Sub-1GHz 6LoWPAN Development kit

User's Guide

Literature Number: SWRU298

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Abbreviations

Abbreviations used in this data sheet are described below.

6LoWPAN	IPv6 over Low Power Wireless Personal Area Networks	IPv6	Internet Protocol version 6
ICMP	Internet Control Message Protocol	UDP	User Datagram Protocol
RS	Router Solicitation	RA	Router Advertisement
NS	Neighbor Solicitation	NA	Neighbor Advertisement
SLLAO	Source Link Layer Addressing Object	PIO	Prefix Information Object
ABRO		ARO	
DODAG	Destination Oriented Directed Acyclic Graph	DIS	DODAG Information Solicitation
DIO	DODAG Information Object	DAO	Destination Advertisement Object
DAO-ack	DAO acknowledge	ER	Edge Router

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1 6LoWPAN Kit Overview

This document describes the TI 6LoWPAN evaluation kit for use in the 868/915MHz bands. The kit is based on hardware from TI and 6LoWPAN software (NanoStack) from TI third party Sensinode Ltd. The CC-6LOWPAN-DK-868 kit provides easy way for users to start developing their own wireless sensor network applications based on 6LoWPAN technology. There are two different APIs for communicating with the NanoStack, based on if you use CC1180 Network Processor or the CC430 SoC. The API used for CC1180 is called NAPSocket, while the API for CC430 is called NanoSocket.

The kit contains a 6LoWPAN Edge Router (access point/gateway to IPv6) based on TI's OMAP-L138 processor. The Edge Router (ER) uses a CC1180EM as radio interface. The Edge Router is running Sensinode Ltd NanoRouter 2.0 software and can connect wireless sensor nodes running Sensinode Ltd NanoStack 2.0 lite. The evaluation version of NanoRouter 2.0 included in the kit is limited to 10 nodes per Edge Router.

Included in the kit are two EM430F5137RF900 Rev 3.2 boards and two CC1180DB boards. The EM430F5137RF900 and CC1180DB boards are used as wireless sensor devices in the kit. CC430 comes with library support for Sensinode NanoStack 2.0 lite (NanoSocket [8]). This library model allows easy implementation of user applications, built directly on top of the NanoSocket library.

The CC1180DB contains a Wireless Network Processor (WNP), CC1180, which handles all 6LoWPAN network communication. Connected to the WNP is a host processor (MPS430F5438A) running the user application. The hardware interface between the network processor and the host processor is UART. The software interface between the network processor and the host MCU is Sensinode NAPSocket API [12]. The NAPSocket API acts as a wrapper library to parse Sensinode NAP protocol messages [9].

The kit provides Edge Router (NanoRouter) control and testing software (Sensinode NodeView 2.0 [10]). NodeView 2.0 can be used to control NanoRouter software running on the Edge Router in real time and provides e.g. address information of the connected nodes. The control protocol is based on Sensinode proprietary UDP communication. The NodeView 2.0 tool also provides a simple way to create user's own java applications that are included in the NodeView 2.0 GUI in the form own separate tabs.

All nodes can act as routers inside the 6LoWPAN network. The radio transceivers on the nodes are thus always on, which makes the system less suitable for battery-powered devices.

This documentation gives detailed information of the kit contents and behavior, its configuration and how the different 6LoWPAN standards are implemented.

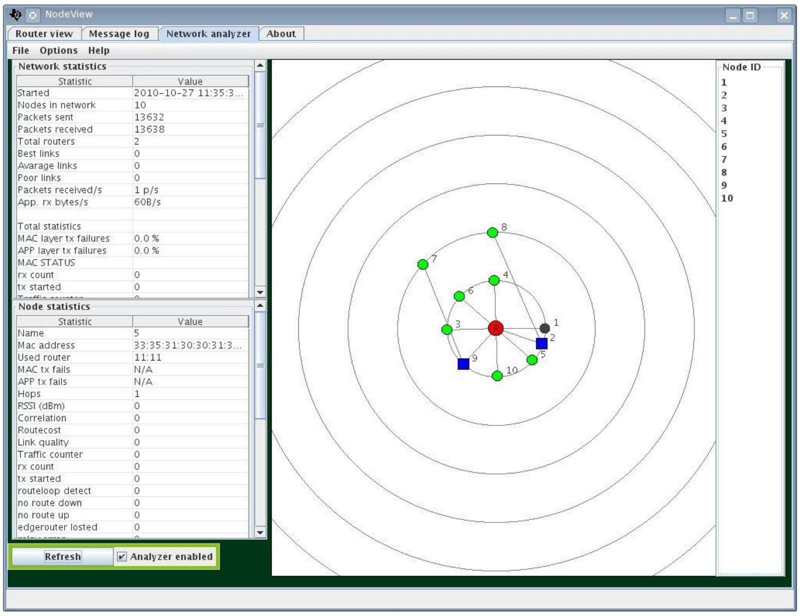


Figure 1. Sensinode NodeView Network Analyzer tool

1.1 Features

- IP-based networking, enabling the “Internet of Things”
- CC1180 Over-Network Download (OTA), future proofs:
    - Device applications and network upgrades
- Low memory footprint;
    - CC1180 6LoWPAN stack is less than 32kB
    - CC430 6LoWPAN stack is about 17kB
- Sensinode 6LoWPAN software can run on all frequencies that CC1180 and CC430 support, providing a sub-GHz mesh solution. Note: The kit hardware is for use in the 868/915 MHz bands.
- Low development complexity, customers used to IP programming will be up and running in no time with the simple socket API approach.
- Configurable RF interface:
    - Output power: -30dBm to +10dBm
    - Date rates: 50, 100, 150 and 200kbit/s
    - RX Attenuation, for close-in systems
    - AES-CCM* secured IEEE802.15.4e payloads, using network-wide key.
- Coordinated mesh networking (modified RPL)
- IEEE802.15.4g/e PHY and MAC
- Compressed IPv6 headers (subset of IP header compression)
- ICMPv6 Neighbor Discovery (subset of ND)
- User application uses User Datagram Protocol (UDP) to send data
- Short address link-layer communication (based on allocated two byte address, unique under a simple 6LoWPAN, allocation coordinated by a single Edge Router)
- Fully automatic bootstrap process, automatic route discovery
- Self-healing mesh
- Each node replies to ICMPv6 echo requests
- P2P communication
- Synchronous frequency hopping possible, using 50 FHSS channels

Figure 2. CC-6LOPWAN-DK-868 kit

1.2 What's included in the kit?

- 2 CC1180DB nodes (CC1180 NWP plus MSP4305438A host MCU)
- 2 EM430F5137900 (CC430 SoC) nodes
- 1 OMAP-L138 based Edge Router Board (Gateway, running Linux)
- 1 Adapter board, for connection of CC1180EM to OMAP-L138 board
- 1 CC1180EM (radio interface to OMAP-L138 board)
- MSP-FET430UIF Debugger, used to debug and download code to nodes.
- Ethernet Cable (Crossover, for direct connection to PC)
- RS-232 NULL modem cable (used for Linux debug console)
- Power supply for OMAP-L138 board, incl. cables
- USB cable for MSP-FET430UIF Debugger
- Antennas, for 868/915 MHz band
- Batteries (incl. holders for CC430 boards)
- Quick Start Guide
- Sensinode NodeView 2.0 Network Analyzer PC SW
- Software application examples

2 Getting Started

This chapter gives the user a quick start to using the kit. The 6LoWPAN network is completely self healing and self organizing. The only thing the user needs to do in order to get the network up and running is to set up the Edge Router, verify that the Edge Router has Ethernet connection with IPv6 support and start it. When the NanoRouter application on the Edge Router board boots up, automatic scripts configures the NanoRouter software and starts advertising the network over the radio interface. For a more detailed procedure please see the Quick Start Guide [14].

If the pre-programmed nodes from the kit are powered up, they will automatically search for and join to available network, allocate IPv6 addresses and are ready to go with no user input needed at all. The following chapter provides more detailed information what happens behind the scenes. The below picture describes an architectural overview for the complete system. Note that the 6LoWPAN stack handles exactly which node connects to which node automatically, hence forming a fully automatic 6LoWPAN network.

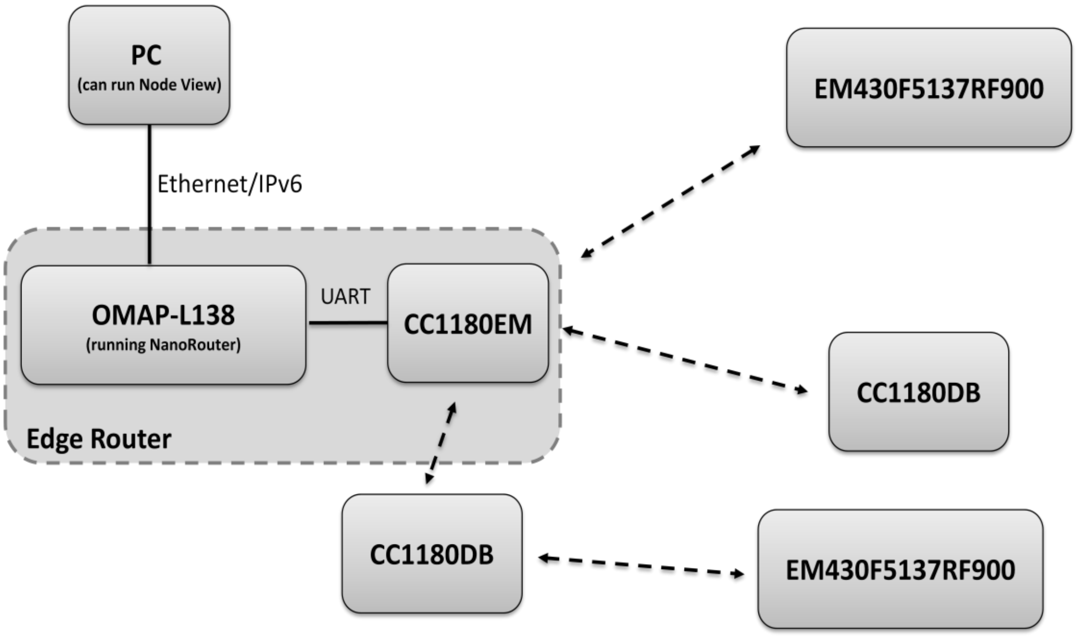


Figure 3. Kit System Overview

2.1 Setting up IPv6 on your PC

Most Internet hosts are still using IPv4 only a few are using the new IPv6 protocol. The Sensinode NanoStack 2.0 is using IPv6, so you need to have your PC ready also. For Microsoft Windows Vista and 7 IPv6 is supported natively. If you are running Windows XP, make sure that you have the Service Pack 3 installed. In addition, when you have Windows XP Service Pack 3 installed, you also need to check to make sure that the IPv6 protocol is installed in your system. You can verify that this is installed by looking at the properties of any Network Connection on your computer (Start Menu -> Network Connections). As you see from the below screenshot, if you call the properties for any connection, you should have an option called Internet Protocol Version 6 (TCP/IPv6).

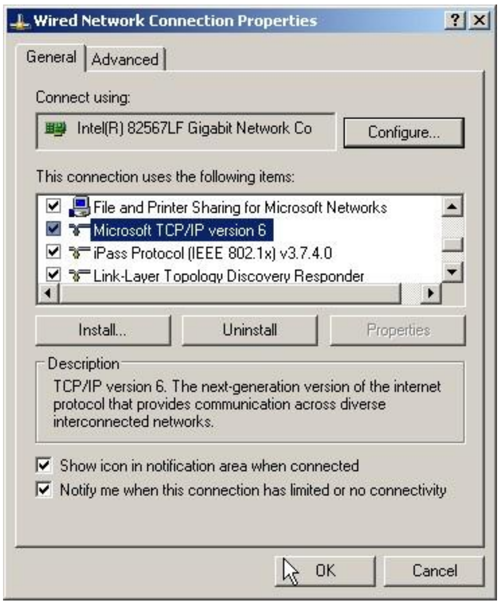


Figure 4. IPv6 enabled for Windows XP

Follow the below steps to install IPv6 for Windows XP if you do not have it installed.

Open a command prompt and write:

```
ipv6 install
```

To be able to communicate with the devices using IPv6 your PC needs to be assigned an IPv6 address. Assigning an IPv6 address and a default route is described for Windows XP, Vista, 7 and for Linux in the steps below.

Assign an IPv6 address to the PC using the command prompt (Run in administrator mode in Windows 7). This example adds the IPv6 address 2001::22 to your PC:

```
netsh interface ipv6 add address “Local Area Connection” 2001::22
```

Set up a default route using the command prompt: (Run in administrator mode in Windows 7)

```
netsh interface ipv6 add route ::/0 “Local Area Connection”
```

Note! You must change “Local Area Connection” to the actual name of the Ethernet connection you want to use. You can get it from Windows Network Connections. The IPv6 address (2001::22 in this example) has to be unique on your network.

For Linux the following commands to add IPv6 address and default route can be used:

```
ifconfig eth0 inet6 add 2001::22/64
route -A inet6 add 2001::/0 dev eth0
```

Note that some antivirus software blocks all incoming IPv6 traffic.

2.2 IPv6 and 6LoWPAN Basics

To fully benefit from the CC-6LOWPAN-DK-868 kit a basic understanding of both IPv6 and 6LoWPAN is needed. This section makes the user familiar with basic IPv6 and 6LoWPAN technologies.

TI's third party Sensinode Ltd. 6LoWPAN solution provides an easy way of passing messages around in a 6LoWPAN network, using a socket approach to both sending and receiving data as well as controlling the network parameters. In small RF networks, i.e. a sensor network, sending data inside the network is usually straight forward. Problems arise when one wants to send data to the internet or intranet. This would normally include either specialized software on devices connected to the network, or translating the RF protocol to a network protocol, i.e. using a proxy. CC-6LOWPAN-DK-868 is therefore based on IPv6 and 6LoWPAN, eliminating such need for application layer gateways.

2.2.1 *IPv6 Introduction*

Internet Protocol (IP) is used in the world's largest networks. Nearly every desktop computer supports IP, which makes IP ideal to use when one wants to hook up a wireless sensor network to a larger backbone network. Setting up a wireless sensor network can even be managed by the IT department on a company, without any knowledge of RF networks at all.

IP is not optimized for low-power, low-cost sensor networks. But since it's a very flexible protocol it can fairly easy be adapted to make a perfect fit for a wireless sensor network, which is exactly what 6LoWPAN does.

2.2.1.1 Addressing

The most obvious difference between IPv4 and IPv6 is the number of supported addresses. IPv4 supports 2^{32} addresses, while IPv6 supports 2^{128} addresses.

A typical IPv6 address might look like this: **`2001:0000:0000:0000:0000:00FF:FE00:0301.`** All leading zeros can be omitted, leaving the address to look like: **`2001:0:0:0:0:FF:FE00:301`**. Finally zeros in the middle can be replaced by a double colon, leaving the address to: **`2001::FF:FE00:301`**

All IPv6 networks have a prefix. All devices in the same network have the same prefix. The prefix is written like this: **`2001:0:0:0:0:FF:FE00:301/64`**, meaning that the prefix is 64 bits long. Thus the prefix for this example is: **`2001:0000:0000:0000`**

Every interface also has a local link address associated with it. The link-local address is only valid within the network and cannot be routed to another network. A link local address start with FE80::

2.2.2 *6LoWPAN Introduction*

Since the IPv6 header alone is 40 bytes, and the Maximum Transmission Unit (MTU) of IP is 1280 bytes, frames to be sent over a low power RF network based on IEEE 802.15.4 has to be compressed in some way. IEEE 802.15.4 has a maximum packet size of 127 bytes, so a 40 byte IPv6 header would take up more than 30% of the packet. The 6LoWPAN adaptation layer bridges those two technologies together, without the need of any application gateways.

Each node in a 6LoWPAN network has a unique IPv6 address, as described in the previous chapter. In addition to the IPv6 address all nodes also has a unique 8 byte IEEE address. The IEEE address is stored in flash memory of the devices. For CC430 based devices the IEEE address is stored on flash address 0xFF70 (MSB on address 0xFF70). On the CC1180 the IEEE address is read and written with a Sensinode bootloader utility called NanoBoot host. NanoBoot host is available for standard Linux platforms and the OMAP platform. On all nodes in the CC-6LOWPAN-DK-868 the preloaded IEEE address are printed on a sticker on each node.

2.3 Edge Router Bootstrap Prosess

The Edge Router board requires an Ethernet cable and main power. Also verify that the CC1180EM radio module is properly connected to the OMAP J30 connector with the adapter board and has an antenna. To start the Edge Router simply power up the board. On the board there is an automatic script which will launch the NanoRouter 2.0 software during Linux kernel boot process. The time for the Linux boot process is about 45 seconds. NanoRouter software status can be easily checked by initiating a NodeView connection to the board IPv6 address, which is described in the next chapter.

2.4 NodeView 2.0

NodeView can be used to control and communicate with the NanoRouter software running on an Edge Router. The NodeView software is a java based cross platform tool designed for 6LoWPAN testing and evaluating purposes. When NodeView is started, it opens the 'Router View' tab. The 'Router View' tab contains 'File' and 'Options' toolbars. To connect NodeView to an Edge Router choose File->Add NanoRouter IPv6 from the menu.

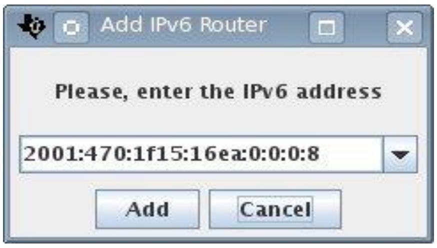


Figure 5. Adding an Edge Router.

The address must be given in a basic IPv6 format seen in the figure above. To connect to the standard Edge Router delivered with the CC-6LOWPAN-DK-868 kit simply enter **2001::11**. After the Edge Router is added, the details can be seen from the NodeView 'router View' tab if the connection was successfully established. When a sensor node joins the network, it can be observed in the Nodes list shown in Figure 2Figure 6. The list is updated based on the Edge Router whiteboard information or by pressing 'Clear and Reload' button. The whiteboard of the Edge Router contains information of all connected nodes.

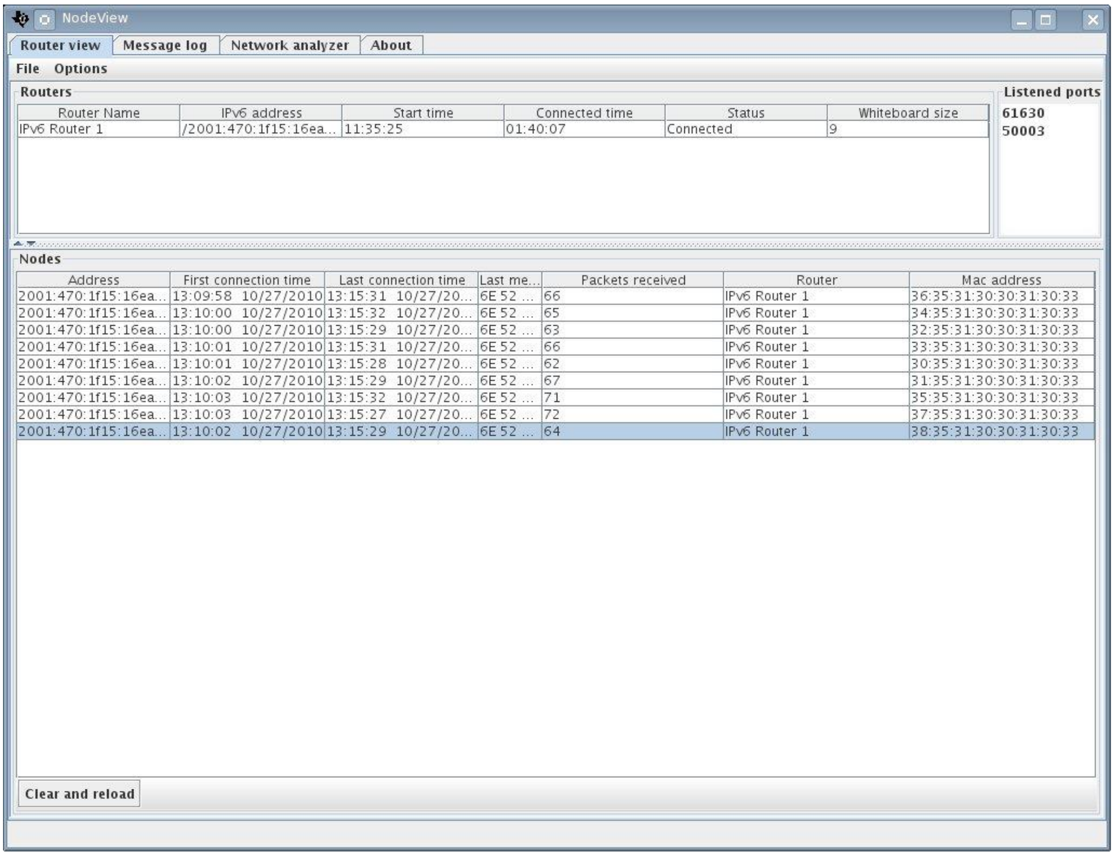


Figure 6. NanoRouter Router View details.

As described earlier in this document nodes automatically scans for and joins available 6LoWPAN networks. When a node has joined a network a Network Analyzer application is launched on the node. The Network Analyzer application sends data about the network to the NodeView tool. The start is trigged by a message from NodeView, the activation message is sent automatically every time when the whiteboard information changes or when user press the 'Clear and Reload' button.

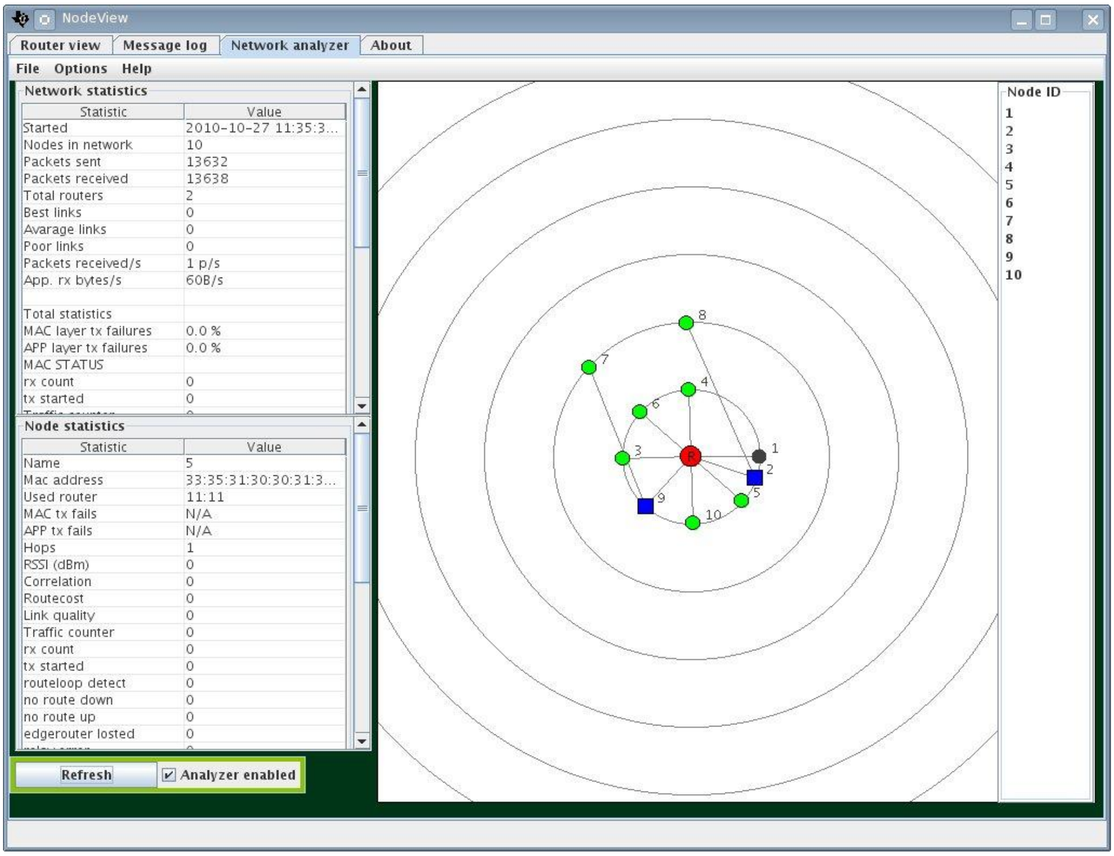


Figure 7. NodeView Network Analyzer tab.

