

QuickLogic's Display Content Restoration and Power Savings Algorithms versus Competing Technologies



••••• QuickLogic White Paper

As display sizes on mobile phones (and other consumer devices) have grown, the importance of power consumption and display viewability has grown accordingly. With increasing numbers of features and functions packed into smaller and smaller devices, batteries are taxed to levels never before seen, or perhaps even anticipated. Since the display often consumes as much as 50% of the system power, system designers and device Original Equipment Manufacturers (OEMs) are constantly looking for ways to reduce the power consumption of the display without any impact to the user's experience. Unfortunately, all previously accepted methods for display power consumption reduction have negative effects on the user's viewing experience, especially when viewing video and mixed-media content. The QuickLogic® Visual Enhancement Engine (VEE) and Display Power Optimizer (DPO) technologies work together to reduce display power consumption significantly, while increasing display viewability in all viewing environments compared to alternative methods. VEE and DPO have been proven in mobile phones, tablets, and smartbooks to extend single-charge battery life up to 41%, while restoring the display content to a TV-like viewing experience even under bright ambient light.

Display Viewability

One common theme amongst all portable devices is problems with display viewability in certain ambient lighting environments, particularly bright sunlight. While simple monochrome E-ink-type displays do not have this issue due to the high contrast ratio of black on white, popular display technologies such as Liquid Crystal Display (LCD), Organic Light-Emitting Diode (OLED), and Active-Matrix Organic Light-Emitting Diode (AMOLED) all suffer from significant display viewability drop-off as reflected ambient light levels increase. In some cases, display content will completely wash-out in bright sunlight, making viewing impossible and forcing the user to either find a lower-lighting environment, or wait until ambient lighting changes enough to allow content viewing.

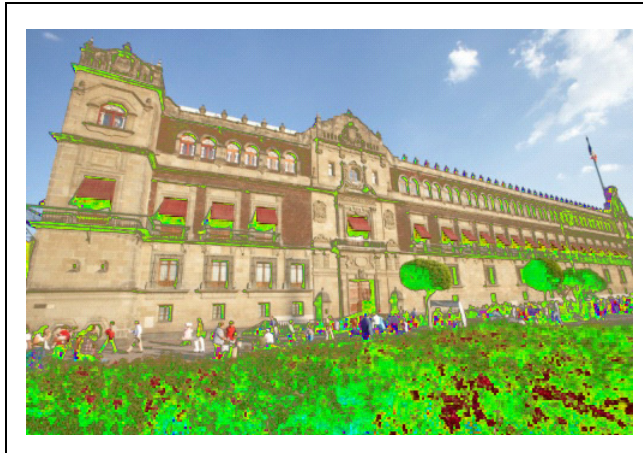
An example of content that is washed out is shown in the following images. In **Figure 1**, a source image is displayed.

Figure 1: Source Image



In **Figure 2**, details in the image which are lost in difficult viewing environments are shown in green. As can be seen, a large amount of detail in the image is lost when viewability is compromised.

Figure 2: Image Details that are Lost in Difficult Viewing Environments (Shown in Green)



Display Power

Typically, as the size of the display gets larger, the power consumption will increase. As an example, a typical 4" LCD mobile phone-type display may consume as much as 650 mW of power at 100% brightness. However, a 10.1" LCD display, like those used in tablets, can consume >2,000 mW at maximum brightness. While it is true that battery capacity will increase when changing form factors (mobile phone to tablet), battery capacity will typically scale linearly with device size, meaning that single-charge battery life generally does not change from a 4" mobile phone to a 10" tablet.

Technologies to Address Display Power Consumption and Viewability Issues

Display power consumption and viewability have been known problems for many years. Several technologies have been developed to address them including:

- QuickLogic's VEE and DPO
- Content Adaptive Backlight Control (CABC)
- Histogram Equalization (HE)
- Ambient Light Compensation (ALC)

Visual Enhancement Engine and Display Power Optimizer Technologies

QuickLogic's VEE and DPO technologies are an implementation of a set of algorithms based on the Orthogonal Retina-Morphic Image Transform (ORMIT), developed by Apical Ltd. (London, UK) and protected by multiple patents. ORMIT is a sophisticated method of Dynamic Range Compression (DRC), which differs from conventional methods such as gamma correction in that it applies different tonal and color transformations to every pixel in an image. These algorithms implement a model of human perception, which results in a displayed image that retains detail, color and vitality even under difficult viewing conditions. The VEE and DPO technologies specifically address the problem of the low contrast ratio of mobile displays to bring a more television-like viewing experience to mobile devices. Conserving power when playing back video content is also a significant issue when designing mobile devices.

QuickLogic's VEE and DPO technologies substantially enhance video quality, and enable a superior viewing experience under low backlight or bright ambient light conditions. Combined with an ambient light sensor, system engineers can adjust the VEE based on ambient light and display backlight or energy level to achieve optimal battery life.

