Modular Programming: Where the rubber meets the Code

Gabriel Hugh Elkaim
Announcements

1. Leave the Uno stack in form
2. No one got beer

Include a bell or timer — reverse motor
The three uses of static

1. Allocates a variable of static type and retains its value between function calls. Public.

2. Scope restriction - cannot be accessed from outside the module. Public/Private.

Encapsulation (1.2)

```
int foo
FunctionA()
FunctionB()
FunctionC()
char bar
```

- Functions
- Data
- Helper function
- Specific
Encapsualtion (2.2)

.h - Interface definition "contract"

.c - Implement the functionality

```
RE_init/RE_and
RE_addPin/RE_remPin
RE_setPin/RE_getPin
```

Module name.h
name.c
What goes into a header file?

**HEADER GUARD**

- Block comment — explaining module (or purpose)
- Prototypes for **public** functions
- Declarations for **public** constants
- Documentation/comments

- Public data structures

```c
/**
 * @brief Describe details here.
 */
```
What shouldn’t be in a header file?

Not going in .h file:

- No Functions
- No Execute Code
- No Module Variables
- No Static Function Prototypes (PRIVATE)
Where do you **#include** the header file?

Everywhere I might need to access its

Predefined:

```
#ifndef _NOTDEFINE_H
#define _NOTDEFINE_H

/* code */
#endif /* _NOTDEFINE_H */
```
Programming Style Issues

Layout within a module

 Một "True" Indentation Style

Use of White Space

Use of Comments

Naming Conventions

Module Level Comment
#include
library/module headers
Public header for this module
Private Constant Definitions
Private Macro Definitions
Private Type Definitions
Private Variables
Private Function Prototypes
Code

TEST NUMBERS
while (1)
{
    MSES_HandleEvents();
}

test[0] + found = 600;
cnt++;

Gabriel Hugh Elkaim
CMPE 118/218 – Intro. to Mechatronics
Module Design by Interface Specification

• **View**
  – The module provides **Services** to the rest of the code

• **Design Activities**
  – **Specify the services**
    • Describe Functionality
  – **Name the Services**
  – **Design the implementation**
Applications Programming Interfaces (API) for the ME218c Master modules

A Real Example

Module: Communications to UI on PC

To avoid hanging up the master during the transmission or reception of messages, this module should implement buffered, interrupt driven transmit and receive. The communications routines for this module will need to be interrupt driven because the UI may send its message at any time.

Char InitializeUICommunications(void);
Do whatever hardware and software initialization necessary to prepare for communications with the UI on SC1.

Void TellUINewUserReady(void);
Should send the message to the UI that a new iButton has been inserted and read.

Unsigned char IsNameReady(void);
Should check to see if a new name is ready from the UI. Return TRUE if a new name is ready, FALSE otherwise.

Unsigned char GetNewName( unsigned char NameSpace[]);
Should copy the name gotten from the UI into the array NameSpace. The copy operation should copy no more than 16 characters, including the terminating NULL. Should return TRUE if there was a new name ready, FALSE otherwise.
Design the interfaces to modules

- Design interface for:
  - Driving the platform
  - Gathering Sensor data

- Produce
  - Public Interface specification
  - What are the details that are being hidden?
uint8_t DriveInit(void)
DriveFullStop(void)
DriveStraight(int8_t speed)

DriveTurn(enum type, int8_t speed)

DriveEnd(void)
Hierarchical State Machines

- Harel Statecharts

allows me to zoom in or out depending on behavior

1980s
A Possible Top-Level State Diagram

- Finding Tape I
  - Enter
  - Found Tape
    - Tracking Tape
      - Found Tape
      - Found Tape II
    - Stop
      - Found Tape
Work out State Diagrams to Implement Finding Tape
1 - Exit

1 \rightarrow 2 \leftarrow 2 - Entry

2 ready
Finding Tape

Enter → Acquiring → Beacon Acquired → Diving to Tape → Hit Tape → Stop
Acquiring

Entry

Turning CW

Left Sensor Peaks
Set Slow Speed, Reverse

Turning CCW

L ≈ R
Stop Turning, Post Beacon Acquired

Acquired
Implementing Hierarchical State Machines

- What do you need?

