

## Description

2100W, Single plate Induction cooktop design, using iW248 single chip ASSP offers a high efficiency and high reliability performance. The design gives the flexibility to adjust the power in +/-10W steps, which allows the users to cook at simmering condition. RL78/G15 based HMI card offers low pin count, multiple matrix switch, LED Indication, and 7-Segment display. Over temperature detection using three NTCs are provided in the ASSP.

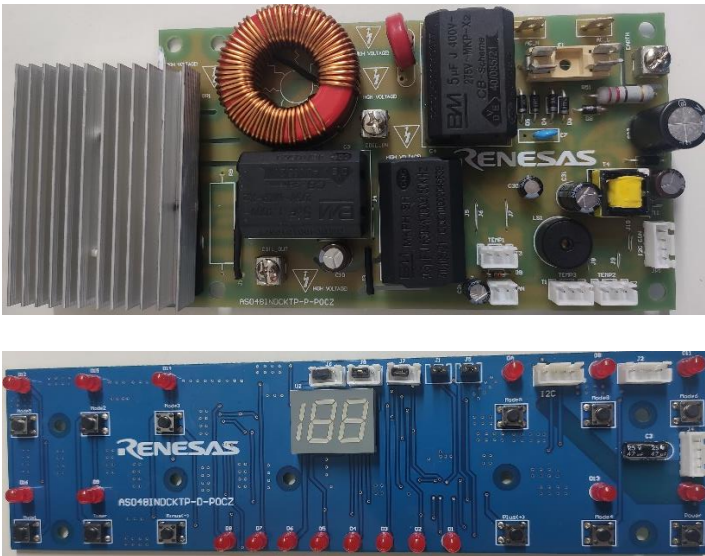
## Kit Contents

- AS048INDCKTP-D-POCZ HMI Display Card
- AS048INDCKTP-P-POCZ Power Card

## Features

- Integrated ASSP design offers Low cost, Low Component count system.
- AC Input, IGBT Voltage spike detection, Current sense using iW248 helps in fast protection response. It is a Digital controller with analog driver blocks using state machine offers much faster response.
- Controlled speed and soft start of the blower fan.
- Patented Low Power technology, gives adjustable to +/- 10W allows uses to cook at Simmer condition.

## Evaluation Board



**Figure 1. AS048 Energy Efficient Single Burner Induction Cooktop Board**

## Contents

Description.....	1
Kit Contents.....	1
Evaluation Board.....	1
Features.....	1
Contents.....	2
AS048 Overview.....	3
Hardware Overview.....	5
Software Overview.....	9
Test Data.....	13
Device Setup.....	14
AS048 Application Schematic.....	16
Bill of Materials (BOM).....	18
Board Layout.....	22

## AS048 Overview

The block diagram below highlights the main parts of the system:

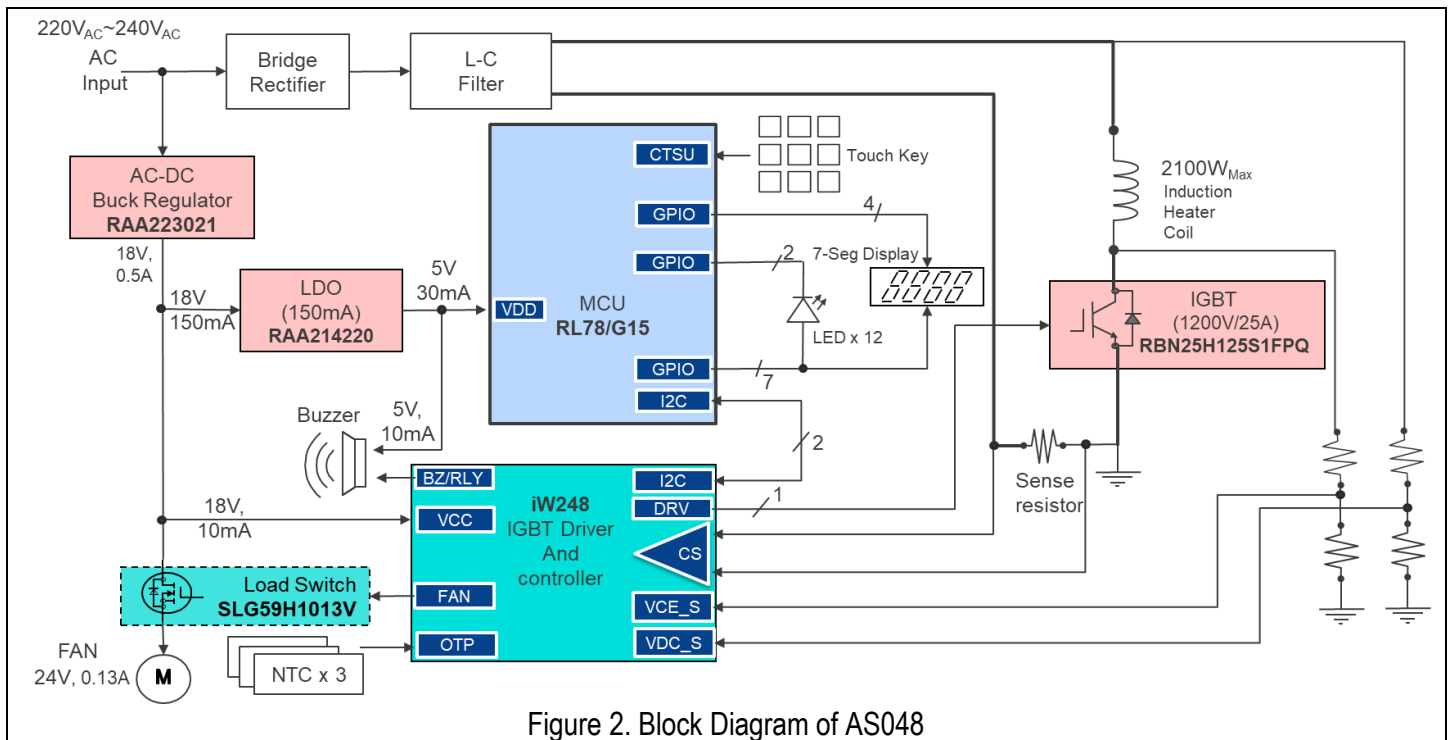


Figure 2. Block Diagram of AS048

The building blocks of the AS048 and their functionality are listed below:

1. [RAA214250](#): The RAA214250 is a low-dropout linear voltage regulator that operates from 2.5V to 20V and provide up to 500mA of output current with a typical dropout of 269mV. The output voltage is adjustable with external feedback resistors anywhere from 1.224V to 18V.
2. [RAA223021](#): The RAA223021 is a universal input AC/DC switching buck regulator with ultra-low standby power that features a 700V integrated MOSFET capable of delivering up to 12W output power. It supports output voltage as low as 5V.
3. [RBN25H125S1FPQ](#): RBN25H125S1FPQ-A0 is a Trench gate and thin wafer technology (G8H series) IGBT, which is 1250V VCE and 25A collector current in TO-247A package. It has built in fast recovery diode in one package. It has a low collector to emitter saturation voltage  $V_{CE(sat)} = 1.8\text{ V typ. (at } I_C = 25\text{ A, } V_{GE} = 15\text{ V, } T_a = 25^\circ\text{C)}$ . It has a short circuit withstands time (10  $\mu\text{s min.}$ ). The IGBT is suitable for high-speed switching.
4. [RL78/G15](#): The RL78/G15 is a general-purpose microcontroller with a 16MHz operating frequency. There is a wide lineup available, including the smallest 8-pin package in the RL78 Family, and support for a wide range of operating ambient temperatures from  $-40^\circ\text{C}$  to  $125^\circ\text{C}$ . The built-in high-speed on-chip oscillator with high accuracy ( $\pm 1.0\%$ ), the data flash, the rich serial interfaces, and the comparator make it ideal for compact applications where space comes at a premium.
5. [iW248](#): The iW248 provides a unique combination of digital controller and analog driver blocks in one IC, resulting in an optimized solution for driving induction heating elements in rice cookers and induction cooktop appliances. Integrating virtually all discrete components normally used to drive and protect IGBTs, plus an optimized state machine digital core that replaces a traditional microcontroller, the iW248 significantly reduces solution size. The iW248 also features a proprietary low-power continuous mode that allows for smooth operation at low power states and control in 10W increments for induction cooktop applications up to 2100W.

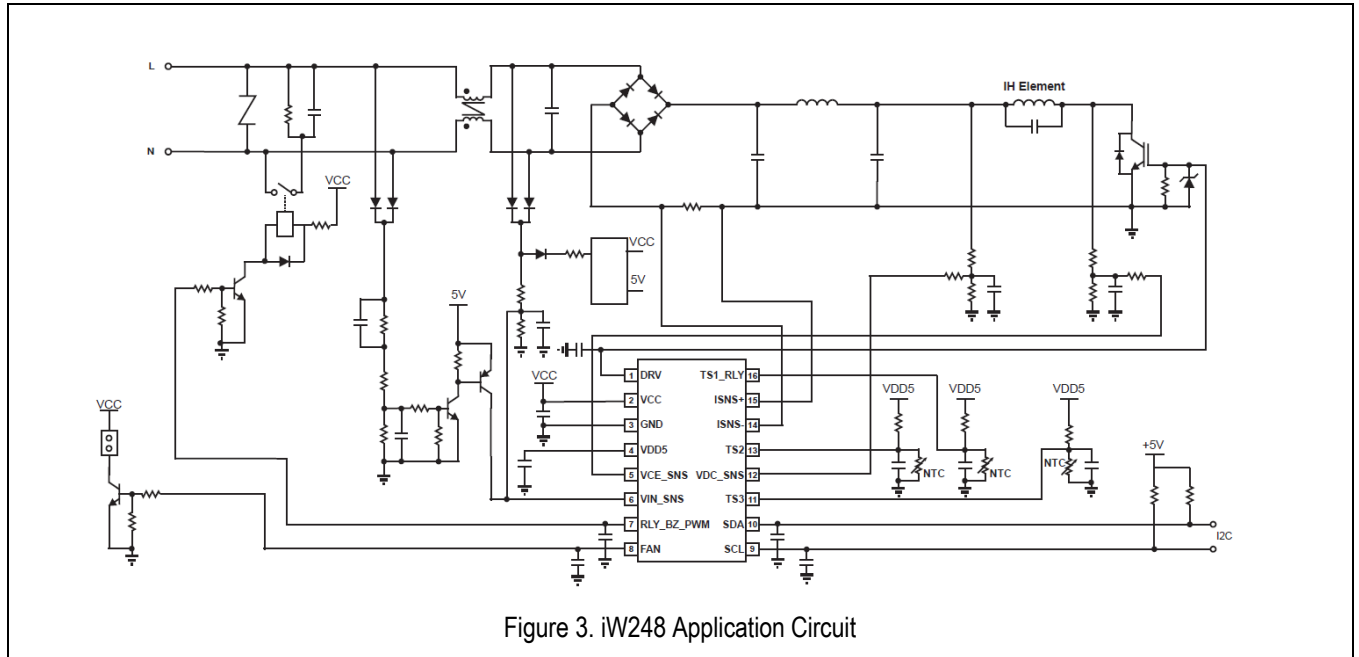


Figure 3. iW248 Application Circuit

## Hardware Overview

The following block diagrams have specific applications explained below.

