OVERVIEW

This Application Note describes an automotive exterior lighting control module using a PIC16C433. This unit also communicates over a Local Interconnect Network (LIN) bus as a slave controller. The non-networked functions are similar to General Motors’ Twilight Sentinel®. Networked functions allow lighting control to be taken over by the integrated body computer, a remote keyless entry unit, or a security system.

Features

- **Self-Contained Unit Functions**
  - Turn on lights in dim light (Light conditions persistent for greater than 30 accumulated seconds)
  - Turn off lights in daylight (Light conditions persistent for greater than 30 accumulated seconds)
  - Turn off headlights after a selected time after ignition off (Time interval selected by potentiometer)

- **Network Functions**
  - Commanded by a remote master node (Body Computer, RKE, etc.)
  - LIN slave node
  - Flash parking lights ($n$-times to forever)
  - Flash headlamps ($n$-times to forever)
  - Can be added to existing wiring harness without modification

The LIN protocol was devised to address low cost automotive networks. The LIN standard is meant to replace the myriad of low end multiplex wiring solutions in current use.

The LIN standard includes the specification of the transmission protocol, the transmission medium, the interface between, development tools, and the interfaces for software programming.
GENERAL DESCRIPTION

This control module provides automatic on-off control of the exterior lamps. It will also keep the exterior lamps turned on for a preselected period of time after the ignition switch is turned "OFF".

The system consists of a CdS photocell, a time delay rheostat with an on-off switch, and the microcontroller module with built-in relays. Connections to the vehicle lamps parallel the regular lamp switch connections. The headlamp switch must be in the "OFF" position to allow automatic control.

The photocell is mounted in the upper surface of the instrument panel to obtain an unobstructed view through the windshield. The control module and time delay control/on-off switch is mounted adjacent to the headlamp switch.

Automatic Operation

The LightKeeper automatically switches the lights on or off by sensing the ambient light level.

The module operates automatically when the ignition switch is "ON", the headlight switch is "OFF", and the control rheostat is in the "ON" position

When the headlamp switch is in "PARK" or "ON", or the control unit is powering the exterior lamps and instrument panel lamps, the "Lights-ON" warning will function.

As the intensity of light reaching the photocell decreases, its resistance increases. When the module senses a high resistance in the photocell, the module allows battery voltage to be applied to the headlamps, parking, side-marker, and tail lamps.

With the headlamp dimmer switch in the "DIP" position, the low beam headlamps are "ON". With the headlamp dimmer switch in the "MAIN" position, the high beam headlamps and indicator are "ON".

As the intensity of light reaching the photocell increases, the resistance decreases. When the resistance is low enough, the module turns all lamps "OFF".

A delay timer routine in the module reduces the chance of switching the lamps on and off while passing under viaducts, trees, bright lights, or any other condition where lamp control is not wanted.

If you move the control all the way to "MAX", the lights will remain on for approximately three minutes after the engine has been turned off. If the control is set to "MIN", so it is just on, the lights will go off almost immediately after the ignition is off. This delay time can be changed from less than a second to almost three minutes.

Manual Lamp Operation

The system can be turned off by setting the time delay rheostat to the "OFF" position. This allows non-automatic control of the exterior lamps to be used instead of the regular switch.

If exterior lamps are desired during daylight, either of two methods can be used.

Exterior lamps can be operated with the regular headlamp switch. The headlamp switch is wired in parallel with the control module and can bypass the system, whether the rheostat is "ON" or "OFF". If the headlamp switch is turned "ON", all lamps will remain on after the ignition is turned "OFF"; however, when a vehicle is equipped with a tone alarm package, a warning tone sounds as a reminder.

The photocell can be covered to block out light. This causes the lamps to turn on and still enables the system to turn the lamps off automatically when the ignition is turned "OFF". If the photocell has been exposed to light, the time delay must elapse before the lamps will turn on.

Network Operation

The network message protocol conforms to the Local Interconnect Network standard as outlined in the following documents:

- "LIN Specification Package", Revision 1.2, November 17, 2000
- Microchip’s Application Note AN729, “LIN Protocol Implementation Using Picmicro® MCUs” (DS00729)

The LightKeeper unit is connected to a LIN interface bus as a slave node. Two command frames and one interrogation frame are decoded by the firmware.

- Flash parking lights (n-times to forever)
- Flash headlamps(n-times to forever)
- Report status (2, 4, or 8 bytes)

Any of these commands can be initiated by either the body computer, or the Remote Keyless Entry (RKE) module.