**End**

Fall through to lowest level

↓

either consumed — EL_no_EVENT
not consumed — EVENT

remain call to EL_EMPTY/EL_EXIT on change of state
SUB麻雀 POSTS TO MAN QUEUE
State Machine Function Template

If current state is state one
    Execute During function for state one
    If an event is active
        If event is event one
            Execute action function for state one : event one
            Decide what the next state will be
        Endif
        If event is event two
            Execute action function for state one : event two
            Decide what the next state will be
        Endif
        Repeat the block above as required for each of the possible events affecting this state.
    If next state is different from current state
        Execute exit function for state one
        Execute entry function for new state
        Modify state variable to reflect the new state
    Endif
Endif
Return from state machine function
Module

d:\me218b\Lectures\Lecture 29\SMTemplate.c

Description

This is a template file for implementing state machines.

Notes

History

<table>
<thead>
<tr>
<th>When</th>
<th>Who</th>
<th>What/Why</th>
</tr>
</thead>
<tbody>
<tr>
<td>02/18/99</td>
<td>jec</td>
<td>built template from MasterMachine.c</td>
</tr>
<tr>
<td>02/14/99</td>
<td>jec</td>
<td>Began Coding</td>
</tr>
</tbody>
</table>

/**--------------------------------------------- Include Files ---------------------------------------------*/

/* include header files for this state machine as well as any machines at the next lower level in the hierarchy that are sub-machines to this machine */

/**--------------------------------------------- Module Defines ---------------------------------------------*/

// define constants for the states and event for this machine
void RunStateMachine(unsigned char CurrentEvent )
{
    unsigned char NextState = CurrentState;

    switch ( CurrentState )
    {
    case STATE_ONE :     // If current state is state one
        DuringStateOne();   // Execute During function for state one
        if ( CurrentEvent != NO_EVENT )   // If an event is active
        {
            switch ( CurrentEvent )
            {
            case EVENT_ONE :      // If event is event one
                // Execute action function for state one : event one
                NextState = STATE_TWO ; // Decide what the next state will be
                break;
            }
            // If next state is different from current state
            if ( NextState != CurrentState )
            {
                // Execute exit function for current state
                // Execute entry function for new state
                CurrentState = NextState;   // Modify state variable
            }
        }
    }
    return;
Function
StartStateMachine

Parameters
None

Returns
None

Description
Does any required initialization for this state machine

Notes

Author
J. Edward Carryer, 2/18/99, 10:38AM

void StartStateMachine ( void )
{
    CurrentState = ENTRY_STATE;
    // call the (optional) entry function for the ENTRY_STATE
    // any other initialization necessary to re-start the state machine
}
Questions?
Noise Isolation:
Keeping the Gremlins Out!

Gabriel Hugh Elkaim
How noise gets into your circuits

Figure 1-11. Before noise can be a problem, there must be a noise source, a receptor that is susceptible to the noise, and a coupling channel that transmits the noise to the receptor.
Key Characteristics of the noise source

- **Voltage**
  - high voltage \( \frac{dV}{dt} \)
  - stray electric field
  - capacitive coupling

- **Current**
  - high current \( \frac{dI}{dt} \)
  - stray magnetic field
  - inductive coupling

- **Frequency**
  - high frequency
  - radiation / radiative coupling
  \[ 0 \leq \text{distance} \leq \text{near high} \]
  - direct contact
  - conductive coupling
What is the most likely coupling mechanism for:

- Florescent Light noise - 100's volts, capacitive coupling

- Arc Welding Noise - 100's amps (low voltage) inductive

- Digital Clock Noise - Capacitive coupling
Conductive coupling (1.2)

[Diagram showing conductive coupling between a power supply, common line impedances, a source impedance, and connections to a motor and sensor.]
Conductive coupling (2.2)

Motor

+12V

CIRCUIT 1

GROUND CURRENT 1

GROUND VOLTAGE CIRCUIT 1

GROUND CURRENT 2

GROUND VOLTAGE CIRCUIT 2

"NECCA GRAND"

COMMON GROUND IMPEDANCE
How should I wire these up?

