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Design Microwave Oven Using S08PT Family

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Contents

1 Introduction

Safety design consideration is one of the key factors to protect a system in abnormal operating conditions and eliminate any incidental injury for the end-user. This application note describes how to use S08PT family MCU in applications with emphasis on the safety aspect. Different techniques in circuit design, intelligent software control, and reliable mechanical structure are illustrated in this application note to show how to achieve a product design with protection features for handling faults in extreme conditions. Most of the critical scenario and unexpected use cases from the end-user point of view must be fully studied and well-covered in advance to prevent any serious flaw persisting in final design stage which causes significant delay in the whole project schedule.

2 System overview

A completed microwave oven reference design using the MC9S08PT60 MCU is developed as a quick-start solution for the customers working on similar product design with safety requirements. The documents, *AN4476: System Design Guideline for 5V 8-bit families in Home Appliance Applications*, and *AN4463: How to Develop a Robust Software in Noise Environment*, available on **freescale.com**, provide detail descriptions on EMC design considerations. This application note focuses only on hardware, firmware, and mechanical design techniques for safety enhancement.

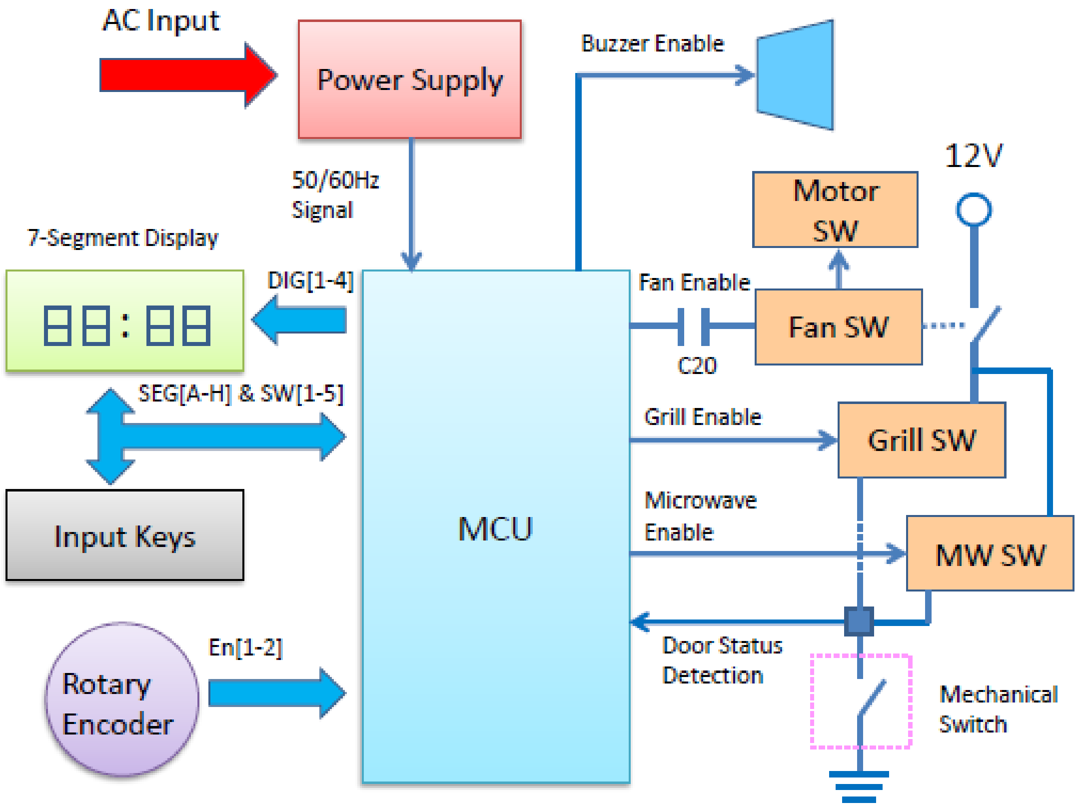

Figure 1. System block diagram

The microwave oven system block diagram is shown in Figure 1. The AC power line voltage is converted down and regulated to 12 V and 5 V in the power supply module. All power relay switches are controlled by 12 V driving circuits but the power stage high currents are drawn from AC power line input directly. The 5 V supply is the main supply for the whole system including MCU, I/O, display and rotary encoder. However, the buzzer circuit is driven by 12 V.

The MC9S08PT60 MCU is used for all signal detections on user interface, power stage controls with sequential order and system protection in fault conditions. In normal operation, an event triggered by the end-user through input keys or rotary encoder is decoded in MCU and the corresponding message or system status is shown in the 7-segment display as confirmation or indication. The control scheme for power stages must be able to turn on or off high-power devices with limited voltage stress on the power line. The status of the oven door, open or close is monitored periodically as one of the error signals for system protection. A mechanical switch is used as a reliable method to cut off the ground connection for grill and microwave power stages when the oven door is open. Different sound patterns generated from the buzzer are used as alert signals when fault conditions are detected.

