

# Automotive HVAC Control System with LCD Interface for S12ZVH Family Devices

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**Chapter 1  
Introduction**

1.1.	Application features and components .....	5
1.2.	Advantages and features of MC9S12ZVH128 .....	6

**Chapter 2  
Hardware Description**

2.1.	Introduction .....	9
2.2.	Hardware interface .....	10
2.2.1.	Power supply .....	10
2.2.2.	MC9S12ZVH128 MCU .....	11
2.2.3.	Liquid Crystal Display (LCD) .....	17
2.2.4.	Actuator motor driver .....	19
2.2.5.	Blower motor driver .....	21
2.2.6.	MC9S08PT60 for touch sense .....	22
2.2.7.	IR receiver .....	24
2.2.8.	Temperature sensor .....	24
2.2.9.	Background debug mode (BDM) .....	25
2.2.10.	Audio interface .....	26
2.2.11.	Ignition control .....	27

**Chapter 3  
Design Architecture and Features**

3.1.	Introduction .....	28
3.2.	Design architecture .....	28
3.2.1.	LCD graphics display .....	30
3.2.2.	User interface .....	31
3.2.3.	Motor control .....	34
3.2.4.	Temperature sensor .....	36
3.2.5.	Real time clock .....	36

**Chapter 4  
Testing and Measurements**

4.1.	Hardware setup .....	37
4.2.	Debugging and measurement .....	39
4.2.1.	LCD .....	39
4.2.2.	User interface .....	39
4.2.3.	Motor control .....	41
4.3.	Temperature sensor .....	45

**Appendix A**

A.1	Schematic .....	47
A.2	Layout .....	51
A.2.1	Silkscreen top .....	51
A.2.2	Silkscreen bottom .....	51
A.2.3	Top .....	52
A.2.4	Bottom .....	52

**Appendix B  
Bill of Material**

## Chapter 1 Introduction

This document describes the reference design of an automotive Heating, Ventilation, and Air Conditioning (HVAC) control system with LCD interface board based on MC9S12ZVH128.

The purpose of the design is to replace the existing mechanical switches, which are prone to wear and tear, with interactive LCD based system for longevity and robustness of the system. Freescale has a full portfolio of HVAC design for the entire four-wheeler segments. The design described in this document is intended for lower and mid segment four-wheelers.



Figure 1. **Conventional HVAC**

Block diagram of MC9S12ZVH128 based HVAC system is shown in [Figure 2](#).

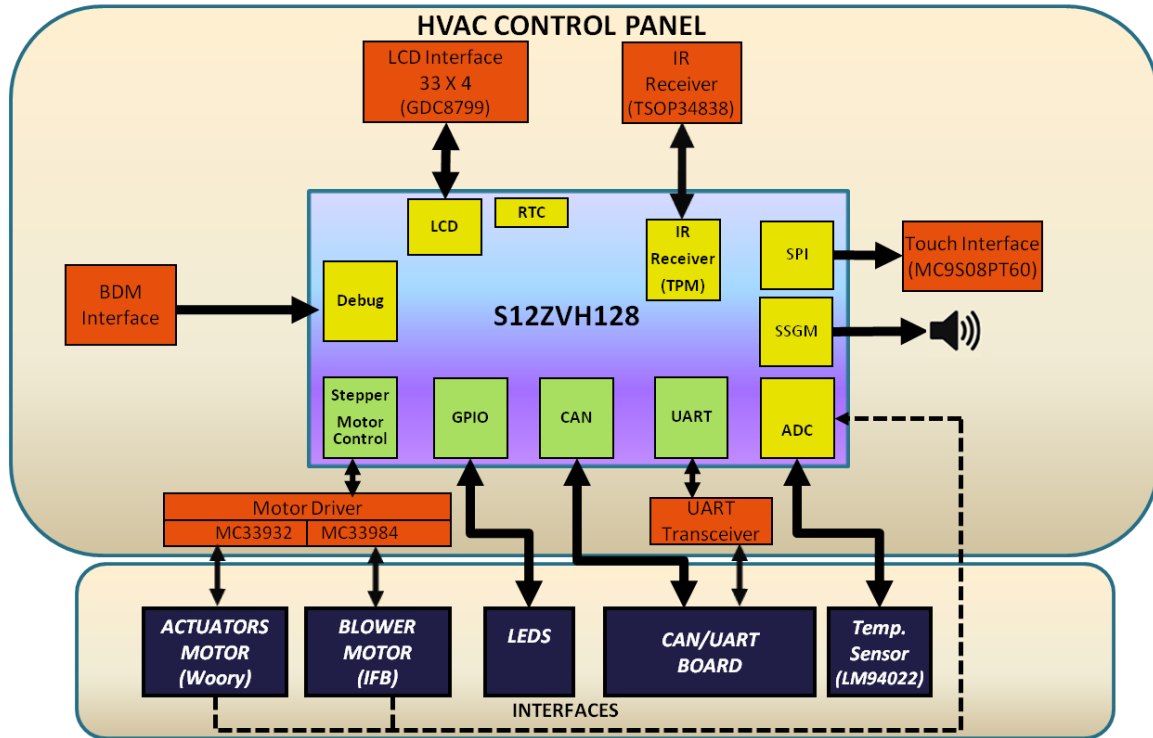


Figure 2. Block diagram

## 1.1. Application features and components

The salient features of the reference design are as follows:

- LCD based Graphics Interface
- Control for airflow (Face, Foot, Defrost, Face & Defrost and Face & Foot) directions using actuator motors
- Control for recirculation using actuator motor
- 5-level control for blower speed using PMDC motor
- 9-level control for cooling/warming using actuator motor
- Car cabin's temperature display
- Real Time Clock display and adjustment
- Date display and adjustment
- IR remote interface
- 8 Touch pad interface
- Low Power Mode interfaced through Ignition

## Introduction

The package that shall be supplied to the user for developing the HVAC system based on MC9S12ZVH128 MCU includes:

- Hardware – Reference HVAC board
- Software – Source code
- Documentation – DRM, BOM, Schematics

## 1.2. Advantages and features of MC9S12ZVH128

Advantages of using MC9S12ZVH128 include:

- In-built 5 V regulator (VREG) which directly takes 12 V battery supply as input and supplies 5 V to MCU as well as other peripherals
- Supply voltage sense with low battery warning
- Low-voltage detect (LVD) with low-voltage interrupt (LVI) and Low-voltage reset (LVR)
- On Chip Temperature Sensor for over-temperature protection and interrupt
- On Chip CAN physical layer
- In-built LCD driver capable of driving 160 segments
- In-built Real Time Clock (RTC) with Hour/Minute/Second function
- Stepper Motor Controller and Stepper Stall Detect modules
- Simple Sound Generation (SSG) for monotonic tone generation
- MCU security mechanism that prevents unauthorized access to the Flash memory
- Two static low-power modes Pseudo Stop and Stop Mode to facilitate power saving when full system performance is not required

The general features of MC9S12ZVH128 MCU are:

- S12Z CPU core
- 128- or 64-KB on-chip flash with ECC
- 4-KB EEPROM with ECC
- 8- or 4-KB on-chip SRAM with ECC
- Phase locked loop (IPLL) frequency multiplier with internal filter
- 1 MHz internal RC oscillator with +/-1.3% accuracy over rated temperature range
- 4-16 MHz amplitude controlled pierce oscillator
- 32 kHz oscillator for RTC and LCD
- Internal COP (watchdog) module
- LCD driver for segment LCD with 40 frontplanes x 4 backplanes
- Stepper Motor Controller with drivers for up to four motors
- Up to four Stepper Stall Detector (SSD) modules (one for each motor)
- Real Time Clock (RTC) support of the Hour/Minute/Second function and frequency

compensation

- One Analog-to-Digital Converters (ADC) with 10-bit resolution and up to 8 channels available on external pins
- Two Timer module (TIM) supporting input/output channels that provide a range of 16-bit input capture & output compare (8 channels)
- One Pulse Width Modulation (PWM) modules with up to 8 x 8-bit channels
- Simple Sound Generation (SSG) for monotonic tone generation
- One Inter-Integrated Circuit (IIC) module
- One Serial Peripheral Interface (SPI) module
- Two Serial Communication Interface (SCI) module supporting LIN 1.3, 2.0, 2.1, and SAE J2602 communications
- Up to one on-chip high-speed CAN physical layer transceiver
- One MSCAN (up to 1 Mbit/s, CAN 2.0 A, B compliant) module
- On-chip Voltage Regulator (VREG) for regulation of input supply and all internal voltages
- Autonomous Periodic Interrupt (API) (combination with cyclic, watchdog)
- Supply voltage sense with low battery warning
- Chip temperature sensor
- Available in 100 LQFP and 144 LQFP packages

## S12ZVH: S12 MagniV Mixed-Signal MCU

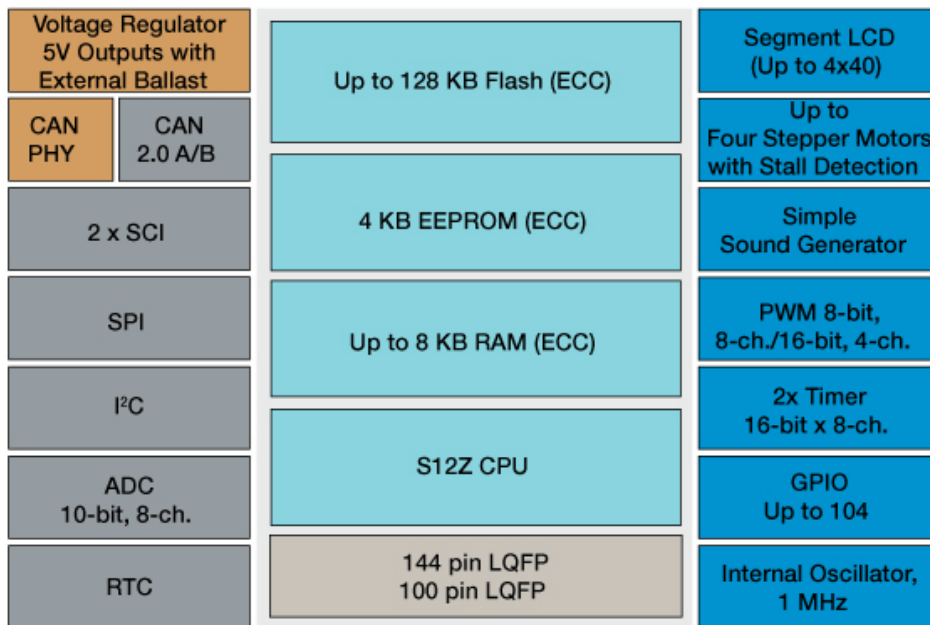


Figure 3. Block diagram of S12ZVH family

## Chapter 2 Hardware Description

### 2.1. Introduction

The reference design consists of:

- Power supply section
- 144-pin LQFP packaged MC9S12ZVH MCU
- 132 segment (33X4) LCD Glass interface with backlight control
- Intelligent High-current Self-protected Silicon High Side Switch, MC33984, capable of driving two blower motors of 15 A each
- Two Throttle Control H-Bridge, MC33932, for controlling four high current actuator motors, three of these are used for temperature, vent position, and re-circulation, while one of the motor control has been kept for future use
- 64-pin MC9S08PT60 which has Touch Sense Input (TSI) module for eight touch pad interface
- IR remote interface, provided especially for the ease of control for rear-seat passengers
- Temperature sensor for measuring cabin temperature
- CAN interface for communication with various other units
- Ignition control section for low power mode simulation

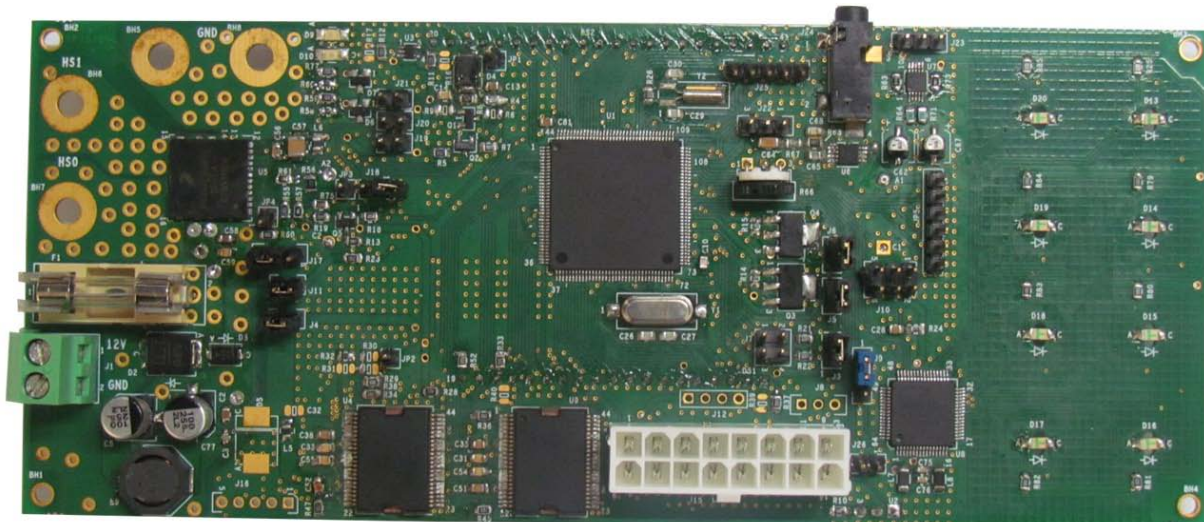


Figure 4. MC9S12ZVH128-based HVAC reference design PCB—MCU side



Figure 5. MC9S12ZVH128-based HVAC reference design PCB-LCD side

## 2.2. Hardware interface

The following section details each hardware block with the corresponding schematic.

### 2.2.1. Power supply

The reference design board is switched on from an automotive battery, 12 V, 32 AH. It is connected directly with

- MCU, MC9S12ZVH128
- Blower motor driver, MC33984, as the blower motor is 12 V compatible
- Actuator motor driver, MC33932, as the actuator motors are 12 V compatible

Signal conditioning circuitry has been added on 12 V supply to avoid any negative spikes.

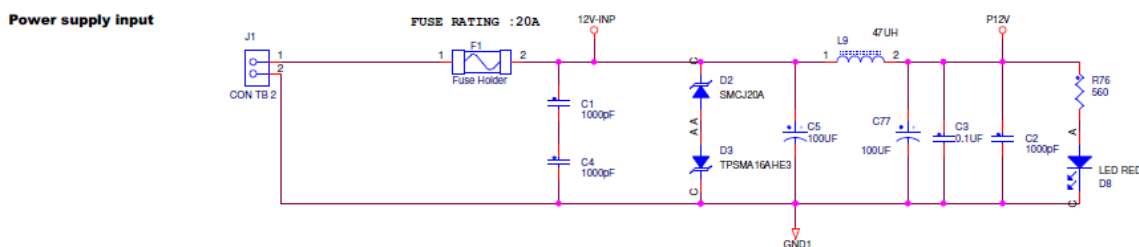


Figure 6. Signal conditioning circuitry on input supply

## 2.2.2. MC9S12ZVH128 MCU

The MC9S12ZVH-Family delivers an optimized solution with the integration of several key system components into a single device, optimizing system architecture, and achieving significant PCB space savings. The MC9S12ZVH-Family is targeted at automotive and motorcycle instrument cluster applications requiring CAN connectivity, stepper motor gauges, and segment LCD displays.