Two LIN identifiers have been selected for this application, ‘0Ah’ and ‘0Bh’. Identifier ‘0Bh’ denotes a two-byte master message frame. Two subcommands are selected by the first data byte following the identifier ‘0Bh’.
The ‘0Ah’ identifier can be a 2-, 4-, or 8-byte slave response frame. The number of status bytes requested depends on the amount of data needed by the master. Currently, the status frame returned is shown in Table 2. Notice that data bytes 3, 5, and 9 are reserved for checksum values. These data bytes will be used as checksum scratchpad areas for the three frame sizes. This allows the other status fields to be updated without regard to the response frame size requested by the master. If these fields were to be used for storing status data, their values would be over-written, if the master requests a smaller response frame. This would require the slave to be aware of the last status frame size requested and to rewrite the corrupted data value. User status bytes 0 and 1 are not currently defined, so their values are zeros.

### TABLE 1: LIN COMMAND FRAMES FOR IDENTIFIER 0Bh

<table>
<thead>
<tr>
<th>ID</th>
<th>1st Data Byte</th>
<th>2nd Data Byte</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0Bh</td>
<td>00h</td>
<td>x</td>
<td>Reserved</td>
</tr>
<tr>
<td>0Bh</td>
<td>01h</td>
<td>Flash Number</td>
<td>Flash Park</td>
</tr>
<tr>
<td>0Bh</td>
<td>02h</td>
<td>Flash Number</td>
<td>Flash Main</td>
</tr>
<tr>
<td>0Bh</td>
<td>03h-0Fh</td>
<td>x</td>
<td>Not Used</td>
</tr>
</tbody>
</table>

**Note:** (‘01h’ = Flash Park, ‘02h’ = Flash Main). The number of flashes are defined by the second data byte. Values between 1 and 254 are valid. A value of 255 will cause continuous flashing. If the ignition should be turned on at any time, the flash sequence will abort.

### TABLE 2: STATUS RESPONSE FRAME FOR IDENTIFIER ‘0Ah’

<table>
<thead>
<tr>
<th>Status</th>
<th>Data 1</th>
<th>Data 2</th>
<th>Data 3</th>
<th>Data 4</th>
<th>Data 5</th>
<th>Data 6</th>
<th>Data 7</th>
<th>Data 8</th>
<th>Data 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-byte</td>
<td>User Status 0</td>
<td>User Status 1</td>
<td>Checksum&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4-byte</td>
<td>User Status 0</td>
<td>User Status 1</td>
<td>not used&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>Integral Counter Value</td>
<td>Checksum&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>8-byte</td>
<td>User Status 0</td>
<td>User Status 1</td>
<td>not used&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>Integral Counter Value</td>
<td>not used&lt;sup&gt;(5)&lt;/sup&gt;</td>
<td>System Status Flags</td>
<td>Delay Control Value</td>
<td>Light Sensor Value</td>
<td>Checksum&lt;sup&gt;(3)&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Note:**
1: This is the checksum value of the current 2-byte response frame.
2: This is the checksum value of the current 4-byte response frame.
3: This is the checksum value of the current 8-byte response frame.
4: This is the checksum value from a previous 2-byte response frame, not valid information.
5: This is the checksum value from a previous 4-byte response frame, not valid information.
6: The values and definitions of the variables described above are in the software source code.
HARDWARE

Refer to Figure 7, Module Schematics.

Power Supply

The power supply is built around an automotive-grade, low dropout, linear voltage regulator. It is internally protected from reverse polarity connection, load dump, and short circuit. The diodes, D10 and D8, provide some level of protection if simple commercial-grade regulators are used.

Input Circuits

R3 and R4 provide input current limiting and, along with C3 and C5, isolate the analog channels from high frequency noise. Although the variable resistor inputs are powered from the onboard Vcc bus and referenced to system ground, high speed Schottky diodes D5-7 and 9, make sure that the input voltages are clamped to Vcc and ground.

R5 and R6 constitute a voltage divider to reduce the incoming signal from 0 to 12-14 VDC, down to a nominal 0-5 VDC. Again, diodes (D11,12) are used to clamp the input between Vcc and ground.

The photocell and R2 form a voltage divider reference to Vcc and ground, connected to Analog Channel 0. The value of R2 is dependent on the type and specification of the chosen CdS photocell. The value is selected by measuring the voltage at J12 in total darkness and full sunlight. The resistor is sized to obtain a reasonably close reading to the voltage rails at both extremes. The final voltage threshold is adjusted in software.

