Doodle Labs Smart Radio Integration Guide

Quick-Start Guide (Bench Testing)

Embedded -2H

Embedded -2J

External

This section includes a basic hardware setup, a quick peek at the software GUI, and an overview of the basic network setup. When satisfied with the results, please consult the hardware integration section for suggestions on how to integrate the Smart Radio with your system.

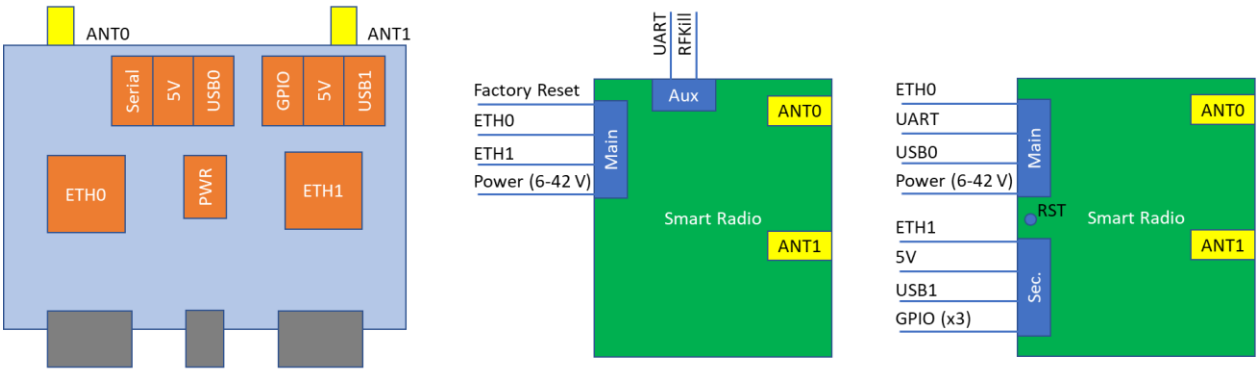
The Smart Radio is available in two forms, an embedded version (-M) which is designed to be embedded into an end-product such as a router or a robot, and an external version (-E) which is designed to be used stand-alone.

The Smart Radio evaluation kit contains an Ethernet connector board, two low-gain frequency-tuned antennas, and all cables. This will allow quick bench testing of performance using a pair of laptops and off-the-shelf power supplies.

For more details and datasheets, please visit: https://www.doodlelabs.com/smart-radio

Setup Information

A diagram of the Smart Radio's hardware interfaces is shown below. For initial testing, you need only a power source, one Ethernet port, and the two antennas.

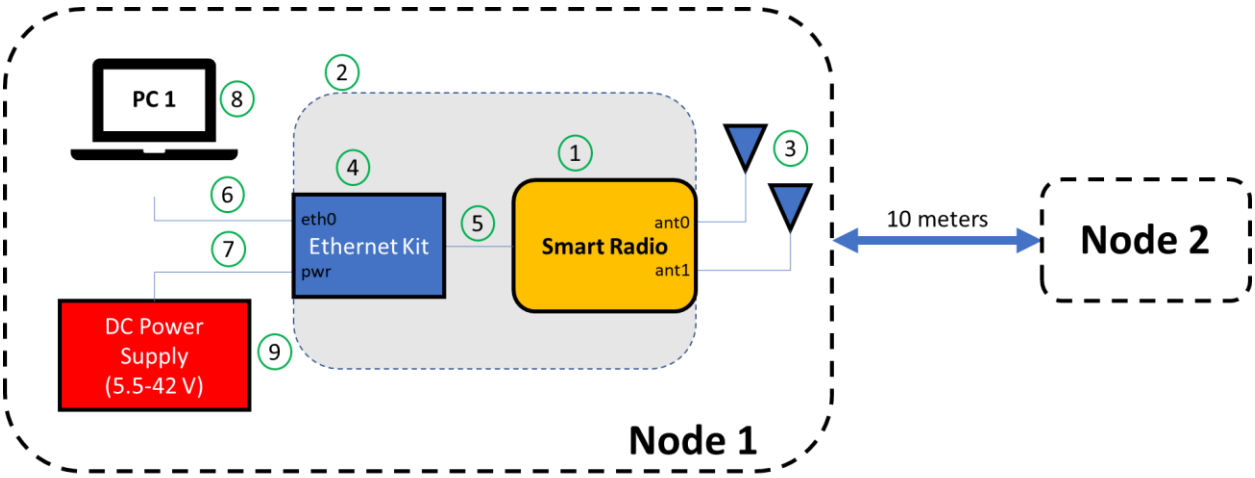


External **Embedded (v2)** **Embedded (v3)**

The diagram below shows a setup for quick evaluation of the Smart Radio. Ideally, the two PCs should be running Linux (our testing was done with Ubuntu 18.04.1 LTS). The setup for Nodes 1 and 2 is the same. The nodes should be physically separated as far as possible (minimum 10m distance is suggested to avoid oversaturating the Rx front-end).

In the Smart Radio's default configuration,

- ETH1 is setup with a static IP address and is designed to be a configuration port.
- ETH0 is bridged to the mesh network and is meant to be the data interface.
    - It has a pre-defined static IP address equal to `10.223.x.y` where `x.y` is the last four hexadecimal digits of the wireless MAC address. For example, a unit shipped with MAC address `00301A4E7AB0` has the last four HEX digits `7AB0` and `x.y` is equal to `122.176`.
    - It also acts as a DHCP client, and can accept a second IP address from a DHCP server.



1. Smart Radio (embedded version)
2. Smart Radio (external version)
3. Antennas
4. Ethernet test kit (embedded version only)
5. 12-wire Main Cable (embedded version only)
6. Cat 5 (or higher) Ethernet cable
7. Power cable with 2.5mm Jack
8. Host PC
9. DC Power Supply (5.5 – 42 V)

Note that in the diagram, PC1 is connected to ETH0 of the Ethernet test kit. ETH1 can be left alone for now.

PC1 and PC2 should be configured with static IP addresses on the 10.223.0.0/16 subnet. For example. PC1 can be 10.223.100.50 and PC2 can be 10.223.0.150.

At this point, a connection should already be established between PC1 and PC2. You can check the connection by pinging PC2 from PC1. In Linux, open a terminal at PC1 and type:

```
ping 10.223.0.150
```

If everything is set up properly, you will receive a response from PC2. In order to check that a good connection is established, you can use iperf3 to measure the network throughput. On PC2, type:

```
iperf3 -s
```

On PC1, type:

```
iperf3 -c 10.223.0.150 -t 10 -i 1
```

A table will be generated with throughput results. There are plenty of good tutorials on iperf usage on the internet (e.g. https://openmaniak.com/iperf.php), however we recommend using iperf3 over iperf.

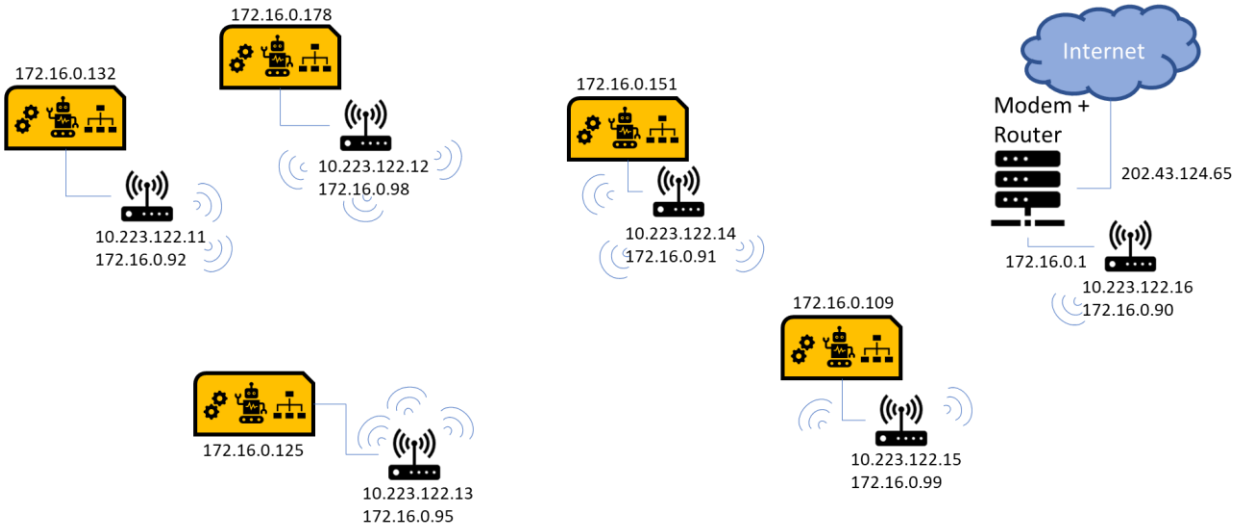
Bench Testing Results

The table below shows indicative results to expect during over the air bench testing. In order to maximize throughput, the received signal strength should be within the radio's sweet spot of **-40 dBm** to **-70 dBm**.

