Phosphor Decay Times of Iiyama HM204DT monitors

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Last modified: May 27, 2005

1 Motivation

In order to perform psychological visual experiments in which stimuli have to be presented for very short times, many scientists use CRT (cathode ray tube) monitors. Such monitors produce their pictures by means of cathode rays that illuminate phosphor of single points on the screen. Immediately after the activation of the phosphor it starts decaying, i. e. the picture starts fading.

If one wants to know how long a picture is presented after its activation one has to measure the time course of this phosphor decay. This was done here by a photodiode and an oscilloscope for the monitor *Iiyama HM204DT*.

2 Procedure

The monitor was run with a resolution of 800x600 and a frame rate of 200 Hz. The contrast was set to 100%. Three levels of brightness have been taken into account: 0%, 50%, and 100%.

For each brightness, the colors red, green, blue, and white were measured, and for each color three different pictures: One single horizontal line on a black background, 10 successional horizontal lines on a black background, and finally the whole screen. Most measurements have been repeated for five times, a few were performed only once.

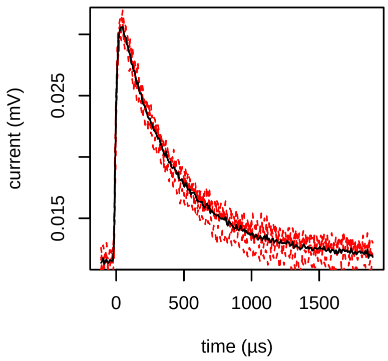
3 Results

3.1 Single measurements

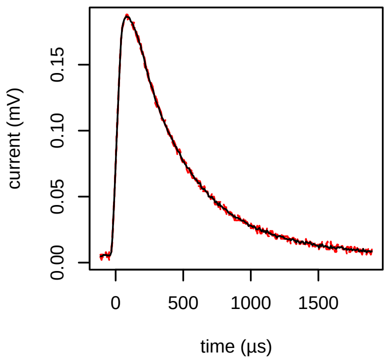
The following figures show the single measurements. Dotted lines represent the measured values, solid lines the means over the respective trials. If there was only one single measurement in a condition then this is represented by a single solid line.

3.1.1 Brightness 0%

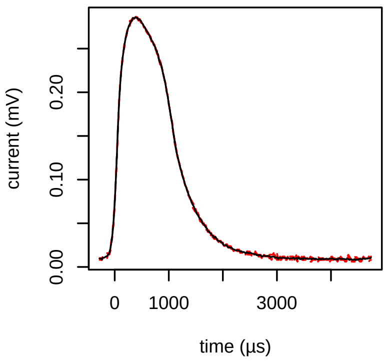
Brightness: 0%, Red, 1 Line(s)



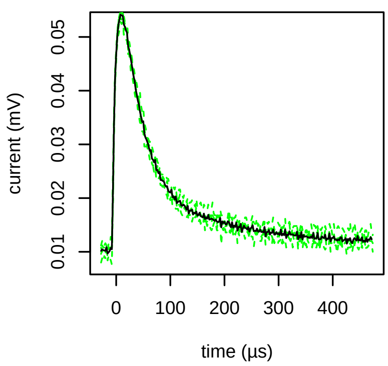
Brightness: 0%, Red, 10 Line(s)



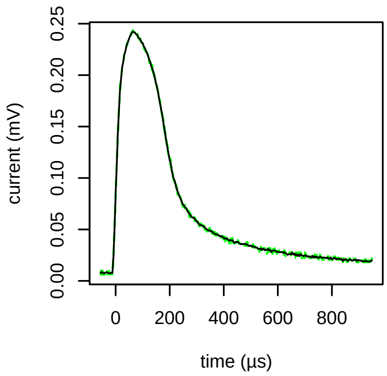
Brightness: 0%, Red, Fullscreen



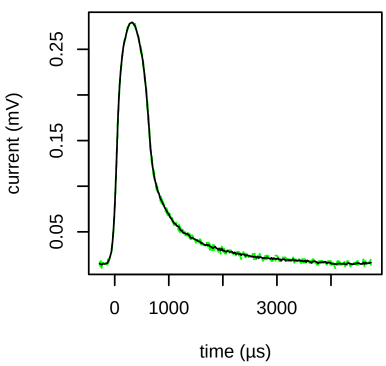
Brightness: 0%, Green, 1 Line(s)



