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APPLICATION NOTE 4913

A Simple Implementation of LCD Brightness Control Using the MAX44009 Ambient-Light Sensor

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Abstract: This application note describes an implementation using the MAX44009 ambient-light sensor for backlight control in portable applications such as smartphones and tablet computers. Two different control schemes are presented for adjusting backlight brightness. The application note provides additional tips for improving performance, as well as sample code to implement algorithms discussed in the article.

Overview

Ambient-light sensor (ALS) ICs are increasingly used in a variety of display and lighting applications to save power and improve the user experience. With ALS solutions, system designers can automatically adjust display brightness based on the amount of ambient light. Since backlighting accounts for a significant portion of the system's power budget, dynamic brightness control can translate into substantial power savings. It can also improve the user experience, allowing screen brightness to be optimized based on ambient-light conditions.

Implementing such a system requires three sections: a light sensor to monitor the amount of ambient light, a device (usually a microcontroller) to process the data, and an actuator to control the current through the backlight.

Backlight Control: the Ambient-Light Sensor

Figure 1 provides an example block diagram of a system that implements backlight control. The light sensor is a key part of this setup, as it provides information about the environment's light level to the rest of the system. The light sensor must contain a transducer (e.g., a photodiode or CdS photoresistor) to convert light to an electrical signal, some amplification and/or signal conditioning, and an analog-to-digital converter (ADC).

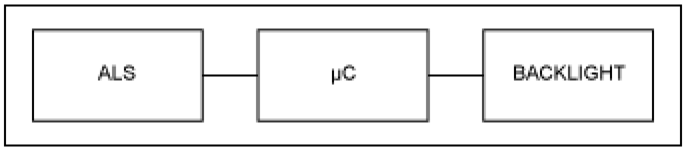


Figure 1. Block diagram for a system that implements backlight control.

Figure 2 shows a discrete implementation of a photodiode circuit. As you can see, the circuit requires one or more operational amplifiers: one for I-to-V conversion and, perhaps, a second for additional gain. It also includes extra routing to power all of these components and ensure a robust signal chain. In applications where space is at a premium, the large number of components required may be problematic.

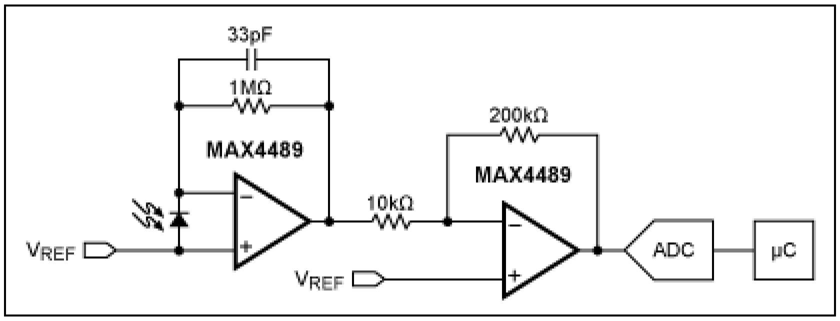


Figure 2. Discrete implementation of a photodiode circuit.

There is a second, more subtle, issue at hand here. Specifically, it is desirable to ensure that the ambient light is measured in a way that replicates the optical response of the human eye to light. This is often described with the CIE photopic curve (**Figure 3**). However, photodiodes rarely replicate this response, since they often have a heavy infrared (IR) sensitivity. This sensitivity causes false readings under IR-heavy light, such as that from incandescent bulbs or the sun.

One way around this is to use two photodiodes: one with a visible light plus infrared component, and one with only an infrared component. It is then possible to subtract the two responses from one another to obtain only the visible light portion, with a minimized infrared section.

Although effective, this solution adds to the space required by the discrete circuit described above. Additionally, it is very difficult, if not impossible, to match the discrete photodiodes closely enough to eliminate infrared interference. Dynamic range would likely be limited without very sophisticated implementations of the amplifier, such as log amps. It is difficult to obtain repeatable results with such a setup.

