LX1970 VISIBLE LIGHT SENSOR

AN-28

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TABLE OF CONTENTS

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INTRODUCING TO LX970

The LX1970 light sensor can be used in conjunction with an LCD Front or Back Light Controller such as the LX1992 for LEDs or the LX1689 for CCFLs. This application note describes how to design in the LX1970.

KEY FEATURES

- Approximate Human Eye Spectral Response
- Low IR Sensitivity
- Highly Accurate & Repeatable Output Current vs. Light
- Voltage Scalable
- Temperature Stable
- Integrated High Gain Photo Current Amplifiers
- Complementary Current Outputs
- No Optical Filters Needed

APPLICATIONS

- PDA
- Notebook PC
- LCD TV
- Table PC
- Cell Phones

PART SPECIFIC INFORMATION

IC	EVALUATION BOARDS
LX1970	LX9170EVAL
LX1970	LX1970MINI EVAL

TABLE 1 – EVALUATION BOARD INFORMATION

IC BLOCK DIAGRAM

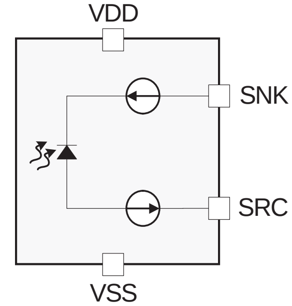


FIGURE – SIMPLIFIED BLOCK DIAGRAM

LX1970 CHARACTERISTICS

The first step is to become familiar with the LX1970. The LX1970 has two current source outputs that produce currents that are proportional to the intensity of light that reaches the sensor. The SRC output is designed to source current into a resistor wired to ground. The SNK output is designed to sink current from a resistor wired to a high potential such as the V_{CC}. When only one output is used, the other output is left unconnected to reduce power consumption.

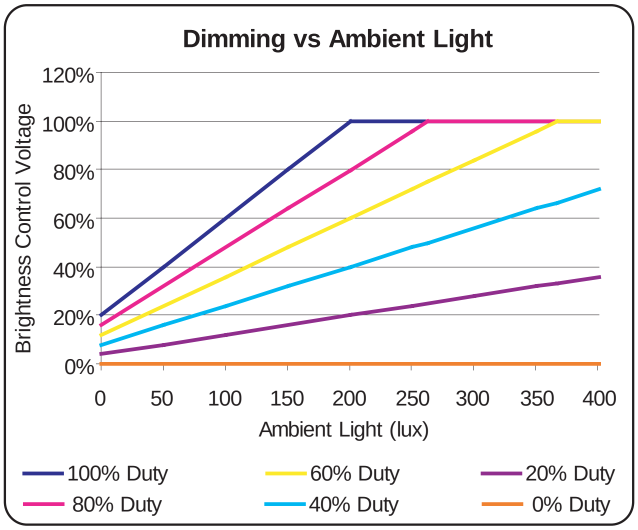
The value of the resistor can be used to scale the voltage produced at the LX1970 output within certain limits. One limit is the light saturation of the LX1970 internal diodes; this occurs at approximately 500µA to 1500µA of output current. The range of the LX1970 can be extended by attenuating the light allowed to reach the sensor. This can be done using a neutral density filter or reducing the aperture of the hole in the cover above the light sensor to let in less light. Another factor that limits range is the compliance voltage of the LX1970 current source. The current source needs about 300mV of headroom. If a large resistor is used, the current source may run out of headroom and appear as if the current source has saturated; in this case, the range can be extended by lowering the value of resistor. For brightness control circuits that require input voltage limiting, the compliance of the LX1970 can be used as a maximum output voltage clamp as described later.

One last precaution regarding the use of the LX1970 is the response time. Typically, the LX1970 is much faster than the human eye. Most light sources produce light that varies considerably over a 60Hz cycle and the LX1970 can easily track this. To avoid this variation affecting sensitive downstream circuitry, we recommend putting a capacitor across the resistor to set the time constant to around ½ a second.

GOAL OF THE LX1970 AUTOMATIC LIGHT CONTROL

When the dimming control is done manually, the user will normally increase the intensity of the LCD as the room ambient lighting increases. With an automatic light control system, the user adjusts the level of LCD brightness to their preference, and as the ambient lighting changes, the display brightness adjusts to make the display appear to stay consistent at the same perceived level. This not only provides better comfort for the user, but it saves power under low ambient lighting conditions and prevents premature aging of the LCD light sources.