In Figure 7, the green node indicates a normal node, while the blue color indicates a routing node. The black/grey color indicates a node that has no longer connectivity to the NodeView. The red color indicates a configured Edge Router. The circles describe a logical position of a node in the network in hops. 'File', 'Options' and 'Help' contains useful information and configurations that can be useful. The set Global Transmit Interval found in Options can be used to change how often the nodes are set to send their network analyzer data to the Edge Router, the default value is 40s. Pay attention when setting this value, since setting it too low in a large network can degrade the network overall performance. One feature that can be useful when analyzing routing paths is the ability to have a background image in NodeView. To enable this feature place your background image (must be in .jpg format) in the same folder as NodeView, the go to Options->Use background. More information on how to use NodeView 2.0 can be found in [10].

2.5 Network Analyzer Application

All sensor nodes come with a pre-programmed Network Analyzer firmware. The network analyzer application is used to gather information about the network such as RSSI on different links, network topology and application layer data traffic etc. This section describes behavior of the LEDs and buttons that user may use on the nodes. The network analyzer application software for the nodes is described in detail later in this document.

CC1180DB and CC430F5137 both have a green and a red led. The CC1180DB also has LEDs that are controlled by the MSP4305438A host MCU. Radio LEDs (D1 and D2) are located in left bottom corner when holding CC1180DB with jumpers and buttons pointing upwards. The CC1180 contains a bootloader, Sensinode NanoBoot 1.0, and a NanoStack 2.0 Wireless Network Processor firmware. The user can control which state (mode) that CC1180 is in, either bootloader mode or application mode.

When the NanoBoot mode is chosen, both LEDs are on. The mode can be switched by pressing the button S1. This will cause a falling edge interrupt to the CC1180 chip (grounding P1.2). Both LEDs will be now disabled until a network connection is established (indicated with green LED). If the red LED blinks with 1 second interval the network is disabled. The red LED also blink very rapidly during any RF event but mainly remains inactive. Please note that the connection will not be established if the MSP4305438A host MCU doesn't send a networking enable message or there is no active NanoRouter available within the range with correct RF settings.

When the connection is established, green LED remains active and the red LED blinks on every RF event.

Green LED active, red LED disabled but blinking	Red LED blinking with 1 second interval	Green LED inactive, red LED blinking rapidly.	Both LEDs are active
Network connection established	Networking is not enabled	Scanning for network	Bootloader mode

Table 1. CC1180 controlled LED (D1 and D2) behavior.

Table 1 applies also for the CC430F5137 LEDs except for the bootloader LED usage, since there is no NanoBoot 1.0 in use in CC430F5137). The MSP4305438A host MCU has a Network Analyzer application programmed by default as describe earlier in this document. The RSSI for the node is displayed using the LEDs. The LED control of the Network Analyzer application is defined in Table 2.

Red LED toggling with 1 second interval	Both LEDs disabled	Green LED active, red LED disabled	Both LEDs remains active	Red LED remains active, green LED disabled
3 concurrent reply messages missed or Analyzer is not activated	Reply message measured RSSI level above -40 dBm.	Reply message measured RSSI level between -40 and -65 dBm	Reply message measured RSSI level between -65 and -90 dBm.	RSSI reading below -90 dBm.

Table 2. MSP4305438A controlled LED (D3 and D4) behavior.

3 Software

Sensinode NanoStack 2.0 lite operating system core is event based, all the peripherals such as timers, trigger events are executed in the main program. Interrupt service routines are used by hardware drivers which may trigger events.

3.1 Sensinode NAPSocket and NanoSocket interface

There are, as described earlier, two different APIs for using Sensinode NanoStack 2.0 lite. Network Processor (NAPSocket API [12]) and the library model (NanoSocket API [8]) provide easy-to-use interfaces. NanoStack 2.0 lite networking must be initialized properly, networking is off by default. User is provided an interface which allows enabling of networking; e.g. polling connectivity and configuring the RF interface setup for user needs. For the Network Processor, NAPSocket library [12] is an interface library running on a host MCU controlling the Network Processor (CC1180). The library model of NanoStack 2.0 lite uses a function call interface which allows direct access to configure networking features as well as other configurations, e.g. RF configuration. This interface system is called NanoSocket API [8]. NanoSocket API is linked into user IAR application project and it contains a .lib file of NanoStack 2.0 lite and a few header files. Both interfaces encapsulate UDP communication into a simple socket system, making RF easy! The Sensinode NAPSocket and NanoSocket APIs are described in detail below.

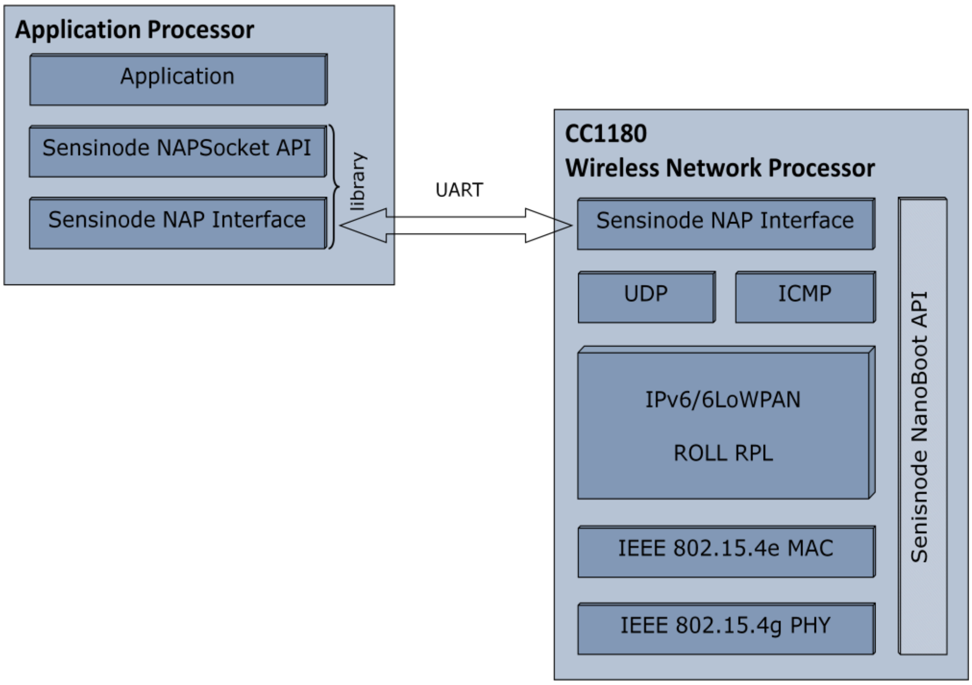


Figure 8. Stack overview CC1180 based system, using NAPSocket API

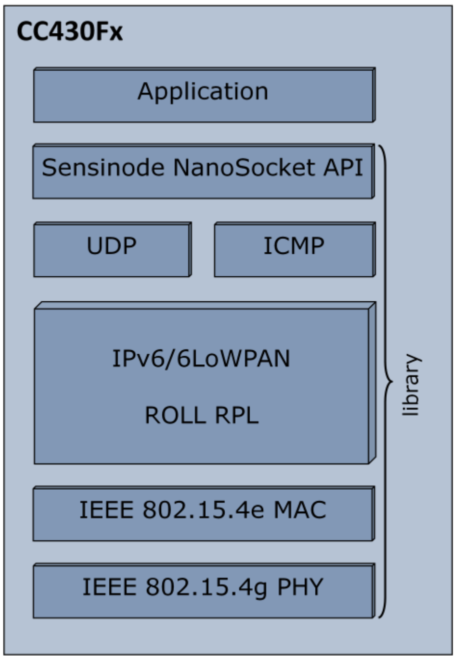


Figure 9. Stack Overview CC430 based system, using NanoSocket API

3.2 Sensinode NanoStack 2.0 lite

Sensinode NanoStack 2.0 lite is an embedded operating system and a 6LoWPAN protocol stack designed especially for low power and cheap wireless sensor devices.

The protocol stack is designed to comply with a set of standards mostly provided by IETF 6LoWPAN working group. Table 3 describes the layer structure of the protocol stack and the used standards for each protocol layer.

Layer	Standard	Description
PHY	802.15.4g [4]	Link layer communication -GFSK modulation -FHSS support -Single band in EU
MAC	802.15.4e [5]	Link layer communication -Addressing modes (16 bit addressing mode) -AES-128 bit CCM* support
IP	draft-ietf-6lowpan-hc-13 [1]	Network layer communication, routing -Addressing modes (128 bit, multicast group 2, link local)
Neighbour Discovery	draft-ietf-6lowpan-nd-13 [2]	Network layer communication, address registration, network scan. Neighbour resolution.
Routing method	Draft-ietf-roll-rpl-13 [3]	Network layer communication, coordinator controlled routing.

Table 3. Sensinode 6LoWPAN Stack Layer Definitions.

3.2.1 *Bootstrap process*

When a node is powered up and set to search for network, it activates the MAC and PHY radio operations automatically, providing a fully automatic bootstrap process.

3.2.2 *Synchronization*

All nodes must synchronize to a simple 6LoWPAN Edge Router since the radio PHY supports frequency hopping system. When the synchronization is established, each node will start hopping on the predefined channels. Each node remains in a channel for 350 ms, this time period is called an active period. After each active period, a new channel is chosen and nodes remain in a guard period for 50ms. During that period, radio receivers are disabled and no communication is performed. Each 50ms slot in the active period and the guard period is called a superframe. Each superframe consists of 330 microsecond slots. Each superframe causes an interrupt for the radio module. This interrupt is served by a crystal; the crystal must follow tolerances stated in the respective datasheet in order to keep up the synchronization. Note that the synchronization is established even if the system is of single channel type. During the active period, RF receiver is active and MCU is running. (In CC430F5137 CPU sleeps if no other operations are performed in order to keep the power consumption at a minimum).

The synchronization process is described here. First, a powered and activated node scans for the beacon by broadcasting a beacon request periodically. Each node which is already joined to the network will reply with a unicast beacon to the originator of the beacon requests. The beacon contains timing information of the superframe. The beacon payload is described in Table 4.

Byte	1	2	3	4	5
Value	'S'	'F'	Remaining slots in superframe	Superframe ID	Next channel table index

Table 4. Beacon payload.

Here, the 'S' and the 'F' are header bytes to discard beacons of other systems. The remaining slots field in the superframe message describe how many 330 us slots are left in a current superframe. The superframe ID describes the number of the current superframe. Superframes are numbered from 0 to 7; where 1 to 7 is the active period superframes and superframe 0 indicates the guard period. Beacons and beacon requests are built according to IEEE802.15.4e specification [5]. After synchronization is performed, it is updated with ~10 second interval by sending unicast beacon request to the node that responded to the beacon.

3.2.3 *Neighbour Discovery and Router Solicitation*

When a node is synchronized, the ICMP (Internet Control Message Protocol) layer is activated. The ICMP layer scans for suitable routing nodes or Edge Routers by broadcasting a Router Solicitation (RS) message. On reception of a RS, a routing node responds by sending a link local (unicast) Router Advertisement (RA) to the scanning node.

On reception of a RA, the joining node receives the IPv6 prefix of the network. The prefix is used to communicate within a simple 6LoWPAN network. Here, the prefix is defined to be 8 first bytes of the IPv6 address that the NanoRouter advertises. After the prefix information is solicited, the node sends a Neighbour Solicitation (NS) message. The NS message is used to solicit neighbour information of the network. Here, a neighbour cache size is zero and therefore contains no entries. The NS also contains a header field to register an allocated 16-bit short address. As a response to the NS, a Neighbour Advertisement (NA) is sent. The NA message contains information of advertising node and status fields if the address allocation was successfully performed.

The NS is sent first to a routing node which then delivers it to the Edge Router using RPL routing, if the scanning node cannot reach the Edge Router directly. The NA message is sent from the Edge Router to the routing node, which then sends it to the registrating node by using the link local unicast. More detailed information can be found from Draft-ietf-6lowpan-nd-13 (draft-ietf-6lowpan-nd-13) [2].

3.2.3.1 Fixed packet formats

In order to achieve a very lightweight 6LoWPAN stack, some packet formats need to be fixed to avoid unnecessary packet processing. In this section fixed packet formats are described. Table 5 describes fixed packet formats of Neighbour Discovery messages.

Message	Format
Router Solicitation (RS)	SLLAO
Router Advertisement (RA)	PIO, ABRO, SLLAO
Neighbour Solicitation (NS)	ARO, SLLAO
Neighbour Advertisement (NA)	ARO, SLLAO

Table 5. Fixed Neighbor Discovery packet formats.

If other packet formats of Neighbour Discovery messages are received, they are discarded silently. Detailed explanation of SLLAO, PIO, ABRO and ARO can be found from [2].

3.2.4 *RPL: IPv6 Routing Protocol for Low power and Lossy Networks*

In order to achieve a lightweight 6LoWPAN stack, routing is based on RPL control messages (DIS, DIO, DAO and DAO-ACK). The routing is coordinated by the NanoRouter 2.0 software running on the Edge Router, which keeps record of routing tables as well as whiteboards over time.

Nodes form topological paths extending from the access point. Each node ‘knows’ their RPL parent. Each node allows an unlimited amount of child nodes, but only one child may continue routing. This is controlled by RPL poisoning and by sharing DIO message information required for routing. Each node is registered into the Edge Router (NS, DAO), so the Edge Router can form a whole path into a single node by summarizing all the registration data. Finally, the Edge Router knows the destination address, path and depth in a network and therefore is able to route data to the destination. Forwarded messages are also having a flag (RPL hop-by-hop option header) which indicates the direction of forwarded data (up and down).

In routing systems where flow paths are used, each ‘knot’-node can become a problem. As a flow spreads into separate flows, routing becomes impossible. Each node can have only one routing child, but unlimited amount of non-routing child nodes. Therefore routing is allowed only in a node which was connected to a routing node as the first child. This logic is controlled by a timer, by keeping the first child addressing information in memory and by restricting routing using RPL control message (DIO).

Draft-ietf-roll-rpl-13 [3] defines the used routing protocol. It contains a few ICMP layer messages called RPL control messages. These messages contain information of routing nodes and hosts. The information is gathered to the Edge Router and routing configurations are sent all over the simple 6LoWPAN network. Table 6 illustrates a basic description of each message type.

Message type	Description	Addressing options
DIS	Used to scan for RPL DODAG.	Multicast, unicast
DIO	Used to advertise RPL DODAG.	Multicast, unicast
DAO	Contains routing information from source to the next hop parent.	Unicast
DAO-ACK	Acknowledge message for DAO.	Unicast

Table 6. RPL control messages

When the node has accomplished Neighbour Discovery, the RPL routing protocol takes place. A joining node scans for a Destination Oriented Directed Acyclic Graph (DODAG) Information Object (DIO) by broadcasting a DODAG Information Solicitation (DIS) message. When a routing node receives the DIS message, it sends the DIO as a response. The DIO may, or may not, contain DODAG information. All details of this functionality are described in [3].

The DIO message also contains address information of the parent and a RPL root which is the Edge Router. On reception of the DIO, a Destination Advertisement Object (DAO) is sent to the RPL root after a predefined time. The DAO contains route information from the RPL host to the RPL parent. Here, this information represents one logical interconnection within the simple 6LoWPAN network.

When the root receives the DAO, it gathers route information of the DAOs to a routing table. The routing table can be used to build a whole path from the root to the destination node. This allows the root to send data to any registered and joined node within a RPL DODAG. As a response to the DAO, a DAO-ack is sent if requested.

In order to achieve a lightweight 6LoWPAN stack, P2P data (data going from node to node) has to be delivered to the Edge Router and then routed from the Edge Router to the destination node. More detailed information of each packet format can be found from [3]. It is however possible to send data directly from one node to another by using the multicast feature, given that the nodes are within the same physical RF range.

3.2.4.1 Fixed packet formats

Draft-ietf-roll-rpl-13 [3] defines multiple formats for RPL control messages and their options. Table 7 describes fixed packet formats for each RPL control message.

RPL control message	Options
DIS	No options
DIO	DODAG configuration, metric container or only metric container
DAO	RPL target, transit information
DAO-ack	No options

Table 7. Fixed formats of RPL control messages.

Any other formats of RPL control messages are discarded silently.

3.2.4.2 DODAG configuration option

This CC-6LOWPAN-DK-868 kit uses a custom RPL objective function, please see [3] for more information. Here, an Objective Code Point (defined in a DODAG configuration in [3]) is defined to be:

MSB byte	LSB Byte
's'	'n'

Table 8. RPL Objective Code Point.

The Objective Code Point indicates a used objective function. The Objective Function requires a metric container. The metric container has the following format:

Byte 1	Byte 2	Byte 3	Byte 3
Type = 2	Length = 2	's'	Hop count

Table 9. RPL Metric container format.

The metric container must be included within a DIO and if it not exists, the DIO is discarded silently. A node that doesn't receive DODAG configuration must advertise its rank as INFINITE_RANK (0xffff).

3.2.4.3 Sensinode custom Objective Function

The used Objective Function is based on a link quality metric where the received signal strength indicator is graded from 1 to 8, where 1 is the best possible link and 8 is the worst link. The rank used in RPL control messages is then calculated on the reception of a DIO message. The calculated link quality grade is added to the received rank. The calculated rank is then divided by a hop count within the metric container and is compared to the current rank divided with current hop count. If the new rank is smaller than the old rank, a topology change is made. Therefore a DODAG configuration defines minimal rank increase of 255*1 and maximum rank increase of 8*255. For platforms not supporting RSSI calculation, default rank increase of 3 can be used. Table 10 summarizes these definitions.

Definition	Value
Minimum rank increase	255*1
Maximum rank increase	255*8
Default rank increase	255*3

Table 10. DODAG configuration parameters.

A more detailed explanation of these parameters can be read from [3]

3.2.5 *Periodic processes*

This section describes the periodic messaging within a simple 6LoWPAN network. In order to update the routing information, the RPL protocol sends messages periodically to maintain and update routes. The period is mainly controlled by Edge Router (NanoRouter) but may change dynamically due to RF events within a network.

In order to verify the connectivity and avoid duplicate address allocation, also the Neighbour Discovery process is performed periodically. The period may change depending on failure events within a network.

The synchronization is also updated periodically as explained in 3.2.2. Timings may also change due to RF errors and accepted beacons.

3.2.6 *Error situations*

Users of the kit need to be aware of and fully understand the limits of the radio range of the used devices. If the node doesn't have a network within its radio range, it is not able to join the network. If default firmware (Network Analyzer application) are used, the LEDs will indicate (via RSSI) this kind of a communication problem as explained in Table 1.

As the routes are maintained based on periodic scans and advertisements, the network do not support a high grade of mobility. There will be communication losses if a node has been joined to an existing network but then is moved to a different location within the network. This is due to the fact that the nodes cannot realize the change in topology very fast. However, the network is able to do self-healing in these situations by listening to advertisements all the time.

3.3 CC-6LOWPAN-DK-868 Software Projects

Included in the kit are example projects to be used with IAR Embedded Workbench. This section describes the setup, use of, and installation of those projects.

3.3.1 *IDE installation*

The projects included in the kit are for the IAR Embedded Workbench IDE 5.20 for MSP. It is possible to use the "Kick-start" version of the IAR Embedded Workbench to build the application examples for CC1180DB. The IAR “Kick-start” version allows the user to build applications not exceeding 8kB. The demo application (Network Analyzer) for CC1180DB in the kit is using the NAPSocket library, and the build size is about 4kB of Flash and 2kB of RAM (including the NAPSocket library).

To be able to build a CC430 application one must use the full version of IAR Embedded Workbench, due to the size of the 6LoWPAN CC430 NanoSocket library. The build size for the CC430 demo application (including 6LoWPAN stack) is about 19kB of Flash and 3kB of RAM. This leaves 13kB of flash and about 1kB of RAM to the user application.

For software development and modification of the preprogrammed firmware (Network Analyzer) the following steps are needed:

1. Install IAR Embedded Workbench for MSP, all versions can be found here: IAR Embedded Workbench
2. Download the CC-6LOWPAN-DK-868 Application Example zip files from http://www.ti.com/6lowpan and unzip the files.
3. Download the NAP Socket library source from http://www.ti.com/6lowpan; this is needed to get the .lib file that the CC1180 example application is using. It is also needed if you want to run/port the application in/to another host MCU.

Make sure to extract the NAP Socket library and Example Application into the same folder, in order to not have to change the settings in the IAR projects.

For more information on the different IDE options and details please visit http://www.iar.com

The examples are all configured as IAR workspaces, one workspace for CC430 and one for MSP430F45438A (to be used on the CC1180DB). The workspace for CC430 is called CC430NetworkAnalyzer.eww and the workspace for MSP430 (for use on the CC1180DB) is called NanoHOEX.eww.

The files are organized into folders corresponding to their location in the file structure, e.g.:

- Libraries - this contains used library file. Either CC430 NanoSocket library or Sensinode NAP Socket library for MSP430 (for CC1180DB).
- Applications - the sample applications.
- Platform - this contains miscellaneous utilities, such as ADC driver for temperature/battery level measurements.

IAR automatically creates an additional directory, Output, that contains any debug or list files.

The project configurations are all fairly simple to ease the transition to other platforms. Changes to the default project configuration are the following (can be found under project Options-> Project: Options)

CC430 project:

- General Options: Target - change Device to CC430F5137. Library Configuration - CLIB. Library options - Change to Large Printf formatter. Change to Large Scanf formatter. Stack/Heap - Override default and set Stack size: 256, Data16 heap size: 256.
- C/C++ Compiler: Language tick multifile comp. Preprocessor - Under "Additional include directories" the relative paths for all files are added. Otherwise IAR will display a warning if the project directory changes, since IAR by default uses absolute paths in its project configuration. Under Defined symbols: add NS_DEBUG=1 (if debug interface shall be enabled) and MSPCORETYPE=5137.

- Linker: Extra Output - Check Generate Extra Output. Output file: Check override default and name the file *.hex

MSP430 project:

- General Options: Target - change Device to MSP430F5438A. Library Configuration - CLIB. Stack/Heap - Override default and set Stack size: 512, Data16 heap size: 512.
- C/C++ Compiler: Preprocessor : Under "Additional include directories" the relative paths for all files are added. Otherwise IAR will display a warning if the project directory changes, since IAR by default uses absolute paths in its project configuration. Defined symbols: USE_IAR=1
- Linker: Extra Output: Check Generate Extra Output. Output file: Check override default and name the file *.hex

3.3.2 *NanoHost Example (Network Analyzer)*

The nodes included in the kit come preloaded with an application to monitor the 6LoWPAN network topology and to provide link quality data to the user. The Network Analyzer Demo Application on the nodes is used in conjunction with the PC software NodeView 2.0 to monitor and analyze the 6LoWPAN network. NodeView 2.0 software on the PC sends out a message containing information to the nodes on how often they are supposed to report their status to NodeView 2.0. This value is set in NodeView 2.0 and can be changed under "Network Analyzer tab -> Options -> Set Global Interval" Default is 40s.

The Network Analyzer program sequence is this:

1. Node View sends out a "start" message to the connected nodes.
2. Nodes reply with a message containing data such as; short address, parent address, number of hops away from Edge Router and RF signal info. The payload length of this packet is 31 Bytes.
3. Node View sends an ACK message to the node. The payload length of this packet is 9 Bytes.
4. Data is shown in Node View.
5. Nodes keep sending data to Node View with the defined interval.

As is described in chapter 3.4 the NanoHost example project uses the Sensinode NAPSocket library as a parser library to handle the communication between the host MCU (MSP430F5438A) and the network processor (CC1180) on the CC1180DB board.

The files in the IAR project for CC1180 have the following file structure:

- Applications - The network Analyzer application source files.
- Libraries - The NAP Socket library file, which is the API to NAPSocket.
- Platform - Contains platform (i.e. MSP430F5438A) specific files.
- Output - The output .hex file is put here.

You'll also notice that the IAR project has the includes defined in Project Options. These definitions ($PROJ_DIR$/something etc) are there to make the examples portable since IAR by default uses absolute paths. Otherwise when you open the examples you would get an error if your file structure doesn’t exactly match the provided.

The NanoHost example is described in detail in [11].