3 Hardware design

Multiplexed I/O pins for LED driving and input key scanning in this hardware design is a good choice to balance the effort on circuit design and the cost of using high pin count package. Dedicated I/O pins are reserved for critical power stage controls and real time monitoring on system status. The detailed descriptions for each circuit portion are shown in the following subsections. See Figure 6, Figure 7, and Figure 8 for all reference symbols.

3.1 LED driving and key scanning

A traditional 4-digit 7-segment LED module is used as the display and only one of the digits can be active at a time. The display content for each active digit is set by the value applied at the segment pins. Each digit is selected alternately by using a scanning method and it can be combined with the key scanning task in different time slots. Some segment pins are also assigned for key detection. A scanning task with 5 time slots (T1 to T5) is defined for LED and key scanning. The changes of I/O function in one scanning cycle are:

- Time slots 1 to 4: The corresponding digit is selected and all segment pins are set to output with display content for the digit.
- Time slot 5: All the digits are disabled and the segment pins multiplex with key function are set to input for key detection.

The resistor connected in series for each key switch limits the current drawing from output pin when the key is pressed during time slot 1 to 4. To prevent any damage on I/O pin, the segment pin must not be short to ground directly when it is configured as output.

3.2 Rotary encoder

The usage of rotary encoder provides a fast and simple way to adjust a parameter value as compared to the traditional key input method. Two pulse signals (TR1 and TR2) are generated when the knob of the encoder is rotated and the direction is determined by the sequence of TR1 and TR2. It is operated in clockwise direction if the rising-edge of TR1 is ahead of TR2 and vice versa.

3.3 Power stage control

All high-voltage driving circuits are isolated from the control board by using classic power relay as a control switch to protect the system in fault conditions. The control sequence in power stages is a critical design parameter to ensure the system is able to operate in safe conditions. The mechanism of power stage controls is described as follows.

- Both the Grill and Microwave functions are prohibited if the Fan function is not yet enabled.
- The operations of Grill and Microware functions are independent; either one or both can be selected.
- The Motor function is enabled automatically when the Fan function is active.
- Both the Grill and Microwave functions are forced to shutdown immediately, if the oven door is open. The circuit ground point is disconnected by the mechanical switch.

The enable signal for the Fan function is a continuous square wave signal generated from the MCU. The Fan function will be forced to turn off if the enable signal does not toggle periodically. This design feature makes sure the MCU is still running properly once the power stages are active and all power stages will be shutdown automatically if the MCU is reset, or halted up in harsh operating environment.

3.4 AC power detection

Detection of the AC power line frequency is a simple method to indicate whether the input power is stable or not. An optical coupler is used to transform the signal format to match the MCU input requirements. The coupling circuit is used to:

- Provide isolation between AC power line and MCU input
- Step down the voltage to 5 V level for MCU detection
- Convert the sinusoidal signal into square wave signal for frequency measurement in the MCU

The zero-crossing point of the sinusoidal AC signal indicates the best timing to switch on or off a power device with minimum loading effect and low transient noise on the power system. Therefore, all power stages are not changed immediately when a command is received; the action would be delayed until the zero-crossing point is reached.

The state of oven door is an essential parameter for safety checking. The detection pin is pulled down to a low level when the oven door mechanical switch is closed and the system is allowed to operate with Grill and Microwave functions.

3.5 Alert messages

The 7-segment LED display is used as the visual media for displaying the status information, action confirmation, and error messages. A buzzer component is added in the system as an alternative to generate messages in sound format, particularly useful for alert messages when error conditions are detected. For example, a periodic “beep” sound is generated when serious fault conditions are detected. This kind of acoustic alert message can keep end user’s attention for a longer time and eliminate the line of sign limitation on visual display.

4 Firmware design

Proper firmware design with safety considerations improves overall system performance, safety protection, and operating stability in harsh environments. Most of the safety related issues can be avoided if the MCU is able to control all functions in predefined sequences with minimum stress on hardware modules. The user control interface is another factor to address the safety requirements. The interface must be designed with helpful information on how to use the product quickly and the ability to limit end users on selecting a feature which is not allowed at the moment. It is not appropriate to accept all input triggers from the end users without any filtering; the firmware needs to understand the current situation and then make a right decision on corresponding action.

4.1 Firmware structure

The firmware includes all necessary tasks of user input detection, display driving, power stage control, and safety protection which allow the product working in normal condition. The firmware structure consists of two parts:

- Main routine: Handles all tasks in periodic base.
- Interrupt routines: Handles specific tasks in event-driven base.

Figure 2 shows the flow of the main program and the timer interrupt routine.

