Ø A THERMOSTAT DEMO SYSTEM

1. OVERVIEW

A thermostat may be a control unit for a heating or cooling system or a component part of a heater or air conditioner. Thermostats can be constructed in many ways and may use a variety of sensors to measure the temperature. The output of the sensor then controls the heating or cooling apparatus.

The thermostat reference design used Samsung's newly developed microcontroller S3F84ZB, which is ideal for use in a wide range of electronic applications and home appliance requiring simple timer/counter, ADC, LCD display, LVD, UART, watch timer and key strobe. The LCD controller/driver and 10-bit ADC plays an important part in LCD display and temperature detection of thermostat. Also embedded full-flash can be used as EEPROM for storing user's data.

Thermostats are widely applied in industry and home appliance, and the latter is what we focus on. Please refer to Central air-conditioner system (HVAC) structure diagram below and get a overview:

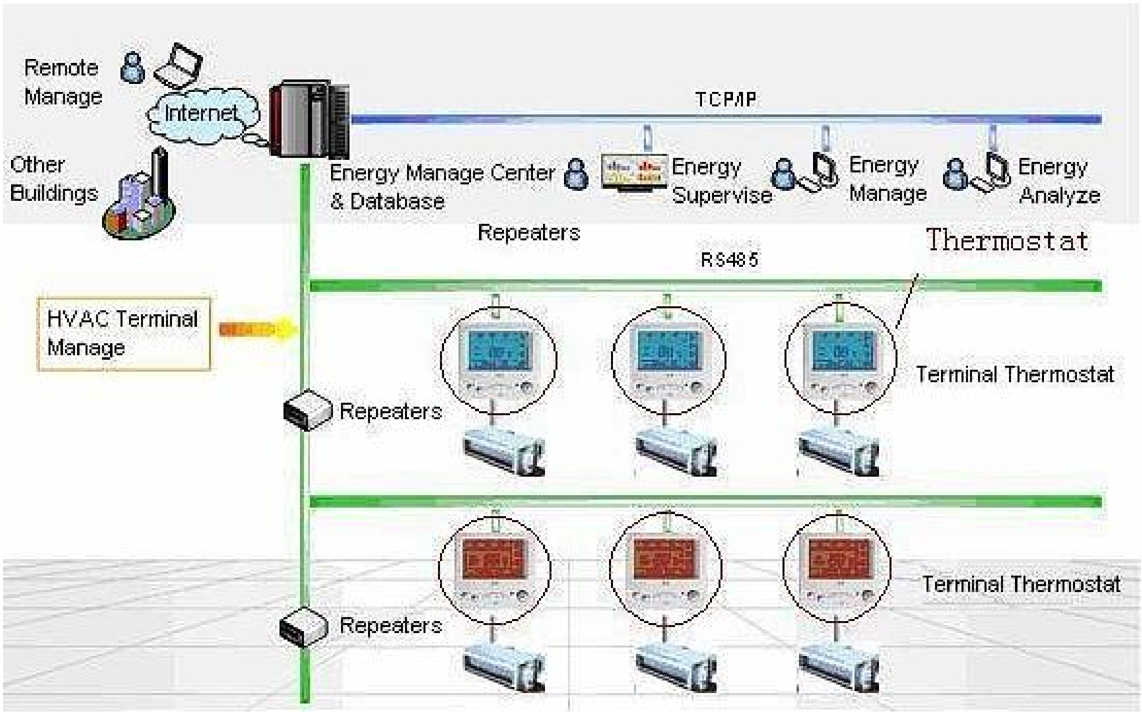

Figure 1-1. HVAC Structure Diagram

1.1 FEATURES

- Ø Automatic temperature control
- Ø 7-day, 24-hour intelligent temperature program
- Ø 4 operating mode (Manual, Auto, Program1, Program2), optional wind speed
- Ø Large LCD display
- Ø Humidity detect & display
- Ø Infrared remote control
- Ø User data holding after power-off
- Ø Convenient communication port, such as RS-485

1.2 OPERATING THEORY

A **thermostat** is a device for regulating the temperature of a system so that the system's temperature is maintained near a desired set point temperature. The thermostat does this by controlling the flow of heat energy into or out of the system. That is, the thermostat switches heating or cooling devices on or off as needed to maintain the correct temperature.

Basically, the thermostat compares current temperature with user set-point, then decides to heating or cooling, users can change set-point, operating mode & wind speed manually, also can program 7day's temperature then thermostat will operate automatically.

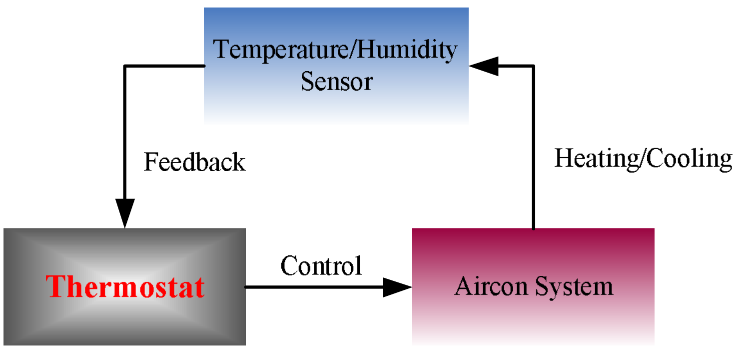

Figure 1-2. System Block Diagram

1.3 SYSTEM BLOCK DIAGRAM

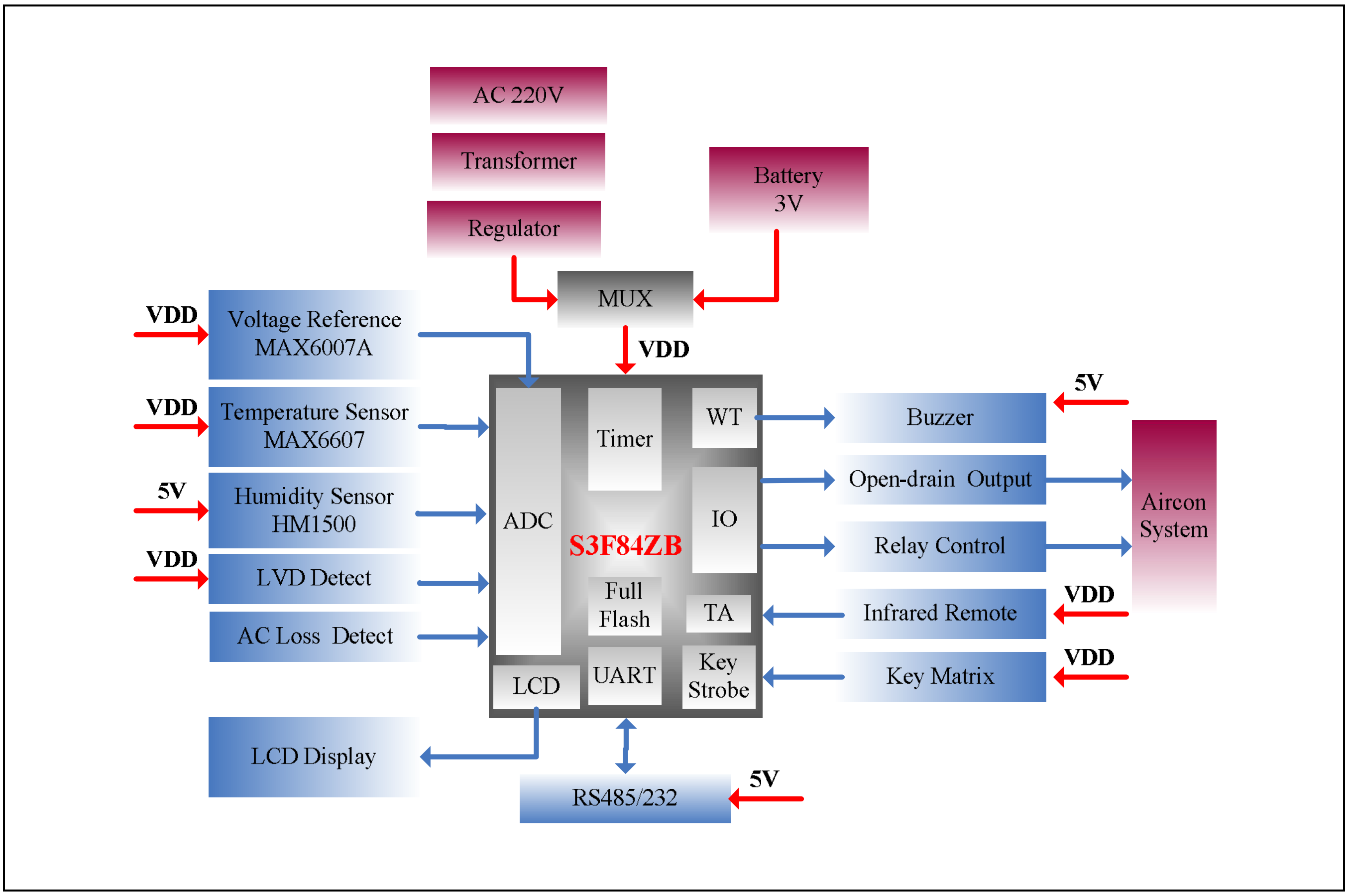

Figure 1-3. System Block Diagram

This figure shows the system structure based on S3F84ZB.

1.4 STATE DIAGRAM

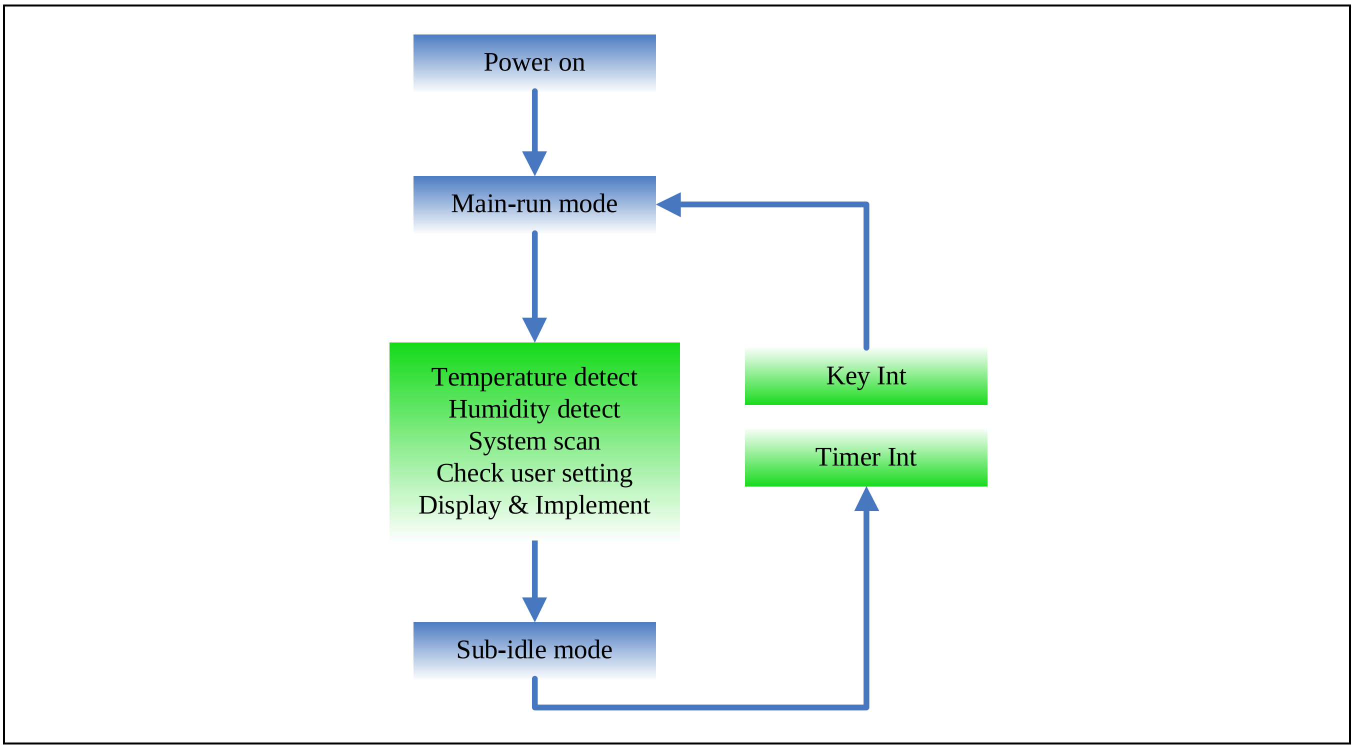

Figure 1-4. State Diagram

Since MCU will be supplied by 3V battery when AC power off, power-saving is more important. After power on, MCU will operate in main-run mode, controls heating or cooling apparatus to regulate temperature. Then switch into Sub-idle mode quickly. In sub-idle mode, peripheral modules (LCD, Timer, IO and so on) will remain operating while CPU stops. Heating/Cooling will continue. Timer interval interrupt will occur every several seconds, then MCU will jump into main-run mode, compares current temperature with set-point, if equals, stops cooling/heating, and checks user program and then jumps into sub-idle mode again. Key Interrupt can also wake up MCU. Power-on/off button is used to shut down system (Please refer to Table 3-2 Key Function).

2. HARDWARE IMPLEMENTATION

2.1 Overview

The thermostat system is divided into 2 boards: Main board and Sensor board. Sensor board which contains temperature sensor and humidity sensor, is placed in the test box while normal operating. The main board contains 14 blocks: MCU, Power supply, Voltage reference, Battery level detect, AC loss detect, LCD display, Key matrix, Relay control, Open-drain output, Buzzer circuit, RS-485 interface, Remote receiver, Clock & Reset circuit and PGM interface. The Sensor board contains 2 blocks: Temperature detection circuit and Humidity detection circuit.