The power heating board controls the power supply for the complete system and the heating power of the induction cooker. The selection of the heating power and the induction cooker on/off state on the power heating board are adjusted according to the current heating power and other settings obtained from the HMI board using I2C communication. The HMI display board uses tactile switch and LED display functions to provide a human-machine interface (HMI) control. The tactile switch can be used to select the desired operating mode while the LED display function is used to display the current selected operating mode and power setting.

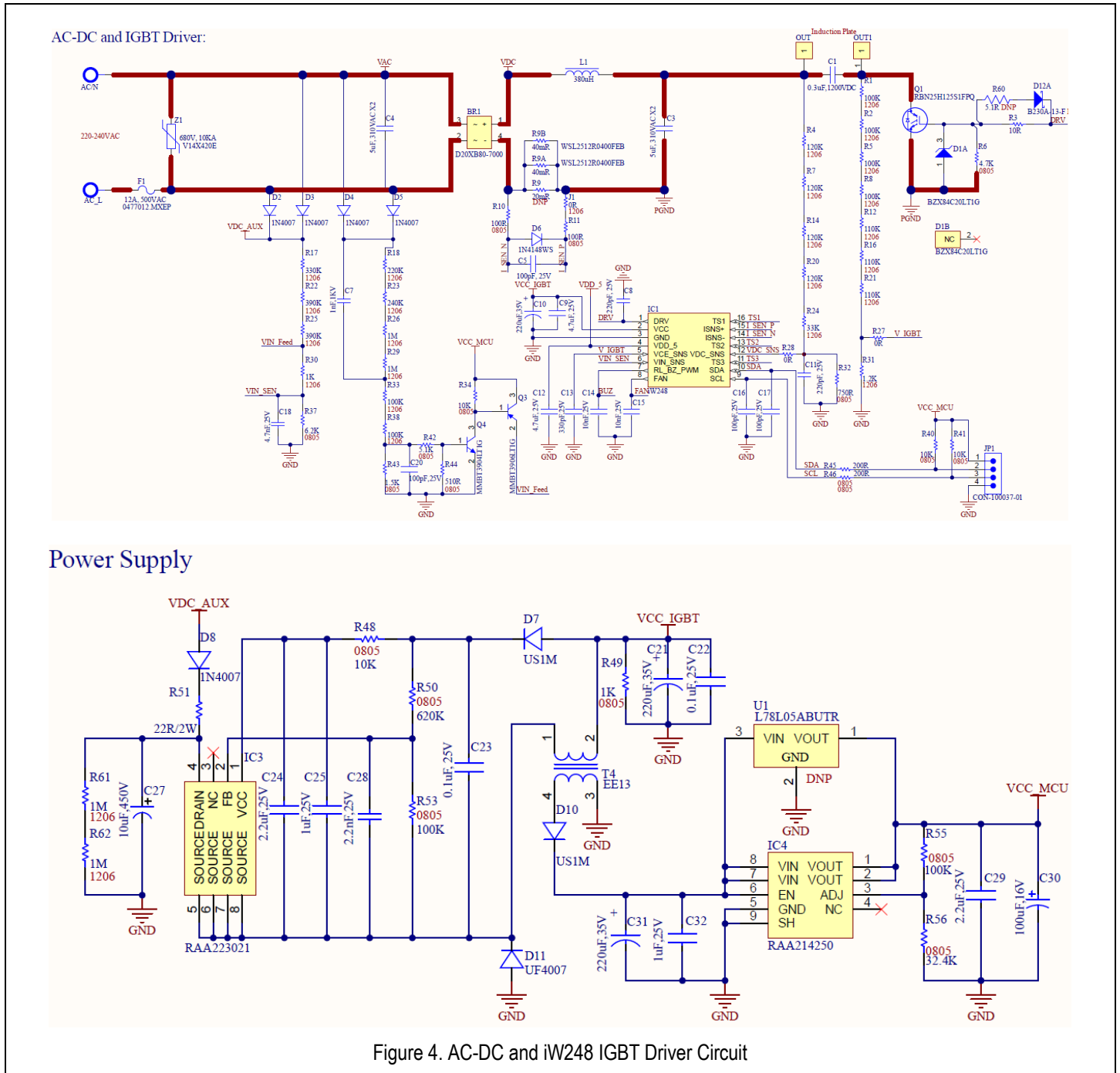


Figure 4. AC-DC and iW248 IGBT Driver Circuit

The AC supply for the power heating board is divided into two paths after passing through the EMI filter circuit. One path is to the switching power circuit and the other is to the resonance circuit (3), being used as the heating main power circuit. The mains AC line input with the Diode Bridge, Storage Capacitor(s), EMI-reduction Choke as well as safety and protection components like Fuse or Fusible Resistor, MOV and X-Capacitor. The input surge section consists of 410V MOV (Metal Oxide Varistor). Fuses are ideal candidates for overcurrent protection in SMPS because of their proven safety, reliability, low resistance, small size, and cost effectiveness. The Bridge rectifier D20XB80S is used to convert AC to DC supply to power the resonance circuit.

RAA223021 is a universal input AC/DC switching buck regulator with ultra-low standby power that features a 700V integrated MOSFET capable of delivering up to 12W output power. RAA223021 is used to power iW248 IC and the fan circuit. The RAA223021 combines constant off-time control for heavy load and Pulse Frequency Modulation (PFM) for light-load operation. Constant off-time controls switching frequency above the audible frequency around 43kHz. PFM eliminates any potential audible noises while offering superior light-load efficiency and ultra-low power consumption (<20mW at no load). The efficiency is achieved up to 80%.

The switching power circuit outputs +18V and +5V. The +18V power is supplied from RAA223021 flyback converter to the fan control circuit and the main control MCU (iW248) on the power heating board. The +5V power is supplied from RAA214250 LDO to the buzzer and HMI board. The VDD output from the main control MCU is supplied to the power heating board peripherals such as the cooktop surface overheating protection circuit and the IGBT overheating protection circuit.

The induction cooktop power control is implemented depending upon the current detection circuit and the voltage detection circuit. These two circuits are used to detect the present operating current value and the voltage value, which are used to calculate the present power. The system will determine whether to increase or reduce the IGBT in time to adjust the power according to the present operating power. The measured current and voltage values are also used as the reference source for the over/under voltage protection and over current protection functions.

The iW248 is a digital controller with an integrated IGBT driver for inductive (IH) cooking applications. Once  $V_{CC}$  reaches the start-up threshold level, the controller operates in idle mode and is ready to receive instructions from the user interface MCU. Soon after the iW248 receives instructions, it starts to detect and determine the input line voltage. If the input line voltage is within the operating range, the controller enters pot detection mode. The iW248 features an innovative pot detection method by detecting the number of rings on  $V_{CE}$  of the IGBT. A pulse is sent out at DRV pin every second by default, a pot is detected if the number of rings on  $V_{CE}$  is less than nine. When a pot is detected, the iW248 goes to constant power mode operation or constant current mode according to the input line voltage. Figure 4 outlines the state machine diagram of iW248.

The iW248 drives an LC circuit comprised of an induction heating element and resonant capacitor. The controller modulates the  $t_{ON}$  time and delay time ( $t_{DELAY}$ ) to maintain a constant output power requested by the user interface MCU. When the IGBT turns off, the voltage at the collector of the IGBT will quickly rise above the input voltage as the resonant capacitor charges up by the current of the inductor. The voltage at the collector of IGBT will fall from its maximum value when the polarity of the inductor changes. When the voltage on the collector of the IGBT reaches the same value as the voltage on the coil, the internal block of the controller gives the next driving pulse after it waits a programmed delay time ( $t_{DELAY}$ ). This delay time can be adjusted via the digital control bus based on the system requirements. The iW248 directly monitors input voltage and current and the digital control unit inside the iW248 uses these values to calculate the on-time required as a function of requested output power.

As the output power decreases, the energy in the LC tank is insufficient to achieve zero-voltage switching. To prevent the IGBT from overheating from excessive switching loss, the VCE\_SNS pin senses the VCE level for every switching cycle and counts the occurrence when the VCE doesn't reach its valley threshold.