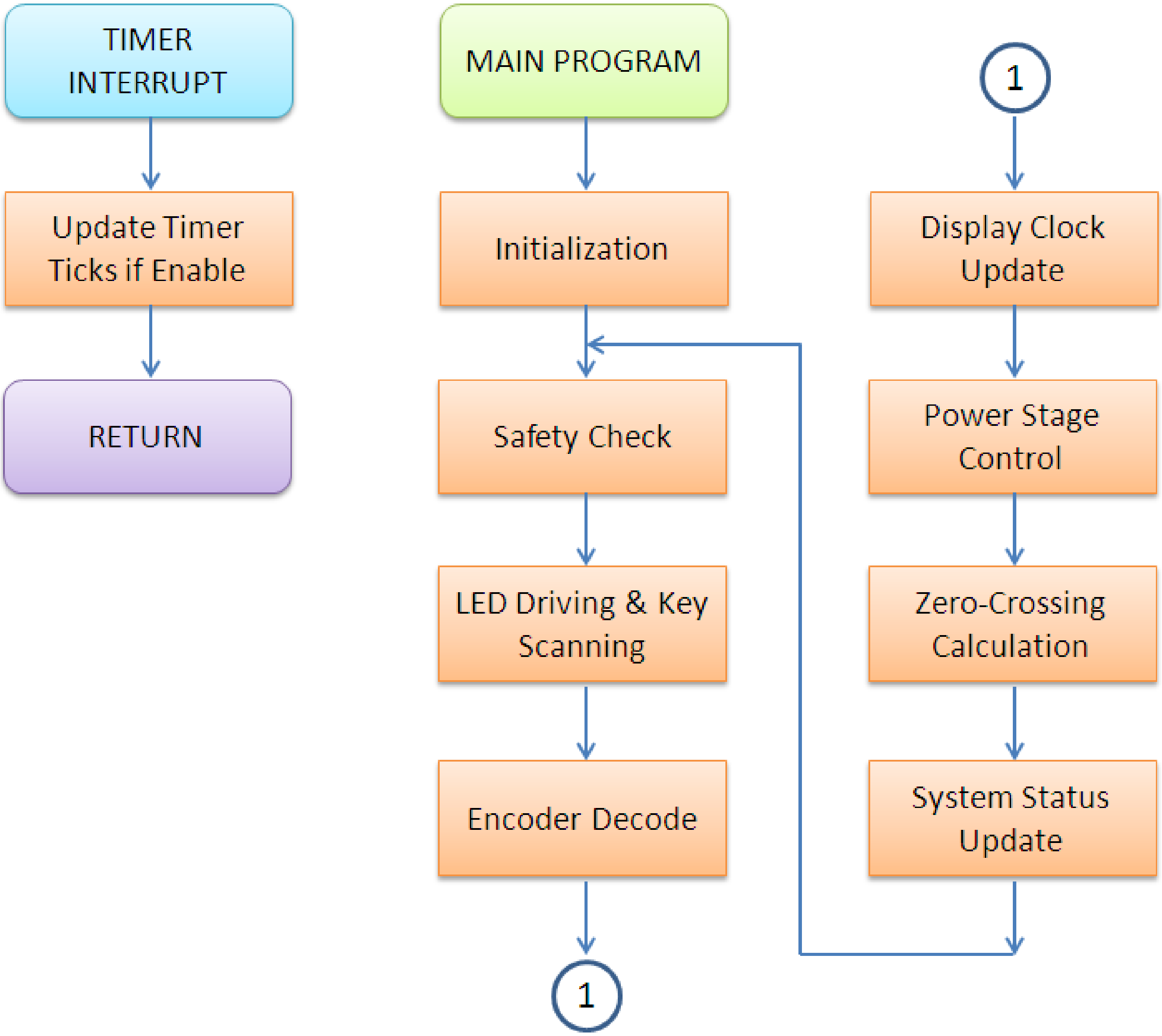

Figure 2. Main program flow

The main program continually executes a series of subroutines after system initialization to control the system according to user's inputs and keep track of all conditions for safety operation. One of the Timer/Pulse-Width Modulation (TPM) modules is configured in Output Compare mode to generate a periodic timing which is used as the core time base component for various software timers. An individual counter variable is assigned for each software timer. It counts up in the Timer interrupt routine and resets to zero when it reaches a predefined threshold. The final period for each software timer is equal to the core time base multiplied by the corresponding counter threshold. Software timers with different period are assigned for specific tasks with timing concern in main loop.

Figure 3 shows the flow of other interrupt routines which are configured in Input Capture mode to handle input events triggered by square wave or pulse signals at rising or falling edges.

- Zero-crossing interrupt: Measures the AC power line frequency, updates clock, and detects the zero-crossing point for power stage output toggle.
- Encoder 1 interrupt: Detects one of the outputs from rotary encoder and determines whether the direction is clockwise or idle.
- Encoder 2 interrupt: Detects other outputs from rotary encoder and determines whether the direction is anticlockwise or idle.