1. Avoid ground loops.

- Uno32
- 12V
- 5V
- Sensor
- Motor

Signal input
Which waveform **must** be conductively coupled?

Why?

- Conductive
- Capacitive
Identifying Characteristics of Conductive Coupling

1. Metallic conduit required
2. Unaffected by cable movement or people
3. Non-zero DC value on its waveform

Break contact

1. Re-route wires (power/ground) back to until
2. Use a line filter
Capacitively coupled noise

Coupling capacitance

Simplified circuit
Physical Representation of capacitively coupled noise

- Noise source
- Conductors
- $V_1$, $C_{1G}$, $R$, $C_{2G}$
- Physical representation
- I can't control anything
Equivalent circuit for capacitively coupled noise

\[ V_N = \frac{j \omega \left[ C_{12} / (C_{12} + C_{2G}) \right]}{j \omega + 1 / R (C_{12} + C_{2G})} V_1 \]

If \( R \gg \frac{j \omega (C_{12} + C_{2G})}{1} \)

\[ V_N = \frac{C_{12}}{(C_{12} + C_{2G})} V_1 \]

If \( R \ll \frac{j \omega (C_{12} + C_{2G})}{1} \)

\[ V_N = j \omega RC_{12} V_1 \]
Reducing Capacitively Coupled Noise

Position my shield to intercept noise
Summary of capacitive noise reduction techniques

1. Reduce capacitive coupling
2. Use a shield, ground only one end
3. Reduce arctic impedance
Isolation

Split my circuit so there are no common paths.
Isolation via magnetic coupling

---

**RELAY**
PCB mount miniature relays
Reed Relay construction

AXIAL LEADS ALLOW VARIOUS MOUNTING CONFIGURATIONS

END FLANGE FOR COIL WINDING RETAINER

NICKEL PLATED STEEL JACKET PROVIDES MAGNETIC SHIELDS

COIL WINDINGS ON REED SWITCH FOR INCREASED ELECTRICAL EFFICIENCIES

ENDS EPOXY SEALED TO PROVIDE ENVIRONMENTAL PROTECTION

Gabriel Hugh Elkaim
Optical Isolation
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ*</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EMITTER</strong></td>
<td></td>
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<tr>
<td>Input Forward Voltage</td>
<td>( I_F = 10 , mA )</td>
<td>( V_F )</td>
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<td>1.50</td>
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<td>V</td>
</tr>
<tr>
<td>Reverse Leakage Current</td>
<td>( V_R = 6.0 , V )</td>
<td>( I_R )</td>
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<td>10</td>
<td></td>
<td>( \mu A )</td>
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<tr>
<td><strong>DETECTOR</strong></td>
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</tr>
<tr>
<td>Collector-Emitter Breakdown Voltage</td>
<td>( I_C = 1.0 , mA, I_F = 0 )</td>
<td>( B V_{CEO} )</td>
<td>30</td>
<td>100</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Collector-Base Breakdown Voltage</td>
<td>( I_C = 100 , \mu A, I_F = 0 )</td>
<td>( B V_{CBO} )</td>
<td>70</td>
<td>120</td>
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<tr>
<td>Emitter-Collector Breakdown Voltage</td>
<td>( I_C = 100 , \mu A, I_F = 0 )</td>
<td>( B V_{ECO} )</td>
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<td>V</td>
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<tr>
<td>Collector-Emitter Dark Current</td>
<td>( V_{CE} = 10 , V, I_F = 0 )</td>
<td>( I_{CEO} )</td>
<td>1</td>
<td>50</td>
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<td>nA</td>
</tr>
<tr>
<td>Collector-Base Dark Current</td>
<td>( V_{CB} = 10 , V )</td>
<td>( I_{CBO} )</td>
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<td>20</td>
<td></td>
<td>nA</td>
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<td>Capacitance</td>
<td>( V_{CE} = 0 , V, f = 1 , MHz )</td>
<td>( C_{CE} )</td>
<td>8</td>
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<td></td>
<td>pF</td>
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</table>

