Automotive HVAC Control System with LCD Interface for S12HY Family Devices

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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 MC9S12HY64.

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**

The reference design replaces mechanical switches used for vent positions, blower speed, and temperature control. This HVAC control system offers a capacitive touch pad interface (controlled through proximity capacitive touch sensor), an IR remote control (provided for the ease of rear-seat passengers) and micro-switches. It drives the actuator and blower motor with the help of a robust H-bridge and intelligent high-current switch. The design provides safety features such as motor stall detection, motor jams/shorting, open load, etc.

The design also features car cabin's temperature (in degree Celsius) display, date and time displays, thus eliminating the need of separate date/time/temperature displays. Date/Time can be easily set through touch pads/remote control.

Block diagram of MC9S12HY based HVAC system is shown in Figure 2.

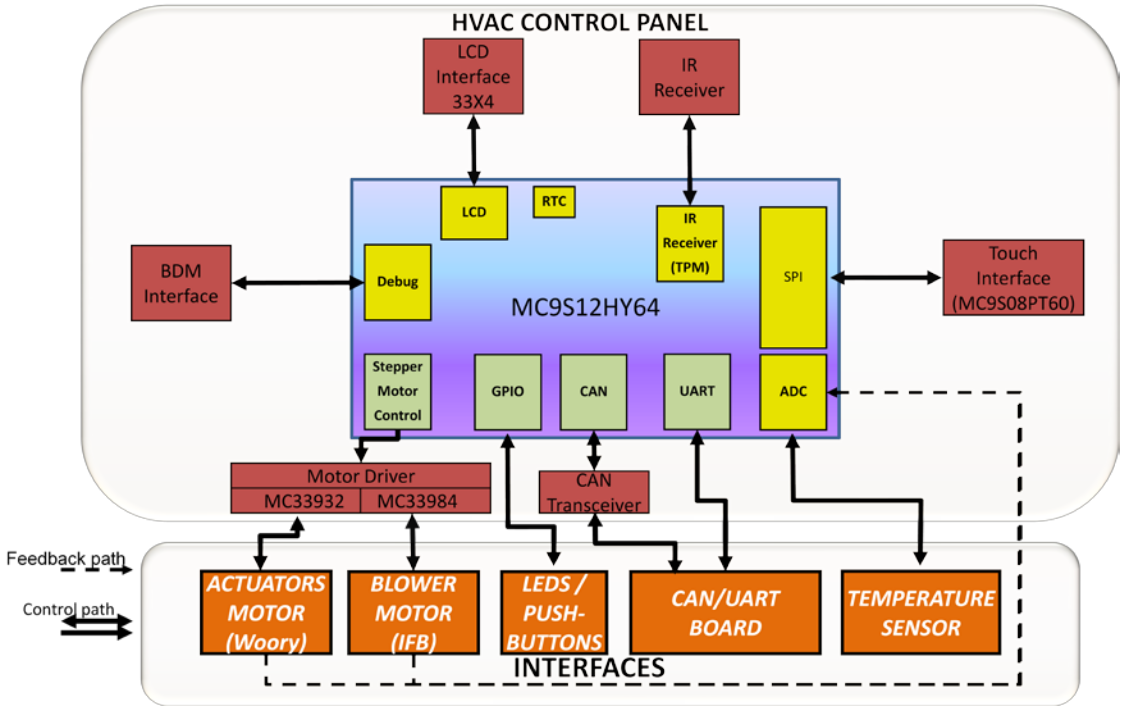


Figure 2. **Block diagram**

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 defogger using actuator motor
- 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 using PT60 MCU
- Low Power Mode interfaced through Ignition

The package that shall be supplied to the user for developing the HVAC system based on MC9S12HY64 MCU includes:

- Hardware – Reference HVAC board
- Documentation – DRM, BOM, Schematics

1.2. Advantages and features of MC9S12HY64 controller

Advantage of using MC9S12HY64:

- In-built LCD driver capable of driving 160 segments
- Stepper Motor Controller
- Low-voltage detect (LVD) with low-voltage interrupt (LVI) and Low-voltage reset (LVR)
- 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 MC9S12HY64 MCU are:

- HCS12 CPU core, 32 MHz bus frequency (64 MHZ core frequency)
- Up to 64 KB on-chip flash with ECC
- 4 KB data flash with ECC
- Up to 4 KB on-chip SRAM
- LCD driver, configurable up to 40 x 4, all LCD pins are multiplexed with GPIOs
- Stepper motor controller with up to four drivers
- Phase locked loop (PLL) frequency multiplier with internal filter
- 4–16 MHz amplitude controlled Pierce oscillator
- 1 MHz internal RC oscillator
- Two timer modules (TIM0 and TIM1) supporting input/output channels that provide a range of 16-bit input capture, output compare, counter, and pulse accumulator functions
- Pulse width modulation (PWM) module with up to eight 8-bit channels
- Autonomous periodic interrupt (API)
- Up to 8-channel, 10-bit resolution successive approximation analog-to-digital converter (ATD)
- One serial peripheral interface (SPI) module
- One serial communication interface (SCI) module supporting LIN 2.0, 2.1, and SAE J2602 communications

- On-chip voltage regulator (VREG) for regulation of input supply and all internal voltages
- One Inter-Integrated Circuit (I2C) module
- One multi-scalable controller area network (MSCAN) module (supporting CAN protocol 2.0A/B)
- Up to 22 key wakeup inputs
- Available in 64 LQFP and 100 LQFP packages

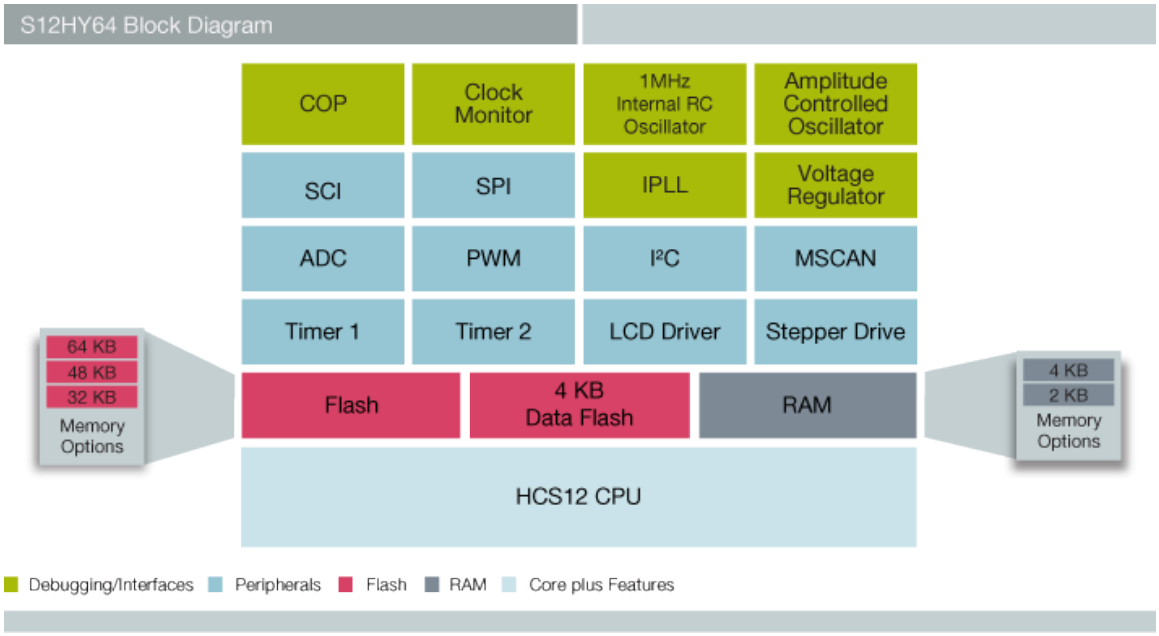


Figure 3. **Block diagram of S12HY family**

Chapter 2
Hardware Description

2.1. Introduction

The reference design consists of:

- Power supply section
- 100-pin LQFP packaged MC9S12HY64 MCU
- 132 segment (33X4) LCD Glass interface with backlight control
- Dual 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 the car's cabin temperature
- CAN interface for communication with various other units
- Ignition control section for low-power mode simulation

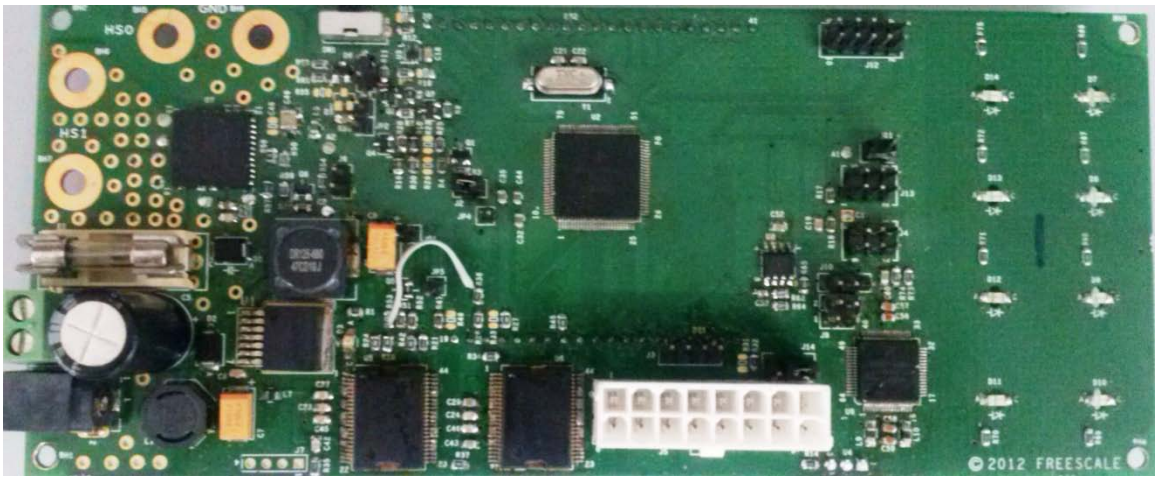


Figure 4. **S12HY based HVAC reference design PCB – MCU side**

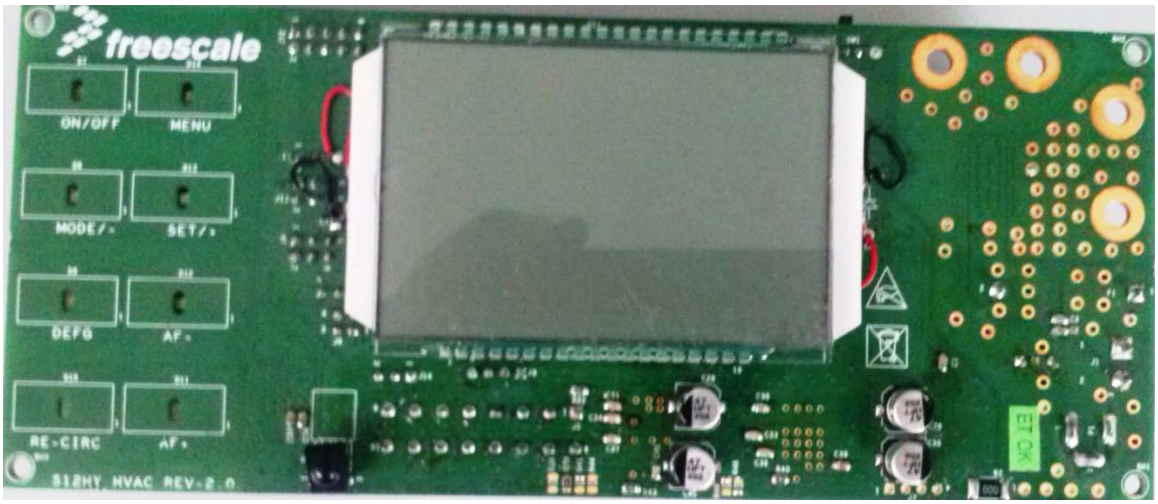


Figure 5. **S12HY based HVAC reference design PCB – LCD side**

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

- 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.

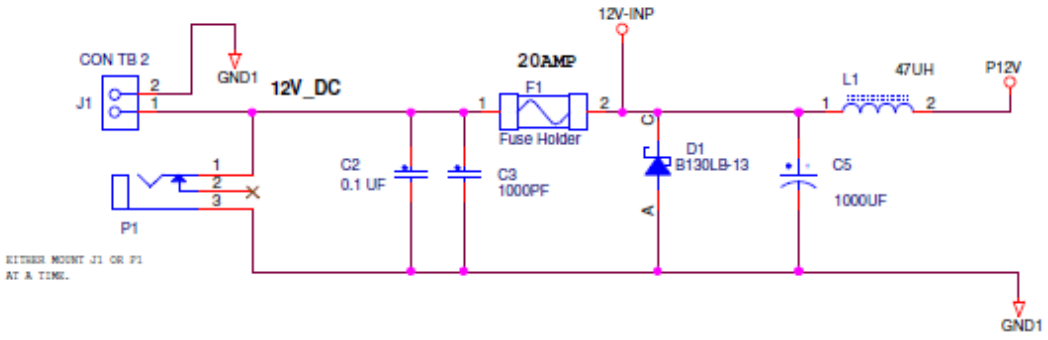


Figure 6. **Signal conditioning circuitry on input supply**

A switching regulator LM2676S-5.0 is used to generate a 5 V power supply to the MCU and the connected peripherals, which include:

- Temperature sensor
- IR receiver
- Digital interface of MC33984
- Digital interface of MC33932
- Controller Area Network transceiver
- LCD Glass backlight

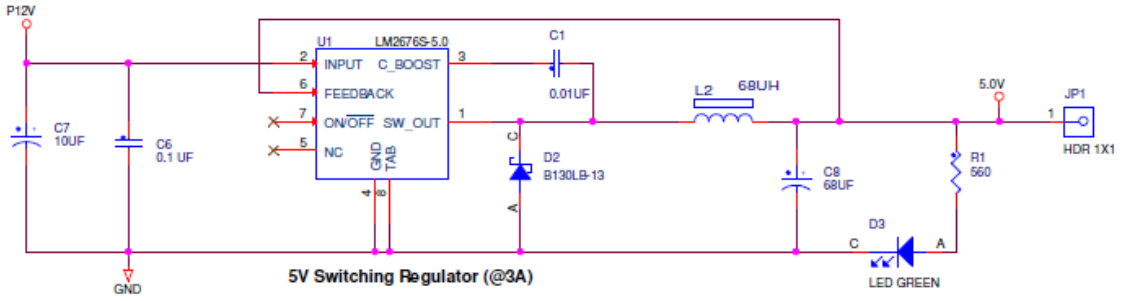


Figure 7. **Switching regulator section**

The design has a power grid controlled by the S12HY MCU to control power consumption during low-power mode.

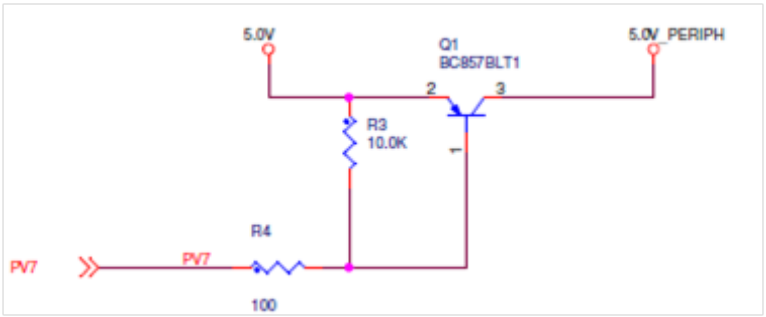


Figure 8. **MCU controlled peripheral power grid**

2.2.2. MC9S12HY64 MCU

MC9S12HY64 is an automotive, 16-bit microcontroller including error correction code (ECC) on flash memory, a separate data-flash module for diagnostic or data storage, a fast analog-to-digital converter (ADC) and a frequency modulated phase locked loop (IPLL) that improves the EMC performance. This family also services generic automotive applications requiring CAN, LCD, Motor driver control, or LIN/J2602. Typical examples of these applications include automotive HVAC system, entry level instrument clusters, automotive audio system, general purpose motor control, and body controllers.

The MC9S12HY family delivers all the advantages and efficiencies of a 16-bit MCU while retaining the low cost, power consumption, EMC, and code-size efficiency advantages.

The reference design utilizes the following modules of MC9S12HY64:

1. LCD controller to drive 33X4 LCD.
2. Motor Controller module to drive Actuator motors.
3. SPI and TIM module for controlling and driving the blower motor driver IC and PT60 for Touch sense application.
4. TIM module for interfacing IR remote control.
5. BKGD for programming.
6. CAN interface for communication.
7. ADC module for Temperature sensor and stall detection of blower and actuator motors.
8. IRQ/XIRQ as a wakeup source.
9. RTI module for time keeping.

The design uses 8 MHz crystal for feeding the PLL and also acts as the source for time keeping.