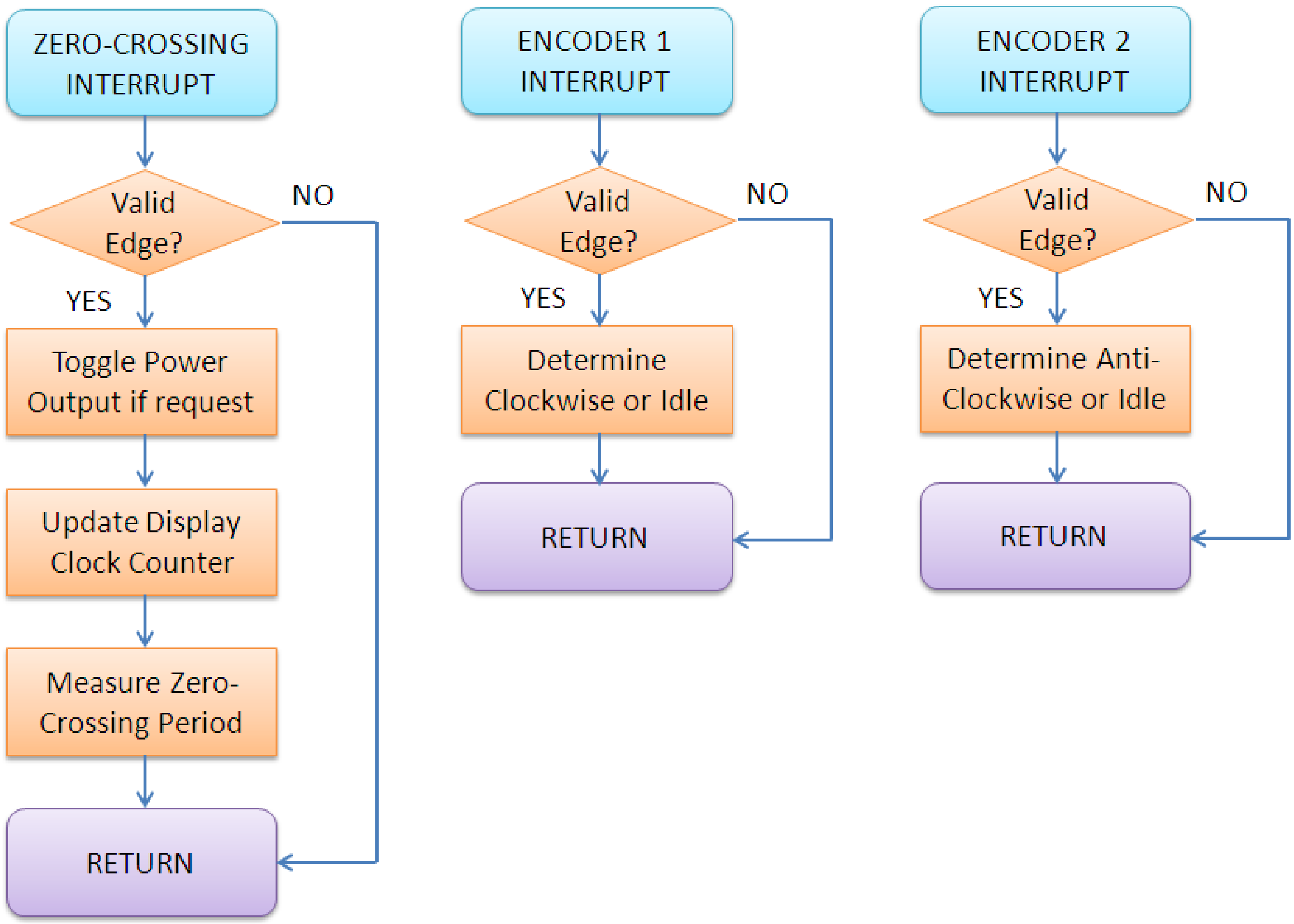

Figure 3. Interrupt routines

4.2 Front panel descriptions

The front panel is shown in Figure 4. End users can control the system through the front panel which consists of five functional keys and a rotary encoder for command input, a 4-digit 7-segment display for system status or error message indication, and a mechanical switch for front door locking. The following subsections discuss each of these briefly.

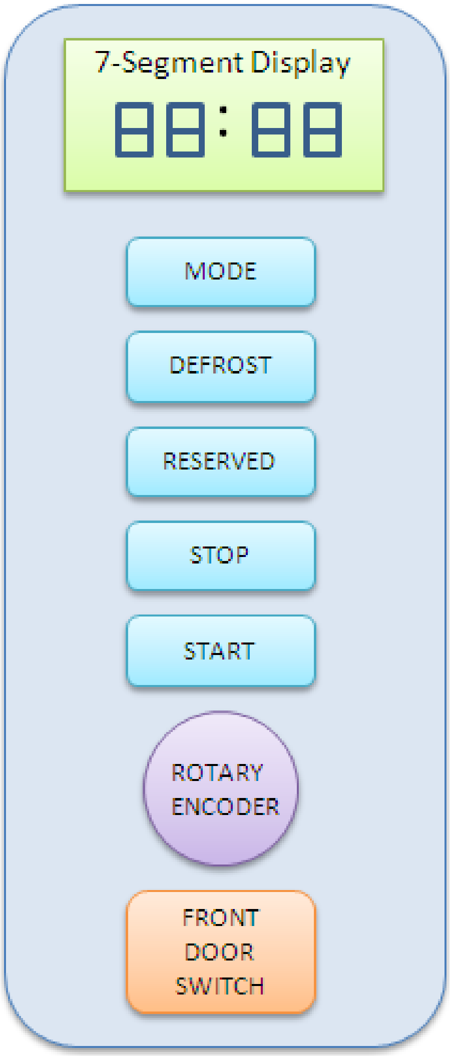

Figure 4. Front panel

4.2.1 7-segment display

The 7-segment display provides a simple way to indicate the system status, error messages or acknowledgement for user input. The display information is limited to a set of characters which can be mapped by using a 7-segment format in terms of shape. For example, the character 'T' is represented by symbol 'r', but there are no capital letter of 'B' or 'R' because the shape of 'B' is same as the number '8' in 7-segment format and shape of 'R' closely resembles letter 'A'. The details of messages using in this design are shown in following table.