\( T_A = 25^\circ C \) unless otherwise specified.
<table>
<thead>
<tr>
<th>DC Characteristic</th>
<th>Test Conditions</th>
<th>Symbol</th>
<th>Device</th>
<th>Min</th>
<th>Typ*</th>
<th>Max</th>
<th>Unit</th>
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<tr>
<td></td>
<td>((I_F = 10\ mA, V_{CE} = 10\ V))</td>
<td>CTR</td>
<td>4N35</td>
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<td>20</td>
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<td>H11A3</td>
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<tr>
<td></td>
<td>((I_F = 10\ mA, V_{CE} = 10\ V, T_A = +100^\circ C))</td>
<td>CTR</td>
<td>4N27</td>
<td>10</td>
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<td>4N28</td>
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<td></td>
<td>4N37</td>
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</tr>
<tr>
<td>Collector-Emitter Saturation Voltage</td>
<td>$\left( I_C = 2 \text{ mA}, I_F = 50 \text{ mA} \right)$</td>
<td>$V_{CE \ (SAT)}$</td>
<td>$\left( I_C = 0.5 \text{ mA}, I_F = 10 \text{ mA} \right)$</td>
<td>$V$</td>
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<td></td>
<td></td>
<td>4N25 4N26 4N27 4N28</td>
<td></td>
<td>0.5</td>
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<tr>
<td>AC Characteristic</td>
<td></td>
<td>4N35 4N36 4N37</td>
<td></td>
<td>0.3</td>
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<tr>
<td>Non-Saturated Turn-on Time</td>
<td>$\left( I_F = 10 \text{ mA}, V_{CC} = 10 \text{ V}, R_L = 100\Omega \right)$ (Fig.20)</td>
<td></td>
<td>H11A1 H11A2 H11A3 H11A4 H11A5</td>
<td>0.4</td>
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<tr>
<td>Non Saturated Turn-on Time</td>
<td>$\left( I_C = 2 \text{ mA}, V_{CC} = 10 \text{ V}, R_L = 100\Omega \right)$ (Fig.20)</td>
<td></td>
<td>4N35 4N36 4N37</td>
<td>2 10</td>
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<td></td>
</tr>
</tbody>
</table>
AC INPUT/PHTOTRANSISTOR OPTOCOUPLERS

H11AA1  H11AA3  H11AA2  H11AA4

DESCRIPTION
The H11AAX series consists of two gallium-arsenide infrared emitting diodes connected in inverse parallel driving a single silicon phototransistor output.

FEATURES
- Bi-polar emitter input
- Built-in reverse polarity input protection
- Underwriters Laboratory (UL) recognized — File #E90700
- VDE approved — File #E94766 (ordering option ‘300’)

APPLICATIONS
- AC line monitor
- Unknown polarity DC sensor
- Telephone line interface

Schematic
PHOTODARLINGTON OPTOCOUPLERS

DESCRIPTION
The CNX48U, H11BX, MOC8080 and TIL113 have a gallium arsenide infrared emitter optically coupled to a silicon planar photodarlington.

FEATURES
- High sensitivity to low input drive current
- Meets or exceeds all JEDEC Registered Specifications
- VDE 0884 approval available as a test option
  - add option .300. (e.g., H11B1.300)

APPLICATIONS
- Low power logic circuits
- Telecommunications equipment
- Portable electronics
- Solid state relays
- Interfacing coupling systems of different potentials and impedances.