The delay time rheostat is connected between Vcc and ground (J15 and J13, respectively) and its wiper terminal is a variable voltage divider connected to Analog Channel 1.

The switched ignition voltage is connected to J16.

Output Circuits

Three high current SPDT automotive relays are driven by a quad 1.5A Darlington low-side driver (U1). This driver interfaces the low level logic signals from the microcontroller. The driver outputs can handle inductive loads, sustaining voltage of 50V at 100 mA.

Channels 1 and 2 are independently controlled by the PIC16C433. Channels 3 and 4 can be assembled to either be a wired-OR of channels 1 and 2, or directly controlled by a third output. These options are selected by jumpers at E1. The wired-OR function is enabled by installing D3 and D4.

TABLE 3: JUMPER E1

<table>
<thead>
<tr>
<th>Jumper Position</th>
<th>Driver Channel</th>
<th>Input Source</th>
<th>Selected Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>4</td>
<td>GND</td>
<td>Channel 4 not used</td>
</tr>
<tr>
<td>1-3</td>
<td>4</td>
<td>GP2</td>
<td>Channel 4 controller by GP2</td>
</tr>
<tr>
<td>2-4</td>
<td>3</td>
<td>GND</td>
<td>Channel 3 not used</td>
</tr>
<tr>
<td>3-4</td>
<td>3</td>
<td>GP2</td>
<td>Channel 3 controller by GP2</td>
</tr>
<tr>
<td>3-5</td>
<td>BACT</td>
<td>GP2</td>
<td>Wake-up signal to GP2/INT</td>
</tr>
<tr>
<td>5-6</td>
<td>BACT</td>
<td>n.c.</td>
<td>Invalid, Do Not Select</td>
</tr>
<tr>
<td>4-6</td>
<td>n.c.</td>
<td>D3 or D4</td>
<td>Invalid, Do Not Select</td>
</tr>
<tr>
<td>1-4</td>
<td>3 and 4</td>
<td>D3 or D4</td>
<td>Channels 3 and 4 together</td>
</tr>
<tr>
<td>2-3</td>
<td>GND</td>
<td>GP2</td>
<td>Invalid, Do Not Select</td>
</tr>
</tbody>
</table>

Note 1: Diodes D3 and D4 must not be installed for these selections.

2: This is the default selection for this firmware implementation.

Network Interface

JP1 is the LIN bus interface port and can be used as an alternative power connection to battery. Depending on the bus capacitance of a specific implementation, C2 may or may not be needed, or its value changed. D2 is meant to shunt any spurious transients that may occur on the LIN bus.
SOFTWARE

The software for this application is composed of three major sections:

- Main program loop, which includes:
  - Light sensor interrogation loop
  - Lights on delay loop
  - SLEEP routine
  - Wake-up routine
- Interrupt routine
- Clock event scheduler

Main Program Loop

LIGHT SENSOR INTERROGATION LOOP

While the ignition switch is "ON", interrogate the photocell and turn the lights on or off, as appropriate. If the ignition is turned "OFF" while in this loop, the program falls through to the Lights On Delay Loop.

LIGHTS ON DELAY LOOP

After the ignition has been turned "OFF", check if the lights were "ON". If they were, wait a period of time equal to the duration set by the delay control rheostat, then turn "OFF" all the lights and go to SLEEP.

If no lights were on when the ignition was turned "OFF", go directly to SLEEP.

SLEEP ROUTINE

When no other events are pending to be executed, the interrupt-on-pin change is setup and the system is put into low power state.

A jump to the RESET vector (0000h) is done when any change is detected in an I/O port pin

WAKE-UP

After either a RESET, or a wake-up from SLEEP, a global initialization is performed and the wake-up routine clears the pin change flags. A reading is taken immediately from the light sensor. If the light level is lower than the threshold, the lights are turned on without any time delay. The program transfers control to the Main Light Sensor Interrogation Loop.
FIGURE 2: MAIN PROGRAM LOOP

RESET

Initialization

Ignition ON?

NO

YES

MAIN

Ignition ON?

YES

Enable Timer for 128 ms interrupt

LightDark bit ON?

NO

YES

Turn Lights ON

Turn Lights OFF

WALKAWAY

LightDark bit ON?

YES

Disable Timer for 128 ms interrupt

DelayDuration

Read Delay Timer Control

Time Delay = 0?