Table 1. 7-segment display symbols

7-segment display symbols	Equivalent characters	Descriptions
norl	Normal	In normal condition
0 to 9	0 to 9	Numeric character 0 to 9
OPT1/2/3/4	Operating Mode 1/2/3/4	Select operating mode
STAr	Start	Start or Confirm a process

Table continues on the next page...

Table 1. 7-segment display symbols (continued)

7-segment display symbols	Equivalent characters	Descriptions
STOP	Stop	Stop or Cancel a process
noTA	Not Allowed	The action is not allowed
eror	Error	Indicate an error
ACer	AC Error	Error due to AC power
OPEn	Open	Front door is open

4.2.2 Functional keys

There are five functional keys for user input:

- MODE: Selects one of the operating modes
  - Mode 1: Enables only the Fan function. This mode is used for testing purpose.
  - Mode 2: Enables the Fan and Grill functions.
  - Mode 3: Enables the Fan and Microwave functions.
  - Mode 4: Enables the Fan, Grill and Microwave functions.
- DEFROST: Selects the upper or lower two digits for defrost time setting
  - Lower two digits: Sets the defrost time by the rotary encoder in 5-second step
  - Upper two digits: Sets the defrost time by the rotary encoder in 1-minute step
- RESERVED: Reserved for further development
- STOP: Stops or cancels the process
- START: Starts or confirms the process

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4.2.3 Rotary encoder function

The rotary encoder provides a fast input method to adjust the timing for defrost function or selection of operating mode.

- Timing adjustment : Increases the time in clockwise direction and vice versa
- Mode selection: Rolls the mode selection from 1 to 4 in clockwise direction and vice versa

4.2.4 Mechanical switch

The mechanical switch is used to lock or release the front door. The open door condition is always detected and shown in the display as an alert message for user.

- In Stop condition: The message 'Open’ is displayed when the door is open.
- In Start condition: The message ‘Error’ is displayed when the door is open.

4.3 Random delay function

The use of multiple reads on input state is a common practice to eliminate any fault alarm triggered by random noises. However, this method is not effective for a noise with periodic pattern that matches the sampling frequency. A random delay time function must be added in each sampling time to make sure that there is no correlation to the periodic noise. The timing diagrams are shown in the following figure.

