Western Washington University
Electronics Engineering Technology

Etec 474
Professor Morton
Senior Project Hardware Description

Relay Controller
“The Automator”
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4/29/03
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INTRODUCTION

The Relay Controller is a self-monitoring, programmable timer/controller capable of independently turning on eight relays at specific times during the day. A simple user interface is used to program up to twelve activation periods for each relay in a 24-hour period. Each activation period is defined by its start and end times. Each of the relays are also controlled by eight corresponding emergency shutoff inputs and external trigger inputs. When a relay is activated, it supplies 12VDC to a device. Both the Relay Controller and the connected devices get their power from a 12VDC battery bank. Figure 1 shows the front view of the chassis.

![Figure 1: Front view of the Relay Controller](image)

CHASSIS

All of the hardware is mounted in a single aluminum enclosure with these dimensions: W=8 1/2” L=7 3/4” H=6 7/8”. The large size allows ample room for the internal circuitry and for all the external connectors. It also allows for future additions to the system. A three-dimensional view of the chassis can be seen in Figure 2.
The enclosure has a connector to input 12VDC to the system. It also has connectors to attach load devices to the relays, and to connect emergency shutoff signals and external trigger signals. User interface devices such as the LCD (liquid crystal display), pushbuttons, scroll wheel, and indicator LEDs will be mounted on the chassis.

Figure 2: Chassis Dimensions

**HARDWARE OVERVIEW**

The Relay Controller is composed of two circuit boards. One is used for the microcontroller and the user interface components (controller circuit board), and the other is used for the relays (relay circuit board).

The system is controlled by the MC9S12DP256B microcontroller (9S12). The microcontroller is used to interface with the user and to control the relays. The major peripheral hardware includes a 4 X 20 LCD, a rotary encoder, 2 pushbuttons, a high accuracy 16MHz crystal, and 16 LEDs (light-emitting diodes). Figure 3 shows the block diagram for this system.
Figure 3: Block Diagram of the Relay Controller

We will now look at the hardware in more detail with reference to the relay circuit board schematic, the controller circuit board schematic, and the system schematic.

POWER SUPPLY

The power is supplied by a bank of 12V lead acid batteries with a total amp-hour rating of 12.8AH. The voltage from the batteries is fed directly to both of the circuit boards. On the controller circuit board, the 12V line is soldered directly to the battery pad (W1). On the relay circuit board, the 12V line is connected to the battery connector (J3).

The devices connected to the relays are powered directly from the battery bank. The battery voltage is also used to activate the relay coils.
Before sourcing power to the digital parts on the controller circuit board, the 12V battery source is converted to 5V through an LM2576 (U3) step-down switching regulator. This regulator is capable of sourcing up to 3A, which is more than enough for the worst case current draw of 1.75A. As seen on the relay control board schematic, C3 is used to stabilize the battery voltage to the input of the regulator. D1 and L1 are used by the switching regulator for switching action, and C4 is used to smooth out the ripple of the 5V output.

Since the system is composed of both analog and digital components, there are separate ground planes for analog and digital parts. This helps to reduce analog noise from entering the digital components. Both of the ground planes are connected together at a point physically close to the battery input (W1).

For further stability, all of the ICs have 0.1uF capacitors placed close to their supply pins to reduce the effects of switching noise.

The system is designed to be always on, so there is no need for a power switch.

**MICROCONTROLLER and SUPPORTING CIRCUITRY**

**Microcontroller**

The Relay Controller is based on the Motorola MC9S12DP256B microcontroller configured to operate in standalone mode. The 9S12 has 12 Kbytes of RAM that will store temporary variables, 4 Kbytes of EEPROM that will store the start/stop times, and 256 Kbytes of Flash EEPROM that will store the program code.

Ports A, K, H, B, T, and AD are used for general purpose I/O. Port P is used for PWM (pulse width modulation). All unused pins are left floating. Unused pins on Ports J, K, B, H, and PWM are configured as outputs. Unused pins on Port E are configured as inputs with internal
pull-up resistors enabled. Pins VREGEN and VRH are tied high. Pins TEST and VRL are tied low.

**Reset Circuitry**

The /RESET pin is an active low signal. R13 ties the reset signal high until it is pulled low by either the MC34064 low voltage reset IC (U2) or the BDM connector (J2). The MC34064 resets the 9S12 when the system voltage drops below 4.59V (typically). This ensures that the 9S12 is operating above the minimum operating voltage of 4.5V.

**Crystal Circuitry**

The crystal (X1) operates at a frequency of 16MHz with an accuracy of 30PPM. This accuracy is needed for the real time clock implemented in software. The crystal, C7 and C8 provide the oscillator circuit which is connected to the EXTAL and XTAL pins.

**PLL Circuit**

The PLL (phase locked loop) circuit is used to obtain clock speeds faster than 8MHz when using a 16MHz crystal. I have configured the 9S12 to run at 24MHz.

**BDM**

J2 is a 12 pin connector that brings out the necessary lines for the BDM pod such as the BDM, RESET, VCC, and GND, as well as the ECLK, MODA, and MODB lines. All of these signals are made available to allow for future upgrades to the system.

**USER INTERFACE**

**Pushbuttons**

Two pushbuttons are used in this system. S1 is used for the cancel button and is connected to PB0. S2 is used for the enter button and is connected to PB1. These switches are
SPST (single-pole, single-throw) and are connected in a normally open configuration. The outputs of the switches are tied high, so when a switch is pressed, an active low signal is sent to the 9S12.

