MASTER THESIS

TITLE : Design of an Arduino shield for ota programming

MASTER DEGREE: Master in Science in Telecommunication Engineering & Management

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Resum

El Centre Internacional de Mètodes Numèrics en la Enginyeria (CIMNE), creat el 1987, és un centre de recerca especialitzat en les simulacions i els mètodes numèrics. El departament de tecnologies de la informació i les comunicacions (TIC) té una línia de investigació dedicada a les xarxes de sensors sense fils (WSN) que utilitza algunes de les tecnologies i dispositius existents per recollir informació de l'entorn i proporcionar-la als sistemes de simulació. CIMNE participa en varis projectes de recerca juntament amb altres empreses i institucions. Aquest projecte va néixer fruit de la necessitat d'alguns projectes de recerca en que està el departament TIC així com les altres empreses dels projectes. CIMNE solia utilitzar les motes MicaZ de Crossbow però el seu elevat va fer que CIMNE busqués alternatives més econòmiques.

Una de les alternatives usades en les WSN és Arduino, una placa electrònica versàtil que consta d'un microcontrolador amb entrades i sortides digitals i analògiques que permeten obtenir dades de sensors i accionar actuadors o altres aparells. L'Arduino és fàcilment programable i està basat en el hardware lliure. No te cap mètode de comunicació inalàmbrica però te la capacitat d'utilitzar Shields, unes plaques que es connecten a l'Arduino i permeten ampliar les seves funcionalitats. Arduino és una tecnologia en creixement que s'usa en diferents camps, des de la domòtica fins a en aplicacions professionals i fins hi tot amb fins educatius per tal d'ensenyar electrònica als estudiants tant d'institut com als universitaris. En part el seu creixement es deu al seu baix cost i a la seva facilitat d'us i de programar.

Com que les WSN es solen utilitzar en llocs concrets, com pot ser en una vinya o en un pont d'una carretera, és important poder gestionar i programar els nodes remotament (OTA). Arduino no disposa d'aquesta funcionalitat però es pot implementar usant un shield. Després de fer una recerca sobre els shields amb connectivitat wifi existents no n'hem trobat cap que tingues la capacitat OTA. Degut a això, CIMNE ha identificat la necessitat de dissenyar i construir un shield wifi que tingui la capacitat OTA. També hem fet un petit repas d'algunes aplicacions, algunes de CIMNE, que poden necessitar aquesta capacitat. El shield wifi amb la capacitat OTA també és important per CIMNE ja que l'increment de l'internet de les coses fa que aquest shield permeti connectar objectes o coses a internet fàcilment, com per exemple uns altaveus.

Per fer el disseny s'ha utilitzat el programa de disseny de circuits electrònics de l'empresa Cadsoft anomenat Eagle ja que és un dels millors que hi ha actualment en el seu camp.

Al final del projecte volem aconseguir un shield wifi amb la capacitat de programació remota de l'arduino que funcioni correctament.

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Overview

The International Center for Numerical Methods in Engineering (CIMNE) is a research organization, created in 1987, that does research in many areas, one of them is Information and Communication Technologies. In this area there is a line specialized in Wireless Sensor Networks (WSN) that uses many of existent technologies or devices to gather data from the real world and sent it to CIMNE server to feed simulation systems. CIMNE participates in many research projects with other companies and institutions.
This project was born from the need of some research projects in ICT group of CIMNE as well as one of their associated companies. Research projects that lead to this project are relative to WSN. CIMNE used to use MicaZ sensor mote from Crossbow but its high cost made CIMNE to look for alternatives.
One of the alternatives used in WSN is Arduino, a versatile board that have a microcontroller digital and analogic inputs and outputs to gather data from sensors and interact with actuators or other gadgets. Arduino is easily programmable and is open hardware. It has not the capability of wireless communications but it has the feature of using shields, boards that connect to Arduino, to expand its functionalities.
Arduino is a growing technology that is used in many different fields; from domotics to professional applications to use it with educational purposes to teach students from high school to university. This grow is due to its low cost, its easiness to use and program.
Since Wireless Sensor Networks usually are deployed in remote places, such as a vineyard or a highway bridge, it is very important to be able to manage and reprogram the sensor nodes remotely. Arduino has not this feature and after doing some research on the state of the art of wireless shields and not finding any shield with this feature. CIMNE has identified the needing of designing a Wi-Fi shield with Over-The-Air (OTA) programming feature. We have done a short review of applications, some of CIMNE, that will need this feature.
Wi-Fi shield with OTA programming capabilities is also important to CIMNE since nowadays the Internet of Things is growing fast and with shield CIMNE can provide Internet to many objects, such as speakers.
To design the shield we have used Cadsoft Eagle software since is one of the best circuit design software available in the market nowadays.
At the end of the project we want to obtain a working Wi-Fi Arduino Shield with OTA capabilities.

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INTRODUCTION

The International Center for Numerical Methods in Engineering (CIMNE) is a research organization, created in 1987, that does research in many areas, one of them is Information and Communication Technologies. In this area there is a line specialized in Wireless Sensor Networks (WSN) that uses many of existent technologies or devices to gather data from the environment and sent it to CIMNE server to feed simulation systems.

ICT department participates in many research projects with other companies, universities and research groups. One of these projects is SITIB project, which stands for Sistema de Informacion Territorial de IBiza y formentera, and project main aim was to deploy a WSN in Ibiza beaches to monitor with buoys, weather stations and webcams the beach conditions in order to inform users through a web page and mobile apps, now resulting in a spin-off company, TAOC and a commercial product, Beaching. At the beginning of the project each WSN node was a MicaZ [1] from Crossbow [2]. *MicaZ* node use *ZigBee* [3] as a communication protocol and needed an extra board, the *MDA320* [4] data acquisition board. Sensor nodes communicate each other and we use a gateway, *MIB600* [5], to gather the WSN data and upload it to our servers in Barcelona. The gateway was placed with the webcam in a near hotel or in a beach bar where using its Internet we upload the data. The cost of each sensor node was high including all sensors and materials needed, near 1000€for weather stations, 2000€for buoys and 420€for each webcam. A part from that, wireless range of *MicaZ* was too low to reduce the number of weather stations per beach and consequently reduce cost per beach.

Due to these difficulties, CIMNE started to look for alternatives, use commercial weather stations or use other inexpensive hardware, to reduce costs with the additional features to be an open hardware concept able to expand their functionalities according to the user needs and developer requirements. Finally CIMNE decided to use Arduino [6], instead of the Crossbow motes, in the sensor nodes. To solve the wireless communication range CIMNE decided to use Wi-Fi. One of the requirements of the system was that had to be managed and reprogrammed remotely so it will need the use of Over The Air (OTA) capabilities.

Arduino is an open hardware platform that is growing fast since its low cost and its versatility, flexibility and easiness to use. The Arduino board has an Atmel [7] microcontroller and some digital and analogic inputs and outputs to gather data from sensors and interact with actuators. But there is not any communication in the device but a USB connection.

To add more communication capabilities or any other functions Arduino uses shields, a layer of complementary boards that are plugged into the Arduino to add some features to it. This feature is very important to understand its growth.

In CIMNE we have detected the lack of Over-The-Air programming capability through Wi-Fi and reviewing the state of the art of the existing Wi-Fi shields we have realized that there are not any shield with that feature in the market. So we decided to design and manufacture one.

This shield will we used in CIMNE research project but since it uses Wi-Fi it can be used by anyone in any other application that makes use of the Internet of Things such as Domotics. To make easy to manage remotely CIMNE will develop a web platform to connect to the devices with no other configuration that connect the shields to a Wi-Fi router.

This document is organised as follows: First of all we will review what is Arduino and what are some of the most common applications, then we will take a look on the state of art of the wireless shields for Arduino. We will take a look into the Over The Air programming feature and we will design and test our shield.

Finally some Results and the complete procedure guidelines are presented.

CHAPTER 1. STATE OF THE ART FOR ARDUINO TECHNOLOGY

In this chapter we will review what is Arduino, its most common applications and a state of the art of wireless shields .

1.1. What is Arduino?

Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.

Arduino technology has many flavours, many boards of different types and features. Most common boards and their features are described in the following table.

	Arduino Duemilanove	**Arduino Uno**	**Arduino Mega**	**Arduino Due**
Microcontroller	ATmega168	ATmega328	ATmega1280	3AT91SAM3X8E
# bits	8	8	8	32
Clock Speed	16MHz.	16MHz.	16MHz.	84MHz.
Digital I/O Pins	14	14	54	54
Analog I/O Pins	6	6	16	12/2
Operating Voltage	5V	5V	5V	3.3V
Flash Memory	16Kb	32Kb	128Kb	512Kb
SRAM	1Kb	2Kb	8Kb	96Kb
EEPROM	512 bytes	1Kb	4Kb	-

Table 1.1: Arduino boards comparison

The evolution of the arduino boards comes from the identified needs by the users, that is, the microcontrollers have more memory to run programs or more power to perform more complex operations and calculations.

An Arduino board used to have an 8-bit *Atmel AVR* microcontroller with complementary components to facilitate programming and incorporation into other circuits. It is important to remark the drastic change on features with the new board, Arduino Due, which has a 32-bit *ARM Cortex M3* that allows more complex operations on the Arduino board. The microcontroller on the board is programmed using the Arduino programming language (based on *Wiring* [8]) and the Arduino development environment (based on *Processing* [9]). Arduino projects can be stand-alone or they can communicate with software running on a computer (e.g. *Processing*, *Max/MSP* [10]). An important aspect of the Arduino is the standard way that connectors are exposed, allowing the CPU board to be connected to a variety of interchangeable add-on modules known as shields. Some shields communicate with the Arduino board directly over various pins, but many shields are individually addressable via an I^2C serial bus, allowing many shields to be stacked and used in parallel.

The Arduino board exposes most of the microcontroller's I/O pins for use by other circuits. The Diecimila, Duemilanove, and current Uno provide 14 digital I/O pins, six of which can produce pulse-width modulated (PWM) signals, and six analog inputs. The Arduino Mega provides 54 digital I/O pins fifteen of that can provide PWM output and 16 analog input pins. The Arduino Due provides 54 digital I/O pins twelve of that can provide PWM output, 12 analog input pins and 2 analog output pins. These pins are on the top of the board, via female 0.1-inch headers.

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. Arduino and Arduino-compatible boards make use of shields, which are printed circuit boards that sit atop an Arduino, and plug into the normally supplied pin-headers. These are expansions to the base Arduino. There are many functions of shields, from motor controls, to breadboarding (prototyping). Most common shields are:

- Arduino Ethernet Shield: to provide Ethernet connectivity.
- Wireless SD Shield: to provide XBee socket, to use any of the Digi communication modules, compatibility to Arduino.
- Arduino GPRS Shield: to provide GSM connectivity.
- Arduino Motor Shield: to provide support and to connect and control stepper motors.

One Important thing about Arduino is its user community where users share their designs close to real world applications and demand new feature that they expect that Arduino board have in the future revisions. Users also ask questions about designs and post how-tos and tutorials and more than 60,000 users of the official user community. [11]

1.2. Arduino Applications

Arduino due to its open hardware feature it is used in many applications, somebody says that everything you want to do it could be done with an Arduino. But if we make a deep look on it we will distinguish three main areas of application.

These areas are the following ones: educational, domotics and professional applications.

1.2.1. Educational

Since Arduino programming language is C and chip burning is done through usb cable from the IDE there are many schools and institutes that teach electronics practical lessons with Arduino. Students can check how work electronic components easily with a breadboard, Arduino and few electronic components. Its versatility allows that a big range of students can use it from high school students to university students and it also allows implementing test applications close to the market.

Typical simple applications in this area are blinking leds, push button detection or beep player where students connect either a led or a button or a beeper to Arduino and make them active or not with the computer.

Other applications are stepper motor control, light bulb controller or multi speaker control where students connect more complex circuits to Arduino and interact with them.

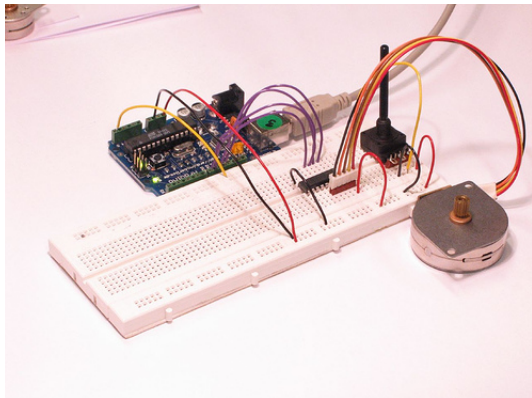

Figure 1.1: Stepper Motor Example [12]

With some basics on electronics and some practice with Arduino students can easily make more complex projects like a robot arm or a sumo fighter robot. Where with just buttons, stepper motors and *Lego* bricks students can build a fully functional robot arm controlled by buttons with Arduino as main microcontroller or with some wheels can make a sumo fighter robot.

Figure 1.2: Sumo Robot built by Students of a university [13]

1.2.2. Domotics

There are many people that use Arduino to make their own home gadgets to control their stuff. Since Arduino costs are low the gadget costs are low so people gets encouraged to make their own gadgets.

The most common gadgets are relative home and car security so there are many people with home theft alarms and GPS car locators done with Arduino. A simple theft alarm can be developed with an Arduino board, an Arduino GPRS shield and a magnetic contact switch to monitor if the door is opened. I have developed one in just 3 hours and if somebody gets in and opens the door the alarm sends an sms and makes a long lost call.

Car locator consists of a GPS and a GPRS shield with an Arduino and batteries that when you make a lost call to the car locator it returns a sms with gps coordinates of the location of the car.

Other gadgets are presence detector to turn on the lights on a room, temperature sensors with temeparture display or a color code display, figure 1.3.

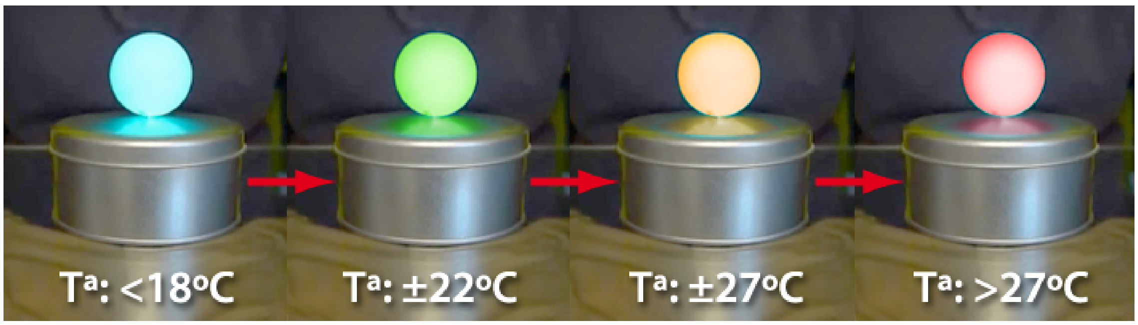

Figure 1.3: Color coded temperature display

Mp3 player, just and speaker and Arduino with mp3 shield and sd card shield to play music from the sd card through the speaker.

1.2.3. Professional applications

Some of the other applications could be a professional application but the main difference is that professional applications are the ones that are built to be sold to other people or companies or applications that are built by request.

There are many applications that can be done with an Arduino board, we will focus on those applications related on our research projects and interests.

We have make a lot of wireless sensor networks with an Arduino but the most important are the ones in Ibiza to monitor beach weather conditions, in the mark of SITIB research project. We had to design weather stations to monitor temperature, humidity, atmospheric pressure, wind speed, wind direction and rain volume in a low cost sensor node. Before start using Arduino we used Crossbow motes but their high cost and the fact that they are closed hardware make us change up our decision and use Arduino boards.

With Arduino we also simplified our design since *MicaZ* motes has analog inputs that allow 3.3V as maximum input voltage and Arduino allows up to 5V so since most of our sensors have a dynamic range from 0 to 5V we reduce the instrumentation needed to connect sensors. We use *XBee* shield to transmit data through WSN and in the gateway we use a GPRS shield to send data to our servers.

The main drawback of using Arduino was that it consumes more than *MicaZ* since Arduino maximum sleeping time is 8 seconds so we have to make it sleep more frequently.

We have also deployed buoys with water temperature and PH sensor to Ibiza using an Arduino board with Xbee shield to get the data.

Figure 1.4: Arduino weather stations in Ibiza

Another application is the sound level meter that we developed to use in SIAC project. SIAC stands for Sistema de Informacion ACustica and its main goal was to be able to make sound maps of Ibiza Island with low cost technology.

We use simple microphone connected to Arduino and using FFT and a A-Weighting filter in Arduino we reduced the data that we have to send allowing us to use *ZigBee* protocol to transmit data between nodes using *Xbee* shields. In the gateway we used a GPRS shield to send data to our servers.

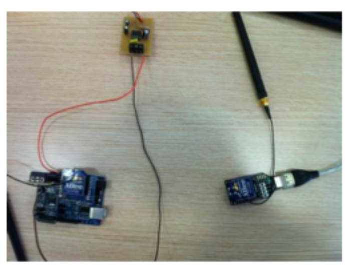

Figure 1.5: Arduino sound meter prototype

Finally from the industrial pount of view it is very important the example of the bassline generator *x0xb0x* [15] that is a clone of the *Roland*'s legendary *TB-303* bassline generator where using Arduino design Adafruit Industries created a prototype using ATmega168 with Arduino bootloader but in the final version it changed the microcontroller to ATmega162.

Roland TB-303 had a selling price of 395$ when it was in the market, from 1982 to 1984. But nowadays its price its about 2000$ and it is hard to find.

x0xb0x clone has a price of 525$ for the pre-build version but as is open hardware you can buy it as a do-it-yourself kit for about 295$.

Figure 1.6: x0xb0xs Bassline generator

1.3. State of art: WIFI shields

Before we decided to create our Wi-Fi shield with OTA capabilities we look if there was any existing shield that met our requirements. We found that there are many solutions available but none have all our requirements.

We have encountered that there are the following Arduino shields with Wi-Fi capability:

- *AsyncLabs WiShield v1.0*
- *AsyncLabs WiShield v2.0*
- *LinkSprite CupperHead WiFi Shield*
- *LinkSprite WiFi Shield*
- *DFRobot Wifi Shield*
- *Watterott RedFly Shield*

The following table summarize each shield features.

	OTA	Standard supported	Security	Communication with Arduino
AsyncLabs WiShield v1.0	NO	802.11b	WEP, WPA/WPA2	SPI
AsyncLabs WiShield v2.0	NO	802.11b	WEP, WPA/WPA2	SPI
LinkSprite CupperHead WiFi Shield	NO	802.11b	WEP, WPA/WPA2	SPI
LinkSprite WiFi Shield	NO	802.11b	WEP	Serial
DFRobot Wifi Shield	NO	802.11bg	WEP, WPA/WPA2	Serial
RedFly Shield	NO	802.11bgn	WEP, WPA/WPA2	Serial

Table 1.2: Wireless shield comparison

Now we will take a deeper look on each shield.

1.3.1. AsyncLabs WiShield v1.0

Figure 1.7: AsyncLabs WiShield v1.0

Shield manufactured by AsyncLabs until the release of version 2. Uses SPI to communicate with the Arduino board so it leaves serial port free to be used by other shields but then a library to interface with the shield is needed to code software.

It also uses some digital pins that will not be usable by Arduino applications these pins are D2, used for an interrupt, but can be switched to D8 if required and D9 used for a connection status LED this can still be used for other purposes.

1.3.2. AsyncLabs WiShield v2.0

Figure 1.8: AsyncLabs WiShield 2.0

Is an evolution from the previous shield and the main changes are that exposes two devices on the SPI bus, with slave select lines on D7 and D10. WiFi connection status LED, on D9, can now be disabled by removing a jumper to make that pin available for other purposes.

1.3.3. LinkSprite CupperHead WiFi Shield

This shield is exactly the same than the AsyncLabs one but manufactured by LinkSprite. This is a quite usual practice when working with open hardware in order to get lower prices or increase company product portfolio.

1.3.4. LinkSprite WiFi Shield

Figure 1.9: LinkSprite WiFi Shield

Since this shield uses Arduino serial to communicate the user, through Arduino board, just configures the WiFi parameters using AT command. User also can simply treat the WiFi as a transparent serial port after some offline configuration. It uses D0 and D1 digital pins, serial pins, to communicate with Arduino so these pins are blocked to be used by other shields at the same time.

1.3.5. DFRobot Wifi Shield

Figure 1.10: DFRobot Wifi Shield

This shield uses serial port to communicate with Arduino so user need to set Wi-Fi parameters via AT commands too and D0 and D1 digital pins are blocked to be used by other shields. This shield has other features like the Ethernet to Wireless Bridging; enable wired network device to have wireless communication interface. It uses the Ethernet port on the shield to simply send data from/to Wi-Fi module without Arduino interaction. It also has a built-in Web server to configure the shield via standard web browser. It is the shield, which is more similar with the one we want to design but has no OTA capability.

1.3.6. Watterott RedFly Shield

Figure 1.11: Watterott RedFly Shield

This shield uses serial port to communicate with Arduino so user need to set Wi-Fi parameters via AT commands too and D0 and D1 digital pins are blocked to be used by other shields. It also uses D2 and D3 digital pins to interact with Arduino so these pins are not available to use by other purposes. This shield also supports up to 8 sockets at the same time.

1.3.7. Concluding remarks

The review of the existing shields has made us to realize that are some important things to take into account in order to make an Arduino shield. The most important ones are how the shield will interact with Arduino, using serial connection or SPI, and how many extra pins will the shield need.

To support using various shields at the same time and to be able to program Arduino remotely our shield will interact with Arduino through SPI and it will also work through serial connexion using a digital pin to select the wireless shield.

To be able to program the Arduino remotely we will need to interrupt the Arduino processor in order to make it attend our commands so we will need one of two interruption pins available, D2 and D3, in the Arduino board.

CHAPTER 2. OVER-THE-AIR PROGRAMMING

Over-the-air programming (OTA) refers to various methods of distributing new software updates or configuration settings to devices like cellphones and set-top boxes. More recently, with the new concepts of Wireless Sensor Networks and the Internet of Things, where the networks consist of hundreds or thousands of nodes, OTA is taken to a new direction: for the first time OTA is applied using unlicensed frequency bands (2.4 GHz, 868 MHz, 900 MHz) and with low consumption and low data rate transmission using protocols such as 802.15.4 and ZigBee.

Motes are often located in places that are either remote or difficult to access. This system enables firmware upgrades without the need of physical access, saving time and money if the nodes must be re-programmed.

The OTA mechanism requires the existing software and hardware of the target device to support the feature, namely the receipt and installation of new software received via the wireless network.

2.0.8. Why OTA?

For our project is essential to provide end users with the possibility of change parameters and, even more, some pieces of code once systems are installed. OTA is the key point of our shield so it is the key point of our project. There are many Wi-Fi shields but no one have OTA capability as we reviewed before.

CIMNE has many applications done with Arduino boards that are spread along Ibiza and other places in Spain like vineyards near Sant Sadurni d'Anoia. Before using Arduino we used *Micaz* motes from crossbow and we developed a web platform to control and remotely change parameters of each mote through the web, like data acquisition time interval and many others like sleep-wake cycles. Now with Arduino that is not possible and if there is any change to be done we need to go there with a laptop and reprogram Arduino boards manually.

