Fully Automated Stability

White Paper • November 2006

display
SOLUTIONS

- Introduction of Fully Automated Stability
- Fundamentals of Medical Grade Display Design
- Systems to Maintain Stability and Check Consistency
- Benefits of the Siemens Approach to Fully Automated Stability
- Conclusion

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1 Introduction

This white paper will describe a complete approach to display consistency management, referred to as fully automated stability.

Consistency from display to display and stability within a display is important in medical imaging for numerous reasons. Display users suffer less fatigue when there is good consistency from display to display. Stability within a display assures that anatomy looks the same over time, making for better diagnostic interpretation.

For these reasons, the fully automated stability system was created to optimize display performance.

This paper will describe:

1) The fundamentals of medical grade displays as related to stability and consistency.
2) Description of the fully automated stability system used with Siemens displays
3) The proven benefits of the fully automated stability system in achieving display-to-display consistency and within display stability.

2 Fundamentals of Medical Grade Display Design

2.1 Key display components

A medical grade display consists of a relatively few major sub assemblies. The Active Matrix TFT Liquid Crystal Module is at the heart of the display. Also important is the backlight, controller board, stabilization sensors, and sensors dedicated to checking consistency. Please see Figure 1 for a graphical representation of a medical grade display.

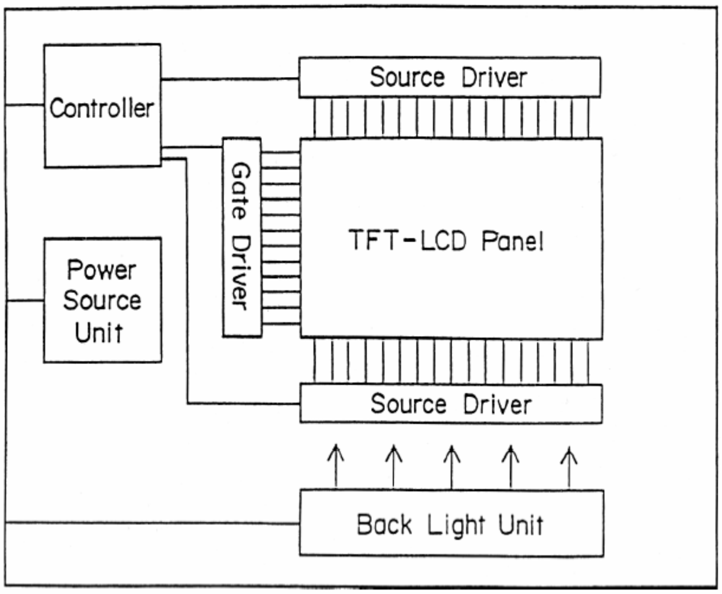


Figure 1 – Schematic for a medical grade display

Sensors are typically located either on the front glass of the display and/or behind the backlight of the TFT array. A small hole in the backlight unit allows light to pass back to the sensor so as not to interfere with the uniformity of light at the center of the display.

2.1.1 How the Siemens Fully Automated Stability system controls the display

The image matrix is passed to the controller board from the graphics card located on the workstation. For most medical imaging applications, PACS in particular, the image data is passed as digital data to the display controller. A digital driving level (DDL) is assigned for each pixel. The DDL is passed to a look-up-table so that a corrected value can be passed to the panel electronics. A look-up-table built into the display controller makes it possible to correct the gray levels to achieve perceptual linearization or other desired calibrations of the display. Stabilization sensors are calibrated at the factory to achieve maximum resolution over the dynamic range. This sensor is used to control the stability of the backlight which will produce a stabilized maximum and minimum luminance.

2.2 Impact of Key Display Components on Stability

2.2.1 Backlight aging

The key challenge in maintaining display stability is compensating for backlight aging. Whether using CCFL backlights most common to medical displays or the custom Xenon gas backlights used with Siemens flagship displays, backlights will generally decrease in intensity over time.