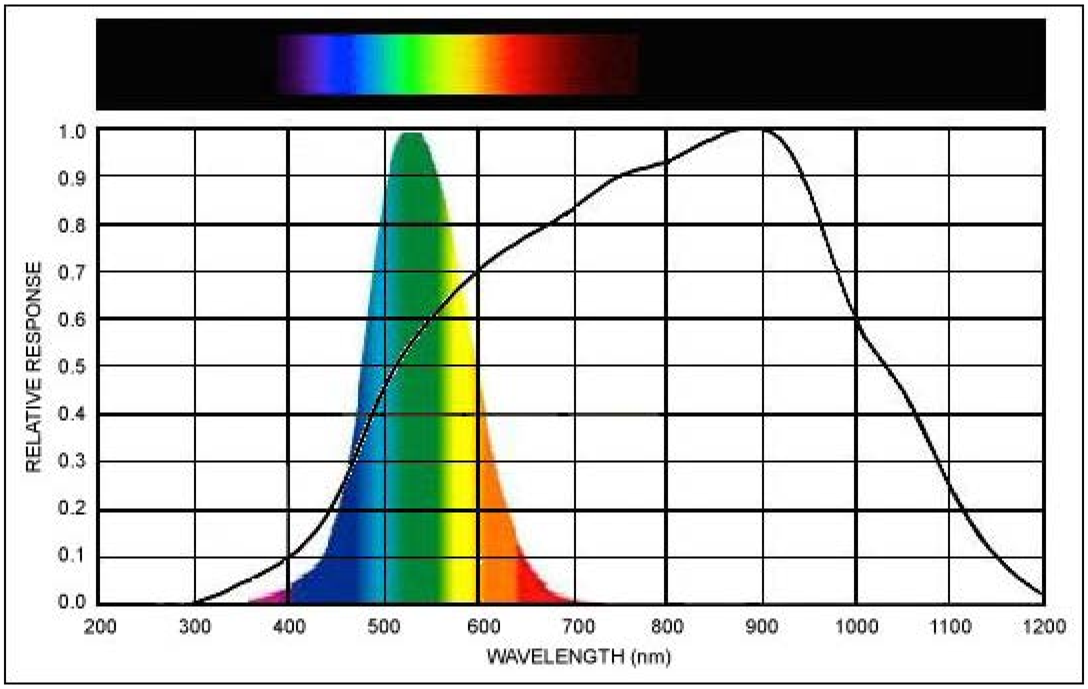


Figure 3. CIE curve vs. a typical photodiode.

An integrated solution not only yields a light reading that is far truer to the optical response of the human eye, but also saves a great deal of space. A device such as the MAX44009 ambient-light sensor integrates all signal conditioning and A/D conversion circuitry into a small form factor (2mm x 2mm UTDFN), saving considerable board real estate in space-constrained applications.

Figure 4 shows the functional block diagram for the MAX44009. It uses the I²C communication protocol to allow for a fast, simple method of interfacing to a microcontroller. In addition to this, the integrated nature of this solution enables it to be placed on a flex cable, and set in a desired location away from the main circuit board.

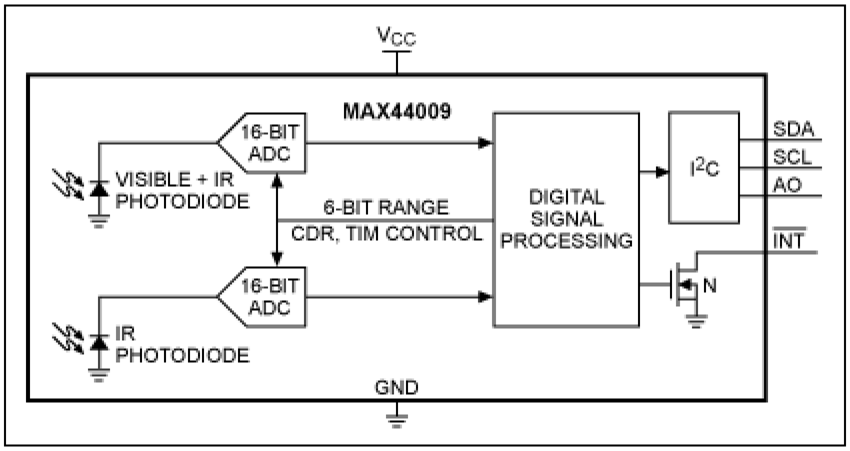


Figure 4. Functional block diagram for the MAX44009.