This solution has very high costs since we have to spent time and money getting where Arduino boards are and program them with new parameters. Sometimes we have to take planes and stay more than a day in place since there are a lot of network nodes to re-program or simply there is no way to get access to all nodes the same day. In buoys the problem is bigger since we have to get to the buoy, remove the buoy and get it to the coast, open the buoy, reprogram the buoy, then close and seal the buoy and get it into the sea again which requires to rent a boat and divers.

With Over-the-air programming feature we could do the reprogramming from our office using a web platform reducing costs and time. It also would help us to increase the features of our networks like command actuators remotely and enable the remote machine control.

Wi-fi shield with over-the-air capability also allows programming the Arduino using GPRS or Xbee shields since it is configurable to get data through shields serial port.

CHAPTER 3. SHIELD DESIGN

In this chapter we will review the shield design process.

3.1. Prerequisites

To design the wifi shield with OTA capabilities CIMNE have some previous requirements. These requirements are:

- To use *Microchip* processor: *PIC24FJ256GA106* [16] running at 32MHz.
- To use *Microchip* wireless module: *MRF24WB0MA*. [17]
- To get power from *Arduino*.

These requisites derive from some previous projects in CIMNE.

CIMNE have the *Microchip PIC24FJ256GA106* and *MRF24WB0MA* development kits and they software engineers are used to work and develop with microchip components. For this project we could use components from other companies like *Atmel* or *Texas Instruments* but then CIMNE would have had to buy new development kits and their software engineers would have had to learn how to code software for the new components and it would delay the shield firmware development.

Microcontroller features are described in the table 3.1

Value	**Value**
Architecture	16 bits
CPU Speed (MIPS)	16
Memory Type	Flash
Memory (KB)	256
RAM Bytes	16384
Operating Voltage Range (V)	2 - 3.6
I/O Pins	53

Table 3.1: *PIC24FJ256GA106* features.

These features are enough to run the firmware with the OTA function and the web interface to configure and upload sketches. microcontroller need to have the clock set at 32 MHz to be able to provide the 16MIPS that are shown in the microcontroller specifications.

Since we are using this microcontroller the Wi-Fi module that best performance gives is the *Microchip MRF24WB0MA* because of it is made for *Microchip* microcontrollers, it works through a SPI interface with Microchip microcontrollers, and it provide full compatibility with *PIC24FJ256GA106* firmware development environment *MPLAB* [18].

We have to get power from Arduino since we want to deploy the shield to new applications and in our existing applications with the shield everywhere we can use it and if we get power from the Arduino board we will avoid using external voltage converters to power our shield. It will work just connecting the shield to Arduino and powering Arduino board, we will not need to make other changes to our installation.

3.2. Design considerations

We will use *CadSoft* design software called *Eagle* [19] to design our device. Our system block diagram is displayed on figure 3.1

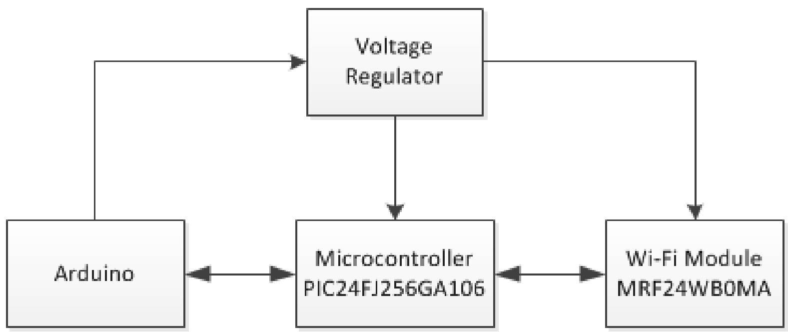

Figure 3.1: Bloc diagram of our design.

The microcontroller *PIC24FJ256GA106* is a 16 bit microcontroller ideal for low power and connectivity applications that need multiple serial ports. Its large ram memory and its large flash allow embedding control and monitoring applications on it. It also allows hosting a web page to manage the device so data gathered by its inputs can be easily accessed using a web navigator.

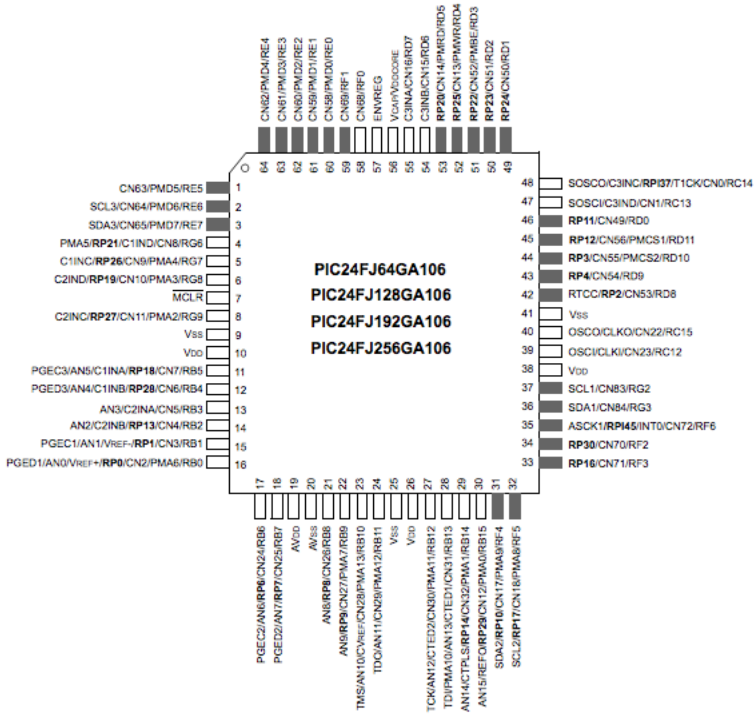

Figure 3.2: *PIC24FJ256GA106* overview.

This last feature needs that the device has to be able to connect to Internet so we will use the microchip wireless module *MRF24WB0MA* to provide Internet connection to the microcontroller.

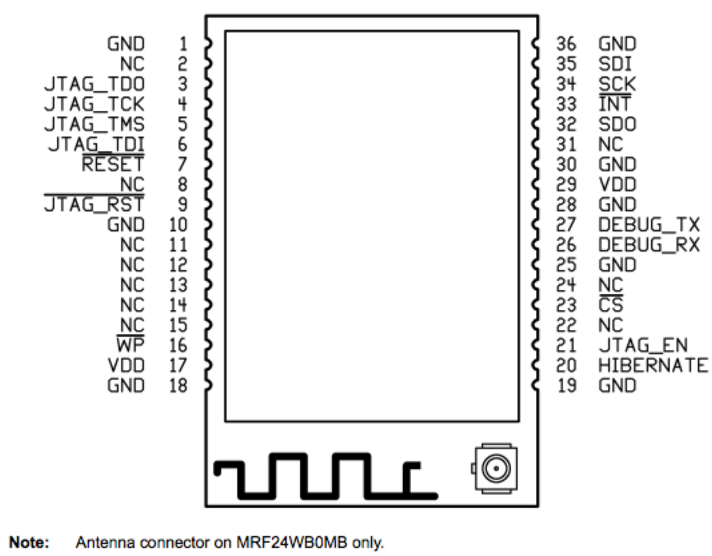

Figure 3.3: *MRF24WB0MA* overview.

MRF24WB0MA is a wireless RF transceiver module that is IEEE 802.11 compliant and it have a serialized unique MAC so user have not to pay for a MAC address. It also has an integrated antenna and has certification to be used in USA, Canada, Europe and Japan. It is specially designed to use with microchip microcontrollers since connection between them is very easy using microchip SDK. It has hardware support for most common Wi-Fi security protocols, AES and TKIP (WEP, WPA and WPA2). It is connected with the microcontroller through the SPI Interface.

To make our system work properly we need to perform the following tasks:

- Provide all required connections, stated on its datasheet, to the microcontroller.
- Provide all required connections, stated on its datasheet, to the wifi module.
- Connect the microcontroller with the Wi-Fi module.
- Provide connections from Arduino to the microcontroller.
- Provide power from Arduino to voltage regulator.

3.2.1. Microcontroller design

We have decided to start the design from the microcontroller, so lets get a quick look on its datasheet to see basic connection requirements of it to make it work.

Minimum connections, as thery are stated in the datasheet, are:

- Power supply pins.
- Master Clear (MCLR).
- Voltage regulator pin.
- Oscilator output.
- ICSP Pins.

So lets take a look on each requiered connection and what are they needs.

3.2.1.1. Power supply pins

We need to connect all the power outputs, V_{DD} and V_{SS}, to 3.3V and ground respectively and decouple it with some capacitors to avoid ElectroMagnetic Coupling (EMC) problems that affect the device normal function.

Following datasheet recommendations we will use ceramic capacitors of 100nF in range 10-20V and with low ESR. We will place them as near as possible to the microcontroller.

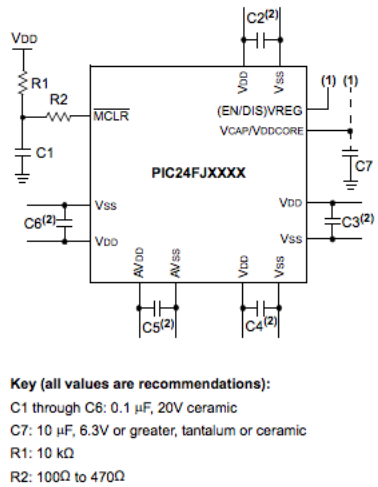

Figure 3.4: Power Supply connections.

3.2.1.2. *Master Clear*

The MCLR pin provides two specific device functions: device Reset, and device programming and debugging.

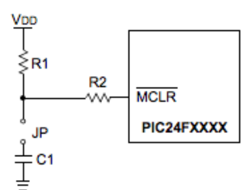

Figure 3.5: Master Clear connections.

Following the recommended design we will implement master clear as a voltage divider but since we want to program our device through the ISCP port we will use a push button (JP on the figure 3.5) and a connection to the ISCP port to be able to program it. R_1 and R_2 values are suggested in the datasheet to be $R_1 \leq 10k\Omega$ and $R_2 \leq 470\Omega$ since in the datasheet recommends $10k\Omega$ as starting value for R_1 we will use it. For R_2 we will use 330Ω since it guarantees that any current leak is below 10mA.

3.2.1.3. *Voltage Regulator pin*

We will use the internal voltage regulator to ensure that 2.5V are generated to power the core of the microcontroller. So we need to attach 3.3V to the voltage regulator pin and, derived from the datasheet, we will need to connect a low ESR capacitor between V_{cap} pin and ground.

We will use a 10uF 16V ceramic capacitor as is recommended by the datasheet.

3.2.1.4. External Oscillator Pins

We need to use an external oscillator to make microcontroller work at 32 MHz. as is required. Connecting an oscillator is not just a pick and place job since it is very important its placement the nearest possible to the oscillator pins.

In the datasheet microchip recommends that: "The oscillator circuit should be placed on the same side of the board as the device. Place the oscillator circuit close to the respective oscillator pins with no more than 0.5 inch (12 mm) between the circuit components and the pins. The load capacitors should be placed next to the oscillator itself, on the same side of the board."

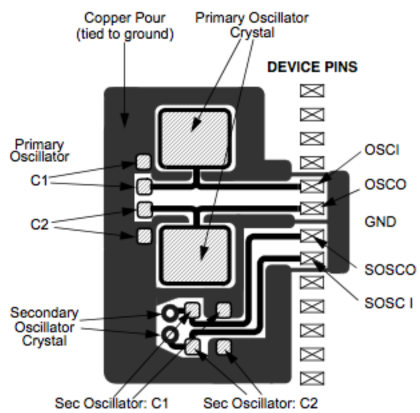

Figure 3.6: Oscillator connections.

In the figure 3.6 we realize that we will need two capacitors. Their value depends on what oscillator is chosen. We want to have 32MHz as oscillating frequency so we will choose a inexpensive crystal. After some search we will use Aker CAA-32.000-18-3050-X, it is a HC49 smd crystal that fulfills our needs, run at 32 MHz and low cost.

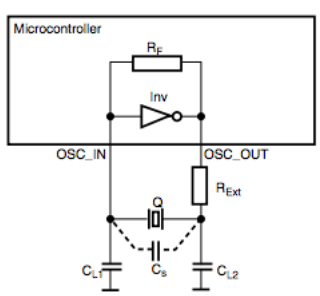

Figure 3.7: Oscillator's capacitors.

Real model of our oscillator circuit is shown in the figure 3.7. R_{Ext} in our case it is inside the microcontroller and we have not to bother about that. To guarantee the correct oscillation of our circuit we have to ensure that the equivalent C_L it is 18pF as is stated by the manufacturer on the datasheet,it also states that $C_S = 7pF$. With the 3.1 equation we derive C1 and C2 values, to make easier the design we will assume that C1 and C2 have equal values.

$$C_L - C_S = \frac{C_1 \cdot C_2}{C_1 + C_2}; 18pF - 7pF = \frac{C_1^2}{2C_1}; \frac{C_1}{2} = 11pF; C_1 = 22pF \tag{3.1}$$

For this oscillator C_1 and C_2 have to be of $22pF$ to guarantee the correct oscillation of the oscillator system. This value is a good value since is a kind of standard value since crystal oscillators use to have 18pF as C_L value and 7pF as C_S value.

3.2.1.5. ICSP pins

ICSP stands for In-Circuit Serial Programing and it is a method to direct program micro-controllers so we have to provide connection to ICSP pins in order to be able to program our microcontroller once the board is assembled. To be able to use microchip programmer, PicProg, we will use a 5 pins 2.54mm header. ICSP pins are MCLR, +3V3, GND, PGD and PGC.

3.2.2. Wireless module design

Wireless module minimum required connections are SPI bus, power and JTAG connections. Since we will not use JTAG we will make connections to disable it, and enhance the security and robustness of our device avoiding possible problems with wifi connections. All the requiered connections are shown in the figure 3.8.

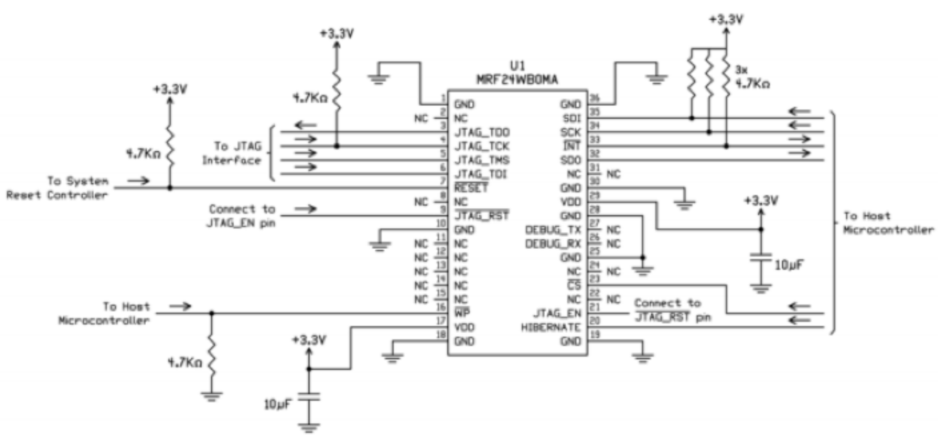

Figure 3.8: *MRF24WB0MA* module connections.

3.2.3. Other needed components

We will use pin header and receptacles to connect the board to Arduino so we will need two receptacles with long legs of 7 pins for Arduino digital connections and two of 6 pins for analogic and power section. We will also need a two row 3 pins receptacle to connect to Arduino ICSP pins.

We also will need two buttons; one to restart the microcontroller and the other to reset wireless settings if is needed, it will work with a long press.

To make it compatible with other boards we will require and input of 5V so we will need a voltage regulator on board to get the 3.3V that the microcontroller and Wi-Fi module need. We will use *LP38691DT-3.3* from National Semiconductor that gives stable 3.3V for any input between 3.3 and 5V.

We will use 4 leds. 1 power led and 3 reconfigurable from the microcontroller.

3.3. Schematic design

Using Eagle software we will start designing our device by designing its schematics in order to check that all connections needed are there and well connected. For the design we will use 0805 SMD resistors and capacitors.

As we said before we will start from the microcontroller so we will follow the same order than before. Since there is not the microcontroller in the eagle component libraries we have to create it from the information available in the datasheet.

In the Component editor we select a 64-pin TQFP package layout for our component layout. Then we draw the schematic of our chip using the chip shape as a reference once drown we will put all 64 pins and connect it to the pins of the layout selected before. With this we now have the microcontroller component on our Eagle component library ready to use it.

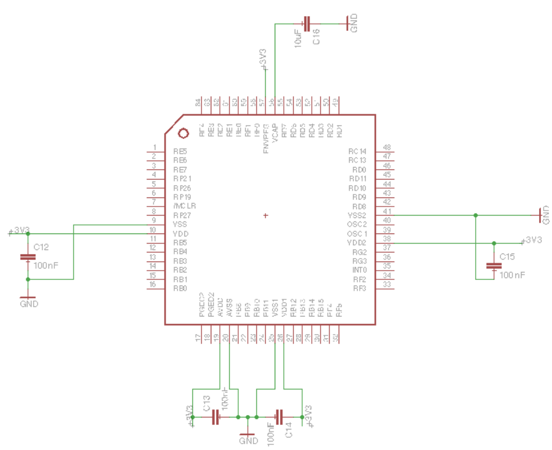

Figure 3.9: *PIC24FJ256GA106* power connections.

First of all we select our microcontroller component created just before and we place it in our schematic to start designing our device; we will start connecting all the power pins of the microcontroller and connecting all capacitors needed to decouple the power. We also connect a capacitor on voltage regulator pin to enable it.

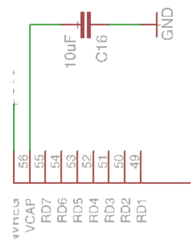

Figure 3.10: Voltage regulator connection detail.

Once connected all power pins we will connect Master Clear like is shown in figure 3.11.

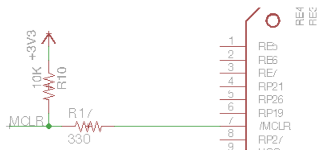

Figure 3.11: Master Clear connection detail.

Once connected master clear we will face off the external oscillator. Oscillator needs two capacitors and the crystal in a π-shape design, as stated in the datasheet. We connect the two 22pF capacitors and the crystal tot the microcontroller like is shown in the Figure 3.12.

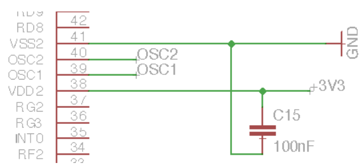

Figure 3.12: Oscillator circuit detail.

To finish with required connections we will connect the ICSP pins to the microcontroller to be able to program it. We will leave a 5-pin, 2.54 mm pitch spacing, male pin header in order to connect the *PicProg* to burn the microcontroller. We will connect, in this order, to the ICSP pin header: MCLR, +3V3, GND, PGD and PGC.

Next we will make all required connections for our Wi-Fi module. First of all we will design our module in the component editor and when finish we place it to our schematics. We connect all power pins with its decoupling capacitors, 1uF. As we do not want to use JTAG interface we will disable it placing resistors to ground at JTAG enable pin and JTAG reset pin; we also put a pull-up resistor at JTAG TCK pin to fully disable it.

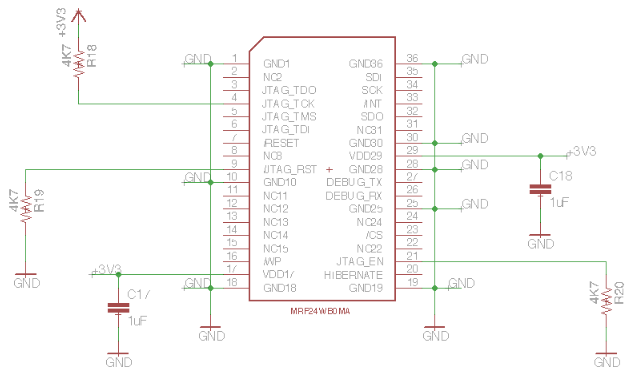

Figure 3.13: Wireless module power connections detail.

Now we have an operating microcontroller and an operating Wi-Fi module but they do not see each other so we have to connect each other. We will start by defining the needed connections on Wi-Fi module. So we will connect the SPI pins, used to communicate with the microcontroller, these pins are: SDI, SCK, SDO, CS, UTX, URX, CE, RESET, INT and . To avoid messing up with microcontroller pins we will rename all but RES to make these starting by "MRF_".

We will place some 0Ω resistors at RES pin to avoid any electrical couplings. We will place a pull-down resistor on MRF_CE of $10k\Omega$ and a pull-up resistor on MRF_INT of $4k7\Omega$ to guarantee the correct function of our module.

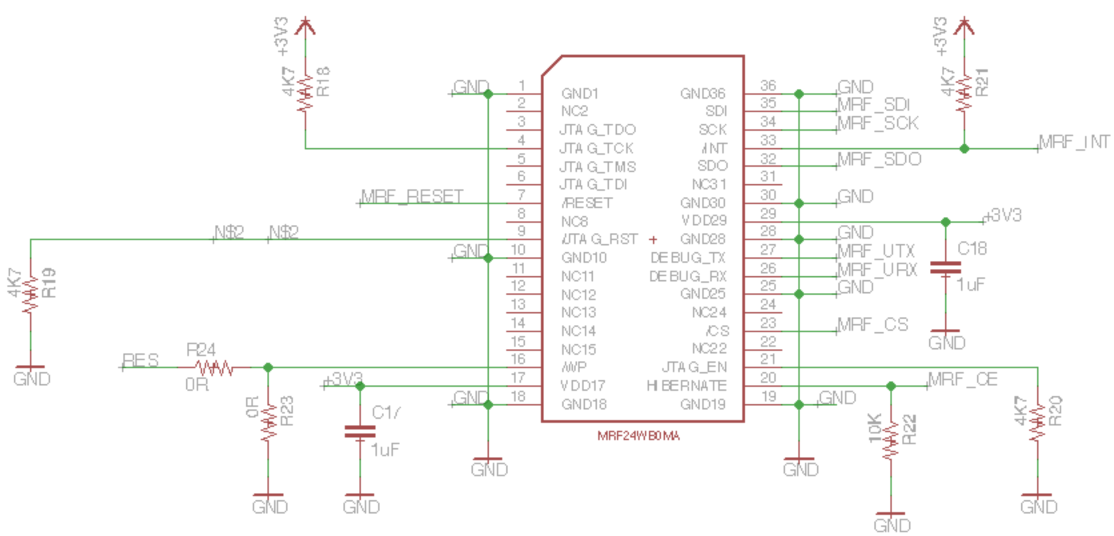

Figure 3.14: Wireless module connections detail.

From now we know what connections we need to make to our microcontroller to assure than the module and the microcontroller can communicate each other so we have to connect them but before we have to take into account that we will have to route this connections in our board layout so we will connect them to the remapable pins by avoiding that routes cross each other. We also have taken into account not to drive module pins to the farthest side of our microcontroller. So we will use the available pins from 1 to 16 of our microcontroller, as is shown in figure 3.15.