2x2 MIMO Radio	Max TCP/IP and UDP Throughput (Mbps)							
channel size (MHz)	MCS8 BPSK	MCS9 QPSK	MCS10 QPSK	MSC11 16QAM	MCS12 16QAM	MCS13 64QAM	MCS14 64QAM	MCS15 64QAM
3	1.31	2.61	3.84	4.93	7.36	9.41	10.3	10.1
5	2.42	4.85	6.86	9.33	12.9	16.4	19.7	21.2
10	4.84	9.6	14.1	16.1	21.9	31.7	30.6	33.6
20	9.2	18.1	26.5	33.8	47.7	63.3	66.2	71.8

Default Network Topology

By default, the Smart Radio is configured to connect to a mesh network as shown in the diagram below. There are two Ethernet ports on the radio; ETH0 is configured as DHCP client and has an addition static IP address (10.223.0.0/16), and ETH1 has a static IP address equal to 192.168.1.1. ETH0 is bridged to the mesh network, and ETH1 is meant to be used as a configuration port. **ETH1 is not bridged to the mesh network.**

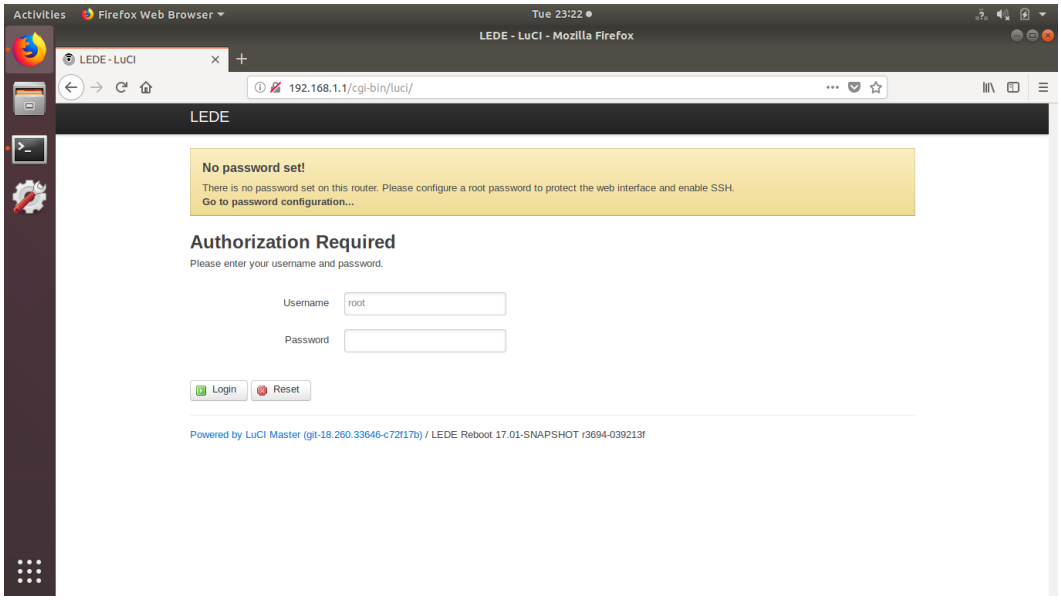


In this configuration, a Router is connected to one of the Smart Radios at ETH0, which acts as an Internet Gateway for the mesh. The Router runs a DHCP server which provides IP addresses to all of the host devices in the mesh. In the absence of the Gateway Router, the user will need to manually enable the embedded DHCP server in one of the Smart Radios or assign static IP addresses to all hosts in the network in the 10.223.0.0/16 subnet.

Logging in to the smart radio

To be able to configure a Smart Radio, you will need to be able to login to the Smart Radio.

1. Ensure that the PC is on the same subnet as the Smart Radio as discussed above.
    a. If you are using ETH1, use the 192.168.1.0/24 subnet
    b. If you are using ETH0, use the 10.223.0.0/16 subnet, or the subnet used by your router's DHCP server.
2. Open a web browser and navigate to the IP address of the Smart Radio.
    a. The first time you login, you will be directed to a page warning you of an SSL authenticity problem. This happens because the certificate used by the Smart Radio is self-signed. It is okay to proceed.
3. By default, no password is set. Click `Login`



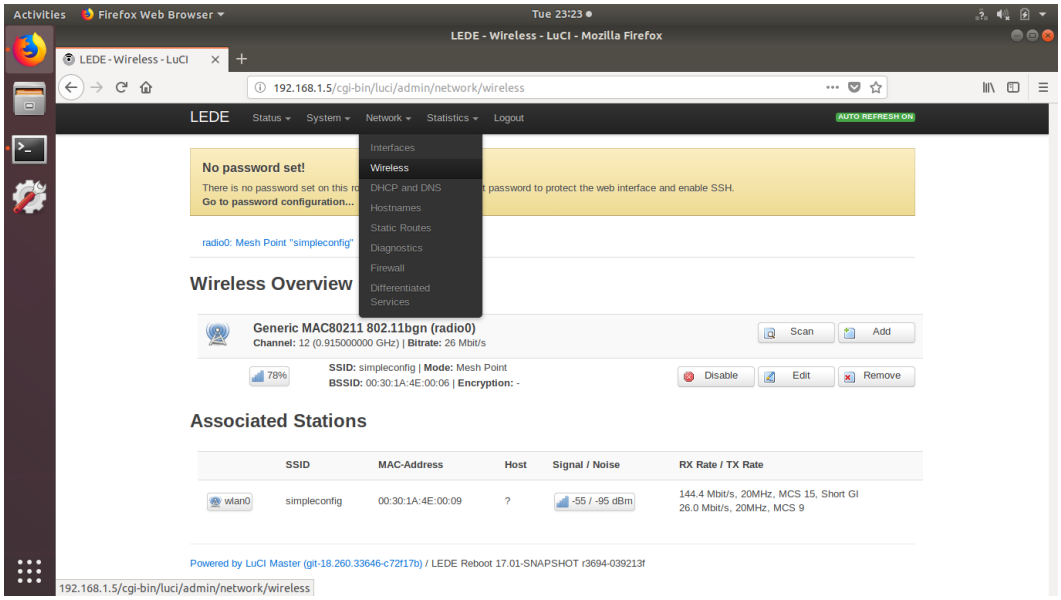
4. To modify the network interface settings, navigate to `Network → Interfaces`.

Basic Radio Configuration

In its default configuration, the Smart Radio has the following wireless configuration:

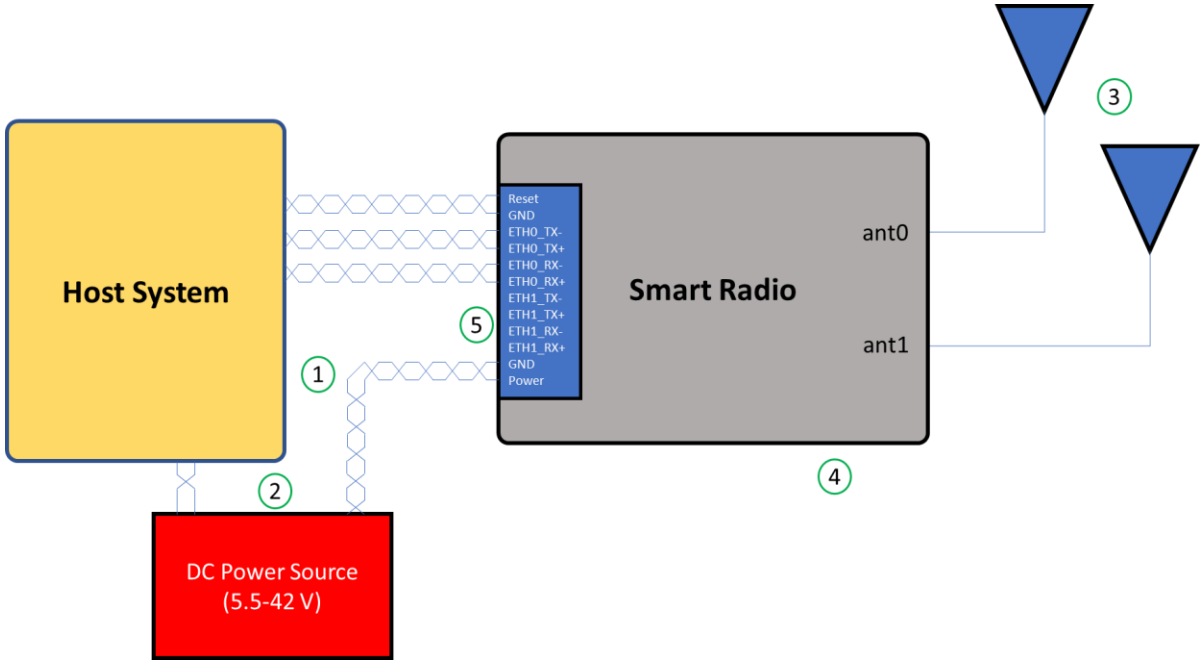
Mesh ID	simpleconfig
Channel	12
Channel Center Frequency	{Model Dependent}
Bandwidth	{Model Dependent}
Encryption	128-bit AES
AES Encryption Key	DoodleSmartRadio

In the Web GUI, navigate to the tab `Network → Wireless`. This page shows the status of the wireless network. In the wireless page you can quickly assess whether the network is setup properly as all stations connected to the Smart Radio will show up in the Associated Stations table with an indication of the signal strength. Click `Edit` to modify wireless network settings.

