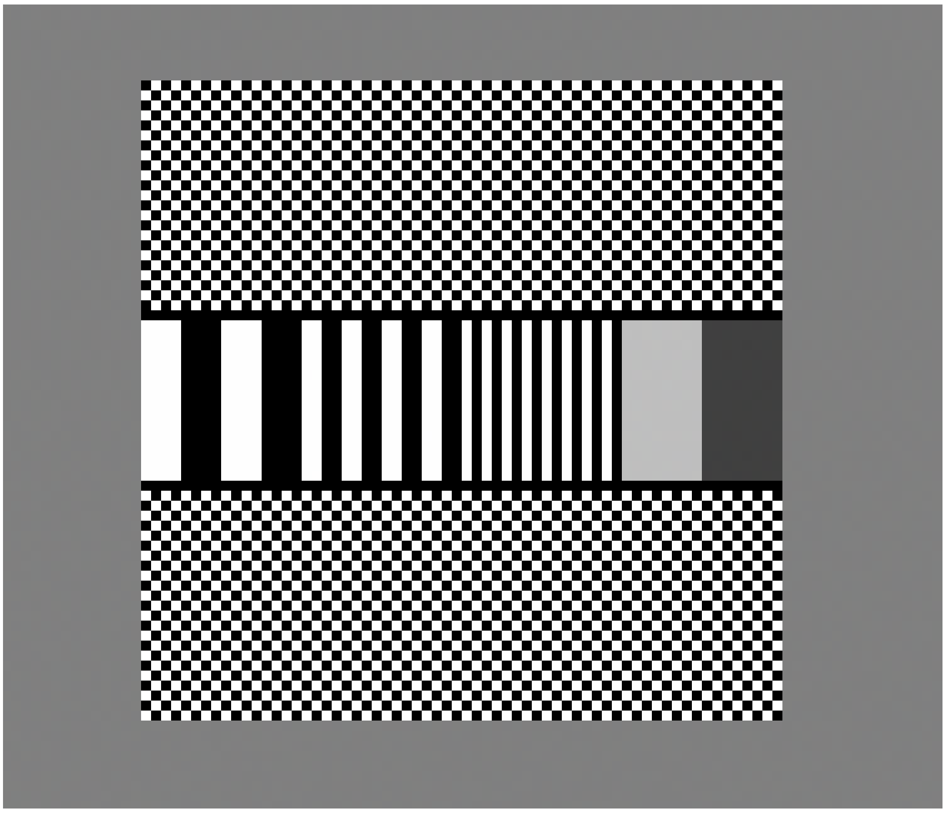
Introduction: Displayed Resolution

It seems with every new TV system there are challenges in clearly defining it. In the case of measuring the resolving power of a display one might think all possible methods of figuring it out are well known. In moving into UHD manufacturers are adding capabilities, such as higher light output for high dynamic range (HDR). While you might wonder how that would affect measuring resolution, we are seeing some approaches to getting this light output that are effecting what we see in resolution. These differences weren't anticipated in some of the resolution measurements methods currently in use, to the point where we need to take another look at how to interpret what we are seeing.

The principal and methods behind some of our current resolution measurements date back to the analog black and white CRT days. Since then we've migrated from black and white to color, analog to digital, beam spot size to lighting up colored phosphor dots or strips to a pixel structure. In today's world we anticipate the pixel count to define the display capability. If we send a 3840 by 2160 signal into the set, one of the specified pixel counts for UHD TV, we expect a 3840 by 2160 UHD display to resolve everything in the signal. One might guess if we were to create a single pixel checkerboard pattern we'd be able to see it on the display.



Two single checkerboard patterns with a horizontal grille in the middle

There are those who would argue that with at least some display technologies the checkerboard presents a significant challenge. Perhaps it is enough to expect the set to reproduce a horizontal or vertical single pixel grille patterns instead of the single pixel checkerboard. Others might argue the checkerboard more closely represent random small image detail you might expect to see in a picture and therefore the set should be expected to reproduce it. This difference in positions is just a starting point for issues to be resolved.

We know from experience some display technologies can clearly show single pixel lines or columns but not show a single pixel checkerboard pattern. In the cases where the checkerboard doesn't work often times the single pixel transition in H, more than V grilles, aren't reproduced at anywhere near full amplitude.

Looking at all of the iterations in our measurement methods some believing we can accept a falloff in level of 50% to 75% in these single pixel line and column patterns and still declare the set is performing at full resolution. Certainly the majority of display types such as LCD's are analog in the last step of the display so it would seem an analog based qualification might still be valid.

Performance-questions

In comparing displays we might find one with a 5% falloff in level of the H & V grilles and a 50 to 75% falloff in another. By current measurement standards both are said to be full resolution. Should there not be a distinction for one being better than the other? What if one can also reproduce the single pixel checkerboard and the other can't? Should there be a further distinction in the display's capability to cover this? What if we were to consider color resolution in addition to luminance resolution? Our current measurement methods seem to connect the two, saying it is only necessary to measure luminance resolution to know the color resolution, if color resolution is even important.

As such discussions are taking place in standards organizations the test signals themselves are being questioned, single pixel checkerboards versus H & V grid patterns and individual colors in each. An argument is being made that the majority of program content being distributed at 4:2:0 would never challenge the upper limit in color. This is interesting territory, one we'll cover in a moment, but for the purposes of determining the display's capability, are limitations in some source signals relevant? Just because some content may not go out to the numerical resolution of the display doesn't mean the display should be allowed to get away with claiming a resolution capability if it can't do it in at least luminance if not color. Then there is what the set itself might be doing in the processing ahead of the display. We often use the example of sets claiming to be Full HD when they are only Full HD if the viewer chooses the right options in the TV's menu system (aspect ratio, overscan and sharpness in particular). As these sets come from the factory they don't display Full HD yet claim a Full HD capability.

Program production is driving technology

A discussion of what is provided in image resolution in program production is important only in that if the challenge is there in the content we must be more vigilant about having that capability in any display declaring itself capable of full resolution. We do have a history in program content distribution of not always taking full advantage of system capability. Sometimes not taking full advantage is an artistic decision. Black and white content would be an example. Where's the color challenge in that? In answering that please pretend the set can do a uniform color of gray. Sometimes it is a cost of production issue. It takes a good 8K camera to produce a full resolution 4K image. Often times special effects or the whole post production of a movie are done in 2K instead of 4K to save on the production budget.

There are those in content production who choose to take full advantage of the system, transferring film at 6K for 35mm film and 8K for 65 or 70mm film, shooting with 8K cameras. Throughout our history of distributing program content in video there have been people interested in pushing the limits as far as they can to deliver something that looks spectacular. In the 1980's it was component mastering for the composite laserdisc format or HD mastering for DVD. DVD ushered in component video for consumers and more important the use of digital video. It was expanding standard definition delivery capability. HDTV eventually brought us a digital connection to the TV, getting us passed the detail falloff of converting digital to analog.

There are challenges in content production. The brand of editing system JKP used for DVE HD-Basics assumed we'd be displaying the output on an analog TV where a significant falloff from full 1080p resolution was expected. Therefore, the system deliberately filtered the digital content, figuring the extra detail would never show up on an analog TV set. We had to remove the filters before we could start the edit.

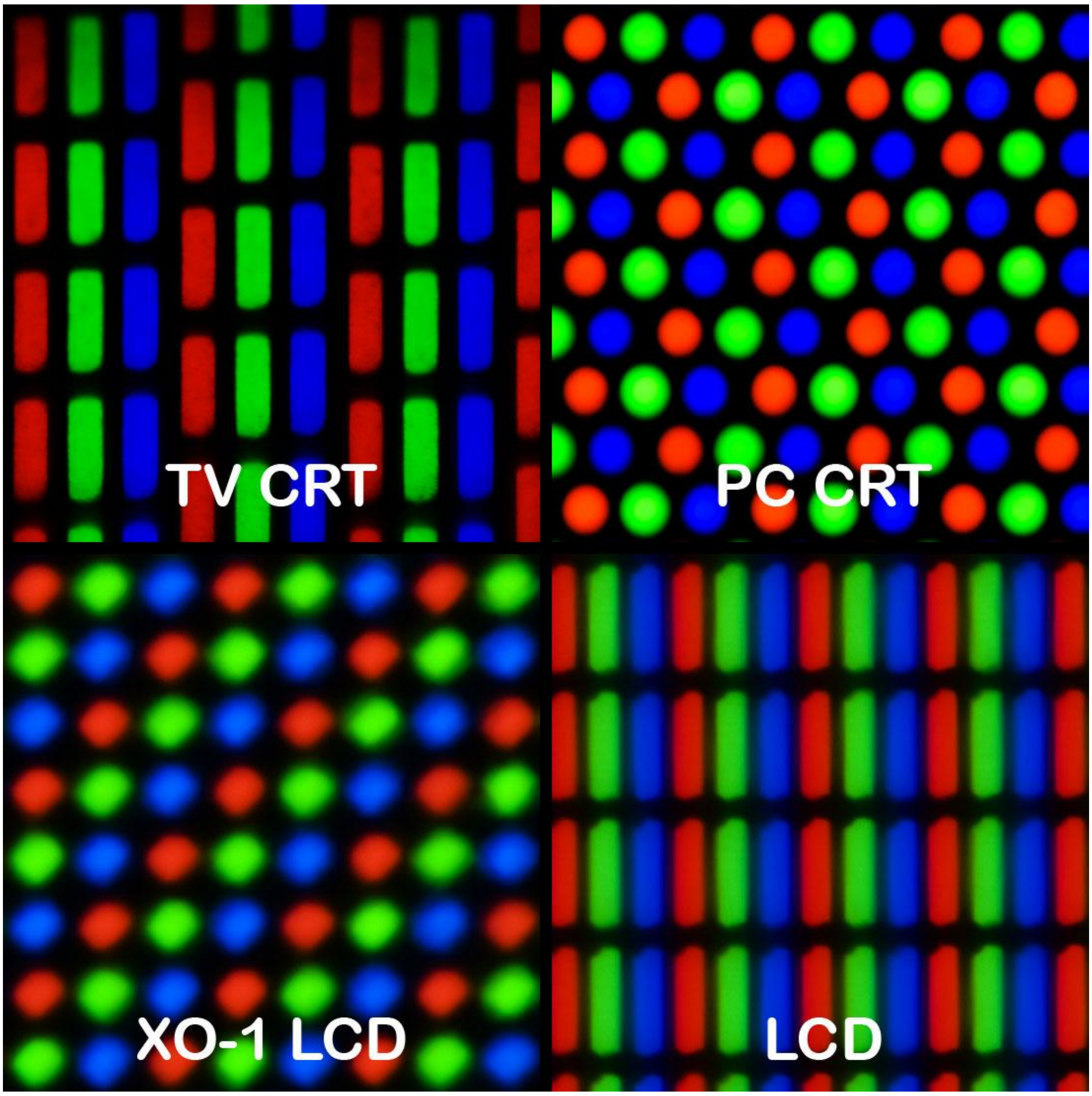
In producing our 1080p program the film content was scanned at 6K and then down converted to 1080p to make sure it contained every bit of detail that was in the film. Along the way we discovered some noise limitations that were resolved by double flashing every film frame. Graphics in the program were done at 1080p without any filters to limit the sharpness of the edges. This full resolution content was delivered to the consumer in the 4:2:0 Blu-ray format where only the luminance information was full resolution. We used the disc to check Blu-ray players to make sure they weren't doing their own filtering. On the display design side of the signal we provided 4:4:4 versions of all of our test signals so we could test the RGB capability of the device. Once all of this was done, a good 4:4:4 source and a good 4:4:4 display, we were able to illustrate the ugly part of 4:2:0 versus 4:4:4. On a good display there is a noticeable difference. This all goes to our wanting to include color resolution in qualifying something claiming to be Ultra High Definition. We're never going to move forward in our resolution capability if you can't see the difference in the display.

Many of the new video system technologies have forced an increase capability in content production. Warner Brothers, as an example, exploited the capability of HD on one of their first HD DVD's. The movie was *Casablanca*. It was transferred at 4K and converted to 1080p. When it came out it was said by many in the industry to be too good. Warner had to set up a screening of an original 1942 nitrate print at UCLA to show those interested that what you saw in detail in the HD DVD was in the print. Upon seeing the projected print you were asked to factor out the gate weave and focus issues of the projector and periodic dirt in the print to see the HD DVD. The disc, instead of being too good, fairly represented what was in the print. Yes the video version was better in that it didn't have the issues of the film projector or dirt and scratches. This HD-DVD certainly challenged the luminance resolution capability of the 1080p system.

Among the things we've learned is to test the entire production chain for its capability of meeting the resolution of the system in which we are editing. It is now common to be able to create content that can challenge of the system in luminance resolution.

What about color resolution? In distributed content some menu systems promoting content are in RGB. Pictures you take and display on your set are in an RGB format. Computer and game graphics are in the RGB domain. At Quality.TV, as well as our individual companies AVTOP and JKP, we are creating and distributing test materials in 4:4:4 to help us determine the state of displays in reproducing that resolution.

Reviewing our history of making display resolution measurements, in the analog black and white time period engineers would put up horizontal or vertical frequency bursts or frequency sweep patterns. When color came along the white in the grid was defined as red, plus green plus blue. Since the majority of color sets were based on red, green and blue elements, even if some were in a delta configuration or some striped configurations, the established method for measuring resolution capability held fast in the transition from black and white to color.



Various configurations of RGB

There have been advances in display technology forcing us to update at least some parts of the basic resolution measurement methods. An example from our history of changes would include the upper limit of frequency response had to be extended on NTSC measurements with the coming of the laserdisc. The laserdics had an upper horizontal frequency limit of 6MHz instead of the NTSC's 4.18MHz. We had more picture detail capability than most TV set could reproduce. Line doublers connected to data projectors could reproduce this increase in source signal capability so expectations of TV sets went up. The quality of the content drove innovations in video input circuits to TV sets.

Resolution capabilities kept going up. The DVD could outperform the laserdisc, just one part of the never ending story that has evolved into the coming of 8K.

Resolution of digital signals

While DVD is a digital format it was long after the coming of HD before we got a digital connection to the TV set. The set itself became an array of pixels matching the HD source signal pixel count. In creating content each pixel has a red, green and blue subpixel structure. From HD forward the pixels are square in shape. The red, green and blue together in each pixel make up the white line structure of the H and V luminance grille patterns used to test the display's resolution.

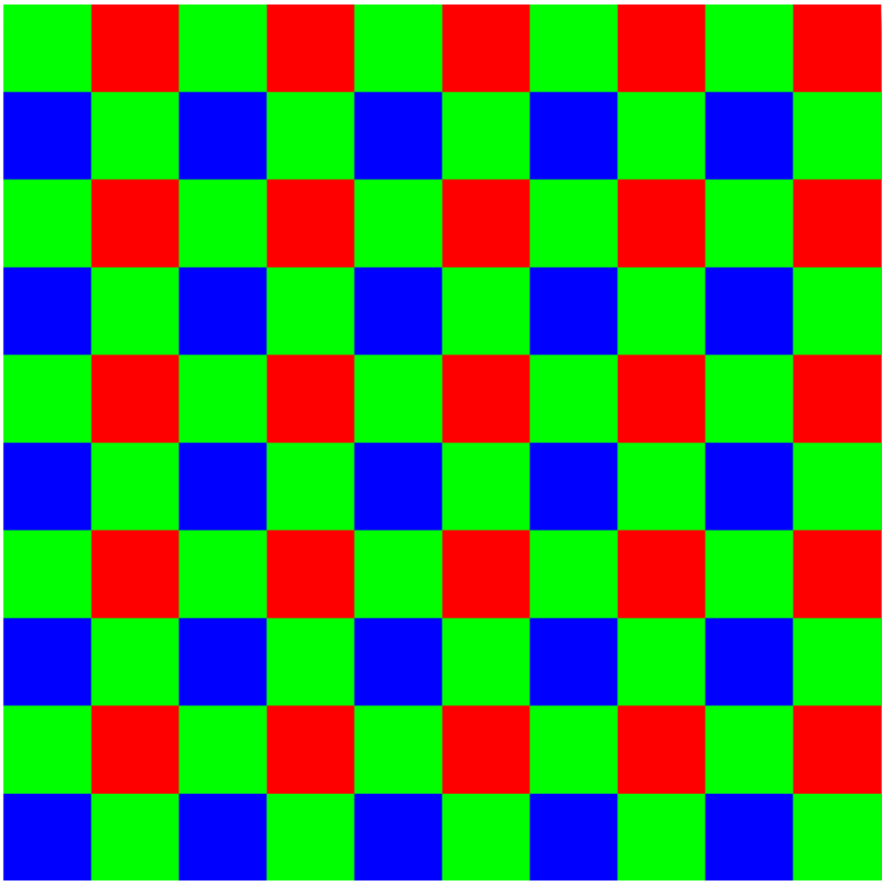
The idea of using a checkerboard to make resolution measurements in a digital system represents a departure from using the grille system. Knowing that some displays can properly show a single pixel checkerboard and others can't it signals a need for a new way of defining the resolution capability of a display. There are issues even here, more than just yes or no to being able to display the checkerboard. Some sets will show the checkerboard in color instead of the black and white. Sometimes the checkerboard is really dim. Sometimes it is a solid gray or maybe even a dark gray, well below the average picture level of the test pattern. Supporters of display types that can't reproduce a single pixel checkerboard have several arguments why it isn't necessary. The most often heard is program content seldom goes out there. They are at least ignoring that luminance in a 4:2:0 system can go out to the limit of the system. They are also ignoring that full HD content looks better on a set that can reproduce a checkerboard pattern, even if it is 4:2:0. Image size and viewing distance are important in these comparisons. In our own demonstrations of properly displayed high quality images we've had some in the industry say 'we'll catch up' or 'I had no idea the system was that good'. It certainly provides incentive for all of us to do better.