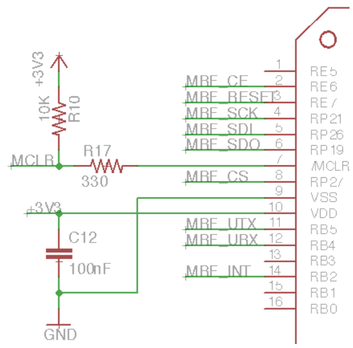

Figure 3.15: Wireless connections at microcontroller.

We, now, have a completed our module-microcontroller communication connections son now we have, still, to connect the voltage regulator, the headers to connect to Arduino and the most important thing that is remaining, the connections to allow to program Arduino remotely. These connections are the ones that Arduino have at its ICSP 2-row header and they are: MISO, MOSI, SCK, RST, 5V and GND. As we did before we will rename SCK and RST to make them to start by "ARD_". A part from that we need an interruption pin to interrupt Arduino to be able to send programming commands and a chip select, CS, pin to enable or disable Arduino; as Arduino interruption pins are digital 2 and 3 we will use digital 2 and for CS we will use digital 4 pin. Since the Arduino ICSP pins are at the opposite side than the WI-FI module we will use microcontroller pins from 33 to 48. Once connected the microcontroller looks like figure 3.16.

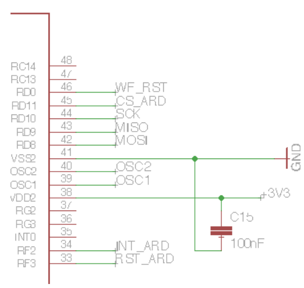

Figure 3.16: Arduino connections at microcontroller.

To be able to communicate with other shield we will use one of two serials available on our microcontroller and we will connect on Arduino digital 0 and 1 pins. The other serial available we will use in order to be able to debug our firmware using a debug header.

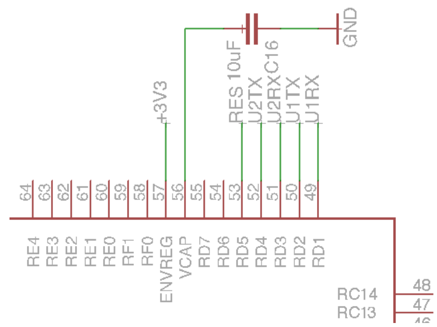

Figure 3.17: Serial connections at microcontroller.

As is shown in the voltage regulator datasheet we will make the connections using two 1uF capacitors one for the inpunt and the other for the output. We also will connect the power led using a 100? resistor to drive the current. Power in is goten from arduino 5V at either power header or ICSP header.

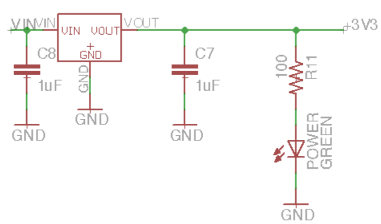

Figure 3.18: Voltage regulator.

The only things that remain are buttons and leds so we will connect it. Leds will be connected on reprogrammable pins in the microcontroller. The emptiest space of our microcontroller is the bottom space so we will use pins from 17 to 32. We will connect three leds, one yellow, one green and one red but the design is the same for each one, we will use a 150Ω resistor for each led.

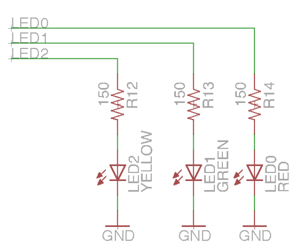

Figure 3.19: Led design.

We will use two buttons, as said before, one for reset Wi-Fi settings and other to restart the board. The one to restart the board will use MCLR pin since the functionality is the same that we want to implement. The other will use a reprogrammable pin, in this case we will call it as WF_RST.

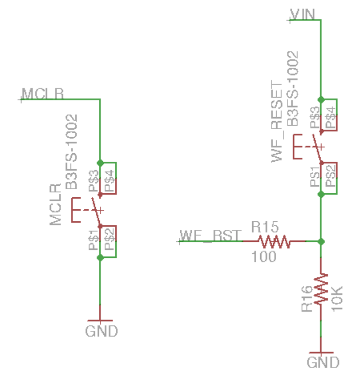

Figure 3.20: Push button design.

For the reset button we will drive MCLR pin to ground using a push button and for the Wi-Fi reset button we will drive 5v to the reset pin using two resistors to avoid damaging our microcontroller; one of 100Ω to ensure that we do not drive to much current to our microcontroller and the other of $10k\Omega$.

The schematic is now finished, figure 3.21 . We have to design our layout now to get the board.

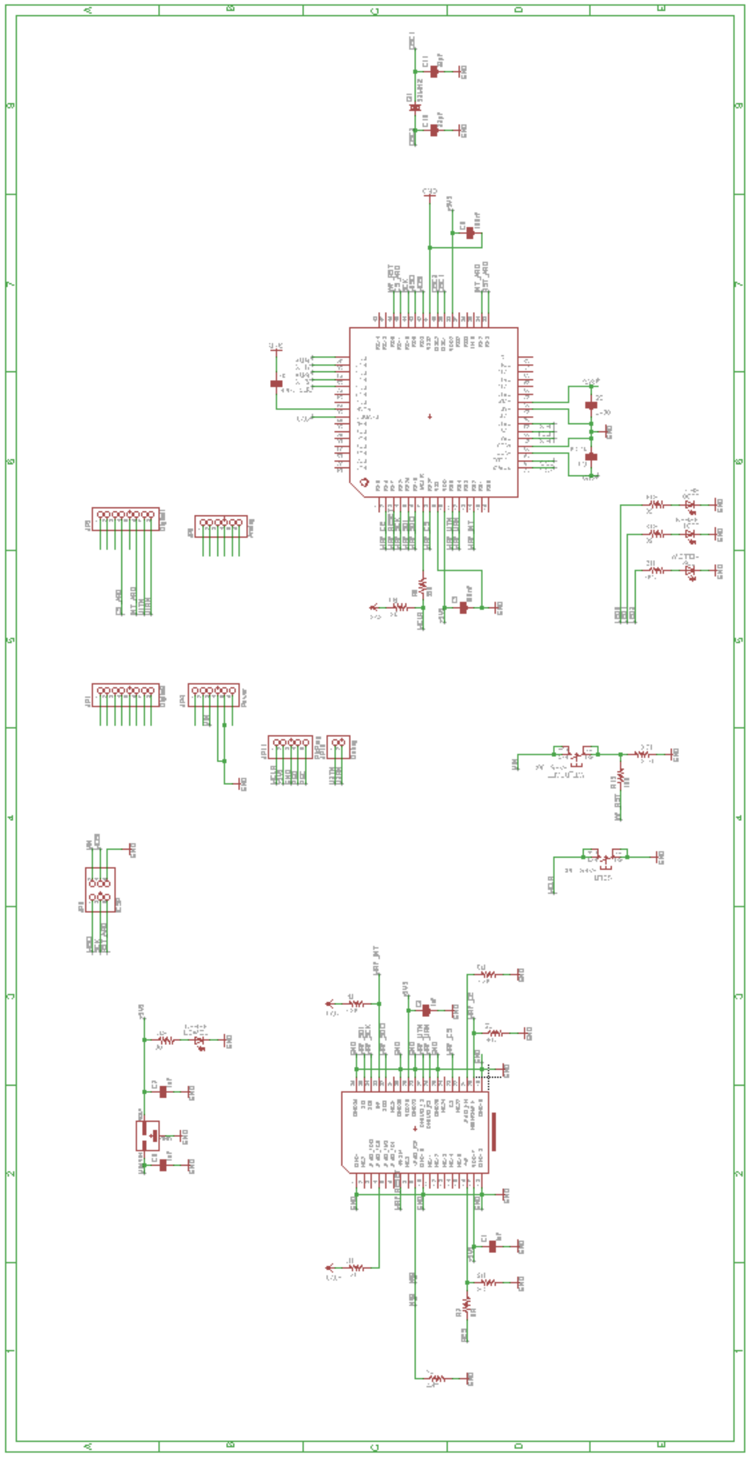

Figure 3.21: Schematic design.

3.4. Board layout

Since we want to make an Arduino shield we will use a board outline with the same size and shape that the Arduino board so first of all we will make it using the Arduino dimensions gotten from the Arduino website documentation. We also place the pin headers that match with the Arduino ones at their place.

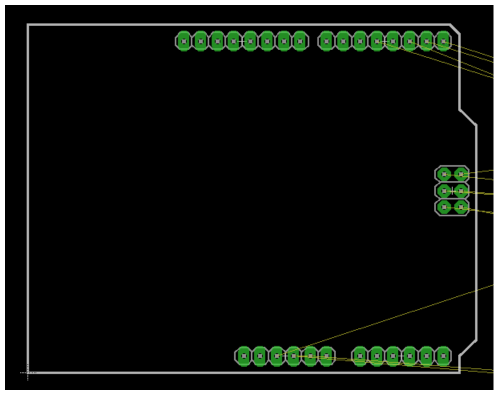

Figure 3.22: Arduino board outline.

Once the board outline its done we will place the microcontroller and the wifi module on it. Then the needed resistors and capacitors; the oscillator and the voltage regulator trying to avoid crossed lines to make easiest the routing part. Finally we place the leds, the buttons and the *PicProg* and debug headers on it. Now the board looks like figure 3.23.

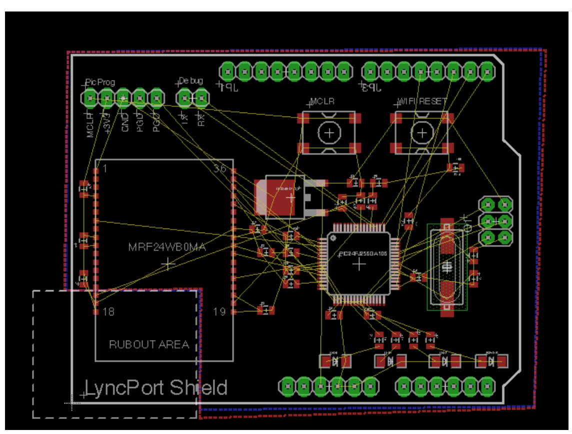

Figure 3.23: Board layout with placed components.

To start the routing process we will define the ground planes on each side of the board, the red colour is for the top side and the blue for the bottom side. Ground plane are shown as a dot line in the figure 3.23. We start routing the closest connections on the microcontroller and then the connections with wifi module finishing with leds and buttons. Once routed the board layout looks like the figure 3.24.

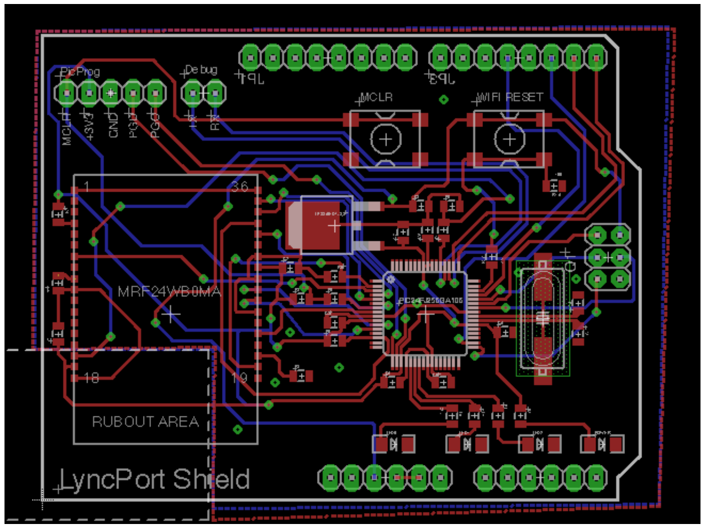

Figure 3.24: Board layout routed.

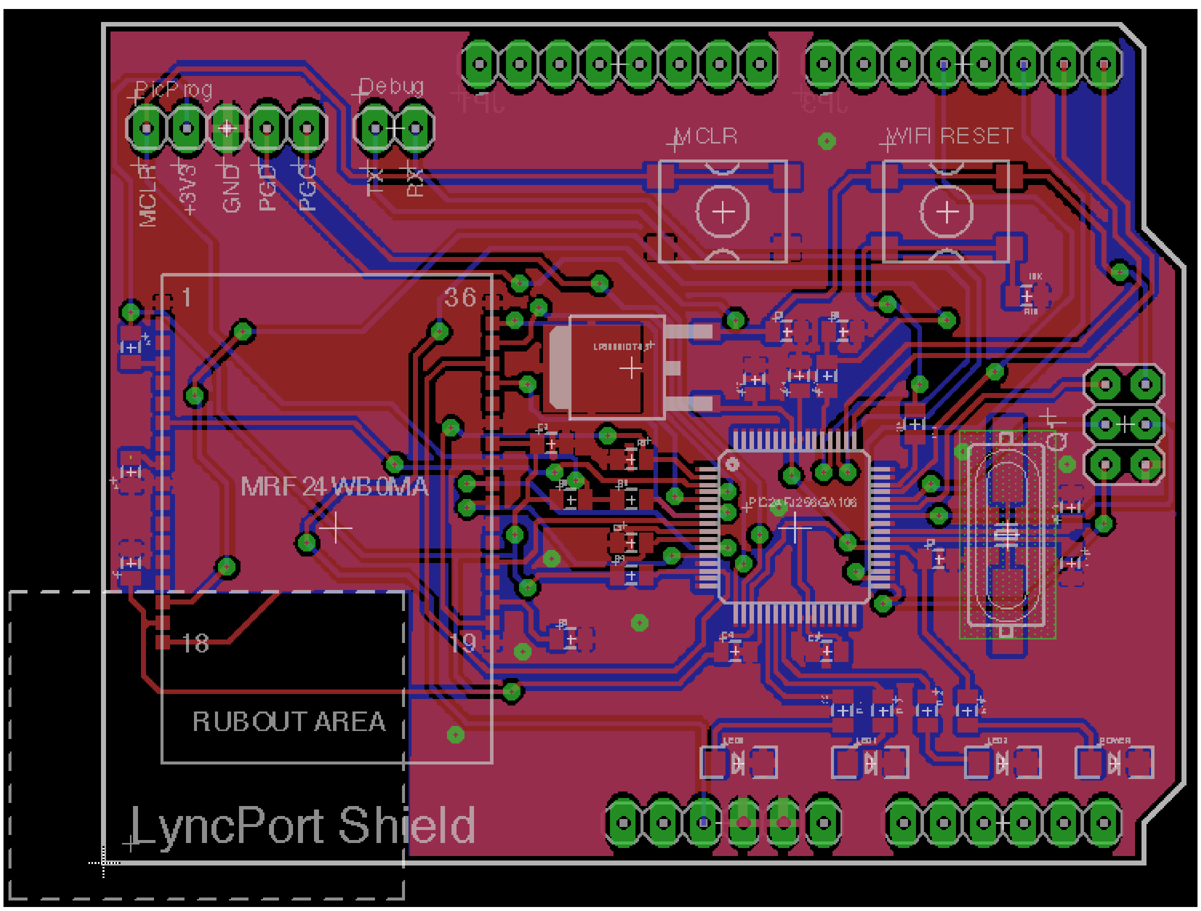

Figure 3.25: Board layout finished.

3.5. Circuit board production and assembly

The board will be produced and assembled in China by *Chuan Way Technology* since prices there are cheaper than companies here. The talbe 3.2 shows the price comparison for different companies. One from China and two from Spain.

We have worked with *CircArt* and *Madritonic* in past projects but for this project we get the contact of a Chinese company, *Chuan Way*, and we asked them a quote of our board getting best prices.

Quantity $	Chuan Way $	Chuan Way €	Cirat	Madritonic
1	150$	115.38€	-	359.90€
10	75$/u	57.69€/u	92,50€/u	163.38€/u
50	59.60$/u	45.85€/u	64.17€/u	81.53€/u
500	42.40$/u	32.62€/u	59.15€/u	58.70€/u
1000	37.80$/u	29.08€/u	53.25€/u	58.12€/u

Table 3.2: Price comparison

Euro currency was 1.30 Dollars when we applied for the quotation. Shipping costs are included in the board price. Fastest production time was the one from *Chuan Way* it took only 3 weeks to produce and assembly all the boards. The shipment took only 3 days.

Once we received board we took a look at the boards and them look like the figure 3.26.

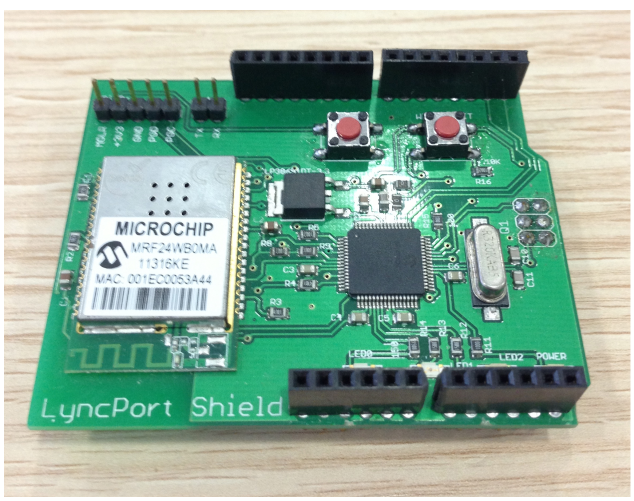

Figure 3.26: Finished shield.

Now we will burn the firmware and we will test it. After that we could say that the board is fully working.

CHAPTER 4. RESULTS

Once we get the firmware developed at CIMNE programmed into the shield, using *Microchip's MPLAB ICD 3* programmer [20], we are able to test our module. This firmware includes a web interface to configure the device and the code to upload sketches to Arduino board.

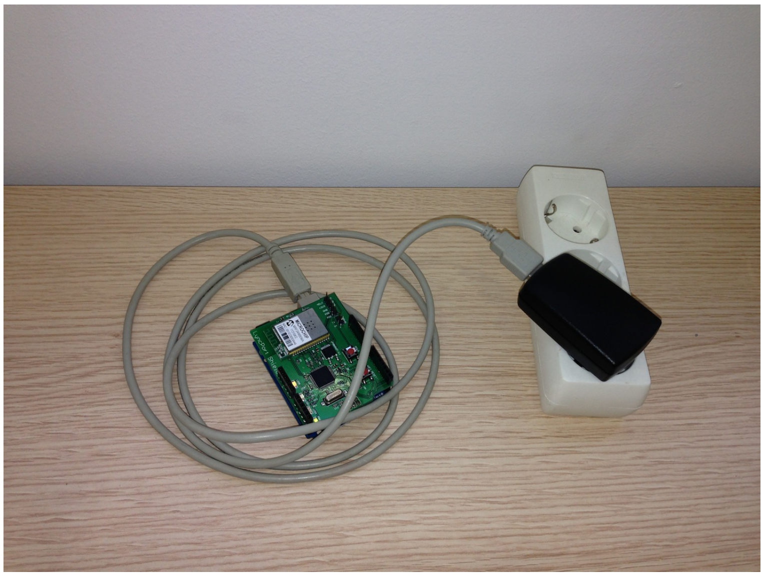

Figure 4.1: Board plugged in and ready to work

Once finished we connect our brand new shield to the Arduino Board and we connect it, powering through the usb port, and we check if the device is found in the wifi networks of our laptop. It appears with Lync053a44 name, if it does not appear we have to reset the wifi settings pressing the wifi reset button since it will have a previously saved wifi setting. We connect to the wifi shield and then we open a web browser and we type in Lync.local, which is the default host name, as the web address that we want to access.

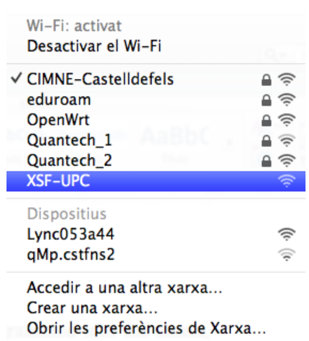

Figure 4.2: Wifi selection with our shield displayed

It shows up the main screen of our wifi shield where we can select to setup the wireless settings, to discover other shields on the Ethernet or to upload an Arduino sketch.

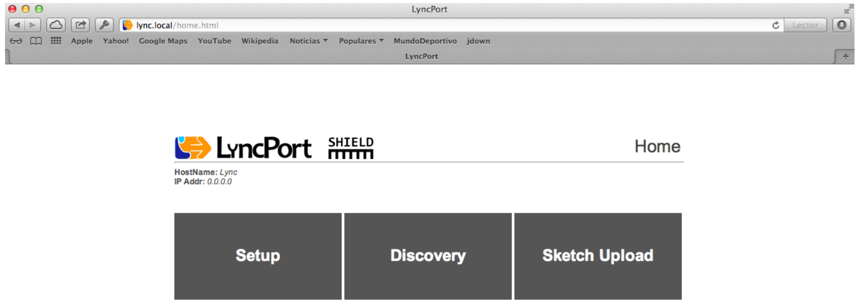

Figure 4.3: Hompage for control of our shield

In the setup tab in the general section, figure 4.4, we can change the name, the type and the description of our wireless shield to make easy to locate it.

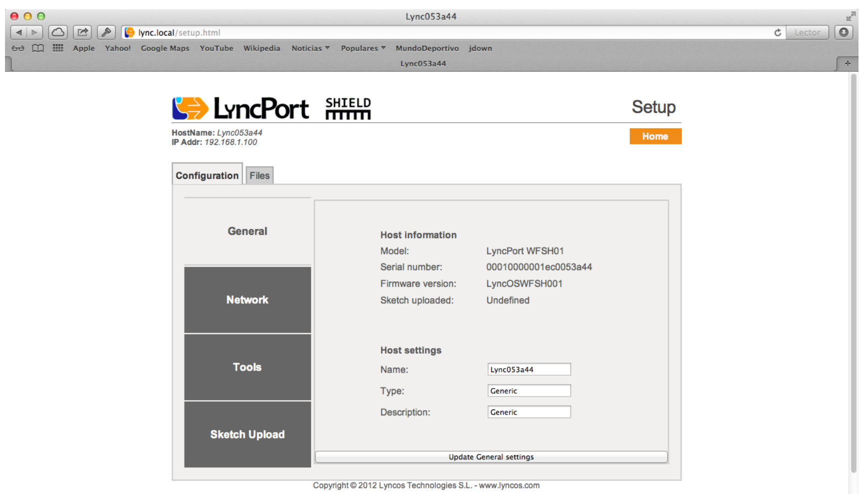

Figure 4.4: Configuration page of our shield

In the network section, figure 4.5, we can change the network mode from AD-HOC to network device and connect to an existent wireless network and change the IP settings.

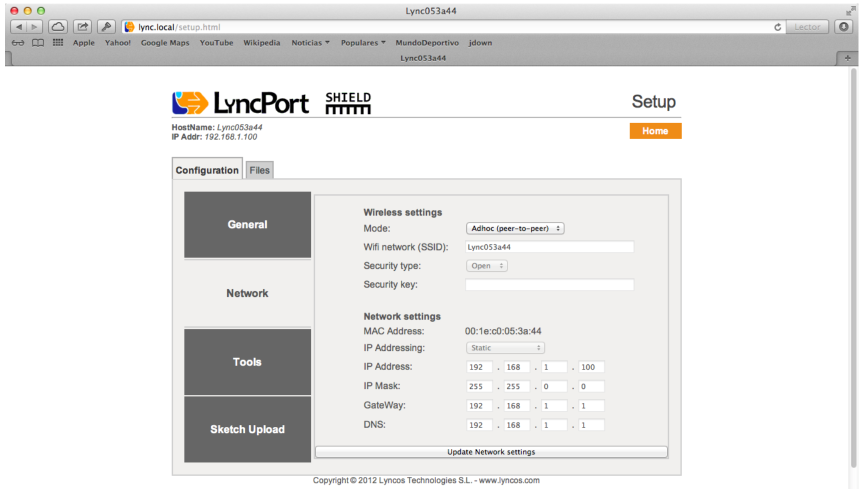

Figure 4.5: Network configuration page of our shield

In the sketch upload, figure 4.6, we can select our sketch to be uploaded. To upload a sketch we need the compiled hexadecimal version of our Arduino program. To get it we have to compile it through the Arduino IDE and then select the hex file that is generated.