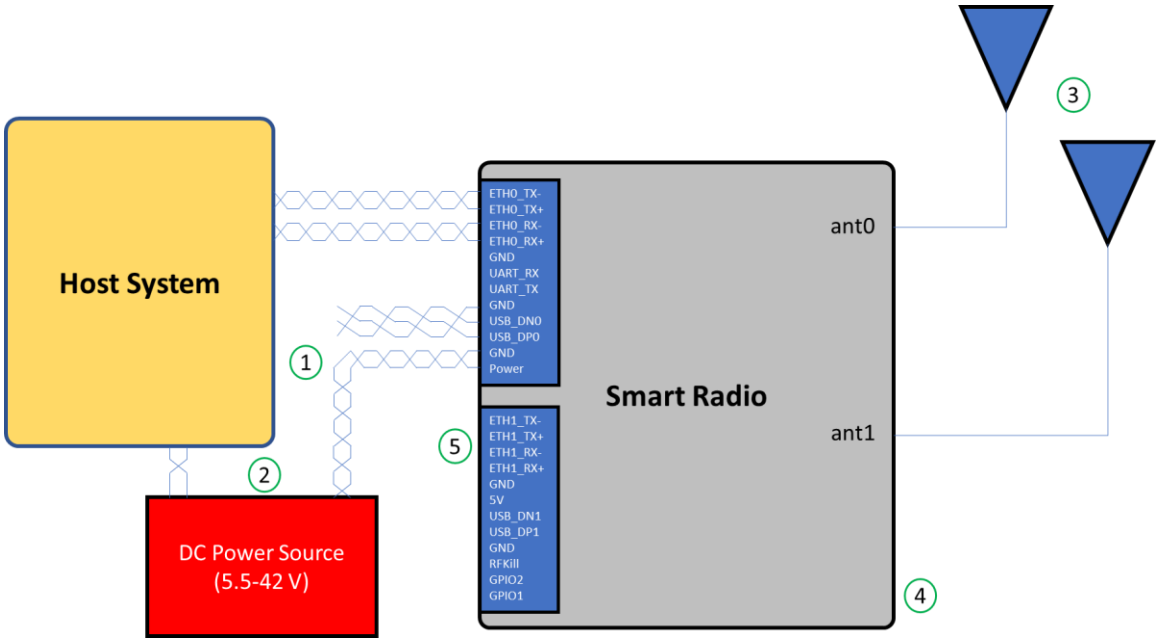


Hardware Integration

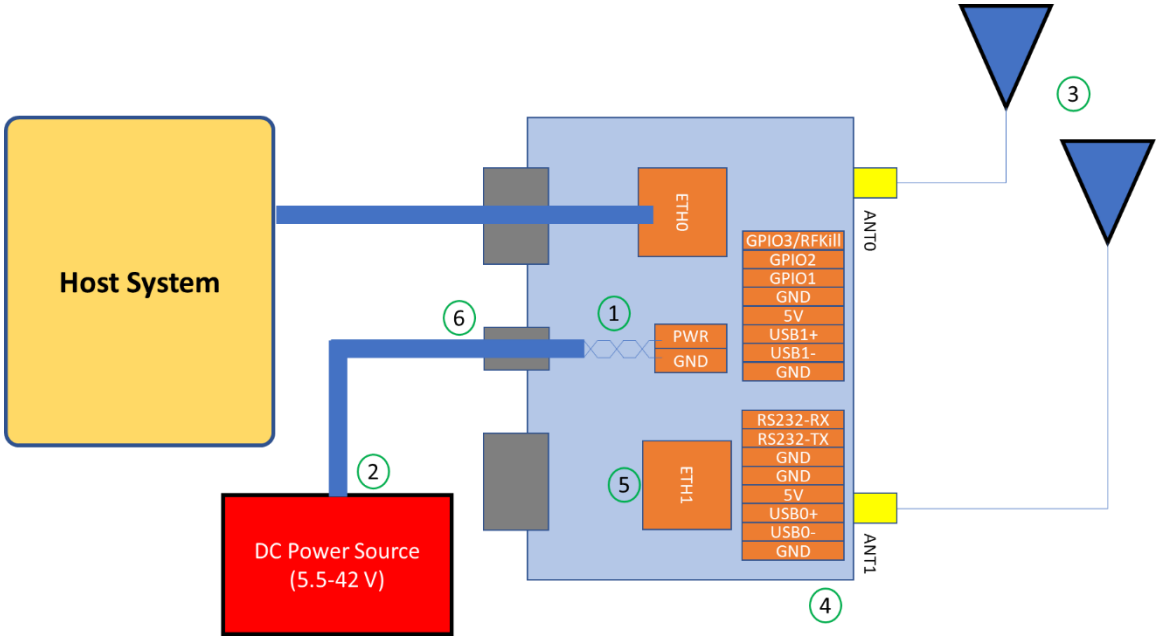
The figure below shows how the Smart Radio can be integrated with a host system, along with some recommendations.



Embedded Version (-2H)



Embedded Version (-2J)



External Version

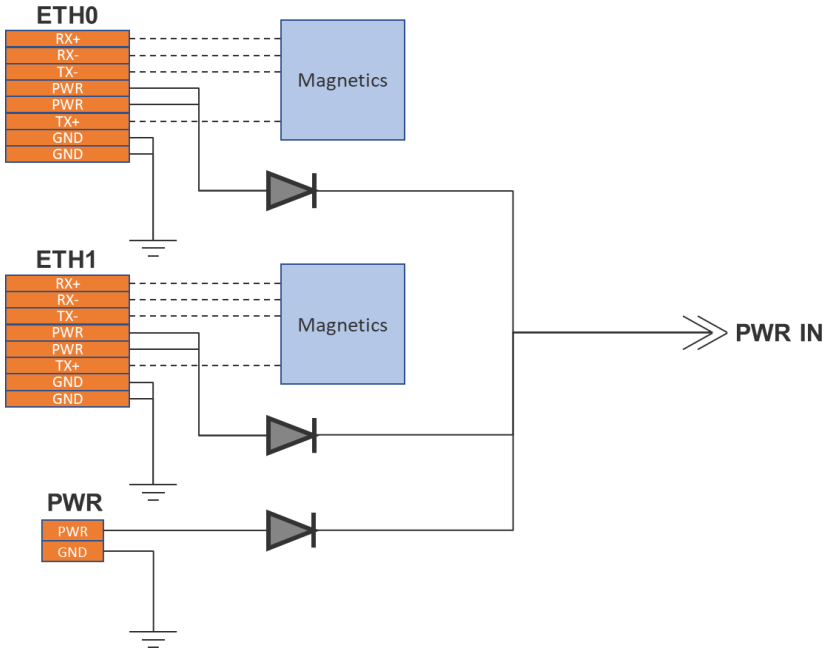
1. Cable pairs should be twisted to reduce EMI. Note that USB cables should be twisted with GND.
2. Power should be routed in a star topology; avoid unnecessary grounding loops.
3. Adjust antennas (cross polarized or both vertical) to suit the application's needs. Please read the configuration guide (Appendix D) for a discussion on long range optimization.
4. The Smart Radio should be mounted on a suitable heat sink. Consult the heat model in Appendix C
5. ETH1 is useful for configuration if the device is in gateway mode (see configuration guide)
6. Insert only a single jacketed wire harness through each cable gland

RFKill, UART, USB, GPIO

1. The RFKill pin is internally pulled down to GND with a 300-kohm resistor. Pull the RFKill pin to 3.3-V in order to quickly disable any RF transmissions.
2. The UART interface is 3.3-V TTL.
3. A single 5-V supply is provided which can provide up to 1 A of DC current (version 3 hardware only). It is recommended to twist the differential USB pair with GND and 5-V.
4. GPIOs use 0 and 3.3-V logic and can source/sink. The maximum current source/sink capability of these pins is 25 mA.

Power Over Ethernet (-2J Hardware)

Passive POE is available in the External version of the Smart Radio and in the Ethernet Test Kit. The diagram below indicates how Passive POE is implemented. The orange connectors represent the customer-facing connectors.



Additional Notes

1. The RF ports of the Smart Radio use an MMCX-female connector. The ports are terminated with 50 ohms. Any antenna with desired gain, directivity, and 50 ohm impedance will be compatible. RF ports include a protection circuit, so even in case of an open connection the Smart Radio will not be damaged.
2. During ground testing, be aware that the antenna height and Fresnel zone may play a significant role in achieving long range. Consult the Configuration Guide for more tips.
3. Because the Smart Radio modules generate a fair amount of heat, we recommend mounting them on the system casing itself for best heat dissipation. The power amplifiers are located on the top-right corner (near the RF ports, while looking down) of the radio and generate the most heat. The bottom surface of the radio provides maximum heat conduction out of the module. Please refer to Appendix C for Heat Power model. **Please note that the system thermal design should ensure that the Smart Radio skin temperature is maintained below the specified limits.**
4. During the initial design/evaluation phase, the Samples Characteristics Report may be a useful reference. It provides the important sample-specific radio characteristics. This report is always emailed with the shipping documents. Please check with your purchasing coordinator if you don't have it.
5. Refer to Appendix A for a mechanical drawing. CAD models are available upon request.
6. For ISM-band Smart Radios, the equipment label should have a note "Contains FCC ID: xxxxxxxx". Many Doodle Labs radio models have gone through regulatory certifications. This is an ongoing activity so please inquire about the specific certification status of the model # used in your project.
7. **The Smart Radio Power Supply does not include Galvanic Isolation.**

Software Configuration

OpenWRT

Doodle Labs' software is based on OpenWrt, an open source Linux operating system targeting embedded devices. It is a mature OS powering millions of wireless routers in the industry. For software developers, there are many online forums and resources to get support.