What is Dynamic Range Compression?

All consumer devices employ DRC to render a source image or video stream suitable for display on an output device. Dynamic range is broadly defined as the difference in intensity between the darkest and brightest of a scene. The human eye can capture a very wide dynamic range of five orders of magnitude. However, typical displays can reproduce information over a range of only a few hundred counts or less.

The dynamic range capability of a display is governed by:

- Display technology
- Power or brightness
- Amount of screen reflection
- Ambient lighting conditions

Therefore, to retain as much information from a real-world scene after digital capture, transmission and display dynamic range must be compressed at each step along the chain. In some applications, dynamic range expansion may be required.

In the case of viewing video on a mobile device, even if the display has a dynamic range capability equal to or exceeding that of the original video, DRC is still required to produce natural-looking video. Because the human eye can apply very strong DRC, a displayed video will only look natural and realistic if the same kind of processing is applied. If the display is large enough that the video fills the viewer's visual field, the eye can apply this processing itself. However, the most common use case in portable devices is that the display fills only the central portion of the field of view. The eye cannot perform this processing optimally and therefore digital processing must be substituted.

Algorithm Background

The VEE and DPO technologies were developed as a result of research into biological visual systems, with particular emphasis on the human. Pre-existing models to ORMIT suffered from a number of limitations, in particular in the generation of artifacts, lack of adaptivity to different scenes, and computational complexity. The key aims in Apical's development of ORMIT were to:

- Develop a set of algorithms that model the dynamic range processing performed by the human visual system
- Overcome clear deficiencies in existing algorithms and models
- Provide a mathematical framework suitable for efficient implementation in digital devices

In effect, the VEE technology automatically generates and applies a different tone curve transform to every pixel in the input video, based on global user parameters which control its general behavior.

The VEE technology is one of several space-variant algorithms. The VEE technology is the only method that has found successful application in digital imaging products, due to its combination of high image quality, lack of artifacts, ability to achieve strong DRC, and high efficiency. The current version is the result of years of intensive development based on the core algorithms, and is robust, high-quality and well-proven.

The VEE technology provides strong enhancement of dark and bright areas of a video, while leaving mid-tones unchanged.

The principal factor limiting the strength of the VEE technology processing is the signal-to-noise ratio of the source video. The basic algorithm does not distinguish between video detail and noise; noise in very dark or bright areas may be rendered visible after processing. Practical implementations of iridix include a gain control feature which limits the strength of processing in different intensity ranges, so that noise is always kept outside the visible range.

More recent developments and additions to the core VEE technology algorithms have been the incorporation of modules for non-linear space-variant color correction, noise reduction, and preservation of fine detail.

To further improve display quality, the VEE technology has been supplemented by additional image and video enhancement blocks such as dithering, hue rotation, color correction, and non-linear sharpness filtering.

The VEE and DPO technologies have been measured in real-world applications. **Table 1** shows the viewing experience and power consumption of two consumer devices using the VEE and DPO technologies

Table 1: Viewing Experience and Power Consumption Using the VEE and DPO Technologies

Display	Use Case	Ambient Light Level	Original Backlight Level ^a	Original System Power	VEE-Enabled Backlight Level ^b	DPO-Enabled System Power	Total System Power Savings	Battery Life Improvement
5" Smartphone	Airplane	10 lux	66%	1.48W	13%	1.26W	220mW	15%
	Indoor	100 lux	80%	1.6W	13%	1.26W	340mW	21%
	Outdoor	10,000 lux	93%	1.72W	26%	1.32W	400mW	23%
7" Tablet	Dark Room	10 lux	40%	1.52W	10%	1.08W	440mW	29%
	Indoor	100 lux	60%	1.71W	20%	1.35W	360mW	21%
	Outdoor	10,000 lux	90%	2.42W	30%	1.42W	1000mW	41%
8.9" Tablet	Airplane	10 lux	45%	4.24W	15%	3.755W	485mW	11%
	Indoor	100 lux	65%	4.63W	25%	3.945W	685mW	15%
	Outdoor	10,000 lux	85%	5.02W	45%	4.325W	695mW	14%
10.1" Table (OEM 1)	Dark Room	10 lux	60%	3.93W	20%	2.70W	1230mW	31%
	Indoor	100 lux	80%	4.53W	30%	2.97W	1560mW	34%
	Outdoor	5000 lux	100%	5.02W	40%	3.36W	1660mW	33%
10.1" Tablet (OEM 2)	Dark Room	10 lux	40%	4.43W	10%	4.12W	310mW	7%
	Indoor	100 lux	60%	4.79W	20%	4.29W	500mW	10%
	Outdoor	10,000 lux	100%	5.7W	30%	4.46W	1240mW	22%

a. Original backlight level was predetermined by the system OEM as the best balance of viewability and power consumption in that specific lighting environment.

b. The VEE-enabled backlight level was the backlight level that VEE needs to match the viewability of the original backlight level.

