AT16225: Atmel Smart Plug Hardware User Guide

Application Note

Introduction

The Atmel® Smart Plug Reference Design provides a system solution for a Wi-Fi® enabled power plug that can turn on/off power from the main plug in three ways: using the QTouch® button, using the Android™ app with a Wi-Fi connection, or using a scheduled on/off from the Android app. It is an IoT application using the ATSAMW25 module (a highly integrated module with ATSAMD21, WINC1500, ECC508A), and an ATM90E26 device to realize ARM® Cortex®-M0+ MCU control, Wi-Fi connection, CryptoAuthentication with secure hardware key storage, QTouch sensing, and energy metering functions with an optimized BOM. This document describes the hardware design of the smart plug reference design.

Features

- Turnkey solution with small form factor
- Three models following either US, EU, or Chinese standards
- AC input 90-265V and 50/60Hz
- Max output power: 2200W(10A)
- Based on ATSAMW25 module
  - ATSAMD21 Cortex-M0+ MCUWINC1500 IEEE 802.11 b/g/n 2.4G Wi-Fi Controller
  - ECC508A hardware Authentication and Encryption
- ATM90E26 power and energy metering function
- QTouch button
- CE/FCC/UL&CUL Certification

Figure 1. Atmel Smart Plug Kits

Table of Contents

1 Overview 3

1.1 System Overview 3

2 MCU Board 4

2.1 MCU Board Overview 4
2.2 ATSAMW25 5
2.3 Programming Interface 7
2.4 Header to Touch Board 7
2.5 Header to Power Board 8
2.6 DataFlash (Not Mounted) 8

3 Touch Board 9

3.1 Touch Board Overview 9
3.2 Touch Sensors 9
3.3 LEDs for Wi-Fi and Power 10
3.3.1 Wi-Fi LED 10
3.3.2 Power LED 10
3.3.3 LED Pin Definition on SAM W25 10

4 Power Board 10

4.1 Power Board Overview 10
4.2 AC-DC 11
4.3 DC-DC 12
4.4 Power Measurement 12
4.5 Power Measurement Calibration 14
4.5.1 Calculation of the GL 14
4.5.2 Calculation of the Ugain 14
4.5.3 Calculation of the Igain 14
4.5.4 Calculation of the PL_Constant 14
4.6 The Relay 14
4.7 Plug and Socket 15

5 PCB Assembly 17

5.1 PCB Stack Structure 17

6 Reprogram the Kit 18

6.1 Open the Kit 18
6.2 Power Supply 18
6.2.1 Onboard AC Power 18
6.2.2 External DC power 19
6.3 Programming Tools 20
6.4 Programming 21

7 Revision History 22

1 Overview

The smart plug consists of three PCBs: Power board, MCU board, and Touch board. The MCU board is vertically mounted to the Power board and the Touch board is connected to the MCU board by a pin connector.

- Touch Board: Touch pad and LEDs.
- MCU Board: ATSAMW25, 32KHz crystal, DataFlash footprint (not mounted).
- Power Board: Socket and Plug, AC-DC, DC-DC, Power Measurement, Relay.

1.1 System Overview

Figure 1-1. System Block Diagram

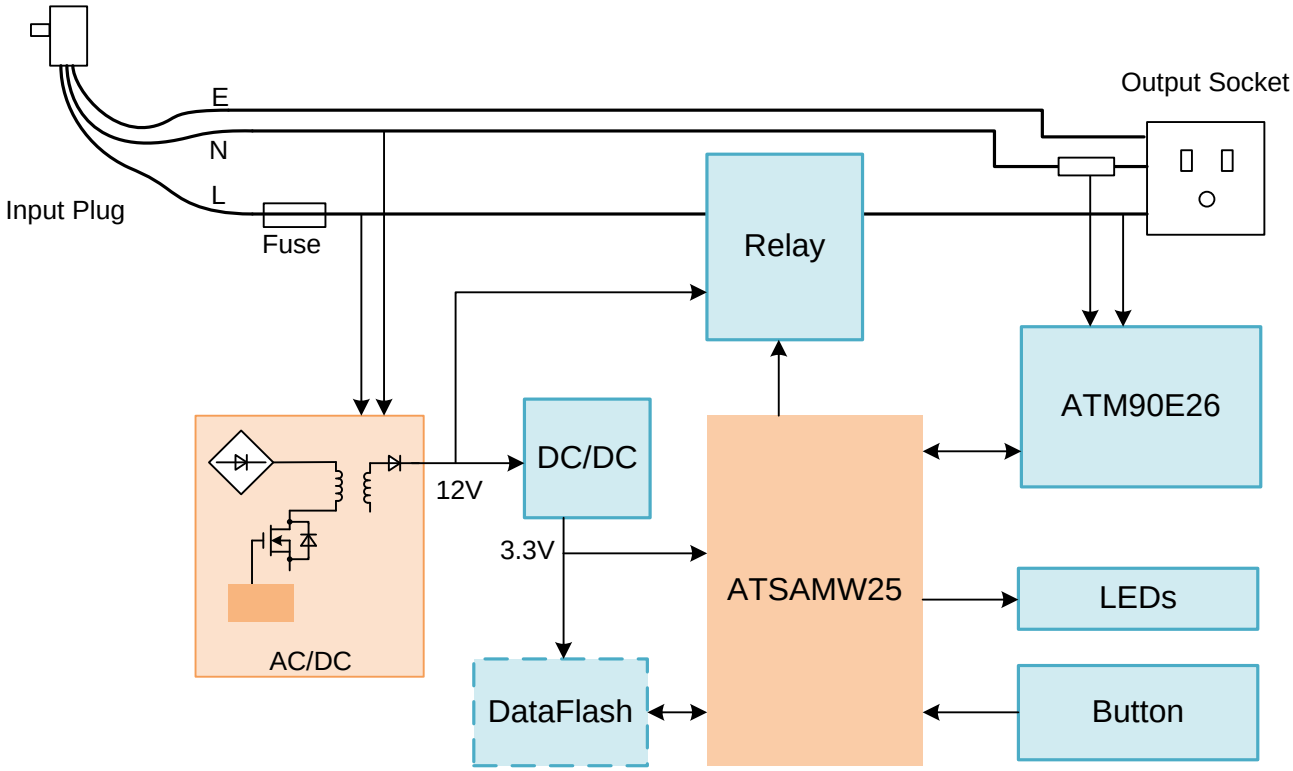
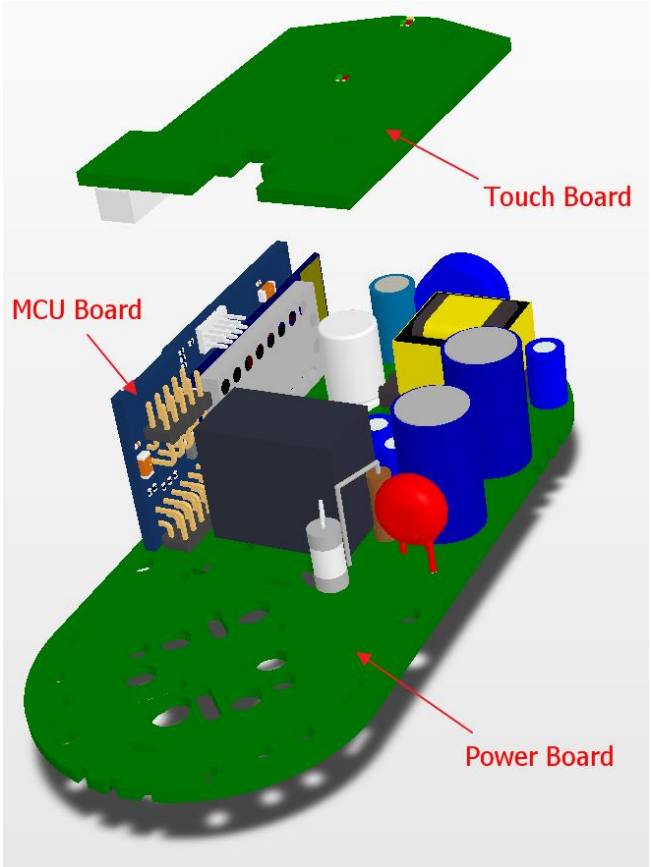


