EECS192 Lecture 3  
Jan. 30, 2018

Notes:
• Handouts: lab rules
• 2/2 project proposal – upload to bcourses by Fri 5 pm
• 2/10: Motor drive/stall, steering servo
• Quiz 1: motor behavior Tues 2/6 (See Motor Worksheet week 2)
• CalDay Sat April 4/21

Topics
• MCUXpresso hint: timing using systime or PIT cval0
• Motor electrical model conclusion
  – Motor electromechanical behavior
• Driving MOSFETs and motor
  – Op amp TLC084
  – MC33883 MOSFET driver
  – H bridge
• PWM issues for motor
• (Back EMF measurement)
Timing from MCUXpresso Tools

- Global Systime (every 100 us)
- Periodic Interrupt Timer PIT-CVAL0 (count down)
- internal module clock frequency (60 MHz)

Step over
Timing from MCUXpresso Tools

~38 clocks for sqrt (hardware floating point) ~0.6 us
~1689 clocks for cos() ~28 us
/* Set timer period for channel 0 */
PIT_SetTimerPeriod(PIT, kPIT_Chnl_0, USEC_TO_COUNT(100U, PIT_SOURCE_CLOCK));
// 100 us timing
    /* Enable timer interrupts for channel 0 */
PIT_EnableInterrupts(PIT, kPIT_Chnl_0, kPIT_TimerInterruptEnable);
    /* Enable at the NVIC */
EnableIRQ(PIT_IRQ_ID);

void PIT0_IRQHandler(void)
{
    systime++; /* hopefully atomic operation */
    PIT_ClearStatusFlags(PIT, kPIT_Chnl_0, kPIT_TimerFlag);
    /* Clear interrupt flag. */
    pitIsrFlag = true;
}
Clock Choice for K64 CPU

- CPU and system clocks = 100 MHz
- Bus clock = 50 MHz
- FlexBus clock = 50 MHz
- Flash clock = 25 MHz

Example to choose clock frequency

```c
#define FTM_SOURCE_CLOCK CLOCK_GetFreq(kCLOCK_BusClk)
```

```
kCLOCK_CoreSysClk,    /*!< Core/system clock    */
kCLOCK_PlatClk,       /*!< Platform clock       */
kCLOCK_BusClk,        /*!< Bus clock            */
kCLOCK_FlexBusClk,    /*!< FlexBus clock        */
kCLOCK_FlashClk,      /*!< Flash clock          */
```
DC Motor Physical Model-review

\[ \vec{F} = i l \times \vec{B} \]

\[ \tau = \vec{r}_1 \times \vec{F}_1 + \vec{r}_2 \times \vec{F}_2 \]
Motor Electrical Model

Also- see motor worksheet……

Note: missing e-stop!
For this problem, consider a DC permanent magnet motor (as used in your car). The car is on a carpet and moves in a straight line with no slip between the wheels and the carpet. The car is initially moving at a speed of 2 meters per second.

You can assume a motor model as shown below. The qualitative shape of the curves is more important than magnitudes.

[4 pts.]  a) Consider the motor driven from a voltage source with voltage $v(t)$, as shown. Sketch car velocity $\dot{x}(t)$ and motor terminal current for the time indicated.

Let peak speed = 5 m/sec  
Accel = 5 m/s²  
k_e = 1 v/(m/sec)  
On board

(for answer see sp99 final solution)
Given: Rm = 0.1 ohms, Vbatt = 7.2 V, Rbat = 0.
Vds = ? \implies \text{Ids} = ? \text{amps}

Driving MOSFETs and motor

MOSFETs and motor drive

(LiPo 11 V!)