We feel you need to see a good picture on a good display in order to understand what can be done. We feel there is a need to push measurement techniques forward to meet system capabilities in both luminance and color. New specifications for measurements should be written including red, green and blue color resolution, with provisions to add cyan, magenta and yellow, should they ever be added to our system specifications.

Measuring the resolution capability of a display

We're returning to the original question at hand. How do we properly qualify the resolution capability of a display? For the time being we are still at a point of officially using H and V grilles and accepting a 50% or better level as being full resolution. Current specifications mention the 25% number as also being acceptable under certain circumstances. We feel adding single pixel checkerboards to the grilles will at least further distinguish one display from another. Eventually we'll come to a point of wanting to know how well the checkerboard is reproduced as well as the V & H grilles.

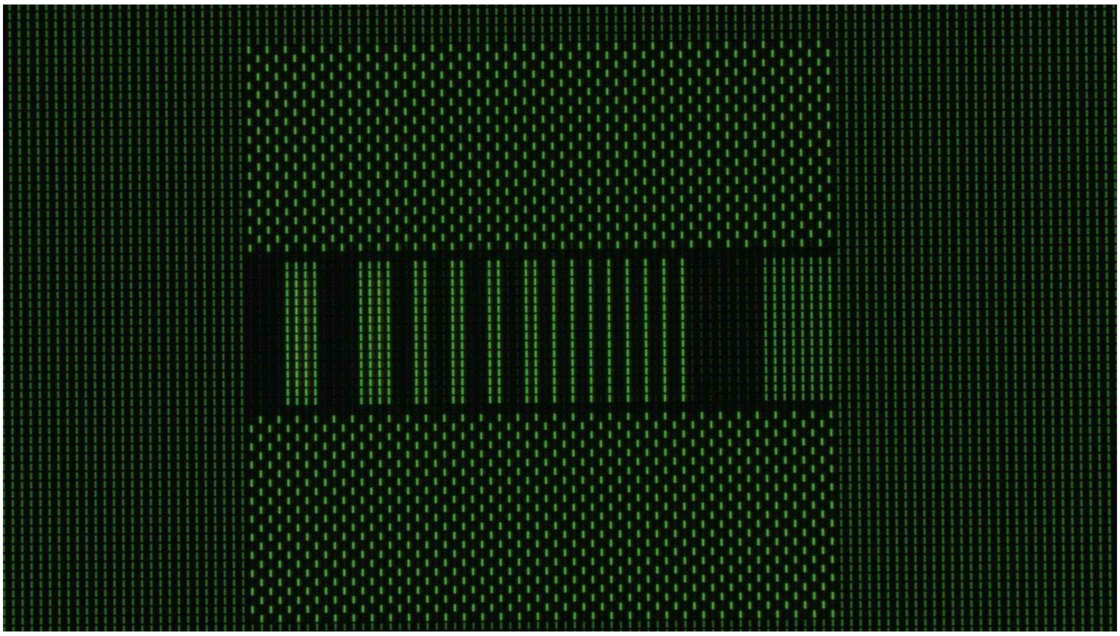
In the past few years of new display technologies we've seen some changes that need further exploration. Some of these changes are outside the traditional ways we reproduce images and will likely require new ways of measuring resolution. The traditional composition of a single pixel in the color display domain has been each pixel has red, green and blue elements or subpixels. Even knowing that most single sensor cameras capture images using a Bayer-pattern, where green pixels are dominating, sooner or later the output of the camera gets converted to RGB, 4:4:4. In modern post production systems, the data from the sensor in a RAW-workflow gets debayered to deliver RGB values for every pixel of the signal.



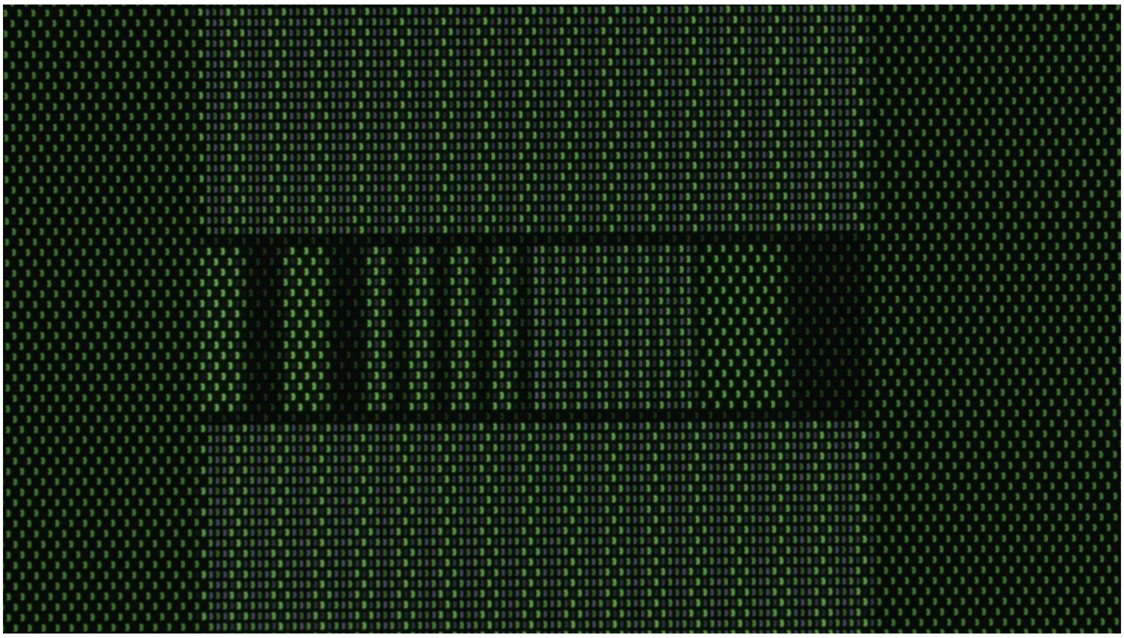
Bayer-pattern array of pixels in a single chip CMOS sensor. Note that the red and blue element count is half that of green

The definition of a pixel in displays is under fire from several new technologies, some adding a fourth element to each pixel, others substituting a white element for one of the red, green or blue elements. Adding a fourth element (be it cyan, magenta, yellow or white), requires at least a fresh look at how well information is being reproduced. The addition of a subpixel could also reshape image elements in addition to changing the color or saturation. In the case where it appears as if white is being substituted for a red, green or blue element the apparent width of the vertical grille lines may not be symmetrical. At the least this will reshape the intended detail. It could also change the color saturation of an image. Should such changes be a part of what is reported in resolution measurements? It could be if resolution is defined to include an accurate ability to reproduce detail in color.

We mentioned seeing substituting one of the red, green and blue elements with white. It will change the shape of elements in the picture, even more so if filtering is applied to avoid reshaping image detail. Doing so can also reduce the contrast at which resolution is displayed. These examples suggest it might now become necessary to measure the individual red, green and blue grilles in addition to the luminance grille. Measuring all four grilles, red, green, blue and white, will give you a better idea of the real shape of the information being displayed.



The green pattern on a LCD-screen with RGB subpixels.



The green pattern on a LCD-screen with RGBW subpixels (pentile structure).

There are many times when measuring the individual parts will help inform you of what to expect when all of the parts are combined. In this case measuring the color grid patterns will point out some really strange things happening to the shape of the lines in the grille. The color grilles will have noticeable jagged edges. If you then look at the white lines when the black and white grille is up you'll see similar jagged edges. The lines are there but they are no longer straight lines. They are no longer being displayed as is intended by the signal. The contrast of the detail won't be as good as it might have been if the pixel elements were the standard red, green and blue configuration - matching the intention of the video signal.

Suggested changes in a communication system

Consideration for the intent of our video communication system is an important consideration in defining the way we measure resolution. It isn't easy to make improvements or changes in the system without complete agreement of all parties involved. Under certain circumstances someone thinking they are making improvements on their own, without changing the communications system, are likely to be making the system performance worse no matter what changes they make.

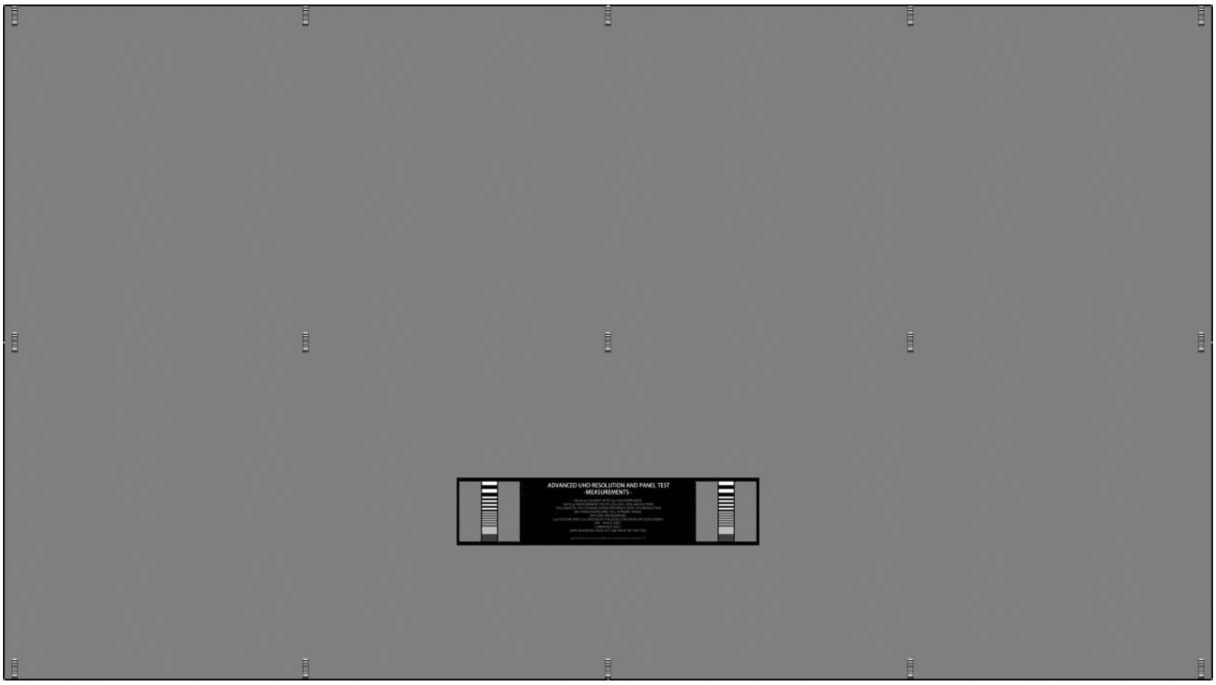
Consider the following. If you speak one language and I speak another chances are little information will be passed from one to another. Neither one of us knows the rules of the other's system. Sometimes we both speak the same language, but a different version of it. In a communication system any deviation away from the rules we both understand will result in some loss of intended information. In the video system that loss is often easy to measure. A shift in defining the elements in a pixel, making it something other than a square representation of red, green and blue subpixels, will have consequences even if the intention is good. It has consequences because an equal change hasn't taken place in the way content is created.

For the purposes of this discussion we are talking about declaring a product follows the rules of the system or it doesn't. We're aiming at a fairly easy pass/fail criteria for resolution of the display. Even if it is as small as a mobile phone, if it is declaring it can display a given resolution there should be an easy way of determining if can actually do it.

We'll start by introducing some new test patterns for making 3840 by 2160 Ultra HD resolution measurements. It is followed by a simplified approach on how to measure spatial resolution of a fixed pixel display, allowing for a visual inspection of the capabilities. The intent is to improve our ability to qualify a display for true 3840 by 2160 capability. Our approach can be scaled to any other resolution being questioned.

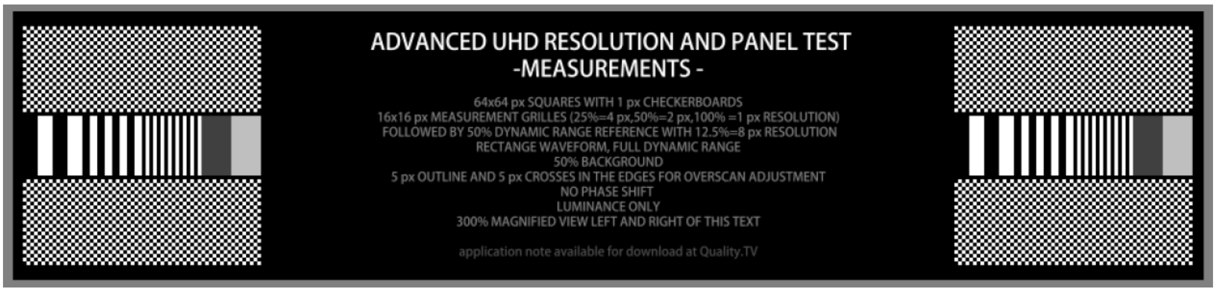
Advanced UHD Resolution & Panel Test Pattern – luminance versions

Function: Test for a panel's ability to display full 2160p resolution in the horizontal and vertical direction as well as checking for an ability to reproduce a single pixel checkerboard representing full horizontal and vertical resolution. The pattern can also be used to determine the approximate depth of modulation or contrast of a display at various steps represented in resolution.

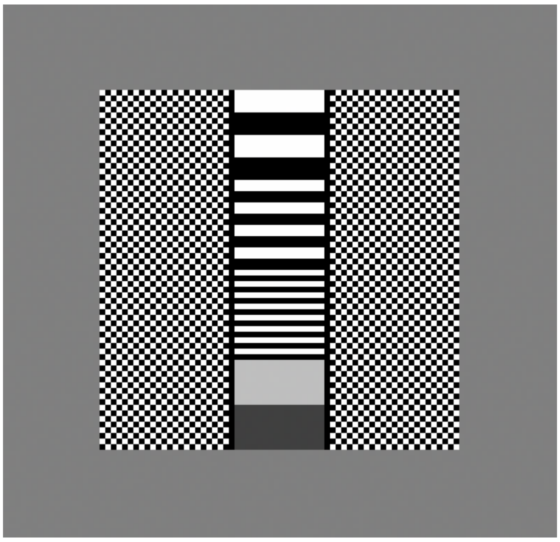


Vertical Resolution w/ single pixel checkerboard

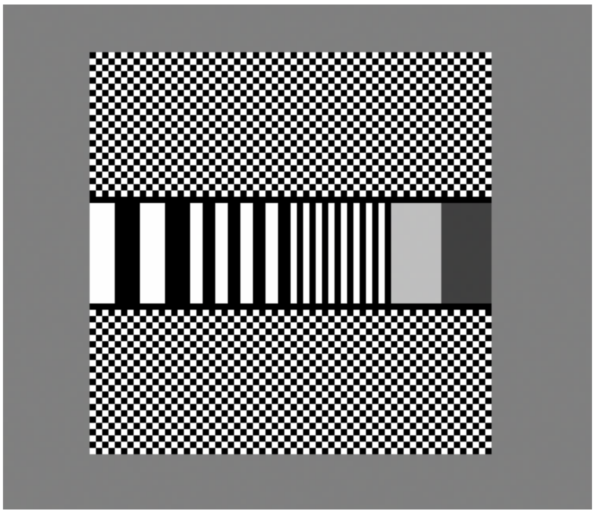
Pattern Layout: There are 15 resolution patches, three rows of five each spaced out in the 3840 by 2160 pattern on a 50% gray background. There is a title area in the lower third of the frame with enlarged versions of the patches to make individual patterns easily recognized.