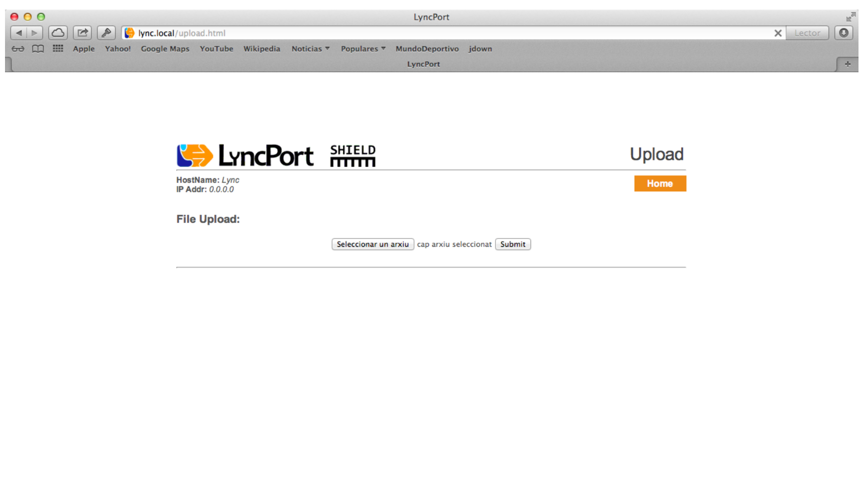

Figure 4.6: Sketch upload page of our shield

Once sketch is uploaded it stats to run automatically.

We have tested with the *BlinkWithoutDelay* Arduino example code changing the waiting time to different values and we noticed that the programming works fine.

We have modified the sketch since the example sketch just runs one loop and we have no time to make sure that the sketch was being run correctly so we decided to add an infinite loop with blink - no blink states for our Arduino.

Code used in the skecth is listed below:

```
// set pin numbers:
const int ledPin =  13;      // the number of the LED pin
// Variables will change:
int ledState = LOW;             // ledState used to set the LED
long interval = 1000;           // interval at which to blink (
   milliseconds)

void setup() {
  // set the digital pin as output:
  pinMode(ledPin, OUTPUT);
}

void loop()
{

  ledState = LOW;
  while (1) {
    if (ledState = LOW)
    {
      ledState=HIGH;
    }
    else {
      letState = LOW;
    }
    digitalWrite(ledPin, ledState);
    delay (interval);
  }

}
```

CHAPTER 5. CONCLUSIONS

At the beginning of the project, the following requirements were established:

- A working Wi-Fi Arduino shield.
- Shield must have OTA capability.
- Powered from Arduino.

A revision of the work done for each stage is presented with comments about results and some proposals for further improvements.

Once this work has been completed we have an Arduino Wi-Fi shield that allows Arduino connecting to Internet. This shield also has OTA capability since we have connected the Arduino CPU programming pins, MISO, MOSI, SCK and Reset, to our shield and we added a connection to an interruption pin to be able to program Arduino without having to press reset button.

Our shield works well since once uploaded its firmware and connected to an Arduino we can find it in the available Wi-Fi networks of our computer and we can connect and access to it from a web browser. With this we also can say that the device is well powered from Arduino since it works without any fault.

OTA capability works since we have tested it uploading different sketches from our computer.

Wi-Fi module supports any encrypted Wi-Fi networks, WEP, WPA and WPA2 with AES128 encrypt algorithm, so, in terms of security, our shield has the same security than any other Wi-Fi device that supports encrypted Wi-Fi networks.

Our shield can program Arduino boards remotely without any problem to make it easily we have a web platform to access shields remotely without having to configure and Static IP or open any port to the routers. We just have to type in the username and password in the shield configuration and it automatically appears in our web platform.

Our shield is also compatible with other shields, so it can work with other shield at the same time but it have a limitation it has to be the first shield since there is not ICSP connections on digital pins. We have no idea of that and we realized when testing our shield with other shields. So if we could redo it we would add it and it rests to future work for future shield updates.

Future work might be updating the shield in order to connect ICSP to digital pins, as we said before, relocate the leds since other shields can cover them, remove the debug pins since there are useless because the debug process is done since software is working correctly.

Maybe it also can derive in a sensor node board without using an Arduino board below just using microcontroller I/O to connect sensors and adding some *ZigBee* module to our design but this is job to do in the future if there is need for that.

5.0.1. Environmental Awareness study

Our project has been done taking into account the environmental factors since we deploy our boards in the field we have make our board using lead free components, as it states the European Commission in their directives.

We have also assured that all components used in our board are recyclable.

We are used to bring all our used board to the recycling center when they are at the end of their live.

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APPENDIX

APPENDIX A. PIC24FJ256GA106 DATASHEET EXTRACT

PIC24FJ256GA110 Family Data Sheet

64/80/100-Pin, 16-Bit,
General Purpose Flash Microcontrollers
with Peripheral Pin Select

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

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Microchip received ISO/TS-16949:2002 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.

PIC24FJ256GA110 FAMILY

64/80/100-Pin, 16-Bit, General Purpose Flash Microcontrollers with Peripheral Pin Select

Power Management:

- On-Chip 2.5V Voltage Regulator
- Switch between Clock Sources in Real Time
- Idle, Sleep and Doze modes with Fast Wake-up and Two-Speed Start-up
- Run mode: 1 mA/MIPS, 2.0V Typical
- Standby Current with 32 kHz Oscillator: 2.6 μA, 2.0V Typical

High-Performance CPU:

- Modified Harvard Architecture
- Up to 16 MIPS Operation at 32 MHz
- 8 MHz Internal Oscillator
- 17-Bit x 17-Bit Single-Cycle Hardware Multiplier
- 32-Bit by 16-Bit Hardware Divider
- 16 x 16-Bit Working Register Array
- C Compiler Optimized Instruction Set Architecture with Flexible Addressing modes
- Linear Program Memory Addressing, Up to 12 Mbytes
- Linear Data Memory Addressing, Up to 64 Kbytes
- Two Address Generation Units for Separate Read and Write Addressing of Data Memory

Analog Features:

- 10-Bit, Up to 16-Channel Analog-to-Digital (A/D) Converter at 500 ksps:
  - Conversions available in Sleep mode
- Three Analog Comparators with Programmable Input/ Output Configuration
- Charge Time Measurement Unit (CTMU)

Peripheral Features:

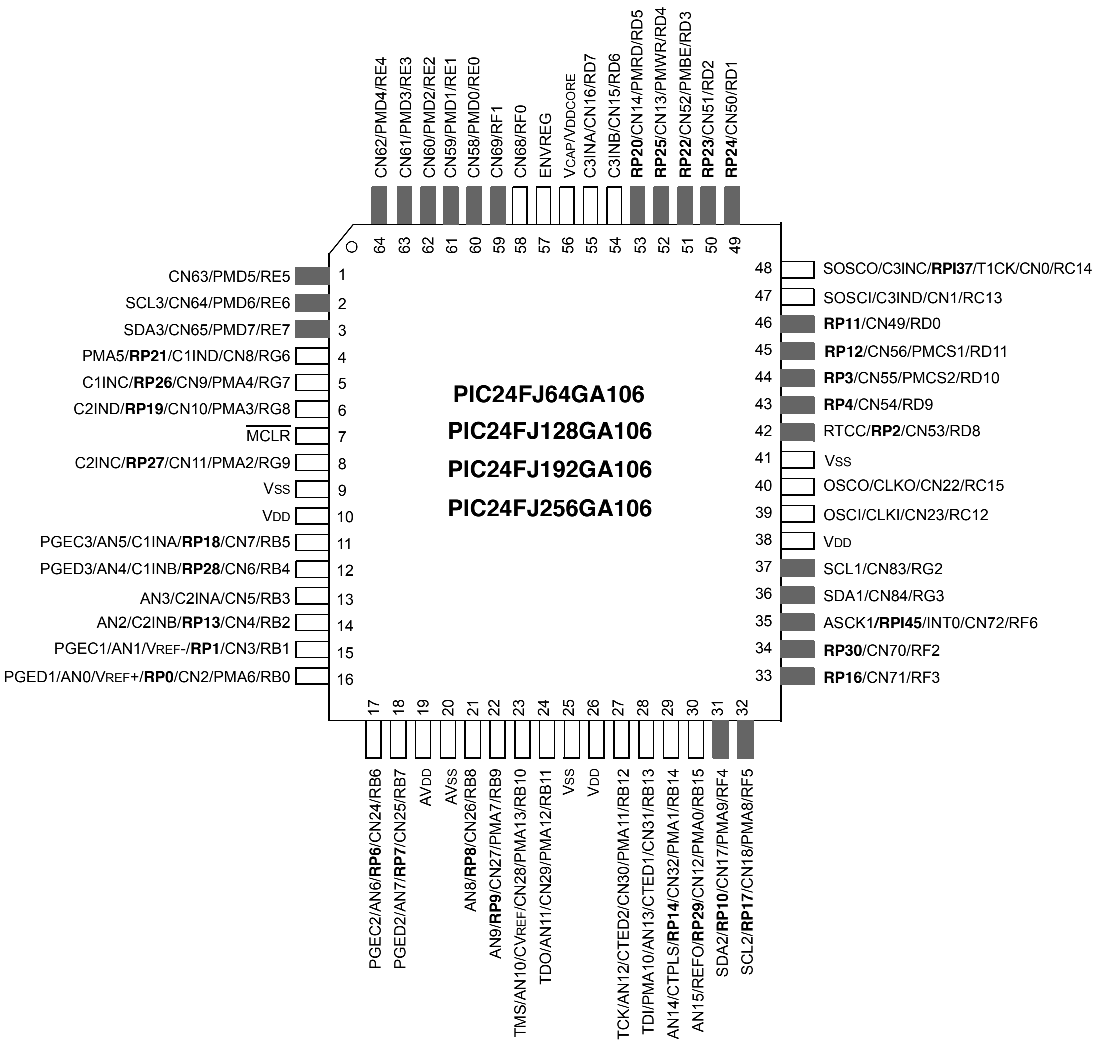
- Peripheral Pin Select:
  - Allows independent I/O mapping of many peripherals at run time
  - Continuous hardware integrity checking and safety interlocks prevent unintentional configuration changes
  - Up to 46 available pins (100-pin devices)
- Three 3-Wire/4-Wire SPI modules (supports 4 Frame modes) with 8-Level FIFO Buffer
- Three I^2C™ modules support Multi-Master/Slave modes and 7-Bit/10-Bit Addressing
- Four UART modules:
  - Supports RS-485, RS-232, LIN/J2602 protocols and IrDA®
  - On-chip hardware encoder/decoder for IrDA
  - Auto-wake-up and Auto-Baud Detect (ABD)
  - 4-level deep FIFO buffer
- Five 16-Bit Timers/Counters with Programmable Prescaler
- Nine 16-Bit Capture Inputs, each with a Dedicated Time Base
- Nine 16-Bit Compare/PWM Outputs, each with a Dedicated Time Base
- 8-Bit Parallel Master Port (PMP/PSP):
  - Up to 16 address pins
  - Programmable polarity on control lines
- Hardware Real-Time Clock/Calendar (RTCC):
  - Provides clock, calendar and alarm functions
- Programmable Cyclic Redundancy Check (CRC) Generator
- Up to 5 External Interrupt Sources

PIC24FJ Device	Pins	Program Memory (Bytes)	SRAM (Bytes)	Remappable Peripherals						I^2C™	10-Bit A/D (ch)	Comparators	PMP/PSP	JTAG	CTMU
				Remappable Pins	Timers 16-Bit	Capture Input	Compare/ PWM Output	UART w/ IrDA®	SPI						
64GA106	64	64K	16K	31	5	9	9	4	3	3	16	3	Y	Y	Y
128GA106	64	128K	16K	31	5	9	9	4	3	3	16	3	Y	Y	Y
192GA106	64	192K	16K	31	5	9	9	4	3	3	16	3	Y	Y	Y
256GA106	64	256K	16K	31	5	9	9	4	3	3	16	3	Y	Y	Y
64GA108	80	64K	16K	42	5	9	9	4	3	3	16	3	Y	Y	Y
128GA108	80	128K	16K	42	5	9	9	4	3	3	16	3	Y	Y	Y
192GA108	80	192K	16K	42	5	9	9	4	3	3	16	3	Y	Y	Y
256GA108	80	256K	16K	42	5	9	9	4	3	3	16	3	Y	Y	Y
64GA110	100	64K	16K	46	5	9	9	4	3	3	16	3	Y	Y	Y
128GA110	100	128K	16K	46	5	9	9	4	3	3	16	3	Y	Y	Y
192GA110	100	192K	16K	46	5	9	9	4	3	3	16	3	Y	Y	Y
256GA110	100	256K	16K	46	5	9	9	4	3	3	16	3	Y	Y	Y

Special Microcontroller Features:

- Operating Voltage Range of 2.0V to 3.6V
- Self-Reprogrammable under Software Control
- 5.5V Tolerant Input (digital pins only)
- Configurable Open-Drain Outputs on Digital I/O
- High-Current Sink/Source (18 mA/18 mA) on all I/O
- Selectable Power Management modes:
  - Sleep, Idle and Doze modes with fast wake-up
- Fail-Safe Clock Monitor Operation:
  - Detects clock failure and switches to on-chip FRC oscillator
- On-Chip LDO Regulator
- Power-on Reset (POR), Power-up Timer (PWRT), Low-Voltage Detect (LVD) and Oscillator Start-up Timer (OST)
- Flexible Watchdog Timer (WDT) with On-Chip Low-Power RC Oscillator for Reliable Operation
- In-Circuit Serial Programming™ (ICSP™) and In-Circuit Debug (ICD) via 2 Pins
- JTAG Boundary Scan Support
- Brown-out Reset (BOR)
- Flash Program Memory:
  - 10,000 erase/write cycle endurance (minimum)
  - 20-year data retention minimum
  - Selectable write protection boundary
  - Write protection option for Flash Configuration Words

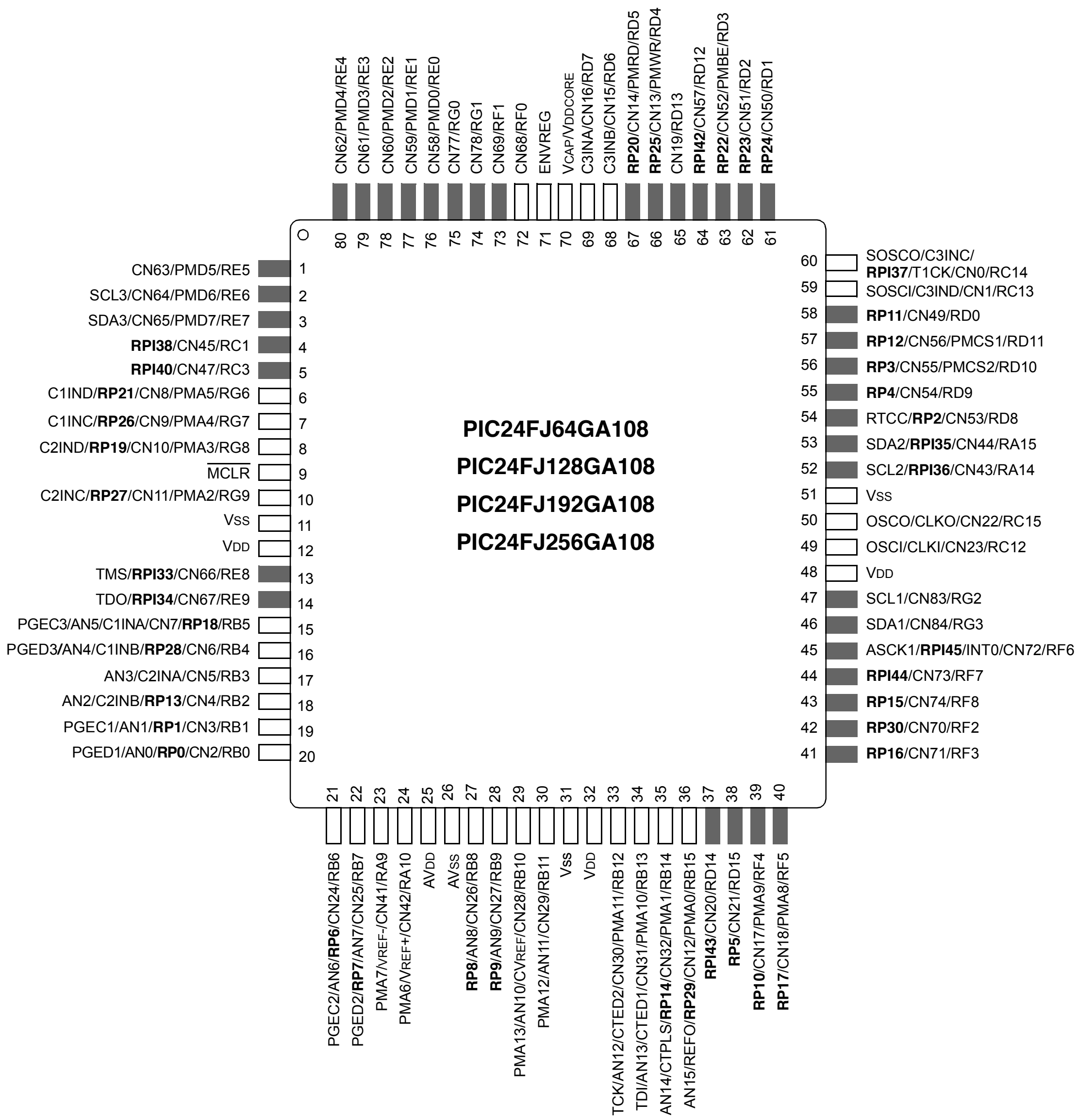
Pin Diagram (64-Pin TQFP and QFN[1])



Legend: **Shaded pins** indicate pins tolerant to up to +5.5 VDC.
RPn represents remappable pins for Peripheral Pin Select (PPS) feature.

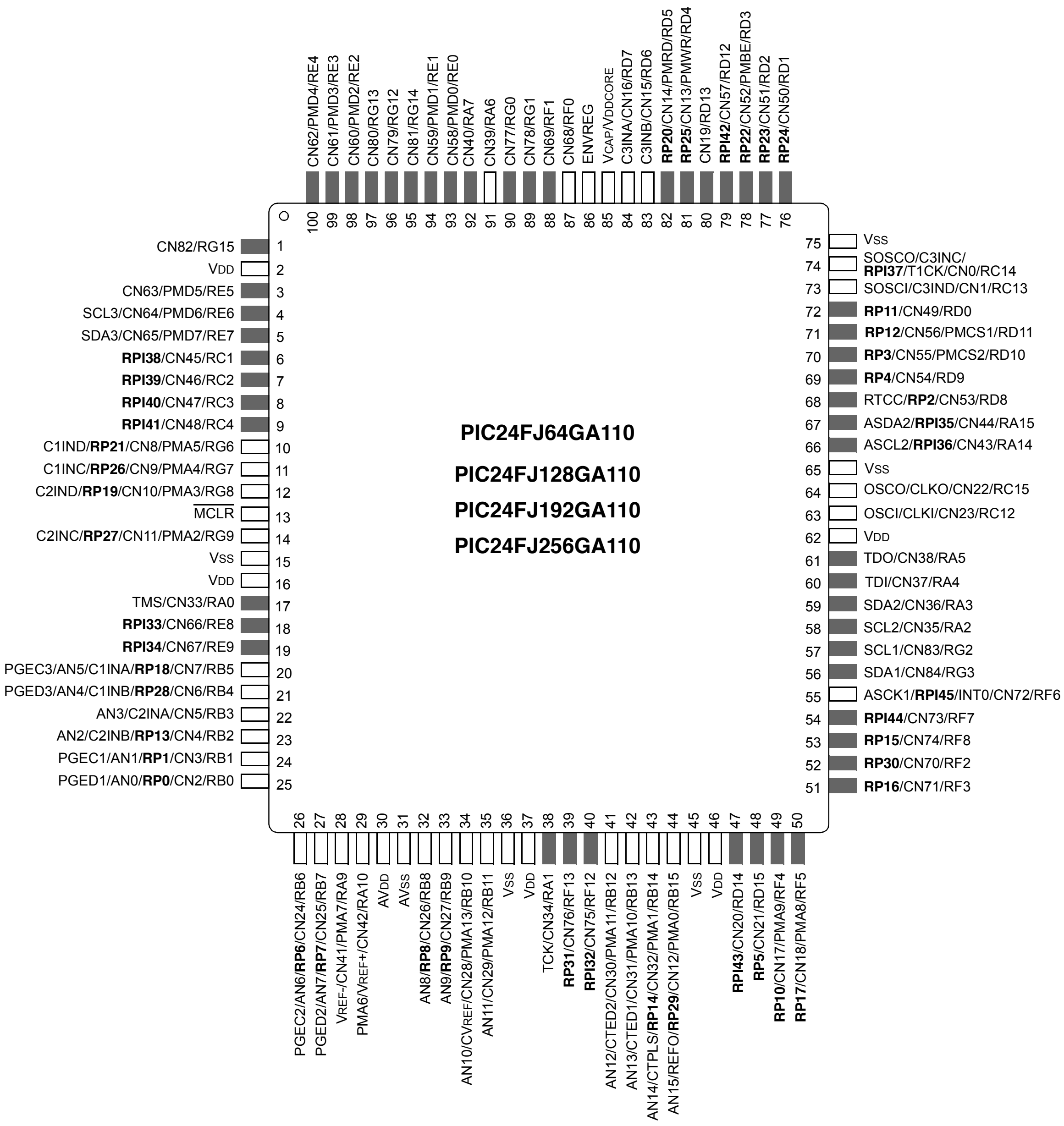
Note 1: For QFN devices, the backplane on the underside of the device must also be connected to VSS.

Pin Diagram (80-Pin TQFP)



Legend: **Shaded pins** indicate pins tolerant to up to +5.5 VDC.
RPn represents remappable pins for Peripheral Pin Select (PPS) feature.

Pin Diagram (100-Pin TQFP)



Legend: **Shaded pins** indicate pins tolerant to up to +5.5 VDC.
RPn represents remappable pins for Peripheral Pin Select (PPS) feature.

Table of Contents

2.0 GUIDELINES FOR GETTING STARTED WITH 16-BIT MICROCONTROLLERS

2.1 Basic Connection Requirements

Getting started with the PIC24FJ256GA110 family family of 16-bit microcontrollers requires attention to a minimal set of device pin connections before proceeding with development.