The reference design utilizes the following modules of MC9S12ZVH128:

1. 5 V regulator (VREG) which directly takes 12 V battery supply as input and supplies 5 V to MCU as well as other peripherals
2. On-chip CAN physical layer
3. LCD controller to drive 33x4 LCD
4. SPI and TIM module for controlling and driving the blower motor driver IC
5. TIM module for interfacing IR remote control
6. SPI module for interfacing with S08PT60
7. BKGD for programming
8. Real Time Clock (RTC) module with Hour/Minute/Second function
9. ADC module for Temperature sensor and stall detection of blower and actuator motors
10. IRQ as a wakeup source
11. Simple Sound Generation (SSG) for monotonic tone generation

The functional pin assignment for MC9S12ZVH128 is described in [Table 1](#) and the schematic in [Figure 7](#).

Table 1. Functional pin assignment

Pin Package	Pin Assignment	Purpose
LQFP 144		
1	FP26	LCD
2	FP25	LCD
3	FP24	LCD
4	VLCD	LCD

## Hardware Description

5	FP23	LCD
6	PT7	GPIO Header
7	NC	
8	NC	
9	PU0	U4, IN1 (Actuator 1)
10	PU1	U4, IN2 (Actuator 1)
11	PU2	U9, IN3 (Actuator 2)
12	PU3	U9, IN4 (Actuator 2)
13	VDDM1	
14	VSSM1	
15	PU4	U9, IN1 (Actuator 3)
16	PU5	U9, IN2 (Actuator 3)
17	PU6	U4, IN3
18	PU7	U4, IN4
19	IOC0_4	IR
20	Not Used	
21	IOC0_5	Used for Edge detect for checking the Stall on blower motor1
22	Not Used	
23	VDDM2	
24	VSSM2	
25	IOC0_6	Used for Edge detect for checking the Stall on blower motor2
26	Not Used	
27	PV6	Control of MC33984 reset pin
28	PV7	Control of MC33932 enable pin
29	NC	
30	NC	
31	PT6	GPIO Header
32	FP22	LCD

33	FP21	LCD
34	FP20	LCD
35	FP19	LCD
36	FP18	LCD
37	FP17	LCD
38	FP16	LCD
39	FP15	LCD
40	FP14	LCD
41	FP13	LCD
42	FP12	LCD
43	FP11	LCD
44	FP10	LCD
45	FP9	LCD
46	FP8	LCD
47	Not Used	
48	Not Used	
49	Not Used	
50	Not Used	
51	Not Used	
52	Not Used	
53	FP1	LCD
54	FP0	LCD
55	TEST	
56	PWM1	Blower Motor1
57	PWM3	Blower Motor2
58	(RXD1)	UART
59	(TXD1)	UART
60	VSS1	
61	VDDF	
62	Not Used	

**Automotive HVAC Control System with LCD Interface for S12ZVH Family devices**

## Hardware Description

63	Not Used	
64	Not Used	
65	Not Used	
66	RESET	
67	EXTAL	4MHz Crystal
68	XTAL	4MHz Crystal
69	VSSX1	
70	VDDX1	
71	Not Used	
72	PT5	GPIO Header
73	VSUP	12V input
74	NC	
75	VDDC	Supply voltage for CAN
76	NC	
77	CANH0	CAN Physical layer
78	NC	
79	VSSC	
80	NC	
81	CANL0	CAN Physical layer
82	NC	
83	SPLIT0	CAN Physical layer
84	NC	
85	NC	
86	VSENSE	Supply Volage Sense
87	BCTL	Ballast Transistor control for VDDX
88	BCTLC	Ballast Transistor control for VDDC
89	MISO0	SPI
90	MOSI0	SPI
91	SCK0	SPI

92	SS0	SPI
93	KWS4	PT60 Interrupt
94	Not Used	
95	XIRQ	Ignition
96	IRQ	Ignition
97	VDDX2	
98	VSSX2	
99	PT0	GPIO Header
100	PT1	GPIO Header
101	PT2	GPIO Header
102	PT3	GPIO Header
103	PT4	GPIO Header
104	SGT0	Hazard warnings
105	SGA0	Hazard warnings
106	PC6	PT60 SPI CS
107	Not Used	
108	BKGD	Debugging MCU
109	PAD0	GPIO Header
110	AN0_1	Actuator 1 Feedback
111	AN0_2	Actuator 3 Feedback
112	AN0_3	Actuator 2 Feedback
113	AN0_4	Temp Sensor Output
114	AN0_5	Feedback for HS0 on MC33984
115	AN0_6	Feedback for HS1 on MC33984
116	AN0_7	Feedback for Actuator
117	VDDA	
118	VSSA	
119	32K_EXTAL	32kHz Crystal for RTC
120	32K_XTAL	32kHz Crystal for RTC
121	VSS2	

**Automotive HVAC Control System with LCD Interface for S12ZVH Family devices**

## Hardware Description

122	VDD	
123	PP0	LCD_BACKLIGHT
124	Not Used	
125	Not Used	
126	BP3	LCD
127	BP2	LCD
128	BP1	LCD
129	BP0	LCD
130	VDDX3	
131	VSSX3	
132	PH7	SHUTDOWN control for U7
133	FP38	LCD
134	FP37	LCD
135	FP36	LCD
136	FP35	LCD
137	FP34	LCD
138	FP33	LCD
139	FP32	LCD
140	FP31	LCD
141	FP30	LCD
142	FP29	LCD
143	FP28	LCD
144	FP27	LCD

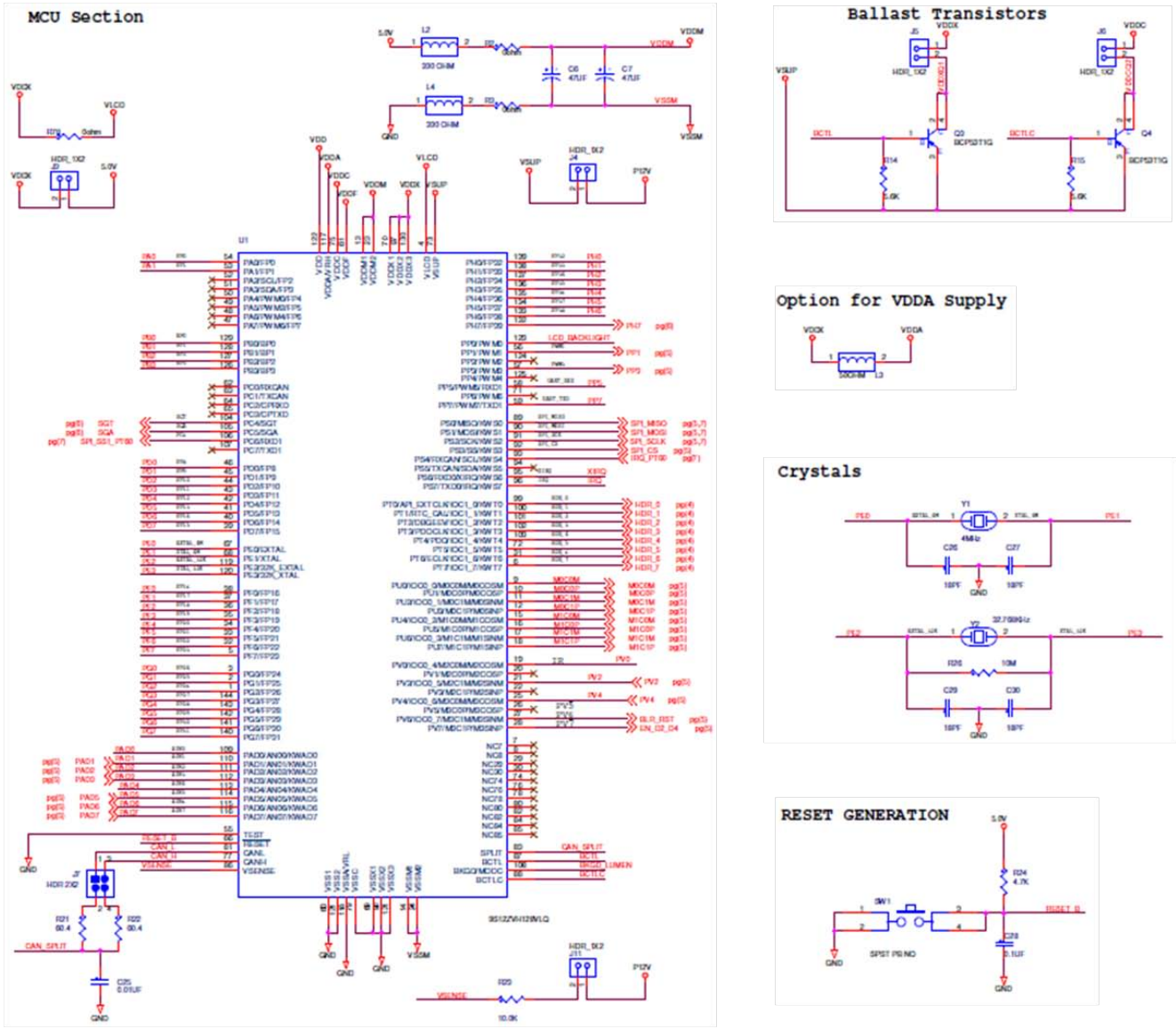


Figure 7. MCU section

The design utilizes two crystals: a 4 MHz crystal used to generate the system bus clock and a 32 kHz crystal dedicated for RTC.

The design has external ballast transistors for generating VDDX and VDDC. VDDC is supply voltage for the on chip CAN physical layer. VDDX is the voltage source to other MCU IPs and 5 V peripherals on the board.

2.2.3. Liquid Crystal Display (LCD)

132 segments (33X4) LCD Glass, GDC8799D, is interfaced with the MCU. The glass has four back planes and 33 front planes and is shown in Figure 8.

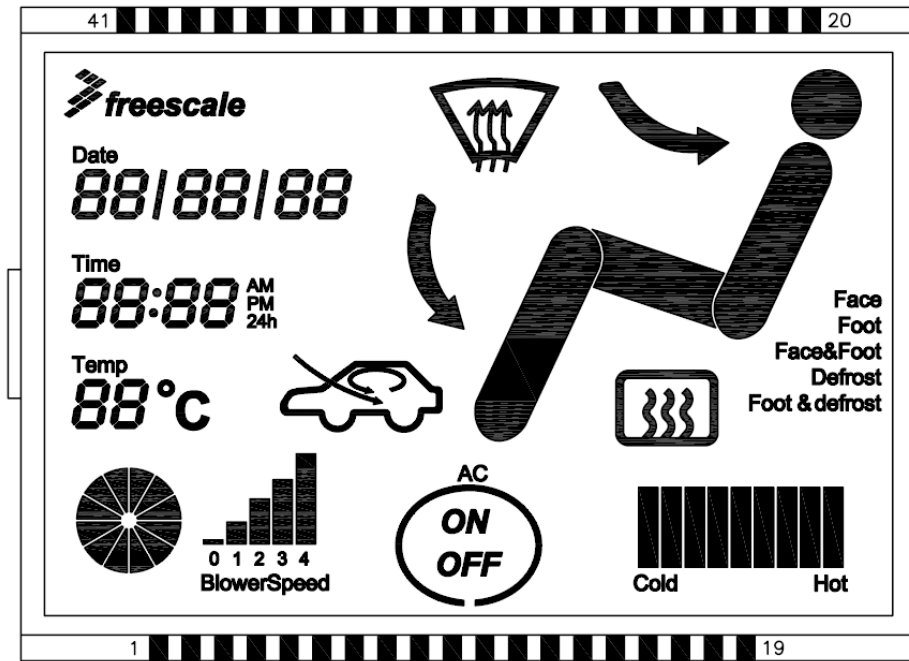


Figure 8. LCD Glass

The details of the LCD glass are as follows:

1. Viewing angle : 6 O'clock
2. LCD Type : TN, Positive, Transreflective
3. Multiplex level : ¼ Duty, 1/3 Bias
4. LCD driving voltage : 5.0 V

As the LCD glass is transreflective, backlight has been added to improve its contrast, which is controlled through the MCU and is shown in figure below.

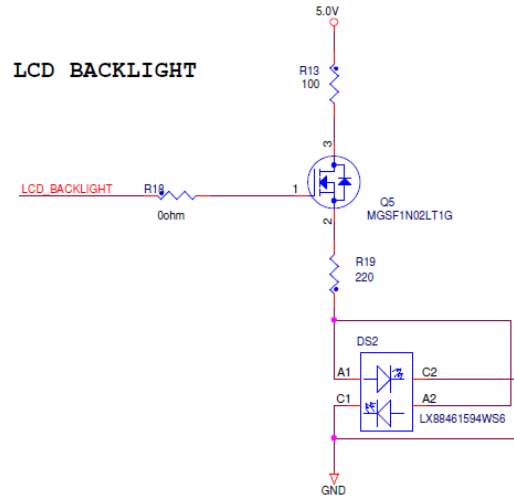


Figure 9. LCD Glass backlight

### 2.2.4. Actuator motor driver

MC33932 is an H-Bridge Power IC that has two independent monolithic H-Bridge Power ICs in the same package, which is used to drive the actuator motors. The present design uses two such ICs, capable of driving four motors. Three of these motor drivers have been utilized while one has been kept for future enhancements. Three actuator motor controls include:

- Cooling control
- Air flow vent position control
- Recirculation control

Each actuator motor requires maximum 400 mA current that is sourced through MC33932. GPIO pins are used to drive the H-Bridge inputs. The schematic of one of the actuator motor interface is shown in the figure below.





## Hardware Description

The reference design has the support for interfacing two blower motors, as there are HVAC units which requires two blower motors to be driven. The blower motor used in the design is of the following specifications:

Table 2. **Blower motor specifications**

S. No.	Parameters	Specifications
1	Motor Type	PMDC
2	Motor Rating	Continuous
3	Rated Voltage	12V
4	No Load Current	1.7A
5	No Load Speed	4500 rpm
6	Rate Torque	0.3Nm
7	Rated Current	14.5 A
8	Rated Speed	3600 $\pm$ 5%
9	Direction of Rotation	CCW

### 2.2.6. MC9S08PT60 for touch sense

The 8-bit MCU S08PT60 has Touch Sense Interface (TSI) module which is utilized in the design for capacitive touch sensing. The touch sensing input (TSI) module provides capacitive touch sensing detection with high sensitivity and enhanced robustness. Each TSI pin implements the capacitive measurement by a current source scan, charging and discharging the electrode, once or several times. A reference oscillator ticks the scan time and stores the result in a 16-bit register when the scan completes. Meanwhile, an interrupt request is submitted to CPU (which is S12ZVH128 in this design) for post-processing. After receiving the interrupt, S12ZVH128 communicates with PT60 on SPI bus and gets the information about which pad is touched.