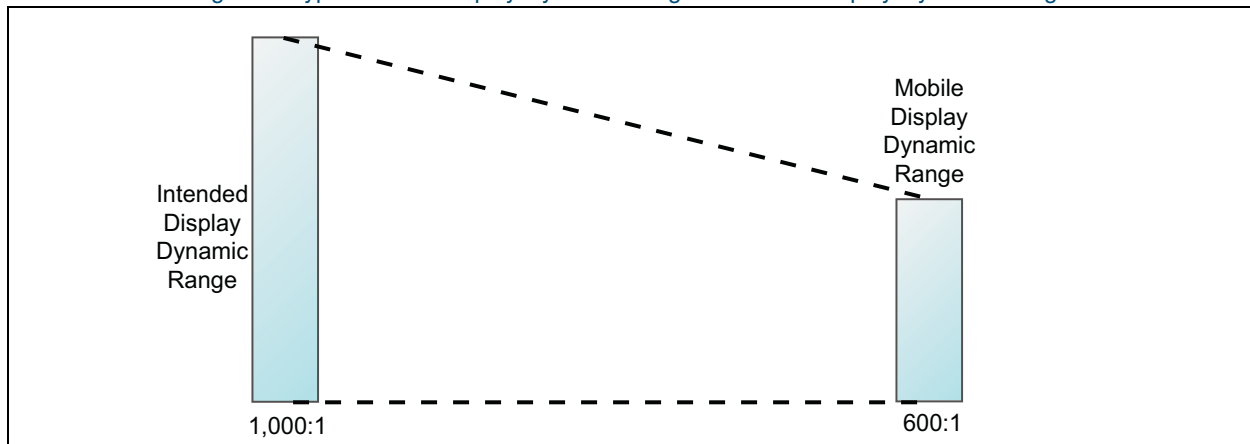
The VEE technology effectiveness can be seen when the original backlight level is compared to the VEE technology-enabled backlight level. In the case of the 7" display tablet, in the outdoor use case, with the VEE technology off the backlight level was set at 90%. When the VEE technology is enabled, the OEM deemed that the display content quality was equal at a backlight level of 30%. The drop from 90% to 30% in backlight intensity allows for a DPO technology-based single-charge battery life improvement of 41%.

Content Adaptive Backlight Control

CABC is a method of compensation in which the display's dynamic range capabilities are mapped to the content's dynamic range.

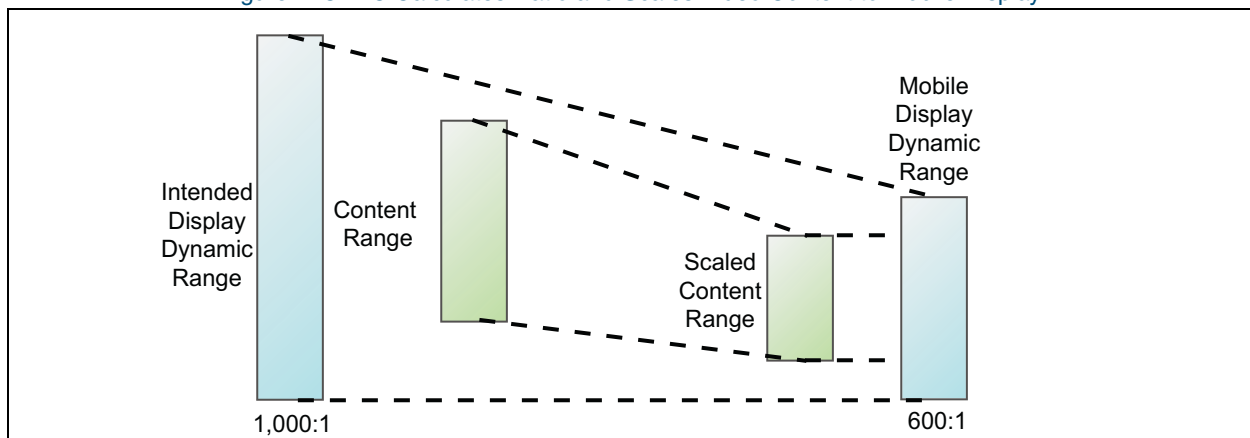
Most video and display content is intended to be viewed on displays with a dynamic range exceeding 1000:1. However, most handheld consumer device displays have a dynamic range of ~600:1 (see **Figure 3**). Note that this mobile display dynamic range (600:1) is stated while in ideal viewing conditions, such as a dark room similar to a movie theatre. These conditions become important later in the discussion.