OpenWrt User Guide -

Smart Radio's Advanced Features

Doodle Labs' branch of OpenWrt (BII – Broadband for Industrial IoT) has several features which may be used to enhance range, throughput, latency, and security in specific scenarios. This section will briefly introduce the features, and more information about configuration can be found in the Configuration Guide.

Customized Bandwidths

Doodle Labs' Smart Radios can be configured with custom signal bandwidths as low as 3 MHz and up to 40 MHz depending on the frequency band and the model category. Narrow channel bandwidths can be used when low throughput and very long range is required.

AES256 Encryption and WPA3 Enhancements

Software-based AES256 Encryption can be used for applications requiring the highest security standards. The Smart Radio can be configured so that sensitive data is sent using AES256 in parallel with bulk data using AES128 encryption. This will allow for security and high throughput at the same time. Additionally, WPA3 enhancements (OWE and SAE) have been included in the Smart Radio for additional security. Note that throughput is capped at 12 Mbps when utilizing AES256 encryption.

DiffServ Configuration

Differentiated Services is a mechanism used to provide QoS in a computer network. More information can be found here. The Smart Radio includes a Differentiated Services configuration menu which allows the user to mark traffic coming from a specific IP address and/or port with a differentiated services code point (DSCP) in the IP header. Video traffic, for example, can be marked with a CS5 code point which would optimize its transmission throughput, while command and control (C&C) traffic can be marked with a CS6 code point which would prioritize latency over throughput.

Ultra-Reliable Low Latency Communication (URLLC)

URLLC is a unique feature added to the Smart Radio which allows small data packets (typically command and control data) to be sent at low latency, with ultra-high reliability. URLLC is enabled in the DiffServ menu.

Video Optimization

The Smart Radio includes protocol optimization for UDP video transmission which can be enabled in the DiffServ menu.

High Rate Multicast

Multicast-to-Unicast conversion can be configured to be performed automatically by the Smart Radio. Smart Radio provides high rate multicast throughput in cases when data is being streamed wirelessly.

Range Optimization

Timing parameters can be optimized for long range by modifying the distance setting in the advanced wireless configuration menu.

List of Known Issues and Upcoming Features

Known issues

This is a list of known issues with the Smart Radio. Some of these issues are inherent to the OpenWrt system and we are working to get them fixed.

1. In AP/Client mode, when attempting to switch to a new wireless network using the Web GUI “scan” option, it may be necessary to first remove the SSID and BSSID fields in the radio interface.
2. In AP/Client mode, when the AP changes its channel bandwidth, the Client will not automatically adjust its channel bandwidth setting.
3. When switching to reduced channel bandwidths, such as 5 MHz, new operating channels will become available depending on the regulatory domain. However, it is necessary to first save and apply the reduced channel bandwidth before switching to a new channel.
4. When switching to reduced channel bandwidths, the web GUI continues to display transmission rates based on 20-MHz bandwidth.
5. If the radio is configured with settings which do not conform to regulatory requirements, the radio interface can become locked-out. Manually re-configuring the radio interface over the command line may be necessary.

Upcoming Features

The Smart Radio operating system is undergoing continual upgrading. Here are some of the upcoming features to look forward to.

1. WPA3. Certain features of WPA3 security including SAE and OWE are in development.
2. Improved analog jamming resistance to high power signals.
3. Auto-channel selection.

Firmware Upgrade

The embedded OpenWrt can be upgraded using either the Web GUI, or the Linux console. Connect the host PC to the ETH1 port of the Smart Radio.

Console Method

1. Copy firmware from PC to the module:

   ```
   scp firmware-sysupgrade.bin root@192.168.1.1:/tmp/
   ```

2. Login to Smart Radio by ssh root@192.168.1.1

3. Use the sysupgrade command to update the firmware.

   ```
   sysupgrade -v /tmp/firmware-sysupgrade.bin
   ```

4. Wait until the update is complete. DO NOT CYCLE THE POWER SUPPLY UNTIL THE FIRMWARE HAS BEEN UPDATED!

Web GUI Method

1. Enter the following into the address bar of your browser

   ```
   192.168.1.1/cgi-bin/luci/admin/system/flashops
   ```

2. At the bottom of the page, de-select the “keep settings” button
3. In the “image” field, click browse and select your firmware image
4. Click `Flash Image`
5. After the system has verified the image, click `Proceed`

Troubleshooting

The purpose of this section is to provide basic trouble-shooting tips for first-time setup of the Smart Radio. For advanced configuration and link optimization, we suggest reading our Configuration Guide.

Radio Resetting

The radio resetting may point to an inadequate power supply or the unit may be overheating. Please ensure that the power supply can provide the current specified in your model’s datasheet. It is necessary to provide adequate thermal management of the unit to ensure maximum performance at highest RF power.

In general, we suggest upgrading to the latest version of the BII software (available on the website).

Cannot Login to the Radio

First Time Login

The Smart Radio can be accessed via either of the Ethernet ports. ETH0 is bridged to the mesh network and has a unique IP address based on the MAC address (see the configuration guide for details). If you are having trouble logging in,

1. Try and login through ETH1.
2. Make sure to set a static IP address on your PC in the 192.168.1.0/24 subnet.
3. Make sure you can “ping” the radio at 192.168.1.1.
4. Temporarily disable the firewall on your PC.
5. Check the routing table to make sure that the route to 192.168.1.1 goes through the correct interface.
   a. Normally this is not necessary and if you have to go to this step, you should probably try a different PC first.
   b. This is an advanced topic with plenty of literature online which you can refer to.

Subsequent Login Fails

If you managed to login in the past, but cannot login due to a bad configuration change, you may need to factory reset your device. During the development stage, we recommend making regular backups of your configuration.

For Hardware Version 2:

1. There is a dedicated reset pin on the main connector. The factory reset pin is internally pulled up to 3.3-V with a 10-kohm resistor.
2. Pull the Factory Reset pin to GND and hold it for between 5 and 30 seconds to reset the configuration to factory settings.
3. The Smart Radio will then reboot.

For Hardware Version 3:

1. Look for a pin hole between the main and secondary connector of the Smart Radio
2. Insert a pin into the pinhole and push the reset button for between 5 and 30 seconds.
3. The Smart Radio will then reboot.

Link Quality is Poor

First Time Setup

The first time you setup the radio, we recommend the following conditions:

1. Do not make any changes to the factory configuration.
2. Keep the two radios at least 5m apart to avoid packet loss due to receiver saturation.
3. For you first time using the radios, we recommend going to a remote location to eliminate the possibility of background noise affecting the link.

Power Supply

1. Use a power supply of 5.5-42 V which can source sufficient power as specified in your model's datasheet.
2. Make sure to use power supply cables which can carry the required current.
3. Use a star connection to avoid noise coupling from external sources.
4. Twist power supply cables for good EMI/EMC performance.

Check RSSI

You can check the RSSI from the webgui or from the command line.

1. For the web browser, navigate to `network->wireless` to see the RSSI.
2. For the CLI, SSH into the unit and type `iw wlan0 station dump`

The CLI shows RSSI for each antenna so its better if you suspect one of the antennas may not be properly connected. If the RSSI is between -40 and -70 dBm, the link speed will be optimal. If the RSSI is poor,

1. Check the Antennas are properly connected. You should feel a slight click when inserting the antenna.
2. Make sure you are not confusing reverse polarity SMA (RP-SMA) with SMA. Antennas usually use RP-SMA connectors which are not compatible with standard SMA connectors (link).

3. If you only intend to use one antenna, you must disable the second antenna port for good performance.
    a. In the latest firmware version, navigate to `network->wireless` and `EDIT` the radio interface. In the `Advanced` settings tab, select which antennas to enable.
    b. In older versions of the firmware, login to the Smart Radio using SSH and enter (you will need to do this each time the radio is reset):

```
ifconfig wlan0 down
iw phy phy0 set antenna 1 1
ifconfig wlan0 up
```

4. Make sure you understand an antenna's radiation pattern before using high gain antennas. We have provided some hints in the configuration guide, and the RSSI can be a useful debugging tool.

Check background noise

The Smart Radio has a spectrum scanner feature which is useful for searching for the best channel to use. Make sure to set the channel bandwidth to at least 10 MHz. After that, navigate to `network->wireless` and click `Spectrum Scan`. Industrial areas often have many different devices using the ISM bands (for example ZigBee, Bluetooth, Lora, and many proprietary protocols).

You can verify that background noise is an issue by testing the setup in a remote location. If background noise is an issue, have a look at our Configuration Guide (Appendix D) for suggestions.

Optimizing Video and Command and Control

Videos links and Command and Control links can be optimized using the differentiated services optimizations. Details can be found in the Configuration Guide.

Modes not working

40-MHz mode

The 40-MHz setting is a bonding of two 20-MHz channels. The additional channel is on the high-side of the selected channel, and therefore only certain channels support 40-MHz mode (2442-MHz does not support a 40-MHz channel bandwidth). For example, if the selected channel is 2422 MHz, then the radio will use the 2422 and 2442 MHz channels. The radio automatically uses both channels only when both channels are clear, so you will often see it switching to 20-MHz mode.

Automatic Channel Selection

There is currently no support for automatic channel selection, although the feature will be added in future. In AP/Client mode, the AP can make channel-switch announcements which all clients will hear and respond to. However, it is still up to the user to choose the best channel. The AP will scan the spectrum and choose the best channel only when it first comes up.