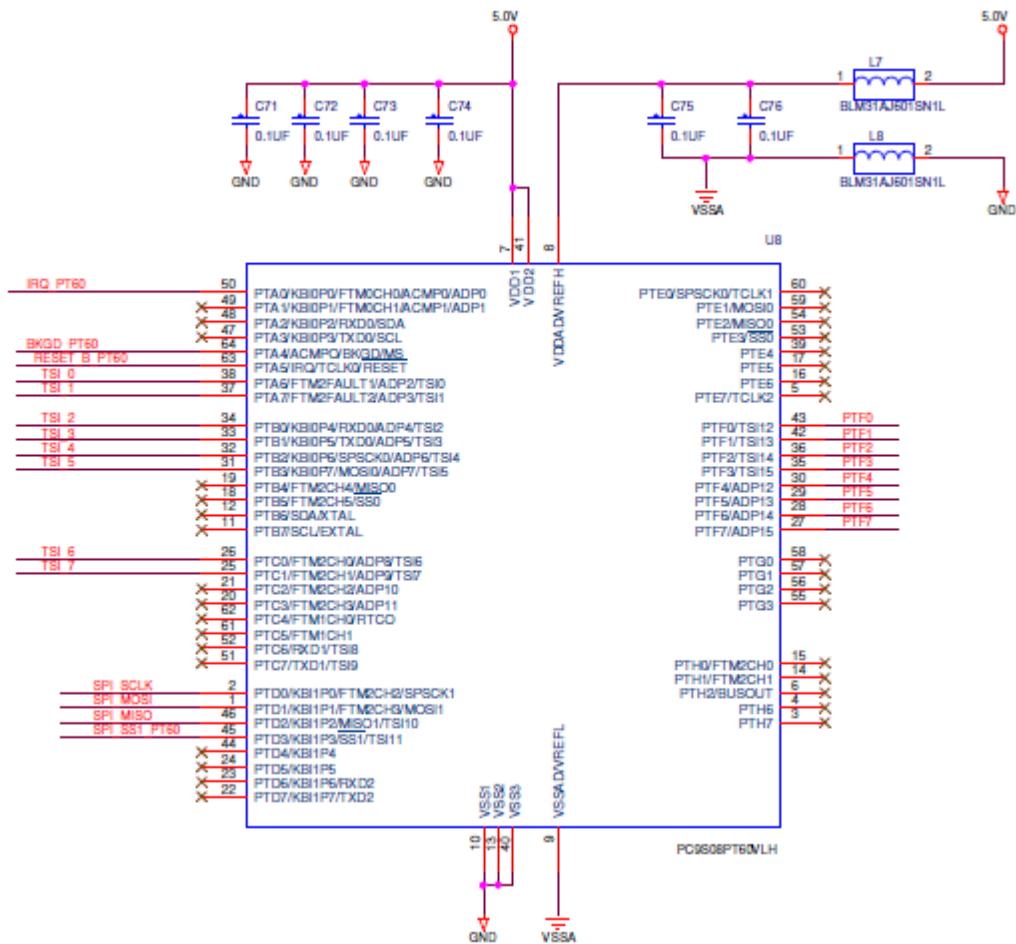


Figure 13. Touch pads

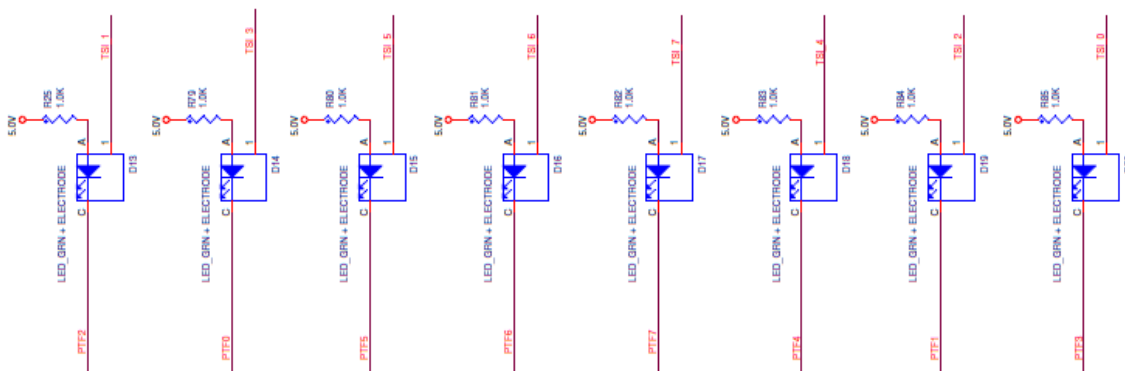


Figure 14. Capacitive touch sensor section

### 2.2.7. IR receiver

NEC based IR remote is used to provide the controllability to the user, especially the rear-seat passengers. IR sensor is interfaced to TIM module channel. The schematic of IR receiver is shown in the figure below.

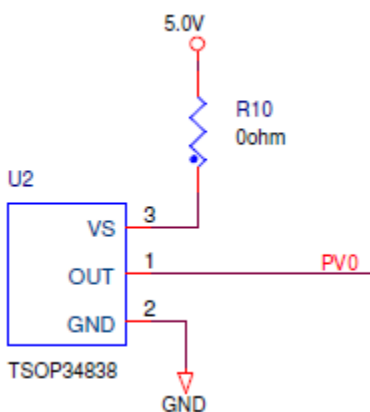


Figure 15. IR receiver section

### 2.2.8. Temperature sensor

Temperature sensor IC LM94022 provides output voltage that is proportional to the ambient temperature. This voltage is fed to an ADC channel of the MCU to provide car cabin's real time temperature, which in turn is displayed on the LCD. The schematic is shown in the figure below.

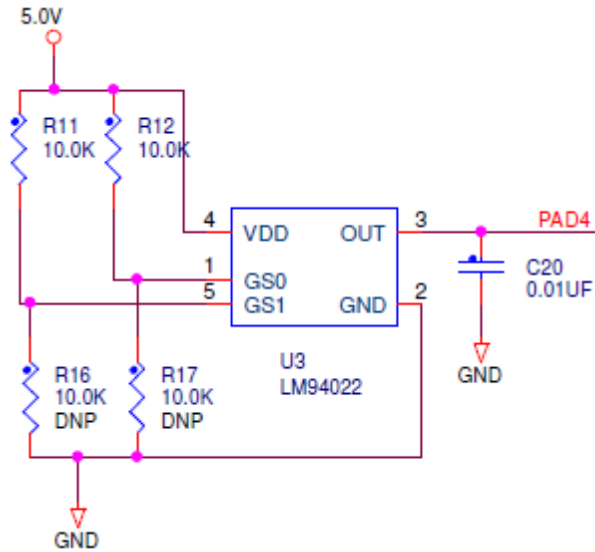


Figure 16. **Temperature sensor section**

### 2.2.9. Background debug mode (BDM)

The BDM communication interface is used for programming and debugging the MCU. P&E's USB multilink is a debug interface which allows a PC to access the BDM on MCU is shown in [Figure 17](#). It connects between a USB port on a PC and the standard 6 pin berg debug connector on the target (MCU). The user can directly control the target's execution, read/write registers and memory values, debug code on the controller and program internal or external FLASH memory devices. The schematic of BDM section is shown in [Figure 18](#).



Figure 17. **PE micro USB multilink**

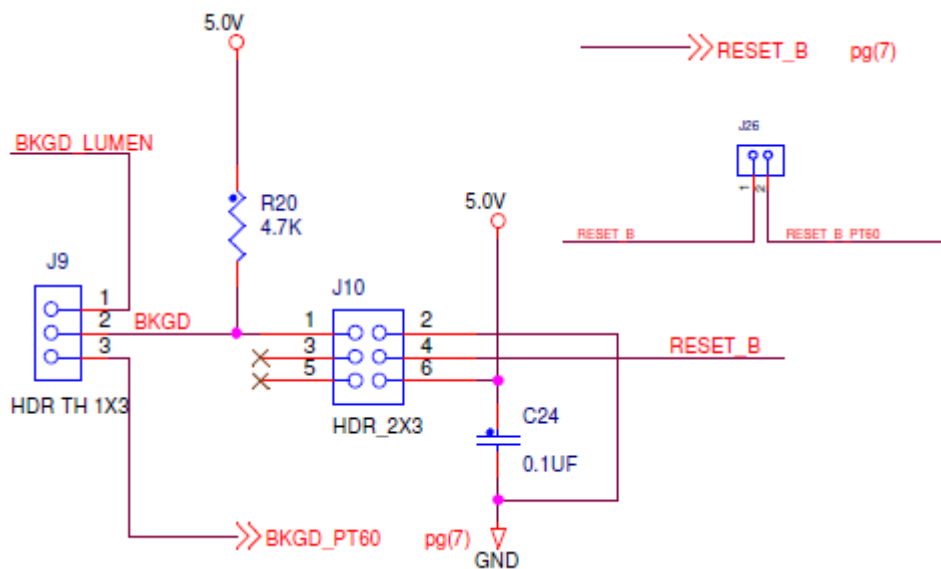


Figure 18. Background debug section

Since there are two MCUs in the design, J9 is provided in the design to program the required MCU.

### 2.2.10. Audio interface

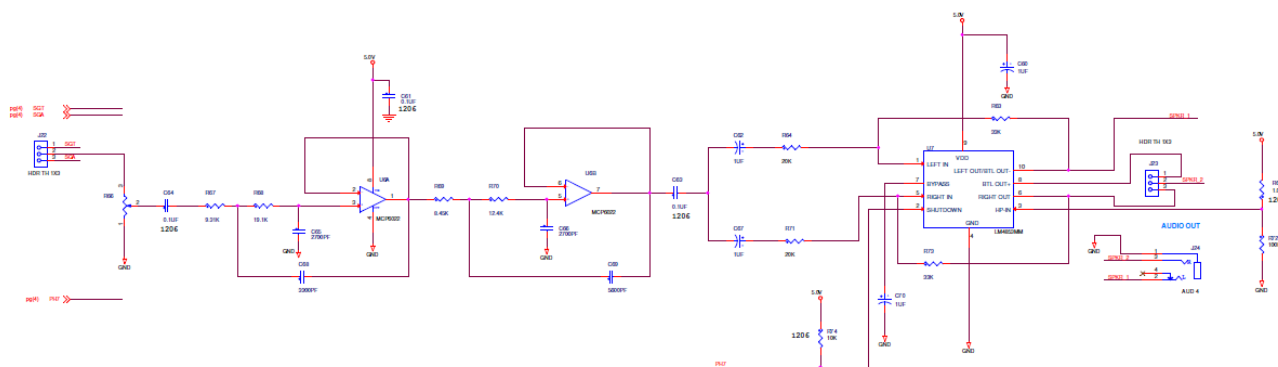


Figure 19. Audio interface circuit

To demonstrate the use of SSG (Simple Sound Generation) module, an audio interface circuit is implemented on the board. It consists of a low pass filter and a power amplifier (LM4853). The input to the filter has option from SGT (tone output) and SGA (encoded amplitude output). The filter output is fed to the amplifier and the output of the amplifier is provided on a 3.5 mm jack on which one can connect external speaker.

## 2.2.11. Ignition control

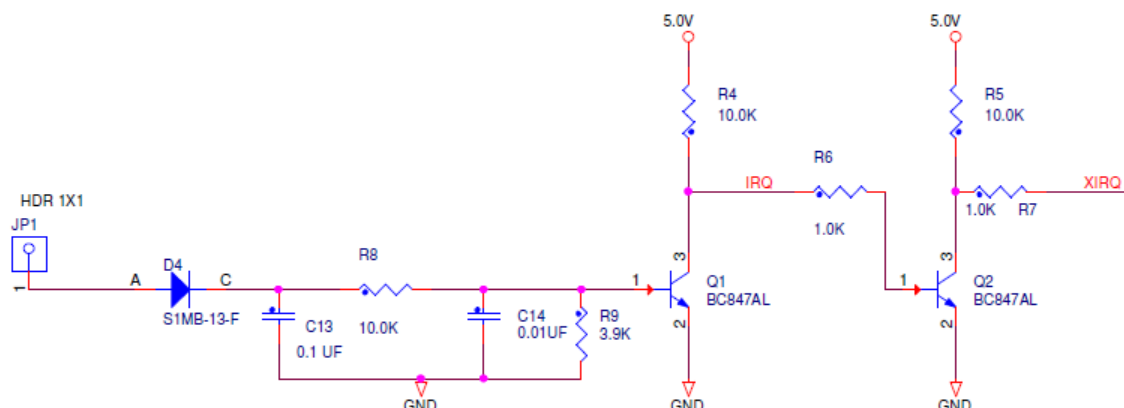


Figure 20. Ignition control

A 5 V signal on JP1 is used to simulate ignition in this design. When there is 5 V signal on JP1, system is in Run mode i.e. S12ZVH128, PT60, MC33984, MC33932 are in Run mode. When JP1 is at 0 V, system is in Low Power mode, that is S12ZVH128, PT60, MC33984, and MC33932 are in Low Power mode. This is done by using GPIO and IRQ interrupt features on IRQ pin of S12ZVH128. IRQ pin has inverted signal as compared to JP1. Hence, the software polls the IRQ pin to detect logic level 1 (which means ignition is OFF) to put the system in stop mode. IRQ pin is also configured as falling edge interrupt pin, hence when ignition comes on JP1, S12ZVH128 wakes up and it also puts other ICs in run mode.

## Chapter 3

# Design Architecture and Features

### 3.1. Introduction

This chapter describes the embedded software design of the HVAC application based on MC9S12ZVH128. All embedded software of this project was written using CodeWarrior Development Studio V10.3 which is Windows supported and can be downloaded from [freescale.com](http://freescale.com).

The software has following main modules:

- LCD graphics display
- User interface
  - Capacitive touch pads
  - IR remote control
- Motor control with stall detection
  - Blower Motor(s)
  - Actuator Motors
- Real time temperature sensing
- Real time clock

### 3.2. Design architecture

Overall system flowchart is shown in the figure below:

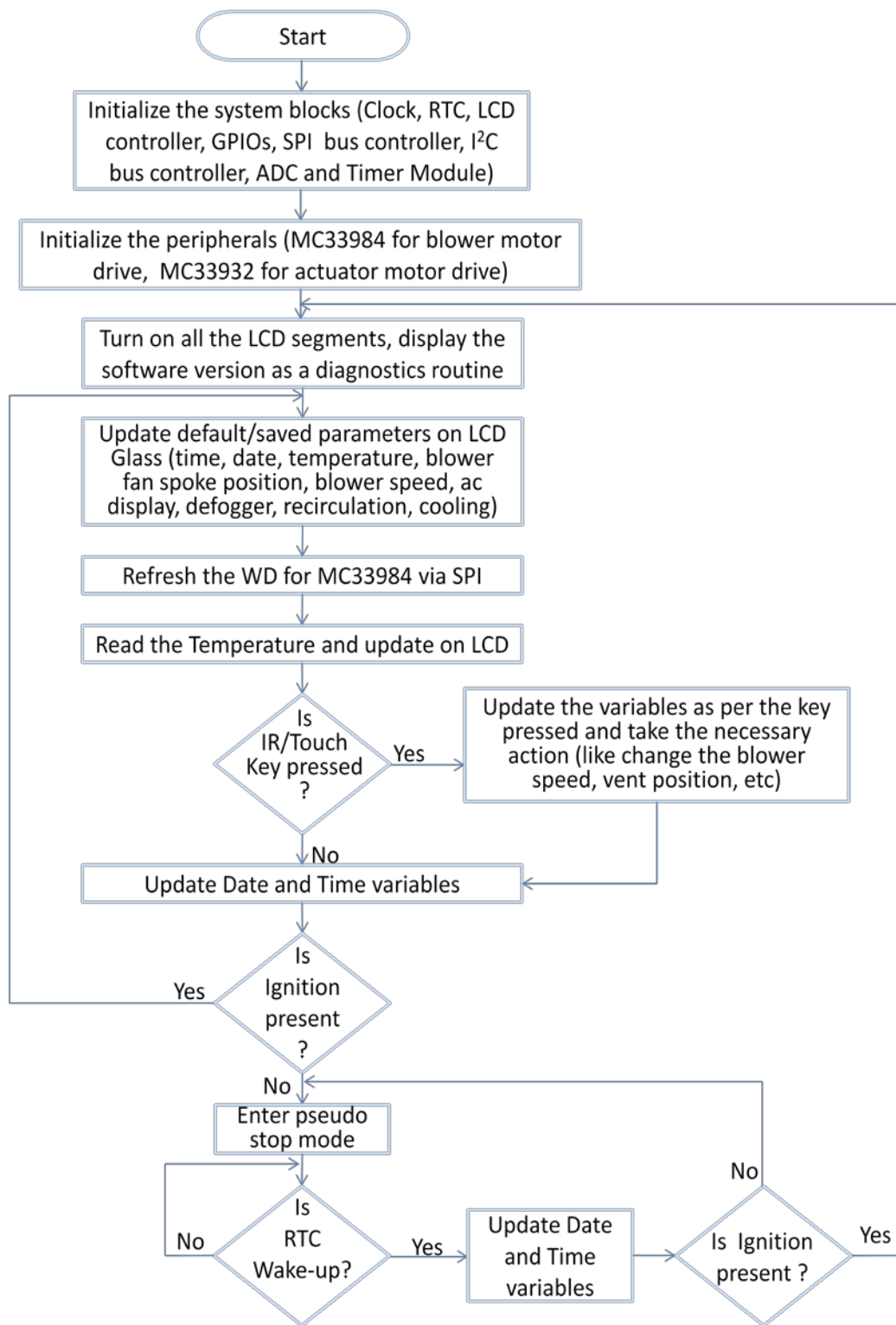


Figure 21. **System flowchart**

The following subsection describes each of the modules and its design flow.