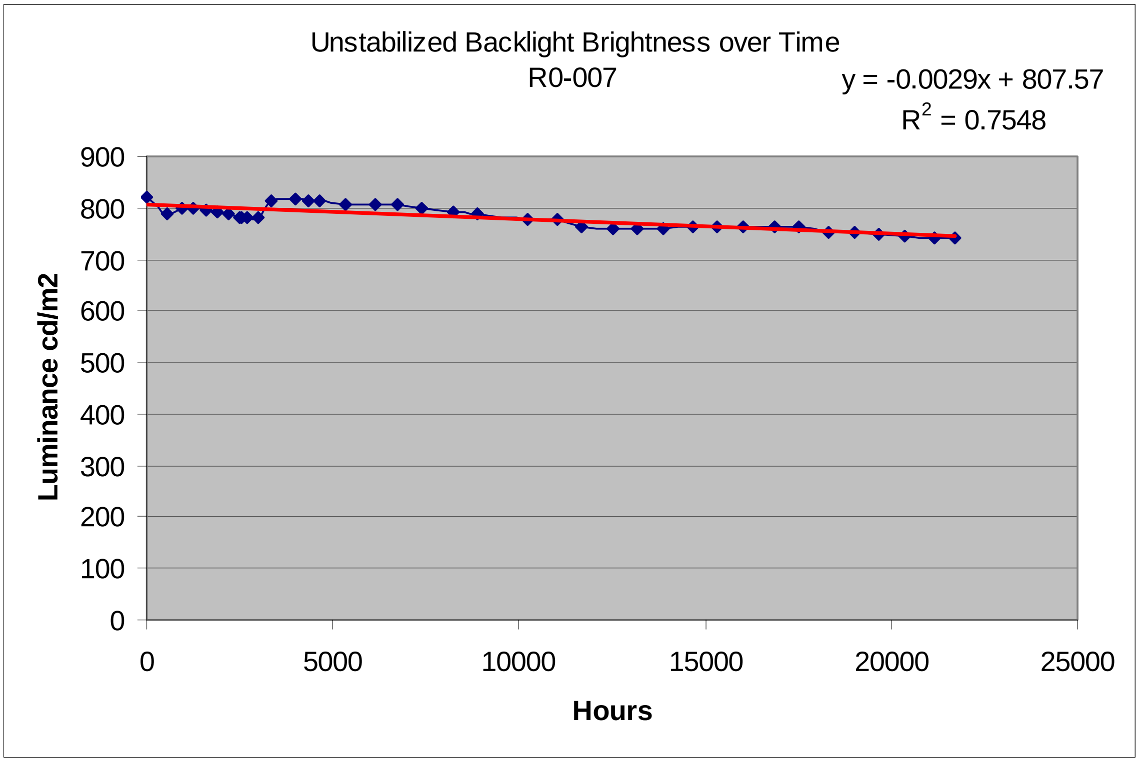


Chart 1 – Typical backlight aging curve for Siemens SMD 21500 5MP display

Chart 1 is data collected for a typical SMD 21500 Siemens display. It shows degradation of backlight intensity from its unregulated maximum possible brightness. Unregulated backlight intensity gives an indication of what the maximum regulated luminance could be for a given time period. For this particular SMD 21500, which utilizes a Xenon gas backlight, it meets the luminance warranty of 400 cd/m^2 at 25,000 hours. Projecting into the future, this display should have a luminance level greater than 500 cd/m^2 at 100,000 hours.

With CCFL backlights, nonuniformity of the backlight must be considered as the backlight ages. CCFL backlights are essentially a fluorescent tube filled with gaseous mercury. Over time, the mercury tends to leave deposits on the backlight, with the greatest buildup at the anode and cathode. This can result in a noticeable discoloration and lower luminance, particularly at both ends of the florescent tube. While a luminance uniformity of 30% was found acceptable for diagnosis, one of the reasons that AAPM TG18 specified this tolerance level for display uniformity was to take the limitations of some backlight technologies into account.

2.2.2 Active Matrix TFT Module

Only a limited number of manufacturers have the financial strength to make the capital investment required to build the state-of-the-art manufacturing facilities used to produce active matrix TFT modules suitable for medical diagnosis. Given their high resolution and the specialized switching technologies used, medical grade displays are produced without the economies of scale offered in the commercial display market, where millions of televisions and computer displays serve to mitigate the TFT's poor production yield. The rejection rate also suffers as the manufacturer's sort out panels that meet the stringent requirements of medical applications. Given the limited number of potential sources for medical grade panels, those manufacturers that chose to compete in this segment employ comparable production techniques and QA criteria to ensure consistent quality from one active matrix TFT panel to the next.

Additionally, there are technical reasons that the TFT module is of uniform quality and stable over time. The native gamma of an IPS panel depends only on the voltage applied to the liquid crystals (LCs), the sensitivity of the LCs to this voltage and the thickness of the LCs. Sensitivity is a measure of how much the LCs are twisted by a specific voltage. The twisting of the LCs determines how much light is allowed to pass through the polarized glass. The voltage itself is applied by the drivers, which convert the digital 8 bit values to an analog voltage. The conversion is very stable over time because of the simplicity of the D/A converter. However, the amount of twist in the crystal can be temperature sensitive.

Luminance non uniformity on a display is caused by the backlight and by variations in the thickness of the LCs. The thickness is controlled by the use of spacers to maintain a uniform gap between the 2 glass plates. An IPS panel has a gap of only 15µm. For this reason, the tolerances of the glass and the spacers are important. The spacers are elastic. If pressure is applied to the glass and then released, the spacers need to return to the former distance exactly (within a fraction of a micron), to avoid changing the uniformity. Because the spacers cannot offer this level of guarantee, the panel uniformity will likely be affected by shock and vibration (e.g. during transportation).

In summary, unless there is some sort of mechanical shock (i.e. dropping the display) or insufficient temperature control, there is no perceptible change to the liquid crystal display over time. Neither light, nor electric currents typically applied to the active matrix TFT will cause degradation in performance. The front and rear polarizers are also known to be stable over time.

2.2.3 Sensors

Unlike commercial grade LCD displays, medical grade displays have integrated sensors. These sensors can be used as part of a feedback loop to regulate light intensity and/or as a secondary check of the complete display system. A system with more than one sensor achieves some degree of redundancy. However, as we will discuss in the section on drift, this is not sufficient to assure true stability over the entire lifetime of the product.

2.2.3.1 Location and Function

A key design issue for flat panel displays is the question of sensor location and sensor function.