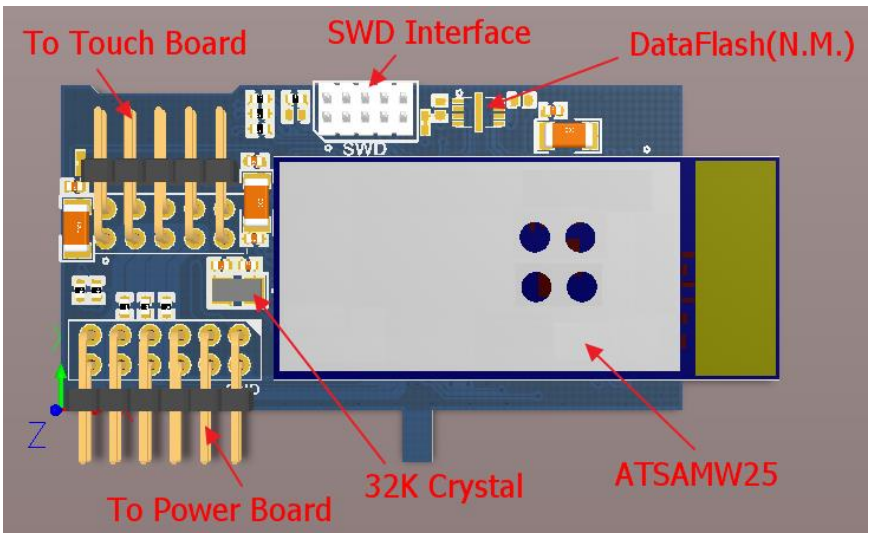
Figure 1-2. Overview of the Smart Plug Kit PCBs



2 MCU Board

2.1 MCU Board Overview

Figure 2-1. MCU Board Overview



2.2 ATSAMW25

The Atmel SmartConnect SAM W25 is a low-power Wi-Fi certified module. This highly integrated module offers the ideal solution for designers seeking Wi-Fi connectivity. The SAM W25 integrates an 802.11 IP stack on top of the Wi-Fi core and fully covers RF certifications.

The SAM W25 module is based on Atmel's industry-leading WINC1500 Wi-Fi core combined with Atmel's latest ARM Cortex-M0+ based microcontroller (SAM D21) technology. This turnkey system provides an integrated software solution with application and security protocols such as TLS and integrated network services (TCP/IP stack).

ATSAMW25 is the control center of the smart plug kit. It covers all the intelligent functions including the Wi-Fi connection, touch button, relay control, temperature sensing and protection, LED indicators, and timing.

Figure 2-2. Schematic for ATSAMW25

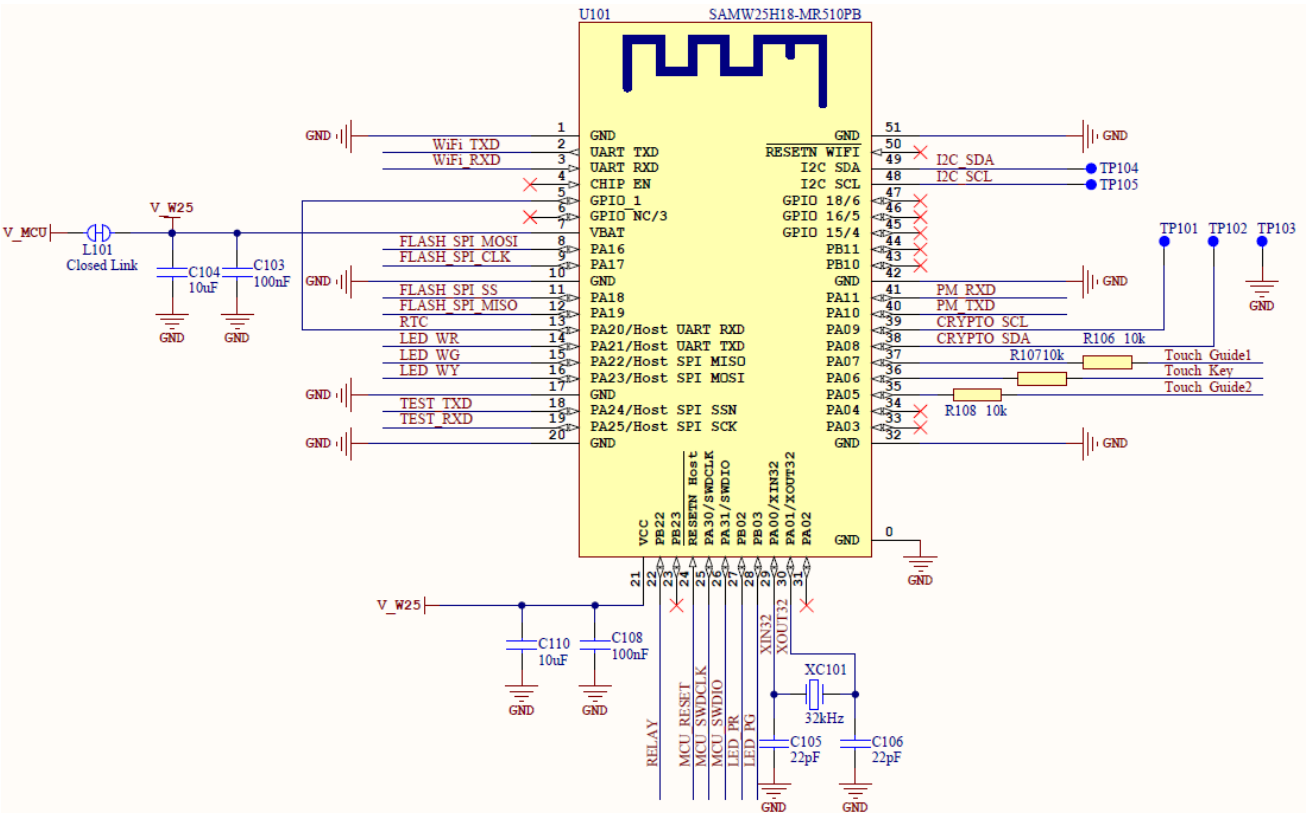


Table 2-1. ATSAMW25 Pinout

Pin #	SAM W25 function	System function	Description
0	GND	GND	Heat sink pads in the bottom
1	GND	GND	
2	UART TXD	Wi-Fi TXD	For ATWINC1500 firmware upgrade
3	UART RXD	Wi-Fi RXD	For ATWINC1500 firmware upgrade
4	Wi-Fi Chip En	NC	
5	Wi-Fi GPIO_1	RTC	Not Used
6	NC	NC	