SCHEMATIC

Gabriel Hugh Elkaim
CMPE 118/218 – Intro. to Mechatronics
<table>
<thead>
<tr>
<th>AC Characteristics</th>
<th>$t_{on}$</th>
<th>$t_{off}$</th>
<th>$H11B1$</th>
<th>$H11B2$</th>
<th>$H11B255$</th>
<th>$H11B3$</th>
<th>$CNX48U$</th>
<th>$MOC8080$</th>
<th>$TIL113$</th>
<th>$\mu s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_C = 10 \ mA$, $V_{CE} = 10 \ V$</td>
<td>$t_{on}$</td>
<td>$t_{off}$</td>
<td>$H11B1$</td>
<td>$H11B2$</td>
<td>$H11B255$</td>
<td>$H11B3$</td>
<td>$CNX48U$</td>
<td>$MOC8080$</td>
<td>$TIL113$</td>
<td>$\mu s$</td>
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<tr>
<td>$R_L = 100 \ \Omega$ (Fig.7)</td>
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<td>$I_F = 1 \ mA$, $V_{CC} = 5 \ V$</td>
<td>$t_{on}$</td>
<td>$t_{off}$</td>
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<td>$R_E = 1k\ \Omega$ (Fig.8)</td>
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</tr>
<tr>
<td>$I_F = 5 \ mA$, $V_{CC} = 10 \ V$</td>
<td>$t_{on}$</td>
<td>$t_{off}$</td>
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<tr>
<td>$I_F = 200 \ mA$, $I_C = 50 \ mA$</td>
<td>$t_{on}$</td>
<td>$t_{off}$</td>
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<td>$V_{CC} = 10 \ V$ (Fig.7)</td>
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</tbody>
</table>
6-Pin DIP Optoisolators
Logic Output

The H11L1 and H11L2 have a gallium arsenide IRED optically coupled to a high-speed integrated detector with Schmitt trigger output. Designed for applications requiring electrical isolation, fast response time, noise immunity and digital logic compatibility.

- Guaranteed Switching Times — $t_{on}, t_{off} < 4 \mu s$
- Built-in On/Off Threshold Hysteresis
- High Data Rate, 1 MHz Typical (NRZ)
- Wide Supply Voltage Capability
- Microprocessor Compatible Drive
- To order devices that are tested and marked per VDE 0884 requirements, the suffix "V" must be included at end of part number. VDE 0884 is a test option.

Applications
- Interfacing Computer Terminals to Peripheral Equipment
- Digital Control of Power Supplies
- Line Receiver — Eliminates Noise
- Digital Control of Motors and Other Servo Machine Applications
- Logic to Logic Isolator
- Logic Level Shifter — Couples TTL to CMOS