- Should sensors be mounted on the front of the display or the back of the display?
- Should the sensor be at the center of the display or at the edge of the display?
- Should the sensor be used as a simple feedback loop to stabilize backlight output or should it be used to calculate a grayscale display function?
- Should the sensor be used solely for checking display performance or should it be used as an electronic control device?

All of these questions must be considered when designing the calibration and control circuitry for flat panel displays.

Front versus back sensors

As noted in the section on the active matrix TFT module, the actual panel itself is very stable over time. Under normal operating conditions, the crystal matrix does not degrade. The prime source of change in the system is the backlight. As such, a strong argument could be made that a rear sensor located on the backlight will produce measurements that are at least as accurate, if not more so, than measurements taken by a front sensor.

Because an active matrix TFT module has a transmission rate of about 10%, a sensor located at the front of the display measures luminance levels that are only a fraction of those measured directly at the source. Given the physics of sensors, measurements taken at lower luminance levels are much less accurate and generally take longer than measurements taken at higher luminance levels. Because the backlight in a medical grade display is designed to operate at consistently high levels, a back sensor takes continuous measurements at the high levels of brightness it was designed for. Light at the front of a display is modulated by the TFT panel. Therefore, a back sensor can deliver a higher degree of precision than a front sensor.

Center versus edge sensors

An edge sensor has the advantage of being the only practical method of placing a sensor on the front side of the display. However, as previously mentioned, for displays with CCFL backlights, the nonuniformity of the display can increase as mercury deposits build up at the anode and cathode over time. The result is that displays using an edge sensor might become artificially brighter than desired at the center of the screen if the edge is used as the stabilized bright point.

The advantage of a center sensor is that light is measured at the prime viewing location. Therefore, luminance is stabilized at the most critical viewing position as suggested by the DICOM standard. The challenge with center sensors is that they must be placed behind the LCD so as not to obstruct image viewing. Given that the TFT array has little impact on overall stability, the impact of the sensor being placed behind the LCD is minimal and in fact, could be more accurate.

2.2.3.2 Drift

All sensors drift. Leakage currents and ground noise can contribute to changes in performance over time. While an error state may eventually be detected, it is not possible to tell if the sensor has maintained ‘truth’. The only way to check a sensor or recalibrate a sensor to ‘truth’ is to use an external device which itself has been calibrated and can trace its calibration history to national standards for the unit being measured.

2.2.4 Memory Effect

If a section of an active matrix is left in an activated constant state for an extended period of time, a memory effect will develop. A residual capacitance can develop that causes the pixels to become stuck in their active state. The so called memory effect is said to develop when the LC loses its ability to fully return to its natural state (i.e. blocking light).

For LCDs, the memory effect can usually be reversed by repeatedly powering the display on and off or by displaying bright and dark images in alternate cycles over an extended period of time. Depending on the severity, this process can take up to several days of cycling to completely remove the memory effect.

This could be of particular concern if a front edge sensor requires that a small section of the display remains in a constant state. If the memory effect is not corrected, the display will no longer be able to achieve its darkest black levels and the front sensor will not be able to accurately estimate the LCD function in other parts of the screen based on the erroneous readings taken at the edge.

2.2.5 Protective glass

In some situations, additional protection for the LCD panel is desired. A protective glass pane over the LCD can make it easier to clean and protect the display from damage caused by mechanical pressure. For example, if excessive force is used to point at images located in the image, an artifact can be created. Also, a protective glass pane can be of particular interest in environments subject to frequent cleaning with potentially harsh cleaners such as operating rooms.

The predominant disadvantage of using protective glass is veiling glare and reflection. The additional layer of glass increases the scattering of light as the light passes from the backlight through to the front of the display. Additionally, the thicker glass can contribute to more reflected ambient light. This additional scattered light will reduce the effective contrast of the display. In most reading environments, avoiding the use of protective glass is the preferred solution. The impact of veiling glare is great enough that it usually outweighs the benefit of protective glass.

3 Systems to Maintain Stability and Check Consistency

This section describes how Siemens Display Technologies implements their sensor philosophy to achieve fully automated stability.

3.1 Integrated Stability System (ISS)

3.1.1 Sensor design

Siemens has chosen to implement a center sensor for stabilized backlight luminance. This approach is implemented on all Siemens medical grade displays. The following diagram shows the basics of the implementation.

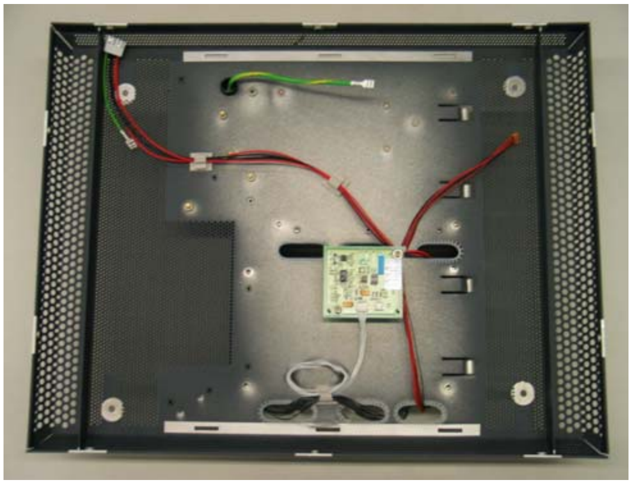


Diagram 1 – Example Placement of Backlight Sensor

In principle, the design is a simple digital controller feedback circuit. At the factory, a backlight control value is established using highly accurate measurement equipment. The generalized formula to express this is:

Desired stabilized luminance = (BL control value / k) + measured value

In practice, the proprietary algorithms and circuitry are capable of compensating for temperature, spectral sensitivity of the eye, and other variables that could potentially cause drift. The sensor itself is a photodiode, with additional circuitry on the sensor chip (linear current amplification), a filter and mechanical design aspects to protect the sensor from dust. Component qualifications and extensive temperature testing during development guarantees very low temperature dependence.

The ISS is featured in all Siemens PACS displays. With a highly accurate sensor at its core, the ISS serves to monitor and control luminance in accordance with DICOM and other applicable medical standards.

3.1.2 Data Supporting Stability with ISS

As an example of the stability that is possible with the ISS, an SMD 21300 3MP display was tested for at least 15,000 hours. While the performance of individual panels may vary, a luminance warranty was developed to provide a standard level of performance. During the study period, the luminance over the complete range of possible luminance values remained stable. Recalibration of the sensor within the study period was not required. Furthermore, the data demonstrates that the display is capable of maintaining stabilized luminance of more than 600 cd/m^2 for well beyond the study period.

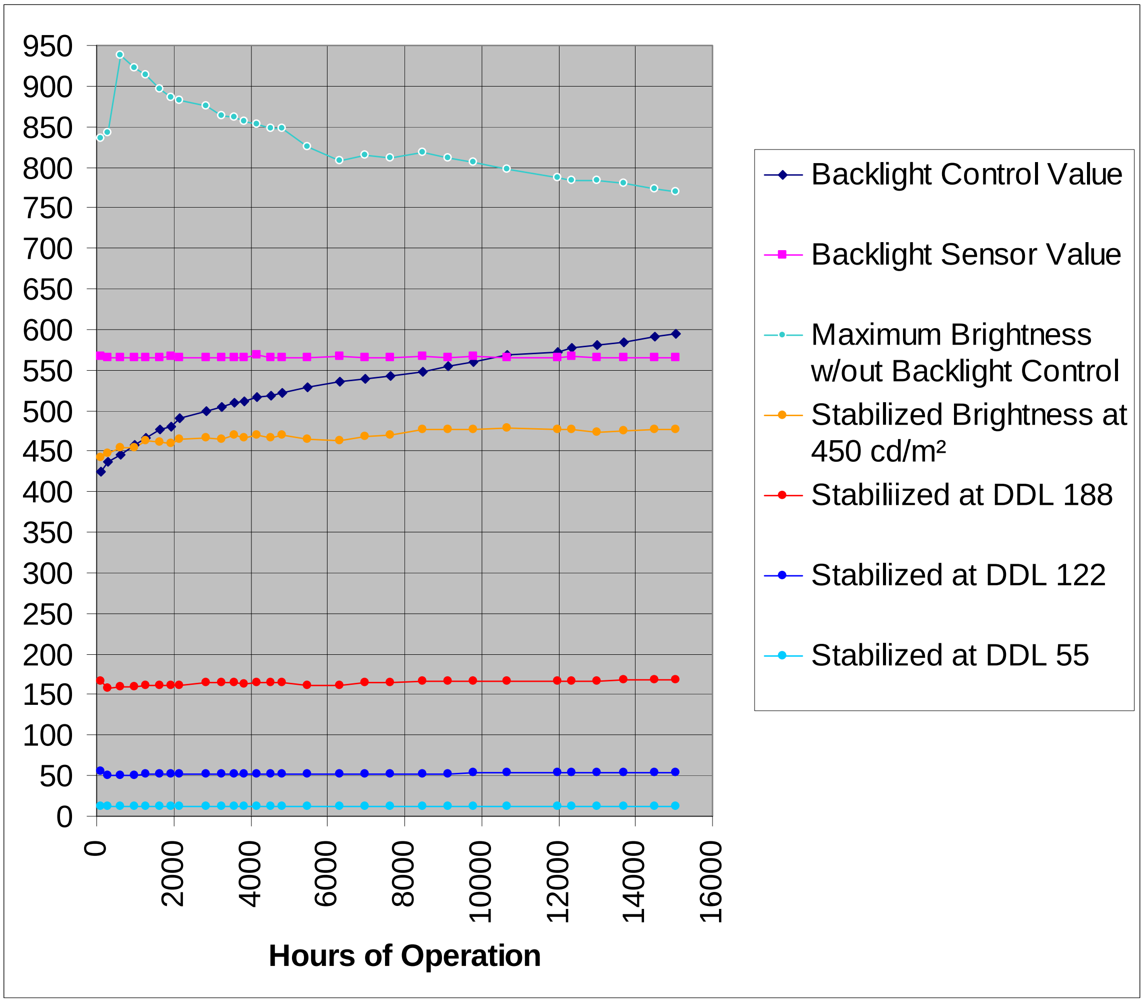


Chart 2 – Stabilized Luminance over time on a SMD 21300 3MP LCD Display

The backlight control value is a measure of voltage required to drive the backlight at the desired luminance. This value goes up over time as the backlight ages. More voltage is required to drive the backlight to the desired brightness. The backlight sensor value is the set point for the backlight sensor. This value remains steady over time, indicating that the stabilization circuitry is capable of maintaining the desired set point. The maximum brightness without backlight control shows the potential maximum brightness of the backlight over time. The maximum possible brightness goes down over time as the backlight ages. Stabilized luminance levels at various digital driving levels (DDLs) are also shown. Note that the desired luminance levels remain stable across the complete spectrum of DDLs over time.