Figure 3: Typical Video Display Dynamic Range vs. Mobile Display Dynamic Range



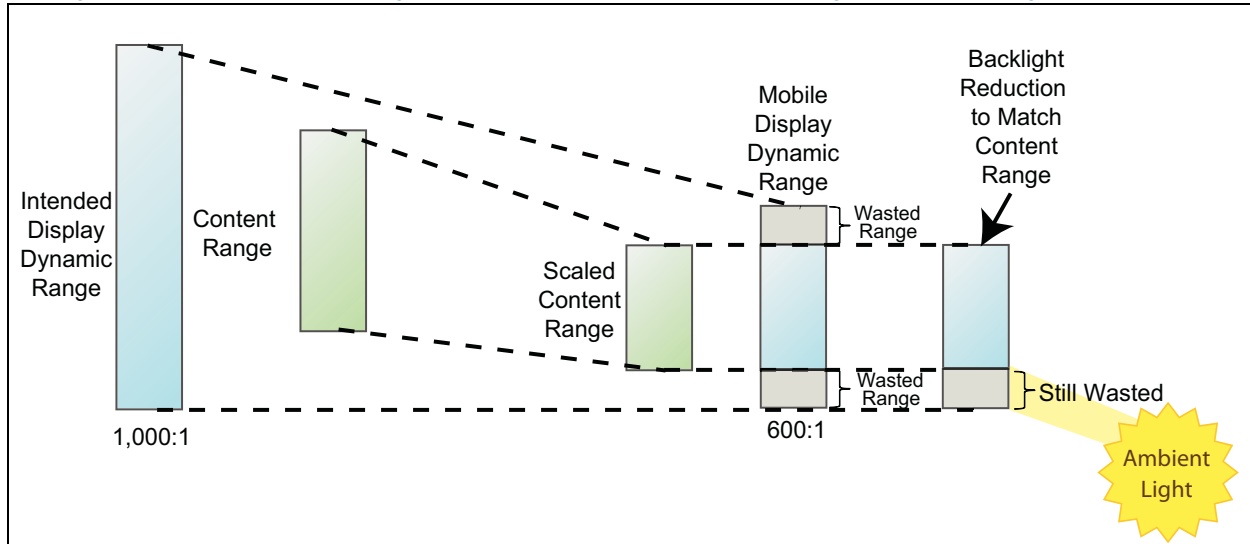
Most video content will not actually have a dynamic range that exceeds 1000:1. CABC will calculate the ratio of the video content's dynamic range to the intended display's dynamic range, and then scale the video content using that ratio to the mobile display (see **Figure 4**).

Figure 4: CABC Calculates Ratio and Scales Video Content to Mobile Display



What results is video content that is scaled to match the original content versus display ratio. CABAC can then reduce the backlight level of the display to eliminate the upper end of the 'wasted range' (see **Figure 5**). However, the lower end remains wasted.

Figure 5: CABAC Reduces Backlight Level to Eliminate Upper Wasted Range, but Lower Range is Still Wasted



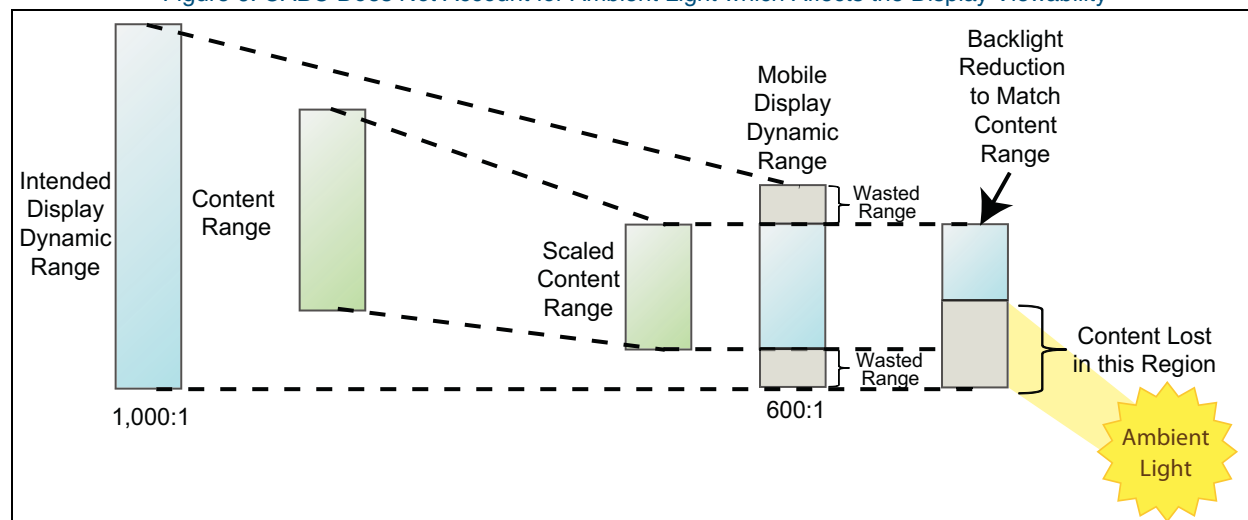
The net result is that CABAC has reduced display power consumption. Evidence shows that users of CABAC can expect system power consumption reductions of about 5% to 10% on average.