NO

YES

Enable Timer for 1 Sec Interrupt

Call CheckEvents

WAKE-UP

Wake-up

Read Light Sensor

Light Level > Light Threshold?

YES

NO

Set LightDark bit ON

Set LightDark bit OFF

Set IntegralCounter = 0FFh

Set IntegralCounter = 00h

Call CheckEvents

Call ProcessLINcommand

DelayDuration

Read Delay Time Control

Elapsed time = DelayDuration?

YES

NO

Turn Lights OFF

SLEEP with Pin Change Interrupt ON
Interrupt Routine

The two interrupt sources are sorted by inspecting the pending interrupt flags. If the source of the interrupt is the timer, the 16-bit system clock word is incremented. If the source should be the pin change detection circuit, the flags are cleared and no further action is taken before resuming main program execution.

Clock Event Scheduler

The first test performed is to determine which event is currently selected.

If the main code being executed is the Light Sensor Interrogation routine, then the system clock is measured in 128 millisecond ticks. Every 128 mS, the photocell is sampled and the value compared to the threshold. If the light level is below the threshold, an internal counter is incremented to a maximum value of 255. If the light level is above the threshold, the counter is decremented to a minimum of 0. The LightDark bit is set when the counter reaches 255, and reset when the counter drops to 0. A continuous light condition will result in a state change in approximately 30 seconds.

If the Light Delay loop was being executed, the system clock is measured in 1 second periods. Every second an internal delay count is incremented and then compared to the time duration value set by the delay control rheostat. When the delay counter is equal to, or greater than the duration value, the time duration bit is cleared, to indicate that the required time has elapsed.

Control is returned to the calling routine.
FIGURE 3: INTERRUPT AND EVENT SCHEDULER

- **Interrupt**
- **Pin Change Interrupt?**
  - **YES**
    - Clear Pin Change Interrupt Flags
  - **NO**
    - **Save Registers**
    - **LIN START bit Interrupt?**
      - **YES**
        - Call LINHandler
      - **NO**
        - **Increment System Clock**
        - **Decode and Process Command Frames**
        - **Restore Registers**
        - **Return From Interrupt**
- **CheckEventTimer**
  - **Disable Interrupts**
  - **Is this a 128 mS interrupt?**
    - **NO**
    - **Has 1 Sec elapsed?**
      - **NO**
      - **Increment Delay Counter**
      - **Delay Counter >= DelayDuration?**
        - **NO**
        - **Set Delay Elapsed Time bit**
        - **Read Light Sensor**
          - **Light Threshold >= Light Level?**
            - **YES**
              - **IntegralCounter = FF?**
                - **YES**
                  - **Clear LightDark bit**
                - **NO**
                  - **Increment IntegralCounter**
            - **NO**
              - **IntegralCounter = 0?**
                - **YES**
                  - **Set LightDark bit**
                - **NO**
                  - **Decrement IntegralCounter**
  - **YES**
    - **Has 128 mS elapsed?**
      - **NO**
      - **Set LightDark bit**
      - **Return**

- **Lin START bit Interrupt?**
  - **Lin START bit Interrupt?**
    - **YES**
    - **Call LINHandler**
    - **NO**
    - **Increment System Clock**
    - **Decode and Process Command Frames**
    - **Restore Registers**
    - **Return From Interrupt**
LIN Protocol Handling Routines

The firmware that receives and transmits a LIN message frame is outlined in the flow charts in Figure 4, LIN Handler Routine, Figure 5, LIN UART Routines, and Figure 6, LIN Data Integrity Routines. This software is described in Microchip’s Application Note AN729, “LIN Protocol Implementation Using PICmicro® MCUs (DS00729).

AUTOBAUD COUNTER

The signal is sampled every 6 instruction cycles. This means the number of counts accumulated over one character time equals $8 \times T_{BIT} / 6T_{CY}$.

**EXAMPLE 1:**

Given:
Desired transmission rate = 19.2 Kbaud
$T_{BIT} = 1 / 19200 = 52 \mu s$
$F_{OSC} = 4 MHz$, $T_{CY} = 1 / F_{OSC} = 1 \mu s$

Therefore:

$8 \times 52 \mu s / 6 \times 1 \mu s = 69 \mu s$ or counts.

To this base count are added a constant of 8 counts to account for software overhead and 2 counts for bus propagation delay. The individual bit time is derived by dividing the total by eight and adding a 2 count delay for the bit timing routines.