2.2 Pin Assignment

Table 2-1 Pin Assignment

Pin	*Net Name*	*Function*
P7.0~7, P8.0~2,	COM0~7, SEG0~10	11×8 LCD display
P4.3	TEMP0	ADC input, for temperature detect
P4.4	5V_DETECT	ADC input, for DC 5V detect
P4.5	HUMIDITY	ADC input, for humidity detect
P4.6	BLD	ADC input, for LVD detect
P9.4~6	COOLER, HEATER, VALVE	Output, for relay control
P9.0~3	FAN_EN, FAN_HIGH, FAN_MID, FAN_LOW	Output, for fan control & fan speed control
P1.2~3	TXD0, RXD0	RS-485 interface
P1.2~3	TXD1, RXD1	UART interface
P1.1	RS485_EN	RS485 Control signal
P1.6	REMOTE	Timer capture input, for infrared remote receive
P1.7	REMOTE_LED	Output, for LED display
P2.0~3, P10.0~4	KINT0~3, KSTR0~4	KINT & key strobe output, for key matrix
P3.7	BUZ	BUZ, for buzzer control
AVREF	AVREF	ADC reference voltage
P4.0~1	SCLK, SDAT	For flash programming
P5.0~3	VLC0~3	Vlc0~3
P5.4~5	CA, CB	LCD bias cap
XIN, XOUT,	XIN, XOUT,	Main oscillator
P5.6~7	XTIN, XTOUT,	Sub oscillator
nRESET	nRESET	RESET pin
VDD	VDD	Power supply
VSS1, VSS2	GND	Ground

2.3 Block Instruction in Main Board

Ø MCU

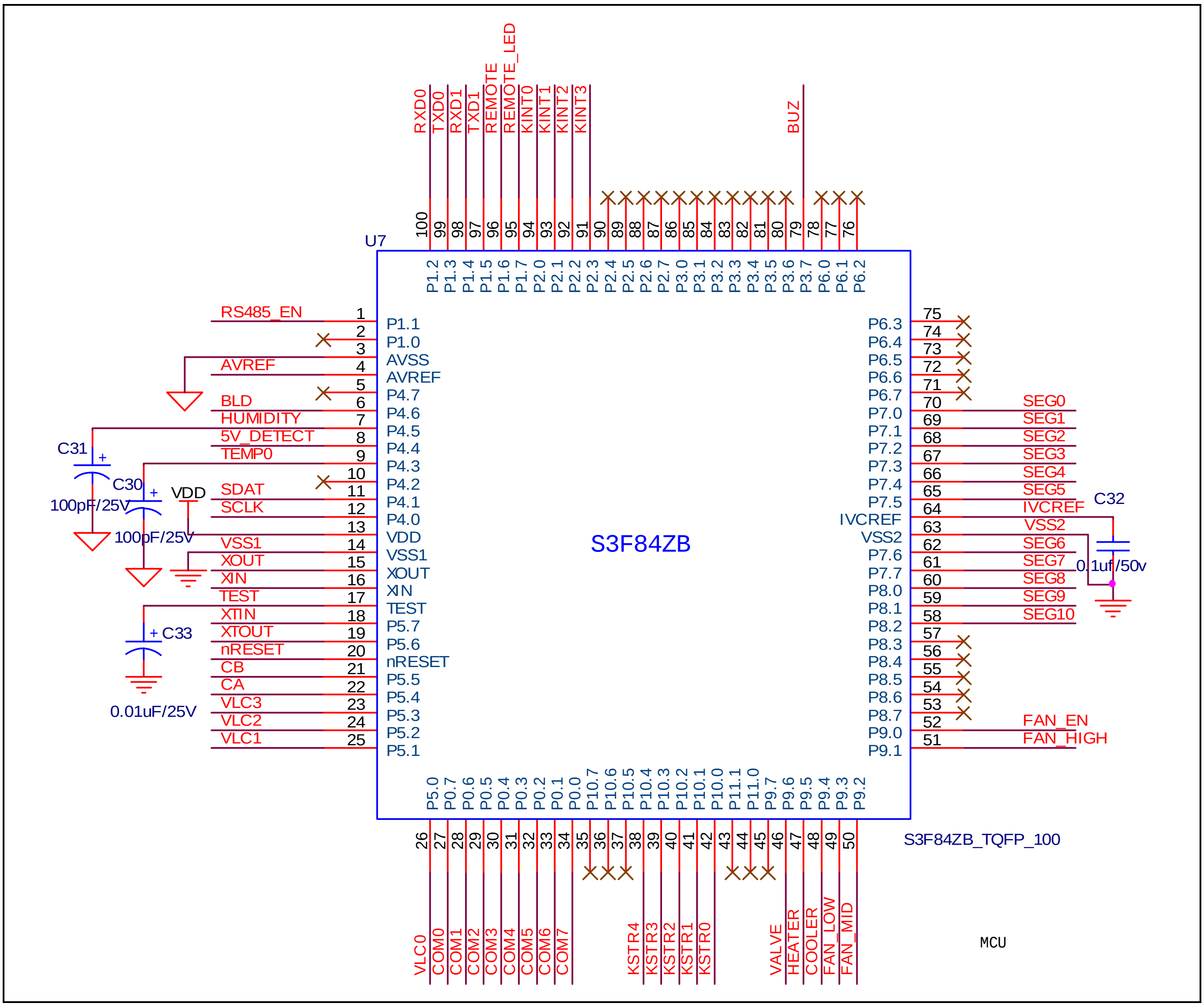

Figure 2-1. Microcontroller

Ø Power Supply

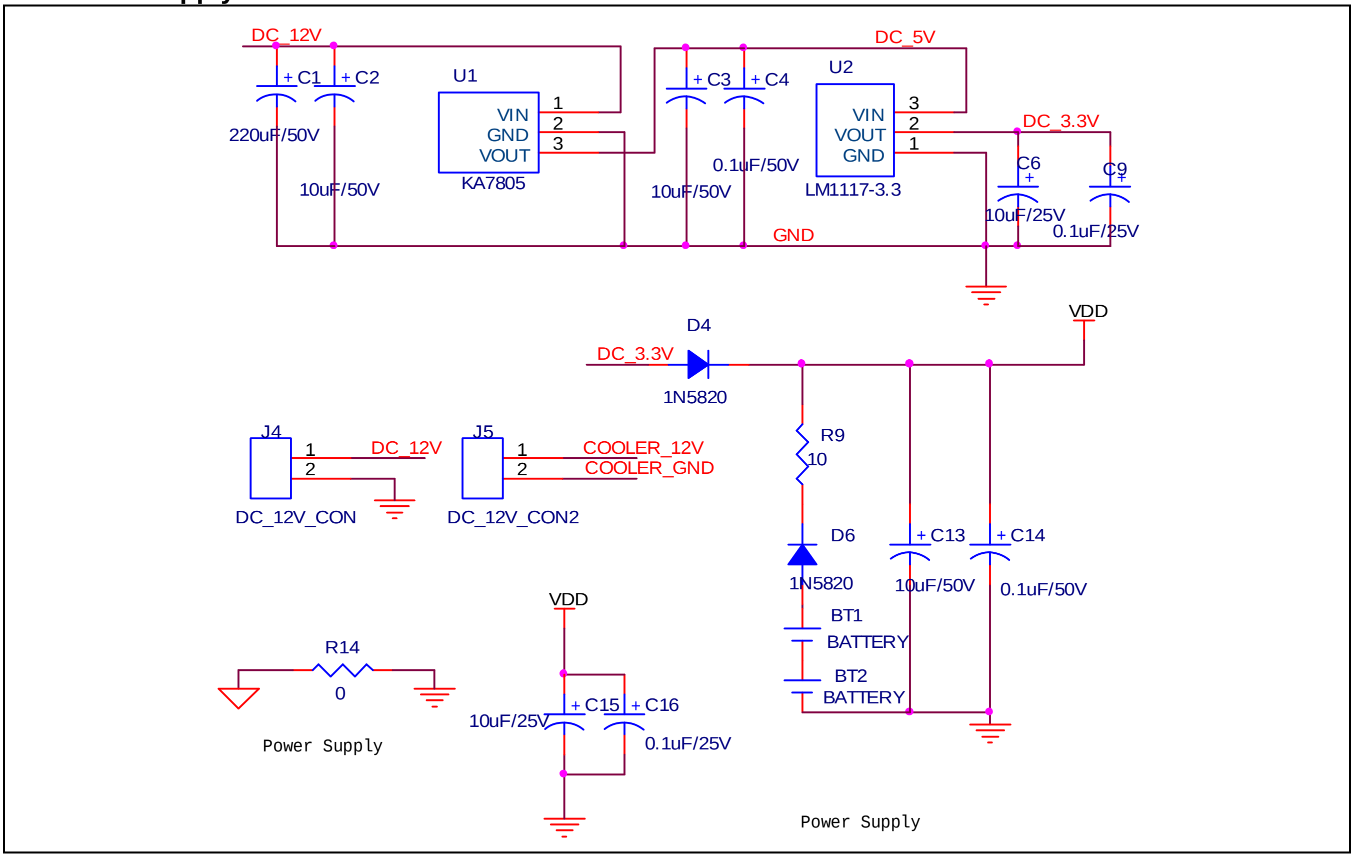

Figure 2-2. Power Supply

Thermostat system can be powered by both AC220V (need external transformer) and DC12V. DC_5V is used for AC_LOSS detection. When AC220V power off, system is powered by 2 AA batteries (3V), at this time only temperature detect/Key/LCD function is enable and VDD is about 2.8V because there is 0.2V voltage drop at D6(1N5820). For higher ADC accuracy, Analog ground is independent with Digital Ground, they're connected through a 0ohm resistor.

Ø Voltage Reference

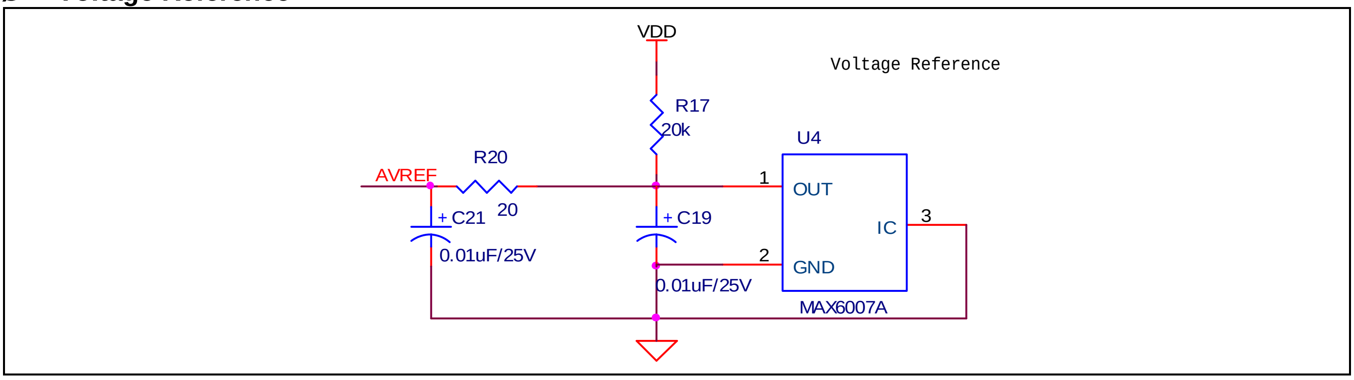

Figure 2-3. Voltage reference Circuit

This is a Voltage reference circuit for AVREF. MAX6007A can generate a stable voltage of 2.048V. Since battery voltage changes all the time, voltage reference is needed.

Ø Battery Level Detect

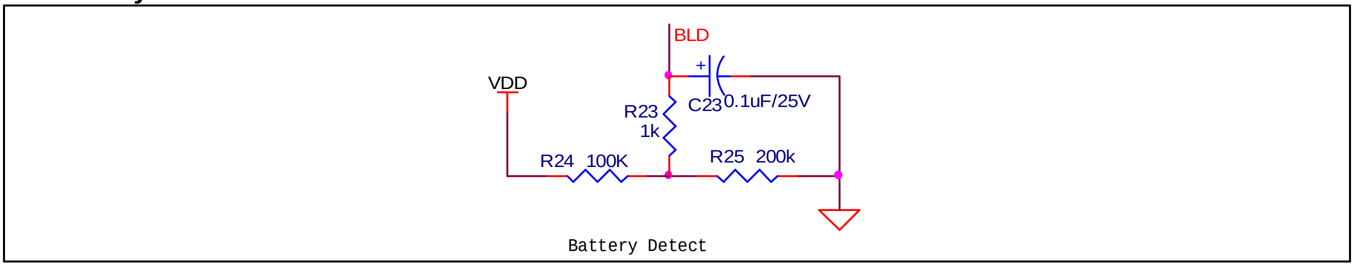

Figure 2-4. Battery Detection Circuit

When system is powered by battery, it's necessary to remind user or shut down system when battery level is too low. BLD signal is connected to MCU ADC input pin. Because AVREF is supplied by 2.048V voltage reference, battery level (max. 3v) must be divided to 2/3 of itself at first, and then operates ADC conversion.

Ø AC Loss Detect

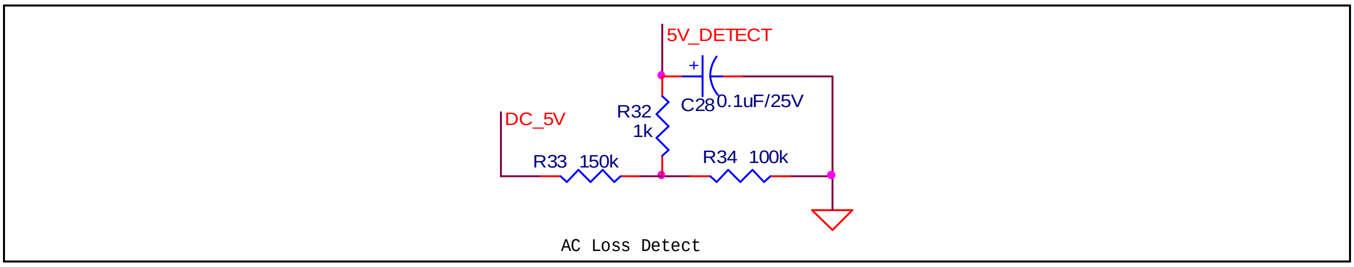

Figure 2-5. AC Loss Detection Circuit

This circuit is used for AC loss detecting. DC_5V is the signal after 7805. 5V_DETECT signal is connected to MCU ADC input pin. Because AVREF is supplied by 2.048v voltage reference, DC_5V (max. 5v) must be divided to 2/5 of itself at first, then operates ADC conversion.