CABAC Issues

While CABAC can save system power, it has a number of drawbacks:

- **Actual power savings are content-dependant and are thus hard to predict**
As shown earlier, CABAC scales content to the display. While the display's dynamic range does not change, display content's dynamic range is always changing. CABAC is constantly sampling and scaling, leading to actual power savings which are difficult, if not impossible, to predict. Content with a high dynamic range, such as movies or television shows, will lead to lesser power savings than low dynamic range content, such as children's cartoons.
- **CABAC does not account for ambient light**
In the description of CABAC earlier, display dynamic range was stated in ideal viewing conditions. The reality of mobile devices is that content is almost never viewed in ideal conditions. As ambient light increases, effective display dynamic range worsens. **Figure 6** illustrates how ambient light affects the display viewability. As ambient light levels increase, the viewability of the display worsens under the CABAC method.

Figure 6: CABAC Does Not Account for Ambient Light which Affects the Display Viewability



- **Changes to backlight levels can show up as flickering**

CABC is constantly adjusting display brightness to display content. As the content's dynamic range increases and decreases, the display will adjust brightness levels. If content is constantly changing dynamic range, display brightness will change just as much, which can result in a 'flickering' effect to the viewer. At minimum, this effect is annoying—at maximum, this effect is enough for some viewers to stop using their device. Flickering is particularly noticeable when video is overlaid onto a desktop-style screen, because flickering shows up easily on icons.

Content Adaptive Backlight Control versus the Visual Enhancement Engine and Display Power Optimizer Technologies

CABC versus the VEE Technology: Display Viewability

CABC and the VEE technology share a number of similarities. Both methods use content data for processing and both methods adapt the display backlight to the display data.

The VEE technology takes the extra step of adapting the display content to ambient light, allowing for a television-like viewing experience in all lighting conditions. CABC cannot adapt for changes in ambient lighting, and is calibrated only for ideal lighting environments. Once the viewing environment changes from ideal, CABC users will notice diminished visual quality compared to the VEE technology users, especially as ambient light levels increase.

CABC's tendency to produce a flicker effect is also a drawback. While it is true that the VEE and DPO technologies use ambient light to affect display brightness, brightness is only changed with changes to ambient lighting, and thus provides no flicker effect to the viewer.

The VEE technology provides a better viewing experience in all lighting conditions compared to CABC.

CABC versus the DPO Technology: Power Savings

While CABC has been shown to save as much as 10% of system battery life, the DPO technology has been demonstrated to extend single-charge battery life as much as 41%.

CABC versus the VEE and DPO Technologies: Verdict

While CABC is an existing, known technology, QuickLogic's VEE and DPO technologies surpass it in both display viewability and power savings. The VEE technology provides a superior viewing experience, while the DPO technology enables the display to consume significantly less power than CABC (see [Table 2](#)).

Table 2: QuickLogic's VEE and DPO Technologies versus CABC

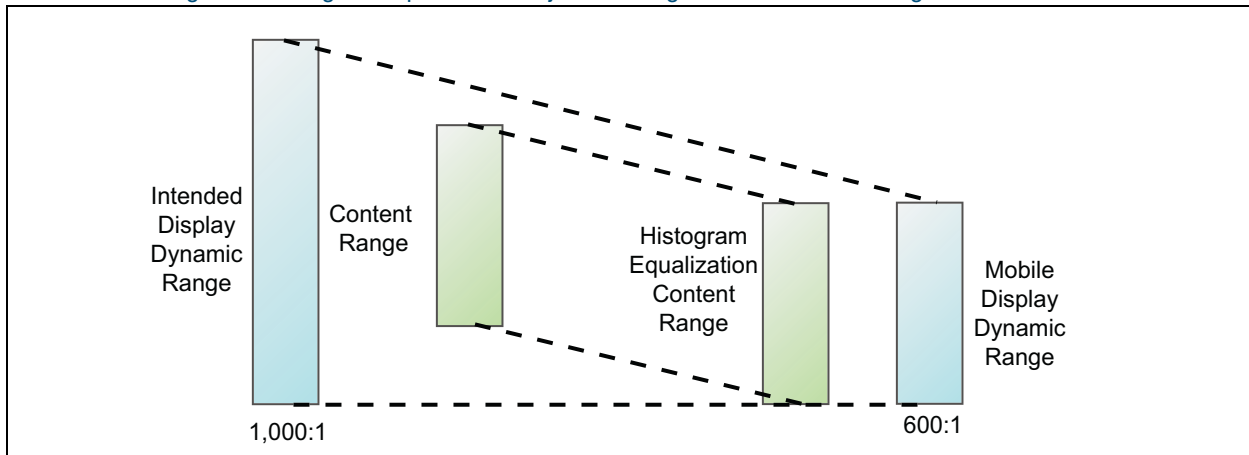
Method	VEE and DPO	CABC
Algorithm uses content data	Yes	Yes
Algorithm adapts backlight to ambient light	Yes	Yes
Algorithm adapts backlight to data ^a	Yes	Yes
Algorithm adapts data to backlight level	Yes	No
Algorithm uses global data statistics	Yes	No
Algorithm adapts data to ambient light	Yes	No
Algorithm uses local data statistics	Yes	No
Peak Power Savings	~41%	~10%

a. Assumes the VEE and DPO technologies are used with an ambient light sensor.