Pin #	SAM W25 function	System function	Description
7	VBAT	VCC	Power supply
8	PA16	Flash SPI MOSI	DataFlash Interface
9	PA17	Flash SPI CLK	DataFlash Interface
10	GND	GND	
11	PA18	Flash SPI SS	DataFlash Interface
12	PA19	Flash SPI MISO	DataFlash Interface
13	PA20	RTC	Not Used
14	PA21	LED WR	Red LED for Wi-Fi
15	PA22	LED WG	Green LED for Wi-Fi
16	PA23	LED WY	Yellow LED for Wi-Fi
17	GND	GND	
18	PA24	Test TXD	Fixture test interface
19	PA25	Test RXD	Fixture test interface
20	GND	GND	
21	VCC	VCC	Power supply
22	PB22	Relay	Relay ON/OFF
23	PB23	NC	
24	RESET_N	MCU Reset	SAM D21 reset pin
25	PA30	MCU SWDCLK	SWD SWDCLK pin
26	PA31	MCU SWDIO	SWD SWDCLK pin
27	PB02	LED PR	Red LED for Power
28	PB03	LED PG	Green LED for Power
29	PA00	XIN32	32kHz External Crystal
30	PA01	XOUT32	32kHz External Crystal
31	PA02	NC	
32	GND	GND	
33	PA03	NC	
34	PA04	NC	
35	PA05	Touch Guard 2	Touch Guard sensor
36	PA06	Touch Key	Touch key sensor
37	PA07	Touch Guard 1	Touch Guard sensor
38	PA08	Crypto SDA	Reserved interface for internal crypto
39	PA09	Crypto SCL	Reserved interface for internal crypto
40	PA10	PM TXD	Interface for Power Measurement device
41	PA11	PM RXD	Interface for Power Measurement device
42	GND	GND	

Pin #	SAM W25 function	System function	Description
43	PB10	NC	
44	PB11	NC	
45	Wi-Fi GPIO_15	NC	
46	Wi-Fi GPIO_16	NC	
47	Wi-Fi GPIO_18	NC	
48	Wi-Fi I^2C SCL	I^2C SCL	Reserved interface for internal WINC1500
49	Wi-Fi I^2C SDA	I^2C SDA	Reserved interface for internal WINC1500
50	Wi-Fi Reset_n	NC	
51	GND	GND	

2.3 Programming Interface

Since SAM W25 uses the SAM D21 as the controller, the user can use the SWD interface to Program and debug the device.

Table 2-2. Pin Definition of SWD Interface

SWD header pin	Pin definition	ATSAMW25 pin
1	SWDCLK	25
2	GND	
3	NC	
4	VCC	
5	SWDIO	26
6	RESET	24
7	NC	
8	NC	
9	NC	
10	NC	

2.4 Header to Touch Board

The Touch Board is connected to MCU Board through a 10-pin header, it contains the tracks for the touch sensors and LEDs. The header also makes it possible to power the MCU externally.

Table 2-3. Header to Touch Board

Touch header pin	Pin definition	ATSAMW25 pin
1	GND (External power input if onboard power is not available)	
2	VCC (External power input if onboard power is not available)	
3	Touch Guard Sensor 1	37
4	Power LED Green	28
5	Touch Key Sensor	36

6	Power LED Red	27
7	Touch Guard Sensor 2	35
8	Wi-Fi LED Red	14
9	Wi-Fi LED Yellow	16
10	Wi-Fi LED Green	15

2.5 Header to Power Board

The MCU Board is mounted directly on the Power Board by a 12-pin header.

Table 2-4. Header to Power Board

Power header pin	Pin definition	ATSAMW25 pin
1	VCC	
2	GND	
3	Wi-Fi TXD (Reserved for Wi-Fi firmware upgrade on fixture)	2
4	Wi-Fi RXD (Reserved for Wi-Fi firmware upgrade on fixture)	3
5	Test RXD (Reserved for fixture)	19
6	Test TXD (Reserved for fixture)	18
7	Power Measurement RXD (Interface for MCU and power measurement device)	41
8	Power Measurement TXD (Interface for MCU and power measurement device)	40
9	MCU Reset (Reserved for fixture)	24
10	Relay Control	22
11	MCU SWDIO (Reserved for fixture)	26
12	MCU SWDCLK (Reserved for fixture)	25

2.6 DataFlash (Not Mounted)

Space for a DataFlash device is reserved (but not mounted) on the board. This can be used to store more data locally if needed.

Figure 2-3. Schematic of DataFlash Part

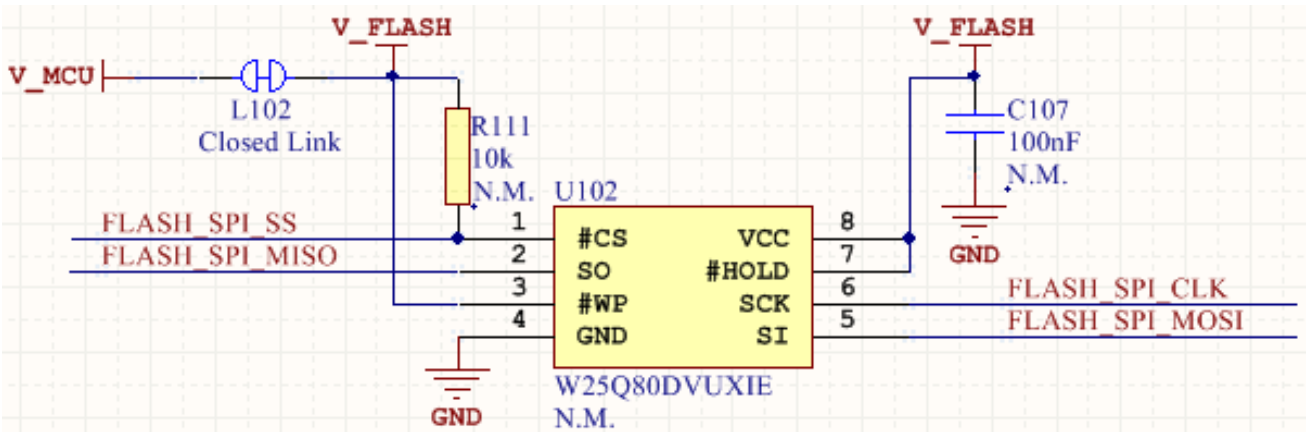


Table 2-5. BoM for the DataFlash Part if Mounted

Designator	Value	Vendor	Part Number	Description
C107	100nF	Murata	GRM155R71H104KE14	Ceramic capacitor, SMD 0402, X7R, 50V, 10%
R111	10k	Yageo	RC0402FR-0710KL	Thick film resistor, SMD 0402, 1/16W, 1%
U102	1M Byte	Winbond	W25Q80DVUXIE	Serial Flash, 8-lead USON 2*3mm

Table below shows the pin definition of SAM W25 for DataFlash.