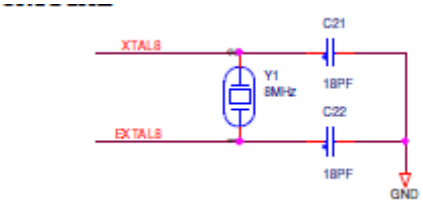


Figure 9. **Crystal section**

The functional pin assignment for MC9S12HY64 is described in Table 1 and the schematic in Figure 10:

Table 1. **Functional pin assignment**

Pin#	Pin Assignment	Purpose	Major Block
1		—	—
2		—	—
3	M0C0M	Actuators (U10_IN1) (Fresh Air)	Actuators
4	M0C0P	Actuators (U10_IN2) (Fresh Air)	Actuators
5	M0C1M	Actuators (U11_IN3) (Temp)	Actuators
6	M0C1P	Actuators (U11_IN4) (Temp)	Actuators

7		Supply	Supply
8		Supply	Supply
9	M1C0M	Actuators (U11_IN1) (Mode)	Actuators
10	M1C0P	Actuators (U11_IN2) (Mode)	Actuators
11	M1C1M	Actuators (U10_IN3)	Actuators
12	M1C1P	Actuators (U10_IN1)	Actuators
13	MISO	SPI (used for Blower motor/PT60)	SPI
14	MOSI	SPI (used for Blower motor/PT60)	SPI
15	SCK	SPI (used for Blower motor/PT60)	SPI
16	SS	SPI (used for Blower motor)	SPI
17		Supply	Supply
18		Supply	Supply
19	IOC1_2	Used for Edge detect for checking the Stall on	Blower Motor
20	PV5	Chip Select for PT60	Touch Sensor
21	PV6	IR data pin	IR
22	PV7	Peripheral power control	Power
23	—	—	—
24	—	—	—
25	RXD	UART (RXD)	UART
26	TXD	UART (TXD)	UART
27	RXCAN	CAN (RX)	CAN
28	TXCAN	CAN (TX)	CAN
29	—	—	—
30	PWM1	IN1 (MC33984)	Blower Motor
31	PWM2	IN2 (MC33984)	Blower Motor
32	—	—	—
33	PT60_IRQ	IRQ for Touch Sensor	Touch sensor
34	BLR_WK	Blower Motor wake up	Blower Motor
35	BLR_FAULT	Blower Motor Fault	Blower Motor
36	BLR_RST	Blower Motor Reset	Blower Motor

37	FP0	LCD (pin 11)	LCD
38	FP1	LCD (pin 10)	LCD
39	FP2	LCD (pin 9)	LCD
40	FP3	LCD (pin 8)	LCD
41	FP4	LCD (pin 7)	LCD
42	FP5	LCD (pin 6)	LCD
43	FP6	LCD (pin 5)	LCD
44	FP7	LCD (pin 4)	LCD
45	—	—	—
46	—	—	—
47	FP10	LCD (pin 3)	LCD
48	FP11	LCD (pin 2)	LCD
49	FP12	LCD (pin 1)	LCD
50		BDM Interface	BDM Interface
51	—	—	—
52	—	—	—
53	FP15	LCD (pin 12)	LCD
54	FP16	LCD (pin 13)	LCD
55	FP17	LCD (pin 14)	LCD
56	FP18	LCD (pin 15)	LCD
57	FP19	LCD (pin 16)	LCD
58	FP20	LCD (pin 17)	LCD
59	FP21	LCD (pin 18)	LCD
60	FP22	LCD (pin 19)	LCD
61		Supply	Supply
62		Supply	Supply
63	PH4	Actuator Motor Control	Actuator
64	FP24	LCD (pin 41)	LCD
65	FP25	LCD (pin 36)	LCD
66	FP26	LCD (pin 35)	LCD

67	FP27	LCD (pin 34)	LCD
68	FP28	LCD (pin 33)	LCD
69		Supply	Supply
70		Supply	Supply
71		Supply	Supply
72		Crystal	Crystal
73		Crystal	Crystal
74	IRQ	Ignition	Ignition
75	PA1	Actuator Motor Control	Actuator
76	FP31	LCD (pin 32)	LCD
77	FP32	LCD (pin 31)	LCD
78	FP33	LCD (pin 30)	LCD
79	FP34	LCD (pin 29)	LCD
80	FP35	LCD (pin 28)	LCD
81	FP36	LCD (pin 27)	LCD
82	FP37	LCD (pin 26)	LCD
83	FP38	LCD (pin 25)	LCD
84	FP39	LCD (pin 24)	LCD
85	BP0	LCD (COM1)	LCD
86	BP1	LCD (COM2)	LCD
87	BP2	LCD (COM3)	LCD
88	BP3	LCD (COM4)	LCD
89	VLCD supply	LCD Controller Supply	LCD Controller Supply
90		BDM Interface	BDM Interface
91		Supply	Supply
92		Supply	Supply
93	AN00	Temp Sensor I/p Data	Temp Sensor
94	AN01	Feedback for Temp Actuator	Feedbacks
95	AN02	Feedback for Mode Actuator	Feedbacks
96	AN03	Feedback for Blower Motor	Feedbacks
97	AN04	M0C0M(DNP) (Fresh Air Actuator)	Feedbacks

98	AN05	M0C0P(DNP) (Fresh Air Actuator)	Feedbacks
99	BLR_CSNS	Blower Motor Sense	Blower Motor
100	—	—	—

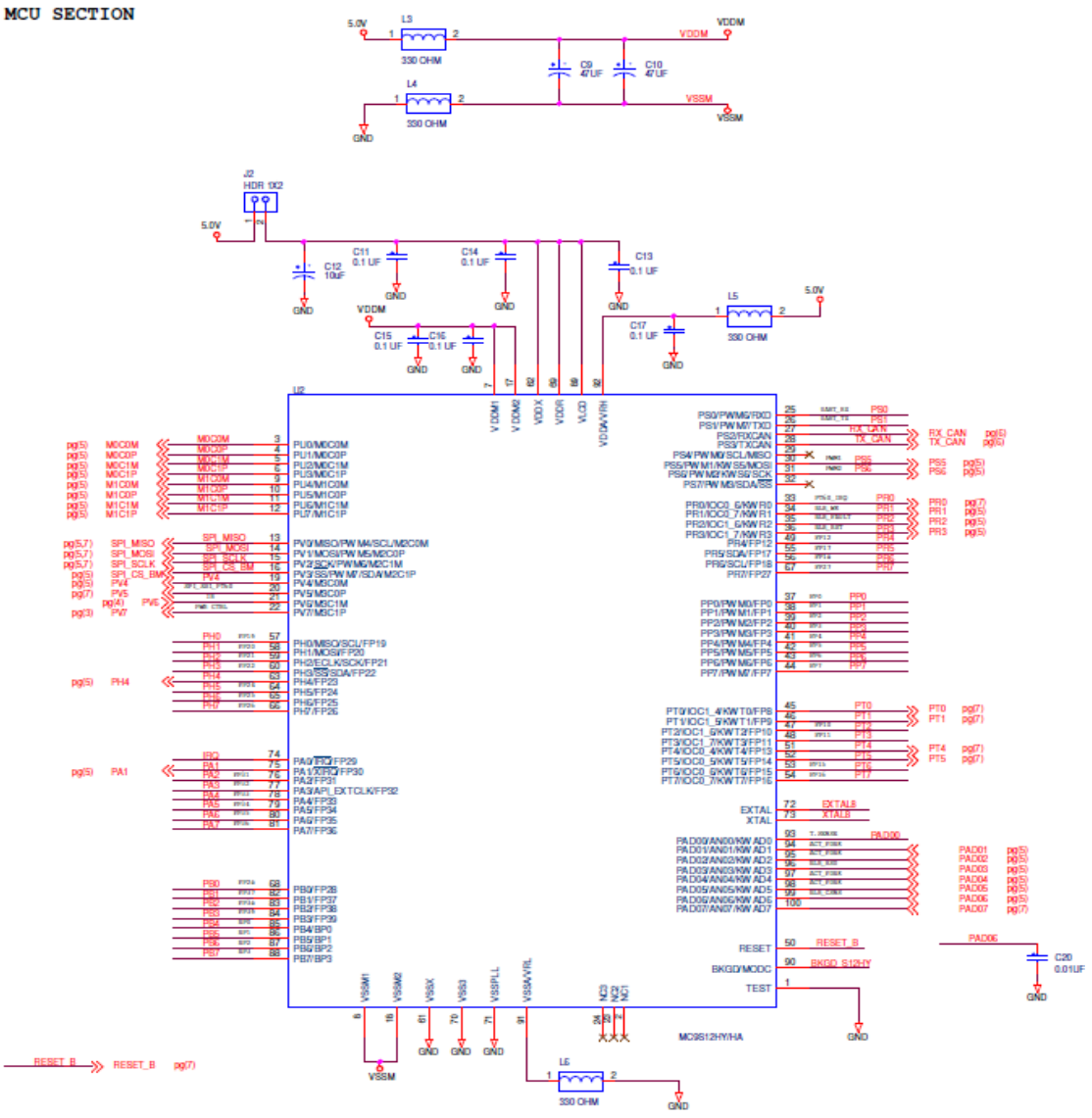


Figure 10. **MCU section**

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 11.

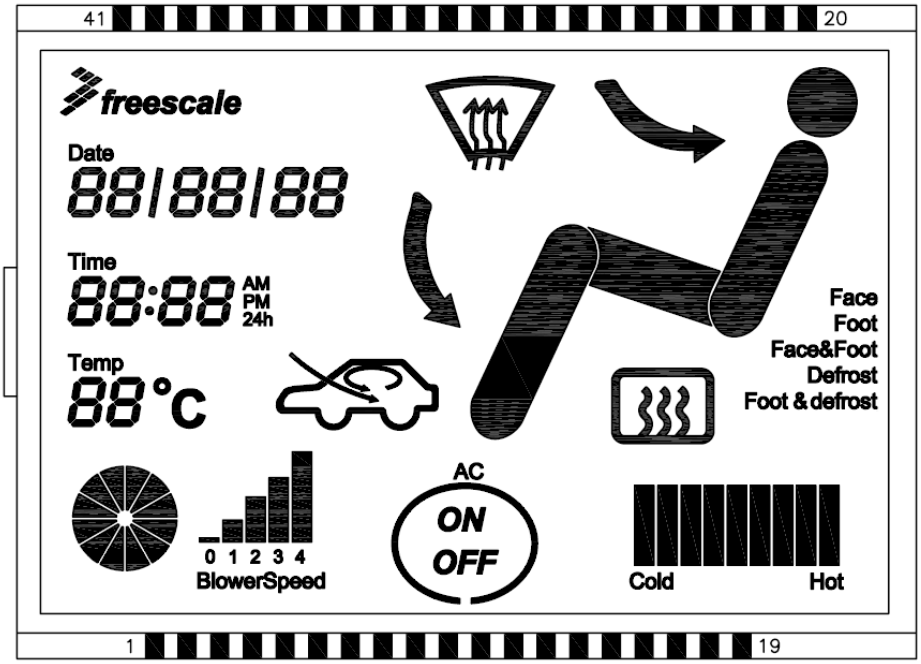


Figure 11. **LCD Glass**

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 12.

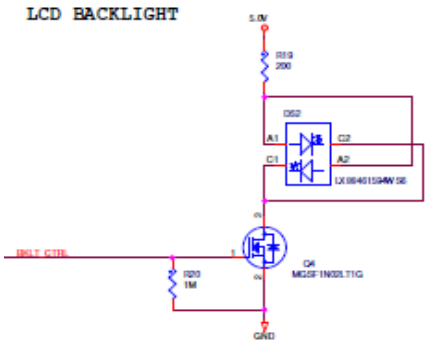


Figure 12. **LCD Glass backlight**

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 motors control include:

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

Each actuator motor requires 200 mA @ 12 V of current, which is sourced through MC33932. SMC module of MCU is used to interface the H-Bridge. The schematic of one of the actuator motor interface is shown in Figure 13:

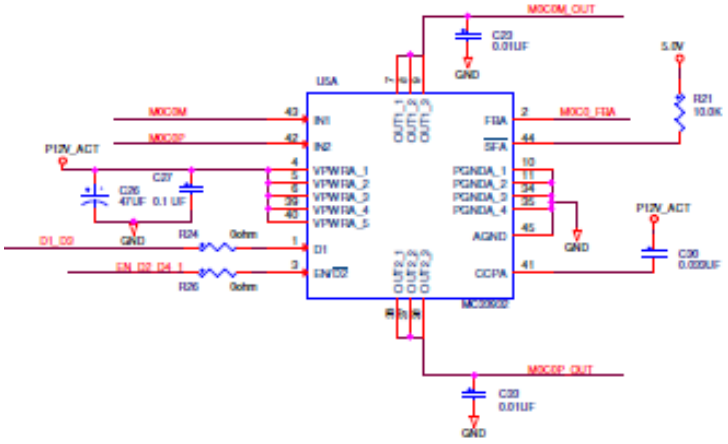


Figure 13. **Actuator motor section**

Two of the actuator motors (temperature and vent position) used in the design have feedback pins, which return the actuator motor position in the form of 0-5 V signal. It is interfaced with the ADC pin of the MCU for stall detection.

Recirculation actuator motor is a two wire actuator motor without any feedback, so the stall detection has been implemented by a different mechanism. The total numbers of cycles, at fixed PWM duty cycle, required to move the motor from one position to the other (internal to external or vice-versa) is known (using the calibration process), after which the driving of the motor pin is stopped to implement the stall.

2.2.5. Blower motor driver

Intelligent, high-current, self-protected, silicon, high side switch MC33984 is used to drive high current blower motor. It is capable of driving two blower motors of 15 A each. It provides many protections, few of which includes:

- Over-voltage fault

- Over-temperature fault
- Under-voltage shutdown
- Open load fault
- Over-current fault
- Enhanced 16 V reverse polarity VPWR protection

MC33984 is programmed and controlled via the Serial Peripheral Interface (SPI). It communicates various fault condition to the MCU via its fault status pin ($\overline{FS}$) and the same can be read over SPI bus.

The current driver is interfaced with the PWM channel of the MCU for controlling the blower motor speed. The output of the blower motor is interfaced to the ADC channel to implement stall so that motor drive could be stopped once the motor jams. The schematic of the blower motor section is shown in Figure 14.

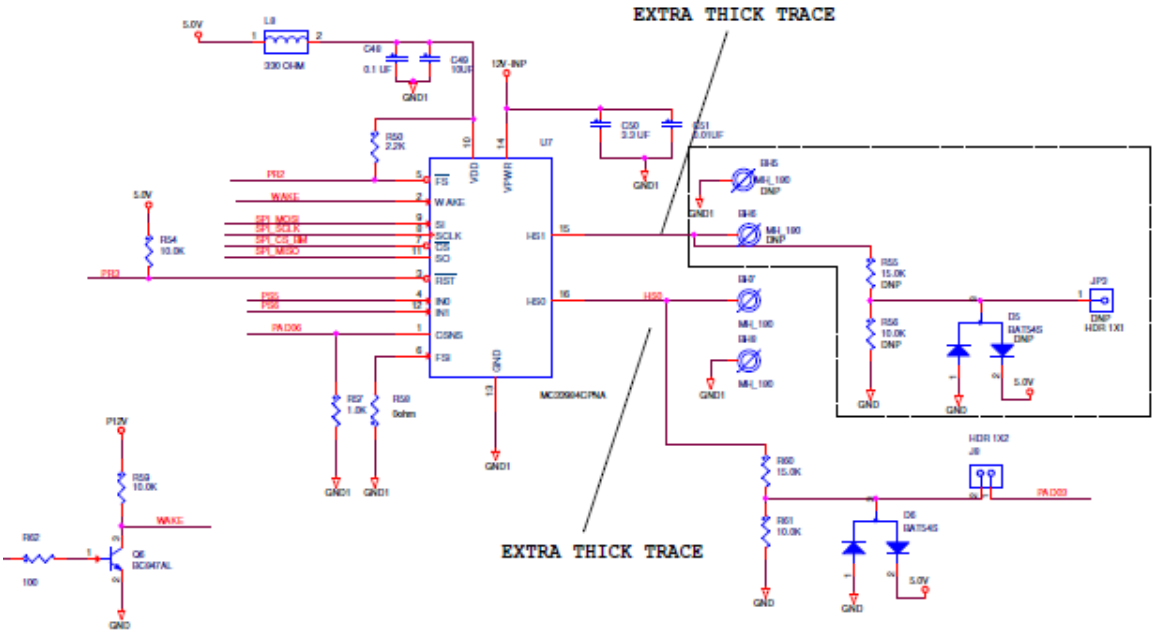


Figure 14. **Blower motor section**

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:

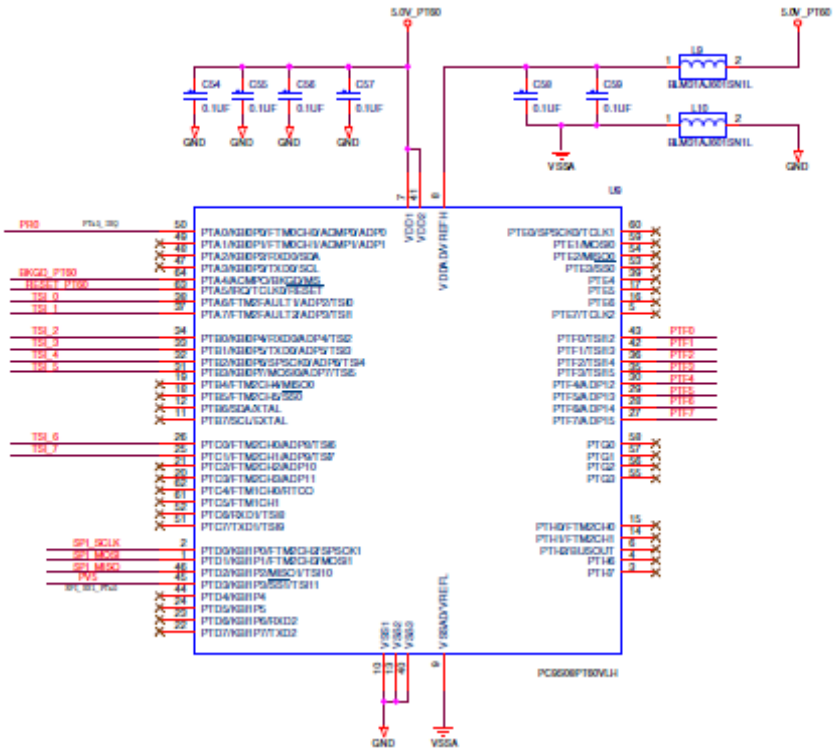
Table 2. **Blower motor specifications**

S. No.	Parameters	Specifications
1	Motor Type	PMDC
2	Motor Rating	Continuous
3	Rated Voltage	12 V

4	No Load Current	1.7 A
5	No Load Speed	4500 rpm
6	Rate Torque	0.3 Nm
7	Rated Current	14.5 A
8	Rated Speed	3600 ± 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. The schematic of the capacitive touch sensor is shown in Figure 15.