3.3.2.1 Getting started with application development for CC1180 (NAPSocket)

1. Open IAR Embedded Workbench for MSP
2. Open workspace NanoHOEX.eww
3. Connect CC1180DB via MSP-FET430UIF Debugger to your PC
4. Select Debug or Release, depending on if you want to debug or just download the hex file to CC1180DB (MSP430F5438A) from the workspace panel.
5. Click Download and Debug in the menu, or use Ctrl-D

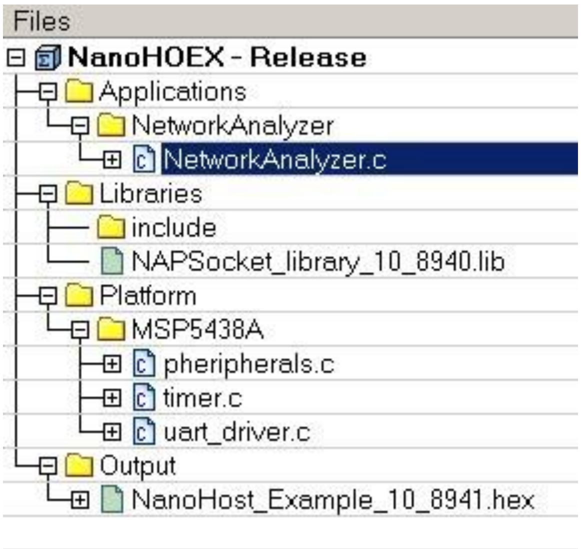


Figure 10. NanoHost Example project

3.3.3 *NAPSocket Library*

The NAPSocket library is provided in source code in order to be able to port the library to other platforms. The NanoHost example application is using the NAPSocket library to send and receive data from the CC1180 Network Processor.

The NAPSocket library is described in detail in the Sensinode document [12].

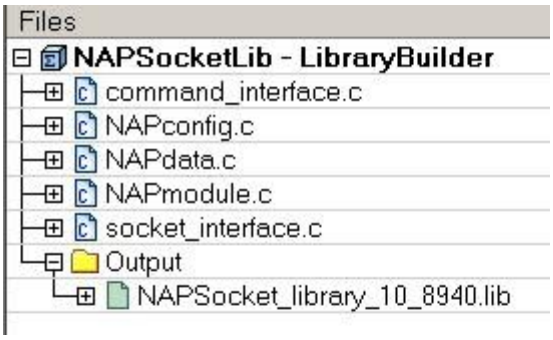


Figure 11. NAPSocket library project

3.3.4 *CC430F5137 Library Model (Network Analyzer)*

The program flow and logic are exactly the same as for the CC1180DB version described in 3.3.2.

The files in the IAR project for CC430 have the following file structure:

- main.c- The Network Analyzer application source file.
- *.lib - The NanoSocket library file, which is the API to NanoSocket.
- Output - The output .hex file is put here.

You'll also notice that the IAR project has the include files defined in Project Options. These definitions ($PROJ_DIR$/something etc) are there to make the examples portable since IAR by default uses absolute paths. Otherwise when you open the examples you would get an error if your file structure doesn't exactly match the provided.

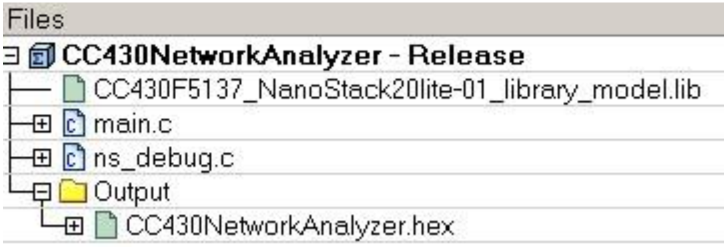


Figure 12. NanoSocket Example project

3.3.4.1 MCU Resources in use by NanoStack 2.0 lite on CC430

The following hardware resources are occupied by the library CC430F5137_NanoStack20lite and therefore not available for user application.

- All timer modules
- Watchdog
- DMA interrupt
- The UART is occupied if application is compiled with NS_DEBUG defined (CC430 provides one UART, UCA0)
- CC1101 radio interface
- LEDS according to EM430F5137RF900 schematic are in use. However, DISABLE_AUTOMATIC_LEDS() function can be used to allow user defined led functionality
- AES engine and CRC engine
- Unified clock system:

```
UCSCTL4 |= SELA_0;
UCSCTL4 |= SELS_5; // Set SMCLK = XT2CLK (26MHz same crystal as radio core)
UCSCTL4 |= SELM_5; // Set MCLK = XT2CLK (26MHz same crystal as radio core)
UCSCTL6 &= ~XT2OFF; // Set XT2CLK on
UCSCTL5 |= DIVS_1; // SMCLK-divider = 2 (26/2 MHz)
```

- Core voltage level must be 3.
- Application must not disable interrupts.

3.3.4.2 NanoSocket Debug Interface

The NanoSocket library provides a debug interface that can print out debug information on the CC430 UART to display on a terminal program on a PC. The NanoSocket Debug Interface is enabled by compiling the CC430 project with NS_DEBUG enabled, see Figure 13. By not including the NS_DEBUG during compile time the UART is free to use for the user application. The UART settings for the Debug Interface are 115200, 8N1, no flow control.

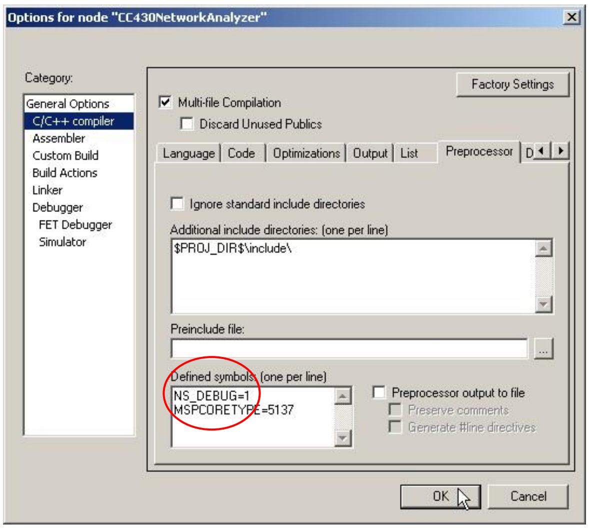


Figure 13. Enabling the NanoSocket Debug Interface

An example of a debug printout is shown below.

```
APP: RF MAC is:
0x00:0x12:0x4B:0x00:0x00:0x0E:0x20:0x17
APP: INIT OK!
Looking for access point...

Connection information:
-----------------------
HWaddr:00124B00000E2017
inet6: 20010000000000000000FFFE004227
parent:20010000000000000000FFFE00D734
Access point:20010000000000000000FFFE000000
hop:    2
-----------------------
Hello world!
```

It is also possible to send data to the CC430 node via the debug interface. Sending ‘h’ to the CC430 Network Analyzer example application will print out “Hello World!” on the debug interface. For more information and details on using the debug interface see the Network Analyzer example application IAR project for CC430.

3.3.4.3 Getting started with application development for CC430 (NanoSocket)

1. Open IAR Embedded Workbench for MSP
2. Open workspace CC430NetworkAnalyzer.eww
3. Connect EM430F5137RF900 via MSP-FET430UIF Debugger to your PC
4. Select Debug or Release, depending on if you want to debug or just download the hex file to the CC430 based board from the workspace panel.
5. Click Download and Debug in the menu, or use Ctrl-D
6. Click start, or F5.

Note: Debug using breakpoints when running a 6LoWPAN network is not possible, since the 6LoWPAN stack is implemented as a real time OS and the nodes are time synchronized. However debug can be used before stack is initialized. Use the debug interface described in 3.3.4.2 to print debug information when NanoStack is running.

3.3.5 *Programming the boards*

This section describes two alternatives on how to program the different boards. The boards can either be programmed directly from IAR EW, alternatively if the hex files already exist, the TI Flash Programmer tool can be used. In either case the node (either CC430 or CC1180DB) will have to be connected to the PC via the MSP-FET430UIF Debugger with a USB connection. The following section describes the steps needed to build the projects and download hex files to the hardware using IAR EW.

3.3.5.1 IAR Embedded Workbench (Can only be used on CC1180DB)

1. Open IAR Embedded Workbench for MSP
2. Open the workspace file NanoHOEX.eww with IAR. This file is found in the subfolder \Sources in the folder where you unpacked the CC-6LOWPAN-DK-868 Applications Examples zip file.
3. There are two different configurations for the IAR project; Release and Debug. Use Debug for debugging your source code and release to build smaller hex files without debug information in it.
4. Select Project->Rebuild All. This will perform a full rebuild on the selected project.
5. Connect the CC1180DB board to program to the MSP-FET430UIF Debugger.

6. Connect the MSP-FET430UIF Debugger to the PC with a USB cable.
7. Select Project->Debug to program the MSP430 (application (host) processor on the CC1180DB).
8. Stop the debugger by selecting Debug -> Stop Debugging.
9. Repeat steps 7 to 8 to program additional boards.

3.3.5.2 TI Smart RF Flash Programmer (Can be used on CC430 and CC1180 host MCU)

This procedure is needed since all nodes have an IEEE (i.e. MAC) address that needs to be unique within the 6LoWPAN network. All CC1180 chips has that pre-programmed from TI, however for the CC430 the nodes have the IEEE address stored in the Flash memory at location 0xFF70. Thus the IEEE address has to be written to that flash address in order for the nodes to be able to function. There are several ways of doing this; one way is to use this line of code in the CC430 software:

```
__root __code const uint8_t hard_coded_mac[8] @ 0xff70 = {0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08};
```

This will place the value 0x0102030405060708 at flash address 0xFF70.

Another (more complex) way is to modify the .hex file before it is downloaded to flash on CC430. This is described here, this example adds the IEEE address 00:12:4B:00:00:0E:20:16 to the hex file. You will have to change the IEEE address to your node specific address, for the kit the IEEE address can be found on a sticker on the node.

- Open CC430NetworkAnalyzer.hex e.g. in Notepad.
- Insert `:08FF700000124B00000E2016E8` on the 5th line from the bottom. Do not erase any line, simple add this line to the hex file.
- Save file as e.g. CC430NetworkAnalyzer_N2016.hex and close Notepad.
- Connect the EM-CC430F5137-900 board to MSP-FET430UIF Debugger
- Use Smart RF Flash Programmer to download the hex file CC430NetworkAnalyzer_N2016.hex to the CC430 board.

To add the address `00:12:4B:00:00:0E:17` you would add the line:

`:08FF700000124B00000E2017E7`

Hint; if you increase the IEEE address by one you decrease the CRC (last byte) with one.

The hex file is constructed like this:

`:08FF700000124B00000E2017E7`

Start code

Byte count

Address

Record type

Data (in this case the IEEE/MAC address)

CRC

3.4 Sensinode NAPSocket API

This API is used on a host processor that communicates with the CC1180 network processor via a UART interface. The main goal for the NAPSocket library is to provide a simple way for users to work with NanoStack 2.0 lite CC1180 Network Processor. The user is able to use NAP protocol configuration commands via a simple command interface. Since the NAP protocol also provides transmissions of 6LoWPAN messages, the interface introduces a socket interface to be use with the library. The user is able to send data packets through the socket interface the library converts messages to the NAP protocol format. The library is a parser library, which means that it's the user's responsibility to create suitable drivers and operating system for the chosen platform.

All details on the NAPSocket API are found in the Sensinode documentation [12].

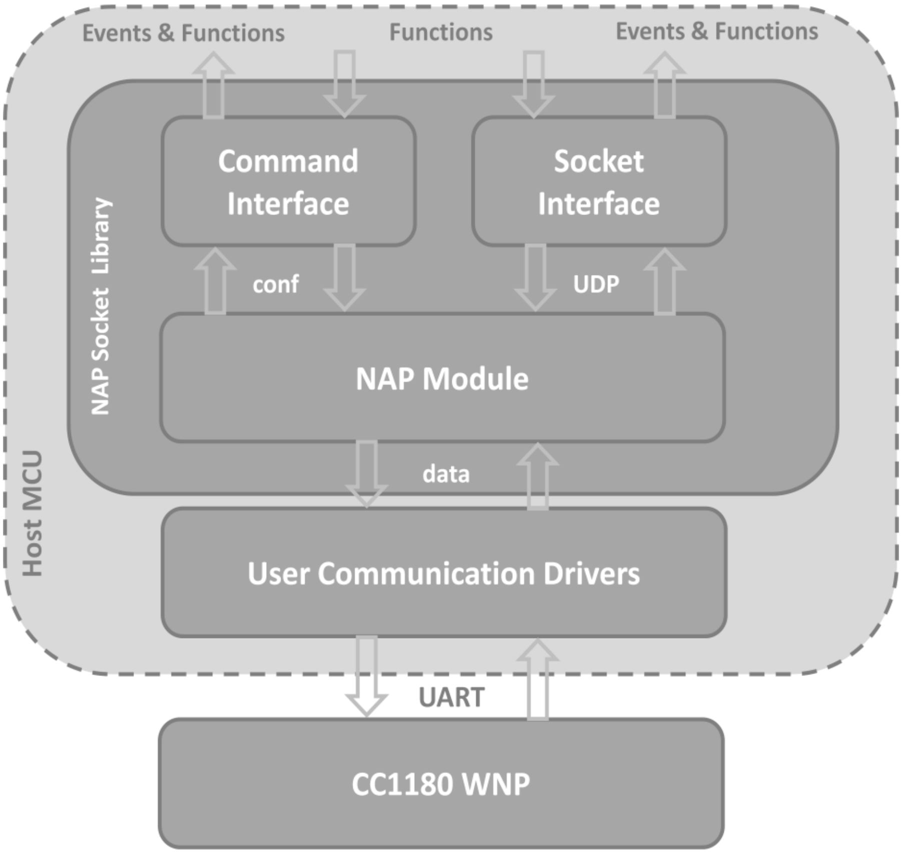


Figure 14. Sensinode NAPSocket library

3.4.1 *Sensinode NAP Protocol API*

The Sensinode NAP interface protocol is used to access the functionality provided by the CC1180 Network Processor with Sensinode NanoStack 2.0 lite. The NAP protocol has been specifically designed to be used over UART. The NAP protocol has been designed to be an easy-to-parse, low-overhead serial protocol that has enough flexibility and extendibility for the Sensinode NanoStack 2.0 Network Processors. The potentially limited serial port data rates have imposed the need for a very low overhead compared to the actual payload data. The NAP protocol defines two main types of packets

· Config for all configuration messages (request and replies) and status queries & answers

· Data for all data communication

The Sensinode NAP protocol can be used directly without NAPSocket library to communicate with the CC1180.

All information about the NAP Protocol API can be found in the Sensinode document [9].

3.5 Sensinode NanoSocket API

This API is used on a CC430 device running both the Sensinode 6LoWPAN stack and the user application. The user is able to use configuration commands via a simple command interface. A socket interface provides transmissions of 6LoWPAN messages. The library contains a sophisticated operating system called NanoStack 2.0, which means that user doesn't need to implement drivers and operating system for the chosen platform.

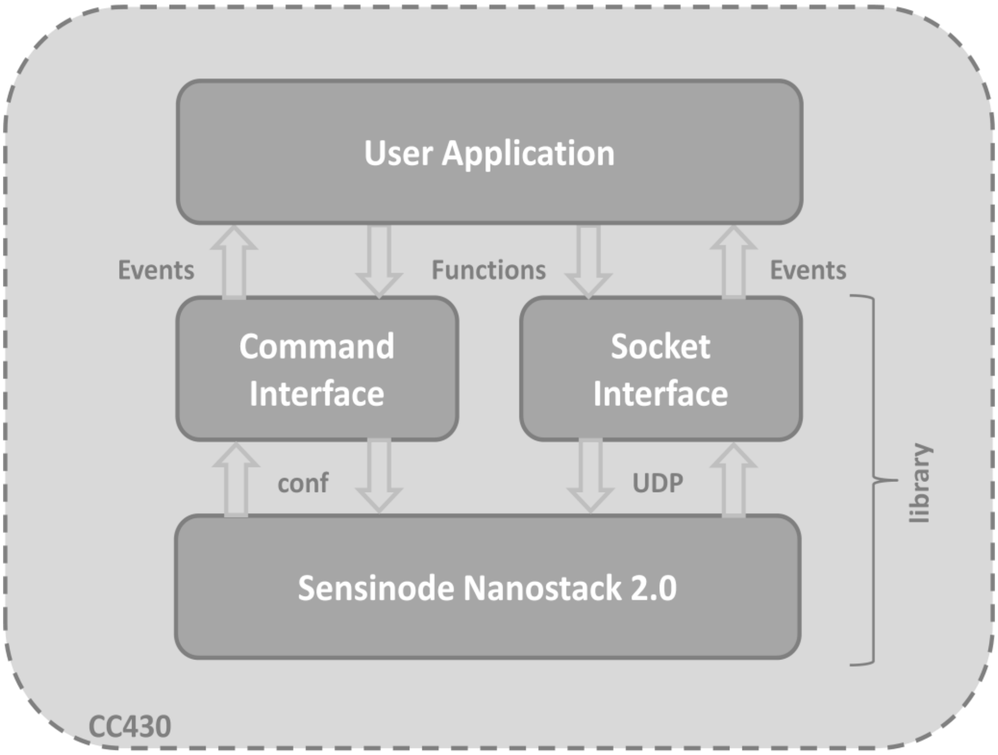


Figure 15. Sensinode NanoSocket API

The NanoSocket API is described in the Sensinode document [8].

3.6 Sensinode RF Dynamic Configuration API

To change RF configuration settings the Dynamic RF Configuration API is used. The API is basically the same both for CC1180 NWP and for CC430 SOC, with minor differences.

Using the API one can make set the following:

- Data rate; 50, 100, 150 and 200kbit/s
- Channel spacing, Frequency spacing between two adjacent channels can be set to 200 or 400 kHz. Only used in FHSS systems.
- Modulation Index, this setting changes the deviation used in GFSK modulation. Possible values for the modulation Index is 0.5 and 1. The deviation is calculated by:

$$\pm f_{dev} = \frac{Modulation\ Index * Data\ Rate}{2}$$

- Base Frequency, for single band system this sets the used channel. For multi band (FHSS) systems this sets the leftmost frequency.
- TX Power level, PA_TABLE0 setting for CC1180 and CC430.
- RX Attenuation, set RX attenuation levels in order to avoid saturation.
- Frequency hopping, Enabled / Disable FHSS. Enables 50 channels FHSS mode. In FHSS mode the base frequency sets the lowest frequency used (leftmost). If FHSS is disabled the base frequency sets the used operating channel.

The RF Dynamic Configuration API is described in [13].

3.6.1 *NanoSocket*

This section describes how to use the Dynamic RF Configuration API in the NanoSocket on CC430 nodes.

```
//default settings for RF interface
```

```
static rf_conf_settings_t rf_configurations = {DATA_RATE_50, CHANNEL_SPACING_200, MODULATION_INDEX_10, 0x21,0x65,0x6a, 0xc3, RX_ATTENUATION_0dbm};

rf_conf_set_params(&rf_configurations); //Set RF Config for CC430
```

The data rate parameter can have the following values: `DATA_RATE_50`, `DATA_RATE_100`, `DATA_RATE_150` and `DATA_RATE_200`.

The channel spacing parameter can be either `CHANNEL_SPACING_200` or `CHANNEL_SPACING_400`.

Modulation index parameter can be set to `MODULATION_INDEX_10` or `MODULATION_INDEX_05`.

The values `0x21, 0x65, 0x6a` in the above example, give the used frequency. The values correspond to the FREQ2, FREQ1 and FREQ0 registers. The values can be obtained from the SmartRF Studio tool, see ti.com for download.

The value `0xc3` in the example above, gives the output power. `0xc3` corresponds to 10dBm output power, use values from data sheet for CC430.

In order to enable FHSS, the function net_enable_fhss() is called. Please see CC430F5137 Library Model Network Analyzer Example project for details.

3.6.2 *NAPSocket*

This section describes how to use the Dynamic RF Configuration API in the NanoSocket on CC1180 nodes.

```
//rf configurations to load...

static rf_conf_settings_t rf_config = {DATA_RATE_50, CHANNEL_SPACING_200, MODULATION_INDEX_10, 0x21, 0x65, 0x6a, 0xc2, RX_ATTENUATION_0dbm, FHSS_DISABLED};

rf_conf_set_params(&rf_config);
```

Please see NanoSocket section for a complete description of the API. The only difference is that FHSS can be enabled and disabled using the `FHSS_DISABLED` parameter. See the CC1110 data sheet SWRS033.pdf, for configuration of the output power parameter.

3.6.3 *Node View 2.0*

This section describes how to change RF Configurations for the Edge Router using the Sensinode Node View 2.0 tool.

1. Double click on the Router whose RF configuration you want to change in the Router View tab.
2. Click on the button “Remove Interface”
3. Click on the button “Create Interface”
4. Fill in the setting you want and click “Add”

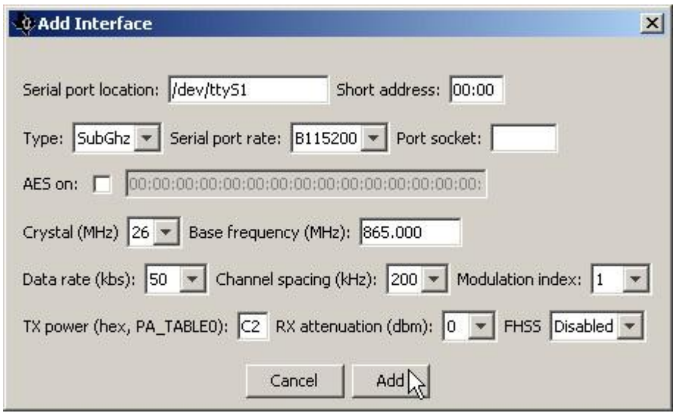


Figure 16. Setting RF Configuration on Edge Router

The NanoRouter software running on the Edge Router saves the RF configuration settings in the file `/last/configFiles/rf_configuration_ttyS1.conf`

An example of this file is shown below.

```
root@da850-omapl138-evm:~/last/configFiles# cat rf_configuration_ttyS1.conf
Interface Id=0
Crystal=26
Data rate=50
Channel spacing=200
Modulation index=10
Base frequency=2180332
TX power=194
RX attenuation=0
Freq. hopping=0
```

3.7 Sensinode NanoBoot API

Loading the Sensinode NanoStack 2.0 lite 6LoWPAN stack to CC1180 is performed using Sensinode NanoBoot API. The CC1180 contains a bootloader called Sensinode NanoBoot, which is used to load the stack and to perform other tasks such as setting and getting the MAC address and toggle between application and bootloader mode.

All details are found in [15].

3.7.1 *Sensinode NanoBoot host tool*

One example application to perform stack update/download and interact with the NanoBoot is provided by Sensinode, the application is called Sensinode NanoBoot_host. The application is available for standard Linux environment and the OMAP-L138 Edge Router board.

The application is located in the `/tools` folder on the Edge Router and can be started on the Edge Router board by:

```
root@da850-omapl138-evm:~/tools# ./NanoBoot_host_10_8552 /dev/ttyS1 ENCRYPTED_CC
1180_AP_FW.hex
```

When the application is started one has to make sure that the CC1180 is in bootloader mode, otherwise it won't be able to interact with the NanoBoot_host tool. Press 1 [ENTER] and then 6 [ENTER] to toggle mode. The present mode is e.g. identified by the LED on the Adapter Board for OMAP-L138, see Table 1 and [15].

Below is the user interface for the Sensinode NanoBoot_host tool.

```
NanoBoot 1.0
Firmware version info:  01 10 01 00 23 93
1
Select packet type:
0. Check mac address (sanity check)
1. Write binary ENCRYPTED_CC1180_AP_FW.hex
2. Set MAC address.
3. Switch to application mode
4. Firmware versions
6. Toggle GPIO line (For mode change).
```

3.8 Sensinode NodeView 2.0 Custom tabs

The network analyzer tool Sensinode NodeView 2.0 can be extended with custom tabs that can run user applications. This is a very powerful feature since it enables users to quickly develop applications that can communicate with the nodes in a 6LoWPAN network without writing the application from the start. This chapter describes setting up a project in Eclipse IDE to develop custom tabs, and how to integrate those in the NodeView 2.0 application. The NodeView 2.0 folder contains by default an example of a custom tab called “ExampleTab”, the source code can be found at `..\NodeView 2.0\TabProject\src\tabs\exampleTab`

3.8.1 *Developing applications to run in custom tabs in NodeView 2.0*

This simple guide describes setting up an eclipse project using Eclipse IDE for Java Developers version: Helios Service Release.