Table 2-6. Pin Definition of DataFlash and SAM W25

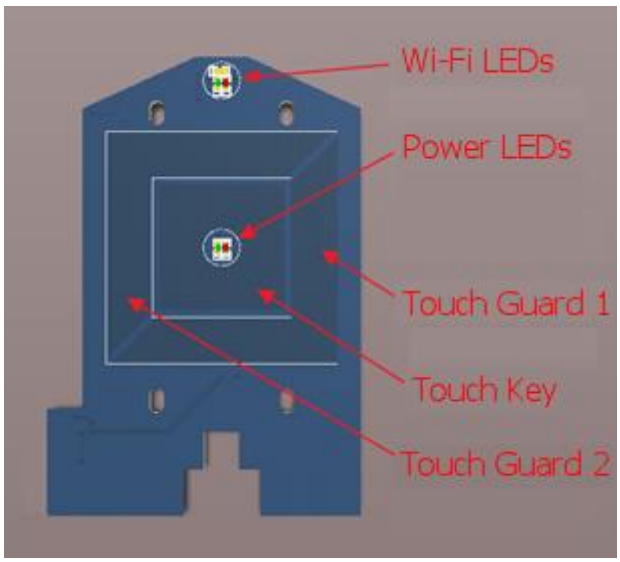
Pin name on DataFlash	Pin name on ATSAMW25	ATSAMW25 pin
FLASH_SPI_SS	PA18	11
FLASH_SPI_MISO	PA19	12
FLASH_SPI_MOSI	PA16	8
FLASH_SPI_CLK	PA17	9

3 Touch Board

3.1 Touch Board Overview

The Touch board contains the Touch sensors and the LEDs for Wi-Fi and Power.

Figure 3-1. Touch Board Overview



3.2 Touch Sensors

Touch sensors are designed based on the self-capacitor using the QTouch technology.

Except the Touch Key which handles the ON/OFF/Reset function, another two touch sensors act as the touch guard. The touch guard sensors will prevent some scenarios from spurious triggering.

Table 3-1. Pin definition of Touch Sensor and SAM W25

Pad name on touch board	Pin name on ATSAMW25	ATSAMW25 pin
Touch Key	PA06	36
Touch Guard 1	PA07	37
Touch Guard 2	PA05	35

3.3 LEDs for Wi-Fi and Power

All LEDs including the Wi-Fi and Power LEDs are driven by the ATSAMW25 GPIOs directly, Logic 1 enables the LEDs.

Note: For better output current performance, the I/O pins needs be set to high drive strength: DRVSTR = 1.

Different color LEDs are used to indicate different status of the plug.

3.3.1 Wi-Fi LED

- Yellow blink: Plug in SoftAP mode, not connected (waiting for Phone to connect)
- Yellow: Plug in SoftAP mode, connected to a phone (during this period, Phone App sends SSID/password to plug)
- Green blink: Plug in STA mode, connecting to home Access Point (AP)
- Green: Plug in STA mode, connected to home AP, connection is good
- Red: In error state

3.3.2 Power LED

- Green when ON
- Red when OFF

3.3.3 LED Pin Definition on SAM W25

Table 3-2. Pin Definition of LEDs and SAM W25

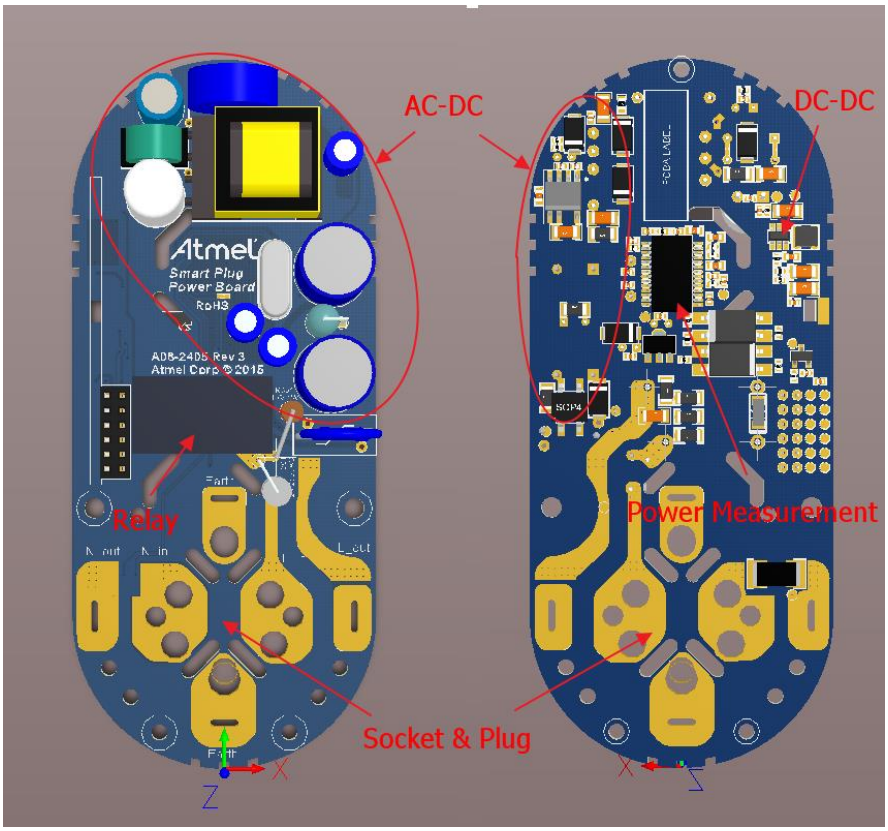
LED name on touch board	Active logic	Pin name on ATSAMW25	ATSAMW25 pin
Wi-Fi Yellow	1	PA23	16
Wi-Fi Green	1	PA22	15
Wi-Fi Red	1	PA21	14
Power Green	1	PB03	28
Power Red	1	PB02	27

4 Power Board

4.1 Power Board Overview

The Power Board contains an AC-DC converter, a DC-DC converter, the power measurement circuit, relay, and the plug and socket.

Figure 4-1. Power Board Overview

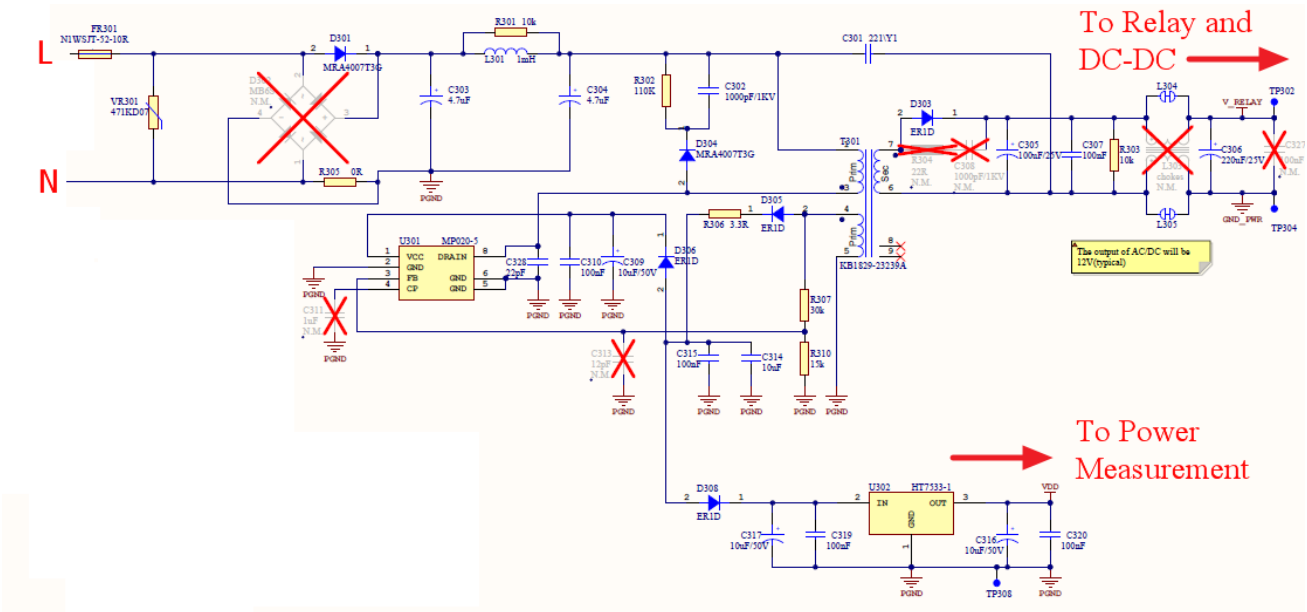


4.2 AC-DC

The AC-DC part transforms the 100V~240V AC input voltage into a 12V/120mA (typical) DC output.