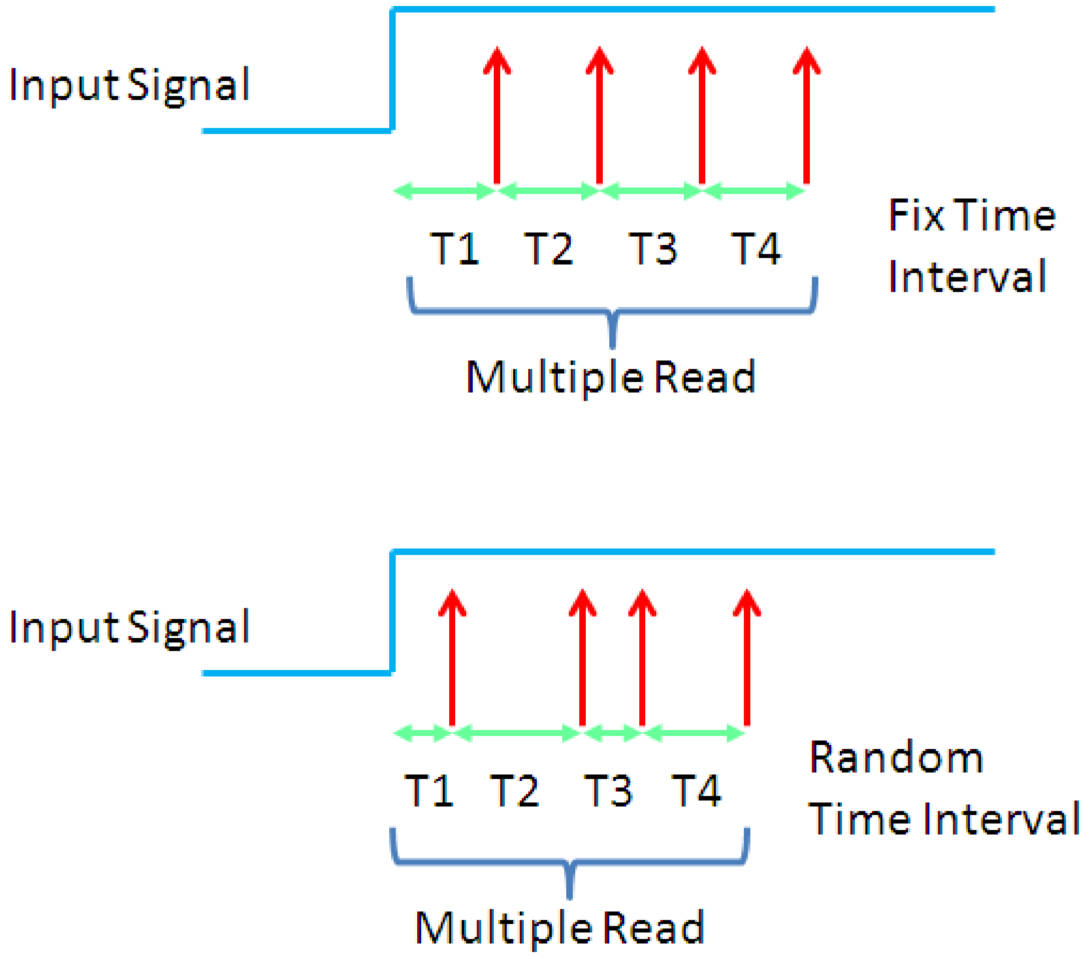

Figure 5. Random delay timing

This type of random delay function can be achieved by reading an internal free-running TPM counter value. The two least significant bits of the counter value are rolling very fast and almost randomly with respect to each time event for sampling. The actual delay is equal to the random 2-bit data multiplied by a fixed time interval.

4.4 Protection features

Smart control on operating flow is very important in system protection point of view. The firmware must be able to identify the current status or conditions before doing processing any input requests. For example, the firmware must not turn on a power control stage if one or more predefined conditions are not satisfied. Following protection rules are implemented in the system:

- The default operating mode is Mode 1(See Functional keys) which means the power control stages for Grill and Microwave functions are kept in inactive state until the users change the state of the functions intentionally.
- Only the STOP key input is still under scanning when the START key input is detected. For example, the users cannot change the operating mode when the power stages are running. It must be stopped before changing the mode setting.
- All active power control stages would be shut down immediately if an open door error is triggered in normal conditions. The shutdown process will be executed straight away irrespective of whether the zero-crossing point is reached or not and the ‘Error’ message is shown in the 7-segment display as an alert message. The periodic ‘beep’ sound is also generated continuously by the buzzer circuit until the front door is closed again.

- The alert message due to open door error will be changed from ‘Error’ to ‘Stop’ when the front door is closed and the user must press the STOP key once to clear the error state. This is a friendly reminder to ensure that the user is aware of the fault condition and is ready to release the lock state for further operation.
- Measuring only the AC power line frequency for error checking is not safe enough. The measurement process would be suspended if the corresponding interrupt routine is not triggered periodically. The measurement routing is kept waiting for new data for calculation. It is necessary to have a dedicated timeout function for AC power detection to make sure that an error signal is asserted when the signal has not toggled since a long time.

5 Conclusion

A complete reference design is illustrated as an example which covers the safety considerations in product design level and couples with hardware and software techniques on product enhancement in safety aspect. It can help customers to adapt Freescale solutions in their products more easily and in a quick time.

6 References

The following reference documents are available on **freescale.com**

- AN4438: EMC Design Considerations for MC9S08PT60
- AN4476: System Design Guideline for 5V 8-bit families in Home Appliance Applications
- AN4463: How To Develop a Robust Software in Noise Environment
- AN2321: Designing for Board Level Electromagnetic Compatibility
- AN2764: Improving the Transient Immunity Performance of Microcontroller-Based Applications

7 Appendix A-1: Schematic 1

The details of MCU I/O connection, LED driving, and input key scanning circuits are shown in the following figure.