**Automotive HVAC Control System with LCD Interface for S12ZVH Family devices**

### 3.2.1. LCD graphics display

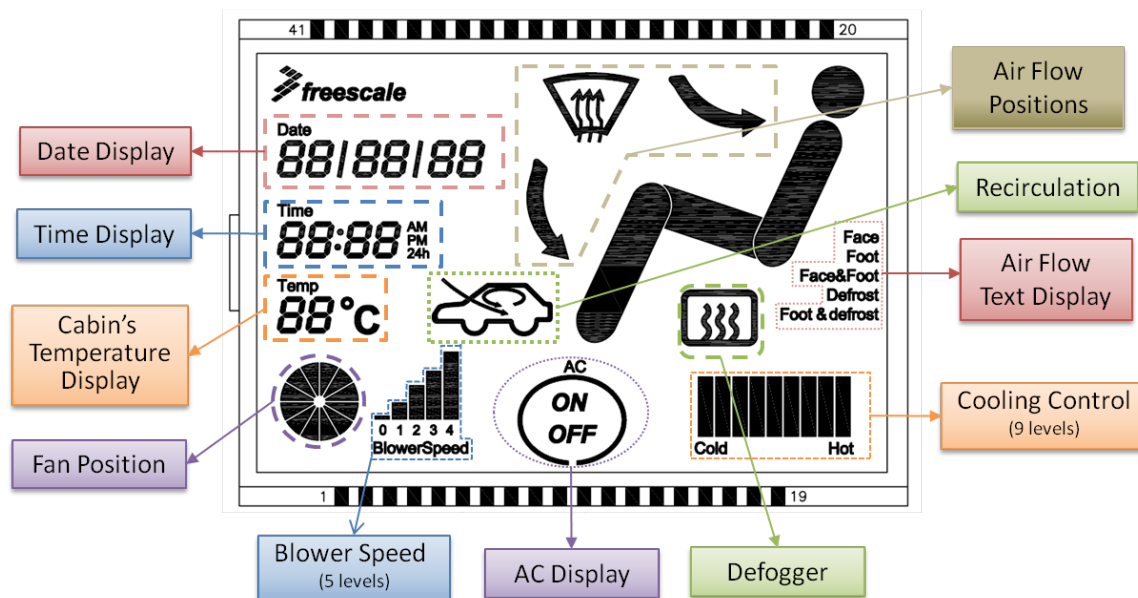


Figure 22. LCD major blocks

The existing HVAC units use mechanical knobs, which in the present design have been shown on LCD. Major blocks of LCD are shown in Figure 22, which include

- Date display – shows the date in DD/MM/YY format.
- Time display – shows the Time in HH:MM format. User can select between 24H/12H display format.
- Cabin temperature display – displays the car’s real time cabin temperature.
- Fan position – A fan is made up of 4 spokes/blades, as is shown in Figure 23. L1 shows the position 1 of all the 4 spokes of the fan, L2 - position 2 and L3 - position 3. Rotation of the fan is a function of blower motor speed, higher the blower motor speed faster the fan will rotate.

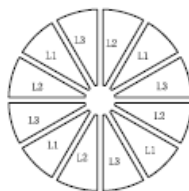


Figure 23. Fan positions

- Blower speed – shows the speed of the blower motor at which it is currently running.
- AC display – shows AC on/off position.
- Defogger – it is shown when the defogger is switched on.

- Cooling control display – it is a 9-level display for showing the level of cooling/heating. Any level indicates the mixing of hot/cold air through the vents using the flap control. The flap will be positioned to one extreme, for level 1 display, allowing only the cold air to flow, while it will be positioned on the other extreme, level 9 allowing only the hot air to flow.
- Air flow position – shows the vent position for the air flow. There are total of five possible positions as per the HVAC units used
  - Face
  - Foot
  - Face & Foot
  - Defrost
  - Foot & defrost

In each of the above case the corresponding text will be displayed

- Recirculation display – shows the air circulation is fresh-air/recirculation-air.

All the above displays, except temperature display can be controlled by user interface. The temperature display shows the cabin's temperature which is directly taken from ADC value of temperature sensor output.

### 3.2.2. User interface

The reference design has two types of interfaces:

- IR remote control
- Capacitive touch pads

These will be discussed in detail in the following sections.

### 3.2.2.1. IR remote control

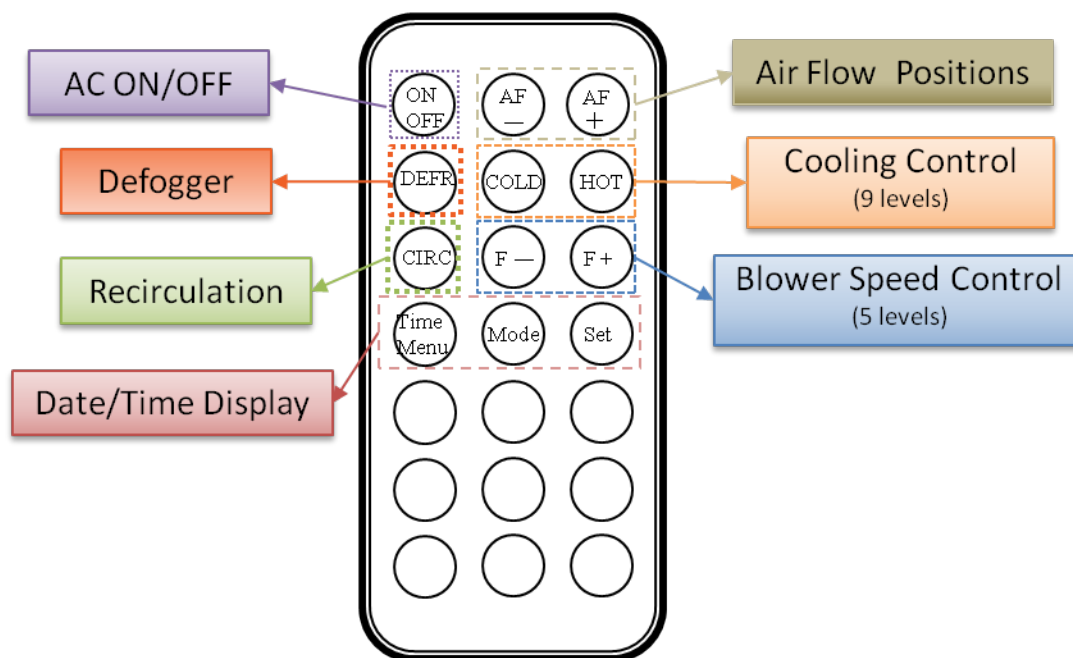


Figure 24. IR remote control along with key descriptions

NEC protocol based IR remote control is used for the reference design. Each key press updates its corresponding section on the LCD and is shown in Figure 24. Unmarked keys are kept for future enhancements. The functionality of each key block is as below:

- AC ON/OFF – AC can be switched ON/OFF with this key, and the corresponding AC status will be display on LCD.
- Air flow positions – AF +/- keys are used to change the vent positions. Each key press will drive the vent position actuator motor and the corresponding text and position on the LCD will be displayed.

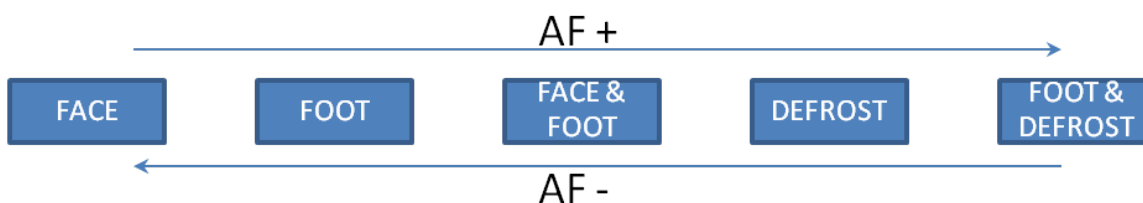


Figure 25. AF+/- key press control flow

- Defogger – defogger can be switched ON/OFF with this key. If the defogger is switched on, the icon will be displayed on LCD.
- Recirculation – CIRC is used to select between fresh-air and recirculation-air, which will drive the fresh air actuator motor and the corresponding arrow on the recirculation section of the LCD will be displayed.

- Cooling Control – COLD & HOT keys are used to change the degree of coldness/hotness in the vehicle. Pressing these keys will drive the cooling actuator motor in the background, while the COLD/HOT level will be updated on the LCD.
- Blower Speed Control – F+ & F- keys are used to update the blower speed by increasing the duty cycle of the PWM used to drive the PMDC blower motor. This will also update the blower speed on the LCD.
- Date/Time display – Time Menu is used to select between the Date and Time display on the LCD. When date display is selected, then the Mode key is used to select between date/month/year, while in time display, it is used to select between hours/minutes/time-format. Set key increments the selected digit, and once the limit is reached, digit is reset to zero. When ‘time-format’ parameter is selected, the display toggles among AM, PM and 24H on pressing Set key.

### 3.2.2.2. Capacitive touch pads

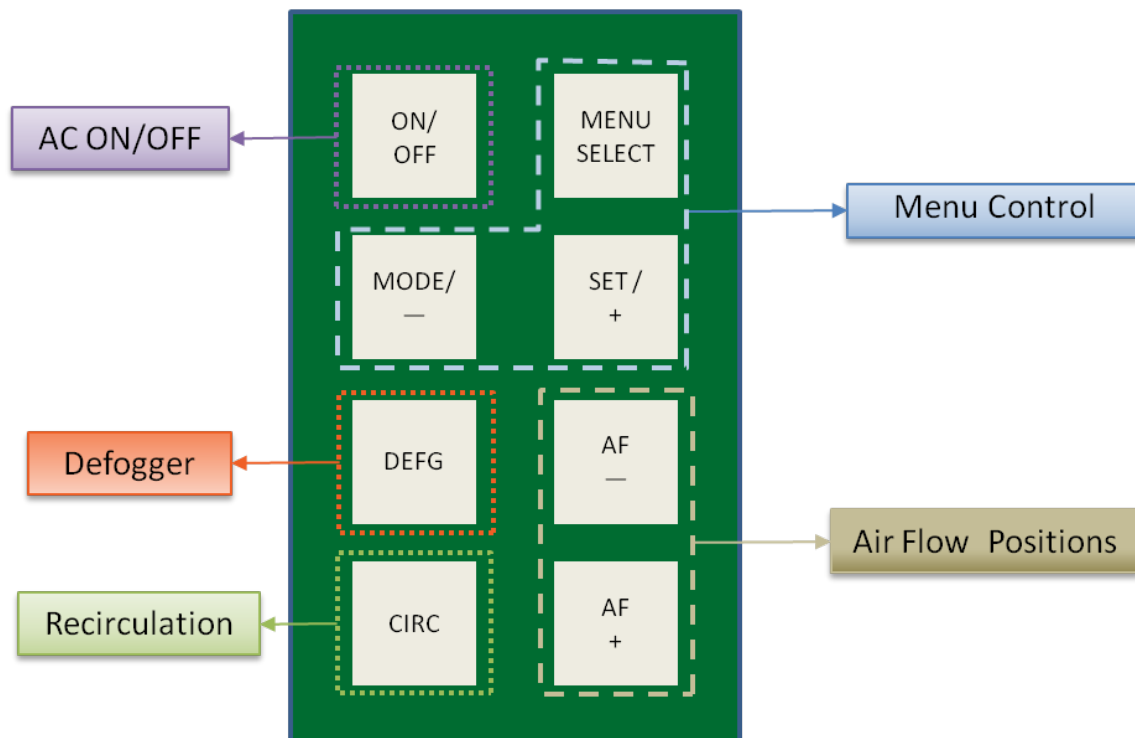


Figure 26. Touch pads along with legends

TSI pins on S08PT60 are used to interface capacitive touch pads. The touched pad is notified by PT60 to main MCU (S12ZVH128) on SPI bus. On every recognised touch, its corresponding section on the LCD is updated. The functionality of touch pads is shown in Figure 27. ON/OFF, DEFG, CIRC, AF+/- have the same usability as the corresponding IR remote keys, which have already been explained in the above section.

## Design Architecture and Features

As the numbers of keys are limited, an innovative way of menu selection has been implemented using the three keys:

- MENU SELECT
- MODE / +
- SET / —

When the AC is switched on, the MENU SELECT key selects between four menu states as shown in figure below, starting from Blower Speed Menu. [Table 3](#) shows the functionality of touch pads MODE/+ and SET/— in each mode, which will emulate the functionality of IR remote keys.

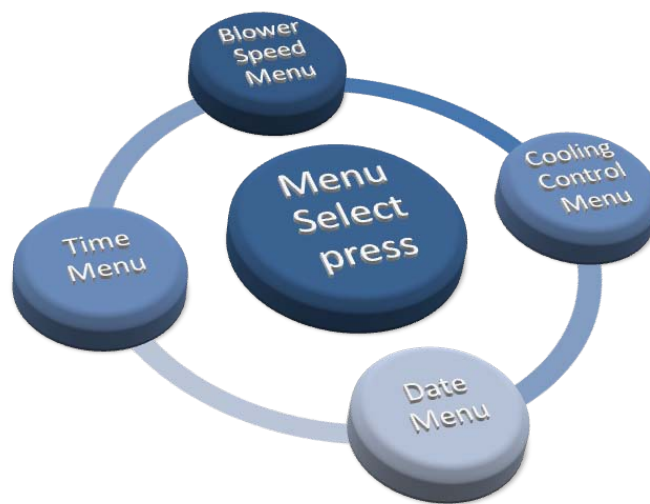


Figure 27. **Menu Select control flow**

Table 3. **Functionality of Mode/Set keys when Menu key is active**

S. No.	Menu Mode	Mode Key Function <sup>1</sup>	Set Key Function <sup>1</sup>
1	Blower Speed	F +	F—
2	Cooling Control	HOT	COLD
3	Date	MODE	SET
4	Time	MODE	SET

1. The touch key function listed here emulates the IR keys function by same name

### 3.2.3. Motor control

The reference design has two types of motor control:

1. Blower motor control
2. Actuator(s) motor control

These will be discussed in detail in the following sections.

### 3.2.3.1. Blower motor control

Blower Motor control is implemented using PWM channel of the MCU and is driven through the high-current switch MC33984. PWM duty cycle is varied as per the blower speed set through the user interface. The duty cycle and the blower speed are shown in the table below.

Table 4. **Blower speed and Duty cycle**

Blower speed levels	Duty cycle (%)
0	0
1	10
2	20
3	40
4	60

#### NOTE

PWM's frequency is 20 Hz (approx).

Blower motor may develop fault due to electromechanical reason because of which it may get jammed. Driving high current blower motor under such condition, may lead to permanent damage of its coils. To avoid this, stall detection is implemented in the design, for which the output of the MC33984 is continuously monitored on the ADC channel of the MCU for generated back E.M.F.