3.1.3 Internal Sensor Stability Testing

The end user can use the ISS for internal stability checking. One of the key features of the SMfit ACT QC tool is its ability to schedule hands-off conformance testing. The internal sensor can perform self checks without disrupting normal display operation at whatever frequency the end user prefers. Once the test is scheduled, it is automatically performed at the set time without requiring any additional user interaction.

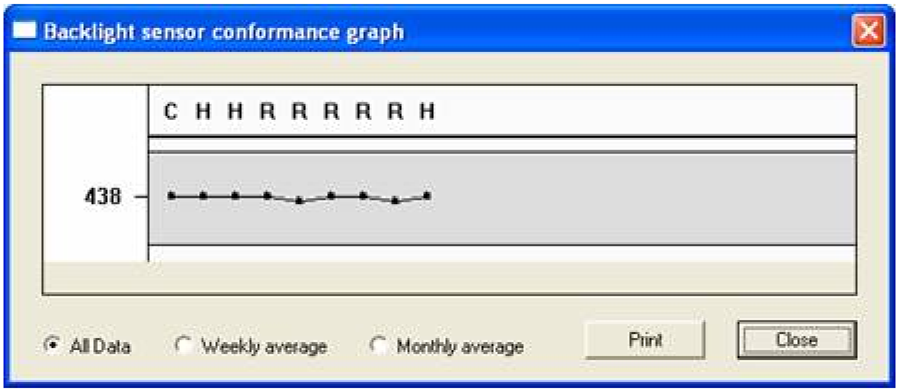


Chart 3 – Backlight Conformance Test

SMfit ACT provides a chart showing the conformance history of the sensor. Included are control limits, the ability to average data over desired time frames, and a letter to indicate if the test was a scheduled test or a special test, possibly performed as part of a routine equipment test by a medical physicist. The Y axis unit of measure is bits. The range of bit values is 1024.

The backlight conformance test, combined with the robust algorithm developed for backlight stabilization, makes display calibration practically unnecessary.

3.2 Integrated Consistency System (ICS)

The ICS is an additional sensor system included with some Siemens display models, offering independent verification of grayscale consistency for reassurance in particularly sensitive applications such as mammography.

The sensor is located in the lower right corner of the display. The area tested is actually beneath the bezel so that it does not obstruct the view of any portion of the active image nor interfere with routine use of the display. To avoid the pitfalls of the memory effect, the ICS is only activated during scheduled or explicit tests. This limits the potential for image retention on the LCD and corresponding erroneous readings taken by the sensor.

This additional sensor offers several features that can be attractive to facilities having stringent quality assurance requirements.

3.2.1 Redundancy

The Internal Consistency System acts as a confirmatory test of the Internal Stability System sensor performance. If the ISS sensor fails, the ICS sensor would detect unexpected drift. In Siemens displays, the ICS sensor is designed to operate as independently as possible from the ISS sensor. This is intended to minimize the likelihood of both sensors drifting because of the same root cause.

3.2.2 Why a secondary sensor can help maintain stability

The ICS sensor measures not only the stabilized maximum light output, but also the light output at 3 additional digital driving levels. This provides a quick check across the complete grayscale display function of light output consistency. It is highly doubtful that an out-of-conformance condition would occur at only one of the digital driving levels. As previously mentioned, control of backlight drift is the key to stability. If there was a failure in the control of backlight drift, light output at all digital driving levels would likely be affected.

This check using the ICS is also part of the SMfit ACT QC tool and can be scheduled to be performed with no user intervention required.

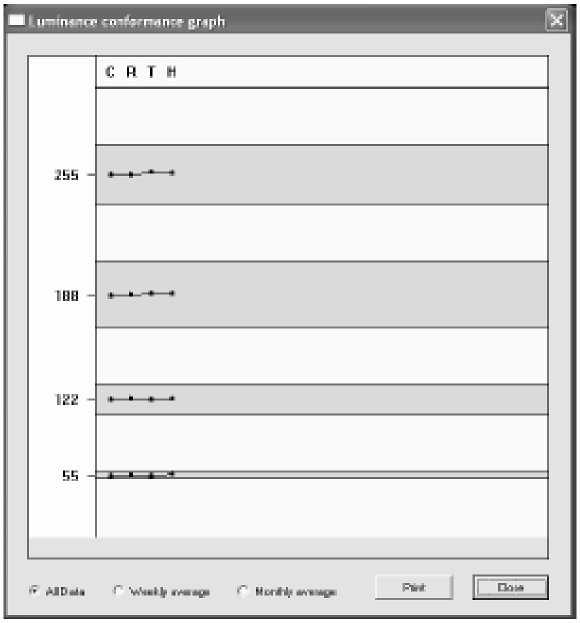


Chart 4 – Front Sensor Consistency Test

The consistency test chart is very similar to the conformance test chart. However, luminance is measured at 4 different levels. The Y axis is the digital driving level. The corresponding luminance for each individual point can be seen by left clicking on the value. Control limits are indicated by the gray zones in the chart. The size of the control limits can be adjusted using the SMfit ACT QC tool.