\(V_{GS} = 20\text{V}\)

Vgs = 20V
Ptrans \sim 35 \text{ W}

Vgs = 6V
Ptrans \sim 72 \text{ W}
Driving MOSFETs and motor

\[ R_m = 0.1 \text{ ohms}, \ V_{batt} = 7.2 \text{ V}, \ R_{bat} = 0. \]

\[ V_{ds} = 3.6 \text{ V} \Rightarrow I_{ds} = \frac{(7.2 - 3.6) \text{ V}}{0.1 \text{ ohm}} = 36 \text{ amps} \]

\[ V_{gs} = 20 \text{ V} \]

\[ P_{trans} \approx 35 \text{ W} \]

\[ V_{gs} = 6 \text{ V} \]

\[ P_{trans} \approx 72 \text{ W} \]

Key design points:
1) High \( V_{gs} \) better than low \( V_{gs} \)
2) Switch quickly
3) Make sure \( V_s = 0 \) (big ground)
Motor Drive Quick and Dirty w/ Op Amp

Details On board….

TLC084 or TLC074 quad op amp

Checklist:
1) Emergency stop
2) Reset Protection
3) Snubbing
Driving MOSFETs and motor

Motor Drive Quick and Dirty w/ Op Amp

- IRFB3006: $C_{GS} = 9000$ pF
- TL084: 50 mA
- $i = C \frac{dV}{dt}$
- $\frac{dV}{dt} = \frac{i}{C} \sim 5$ V/ usec $\Rightarrow$ 2us on + 2us off, PWM $< 100$ us period
- TL084 slew rate: 10 V/usec $\Rightarrow$ exceed current limit
- Series resistor on output of op amp of 200 ohms, limits current to 50 mA ($10V/200$ ohms = 50 mA)
**Driving MOSFETs and motor**

**How to choose PWM frequency?**

### IRFB 3006 Power MOSFET

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_{fs}$</td>
<td>Forward Transconductance</td>
<td>280</td>
<td>---</td>
<td>---</td>
<td>S</td>
<td>$V_{DS} = 25, V$, $I_D = 170, A$</td>
</tr>
<tr>
<td>$Q_g$</td>
<td>Total Gate Charge</td>
<td></td>
<td>200</td>
<td>300</td>
<td>nC</td>
<td>$I_D = 170, A$, $V_{DS} = 30, V$</td>
</tr>
<tr>
<td>$Q_{gs}$</td>
<td>Gate-to-Source Charge</td>
<td></td>
<td>37</td>
<td></td>
<td></td>
<td>$V_{GS} = 10, V$</td>
</tr>
<tr>
<td>$Q_{gd}$</td>
<td>Gate-to-Drain (”Miller”) Charge</td>
<td></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{syn}$</td>
<td>Total Gate Charge Sync. ($Q_g - Q_{gd}$)</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
<td>$I_D = 170, A$, $V_{DS} = 0, V$, $V_{GS} = 10, V$</td>
</tr>
<tr>
<td>$t_{d(on)}$</td>
<td>Turn-On Delay Time</td>
<td>16</td>
<td></td>
<td></td>
<td>ns</td>
<td>$V_{DS} = 39, V$</td>
</tr>
<tr>
<td>$t_r$</td>
<td>Rise Time</td>
<td>182</td>
<td></td>
<td></td>
<td></td>
<td>$I_D = 170, A$</td>
</tr>
<tr>
<td>$t_{off}$</td>
<td>Turn-Off Delay Time</td>
<td>118</td>
<td></td>
<td></td>
<td></td>
<td>$R_G = 2.7, \Omega$</td>
</tr>
<tr>
<td>$t_f$</td>
<td>Fall Time</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
<td>$V_{CSL} = 10, V$</td>
</tr>
<tr>
<td>$C_{iss}$</td>
<td>Input Capacitance</td>
<td>8970</td>
<td></td>
<td></td>
<td>pF</td>
<td>$V_{GS} = 0, V$</td>
</tr>
</tbody>
</table>