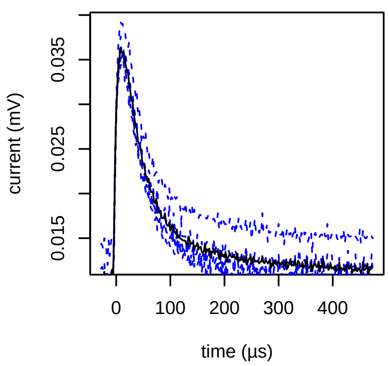
Brightness: 0%, Green, 10 Line(s)



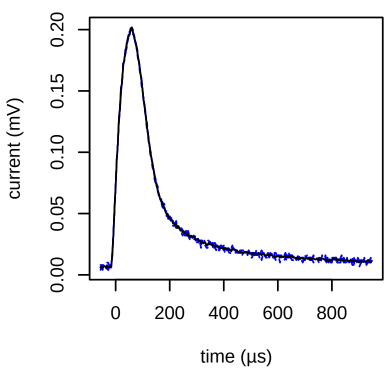
Brightness: 0%, Green, Fullscreen



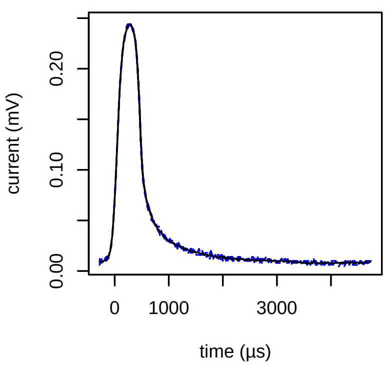
Brightness: 0%, Blue, 1 Line(s)



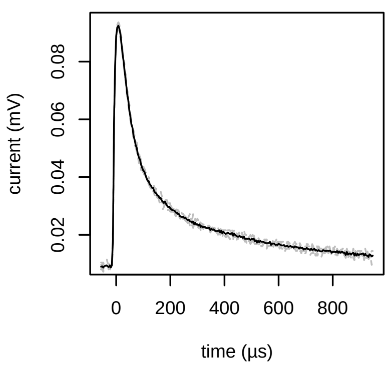
Brightness: 0%, Blue, 10 Line(s)



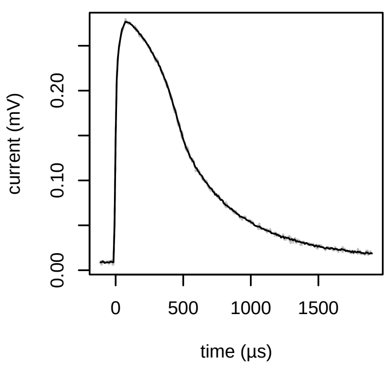
Brightness: 0%, Blue, Fullscreen



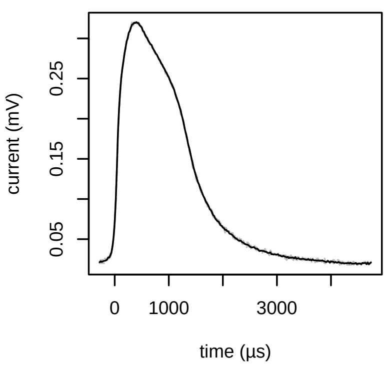
Brightness: 0%, White, 1 Line(s)



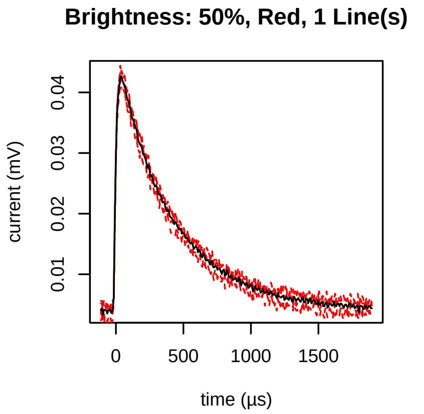
Brightness: 0%, White, 10 Line(s)