The following pins must always be connected:

- All VDD and VSS pins (see **Section 2.2 "Power Supply Pins"**)
- All AVDD and AVSS pins, regardless of whether or not the analog device features are used (see **Section 2.2 "Power Supply Pins"**)
- MCLR pin (see **Section 2.3 "Master Clear (MCLR) Pin"**)
- ENVREG/DISVREG and VCAP/VDDCORE pins (PIC24F J devices only) (see **Section 2.4 "Voltage Regulator Pins (ENVREG/DISVREG and VCAP/VDDCORE)"**)

These pins must also be connected if they are being used in the end application:

- PGECx/PGEDx pins used for In-Circuit Serial Programming™ (ICSP™) and debugging purposes (see **Section 2.5 "ICSP Pins"**)
- OSCI and OSCO pins when an external oscillator source is used (see **Section 2.6 "External Oscillator Pins"**)

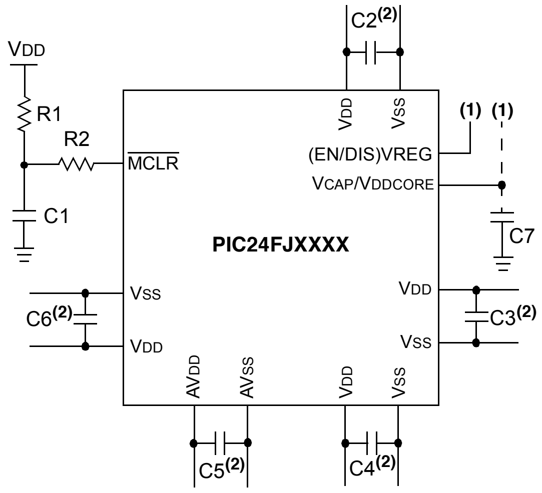
Additionally, the following pins may be required:

- VREF+/VREF- pins used when external voltage reference for analog modules is implemented

Note:	The AVDD and AVSS pins must always be connected, regardless of whether any of the analog modules are being used.

The minimum mandatory connections are shown in Figure 2-1.

FIGURE 2-1: RECOMMENDED MINIMUM CONNECTIONS



Key (all values are recommendations):

C1 through C6: 0.1 μF, 20V ceramic

C7: 10 μF, 6.3V or greater, tantalum or ceramic

R1: 10 kΩ

R2: 100Ω to 470Ω

Note 1: See **Section 2.4 "Voltage Regulator Pins (ENVREG/DISVREG and VCAP/VDDCORE)"** for explanation of ENVREG/DISVREG pin connections.

2: The example shown is for a PIC24F device with five VDD/VSS and AVDD/AVSS pairs. Other devices may have more or less pairs; adjust the number of decoupling capacitors appropriately.

2.2 Power Supply Pins

2.2.1 DECOUPLING CAPACITORS

The use of decoupling capacitors on every pair of power supply pins, such as VDD, VSS, AVDD and AVSS is required.

Consider the following criteria when using decoupling capacitors:

- **Value and type of capacitor:** A 0.1 µF (100 nF), 10-20V capacitor is recommended. The capacitor should be a low-ESR device with a resonance frequency in the range of 200 MHz and higher. Ceramic capacitors are recommended.
- **Placement on the printed circuit board:** The decoupling capacitors should be placed as close to the pins as possible. It is recommended to place the capacitors on the same side of the board as the device. If space is constricted, the capacitor can be placed on another layer on the PCB using a via; however, ensure that the trace length from the pin to the capacitor is no greater than 0.25 inch (6 mm).
- **Handling high-frequency noise:** If the board is experiencing high-frequency noise (upward of tens of MHz), add a second ceramic type capacitor in parallel to the above described decoupling capacitor. The value of the second capacitor can be in the range of 0.01 µF to 0.001 µF. Place this second capacitor next to each primary decoupling capacitor. In high-speed circuit designs, consider implementing a decade pair of capacitances as close to the power and ground pins as possible (e.g., 0.1 µF in parallel with 0.001 µF).
- **Maximizing performance:** On the board layout from the power supply circuit, run the power and return traces to the decoupling capacitors first, and then to the device pins. This ensures that the decoupling capacitors are first in the power chain. Equally important is to keep the trace length between the capacitor and the power pins to a minimum, thereby reducing PCB trace inductance.

2.2.2 TANK CAPACITORS

On boards with power traces running longer than six inches in length, it is suggested to use a tank capacitor for integrated circuits including microcontrollers to supply a local power source. The value of the tank capacitor should be determined based on the trace resistance that connects the power supply source to the device, and the maximum current drawn by the device in the application. In other words, select the tank capacitor so that it meets the acceptable voltage sag at the device. Typical values range from 4.7 µF to 47 µF.

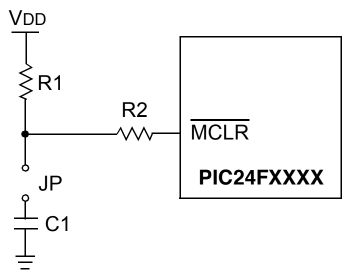
2.3 Master Clear ($\overline{\text{MCLR}}$) Pin

The $\overline{\text{MCLR}}$ pin provides two specific device functions: device Reset, and device programming and debugging. If programming and debugging are not required in the end application, a direct connection to VDD may be all that is required. The addition of other components, to help increase the application's resistance to spurious Resets from voltage sags, may be beneficial. A typical configuration is shown in Figure 2-1. Other circuit designs may be implemented, depending on the application's requirements.

During programming and debugging, the resistance and capacitance that can be added to the pin must be considered. Device programmers and debuggers drive the $\overline{\text{MCLR}}$ pin. Consequently, specific voltage levels (VIH and VIL) and fast signal transitions must not be adversely affected. Therefore, specific values of R1 and C1 will need to be adjusted based on the application and PCB requirements. For example, it is recommended that the capacitor, C1, be isolated from the $\overline{\text{MCLR}}$ pin during programming and debugging operations by using a jumper (Figure 2-2). The jumper is replaced for normal run-time operations.

Any components associated with the $\overline{\text{MCLR}}$ pin should be placed within 0.25 inch (6 mm) of the pin.

FIGURE 2-2: EXAMPLE OF $\overline{\text{MCLR}}$ PIN CONNECTIONS



Note 1: R1 ≤ 10 kΩ is recommended. A suggested starting value is 10 kΩ. Ensure that the $\overline{\text{MCLR}}$ pin VIH and VIL specifications are met.

2: R2 ≤ 470Ω will limit any current flowing into $\overline{\text{MCLR}}$ from the external capacitor, C, in the event of $\overline{\text{MCLR}}$ pin breakdown, due to Electrostatic Discharge (ESD) or Electrical Overstress (EOS). Ensure that the $\overline{\text{MCLR}}$ pin VIH and VIL specifications are met.

2.4 Voltage Regulator Pins (ENVREG/DISVREG and VCAP/VDDCORE)

Note:	This section applies only to PIC24F J devices with an on-chip voltage regulator.

The on-chip voltage regulator enable/disable pin (ENVREG or DISVREG, depending on the device family) must always be connected directly to either a supply voltage or to ground. The particular connection is determined by whether or not the regulator is to be used:

- For ENVREG, tie to VDD to enable the regulator, or to ground to disable the regulator
- For DISVREG, tie to ground to enable the regulator or to VDD to disable the regulator

Refer to **Section 25.2 "On-Chip Voltage Regulator"** for details on connecting and using the on-chip regulator.

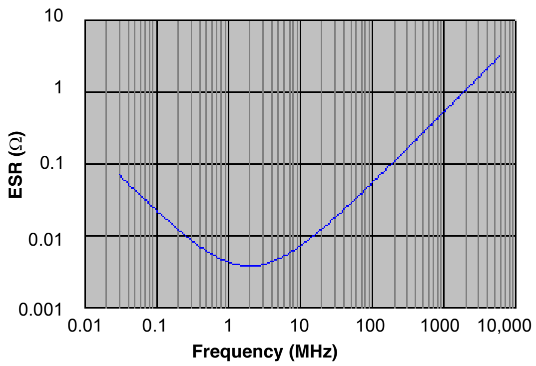
When the regulator is enabled, a low-ESR (< 5Ω) capacitor is required on the VCAP/VDDCORE pin to stabilize the voltage regulator output voltage. The VCAP/VDDCORE pin must not be connected to VDD and must use a capacitor of 10 µF connected to ground. The type can be ceramic or tantalum. Suitable examples of capacitors are shown in Table 2-1. Capacitors with equivalent specification can be used.

Designers may use Figure 2-3 to evaluate ESR equivalence of candidate devices.

The placement of this capacitor should be close to VCAP/VDDCORE. It is recommended that the trace length not exceed 0.25 inch (6 mm). Refer to **Section 28.0 "Electrical Characteristics"** for additional information.

When the regulator is disabled, the VCAP/VDDCORE pin must be tied to a voltage supply at the VDDCORE level. Refer to **Section 28.0 "Electrical Characteristics"** for information on VDD and VDDCORE.

FIGURE 2-3: FREQUENCY vs. ESR PERFORMANCE FOR SUGGESTED VCAP



Note: Typical data measurement at 25°C, 0V DC bias.

TABLE 2-1: SUITABLE CAPACITOR EQUIVALENTS

Make	Part #	Nominal Capacitance	Base Tolerance	Rated Voltage	Temp. Range
TDK	C3216X7R1C106K	10 µF	±10%	16V	-55 to 125ºC
TDK	C3216X5R1C106K	10 µF	±10%	16V	-55 to 85ºC
Panasonic	ECJ-3YX1C106K	10 µF	±10%	16V	-55 to 125ºC
Panasonic	ECJ-4YB1C106K	10 µF	±10%	16V	-55 to 85ºC
Murata	GRM32DR71C106KA01L	10 µF	±10%	16V	-55 to 125ºC
Murata	GRM31CR61C106KC31L	10 µF	±10%	16V	-55 to 85ºC

2.4.1 CONSIDERATIONS FOR CERAMIC CAPACITORS

In recent years, large value, low-voltage, surface-mount ceramic capacitors have become very cost effective in sizes up to a few tens of microfarad. The low-ESR, small physical size and other properties make ceramic capacitors very attractive in many types of applications.

Ceramic capacitors are suitable for use with the internal voltage regulator of this microcontroller. However, some care is needed in selecting the capacitor to ensure that it maintains sufficient capacitance over the intended operating range of the application.

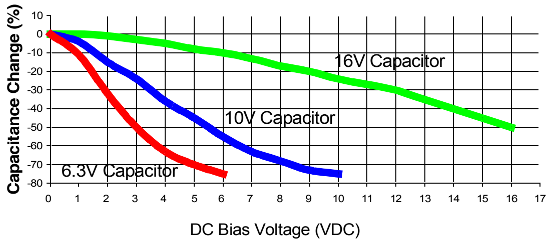
Typical low-cost, 10 μF ceramic capacitors are available in X5R, X7R and Y5V dielectric ratings (other types are also available, but are less common). The initial tolerance specifications for these types of capacitors are often specified as ±10% to ±20% (X5R and X7R), or -20%/+80% (Y5V). However, the effective capacitance that these capacitors provide in an application circuit will also vary based on additional factors, such as the applied DC bias voltage and the temperature. The total in-circuit tolerance is, therefore, much wider than the initial tolerance specification.

The X5R and X7R capacitors typically exhibit satisfactory temperature stability (ex: ±15% over a wide temperature range, but consult the manufacturer's data sheets for exact specifications). However, Y5V capacitors typically have extreme temperature tolerance specifications of +22%/-82%. Due to the extreme temperature tolerance, a 10 μF nominal rated Y5V type capacitor may not deliver enough total capacitance to meet minimum internal voltage regulator stability and transient response requirements. Therefore, Y5V capacitors are not recommended for use with the internal regulator if the application must operate over a wide temperature range.

In addition to temperature tolerance, the effective capacitance of large value ceramic capacitors can vary substantially, based on the amount of DC voltage applied to the capacitor. This effect can be very significant, but is often overlooked or is not always documented.

Typical DC bias voltage vs. capacitance graph for X7R type capacitors is shown in Figure 2-4.

FIGURE 2-4: DC BIAS VOLTAGE vs. CAPACITANCE CHARACTERISTICS



When selecting a ceramic capacitor to be used with the internal voltage regulator, it is suggested to select a high-voltage rating, so that the operating voltage is a small percentage of the maximum rated capacitor voltage. For example, choose a ceramic capacitor rated at 16V for the 2.5V or 1.8V core voltage. Suggested capacitors are shown in Table 2-1.

2.5 ICSP Pins

The PGECx and PGEDx pins are used for In-Circuit Serial Programming (ICSP) and debugging purposes. It is recommended to keep the trace length between the ICSP connector and the ICSP pins on the device as short as possible. If the ICSP connector is expected to experience an ESD event, a series resistor is recommended, with the value in the range of a few tens of ohms, not to exceed 100Ω.

Pull-up resistors, series diodes and capacitors on the PGECx and PGEDx pins are not recommended as they will interfere with the programmer/debugger communications to the device. If such discrete components are an application requirement, they should be removed from the circuit during programming and debugging. Alternatively, refer to the AC/DC characteristics and timing requirements information in the respective device Flash programming specification for information on capacitive loading limits and pin input voltage high (V_{IH}) and input low (V_{IL}) requirements.

For device emulation, ensure that the “Communication Channel Select” (i.e., PGECx/PGEDx pins), programmed into the device, matches the physical connections for the ICSP to the Microchip debugger/emulator tool.

For more information on available Microchip development tools connection requirements, refer to **Section 27.0 “Development Support”**.

2.6 External Oscillator Pins

Many microcontrollers have options for at least two oscillators: a high-frequency primary oscillator and a low-frequency secondary oscillator (refer to **Section 8.0 "Oscillator Configuration"** for details).

The oscillator circuit should be placed on the same side of the board as the device. Place the oscillator circuit close to the respective oscillator pins with no more than 0.5 inch (12 mm) between the circuit components and the pins. The load capacitors should be placed next to the oscillator itself, on the same side of the board.

Use a grounded copper pour around the oscillator circuit to isolate it from surrounding circuits. The grounded copper pour should be routed directly to the MCU ground. Do not run any signal traces or power traces inside the ground pour. Also, if using a two-sided board, avoid any traces on the other side of the board where the crystal is placed.

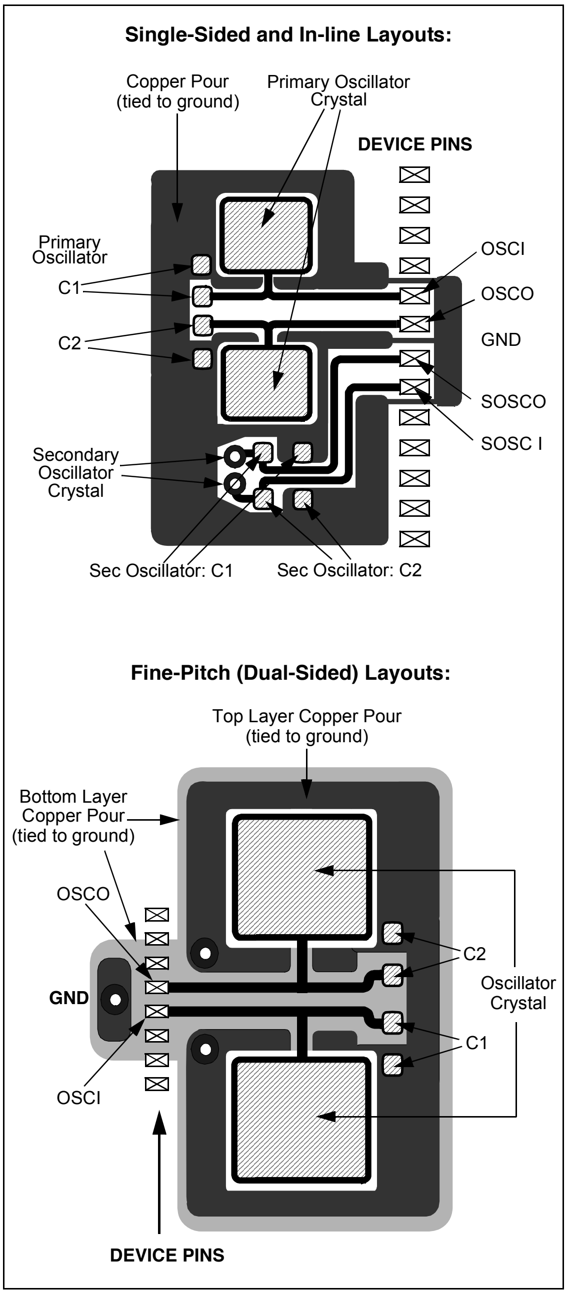
Layout suggestions are shown in Figure 2-5. In-line packages may be handled with a single-sided layout that completely encompasses the oscillator pins. With fine-pitch packages, it is not always possible to completely surround the pins and components. A suitable solution is to tie the broken guard sections to a mirrored ground layer. In all cases, the guard trace(s) must be returned to ground.

In planning the application's routing and I/O assignments, ensure that adjacent port pins, and other signals in close proximity to the oscillator, are benign (i.e., free of high frequencies, short rise and fall times and other similar noise).

For additional information and design guidance on oscillator circuits, please refer to these Microchip Application Notes, available at the corporate web site (www.microchip.com):

- *AN826, "Crystal Oscillator Basics and Crystal Selection for rfPIC™ and PICmicro® Devices"*
- *AN849, "Basic PICmicro® Oscillator Design"*
- *AN943, "Practical PICmicro® Oscillator Analysis and Design"*
- *AN949, "Making Your Oscillator Work"*

FIGURE 2-5: SUGGESTED PLACEMENT OF THE OSCILLATOR CIRCUIT



2.7 Configuration of Analog and Digital Pins During ICSP Operations

If an ICSP compliant emulator is selected as a debugger, it automatically initializes all of the A/D input pins (ANx) as “digital” pins. Depending on the particular device, this is done by setting all bits in the ADnPCFG register(s), or clearing all bit in the ANSx registers.

All PIC24F devices will have either one or more ADnPCFG registers or several ANSx registers (one for each port); no device will have both. Refer to (**choose one xref: Section x.x.x in I/O chapter** or **Section x.0 A/D Chapter**) for more specific information.

The bits in these registers that correspond to the A/D pins that initialized the emulator must not be changed by the user application firmware; otherwise, communication errors will result between the debugger and the device.

If your application needs to use certain A/D pins as analog input pins during the debug session, the user application must modify the appropriate bits during initialization of the ADC module, as follows:

- For devices with an ADnPCFG register, clear the bits corresponding to the pin(s) to be configured as analog. Do not change any other bits, particularly those corresponding to the PGECx/PGEDx pair, at any time.
- For devices with ANSx registers, set the bits corresponding to the pin(s) to be configured as analog. Do not change any other bits, particularly those corresponding to the PGECx/PGEDx pair, at any time.

When a Microchip debugger/emulator is used as a programmer, the user application firmware must correctly configure the ADnPCFG or ANSx registers. Automatic initialization of this register is only done during debugger operation. Failure to correctly configure the register(s) will result in all A/D pins being recognized as analog input pins, resulting in the port value being read as a logic '0', which may affect user application functionality.

2.8 Unused I/Os

Unused I/O pins should be configured as outputs and driven to a logic low state. Alternatively, connect a 1 kΩ to 10 kΩ resistor to VSS on unused pins and drive the output to logic low.

APPENDIX B. MRF24WB0MA DATASHEET

MRF24WB0MA/MRF24WB0MB
Data Sheet

2.4 GHz, IEEE Std. 802.11b™

RF Transceiver Module

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ISO/TS 16949:2009

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MRF24WB0MA/MRF24WB0MB Data Sheet
2.4 GHz IEEE Std. 802.11b™

Features:

- IEEE Std. 802.11-compliant RF Transceiver
- Serialized unique MAC address
- Data Rate: 1 and 2 Mbps
- IEEE Std. 802.11b/g/n compatible
- Small size: 21mm x 31mm 36-pin Surface Mount Module
- Integrated PCB antenna (MRF24WB0MA)
- External antenna option (MRF24WB0MB) with ultra miniature coaxial (U.FL) connector
- Range: up to 400m (1300 ft.)
- Easy integration into final product – accelerates product development, provides quicker time to market
- Radio regulation certification for United States (FCC), Canada (IC), Europe (ETSI) and Japan (ARIB)
- Wi-Fi® certified (WFA ID: WFA7150)
- Designed for use with Microchip microcontroller families (PIC18, PIC24, dsPIC33, and PIC32) with downloadable Microchip TCP/IP Stack

Operational:

- Single operating voltage: 2.7V–3.6V (3.3V typical)
- Temperature Range: -20° C to +85° C extended commercial
- Simple, four-wire SPI interface with interrupt
- Low-current consumption:
  - RX mode – 85 mA (typical)
  - TX mode – 154 mA (+10 dBm typical)
  - Sleep – 250 µA (typical)
  - Hibernate – <0.1 µA (typical)

RF/Analog Features:

- ISM Band 2.400–2.484 GHz operation
- 14 Channels selectable individually or domain-restricted
- DSSS Modulation
- Data Rate – 1000 kbps
- -91 dBm Typical sensitivity at 1 Mbps
- +10 dBm Typical output power with control
- Integrated low phase noise VCO, RF frequency synthesizer, PLL loop filter and PA
- Digital VCO and filter calibration
- Integrated RSSI ADC and I/Q DACs, RSSI readings available to host
- Balanced receiver and transmitter characteristics for low power consumption

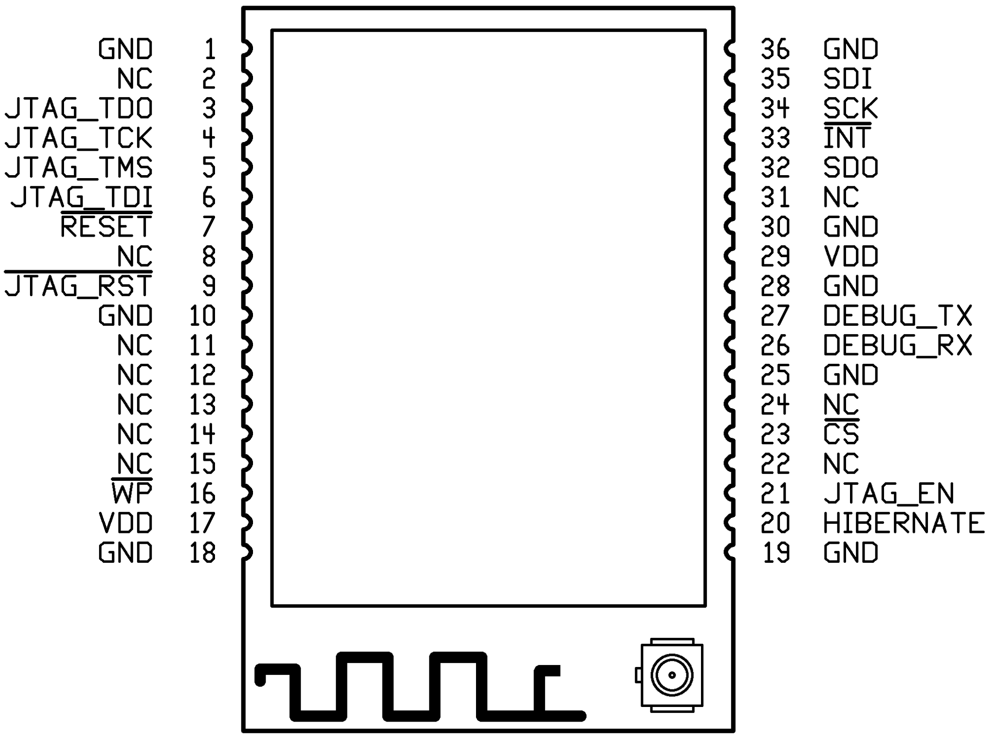
MAC/Baseband Features:

- Hardware CSMA/CA access control, automatic ACK, and FCS creation and checking
- Automatic MAC packet retransmit
- Hardware Security Engine for AES and RC4-based ciphers
- Supports 802.1x, 802.1i security: WEP, WPA-PSK, and WPA-2-PSK.