Backlight Control: Modulating Screen Brightness

The second part of this control scheme involves actuating changes in backlighting on the screen. This can be done in many ways, depending upon the screen module used in the application. Two of the simplest ways are directly via a pulse-width modulation (PWM) scheme or indirectly by using a screen controller chip.

Many display modules now have an integrated controller, which allows the user to directly set brightness by sending serial commands to the device. If this is not available, however, a simple backlight control actuator can be implemented by controlling the power delivered to a series of white LEDs behind the screen, which provide backlighting. One crude way of implementing this is by directly placing a FET in series with the LEDs and switching it on and off quickly using a PWM signal (**Figure 5**). However, this can be done more elegantly and robustly with a single chip: the MAX1698 step-up current regulator for LEDs (**Figure 6**). See application note 3866, "Low-Power PWM Output Controls LED Brightness" for more details on this implementation.

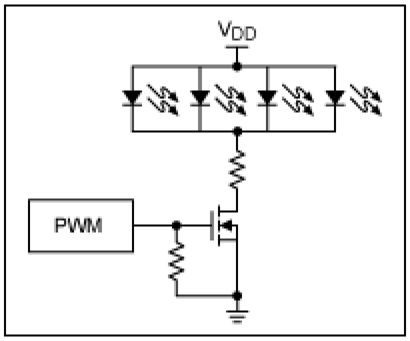


Figure 5. Simple PWM control circuit.

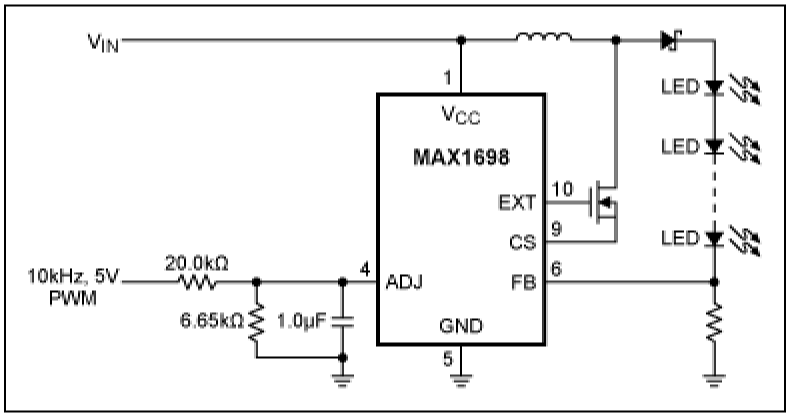


Figure 6. MAX1698-based LED regulator.

Backlight Control: Bridging the Gap

The final step is to bridge the gap between the sensor and the actuator, which is done in the microcontroller. The first question one may ask is: "How does one map ambient light to backlight brightness?" There are, in fact, specifications that describe how this should be done. One example of a mapping is recommended by Microsoft® for computers running Windows® 7.[1] The curve in **Figure 7** is provided by Microsoft to map ambient-light levels to screen brightness as a percentage of full brightness.

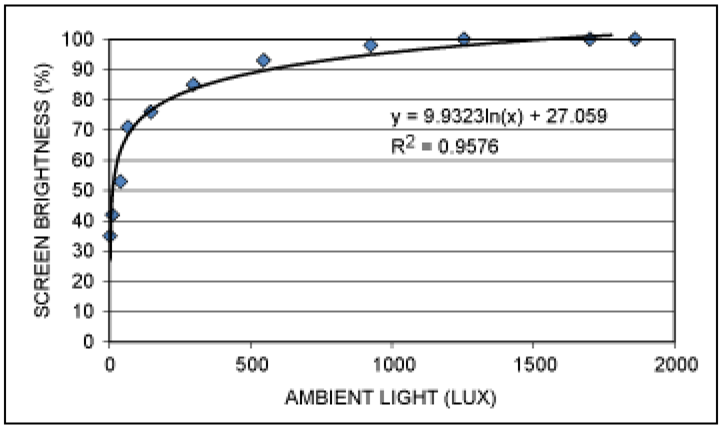


Figure 7. Example brightness curve mapping ambient-light levels to optimal screen brightness.