3.3 Fully Automated Stability Compared to Self-Calibration

Some display manufacturers highlight the ability of their displays to “self-calibrate”. What does this actually mean? Essentially it means that the DICOM LUT will be continually changed to accommodate for drift in the display system.

Siemens Display Technologies chooses not to continually change the DICOM GSDF for several reasons:

1. Sensors that are used for self-calibration do not approach the accuracy and precision of measurement equipment used at the factory. The approach that will give highest display precision and accuracy is to calibrate the display at the factory and then use the internal sensor only to maintain backlight stability.

2. A sensor positioned at the edge of the display does not adequately represent performance at the center of the display. Self calibrating displays must rely on a front sensor at the edge of the display and therefore may be subject to different performance characteristics.

3. An internal sensor on display #1 may be biased as compared to the internal sensor on display #2. In the typical dual head configuration, these multiple independent sensors can contribute to differences from display to display. Unless the same external sensor is used to measure both displays, it is extremely difficult to eliminate the bias between displays.

4. Recalibration using an internal sensor provides no traceability to national standards.

Instead of this approach, Siemens has implemented the fully automated stability system, which makes self-calibration unnecessary. The fully automated stability system manages the display's performance by automatically stabilizing the display and eliminating the need for user involvement. Furthermore, the display does not change unexpectedly due to a self-calibration routine running unexpectedly.

3.4 External verification

The question may be asked, "What happens if my internal sensor has drifted?" In the description of the key display components, it was noted that all sensors drift over time. Even with the most robust of sensor designs, occasional verification (and adjustment if needed) of sensor performance is a prudent consideration in a fully automated stability system.

3.4.1 Why an external sensor / photometer is critical

An external sensor can serve two important functions. First, it assures traceability to national standards for the luminance value being measured.

Second, it reduces measurement induced bias and variability because a common measurement device is used for all displays at a given workstation, thereby reducing potential measurement error.

Measurement as a science can trace its roots back to the realization that a unit of measure needs to be consistent from place to place and time to time. The 'meter' as a measure of length is a classic example of how important standardization is to measurement. By defining a gold standard for the 'meter', it was possible to standardize measurement and therefore gain much greater consistency in measurement.

This same philosophy applies to the measurement of luminance. An external photometer can be sent to an authorized laboratory to assure conformance to national and international measurement standards. This concept is called traceability. Traceability is the establishment of an unbroken chain of comparisons to international reference standards.

With a Siemens display, you can be assured that the accuracy of sensors used internally and externally can be traced back to the gold standard for luminance.

3.4.2 The use of qualitative test images

Probably the simplest method of externally validating display performance is to use standardized images. Images such as the SMPTE pattern, Briggs, and AAPM Task Group 18 images all provide a rough means to verify desired display performance.

Readers are encouraged to consult the AAPM TG18 report for possible interpretations and uses of these test patterns.

3.4.3 The use of quantitative methods to verify sensor performance

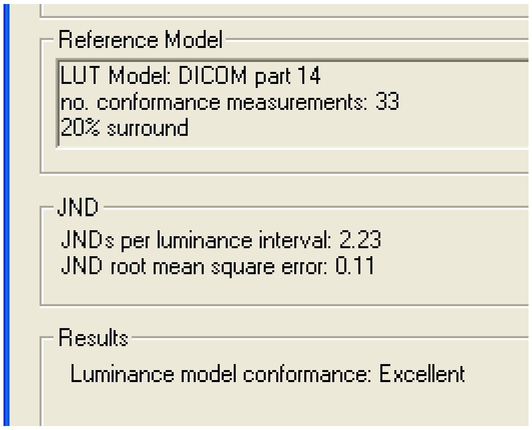
An external photometer can be used to measure minimum and maximum luminance as a quick check that internal sensors have not drifted. Many test patterns are available that can generate these desired luminances.

DICOM Part 14: Grayscale Standard Display Function (GSDF), Annex C provides a method of measuring the accuracy with which a display conforms to the GSDF. Two metrics are proposed.

First a test variable called “FIT” is used to test the “goodness of fit” to the GSDF. The statistical term ‘goodness of fit’ is a way of describing the amount of systematic deviation from the desired display function (say for example a log linear display function is being used instead of the intended DICOM part 14 GSDF). The “FIT” test will fail if there is a systematic deviation from the DICOM part 14 GSDF.

Second, a variable called “LUM” is used to measure the variability of observed results about the GSDF. If there is significant noise in the system or failure to measure at high or low luminance, the test can fail.