Title information in the pattern

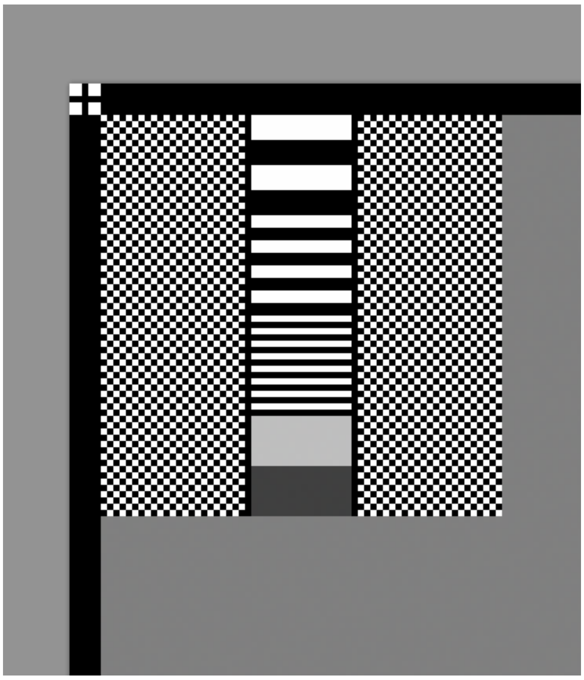


Detail of a vertical patch
Note that the phase of the single pixel checkerboard pattern is reversed from left to right



Detail of a horizontal patch
Note that the phase of the single pixel checkerboard pattern is reversed from top to bottom

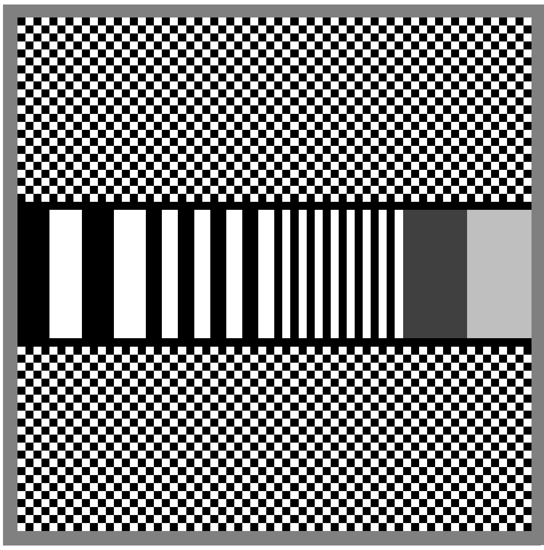
Each patch is square with a dimension of 64 pixel on a side. Each patch contains a single pixel checkerboards to the left and right of the vertical grille or to the top and bottom of the horizontal grille. The checkerboard and grille are full amplitude, going from black to white. The phase of the checkerboard is reversed between the two sections. The vertical resolution grilles represent one-quarter, one-half and full resolution in a square wave starting at the top of the patch for vertical resolution and left edge of the horizontal resolution. The final transition at the bottom of the vertical and right side of the horizontal is an eight pixel section of a 75% and a 25% level. The height or width of these reference levels are larger than anything else in the patch, representing a lower frequency, something that should pass any frequency based limitation in the display. The levels of 75% and 25% represent a symmetrical amplitude of 50% of the total dynamic range of the signal. It represents what up to this point has been considered a minimally acceptable dynamic range for the full resolution grille.



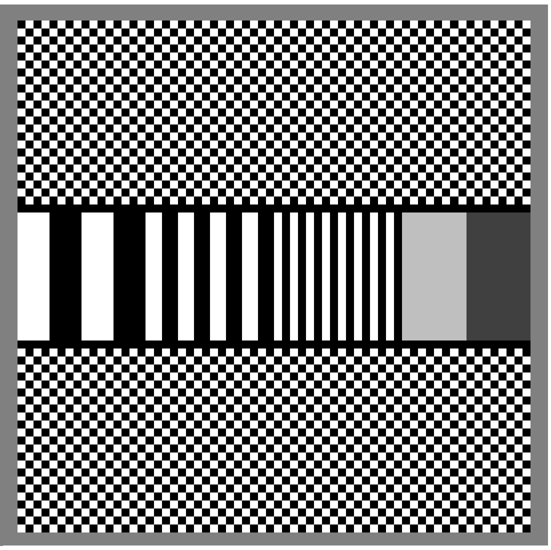
Detail of the 5 pixel wide edge marker in the pattern with the corner patch

At the outside boarders of the image area there are five pixel wide edge markers at black with white corner markers in each of the four corners.

There are sixteen patterns and two video files in this set. They are separated into two basic categories, horizontal and vertical resolution. Each of the H and V patters has two phases, a 180° phase shift in the checkerboard in each patter and 180° shift among two patterns of grilles.



H grille test patter at 0° phase



H grille test pattern at 180° phase

Note that the phase of the single pixel checkerboard is reversed from top to bottom in both patterns

The phase of the single pixel checkerboard is reversed in each pattern between the two sets of checkerboards. The order of this phase reversal is the same in the 0° and 180° versions of the grilles. Each of the phase reversed patterns has four representations, one each for luminance, red, green and blue. They are all presented as 4:4:4 files. There are also two 4:2:0 versions of the files, one in H.264 and one in H.265 encoded video file. They include just the luminance for the time being. We'll be adding the green only version of the patterns upon request. The sixteen 4:4:4 patterns come in three formats, jpg, png and tif.

The sixteen 4:4:4 patterns should be in a single generator with an easy way to navigate among them. The variations in patterns are represented individually, in their own pattern, so that a single camera set up can be used to photograph each of the different circumstances. This helps insure nothing will change in the focus or position of the camera when evaluating all of the variations.

Description of Use: The still patterns are designed to be used for measuring luminance resolution in their RGB, 4:4:4 configuration. The display must be set up to accept an RGB input. In some displays it requires the set to be put in a mode to accept an input from a computer. Some sets provide a clear 4:4:4 path from the USB input to the display. The patterns are designed for observing and measuring resolution. Up to this point in prior methods of measuring resolution in displays we've only been concerned with luminance resolution, therefore the test patterns have been in black and white. This new set of patterns addresses color as well as luminance. There are now displays where individual areas of luminance are represented by something other than or in addition to red, green and blue elements. Because of the change in the way individual pixels can be represented you may need to start the exploration of resolution capability by looking at the three colors individually. Seeing individual colors prior to displaying the luminance version of the pattern will help inform you of what to expect when you get to the luminance observation and measurement.

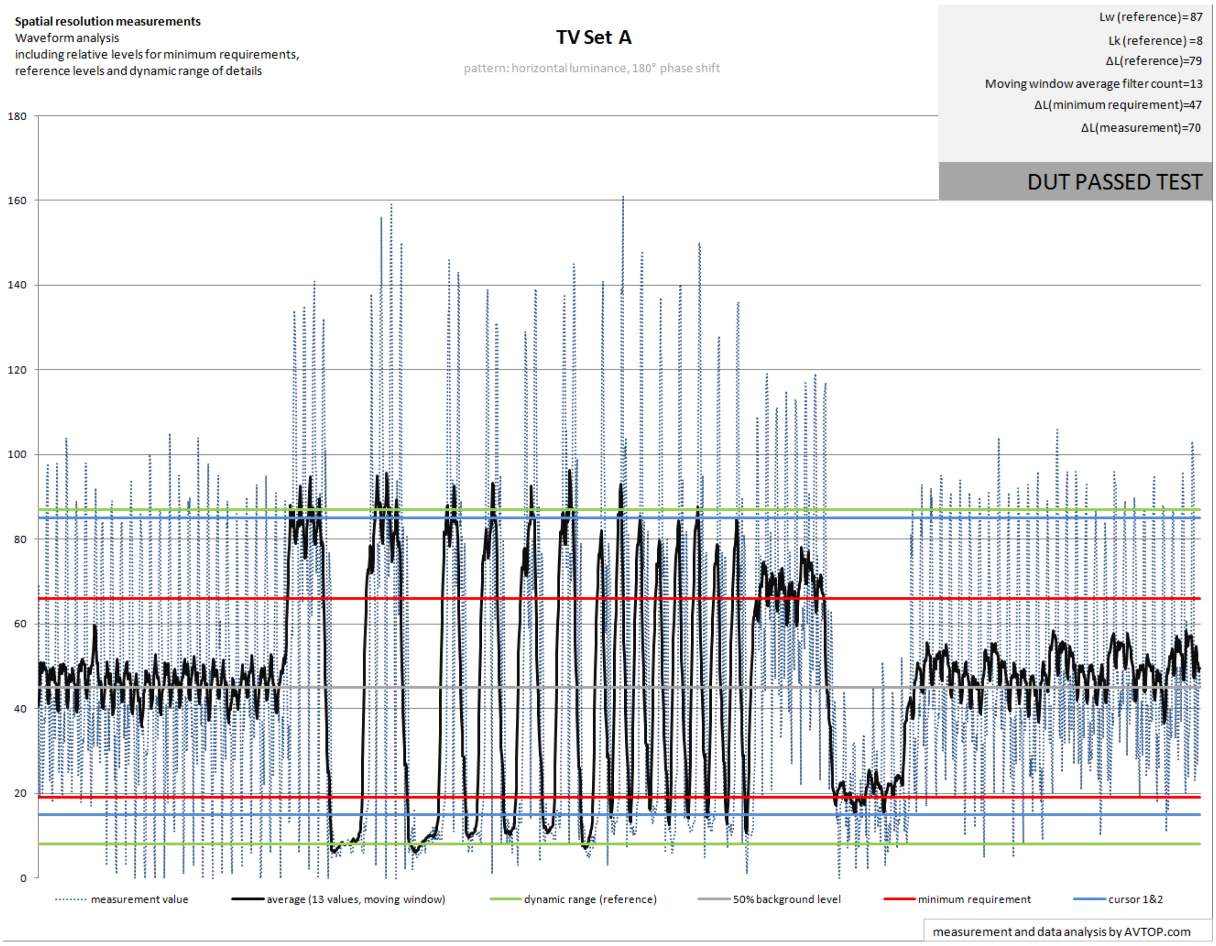
The initial part of using these patterns is observing what the display is doing. Viewing distance should be no more than 1.5 times the picture height away from a set with a 3840 by 2160 pixel count. You will likely need to be closer to the set, depending on different factors. No matter how close you can get to the display, the actual picture size of the display will make a difference in how easy it is to determine a pass/fail criteria. It will be much easier to determine if a 6 meter wide 2160p display is conforming to standards than a 6 centimeter wide 2160p display. Make sure the device under test (DUT) is in a mode that will accept and properly process an RGB input.

The two phases of each grille and checkerboard pattern are presented as often times in configurations of subpixels the phase of the information will completely change the way the image is reproduced. We have examples of that coming up.

The video versions of the patterns are designed to illustrate what happens to the resolution of the display when it is presented with a 4:2:0 signal. In the luminance only portion of the video the 4:2:0 source should provide a 4:4:4 signal to an RGB display. Comparisons should be made among sets with attention paid to user settings.

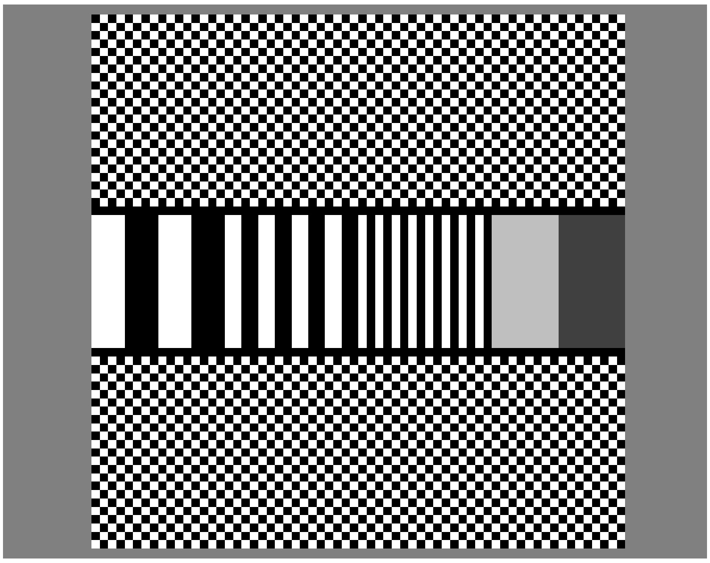
The first level of using these patterns is the observation of how they are being shown on the DUT. The observer may be able to determine pass/fail using the 50% amplitude criteria on this observation alone. Documenting what you are seeing is an important part of the qualification process.

As part of the documentation process it is necessary to photograph at least one of the patches in the 3840 by 2160 pattern. The initial observation will help you determine if it is necessary to document more than one area of the display. Photograph small areas of the display with a high resolution (DSLR) camera with a descent lens, allowing one complete patch to fill the image area of the camera. Most displays will require the use of a macro lens. The digital image from the camera is used to make the measurements. It is preferred that the camera RAW-Data be taken and corrected for a linear OETF, but with the reference markers for minimum requirements, some of that can be ignored.



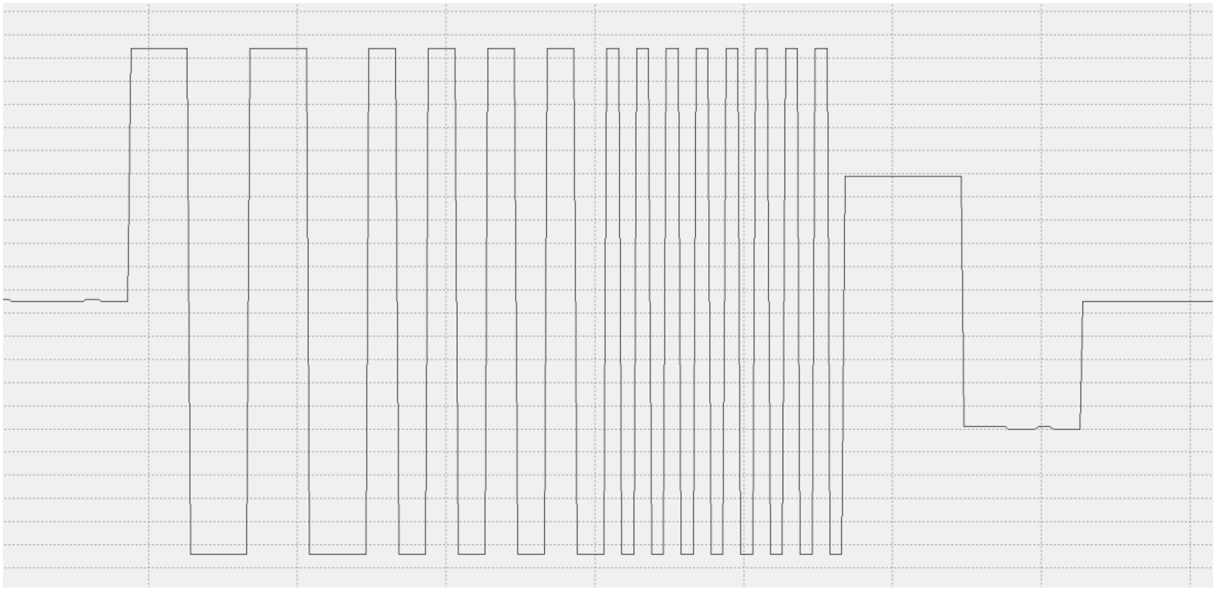
Example measurement for grilles, with markers

There are detailed descriptions to follow of the parts of the process including notes on the practical limitations of what can be done. Both vertical and horizontal measurements in each of the two phases should be made, paying additional attention to how the checkerboard pattern is displayed in each.



H grille at 180° phase

In this particular pattern if you were to measure amplitude along a horizontal line in the middle of the horizontal grille you would enter the grille at a 50% level, see 14 shifts in amplitude going from white to black followed by the 75% and 25% amplitudes and then going back to the 50% gray level upon exiting the grille. The ideal waveform is shown below.