Ø LCD Display

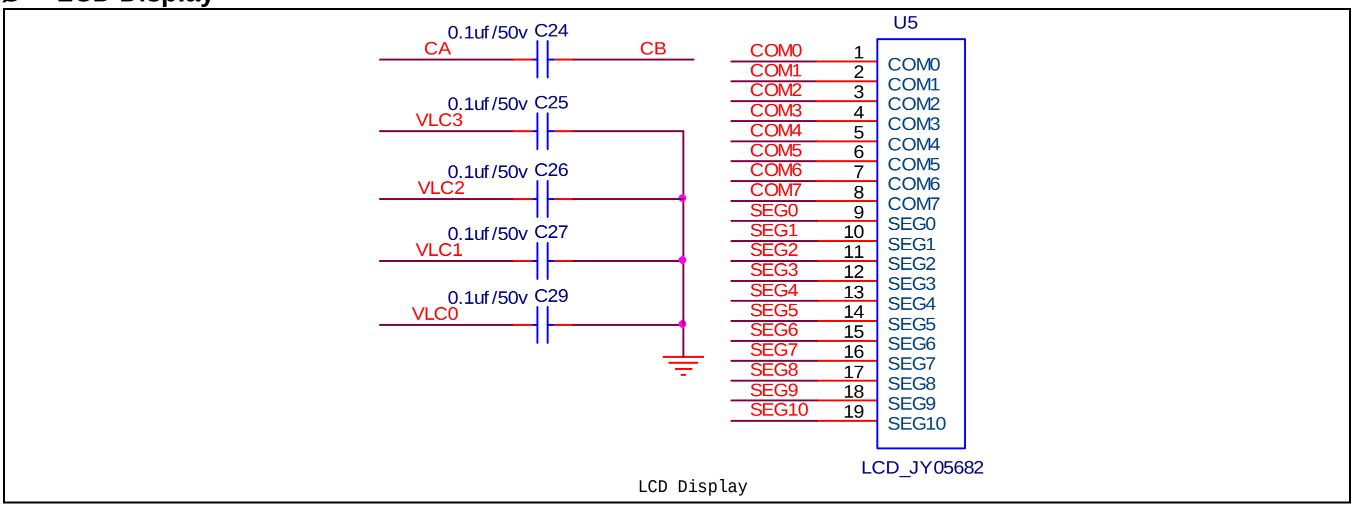

Figure 2-6. LCD Display Circuit

A 11(segment)×8(COM) LCD panel is used. LCD controller integrated is configured as cap-biased mode.

Ø Key Matrix

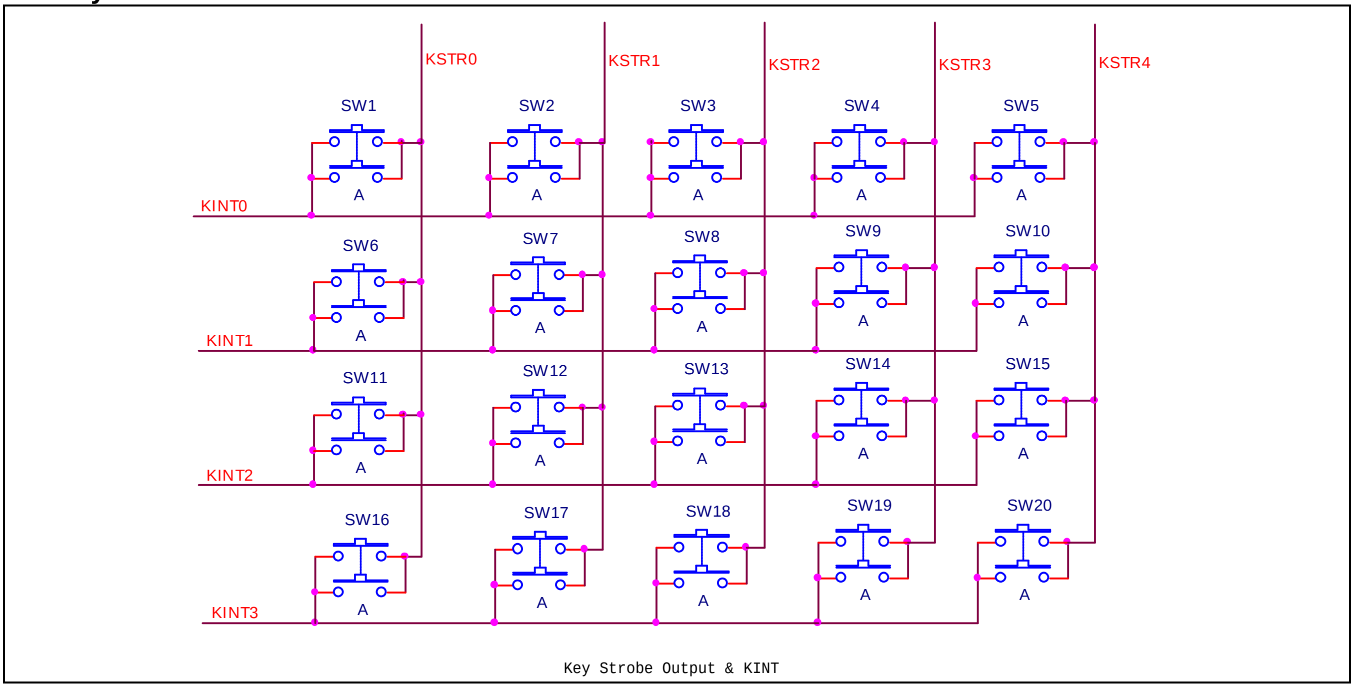

Figure 2-7. Key Matrix Circuit

Since S3F84ZB has KEY STROBE function, it's easy to realize a 4×5 key matrix by 4 KINT ports and 5 key strobe output ports.

Ø Relay Control

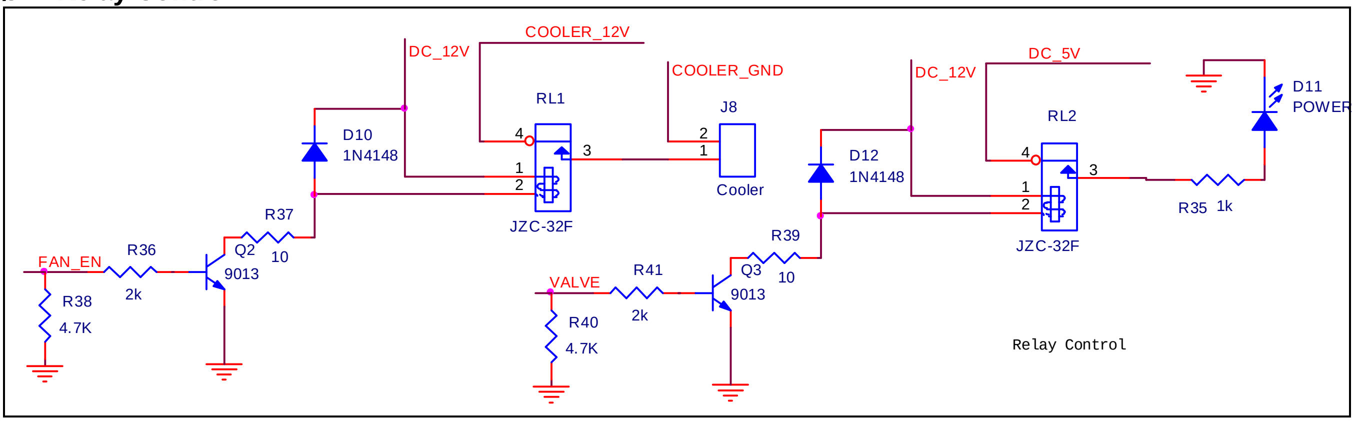

Figure 2-8. Relay Control Circuit

This system has 2-channel relay control output; they are used for fan control and valve control. We can use a semiconductor cooler for demo.

Ø Open-drain Output

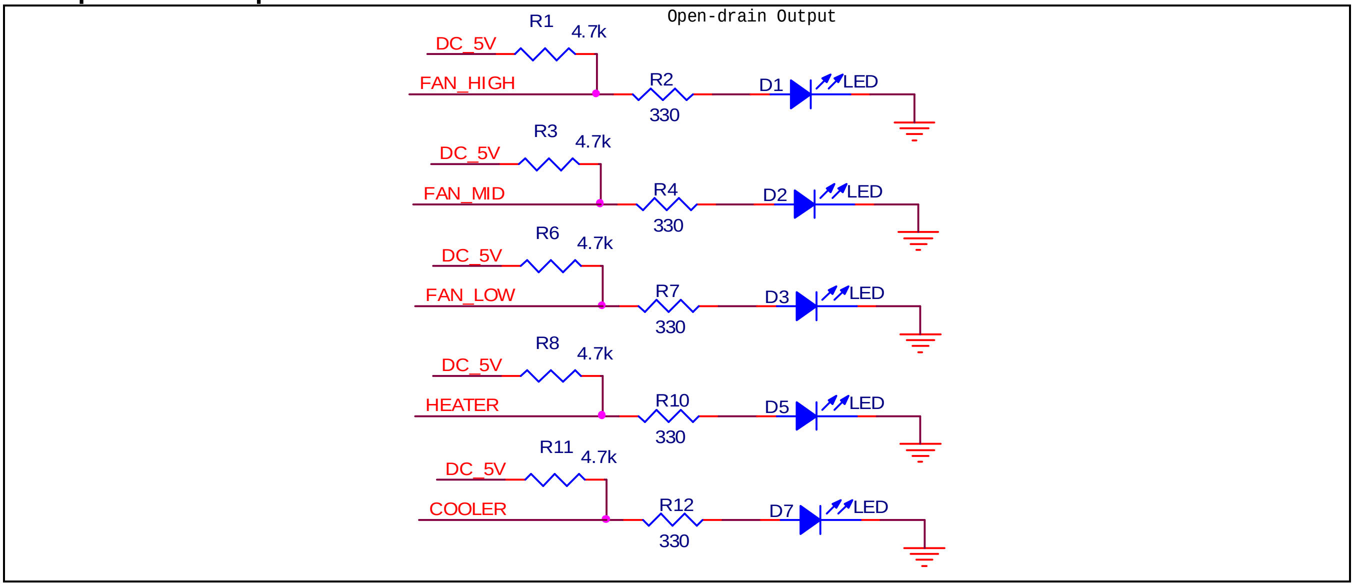

Figure 2-9. Open-drain Output Circuit

FAN_HIGH, FAN_MID and FAN_LOW signal is used to set fan speed, HEATER and COOLER signal is used to enable/disable heater or cooler. Open-drain output can match external voltage level by pulling-up.

Ø Buzzer

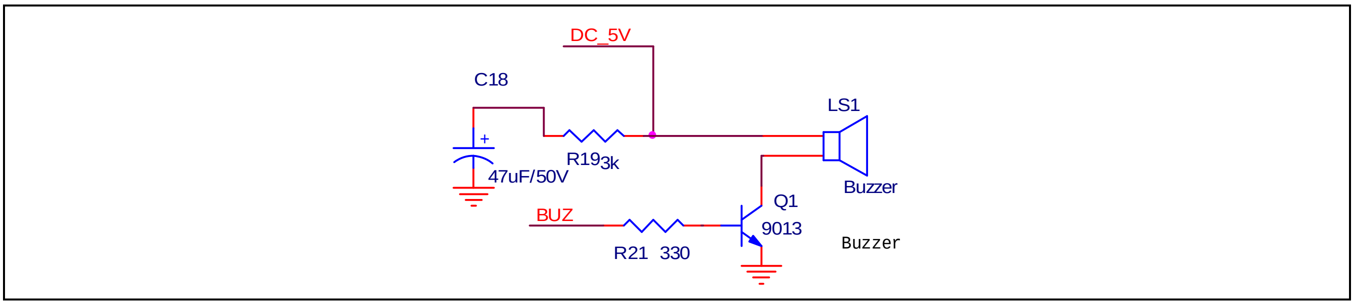

Figure 2-10 Buzzer Circuit

BUZ is used to control buzzer on or off, and control buzzer frequency by software setting.

Ø RS-485 Interface

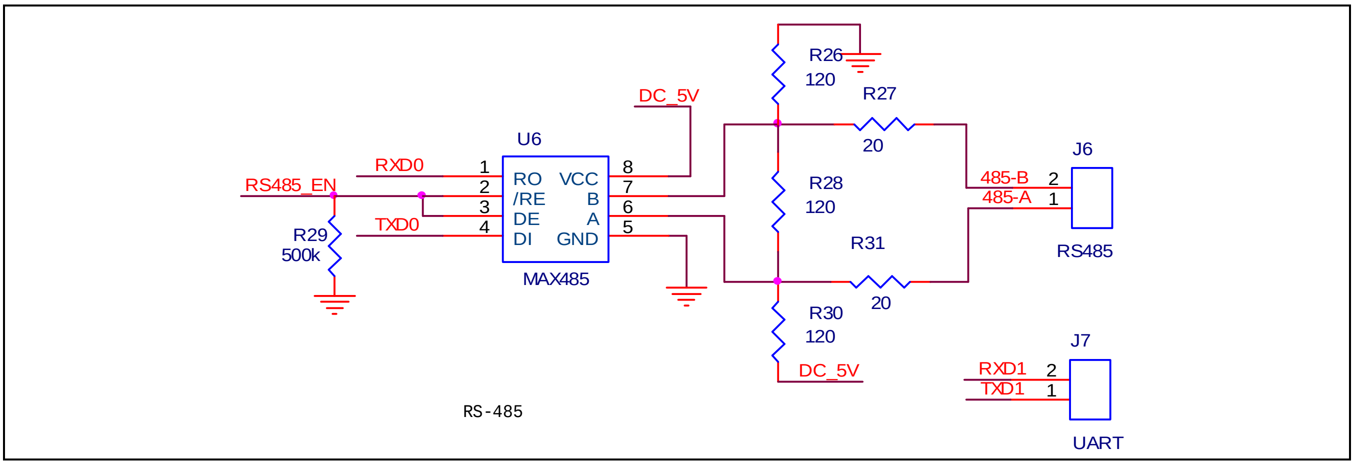

Figure 2-11. RS-485 Interface Circuit

This system has a RS-485 interface for communication, and another UART interface for system expansion.