The SMfit ACT QC tool includes an implementation of a basic DICOM conformance test. Black level, white level and conformance measurement of the gamma function are calculated. JNDs per luminance level are determined. The root means square error is calculated and compared to standards for Siemens Displays. A plot of the JNDs per luminance interval is also provided to evaluate goodness of fit.



Reference Model

LUT Model: DICOM part 14
no. conformance measurements: 33
20% surround

JND

JNDs per luminance interval: 2.23
JND root mean square error: 0.11

Results

Luminance model conformance: Excellent

Diagram 2 – DICOM Conformance Report

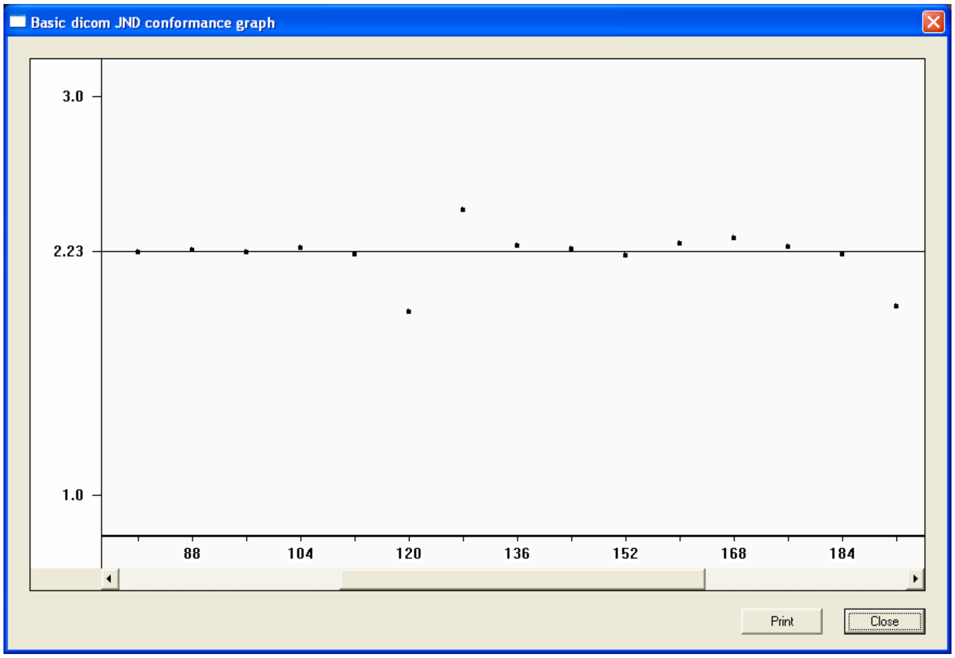


Chart 5 – JNDs per Luminance Level

3.5 Sensor recalibration

If the ISS, ICS, or an external verification photometer indicates that the system is no longer stable, the internal sensors can be recalibrated to reestablish optimal performance.

If the SMfit ACT QC tool's "Measure Backlight Response" box is checked while validating the display's performance, the ISS and ICS will be automatically adjusted to the levels confirmed by the external verification photometer. This not only resets the internal sensors to a traceable standard, it ensures that the desired stabilized luminance levels and LUTs are reestablished. The mammography QC standardization efforts spearheaded by NEMA recognized this method as a means to validate internal sensors in all medical displays.

3.6 Additional Features of SMfit ACT Quality Control Tool

While the SMfit ACT QC tool offers many special features and capabilities this section focuses on a few specific features that relate most directly to stability and consistency.

3.6.1 Automated testing routines

Tests using the ISS and ICS can be automated to be conducted in the background at user defined intervals.

3.6.2 Remote diagnosis and reporting

SMfit ACT Remote allows one to automatically notify service personnel of an error condition via email.

3.6.3 Data management

Error logs and printout of reports and graphs are readily available for maintaining documentation.

4 Benefits of the Siemens Approach to Fully Automated Stability

4.1 Data to support stability

4.1.1 Background

A large institution with a significant installed base of Siemens 3MP grayscale displays collected luminance data on 51 individual displays.

All displays were initially calibrated to Lmax=400 cd/m^2 and Lmin=0.66 cd/m^2 with the DICOM part 14 GSDF.

Displays have been in use for up to 8,000 hours of ‘on’ time. From the time that displays were initially installed to the time at which data collection ended, more than 18 months had elapsed.

The luminance of AAPM TG18 test patterns LN1, LN5, LN9, LN13, and L18 were measured for each display at regular intervals over the course of the study.

The site developed its own criteria for determining if recalibration was needed based on changes in JNDs per interval at the measured luminances.

One photometer was primarily used to perform the measurements, although it was discovered that a backup photometer was used occasionally and may have needed calibration.

Ability to collect data was impacted by time pressures and priority given to radiologists actually using the equipment.

4.1.2 Results

Using a common criteria for recalibration of deviations greater than +/-10%, only 2 data points would have fallen in the category of requiring recalibration. Over the total study time of 8,000 hours, < 4% of displays would fall in the category needing recalibration. At approximately 5,000 hours, two displays were recalibrated.

Three displays, while not failing criteria for recalibration had noticeably different DICOM curves. It is suspected that these displays were measured with the photometer in need of calibration.

A small overall upward trend in luminance was observed. Individual displays had very small indications of drift up or down.