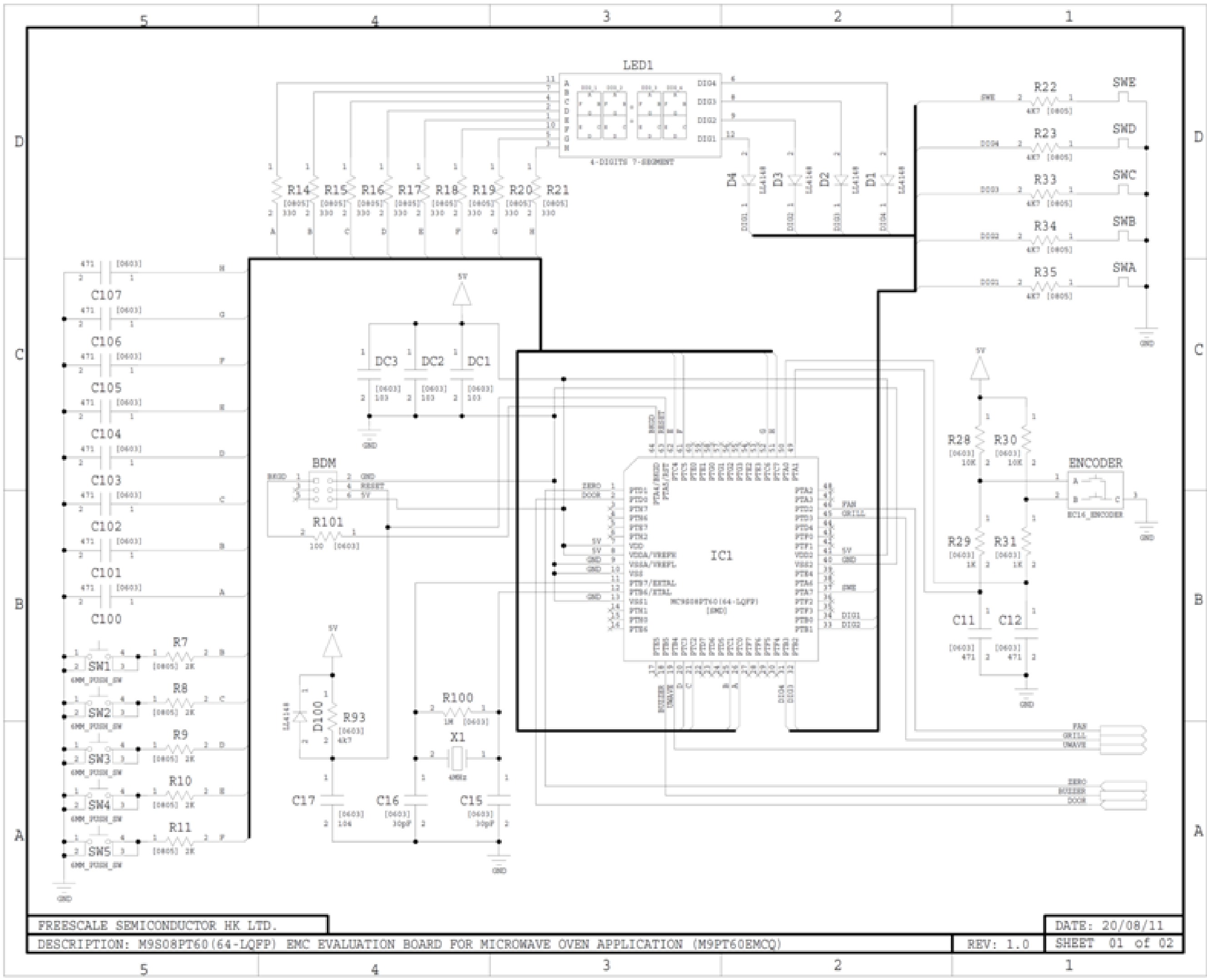

Figure 6. MCU peripheral circuits

8 Appendix A-2: Schematic 2

The details of power-stage control, zero-crossing detection, and buzzer driving circuits are shown in the following figure.