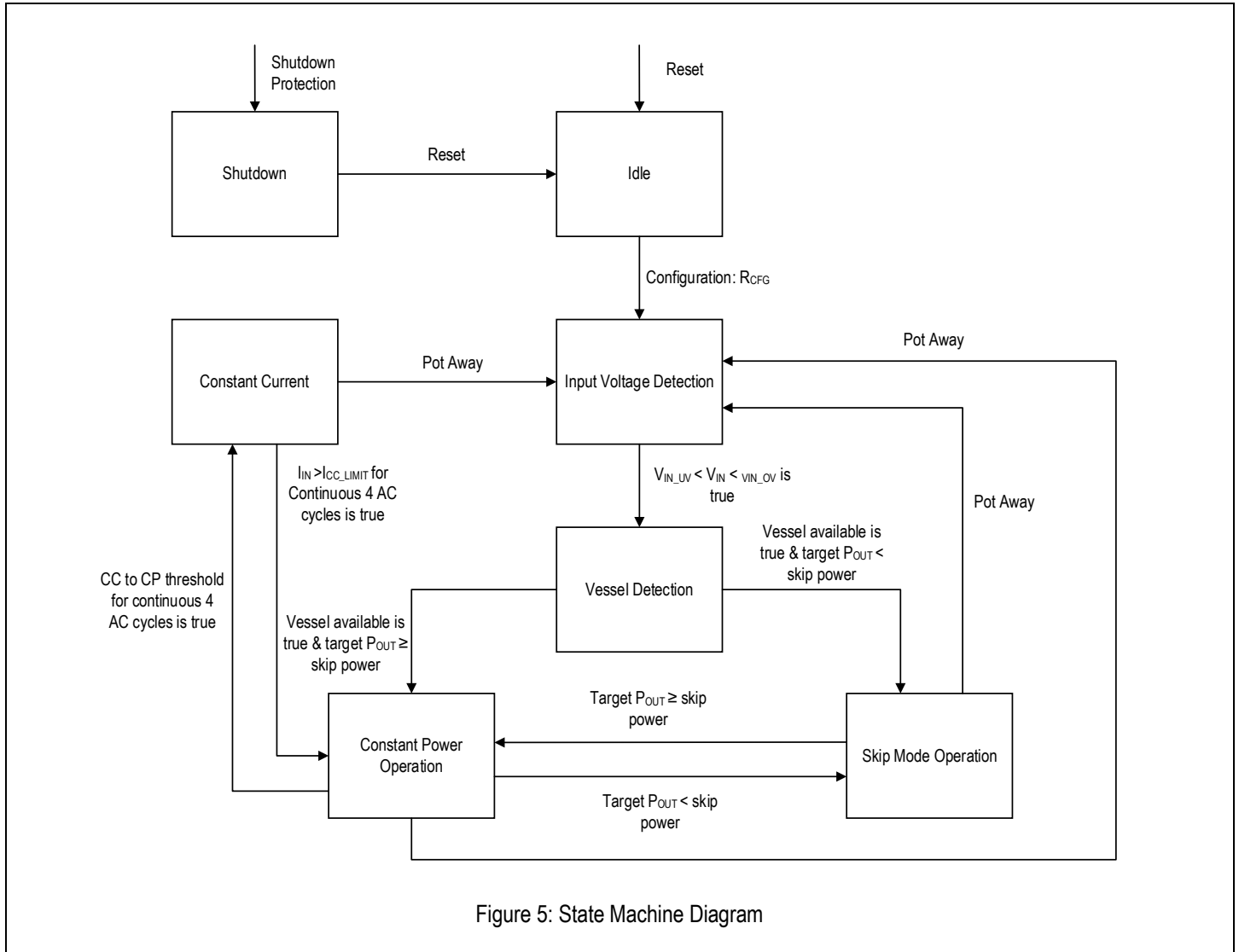
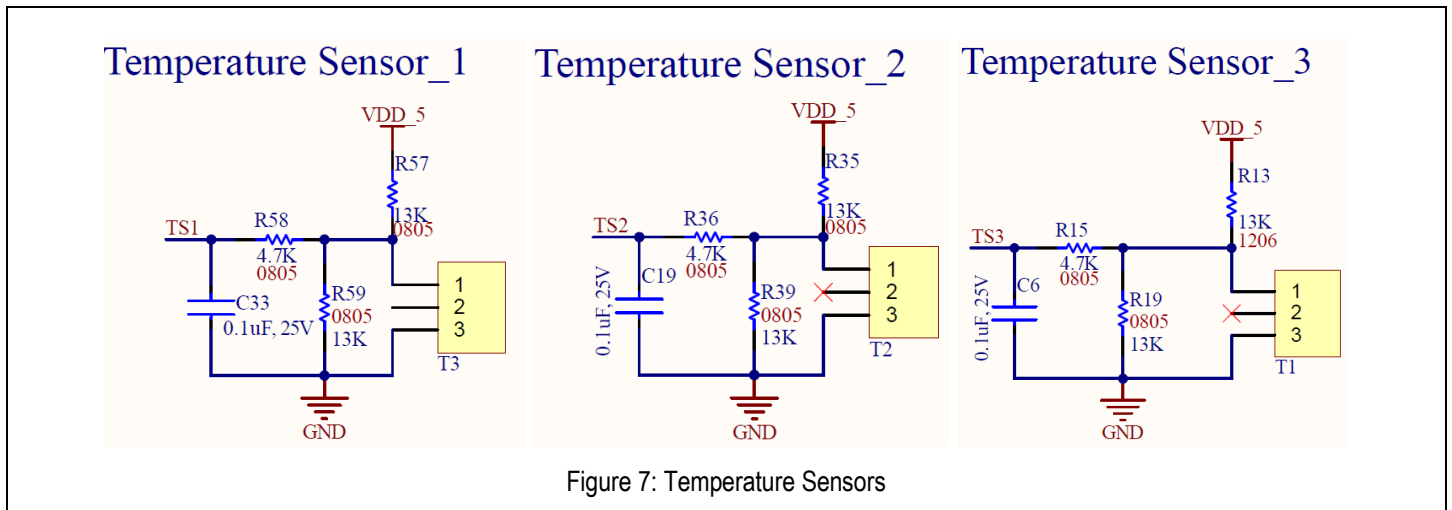
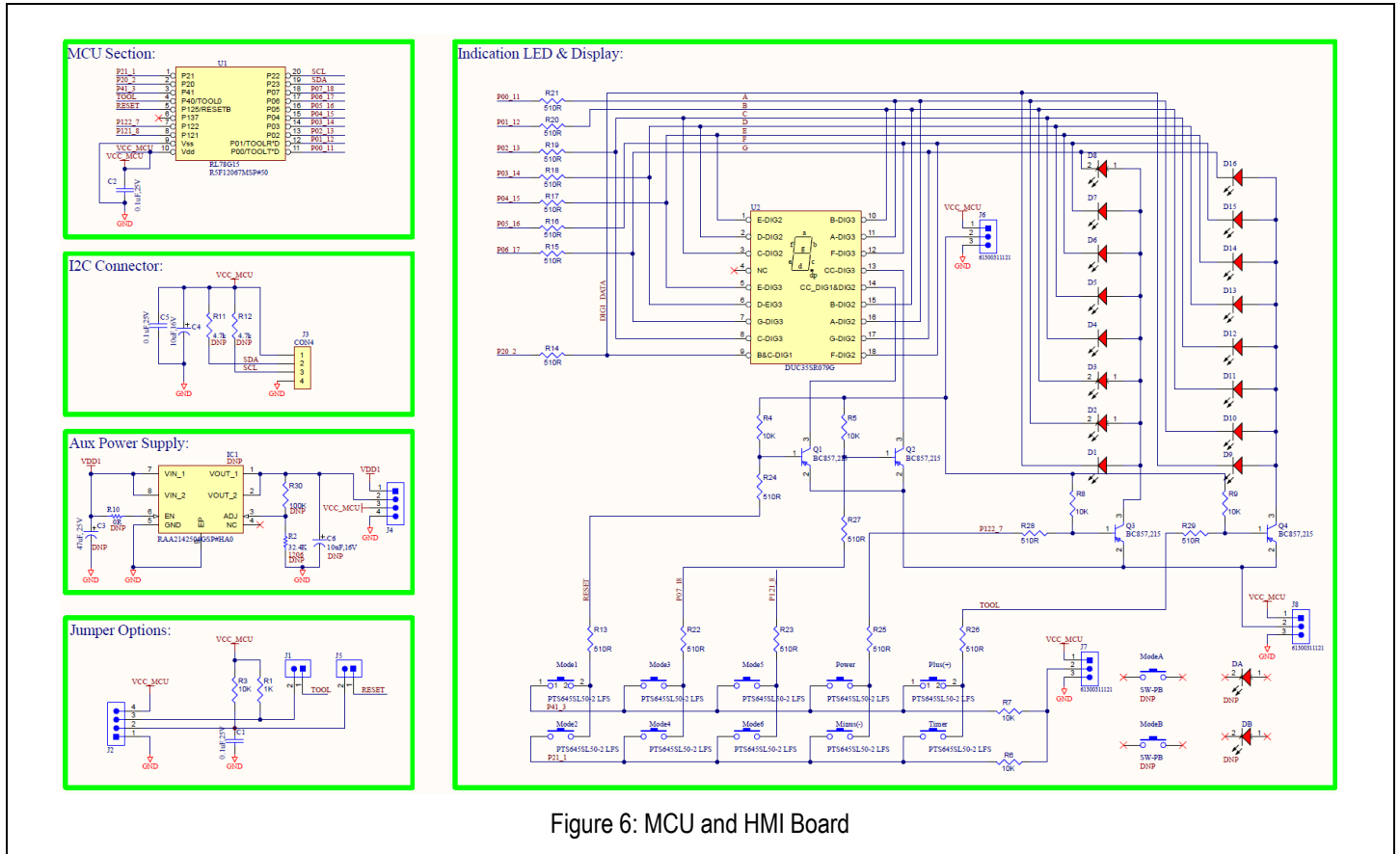


Figure 5: State Machine Diagram

**HMI Board:** The power board provides the power supply 5V to the HMI display board via the I2C connector. This voltage supply is regulated to a 5V voltage output by a voltage regulation filtering circuit and is supplied as the HMI display board main power. The LED's displays the current induction cooker operating mode and function. The tactile switches are provided as a human-machine operating interface, with which functions can be selected. The induction cooker will then control the power heating board operation according to the selected function.



The TS1 works with the circuit as shown in Figure 7 and has a default over temperature threshold of 110°C and a default recovery threshold of 80°C. These are both programmable via the digital control bus.

The TS2 works with the recommended circuit shown in Figure 7 and has a default over temperature threshold of 200°C and a default recovery threshold of 170°C. These are both programmable via the digital control bus.



## Software Overview

- 1) Debugging/Binary flashing:

Hardware Setup:

As per present hardware/layout hardware debugging pins of AS048 GUI board are multiplexed with switch scan functions. Renesas E2 lite emulator can be used to flash binary on to G15.

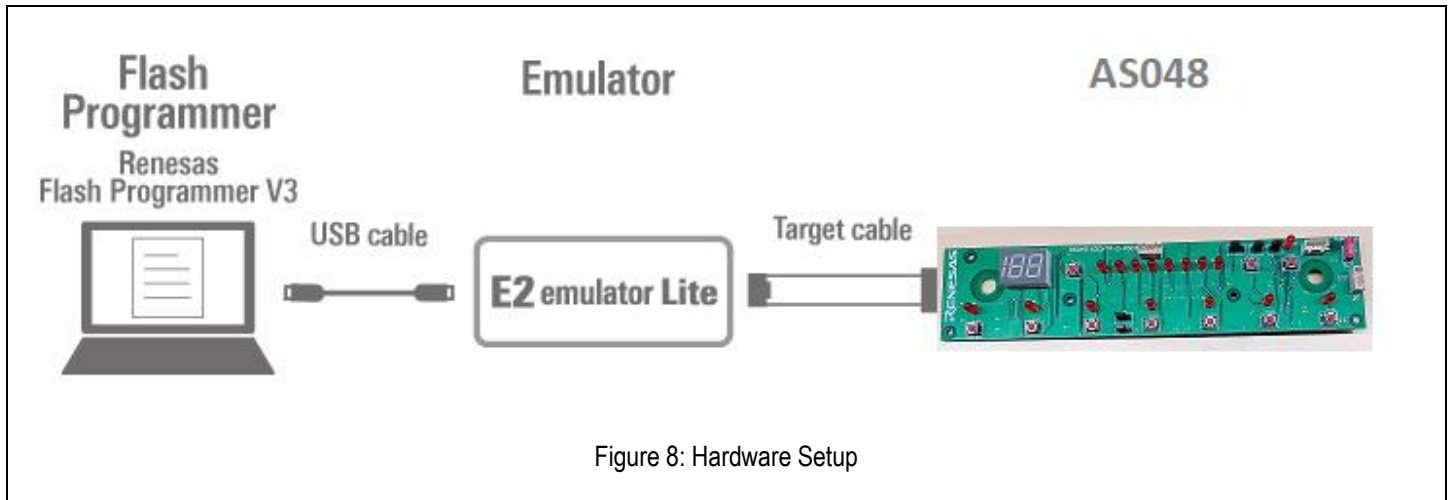


Figure 8: Hardware Setup

Flashing & Flash Programmer Settings: Tool: E2 Emulator Lite, Speed Setting: 115200