Crash Dump Logging

If the OS is suspected to be crashing, modify the `/etc/config/system` file to log crash dump persistently so that the message will be available after reboot or power cycle.

```
config   system
       option log_file '/opt/messages'
```

Please check the crash dump messages for possible causes of the crash or send it to tech-support if needed.

Connect with Tech Support

If none of the above helps, please feel free to contact us (https://www.doodlelabs.com/about-us/tech-support/tech-support-request-form/). Please describe your problem in as much detail as possible, and include photos of the setup if possible. If you are having connectivity issues between nodes, please fill out this table and include it in your email.

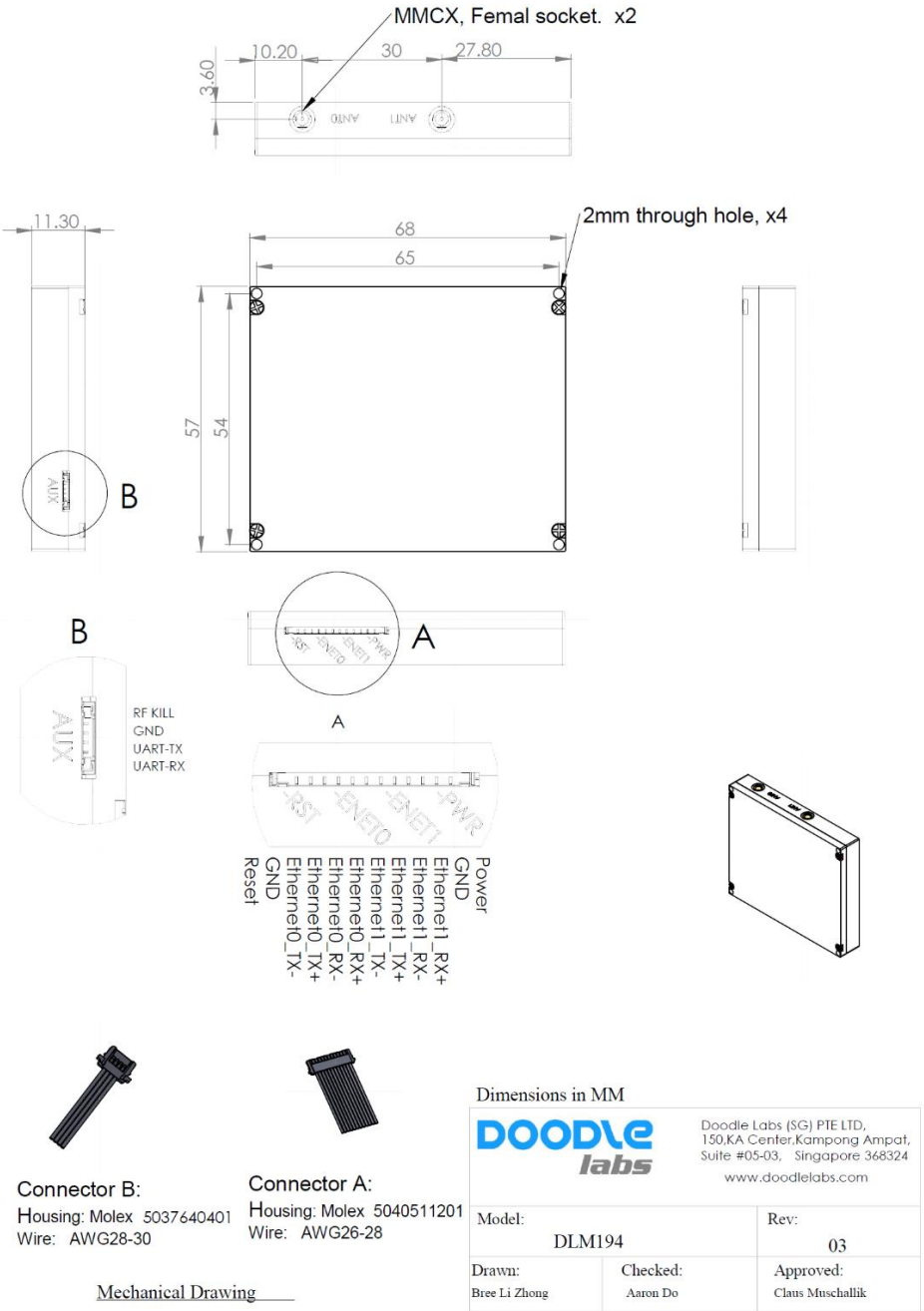
Question	Example
Model Name	RM-2450-2H-XS
Firmware version	firmware-2020-03, r4030-72047dd133
Test setup	Point-to-point, mesh, AP/Client
Type of Data	Video, Control signals, iperf, ping, multicast
Number of Antennas used	1 or 2
If one antenna, which one?	Antenna 0
Distance between nodes	100m
Height of the Antennas	3m
Number of nodes (mesh)	4

Firmware Backup

Additionally, please create a backup of your configuration and send it with your email. You can create a backup in the web GUI by navigating to `system → backup/flash firmware` and clicking `Generate Archive`.

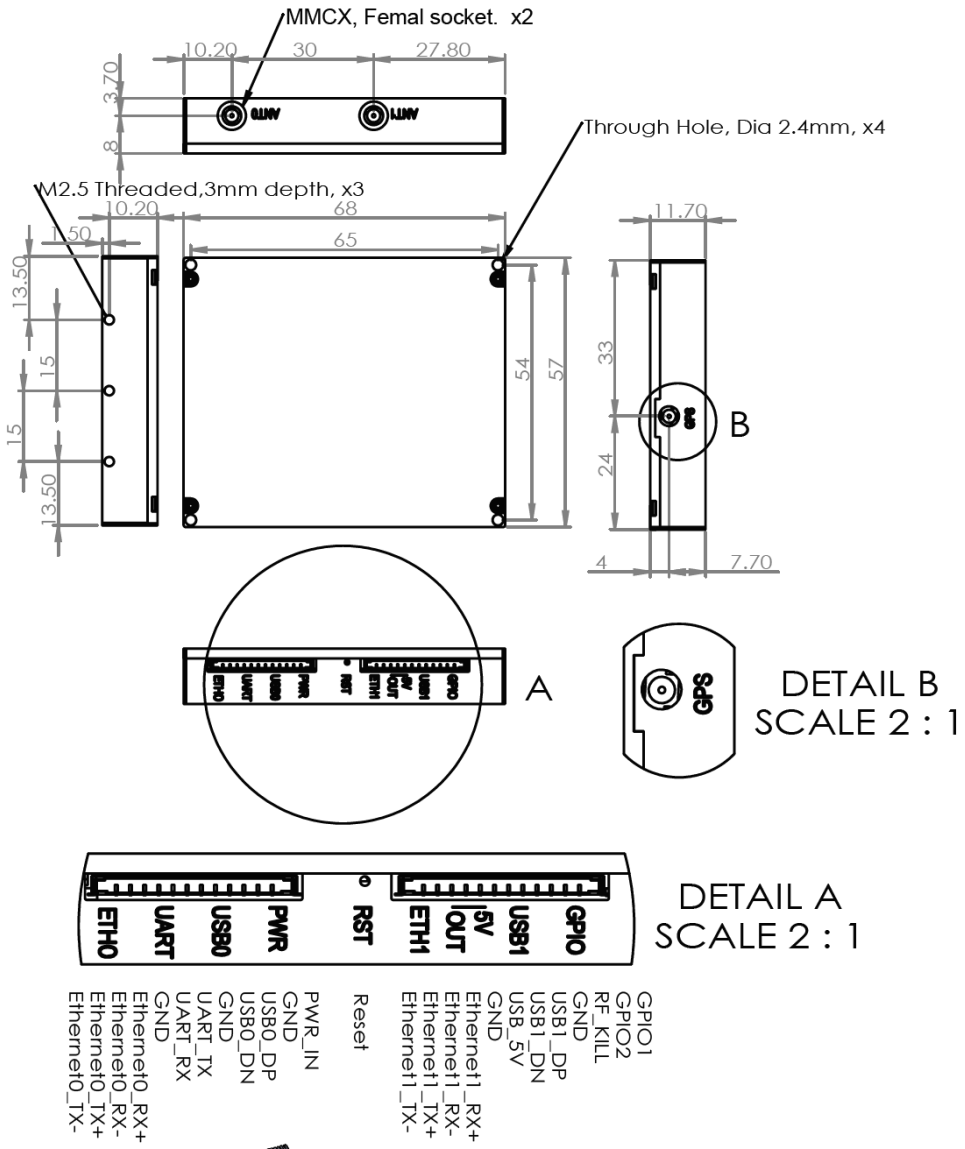
Appendix A – Mechanical Drawings

Smart Radio Embedded (-2H)



Mechanical Drawing

Smart Radio Embedded (-2J)