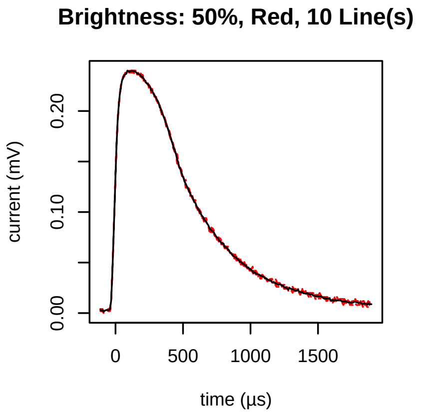


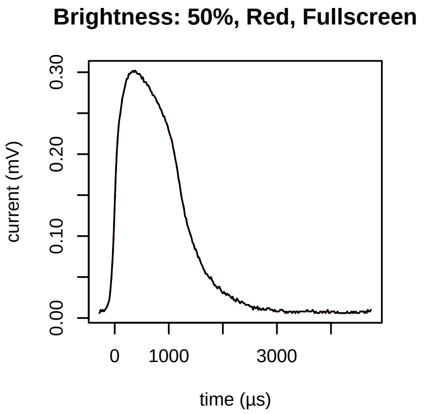
Brightness: 0%, White, Fullscreen

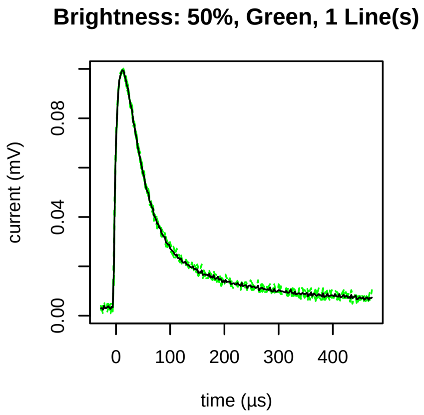


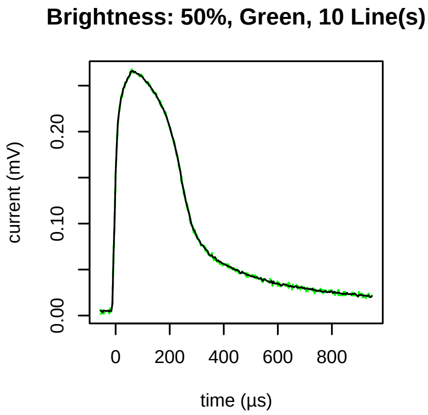
3.1.2 Brightness 50%

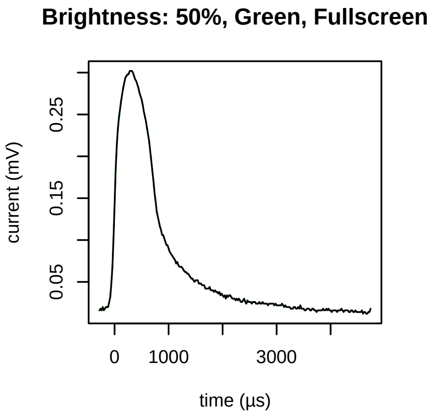


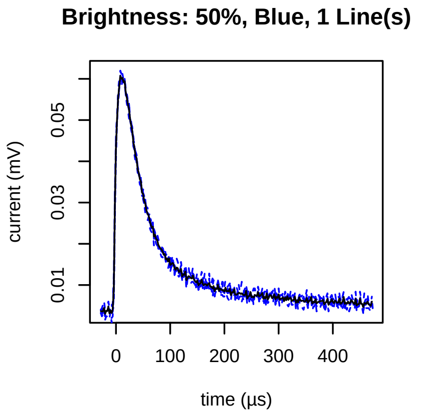


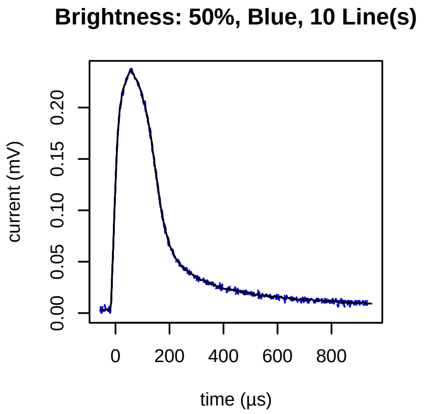


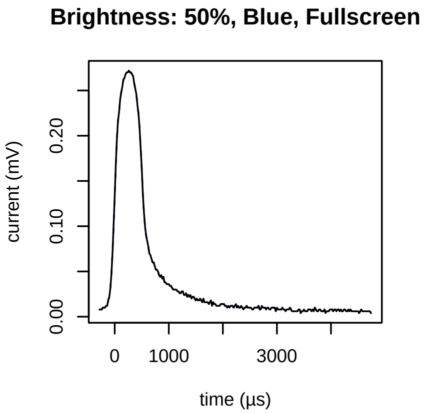