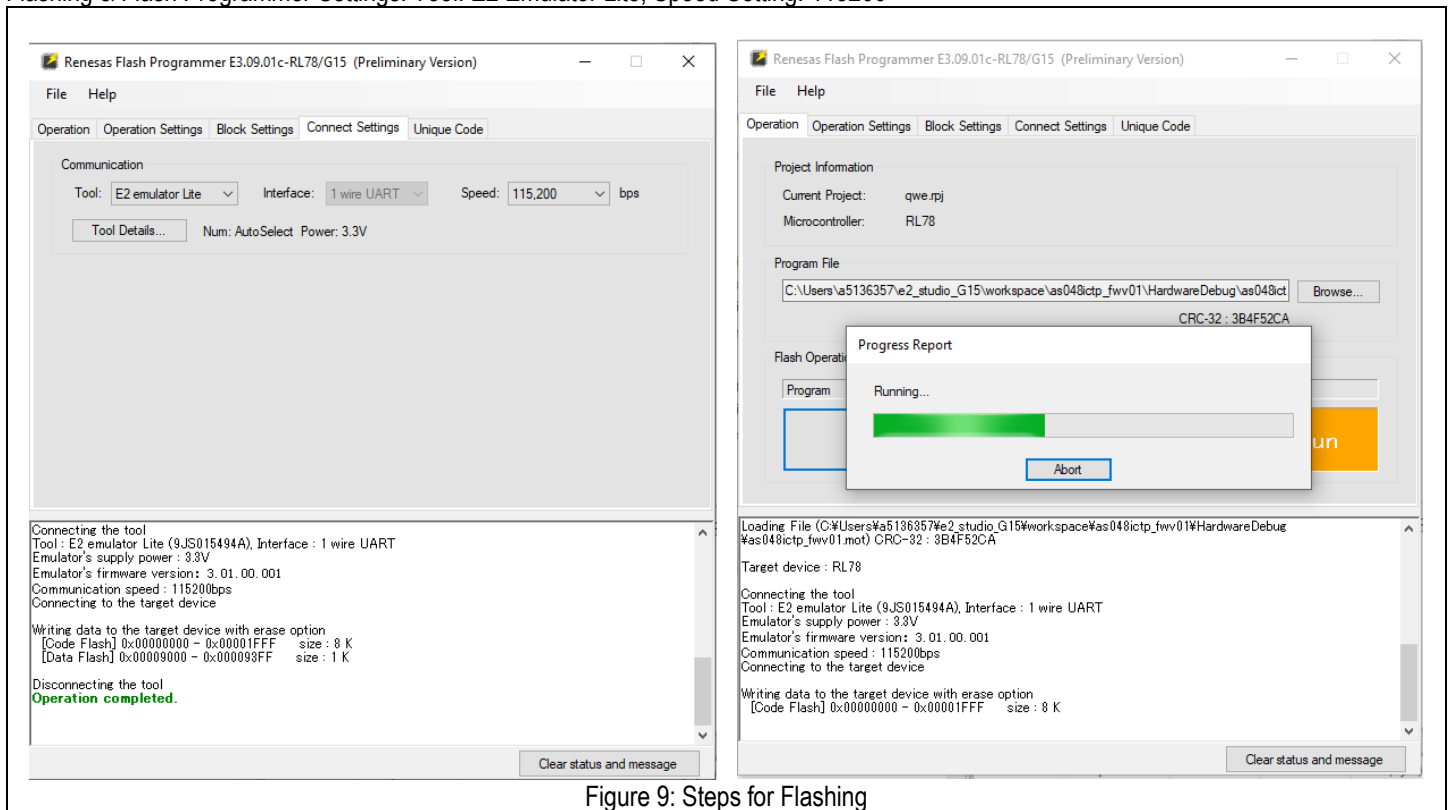


Figure 9: Steps for Flashing

2) Project settings, configuration, and Source code building:

IDE environment used for code development is e2-studio, and Toolchain is Renesas CCRL.

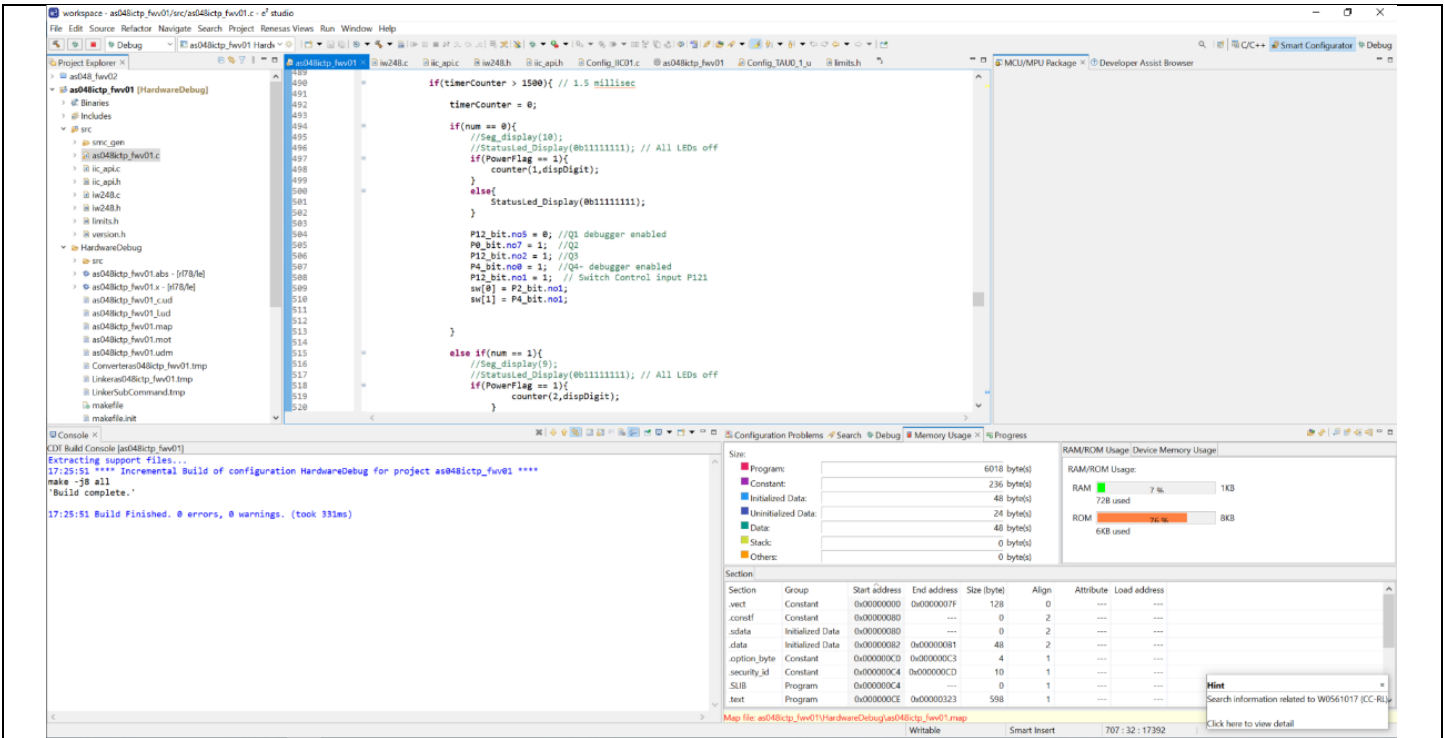


Figure 10: IDE Environment for Code Development

Smart configurator is used to configure RL78/G15 hardware configurations.

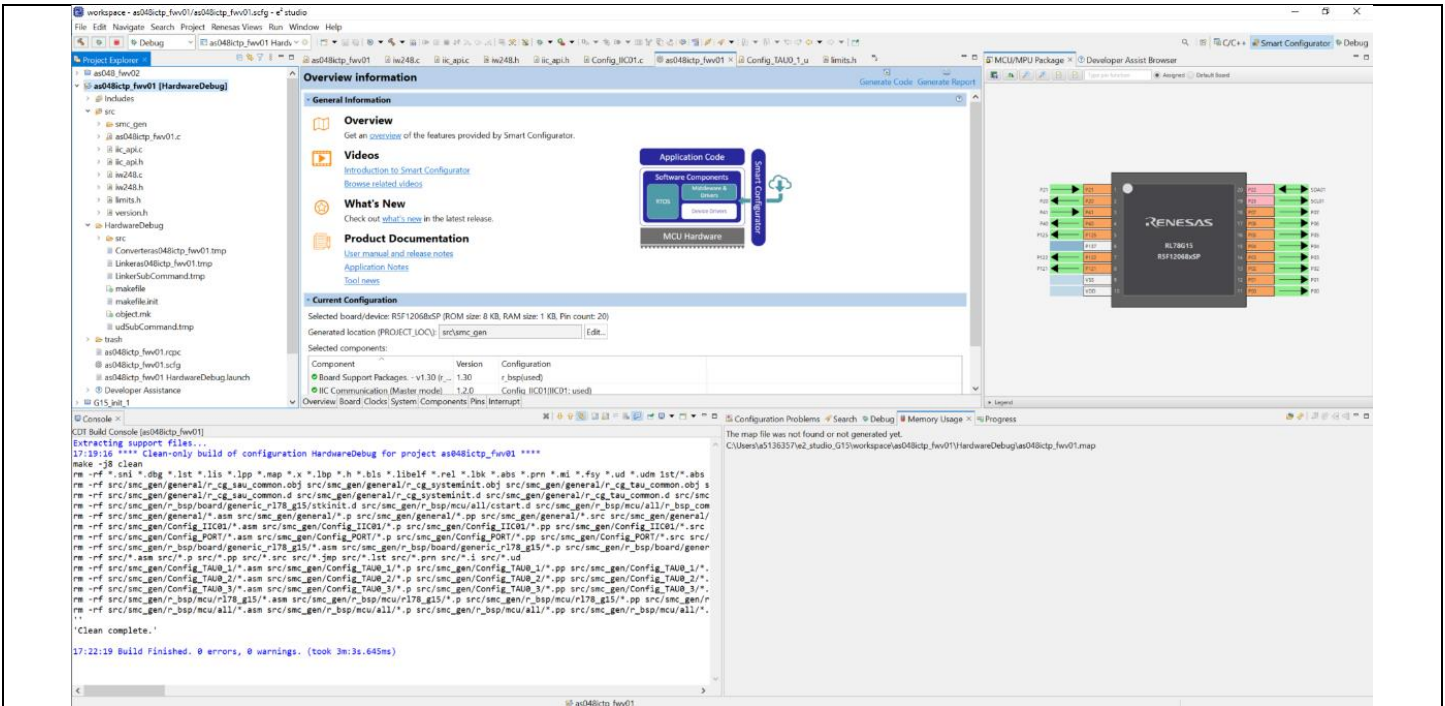


Figure 11: Smart Configurator used to Configure RL78/G15

3) Software State Diagram:

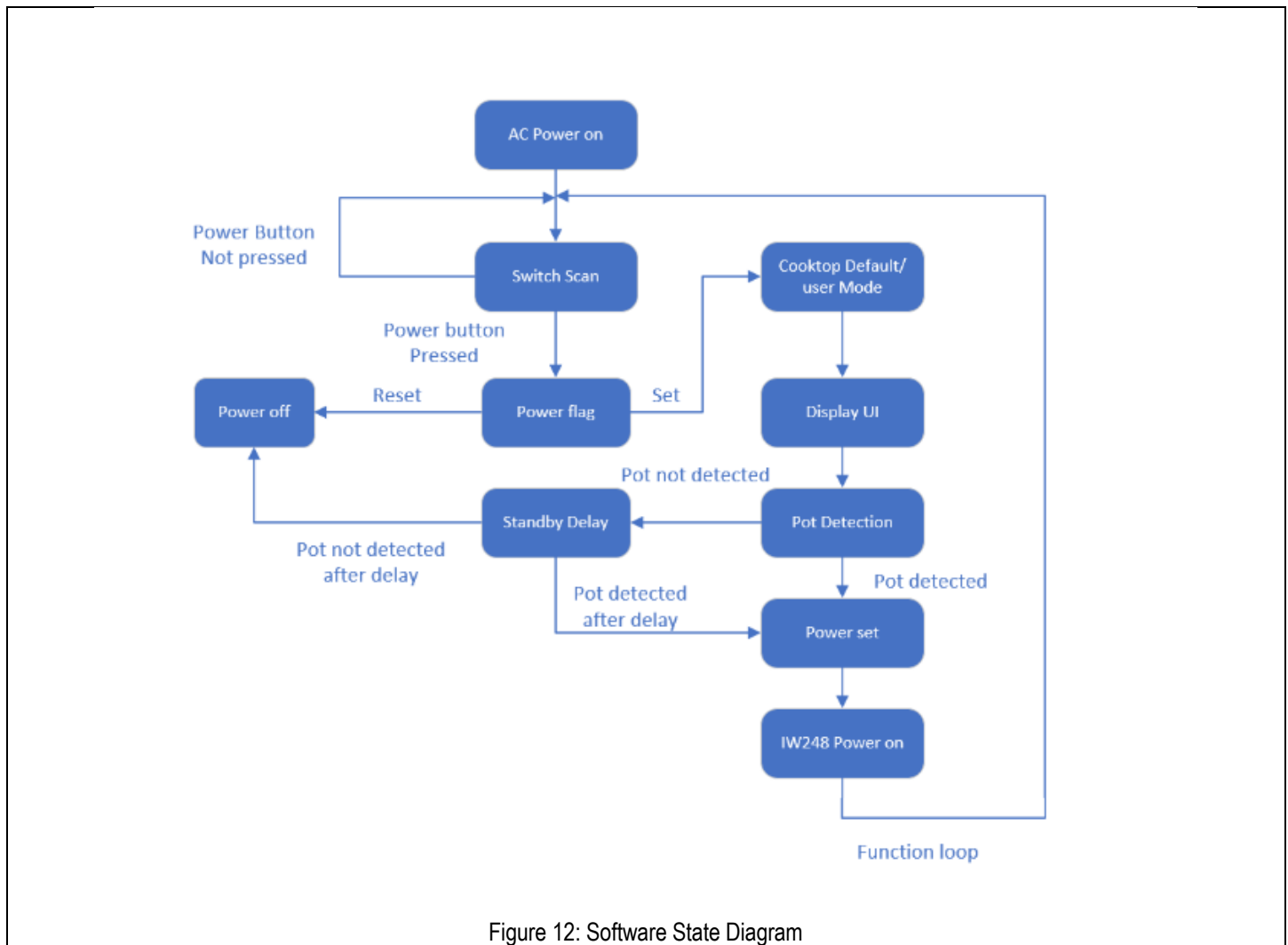


Figure 12: Software State Diagram

4) IW248 library API functions:

- IW248 Power on/off functions

```

void iW248_IIC_PowerON(void)
void iW248_IIC_PowerOFF(void)
  
```

- Fan control PWM-variable speed implementation with external voltage input for fan.

```

void iW248_IIC_FanSpeed(unsigned char spd)
  
```

- IW248 Power Control and output enable.

```

void iW248_IIC_PowerSel(unsigned char ps)
void iW248_IIC_PowerOutput(unsigned char enable)
  
```

- IW248 Buzzer call (Timing will set at initialization)

```

void iW248_IIC_Buzzer(void)
  
```

- IW248 Pot detection API.  
**unsigned char iW248\_IIC\_DetPot(void)**
- IW248 Fault detection.  
**unsigned char iW248\_IIC\_GetFaultFlagH(void)**  
**unsigned char iW248\_IIC\_GetFaultFlagL(void)**
- IW248 Temperature sensor readings  
**unsigned char iW248\_IIC\_GetTempADC\_TS1(void)**  
**unsigned char iW248\_IIC\_GetTempADC\_TS2(void)**  
**unsigned char iW248\_IIC\_GetTempADC\_TS3(void)**
- IW248 Voltage sense.  
**unsigned int iW248\_IIC\_GetVinMax(void)**
- IW248 IIC address (Auto Finder)  
**unsigned char iW248\_IIC\_AutoFindAddr(void)**

Test Data

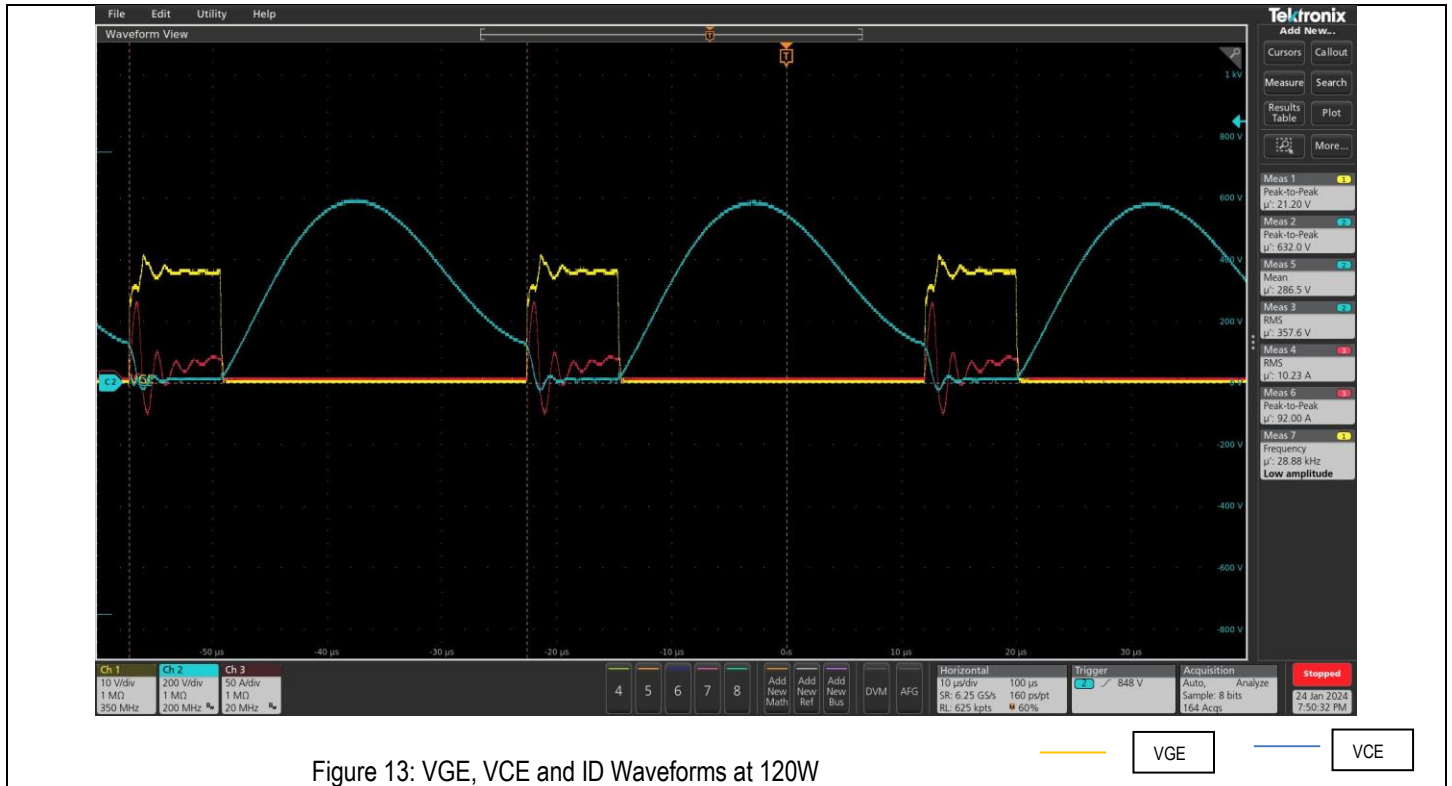


Figure 13: VGE, VCE and ID Waveforms at 120W

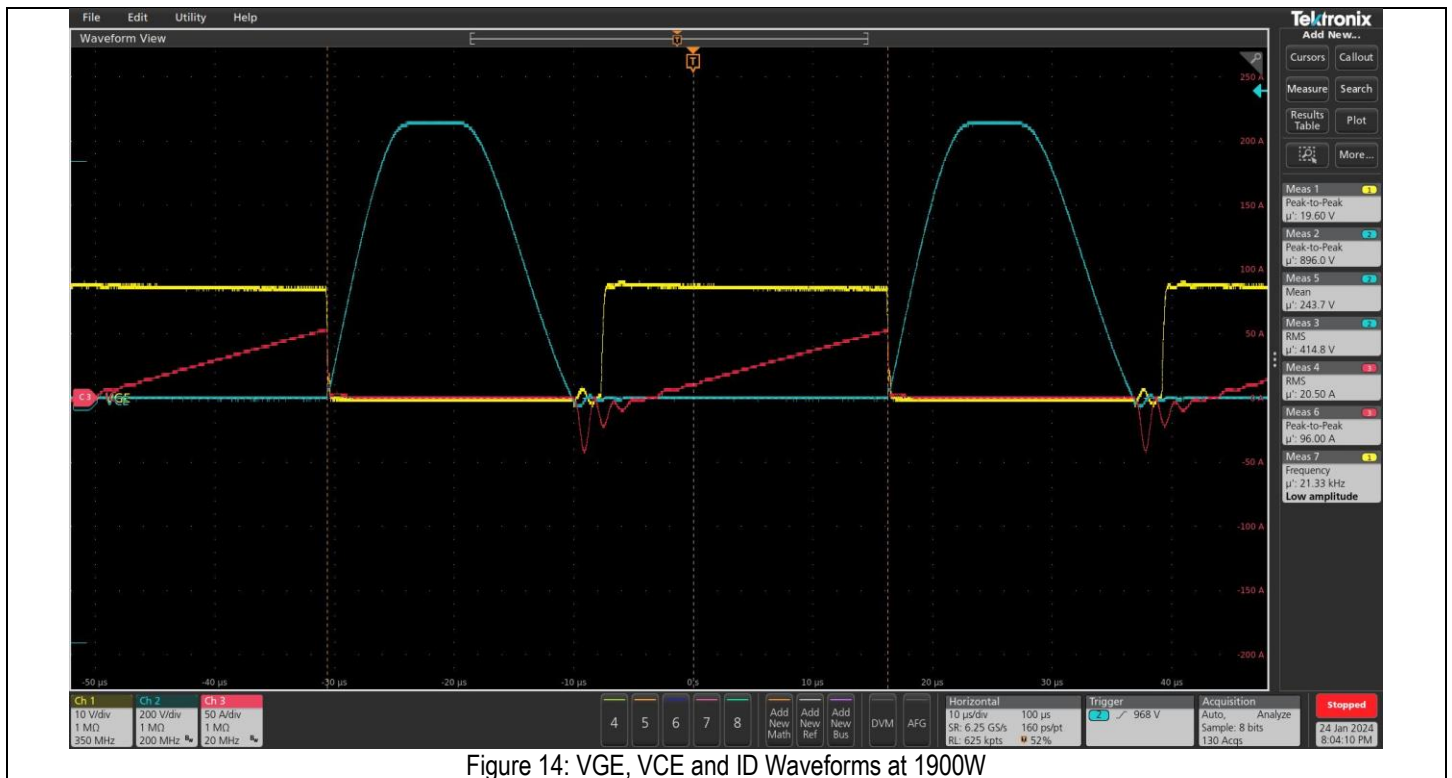


Figure 14: VGE, VCE and ID Waveforms at 1900W

## Device Setup

### Basic Features:

Function	Cooking
Automatic Pan Detection	Yes
Wattage Settings	Variable wattage settings
Compatible Utensils	Stainless Steel Pots, Stainless Steel Rice Cookers, Cast Iron Frying Pots, Oil Boiling Pots, Stainless Steel Water Jugs, Grilling Iron Plates
Control Type	Button
Cooking Modes	6 different intelligent cooking modes for timer and power settings
Indicator	Digital LED Display
Temperature settings	Variable Temperature settings
Fast Heating	Yes

### Power Supply:

Input Voltage	220V-240V
Frequency	50 Hz
Power Consumption	2100 W (Max.)