Ø Remote Receiver

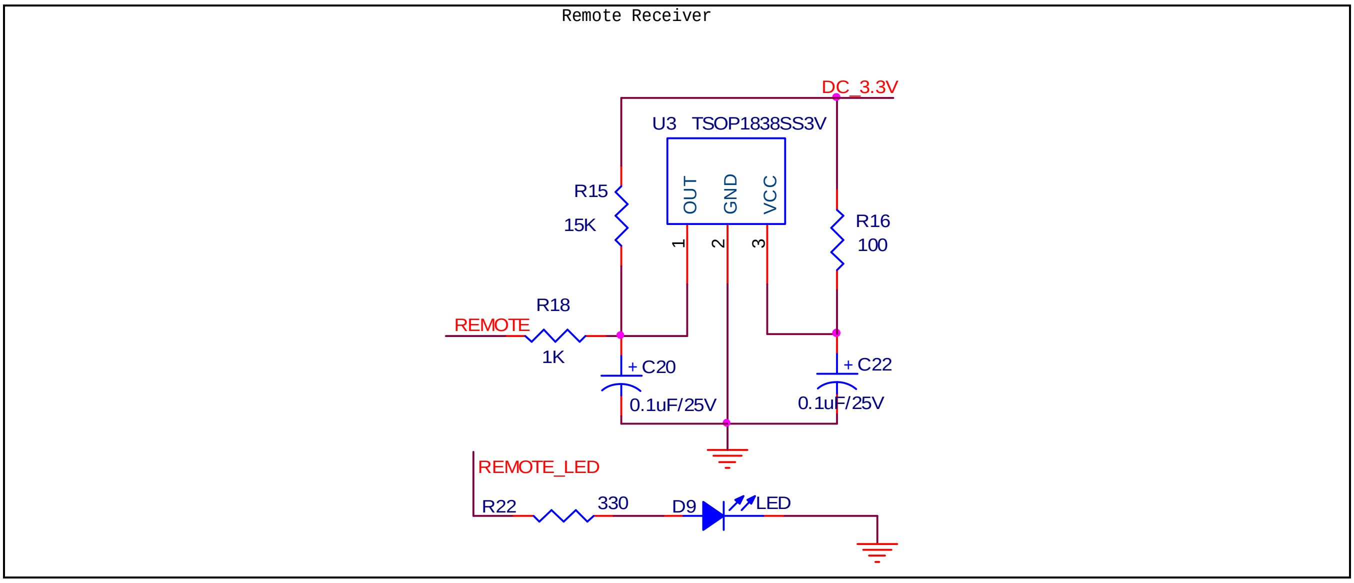

Figure 2-12. Remote Receiver

This system has a infrared remote signal receiver and a LED for display. REMOTE signal is connected to MCU TACAP pin.

Ø Clock & Reset

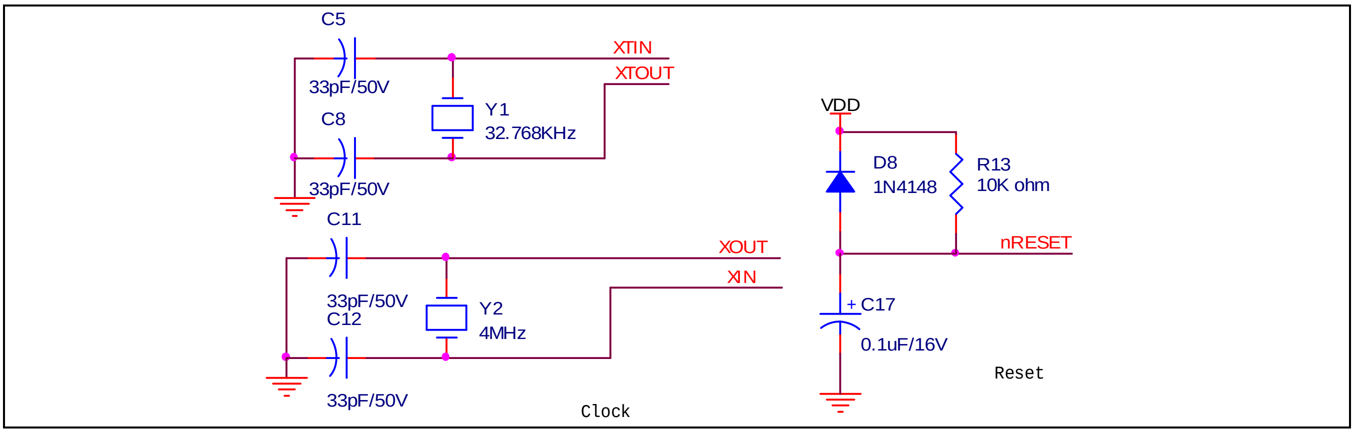

Figure 2-13. Clock & Reset Circuit

Main oscillator is 4MHz, Sub oscillator is 32.768 KHz.

Ø PGM Interface

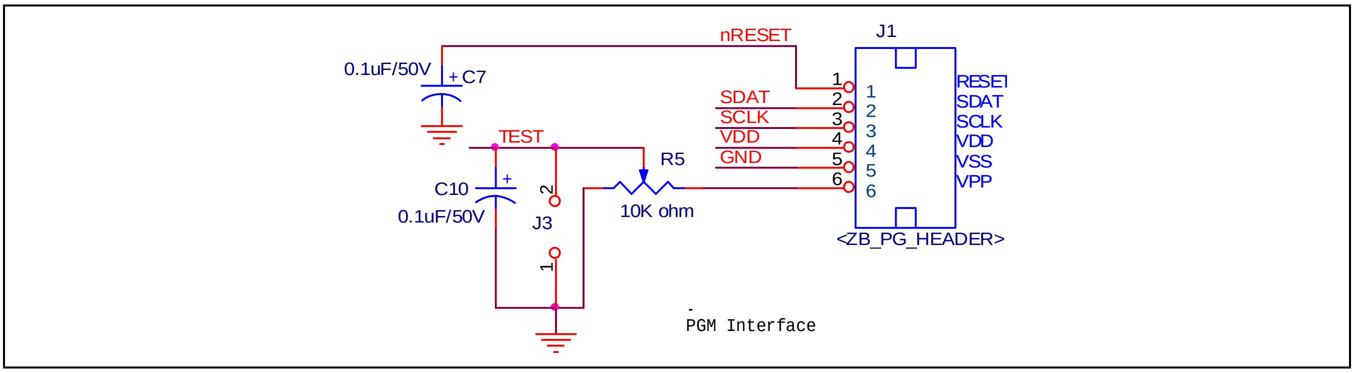

Figure 2-14. PGM Interface

S3F84ZB has a full-flash inside, it needs VPP=5V for PGM, but some tools such as SPW2+ can only output VPP=12.5V, so a variable resistor is needed in the path of VPP/TEST.

2.3 Block Instruction in Sensor Board

Ø Temperature Sensor

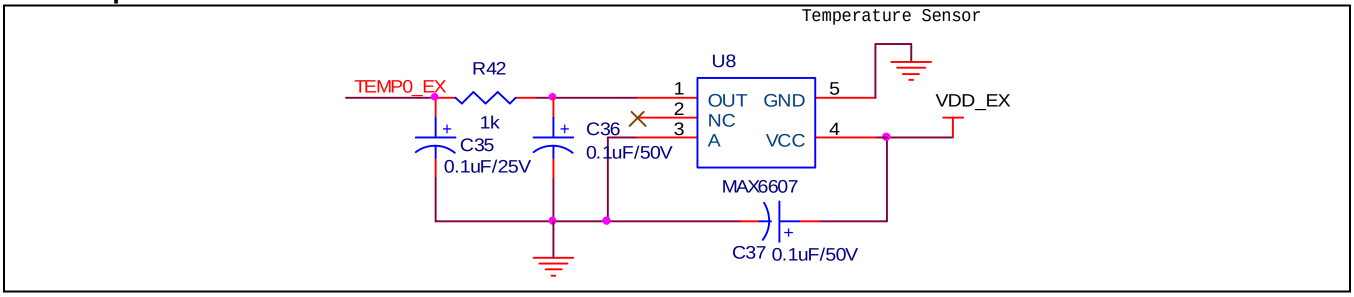

Figure 2-15. Temperature Detection Circuit

MAX6607 is an integrated temperature sensor chip, which has a 1.8V to 3.6V supply voltage range and maximum 15uA supply current over the -20°C to +85°C temperature range. Its accuracy is +/- 0.7°C from TA=0°C to 70°C. And its output voltage is 500mV to 1400mV. TEMP0_EX is connected to MCU ADC input pin.

Ø Humidity Sensor

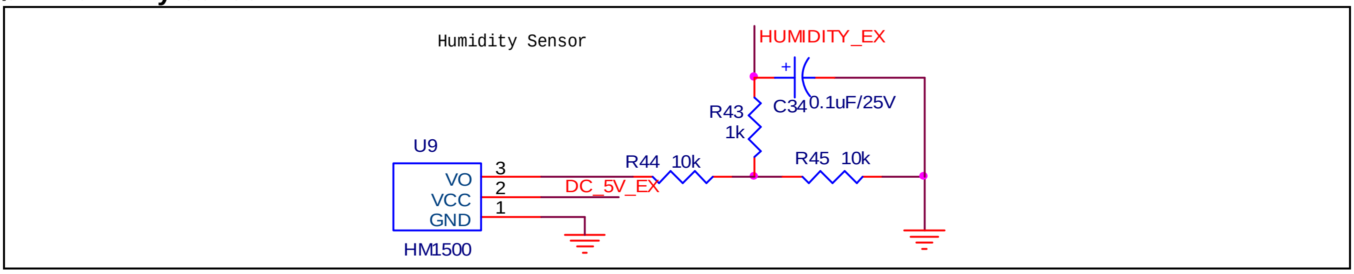

Figure 2-16. Humidity Detection Circuit

HM1500 is a relative humidity module, which has 1 to 4 Volt output for 0 to 100 % RH at 5V DC supply, it can be calibrated within +/- 2% RH @ 55 % RH. Its suitable supply voltage is 3 to 7 Volts, so this module is unavailable when system is powered by battery. HUMIDITY_EX is connected to MCU ADC input pin. Because AVREF is supplied by 2.048V voltage reference, HUMUDITY_EX (max. 4v) must be divided to 1/2 of itself at first, and then operates ADC conversion.

2.4 Interface Between Main Board & Sensor Board

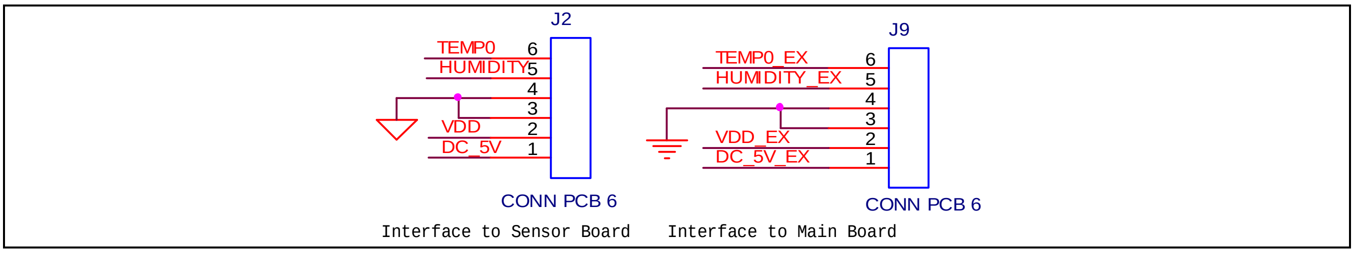

Figure 2-17. Interface Between Main Board & Sensor Board

Main board and sensor board is connected by a 6-pin connector.

3. SOFTWARE IMPLEMENTATION

This section describes the software used in the thermostat reference design. The software is written in C language.

3.1 Source Code Files

The source code includes the following files:

Table 3-1 Source Code Files

File name	Description	Note
ioS3F84ZB.h	Declarations of S3F84ZB register and interrupt vector.	
constant.h	Declarations of variables, arrays and external functions.	
Main.c	Configuration of peripherals, control functions, interrupt service routine and main task.	
sensor.c	Temperature and humidity detection function.	
Lcd_disp.c	LCD display drive program.	
delay.c	Collection of delay functions.	

