Relays

- Common embedded system problem
  - digital control: relatively small I & V levels
  - controlled device requires significantly higher power
- Solution
  - amplify the control power
  - use the control signal to activate a switch
    » switch turns on/off bigger power source
- Electrically controlled switches
  - transistor
    » can be used as a switch but it's really an amplifier since it has gain
    » MOS – voltage controlled, BIPOLAR – current controlled
  - relay
    » control induces magnetic field in coil
    » magnetic field moves a mechanical switch
    » bounce problem?
      - usually not a concern for outputs to non-digital gizmos like motors

Poles and Throws

- Terminology used for switches
  - relay is just an electrically controlled switch
    » pole – controlled
    » throw – contact point
    » relay difference – magnetic movement of pole
      » difference in where the switch is when switch/magnet is off
      » often state usually controlled by a spring

Relay Types

- Basic issue is size
  - control power
    » reed relays – smallish power
      » common in ES designs
    » general purpose – large-ish power
      » you have lots of them in your car
Solid State Relays

- Improvement on mechanical relay problems
  - contact bounce and arcing limit lifetime
  - sensitive to vibrations, EMI issues
  -slow movement of large mechanical pole

Optocoupler
- provides electrical isolation between input (pseudocoil) and output triac (pseudocointact)
  - particularly important in driving large inductive loads
  - zero-voltage detector triggers triac
    - reduces surge currents when triac is switched
    - once triggered
      - triac conducts until next zero crossing

Reed Relays

Solenoids
Interfacing to Inductive Loads

- Interface circuit
  - must provide sufficient current and voltage to activate the device
    - "common error"
      - "my microcontroller puts out 5v but at the device it's only 200 mV"
      - what's the problem?

- Ohm's law
  - current, impedance and voltage are related
  - microcontroller can't provide enough current so voltage is similarly low

- In off state current should be zero
  - BEWARE
    - large L → huge back EMF when coil is turned off
    - fast digital switch causes large di/dt
    - 50 – 200V back is common
    - It will destroy your controller
      - isolation or buffering is required
        - optocoupler
        - or zener diode
        - etc.

Relay Control Examples

Relay & Motor Interfaces
IRF 540 Power Transistor

**Symbol**

<table>
<thead>
<tr>
<th>QUICK REFERENCE DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{GS}$ = 100 V</td>
</tr>
<tr>
<td>$I_{DSS}$ = 20 A</td>
</tr>
<tr>
<td>$R_{DS(on)}$ = 77 mΩ</td>
</tr>
</tbody>
</table>

**Pinning**

<table>
<thead>
<tr>
<th>PIN</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>gate</td>
</tr>
<tr>
<td>2</td>
<td>drain</td>
</tr>
<tr>
<td>3</td>
<td>source</td>
</tr>
<tr>
<td>4</td>
<td>drain</td>
</tr>
</tbody>
</table>

SOT78 (TO220AB)

Isolated Interfaces

- 5 mA in $\Rightarrow$ 1 A out
- 2000% current transfer ratio
- 5V logic compatible (TTL, CMOS)

Split Darlington photodetector

Typical H-Bridge Motor Control

Isolated H-Bridge w/ Direction Control
**Stepper Motors**

- Popular due to inherent digital interface
  - easy to control both position and velocity in an open-loop fashion
- more expensive than simple DC motor
  - still not too bad since may not require feedback sensors
- can be used as shaft encoders
  - measure both position and speed

**Stepper Motor Basics**

- **Stator**
  - stationary frame with electromagnet poles
- **Rotor**
  - teeth are permanent magnets alternating south and north pole teeth

\[
\frac{360 \text{ degrees}}{4 \text{ poles} \times 5 \text{ teeth}} = 18 \text{ degrees per step}
\]

**2 Phase Operation**

- stable state
- reverse phase 1 polarity – unstable state – closest stable state?
2 Phase Operation

next stable state

reverse polarity of phase 2 and movement continues

Continue by Reversing Phase 1

Simple Interface

note this motor has 200 steps – hence 1.8 degrees
Port B output is (10, 9, 5, 6)*
reverse direction? (6, 5, 9, 10)*
Slip & Torque Issues

- **Slip**
  - command issued but motor doesn't move
  - causes
    - motor torque insufficient to drive mechanical load
    - or if computer change is too fast
  - magnetic field is too weak

- **IF no slip can be guaranteed**
  - then computer knows the shaft position
  - and doesn't need a sensor

Stepper Motor Sequence

Control Data Structures (FSM)

```c
const struct State{
  unsigned char Out;  // Output
  const struct State *Next[2]; // CW/CCW
};
typedef struct State StateType;
typedef StateType *StatePtr;
#define clockwise 0  // Next index
#define counterclockwise 1  // Next index
StateType fsm[4] = {
  {0,(fsm[1],fsm[3])},
  {2,(fsm[2],fsm[0])},
  {5,(fsm[3],fsm[1])},
  {6,(fsm[0],fsm[2])}};
unsigned char Pos;  // between 0 and 199
StatePtr Pt;  // Current State
```

Init Ritual

```c
void Init(void){
  Pos = 0;
  Pt = &fsm[0];
  DDRB = 0xFF;
}
```
### Helper Functions

```c
void CW(void){
    Pt = Pt->Next[clockwise]; // circular
    PORTB = Pt->Out;         // step motor
    if(Pos==199){            // shaft angle
        Pos = 0;             // reset
    }else{
        Pos++;}            // CW
}
void CCW(void){
    Pt = Pt->Next[counterclockwise];
    PORTB = Pt->Out; // step motor
    if(Pos==0){        // shaft angle
        Pos = 199;     // reset
    }else{
        Pos--;}        // CCW
}
```

### High Level Control

```c
void Seek(unsigned char desired){
    short CWsteps;
    if((CWsteps=desired-Po)<0){
        CWsteps+=200;
    } // CW steps is 0 to 199
    if(CWstep>199){
        while(desired!=Pos){
            CW();
        }
    }else{
        while(desired!=Pos){
            CW();
        }
    }
}
```

### Concluding Remarks

- **Lots of types of electrical motors**
  - stepper & DC are most common in inexpensive ES's
- **Beware when driving inductive loads**
  - back EMF has to be controlled
  - snub diode is cheap
  - optical isolation is even more secure
- **5780 students**
  - lab 9 will get you provide an Introduction
  - stepper motor kits available for checkout