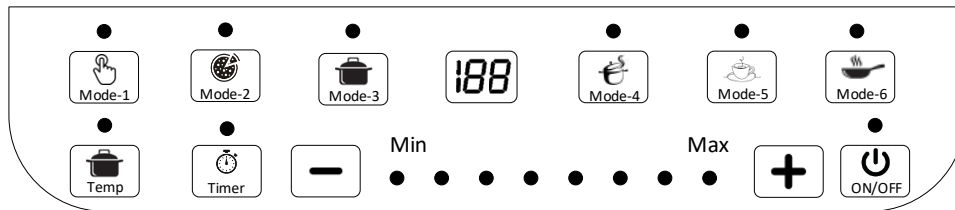


Figure 15: HMI Display with different modes

1. Press the ON/OFF button (⏻) to switch on the appliance, and the ON/OFF indicator lights up.
2. There are six preset cooking modes, which have or can be set with different time and power settings.
3. Press the desired cooking mode button, and the corresponding indicator lights up.
4. The appliance starts working in the selected mode.
5. When the cooking is finished, press the ON/OFF button (⏻) to switch off the appliance.
6. Unplug the appliance after the fan stops working.

### Note:

1. During cooking, you can change the power level by pressing the Increase (+) or Decrease (-) button.
2. There is a fixed delay between changing the power or modes from one rating to another.

Getting to know the cooking modes:

Refer to the tables below for more details of different cooking modes.

**Table 1. Different default Cooking Modes**



Cooking mode	Default cooking time (minute)	Power Range (Watts)	Adjustable cooking time range (minute)
Mode-1	60	1600	1-180
Mode-2	60	1000	1-180
Mode-3	45	800	1-180
Mode-4	60	1300	1-180
Mode-5	120	1600	1-180
Mode-6	60	1700	1-180

**Table 2. Induction Cooker Error Code Introduction**

Error Code	Description
E1	No Cookware Detected
E2	Mains supply Under Voltage
E3	Mains supply Over Voltage
E4	IGBT Overheating

Using the timer:

You can use the Timer button to decide how much time you want the appliance to work at different cooking modes.

1. Press the ON/OFF (  ) button, the ON/OFF (  ) indicator lights up.
2. Press the desired cooking mode button, and the corresponding indicator lights up. The induction cooker starts working in the selected mode.
3. Press the Timer button and the timer indicator lights up.
4. Press the Increase (+) or Decrease (-) button to adjust the time by minute.
5. When the time has elapsed, the induction cooker turns off automatically.

# AS048 Application Schematic

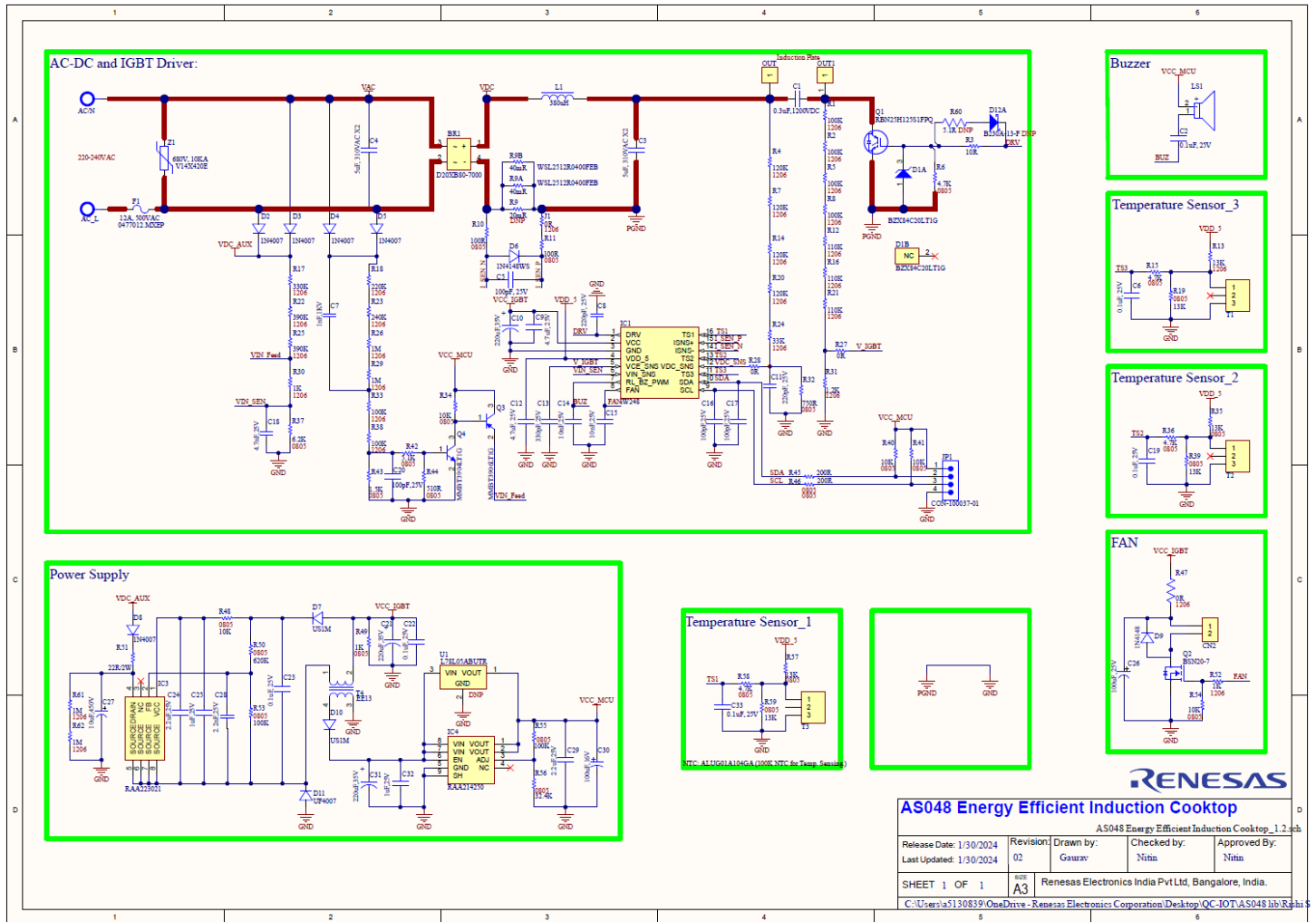


Figure 16. Power Board Schematic

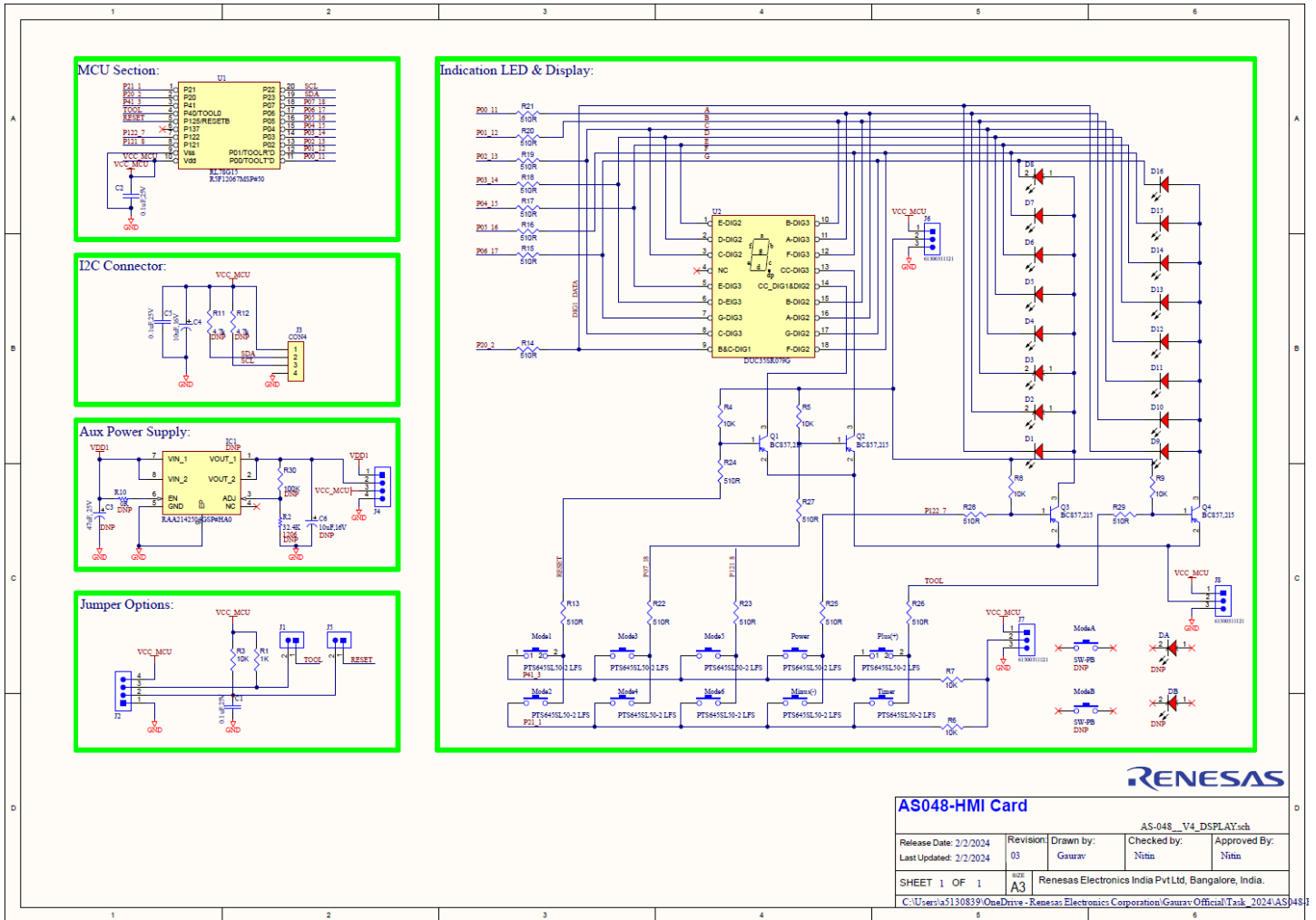
**AS048 Energy Efficient Induction Cooktop**

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Release Date: 1/30/2024	Revision: 02	Drawn by: Gaurav	Checked by: Nitin	Approved By: Nitin
SHEET 1 OF 1				
Renesas Electronics India Pvt Ltd, Bangalore, India.				