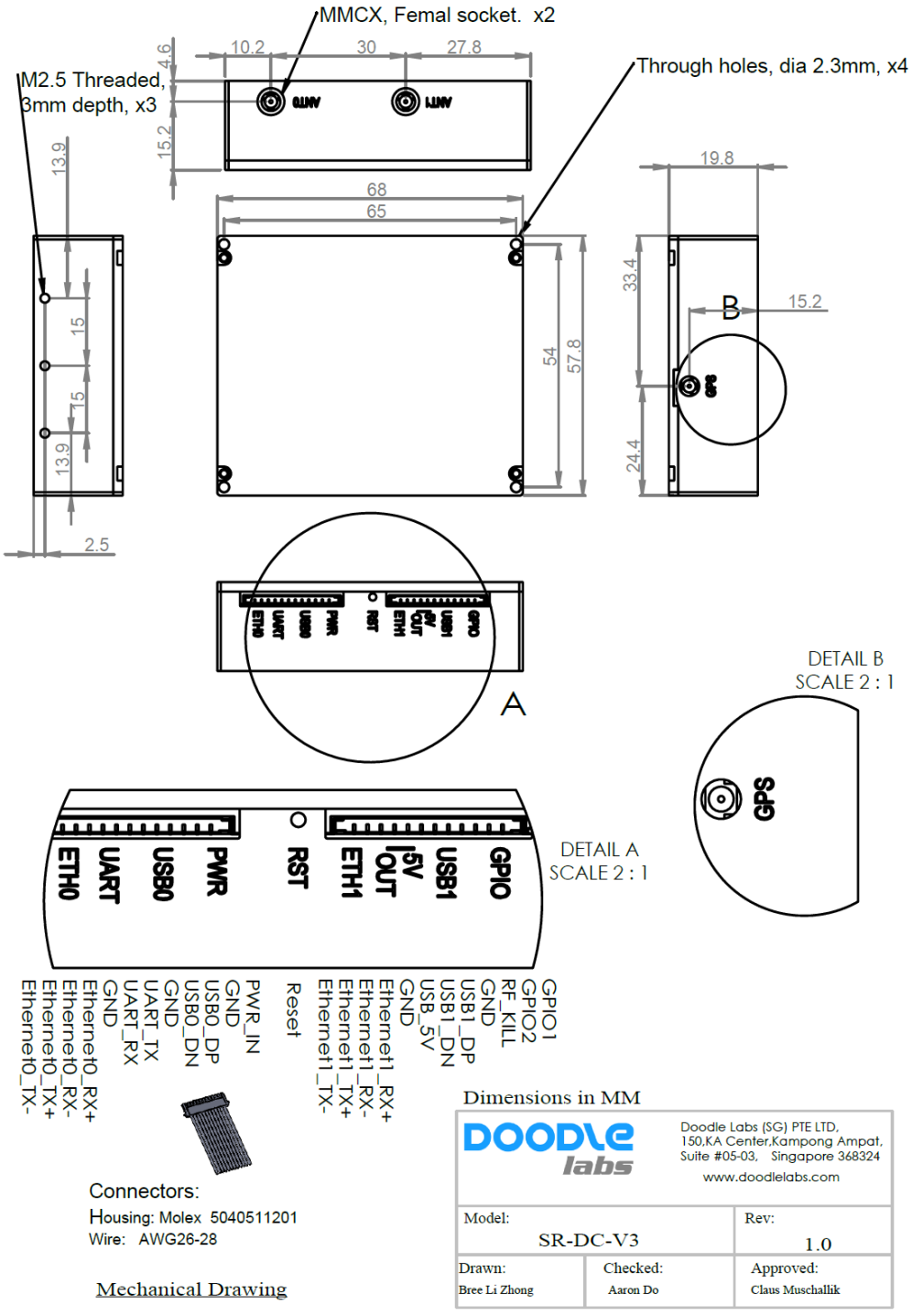
Connectors:
Housing: Molex 5040511201
Wire: AWG26-28

Mechanical Drawing

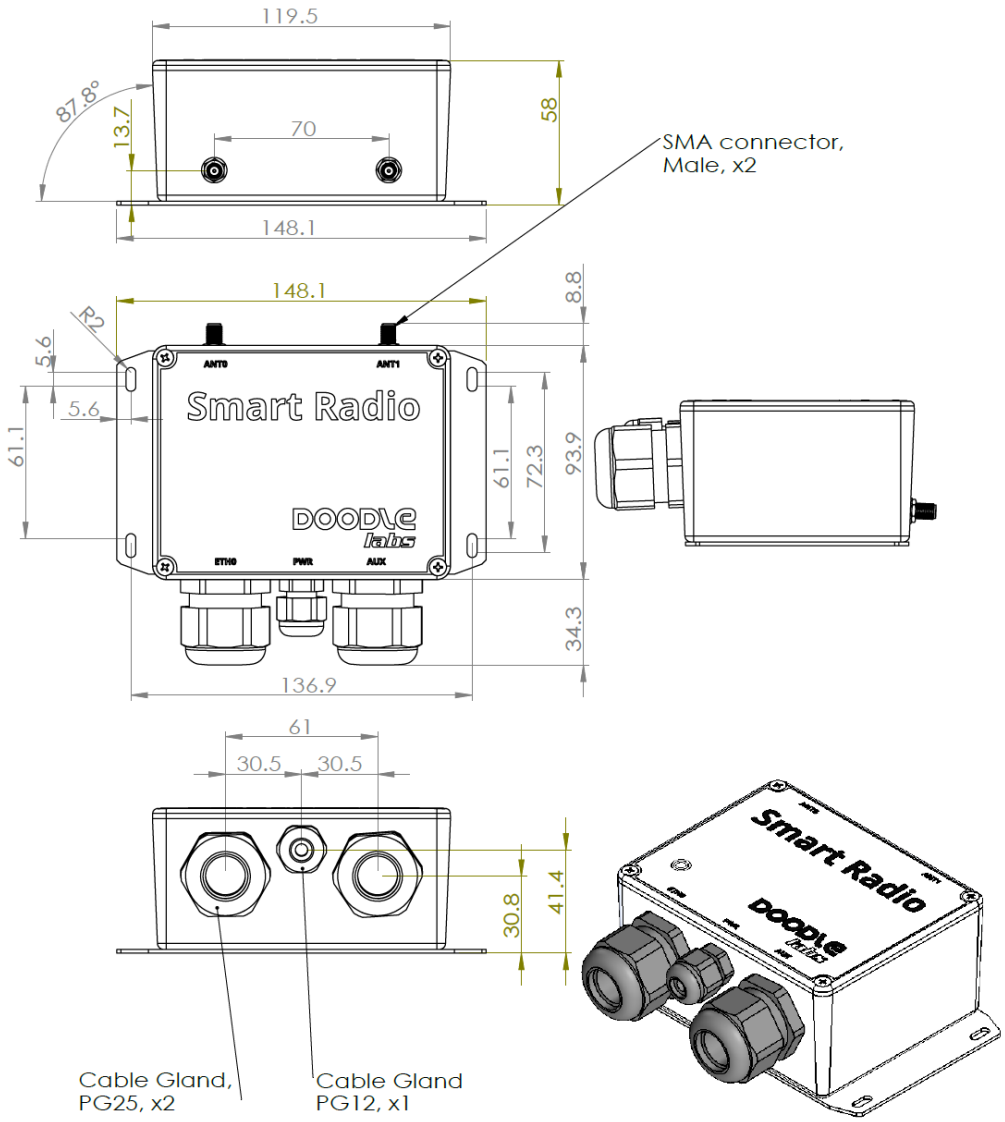
Dimensions in MM

Doodle Labs (SG) PTE LTD, 150,KA Center,Kampong Ampat, Suite #05-03, Singapore 368324 www.doodlelabs.com		
Model: SR-SC-V3		Rev: 1.0
Drawn: Bree Li Zhong	Checked: Aaron Do	Approved: Claus Muschallik

Smart Radio Embedded (RM-4700-2J ONLY)