1. Create a new java project by right-clicking in the package explorer field, and select new -> Java project.

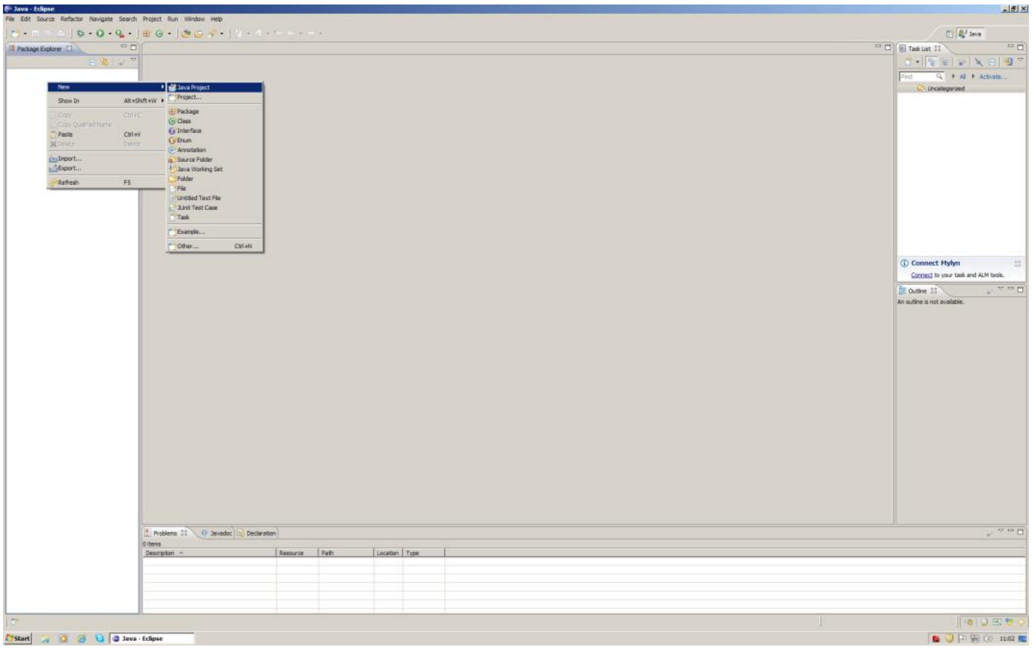


Figure 17. Creating Eclipse project for NodeView 2.0 custom tab

2. Add NodeView 2.0DynPro.jar as an external .jar, by right-clicking your project and select properties -> add external JARs.
3. Create a folder structure as in the screen dump below. NodeView 2.0 will search in the folder “src” for custom tabs, if found they will be displayed in NodeView 2.0. This example will display a custom tab called “LightDemoTab”, similar to the included “ExampleTab”.

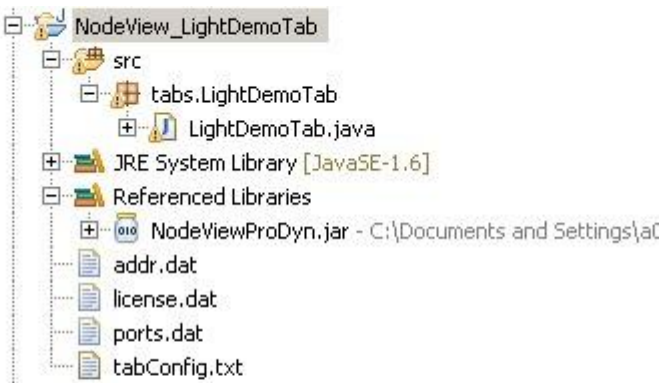


Figure 18. Folder structure for custom tabs

4. Include license.dat and create/include tabConfig.txt in the project root. Addr.dat and ports.dat will be created automatically.
5. Create your tab into the folder “src”, the LightDemoTab is shown as an example. Included in software release is a custom tab called “exampleTab”. There is a JAVADOC API included in

the folder ..\NodeView 2.0\TabProject\APIDoc\index.html in the release that can be used to get familiar with NodeView 2.0 tab interface.

6. Add your tab to the file tabConfig.txt as in Figure below; please note that tabConfig.txt must contain a single empty line after the last class definition.

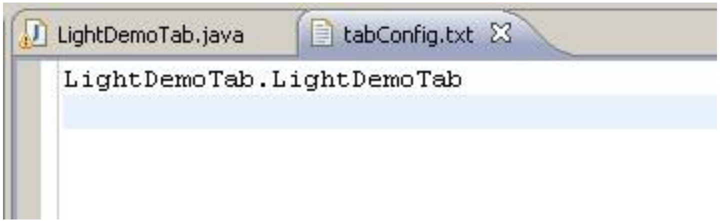


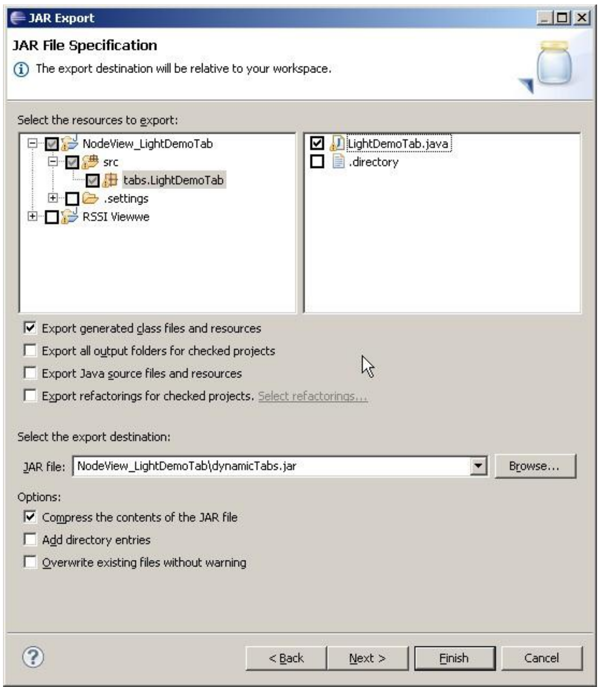
Figure 19. tabConfig.txt file

7. Click NodeViewProDyn.jar and select “Run” from the Run menu. Select NodeviewD – NodeViewDyn to run main.
8. NodeView 2.0 is now including your custom tab.

3.8.2 *Exporting custom tabs to run as stand alone*

When you are finished with the development of your custom tab (or tabs) you can include it to run as a standalone application inside NodeView 2.0. When one launches NodeView 2.0 it looks for the file dynamicTabs.jar if found it will use the file to display your custom tabs. Follow these steps to export your custom tab (or tabs) to a .jar file that NodeViewProDyn.jar (NodeView 2.0) will find and include.

1. Select (mark) your Eclipse project and go to File -> Export
2. Chose JAR file, then click “Next”
3. Use setting from screen dump below. It is important that you name the exported file “dynamicTabs.jar”, since NodeView 2.0 will look for that file during launch. Please note that old dynamicTabs.jar will be overwritten. (You only need to include your .java files)



4. Click Finish. dynamicTabs.jar will now contain your custom tabs.
5. Make sure that license.dat, tabConfig.txt, NodeViewProDyn.jar and dynamicTabs.jar is in the same folder.

6. Double-click NodeViewProDyn.jar to launch NodeView 2.0, it will now launch your tabs inside NodeView.

3.9 Edge Router (OMAP-L138) software

This chapter gives a brief introduction to how the software environment on the OMAP-L138 is setup. The Edge router is running Linux operating system and the Sensinode NanoRouter 2.0 application is running on top of that. The Linux system is including a standard IPv6 stack, drivers for the UART communication to CC1180EM and drivers for controlling the GPIO pins to CC1180EM.

The Linux kernel is placed on the SPI flash on the OMAP-L138 board, while the Linux file system is placed on the provided SD card.

The Edge Router is setup to use the default IPv6 address `2001::11` and IPv4 address `192.168.1.10`, however if one wants to use auto configuration to connect to the Edge Router that's possible by changing the autoconf variable in the script accordingly, see below.

3.9.1 *Sensinode NanoRouter 2.0*

NanoRouter 2.0 acts as a gateway between 6LoWPAN network and IPv6 network. NanoRouter 2.0 runs on embedded Linux which allows IPv6 networking and serial port communication for RF interfaces. NanoRouter 2.0 consists of NanoRouter 2.0, 6routed, ConfSv and NAPSocketServer processes which each has a special task in order to allow communication from IPv6 Ethernet into a 6LoWPAN network. Current level of implementation of NanoRouter 2.0 is meant for simple 6LoWPAN networks where only a single Edge Router is within RF range. The best way to use multiple routers in the same RF coverage area is to use either different frequencies or AES encryption keys.

When a node connects to the 6LoWPAN network the route to that node is added by nanorouter software into the IPv6 routing table, this means that one can get a list of all connected nodes from the Edge Router. Nodes are added into Linux IPv6 routing tables and ND cache behind `tun0` interface by NanoRouter 2.0. Routing table can be read manually by logging in into Edge Router Linux and calling `route -A inet6` from command line. This will list all IPv6 routing information including `tun0` details. The Sensinode nanorouter 2.0 also provides an API to get/set information such as configuration, whiteboards etc form the Edge Router.

The Sensinode NanoRouter 2.0 is described in detail in [6].

3.9.2 *Startup scripts*

When the Edge Router boots up a script called snif.sh is executed, this sets up the networking variables.

Snif.sh script:

```
#!/bin/sh
sysctl -w net.ipv6.conf.all.proxy_ndp=1
sysctl -w net.ipv6.conf.all.forwarding=1
sysctl -w net.ipv6.conf.all.autoconf=0

sysctl -w net.ipv6.conf.default.proxy_ndp=1
sysctl -w net.ipv6.conf.default.forwarding=1
sysctl -w net.ipv6.conf.default.autoconf=0

sysctl -w net.ipv6.conf.eth0.proxy_ndp=1
sysctl -w net.ipv6.conf.eth0.forwarding=1
sysctl -w net.ipv6.conf.eth0.autoconf=0

ifconfig eth0 add 2001::11/64
ifconfig eth0 192.168.1.10
```

When the boot process of the Edge Router is finished the nanorouter application is executed from the script nanorouter-up.sh.

```
#!/bin/sh
#echo "if_full.txt:"
cd /home/root/last/configFiles/
cp default.txt if_full.txt
echo "Starting NanoRouter:"
cd /home/root/last/
./nanorouter>/dev/null&
```

The two scripts (snif.sh and nanorouter-up.sh) that controls the boot process is located in `/etc/init.d/`

3.9.3 *Linux folder structure*

The Linux kernel and the file system are running on the Secure Digital (SD) card connected to the Edge Router. *Do not remove the SD card while OMAP-L138 is powered on since this will cause Linux OS to crash.*

The SD card has two partitions; one FAT32 partition called boot which holds the Linux kernel image, and one ext3 partition which holds the file system including the NanoRouter 2.0 application and tools.

The NanoRouter 2.0 application is located in the home/root/last folder.

3.9.4 *Sensinode NanoBoot host tool*

The Sensinode tool NanoBoot host that can be used on the Edge Router to update the stack on the CC1180EM attached to the OMAP is located in the folder /home/root/tools. In the same folder is a hex image file that contains the 6LoWPAN stack for use on CC1180EM. Launch the tool by entering the following on the command line:

```
root@da850-omapl138-evm:~/tools# ./NanoBoot_host_10_8552 /dev/ttyS1 ENCRYPTED_CC1180_AP_FW.hex
```

For more information on how to use the NanoBoot host tool, please see Sensinode NanoSocket API in chapter 3.5.

3.9.5 *Debug/console interface*

A console interface is available in the Edge Router. Simply connect the attached RS-232 cable to the RS-232 connector on the Edge Router and to your PC. Open a terminal program with the settings: Baud rate: 115200, Data: 8bit, Parity: none, Stop: 1bit, Flow control: none

You log into Linux by entering `root` as username, no password is required.

It is also possible to reach the Linux environment via telnet, use a telnet client and open a session to either `2001::11` or `192.168.1.10`, which is the default IPv6 and IPv4 addresses for the Edge Router. Log into Linux with by entering `root` as username, no password is required.

4 Hardware

This chapter describes all the different hardware components that are included in the kit.

4.1 EM430F5137RF900

The EM430F5137RF900 contains a CC430F5137 SoC running both the Sensinode 6LoWPAN stack and the user application. Full reference design for EM430F5137RF900 can be found here: http://focus.ti.com/docs/toolsw/folders/print/em430f5137rf900.html

This chapter describes the EM430F5137RF900 hardware.

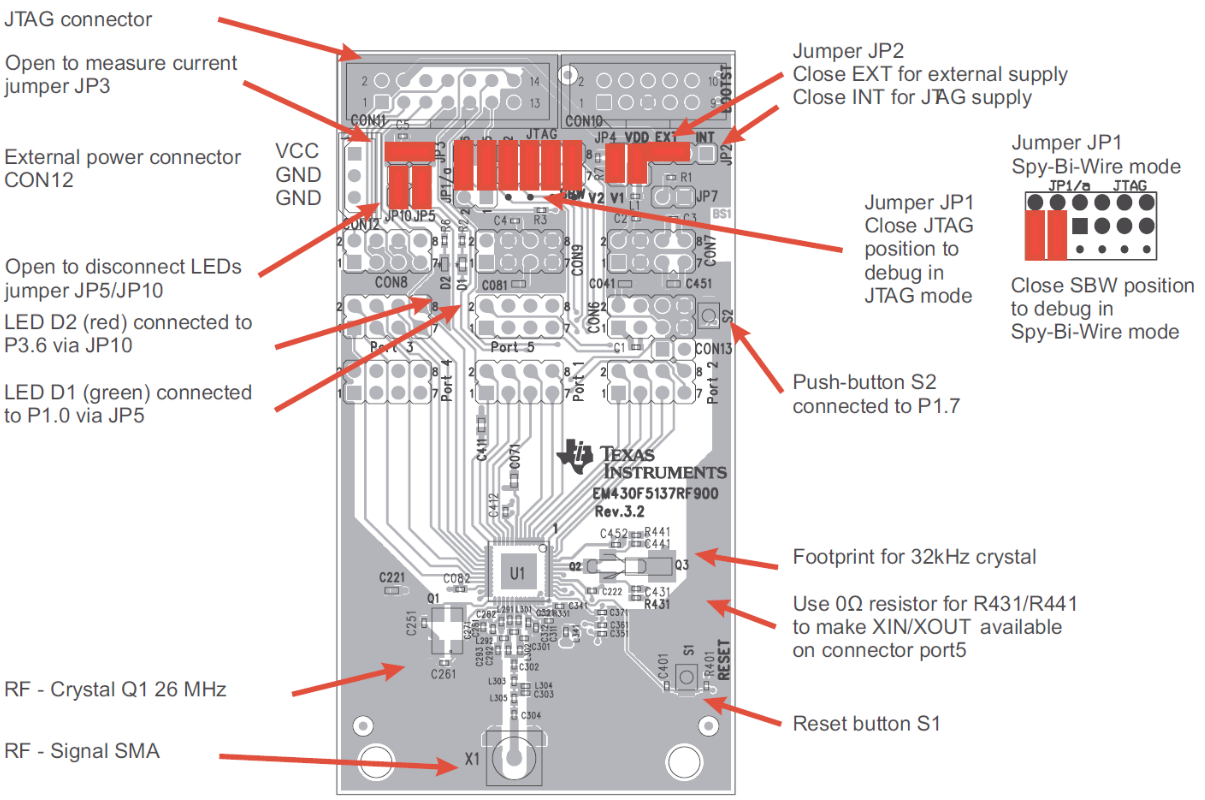


Figure 20. EM430F5137RF900, Logical Description

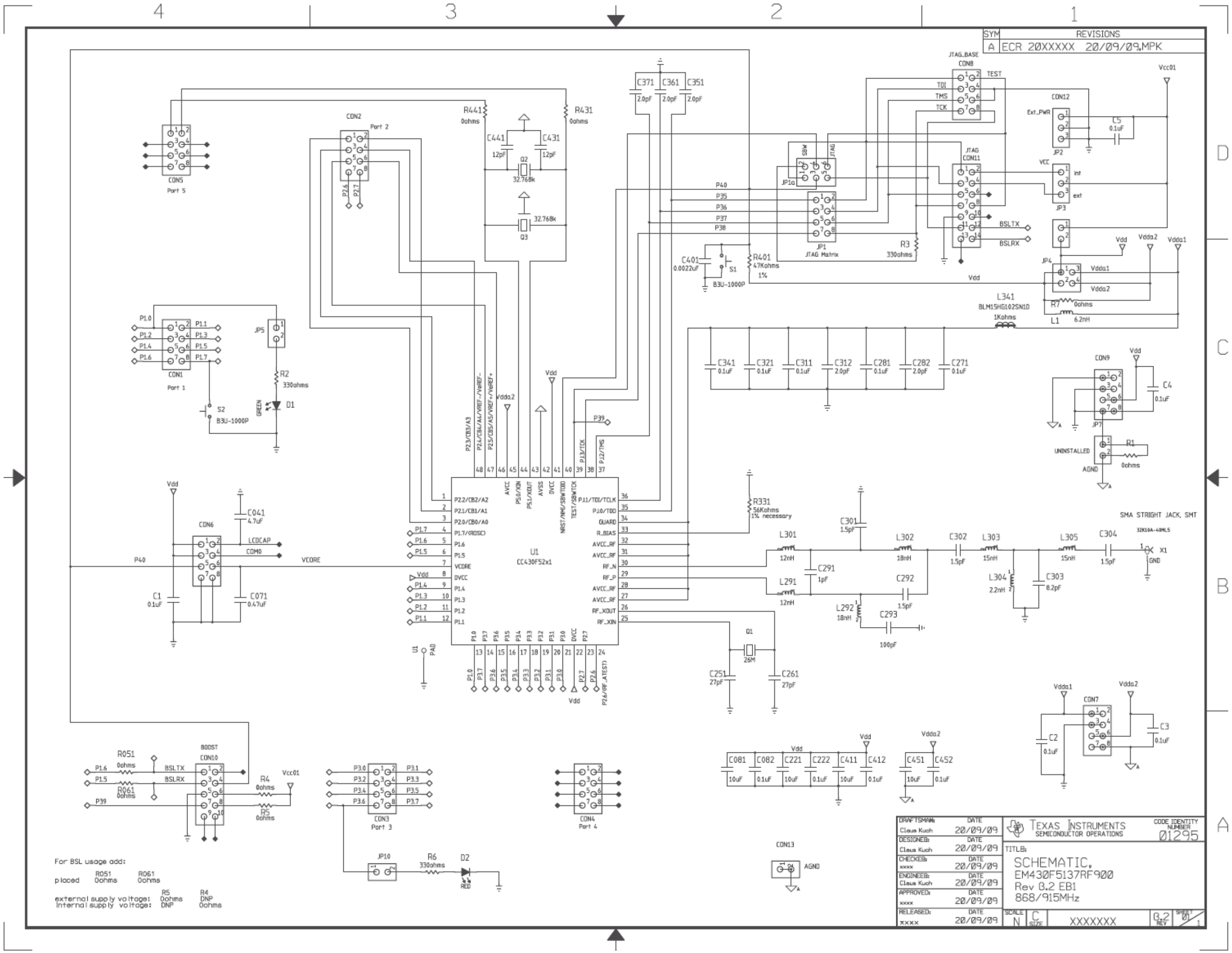
4.1.1 *Programming/Reprogramming the EM430F5137RF900*

- Connect the MSP-FET430UIF Debugger to the JTAG connector (CON11) using the 14 pin JTAG cable.
- Connect the MSP-FET430UIF to your PC with the supplied USB cable.
- Use IAR Embedded Workbench or TI Smart RF Flash programmer to download your software to the CC430 SoC, as described in 3.3.4.1.

4.1.2 *Debug Interface using UART*

The Debug interface that can be used in NanoSocket is using UCA0 UART. The RX pin can be found on EM430F5137RF900 Port1. 7 (CON5.7) and the TX pin on P1.6 (CON5.6). GND can be found on CON9.7. See 4.1.3 for details.

4.1.3 *Schematics, BOM and Layout*



Power Management

VCC01 = external VCC

Vdd = DVCC

Vdda1 = A/DD_RF / A/CC_RF

Vdda2 = A/CC

Port connectors

CON1 ..

CON3 = Port1 .. Port3 of cc430

CON4 = spare

CON5 = 1: XIN 2: XOUT

CON6 = Vdd, GND, Vcore, COM0, LCDCAP

CON7 = Vdda1, Vdda2, GND, AGND

CON8 = JTAG_BASE (JTAG_Port)