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AS048-HMI Card		AS-048_V4_DSPLAYsch		
Release Date: 2/2/2024	Revision: 03	Drawn by: Gaurav	Checked by: Nithin	Approved By: Nithin
Last Updated: 2/2/2024				
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Figure 17. HMI Board Schematic

## Bill of Materials (BOM)

**Table 2. AS048 Power Board BOM**

Quantity	Designator	Description	Manufacturer	Manufacturer Part #
2	AC_L, AC_N	0.205" (5.21mm) Quick Connect Male Solder Connector Non-Insulated	Keystone Electronics	1213
1	BR1	Rectifier Bridge Diode Single 800V 3.5A 4-Pin SIP T/R	Shindengen	D20XB80-7000
1	C1	0.3uF, 1200VDC	BM Capacitors	BM 0.3uF 1200VDC
6	C2, C6, C19, C22, C23, C33	0.1 µF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Wurth Electronics	885012207072
2	C3, C4	5µF Film Capacitor 310V Polypropylene (PP), Metallized Radial	BM Capacitors	BM 5UF 310VAC
1	C7	1000 pF ±20% 1000V (1kV) Ceramic Capacitor X7R 0805 (2012 Metric)	Kemet	C0805C102MDRAC7800
2	C9, C12	4.7 µF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	YAGEO	CC0805KKX7R8BB475
3	C10, C21, C31	CAP ALUM 220UF 20% 35V RADIAL	Wurth Electronics	860010574011
2	C11, C8	220 pF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Wurth Electronics	885012207056
1	C13	330 pF ±10% 25V Ceramic Capacitor C0G, NP0 0805 (2012 Metric)	Wurth Electronics	885012207057
2	C14, C15	10nF/10000 pF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Wurth Electronics	885012207066
4	C5, C16, C17, C20	100 pF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Wurth Electronics	885012207054
1	C18	4700 pF ±10% 25V Ceramic Capacitor C0G, NP0 0805 (2012 Metric)	Wurth Electronics	885012207064
2	C25, C32	1 µF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Wurth Electronics	885382207003
1	C26	Alum. Electrolytic Cap 100µF 25V 6.3mm Radial WCAP-ATG8; Lifetime 2000h +85°C	Wurth Electronics	860010473007
1	C27	10uF 20% 450V Electrolytic capacitor	Würth Elektronik	860241478003
1	C28	2200 pF ±5% 25V Ceramic Capacitor C0G, NP0 0805 (2012 Metric)	Wurth Electronics	885012007042
1	C24, C29	2.2 µF ±10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Wurth Electronics	885012207079
1	C30	Aluminum Electrolytic Capacitor, 100 uF, +/- 20%, 16 V, 2-Pin SMD (Size Code D), -40 to 105 degC, RoHS, Tape and Reel	Wurth Electronics	865060343005
1	CN2	Connector Header Through Hole 2 position 0.098" (2.50mm)	JST Sales America Inc.	B2B-XH-A
1	D1	Zener Diode 20 V 225 mW ±6% Surface Mount SOT-23-3 (TO-236)	On Semiconductor	BZX84C20LT1G
6	D2, D3, D4, D5, D8	VR=1000V IF=1A 15pF	ON Semiconductor / Fairchild	1N4007
1	D6	Diode 100 V 300mA Surface Mount SOD-123	Diodes Incorporated	1N4148W-13-F
1	D9	Diode 100 V 200mA Through Hole DO-35	onsemi	1N4148
2	D7, D10	Diode Standard 1000 V 1A Surface Mount SMA	Diodes Incorporated	US1M
2	D11	Diode Ultra-Fast Recovery Rectifier 1K Volt 1A 2-Pin DO-41 Tape and Reel	ON Semiconductor / Fairchild	UF4007
1	F1	12 A 500 V AC 400 V DC Fuse Cartridge, Ceramic Through Hole 5mm x 20mm (Axial)	Littelfuse Inc.	0477012.MXEP
1	IC1	Integrated IGBT Driver, Optimized State Machine and Advanced Protection Features	Renesas	iW248

1	IC3	700V AC/DC Regulator with Ultra-Low Standby Power and up to 8W Output Power	Renesas	RAA2230214GSP#HA1
1	IC4	20V, 500mA Linear Regulator	Renesas	RAA2142504GSP#HA0
1	JP1	Connector Header Through Hole 4 position 0.098" (2.50mm)	JST Sales America Inc.	B4B-XH-A
1	L1	380 $\mu$ H Unshielded Toroidal Inductor 6.2 A 70mOhm Max Radial, Vertical (Open)	Würth Electronics	744156
1	LS1	Buzzers Piezo 5 V 2mA 4kHz Through Hole PC Pins	MikroElektronika	MIKROE-5389
2	OUT, OUT1	4 Pin Screw Terminal, Power Tap M4 Through Hole	Keystone Electronics	7797
1	Q1	Transistor IGBT N-Channel 1250V 25A 3-Pin TO-247A Box	Renesas	RBN25H125S1FPQ-A0#CB0
1	Q2	N-Channel 50 V 500mA (Ta) 600mW (Ta) Surface Mount SOT-23-3	Diodes Incorporated	BSN20-7
1	Q3	General Purpose Transistor, PNP Silicon, 3-Pin SOT-23, Pb-Free, Tape and Reel	On Semiconductor	MMBT3906LT1G
1	Q4	General Purpose Transistor, NPN Silicon, 3-Pin SOT-23, Pb-Free, Tape and Reel	On Semiconductor	MMBT3904LT1G
6	R1, R2, R5, R8, R33, R38	100 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07100KL
1	R3	10.2 Ohms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-0710R2L
4	R4, R7, R14, R20	120 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07120KL
4	R6, R15, R36, R58	4.7 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-074K7L
1	R9	20 mOhms $\pm$ 1% 3W Through Hole Resistor Axial Current Sense, Non-Inductive Metal Element	Ohmite	13FR020E
2	R10, R11	100 Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-07100RL
3	R12, R16, R21	110 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07110KL
1	R13	13 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-0713KL
1	R17	330 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07330KL
1	R18	220 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07220KL
5	R19, R35, R39, R57, R59	13 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-0713KL
2	R22, R25	390 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07390KL
1	R23	240 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-07240KL
1	R24	33 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-0733KL
2	R27, R28	0 Ohms Jumper 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805JR-070RL
2	R30, R52	1 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-071KL
1	R31	1.2 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-071K2L
1	R32	750 Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-07750RL
5	R34, R40, R41, R48, R54	10K Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-1310KL
1	R37	6.2 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-076K2L

1	R42	5.1 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-075K1L
1	R43	1.5 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-071K5L
1	R44	510 Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-07510RL
2	R45, R46	200 Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-07200RL
1	R47	RES SMD 0 OHM JUMPER 1/4W 1206	YAGEO	RC1206FR-070RL
2	R49	1K Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-131KL
1	R50	620 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-07620KL
1	R51	22 Ohms $\pm$ 5% 2W Through Hole Resistor Axial Wirewound	Ohmite	42J22RE
2	R53, R55	100K Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-13100KL
1	R56	32.4 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-0732K4L
3	T1, T2, T3	Connector Header Through Hole 3 position 0.098" (2.50mm)	JST Sales America Inc.	B3B-XH-A
1	T4	EE16	SR Magnetics	EE16
1	U1	Positive Voltage Regulator, 5V, 4-Pin SOT-89, Tape and Reel	STMicroelectronics	L78L05ABUTR
1	Z1	680 V 10 kA Varistor 1 Circuit Through Hole Disc 17mm	Littelfuse Inc.	V14X420E
2	R61, R62, R26, R29	1 MOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Thick Film	YAGEO	RE1206FRE071ML
1	D12	2 A Surface Mount Schottky Barrier Rectifier, 30 V, -65 to 150 degC, 2-Pin SMA, RoHS, Tape and Reel	Diodes Inc	B230A-13-F
1	R60	Thick Film Resistors 1/8watt 5.1ohms 1% 200ppm	Vishay Dale	CRCW08055R10FNEA
2	R9A, R9B	40 mOhms $\pm$ 1% 1W Chip Resistor 2512 (6432 Metric) Automotive AEC-Q200, Current Sense, Moisture Resistant, Pulse Withstanding Metal Element	Vishay Dale	WSL2512R0400FEB
1	J1	0 Ohms Jumper Chip Resistor 1206 (3216 Metric) Automotive AEC-Q200 Thick Film	Vishay Dale	CRCW12060000Z0EA
1	T2-1	NTC Thermistor 100k Ring Lug	Vishay Beyschlag	NTCALUG01A104GA
1	J1-1	Wire Jumper 20A	Custom Made	Custom

**Table 3. AS048 HMI Board BOM**

Quantity	Designator	Description	Manufacturer	Manufacturer Part #
2	C1, C2, C5	0.1 $\mu$ F $\pm$ 10% 25V Ceramic Capacitor X7R 0805 (2012 Metric)	Würth Elektronik	885012207072
1	C3	Aluminium Electrolytic Capacitor, Wcap-Atg8 Series, 47 F, 20%, 25 V, 5 Mm, Radial Leaded Rohs Compliant: Yes	Würth Electronics	860010472005
1	C4	Cap Alum Poly 10UF 20% 16V SMD	Würth Electronics	875105359001
1	C6	Cap Alum Poly 10UF 20% 16V SMD	Würth Electronics	875105359001
16	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16	LED Uni-Color Red, 100 mW, 30 mA, -55 to 100 degC, 2-Pin THD, RoHS, Bulk	Paralight	LTR5LE1D127G
0	IC1	500mA 20V Wide Input Voltage Range LDO Linear Regulator	Renesas Electronics	RAA2142504GSP#HA0
2	J1, J5	THT Vertical Pin Header WR-PHD, Pitch 2.54 mm, Single Row, 2 pins, Bergstik	Würth Elektronik	61300211121
3	J2, J3, J4	Connector Header Through Hole 4 position 0.098" (2.50mm)	JST Sales America Inc.	B4B-XH-A
3	J6, J7, J8	THT Vertical Pin Header WR-PHD, Pitch 2.54 mm, Single Row, 3 pins	Würth Elektronik	61300311121
10	Minus(-), Mode1, Mode2, Mode3, Mode4, Mode5, Mode6, Plus(+), Power, Timer	Tactile Switch SPST-NO Top Actuated Through Hole	Omron Electronics Inc-EMC Div	B3F-1020
4	Q1, Q2, Q3, Q4	TRANS PNP 45V 100MA TO236AB	NXP USA Inc.	BC857,215
0	R1	1 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-101KL
1	R2	32.4 kOhms $\pm$ 1% 0.25W, 1/4W Chip Resistor 1206 (3216 Metric) Moisture Resistant Thick Film	YAGEO	RC1206FR-0732K4L
7	R3, R4, R5, R6, R7, R8, R9	10 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-1310KL
1	R10	Chip Resistor, 0 Ohm, +/- 1%, 125 mW, -55 to 155 degC, 0805 (2012 Metric)	Vishay Dale	CRCW08050000Z0EAC
2	R11, R12	Chip Resistor, 4.7 KOhm, +/- 1%, 0.125 W, -55 to 155 degC, 0805 (2012 Metric)	YAGEO	RC0805FR-074K7L
17	R13, R14, R15, R16, R17, R18, R19, R20, R21, R22, R23, R24, R25, R26, R27, R28, R29	510 Ohms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-07510RL
1	R30	100 kOhms $\pm$ 1% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Moisture Resistant Thick Film	YAGEO	RC0805FR-10100KL
1	U1	MCU	Renesas	R5F12067GSP#50
1	U2	Display-7Seg	Paralight	A503SRA-NW-L9-A G/W
2	DA,DB	LED Uni-Color Red, 100 mW, 30 mA, -55 to 100 degC, 2-Pin THD, RoHS, Bulk	Paralight	LTR5LE1D127G
2	ModeA, ModeB	Tactile Switch SPST-NO Top Actuated Through Hole	Omron Electronics Inc-EMC Div	B3F-1020