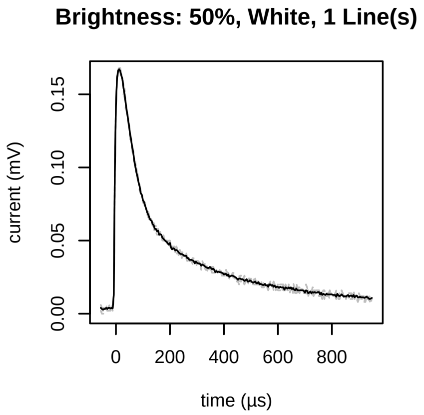


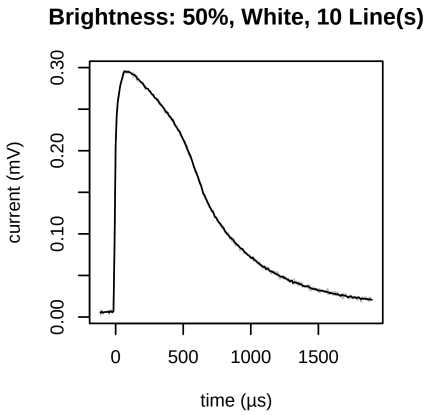


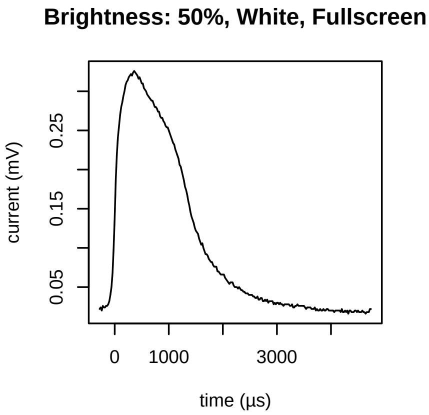




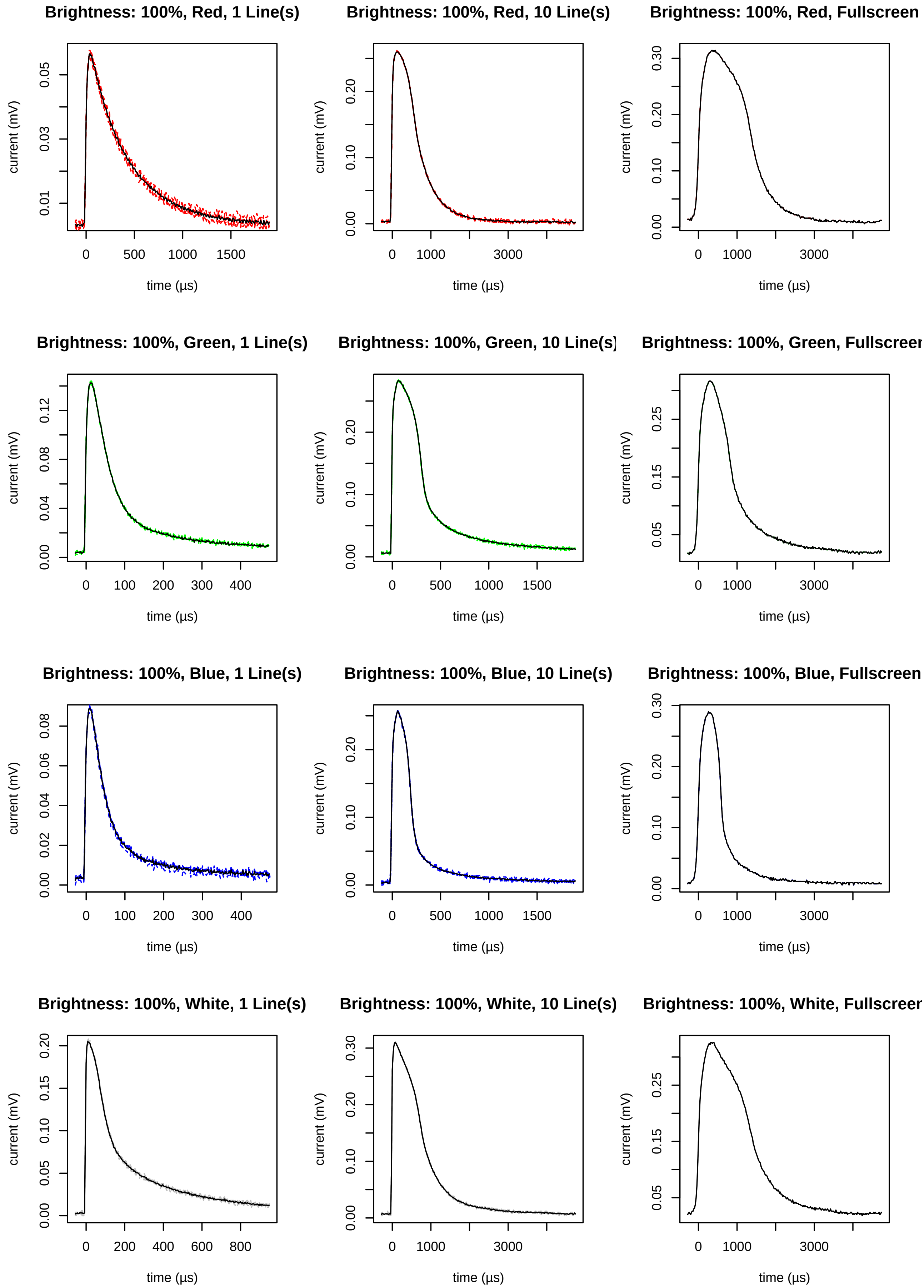








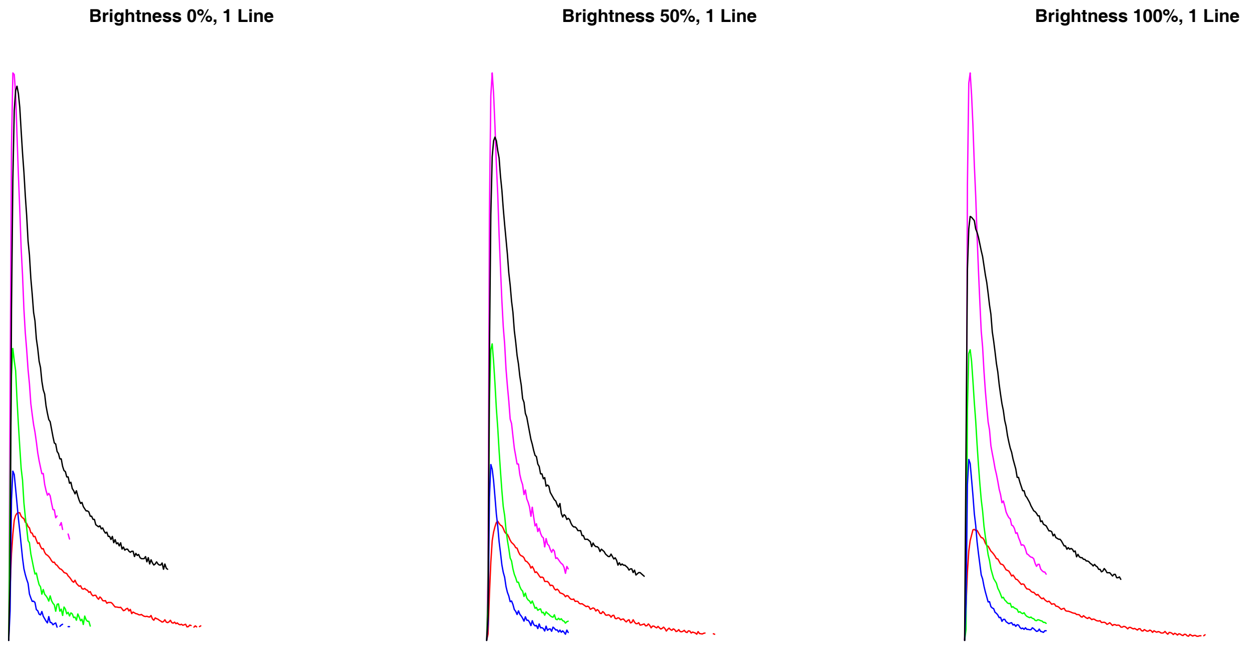
3.1.3 Brightness 100%



3.2 Color comparisons

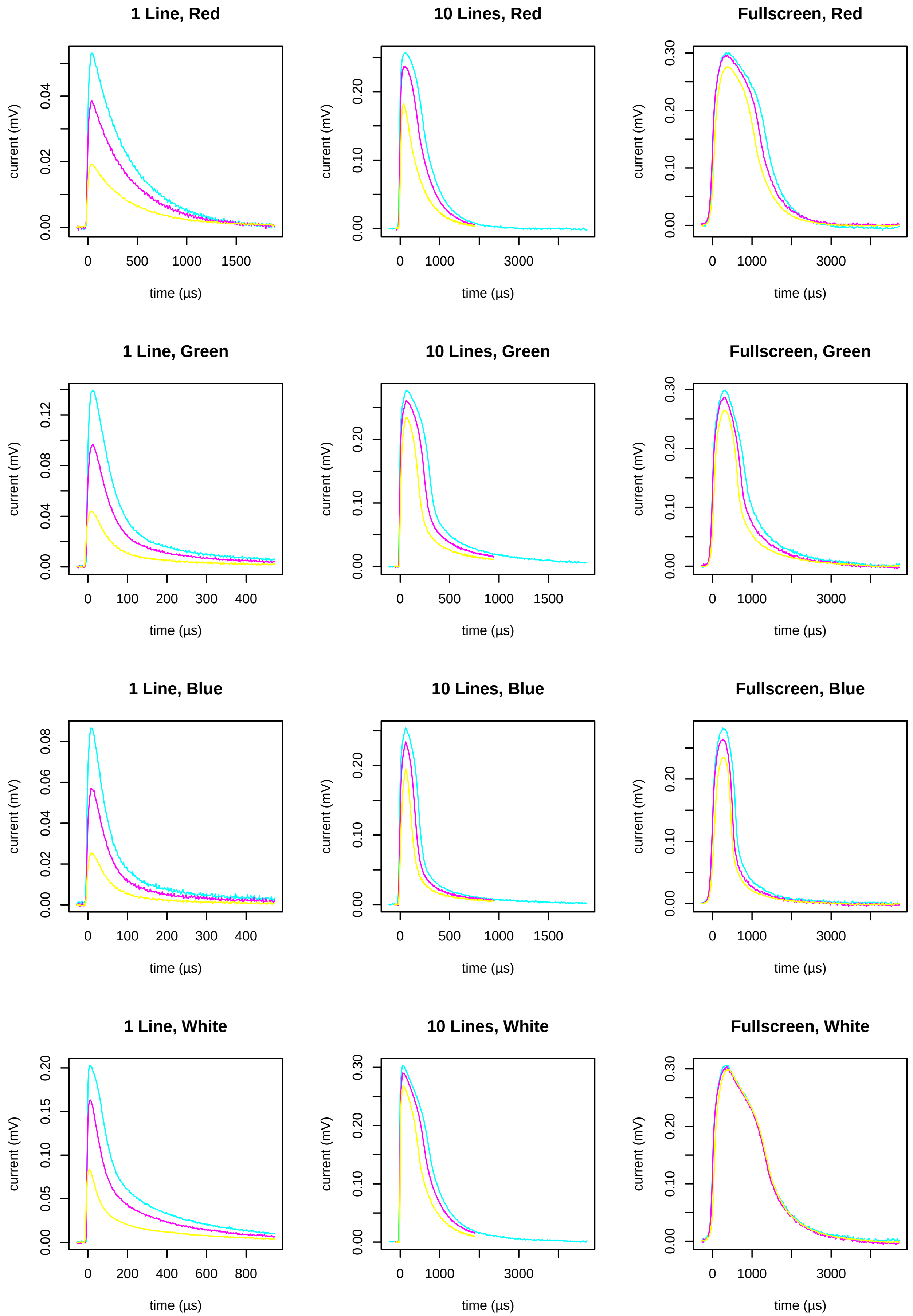
The following plots are normalized, i. e. their baselines are set to zero and the signals start at the same point. The average values are used here. The figures show a comparison of the colors red, green, and blue (represented by the respective plotting colors), and white (black in the plots). In addition, the sum of the red, green, and blue signals is shown (magenta). Obviously, white is not simply the sum of red, green, and blue.

It is not clear whether this is an effect of the monitor or of the photodiode. One possible explanation is that the monitor is unable to separate the colors correctly, i. e. there are portions of other colors if one color is to be displayed. On the other hand, a saturation of the diode which is probable considering the strange brightness effects described below could possibly explain this result.