Smart Radio External



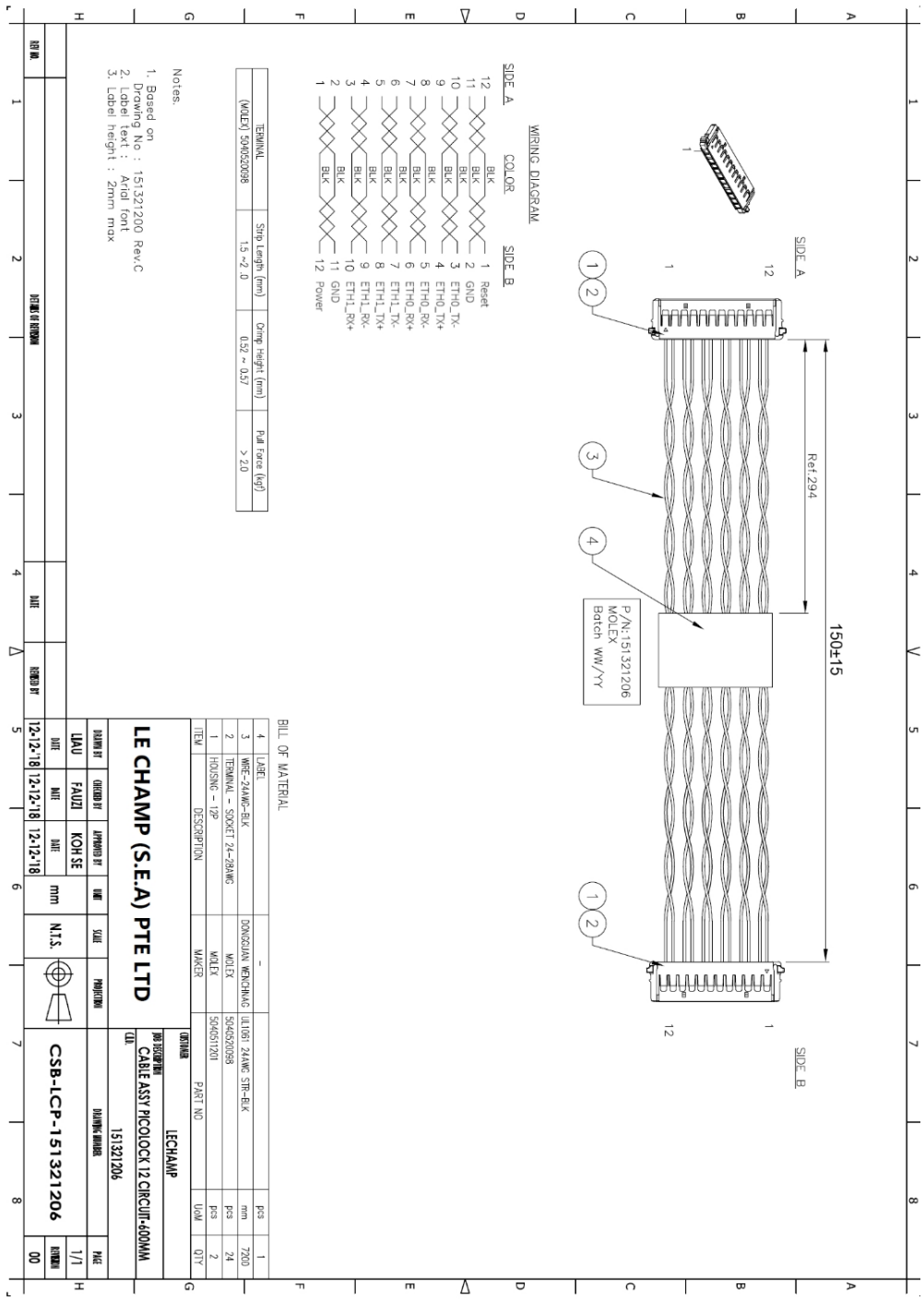
Dimensions in MM

Doodle Labs (SG) PTE LTD, 150,KA Center,Kampong Ampat, Suite #05-03, Singapore 368324 www.doodlelabs.com		
Model: DLM198		Rev: 1.0
Drawn: Bree Li Zhong	Checked: Aaron Do	Approved: Claus Muschallik

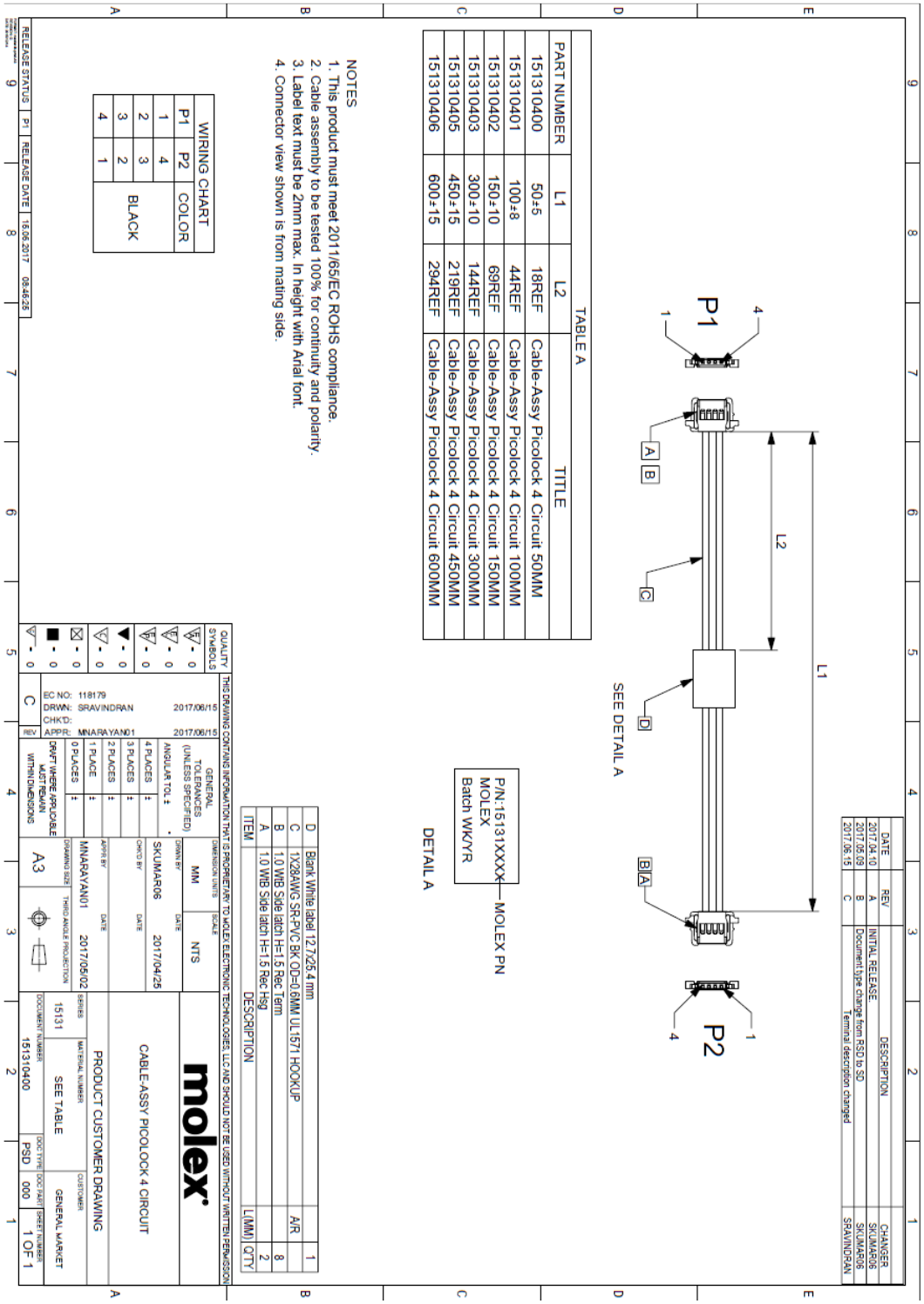
Mechanical Drawing

Appendix B – Cable Drawings (Embedded)

Primary (-2H/-2J) and Secondary (-2J only) Cable Assembly Drawing

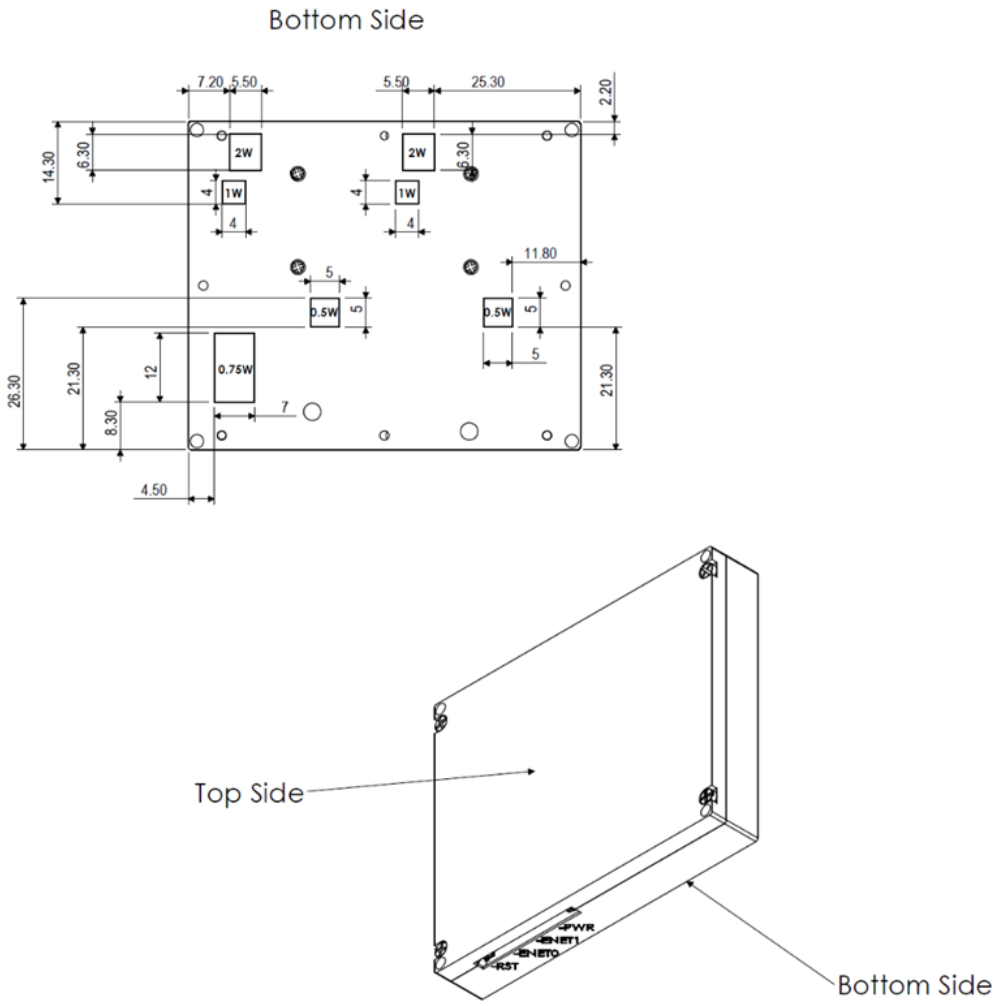


Auxiliary Cable Assembly Drawing (-2H)



Appendix C – Heat Power Models

Smart Radio Embedded (-2H)