Applications:

- Utility and Smart Energy
  - Thermostats
  - Smart Meters
  - White Goods
  - HVAC
- Consumer Electronics
  - Remote Control
  - Internet Radio
  - Home Security
  - Toys
- Industrial Controls
  - Chemical Sensors
  - HVAC
  - Security Systems
  - M2M Communication
- Remote Device Management
  - Location and Asset Tracking
  - Automotive
  - Code Update
- Retail
  - POS Terminals
  - Wireless Price Tags
  - Digital Remote
- Medical, Fitness, and Health care
  - Glucose Meters
  - Fitness Equipment
  - Patient Asset Tracking

Pin Diagram



Note: Antenna connector on MRF24WB0MB only.

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NOTES:

1.0 DEVICES OVERVIEW

The MRF24WB0MA and MRF24WB0MB are low-power, 2.4 GHz, IEEE Std. 802.11-compliant, surface mount modules with all associated RF components – crystal oscillator, bypass and bias passives with integrated MAC, baseband, RF and power amplifier, and built-in hardware support for AES, and TKIP (WEP, WPA, WPA2 security). The integrated module design frees the designer from RF and antenna design tasks and regulatory compliance testing, ultimately providing quicker time to market.

The MRF24WB0MA module is approved for use with the integrated PCB meander antenna.

The MRF24WB0MB comes with an ultra miniature coaxial connector (U.FL) and is approved for use with a list of pre-certified antennas. See Section 2.8, External Antenna, for specific recommendations.

The MRF24WB0MA/MRF24WB0MB modules are designed to be used with Microchip's TCP/IP software stack. The software stack has an integrated driver that implements the API that is used in the modules for command and control, and for management and data packet traffic.

The Microchip TCP/IP software stack is available in the free *Microchip Application Libraries* download (including example applications and source code) from the Microchip web site, http://www.microchip.com/wireless.

The combination of the module and a PIC running the TCP/IP stack results in support for IEEE Standard 802.11 and IP services. This allows, the immediate implementation of a wireless web server.

The MRF24WB0MA/MRF24WB0MB modules have received regulatory approvals for modular devices in the United States (FCC), Canada (IC), and Europe (ETSI). The modular approval removes the need for expensive RF and antenna design, and allows the end user to place the modules inside a finished product and not require regulatory testing for an intentional radiator (RF transmitter). They also have Radio Type Approval Certification for Japan. See Section 3.0, Regulatory Approval, for the specific requirements that should be adhered to by the integrator.

1.1 Interface Description

The block diagram in Figure 1-1 represents a MRF24WB0MA/MRF24WB0MB module. It interfaces to Microchip PIC18, PIC24, dsPIC33, or PIC32 microcontrollers through a four-wire serial slave SPI interface – interrupt, hibernate, reset, power and ground signals. The module runs on a single supply voltage of nominally 3.3V. It also supports optional JTAG and serial debug for testability. The debug port operates at 3.3V and requires a level shifter for operation with RS-232 devices. Figure 1-2 shows a simplified example connection between a Microchip PIC MCU and the module. Table 1-1 lists the pin descriptions.

Data communications with the MRF24WB0MA/MRF24WB0MB are through the SPI interface that is detailed in Section 2.0, Circuit Description. The Microchip PIC microcontroller communicates with the module through a command API from within the Microchip TCP/IP stack. The command API is detailed in the Microchip TCP/IP stack online help that is included in the free *Microchip Application Libraries* download.

FIGURE 1-1: MRF24WB0MA/MRF24WB0MB BLOCK DIAGRAM

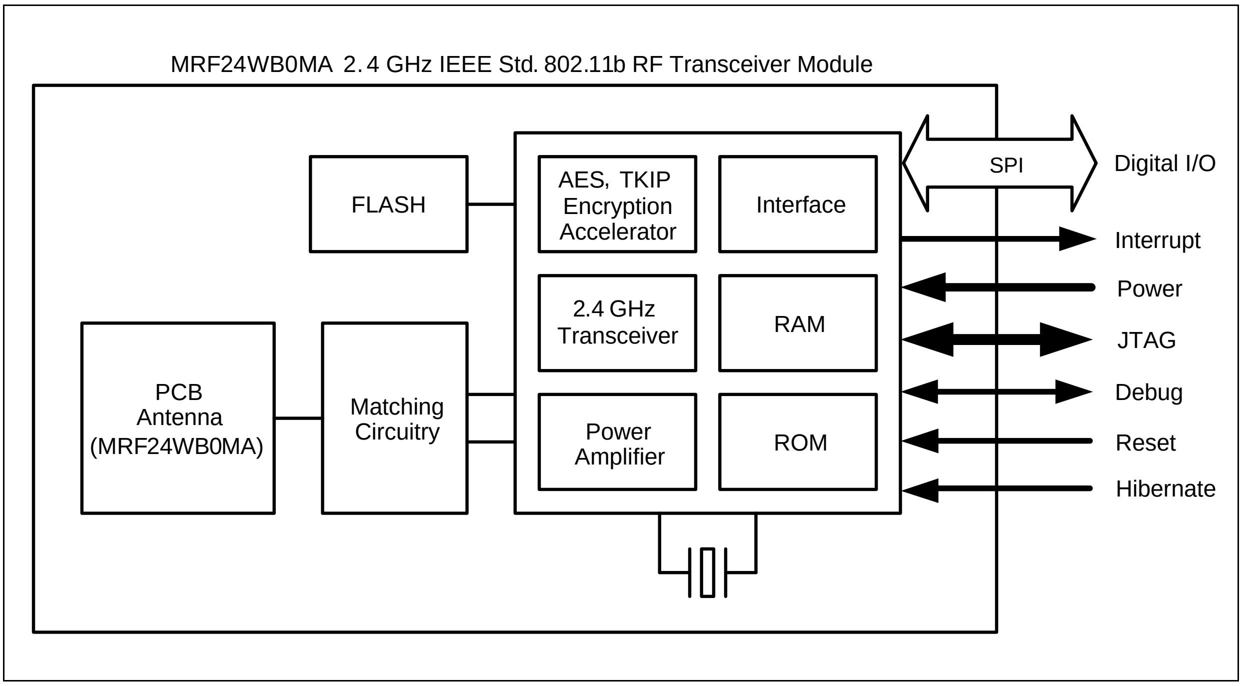


FIGURE 1-2: MICROCONTROLLER TO MRF24WB0MA/MRF24WB0MB INTERFACE

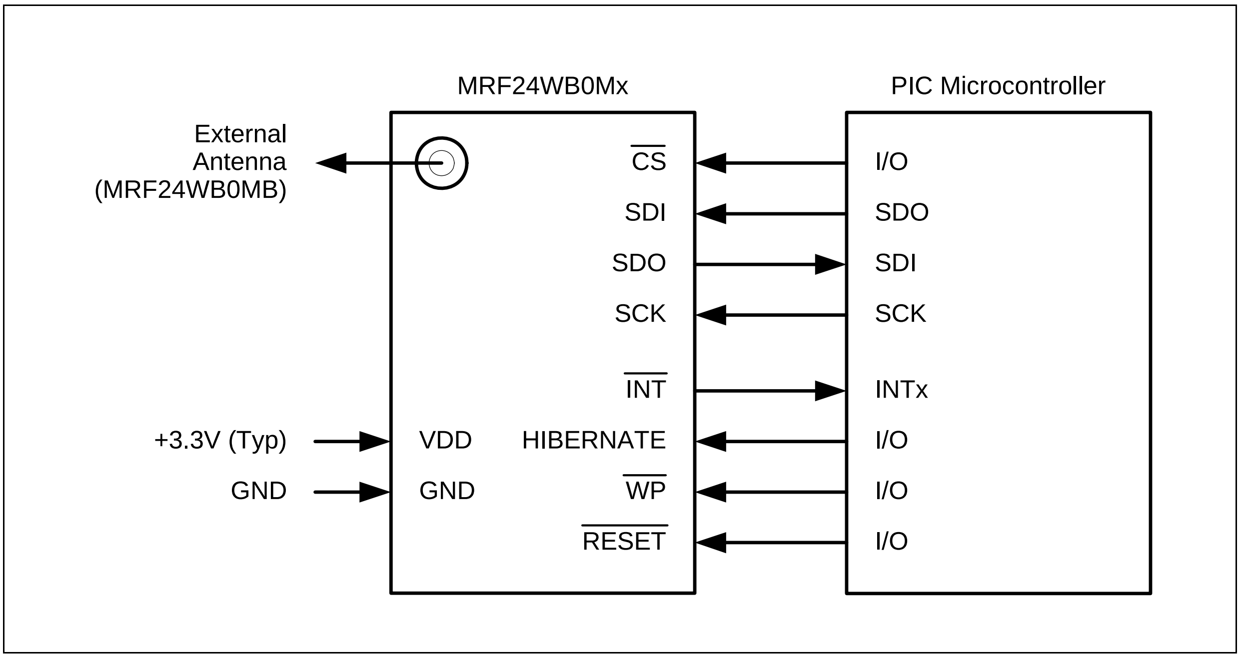


TABLE 1-1: Pin Description

Pin	Symbol	Type	Description
1	GND	P	Ground
2	NC	NC	Do not connect
3	JTAGTDO	O	JTAG test data output
4	JTAGTCK	I: Constant(1)	JTAG clock input
5	JTAGTMS	I	JTAG mode input
6	JTAGTDI	I	JTAG test data input
7	$\overline{\text{RESET}}$	I: Constant(1)	Module Reset input
8	NC	NC	Do not connect
9	$\overline{\text{JTAGRST}}$	I	JTAG Reset input (optional; see Section 2.0, Circuit Description)
10	GND	P	Ground
11	NC	NC	Do not connect
12	NC	NC	Do not connect
13	NC	NC	Do not connect
14	NC	NC	Do not connect
15	NC	NC	Do not connect
16	$\overline{\text{WP}}$(2)	I	Write protect (this pin is used to enable FLASH update)
17	VDD	P	Power
18	GND	P	Ground
19	GND	P	Ground
20	HIBERNATE	I	Hibernate mode enable (high input will disable the module)
21	JTAGEN	I	JTAG test enable
22	NC	NC	Do not connect
23	$\overline{\text{CS}}$	I: Constant(1)	SPI Chip Select input, constant drive or pull-up required
24	NC	NC	Do not connect
25	GND	P	Ground
26	DEBUGRX	I	Serial debug port input (see Section 2.0, Circuit Description)
27	DEBUGTX	O	Serial debug port output (see Section 2.0, Circuit Description)
28	GND	P	Ground
29	VDD	P	Power
30	GND	P	Ground
31	NC	NC	Do not connect
32	SDO	O	SPI data out
33	$\overline{\text{INT}}$	O	Interrupt output (open drain – requires a pull-up)
34	SCK	I	SPI clock input
35	SDI	I	SPI data in
36	GND	P	Ground

Legend: Pin type abbreviation: P = Power input, I = Input, O = Output, NC = Do Not Connect

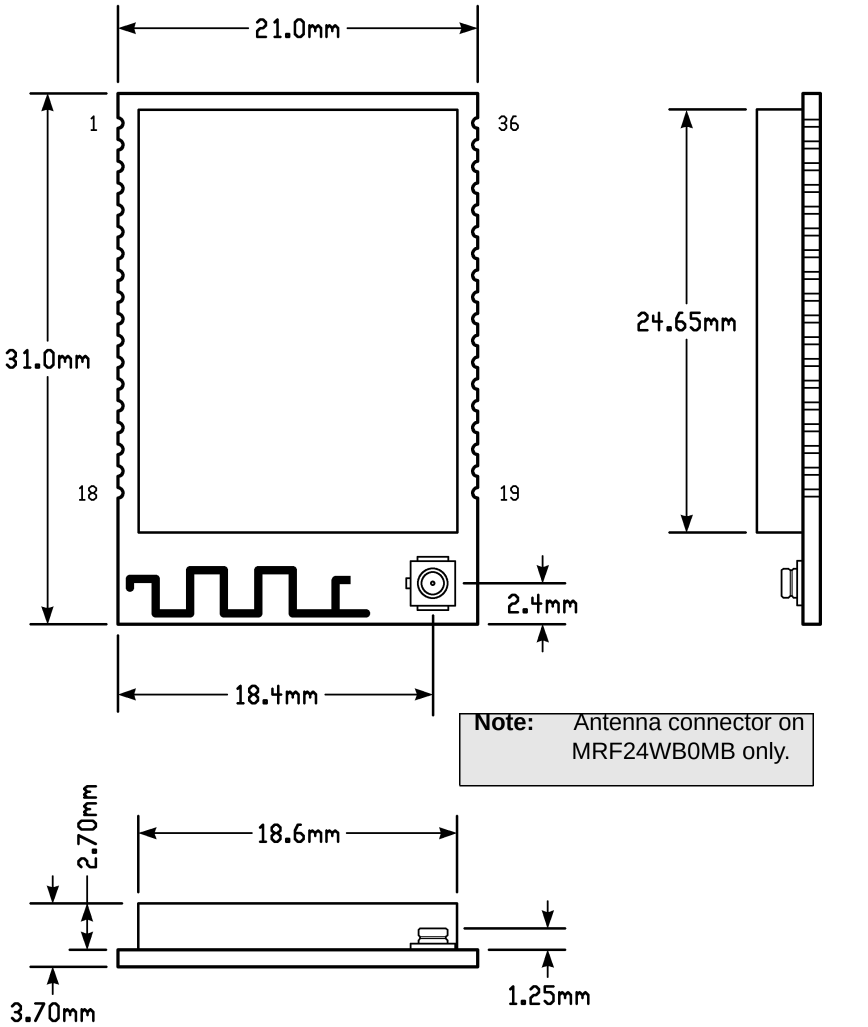
Note 1: Signals of Type “I: Constant” must either be constantly driven by the host or have a pull-up or pull-down (in case the host is likely to tri-state the signal during power down modes). The constant drive is used to ensure defined operation of the part and to minimize leakage current during low power modes.

2: $\overline{\text{WP}}$ is used as write-protect for the internal module SPI Flash. For production use, this pin should be pulled low. This pin can be controlled by the host microcontroller to enable in field Flash updates.

1.2 Mounting Details

The MRF24WB0MA/MRF24WB0MB is a surface mountable module. Module dimensions are shown in Figure 1-3. The module Printed Circuit Board (PCB) is 1 mm thick with castellated mounting points on two sides.

FIGURE 1-3: MRF24WB0MA/MRF24WB0MB MODULE PHYSICAL DIMENSIONS



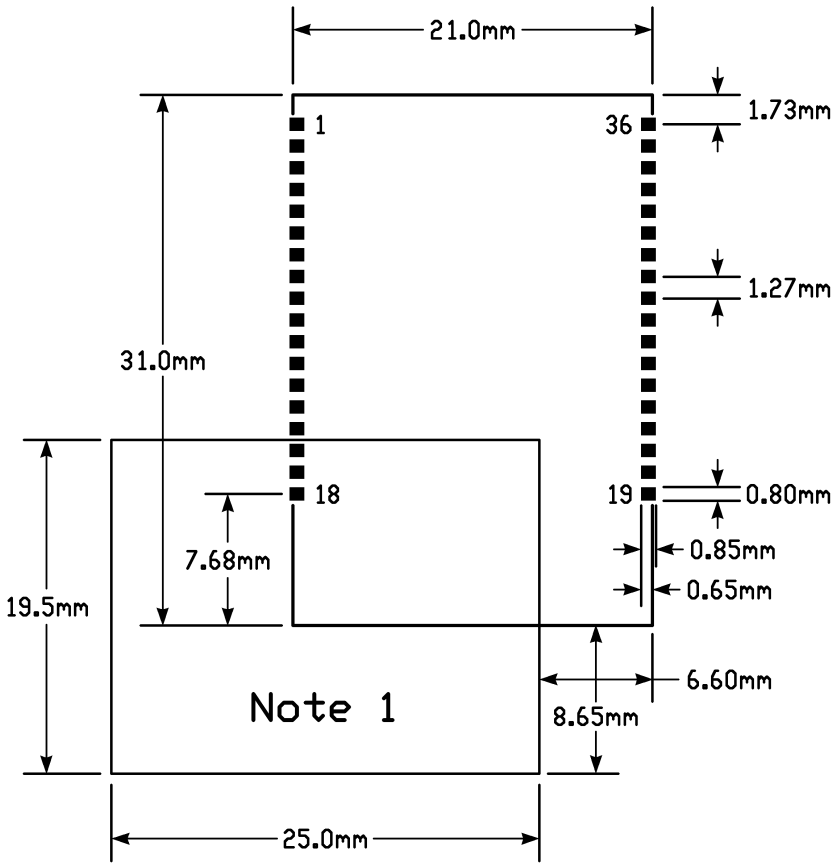
Note: Antenna connector on MRF24WB0MB only.

Figure 1-4 shows the recommended host PCB footprint for the module.

The MRF24WB0MA has an integrated PCB antenna. For best performance, follow the mounting details shown in Figure 1-4.

For best performance, mount the module on the PCB without metal obstructions in the keep out area of Figure 1-4. The antenna is tuned to have FR4 PCB material underneath the module. Do not "cut-out" host PCB material under the antenna.

FIGURE 1-4: RECOMMENDED HOST PCB FOOTPRINT



Note 1: The "Note 1" demarcation specifies the host PCB copper plane keep-out area on underlying board layers. It is alright to route surface escape traces in this area.

Figure 1-5 illustrates the module reflow profile that is recommended for mounting the device onto the host PCB.

FIGURE 1-5: RECOMMENDED MODULE REFLOW PROFILE AND SETPOINTS

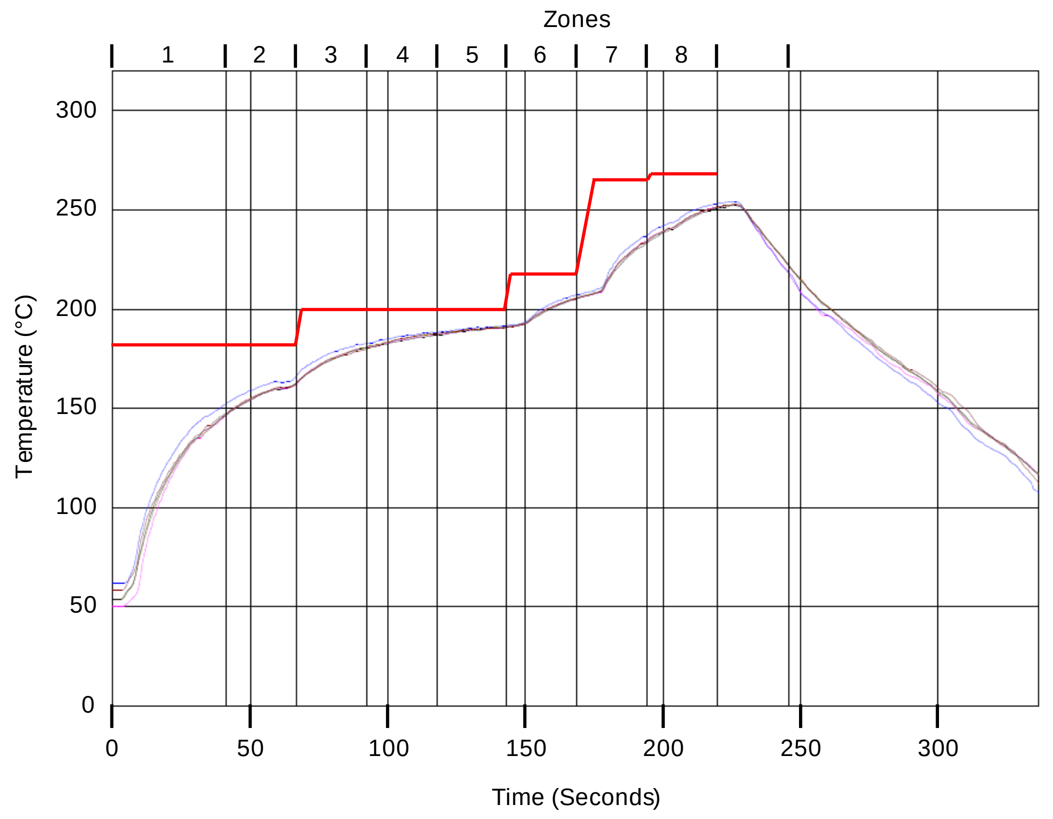


TABLE 1-2: MODULE REFLOW PROFILE(1)

Zone	1	2	3	4	5	6	7	8
Temperature (°C)	**180°**	**180°**	**200°**	**200°**	**200°**	**220°**	**265°**	**270°**

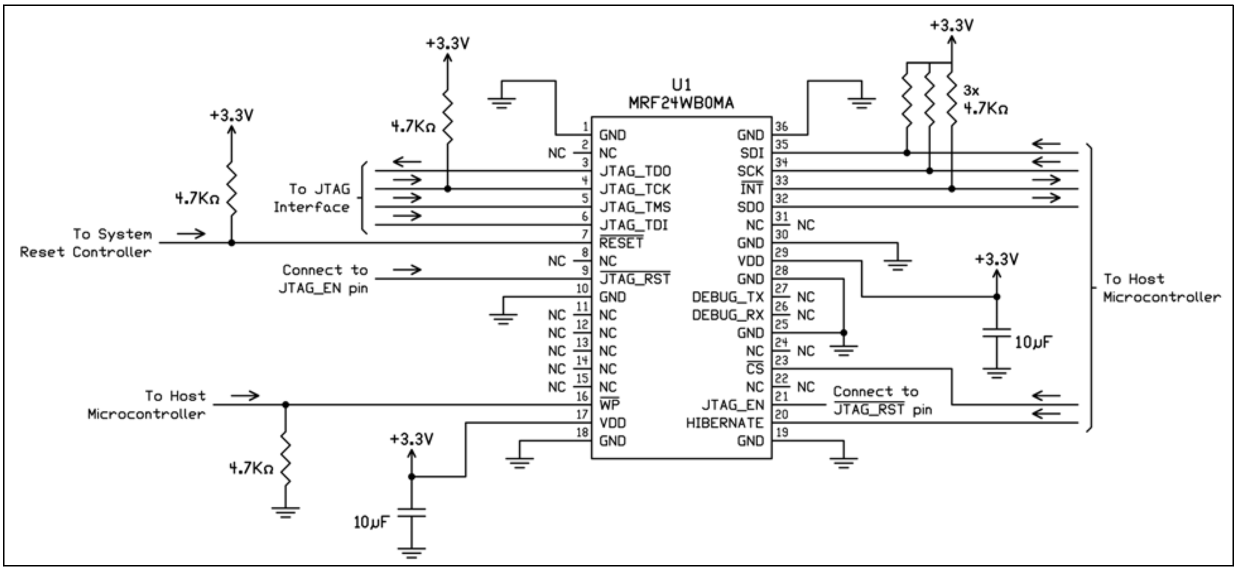
Note 1: Conveyor Speed: 90 cm/min

2.0 CIRCUIT DESCRIPTION

The MRF24WB0MA/MRF24WB0MB interfaces to Microchip PIC18, PIC24, dsPIC33, and PIC32 microprocessors with a minimal of external components through digital-only connections. This section details use of the module, starting with an example host connection as shown in Figure 2-1.