This particular curve can be described by the function:

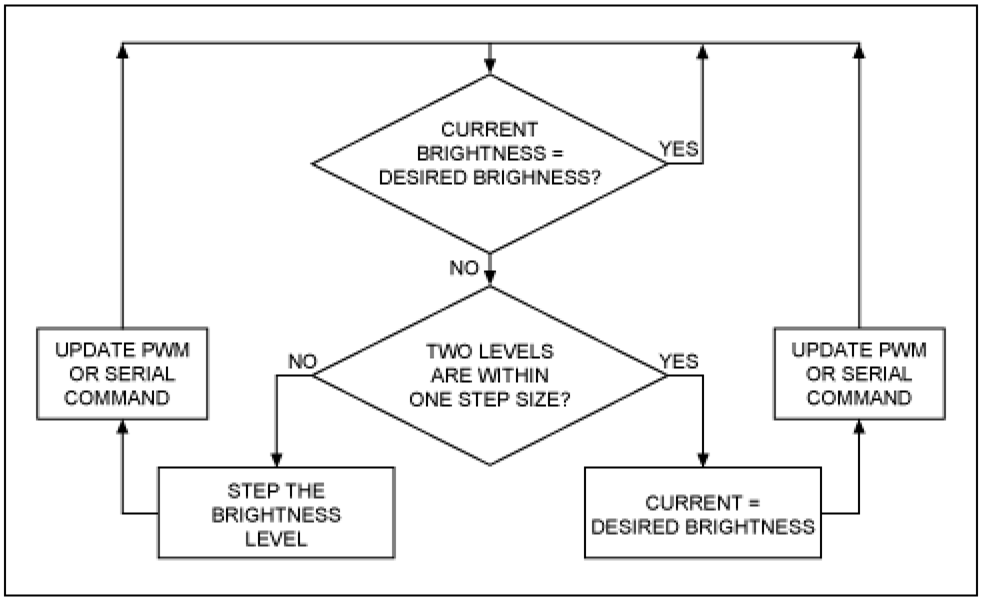
$$f(x) = \begin{cases} 9.9323\ln x + 27.059, & x < 1254\text{lux} \\ 100, & x \geq 1254\text{lux} \end{cases}$$

If the application utilizes an LCD controller chip that has integrated brightness control, then the brightness can easily be set by sending a command to the chip with the desired value. If the application uses PWM to directly control brightness, then one must consider how to map the percentage signal into brightness.

In the example of the MAX1698, one can map the drive current to voltage, as described in the datasheet. From there, one can often assume that an LED's current is almost linearly related to its intensity. Thus, one can multiply constants into the equation above to account for mapping PWM into an effective voltage, which is then mapped into an LED current, thereby translating into screen brightness.

Notes on Implementation

It is best not to jump directly from one setting to another: rather, the backlight brightness should be ramped up and down smoothly to ensure a seamless transition between levels. This is best done by using timed interrupts with either a fixed or variable brightness step size to gradually shift either the PWM value used to control the current through the LEDs or the serial command sent to the display controller chip. **Figure 8** provides an example of such an algorithm.


CURRENT BRIGHTNESS = DESIRED BRIGHNESS?
YES
NO
TWO LEVELS ARE WITHIN ONE STEP SIZE?
NO
YES
UPDATE PWM OR SERIAL COMMAND
UPDATE PWM OR SERIAL COMMAND
STEP THE BRIGHTNESS LEVEL
CURRENT = DESIRED BRIGHTNESS
Figure 8. Example of an algorithm to step brightness.

Another concern is how quickly the system should respond to changes in ambient-light levels. One should avoid changing the brightness level too quickly. The concern is that transient changes in light (e.g., passing by a window or a lamp) can cause undesired changes in the backlight brightness, which some users would find irritating. Furthermore, using a slower response time reduces the need to constantly poll the light sensor, freeing some microcontroller resources.