3.3 Brightness

The following plots show the influence of brightness (yellow: 0%, magenta: 50%, cyan: 100%). Surprisingly, in the fullscreen conditions, especially for white, there are *hardly any differences between the three brightnesses*. This could be a saturation effect of the photodiode, i. e. the fullscreen results are not very reliable. The measurements are to be repeated in the future applying a stronger resistance.


1 Line, Red
current (mV)
0.00
0.02
0.04
0
500
1000
1500
time (µs)
10 Lines, Red
current (mV)
0.00
0.10
0.20
0
1000
3000
time (µs)
Fullscreen, Red
current (mV)
0.00
0.10
0.20
0.30
0
1000
3000
time (µs)
1 Line, Green
current (mV)
0.00
0.04
0.08
0.12
0
100
200
300
400
time (µs)
10 Lines, Green
current (mV)
0.00
0.10
0.20
0
500
1000
1500
time (µs)
Fullscreen, Green
current (mV)
0.00
0.10
0.20
0.30
0
1000
3000
time (µs)
1 Line, Blue
current (mV)
0.00
0.02
0.04
0.06
0.08
0
100
200
300
400
time (µs)
10 Lines, Blue
current (mV)
0.00
0.10
0.20
0
500
1000
1500
time (µs)
Fullscreen, Blue
current (mV)
0.00
0.10
0.20
0
1000
3000
time (µs)
1 Line, White
current (mV)
0.00
0.05
0.10
0.15
0.20
0
200
400
600
800
time (µs)
10 Lines, White
current (mV)
0.00
0.10
0.20
0.30
0
1000
3000
time (µs)
Fullscreen, White
current (mV)
0.00
0.10
0.20
0.30
0
1000
3000
time (µs)

3.4 Fitting

This section investigates the courses of the decay functions and whether there are functional fits with only a few number of parameters for characterization. Warning: This can only be considered as a first approach.

In many cases in our world decay processes occur exponentially, i. e. they can be approximated by exponential functions. Surprisingly, this could not be done with the measured data of phosphor decay, especially not for the colors green and blue. The beginning of their time course follows an exponential pattern, however, later in the time course it approaches more and more a power law ($x^{-\alpha}$). One possible explanation for this finding is that electrons get trapped and this trapping effect becomes stronger and stronger with increasing time.

There are mathematically elegant approaches to approximate such combined decay processes (e. g. with the help of fractional Mittag–Leffler functions) which are numerically complicated and not efficient (at least the author does not know any efficient method of this kind). Thus, here an initial exponential function and a power function are combined, and for simplicity the power function starts at the inflection point of the exponential function (another idea would have been to chose a point where the derivatives of both functions are equal, but there is no algebraic solution to this problem, so additional numerical fitting would have been required).

For the cases of blue and green, this procedure can be reduced to only two or even one parameter to be fitted, i. e. the funcitonal approximation is then tolerably characterized by a single number. This works as follows: As we are interested in the later time course, we chose as an only coarse initial exponential approximation a function which is applied in neuroscience to approximate the firing behavior of neurons, the so–called $\alpha-$ function.

The course of this function resembles the beginning of the decay signal and is usually characterized by one parameter determining the rise and another one determining the decay. Since for our purpose the exact shape of the rise is not so relevant as we are interested in the decay times, and, in addition, want to calculate the time until the phosphor has decayed to a certain percentage of the original brightness, it was chosen here to fix the rising parameter in a way that the function has a *fixed maximum* which is set to the maximum of the respective signal. We receive for the initial course:

$$\alpha(x, a, m) := \frac{mx}{a} e^{1-\frac{x}{a}}, \tag{1}$$

where m is the maximum value of the signal and therefore fix. Parameter a is then applied to fit the function to the beginning of the decay, i. e. we shift the maximum until the best fit is realized. Admitting a less precise approximation, we can even fix not only the maximum value but the whole maximum point of (1), i. e. we do not have any free parameter then. As already mentioned, we approximate our signal by (1) until the *reflection point* of (1) (the $x-$value of which is $2a$). From then on, we fit the following power function:

$$p(x,k,a,m) := (x - s(a,m))^{-k}, \tag{2}$$

where s is depends on a and m:

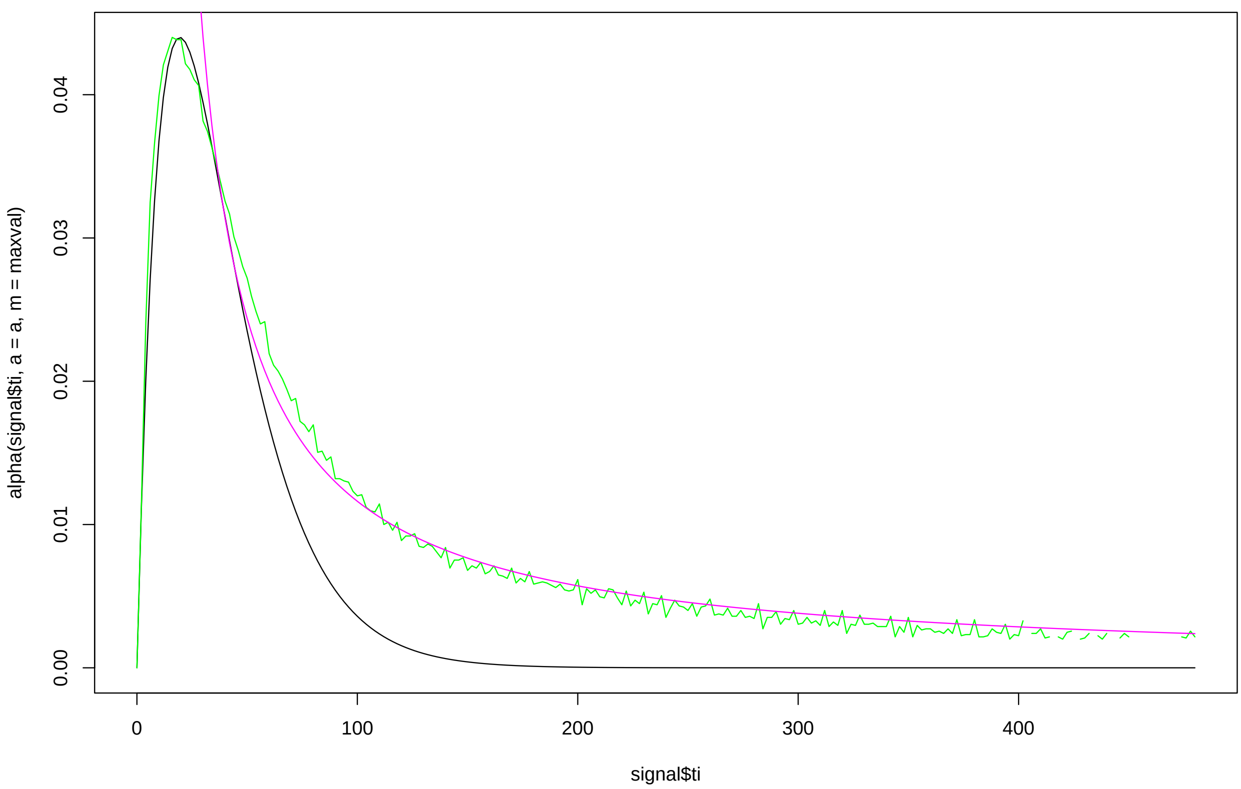
$$s(a,m) := 2a - \left(\frac{2}{e}\right)^{-\frac{1}{k}} \cdot m^{-\frac{1}{k}},$$

and k is to be fitted to the signal. From (1) and (2) we receive the following function approximating the signals for green and blue:

$$f(x,a,k,m) := \begin{cases} \alpha(x,a,m), & \text{if } x \leq 2a, \\ p(x,k,a,m), & \text{if } x > 2a. \end{cases} \tag{3}$$

By setting $a := m_x$ and $m := m_y$ where m_x and m_y are the coordinates of the signal maximum, we are left with only one free parameter. (This has not been done in the following figures.)

The following figure show the signal for green, 1 line, brightness 0% (green), function p (magenta), and function α (black), parameters: $a = 19.45$, $k = 0.98$



What are the implications of the course of the decay functions? One often reads that vision scientists implicitly assume decay constants, i. e. they report the time until the brightness reaches $x\%$ of its maximum. However, this value is only sensible if you can approximate the time course by a scale invariant function, for example an exponential one. Power functions are not scale invariant, that is, the time until the brightness reaches $x\%$ of its maximum depends on the maximum itself.

What things are to be done in the future concerning phosphor decay? The measurements described here should be repeated using different photodiodes to investigate the saturation effects described above. Moreover, it would be fruitful to have a general approximation to the decay functions applicable to all colors and all CRT monitors.