2.1 Schematic

FIGURE 2-1: MRF24WB0MA/MRF24WB0MB EXAMPLE APPLICATION SCHEMATIC

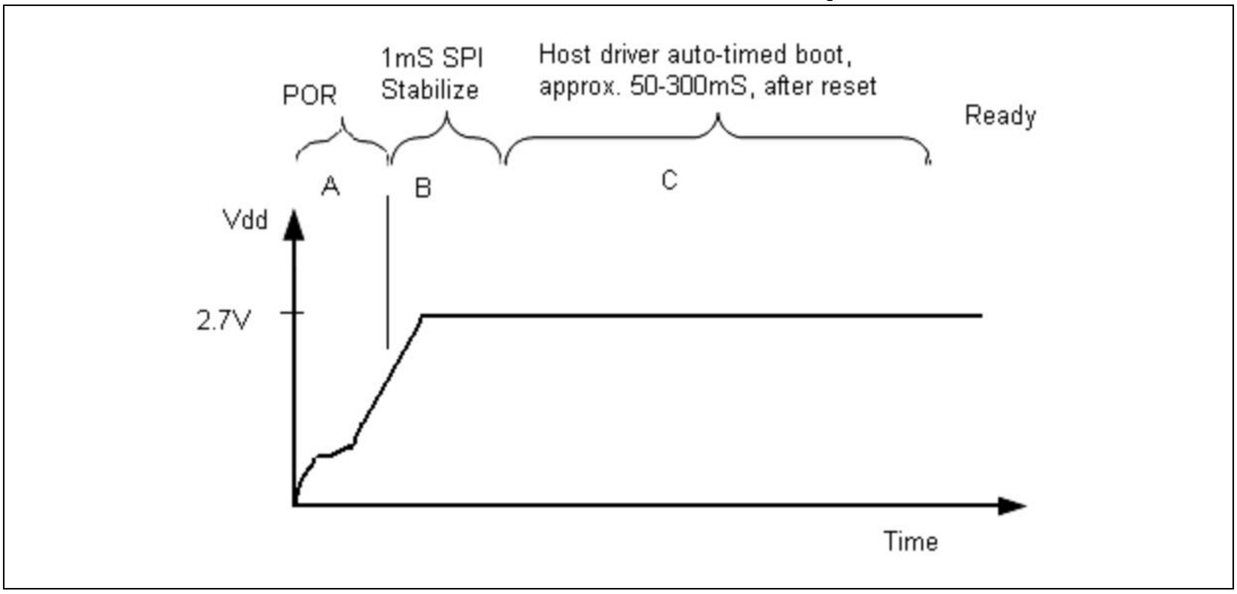


2.2 Power-On Sequence

The internal regulators for the digital and analog core power supplies are disabled by driving the HIBERNATE pin high. Figure 2-2 shows the power up sequence for the MRF24WB0MA/MRF24WB0MB.

There is an internal Power-on-Reset (POR) circuit which keeps the module in reset until VDD is within specification. The Hibernate and Reset signals are also used to control startup. In Figure 2-2, section A is controlled by the internal POR and section B is an allowance for the SPI bus to stabilize when the module supplies are enabled. Once Hibernate is disabled, the host software provides 1mS of startup to allow the SPI to stabilize. This time is pre-programmed into the host driver, and may need to be increased if insufficient initial drive current is not provided to the MRF24WB0M module. Section C is the driver controlled release from Reset period. This takes approximately 300 mS and is monitored by the stack driver. No additional time needs to be provided by user software for startup.

FIGURE 2-2: MRF24WB0MA/MRF24WB0MB POWER-ON SEQUENCE TIMING



2.3 Power States

The MRF24WB0MA/MRF24WB0MB has several power states. These are Hibernate, Sleep and Active (two sub-states), as shown in Figure 2-3. The selection of power state directly affects system behavior, and overall power consumption or battery life. There is also a “Standby” state that is not user-controlled.

2.3.1 HIBERNATE STATE

An “Off” state is defined as no power applied to the device. The Hibernate mode is the closest to controlled off that the module can approach. It is controlled through the HIBERNATE pin (high input puts the module into Hibernate). When in Hibernate, the module only consumes leakage current, but does not maintain state. Hibernate has to be fully controlled by the PIC MCU and requires the TCP/IP stack to restart on an awake.

The module contains about 70µF of internal bulk capacitance. Supplies should be provisioned to supply sufficient charge on release of hibernate for desired start time or sufficient delay must be provided in software after hibernate release and before releasing reset.

This state provides the best battery life for embedded products. Entering Hibernate for intervals of less than 30 seconds is not likely to save power. Battery life expectation can be more than a year for devices operating on AA cells that would be in Hibernate except to wake up every hour for a small data transfer (<500 Bytes).

2.3.2 SLEEP STATE

The Sleep state is a low power dynamic state that automatically implements the 802.11 Power Save feature. In this mode, if enabled, the module will enter Power Save mode when all activity is complete.

The module will wake autonomously to any PIC intervention so it can check DTIM beacons from the Access Point. If any traffic is listed as queued for the module, then it will awaken and get the data from the Access Point on the next possible opportunity. When data is acquired, the module will interrupt the PIC microcontroller on a normal “data available” indication. If no data is available on a DTIM check, the module reenters the Power Save state until the next DTIM. The DTIM interval is programmed at the Access Point. This state can provide “as if on” behavior of the radio with a significant power savings versus “always on”. The battery life expectation of this mode is several days to several weeks. This mode is characterized by a very low latency (as low as 200 mS) to begin data transfer from the low power state.

2.3.3 ACTIVE STATE

The Active state is identified as one of two states where the radio circuitry is fully on. The two active states are the Receive state (RX ON) and the Transmit state (TX ON).

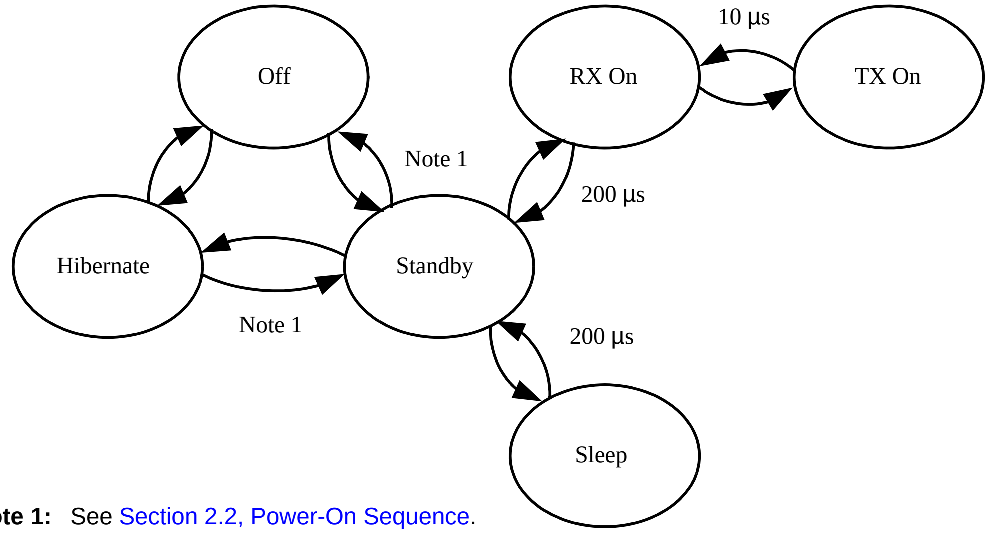
2.3.4 STANDBY STATE

The Standby state is not user-controlled but is noted as it helps identify and track certain operations of the module during power tracing.

TABLE 2-1: MRF24WB0MA/MRF24WB0MB POWER STATE DEFINITIONS

State	V_{DD}	$\overline{CS}$	Description
Off	0V	0V	Power is completely disconnected
Hibernate	3.3V	3.3V	All internal power regulators are OFF – enabled by HIBERNATE pin
Sleep	3.3V	0V	Enabled by TCP/IP driver
RX ON	3.3V	0V	Receive circuits are on and receiving
TX ON	3.3V	0V	Transmit circuits are on and transmitting
Standby	3.3V	0V	State machine transition state only – not user controlled

FIGURE 2-3: MRF24WB0MA/MRF24WB0MB POWER-STATE DIAGRAM



Note 1: See Section 2.2, Power-On Sequence.

2.4 JTAG Interface

Joint Test Action Group (JTAG) is the common name used for the IEEE 1149.1 standard entitled *Standard Test Access Port and Boundary-Scan Architecture* for test access ports that are used for testing printed circuit boards using boundary scan. The MRF24WB0MA/ MRF24WB0MB supports JTAG boundary scan. The JTAG port provides the optional hardware JTAG Reset input, $\overline{\text{JTAGRST}}$. JTAG_EN and $\overline{\text{JTAGRST}}$ need to be driven high to enable JTAG mode. JTAG should not be enabled during normal functional operation. This function affects power state current.

2.5 Debug Serial Interface

The MRF24WB0MA/MRF24WB0MB incorporates a Transmit Data pin (DEBUGTX) and a Receive Data pin (DEBUGRX) for serial debugging purposes. These pins can be connected to commercially available RS-232 line drivers/receivers with appropriate external level shifters. The serial interface operates at 19200, 8, N, 1, N.

2.6 SPI Interface

The slave Serial Peripheral Interface (SPI) is used to interface with the host PIC microcontroller. The slave SPI interface works with the Interrupt line ($\overline{INT}$). When data is available for the PIC microcontroller during operation, the $\overline{INT}$ line is asserted (logic low) by the MRF24WB0MA/MRF24WB0MB module. The $\overline{INT}$ line is de-asserted (logic high) by the MRF24WB0MA/MRF24WB0MB after the data is transferred to the host PIC microcontroller. The SPI SCK frequency can be up to 25 MHz.

The slave SPI interface implements the [CPOL=0; CPHA=0] and [CPOL=1; CPHA=1] modes (0 and 3) of operation. That is, data is clocked in on the first rising edge of the clock after Chip Select ($\overline{CS}$) is asserted.

Data is placed on the bus with most significant bit (MSb) first.

The $\overline{CS}$ pin must be toggled with transfer blocks and cannot be held low permanently. The falling edge of $\overline{CS}$ is used to indicate the start of a transfer. The rising edge of $\overline{CS}$ is used to indicate the completion of a transfer.

Figure 4-1 in Section 4.0, Electrical Characteristics shows the SPI timing diagram. Table 4-7 details the SPI timing AC characteristics.

2.7 PCB Antenna

For the MRF24WB0MA, the PCB antenna is fabricated on the top copper layer and covered in solder mask. The layers below the antenna have no copper trace.

It is recommended that the module be mounted on the edge of the host PCB. It is permitted for PCB material to be below the antenna structure of the module as long as no copper traces or planes are on the host PCB in that area. For best performance, place the module on the host PCB according to the details shown in Figure 1-4.

The antenna patterns shown in the following plots, designated as Figure 2-4, Figure 2-5 and Figure 2-6, refer to three separate axis of measurement that correspond to the orientation of the module (drawn in the center of each plot).

The horizontal and vertical data, blue and red respectively, in each plot correspond to the orientation (polarization) of the measurement antenna rotated 360 degrees around the module.

The horizontal measurement was done with the receive antenna parallel with the module PCB. The vertical measurement was done perpendicular to the module PCB.

These patterns allow the designer to understand the performance of the module with respect to the position of the receive/transmit antenna at the other end of the link. Figure 2-4, Figure 2-5 and Figure 2-6 show the simulated radiation patterns expected from the PCB antenna.

FIGURE 2-4: AZIMUTH RADIATION PATTERN, 2.44GHZ

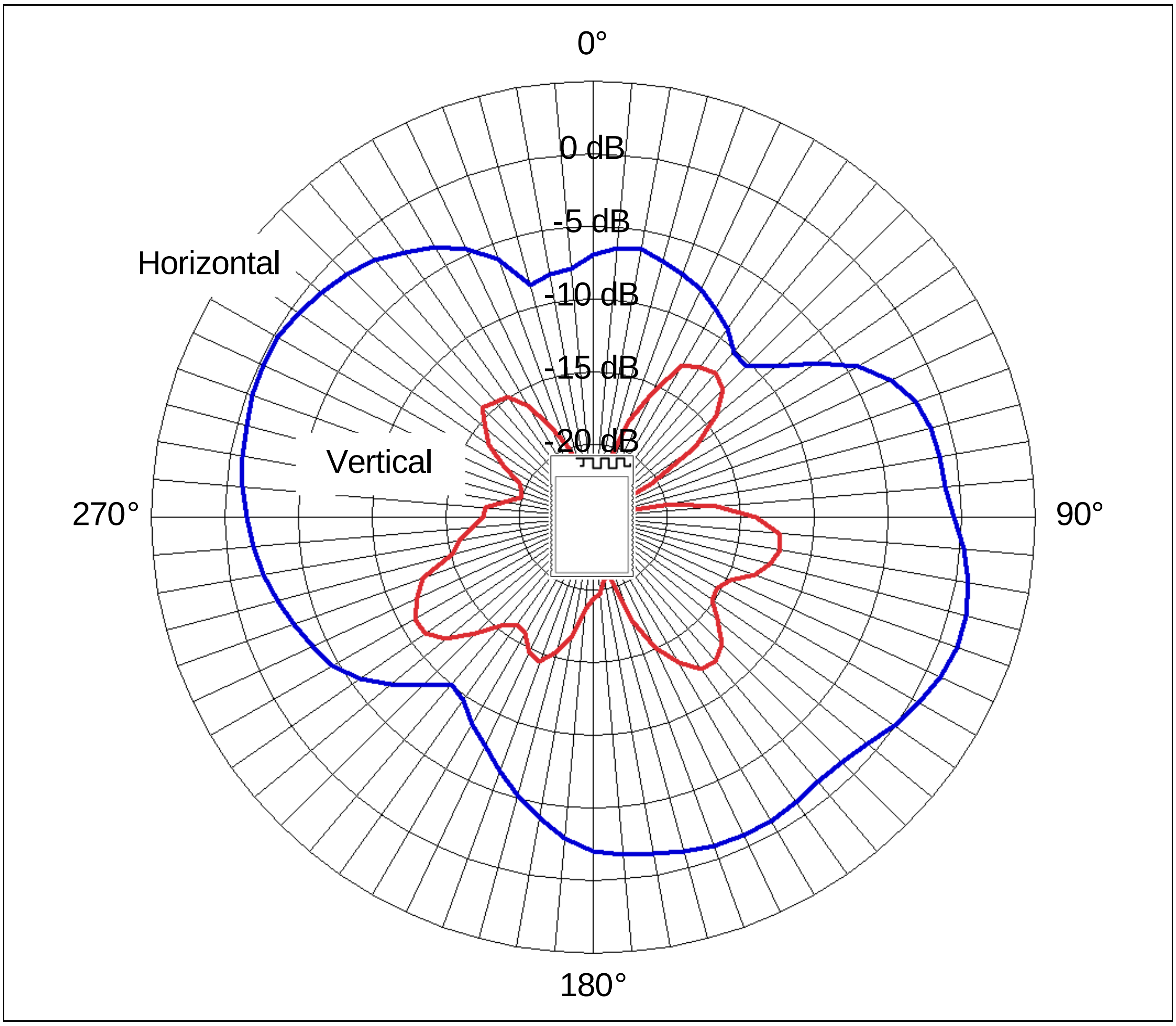


FIGURE 2-5: RADIATION PATTERN ON SIDE WITH PCB ANTENNA, 2.44GHZ

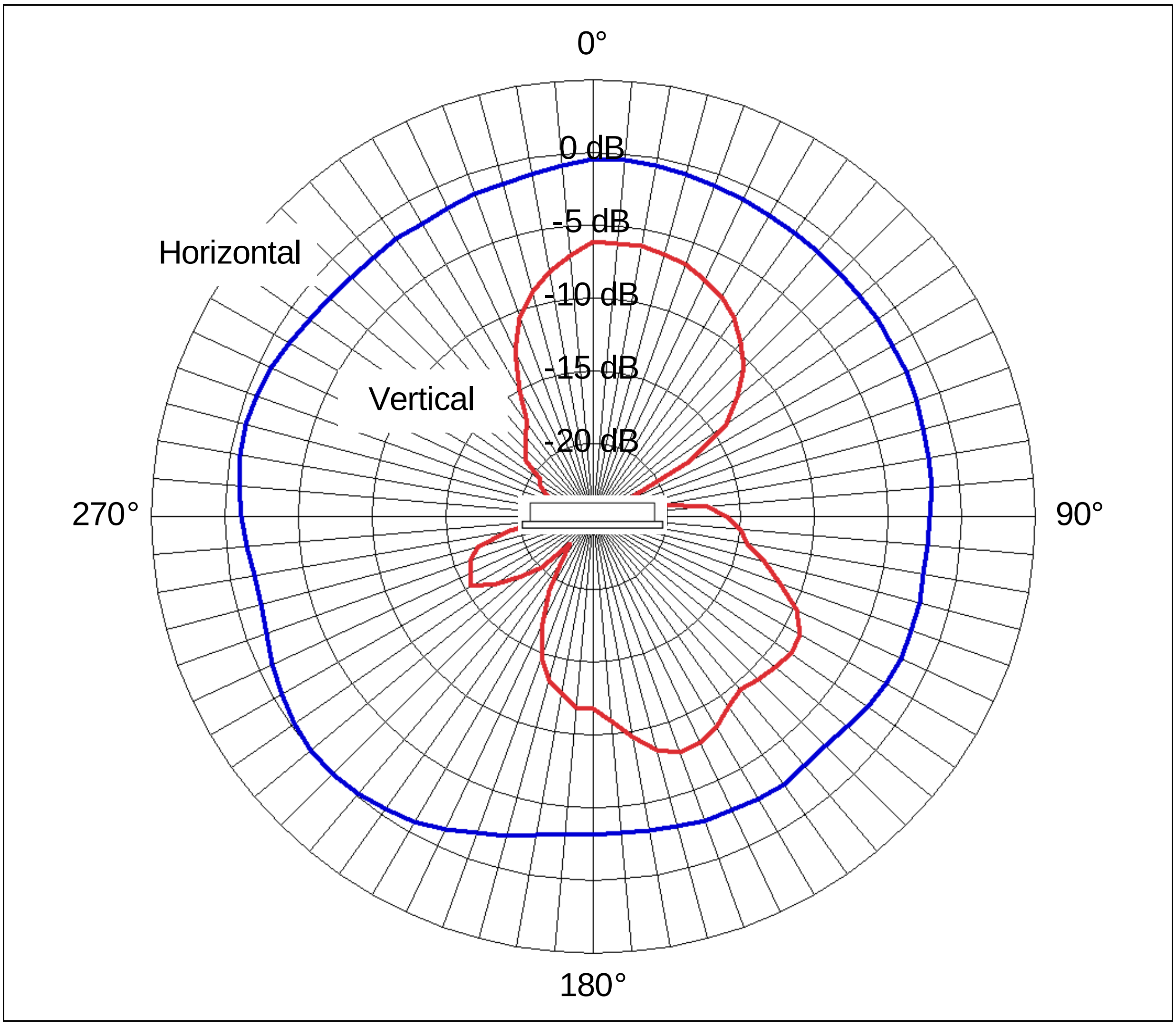
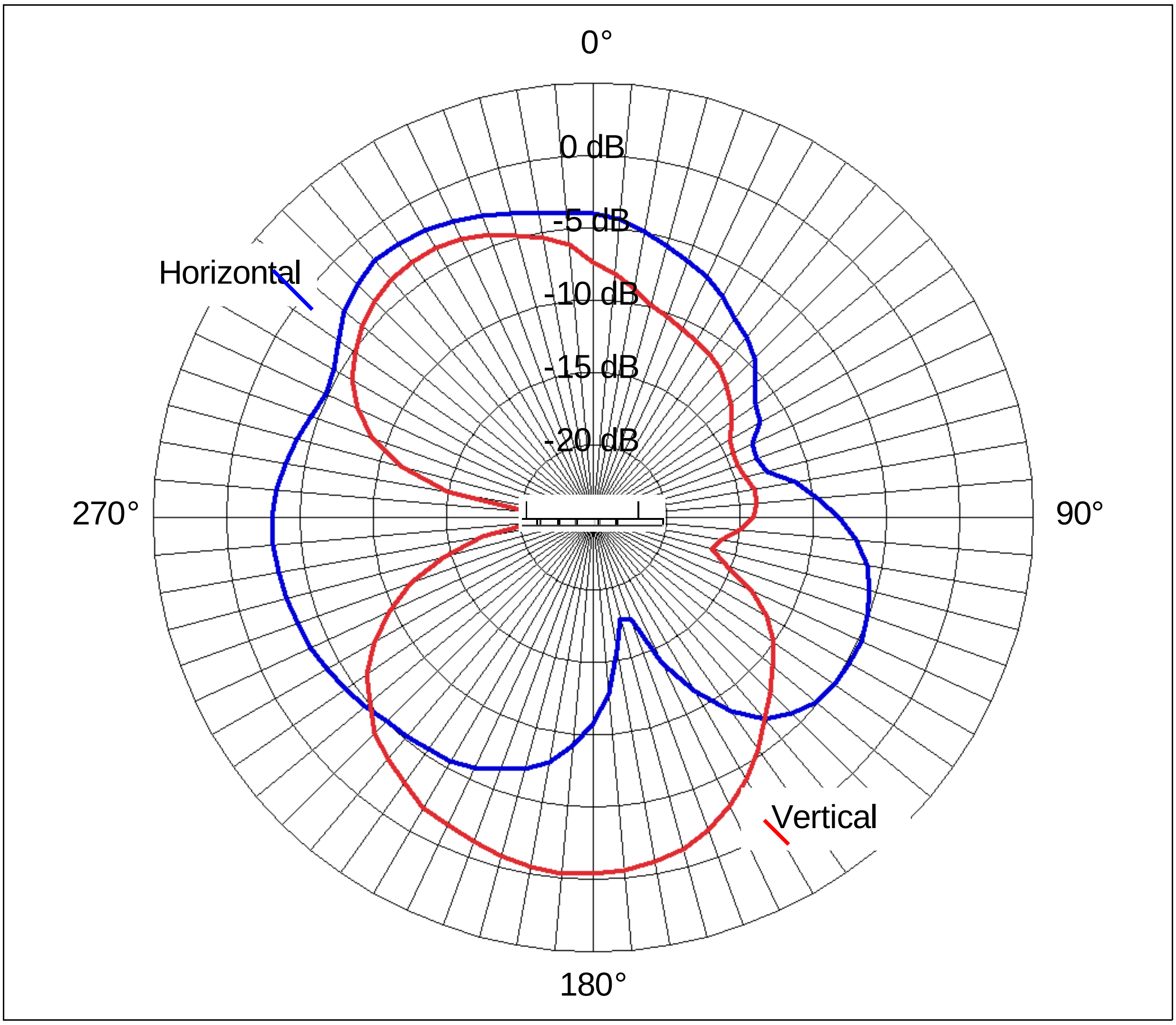


FIGURE 2-6: RADIATION PATTERN ALONG PIN EDGE, 2.44GHZ



2.8 External Antenna

The MRF24WB0MB has been regulatory certified for use with a number of antennas. The modular certifications hold only if the following antennas, or antennas that are materially and functionally equivalent, are used. All antennas connect to the module through an ultra miniature coaxial (U.FL or IPEX) connector.