Automotive HVAC Control System with LCD Interface

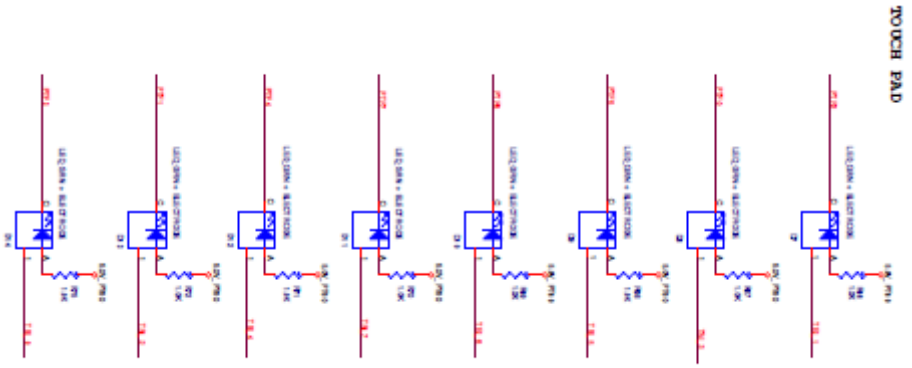


Figure 15. **Capacitive touch sensor section**

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 Figure 16.

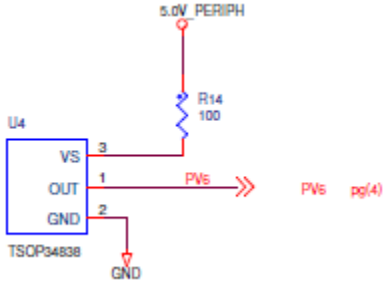


Figure 16. **IR receiver section**

2.2.8. Temperature sensor

Temperature sensor interfaced to the ADC channel of the MCU provides car cabin's real time temperature, which in turn is displayed on the LCD. The sensor provides the voltage that is proportional to the temperature. The schematic is shown in Figure 17.

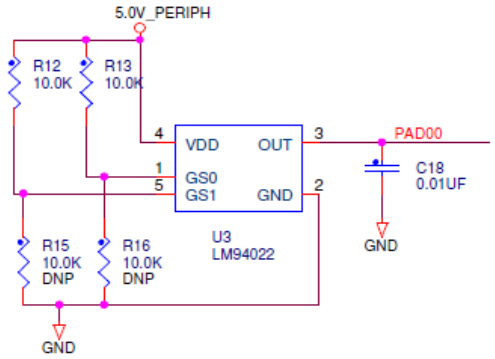


Figure 17. **Temperature sensor section**

2.2.9. Controller Area Network (CAN)

This design provides the CAN interface for communication with other system units and the schematic is shown in Figure 18.

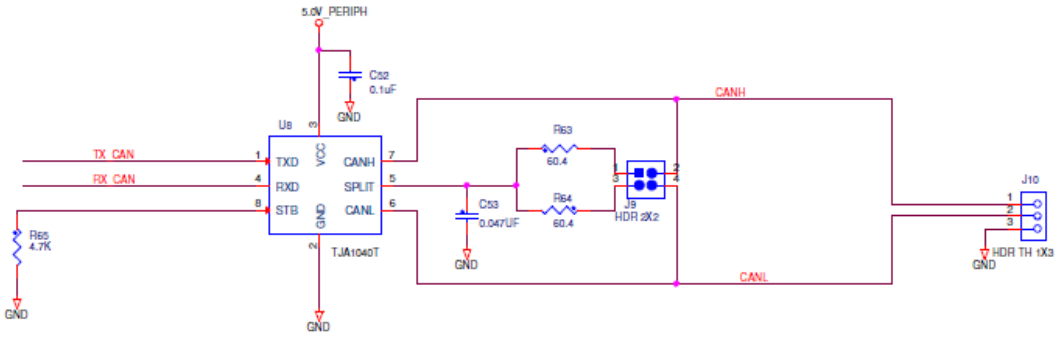


Figure 18. **CAN section**

2.2.10. 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 19. 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 20

Figure 19. **PE micro USB multilink**

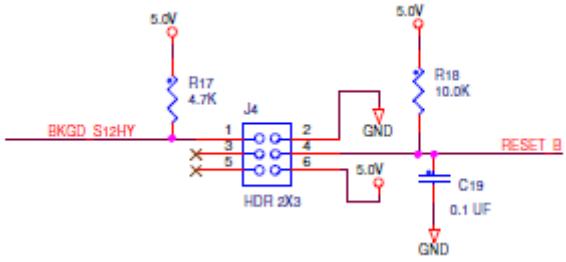


Figure 20. **Background debug section**

Chapter 3
Software Design

3.1. Introduction

This chapter describes the embedded software design of the HVAC application based on MC9S12HY64. This application's main purpose is to demonstrate MC9S12HY64's capability to interface LCD, drive the motors, provide user interface, while maintaining the calendaring information at the same time.

All embedded software of this project was written using CodeWarrior Development Studio for Freescale S12(X) Microcontrollers, V5.1 which is Windows supported and can be downloaded from freescale.com.

Software design mainly consists of graphics display, user interface, motor control, real-time temperature sensing & display, and RTI for time keeping. The controller uses external crystal (8 MHz) and internal PLL to generate the core/bus clock of 40 MHz/20 MHz.

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. Software architecture

MC9S12HY64 is based on a high-speed S12 CPU, 16-bit processing unit that has a programming model identical to that of the industry standard M68HC11 CPU. All the tasks are scheduled on round robin basis.

Overall system flowchart is shown in Figure 21 and the system memory map in Table 3.

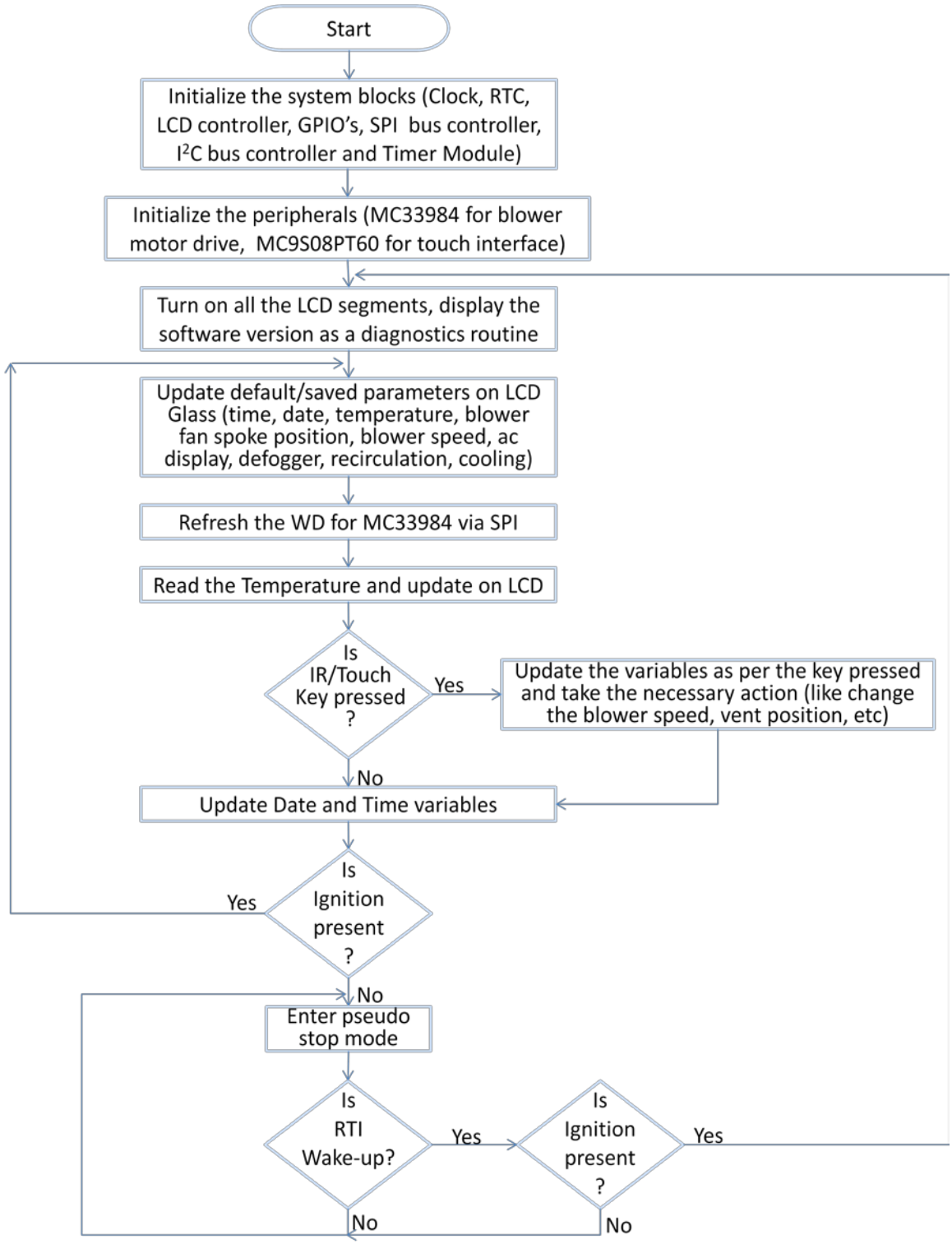


Figure 21. **System flowchart**

Table 3. **Memory map**

Module Name	Code Memory	Data Memory
ADC	65	1
Actuator Motors	1,812	122
Blower Motor	538	13
Clock	30	0
IR Remote	727	17
LCD	8,245	27
Push Buttons	129	0
RTC	351	11
Temperature Sensor	80	6
Touch	250	1
Data Page	185	0
Main	2,513	27
Total	14,925	225

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

3.2.1. LCD graphics display

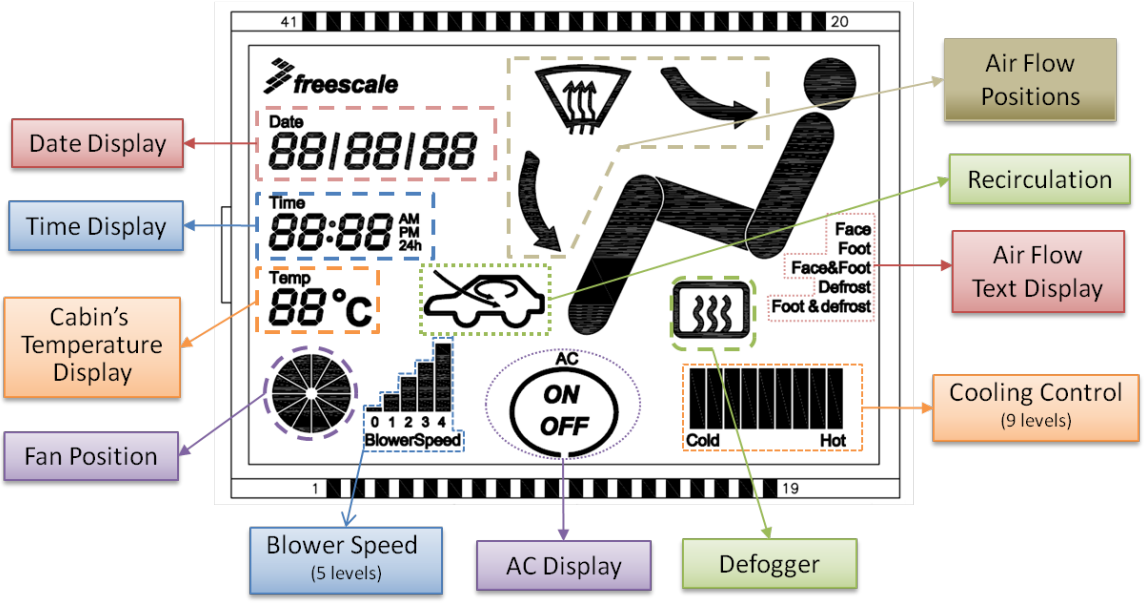


Figure 22. **LCD major blocks**

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 four spokes/blades, as is shown in Figure 23. L1 shows the position 1 of all the four spokes of the fan, L2 shows position 2, and L3 shows position 3. Rotation of the fan is a function of blower motor speed, higher the blower motor speed faster the fan will rotate.

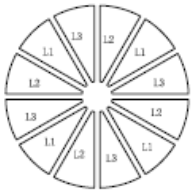


Figure 23. **Fan positions**

- 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 not modifiable by any user interface.

3.2.2. User interface

The reference design has two types of interfaces:

1. IR remote control
2. Capacitive touch pads

These will be discussed in detail in the following section.

3.2.2.1. IR remote control

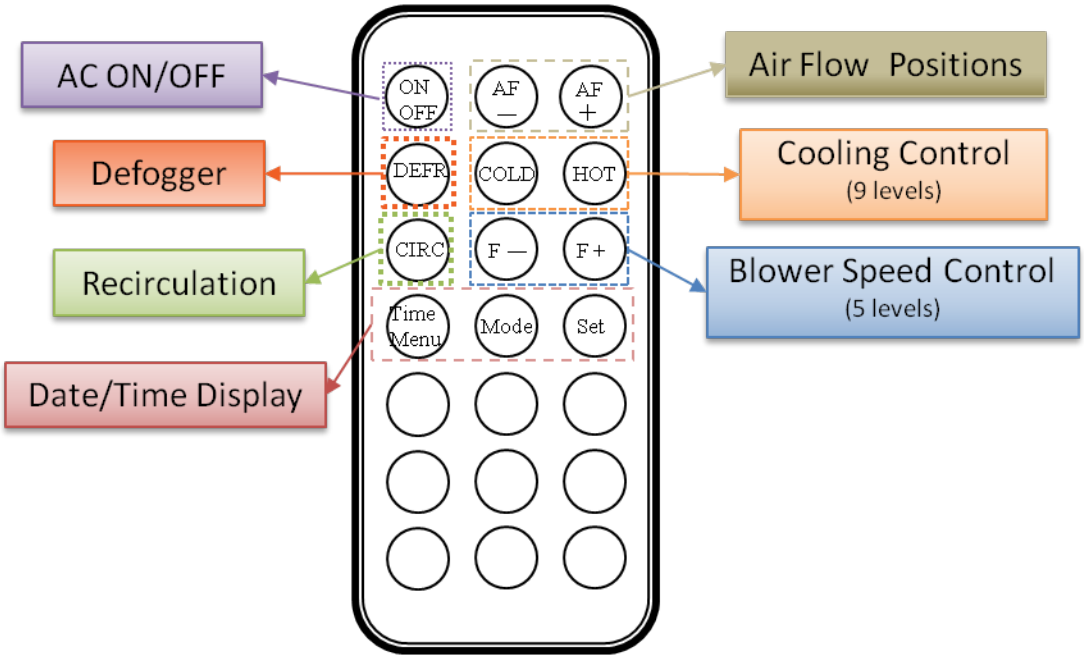


Figure 24. **IR remote control along with key descriptions**

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.

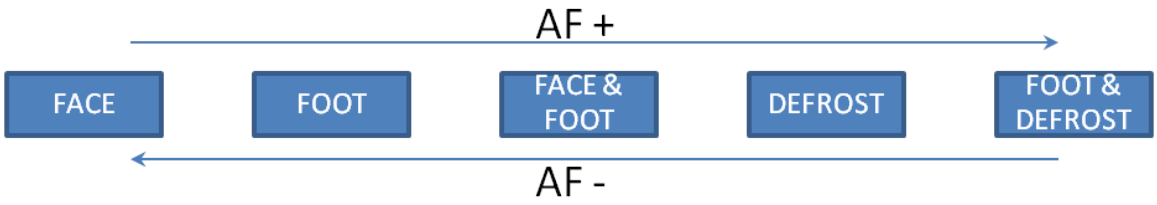


Figure 25. **AF+/- key press control flow**

- 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 key are used to change the degree of coldness/hotness in the vehicle. Pressing this key will drive the cooling actuator motor in the background, while the COLD/HOT level will be updated on the LCD.
- Blower Speed Control – 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 (AM/PM/24H). Set key increments the selected digit, and once the limit is reached, digit is reset to zero.

3.2.2.2. Capacitive touch pads

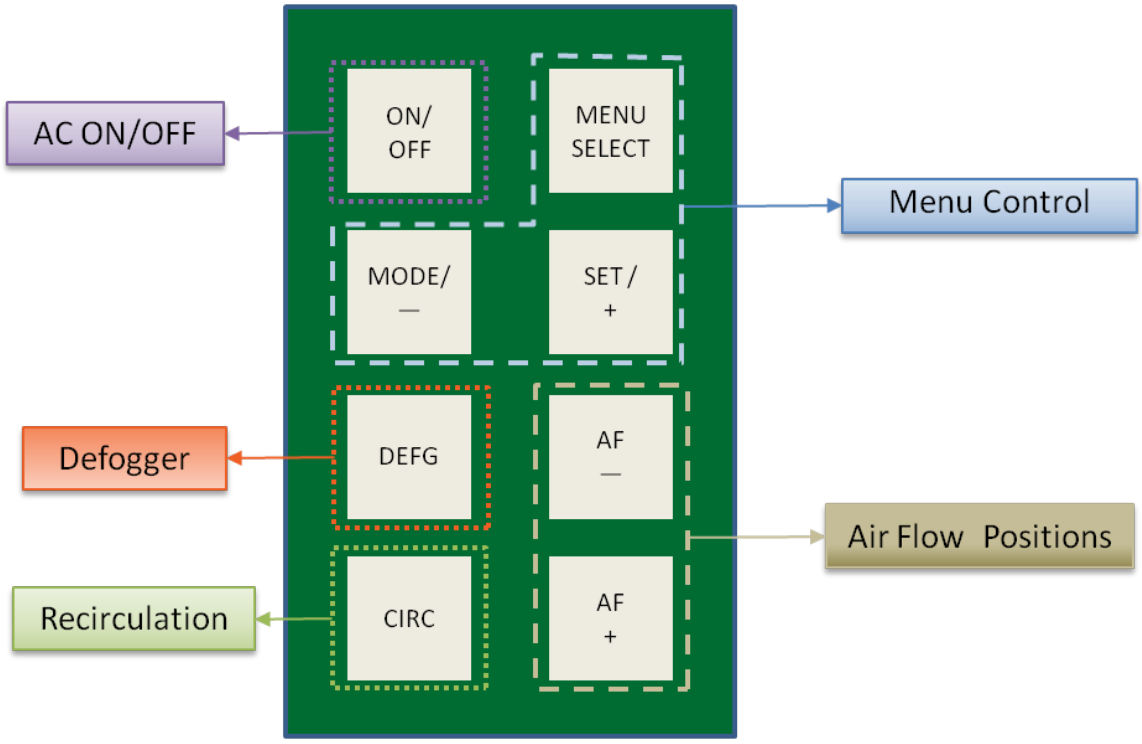


Figure 26. **Touch pads**

Proximity Capacitive Touch Sensor Controller PT60 is interfaced to the MCU via SPI bus, through which it communicates the various touch pad pressed. Each touch pad updates its corresponding section on the LCD and is shown in Figure 26. ON/OFF, DEFG, CIRC, AF+/- have the same functionality as the corresponding IR remote key, which have already been explained in the above section.