CON9 = Vdd, GND, AGND

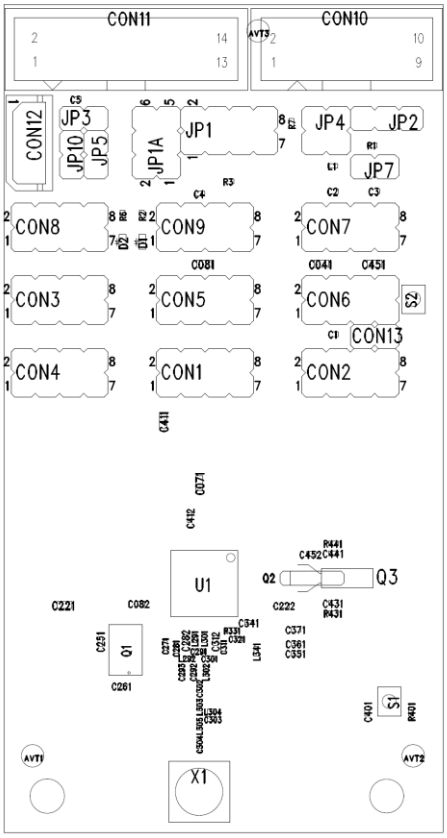


Figure 21. EM430F5137RF900, PCB Components Top Layer

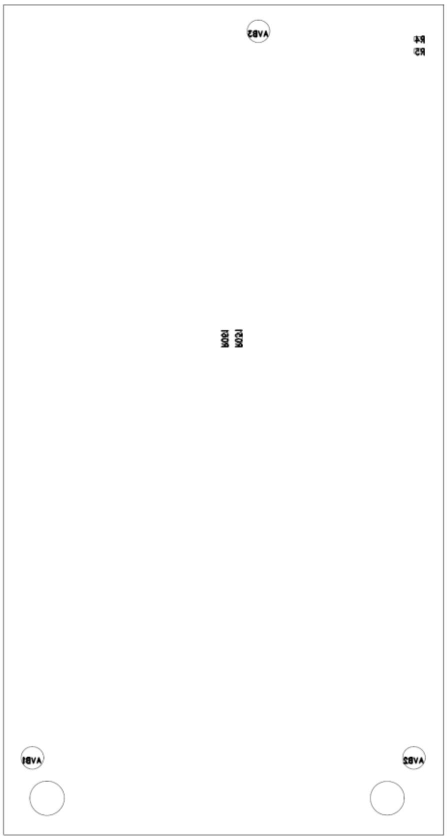


Figure 22. EM430F5137RF900, PCB Components Bottom Layer

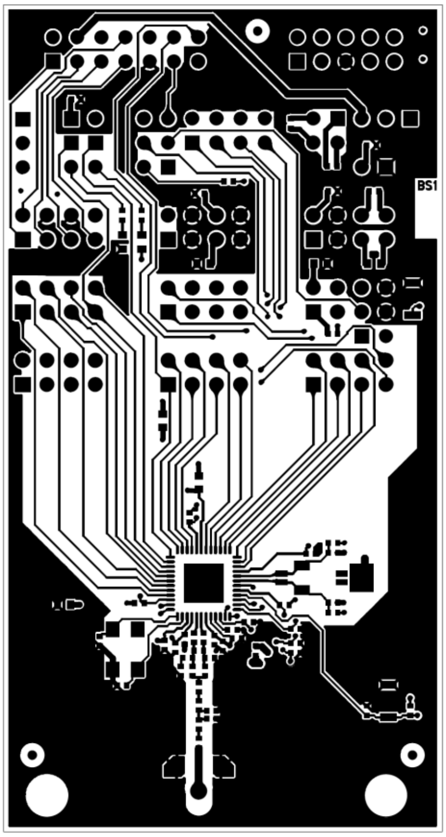


Figure 23. EM430F5137RF900, Layout Top Layer

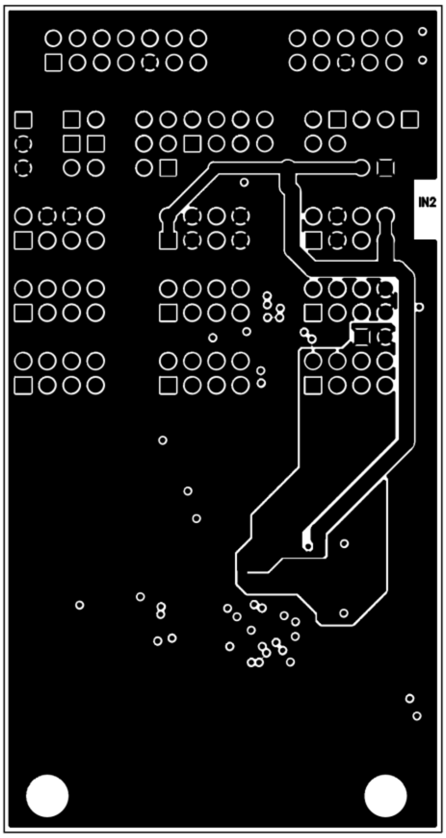


Figure 24. EM430F5137RF900, Layout Layer 2

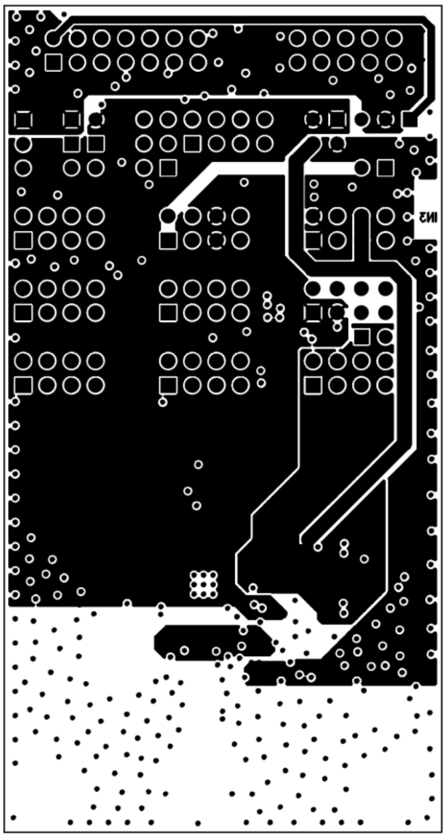


Figure 25. EM430F5137RF900, Layout Layer 3

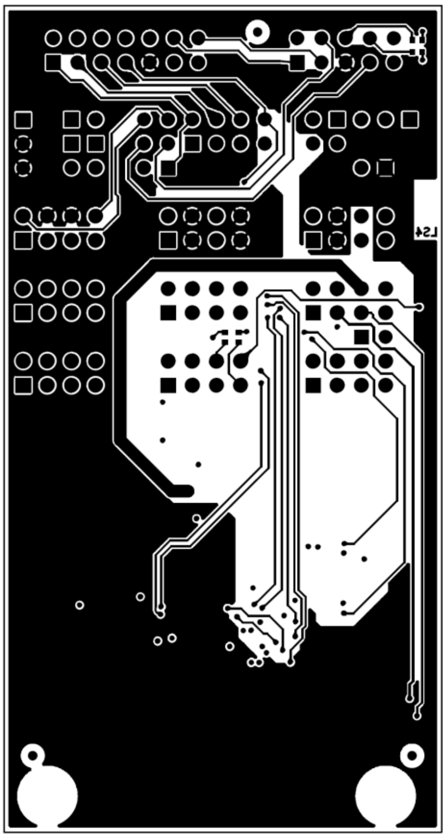


Figure 26. EM430F5137RF900, Layout Bottom Layer

Item	Reference	Qty	Description	Value	Part Number	Manuf.
1	Q1	1	(CUSTOMER SUPPLY) CRYSTAL, SMT, 4P, 26MHz	26M	ASX-531(CS)	AKER ELECTRONIC
2	C1-C5, C082, C222, C271, C281, C311, C321, C341, C412, C452	14	CAPACITOR, SMT, 0402, CER, 16V, 10%, 0.1uF	0.1uF	0402YC104KAT2A	AVX
3	C071	1	CAPACITOR, SMT, 0603, CERAMIC, 0.47uF, 16V, 10%, X5R	0.47uF	0603YD474KAT2A	AVX
4	R401	1	RES0402, 47.0K	47kΩ	CRCW04024702F100	DALE
5	CON11	1	HEADER, THU, MALE, 14P, 2X7, 25.4x9.2x9.45mm		09 18 514 6323	HARTING
6	CON10	0	HEADER, THU, MALE, 10P, 2X5, 20.32x9.2x9.45mm		09 18 510 6323	HARTING
7	D1	1	LED, SMT, 0603, GREEN, 2.1V	active	APT1608MGC	KINGBRIGHT
8	D2	1	LED, SMT, 0603, RED, 2.0V	active	APT1608EC	KINGBRIGHT
9	Q3	0	UNINSTALLED CRYSTAL, SMT, 3P, MS1V (Customer Supply)	32.768k	MS1V-T1K (UN)	MICRO CRYSTAL
10	CON12	1	HEADER, THU, MALE, 3P, 1x3, 9.9x4.9x5.9mm		22.05.5035	MOLEX
11	C251, C261	2	50V, 5%, 27pF	27pF	GRM36COG270J50	MURATA
12	L341	1	FERRITE, SMT, 0402, 1.0kΩ, 250mA	1kΩ	BLM15HG102SN1D	MURATA
13	C293	1	CAPACITOR, SMT, 0402, CERAMIC, 100pF, 50V, 0.25pF, C0G(NP0)	100pF	GRM1555C1H101JZ01	MURATA
14	L304	1	INDUCTOR, SMT, 0402, 2.2nH, 0.1nH, 220mA, 500MHz	0.0022uH	LQP15MN2N2B02	MURATA
15	L303, L305	2	INDUCTOR, SMT, 0402, 15nH, 2%, 450mA, 250MHz	0.015uH	LQW15AN15NG00	MURATA
16	L292, L302	2	INDUCTOR, SMT, 0402, 18nH, 2%, 370mA, 250MHz	0.018uH	LQW15AN18NG00	MURATA
17	C291	1	CAPACITOR, SMT, 0402, CERAMIC, 1pF, 50V, 0.05pF, C0G(NP0)	1pF	GRM1555C1H1R0WZ01	MURATA
18	C303	1	CAPACITOR, SMT, 0402, CERAMIC, 8.2pF, 50V, 0.05pF, C0G(NP0)	8.2pF	GRM1555C1H8R2WZ01	MURATA
19	C292, C301-C302, C304	4	CAPACITOR, SMT, 0402, CERAMIC, 1.5pF, 50V, 0.05pF, C0G(NP0)	1.5pF	GRM1555C1H1R5WZ01	MURATA
20	L291, L301	2	INDUCTOR, SMT, 0402, 12nH, 2%, 500mA, 250MHz	0.012uH	LQW15AN12NG00	MURATA
21	C282, C312, C351, C361, C371	5	CAPACITOR, SMT, 0402, CERAMIC, 2pF, 50V, 0.1pF, C0G	2.0pF	GRM1555C1H2R0BZ01	MURATA
22	L1	1	INDUCTOR, SMT, 0402, 6.2nH, 0.1nH, 130mA, 500MHz	6.2nH	LQP15MN6N2B02	MURATA
23	S1-S2	2	ULTRA-SMALL TACTILE SWITCH, SMT, 2P, SPST-NO, 1.2x3x2.5mm, 0.05A, 12V		B3U-1000P	OMRON
24	R4-R5, R051, R061, R431, R441	0	UNINSTALLED RESISTOR/JUMPER, SMT, 0402, 0 Ω, 5%, 1/16W	0Ω	ERJ-2GE0R00X	PANASONIC
24a	R7	1	RESISTOR/JUMPER, SMT, 0402, 0 Ω, 5%, 1/16W	0Ω	ERJ-2GE0R00X	PANASONIC
25	R2-R3, R6	3	RESISTOR, SMT, 0402, THICK FILM, 5%, 1/16W, 330	330Ω	ERJ-2GEJ331	PANASONIC
26	C431, C441	0	CAPACITOR, SMT, 0402, CER, 12pF, 50V, 5%, NPO	12pF	ECJ-0EC1H120J	PANASONIC
27	C401	1	CAPACITOR, SMT, 0402, CER, 2200pF, 50V, 10%, X7R	0.0022uF	ECJ-0EB1H222K	PANASONIC
28	R331	1	RESISTOR, SMT, THICK FILM, 56K, 1/16W, 5%	56kΩ	ERJ-2GEJ563	PANASONIC
29	C081, C221, C411, C451	4	CAPACITOR, SMT, 0603, CERAMIC, 10uF, 6.3V, 20%, X5R	10uF	ECJ-1VB0J106M	PANASONIC
30	R1	1	RESISTOR/JUMPER, SMT, 0402, 0 Ω, 5%, 1/16W	0Ω	ERJ-2GE0R00X	PANASONIC
31	C041	0	UNINSTALLED CAP CERAMIC 4.7UF 6.3V X5R 0603	4.7uF	ECJ-1VB0J475K	PANASONIC
32	X1	1	SMA STRIGHT JACK, SMT		32K10A-40ML5	ROSENBERGER

33	Q2	0	CRYSTAL, SMT, 4P, 32.768 kHz	32.768k	SSP-T7-F	SEIKO
34	U1	1	DUT, SMT, PQFP, RGZ-48, 0.5mmLS, 7.15x7.15x1mm, THRM.PAD		CC430F52x1	TI
35	JP1	1	Pin Connector 2x4pin		61300821121	WUERTH
36	CON1-CON9	0	Pin Connector 2x4pin		61300821121	WUERTH
37	JP2	1	Pin Connector 1x3pin		61300311121	WUERTH
38	JP3, JP5, JP10	3	Pin Connector 1x2pin		61300211121	WUERTH
38a	JP7, CON13	0	Pin Connector 1x2pin		61300211121	
39	JP4	1	Pin Connector 2x2pin		61300421121	WUERTH
40	JP1a	1	Pin Connector 2x3pin		61300621121	WUERTH

Table 11. EM430F5137RF900, Bill of Material

4.2 CC1180DB

The CC1180DB contains a MSP430F5438A acting as a host processor and a CC1180 acting as a Wireless Network Processor. The CC1180DB hardware is described in this chapter.

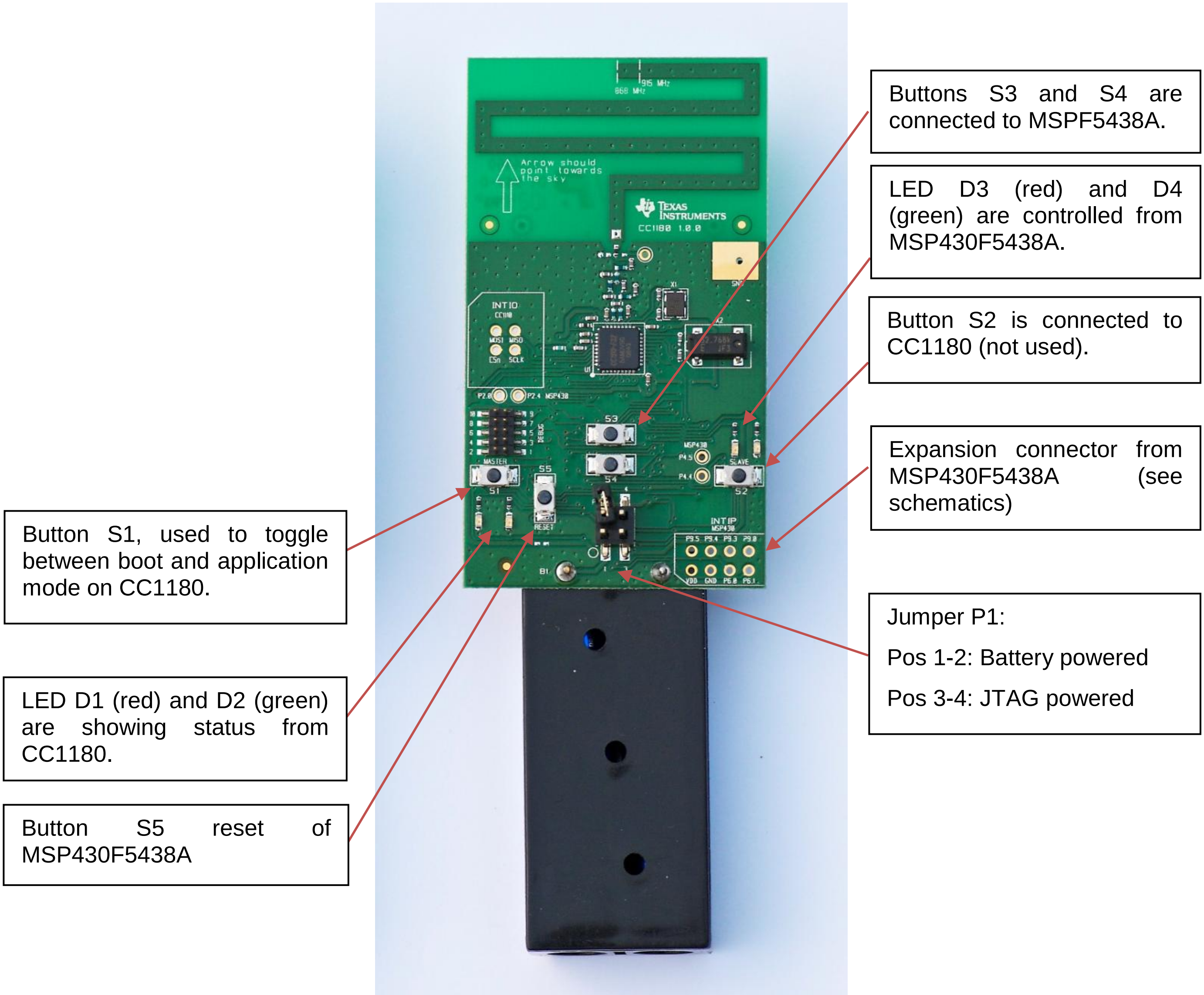


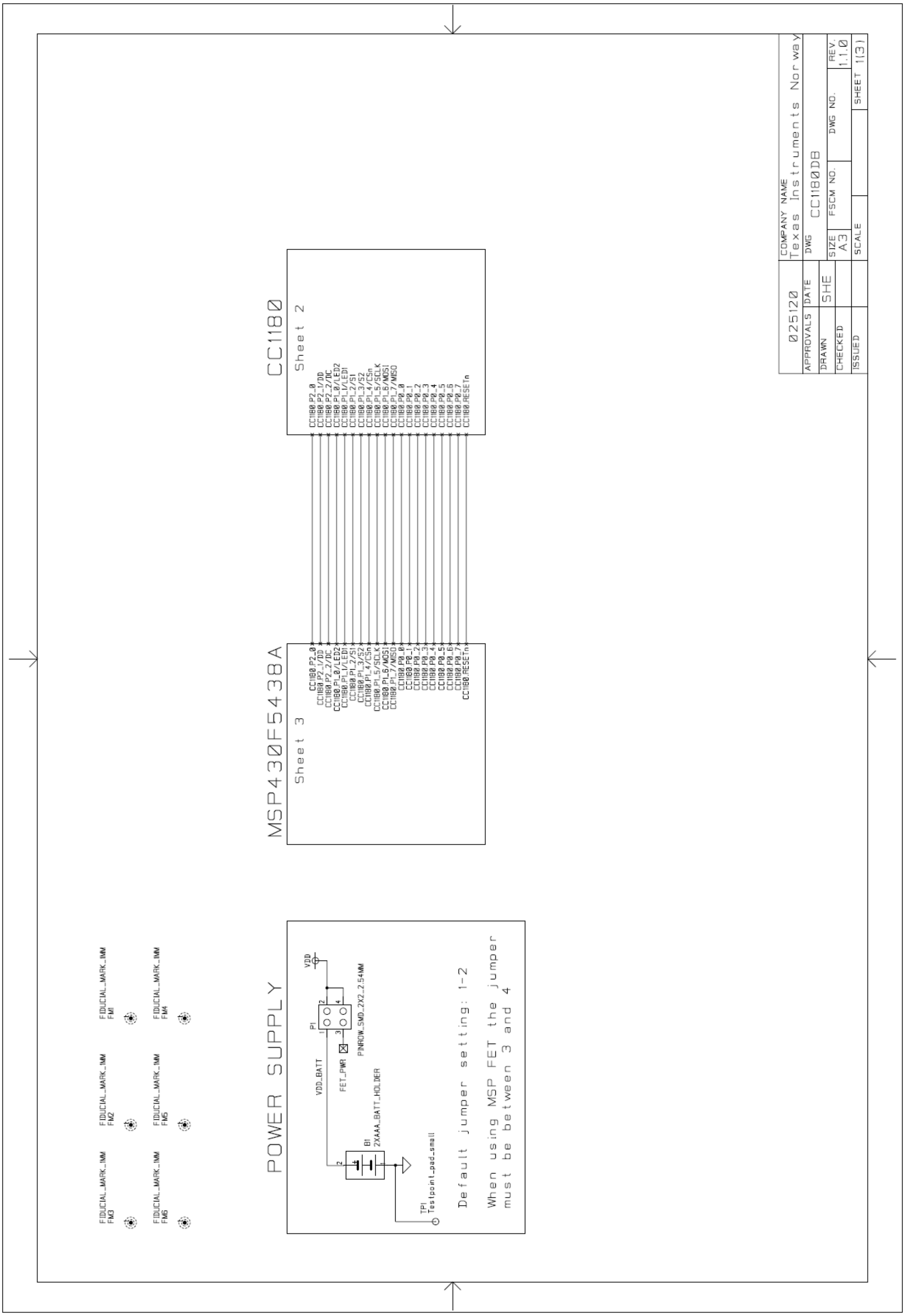
Figure 27. CC1180DB, Logical Description

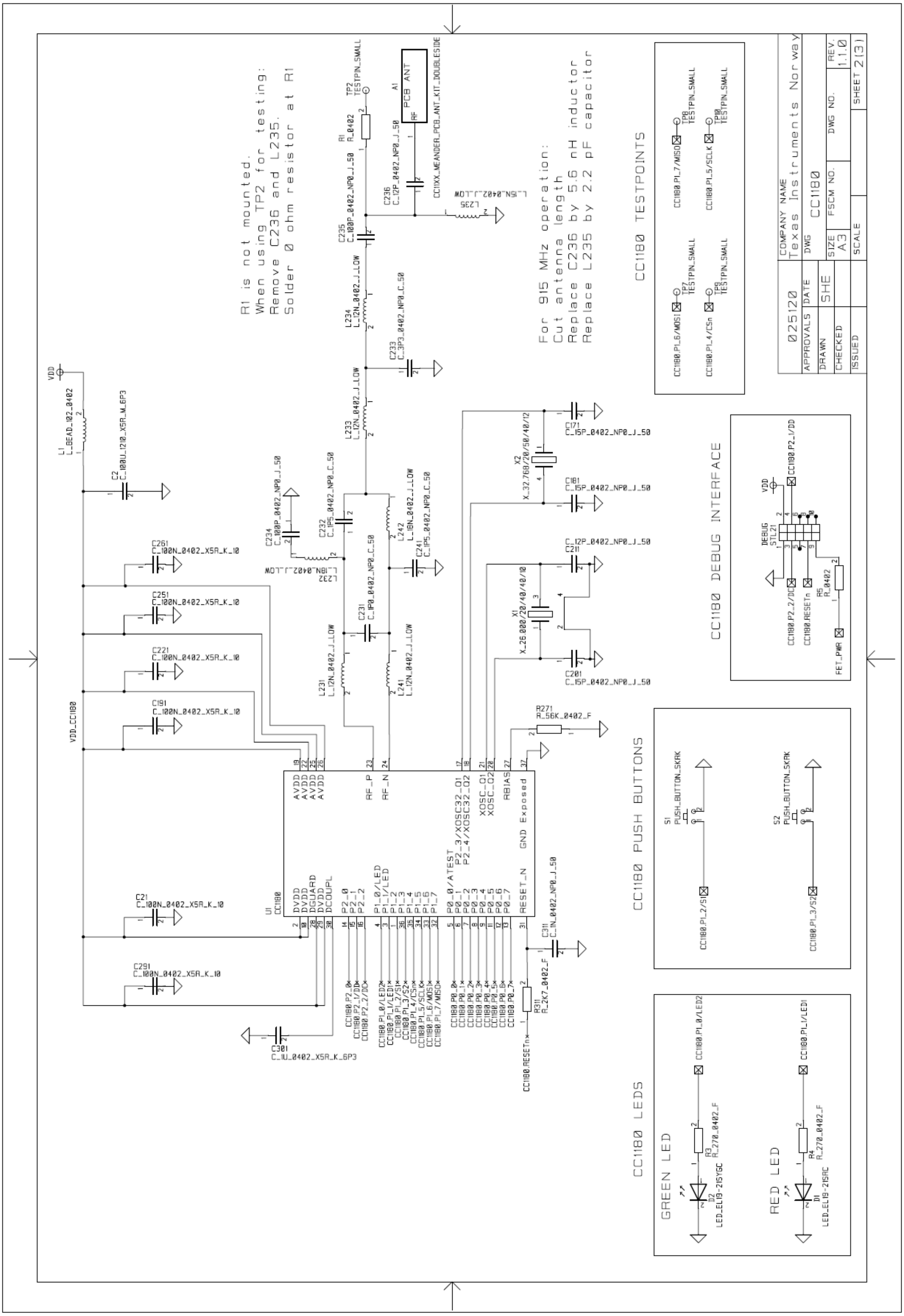
4.2.1 *Programming/Reprogramming the CC1180DB*

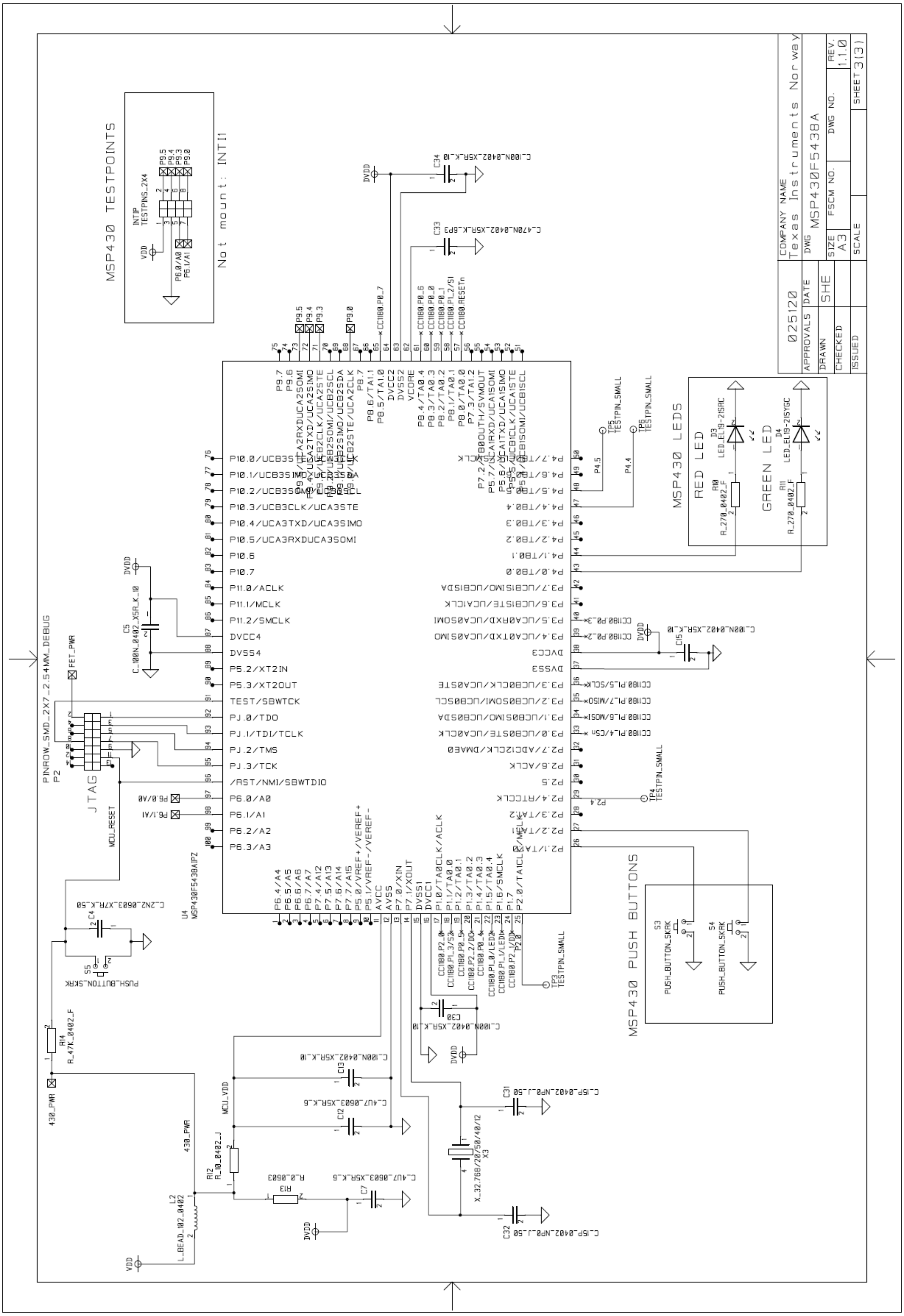
Note: CC1180 has a locked debug interface. The Flash area where the bootloader is placed is protected to prohibit erasure of the NanoStack 6LoWPAN software. Updated of the stack is done via the NanoBoot API.