A rudimentary approach is to poll the light sensor once every second or two, and then change the brightness. A better approach is to change the brightness only when the light level leaves a certain region for a specific amount of time. For example, if the current light level is 200lux, one may only want to change the brightness if the light level falls below 180lux or rises above 220lux for longer than a few seconds. Fortunately, the MAX44009 has an interrupt pin and threshold registers, making this very easy to do.

Appendix: Sample Code

```
#define MAX44009_ADDR   0x96
// begin definition of slave addresses for MAX44009
#define INT_STATUS      0x00
#define INT_ENABLE      0x01
#define CONFIG_REG      0x02
#define HIGH_BYTE       0x03
#define LOW_BYTE        0x04
#define THRESH_HIGH     0x05
#define THRESH_LOW      0x06
#define THRESH_TIMER    0x07
// end definition of slave addresses for MAX44009

extern float SCALE_FACTOR;      // captures scaling factors to map from %
brightness to PWM
float currentBright_pct;        // the current screen brightness, in % of
maximum
float desiredBright_pct;        // the desired screen brightness, in % of
maximum
float stepSize;                 // the step size to use to go from the
current
                                // brightness to the desired brightness
uint8 lightReadingCounter;
```

```
/**
 *      Function:       SetPWMDutyCycle
 *
 *      Arguments:      uint16 dc - desired duty cycle
 *
 *      Returns:        none
 *
 *      Description:    Sets the duty cycle of a 16-bit PWM, assuming that in
this
 *                      architecture, 0x0000 = 0% duty cycle
 *                      0x7FFF = 50% and 0xFFFF = 100%
**/
extern void SetPWMDutyCycle(uint16 dc);

/**
 *      Function:       I2C_WriteByte
 *
 *      Arguments:      uint8 slaveAddr - address of the slave device
 *                      uint8 command - destination register in slave device
 *                      uint8 data - data to write to the register
 *
 *      Returns:        ACK bit
 *
 *      Description:    Performs necessary functions to send one byte of data
to a
 *                      specified register in a specific device on the I2C
bus
**/
uint8 2C_WriteByte(uint8 slaveAddr, uint8 command, uint8 data);

/**
 *      Function:       I2C_ReadByte
 *
 *      Arguments:      uint8 slaveAddr - address of the slave device
 *                      uint8 command - destination register in slave device
 *                      uint8 *data - pointer data to read from the register
 *
 *      Returns:        ACK bit
 *
 *      Description:    Performs necessary functions to get one byte of data
from a
 *                      specified register in a specific device on the I2C
bus
**/
uint8 I2C_ReadByte(uint8 slaveAddr, uint8 command, uint8* data);

/**
 *      Function:       getPctBrightFromLuxReading
 *
 *      Arguments:      float lux - the pre-computed ambient light level
 *
 *      Returns:        The % of maximum brightness to which the backlight
should be set
 *                      given the ambient light (0 to 1.0)
 *
 *      Description:    Uses a function to map the ambient light level to a
backlight
 *                      brightness by using a predetermined function
**/
float getPctBrightFromLuxReading(float lux);

/**
 *      Function:       mapPctBrighttoPWM
 *
 *      Arguments:      float pct
 *
 *      Returns:        PWM counts needed to achieve the specified %
brightness (as
 *                        determined by some scaling factors)
**/
uint16 mapPctBrighttoPWM(float pct);

/**
 *      Function:       getLightLevel
 *
 *      Arguments:      n/a
 *
 *      Returns:        the ambient light level, in lux
 *
 *      Description:    Reads both the light registers on the device and
returns the
 *                      computed light level
**/
float getLightLevel(void);

/**
 *      Function:       stepBrightness
 *
 *      Arguments:      n/a
 *
 *      Returns:        n/a
 *
 *      Description:    This function would be called by an interrupt. It
looks at the
 *                      current brightness setting, then the desired
brightness setting.
 *                      If there is a difference between the two, the current
brightness
 *                      setting is stepped closer to its goal.