MAXIMUM RATINGS ($T_A = 25^\circ C$ unless otherwise noted)
### H11L1 H11L2

**ELECTRICAL CHARACTERISTICS** ($T_A = 25^\circ C$ unless otherwise noted)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUT LED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse Leakage Current ($V_R = 3 \text{ V}, R_L = 1 \text{ M}\Omega$)</td>
<td>$I_R$</td>
<td>0.05</td>
<td>10</td>
<td></td>
<td>$\mu\text{A}$</td>
</tr>
<tr>
<td>Forward Voltage ($I_F = 10 \text{ mA}$)</td>
<td>$V_F$</td>
<td>1.2</td>
<td>1.5</td>
<td></td>
<td>Volts</td>
</tr>
<tr>
<td>($I_F = 0.3 \text{ mA}$)</td>
<td></td>
<td>0.75</td>
<td>0.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitance ($V_R = 0 \text{ V}, f = 1 \text{ MHz}$)</td>
<td>$C$</td>
<td>18</td>
<td>18</td>
<td></td>
<td>pF</td>
</tr>
<tr>
<td><strong>OUTPUT DETECTOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>$V_{CC}$</td>
<td>3</td>
<td></td>
<td>15</td>
<td>Volts</td>
</tr>
<tr>
<td>Supply Current ($I_F = 0, V_{CC} = 5 \text{ V}$)</td>
<td>$I_{CC(\text{off})}$</td>
<td>1</td>
<td>5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Output Current, High ($I_F = 0, V_{CC} = V_O = 15 \text{ V}$)</td>
<td>$I_{OH}$</td>
<td>—</td>
<td>100</td>
<td></td>
<td>$\mu\text{A}$</td>
</tr>
<tr>
<td><strong>COUPLED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply Current ($I_F = I_{F(\text{on})}, V_{CC} = 5 \text{ V}$)</td>
<td>$I_{CC(\text{on})}$</td>
<td>1.6</td>
<td>5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>Output Voltage, Low ($R_L = 270 \text{ \Omega}, V_{CC} = 5 \text{ V}, I_F = I_{F(\text{on})}$)</td>
<td>$V_{OL}$</td>
<td>0.2</td>
<td>0.4</td>
<td></td>
<td>Volts</td>
</tr>
<tr>
<td>Threshold Current, ON ($R_L = 270 \text{ \Omega}, V_{CC} = 5 \text{ V}$)</td>
<td>H11L1</td>
<td>1.2</td>
<td>1.6</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>(H11L2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold Current, OFF ($R_L = 270 \text{ \Omega}, V_{CC} = 5 \text{ V}$)</td>
<td>H11L1</td>
<td>0.3</td>
<td>0.75</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>(H11L2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hysteresis Ratio ($R_L = 270 \text{ \Omega}, V_{CC} = 5 \text{ V}$)</td>
<td>$I_{F(\text{off})}$</td>
<td>0.5</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$I_{F(\text{on})}$</td>
<td>0.5</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolation Voltage&lt;sup&gt;(2)&lt;/sup&gt; 60 Hz, AC Peak, 1 second, $T_A = 25^\circ C$</td>
<td>$V_{ISO}$</td>
<td>7500</td>
<td>—</td>
<td>—</td>
<td>Vac(pk)</td>
</tr>
<tr>
<td>Turn–On Time</td>
<td>$t_{on}$</td>
<td>1.2</td>
<td>4</td>
<td></td>
<td>$\mu\text{s}$</td>
</tr>
<tr>
<td>Fall Time</td>
<td>$t_f$</td>
<td>0.1</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn–Off Time</td>
<td>$t_{off}$</td>
<td>1.2</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rise Time</td>
<td>$t_r$</td>
<td>0.1</td>
<td>—</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Always design to the specified minimum/maximum electrical limits (where applicable).
2. For this test, IRED Pins 1 and 2 are common and Output Gate Pins 4, 5, 6 are common.
3. $R_L$ value effect on switching time is negligible.
Create a design to connect

- Uno32
- PS2501 Opto-Isolator
- L-298 H-Bridge

3.3V

GALVANIC ISOLATION
Questions?
Timers and Analog to Digital Conversion: Tick tock tick tock...

Gabriel Hugh Elkaim
The world

- HD2
- I/O Pins
- Comm

Actuators

CMPE 118/218 – Intro. to Mechatronics
Timers

Counter

Stream of 1's at ports

Timer

Counter which is driven by a fixed time base
controller - medium complexity  \[
\begin{align*}
5 & \text{ 16 bit units} \\
253 & \text{ 32 bits} \\
485 & \text{ 32 bits}
\end{align*}
\]

Dedicated chips (SPI)

RTCC - 1 ppm/year

GPS - $\sqrt{2}$ PPS 1 ppm/year
Catalyst size: $\frac{8}{16}$, 0 - 25°C, 0 - 65h, 3L, 0 - 4 Billion.