- Connect the MSP-FET430UIF Debugger to the JTAG connector on the bottom side using the 14 pin JTAG cable.
- Connect the MSP-FET430UIF to your PC with the supplied USB cable.
- Use IAR Embedded Workbench or TI Smart RF Flash programmer to download your software to the MSP430F5438A on CC1180DB, as described in 3.3.4.1.

4.2.2 *Schematics, BOM and Layout*


CC1180
Sheet 2
MSP430F5438A
Sheet 3
POWER SUPPLY
Default jumper setting: 1-2
When using MSP FET the jumper must be between 3 and 4
VDD
VDD_BATT
FET_PWR
PINROW_SMD_2X2_2.54MM
B1
2XAAA_BATT_HOLDER
TP1
Testpoint_pad_small
COMPANY NAME
Texas Instruments Norway
DWG
CC1180DB
025120
APPROVALS
DATE
DRAWN
SHE
CHECKED
ISSUED
SIZE
A3
FSCM NO.
DWG NO.
REV.
1.1.0
SCALE
SHEET 1(3)


R1 is not mounted.
When using TP2 for testing:
Remove C236 and L235.
Solder 0 ohm resistor at R1
For 915 MHz operation:
Cut antenna length
Replace C236 by 5.6 nH inductor
Replace L235 by 2.2 pF capacitor
CC1180 TESTPOINTS
CC1180 DEBUG INTERFACE
CC1180 PUSH BUTTONS
CC1180 LEDS
GREEN LED
RED LED
COMPANY NAME
Texas Instruments Norway
DWG
CC1180
APPROVALS
DATE
025120
DRAWN
SHE
CHECKED
ISSUED
SIZE
A3
FSCM NO.
DWG NO.
REV.
1.1.0
SCALE
SHEET 2(3)


MSP430 TESTPOINTS
Not mount: INTI1
JTAG
MSP430 LEDS
RED LED
GREEN LED
MSP430 PUSH BUTTONS
MSP430F5438AIPZ
COMPANY NAME
Texas Instruments Norway
DWG
MSP430F5438A
025120
APPROVALS
DATE
DRAWN
SHE
CHECKED
ISSUED
SIZE
A3
FSCM NO.
DWG NO.
REV.
1.1.0
SCALE
SHEET 3(3)

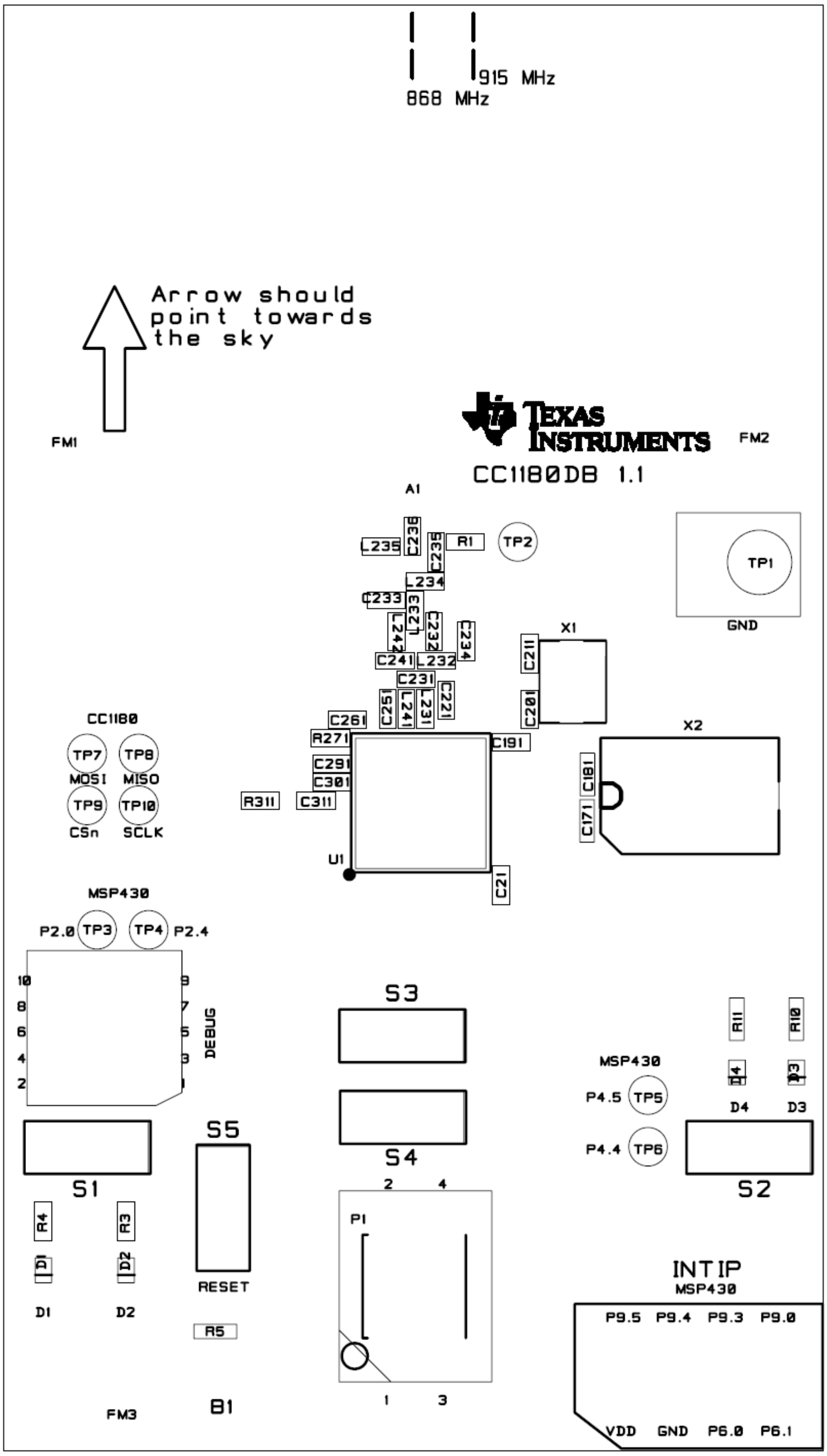


Figure 28. CC1180DB, PCB Components Top Layer

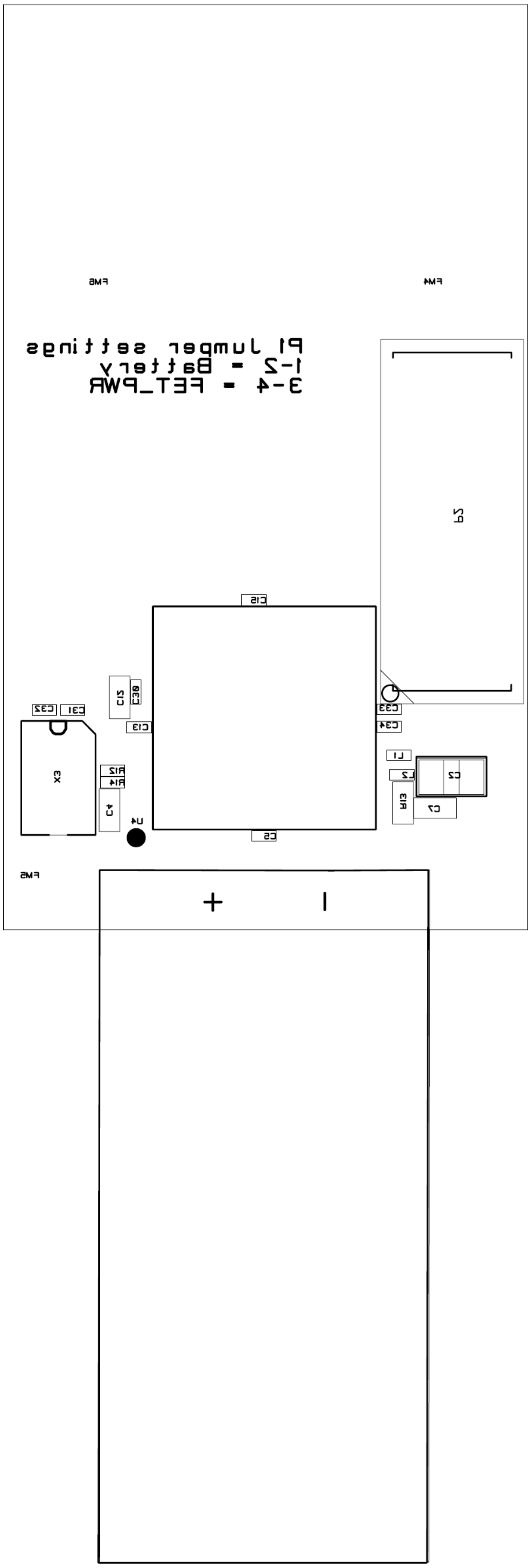


Figure 29. CC1180DB, PCB Components Bottom Layer

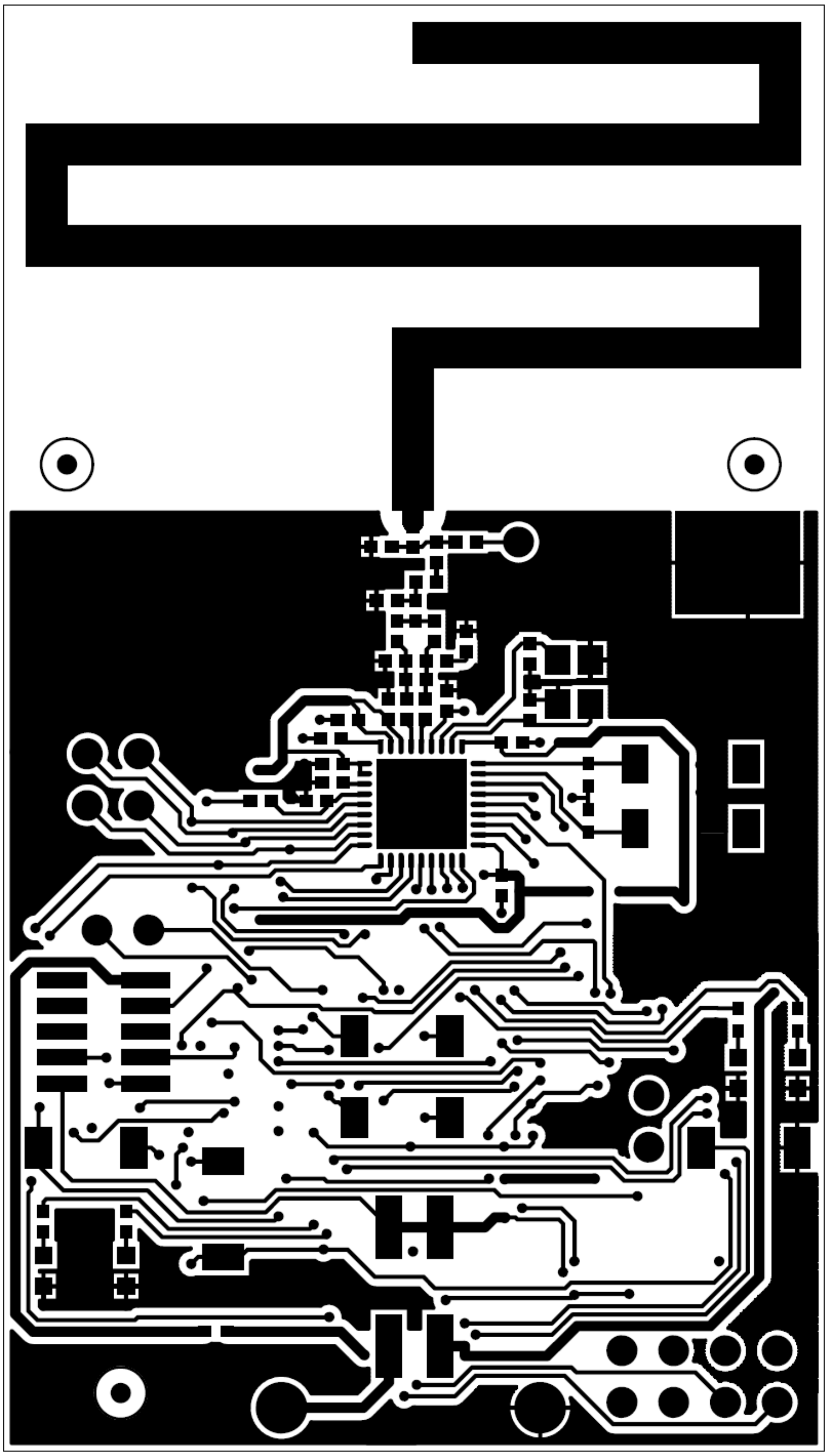


Figure 30. CC1180DB, Layout Top Layer

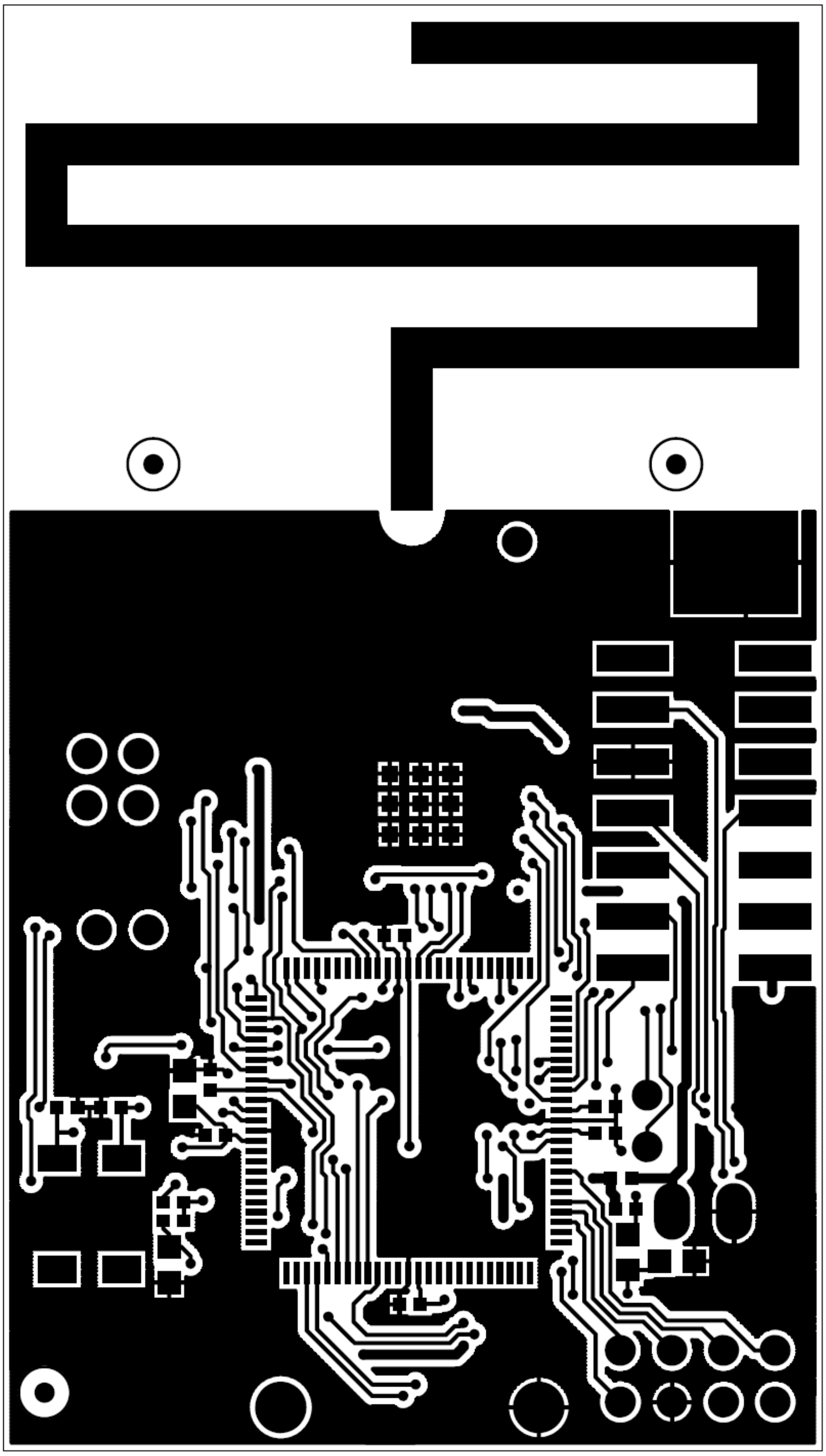


Figure 31. CC1180DB, Layout Bottom Layer

Ref.	Part Name	Pcs/unit	Description	Manuf.	Part Number
B1	2XAAA	1	2xAAA battery holder, 2CELL AAA PC MNT	Keystone	2468
U1	CC1180	1	6LoWPAN Network Processor	TI	CC1180
C5;C13;C15;C21;C30;C34;C191;C221;C251;C261;C291	C_100N_0402_X5R_K_10	11	Capacitor, 100n, 0402, X5R, 10%, 10V	Murata	GRM155R71A104KA01D
C234-235	C_100P_0402_NP0_J_50	2	Capacitor, 100p, 0402, NP0, 5% 50V	Murata	GRM1555C1H101JZ01D
C2	C_100U_1210_X5R_M_6P3	1	Capacitor, 100u, 1210, X5R, 20%, 6.3V	Murata	GRM32EE70G107ME19L
C211;C236	C_12P_0402_NP0_J_50	2	Capacitor, 12p, 0402, NP0, 5%, 50V	Murata	GRM1555C1H120JZ01D
C31-32;C171;C181;C201	C_15P_0402_NP0_J_50	5	Capacitor, 15p, 0402, NP0, 5%, 50V	Murata	GRM1555C1H150JZ01D
C311	C_1N_0402_NP0_J_50	1	Capacitor, 1n, 0402, NP0, 5%, 50V	Murata	GRM1555C1H102JA01D
C231	C_1P0_0402_NP0_C_50	1	Capacitor, 1p, 0402, NP0, +/-0.25pF 50V	Murata	GRM1555C1H1R0CZ01D
C232;C241	C_1P5_0402_NP0_C_50	2	Capacitor, 1p5, 0402, NP0, +-0.25pF, 50V	Murata	GRM1555C1H1R5CZ01D
C301	C_1U_0402_X5R_K_6P3	1	Capacitor, 1u, 0402, X5R, 10%, 6.3V	Murata	GRM155R60J105KE19D
C4	C_2N2_0603_X7R_K_50	1	Capacitor, 2n2, 0603, X7R, 10%, 50V	Murata	GRM188R71H222KA01D
C233	C_3P3_0402_NP0_C_50	1	Capacitor, 3p3, 0402, NP0, +-0.25pF, 50V	Murata	GRM1555C1H3R3CZ01D
C33	C_470N_0402_X5R_K_6P3	1	Capacitor, 470n, 0402, X5R, 10%, 6.3V	Murata	GRM155R60J474KE19D
C7;C12	C_4U7_0603_X5R_K_6	2	Capacitor, 4u7, 0603, X5R, 10%, 6.3V	Murata	GRM188R60J475KE19D
D1;D3	LED_EL19-21SRC	2	LED, red, 0603, 1.7V, 19mcd	Everlight	19-21SDRC/S530-A3/TR8
D2;D4	LED_EL19-21SYGC	2	LED, green, 0603, 2.0V, 16mcd	Everlight	19-21SYGC/S530-E1/TR8
L231;L233-234;L241	L_12N_0402_J_LQW	4	Inductor, 12n, 0402, ±5%, wire-wound type	Murata	LQW15AN12NJ00D
L235	L_15N_0402_J_LQW	1	Inductor, 15n, 0402, ±5%, wire-wound type	Murata	LQW15AN15NJ00D
L232;L242	L_18N_0402_J_LQW	2	Inductor, 18n, 0402, ±5%, wire-wound type	Murata	LQW15AN18NJ00D
L1-2	L_BEAD_102_0402	2	EMI filter bead, 0402 1Kohms Tape GHz Band Gen Use	Murata	BLM15HG102SN1D
U4	MSP430F5438AIPZ	1	100 pins microcontroller	TI	MSP430F5438AIPZ
P1	PINROW_SMD_2X2_2.54MM	1	2x2 pinrow, 2.54mm pitch, SMD type	GradConn	BB02-HP041-KB3-060B00
P2	PINROW_SMD_2X7_2.54MM_DEBUG	1	JTAG SMD Connector	GradConn	BB02-HR141-K08-00000
S1-5	PUSH_BUTTON_SKRK	5	Momentary push-button, SMD 3.9*2.9*2 mm	Alps	SKRKAEE010
R1;R5	R_0402	2	Resistor, general, 0402; Do not mount		
R13	R_0_0603	1	Resistor, 0 ohm, 0603, ±1%	Koa	RK73Z1JTTD
R12	R_10_0402_J	1	Resistor, 10 ohms, 0402, 5%	Koa	RK73H1ETTP10R0F (±1%)
R3-4;R10-11	R_270_0402_F	4	Resistor, 270 ohms, 0402, ±1%	Koa	RK73H1E270RF-MR or RK73H1ETTP2700F
R311	R_2K7_0402_F	1	Resistor, 2k7 ohms, 0402, ±1%	Koa	RK73H1ETTP2701F
R14	R_47K_0402_F	1	Resistor, 47k ohms, 0402, ±1%	Koa	RK73H1ETTP4702F
R271	R_56K_0402_F	1	Resistor, 56k ohms, 0402, ±1%	Koa	RK73H1ETTP5602F
DEBUG	STL21	1	10 pins connector	MPE-Garry GmbH	STL21-A01XX-010-TRU
X1	X_26.000/20/40/40/10	1	Crystal, 26.000000MHz, 10.0pF, 50 ohms max, 20/40 ppm, -40C to +85C	NDK	NX3225GA, EXS00A-CG01972

X2-3	X_32.768/20/50/40/12	2	Crystal, 32.768 kHz, 12.5pF, 20/50 ppm,SMD package	Epson Toyocom	MC-306
Total number of components		**69**			

Table 12. CC1180DB, Bill of Material

4.3 Edge Router, OMAP-L138 Experimenters Board

The Edge Router is based on the OMAP-L138 Experimenter's kit from TI. Full documentation, schematics and layout for the OMAP-L138 Experimenter's board can be found here: http://focus.ti.com/docs/toolsw/folders/print/tmdsexpl138.html. Please note that the OMAP board in the CC-6LOWPAN-DK-868 does not include the LCD display.

It is very important that the switch S7-2 is in position ON, all other switches on S2 and S7 shall be in position OFF.