Ideal waveform for the horizontal grille

The width of the first set of square waves is four pixels at white followed by four pixels at black. The second set of square waves is two pixels wide for white followed by two pixels at black. The third set of square waves represents single pixel transitions. It's flowed by five pixel wide 75% and five pixel wide 25% amplitudes representing a reference for a 50% reduction in level from the 100% levels of the grilles. The signal then returns to the 50% level of the background around the patches.

The 75% to 25% represents the worst case we'd like to see for the amplitude of any of the grille levels in order to pass existing guidelines. If these guidelines are revised, as many sets today can maintain a much better level, our amplitude reference will be changed in a new version of the pattern. In most cases the one quarter resolution grilles are low enough in frequency so they can act as a 100% dynamic range reference for the remainder of the grilles.

Existing methods and a simplified approach

Some of the existing measurement methods for spatial resolution of a display can be challenging to make. You'll see that in our illustrations of the waveforms resulting from the photographs. We would suggest these factors may be impeding the accuracy of the measurements. They may be compensating for nonlinearities in the display and capturing camera, finding the right exposure times, taking spectral response and glare into account and much more. In other words there are way too many factors in this process to get an accurate numerical answer.

The numbered results obtained from traditional measurements are usually presented as the contrast ratio of the fine details. If pass/fail criteria is our goal we don't need to be concerned with how much more effort it will take to provide an actual grade. You'll see where providing an actual grade isn't easy. A picture of the test patch and a diagram of the waveform will be helpful in illustrating the pass/fail results.

Simplified approach

In a simplified approach, instead of presenting numbers differing from measurement to measurement in contrast modulation values - no manufacturer publishes the numbers anyway - we suggest presenting the images used to determine a pass/fail criteria.

An example could state:

UHD spatial resolution tests passed (Contrast value > 50% for horizontal and vertical luminance patches as well as individual colors using a RGB source)

A visual representation of the perceived image and measured waveform together with some indicators for minimum and ideal dynamic range together with details on the set-up of the device should be kept as a communication basis for discussions, no matter if between consumers, manufacturers or other parties such as reviewers.

Benefits of using a simplified measurement method (image acquisition as described in the previous sections) with a visual/waveform reference for minimum requirements:

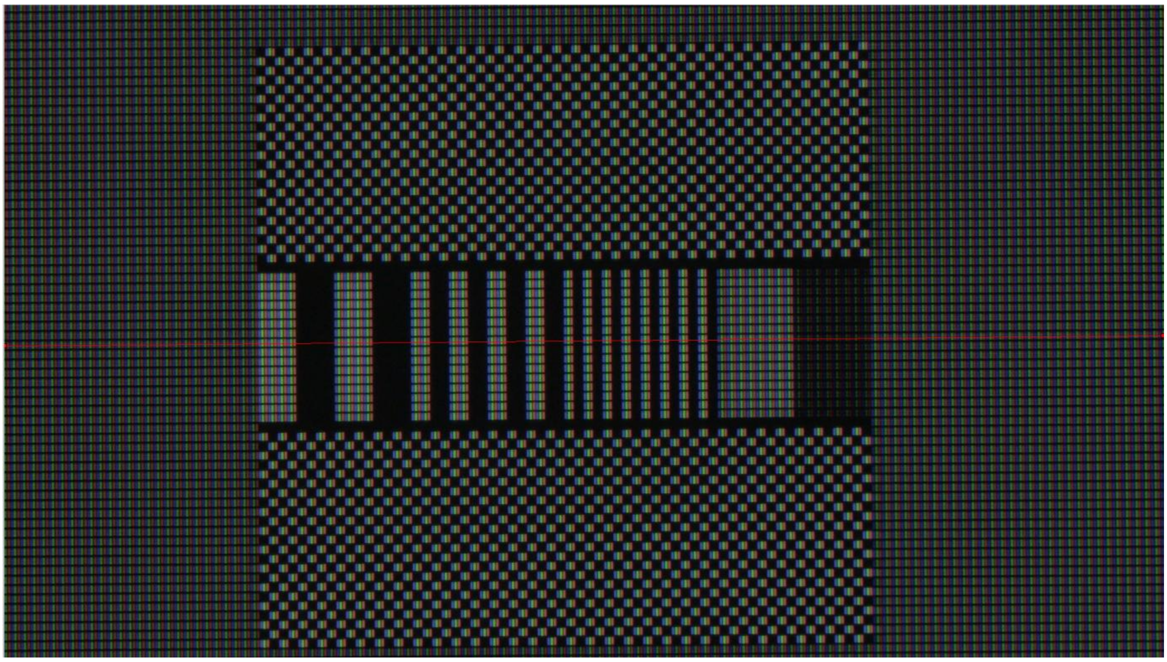
- Fast visual inspection for pass/fail
- No need for extensive calculations in order to compensate for nonlinearities of a (DSLR) camera sensor
- proof and easy-to-understand communication tools (images, waveforms, markers) for solving problems as well as self-compliance-declarations

The measurement method step-by-step:

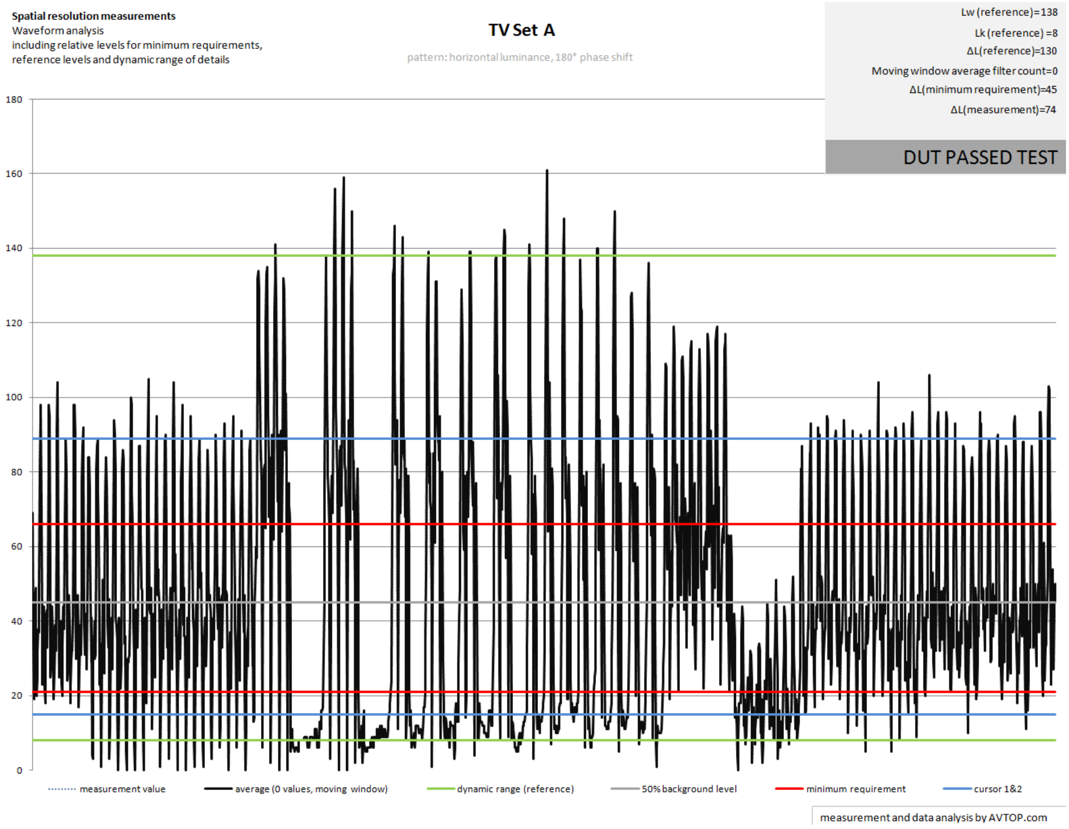
1) Display the Quality.TV advanced UHD resolution test patterns from an RGB source file on the DUT, using a descent 4:4:4 source signal with full resolution.
2) Select a neutral mode in the display, one that will accept and properly process an RGB 4:4:4 signal. Turn off any overscan and edge enhancement options in the selected mode.
3) Confirm the full picture is visible on screen, including the edge markers.
4) If the individual patches don't appear to be as clear as they should try to improve the appearance of the finer patches in the rest of the pattern by eliminating all potential adjustment issues, including searching for a mode that will properly pass the RGB source signal. *An enlarged reference for how each of the patches should be displayed is in the title area of each pattern.*
5) Set up the camera on a tripod with a focus rail that will allow the camera placement away from the set for best possible focus. A camera with an excellent macro lens should be set in a reasonably neutral picture mode of exposure. The exposure time of the camera should be at least twice as long as the frame time of the source signal. The lens should deliver a uniform image over the entire camera image area. Using the manual focus on the lens and the position of the camera on the rail away from the set find the exact position where all pixels in the picture are focused on a complete single patch in the test pattern. The patch should fill the height of the camera's image area as show in the examples below.
6) Take a picture in manual mode, making sure nothing is overexposed, shutter time is long enough to avoid temporary effects and reflections as well as camera movements during the exposure are minimized. You may want to use a remote shutter release to avoid touching the camera when taking a picture.
7) For a full analysis of the DUT take images from all sixteen versions of the patterns, luminance and three colors, vertical and horizontal resolution with two phases of each. The camera remains in a fixed position while the patterns are changed.
8) Start analyzing the images by visual inspection of the images taken by the camera. If the DUT can't show the waveform at all, making it possible to identify the individual bright and dark bars of the signal, the test failed and full special resolution is not possible. If this is the case go back to step 4 above and see if there is any way to improve the picture.
9) Open the picture data from the camera in a computer program that will allow the selection of a row or column of pixels for analysis. You may create your own tool for doing something like this, but there are also mathematic lab tools such as MATLAB to work with image files and analyze or export data. http://www.mathworks.com/
10) Using the selected or exported data, start analyzing it with a properly prepared tool. It is possible to do things like this in Microsoft Excel, if no other tools are available.
11) Use a moving window average filter of variable size in order to allow a more precise analyze of the waveform, eliminating non-visible components like structures of the subpixel mask.
12) Set limits for maximum dynamic range and minimum requirement based on the filtered waveform and calculate the difference of the luminance values (ΔL). See the examples we've provided.

13) Measure the dynamic range of highest frequency patches (1 pixel lines), while making sure the 8 peaks of the signal are represented. If the number of peaks is not equal to the source - no matter what average filter is used - the DUT fails the test.
14) If the measured dynamic range is higher than the minimum requirement, the DUT passes the test.
15) In the case of this test we are concerned with only one resolution capability, 3840 by 2160. The DUT could be 4069 by 2160 or the widescreen UHD format of 5120 by 2160 or be 3840 wide by a vertical number of pixels larger than 2160; say by 2400. By introducing side bars or letterbox bars to the picture and maintaining a 1:1 pixel reproduction, they could all pass the 3840 by 2160 tests, including all variations in color and phase.
16) The set of test patterns suggests a need for compliance in color resolution as well as luminance resolution. The color resolution requirement comes about because of variations in the way color is reproduced on individual displays.
17) Document all performed tests, images and waveforms within the declaration of conformance to the UHD resolution.

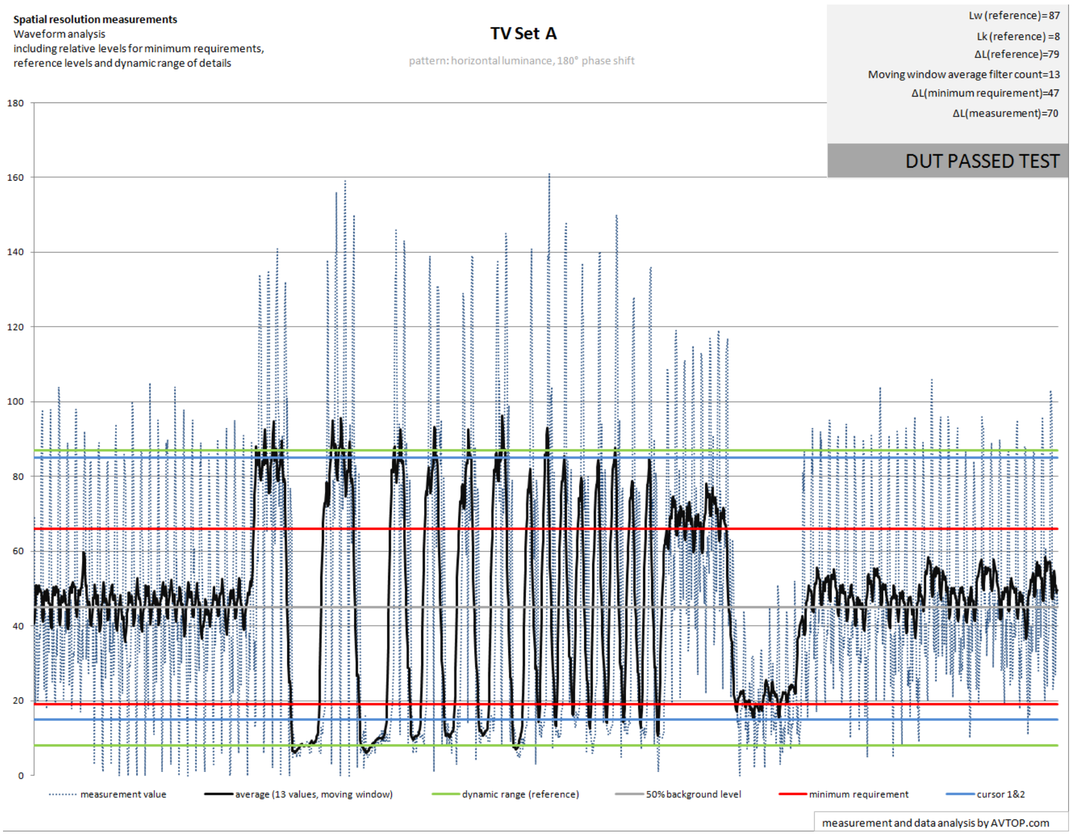
Illustration of the measurement method using the images captured by the camera:



TVA-M-P1: *In case of using a camera, a single line of pixels needs to be selected for waveform analysis. In the example shown here the visual inspection is passed in this case.*

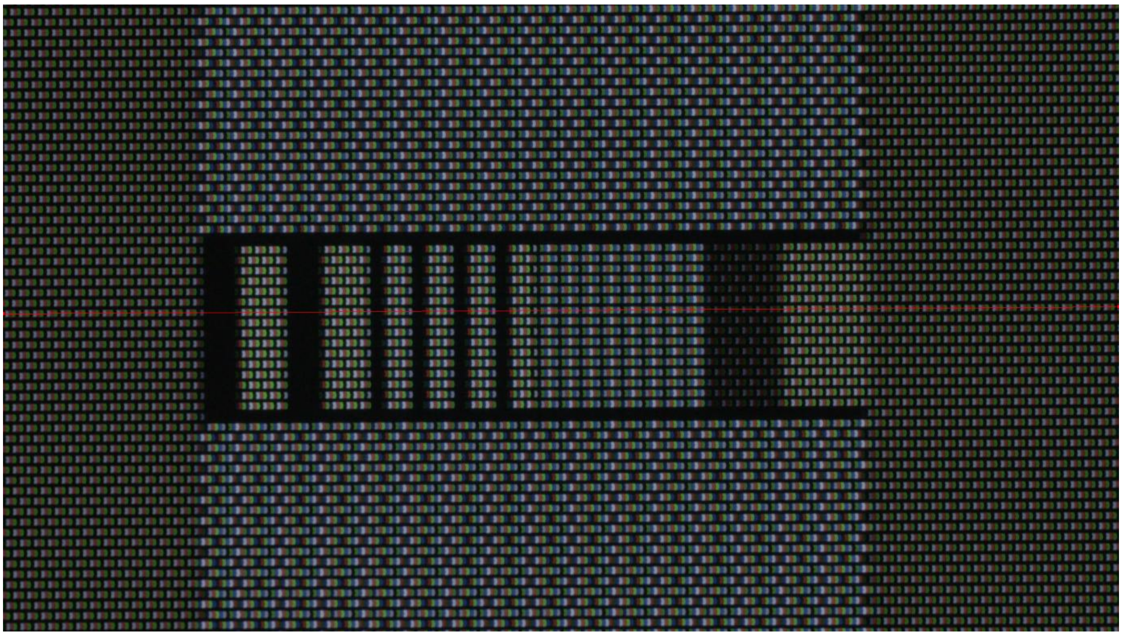


TVA-M-P2: *Without setting a proper moving window average filter, the measurements can be difficlut to determine – optimize the size of the averaging window.*