The 12V DC supplies the relay and the DC-DC converter.

Figure 4-2. Schematic of AC-DC Part



The transformer T301 is a custom component with the parameters below.

Figure 4-3. Transformer Design

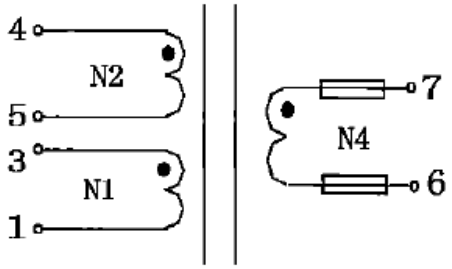


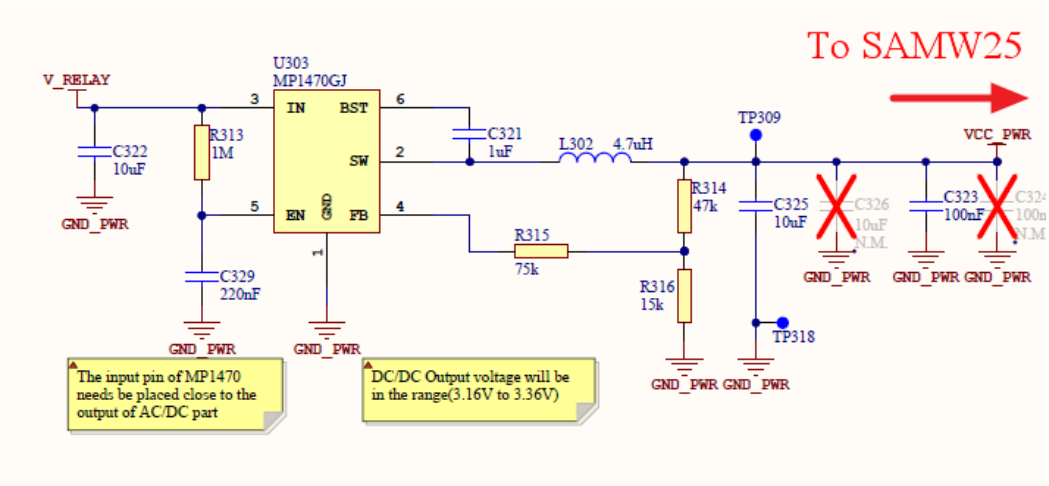
Table 4-1. Wire Definition of Transformer

Wire	Type	Start to end	Turns	Tape
N1	2UEW Φ 0.15x1P	3-1	70Ts	1Ts
N2	2UEW Φ 0.15x1P	4-5	23Ts	2Ts
N4	TRWB Φ 0.35x1P	7-6	24Ts	3Ts

4.3 DC-DC

The DC-DC converter converts the DC voltage level from 12V to 3.3V for the SAM W25 module. The MP1470 is a typical buck DC-DC converter, with the output range set to 3.16V to 3.36V.

Figure 4-4. Schematic of DC-DC Part

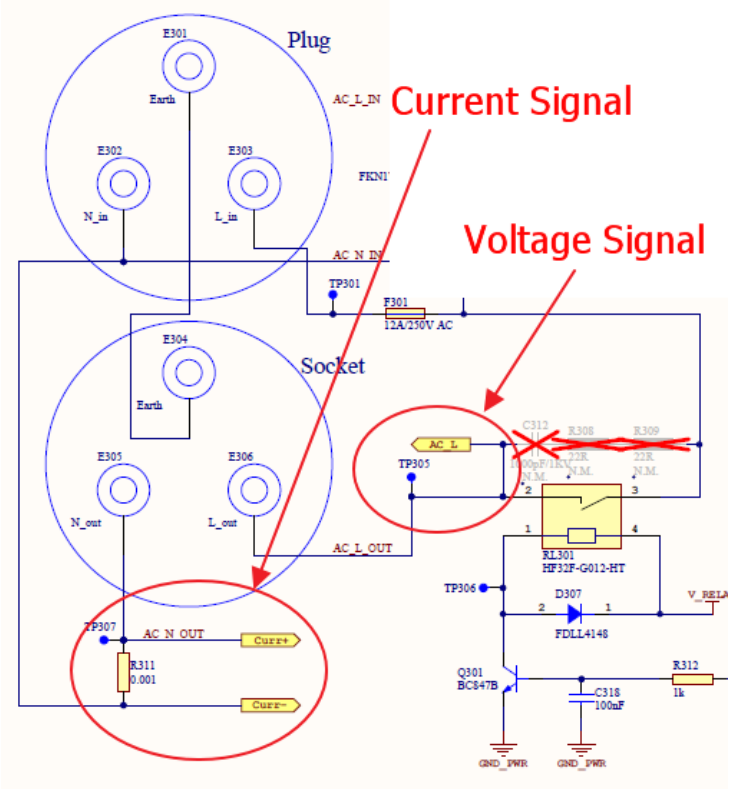


4.4 Power Measurement

The ATM90E26 works as the power measurement device to get the actual output power.

There are two signals sampled by ATM90E26, one is the voltage which comes from the L line, another is the differential voltage based on the current in sense resistor R311.

Figure 4-5. Sampled Signal of Power Measurement



The power measurement device will calculate and output the sampled voltage, current, and power to SAM W25 through the UART port. Considering the different power supply system, 2 optocouplers are used to isolate the SAM W25 and M90E26.

