areas of letters may over-represent one of the two flicker patterns in subregions, creating local areas of high 30 Hz flicker that cannot average to low 60 Hz flicker, such as in pixels B, C, and D in the previous slides. Also note that in these areas, there is high color-to-color flicker as the green flicker is in the opposite phase compared to the red and blue flicker within each pixel.
- Similarly, complex graphics may have subregions of high 30 Hz flicker, including color-to-color flicker, depending on the pattern of pixel illumination.

MacBook Air displayed on Dell CCFL Monitor

- If the MacBook Air is connected to the Dell monitor for display, the flicker patterns are very similar to those when the Dell Desktop computer is connected to the Dell Monitor.
- The patterns on the MacBook Air display are not seen. The “overlapping feather” pattern is not present and the 60 Hz pattern is different from that on the MacBook Air screen.
- This has been measured for specific RGB colors. Data (not shown here) for MacBook Air displayed on Dell Monitor in folder: MacBookAir13/ MacBookAir_sRGB_DellMonitor_100Bright

Questions

- How do backlight flicker, subpixel flicker, and temporal dithering contribute to the measured flicker?
- Why is there 60 Hz flicker at mid-color values, but not when the RGB values are brightest? Is adding 30 Hz subpixel flicker a strategy for reducing color channel luminosity? Does that then average to be the 60 Hz flicker?
- Is the “overlapping feather” flicker pattern due to backlight flicker or something else? It’s present throughout backlight dimming range, but increases in depth of flicker, especially In the lowest half of the dimming range.
- If there is temporal dithering of colors, how could it be detected? Temporal dithering could occur in a complex 2-dimensional pattern. Normal 30 Hz subpixel flicker could make it hard to find.

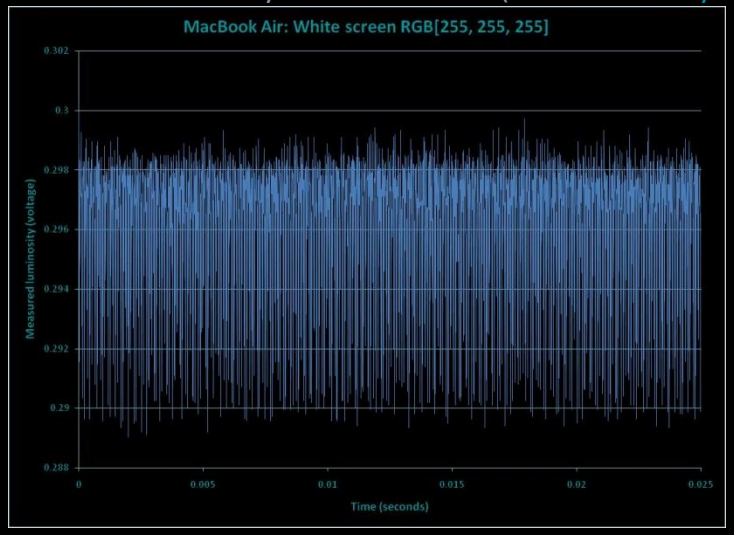
Questions

- Is the “overlapping feather” pattern of flicker part of the reason why this screen is so rapidly inducing of concussion-like symptoms for me? The pattern is somewhat similar to, although seemingly of higher frequency than, the dimmed pattern of flicker for the DEEPLite LED battery-powered lamp, which may be the most dangerous concussion symptom-inducing LED light I’ve yet encountered (see HealthData_LightFlicker).
- Likewise, was my prior exposure to the MacBook Air “overlapping feather” flicker a reason why a couple seconds of the DEEPLite were able to trigger such strong immediate shock-like feelings in the head, intense nausea for a few moments afterward, and persistent head pressure for hours?

Brightest MacBook Air vs. Partially Dimmed DEEPLite Lamp

MacBookAir: Luminosity vs. Time: 0.005s (zoomed x and y-axes)

MacBookAir: Luminosity vs. Time: 0.025s (zoomed x and y-axes)