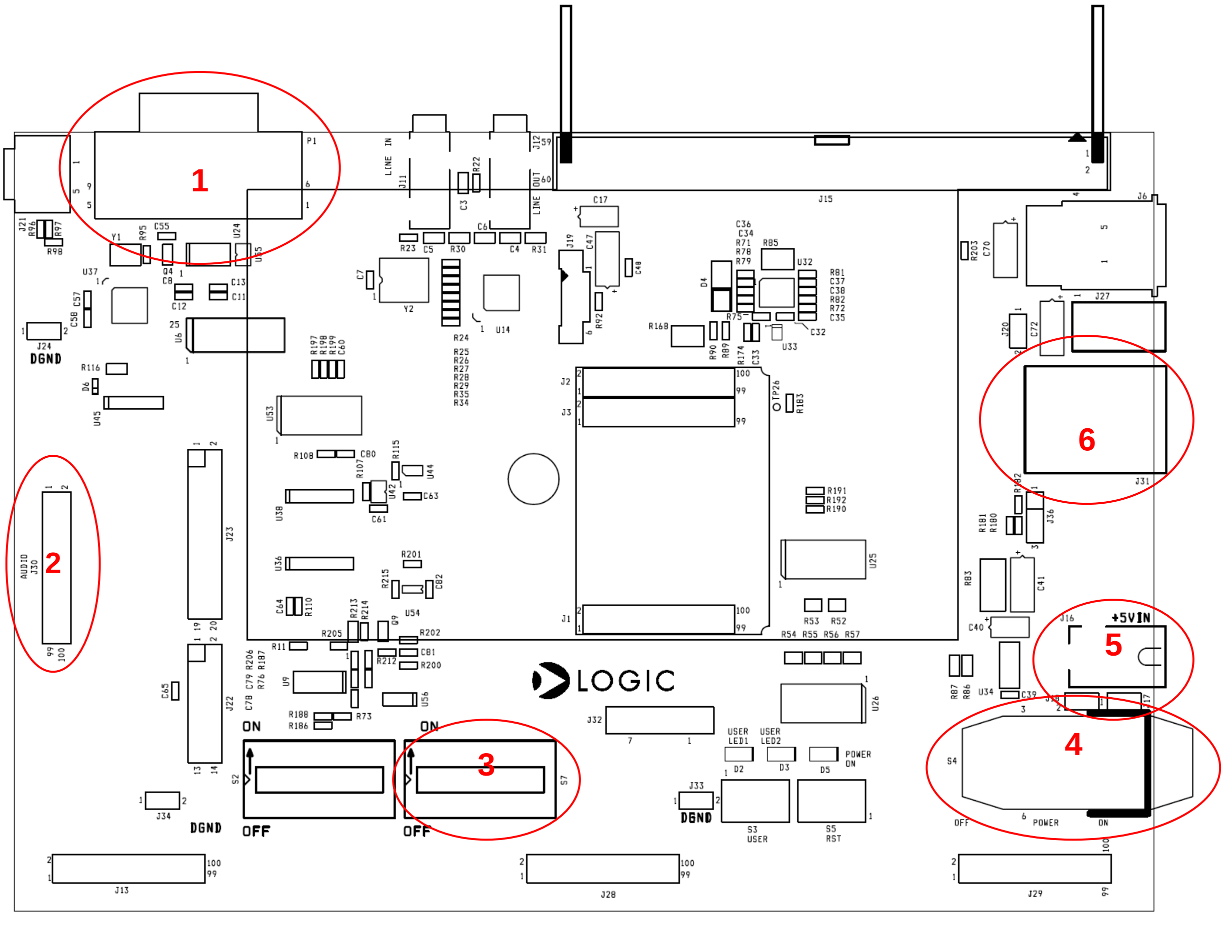


Figure 32. OMAP-L138 Experimenter's Board Overview

- 1 – RS-232 Connection for Linux Console port.
- 2 – Connector J30, connection for CC1180EM using the Adapter Board.
- 3 – Switch S7. Position 2 need to be in ON position.
- 4 – Power switch
- 5 – Power connector
- 6 – Ethernet Connector

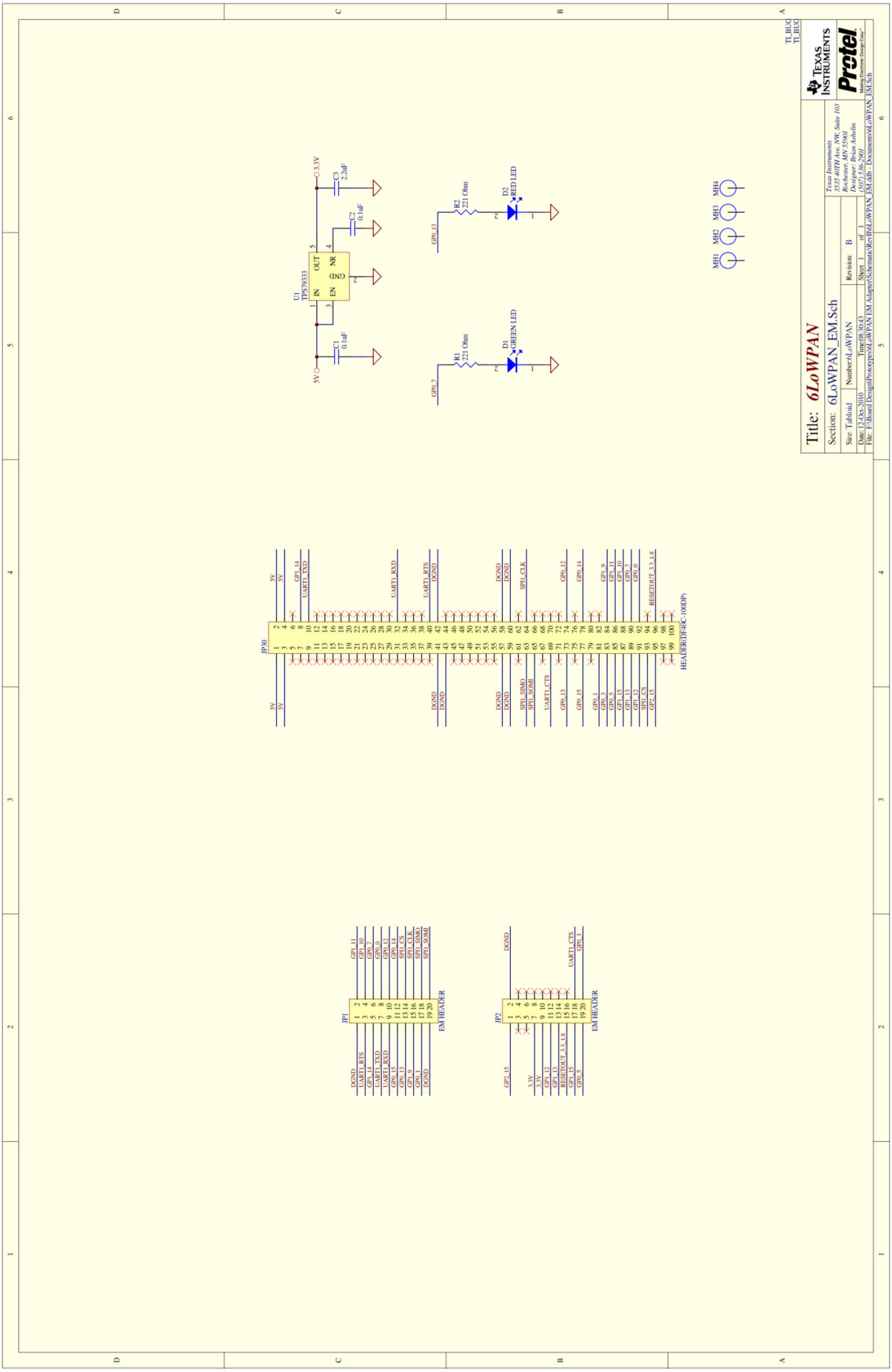
4.3.1 *Adapter Board*

The adapter board is used to enable connection of CC1180EM to the OMAP-L138 Experimenter's Board, providing the RF interface for the Edge Router. The adapter board contains two LEDs with function as described in the table below.

Green LED remains active Red LED toggling	**Both LEDs remains active**
RF interface created, red LED blinks when there is RF activity.	The CC1180 is in bootloader mode, accepting NanoBoot API commands.

Table 13. Adapter Board LED functionality

4.3.1.1 Schematics, BOM and Layout


Title: 6LoWPAN
Section: 6LoWPAN_EM.Sch
Size: Tabloid
Number: 6LoWPAN
Revision: B
Texas Instruments
3535 40TH Ave. NW, Suite 103
Rochester, MN 55901
Designer: Brian Ashelin
(507) 536-2901
TEXAS INSTRUMENTS
Protel
U1
TPS79333
JP30
JP1
JP2
EM HEADER
MH1
MH2
MH3
MH4

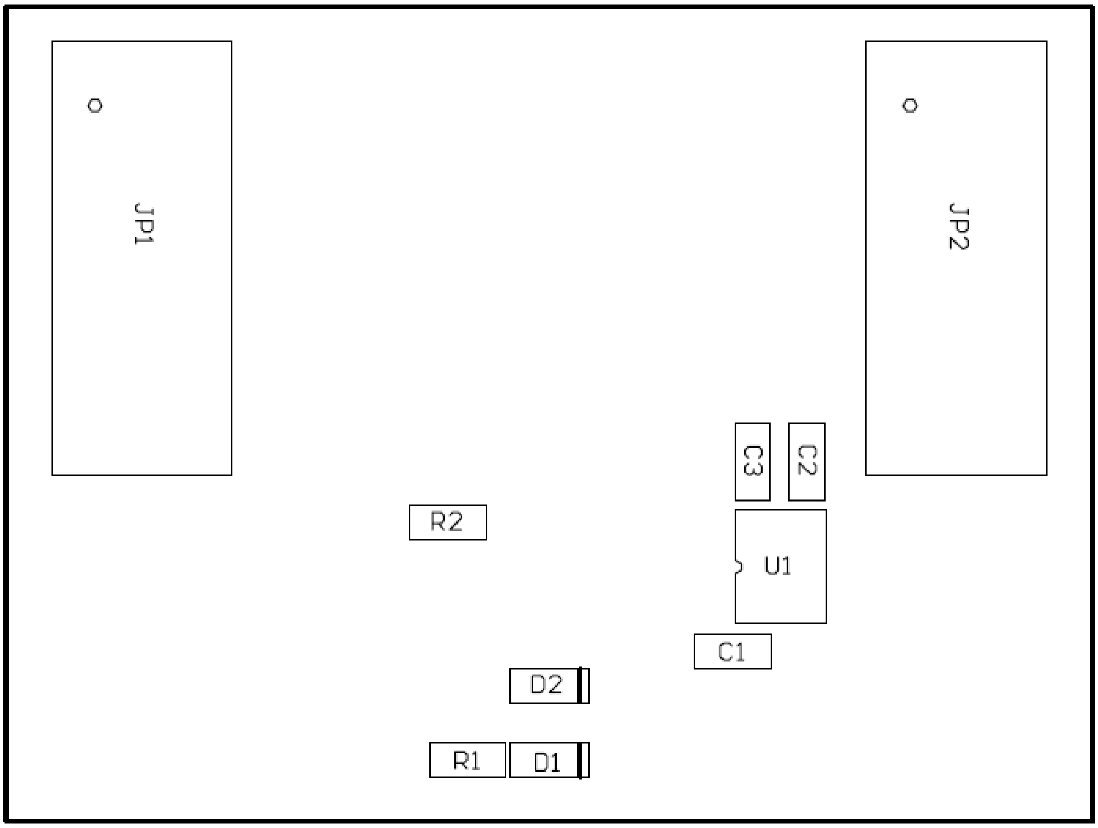


Figure 33. Adapter Board, PCB Components Top Layer

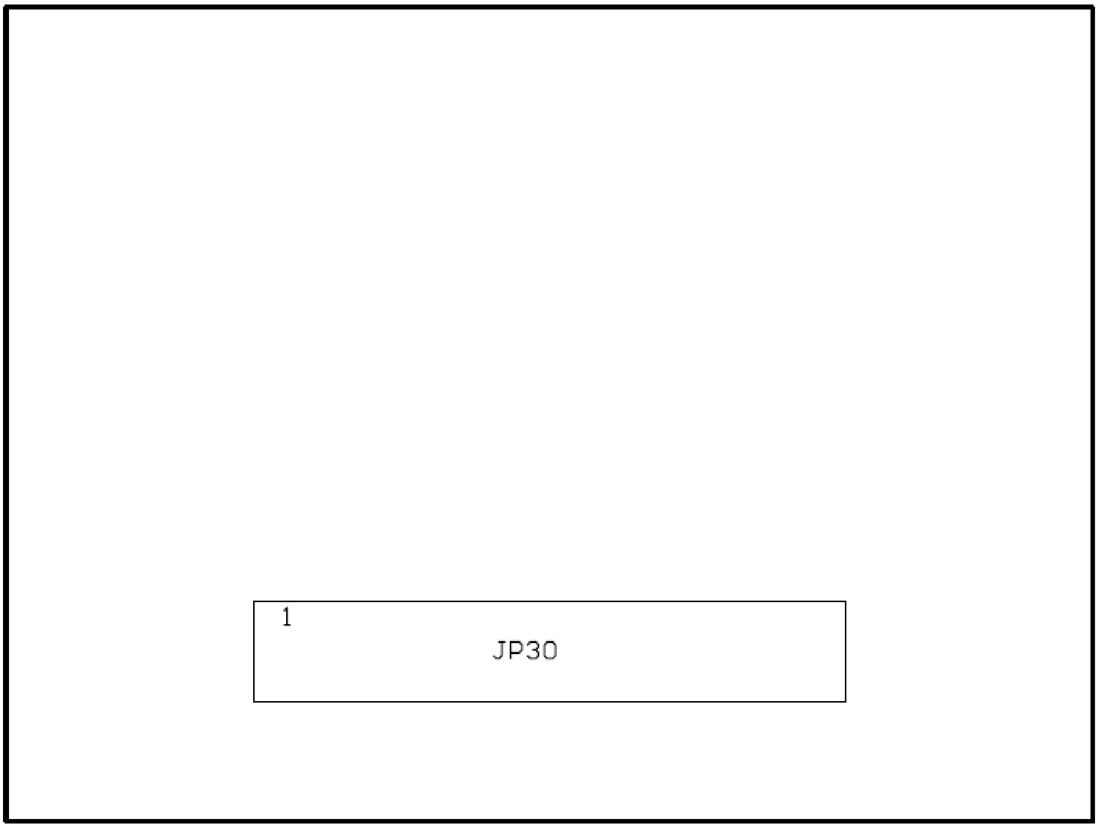


Figure 34. Adapter Board, PCB Components Bottom Layer

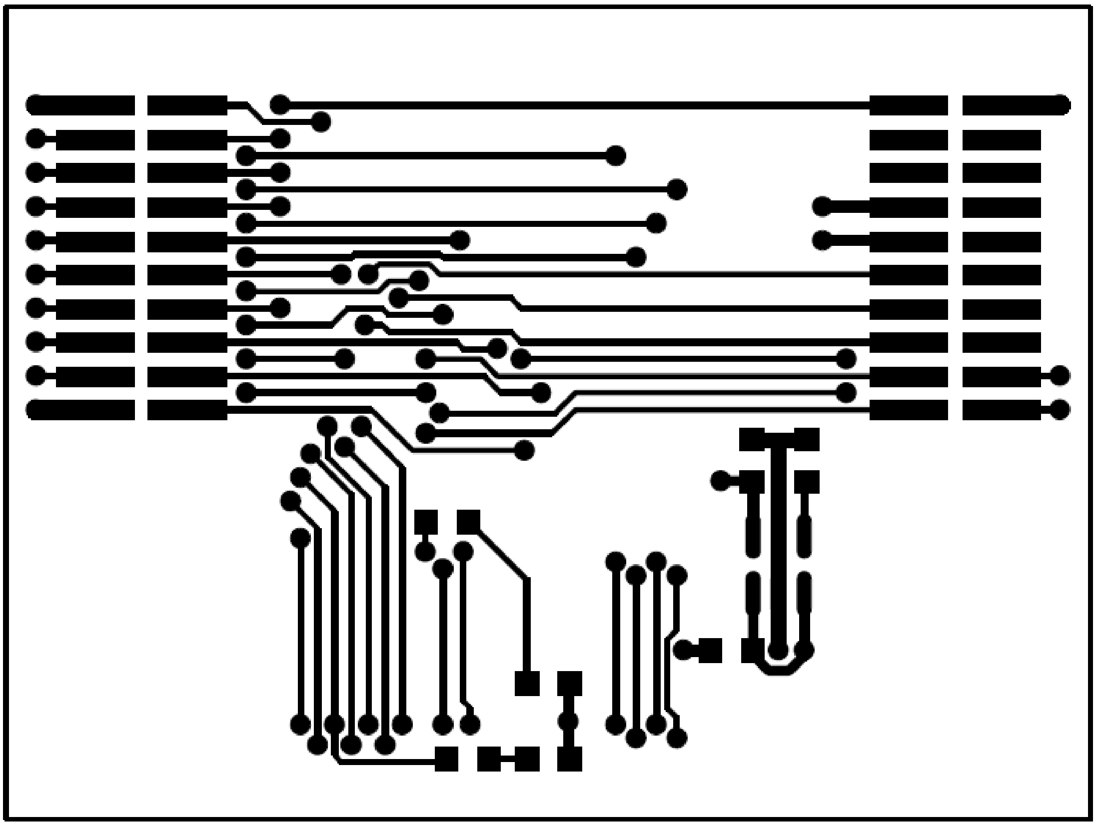


Figure 35. Adapter Board, Layout Top layer

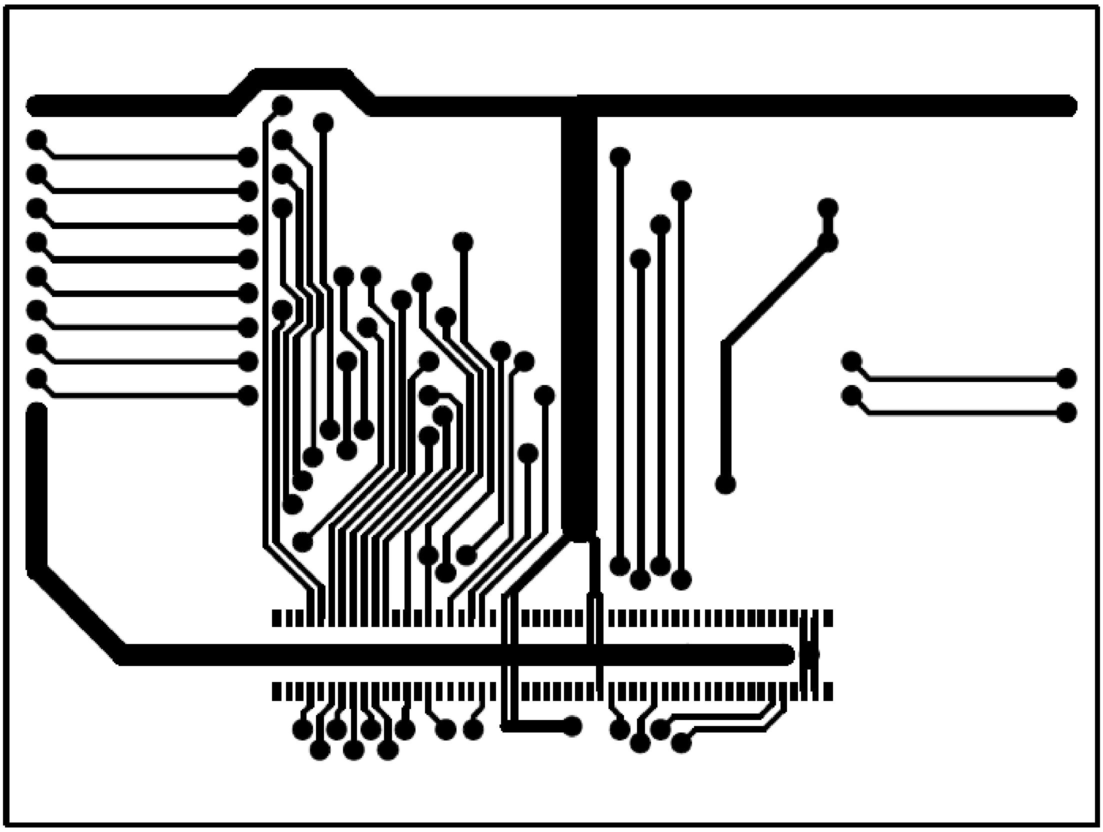


Figure 36. Adapter Board, Layout Bottom Layer

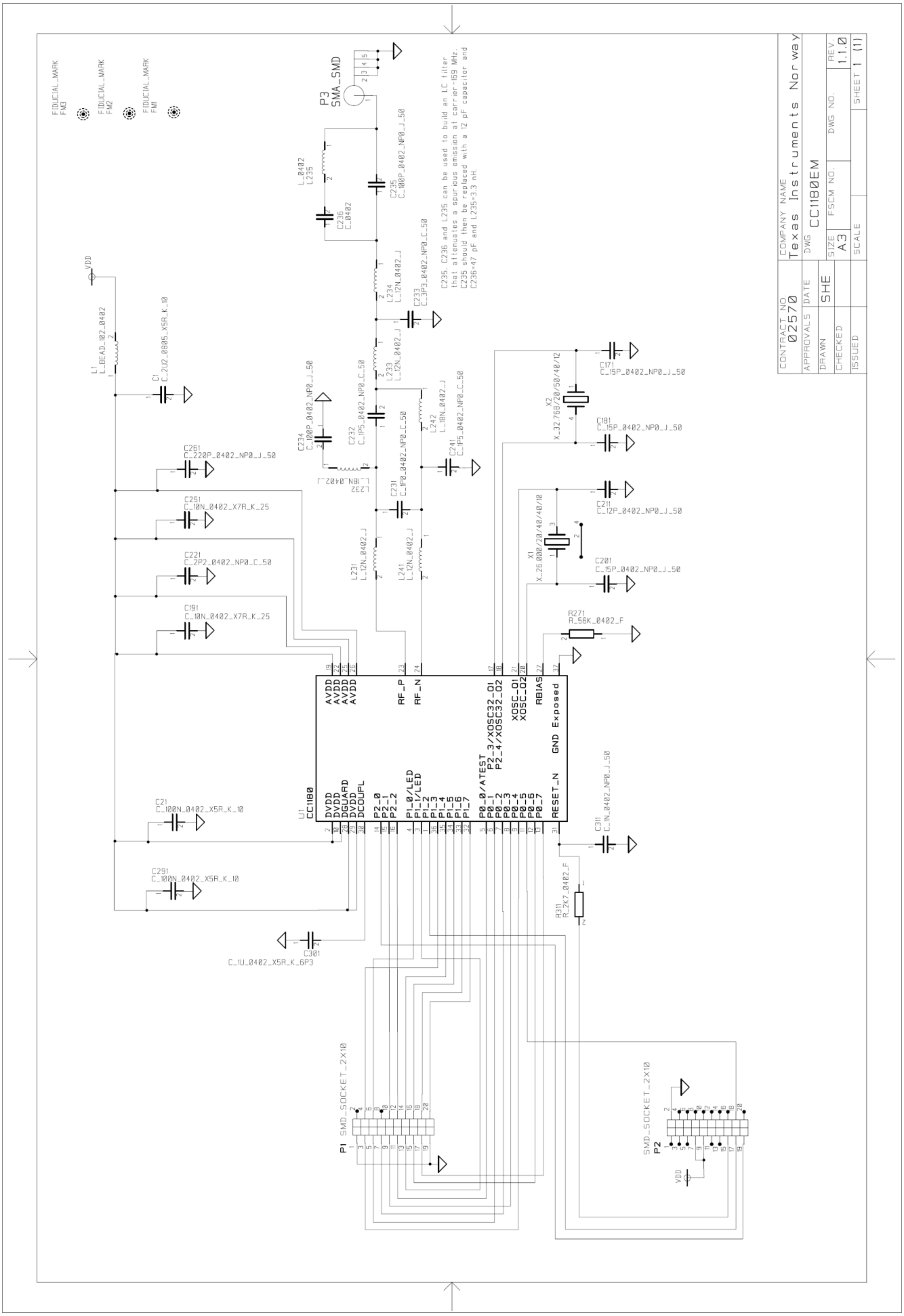
Part Type	Designator	Footprint	Description	Part Number	Manuf.
0.1uF	C1	CAP_0603	CAPACITOR	ECJ1VB1C104K	Panasonic
0.1uF	C2	CAP_0603	CAPACITOR	ECJ1VB1C104K	Panasonic
2.2uF	C3	CAP_0603	CAPACITOR	GRM188R61C225KE15D	Murata
EM HEADER	JP1	HEADER 10X2(SAM-TFM)(SMT)	CONNECTOR	TFM-110-02-SM-D-A-K-TR	Samtec
EM HEADER	JP2	HEADER 10X2(SAM-TFM)(SMT)	CONNECTOR	TFM-110-02-SM-D-A-K-TR	Samtec
HEADER(DF40C-100DP)	JP30	HEADER(DF40C-100DP)	CONNECTOR	DF40C-100DP-0.4V(51)	Hirose
GREEN LED	D1	LED(SMT0603)	DIODE	19-21SYGC	Everlight
RED LED	D2	LED(SMT0603)	DIODE	19-21SURC	Everlight
TPS79333	U1	SOT23(5)(DBV)	IC	TPS79333DBV	Texas Instruments
221 Ohm	R1	RES_0603	RESISTOR	ERJ3EKF2210V	Panasonic
221 Ohm	R2	RES_0603	RESISTOR	ERJ3EKF2210V	Panasonic

Table 14. Adapter Board, Bill of Material

4.3.2 *CC1180EM*

The CC1180EM is the RF interface for the OMAP-L138 (acting as Edge Router).