Figure 4-6. Schematic of Power Measurement

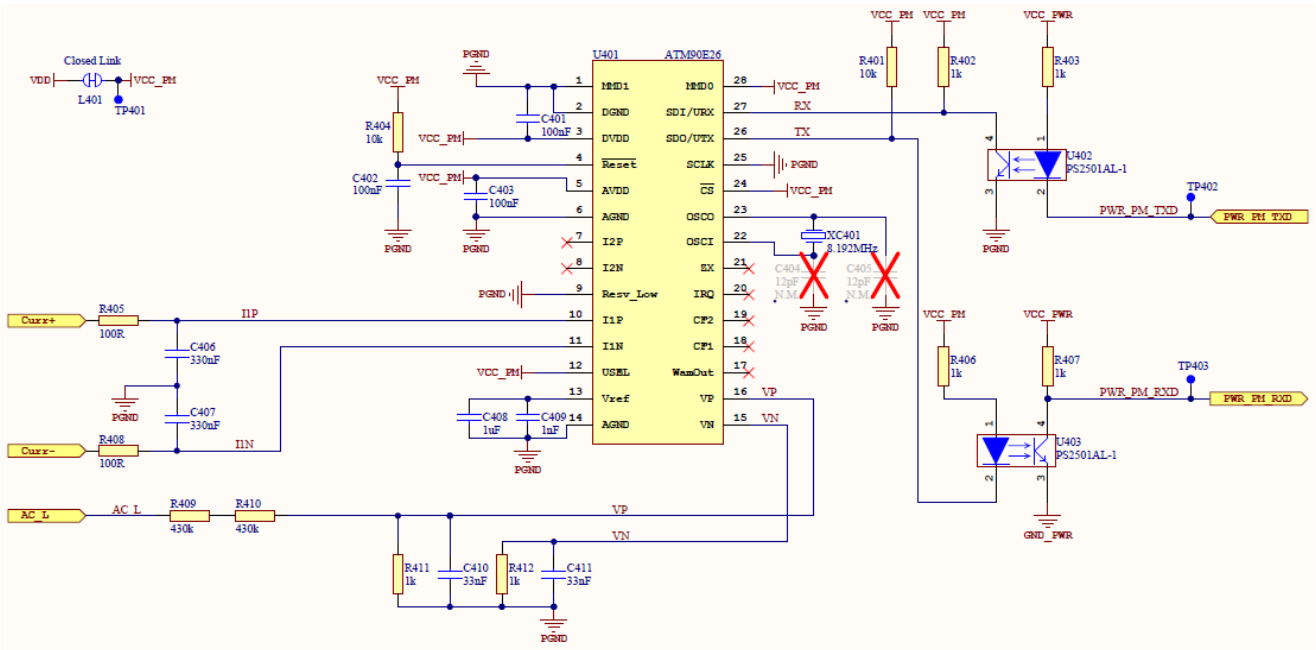


Table 4-2. Pin Definition of Power Measurement and SAM W25

Pin Name for Uart	Pin name on ATSAMW25	ATSAMW25 pin
PWR_PM_TXD	PA10	40
PWR_PM_RXD	PA11	41

4.5 Power Measurement Calibration

Before using the ATM90E26 in user application, some parameters need be calculated, such as GL, Ugain, Igain, and PL_Contant.

- MC: Pulse constant of the energy meter, unit is imp/kWh or imp/kvarh; Assume MC = 10000
- Un: Reference voltage, unit is V; Assume Un = 220V
- Ib: Basic current, unit is A; Assume Ib = 1A
- GL: L line current circuit gain
- VL: Sampling voltage of the L line circuit at Ib, unit is mV
- VU: Sampling voltage of the voltage circuit at Un, unit is mV

4.5.1 Calculation of the GL

With the shunt resistor = 1mΩ, Max. current I = 10A.

When, GL = 24

VLsample = 1mΩ * 10A * 24 = 240mV

4.5.2 Calculation of the Ugain

The default Ugain is based on the condition below:

Ugain = 26400 (6720H), Voltage divider coefficient = 880,

Assume Un = 220V, VL = 220 / (880 + 1)

Considering the voltage divider resistors used in smart plug, Voltage divider coefficient = (430 + 430) = 860

So, Ugain = 26400 * (220 / (860 + 1)) / (220 / (880 + 1)) = 27013 (6985H)

4.5.3 Calculation of the Igain

From AN 46102,

R = 200μΩ, I = 5A, Lgain = 24 <=> Igain = 31251 (7A13H) by default

In SmartPlug solution,

R = 1mΩ, I = 2A, Lgain = 24 <=> Igain = 31251 * (1000 * 2A * 24) / (200 * 10A * 24) = 62502 (F426H)

4.5.4 Calculation of the PL_Constant

PL_Constant = int (838860800 * GL * VL * Vu / MC * Un * Ib)

= 838860800 * 24 * 1 * (220 / (860 + 1)) / 10000 * 220 * 1 = 2338287(23ADEFH)

4.6 The Relay

The relay is cascaded in the AC input and output. So, the Relay can direct control the ON/OFF of the AC output.

The rated current of the relay is 10A, this means the output power is limited to Max 2200W (@ 220V AC).

Note: Some electronic devices may generate a surge current far larger than the rated current; damaging the relay by welding the contact shut. When this happens the output will be always ON and the kit will be out of control. If this happens you must cut the input voltage manually immediately. From testing it has been observed that a surge current of less than 50A can make the contactor adhere.