Graph 1 illustrates this optimum light control condition; the curves represent various levels of user adjusted dimmer adjustment settings and how the display intensity varies over ambient lighting conditions.



GRAPH 1 – CLOSED LOOP DIMMING SYSTEM RESPONSE

In Graph 1 it can be seen that at any ambient light level, with the LX1970 prescribed dimming control, the user can adjust the Dimming output from “off” (0% Duty) to an ambient specific maximum level (100% Duty). Furthermore, for a given user adjustment level (or fixed PWM duty cycle), the Dimming signal will increase (decrease) as the ambient light increases (decreases). There are two key points on the graph that are design parameters; the dark level dimming output, which is 100% duty cycle at 0 lux, and the 100% duty cycle saturation current, $I_{SRC(MAX)}$, which occurs where the 100% duty cycle curve reaches the full-scale level. The saturation current corresponds to the minimum ambient light level that provides the maximum light output at the full-scale dimmer setting. These two points will be programmed to give the desired response.

The best approach to designing the control system is as follows:

1. Determine the level of display brightness desired in total darkness (at full-scale dimming setting) and the light source dimming control voltage that corresponds to this display brightness. Design dark level brightness control bias.
2. Determine how the sensor will be mounted and create a mockup to determine the sensor sensitivity in your application.

3. Determine the maximum level of allowable display brightness and the corresponding dimming voltage. Then determine the minimum level of ambient light where this maximum level of brightness may be needed. Measure the light sensor output current using the mockup in this level of ambient. This current is $I_{SRC(SAT)}$.
4. Choose the dimming control component values as described below.

PWM DIMMING INTERFACE CONVERSION

The majority of applications for the LX1970 involve using it in conjunction with a lighting control system that is dimmed using a PWM signal from a microprocessor; usually the resultant brightness of the controlled light source is a function of the duty cycle of the PWM signal. In this type of system the light sensor is best integrated by creating a resultant dimming signal that is the product of the light sensor output multiplied by the PWM duty cycle. Typically there is a minimum level of brightness required in total darkness, so there is some control from the PWM signal that must get through when the light sensor output is zero (which wouldn't happen if they were truly a product function only). The circuit used to perform this function is illustrated below:

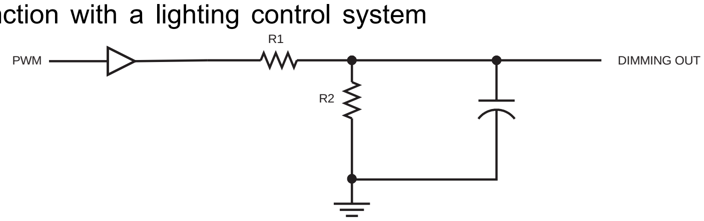


Figure 1A - System without Light Sensor

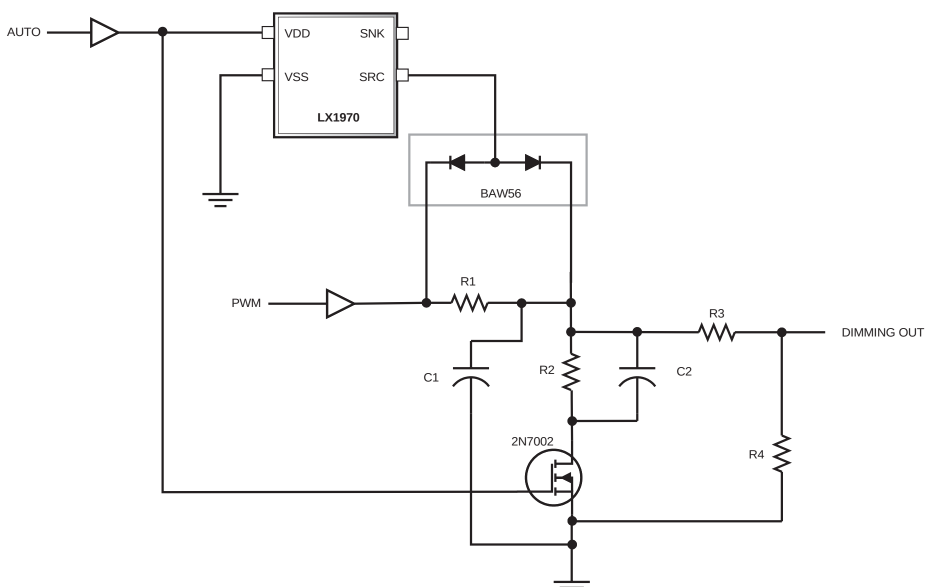


Figure 1B - System with Light Sensor Added

The circuit of figure 1A is a low pass filter that takes in the PWM input and extracts the DC component. The DC component then drives dimming control circuitry such as the ADJ input of the LX1992 LED driver. (See LX1992 specification.) In the LX1992 LED driver, with a 15 ohm current sense resistor, the LED current will vary from 2mA to 20mA as the ADJ voltage is varied from 30mV to 300mV. If the circuit in Figure 1A is driven from 3.3V CMOS logic, with a 10 to 90% duty cycle range, the resistors would be selected such that R1 = 9 x R2 so a 10 to 1 attenuation of the PWM signal is achieved.

Figure 1B shows that it is relatively simple to add the light sensor control to this type of dimming circuit. There are two modes of operation in this circuit; the Auto = Hi mode, where the light sensor works in conjunction with the PWM input and the Auto = Lo mode, where the light sensor influence is removed. When Auto = Lo, the light sensor is shut off and the back biased diodes isolate it from the rest of the circuit. The MOSFET is also turned off so the influence of R2 is removed; the circuit now resembles the circuit in Figure 1A, except that R2 in figure 1A is represented by the sum of resistor values R3 + R4 in Figure 1B and the filter capacitor is moved closer to the source. The real interest in the circuit is when Auto = Hi. In this case the LX1970 sources a current (proportional to the ambient light) to the current steering diodes. When the PWM input is high the LX1970 current is steered to the output, when the PWM input is low, the LX1970 current is steered to the PWM driver. The resistor R1 serves to direct some current from the PWM driver to the output when in total darkness. The output will clamp when the voltage at the summing node of R1, R2, and R3 approaches the compliance voltage of the LX1970 output plus a small voltage drop in the ORing diode. Capacitor C1 serves to filter the PWM signal in Auto "off" mode when the node impedance is higher. The value of C2 is switched in during Auto "on" mode when the node impedance is lowered by the MOSFET switch and is usually a large value to add a slow time constant to the light sensor output. The voltage divider, R3 and R4, attenuate the signal to be compatible with the down stream lamp control circuit operating range.

The describing equations for the circuit are:

Auto = Lo:

$$\text{DimOut} = V_{CC} \times \text{dutycycle} \times \frac{R4}{(R1 + R3 + R4)}$$

Auto = Hi:

$$\text{DimOut} = \text{dutycycle} \times \left[\left\{ \frac{V_{CC} \times R2 \times R4}{\left[(R1+R2)\times(R3+R4)\right]+(R1\times R2)} \right\} + \left\{ \frac{I_{SRC} \times R1 \times R2 \times R4}{\left[(R1+R2)\times(R3+R4)\right]+(R1\times R2)} \right\} \right]$$

$$\text{DimOut}_{(MAX)} = \left(V_{CC} - V_{SAT} - V_{DIODE}\right) \times \frac{R4}{(R3+R4)}$$

The first major term in the brackets of the Auto = Hi equation is the Dim Output in total darkness. The second term introduces the effect of the light sensor. The last equation shows that when the LX1970 output clamps due to compliance headroom, the maximum output voltage is this voltage attenuated by the voltage divider made up of R3 and R4.

DESIGN EXAMPLES

For this example the following parameters are defined by the application:

- Dim Out range = 0 to 300mV for a 0% to 100% PWM duty cycle (Auto = Lo).
- Dim Out range = 0 to 60mV in absolute darkness (Auto = Hi).
- Dim Out range = 0 to 300mV for ISRC = 0 to 76uA (Auto = Hi)
- Vcc = 3.3V
- One second response time to change in lighting or PWM input.