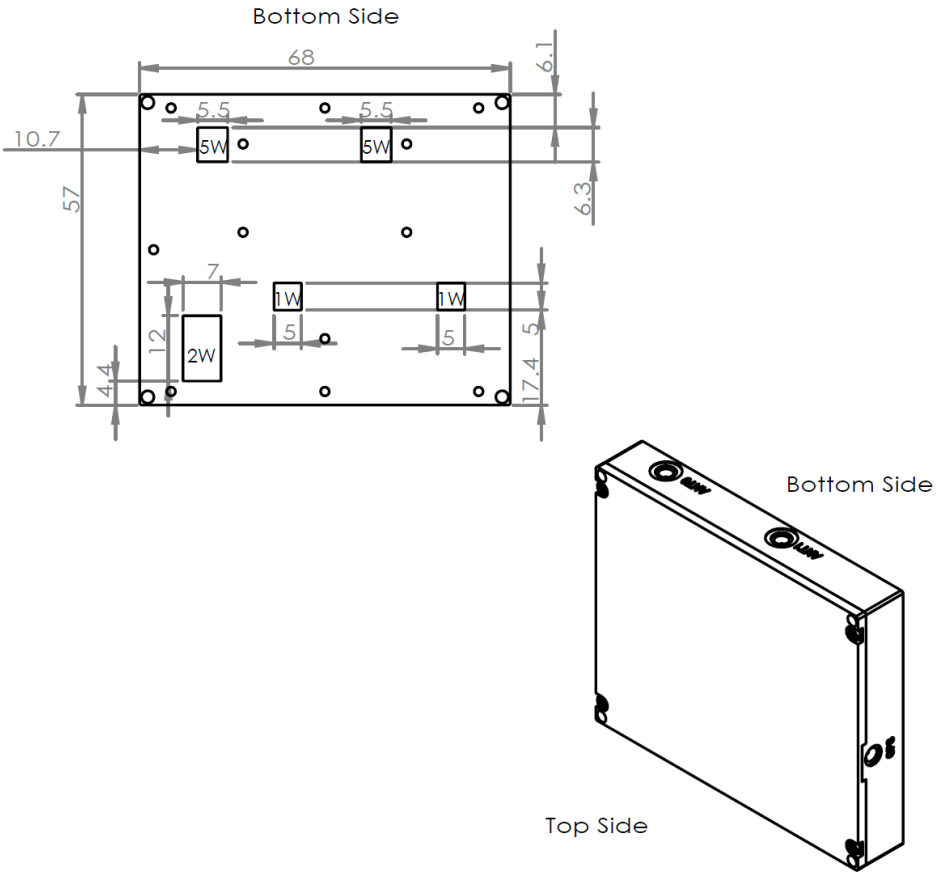


Dimensions in MM

Doodle Labs (SG) PTE LTD, 150,KA Center,Kampong Ampat, Suite #05-03, Singapore 368324 www.doodlelabs.com		
Model: DLM194		Rev: 03
Drawn: Bree Li Zhong	Checked: Aaron Do	Approved: Claus Muschallik

Heat Model

Smart Radio Embedded (-2J)



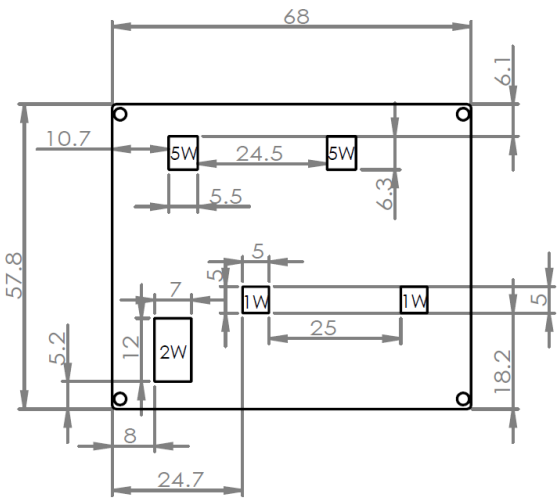
Dimensions in MM

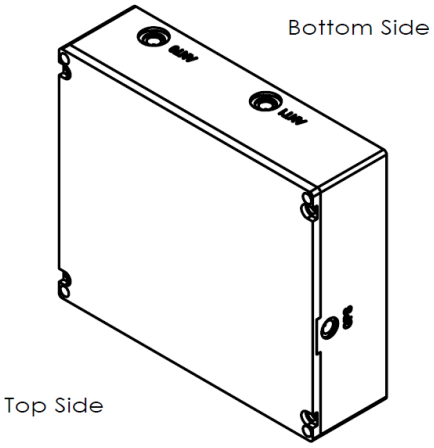
Doodle Labs (SG) PTE LTD, 150,KA Center,Kampong Ampat, Suite #05-03, Singapore 368324 www.doodlelabs.com		
Model: SR-SC-V3		Rev: 1.0
Drawn: Bree Li Zhong	Checked: Aaron Do	Approved: Claus Muschallik

HEAT MODEL

Smart Radio Embedded (RM-4700-2J ONLY)

Bottom Side





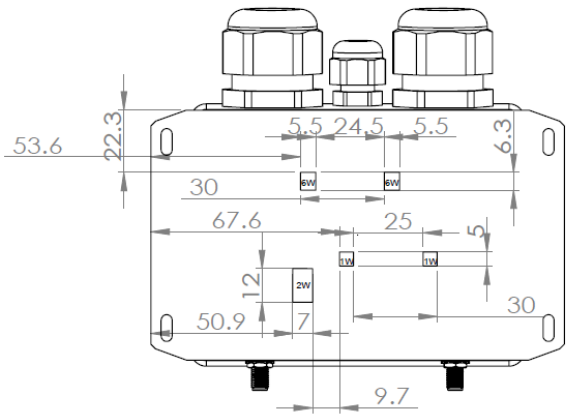
Dimensions in MM

Doodle Labs (SG) PTE LTD, 150,KA Center,Kampong Ampat, Suite #05-03, Singapore 368324 www.doodlelabs.com		
Model: SR-DC-V3		Rev: 1.0
Drawn: Bree Li Zhong	Checked: Aaron Do	Approved: Claus Muschallik

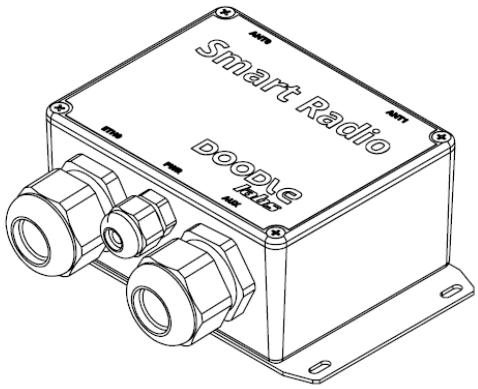
HEAT MODEL

Smart Radio External

BOTTOM SIDE



TOP SIDE



BOTTOM SIDE

Dimensions in MM

DOODLE labs Doodle Labs (SG) PTE LTD, 150,KA Center,Kampong Ampat, Suite #05-03, Singapore 368324 www.doodlelabs.com		
Model: DLM198		Rev: 1.0
Drawn: Bree Li Zhong	Checked: Aaron Do	Approved: Claus Muschallik

HEAT MODEL

Appendix D – BOM List for Cables

Embedded (-2H)

S.No	Description	Manufacturer	MPN
1	Power/Data Connector/Reset	Molex	5040501291
2	Auxilliary	Molex	5037630491
3	MMCX Connector	S-Conn	MM212N0G29
4	Power/Data Connector/Reset Cable	Molex	15132-1202
5	Auxilliary Cable	Molex	15131-0402

Embedded (-2J)

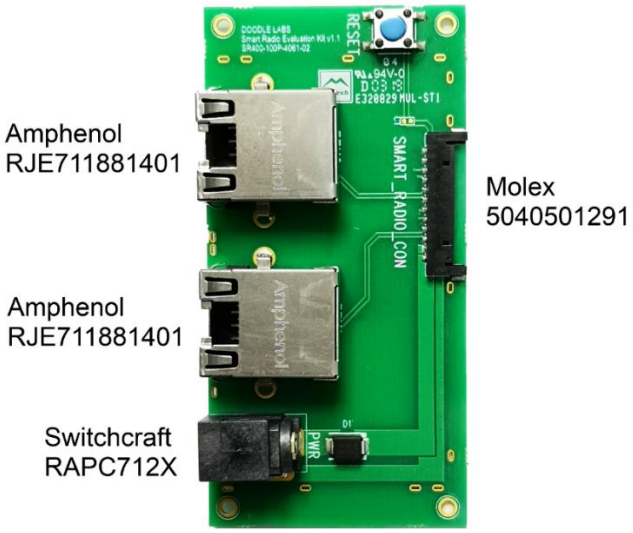
S.No	Description	Manufacturer	MPN
1	Main	Molex	5040501291
2	Secondary	Molex	5040501291
3	MMCX Connector	S-Conn	MM212N0G29
4	Main Cable	Molex	15132-1202
5	Secondary Cable	Molex	15132-1202

External

S.No	Function	Manufacturer	Part No.	Description
1	ETH0	-	-	Standard RJ45
2	ETH1	-	-	Standard RJ45
3	All Others	CUI Devices	TBL002A-350	spring latch wire terminal

Appendix E – Ethernet Test Kit

Embedded (-2H)



Embedded (-2J)