Figure 4-7. Schematic of Relay Control

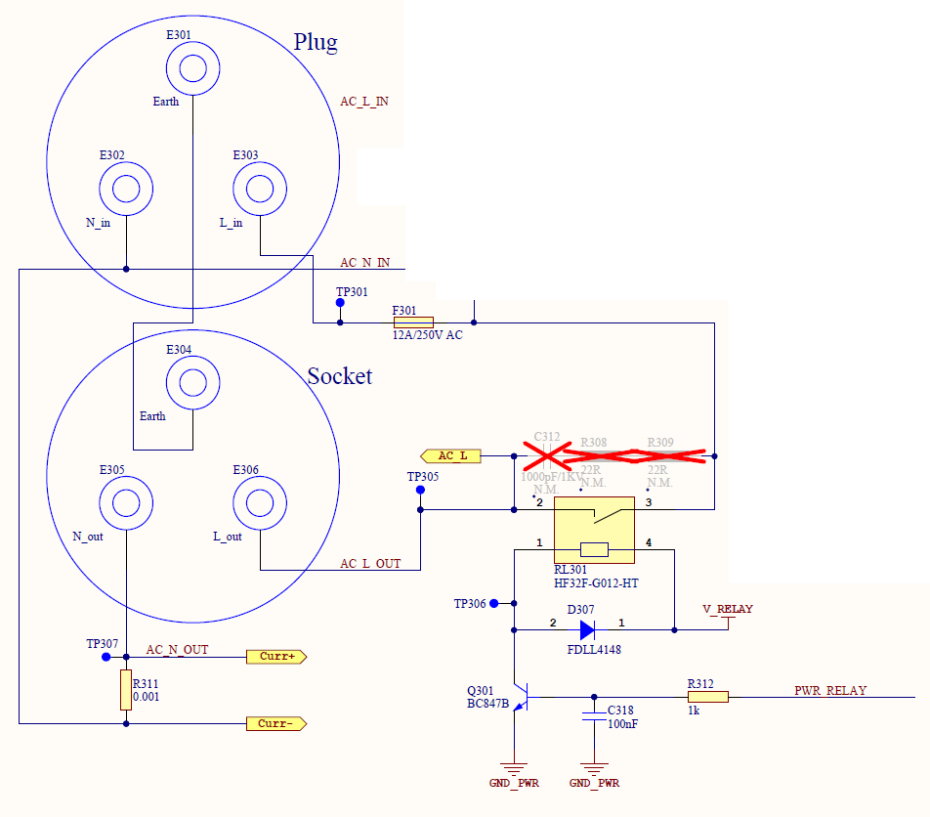


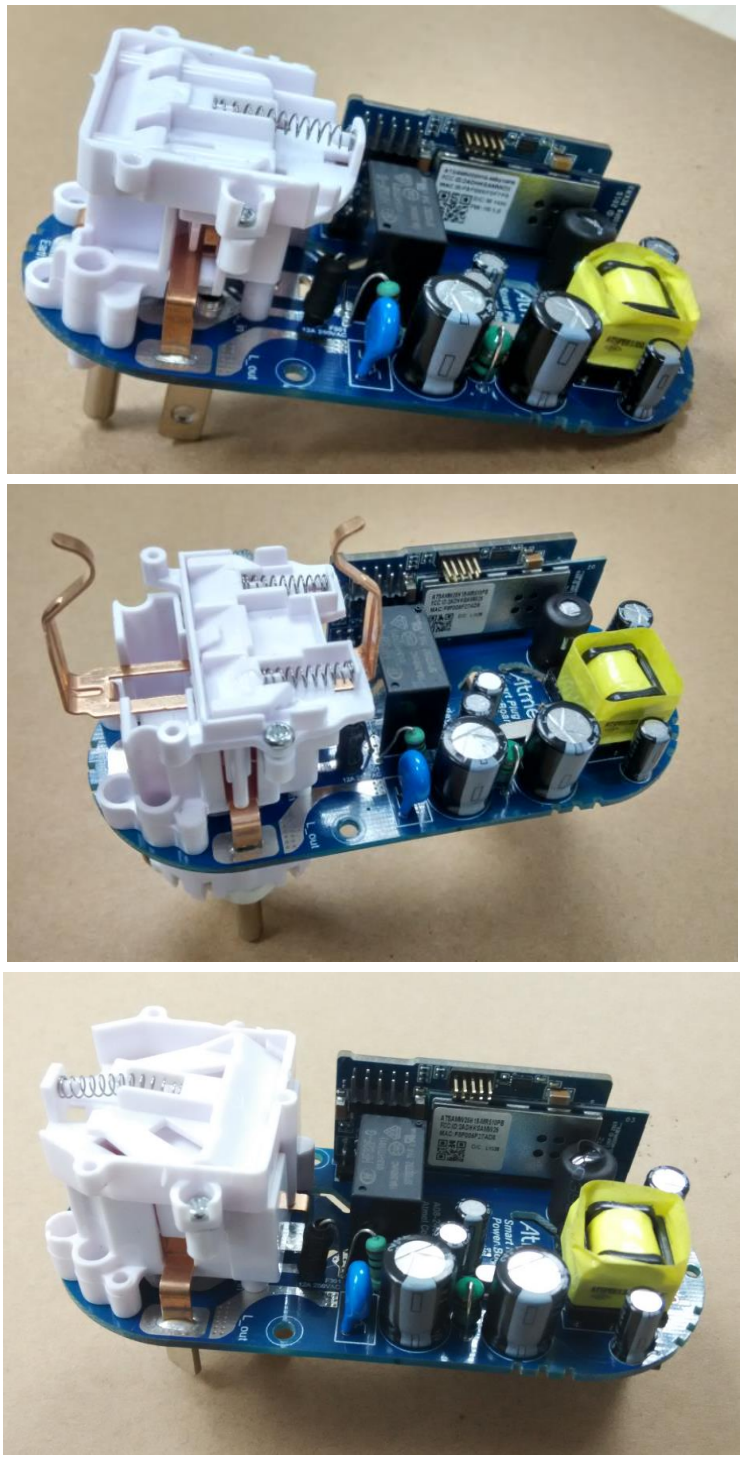
Table 4-3. Pin Definition of Relay

Relay Contorl Name	Active Logic	Pin name on ATSAMW25	ATSAMW25 pin
PWR_RELAY	1	PB22	22

4.7 Plug and Socket

There are three types of the Plug and Socket: US, EU, and CN. They share the same PCB.

Figure 4-8. US, EU, and CN standard of Plug and Socket



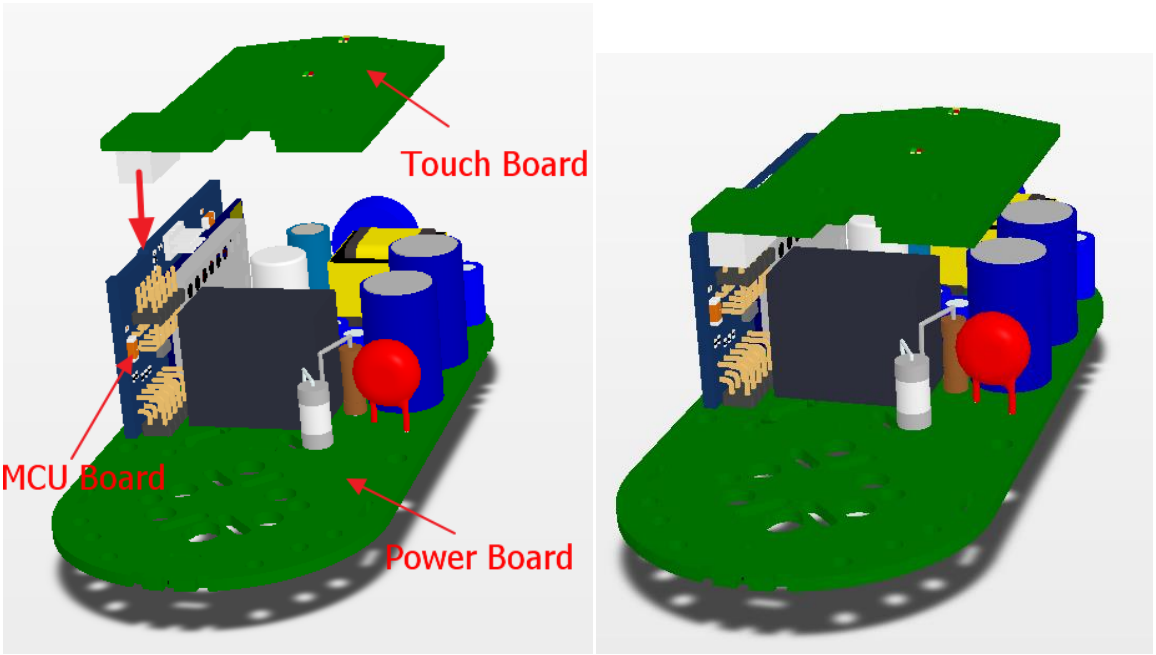
5 PCB Assembly

5.1 PCB Stack Structure

The touch board is assembled in the front case of the kit, and the power board together with the MCU board is fixed in the rear case.

When the front and rear case are closed, make sure the touch board connector is aligned with the MCU board pin header.

Figure 5-1. PCB Stack Structure Overview



6 Reprogram the Kit

6.1 Open the Kit

If the user needs to reprogram the kit with custom code, the kit needs be opened first.

Figure 6-1. Remove the Silica Gel and Screws

Figure 6-2. Open the Kit

6.2 Power Supply

There are two methods to power the Kit while reprogramming: Onboard AC power and external DC power.

6.2.1 Onboard AC Power

At first, connect the programming tools and Kit with the 10-pin SWD connector.

Then, plug the Kit into the AC socket and the kit will be powered by the onboard power supply.

After programming, the user needs to remove the kit from the AC socket first and then disconnect the programmer/debugger from the SWD header.

Note: The user needs be very carefully during operation and avoid touching any of the components since they are not isolated and can easily lead to an electrical shock.

Figure 6-3. Kit Powered by the Onboard AC Input

6.2.2 External DC power

As described in the MCU board chapter, the kit can also be powered by an external 3.3VDC supply.

Before connecting the 3.3VC, the user needs to make sure the kit is not connected to the AC input.

Connect the 3.3V power supply on pin1 and pin2 of Touch header and make sure the polarity is correct.

Note: It is recommended to use the external DC to power the board while reprogramming since it is far safer than the AC power.