When the LX1970 output reaches the compliance limit, the diode voltage drop and compliance voltage are each about 500mV, so with a V_{CC} = 3.3V, the clamp voltage is 2.3V. For the output voltage to be 300mV when the clamp voltage is 2.3V, the ratio of R4 to R3 can be calculated to be:

$$0.300 = 2.3 \times \frac{R4}{(R3 + R4)}$$

R4 = 0.150 x R3

When Auto = Lo, at 100% duty cycle, the output voltage should be 300mV. This implies that:

$$0.300 = 3.3 \times \frac{R4}{(R1 + R3 + R4)}$$

This can be solved to show that:

R4 = 0.1 x (R1 + R3)

Knowing this, we can now express R3 and R4 in terms of R1:

R3 = 2.00 x R1

R4 = 0.300 x R1

When Auto = Hi, and there is no light, at 100% duty cycle, the output voltage should be 60mV. This implies that:

$$0.06=\frac{3.3\times R2\times(0.300\times R1)}{\left[(R1+R2)\times(2.3\times R1)\right]+(R1\times R2)}$$

These values can be plugged into the equation for I_{SRC} to find R2 in terms of R1.

This reduces to:

R2 = 0.174 x R1

When Auto = Hi, with sufficient ambient lighting to produce ISRC = 76uA, at 100% duty cycle, the output should be 300mV. This implies that:

$$0.300=\frac{\left[3.3\times(0.174\times R1)\times(0.300\times R1)\right]+\left[76\mu A\times R1\times(0.174\times R1)\times(0.300\times R1)\right]}{\left[(1.174\times R1)\times(2.30\times R1)\right]+\left(R1\times(0.174\times R1)\right)}$$

Solving for R1, and then the other resistor values:

R1 = 174K

R2 = 30.3K

R3 = 348K

R4 = 52.2K

The value of C1 works into the impedance of R1 in parallel with R3 + R4, which has an equivalent resistance of 121K. The value of C2 works into the impedance of R2 in parallel with 121K, which has an equivalent resistance of 24.2K. C1 can be set for a time constant of 0.01 seconds to filter out the PWM signal. C2 can be set for a time constant of ½ second to filter out fast changes in light. The values needed are:

$$C1=\frac{0.01}{121K}=83nF$$

$$C2=\frac{0.5}{24.2K}-C1=21\mu F$$

DC DIMMING INTERFACE CONVERSION

All the benefits of the previous PWM dimming conversion circuit can be implemented into a system that uses a DC dimming interface; this can be done using the LX1695 (Switched Royer CCFL Inverter Monitor IC) to convert the DC dimming signal to a PWM signal. In the next section an alternative method using a C555 timer IC and a comparator is presented. The circuit of Figure 2 can be used to convert a 300mV to 2.5V dimming signal to a 12% to 100% PWM signal at about 600Hz. The output (PWM OUT) can be fed directly into the PWM dimming circuit discussed earlier.

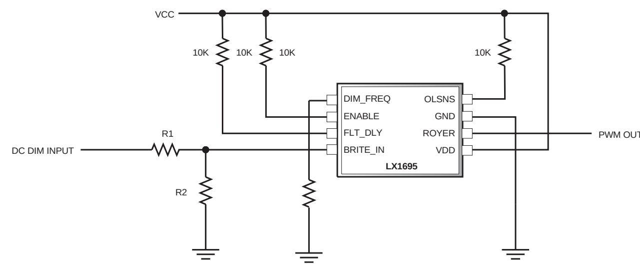


FIGURE 2 – CONVERTING DC DIMMING SIGNAL TO PWM

The LX1695 is designed to convert a Dimming Signal with a 2Vpp amplitude. Resistors R1 and R2 are used to attenuate our 2.5V dimming signal by 2/2.5 or 0.8. If a value of 100K is chosen for R2, R1 = 100K x (1-0.8)/0.8 = 25K (use 24.9K).

ALTERNATIVE DC DIMMING INTERFACE CONVERSION

An alternative method to convert the DC dimming interface can be implemented using a C555 timer IC and a comparator. The circuit of Figure 3 can be used to convert a 250mV to 2.5V dimming signal to a 10% to 100% PWM signal at about 15KHz. The output (VPWM) can be fed directly into the PWM dimming circuit discussed earlier.