**/
void stepBrightness(void);

/**
 *      Function:       timerISR
 *
 *      Arguments:      n/a
 *
 *      Returns:        n/a
 *
 *      Description:    An interrupt service routine which fires every 100ms
or so. This
 *                      handles all the ambient light sensor and backlight
 *                      control code.
**/
void timerISR(void);

void main() {

        SetupMicro();                           // some subroutine which
initializes this CPU

        I2C_WriteByte(MAX44009_ADDR, CONFIG_REG, 0x80); // set to run
continuously

        lightReadingCounter = 0;
        stepSize = .01;
        currentBright_pct = 0.5;
        desiredBright_pct = 0.5;
        SetPWMDutyCycle(mapPctBrighttoPWM(currentBright_pct));
        InitializeTimerInterrupt();             // set this to fire every
100ms

        while(1) {
                // do whatever else you need here, the LCD control is done in
interrupts
                Idle();
        }
```

```
} // main routine

// the point at which the function clips to 100%
#define MAXIMUM_LUX_BREAKPOINT  1254.0
float getPctBrightFromLuxReading(float lux) {
        if (lux > MAXIMUM_LUX_BREAKPOINT)
                return 1.0;
        else
                return (9.9323*log(x) + 27.059)/100.0;
} // getPctBrightFromLuxReading

uint16 mapPctBrighttoPWM(float pct) {
        return (uint16)(0xFFFF * pct * SCALE_FACTOR);
} // mapPctBrighttoPWM

float getLightLevel(void) {
        uint8* lowByte;
        uint8* highByte;
        uint8 exponent;
        uint8 mantissa;
        float result;

        I2C_ReadByte(MAX44009_ADDR, HIGH_BYTE, highByte);
        I2C_ReadByte(MAX44009_ADDR, LOW_BYTE, lowByte);

        exponent = (highByte & 0xF0) >> 4;// upper four bits of high byte
register
        mantissa = (highByte & 0x0F) << 4;// lower four bits of high byte
register =
                                          // upper four bits of mantissa
        mantissa += lowByte & 0x0F;       // lower four bits of low byte
register =
                                          // lower four bits of mantissa

        result = mantissa * (1 << exponent) * 0.045;

        return result;
} //getLightLevel

void stepBrightness(void) {
        // if current is at desired, don't do anything
        if (currentBright_pct == desiredBright_pct)
                return;
        // is the current brightness above the desired brightness?
        else if (currentBright_pct > desiredBright_pct) {
                // is the difference between the two less than one step?
                if ( (currentBright_pct-stepSize) < desiredBright_pct)
                        currentBright_pct = desiredBright_pct;
                else
                        currentBright_pct -= stepSize;
        } // else if
        else if (currentBright_pct < desiredBright_pct) {
                // is the difference between the two less than one step?
                if ( (currentBright_pct+stepSize) > desiredBright_pct)
                        currentBright_pct = desiredBright_pct;
                else
                        currentBright_pct += stepSize;
        } // else if

        SetPWMDutyCycle(mapPctBrighttoPWM(currentBright_pct));
        return;
} // stepBrightness

void timerISR(void) {
        float lux;
        float pctDiff;

        stepBrightness();
        if (lightReadingCounter)
```

```
                lightReadingCounter--;
        else {
                lightReadingCounter = 20;       // 2 second delay
                lux = getLightLevel();
                desiredBright_pct = getPctBrightFromLuxReading(lux);
                pctDiff = abs(desiredBright_pct - currentBright_pct);
                stepSize = (pctDiff <= 0.01) ? 0.01:pctDiff/10;
        } // else

        ClearInterruptFlag();
} // timerISR
```

[1]https://docs.microsoft.com/en-us/windows-hardware/drivers/sensors/supporting-ambient-light-sensors

Related Parts		
MAX1698	High-Efficiency Step-Up Current Regulator for LEDs	Free Samples
MAX44007	Low-Power Digital Ambient Light Sensor with Enhanced Sensitivity	Free Samples
MAX44009	Industry's Lowest-Power Ambient Light Sensor with ADC	Free Samples
MAX4489	SOT23, Low-Noise, Low-Distortion, Wide-Band, Rail-to-Rail Op Amps	Free Samples
MAXQ2000	Low-Power LCD Microcontroller	Free Samples