### 3.2.3.2. Actuator motor(s) control

Actuator motor(s) control is implemented using MCU GPIOs and is driven through the high-current H-Bridge of MC33932. Actuator motor control consists of:

- Cooling control actuator motor – controls the mixing of hot and cold air. It controls the flap position of the mixer unit as per the degree of coldness/hotness set through the user interface.
- Air flow vent position control – controls the air direction flow. It controls the flap position of the actuator motor, having five possible positions, settable through user-interface. These are:
  - Face
  - Foot
  - Face & Foot
  - Defrost



- Defrost & Foot
- Recirculation control – controls the fresh air circulation in the vehicle. It controls the recirculation actuator motor, which open/closes the flap for inlet of the fresh air. This is controlled using the CIRC key/pad on IR remote/Touch pads.

### 3.2.4. **Temperature sensor**

A temperature sensor has been interfaced with the MCU on the ADC channel, which is used to monitor the vehicle's cabin temperature. The temperature is read continuously and the average temperature is shown on the LCD.

### 3.2.5. **Real time clock**

The application integrates the Real time clock and calendaring information and displays it on the LCD. S12ZVH128 has dedicated RTC module for this purpose, which has dedicated second, minute and hour register to directly read time. In the reference design, a 32 kHz crystal provides dedicated clock to the module.

The application supports the setting of date and time through user interface. User can also select the time format as 24 H/12 H.

## Chapter 4 Testing and Measurements

### 4.1. Hardware setup

The jumper and test point placement on the board are shown in [Figure 28](#) and their settings in [Table 5](#), which are useful for board bring up.

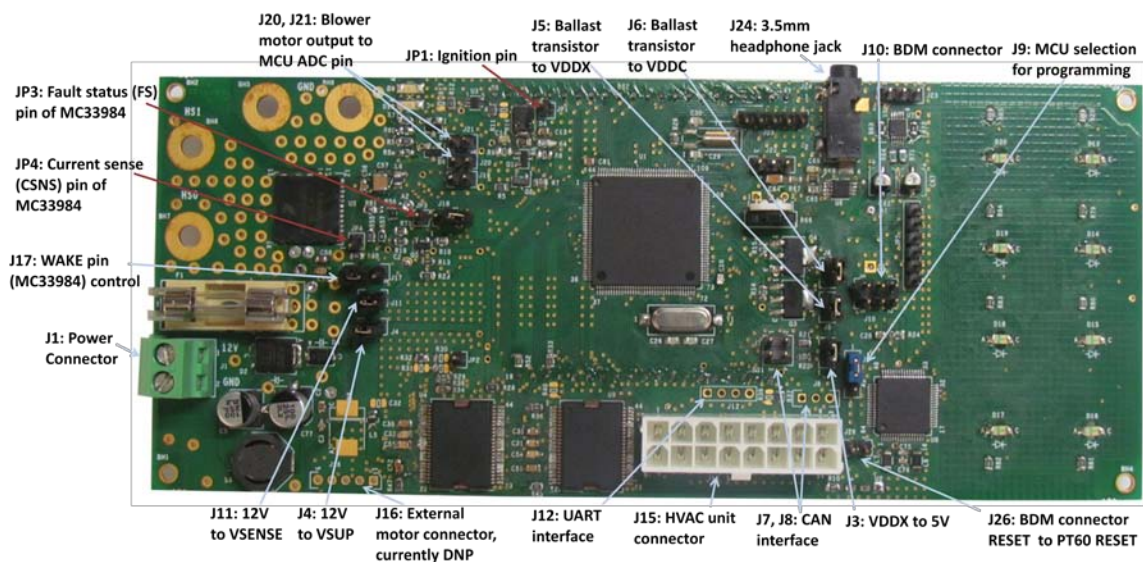


Figure 28. Jumper and test point placement

Table 5. Jumper settings

Jumper	Functionality	Connection
J1	Power connections on the board	1: +12V 2: GND
J3	VDDX to 5V	1: 5V 2: VDDX
J4	12V to VSUP	1: 12V 2: VSUP
J5	Ballast transistor to VDDX	1: VDDXQ1

## Testing and Measurements

		2: VDDX
J6	Ballast transistor to VDDC	1: VDDCQ2 2: VDDC
J7	CAN interface	1: CAN L 3: CAN H
J8	CAN interface	1: CAN H 2: CAN L
J9	MCU selection for programming	1: BKGD S12ZVH128 2: BKGD on BDM connector 3: BKGD PT60
J10	BDM connector	—
J11	12V to VSENSE	1: 12V 2: VSENSE
J12	UART interface	1: 5V 2: UART RXD 3: UART TXD 4: GND
J15	HVAC connector	—
J16	External motor connector interface	—
J17	Wake pin (MC33984) control	1: 12V 2: WAKE 3: GND
J20	Blower motor output to ADC pin	1: HS1 2: PAD6
J21	Blower motor output to ADC pin	1: HS0 2: PAD5
J24	3.5mm headphone jack	—
J26	BDM connector RESET to PT60 RESET	1: RESET_B 2: RESET_B_PT60
JP1	Ignition pin	—

<b>JP3</b>	MC33984 Fault Status (FS) pin	—
<b>JP4</b>	MC33984 Current Sense (CSNS) pin	—

## 4.2. Debugging and measurement

In this section, waveforms are shown for each section.

### 4.2.1. LCD

For testing the LCD, probe any of the frontplane pin, on which there is one ON segment. The waveform on such a pin will be as shown below:

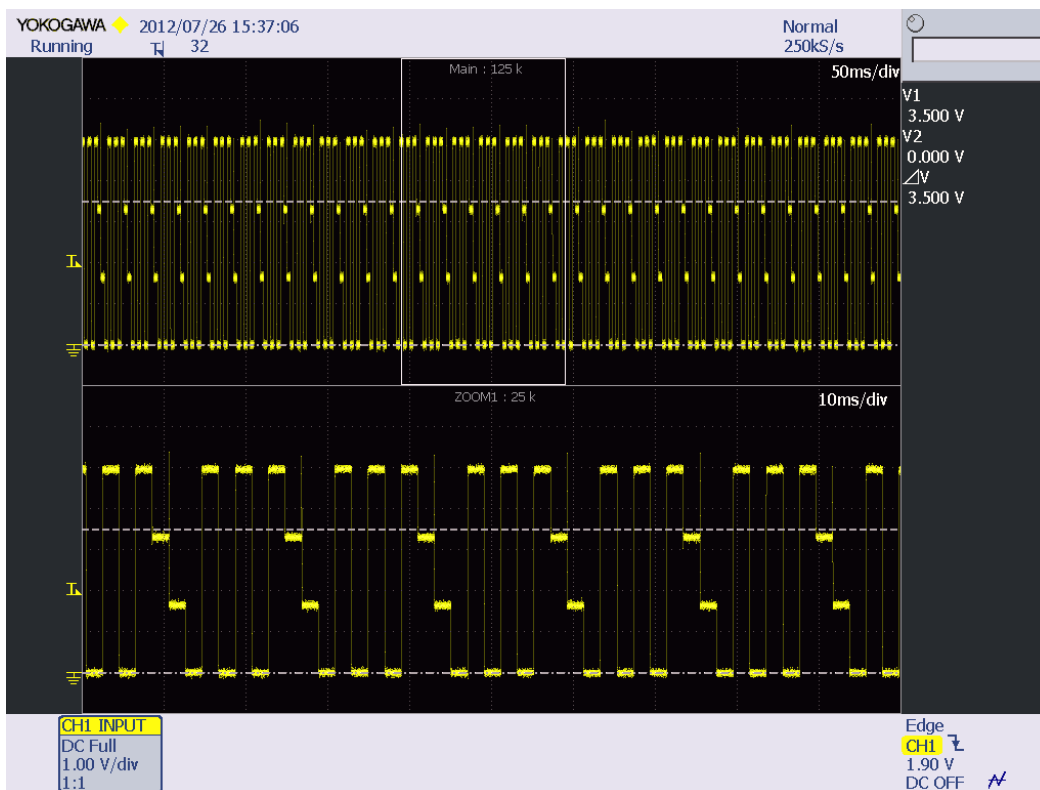


Figure 29. Waveform - a front plane with exactly one ON segment

### 4.2.2. User interface

For testing the IR receiver section, IR receiver data pin should be probed. The following waveform will be observed when a single key is pressed for a long time.

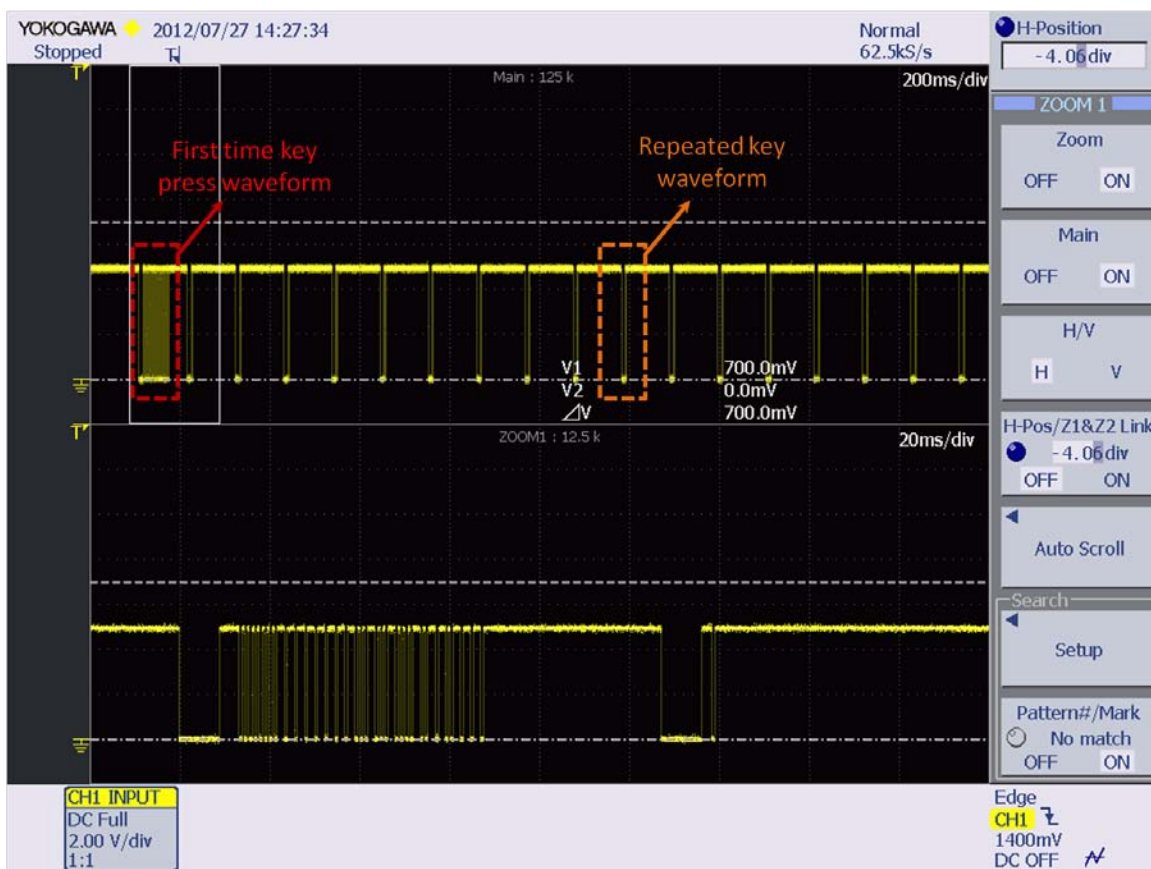


Figure 30. Waveform – when a single IR key is pressed for a long time

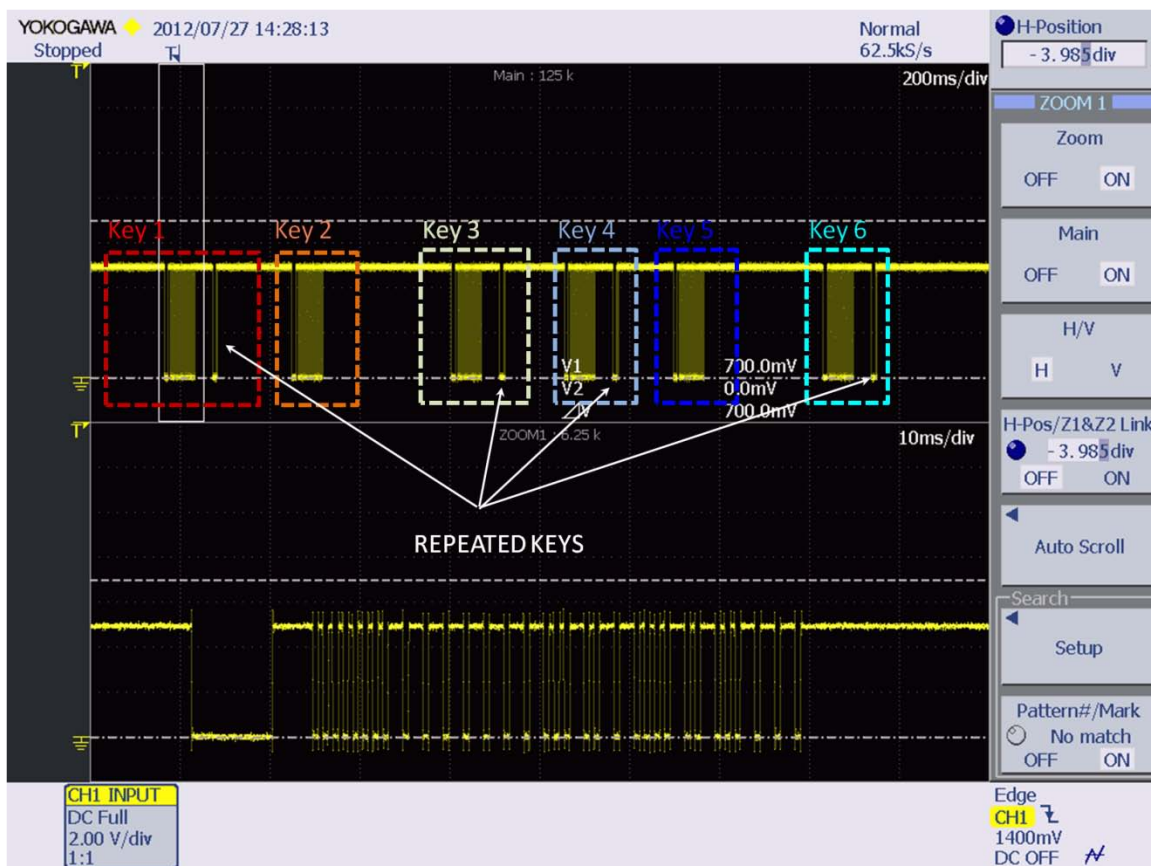


Figure 31. Waveform – when multiple IR keys are pressed at a very fast pace

### 4.2.3. Motor control

Waveforms for each of the interfaces are shown in following sections.