Cock pulse: FCY, Announced mistaken.

TMRx: 0.1 ppm, TCXO.
Figure 16-1: Output Compare Module Block Diagram

Output Logic

Set Flag bit OCxF(1)

OCxRS(1)
OCxR(1)
Comparator

TMR register inputs from time bases(3)
Period match signals from time bases(3)

OCSEL

OCxF(1)
OCxA or OCxF(2)
Output Enable

OCSEL

16
16
3

Mode Select

OCM~2:0~
Gated timer indicator
$f = \frac{1}{\text{Period}}$

Duty Cycle = \frac{\text{Duty}}{\text{Period}} \times 100$

0 - 99.9\%
Period path

Interrupt
FPB = \( \frac{F \cdot \Delta y}{2} = \frac{80 \times 10^6}{2} = 40 \times 10^6 \)

dT = curr - prev

\( \Delta y = \frac{1}{32} \text{ inch} \approx 0.03125 \text{ inch} \approx 0.8064 \text{ mm} \)
Pulse-Drive Mode

\[ I \text{ vs } t \]

Left Edge Aligned

Center Aligned (DCDC)
ADC conversion

Figure 17-1: 10-bit High-Speed ADC Block Diagram

Note 1: VREF+ and VREF- inputs can be multiplexed with other analog inputs.

Successive approximation register.
Single slope ADC.

Double slope ADC.
S.R. 3.3

78 kHz

V_in

CMPE 118/218 – Intro. to Mechatronics
\[ Y = \frac{1}{2} u(150) \text{ADOS} \]

\[ \text{Delay} = \frac{1}{2} \text{ST} \]

\[ \text{Slope} \frac{1}{\text{ST}} \] expected slope
CLAUDE SHANNON

NYQUIST \(-\frac{3\pi}{2}\)

ANTI-ALIASING FILTER

\[ \frac{\theta_0}{2} \]
Figure 19.1: Comparator Block Diagram

Comparator 1

Comparator 2

Note 1: On devices with a USB module, and when the module is enabled, this pin is controlled by the USB module, and therefore, is not available as a comparator input.

Note 2: Internally connected.
Comparator Voltage Reference

Figure 20.1: Comparator Voltage Reference Block Diagram

Note 1: These bits are not available on all devices. On such devices, CVREF is generated by the resistor network and IVREF is connected to 1.2V. Refer to the specific device data sheet for availability.
Offset error of a Linear 3-Bit Natural Binary Code Converter (Specified at Step 000)

(a) ADC

(b) DAC

Digital Output Code

Analog Output Value (LSB)

Nominal Offset Point

Offset Error (+1 1/4 LSB)

Ideal Diagram

Actual Diagram

Actual Offset Point

Analog Input Value

Offset Error (+1 1/4 LSB)

Digital Input Code

Nominal Offset Point

0 0 0

0 0 1

0 1 0

0 1 1

0 1 1

1 0 0

1 0 1

1 1 0

1 1 1
Gain Error of a Linear 3-Bit Natural Binary Code Converter (Specified at Step 111), After Correction of the Offset Error
End-Point Linearity Error of a Linear 3-Bit Natural Binary-Coded ADC or DAC (Offset Error and Gain Error are Adjusted to the Value Zero)
Differential Linearity Error of a Linear ADC or DAC
Absolute Accuracy or Total Error of a Linear ADC or DAC

(a) ADC

Digital Output Code

0...111
0...110
0...101
0...100
0...011
0...010
0...001
0...000

Analog Input Value (LSB)

0
1
2
3
4
5
6
7

Total Error
At Step 0...101
(±1 1/4 LSB)

Total Error
At Step 0...001 (1/2 LSB)

(b) DAC

Digital Input Code

0
0
1
0
1
1
1
1

Analog Output Value

0
1
2
3
4
5
6
7

Total Error
At Step 0...011
(1 1/4 LSB)
Questions?