As the number 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 below in Figure 27, starting from Blower Motor Menu.

Table 4 shows the functionality of touch pads MODE/+ and SET/ in each mode, which will emulate the functionality of IR remote keys.

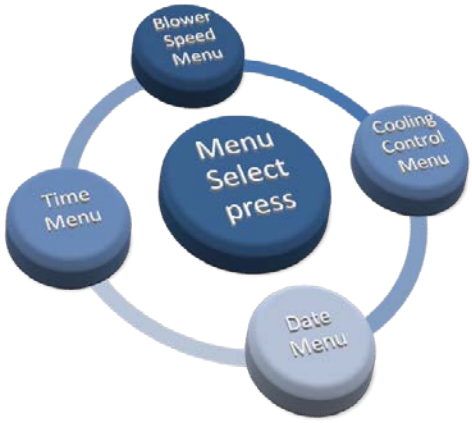


Figure 27. **Menu Select control flow**

Table 4. **Functionality of Mode/Set keys when Menu key is active**

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

1. The touch key function emulates the IR keys are listed here

3.2.3. Motor control

The reference design has two types of motor control

- Blower motor control
- Actuator(s) motor control

These will be discussed in detail in the following section

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 Table 5.

Table 5. 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 mechanical or electrical reason because of which it may be 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 Motor Controller module of the MCU and is driven through the high-current H-Bridge 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; RTI is used for this purpose, which generates the interrupt periodically. In the reference design the periodicity of the interrupt is 250 ms.

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

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 6, which are useful for board bring up.

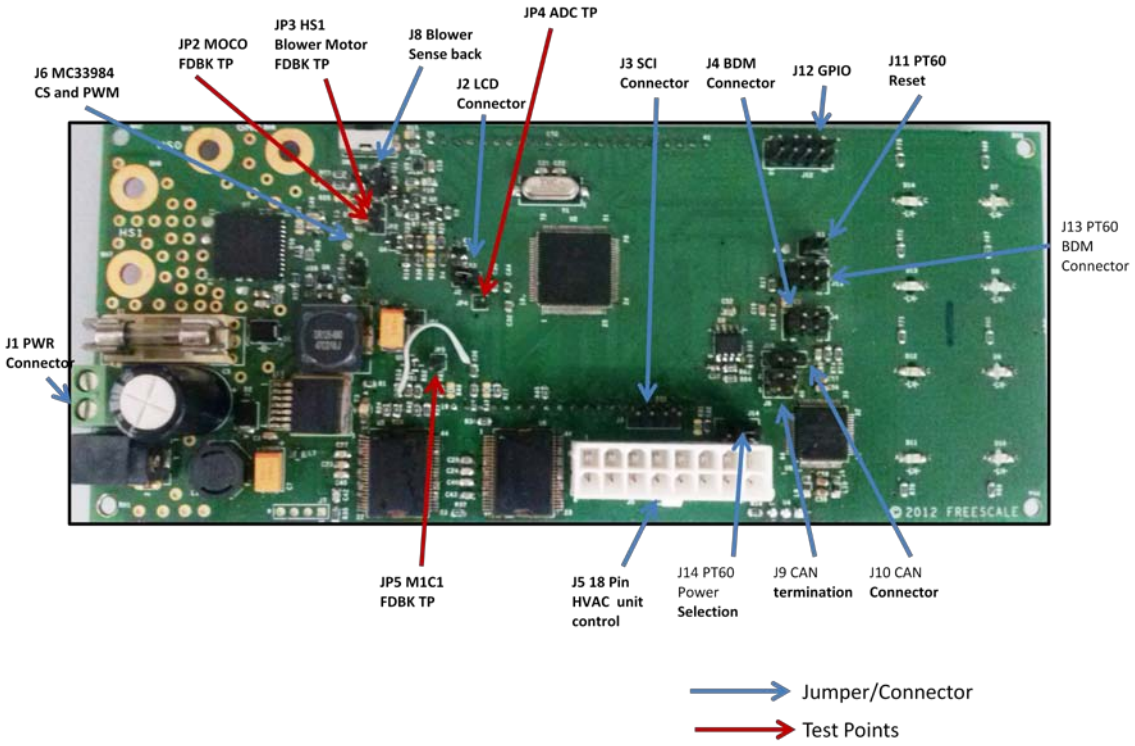


Figure 28. **Jumper settings**

Table 6. **Jumper settings**

Jumper	Functionality	Connection
J1	Power connections on the board	1: +12V 2: GND
J2	VLCD	1-2
J3	SCI connector	—
J4	S12 BDM Connector	—
J5	HVAC unit 18 pin connector	—

J8	MC33984 Sense back HS0 Blower motor feedback connected to ADC channel	—
J9	CAN termination connector	—
J10	CAN connector	—
J11	PT60 Reset Connector	—
J12	GPIO Connector	—
J13	PT60 BDM connector	—
J14	PT60 Power Selection Pin	2-3

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:

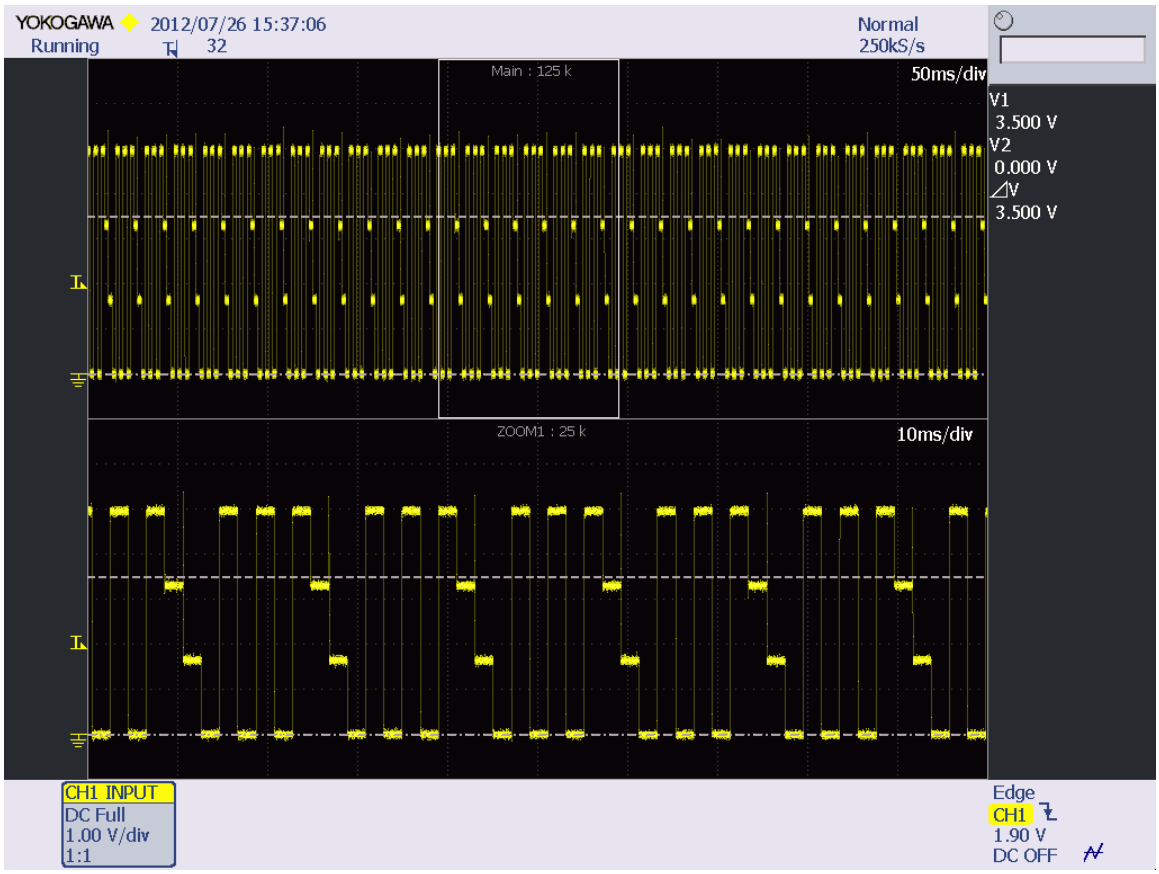


Figure 29. **Waveform - a front plane with exactly one ON segment**

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.

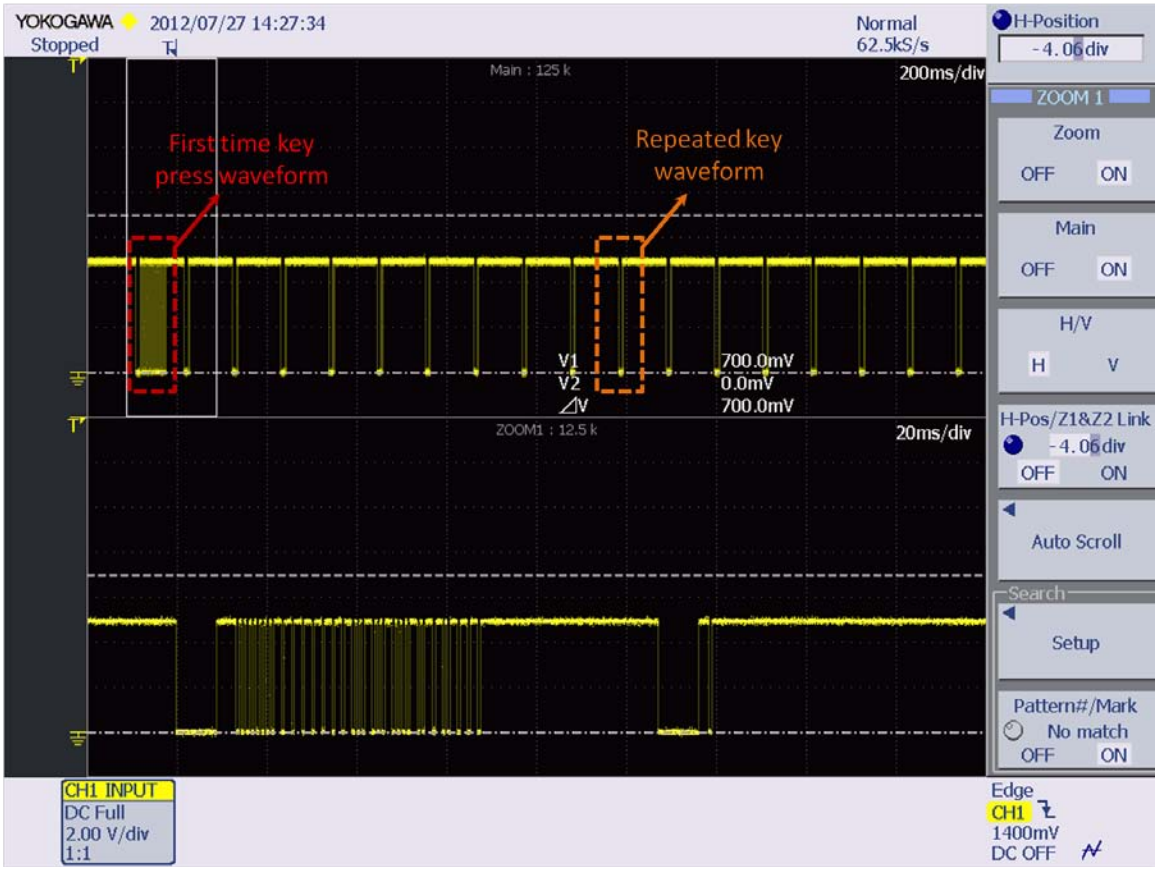


Figure 30. **Waveform – when a single key is pressed for a long time**

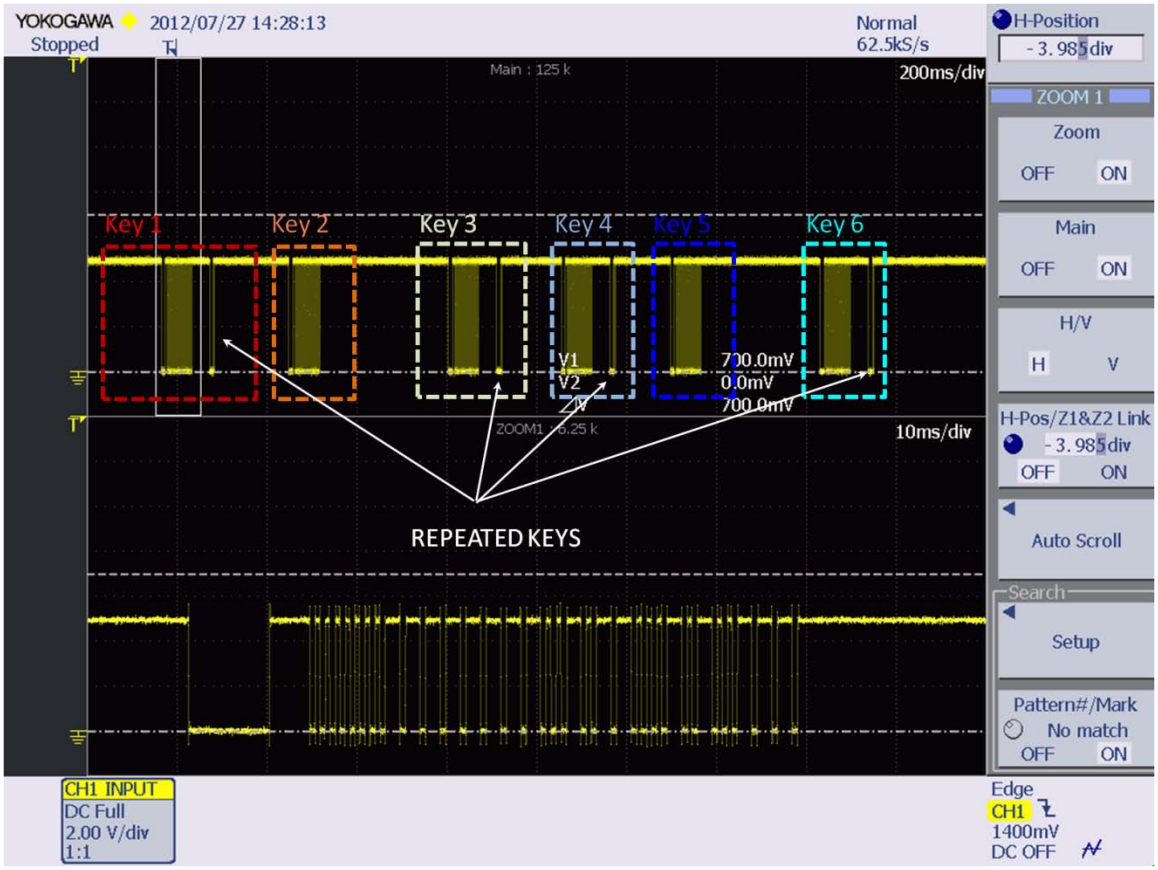


Figure 31. **Waveform – when multiple IR keys are pressed at a very fast pace**

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:

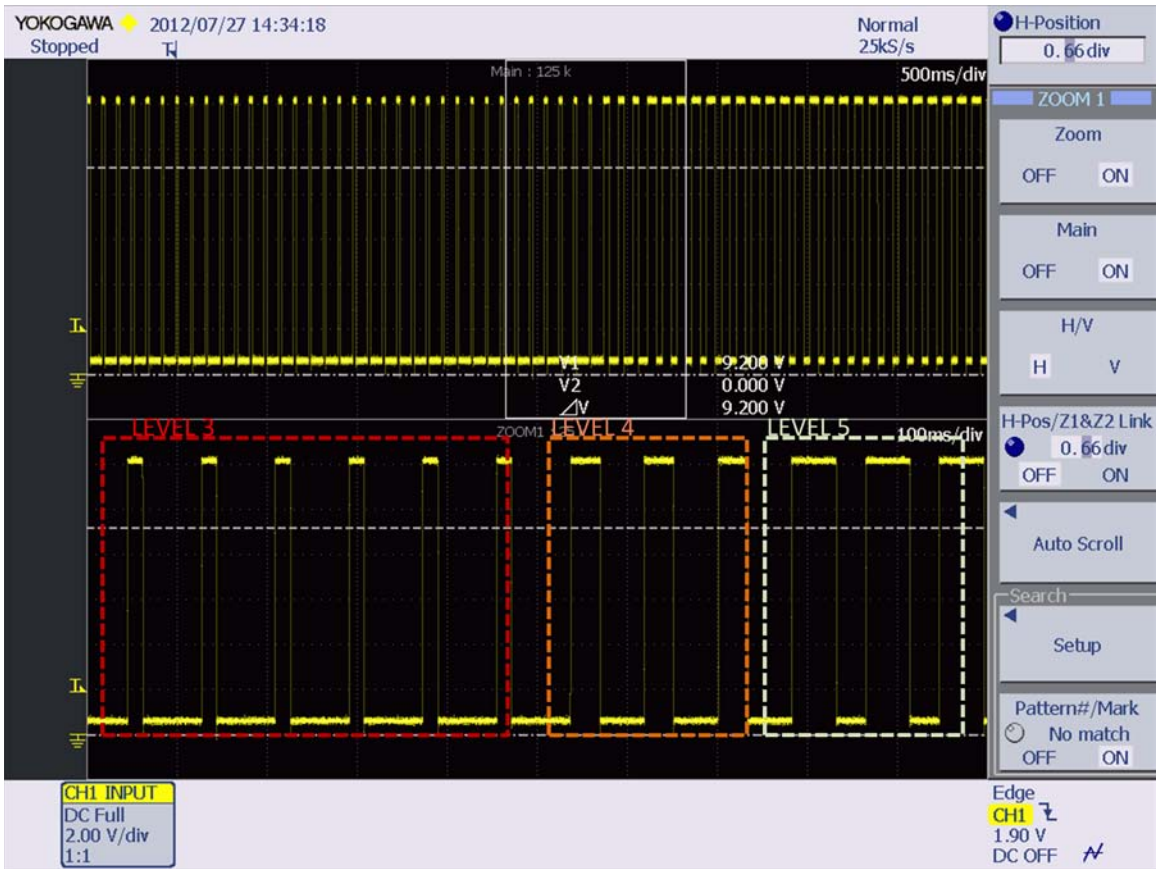


Figure 32. **Waveform – Blower motor control at different speed levels**

4.2.3.2. Actuators Motor

Waveforms for recirculation actuator motor control in different position, with and without the actuator motor being interfaced to MC33932, are shown in Figure 33 to Figure 36. The major difference in the two waveforms when the actuator motor is connected/not connected is the flyback voltage (below the Gnd level) marked in Figure 33 and Figure 34.