#### 4.2.3.1. Blower motor

Waveform for blower motor control at different levels (changed using the user interface) is probed at the MC33984 HS0 pin and is shown in figure below:

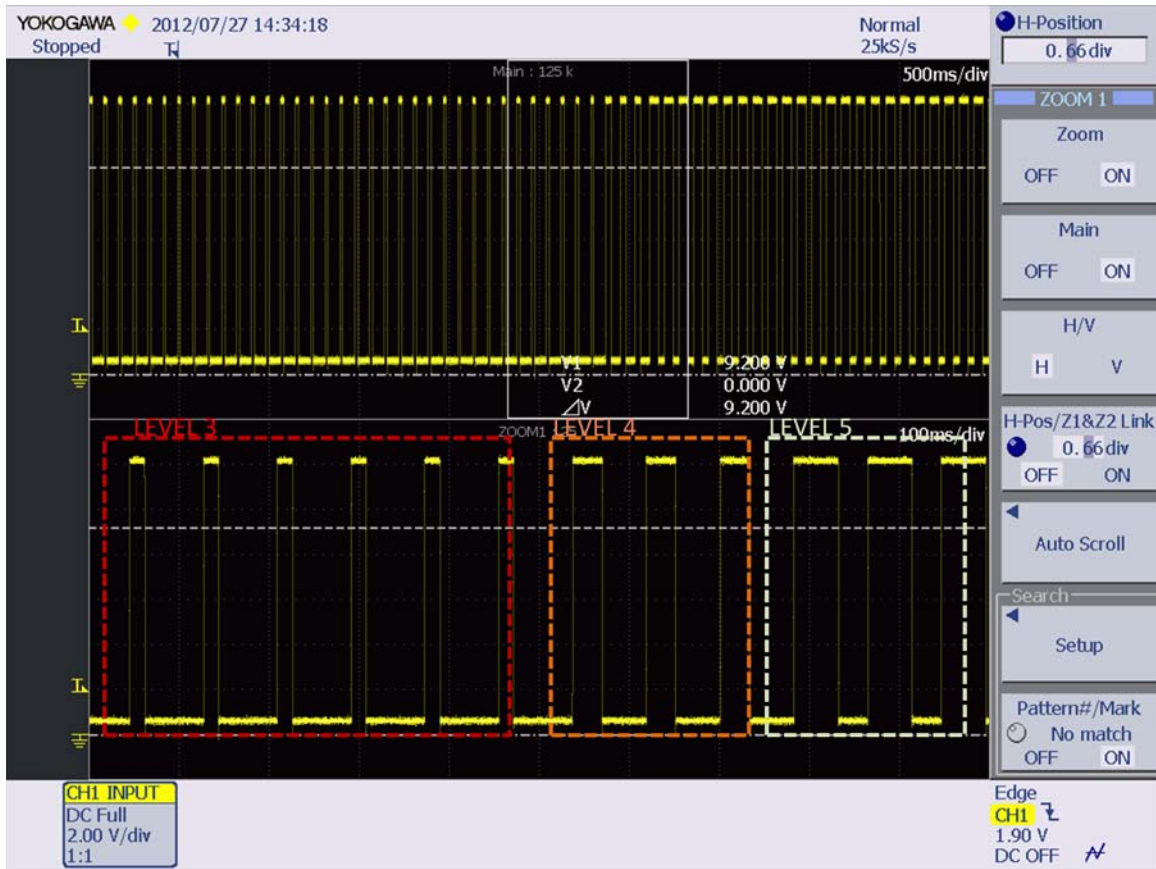


Figure 32. **Waveform – Blower motor control at different speed levels**

#### 4.2.3.2. Actuators motor

Waveform for recirculation actuator is shown in the figure below:

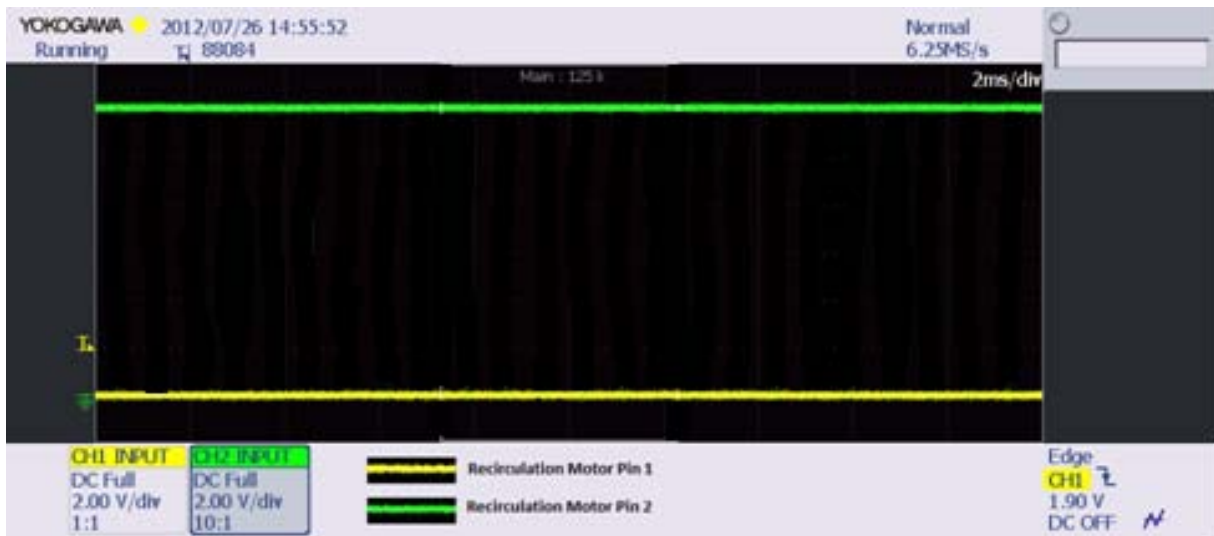


Figure 33. Recirculation motor control waveform for fresh air to internal circulation

Waveforms for air flow control actuator in different positions are shown in Figure 34 - Figure 36. We have captured the initial phase, transition phase, and the final phase of the waveforms.

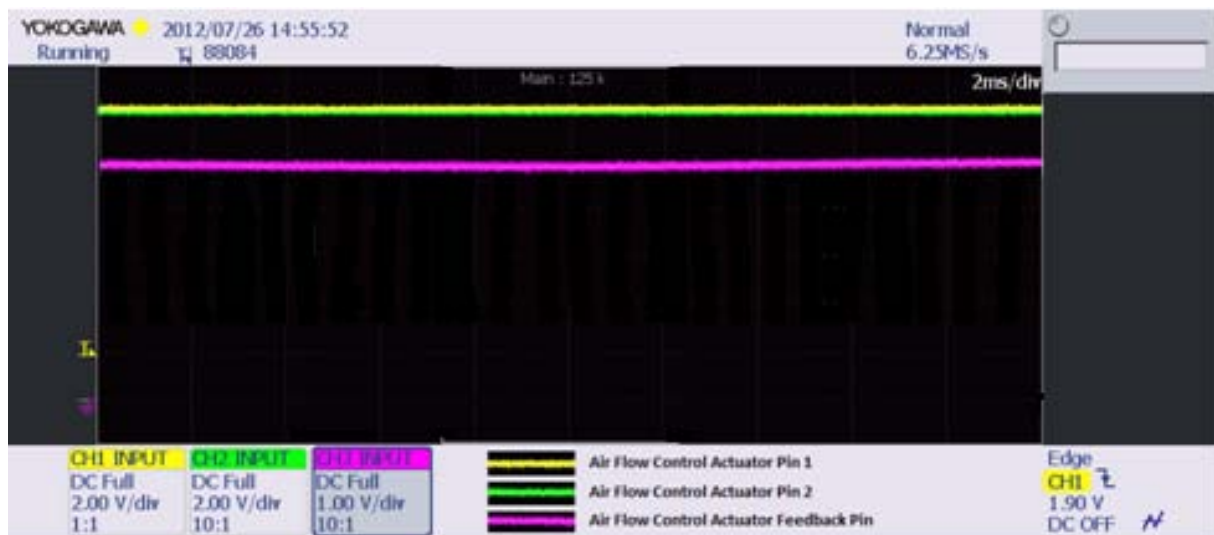


Figure 34. Air flow actuator motor control waveform for defrost position to face & foot position - initial phase

Testing and Measurements

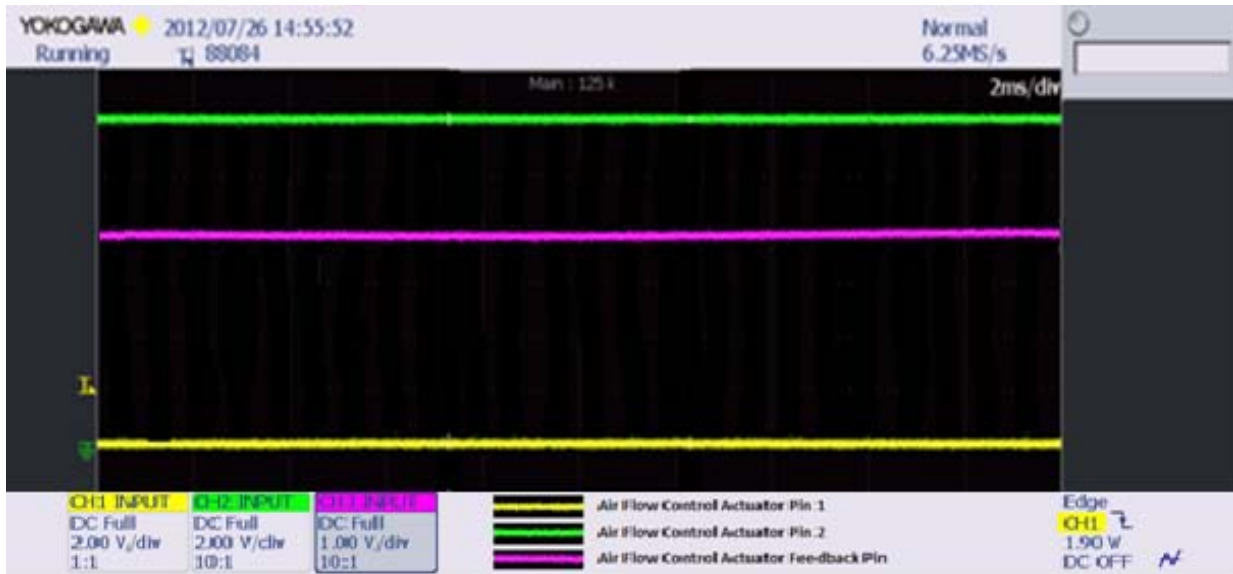


Figure 35. Air flow actuator motor control waveform for defrost position to face & foot position – transition phase



Figure 36. Air flow actuator motor control waveform for defrost position to face & foot position – final phase

Waveform for temperature actuator motor control is shown in the figure below.

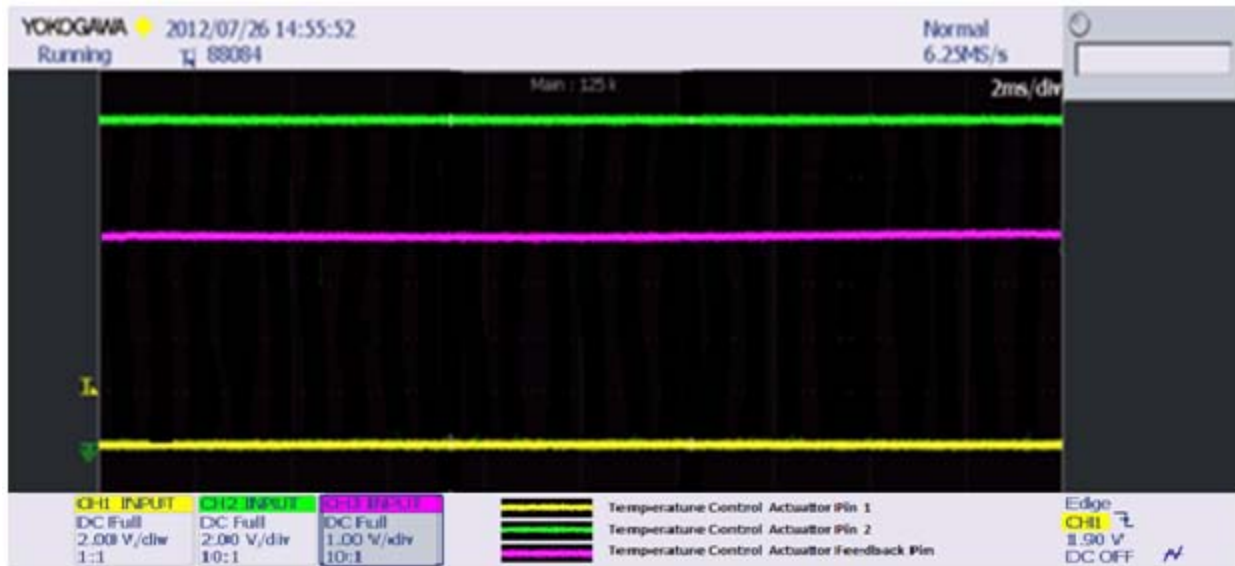


Figure 37. Driving the temperature actuator motor

### 4.3. Temperature sensor

Waveform for the temperature sensor is shown in the figure below when the temperature on the sensor is increased. We have captured the waveform, by bringing the solder rod @ 200 °C close to the sensor for 2 seconds (approx).

Testing and Measurements

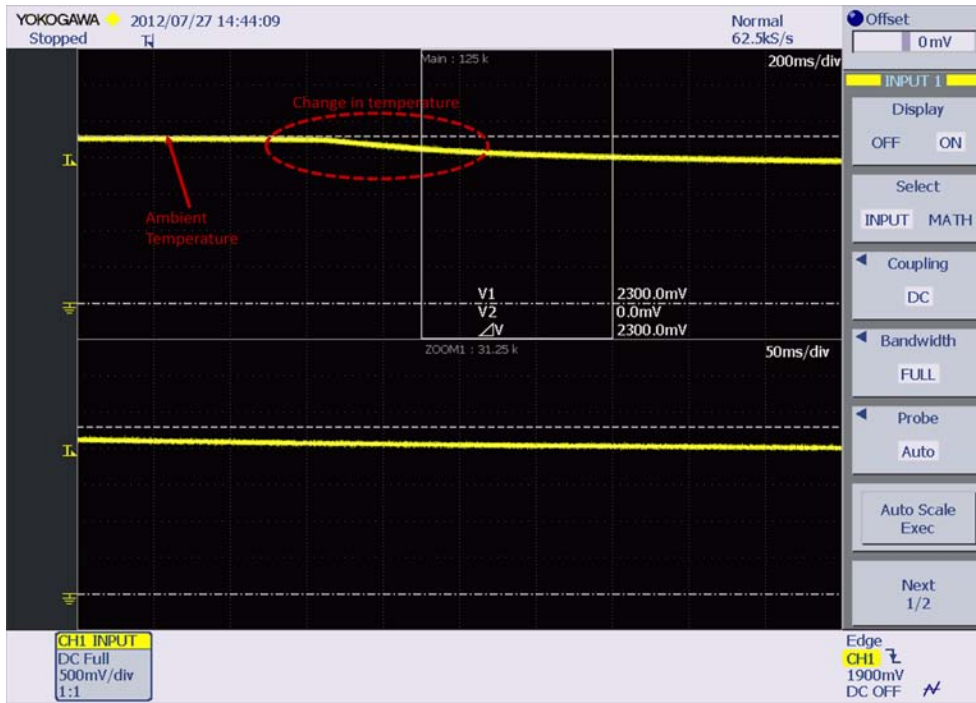
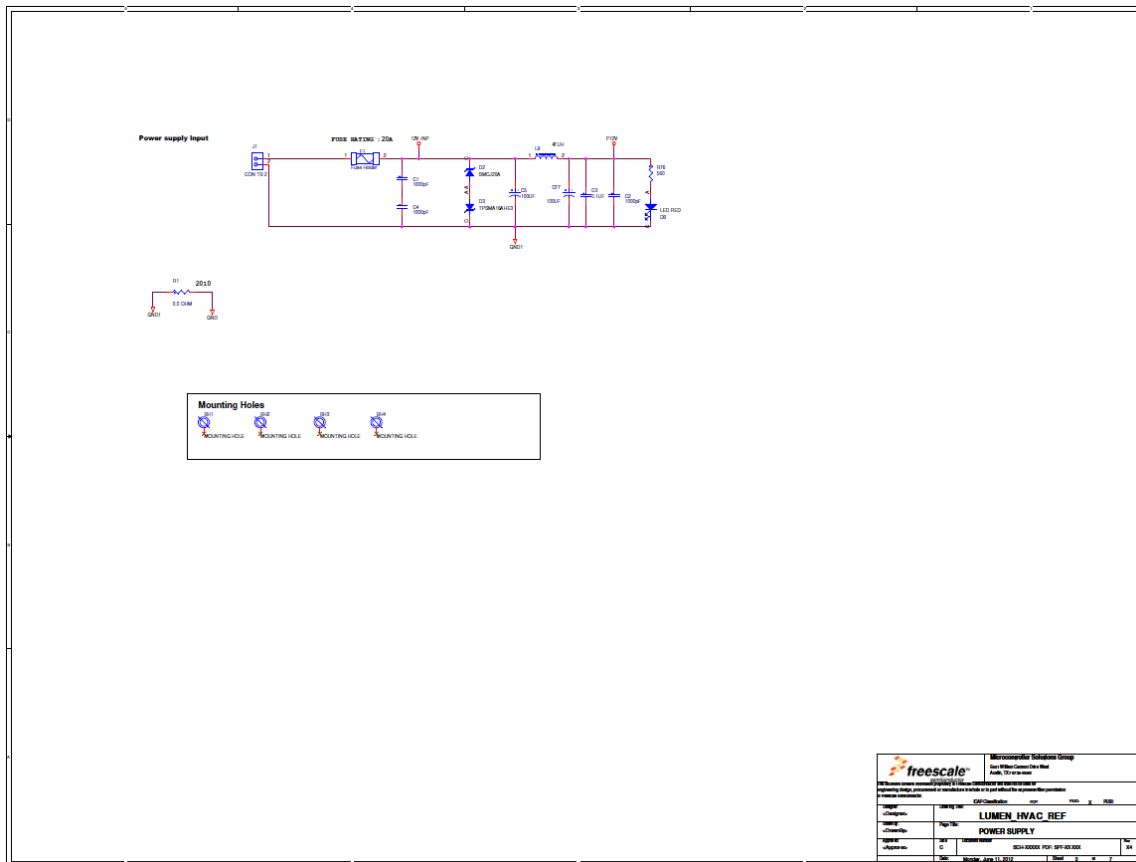