4.3.2.1 Schematics, BOM and Layout


C235, C236 and L235 can be used to build an LC filter that attenuates a spurious emission at carrier-169 MHz. C235 should then be replaced with a 12 pF capacitor and C236=47 pF and L235=3.3 nH.
CONTRACT NO 02570
COMPANY NAME Texas Instruments Norway
DWG CC1180EM
DRAWN SHE
SIZE A3
REV. 1.1.0
SHEET 1 (1)

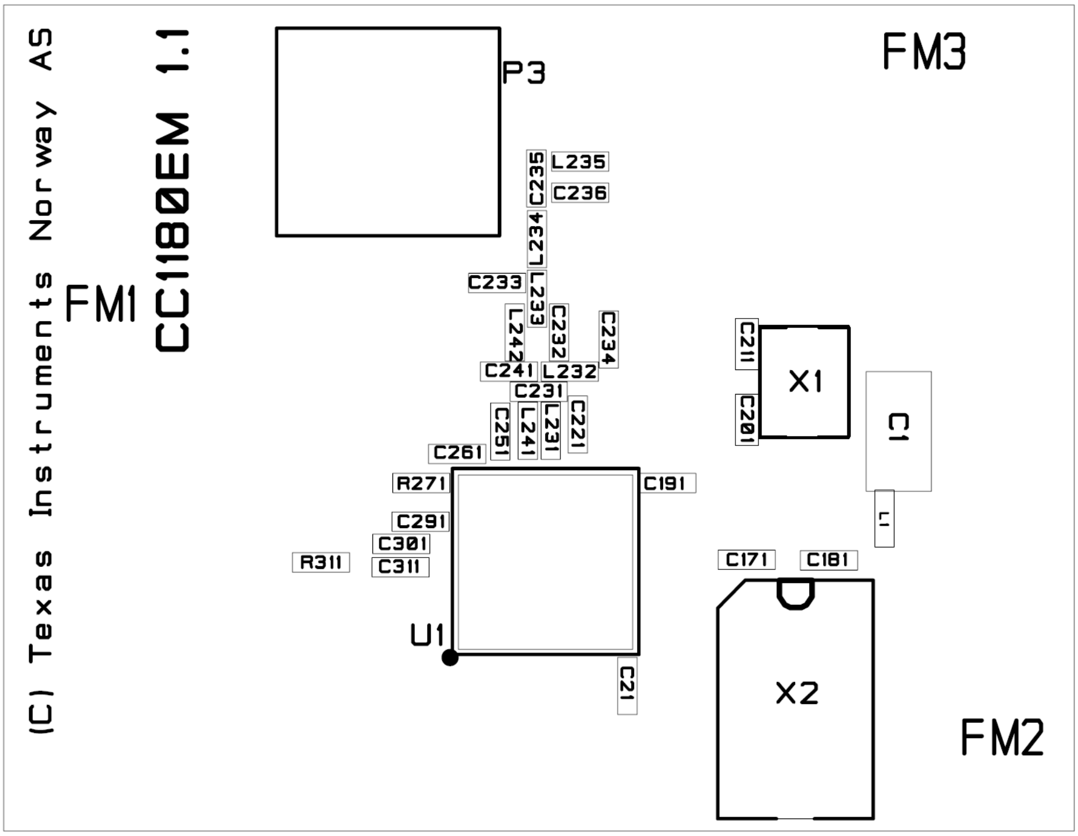


Figure 37. CC1180EM, PCB Components Top Layer

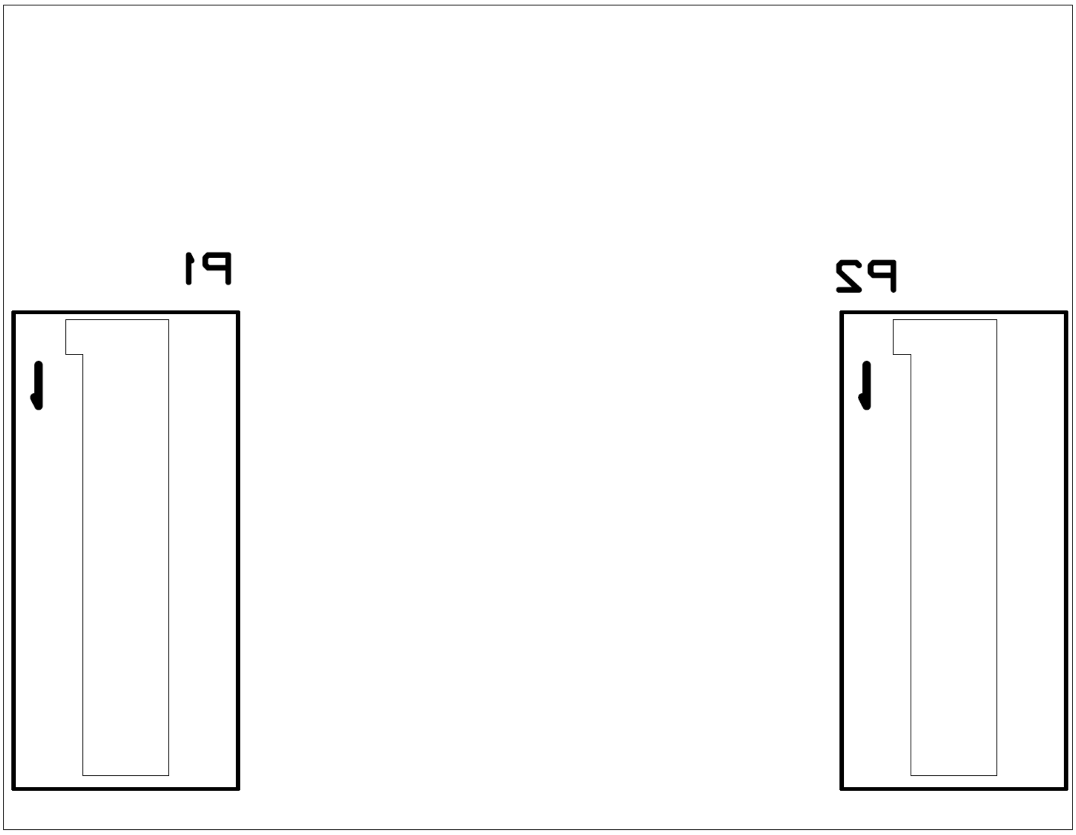


Figure 38. CC1180EM, PCB Components Bottom Layer

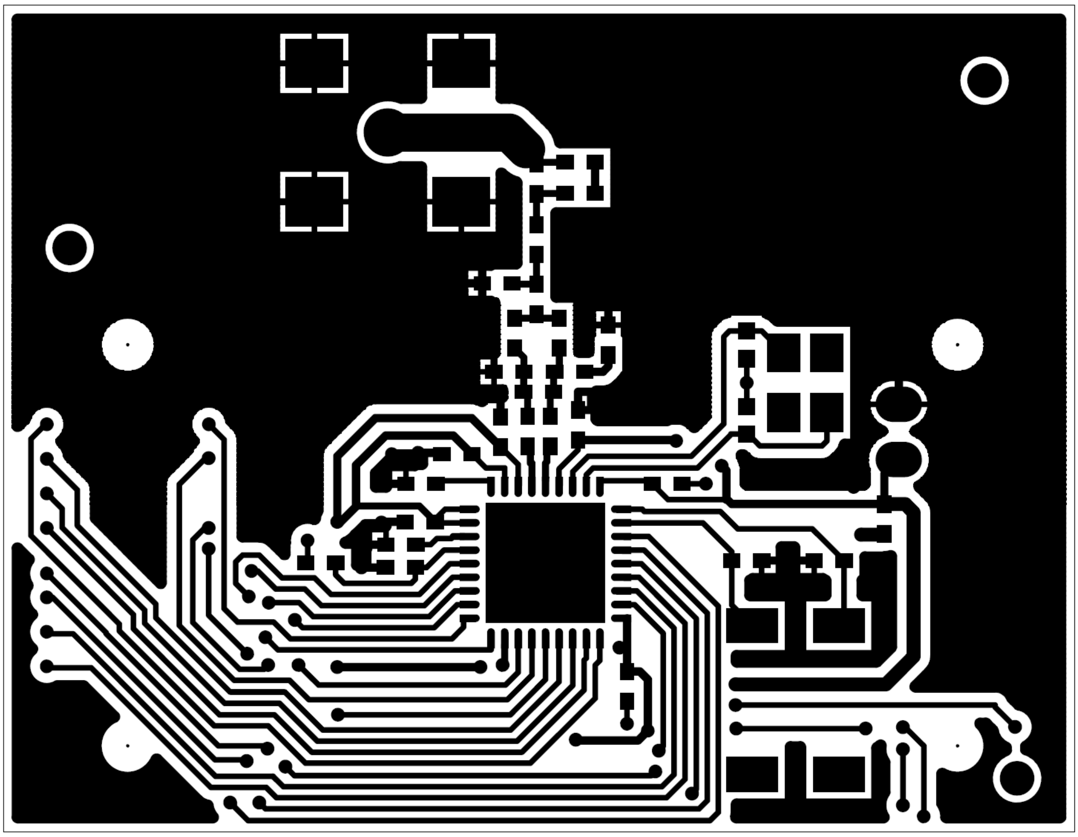


Figure 39. CC1180EM, Layout Top Layer

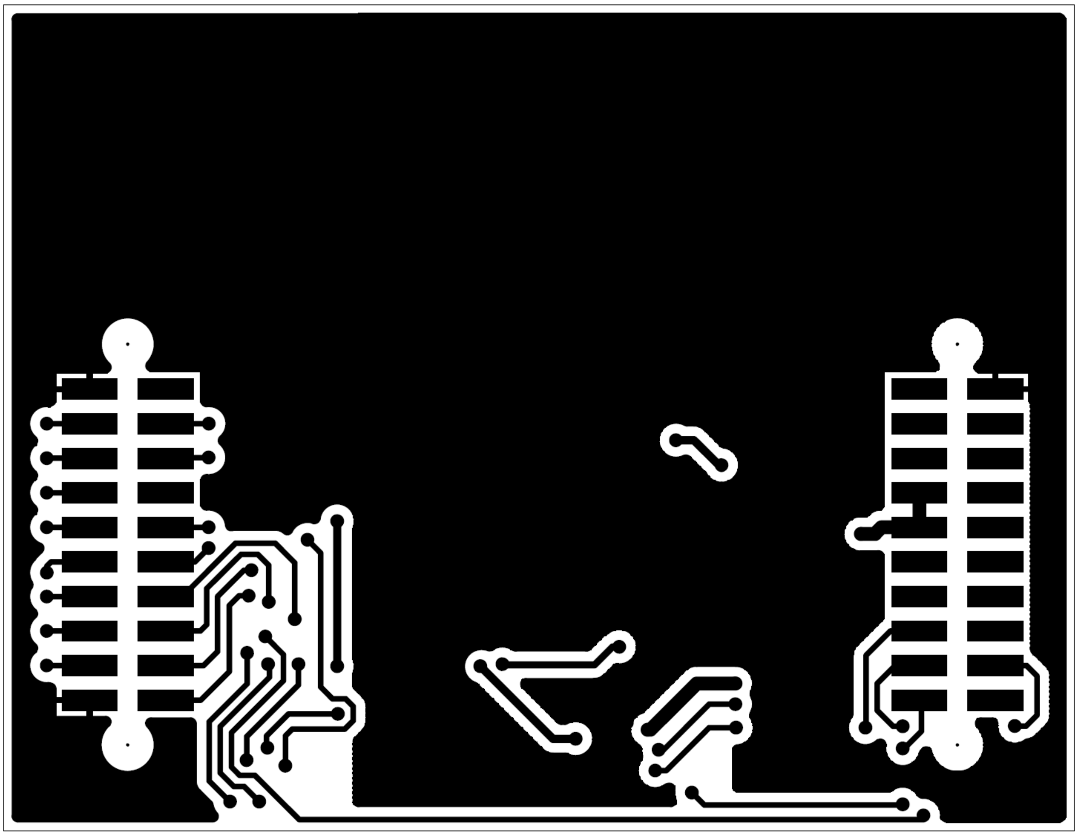


Figure 40. CC1180EM, Layout Bottom Layer

Ref.	Part Name	Pcs/unit	Description	Manuf.	Part Number
U1	CC1180	1	6LoWPAN Network Processor	TI	CC1180
C236	C_0402	1	Capacitor, general, 0402; Do not mount		
C21;C291	C_100N_0402_X5R_K_10	2	Capacitor, 100n, 0402, X5R, 10%, 10V	Murata	GRM155R71A104KA01D
C234-235	C_100P_0402_NP0_J_50	2	Capacitor, 100p, 0402, NP0, 5% 50V	Murata	GRM1555C1H101JZ01D
C191;C251	C_10N_0402_X7R_K_25	2	Capacitor, 10n, 0402, X7R, 10%, 25V	Murata	GRM155R71E103KA01D
C211	C_12P_0402_NP0_J_50	1	Capacitor, 12p, 0402, NP0, 5%, 50V	Murata	GRM1555C1H120JZ01D
C171;C181;C201	C_15P_0402_NP0_J_50	3	Capacitor, 15p, 0402, NP0, 5%, 50V	Murata	GRM1555C1H150JZ01D
C311	C_1N_0402_NP0_J_50	1	Capacitor, 1n, 0402, NP0, 5%, 50V	Murata	GRM1555C1H102JA01D
C231	C_1P0_0402_NP0_C_50	1	Capacitor, 1p, 0402, NP0, +/-0.25pF 50V	Murata	GRM1555C1H1R0CZ01D
C232;C241	C_1P5_0402_NP0_C_50	2	Capacitor, 1p5, 0402, NP0, +-0.25pF, 50V	Murata	GRM1555C1H1R5CZ01D
C301	C_1U_0402_X5R_K_6P3	1	Capacitor, 1u, 0402, X5R, 10%, 6.3V	Murata	GRM155R60J105KE19D
C261	C_220P_0402_NP0_J_50	1	Capacitor, 220p, 0402, NP0, 5%, 50V	Murata	GRM1555C1H221JA01D
C221	C_2P2_0402_NP0_C_50	1	Capacitor, 2p2, 0402, NP0, +-0.25pF, 50V	Murata	GRM1555C1H2R2CZ01
C1	C_2U2_0805_X5R_K_10	1	Capacitor, 2u2, 0805, X5R, 10%, 10V	Murata	GRM219R61A225KA01D
C233	C_3P3_0402_NP0_C_50	1	Capacitor, 3p3, 0402, NP0, +-0.25pF, 50V	Murata	GRM1555C1H3R3CZ01D
L235	L_0402	1	Inductor, general, 0402; Do not mount		
L231;L233-234;L241	L_12N_0402_J	4	Inductor, 12n, 0402, ±5%	Murata	LQG15HS12NJ02D
L232;L242	L_18N_0402_J	2	Inductor, 18n, 0402, ±5%	Murata	LQG15HS18NJ02D
L1	L_BEAD_102_0402	1	EMI filter bead, 0402 1Kohms Tape GHz Band Gen Use	Murata	BLM15HG102SN1D
R311	R_2K7_0402_F	1	Resistor, 2k7 ohms, 0402, ±1%	Koa	RK73H1ETTP2701F
R271	R_56K_0402_F	1	Resistor, 56k ohms, 0402, ±1%	Koa	RK73H1ETTP5602F
P3	SMA_SMD	1	SMA connector, straight SMD-mount	Hus-Tsan Group Taiwan	SMA-10V21-TGG
P1-2	SMD_SOCKET_2X10	2	SMD pinrow socket, .050 spacing, 2x10	Samtec	SFM-110-02-SM-D-A-K-TR
X1	X_26.000/20/40/40/10	1	Crystal, 26.000000MHz, 10.0pF, 50 ohms max, 20/40 ppm, -40C to +85C	NDK	NX3225GA, EXS00A-CG01972
X2	X_32.768/20/50/40/12	1	Crystal, 32.768 kHz, 12.5pF, 20/50 ppm,SMD package	Epson Toyocom	MC-306
Total number of components		**36**			

Table 15. CC1180EM, Bill of Material

5 FAQ

5.1 Send UDP packets from PC

One easy way to communicate with the nodes in the 6LoWPAN network using UDP from a PC is via the Netcat program. Netcat is a tool that are included in almost every Linux distribution, to check if you have netcat installed run the nc command in Linux. For Windows users' netcat6 can be downloaded from here.

Netcat can be used to send raw ASCII UDP packets to the nodes. This is how to open a UDP connection on port 61641 to the IPv6 address `2001:0:0:0:0:ff:fe00:7854` using nc6 for Windows. Destination port is 61641.

```
nc6 -u -p 61641 2001:0:0:0:0:ff:fe00:7854 61641<enter>
```

After opening a connection to the IPv6 address you can send any ASCII data followed by <enter>. nc6 will add a new line at the end of the data and the data (ASCII string) will be send to the specific IPv6 address.

To close the connection press <ctrl-c>.

For more details on nc6 run the command nc6 -help, if you're using nc in Linux the command would be nc -help.

NOTE: If using the nc tool on Linux, one has to specify that the tool shall use IPv6 by the -6 syntax:

```
nc -6 -u -p 61641 2001:0:0:0:0:ff:fe00:7854 61641<enter>
```

This tool enables simple communication with nodes (or any IPv6 address) without the need of a special program.

5.2 Too Much Code

The free version (kick start) of IAR for MSP430 is limited to 8kB of code. If you get this error:

"Fatal Error[e89]: Too much object code produced (more than 0x2000 bytes) for this package "

This means that you have exceeded the 8kB limit. The size of the CODE + CONST must be less than 8kB. You can check the size by looking at the bottom of the Linker Listing (HTML file generated by the compiler, located in the Output directory). You can either trim down your application, port your application to Code Composer (which has a 16kB limit for the free version), buy a full license of IAR, or try the 30 day evaluation edition of IAR. If changing IAR version, remember to clean your project before rebuilding.

5.3 Linux kernel and File System

The current Linux kernel and File System that is used on the OMAP-L138 board in the kit can be obtained from TI. Please contact your local support.

6 References

[1] Draft-ietf-6lowpan-hc-13 (draft-ietf-6lowpan-hc-13)

[2] Draft-ietf-6lowpan-nd-13 (draft-ietf-6lowpan-nd-13)

[3] Draft-ietf-roll-rpl-13 (draft-ietf-roll-rpl-13)

[4] IEEE 802.15.4g specification

[5] IEEE 802.15.4e specification

[6] Sensinode NanoRouter2.0.pdf

[7] Sensinode NanoStack2.0lite-v1.0-01.pdf

[8] Sensinode NanoSocket API 1.0.pdf

[9] Sensinode NAPProtocol1.0.pdf

[10] Sensinode NodeView2.0.pdf

[11] Sensinode NanoHost Example 1.0-01.pdf

[12] Sensinode NAPSocketLibrary1.0-01.pdf

[13] Sensinode RFConfigurationAppNote1.0.pdf

[14] CC-6LOWPAN-DK-868 Quick Start Guide (SWRU276.pdf)

[15] CC1180 Datasheet (SWRS113.pdf)

7 Development Kit Ordering Information

Orderable Evaluation Module	Description	Minimum Order Quantity
CC-6LOWPAN-DK-868	6LoWPAN Development Kit, 868/915 MHz	1

Table 16. Development Kit Ordering Information

8 General Information

8.1 Document History

Revision	Date	Description/Changes
SWRU298	12.09.2011	First User's Guide release.

Table 17. Document History

EVALUATION BOARD/KIT/MODULE (EVM) ADDITIONAL TERMS

Texas Instruments (TI) provides the enclosed Evaluation Board/Kit/Module (EVM) under the following conditions:

The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies TI from all claims arising from the handling or use of the goods.

Should this evaluation board/kit not meet the specifications indicated in the User's Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING LIMITED WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. EXCEPT TO THE EXTENT OF THE INDEMNITY SET FORTH ABOVE, NEITHER PARTY SHALL BE LIABLE TO THE OTHER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.

Please read the User's Guide and, specifically, the Warnings and Restrictions notice in the User's Guide prior to handling the product. This notice contains important safety information about temperatures and voltages. For additional information on TI's environmental and/or safety programs, please visit www.ti.com/esh or contact TI.

No license is granted under any patent right or other intellectual property right of TI covering or relating to any machine, process, or combination in which such TI products or services might be or are used. TI currently deals with a variety of customers for products, and therefore our arrangement with the user is not exclusive. TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein.

REGULATORY COMPLIANCE INFORMATION

As noted in the EVM User's Guide and/or EVM itself, this EVM and/or accompanying hardware may or may not be subject to the Federal Communications Commission (FCC) and Industry Canada (IC) rules.

For EVMs **not** subject to the above rules, this evaluation board/kit/module is intended for use for ENGINEERING DEVELOPMENT, DEMONSTRATION OR EVALUATION PURPOSES ONLY and is not considered by TI to be a finished end product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC or ICES-003 rules, which are designed to provide reasonable protection against radio frequency interference. Operation of the equipment may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

General Statement for EVMs including a radio

User Power/Frequency Use Obligations: This radio is intended for development/professional use only in legally allocated frequency and power limits. Any use of radio frequencies and/or power availability of this EVM and its development application(s) must comply with local laws governing radio spectrum allocation and power limits for this evaluation module. It is the user's sole responsibility to only operate this radio in legally acceptable frequency space and within legally mandated power limitations. Any exceptions to this are strictly prohibited and unauthorized by Texas Instruments unless user has obtained appropriate experimental/development licenses from local regulatory authorities, which is responsibility of user including its acceptable authorization.

For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant

Caution

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

For EVMs annotated as IC – INDUSTRY CANADA Compliant

This Class A or B digital apparatus complies with Canadian ICES-003.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

Concerning EVMs including radio transmitters

This device complies with Industry Canada licence-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concerning EVMs including detachable antennas

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication.

This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Cet appareil numérique de la classe A ou B est conforme à la norme NMB-003 du Canada.

Les changements ou les modifications pas expressément approuvés par la partie responsable de la conformité ont pu vider l'autorité de l'utilisateur pour actionner l'équipement.

Concernant les EVMs avec appareils radio

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante.

Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

【Important Notice for Users of this Product in Japan】

This development kit is NOT certified as Confirming to Technical Regulations of Radio Law of Japan

If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or
3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

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【ご使用にあたっての注】

本開発キットは技術基準適合証明を受けておりません。

本製品のご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。

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EVALUATION BOARD/KIT/MODULE (EVM)
WARNINGS, RESTRICTIONS AND DISCLAIMERS

For Feasibility Evaluation Only, in Laboratory/Development Environments. Unless otherwise indicated, this EVM is not a finished electrical equipment and not intended for consumer use. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

Your Sole Responsibility and Risk. You acknowledge, represent and agree that:

1. You have unique knowledge concerning Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the EVM for evaluation, testing and other purposes.
2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using the EVM. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.
3. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.
4. You will take care of proper disposal and recycling of the EVM’s electronic components and packing materials.

Certain Instructions. It is important to operate this EVM within TI’s recommended specifications and environmental considerations per the user guidelines. Exceeding the specified EVM ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings please contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, some circuit components may have case temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use these EVMs.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the EVM that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if the EVM fails to perform as described or expected.

Safety-Critical or Life-Critical Applications. If you intend to evaluate the components for possible use in safety critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify TI of such intent and enter into a separate Assurance and Indemnity Agreement.

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