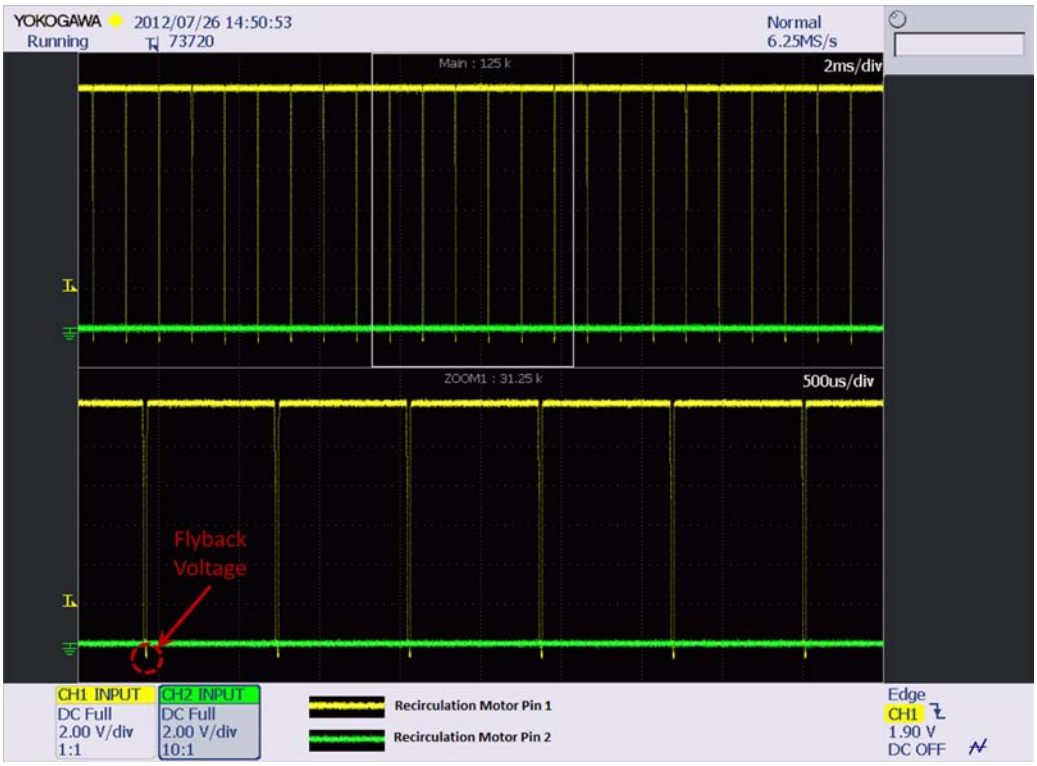


Figure 33. **Recirculation motor control waveform for fresh air to internal circulation, when motor is connected**

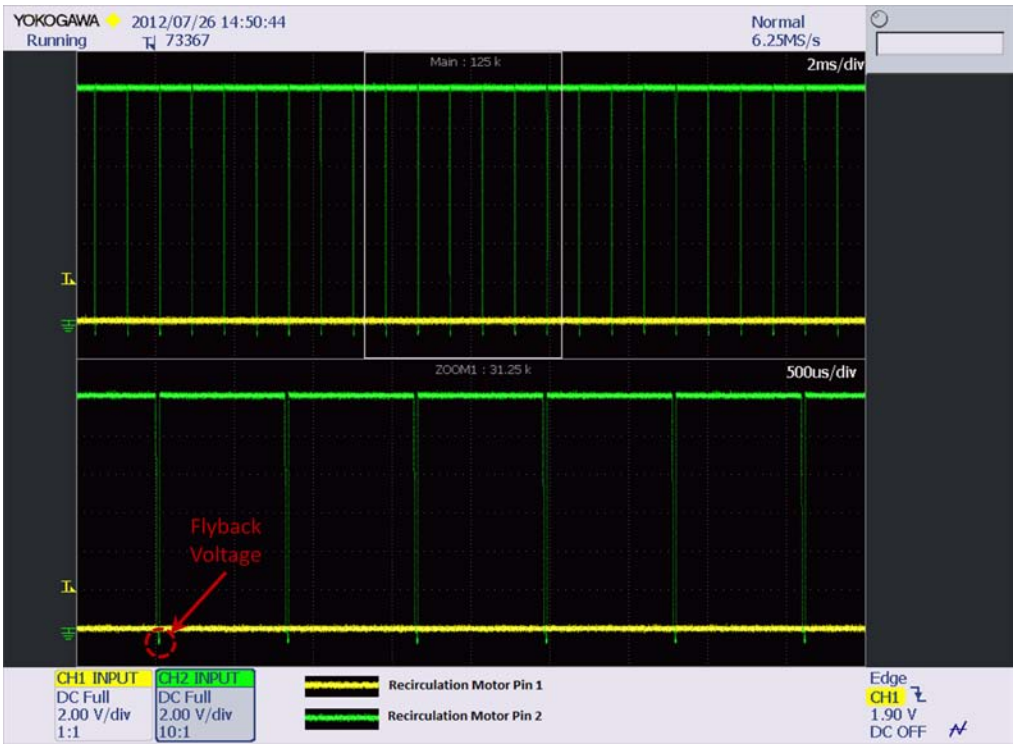


Figure 34. **Recirculation motor control waveform for internal to fresh air circulation, when motor is connected**

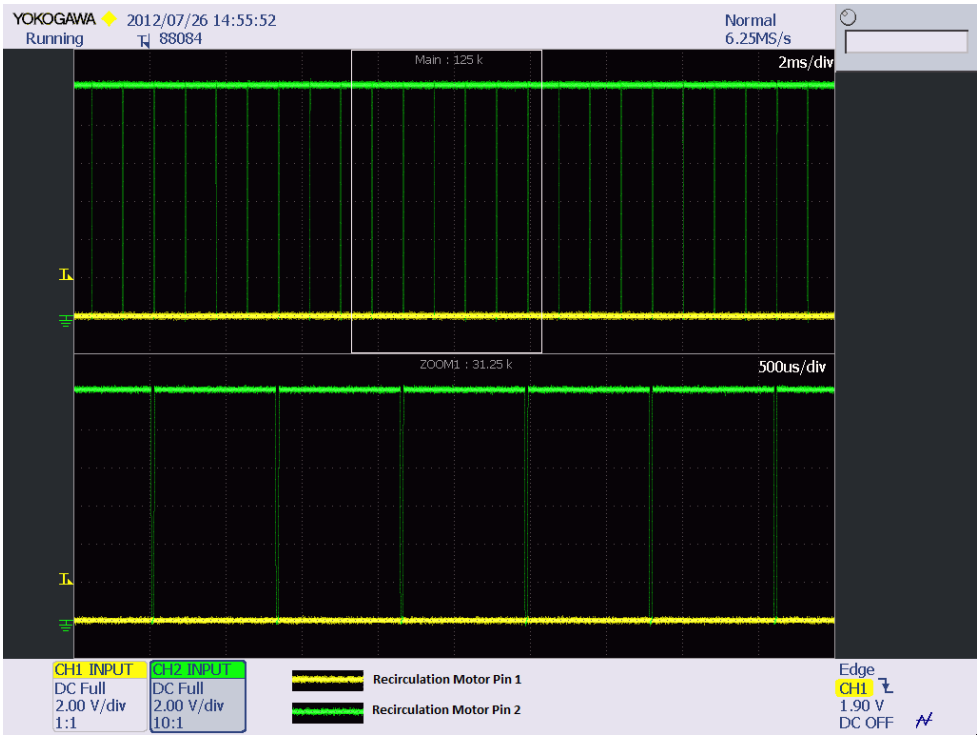


Figure 35. **Recirculation motor control waveform for fresh air to internal circulation, when motor is not connected**

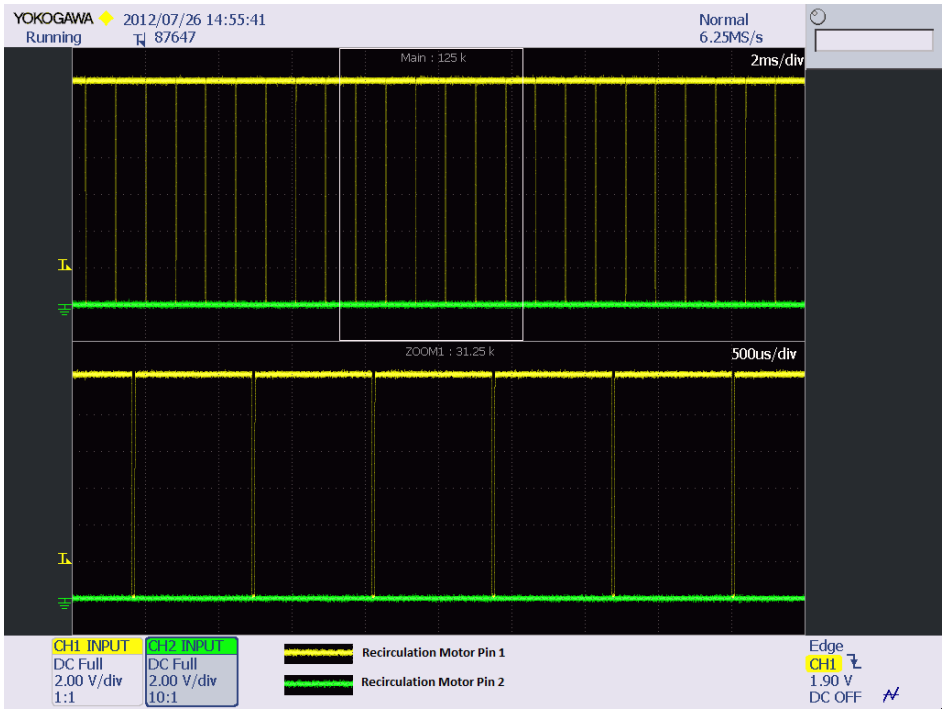


Figure 36. **Recirculation motor control waveform for internal to fresh air circulation, when motor is not connected**

Waveforms for air flow vent position actuator motor control in different positions are shown in Figure 37 to Figure 42. For each position change we have captured the initial phase, transition phase and the final phase of the waveforms.

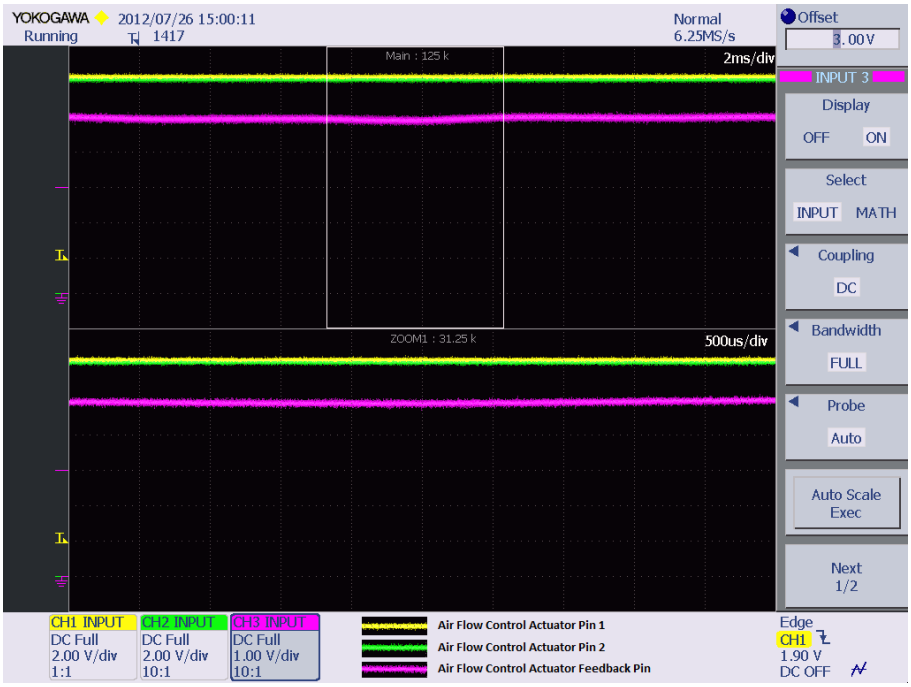


Figure 37. **Air flow actuator motor control waveform for defrost position to face & foot position - initial phase**

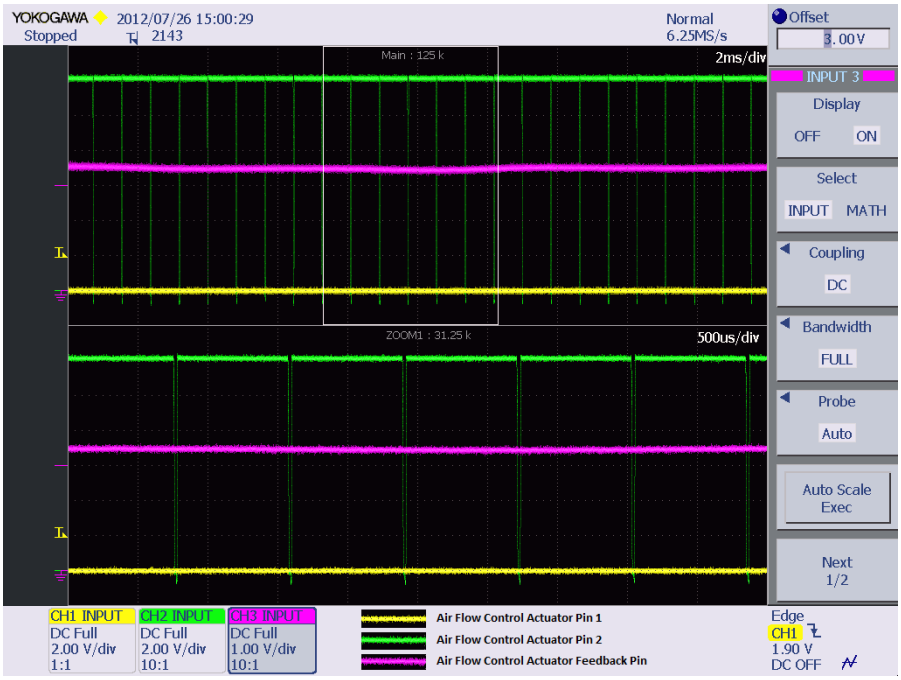


Figure 38. **Air flow actuator motor control waveform for defrost position to face & foot position – transition phase**

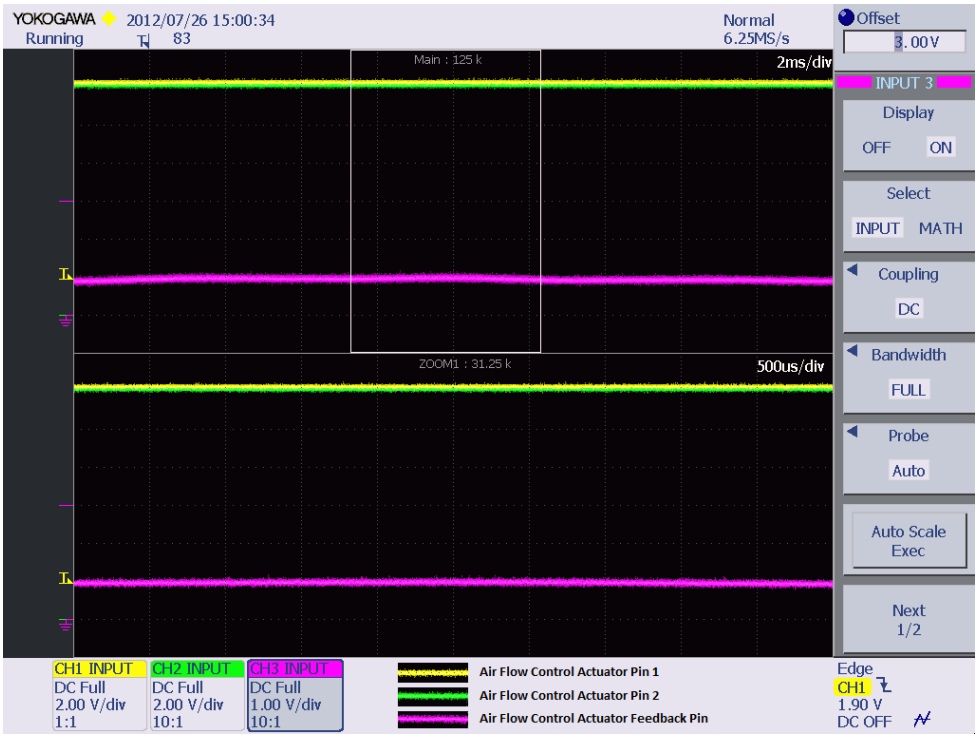


Figure 39. **Air flow actuator motor control waveform for defrost position to face & foot position – final phase**