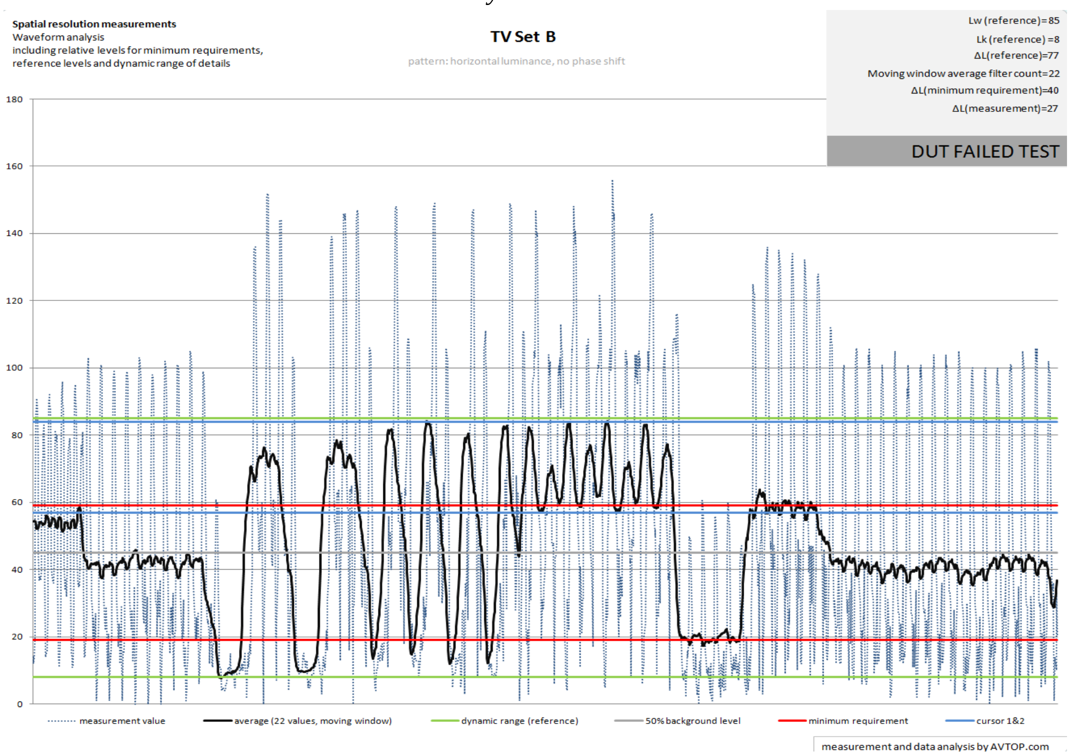


TVA-M-P3: *After setting a proper moving window average filter, the measurements are relatively easy. Setting all markers and analyzing the ranges, this display clearly exceeds the minimum requirements and passes the test.*

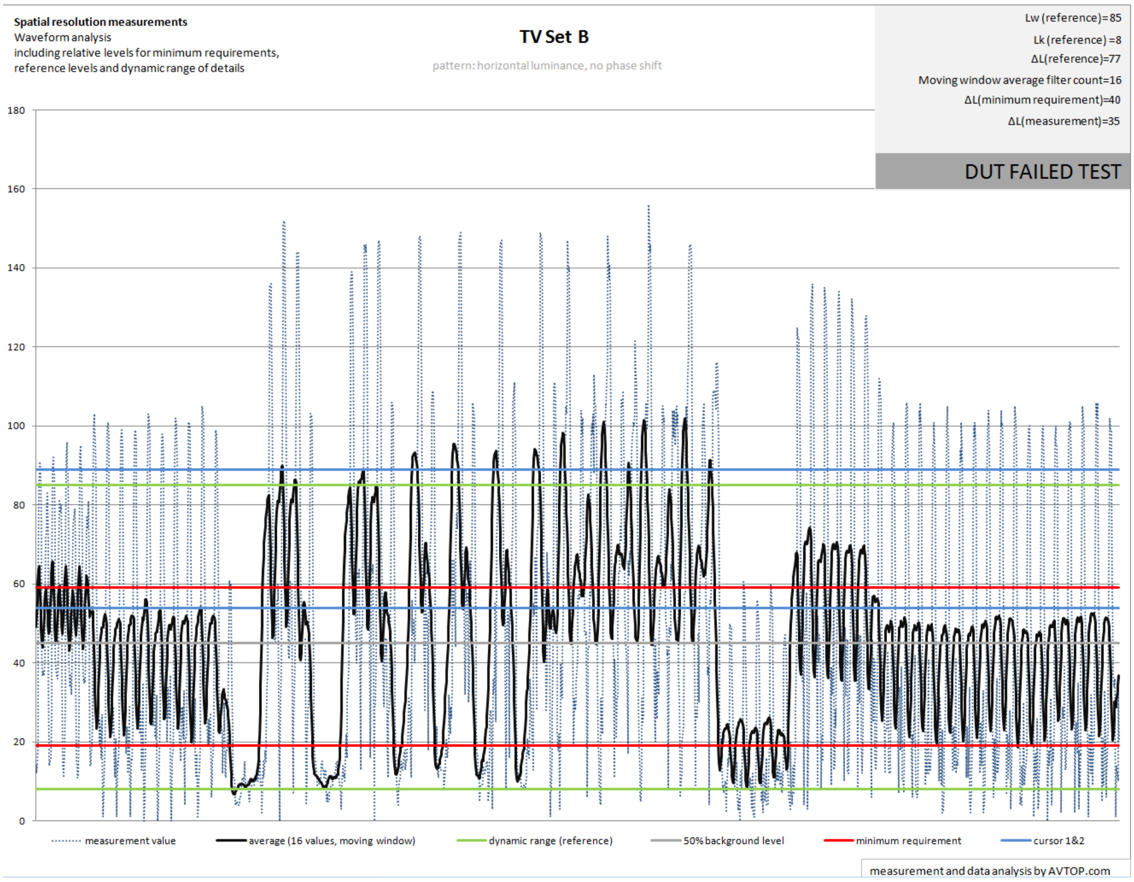
The next step is looking at the alternate phase of the horizontal resolution test. In this case we are illustrating an image where the DUT fails the test.



TVB-M-P1: *In case of using a camera, a single line of pixels need to be selected for waveform analysis. The visual inspection tells us that the individual pixel grilles are lost and the white bars are much wider than they should be.*



TVA-M-P2: *As you can see in the 50% flat field area, there are many dark gaps in between the subpixels.In order to allow a measurement of the light characteristic, the supersampled data needs to be filtered in order to allow a measurement. This device shows 8 signal peaks, but the dynamic range is much smaller than the minimum requirement.*



TVA-M-P3: *Decreasing the size of the filter, we still receive a dynamic range significantly lower than the minimum requirement. This device failed the test.*

Examples of test results using the horizontal version of the test pattern

TV Set A – Horizontal Resolution Pattern:

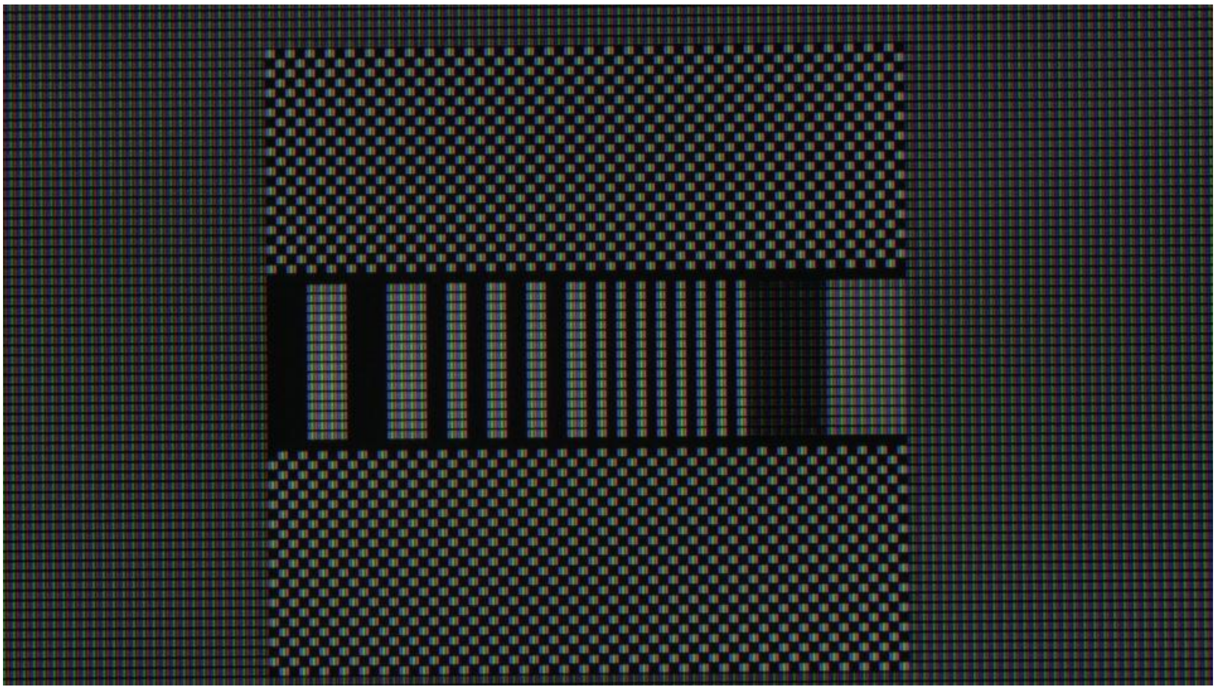
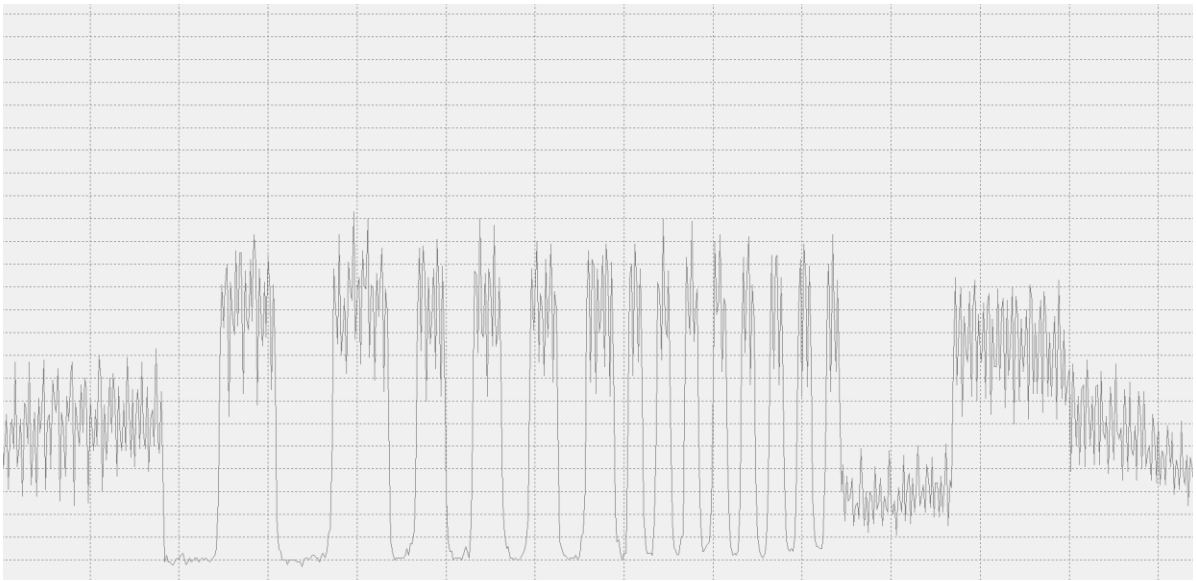


Image from a DSLR camera aimed at a single patch in the horizontal pattern

Visual inspection of the photographed image: This set **PASSED**

We're starting with the horizontal phase shifted pattern, making it easier to see the ideal image and waveform. In this illustration the horizontal phase of the grille patterns starts at black. All of the white bars are exactly as wide as anticipated. The white parts of each bar are clearly brighter in amplitude than the 50% reference. The checkerboard structure is properly reproduced with each pixel clearly above the 50% reference in amplitude.

The matching waveform is shown below.



Waveform created from the camera image

Measurement based on the waveform generated from the image: This set **PASSED**

This waveform comes from measuring the amplitude of a horizontal line in the middle of the grille. You'll notice what appears to be noise in the higher portions of the signal. This is a product of the elements of sub pixels that make up each pixel. In a traditional display the sub pixels have red, green and blue elements separated by small black areas between the elements. The amplitude of the red green and blue elements are not equal making it a bit more difficult to determine the value of white. Reading this waveform, beyond the issues of the individual elements of the pixel, you can see the width of each square wave is similar to our ideal image. There is little noise in the black area on the waveform as there is no light coming from those elements. Dynamic range of the grilles is certainly above and below the 25% and 75% markers that follow the single pixel transitions.

We mentioned patterns with a 180° phase shift in the checkerboard and the horizontal grille being a part of the set of test patterns. In this example, if you look at the top left of the top checkerboard you'll see it starts with black where the grille below starts at white. The grilles are reversed top to bottom in the horizontal pattern and let to right in the vertical pattern. The reversed phase should be checked at least by visual inspection because we've seen it cause problems in some sets.

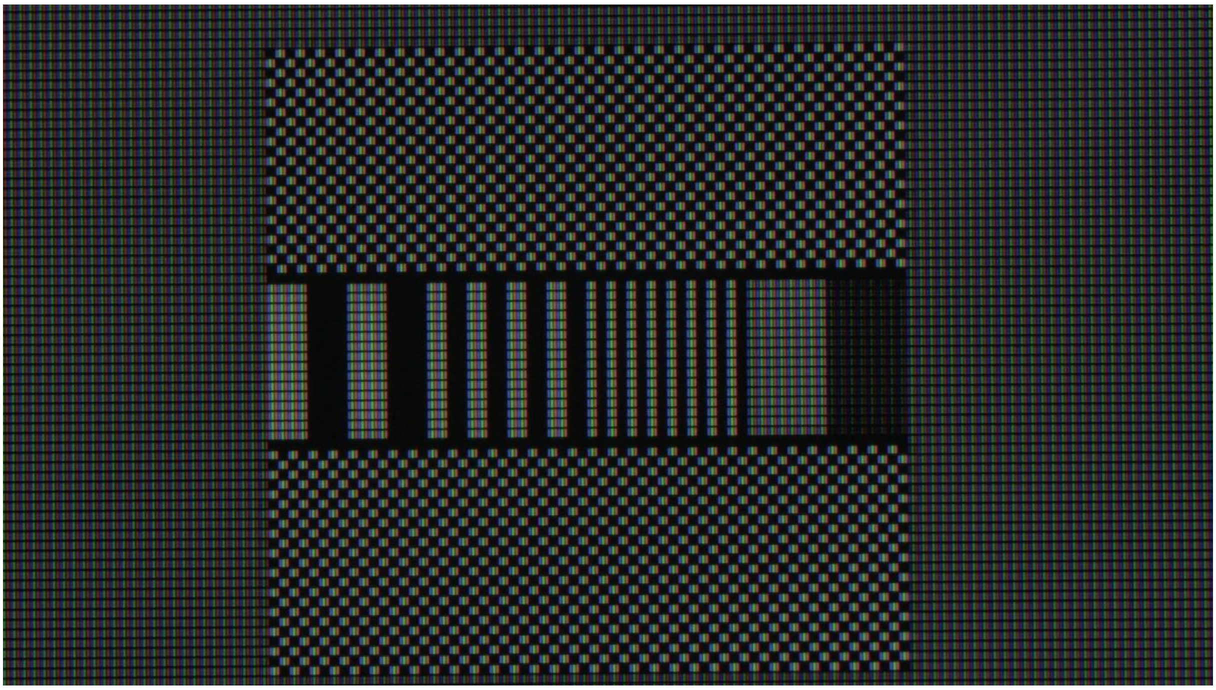
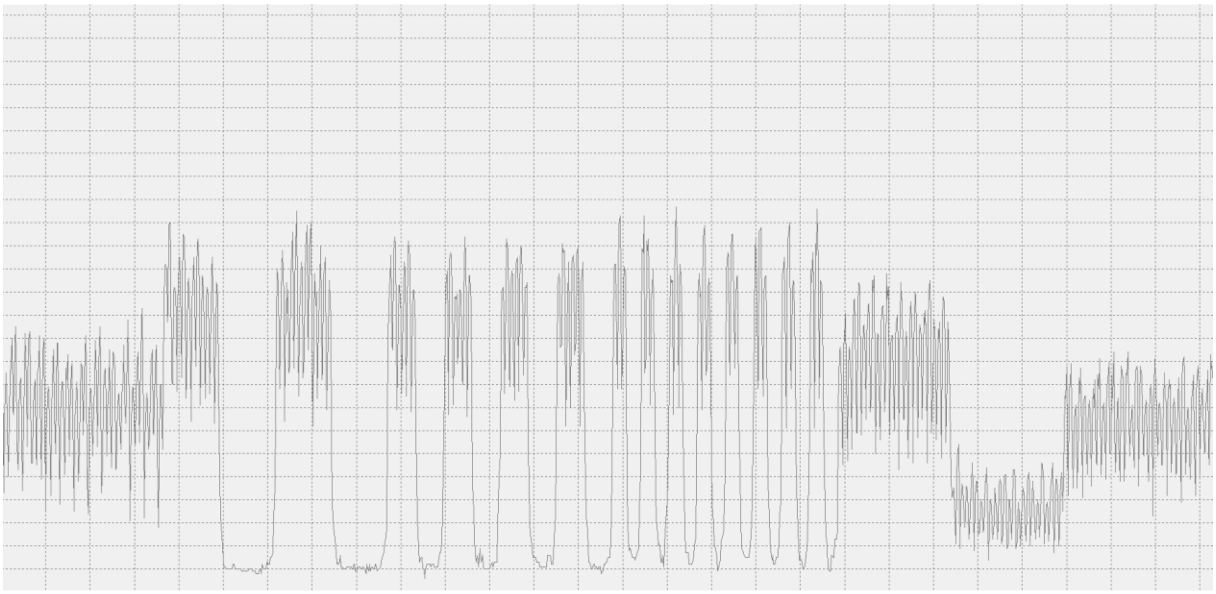