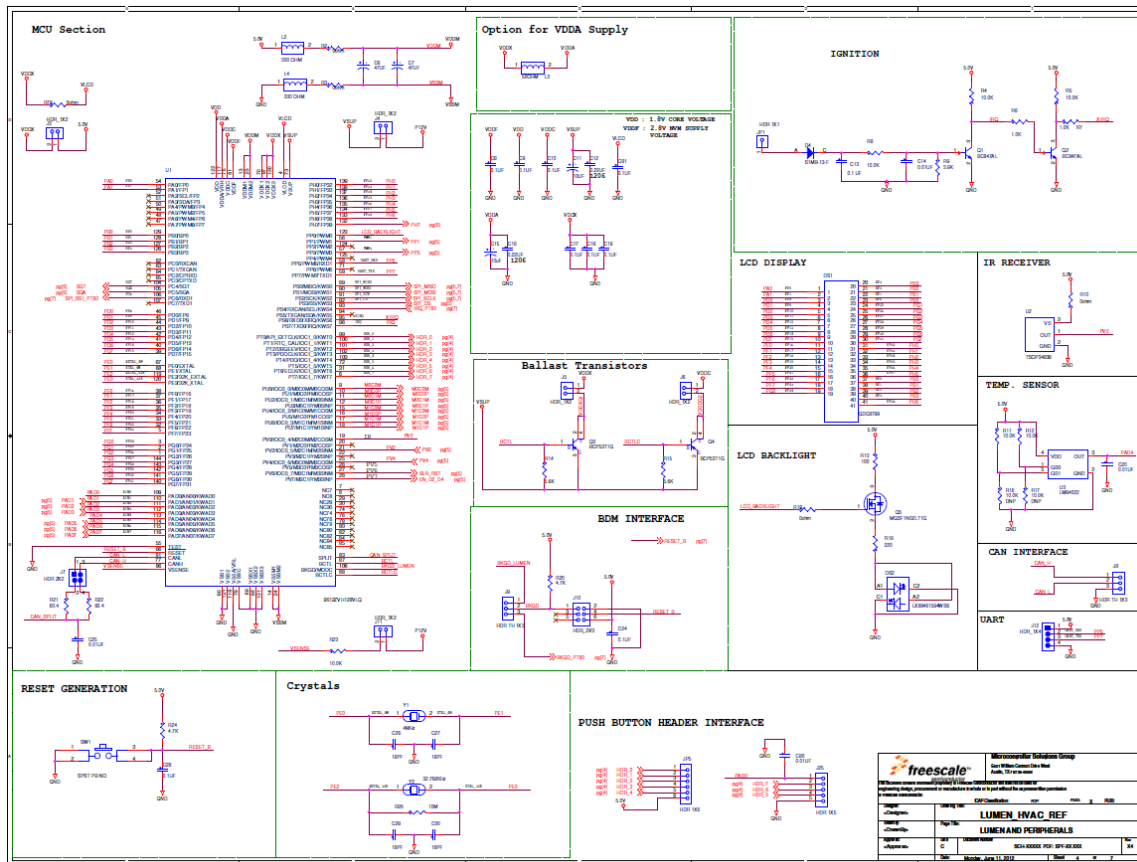
Figure 38. Waveform for temperature sensor output when temperature is increased drastically from the ambient temperature

# Appendix A

## A.1 Schematic



# Testing and Measurements

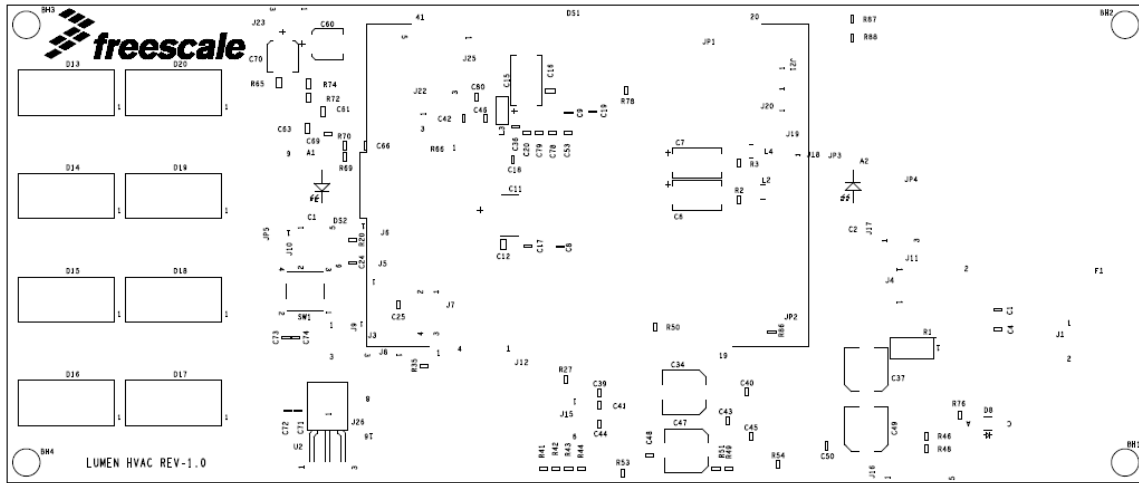




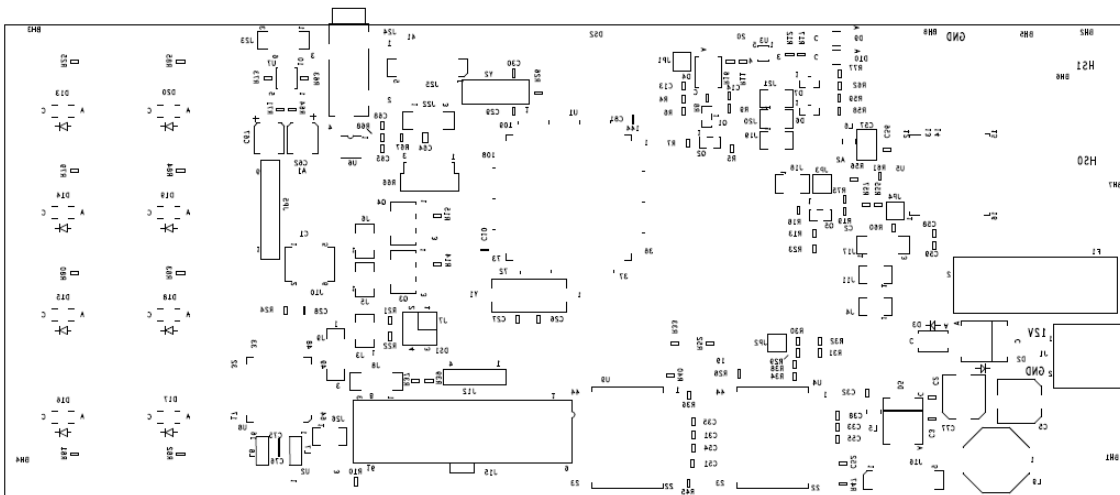


## A.2 Layout

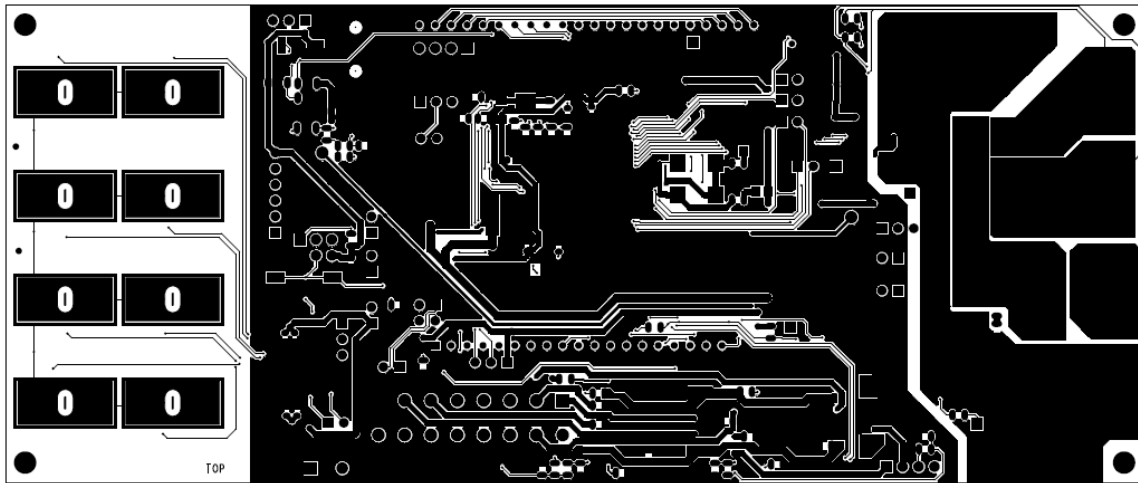
### A.2.1 Silkscreen top



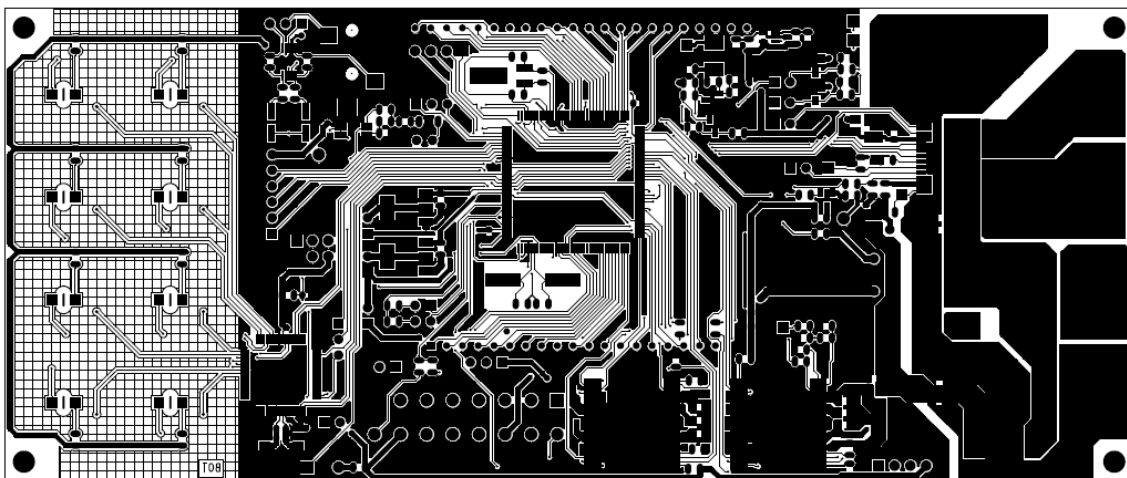
### A.2.2 Silkscreen bottom



### A.2.3 Top



### A.2.4 Bottom



# Appendix B

## Bill of Material

Item	Quantity	AgilePN	ASSY_OPT	Reference	Value	Description	Mfg Name	Mfg Part Number	PCB Footprint
1	4	280-76468		BH1,BH2,BH3,BH4	MOUNTING HOLE	MOUNTING HOLE DRILL 108 PAD 140 PLATED TH NO PART TO ORDER	NO PART TO ORDER	Mounting Hole - 108mil Drill PTH	MH140P108
2	4	280-76617		BH5,BH6,BH7,BH8	MH_180	MOUNTING HOLE DRILL 135 PAD 180 PLATED TH NO PART TO ORDER	NO PART TO ORDER	Mounting Hole - 135mil Drill PTH	MH180-135P
3	3	150-77331		C1,C2,C4	1000pF	CAP CER 1000PF 50V 5% X7R 0805	KEMET	C0805C102J5 RACTU	CC0805_OV
4	16	150-75016		C3,C8,C9,C10,C17,C18,C19,C24,C28,C71,C72,C73,C74,C75,C76,C81	0.1UF	CAP CER 0.10UF 25V 10% X7R 0603	KEMET	C0603C104K3 RAC	CC0603_OV
5	2	150-78769		C5,C77	100UF	CAP ALEL 100uF 25V 20% -- SMD	LELON ELECTRONICS CORP	VE-101M1ETR-0607	cce63x55
6	2	150-75127		C6,C7	47UF	CAP TANT 47UF 16V 10% -- 7343-31	VISHAY INTERTECHNOLOGY	293D476X901 6D2TE3	CC7343A
7	1	150-77543		C11	10UF	CAP TANT 10UF 50V 20% -- 7260-38	VISHAY INTERTECHNOLOGY	595D106X005 0R2T	CC7260-38-R
8	2	150-77451		C12,C16	0.22UF	CAP CER 0.22UF 50V 20% X7R 1206	VENKEL COMPANY	C1206X7R500 -224MNE	CC1206_OV
9	6	150-75018		C13,C35,C38,C48,C50,C56	0.1 UF	CAP CER 0.1UF 50V 10% X7R 0805	KEMET	C0805C104K5 RAC	CC0805_OV
10	15	150-75010		C14,C20,C25,C31,C33,C41,C43,C44,C45,C54,C55,C59,C78,C79,C80	0.01UF	CAP CER 0.01UF 50V 10% X7R 0805	VENKEL COMPANY	C0805X7R500 -103KNE	CC0805_OV
11	1	150-78701		C15	10uF	CAP TANT 10UF 35V 10% -- 7343-31	Kemet	B45196P6106 K409	CC7343-31
12	4	150-75966		C26,C27,C29,C30	18PF	CAP CER 18PF 50V 5% COG 0805	AVX	08055A180JA T2A	CC0805_OV
13	1	150-30066	DNP	C32	1uF	CAP CER 1UF 50V 10% X7R 0805	SMEC	MCCE105K2N RTF	CC0805_OV
14	4	150-75610		C34,C37,C47,C49	47UF	CAP ALEL 47UF 50V SM 6.3X6.3X5.3	VISHAY INTERTECHNOLOGY	MAL2153754 79E3	cce63x55
15	4	150-75168		C36,C42,C46,C53	1uF	CAP CER 1uF 16V 10% X7R 0805	KEMET	C0805C105K4 RAC	CC0805_OV