3.2 Software Flow Chart

3.2.1 Main Task

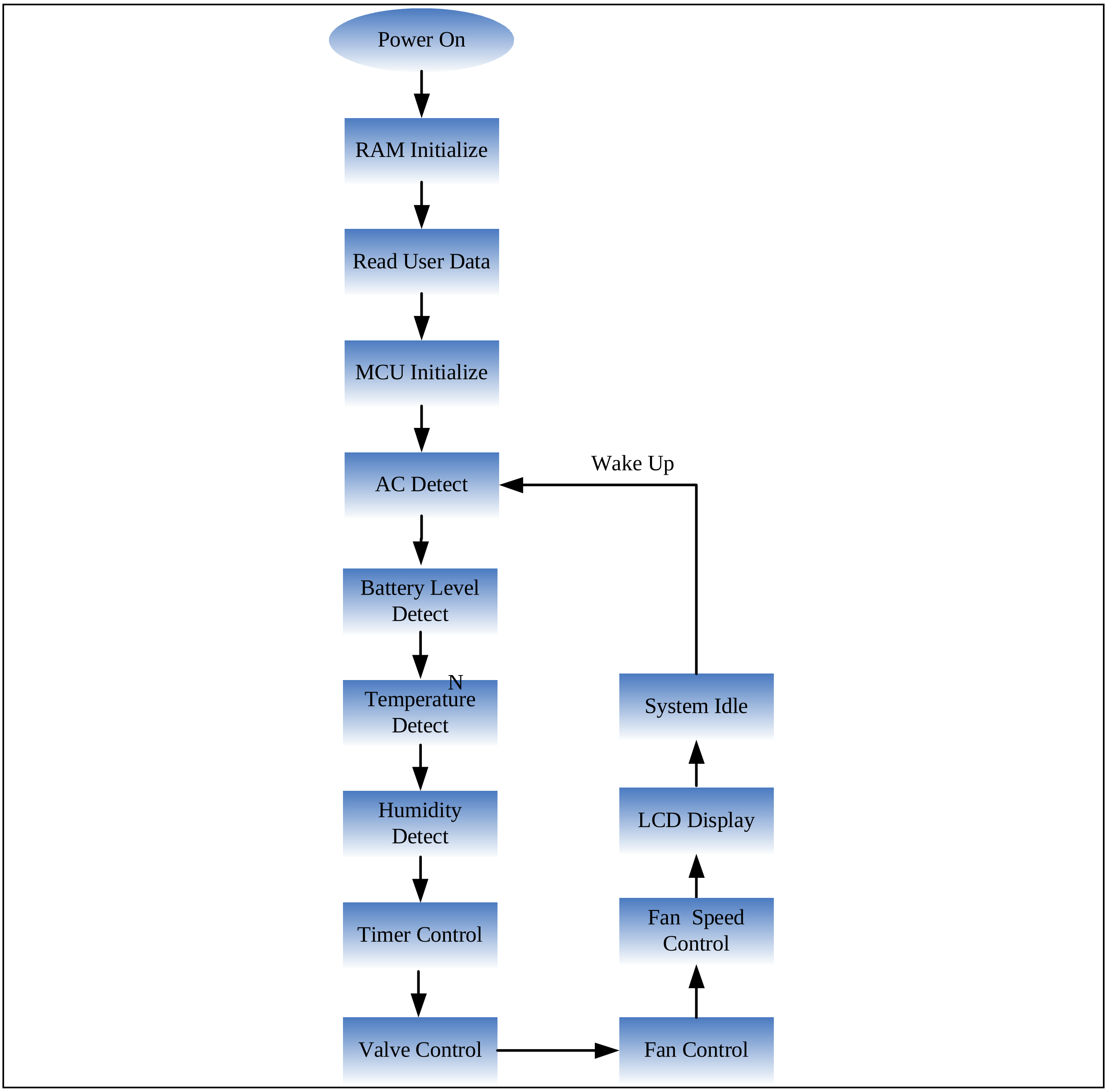

Figure 3-1. Main Task Flow Chart

This part describes the main cycle of system. An area of full-flash is used for storing user data, after power on, these data will be loaded into RAM, and that it will also be saved when key is pressed (Please refer to Table 3-2 Key Function). After each implement cycle, MCU will switch into sub-idle mode for power saving, it will be waked up by watch timer interrupt or key interrupt.

3.2.2 Watch Timer ISP

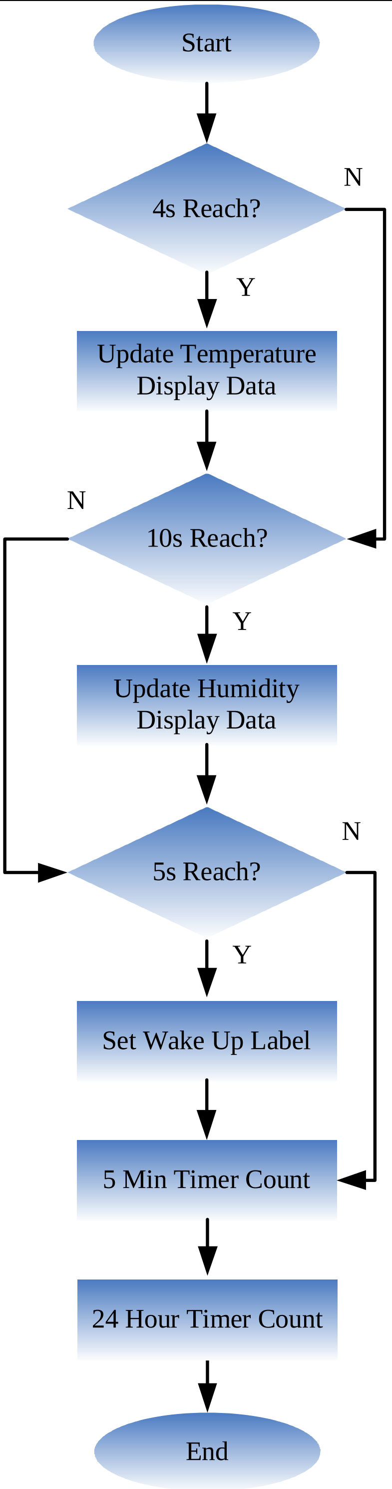

Figure 3-2. WT ISP Flow Chart

Watch timer is operating all the time and clocked by sub-oscillator, it will never stop even when MCU idle. MCU is waked up by WT interrupt every several second ignoring key interrupt. It also acts as a timepiece and reference for other control.

3.2.3 Key ISP

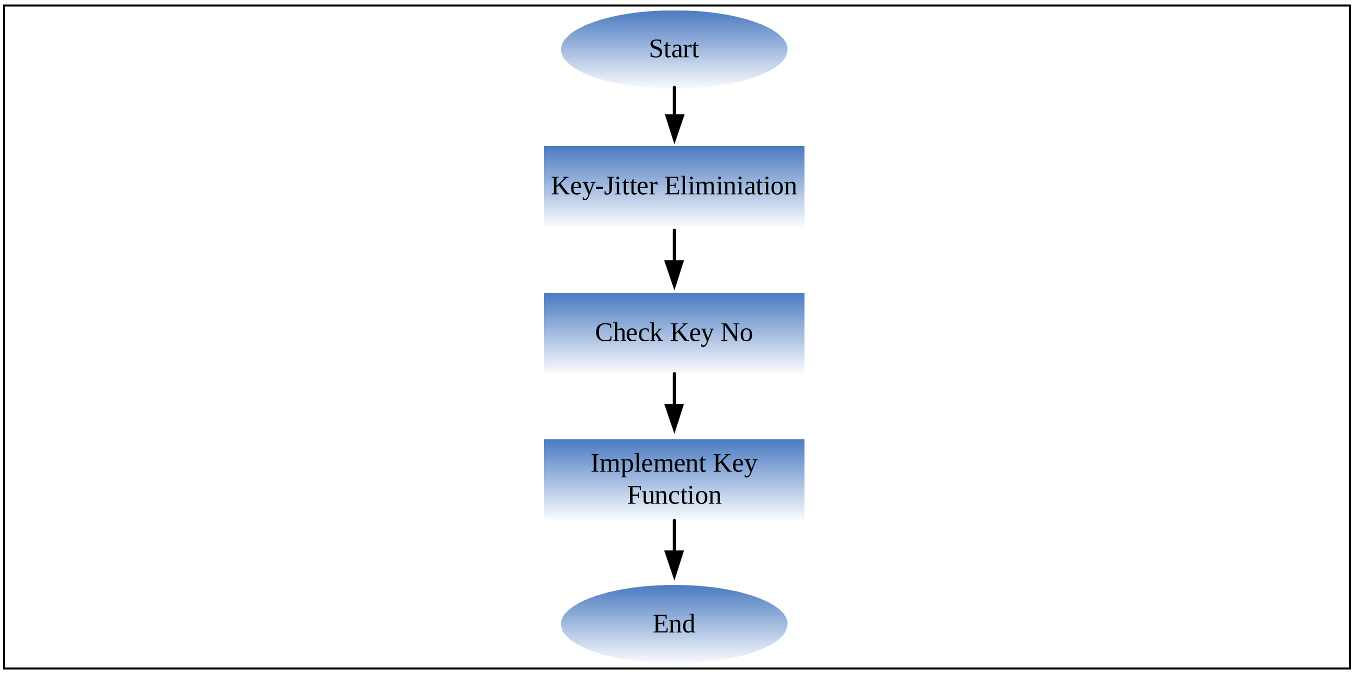

Figure 3-3. Key ISP Flow Chart

There are totally 20 keys in this system which is realized by key strobe module. 9 keys are used for basic function while other 11 keys for advanced function. Below is detailed key function.

Table 3-2 Key Function

Key Style	Key No	Key Name	Function
Basic Key **(Normal mode)**	1	ON/OFF	Power ON/ OFF
	2	MODE	Select Mode（Manual, Auto,Prog1, Prog2）
	3	TIMER	Timer for Power OFF
	4	FAN	Select Fan Speed (High, Mid, Low)
	5	+	Increase expected temperature (Max. 30℃)
	6	-	Decrease expected temperature (Min. 16℃)
	7	LOCK	Key Lock
	8	C/F	Select Unit: Centigrade/ Fahrenheit
Advanced Key (Program Mode, for system programming)	9	PGM	Program Switch (Prog1, Prog2)
	10	DAY UP	Next Day (Used to set current date in normal mode)
	11	DAY DOWN	Previous Day (Used to set current date in normal mode)
	12	TIME	Set Node Time
	13	TEMP.	Set Node Temperature
	14	LEFT	Left Shift (Used to set current time in normal mode)
	15	RIGHT	Right Shift (Used to set current time in normal mode)
	16	UP	Increase (Used to set current time in normal mode)
	17	DOWN	Decrease (Used to set current time in normal mode)
	18	ON TIME	Set Power ON Time
	19	OFF TIME	Set Power OFF Time
	20	ENTER	Enter (Single click to store current node, double click to store Prog1/Prog2 and exit program mode; Used to store user data to flash in normal mode)

3.2.4 Battery Level Detect

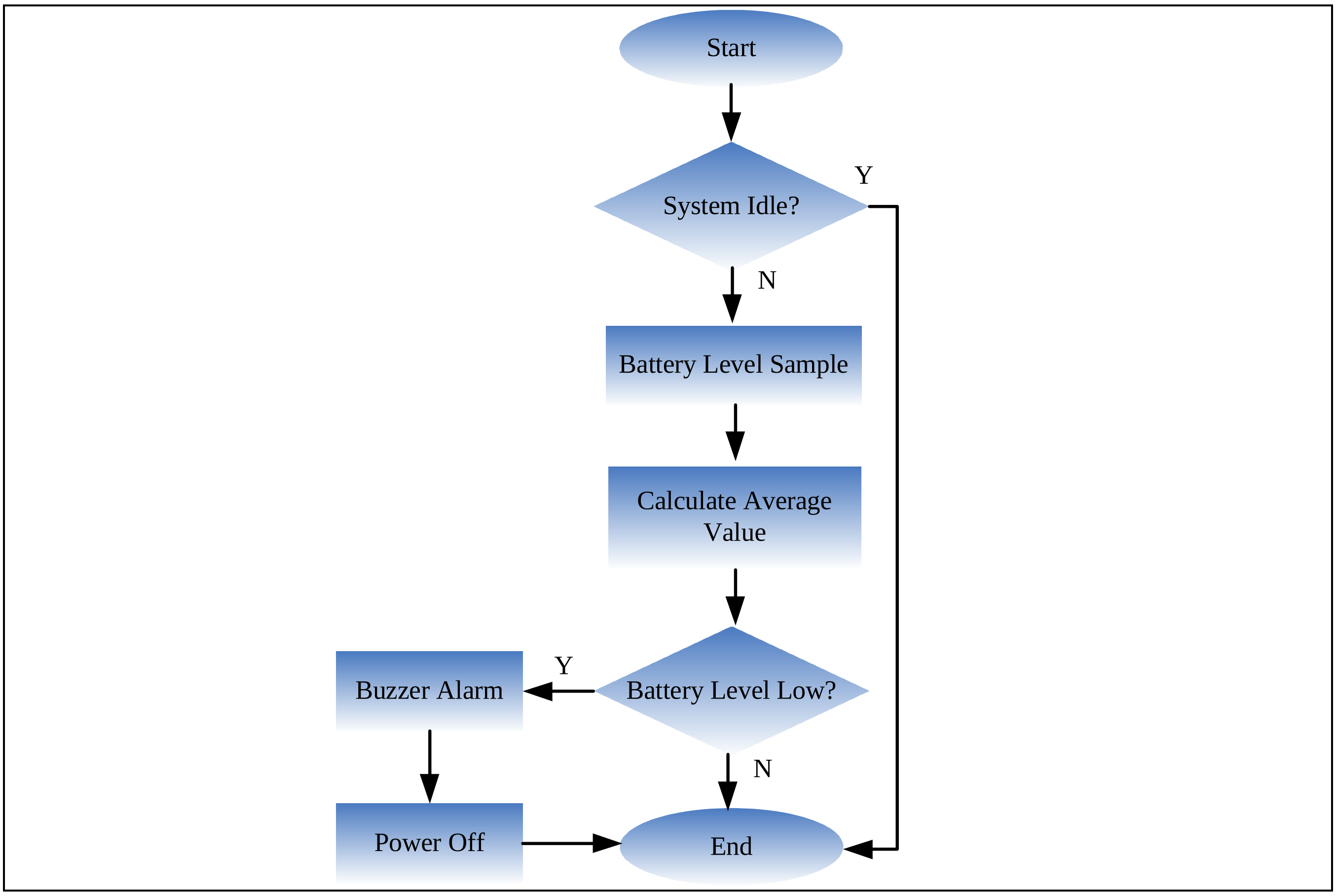

Figure 3-4. BLD Flow Chart

Battery level detect for low level protection.