Histogram Equalization

Histogram Equalization is a simple method of adjusting the signal based on the range of the content, not the original display (see [Figure 7](#)).

Figure 7: Histogram Equalization Adjusts the Signal Based on the Range of the Content



Histogram equalization increases the global contrast of the display content, especially where the display content consists of close contrast values. Through this adjustment, the intensities can be better distributed on the histogram (and thus the display). This enables areas of lower local contrast to gain a higher contrast. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values.

Histogram Equalization Issues

Histogram equalization is a known method of image enhancement; however, it is widely considered to not be ideal for video and photographs.

- **Histogram equalization algorithms are indiscriminate**
Histogram equalization does not identify 'good' versus 'bad' content. It can increase the contrast of background noise, while decreasing the usable signal.
- **Undesirable effects**
Histogram equalization can produce undesirable effects (such as visible image gradient) when applied to images with low color depth.
- **Global correction**
Changes are made to the entire image or video. In practice, only shadows and midtones should be adjusted. Midtones/highlights already have optimal contrast, and any change to them results in image quality degradation (saturation or even clipping of colors in important regions).

Histogram Equalization versus the Visual Enhancement Engine and Display Power Optimizer Technologies

Histogram Equalization versus the VEE Technology: Display Viewability

While histogram equalization and the VEE technology both use display content as a primary source for viewability increases, the similarities stop there.

The VEE technology adapts the display content and display brightness to ambient light, enabling a television-like viewing experience in all lighting conditions. Histogram equalization does not adapt for changes in ambient lighting or display brightness. Additionally, the VEE technology emphasis on local tone mapping ensures that fine details in the image are not washed out, while the global mapping employed by histogram equalization often results in saturation or clipping of colors.

The VEE technology provides a better viewing experience in all lighting conditions compared to histogram equalization.

Histogram Equalization versus the DPO Technology: Power Savings

Histogram equalization does not provide any power savings benefits, the DPO technology has been demonstrated to extend single-charge battery life as much as 41%.

Histogram Equalization versus the VEE and DPO Technologies: Verdict

QuickLogic's VEE and DPO technologies surpass histogram equalization in both display viewability and power savings (see **Table 3**). The VEE technology provides a superior viewing experience, while the DPO technology enables the display to consume significantly less power. Histogram equalization provides no power savings benefits.

Table 3: QuickLogic's VEE and DPO Technologies versus Histogram Equalization

Method	VEE and DPO	Histogram Equalization
Algorithm uses content data	Yes	Yes
Algorithm adapts backlight to ambient light	Yes	No
Algorithm adapts backlight to data ^a	Yes	No
Algorithm adapts data to backlight level	Yes	Yes
Algorithm uses global data statistics	Yes	Yes
Algorithm adapts data to ambient light	Yes	No
Algorithm uses local data statistics	Yes	No
Peak Power Savings	41%	0%

a. Assumes the VEE and DPO technologies are used with an ambient light sensor.