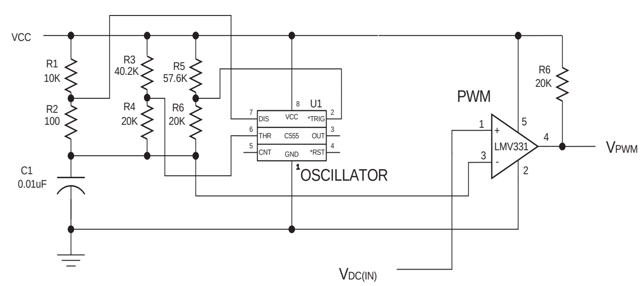


FIGURE 3 – DC DIMMING TO PWM CONVERSION

The Oscillator (U1) creates the saw tooth ramp that becomes the input to the PWM comparator. The Value of R1 and C1 determine the saw tooth frequency which is around 15KHz and suitable for most applications. The values of R3 & R4 and R5 & R6 determine the peak and valley levels of the sawtooth and are really the only values that need to be determined for a given application. Usually the saw tooth peak will be set equal to the maximum V_{DC} level and the valley is set to 10% of V_{CC} (which is limited by the accuracy of the oscillator). The internal C555 thresholds for THR and TRIG are 0.66Vcc and 0.33Vcc, respectively. The voltage divider of R3 and R4 adjust the peak level of the sawtooth (appearing across C1) to equal 0.66Vcc and the voltage divider of R5 and R6 adjust the valley level of the sawtooth to equal 0.33Vcc. For the peak threshold (V_{PK}) the equation is:

$$R3=\frac{0.33\times V_{CC}\times R4}{\left(0.66\times V_{CC}\right)-V_{PK}}$$

If V_{PK} is greater than 0.66Vcc, then R3 should connect from THR to ground and the equation for R3 becomes:

$$R3=\frac{0.66\times V_{CC}\times R4}{V_{PK}-\left(0.66\times V_{CC}\right)}$$

For the valley threshold (V_{VT}) the equation is:

$$R5=\frac{0.66\times V_{CC}\times R6}{\left(0.33\times V_{CC}\right)-V_{VT}}$$

DESIGN EXAMPLE

For this example the following parameters are defined by the application:

- 100% duty at V_{DIM} = 2.5V.
- 2) < 10% duty at V_{DIM} = 250mV
- 3) V_{CC} = 5V.

The values of R4 and R6 are chosen to be 20KΩ. R3 and R5 can be calculated as:

$$R3=\frac{0.33\times 5.0\times 20K}{\left(0.66\times 5.0\right)-2.5}=41.25K$$

$$R5=\frac{0.66\times 5.0\times 20K}{\left(0.33\times 5.0\right)-.25}=47.14K$$

ADDING AUTO SHUTDOWN AT HIGH AMBIENT

When lighting transflective displays, it may be preferred to shut off the display lighting when the ambient lighting alone is sufficient to illuminate the display. Since the LX1970 has two current outputs, its possible to use one output (typically SRC) for the dimming control and the second output (typically SNK) for the shutdown threshold. The circuit below shows the implementation for this function:

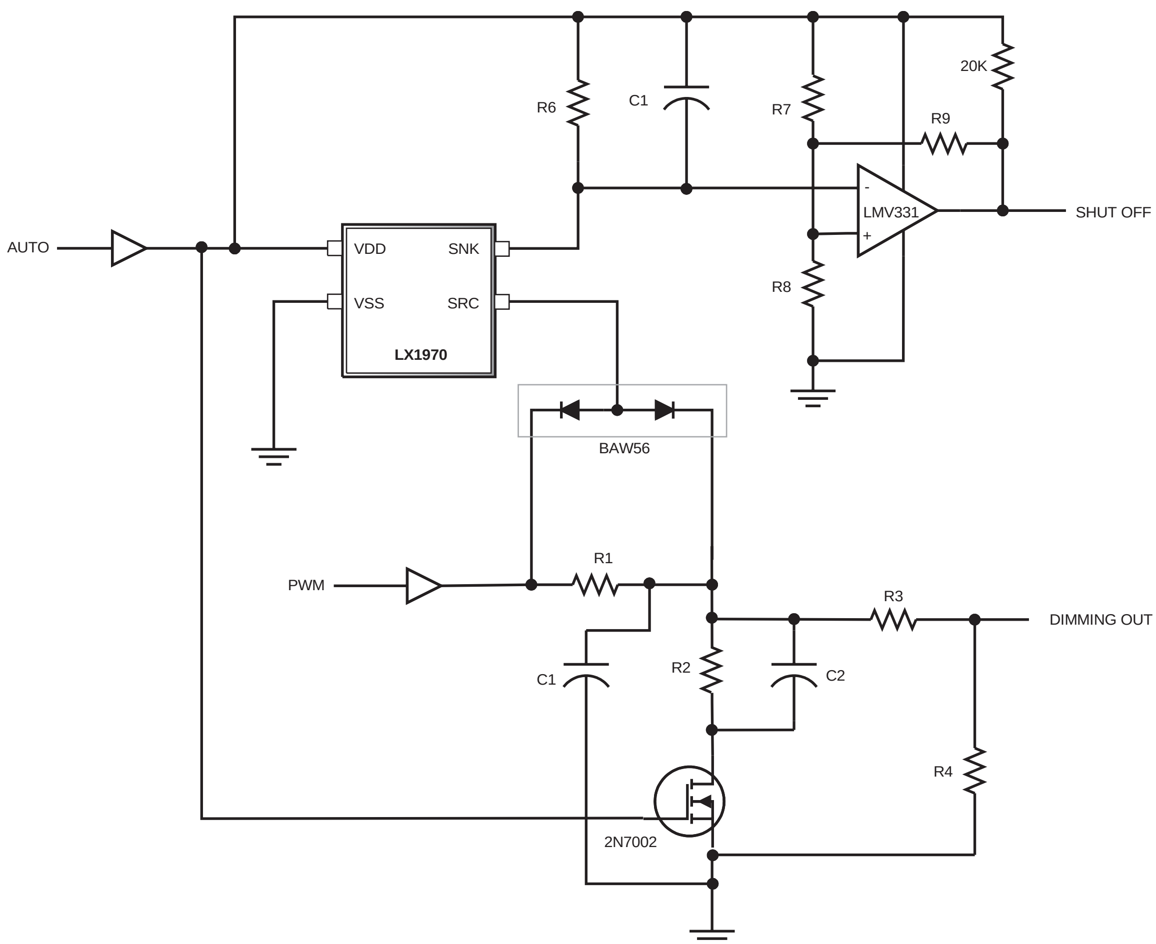


FIGURE 4 – SYSTEM WITH HIGH AMBIENT SHUT-OFF ADDED

The Comparator senses when the current through R6 exceeds the threshold set by R7 and R8. Hysteresis is provided by R9. A low pass filter capacitor C1 is needed to slow down the reaction time of the SNK output to avoid triggering on 60Hz light fluctuations. The shut off threshold for the SNK output would typically be set well above the compliance saturation point of the SRC output but below 500µA (where the LX1970 PIN diodes may start to saturate). In the previous example the SRC saturation point was set for 76µA. A reasonable value for the shut off threshold would be 350µA or roughly 5 times the ambient level that would result in maximum display brightness.

The equation for the shut off threshold current level is:

$$I_{THRESHOLD\ (TURN\ OFF)} = \frac{V_{CC}}{R6} \times \frac{R7\times(R8+R9)}{(R7\times R8)+(R7\times R9)+(R8\times R9)}$$

The equation for the turn on threshold is:

$$I_{THRESHOLD\ (TURN\ ON)} = \frac{R9}{(R8+R9)} \times I_{THRESHOLD\ (TURN\ OFF)}$$

The value of C1 should be chosen such that the time constant is ½ Hz:

$$0.5 = R6 \times C1$$

DESIGN EXAMPLE

For this example the following parameters are defined by the application:

- Turn off threshold at 350µA.
- Turn on threshold at 250µA
- Vcc = 3.3V

To insure adequate headroom, choose R6, such that the thresholds are centered around 50% of Vcc or:

$$R6 = \frac{3.3}{(250u + 350u)} = 5.5K$$

Select a value for R9 of 499K and solve for R8.

$$R8=R9\times\frac{\left(I_{THRESHOLD(TURNOFF)}-I_{THRESHOLD(TURNON)}\right)}{I_{THRESHOLD(TURNON)}}=143K$$

Finally calculate R7.

$$R7=\left(\frac{R8\times R9}{R8+R9}\right)\times\frac{\left(R6\times I_{THRESHOLD(TURNOFF)}\right)}{V_{CC}-\left(R6\times I_{THRESHOLD(TURNOFF)}\right)}=155K$$

Select a value for C1:

C1 = 0.5/R6 = 90µF

USING THE LX1970 WITH A POTENTIOMETER

The LX1970 is easily integrated into systems that use a potentiometer for dimming control. In this case the LX1970 SRC output drives the potentiometer with a signal proportional to the ambient light and the wiper provides a level of brightness depending on the potentiometer setting; thus a product function can be obtained. Figure 5 shows the circuitry needed:

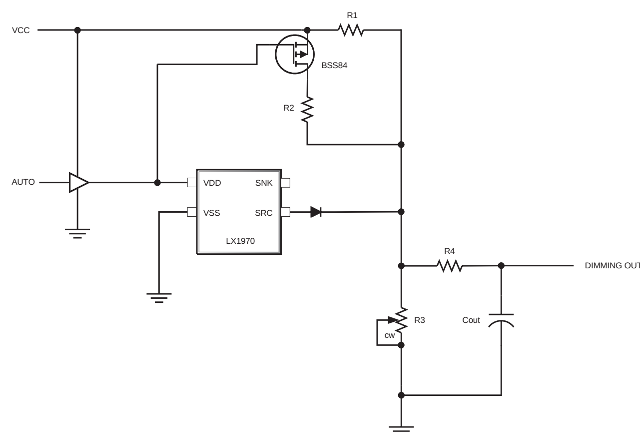


FIGURE 5 – SYSTEM WITH POTENTIOMETER

The describing equations for the circuit are (R3 refers to the adjusted value):

Auto = Lo:

$$DimOut = V_{CC} \times \frac{R3\times(R1+R2)}{(R1\times R2)+(R1\times R3)+(R2\times R3)}$$

Auto = Hi:

$$DimOut = \left[V_{CC} \times \frac{R3}{(R1+R3)}\right] + \left[I_{SRC} \times \frac{(R1\times R3)}{(R1+R3)}\right]$$

$$DimOut_{MAX} = \left(V_{CC}-V_{SAT}-V_{DIODE}\right)$$

The first major term in the brackets of the Auto = Hi equation is the Dim Output in total darkness. The second term introduces the effect of the light sensor. The maximum output voltage is determined by the compliance voltage of the LX1970. By buffering the

Dimming Output and adding an attenuator (voltage divider), the Dimming Out signal can be scaled to the lamp control module if necessary.

USING THE LX1970 WITH A MULTIPLYING DAC

The LX1970 is easily integrated into systems that use a DAC for dimming control. In this case the LX1970 SRC output drives the Reference input to the DAC with a signal proportional to the ambient light and the digital DAC setting provides a level of brightness depending on the binary input; thus a product function can be obtained. Figure 6 shows the circuitry needed. If the DAC reference input is a low impedance, it is necessary to buffer the signal with a voltage follower configured op amp. To obtain the dimming profiles of Graph 1, it is necessary to add a voltage clamp to the Dimming Output of the DAC.

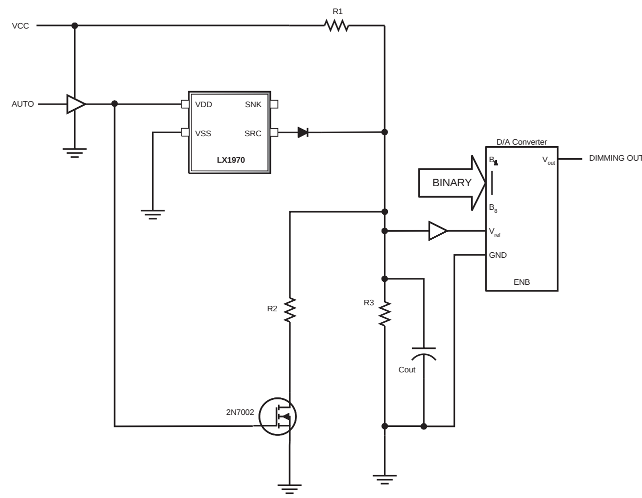


FIGURE 6 – SYSTEM WITH MULTIPLYING DAC

The describing equations for the circuit are:

Auto = Lo:

$$\text{DimOut}=\text{Binary\%fullscale}\times V_{CC}\times\frac{R3}{(R1+R3)}$$

Auto = Hi:

$$\text{DimOut}=\text{Binary\%fullscale}\times\left[\frac{\left[V_{CC}\times(R2\times R3)\right]+\left[I_{SRC}\times R1\times R2\times R3\right]}{(R1\times R2)+(R1\times R3)+(R2\times R3)}\right]$$