Image from a camera aimed at a single patch in the pattern – note the phase reversal

Visual inspection of the photographed image: This set **PASSED**

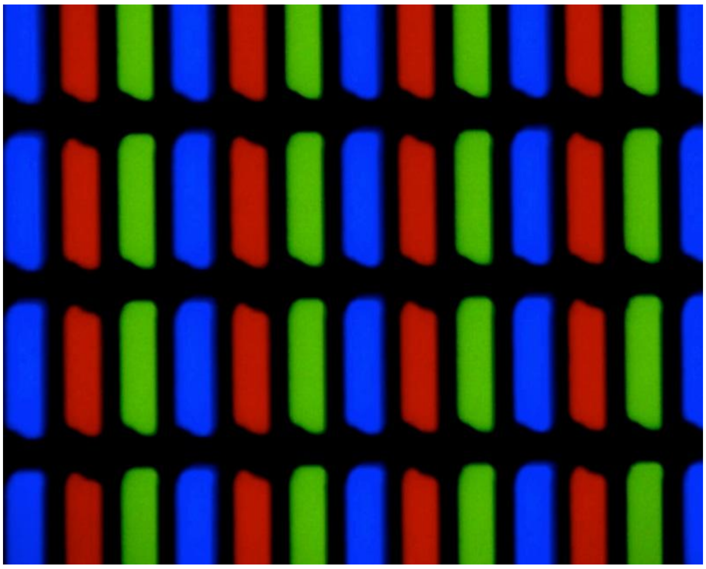
All white bars are exactly as wide as anticipated. The white parts of each bar are clearly brighter in amplitude than the reference for level at the right end of the grille. The checkerboard structure is properly reproduced with each pixel clearly above the reference at the right end of the grille.



Waveform created from the DSLR image

Measurement based on the waveform generated from the image: This set **PASSED**

You'll notice what appears to be noise in the higher amplitudes. This is a product of the elements of sub pixels that make up each pixel. In a traditional display the sub pixels are red, green and blue. They often have a small black area between the elements and the amplitude of the red green and blue elements are not equal. Reading this waveform, beyond the issues of the individual elements of the pixel, you can see the width of each square wave is similar to our ideal image. There is little noise in the black are as there is no light coming from those elements. Dynamic range of the grilles is certainly above and below the amplitude reference markers at the right side of the grille pattern.



LCD display pixel structure showing the black areas between elements of each pixel The black area between the red, green and blue is what cause the intensity excursions seen in the top of the waveform. The raw file from the camera may not show the true amplitudes or red, green and blue

TV Set A – Vertical Resolution Pattern:

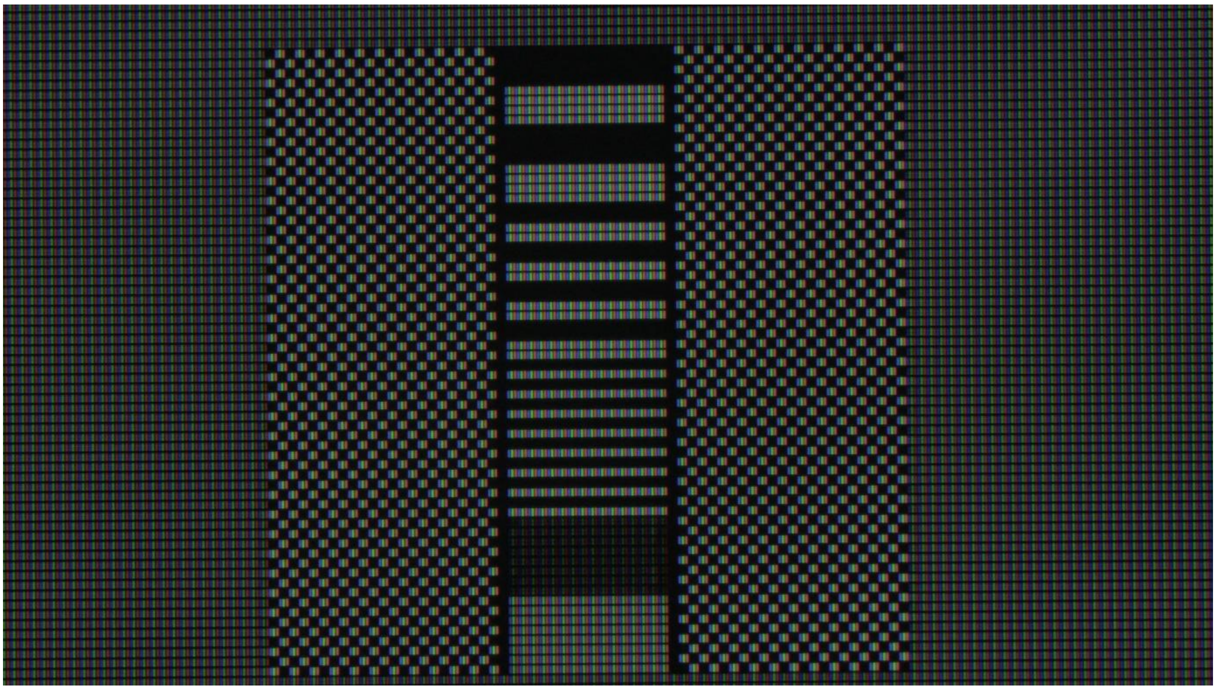
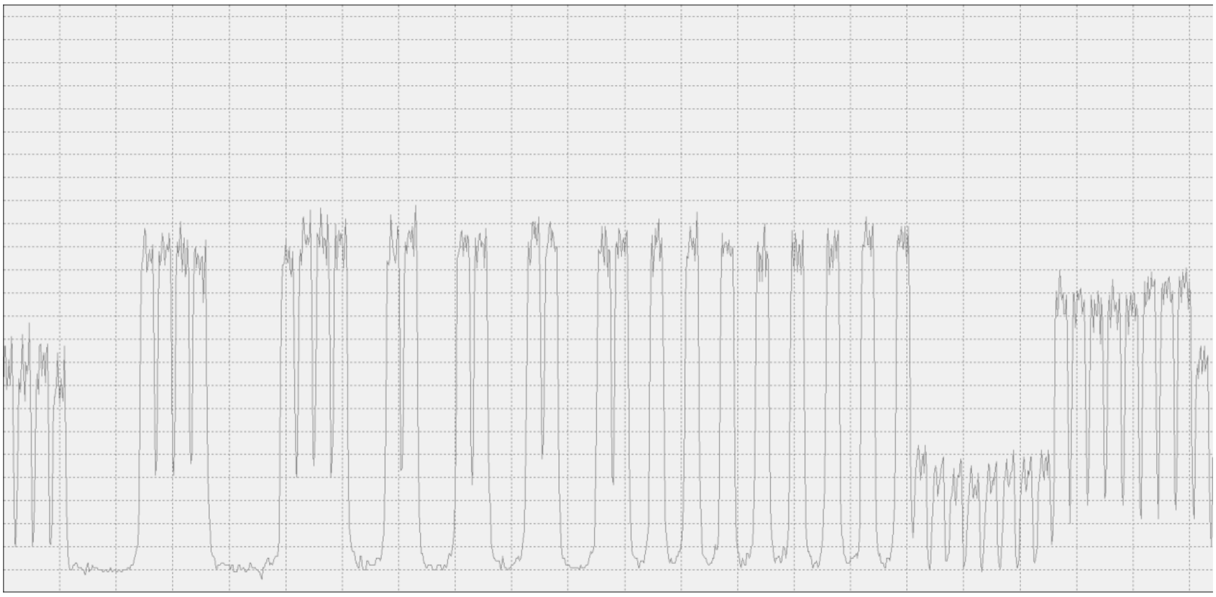


Image from a camera aimed at a single patch in the vertical pattern

Visual inspection of the photographed image: This set **PASSED**

Here we're looking at the vertical pattern. All of the white bars are as bright in intensity as we anticipated from the pattern. The white parts of each bar are clearly brighter in amplitude than the 50% reference at the lower part of the patch. The checkerboard structure is properly reproduced with each pixel clearly above the reference in amplitude at the bottom of the grille pattern.



Waveform created from the DSLR image

Measurement based on the waveform generated from the image: This set **PASSED**

This waveform comes from measuring the amplitude of a vertical line in the middle of the grille. The time it takes to go vertically is much longer than it takes to go horizontally so there is more time for the dark area between pixels to show up. You'll notice what appears to be noise in the higher amplitudes. This is a product of the elements of sub pixels that make up each pixel (pictured above). In a traditional display the sub pixels are red, green and blue. They have a small black area between the elements and the amplitude of the red green and blue elements are not equal. Reading this waveform, beyond the issues of the individual elements of the pixel, you can see the width of each square wave is similar to our ideal image. There is little noise in the black area as there is no light coming from those elements. Dynamic range of the grilles is certainly well above and below the reference markers at the bottom of the grille. In most case we would expect the amplitude to be better in the vertical direction than in the horizontal direction.

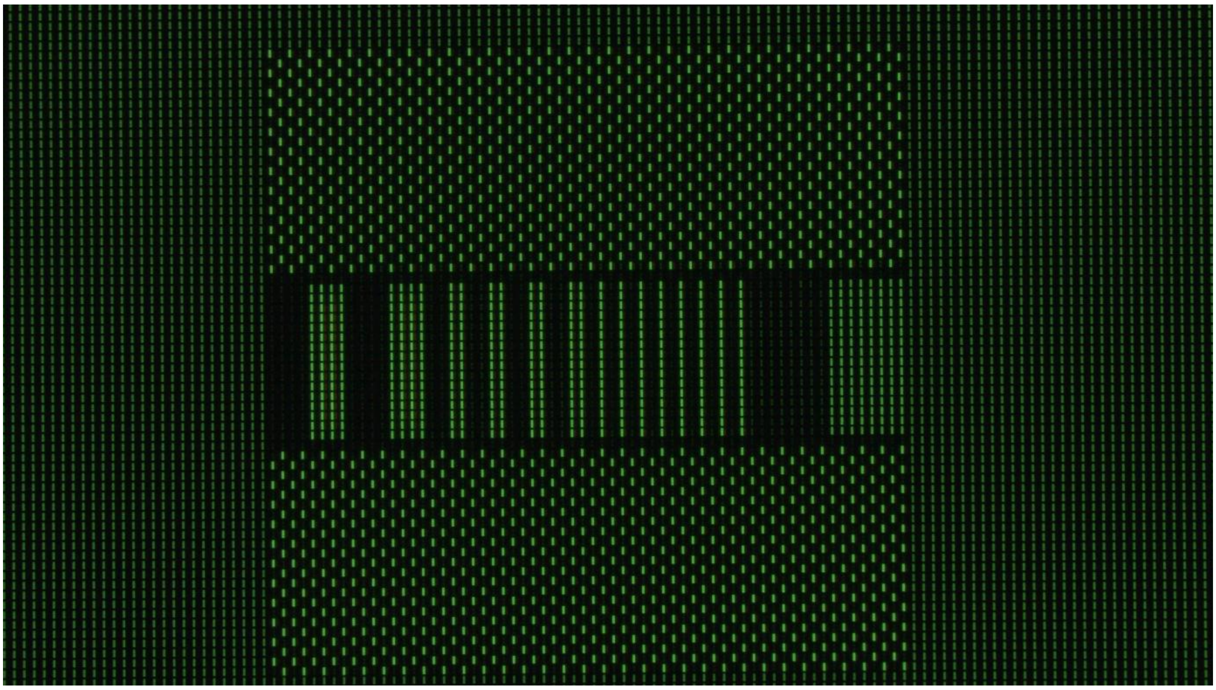
Looking at individual colors:

When pixel configurations were all equal, containing just subpixel elements of red, green, and blue for each pixel, it seemed unnecessary to go beyond a luminance grille measurement for resolution. As new configurations of a pixel evolve it has become necessary to measure the resolution of individual colors, if for no other reason than to inform us of what to expect in luminance we might have otherwise overlook. Color saturation can also be affected if a signal is delivered to something other than the anticipated red, green and blue elements.

We're seeing some changes in the makeup of a pixel in some displays which is why we are advocating an update to the way resolution is measured. One is the changes is the addition of a forth element. So far it is either white or yellow but we expect changes won't stop there. We anticipate cyan and or magenta elements to be added to the pixel structure. We're seeing what appears to a substitution of white for one of the three colors in each pixel. It would go something like white in place of red in one pixel, white in place of green in the next, white in place of blue in the third, with this configuration being repeated in the entire display. We're also seeing a variation of the number of subpixel elements that are being lit up. Defining a pixel based on the source signal we might find one pixel lighting up four or five subpixel elements in the display and the next occupying only two subpixels. This completely changes the geometry of the individual parts of the image. It's being done to get light output, almost like blooming in the CRT days where a bright spot would be larger than a dark spot. This gets complicated in what we see because we have different subpixel elements making up each pixel. The width of a pixel becomes variable.