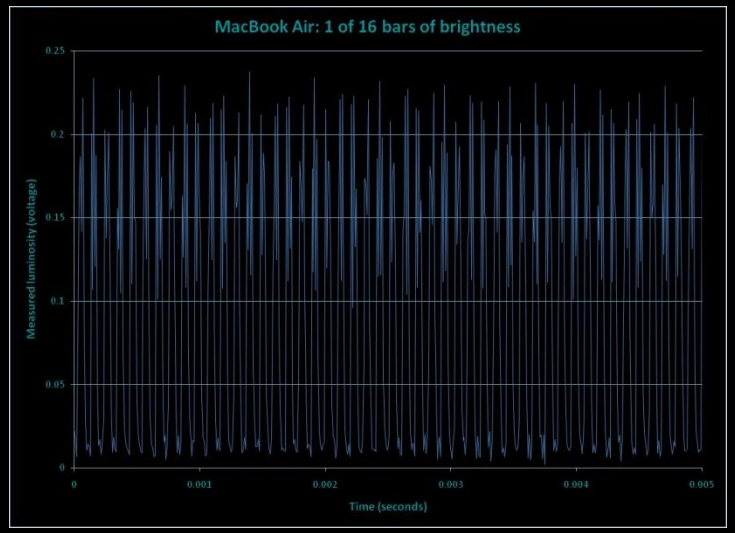


MacBookAirMonitor_100Bright_255_255_255c

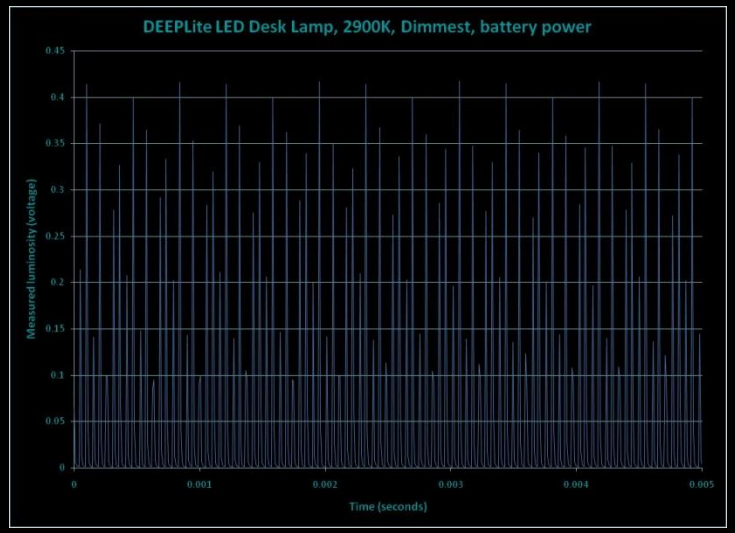
DeepLite: Luminosity vs. Time: 0.025s

Dimmed MacBook Air vs. Dimmed DEEPLite Lamp

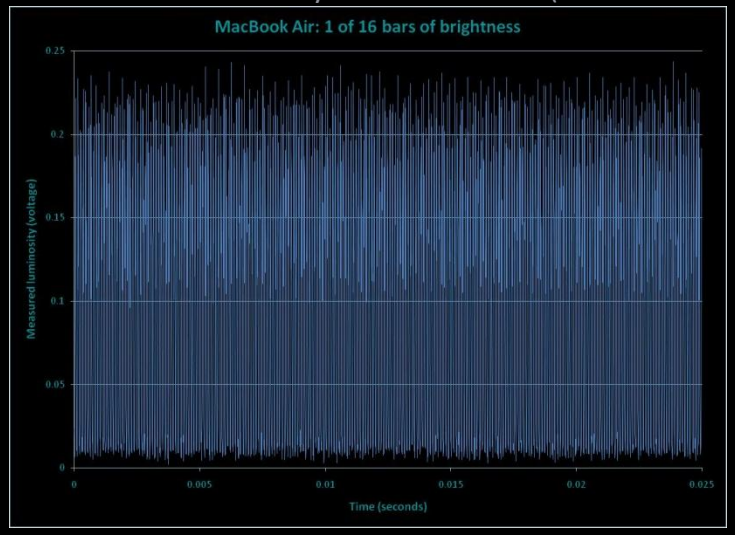
MacBookAir: Luminosity vs. Time: 0.005s (zoomed x-axis)



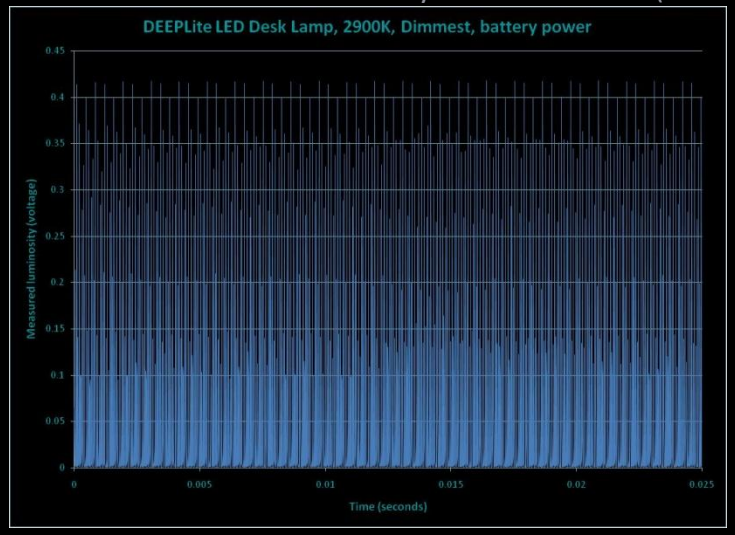
DeepLite: Luminosity vs. Time: 0.005s (zoomed x-axis)



MacBookAir: Luminosity vs. Time: 0.025s (zoomed x-axis)



DEEPLite: Luminosity vs. Time: 0.025s (zoomed x-axis)



File: MacBookAirMonitor_01BarsBright_255_255_255

File: DEEPLite_LED_DeskLamp_dimmest1b

Summary

- How does the color-to-color flicker, which may be a component of many RGB colors, contribute to causing concussion-like symptoms?
- What are the relative roles of 9663 Hz flicker and its “overlapping feather” pattern, 60 Hz flicker, and 30 Hz subpixel flicker in causing concussion-like symptoms?