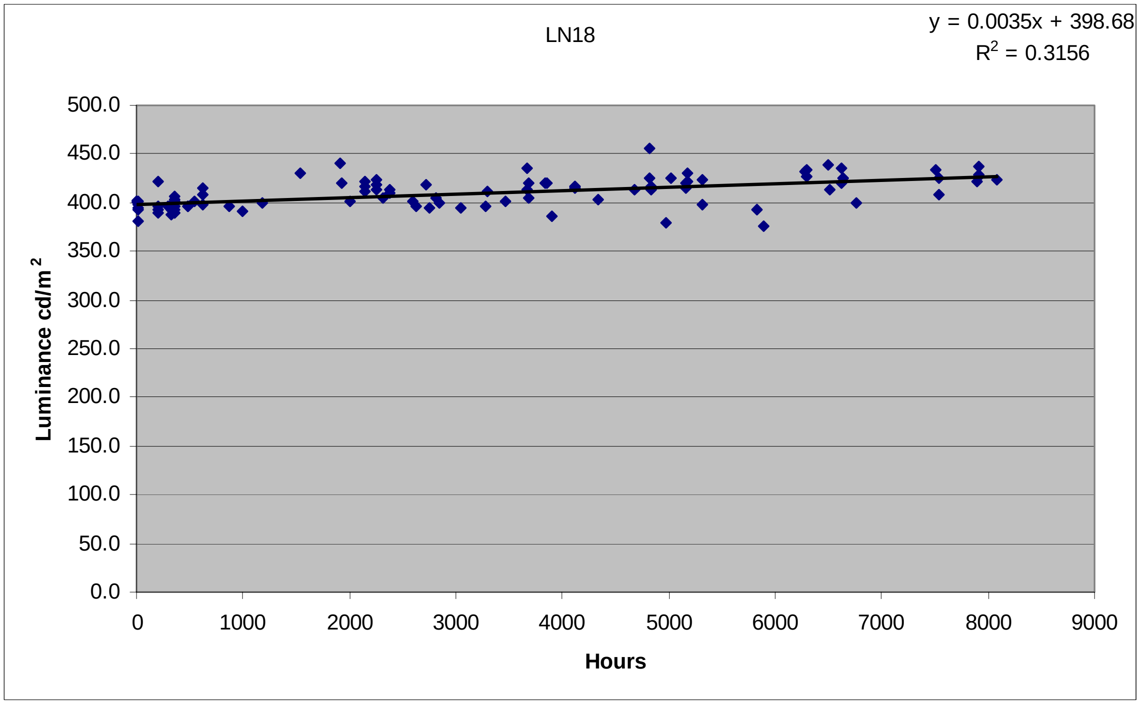


Chart 6 – Change in luminance over time for 51 3MP displays

Using Analysis of Variance Techniques (ANOVA), there was no detectable difference in the mean luminance from display to display (excluding the 5 displays in question).

A sample of the ANOVA analysis is included for LN18. With a p-value of 0.443, there is no significant difference in mean values.

```
Analysis of Variance for LN18
Source      DF        SS         MS        F        P
ID          46     10341        225     1.04    0.443
Error       66     14335        217
Total      112     24676
Pooled StDev =     14.74
```

4.1.3 Conclusion

Displays exhibited very good consistency from display to display.

Using a criterion of +/- 10% deviation, the typical display would hold stability for at least 11,000 hours before requiring recalibration. Using the regression equation in chart 6 with a starting point of 400 cd/m^2, it would take approximately 11,000 hours to reach 440 cd/m^2. Assuming a typical usage of 3,000 hours per year, the typical display could be used for up to four years without sensor recalibration.

4.2 Impact on Testing Frequency

4.2.1 Internal checks

Internal checks that utilize the ISS and ICS sensors can be scheduled to run automatically at a frequency that is specified by the facility. These tests can be set up to run daily and the frequency can easily be adjusted as desired.

4.2.2 External checks

Routine calibration is not required. We recommend using an external photometer to verify continued DICOM conformance. If conformance is maintained, there is no need to calibrate. This suggested test frequency is conservative given the results of testing by the manufacturer and confirmation in the clinical environment.

4.3 Impact on Reader Performance

Display to display consistency and within display stability are keys to effective diagnosis.

The human visual system is highly sensitive and can be easily distracted from optimal performance by seemingly minor deviations from desired reading room conditions. These distractions can contribute to eye fatigue and decreased reader performance.

A radiologist seated at proper viewing distance has a three inch diameter effective viewing area. It is within this area that display performance is critical.

The promise of the DICOM Part 14 Grayscale Display Function hinges on a well designed display system. The system not only needs to be able to be calibrated to DICOM part 14, but must remain stable over time and provide consistent viewing conditions from display to display.

5 Conclusion

Siemens' fully automated stability system is a complete approach to display management to guarantee consistency from display to display and the stability of a display over time.

The Internal Stability System (ISS) utilizes highly accurate factory calibration, a center sensor for best performance in the prime viewing area, and can be externally verified against national standards on an annual basis. The ISS automatically stabilizes the display, eliminating the need for self-calibration. The Internal Consistency System provides additional confidence in display performance for the most demanding applications, such as mammography.

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