A list of antennas for use with the module is provided in Table 2-2.

TABLE 2-2: LIST OF CERTIFIED EXTERNAL ANTENNAS

Part Number	Type	Gain (dBi)	VSWR Max.	Connector	Vendor
RFA-02-P05	PCB	2	2.0	IPEX	Aristotle
RFA-02-L6H1-70-35	Dipole	2	2.0	IPEX	Aristotle
RFA-02-D3	Dipole	1.5	2.0	IPEX	Aristotle
RFA-02-L2H1	Dipole	2	2.0	IPEX	Aristotle
RFA-02-3-C5H1	Dipole	3	2.0	IPEX	Aristotle
RFA-02-5-C7H1	Dipole	5	2.0	IPEX	Aristotle
RFA-02-5-F7H1	Dipole	5	2.0	IPEX	Aristotle
WF2400-15001A	Dipole	5	2.0	IPEX	Saytec
WF2400-15001AR	Dipole	5	2.0	RF-IPEX	Saytec
WF2400-10001I	Dipole	2	2.0	IPEX	Saytec
WF2400-10001R	Dipole	2	2.0	RF-IPEX	Saytec
AN2400-5901RS, used with connector SMASFR8-3152H-00X00I	Omni	9	2.0	IPEX	Saytec
AN2400-5901RS, used with connector SMASFR8-3152H-00X00IR	Omni	9	2.0	RF-IPEX	Saytec

NOTES:

3.0 REGULATORY APPROVAL

The MRF24WB0MA/MRF24WB0MB module has received regulatory approvals for modular devices in the United States, Canada and European countries. Modular approval allows the end user to place the MRF24WB0MA/MRF24WB0MB module inside a finished product and not require regulatory testing for an intentional radiator (RF transmitter), provided no changes or modifications are made to the module circuitry. Changes or modifications could void the user's authority to operate the equipment. The end user must comply with all of the instructions provided by the Grantee, which indicate installation and/or operating conditions necessary for compliance.

The integrator may still be responsible for testing the end product for any additional compliance requirements that become necessary with this module installed (for example, digital device emission, PC peripheral requirements, etc.) in the specific country that the end device will be marketed.

Refer to the specific country radio regulations for details on regulatory compliance.

3.1 United States

The MRF24WB0MA/MRF24WB0MB has received Federal Communications Commission (FCC) CFR47 Telecommunications, Part 15 Subpart C "Intentional Radiators" 15.247 and modular approval in accordance with FCC Public Notice DA 00-1407 Released: June 26, 2000, Part 15 Unlicensed Modular Transmitter Approval. The MRF24WB0MA/MRF24WB0MB module can be integrated into a finished product without obtaining subsequent and separate FCC approvals for intentional radiation.

The MRF24WB0MA/MRF24WB0MB module has been labeled with its own FCC ID number, and if the FCC ID is not visible when the module is installed inside another device, then the outside of the finished product into which the module is installed must also display a label referring to the enclosed module. The following examples present terminology that could be used:

> Contains Transmitter Module FCC ID: W7OZG2100-ZG2101
>
> or
>
> Contains FCC ID: W7OZG2100-ZG2101
>
> 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.

A user's manual for the product should include the following statement:

> 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.

3.1.1 RF EXPOSURE

All transmitters regulated by FCC must comply with RF exposure requirements. OET Bulletin 65, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radio Frequency Electromagnetic Fields*, provides assistance in determining whether proposed or existing transmitting facilities, operations or devices comply with limits for human exposure to Radio Frequency (RF) fields adopted by the Federal Communications Commission (FCC). The bulletin offers guidelines and suggestions for evaluating compliance.

If appropriate, compliance with exposure guidelines for mobile and unlicensed devices can be accomplished by the use of warning labels and by providing users with information concerning minimum separation distances from transmitting structures and proper installation of antennas.

The following statement must be included as a CAUTION statement in manuals and OEM products to alert users of FCC RF exposure compliance:

> To satisfy FCC RF Exposure requirements for mobile and base station transmission devices, a separation distance of 20 cm or more should be maintained between the antenna of this device and persons during operation. To ensure compliance, operation at closer than this distance is not recommended.
>
> The antenna(s) used for this transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

If the MRF24WB0MA/MRF24WB0MB module is used in a portable application (i.e., the antenna is less than 20 cm from persons during operation), the integrator is responsible for performing Specific Absorption Rate (SAR) testing in accordance with FCC rules 2.1091.

3.1.2 HELPFUL WEB SITES

Federal Communications Commission (FCC):
http://www.fcc.gov.

3.2 Canada

The MRF24WB0MA/MRF24WB0MB module has been certified for use in Canada under Industry Canada (IC) Radio Standards Specification (RSS) “RSS-210” and “RSS-Gen”.

From “Section 7.1.1, RSS-Gen”, Issue 2, June 2007, *Modular Transmitter Approval*:

> “Host devices which contain separately certified modules do not need to be recertified, provided that they meet the following conditions:
>
> a)The host device, as a stand-alone unit without any separately certified modules, complies with all applicable Radio Standards Specifications.
>
> b)The host device and all the separately certified modules it contains jointly meet the RF exposure compliance requirements of “RSS-102”, if applicable.
>
> c)The host device complies with the certification labeling requirements of each of the modules it contains.”

The following example demonstrates labeling compliance.

> NOTE: Compliance of a module in its final configuration is the responsibility of the applicant. A host device will not be considered certified if the instructions regarding antenna configuration provided in the original description, of one or more separately certified modules it contains, were not followed.

From “Section 5.2, RSS-Gen”, Issue 2, June 2007, *Equipment Labels*:

> “All Category I radio equipment intended for use in Canada shall permanently display on each transmitter, receiver or inseparable combination thereof, the applicant’s name (i.e., manufacturer’s name, trade name or brand name), model number and certification number. This information shall be affixed in such a manner as to not be removable except by destruction or defacement. The size of the lettering shall be legible without the aid of magnification, but is not required to be larger than 8-point font size. If the device is too small to meet this condition, the information can be included in the user manual upon agreement with Industry Canada.”

The label is shown in the following example:

> Contains IC: 8248A-G21ZEROG

From "Section 7.1.6, RSS-Gen", Issue 2, June 2007, *Digital Circuits*:

> "If the device contains digital circuitry that is not directly associated with the radio transmitter, the device shall also have to comply with ICES-003, Class A or B as appropriate, except for ICES-003 labeling requirements. The test data obtained (for the ICES-003 tests) shall be kept by the manufacturer or importer whose name appears on the equipment label, and made available to Industry Canada on request, for as long as the model is being marketed in Canada."

3.2.1 HELPFUL WEB SITES:

Industry Canada: http://www.ic.gc.ca/

3.3 Europe

The MRF24WB0MA/MRF24WB0MB module has been certified for use in European countries. The following testing has been completed:

Test standard ETSI EN 300 328 V1.7.1 (2006-10):

- Maximum Transmit Power
- Maximum EIRP Spectral Density
- Frequency Range
- Radiated Emissions

Test standards ETSI EN 301 489-1:2008 and ETSI EN 301 489-17:2008:

- Radiated Emissions
- Electro-Static Discharge
- Radiated RF Susceptibility

The modules are fully compliant with

- Radiated Emissions EN 55022
- Electrostatic Discharge EN 61000-4-2
- Radiated Immunity EN 61000-4-3
- EN 60950-1
- CE-Mark
- RoHS

ETSI does not provide a modular approval similar to the USA (FCC) and Canada (IC). However, the testing completed above can be used as part of the customer's application for certification. The test report data can be included in their test plan and can significantly the lower customer's certification burden.

A helpful document that can be used as a starting point in understanding the use of Short Range Devices (SRD) in Europe is the European Radio Communications Committee (ERC) Recommendation "70-03 E", downloadable from the European Radio Communications Office (ERO): http://www.ero.dk/

The end user is responsible for ensuring compliance with harmonized frequencies and labeling requirements for each country in which the end device is marketed and sold.

3.3.1 HELPFUL WEB SITES:

Radio and Telecommunications Terminal Equipment (R&TTE):
http://ec.europa.eu/enterprise/rtte/index_en.htm

European Conference of Postal and Telecommunications Administrations (CEPT):

http://www.cept.org/
European Telecommunications Standards Institute (ETSI):

http://www.etsi.org/

European Radio Communications Office (ERO):
http://www.ero.dk/

3.4

Should other regulatory jurisdiction certification be required by the customer, or the customer need to recertify the module for other reasons, a certification utility is available. The utility runs on a Window's PC and utilizes a USB to SPI converter to interface to the MRF24WB0M module. In order to use the utility, the MRF24WB0M module must be out of reset and not accessed by the system host. That is, the SPI signals to the MRF24WB0M must be tri-state, with Reset and Hibernate deasserted. The following signals will need to be brought from the MRF24WB0M for connection to the PC (through the USB adapter):

- SDO
- SDI
- $\overline{\text{CS}}$
- SCK
- $\overline{\text{INT}}$
- GND

For further regulatory Certification Utility and documentation, contact your local Microchip salesperson.

3.5 Wi-Fi® Alliance

Wi-Fi Alliance Certification focuses on interoperability testing of devices based on 802.11 standards.

Historically, when the certification process and programs were developed by Wi-Fi Alliance members, the vast majority of the 802.11 clients were PC-centric, and certification testing adequately addressed those types of devices. In subsequent years, the number of Wi-Fi devices that are not PC-centric has grown significantly.

These non-standard devices, as a class of products, have been dubbed Application Specific Devices (ASDs) by the Wi-Fi Alliance. ASDs are 802.11 devices, for example clients or access points (APs), which cannot be tested under a standard Alliance test plan because they do not comply with the standard test configuration and/or because they are designed to perform a specific application. Examples include, but are not limited to: bar code scanners, pagers, recording devices, monitoring equipment, and cable modems.

The APs or clients that are used to validate ASD compliance (from the standard test bed) will meet all of the requirements specified in the applicable System Interoperability Test Plans (referred to as the “standard test plan”), unless specifically exempted. The MRF24WB0MA and MRF24WB0MB modules are in the ASD category.

The modules are certified under Wi-Fi 802.11 with WPA2, WPA, and WEP System Interoperability ASD Model Test Plan with Test Engine For IEEE 802.11a, b, and g Devices (Version 1.0).

Per the Wi-Fi Alliance approved ASD test plan, the definition of the Microchip MRF24WB0MA and MRF24WB0MB modular solutions is expressed in the following statements:

> “Member Wireless solution is a single-chip 802.11b module including MAC, baseband, RF and power amplifier personal STA. It utilizes a simple to use API for embedded markets, and an OS is not a requirement for operation. It supports 1 and 2 Mbps (TX and RX). It also supports WEP, WPA Personal, and WPA2 Personal security. Ciphers supported are AES and TKIP. The Member Wireless solution interfaces with the HOST through SPI Bus. Some applications for the Member Wireless solution are as following:
>
> - Sensors/Controls suchas Industrial & Factory sensors, HVAC, & Lighting
> - Consumer Electronic such as remote controls, toys, and internet radio
>
> This certification ensures that the MRF24WB0MA and MRF24WB0MB modules have passed rigorous testing for interoperability across existing consumer and business Wi-Fi equipments, and their certifications are completed (WFA ID: WFA7150). The certification effort undertaken will save customers time and money. For modular policy, refer to WFA Module Policy (Version 2.2; MARCH 2006).”

4.0 ELECTRICAL CHARACTERISTICS

TABLE 4-1: DIGITAL ELECTRICAL CHARACTERISTICS (NOMINAL CONDITIONS: 25C, V_{DD} = 3.3V)

Parameters	Min	Typ	Max	Units
V_{IL} (Input low voltage)	-0.3	—	0.8	V
V_{IH} (Input high voltage)	2	—	5.5	V
V_{OL} (Output low voltage)	—	—	0.4	V
V_{OH} (Output high voltage)	2.4	—	—	V
I_{OL} (Output low level current at V_{OL} Max)	—	8.5	—	mA
I_{OH} (Output high level current at V_{OH} Min)	—	15.4	—	mA

TABLE 4-2: ABSOLUTE MAXIMUM RATINGS(1)

Parameters	Min	Max	Notes
Storage Temperature	-40C	+125C	—
V_{DD}	0V	4.2V for 0.5mSec	V_{DD} above this level and duration will disable Radio
V_{IN} on SDI, $\overline{CS}$, SCK	-0.3V	5.5V	—

Note 1: Listed Absolute Maximum Ratings are not meant for functional operation. Operation at these levels is not guaranteed, and may reduce the operating life of the component.

TABLE 4-3: RECOMMENDED OPERATING CONDITIONS

Parameters	Min	Typ	Max	Units
Ambient Temperature(2)	-20	—	+85	Degrees Celsius
V_{DD} – for FCC and IC	2.70	3.3	3.63(1)	Volts

Note 1: While 3.63V is the maximum operating voltage, the module will detect an overvoltage condition at 4.2V and disable the RF Transmit function after 0.5 ms. This is an RF certification requirement pertaining to disabling transmission in unforeseen overvoltage conditions.

2: Ambient temperature for industrial part number is minimum -40C to maximum +85C. Contact Microchip Sales for industrial temperature parts.

TABLE 4-4: CURRENT CONSUMPTION(3) (NOMINAL CONDITIONS: 25C, V_{DD} = 3.3V)

Parameters	Min	Typ	Max	Units
I_{DD}, Hibernate = 3.3V	—	0.1	—	µA
I_{DD}, Sleep (software enabled)	—	250(1)	—	µA
I_{DD}, Standby (transitional state)	—	10	—	mA
I_{DD} core(2), RX on, Receive @-83dBm with 2Mbps modulated signal at antenna port	—	85	—	mA
I_{DD} core, TX on, +0 dBm	—	115	—	mA
I_{DD} core, TX on, +10 dBm	—	154	—	mA

Note 1: Sleep current is current consumed during periods of “standby” between DTIM beacons. The module will awake 2 mS before a DTIM and turn on its receiver, and possibly its transmitter (if data is available for it).

2: I_{DD} core is current consumed by the part not including the I/O consumption of the SPI port.

3: Current Consumption values represent Typical Peak currents, and the measured current conditions were done with 85% duty cycle modulated signal. Wi-Fi applications typically operate at less than 85% TX duty cycle. TX current is dependent on such criteria as transmit power setting, and transmit data rate and bandwidth being used. RX current is affected by connection distance.

TABLE 4-5: RECEIVER AC CHARACTERISTICS(1)

Parameters	Min	Typ	Max	Units
Flo	2412	—	2484	MHz
RX Min Input Level Sensitivity, 1Mbps, 8% PER	—	-91	—	dBm
RX Min Input Level Sensitivity, 2Mbps, 8% PER	—	-88	—	dBm
RX Max Input Level (Power), 1Mbps, 8% PER	—	-4	—	dBm
RX Max Input Level (Power), 2Mbps, 8% PER	—	-4	—	dBm

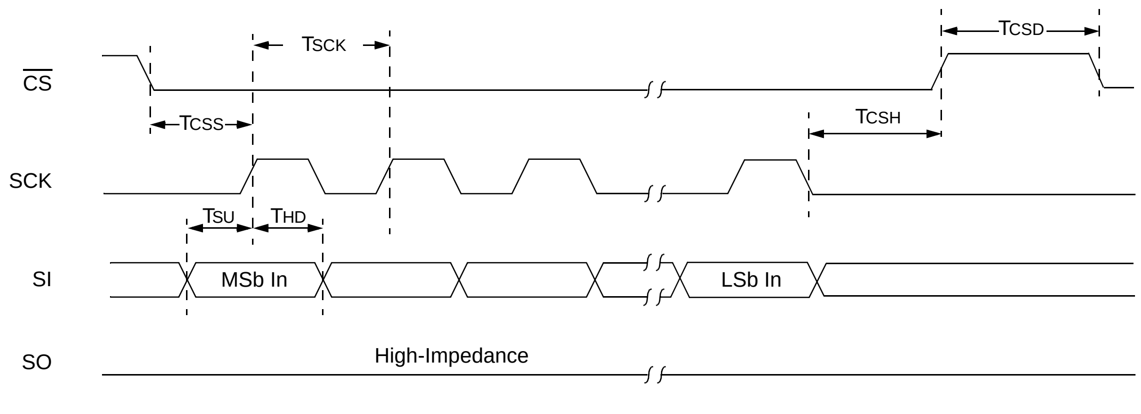
Note 1: Nominal conditions: 25C, V_{DD} = 3.3V, Flo = 2437 MHz, measurements at antenna port.

TABLE 4-6: TRANSMITTER AC CHARACTERISTICS(1)

Parameters	Min	Typ	Max	Units
Flo	2412	—	2484	MHz
Average Pout (transmit spectrum mask compliant)	—	+10	—	dBm
Average Pout gain step resolution from +5 to +10dBm	—	0.5	—	dB
Average Pout gain step resolution from -5 to +5dbm	—	1.0	—	dB
Average Pout settled variation	-0.5	—	0.5	dB

Note 1: Nominal conditions: 25C, V_{DD} = 3.3V, Flo = 2437 MHz, 2 Mbps. modulated signal measured at antenna port.

FIGURE 4-1: SPI INPUT TIMING



$\overline{CS}$ must be toggled for each SPI block transfer.

FIGURE 4-2: SPI OUTPUT TIMING

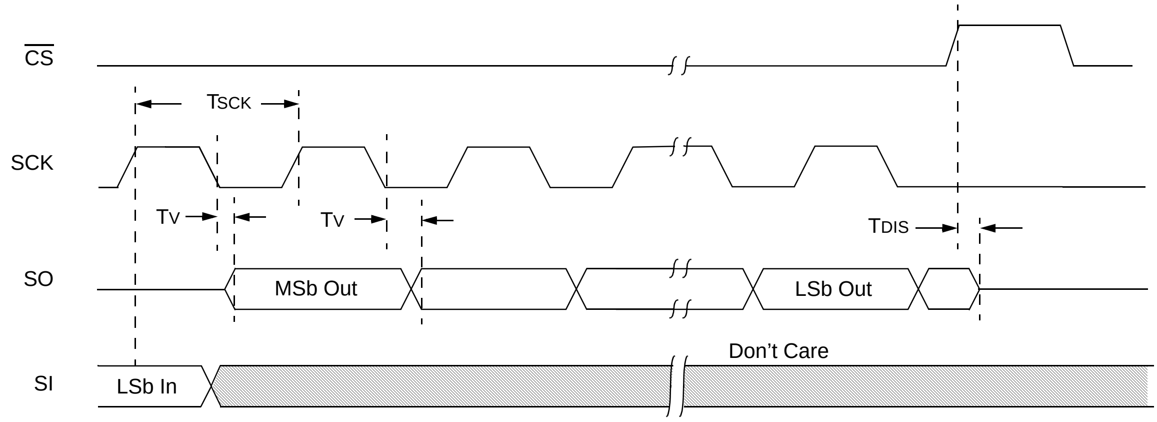


TABLE 4-7: SPI INTERFACE AC CHARACTERISTICS

Symbol	Parameters	Min	Max	Units
T_{SCK}	SCK Period	40	—	nS
T_{CSD}	$\overline{CS}$ High time	50	—	nS
T_{CSS}	$\overline{CS}$ Setup time	50	—	nS
T_{CSH}	$\overline{CS}$ Hold time	50	—	nS
T_{SU}	SDI Setup time	10	—	nS
T_{HD}	SDI Hold time	10	—	nS
T_{V}	SDO Valid time	—	15	nS

NOTES:

APPENDIX A: REVISION HISTORY

Revision A (April 2010)

This is the initial release of the document.

Revision B (June 2011)

This revision includes the following updates:

- UpdatedSection , Operational: Changed temperature range to -20° C to +85° C
- UpdatedTable 1-1: Added type and pin description to pin 23.
- UpdatedTable 4-3
- ReplacedFigure 2-2
- UpdatedSection 2.0, Circuit Description
- AddedSection 3.4,
- Updated the temperature on the order code in Section , Product Identification System
- Minor changes to the text and formatting were incorporated throughout the document.

NOTES:

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Literature Number: DS39957C

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____

____

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____

____

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____

____

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____

____

5. What deletions from the document could be made without affecting the overall usefulness?

____

____

6. Is there any incorrect or misleading information (what and where)?

____

____

7. How would you improve this document?

____

____

PRODUCT IDENTIFICATION SYSTEM

To order parts, including industrial, or obtain information, for e.g., on pricing or delivery, refer to the factory or the listed sales office.

PART NO.	M	X	T	-X
Device	Module	Module Type	Tape and Reel	Temperature Range

Device	MR24WB0MA/MRF24WB0MB; V_{DD} range 2.7V to 3.6V		
Temperature Range	-20°C to	+85°C	(Extended commercial)
	-40°C to	+85°C	(Industrial Temp)

Examples:

a) MRF24WB0MA/RM = Extended commercial temp. tray

b) MRF24WB0MB/RM = Extended commercial temp. tray

NOTES:

Worldwide Sales and Service

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Fax: 61-2-9868-6755

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Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

China - Chengdu
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

China - Chongqing
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

China - Hangzhou
Tel: 86-571-2819-3180
Fax: 86-571-2819-3189

China - Hong Kong SAR
Tel: 852-2401-1200
Fax: 852-2401-3431

China - Nanjing
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

China - Qingdao
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

China - Shanghai
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

China - Shenyang
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

China - Shenzhen
Tel: 86-755-8203-2660
Fax: 86-755-8203-1760

China - Wuhan
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

China - Xian
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

China - Xiamen
Tel: 86-592-2388138
Fax: 86-592-2388130

China - Zhuhai
Tel: 86-756-3210040
Fax: 86-756-3210049

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India - Bangalore
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

India - New Delhi
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Fax: 91-11-4160-8632

India - Pune
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

Japan - Yokohama
Tel: 81-45-471- 6166
Fax: 81-45-471-6122

Korea - Daegu
Tel: 82-53-744-4301
Fax: 82-53-744-4302

Korea - Seoul
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

Malaysia - Kuala Lumpur
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

Malaysia - Penang
Tel: 60-4-227-8870
Fax: 60-4-227-4068

Philippines - Manila
Tel: 63-2-634-9065
Fax: 63-2-634-9069

Singapore
Tel: 65-6334-8870
Fax: 65-6334-8850

Taiwan - Hsin Chu
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Fax: 886-3-6578-370

Taiwan - Kaohsiung
Tel: 886-7-213-7830
Fax: 886-7-330-9305

Taiwan - Taipei
Tel: 886-2-2500-6610
Fax: 886-2-2508-0102

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