3.2.5 AC Loss Detect

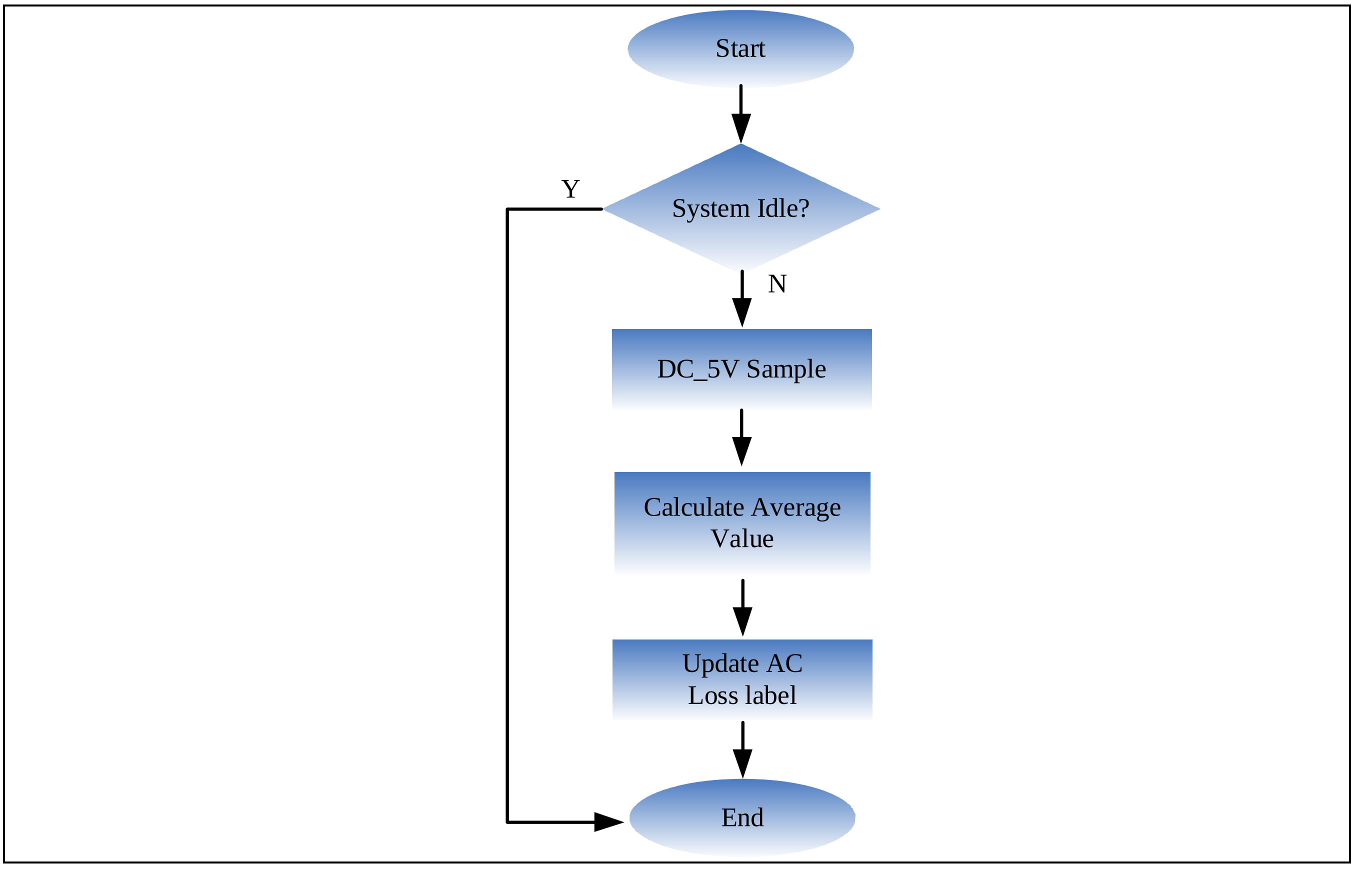

Figure 3-5. AC Loss Detect Flow Chart

Since DC_5V is derived from AC power, it's detected to check whether AC power is loss. If AC power loss, some functions, such as relay control, humidity detect, buzzer control and so on will not be implemented, and other functions, such as LCD display, temperature detect, key function will be active.

3.2.6 Temperature Detect

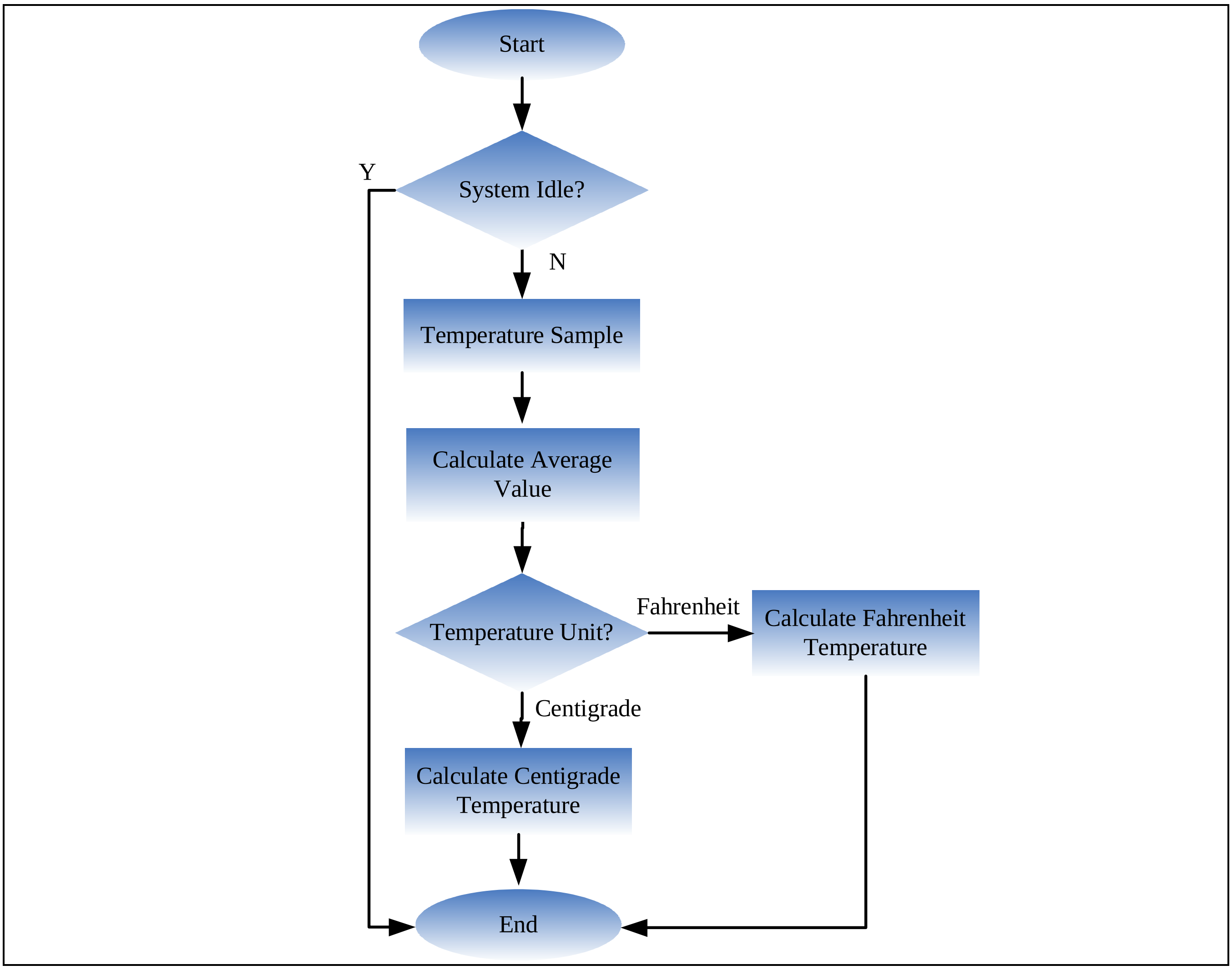

Figure 3-6. Temperature Detect Flow Chart

Two kinds of temperature are supported: Centigrade temperature and Fahrenheit temperature, it's decided by key, default is Centigrade temperature.

3.2.7 Humidity Detect

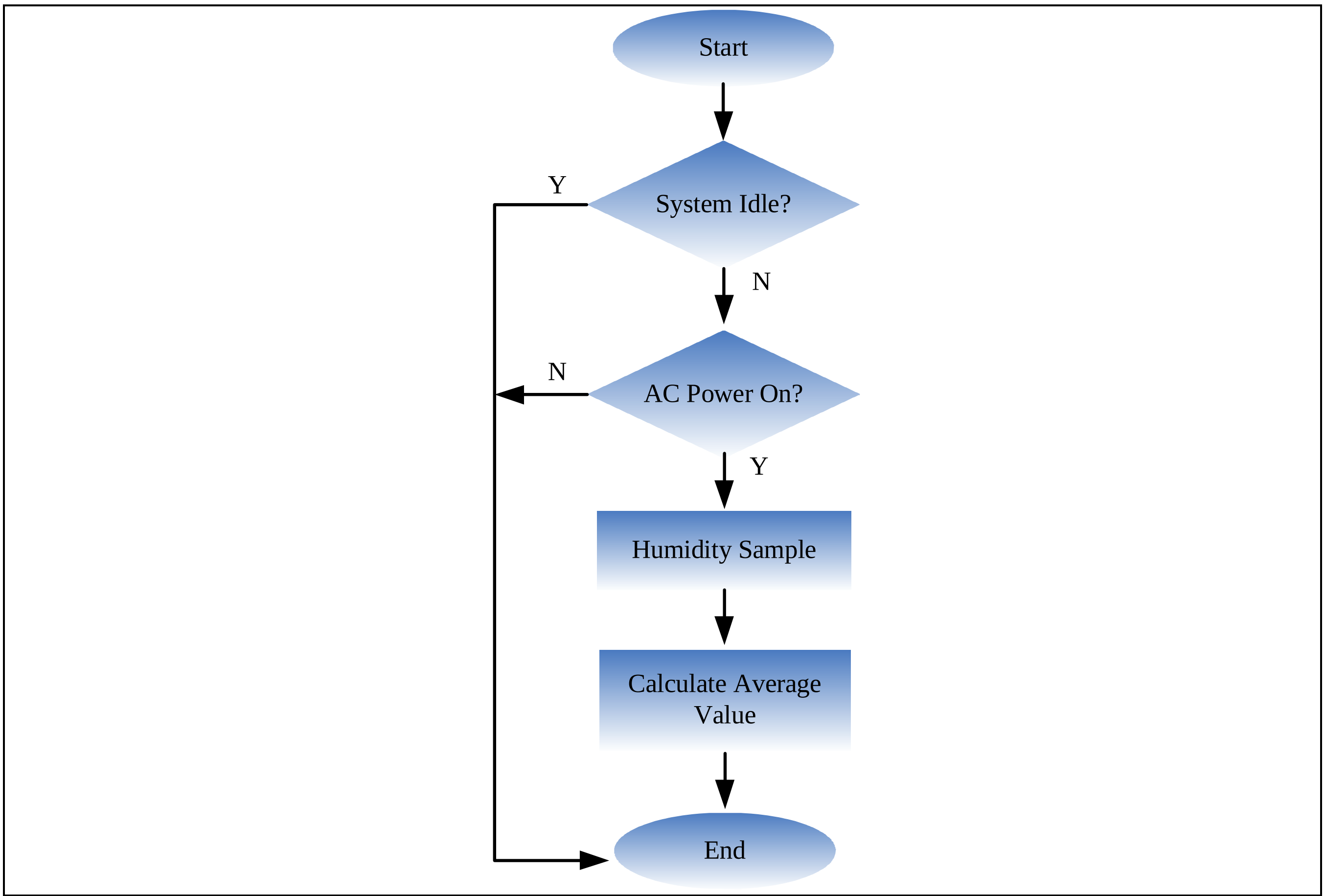

Figure 3-7. Humidity Detect Flow Chart

Humidity detect result will be stable in 10 second, and it's available only when AC power on, because its suitable supply voltage is 3 to 7 Volts.

3.2.8 Fan & Valve Control

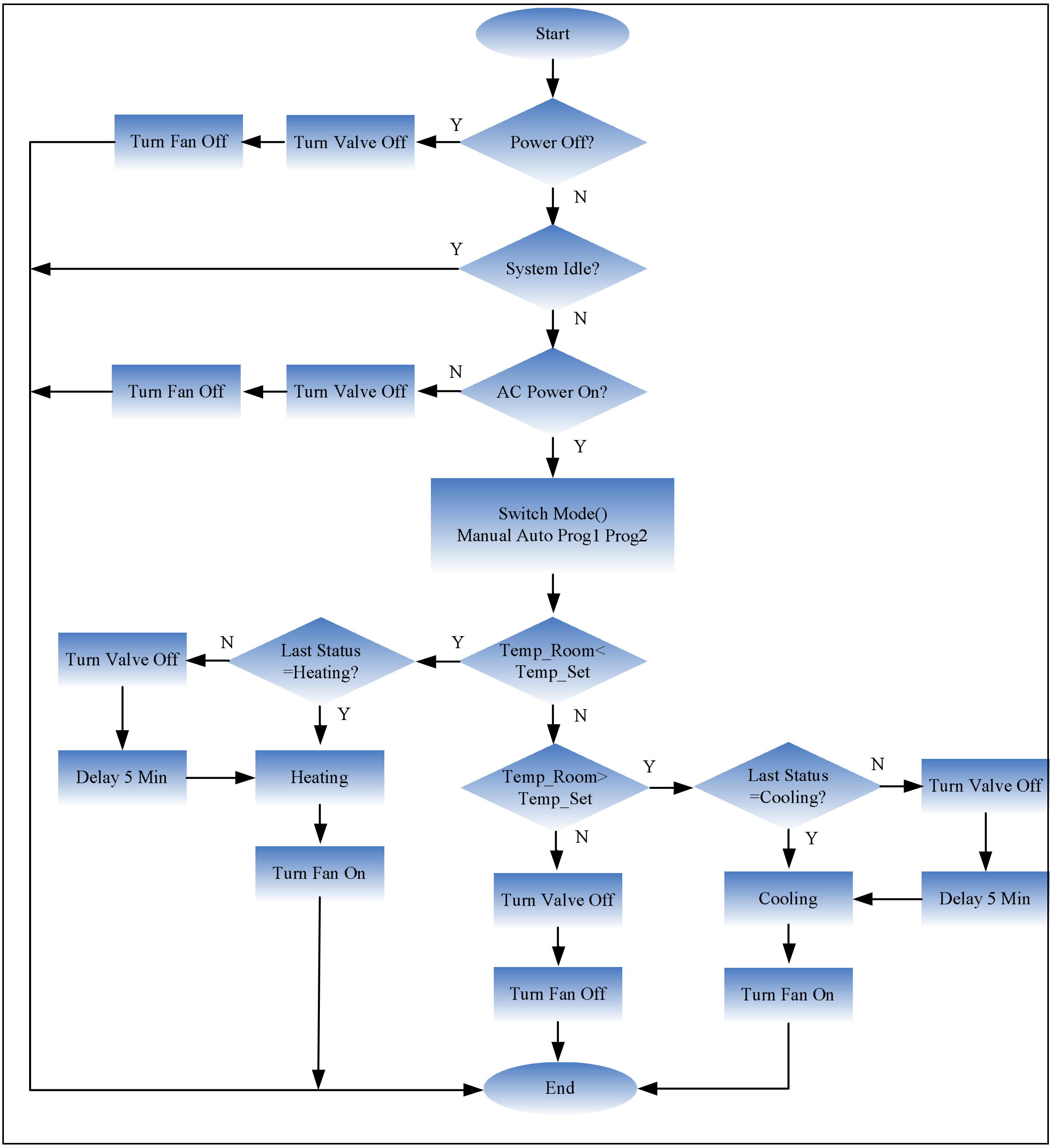

Figure 3-8. Fan & Valve Control Flow Chart

Fan & Valve is the main apparatus for heating or cooling. It's controlled by relay circuit.