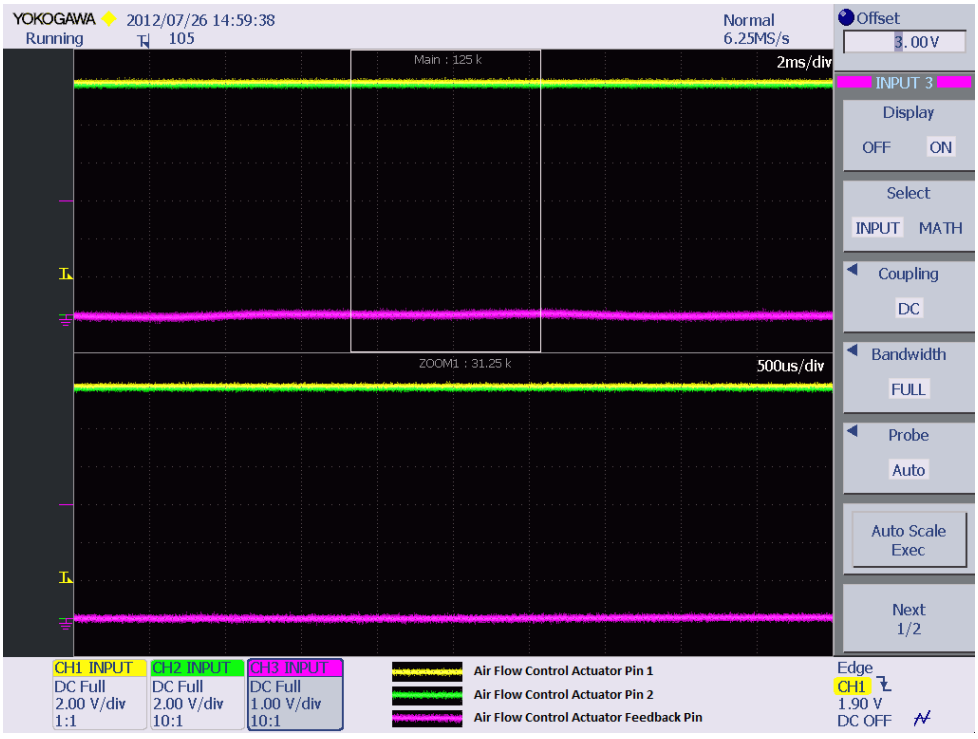


Figure 40. **Air flow actuator motor control waveform for face position to foot position – initial phase**

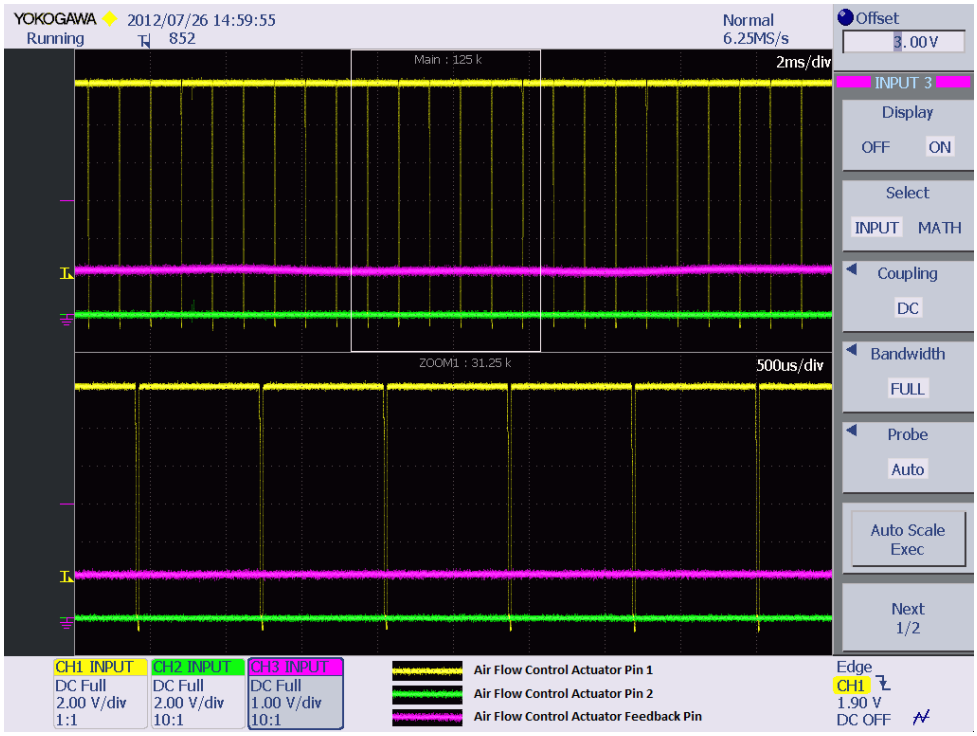


Figure 41. **Air flow actuator motor control waveform for face position to foot position – transition phase**

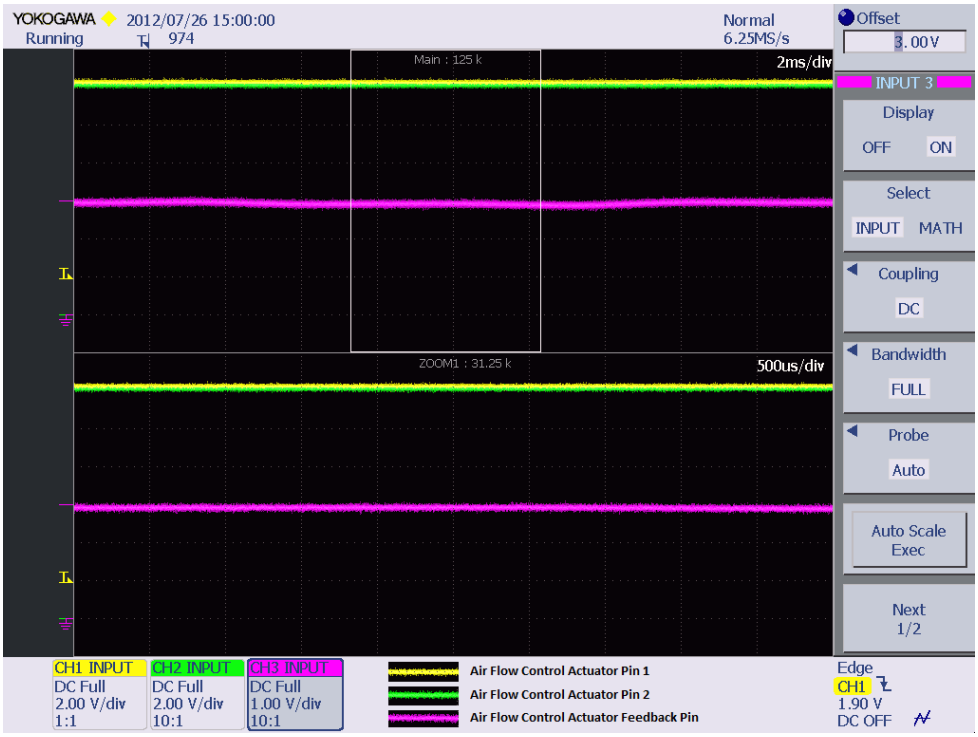


Figure 42. **Air flow actuator motor control waveform for face position to foot position – final phase**

Waveforms for temperature actuator motor control at different degree of coldness/hotness levels are shown in Figure 43 and Figure 44.

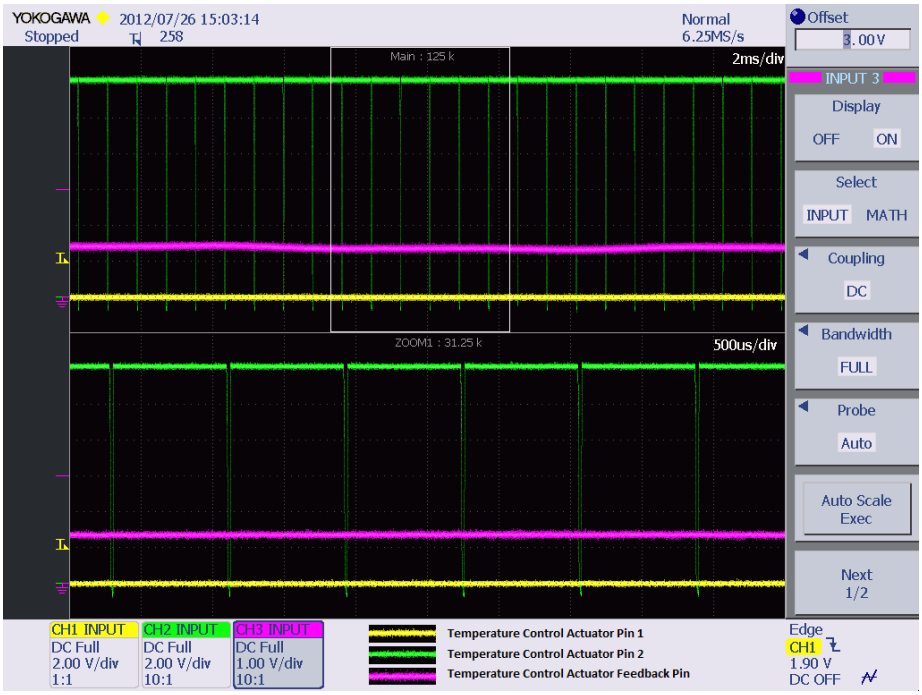


Figure 43. **Waveform when the degree of coldness is decreased**

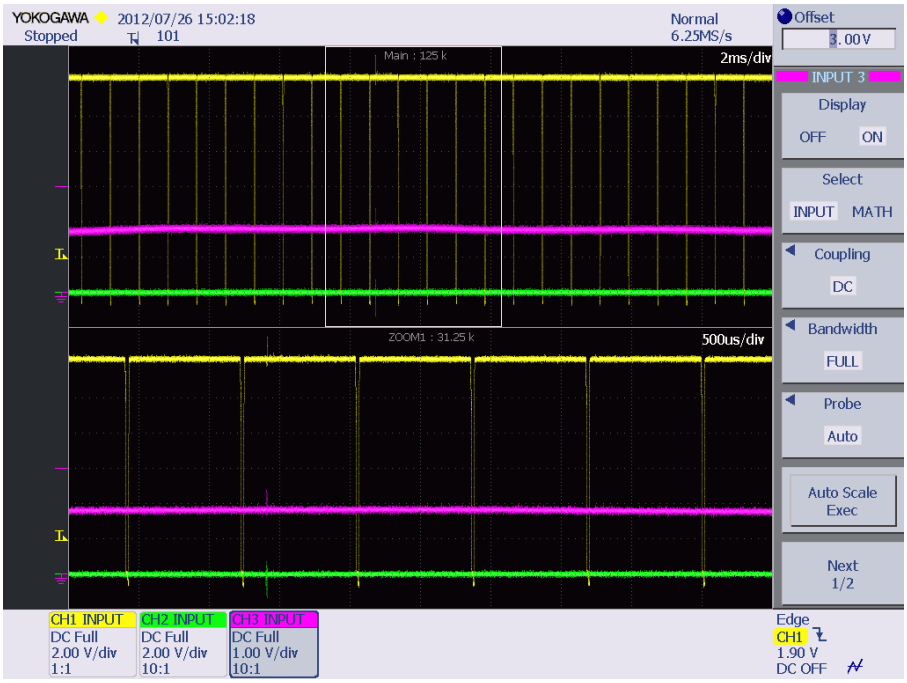


Figure 44. **Waveform when the degree of coldness is increased**

4.3. Temperature sensor

Waveform for the temperature sensor is shown in Figure 45 when the temperature on the sensor is increased. The waveform is captured by bringing the solder rod @ 200°C close to the sensor for 2 seconds (approx).

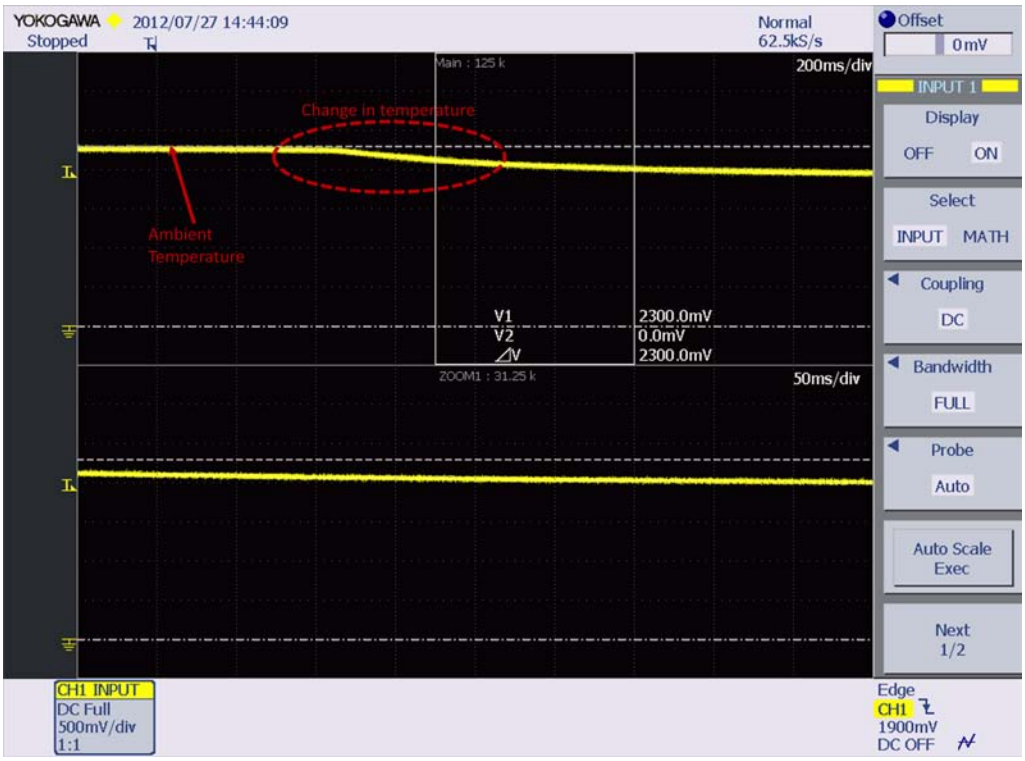
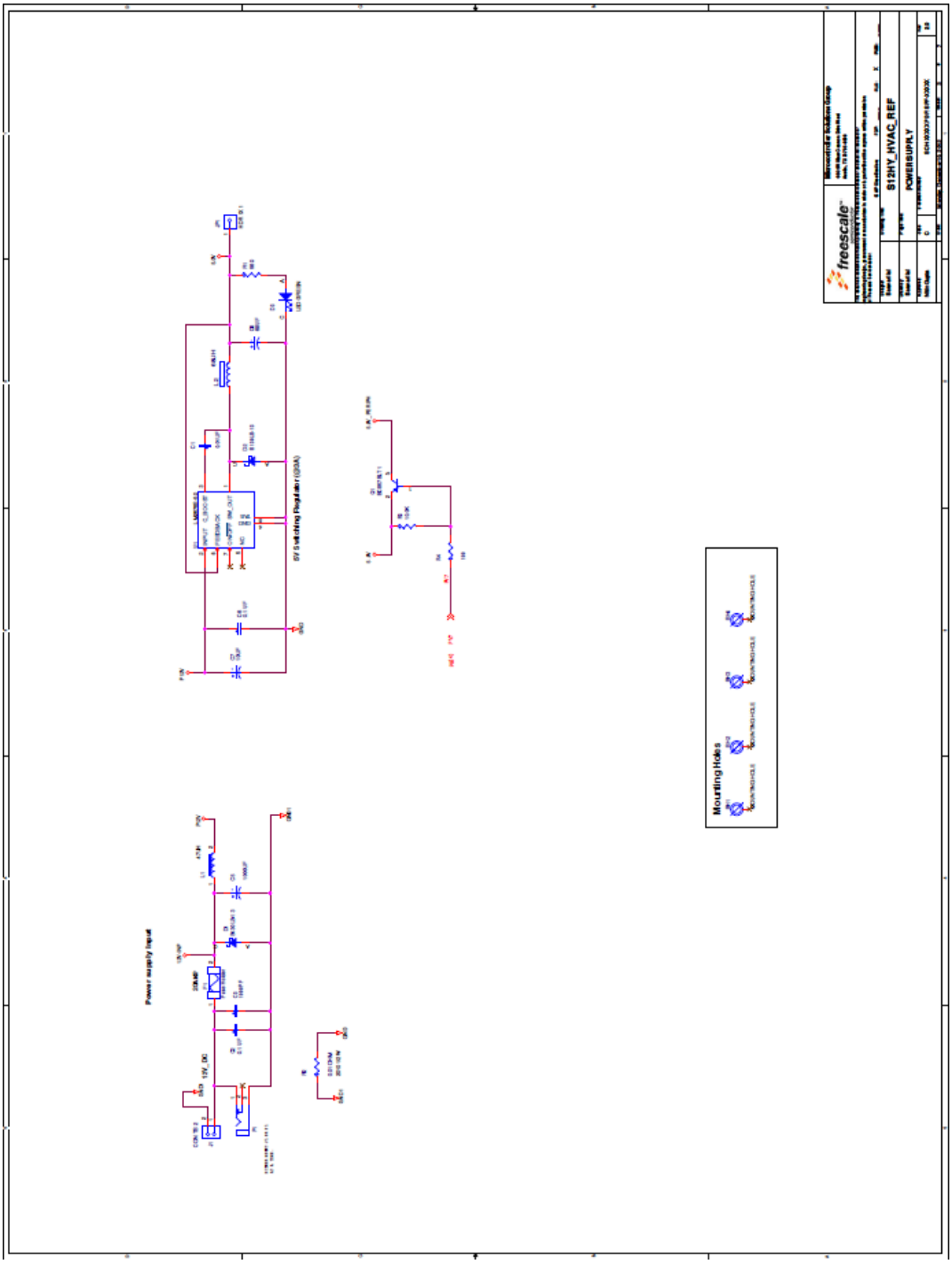
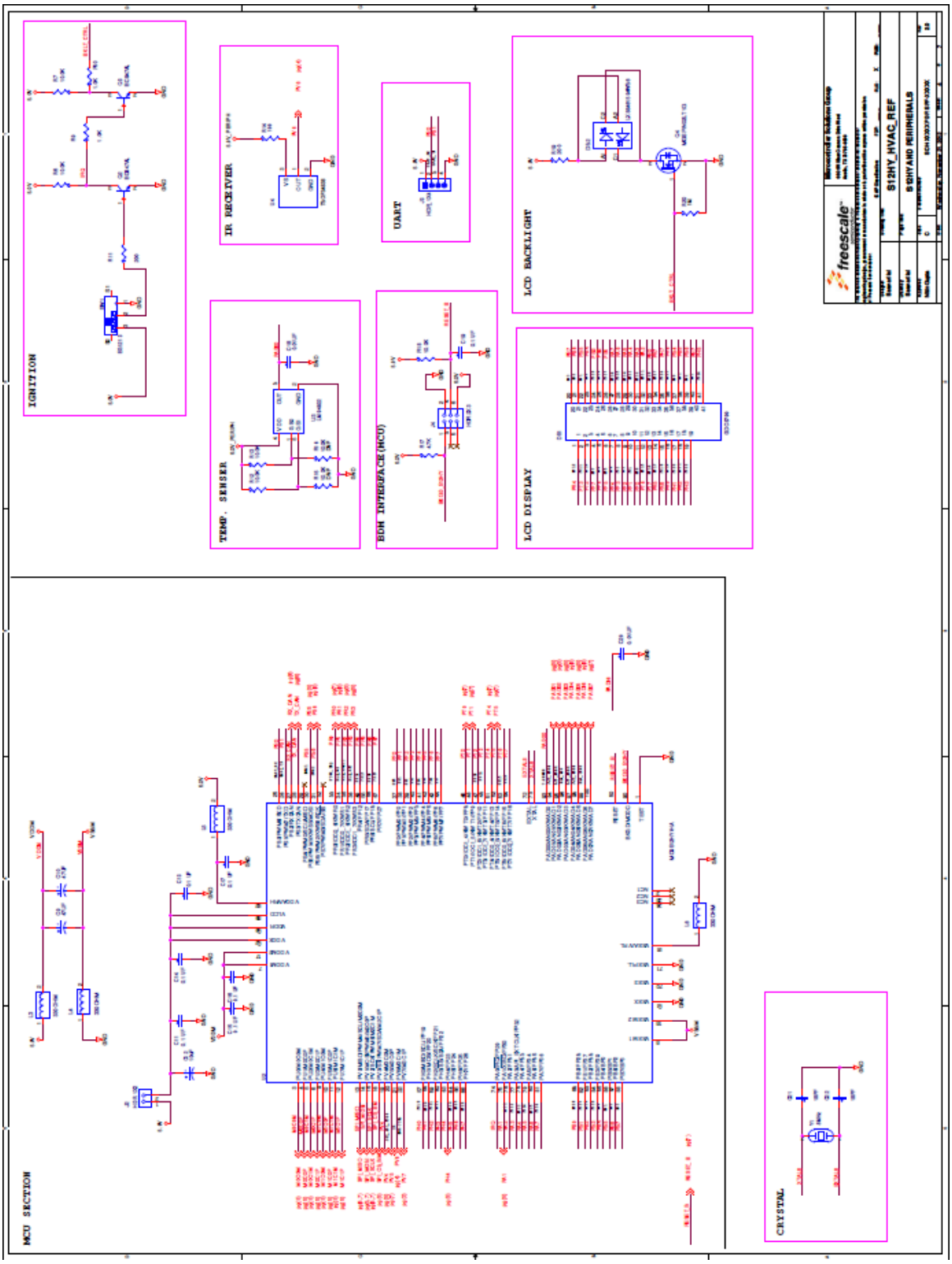