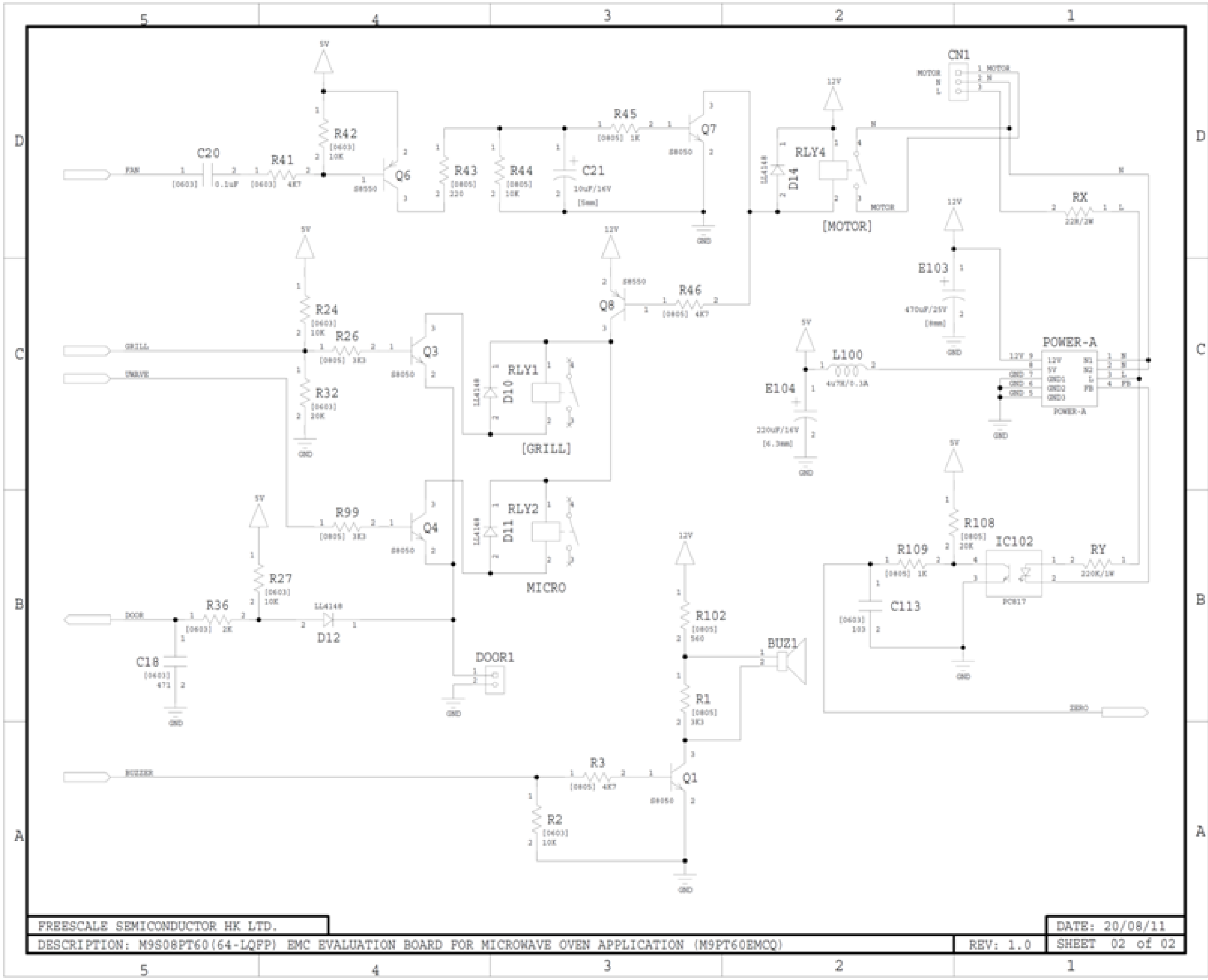

Figure 7. Power stage control circuits

9 Appendix A-3: Schematic 3

The details of switching mode power supply circuit are shown in the following figure.

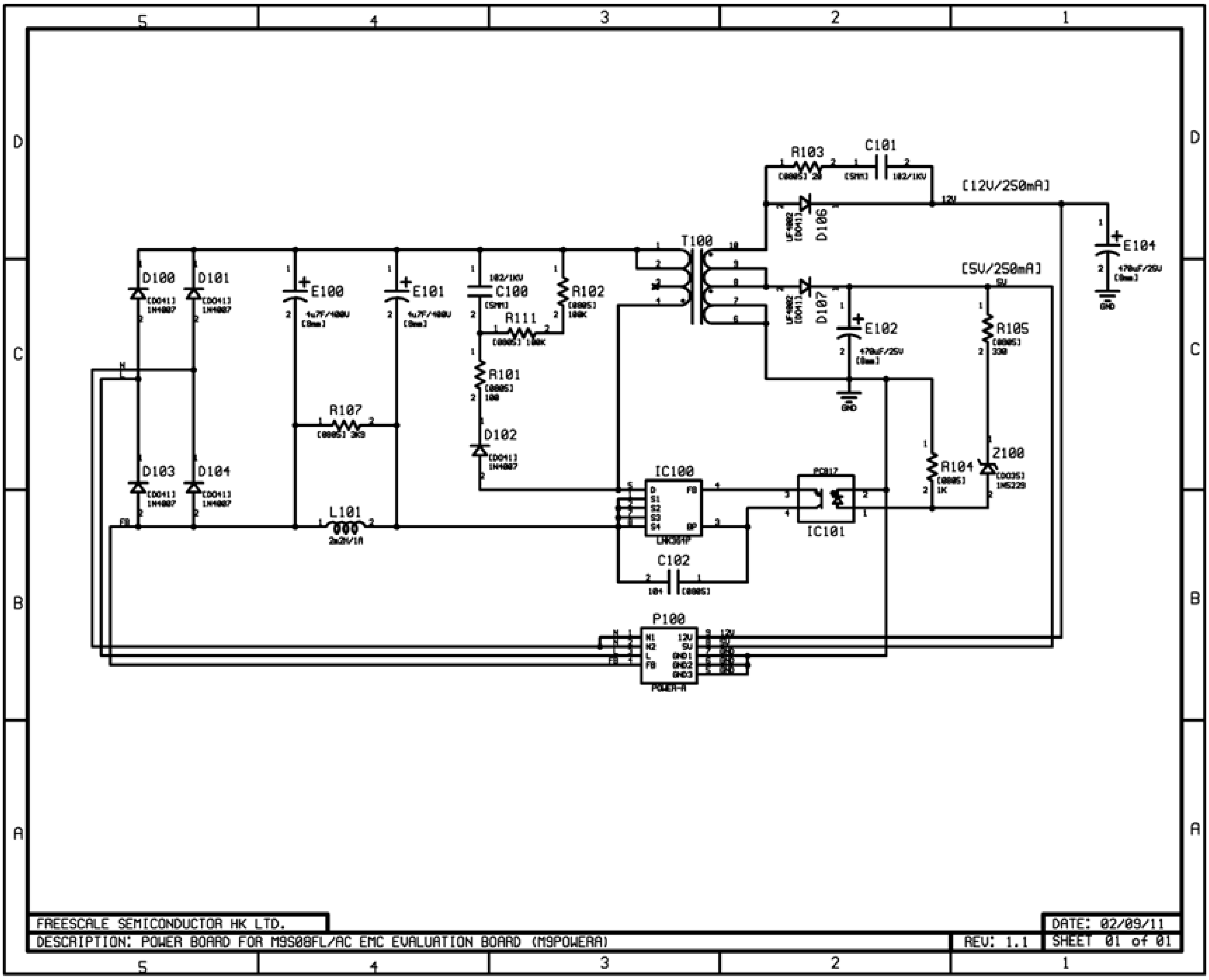

Figure 8. Switching mode power supply circuit

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