3.2.9 Fan Speed Control

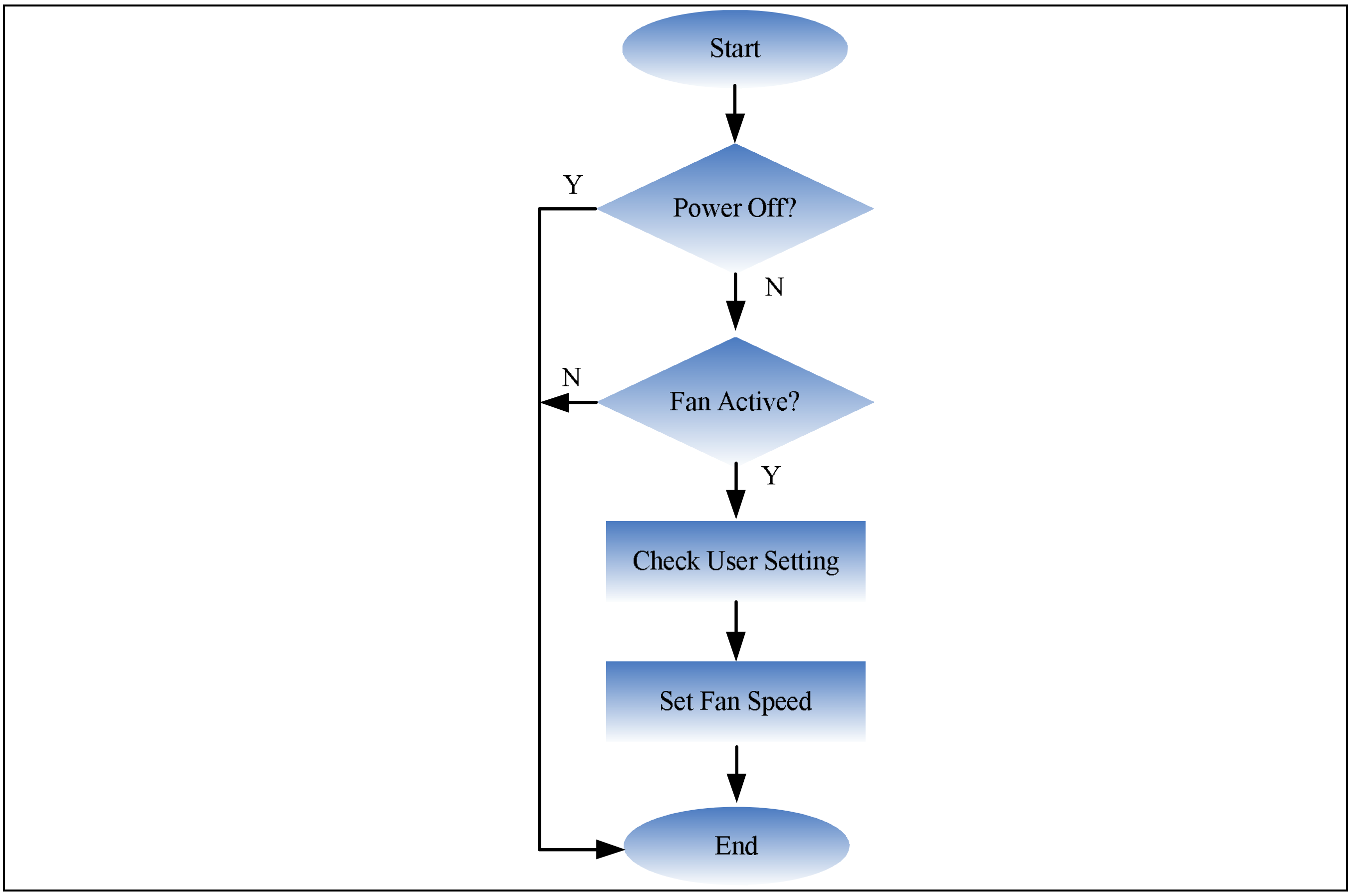

Figure 3-9. Fan Speed Control Flow Chart

Totally 3 options are selectable: high speed, middle speed and low speed. It's decided by key.

3.2.10 Timer Function

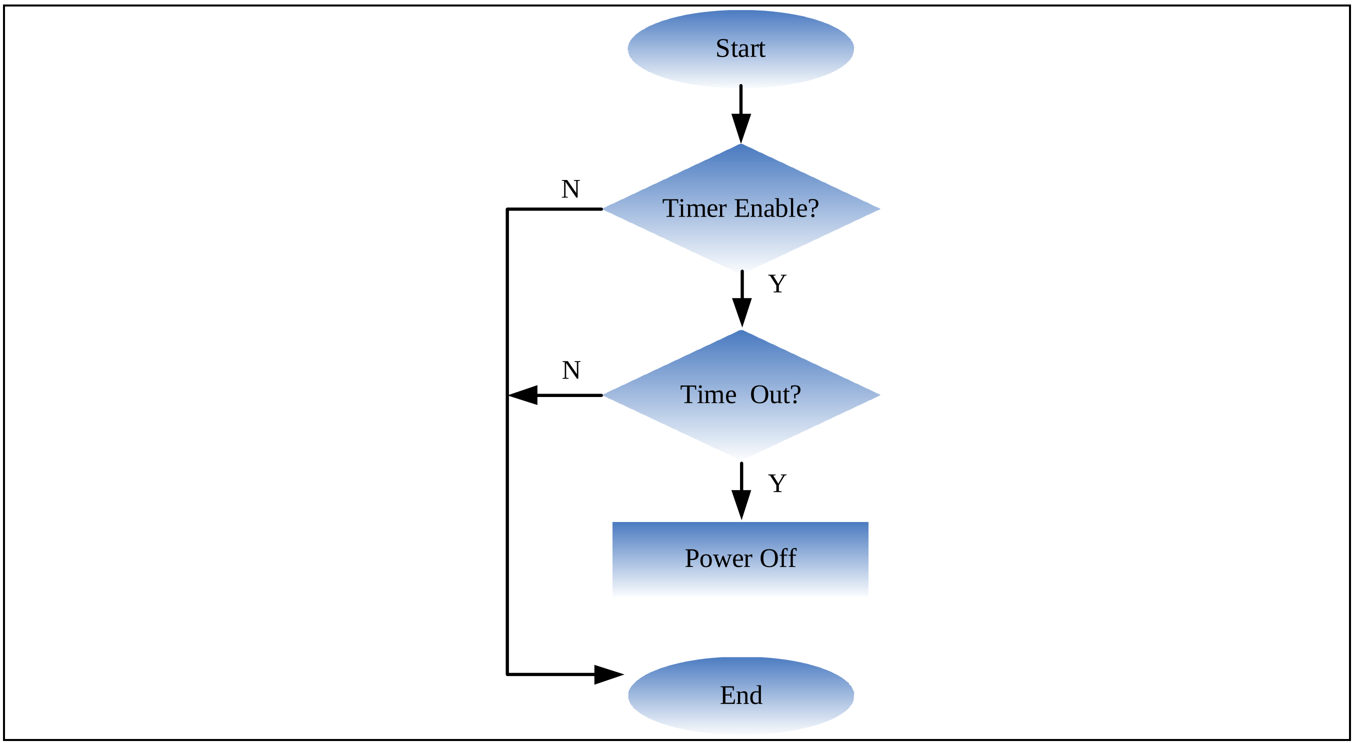

Figure 3-10. Timer Function Flow Chart

Totally 8 options are selectable: 15 min, 30 min, 1 hour, 2 hour, 3 hour, 4 hour, 5 hour and 6 hour. It's decided by key.

3.2.11 LCD Display

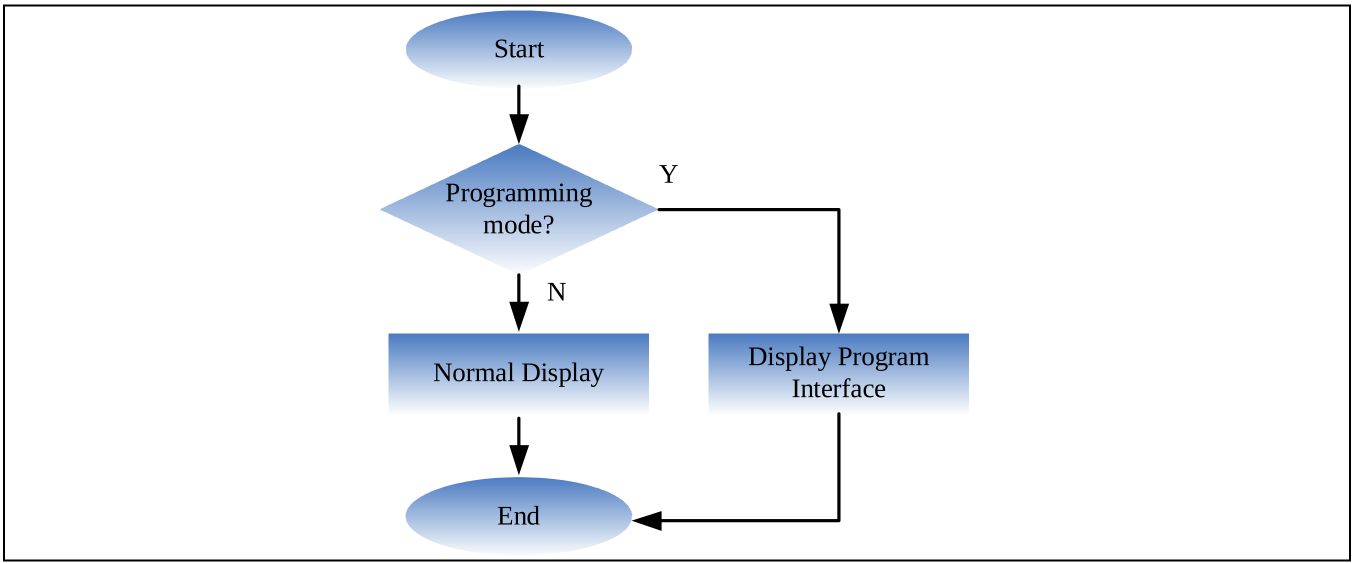

Figure 3-11. LCD Display Flow Chart

This part displays date, time, temperature, humidity, mode, fan speed, program interface and so on.

3.2.12 Flash Read

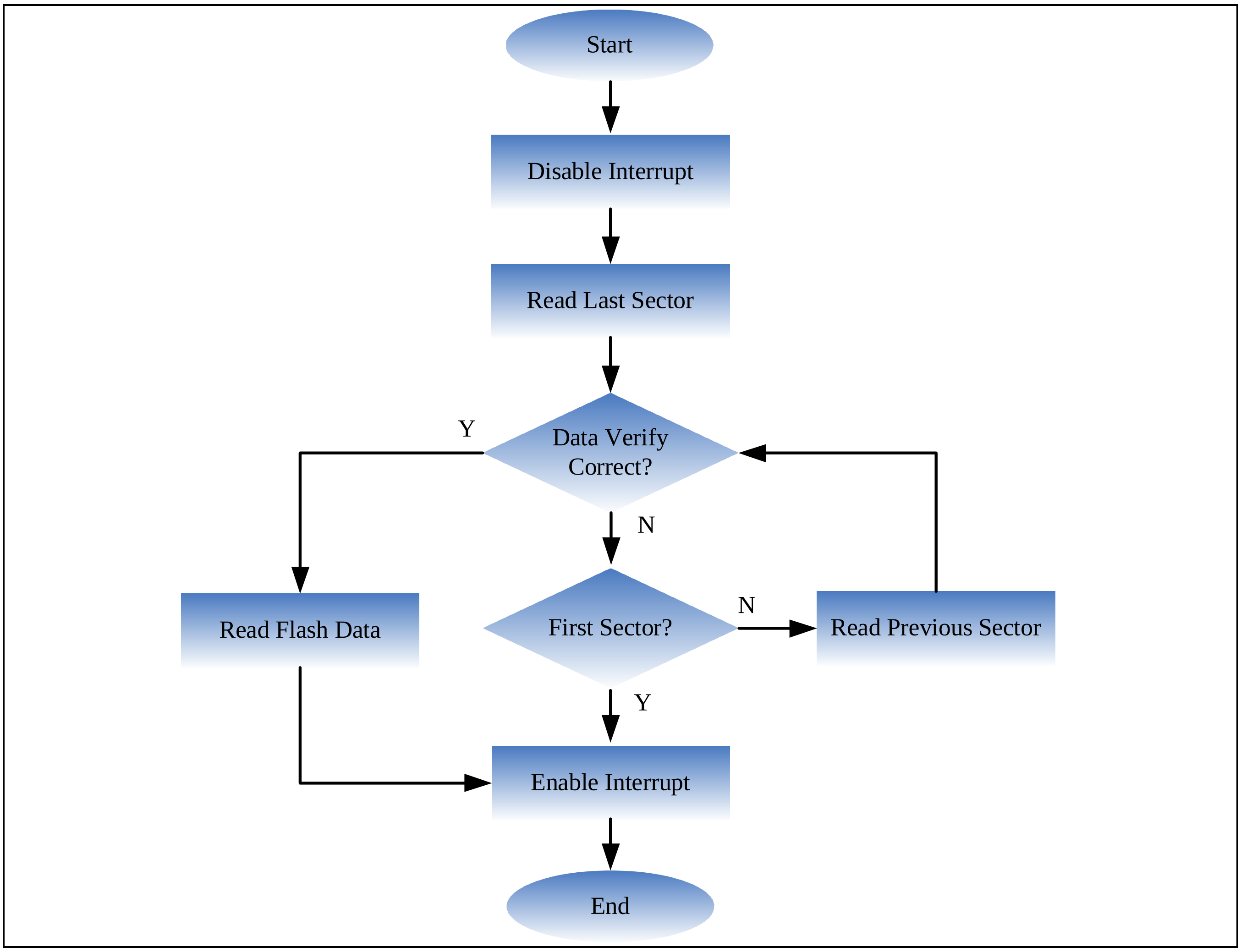

Figure 3-12. Flash Read Flow Chart

This part shows how to read user data from flash to RAM. Since full-flash can be read, programmed and erased on-line, it can act as an EEPROM. In this case, 32 sectors (from 0xe000 to 0xefff) are used for storing user data, each time 1 sector is used. Several bytes are used to verify this sector is active or not. The active sector will be found and loaded into RAM. When power on, flash data is read.