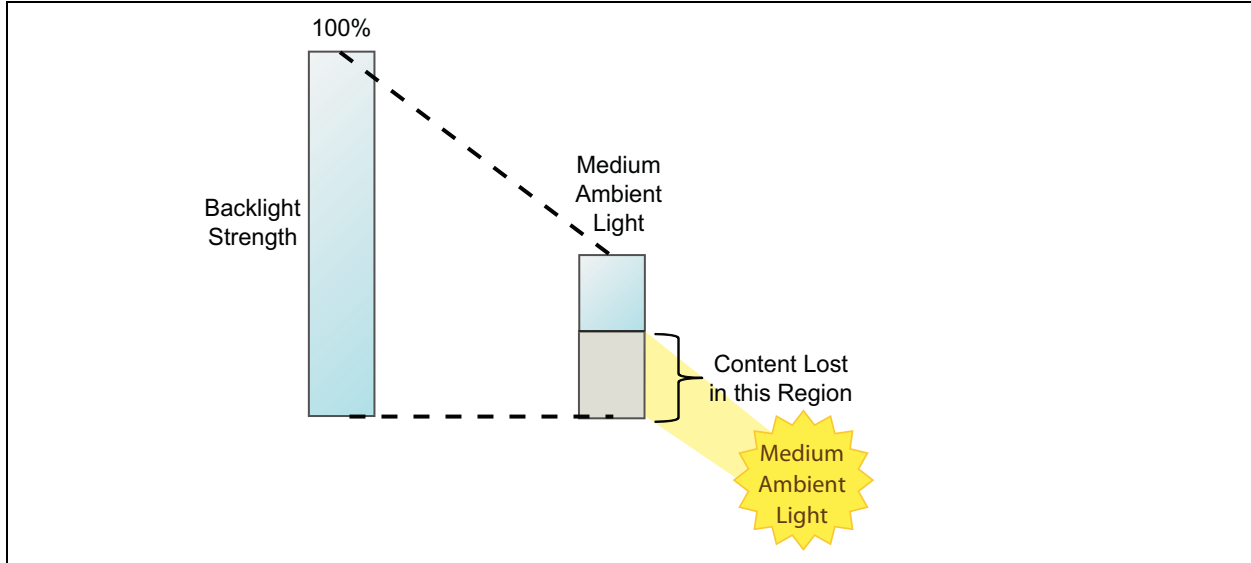
Ambient Light Compensation

ALC is a very simple method of display power savings where the display backlight intensity is changed according to the ambient light conditions. As the ambient light level increases, display brightness increases, and as ambient light decreases, display brightness decreases. ALC algorithms are so simple that they tend to be included in mobile device operating system programming available to OEMs.

ALC Issues

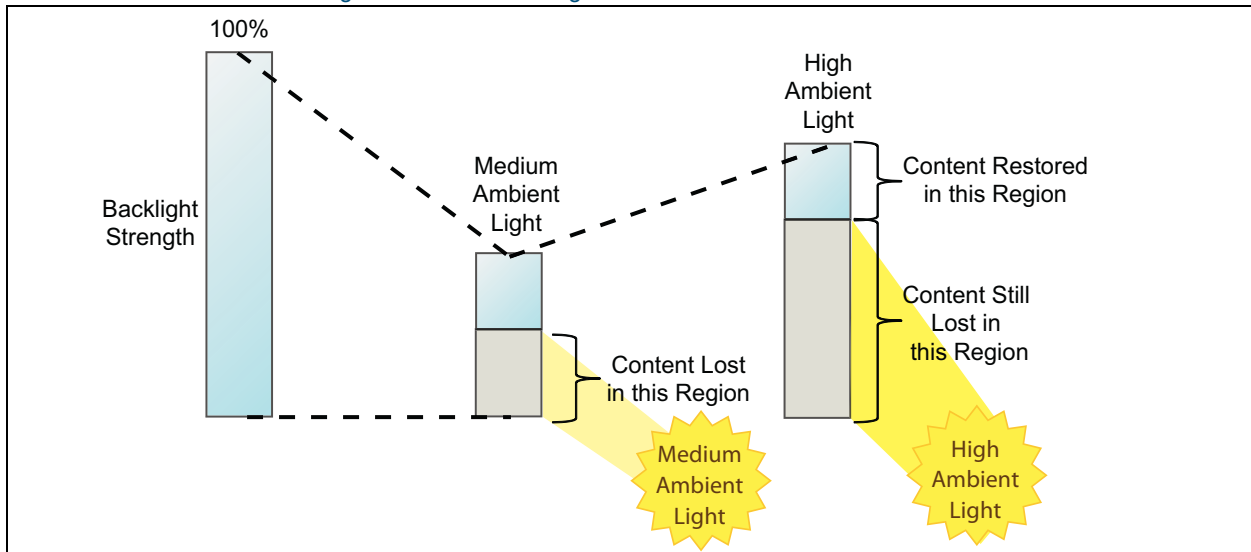
The primary issue with ALC is that it does not affect the display content at all—only the display backlight is changed. As ambient light increases, details in the dark are immediately lost (see **Figure 8**).

Figure 8: ALC Changes Display Backlight Intensity According to the Ambient Light Conditions



As ambient light increases, more content is lost (see **Figure 9**).

Figure 9: As Ambient Light Increases More Content is Lost



ALC versus the VEE and DPO Technologies

ALC versus the VEE Technology: Display Viewability

ALC performs only a very basic ambient light to display power adaptation, the VEE technology also performs content analysis and restoration.

The VEE technology adapts the display content to the display brightness and ambient lighting, enabling a television-like viewing experience in all lighting conditions. Additionally, the VEE technology emphasis on local tone mapping ensures that fine details in the image are not washed out, whereas the ALC display quality diminishes with detail content loss in all lighting conditions.

The VEE technology provides a better viewing experience in all lighting conditions compared to ALC.

ALC versus the DPO Technology: Power Savings

ALC does provide power savings benefits, but the amount is wholly dependent on the ambient light conditions—in high ambient light, ALC provides no benefits. The DPO technology has been demonstrated to extend single-charge battery life as much as 41% in all lighting conditions.

ALC versus the VEE and DPO Technologies: Verdict

QuickLogic's VEE and DPO technologies surpass ALC in both display viewability and power savings (see **Table 4**). The VEE technology provides a superior viewing experience, while the DPO technology enables the display to consume significantly less power.