## Board Layout

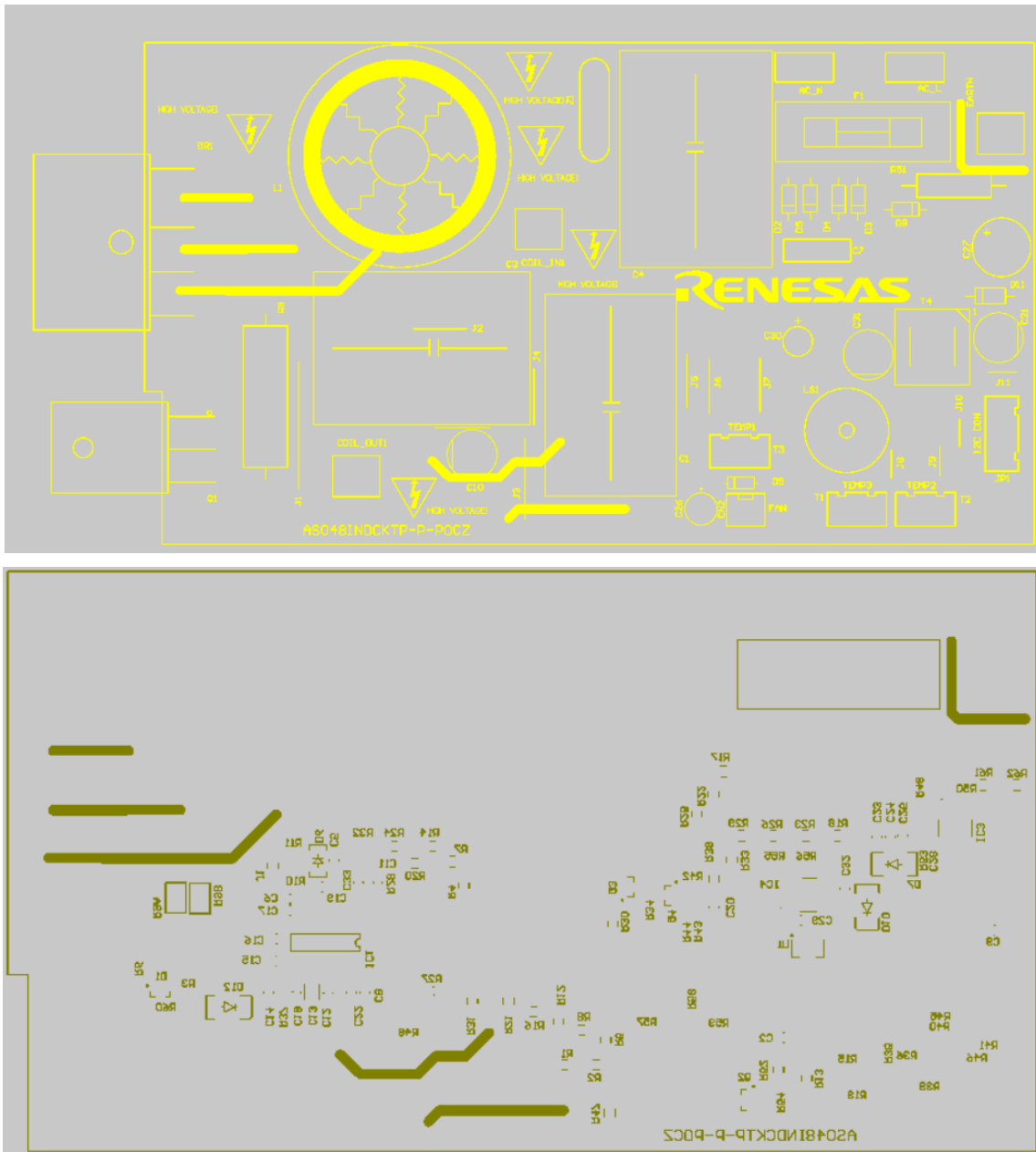


Figure 18. Silkscreen Top and Silkscreen Bottom (Power Card)

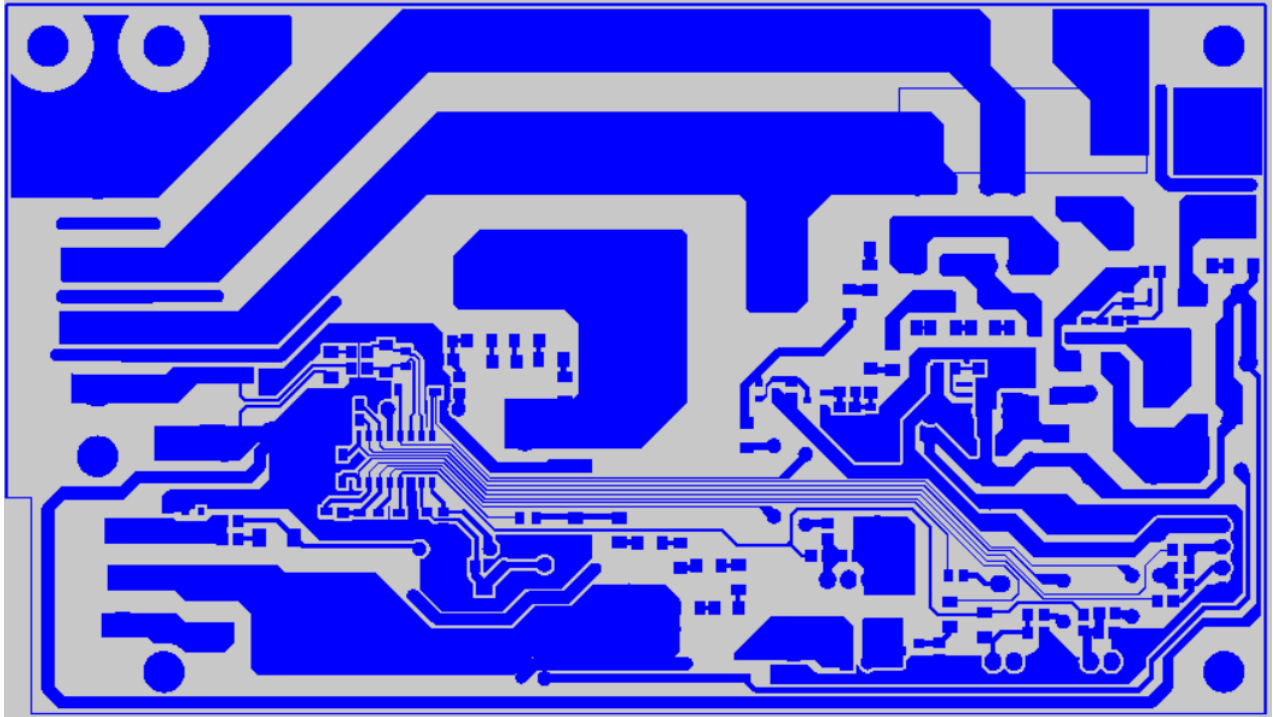


Figure 19. Copper Bottom (Power Card)

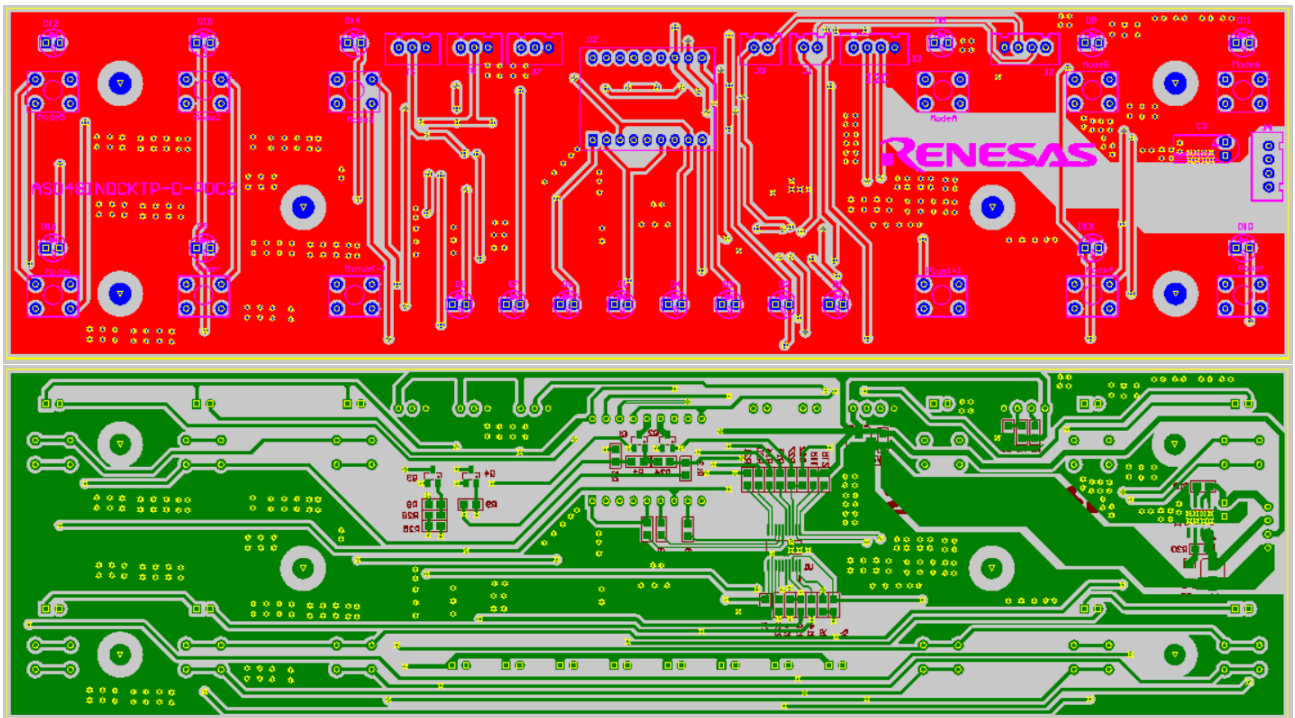


Figure 20. HMI Card