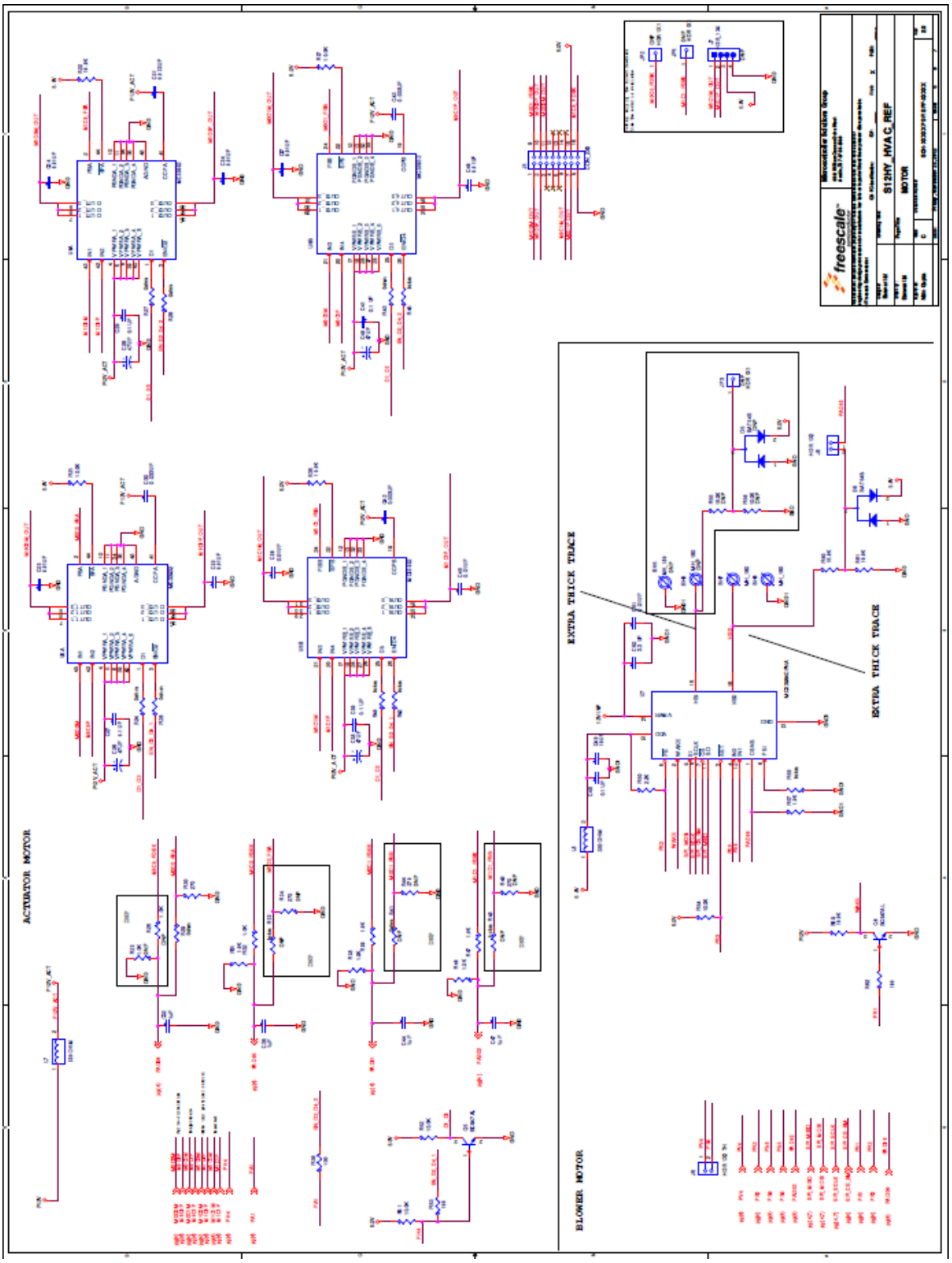
Figure 45. **Waveform for temperature sensor output when temperature is increased drastically from the ambient temperature**

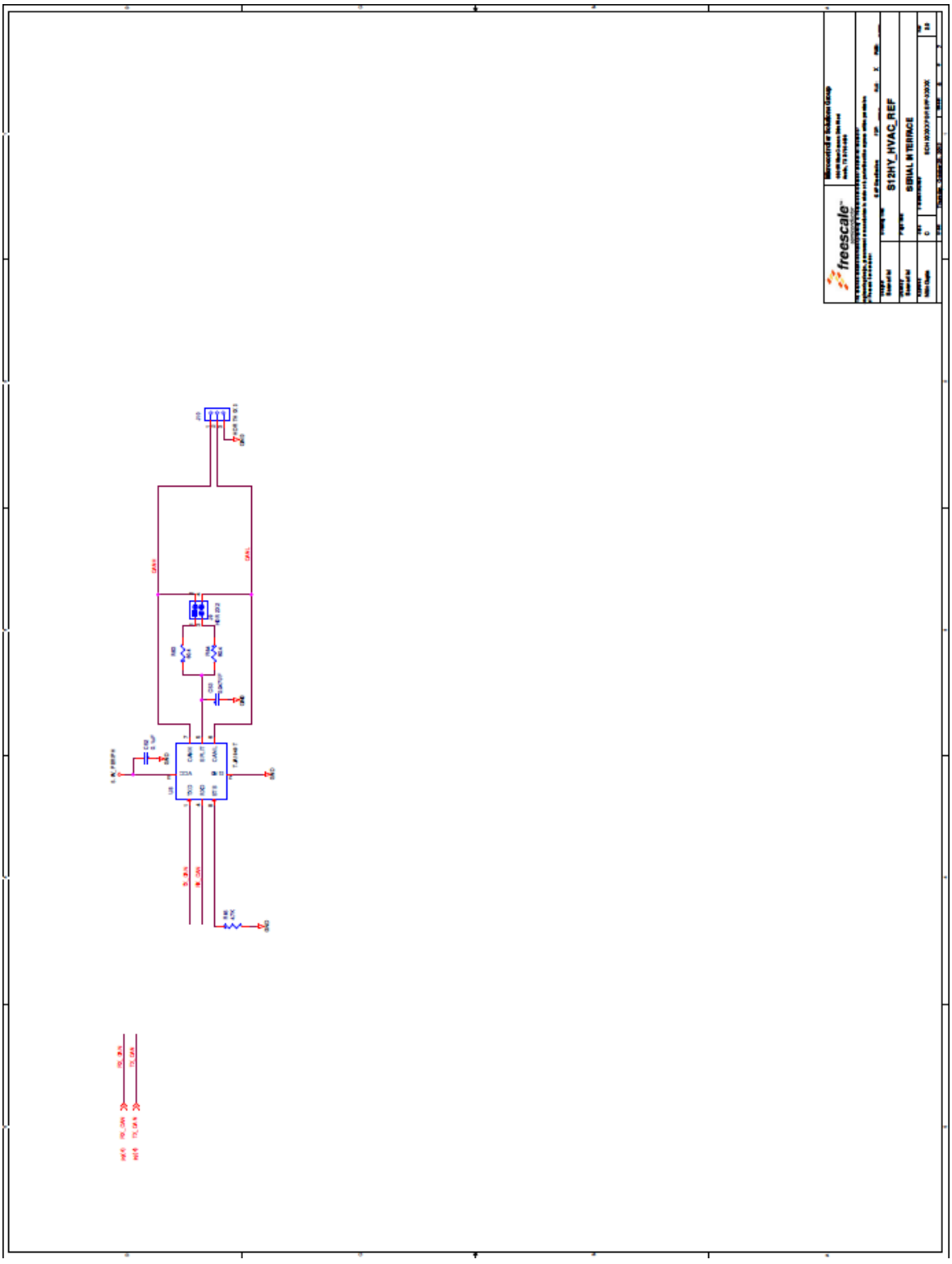
Appendix A

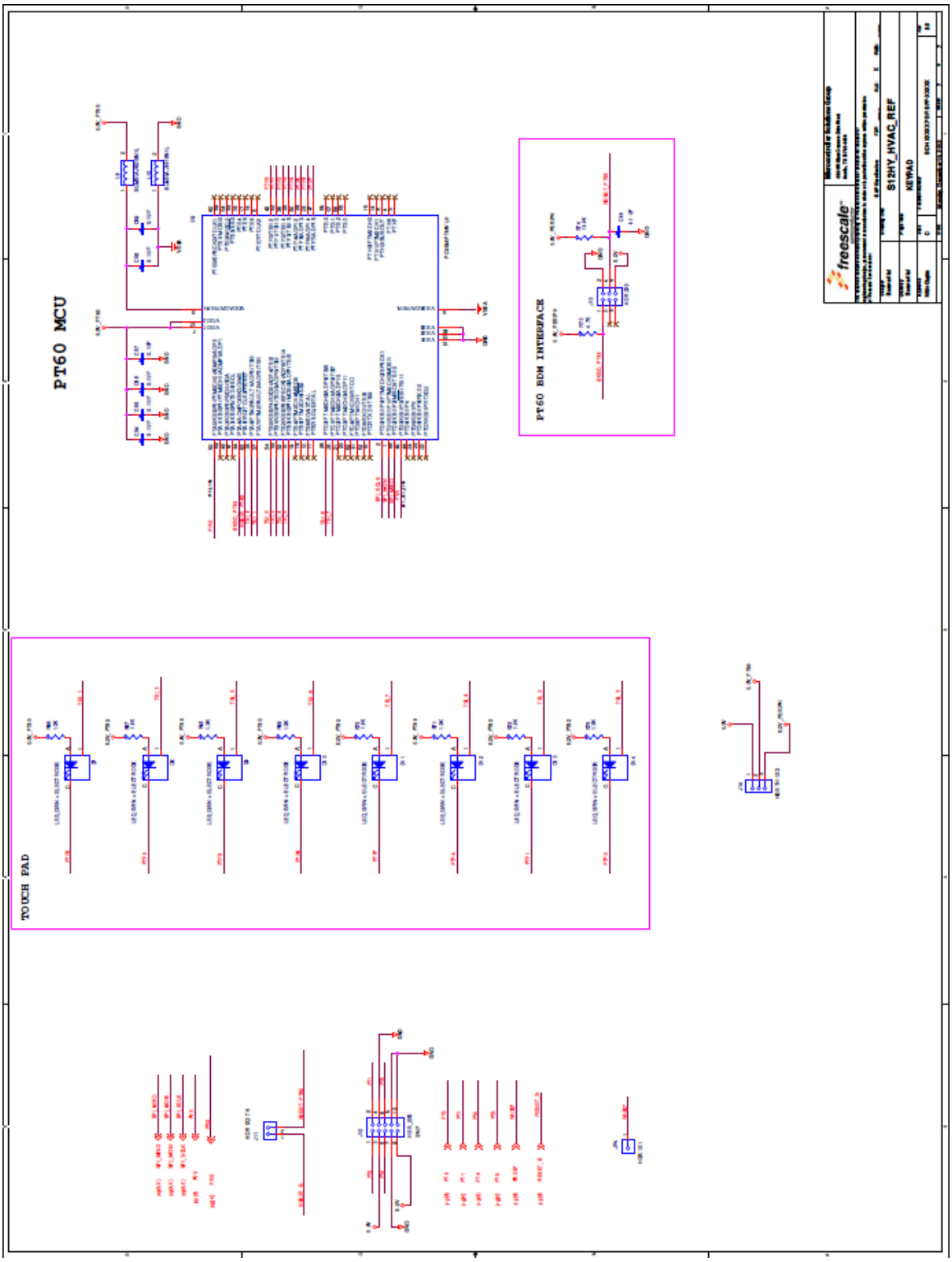
A.1 Schematic




IGNITION
IR RECEIVER
UART
LCD BACKLIGHT
TEMP. SENSER
EGH INTERFACE(HCU)
LCD DISPLAY
MCU SECTION
CRYSTAL
freescale
S12HY_HVAC_REF
S12HYAND PERIPHERALS