The switches are mounted on the chassis and are soldered to the button pad (W2) on the controller circuit board.

**Rotary Encoder**

A rotary encoder (S3) with 24 detents is used as a scroll wheel to scroll between options on the LCD. The rotary encoder has two outputs; A and B, which are both active low. Channel A is connected to PB3 and channel B is connected to PB2. Clockwise rotation causes channel A to output an active low signal that leads channel B by 90 degrees. Counter clockwise rotation causes channel B to output an active low signal that leads by 90 degrees.

The rotary encoder is also mounted on the chassis and is soldered to the button pad (W2) on the controller circuit board.

**LCD**

The LCD module (LCD1) is a 4 x 20 character display with a backlight. It is connected to the 9S12 by eight bi-directional address/data lines connected to Port A, and three control lines connected to bits 0-3 of Port K. The module is powered by 5V and the ground is connected to DGND.

The contrast of the LCD is set by the voltage divider network consisting of resistors R5 and R6. The electroluminescent backlight is controlled by PH0 on the 9S12. The active high signal from PH0 is used to turn on an NPN transistor (T1) which in turn supplies power to a power inverter (U8). The power inverter supplies 100VAC to the backlight. The ground for the backlight is AGND.
In case T1 burns out, there is a current limiting resistor (R7) between PH0 and the base of the transistor.

The LCD is mounted on the chassis and all 16 lines of the LCD are soldered to the relay control board on the LCD pad.

**LEDs**

There are eight red LEDs (LED9-16) which correspond to the eight emergency shutoff inputs. A red LED will light up when the corresponding emergency shutoff input is activated. These LEDs are mounted on the chassis and are wired to the relay control board at the red LED pad (W4).

There are also eight green LEDs (LED1-8) which correspond to the eight relays. A green LED will light up when the corresponding relay is activated. These LEDs are also mounted on the chassis and wired to the relay control board at the green LED pad (W3).

All of these LEDs are controlled by an octal buffer/driver with enable (74HCT244N). The red LEDs are controlled by U5, and the green LEDs are controlled by U4. The enable line is active low and is connected to an active low PWM signal on PWM0 of the 9S12. The PWM is used to control the intensity of the LEDs.

**EXTERNAL INPUT SIGNALS**

**External Trigger Inputs**

There are eight external trigger inputs which correspond to the eight relays. When an external trigger input is activated, and the system is in either the trigger or combo mode, the corresponding relay is turned on. To protect the 9S12 from the input signals, a 74HCT244N (U7) is used as a buffer. The enable pins of U7 are active low and are tied low.
The user can connect any TTL level signal to pins 1 and 2 of the multi-signal Molex connectors (J6-J13). These connectors are mounted on the chassis and are wired to the controller circuit board at the external trigger input pad (W6).

**Emergency Shutoff Inputs**

There are eight emergency shutoff inputs which correspond to the eight relays. When an emergency shutoff input is activated, the corresponding relay is turned off. These inputs override all other signals that turn the relays on. To protect the 9S12 from the input signals, a 74HCT244N (U6) is used as a buffer. The enable pins of U6 are active low and are tied low.

The user can connect any TTL level signal to pins 3 and 4 of the multi-signal Molex connectors (J6-J13). These connectors are mounted on the chassis and are wired to the controller circuit board at the emergency shutoff input pad (W5).

**RELAY CIRCUITRY**

All of the connections to the relay circuit board are made with connectors so that the user can easily replace the relay board with relays that have higher current carrying capabilities.

Eight relays (RELAY1-8) are individually triggered by the eight bits of Port T. Since the coil resistance is 27 ohms, connecting the relay coils directly to Port T of the 9S12 would require a current draw of nearly 190mA. This of course exceeds the maximum current sourcing capabilities of the port, so transistors (T2-T9) on the controller circuit board are used to provide enough current to activate the relays.

Current limiting resistors (R30-37) are placed between the 9S12 and the base of the transistors in case a transistor burns out and shorts the base to ground. The emitter and collector of these transistors are brought out to the relay board connector (J1). This is done so that the
transistor collectors can be connected to the relay coils which can then be connected to the 12V supply. This is better than connecting the collectors to the 5V supply because it would place a heavy load on the 5V regulator.

Each relay coil has a diode (D2-9) wired in parallel to protect each transistor from the flyback current of the relay coils. These diodes are rated for 400V at 1A.

J4 on the relay circuit board connects the relays to J1 on the controller circuit board. When the relays are activated they connect the load devices to the 12V supply. The 12V sources supplied by the relays are brought out to the device connector (J5). From there, the 12V source is brought out to pins 5 and 6 of the Molex connectors that are mounted on the chassis.
Figure 4: Memory Map of the 9S12DP256B (normal single chip mode is used)
source: Motorola user guide, 9S12DP256BDGV2.pdf
## PARTS LIST

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<thead>
<tr>
<th>Item</th>
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<td>Capacitor - ceramic 10% 330pF</td>
<td>C9</td>
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<td>C6, C18</td>
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<td>1</td>
<td>Capacitor - electrolytic 10% 100uF</td>
<td>C3</td>
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<td>2</td>
<td>Resistor - 15K Ohm, 1%</td>
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<td>Resistor - 10.2K Ohm, 1%</td>
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<td>Resistor - 226 Ohm, 1%</td>
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<td>Resistor - 10K Ohm, 1%</td>
<td>R8 - R11, R13</td>
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<td>Voltage regulator, step-down, switching, 5V, 3A, LM2576</td>
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*Figure 5: Parts List*