Staying with DUT Set A, looking at individual colors:

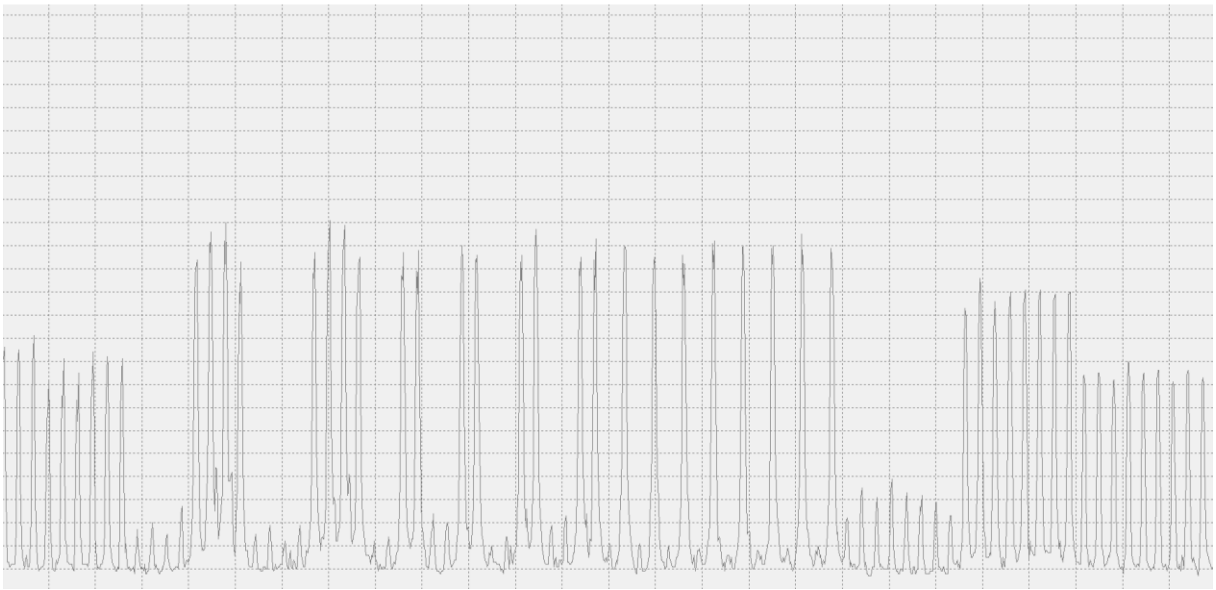
We're only going to show the green channel in this illustration



Green only signal - Image from a camera of a single patch in the pattern

Visual inspection of the photographed image: This set **PASSED**

The green bars are exactly as big as anticipated; the active area of the signal is as big as the inactive area. The width of the bars is reduced by 50% for each of the frequency steps. The checkerboard structure is reproduced as a checkerboard.



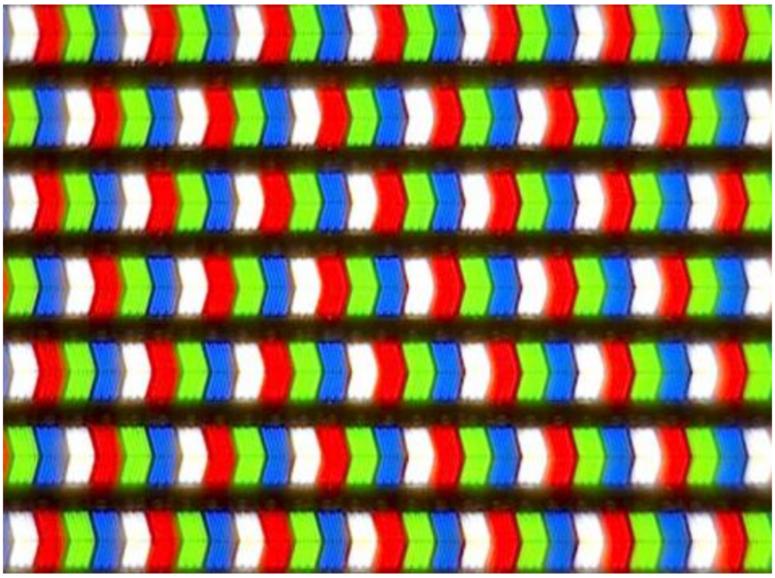
The waveform might be a little more difficult to interpret because the red and blue are missing

Measurement based on the waveform generated from the image: This set **PASSED**

Active and inactive areas of the signal are approximately equal in size, allowing for measuring the expected increments in frequency. Dynamic range is significantly better than the minimum requirement (averaging active and inactive signal area of the last slope).

DUT Set B – Horizontal Resolution Pattern:

Our TV set B has a different configuration of the elements in the pixel. It has an additional white and the white is spaced in such a way that it doesn't line up vertically or horizontally, creating the effect of substituting white for one of the three colors in each pixel. You'll notice the position of the white changing from one pixel to the next.



In this RGBW configuration none of the colors line up either horizontally or vertically. In this illustration there seems to be less black between the pixels than we are seeing in the example below

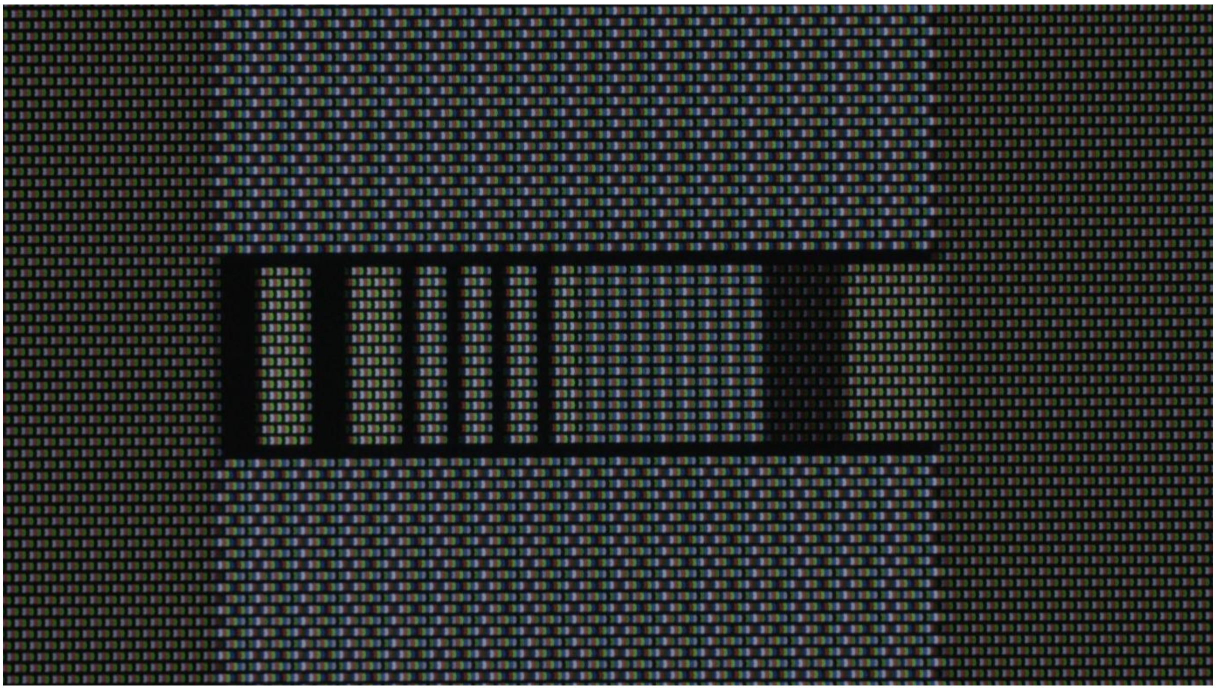
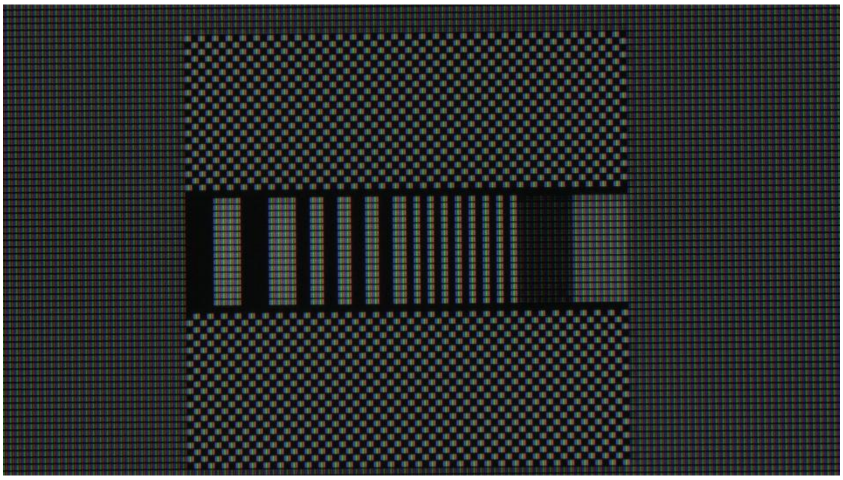


Image from a camera aimed at a single patch in the horizontal pattern. Note that the dark space between the pixels appears to be larger than the illustration shown above

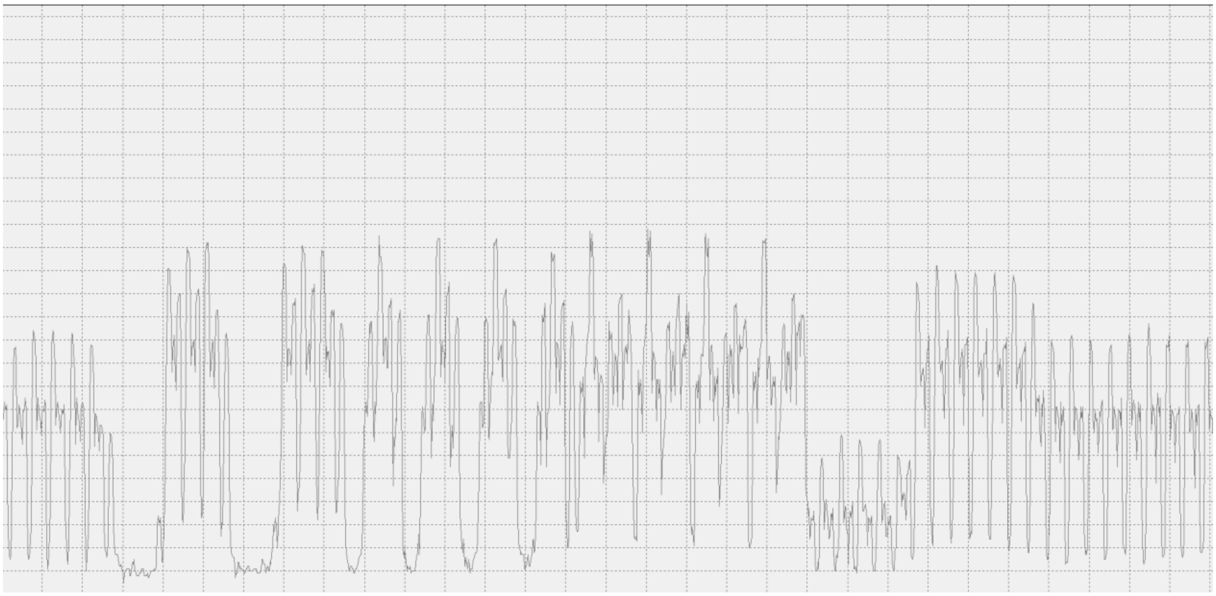
Visual inspection: FAILED

All white bars are significantly wider than they should be. Notice that even at one quarter resolution the square wave is no longer symmetrical. It's not symmetrical at half resolution and it looks almost continuous at full resolution. At the single pixel transitions in the signal the individual lines are 5 subpixels wide, leaving only one subpixel for the black lines. The checkerboard structure is completely lost. If you were to back away slightly from the display the checkerboard would look almost solid with slight diagonal lines running through it.

Rather than ask you to go way back in this document to see what it should look like we'll repeat the results from set A below.



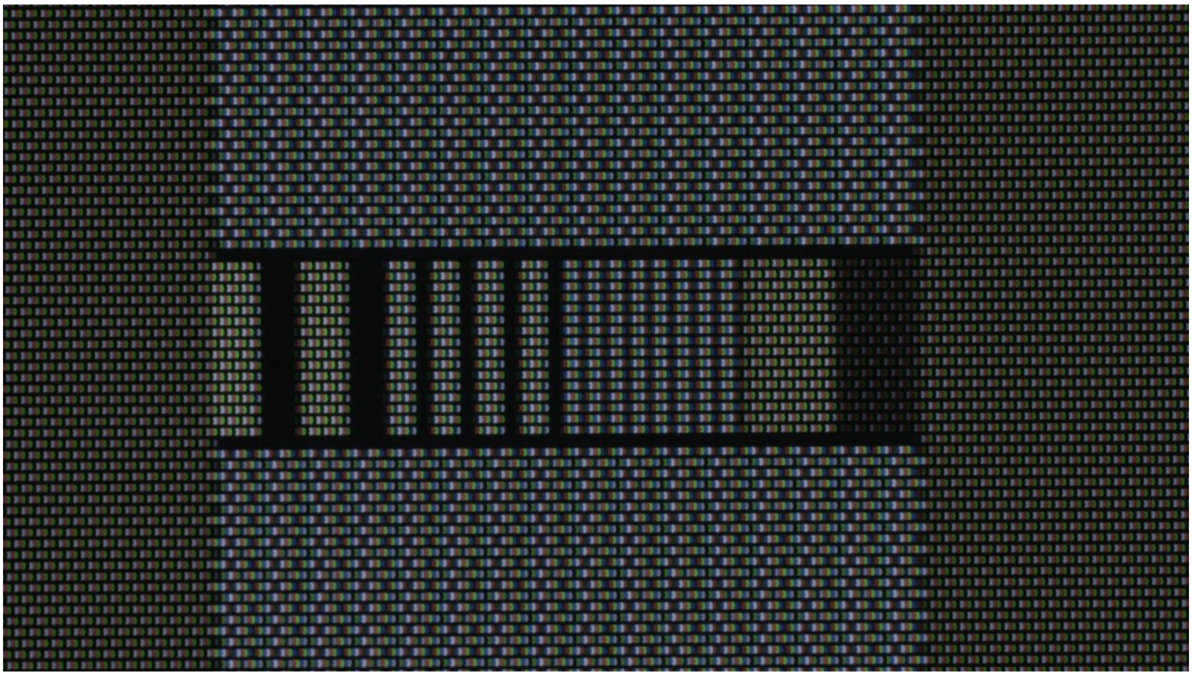
Reminder of what the H grille should look like



The derived waveform from the picture of Set B

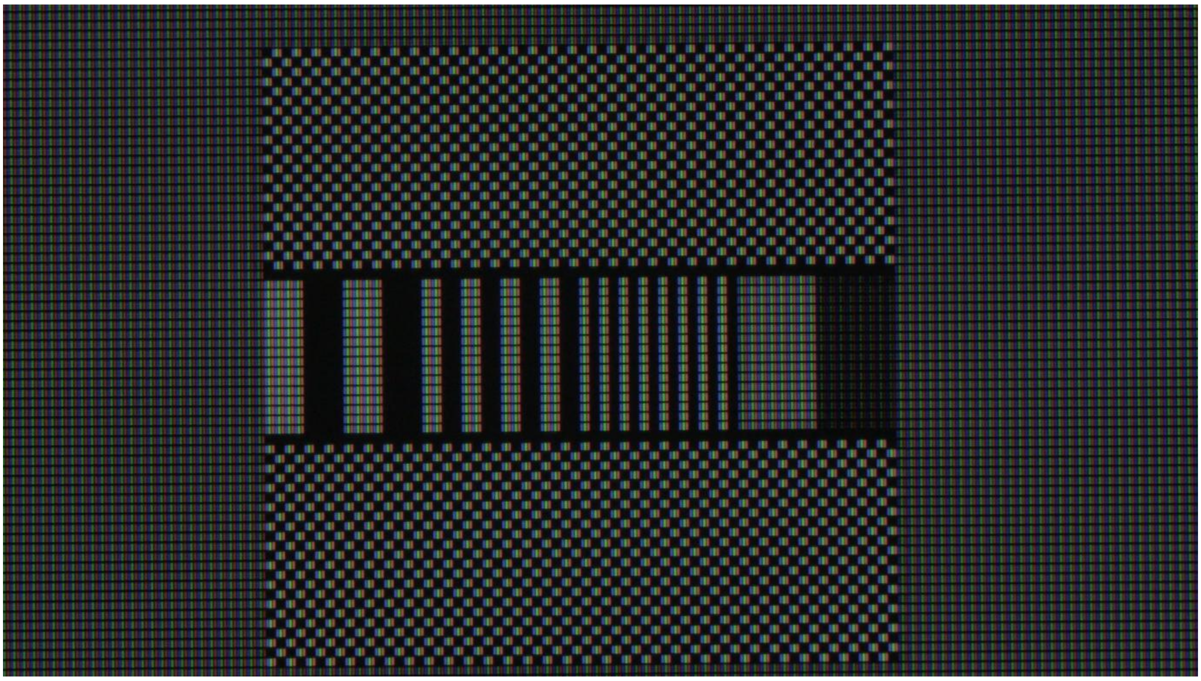
Measurement based on the waveform generated from the image: Set B **FAILED**

At the highest frequencies of the signal, there are only 4 significant signal peaks (instead of 8). The dynamic range is lower than the minimum requirement (averaging active and inactive signal area of the last slope).