$((69 + 10) / 8) - 2 = 7.875$ = AUTOBAUD value 8.

The actual transmission baud rate is then:

$(((8 + 2) \times 8) - 10) \times (6 \times 1 \mu s) / 8 = 19048$ baud

This value lies within the frequency range (1 kHz to 20 kHz) allowed in the LIN specification.
FIGURE 4: LIN HANDLER ROUTINE

- LINHandler
  - Is BREAK character complete? NO
    - YES
  - START bit of SYNC complete? NO
    - YES
  - Is bit low? YES
    - Increment AUTOBAUD
    - Increment bit COUNTER
    - bit COUNTER = 8 ?
      - YES
        - Add Correction Constant to AUTOBAUD
        - Divide AUTOBAUD by 8
        - AUTOHALF = AUTOBAUD / 2
      - NO
    - NO
  - Is bit high? NO
    - Increment AUTOBAUD
    - Increment bit COUNTER
    - bit COUNTER = 8 ?
      - YES
        - Add Correction Constant to AUTOBAUD
        - Divide AUTOBAUD by 8
        - AUTOHALF = AUTOBAUD / 2
      - NO
  - AUTOBaud = AUTOBaud - 2
  - AUTOMHALF = AUTOMHALF - 2
  - STOP bit complete? NO
    - YES
  - Call RECEIVE to get Identifier Byte
    - MESSAGE_COUNTER = # data bytes in frame
  - Slave transmit? NO
    - YES
      - TransmitMode
      - Call CheckParityBits
      - Call CheckCRC (Generate Mode)
      - Call TRANSMIT (send 1 data byte from buffer)
      - Decrement MESSAGE_COUNTER
      - MESSAGE_COUNTER = 0 ?
        - YES
          - Call CheckParityBits
        - NO
      - Call CheckCRC (Verify Mode)
      - Message_COUNTER = 0 ?
        - YES
          - Call CheckParityBits
        - NO
  - ReceiveMode
    - Call RECEIVE (get 1 data byte from buffer)
    - Decrement MESSAGE_COUNTER
    - MESSAGE_COUNTER = 0 ?
      - YES
        - Call CheckParityBits
      - NO
    - RETURN

- AUTOHALF = AUTOHALF - 2
FIGURE 5: LIN UART ROUTINES

RECEIVE

START bit falling edge?

YES

NO

Call DelayHalfBit

Call DelayFullBit

Shift Received bit into RXTX_REG

Call DelayFullBit

8 bits received?

YES

NO

Get STOP bit

Call DelayFullBit

Return

TRANSMIT

Is bus IDLE?

YES

NO

Send START bit

Call DelayFullBit

Shift Transmit bit out of RXTX_REG

Call DelayFullBit

8 bits transmitted?

YES

NO

Send STOP bit

Call DelayFullBit

Return

Decrement AUTOBAUD

AUTOBAUD = 0?

YES

NO

Return

Decrement AUTOHALF

AUTOHALF = 0?

YES

NO

Return
FIGURE 6: LIN DATA INTEGRITY ROUTINES

**CheckCRC**
- Get Data Byte from Buffer
  - Get next Data Byte from Buffer
    - Add Data Bytes + Carry
      - All data bytes in buffer done?
        - YES
          - Is the CRC to be generated?
            - YES
              - Add CRC from Buffer to Data Bytes
                - Write Complemented CRC to Data Buffer
                  - Return OK
            - NO
              - Return OK
        - NO
          - Return ERROR

**CheckParityBits**
- tempbit = ID.0 xor ID.1 xor ID.2 xor ID.3 xor ID.4
  - tempbit = 0?
    - YES
      - P0 = 0?
        - YES
          - Return ERROR
        - NO
          - P1 = 0?
            - YES
              - Return OK
            - NO
              - Return ERROR
SCHEMATICS

The first schematic shown is of the module itself. The second is of a typical system application.

Power can be applied to the unit, either from the LIN connector (JP1) and/or through the individual power connections, JP2 and JP3.

FIGURE 7: MODULE SCHEMATICS
FIGURE 8: SYSTEM SCHEMATIC
FIGURE 9: TWO-LAYER PCB LAYOUT

Referenced Documents:

- "LIN Specification Package", Revision 1.2, November 17, 2000
- Microchip's Application Note AN729, "LIN Protocol Implementation Using PICmicro® MCUs", (DS00729)

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