### Automotive HVAC Control System with LCD Interface for S12ZVH Family devices

### Testing and Measurements

16	4	150-75120		C39,C40,C51,C52	0.033UF	CAP CER 0.033UF 50V 10% X7R 0805	AVX	08055C333KA T2A	CC0805_OV
17	1	150-75086		C57	10UF	CAP CER 10UF 16V 10% X5R 1210	AVX	1210YD106KA T2A	CC1210
18	1	150-75218		C58	3.3 UF	CAP CER 3.3UF 10V +80%/-20% Y5V 0805	KEMET	C0805C335Z8 VAC	CC0805_OV
19	4	150-75457		C60,C62,C67,C70	1UF	CAP ALEL 1UF 50V 20% X5R SMT	PANASONIC	EEE1HS010SR	CCE40X54
20	3	150-30292		C61,C63,C64	0.1UF	CAP CER 0.1UF 100V 10% X7R 1206	VENKEL COMPANY	C1206X7R101 -104KNE	CC1206_OV
21	2	150-77473		C65,C66	2700PF	CAP CER 2700PF 50V 5% COG 0805	KEMET	C0805C272J5 GACTU	CC0805_OV
22	1	150-77313		C68	3300PF	CAP CER 3300PF 50V 5% COG 0805	MURATA	GRM2165C1H 332JA01D	CC0805_OV
23	1	150-30307		C69	5600PF	CAP CER 5600PF 50V 10% X7R 0805	KEMET	C0805C562K5 RAC	CC0805_OV
24	1	TMP-WF- 16632		DS1	GDC879 9	LCD DISPLAY 5V CUSTOM TH	Dalian Good Display Co.Ltd ( <a href="http://www.good-lcd.com">http://www.good-lcd.com</a> )	GDC8799	lcd41_2p54_ 70x51mm
25	1	TMP-WF- 16634		DS2	LX88461 594WS6	LCD BACK-LIGHT MODULE 3V TH	DALIAN GOOD DISPLAY CO.,LTD	LX88461594 WS6	lcd4_5p02_7 9x45mm
26	1	480-78069		D2	SMCJ20A	DIODE TVS 46.3A 20V 1500W DO- 214AB	LITTLEFUSE	SMCJ20A	do214ab_sm
27	1	480-78061		D3	TPSMA1 6AHE3	DIODE TVS 40A 16V SMD	VISHAY INTERTECHNOLOGY	TPSMA16AHE 3	sma
28	1	480-78040		D4	S1MB- 13-F	DIODE RECT 1A 1000V SMB	DIODES INC	S1MB-13-F	smb_4p57x3 p94mm
29	1	480-30012	DNP	D5	1SMC12 AT3	DIODE ZNR 5UA 12V 5% SMC	ON SEMICONDUCTOR	1SMC12AT3G	D_SMC
30	2	480-75079		D6,D7	BAT54S	DIODE DUAL SCH 200MA 30V SOT23	FAIRCHILD	BAT54S	SOT-23
31	1	370-75084		D8	LED RED	LED RED SGL 30MA SMT	KINGBRIGHT	APT3216SURC K	1206LD
32	2	370-75142	DNP	D9,D10	LED GREEN	LED GRN -- 25MA SMT 1206	KINGBRIGHT	APT3216SGC	1206LD
33	8	750-77163		D13,D14,D15,D16, D17,D18,D19,D20	LED_GR N + ELECTRO DE	SUBASSEMBLY LED GRN SGL 20MA 1206 + RECTANGULAR ELECTRODE 590X270MIL	SUBASSEMBLY	510-77640, 370-76519	LED2_ELECT RODE
34	1	510-00422- 00		F1	Fuse Holder	FUSE CLIP,5X20 FUSE,PC MOUNT	COOPER BUSSMANN	HTC-15M	fuse_26x9

35	4	210-75767		JP1,JP2,JP3,JP4	HDR 1X1	HDR 1X1 TH -- 330H AU 100L	SAMTEC	HTSW-101-07-SM-S	HDR101
36	1	210-10091-00		JP5	HDR 1X6	HDR 1X6 TH 100MIL SP 330H AU 100L	SAMTEC	TSW-106-07-S-S	con_skt1x6_th
37	1	210-79507		J1	CON TB 2	CON 1X2 TB TH 200MIL SP 709H - 197L	PHOENIX CONTACT	1711725	con_2x1_5p08
38	5	210-75673		J3,J4,J5,J6,J11	HDR_1X 2	HDR 1X2 TH 100MIL SP 375H AU	TYCO ELECTRONICS	826629-2	HDR102
39	1	210-10345-00		J7	HDR 2X2	HDR 2X2 TH 2.54MM CTR 330H AU	SAMTEC	TSW-102-07-G-D	JUMP2X2-6040
40	5	210-75726		J8,J9,J17,J22,J23	HDR TH 1X3	HDR 1X3 TH 100MIL SP 339H AU 100L	SAMTEC	TSW-103-07-G-S	HDR103
41	1	210-79360		J10	HDR_2X 3	HDR 2X3 TH 100MIL CTR 330H SN 115L	Samtec	TSW-103-23-T-D	HDR203
42	1	210-75688		J12	HDR_1X 4	HDR 1X4 TH 100MIL SP 336H AU 100L	SAMTEC	TSW-104-07-G-S	JUMP1X4-6040
43	1	TMP-WF-16368		J15	CON_2X 8	CON 2X8 PLUG SHRD TH 4.2MM SP 516H SN 140L	Molex	39-28-8160	hdr2x8_4p2_shrd_th
44	1	210-75443		J16	HDR_1X 5	HDR 1X5 TH 100MIL SP 330H AU	SAMTEC	TSW-105-07-S-S	HDR105
45	3	210-75439		J18,J19,J26	HDR 1X2 TH	HDR 1X2 TH 100MIL SP 339H AU 98L	SAMTEC	TSW-102-07-G-S	HDR102
46	2	210-76752		J20,J21	HDR 1X2	HDR 1X2 TH 100MIL SP 330H SN 115L	SAMTEC	TSW-102-07-T-S	hdr102
47	1	211-30007		J24	AUD 4	CON 4 AUD JACK 3.5MM SKT RA SMT -- 197H --	KYCON	STX-3500-4N	4_4_PIN_TH
48	1	210-00096-00		J25	HDR 1X5	HDR 1X5 TH 100MIL CTR 330H SN 100L	SAMTEC	TSW-105-07-TS	HDR105
49	4	180-30021		L2,L4,L5,L6	330 OHM	IND FER BEAD 330OHM@100MHZ 2.5A -- SMT	TDK	MPZ2012S33 1A	IND_0805
50	1	180-30000		L3	500OHM	IND FER BEAD 50 OHM@100MHZ 3A 25%	MURATA	BLM31PG500 SN1L	IND_1206
51	2	180-75935		L7,L8	BLM31AJ 601SN1L	IND FER BEAD 600OHM@100MHZ 200MA 25% 1206	MURATA	BLM31AJ601S N1L	IND_1206
52	1	180-77695		L9	47UH	IND PWR 47UH@100KHZ 1.65A 30% SMT	Bourns	SRU1038-470Y	ind_sru1038_sm
53	2	480-75156		Q1,Q2	BC847AL	TRAN NPN GEN 45VDC	ON SEMICONDUCTOR	BC847ALT1G	SOT23

**Automotive HVAC Control System with LCD Interface for S12ZVH Family devices**

### Testing and Measurements

54	2	480-77979		Q3,Q4	BCP53T1G	TRAN PNP AUD 1.5A 80V SOT223	ON Semiconductor	BCP53T1G	sot223
55	1	480-75197		Q5	MGSF1N02LT1G	TRAN NMOS PWR 750MA 20V SOT-23	ON SEMICONDUCTOR	MGSF1N02LT1G	SOT23
56	1	470-80207		R1	0.0 OHM	RES MF 0.01 OHM 1/2W 1% 2010	VISHAY INTERTECHNOLOGY	WSL2010R0100FEA	RC2010
57	11	470-76111		R2,R3,R10,R18,R31,R33,R34,R50,R52,R61,R78	0ohm	RES 0.0 OHM 1/8W 5% 0805 SMD	YAGEO (VA) V	RC0805JR-070RL	RC0805_OV
58	16	470-75461		R4,R8,R11,R12,R23,R27,R28,R45,R47,R55,R57,R58,R59,R62,R77,R86	10.0K	RES MF 10.0K 1/8W 1% 0805	VENKEL COMPANY	CR0805-8W-1002FT	RC0805_OV
59	1	470-75461	<ASSY_OP T>	R5	10.0K	RES MF 10.0K 1/8W 1% 0805	VENKEL COMPANY	CR0805-8W-1002FT	RC0805_OV
60	12	470-75460		R6,R7,R35,R36,R37,R38,R41,R42,R46,R48,R53,R54	1.0K	RES MF 1.00K 1/8W 1% 0805	KOA SPEER	RK73H2ATTD1001F	RC0805_OV
61	1	470-75972		R9	3.9K	RES MF 3.9K 1/8W 5% 0805	BOURNS	CR0805-JW-392ELF	RC0805_OV
62	1	470-75509		R13	100	RES MF 100 OHM 1/8W 5% 0805	SMEC	RC73L2D101JTF	RC0805_OV
63	2	470-75660		R14,R15	5.6K	RES MF 5.6K 1/8W 5% 0805	BOURNS	CR0805-JW-562ELF	RC0805_OV
64	2	470-75461	DNP	R16,R17	10.0K	RES MF 10.0K 1/8W 1% 0805	VENKEL COMPANY	CR0805-8W-1002FT	RC0805_OV
65	1	470-75968		R19	220	RES MF 220 OHM 1/8W 5% 0805	VENKEL COMPANY	CR0805-8W-221JT	RC0805_OV
66	2	470-75908		R20,R24	4.7K	RES MF 4.7K 1/8W 5% 0805	VENKEL COMPANY	CR0805-8W-472JT	RC0805_OV
67	2	470-77684		R21,R22	60.4	RES MF 60.4 OHM 1/8W 1% 0805	YAGEO AMERICA	232273466049L	RC0805_OV
68	9	470-75989		R25,R60,R79,R80,R81,R82,R83,R84,R85	1.0K	RES MF 1.0K 1/8W 5% 0805	ROHM	MCR10EZPJ102	RC0805_OV
69	1	470-78687		R26	10M	RES MF 10.0M 1/8W 1% 0805	YAGEO AMERICA	RC0805FR-0710ML	RC0805_OV
70	2	470-75460	DNP	R29,R30	1.0K	RES MF 1.00K 1/8W 1% 0805	KOA SPEER	RK73H2ATTD1001F	RC0805_OV
71	1	470-78659		R32	270	RES MF 270 OHM 1/8W 1% 0805	ROHM	MCR10EZH2700	RC0805_OV
72	4	470-76111	DNP	R39,R43,R49,R75	0ohm	RES 0.0 OHM 1/8W 5% 0805 SMD	YAGEO (VA) V	RC0805JR-070RL	RC0805_OV
73	3	470-78659	DNP	R40,R44,R51	270	RES MF 270 OHM 1/8W 1% 0805	ROHM	MCR10EZH2700	RC0805_OV
74	1	470-75584		R56	2.2K	RES MF 2.2K 1/8W 5% 0805	BOURNS	CR0805-JW-222ELF	RC0805_OV

75	2	470-75500		R63,R73	33K	RES MF 33K 1/8W 5% 0805	BOURNS	CR0805-JW- 333ELF	RC0805_OV
76	2	470-30041		R64,R71	20K	RES MF 20K 1/8W 5% 0805	BOURNS	CR0805-JW- 203ELF	RC0805_OV
77	1	470-75754		R65	1.0K	RES MF 1.0K 1/4W 5% 1206	BOURNS	CR1206-JW- 102ELF	RC1206_OV
78	1	470-79991		R66	1.0K	RES POT 1.0K 1/2W 20% TH	Bourns	3352W-1- 102LF	pot3_3352w
79	1	470-80427		R67	9.31K	RES MF 9.31K OHM 1/8W 1% 0805	Yageo	RC0805FR- 079K31L	RC0805_OV
80	1	470-80428		R68	19.1K	RES MF 19.1K OHM 1/8W 1% 0805	Yageo	RC0805FR- 0719K1L	RC0805_OV
81	1	470-80429		R69	8.45K	RES MF 8.45K OHM 1/8W 1% 0805	Yageo	RC0805FR- 078K45L	RC0805_OV
82	1	470-30468		R70	12.4K	RES MF 12.4K 1/8W 1% 0805	YAGEO AMERICA	RC0805FR- 0712K4L	RC0805_OV
83	1	470-30528		R72	100K	RES MF 100K 1/4W 5% 1206	ROHM	MCR18EZHJ1 04	RC1206_OV
84	1	470-75647		R74	10K	RES MF 10K 1/4W 5% 1206	BOURNS	CR1206JW10 3ELF	RC1206_OV
85	1	470-77400		R76	560	RES MF 560 OHM 1/8W 1% 0805	YAGEO AMERICA	23227346560 1L	RC0805_OV
86	2	470-75989	DNP	R87,R88	1.0K	RES MF 1.0K 1/8W 5% 0805	ROHM	MCR10EZPJ10 2	RC0805_OV
87	1	510-75094		SW1	SPST PB NO	SW SPST PB MOM NO SMT 50MA@50V AG, ROHS	E SWITCH	TL3301NF160 QG	SW4_PB_ES W_SM_P177
88	1	TMP-WF- 15243		U1	9S12ZVH 128VLQ	IC MCU AUTOMOTIVE 16BIT 5.5-18V LQFP144	FREESCALE SEMICONDUCTOR	9S12ZVH128V LQ	LQFP144_OP 5_20X20MM
89	1	312-79849		U2	TSOP348 38	IC IR RCVR MODULE 38KHZ 2.5-5.5V TH	VISHAY INTERTECHNOLOGY	TSOP34838	tsop3_2p54 _6x5p6
90	1	315-77325		U3	LM9402 2	IC MULTI-GAIN ANALOG TEMPERATURE SENSOR 1.5-5.5V SC70-5	NATIONAL SEMICONDUCTOR	LM94022BIM GXNOPB	SC70-5_A
91	2	315-77948		U4,U9	MC3393 2	IC THROTTLE CONTROL DUAL H- BRIDGE 8.0-28V HSOP44	FREESCALE SEMICONDUCTOR	MC33932VW	hsop44_11x 16mm
92	1	315-79163		U5	MC3398 4CPNA	IC LIN SW DUAL 4MILLIOHM 6-27V PQFN16	FREESCALE SEMICONDUCTOR	MC33984CPN A	pqfn_16_12 x12_a
93	1	315-78968		U6	MCP602 2	IC LIN OPAMP DUAL 10kHz 1.8-5.5V MSOP8	MICROCHIP TECHNOLOGY INC	MCP6032- E/MS	MSOP_8_OP 65_3X3
94	1	315-79412		U7	LM4853 MM	IC LIN PWR AMP MONO 1.5W/STEREO 300mW 2.4-5.5V	National semiconductor	LM4853MM/ NOPB	MSOP10_OP 5_3P1X3P1_ IPC

**Automotive HVAC Control System with LCD Interface for S12ZVH Family devices**

### Testing and Measurements

						MSOP10			
95	1	330-76687		U8	PC9S08P T60VLH	IC MCU 8BIT 60KB FLASH 4KB RAM 20MHZ 2.7-5.5V LQFP64	FREESCALE SEMICONDUCTOR	PC9S08PT60V LH	lqfp64_0p5_ 10x10
96	1	230-77751		Y1	4MHz	XTAL 4MHZ 18PF 20PPM SMT	Aker Technology Co., Ltd	49M-004000- FD6D10	HC49SDF
97	1	230-30001		Y2	32.768K Hz	XTAL 32.768KHZ PAR 20PPM -- SMT	Citizen	CMR200T32.7 68KDZF-UT	XTL2_ECS_S M



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