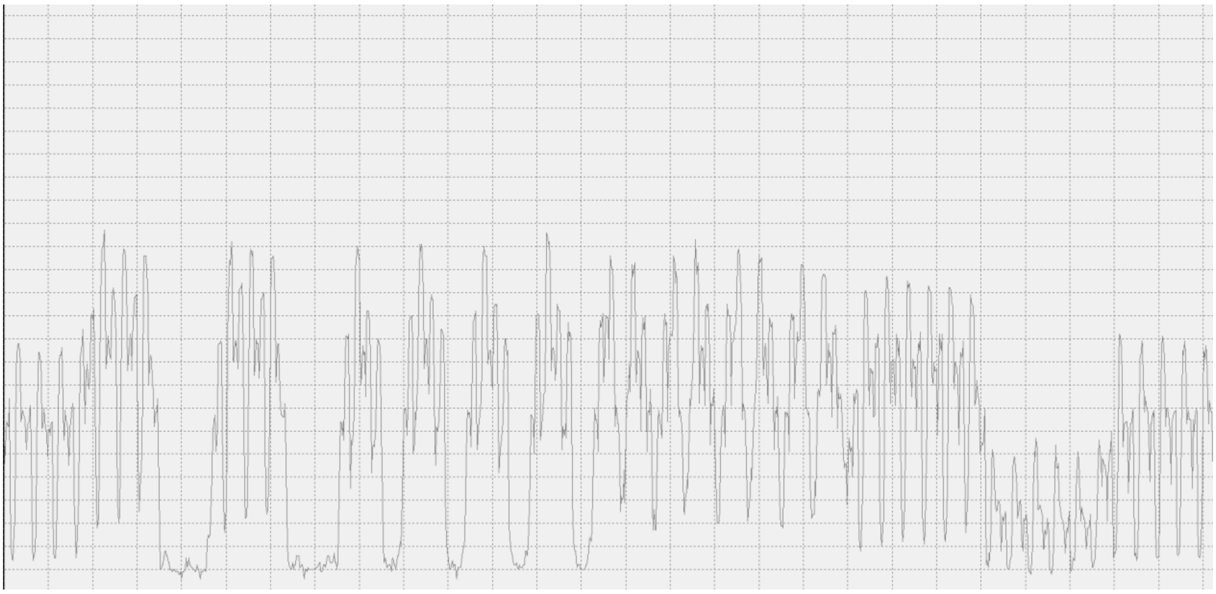
Horizontal pattern phase shifted by 180° as displayed on Set B

Visual inspection of the image from the DSLR camera: Set B **FAILED**



The results from Set A as a comparison

Looking at set B again, the white bars are not symmetrical, with the white part being wider than the black part. The checkerboard structure is completely lost and will probably look more like a solid than a checkerboard.

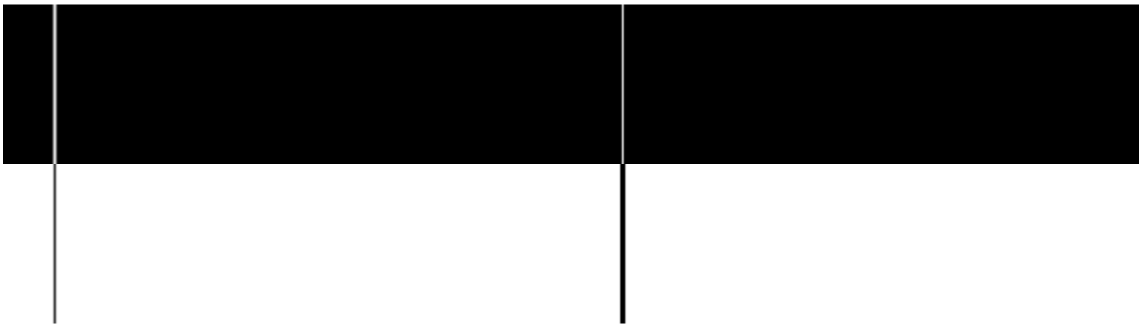


The derived waveform from Set B

Measurement based on the waveform generated from the image: Set B **FAILED**

At the highest frequencies of the signal, there is no waveform structure allowing us to measure a frequency. You'll notice it isn't much different than the five pixel wide background 50% dynamic range reference to follow the single pixel grille. The dynamic range of the single pixel transitions is far below the 50% reference to follow it when you average the active and inactive signal areas.

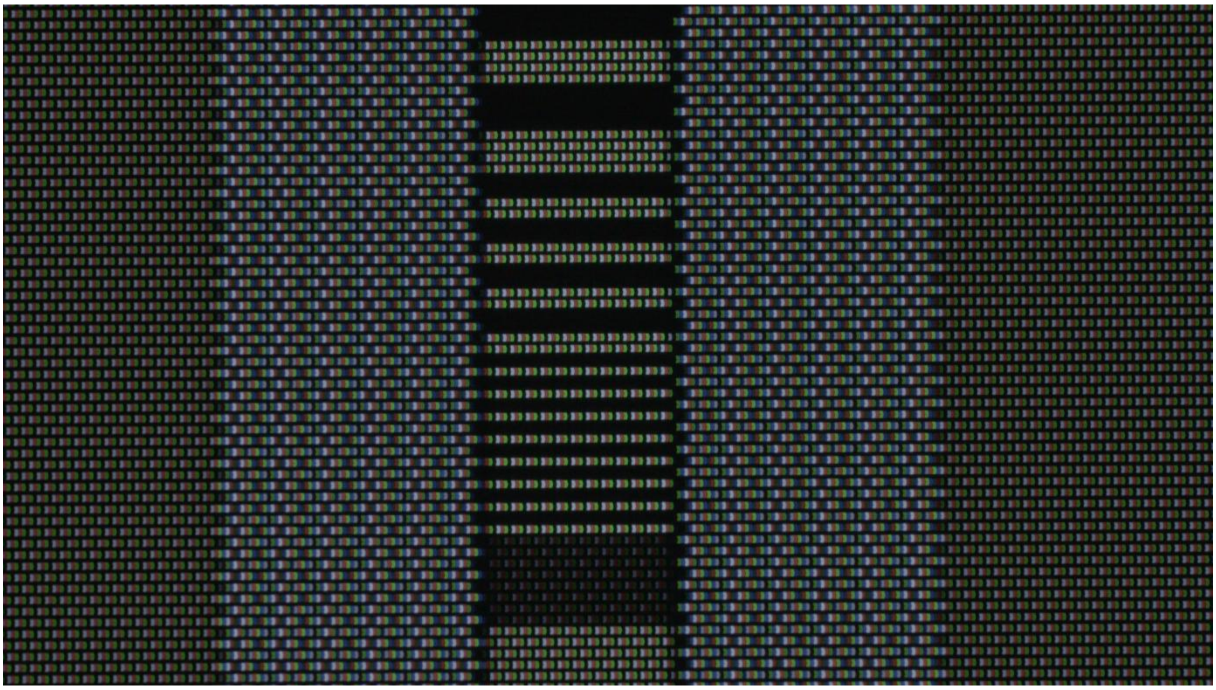
The way the horizontal information is being displayed reminds us of the days of scan velocity modulation in CRT's. You may remember the Needle Pulse Test Pattern.



Needle Pulse pattern displayed correctly – Needle Pulse pattern showing SVM artifacts

In the CRT days the beam creating the picture was sped up or slowed down, whatever was necessary to get more light out of the display. We're seeing something similar in these new displays where a bright part of the picture is represented by a wider area and the dark part of the area is represented by a narrow area. The geometry of the subpixel structure is no longer being respected. We spill over into the next set of elements when we want the image bright. Doing so means there is no fixed definition of a pixel, so how do you count them? What's the real resolution when information isn't displayed properly? The pass fail criteria simplifies the answer. It is either correct or it isn't.

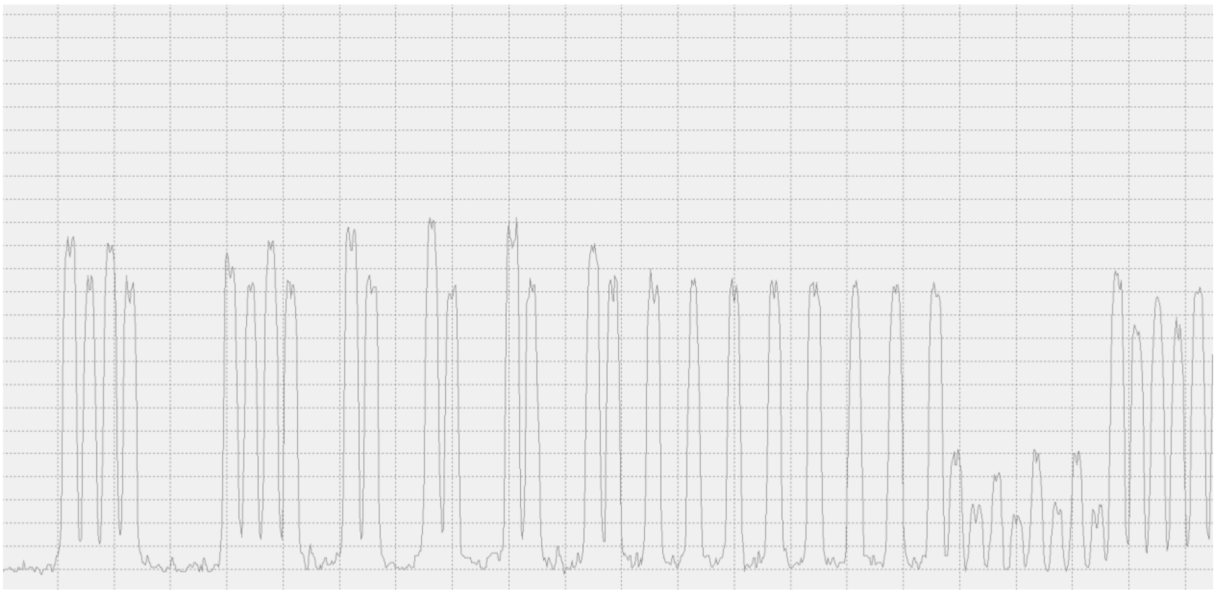
Staying with set B we'll now look at vertical resolution



DSLR image of the vertical resolution pattern – the phase of the pattern is what we call 0°

Visual inspection of the vertical grille pattern: If the grille pattern is our only concern the set **PASSED**

All white bars are exactly as big as anticipated; the active area of the signal is as big as the inactive area. The size of the bars is reduced by 50% for each of the frequency steps. As anticipated from the horizontal pattern the checkerboard structure is essentially lost, but since we are primarily concerned with just vertical resolution we've given the set a pass for this parameter.

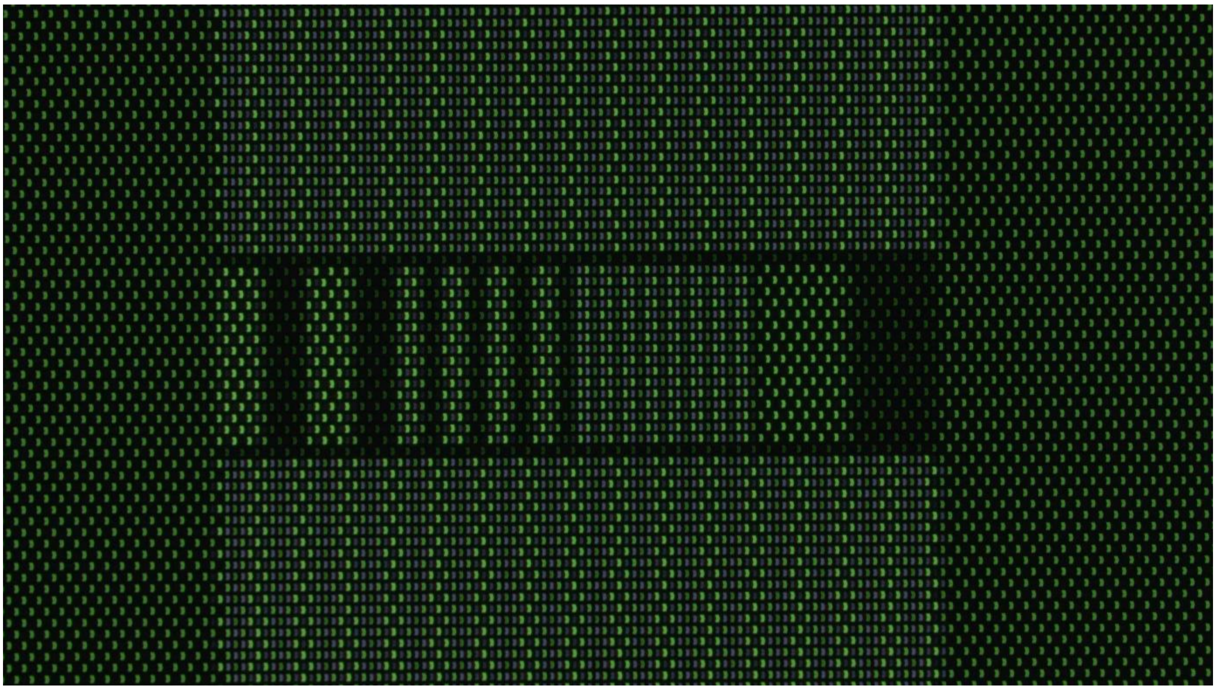


The derived waveform of the vertical grille

Measurement: PASSED

Active and inactive areas of the signal are approximately equal in size, allowing for measuring the expected increments in frequency. Dynamic range is significantly better than the minimum requirement (averaging active and inactive signal area of the last slope).

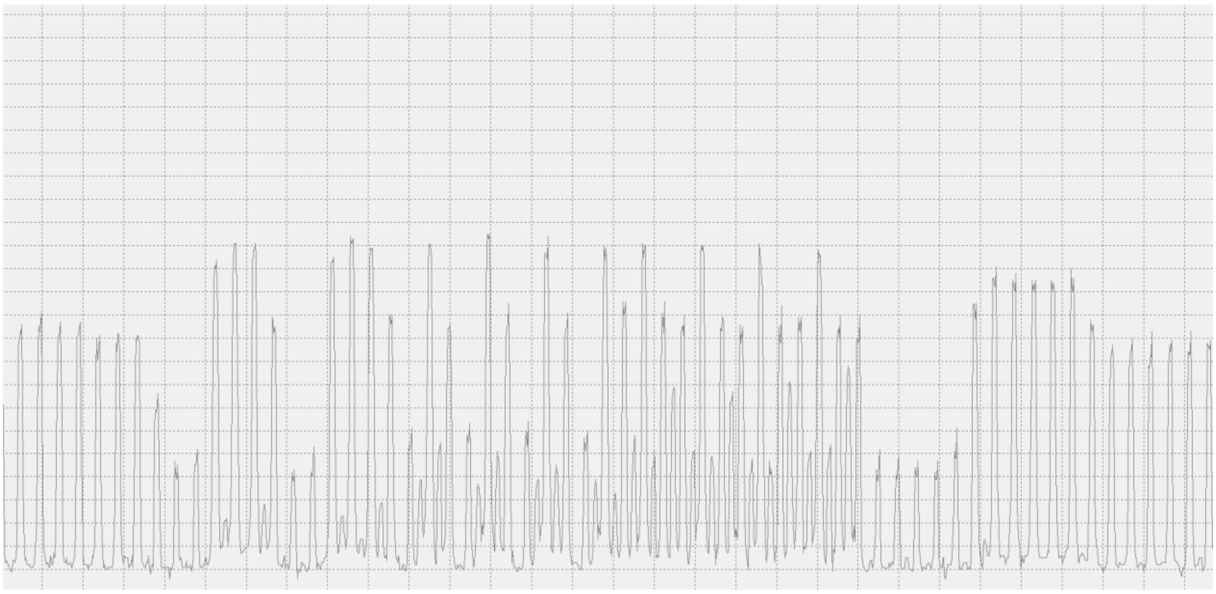
Staying with Set B we'll look at an individual color. We're again picking green and going back to the horizontal resolution patch.



DSLR image of green only horizontal resolution, zero phase shift, on Set B

Visual inspection of the DSLR image: Set B has **FAILED**

The single pixel transitions, which should be one line on followed by one line off show up as jagged edges. There is no clear line structure. The checkerboard structure is completely lost.



Measurement from the derived waveform: Set B **FAILED**

None of the line structures for the resolution steps are symmetrical. At the highest frequency of the signal, there is no waveform structure to use to measure the expected frequency. Dynamic range is significantly better than the minimum requirement (averaging active and inactive signal area of the last slope).