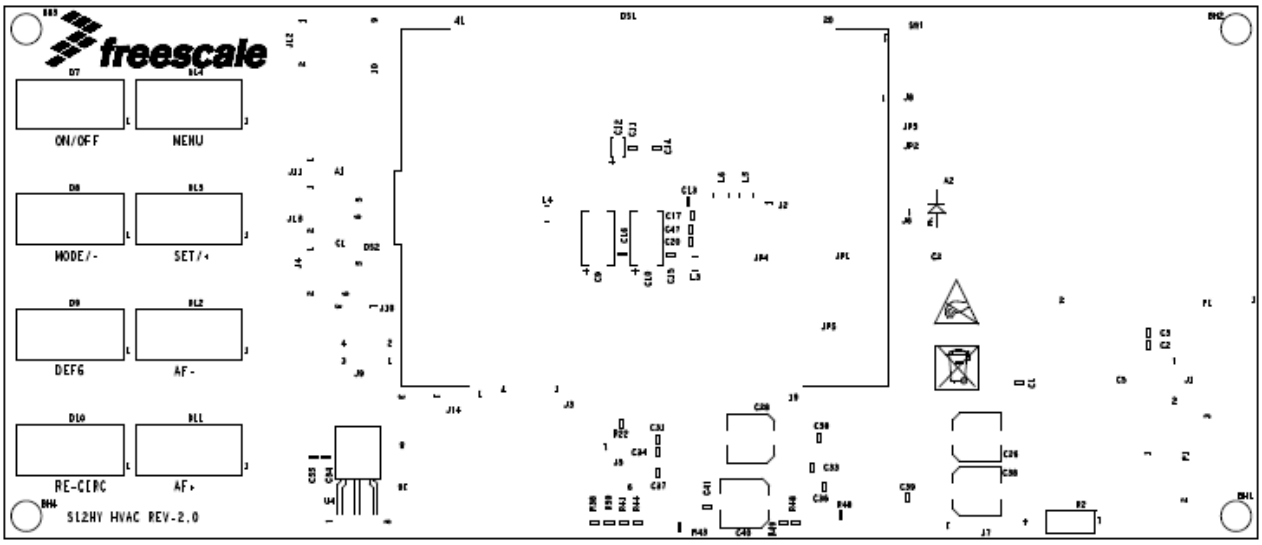

freescale
S12HY_HVAC_REF
MOTOR
ACTUATOR MOTOR
BLOWER MOTOR
EXTRA THICK TRACE
EXTRA THICK TRACE



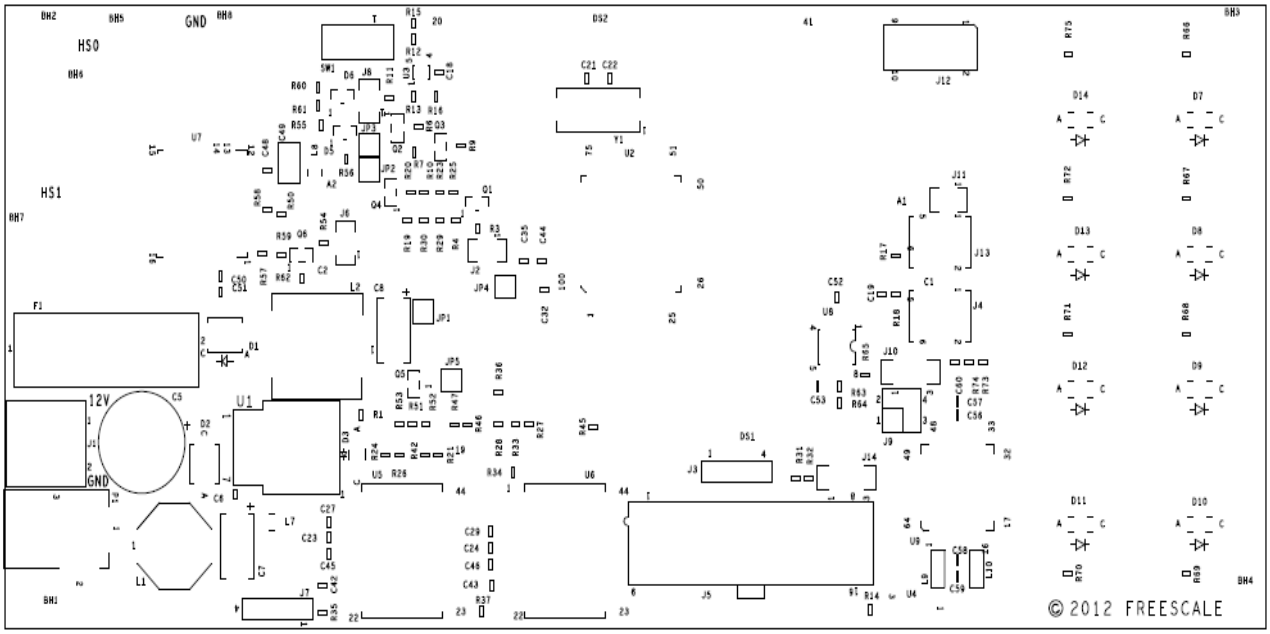

PT60 MCU
PT60 BDM INTERFACE
TOUCH PAD
freescale
S12HY_HVAC_REF
KEYPAD

A.2 Layout

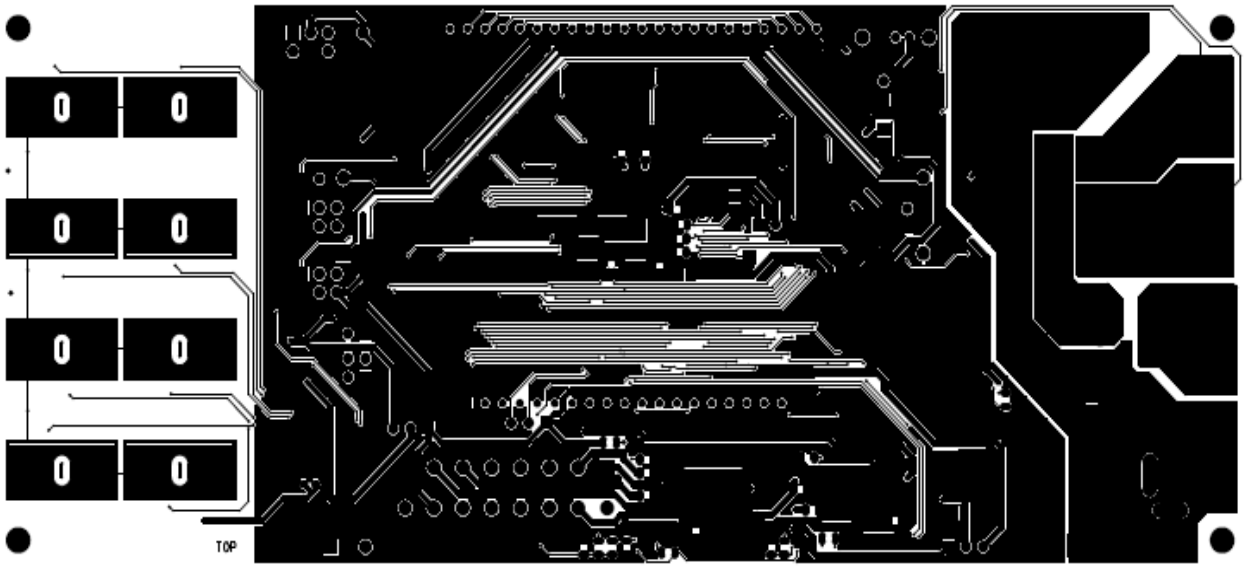
A.2.1 Silkscreen Top



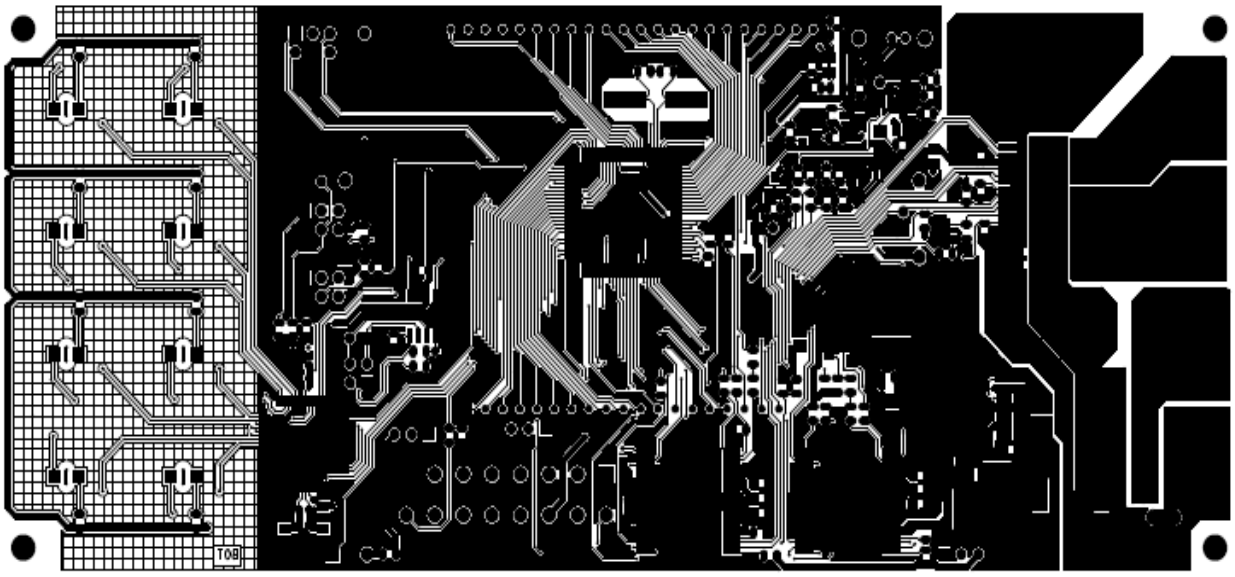
A.2.2 Silkscreen Bottom



A.2.3 Top



A.2.4 Bottom



Appendix B

Bill of Material

Item	Quantity	ASSY_OPT	Reference	Value	Description	Mfg Part Number
1	4		BH1,BH2,BH3,BH4	MOUNTING HOLE	MOUNTING HOLE DRILL 108 PAD 140 PLATED TH NO PART TO ORDER	Mounting Hole - 108mil Drill PTH
2	2	DNP	BH5,BH6	MH_180	MOUNTING HOLE DRILL 135 PAD 180 PLATED TH NO PART TO ORDER	Mounting Hole - 135mil Drill PTH
3	2		BH7,BH8	MH_180	MOUNTING HOLE DRILL 135 PAD 180 PLATED TH NO PART TO ORDER	Mounting Hole - 135mil Drill PTH
4	12		C1,C18,C20,C23,C24,C33,C34,C36,C37,C45,C46,C51	0.01UF	CAP CER 0.01UF 50V 10% X7R 0805	C0805X7R500-103KNE
5	15		C2,C6,C11,C13,C14,C15,C16,C17,C19,C27,C29,C39,C41,C48,C60	0.1 UF	CAP CER 0.1UF 50V 10% X7R 0805	C0805C104K5RAC
6	1		C3	1000PF	CAP CER 1000PF 50V 5% C0G 0805	C0805C0G500-102JNE
7	1		C5	1000UF	CAP ALEL 1000UF 50V 20% -- RADIAL	UVZ1H102MHD
8	1		C7	10UF	CAP TANT ESR=.125 OHMS 10UF 35V 10% 7343-31	TPSD106K035R0125
9	1		C8	68UF	CAP TANT ESR=0.045 OHMS 68UF 25V 10% -- 7343-43	TPME686K025R0045
10	2		C9,C10	47UF	CAP TANT 47UF 16V 10% -- 7343-31	293D476X9016D2TE3
11	1		C12	10uF	CAP TANT 10uF 10V 10% -- 2013	T491R106K010AT
12	2		C21,C22	18PF	CAP CER 18PF 50V 5% C0G 0805	08055A180JAT2A

13	4		C26,C28,C38,C40	47UF	CAP ALEL 47UF 50V SM 6.3X6.3X5.3	MAL215375479E3
14	4		C30,C31,C42,C43	0.033UF	CAP CER 0.033UF 50V 10% X7R 0805	08055C333KAT2A
15	4		C32,C35,C44,C47	1uF	CAP CER 1uF 16V 10% X7R 0805	C0805C105K4RAC
16	1		C49	10UF	CAP CER 10UF 16V 10% X5R 1210	1210YD106KAT2A
17	1		C50	3.3 UF	CAP CER 3.3UF 10V +80%/-20% Y5V 0805	C0805C335Z8VAC
18	1		C52	0.1uF	CAP CER 0.10UF 50V 5% X7R 0805	MCCE104J2NRTF
19	1		C53	0.047UF	CAP CER 0.047UF 50V 5% X7R 0603	GMC10X7R473J50NTLF
20	6		C54,C55,C56,C57,C58,C59	0.1UF	CAP CER 0.10UF 25V 10% X7R 0603	C0603C104K3RAC
21	1		DS1	GDC8799	LCD DISPLAY 5V CUSTOM TH	GDC8799
22	1		DS2	LX88461594WS6	LCD BACK-LIGHT MODULE 3V TH	LX88461594WS6
23	2		D1,D2	B130LB-13	DIODE SCH RECT 1A 30V SMB	B130LB-13-F
24	1		D3	LED GREEN	LED GRN -- 25MA SMT 1206	APT3216SGC
25	1	DNP	D5	BAT54S	DIODE DUAL SCH 200MA 30V SOT23	BAT54S
26	1		D6	BAT54S	DIODE DUAL SCH 200MA 30V SOT23	BAT54S
27	8		D7,D8,D9,D10,D11,D12,D13,D14	LED_GRN + ELECTRODE	SUBASSEMBLY LED GRN SGL 20MA 1206 + RECTANGULAR ELECTRODE 590X270MIL	510-77640, 370-76519
28	1		F1	Fuse Holder	FUSE CLIP,5X20 FUSE,PC MOUNT	HTC-15M
29	2		JP1,JP4	HDR 1X1	HDR 1X1 TH -- 330H AU 100L	HTSW-101-07-SM-S
30	3	DNP	JP2,JP3,JP5	HDR 1X1	HDR 1X1 TH -- 330H AU 100L	HTSW-101-07-SM-S
31	1		J1	CON TB 2	CON 1X2 TB TH 200MIL SP 709H - 197L	1711725

32	2		J2,J8	HDR 1X2	HDR 1X2 TH 100MIL SP 330H SN 115L	TSW-102-07-T-S
33	1		J3	HDR_1X4	HDR 1X4 TH 100MIL SP 336H AU 100L	TSW-104-07-G-S
34	2		J4,J13	HDR 2X3	HDR 2X3 TH 2.54MM SP 340H AU 118L	M20-9980345
35	1		J5	CON_2X8	CON 2X8 PLUG SHRD TH 4.2MM SP 516H SN 140L	39-28-8160
36	2		J6,J11	HDR 1X2 TH	HDR 1X2 TH 100MIL SP 339H AU 98L	TSW-102-07-G-S
37	1	DNP	J7	HDR_1X4	HDR 1X4 TH 100MIL SP 336H AU 100L	TSW-104-07-G-S
38	1		J9	HDR 2X2	HDR 2X2 TH 2.54MM CTR 330H AU	TSW-102-07-G-D
39	2		J10,J14	HDR TH 1X3	HDR 1X3 TH 100MIL SP 339H AU 100L	TSW-103-07-G-S
40	1	DNP	J12	HDR_2X5	HDR 2X5 TH 100MIL CTR 330H AU	TSW-105-08-G-D
41	1		L1	47UH	IND PWR 47UH@100KHZ 1.65A 30% SMT	SRU1038-470Y
42	1		L2	68UH	IND PWR 68UH@100KHZ 2.22A 20% SMT	DR125-680-R
43	6		L3,L4,L5,L6,L7, L8	330 OHM	IND FER BEAD 330OHM@100MHZ 2.5A -- SMT	MPZ2012S331A
44	2		L9,L10	BLM31AJ601SN1L	IND FER BEAD 600OHM@100MHZ 200MA 25% 1206	BLM31AJ601SN1L
45	1		P1	CON_1_PWR	CON 1 PWR PLUG RA TH 1A -- 430H NI	RAPC722X
46	1		Q1	BC857BLT1	TRAN PNP GEN 100MA 45V SOT23	BC857BLT1G
47	4		Q2,Q3,Q5,Q6	BC847AL	TRAN NPN GEN 45VDC	BC847ALT1G
48	1		Q4	MGSF1N02LT1G	TRAN NMOS PWR 750MA 20V SOT-23	MGSF1N02LT1G
49	1		R1	560	RES MF 560 OHM 1/8W 1% 0805	232273465601L
50	1	2010 1/2W	R2	0.01 OHM	RES MF 0.01 OHM 1/2W 1% 2010	WSL2010R0100FEA

51	16		R3,R6,R7,R12, R13,R18,R21,R 22,R35,R37,R51 ,R52,R54,R59,R 61,R74	10.0K	RES MF 10.0K 1/8W 1% 0805	CR0805-8W-1002FT
52	5		R4,R14,R36,R5 3,R62	100	RES MF 100 OHM 1/8W 5% 0805	RC73L2D101 JTF
53	8		R9,R10,R31,R3 2,R38,R39,R46, R47	1.0K	RES MF 1.00K 1/8W 1% 0805	RK73H2ATTD 1001F
54	2		R11,R19	200	RES MF 200 OHM 1/8W 1% 0805	CR0805FX20 00ELF
55	3	DNP	R15,R16,R56	10.0K	RES MF 10.0K 1/8W 1% 0805	CR0805-8W-1002FT
56	3		R17,R65,R73	4.7K	RES MF 4.7K 1/8W 5% 0805	CR0805-8W-472JT
57	1		R20	1M	RES MF 1M 1/10W 5% 0805	RC73L2A105 JTF
58	2	DNP	R23,R25	1.0K	RES MF 1.00K 1/8W 1% 0805	RK73H2ATTD 1001F
59	10		R24,R26,R27,R 28,R29,R40,R42 ,R43,R45,R58	0ohm	RES 0.0 OHM 1/8W 5% 0805 SMD	RC0805JR-070RL
60	1		R30	270	RES MF 270 OHM 1/8W 1% 0805	MCR10EZHF 2700
61	3	DNP	R33,R41,R48	0ohm	RES 0.0 OHM 1/8W 5% 0805 SMD	RC0805JR-070RL
62	3	DNP	R34,R44,R49	270	RES MF 270 OHM 1/8W 1% 0805	MCR10EZHF 2700
63	1		R50	2.2K	RES MF 2.2K 1/8W 5% 0805	CR0805-JW-222ELF
64	1	DNP	R55	15.0K	RES MF 15.0K 1/8W 1% 0805	RK73H2ATTD 1502F
65	9		R57,R66,R67,R 68,R69,R70,R71 ,R72,R75	1.0K	RES MF 1.0K 1/8W 5% 0805	MCR10EZPJ1 02
66	1		R60	15.0K	RES MF 15.0K 1/8W 1% 0805	RK73H2ATTD 1502F
67	2		R63,R64	60.4	RES MF 60.4 OHM 1/8W 1% 0805	23227346604 9L
68	1		SW1	EG1213	SW SPDT SLD RA 200MA 30V TH	EG1213
69	1		U1	LM2676S-5.0	IC VREG SWT 5V 3A 8.0-40V TO-263	LM2676S-5.0/NOPB
70	1		U2	MC9S12HY/ HA	IC MCU 16BIT 64K FLASH 4K RAM 4.5-5.5V LQFP100	P9S12HY64J 0MLL

71	1		U3	LM94022	IC MULTI-GAIN ANALOG TEMPERATURE SENSOR 1.5-5.5V SC70-5	LM94022BIMGXNOPB
72	1		U4	TSOP34838	IC IR RCVR MODULE 38KHZ 2.5-5.5V TH	TSOP34838
73	2		U5,U6	MC33932	IC THROTTLE CONTROL DUAL H-BRIDGE 8.0-28V HSOP44	MC33932VW
74	1		U7	MC33984CPNA	IC LIN SW DUAL 4MILLIOHM 6-27V PQFN16	MC33984CPNA
75	1		U8	TJA1040T	IC XCVR CAN HS 5V SO8	TJA1040T
76	1		U9	PC9S08PT60VLH	IC MCU 8BIT 60KB FLASH 4KB RAM 20MHZ 2.7-5.5V LQFP64	PC9S08PT60VLH
77	1		Y1	8MHz	XTAL 8MHz -- SMT	AT-51CD2-8.000M-STD-PFE-2

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