### TLC084 Op amp (same pinout as TL974)

<table>
<thead>
<tr>
<th>$V_{OH}$</th>
<th>High-level output voltage</th>
<th>$V_{IC} = 2.5, V$</th>
<th>$I_{OH} = -1, mA$</th>
<th>$I_{OH} = -20, mA$</th>
<th>$I_{OH} = -35, mA$</th>
<th>$I_{OH} = -50, mA$</th>
<th>$V$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>25°C</td>
<td>25°C</td>
<td>25°C</td>
<td>25°C</td>
<td>Full range</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.1</td>
<td>3.7</td>
<td>3.4</td>
<td>3.2</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.3</td>
<td>4</td>
<td>3.8</td>
<td>3.6</td>
<td>3</td>
</tr>
<tr>
<td>$V_{OL}$</td>
<td>Low-level output voltage</td>
<td>$V_{IC} = 2.5, V$</td>
<td>$I_{OL} = 1, mA$</td>
<td>$I_{OL} = 20, mA$</td>
<td>$I_{OL} = 35, mA$</td>
<td>$I_{OL} = 50, mA$</td>
<td>$V$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25°C</td>
<td>25°C</td>
<td>25°C</td>
<td>25°C</td>
<td>Full range</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
<td>0.35</td>
<td>0.43</td>
<td>0.45</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
<td>0.39</td>
<td>0.55</td>
<td>0.7</td>
<td>0.45</td>
</tr>
<tr>
<td>$I_{OS}$</td>
<td>Short-circuit output current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25°C</td>
<td>25°C</td>
<td>25°C</td>
<td>25°C</td>
<td>100</td>
</tr>
<tr>
<td>$I_O$</td>
<td>Output current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>$V_{OH} = 1.5, V$ from positive rail</td>
<td>25°C</td>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_{OL} = 0.5, V$ from negative rail</td>
<td>25°C</td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How to choose PWM frequency (if using op amp)?

(9000 pF on board)
Driving MOSFETs and motors

**H-Bridge Gate Driver IC**

The 33883 is an H-bridge gate driver (also known as a full-bridge pre-driver) IC with integrated charge pump and independent high and low side gate driver channels. The gate driver channels are independently controlled by four separate input pins, thus allowing the device to be optionally configured as two independent high side gate drivers and two independent low side gate drivers. The low side channels are referenced to ground. The high side channels are floating.

The gate driver outputs can source and sink up to 1.0 A peak current pulses, permitting large gate-charge MOSFETs to be driven and/or high pulse-width modulation (PWM) frequencies to be utilized. A linear regulator is incorporated, providing a 15 V typical gate supply to the low side gate drivers.

This device powered by SMARTMOS technology.

**Features**

- $V_{CC}$ operating voltage range from 5.5 V up to 55 V
- $V_{CC2}$ operating voltage range from 5.5 V up to 28 V
- CMOS/LSTTL compatible I/O
- 1.0 A peak gate driver current
- Built-in high side charge pump
- Under-voltage lockout (UVLO)
- Over-voltage lockout (OVLO)
- Global enable with <10 μA Sleep mode
- Supports PWM up to 100 kHz

**ORDERING INFORMATION**

<table>
<thead>
<tr>
<th>Device</th>
<th>Temperature Range ($T_A$)</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC33883HEG</td>
<td>-40 °C to 125 °C</td>
<td>20 SOICW</td>
</tr>
</tbody>
</table>

**Figure 1. 33883 Simplified Application Diagram**
MC3383 + H bridge

!!!CAUTION!!!!
Software fries hardware....
Need protection logic- 74HCxxx
Estop?

Figure 14. Application Schematic with External Protection Circuit

Driving MOSFETs and motor
Driving MOSFETs and motor

MC3383 protection

Figure 12. Gate Protection and Flyback Voltage Clamp

Caution: don’t run motor current through here
PWM Issues for Motor

https://github.com/ucb-ee192/SkeletonMCUX/tree/master/frdmk64f_pwm

FTM_UpdatePwmDutycycle
(BOARD_FTM_BASEADDR, BOARD_FTM_CHANNEL,
kFTM_CenterAlignedPwm, updated_duty_cycle);

Figure 40-21. CPWM period and pulse width with ELSnB:ELSnA = 1:0
PWM for Main Motor control

\[ <i_m> = \left( \frac{T}{T_0} \right) i_{\text{max}} \]

Is \( i_{\text{max}} \) constant?
Extra Slides
peripherals

**Bus_clock.outFreq**, value: 60 MHz

Figure 5-1. Clocking diagram

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Note: See subsequent sections for details on where these clocks are used.