Figure 6-4. Kit Powered by the External DC Input

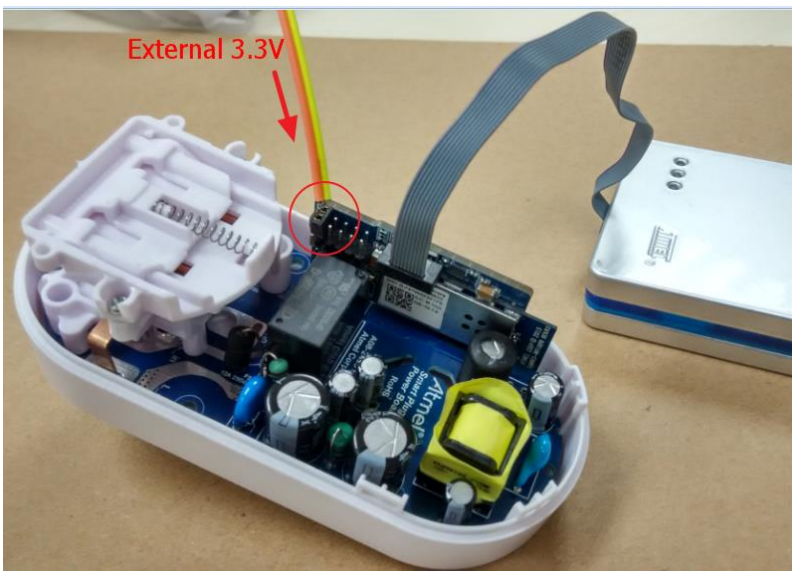
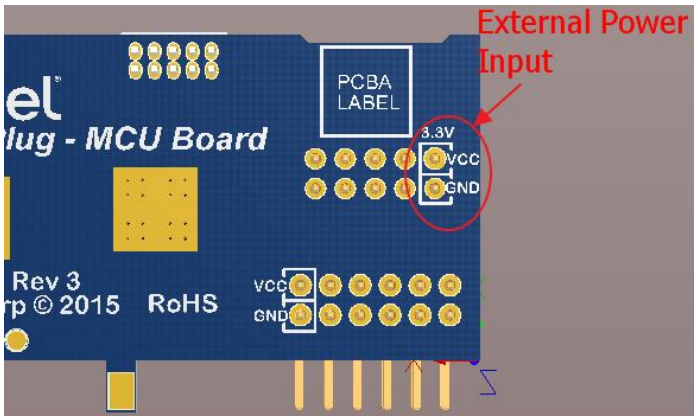


Figure 6-5. External Power Input



Note: The Power Pins in on the touch header is connected in parallel with the power supply (3.3V) on the power board. Never connect an external power supply while the onboard power is available.

6.3 Programming Tools

The smart plug uses the SWD as the programming and debug\interface, it supports all tools which supports the SWD interface. Some tools support a direct connection with the 1.27mm pitch, 10-pin socket. Figures below show the connection example of programming tools.

Figure 6-6. Atmel-ICE Connection

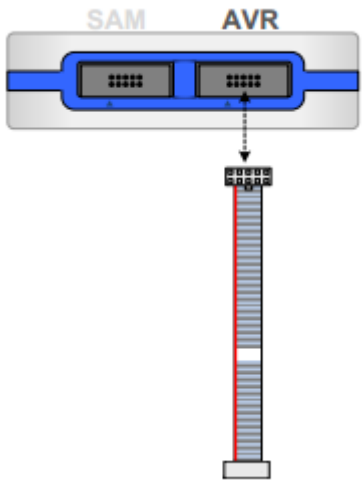


Figure 6-7. JTAGICE3 Connection

For other programming tools which do not have the 1.27mm pitch, 10-pin socket, the user needs to connect the SWD lines manually.

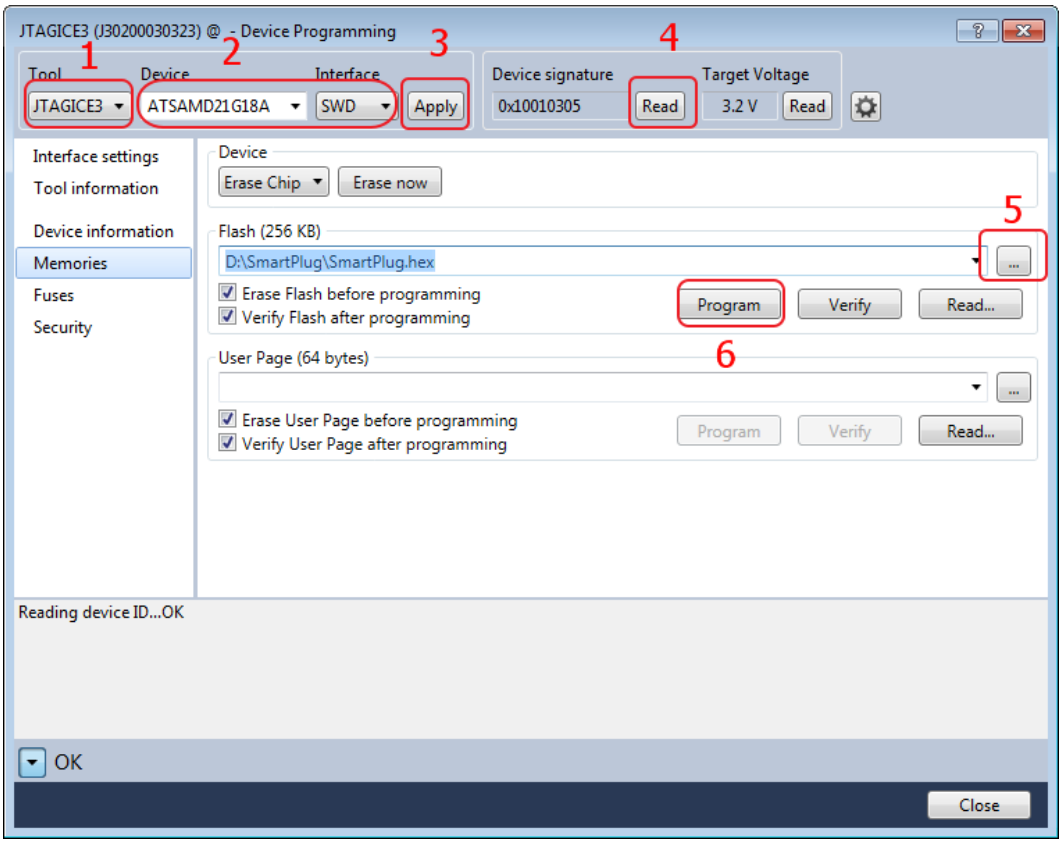
6.4 Programming

Connect the kit to a PC with Atmel Studio installed.

Click Tools → Device Programming to open the programming dialog. Then, program the kit as show below.

Note: The Device selector must be set to ATSAMD21G18A.

Figure 6-8. Reprogramming Flow by Atmel Studio



Programming steps:

1. Select the programming tool.
2. Choose device (must be ATSAMD21G18A) and select the interface (must be SWD).
3. Apply the setting.
4. To ensure the correct connection, press ‘Read’ to get the device signature and target voltage.
5. Browse to the folder where the code located, and select it.
6. Program the device. The status can be displayed in the information frame below.

7 Revision History

Doc Rev.	Date	Comments
42689A	03/2016	Initial document release.

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