3.2.13 Flash Write

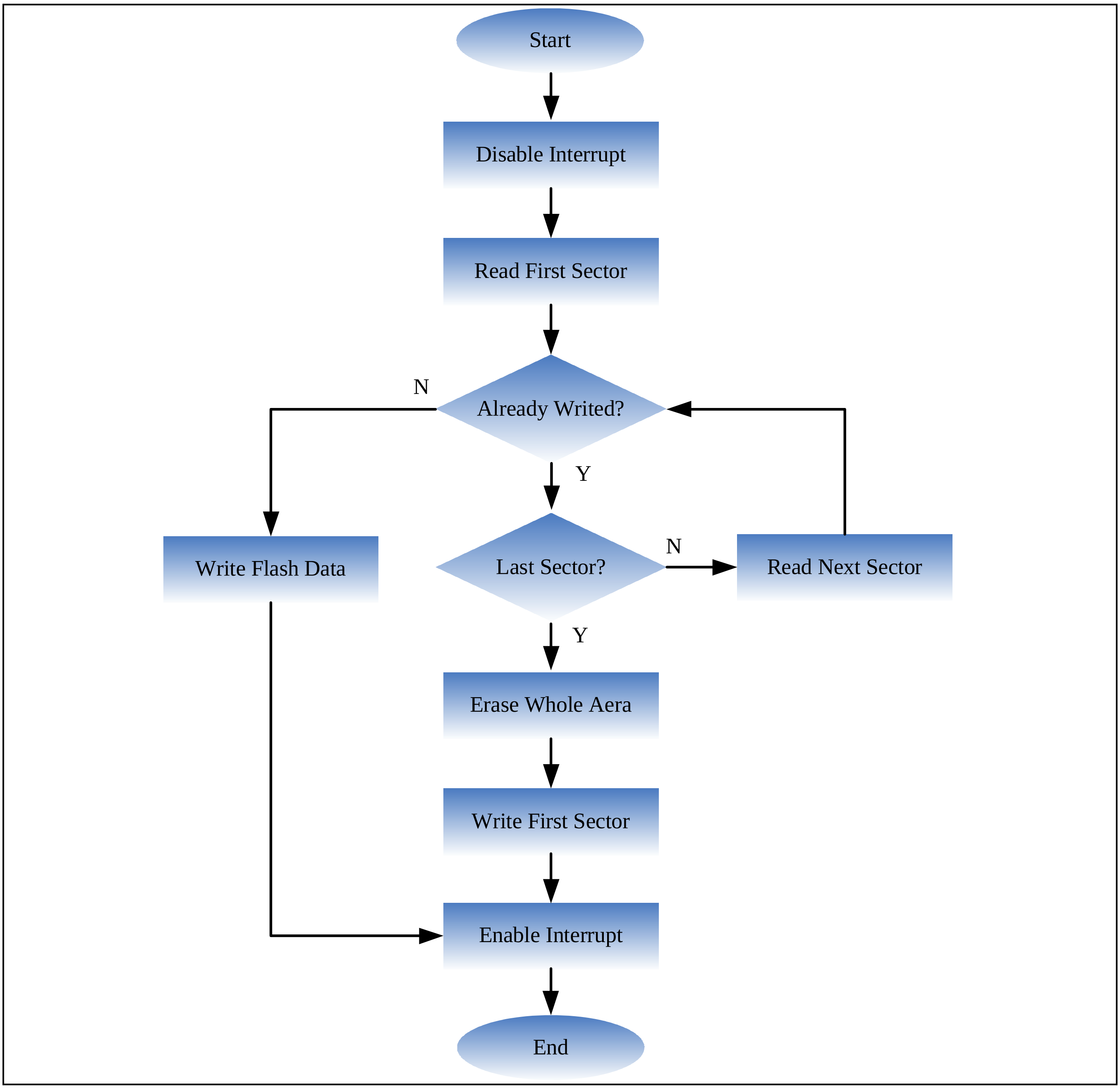

Figure 3-13. Flash Write Flow Chart

This part shows how to store user data to flash. It's similar with flash read function. It will be done when key is pressed, please refer to Table 3-2 Key Function.

4. APPENDIX1: THERMOSTAT DEMO SYSTEM

The demo system is divided into 3 parts: Control board, Test box and Power supply. Control board contains MCU, LCD, Key Matrix & other control circuit. Test box is for real system simulation which contains an Aircon system. Sensor board is located in test box, including temperature sensor and humidity sensor. In normal operation, control board receives sensor signal from test box (sensor board), and also sent control signal to it for cooling or heating. Then the temperature in test box is approached to expected value gradually. The Power Supply converts 220v AC into 2-channel 12v DC, to support control board and test box.

Thermostat can work on Manual mode, Auto mode, PROG1 mode and PROG2 mode, the latter two is user program mode, in these modes users can program 7day's temperature then thermostat will operate automatically.

Figure 4-1 and 4-2 shows the demo system.

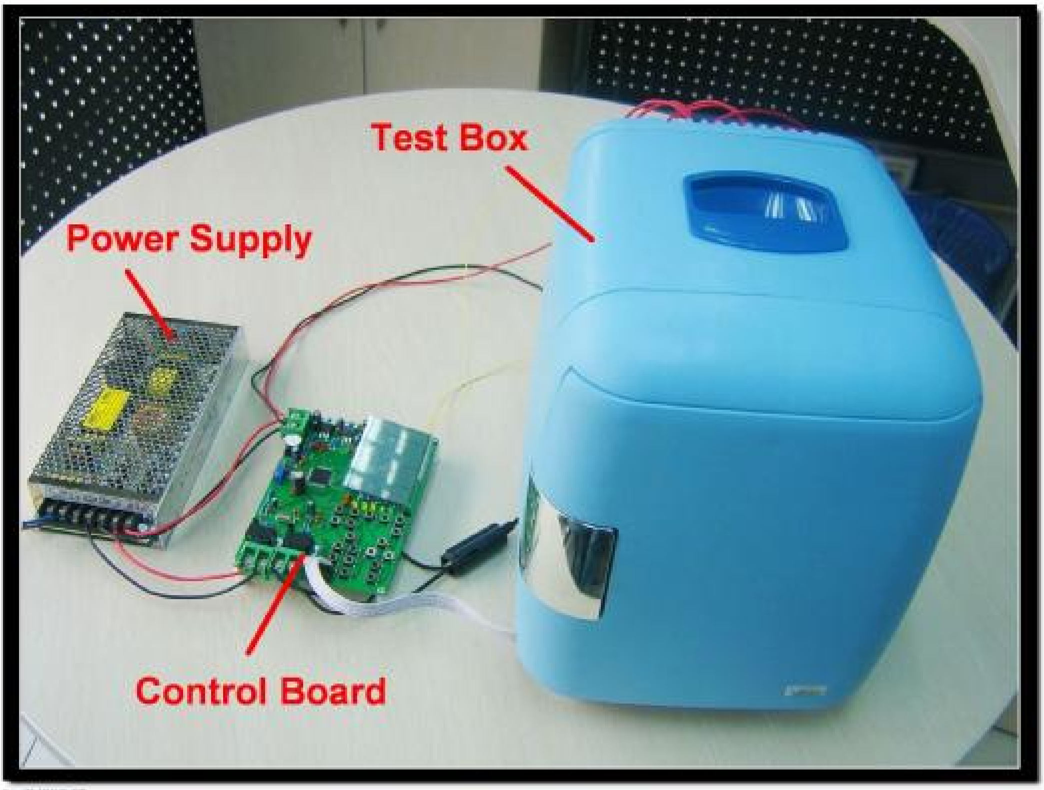

Figure 4-1. Thermostat Demo System (1)

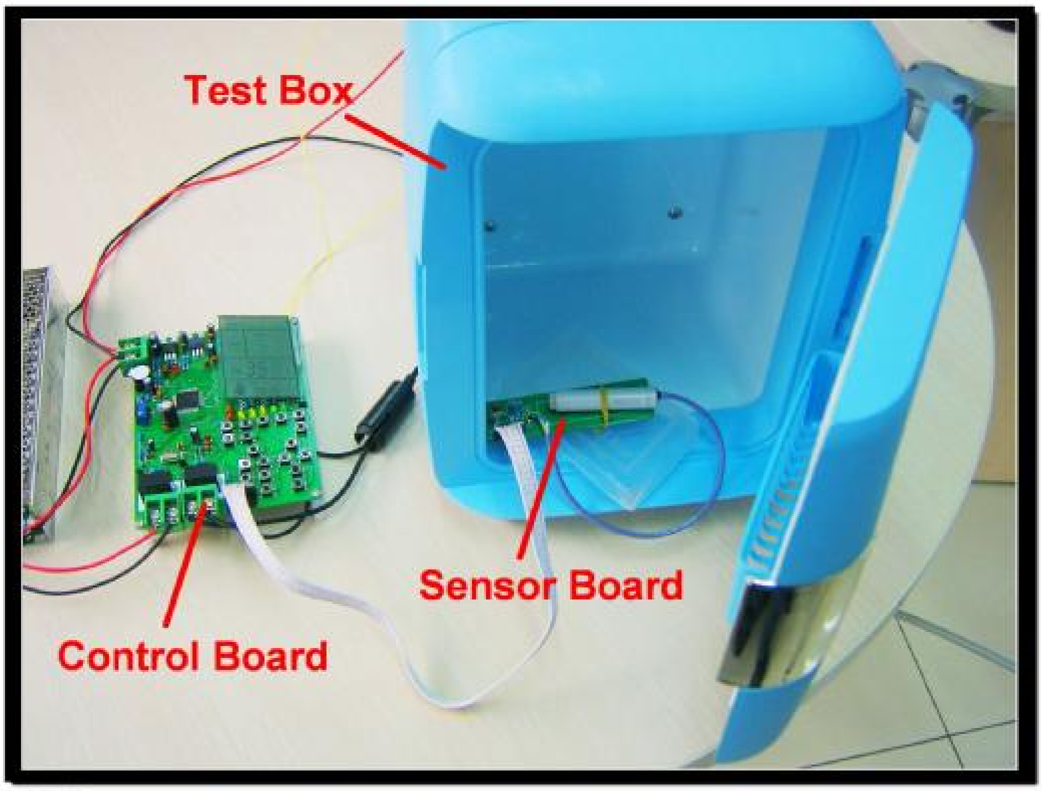

Figure 4-2. Thermostat Demo System (2)

Figure 4-3 shows a close look of thermostat demo control board.

Since system is supplied by battery after AC power off, current consumption is important. The AA battery used is Duracell MN1500, due to S3F84ZB's minimum operating voltage is 2.0V when Fxx=4MHz, and diode 1N5820 has about 0.2V voltage drop (Please refer to Figure 2-2. Power Supply), so battery level must be at least 2.2V, each MN1500 must be at least 1.1V, in this case 2-set MN1500 has about 3500mAh capacity. Because a thermostat's life is more than 2 years, the target average current consumption must be less than 3500mAh/(24hour×365×2) = 0.1997mA.

The real current consumption can be tested through the voltage drop at a small resistor on VDD path. When battery level = 3v, the average voltage drop between the resistor is 2mV and the resistor value is 10.3Ω, so the real current consumption is 2mV/10.3Ω = 0.1941mA, inside the range of target value (Please refer to Table 4-1. Current Consumption Contrast). Note that current consumption will be decreasing while battery voltage drop.

Table 4-1 Current Consumption Contrast

Item	Current Consumption	Conclusion
Target Value	0.1997mA.	Current consumption meets thermostat application requirement, can guarantee a two-year life.
Real Value	0.1941mA	

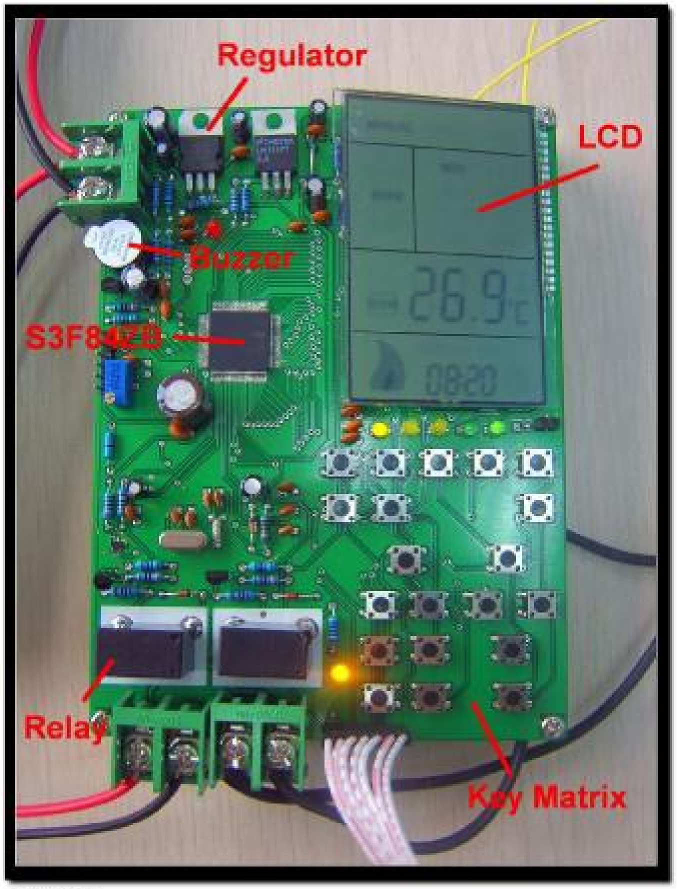

Figure 4-3. Thermostat Demo Control Board

5. APPENDIX2: SOURCE CODE

Please refer to Src_Thermostat.rar.