Table 4: QuickLogic's VEE and DPO Technologies versus ALC

Method	VEE and DPO	ALC
Algorithm uses content data	Yes	No
Algorithm adapts backlight to ambient light	Yes	Yes
Algorithm adapts backlight to data ^a	Yes	No
Algorithm adapts data to backlight level	Yes	No
Algorithm uses global data statistics	Yes	No
Algorithm adapts data to ambient light	Yes	No
Algorithm uses local data statistics	Yes	No
Peak Power Savings	41%	Varies on ambient lighting

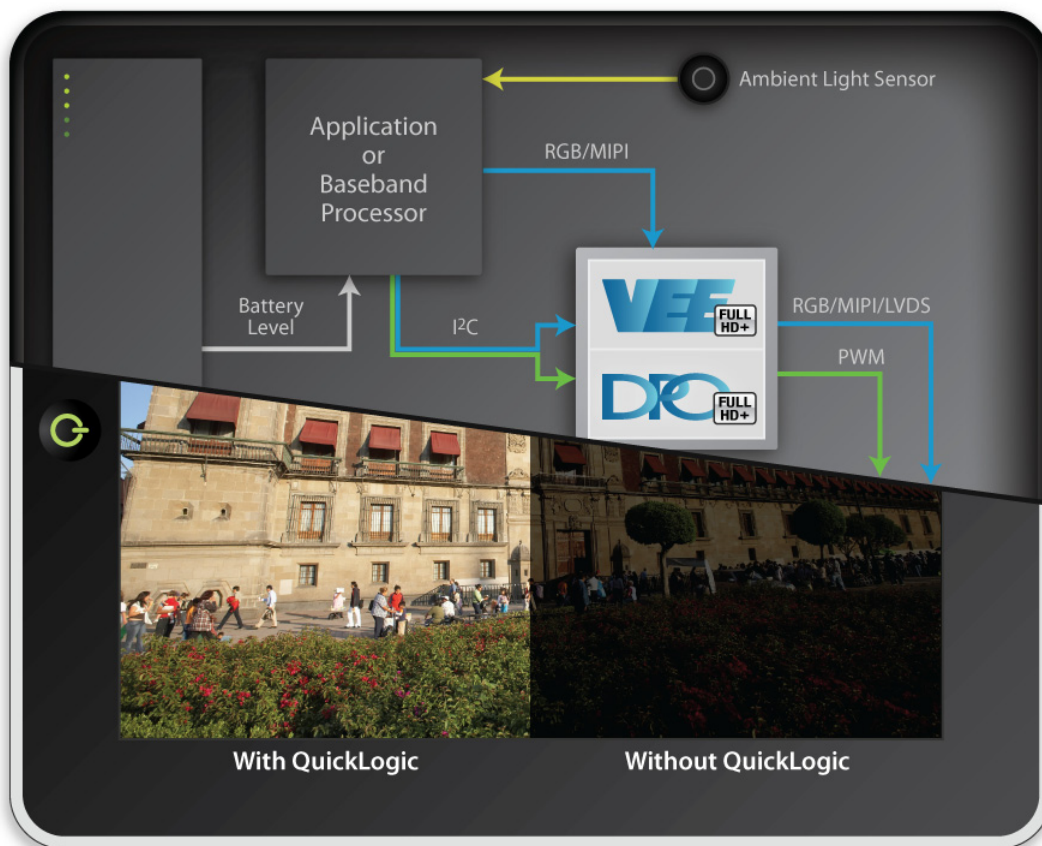
a. Assumes the VEE and DPO technologies are used with an ambient light sensor.

Summary

QuickLogic's VEE and DPO technologies are the only display technologies that adequately address the display viewability and display power savings concerns of consumer device OEMs. The VEE and DPO technologies provide tangible benefits to mobile device OEMs, Original Device Manufactures (ODMs), and users.

Implementation of the VEE and DPO technologies is done through QuickLogic's Customer-Specific Standard Product (CSSP) product offering. **Figure 10** demonstrates a typical system implementation of the VEE and DPO technologies.

Figure 10: VEE 2.0 and DPO Technology Architecture



Contact Information

Phone: (408) 990-4000 (US)
(647) 367-1014 (Canada)
+(44) 1932-21-3160 (Europe)
+(886) 2-2345-5600 (Taiwan)
+(86) 21-5116-0532 (China)

E-mail: info@quicklogic.com

Sales: America-sales@quicklogic.com
Europe-sales@quicklogic.com
Asia-sales@quicklogic.com
Japan-sales@quicklogic.com

Support: www.quicklogic.com/support

Internet: www.quicklogic.com

Revision History

Revision	Date	Originator and Comments
A	August 2010	Paul Karazuba and Kathleen Bylsma
B	February 2011	Paul Karazuba and Kathleen Bylsma
C	May 2011	Paul Karazuba and Kathleen Bylsma
D	May 2013	Paul Karazuba and Kathleen Bylsma

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