APPLICATION NOTE

AT09567: ISM Band PCB Antenna Reference Design

Atmel Wireless

Features

- Compact PCB antennas for 915MHz and 2.4GHz ISM bands
- Easy to integrate Altium® design files and gerber files
- Return Loss, Radiation Pattern, Gain, and Efficiency measurement results
- Guidelines to integrate antenna board with RF board

Description

Scope of this application note is to guide customers to design ISM band antenna for 915MHz/2.4GHz ISM bands and use them in applications based on AT86RF212B/AT86RF233 transceivers.

This application note contains some ISM band antennas, brief design note, and integration challenges. The accompanying zip file contains detailed application notes, PCB Gerber files, and the results of antenna measurement.

Table of Contents

1. Introduction

This application note guides in designing a new ISM band PCB antenna based on system requirements, available board space, and layer stack up.

These antenna reference designs can be easily integrated with corresponding ISM band transceivers (915MHz/2.4GHz) to verify their prototypes quickly and it is a better reference for designing a new antenna.

2. Compact ISM Band Antennas

The 915MHz ISM band (902MHz ~ 928MHz) is a commonly used unlicensed band in the United States of America and 2.4GHz ISM band (2.402GHz ~ 2.484GHz) is the most commonly used unlicensed band worldwide for industrial, scientific, and medical applications. Demand for compact antennas operating in ISM bands is increasing day by day. PCB antennas are compact and cost effective for frequencies above 700MHz. Many reference designs are available for designing standard PCB antennas. A few standard antennas are Dipole, Patch, Loop, etc. But, these standard antennas are not suitable for handheld / mobile applications due to their large dimension.

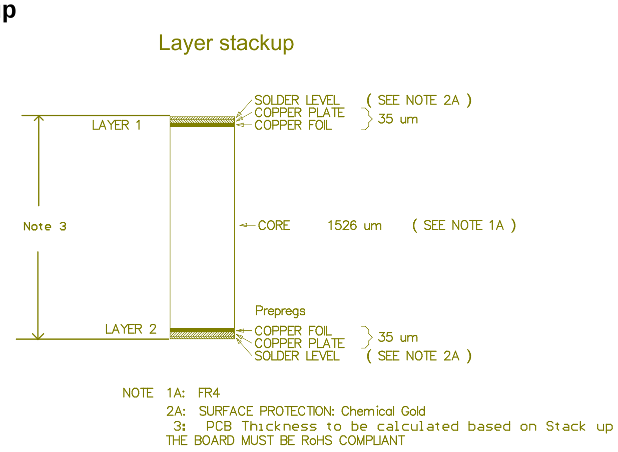
2.1 λ/4 Antennas

The λ/4 antennas are smaller compared to the standard antennas and they are very popular. Well known λ/4 antennas are monopole antenna and Inverted-F antenna which are discussed in Section 2.1.2 and 2.1.3. When the size of the standard λ/4 antennas is large at some frequencies and the antenna cannot be accommodated in the available space on the PCB, the designer can apply some miniaturization techniques to fit the antenna into the available board space, although this might cause some slight degradation in performance.

Table 2-1. PCB Characteristic

PCB Material - Parameter	Value
PCB substrate	FR-4
Dielectric constant (ε_r)	4.4
Loss tangent (tanδ)	0.02
Substrate thickness	1.6mm
Cu thickness	35µm

Figure 2-1. PCB Layer Stack up



If a standard λ/4 antenna is used for the above PCB layer stack up, it requires a $\lambda_g/4$ length of 45mm for 915MHz and 17mm for 2.4GHz excluding ground plane size. Also, the length of the ground plane must be >= $\lambda_g/4$. Any modifications to the size of the ground plane, affects the performance of antenna. The designer should be careful about the ground plane size during the design and it must be fixed to the actual board size of the application.

$$\lambda_g = \frac{C}{\sqrt{\varepsilon_r} f}$$

Where,

λ_g = Guided wavelength

C = Velocity of light

f = Frequency of operation

ε_r = Relative permittivity of dielectric material

Using Folded/Meander miniaturization technique, the size of the antenna can be reduced to fit the available board size with a small degradation in antenna efficiency and radiation characteristics when compared with a standard antenna. Folded/Meander structure actually requires longer trace length (in multiple bends) than λ/4 for its operation. However, it occupies lesser space.

Return Loss, Gain, Directivity, Efficiency, and Far-Filed Pattern Cuts are tuned in simulation before creating the prototype. PCB parameters are specified in Table 2-1. PCB layer stackup is shown in Figure 2-1.

2.1.2 Monopole Antenna

A standard λ/4 Printed Monopole Antenna (λ=wavelength) is widely used in many applications due to its small size and good radiation characteristics. So, it can be used for ISM band application. The operation of monopole is similar to dipole. The ground plane of the Monopole acts as the second arm to perform a dipole operation [1]. Example monopole structures are shown in Figure 2-2 and Figure 2-3.

2.1.3 Inverted-F Antenna

Another example for λ/4 antenna is Printed Inverted-F antenna. One end of the λ/4 arm of the IFA is short circuited and other end is open circuited. Short circuited end acts as a shunt inductor and open circuited end acts as a shunt capacitor. These shunt inductor and capacitor forms a parallel resonant circuit and decides the resonant frequency. By varying these inductor and capacitor values through trace adjustment, its resonant frequency can be varied. Example Inverted-F structures are shown in Figure 2-4.

2.2 PCB Antenna EVKs for ISM Band

The following small size PCB antenna EVK reference designs are available for ISM band application. The accompanying zip file contains application notes, PCB files, and test reports for the following EVKs:

1. 915MHz ISM band Printed Folded Monopole Antenna (ATEVK-900-ANT-FM)
2. 915MHz ISM band Printed Meander Monopole Antenna (ATEVK-900-ANT-M)
3. 915MHz ISM band Printed Inverted-F Antenna (ATEVK-900-ANT-IFA)
4. 2.4GHz ISM band Printed Folded Monopole Antenna (ATEVK-2400-ANT-FM)
5. 2.4GHz ISM band Printed Meander Monopole Antenna (ATEVK-2400-ANT-M)
6. 2.4GHz ISM band Printed Inverted-F Antenna (ATEVK-2400-ANT-IFA)

The structures of ISM band Printed Folded Monopoles are shown in Figure 2-2 Meander antennas are shown in Figure 2-3 and Inverted-F antennas are shown in Figure 2-4.

Figure 2-2. 900MHz and 2.4GHz ISM band Printed Folded Monopole Antenna EVKs

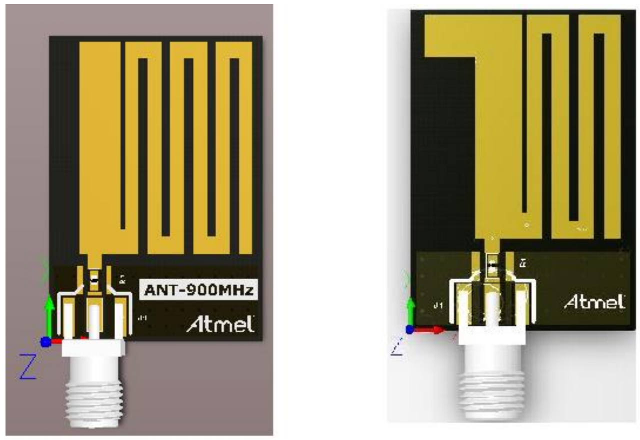


Figure 2-3. 900MHz and 2.4GHz ISM band Printed Meander Monopole Antenna EVKs

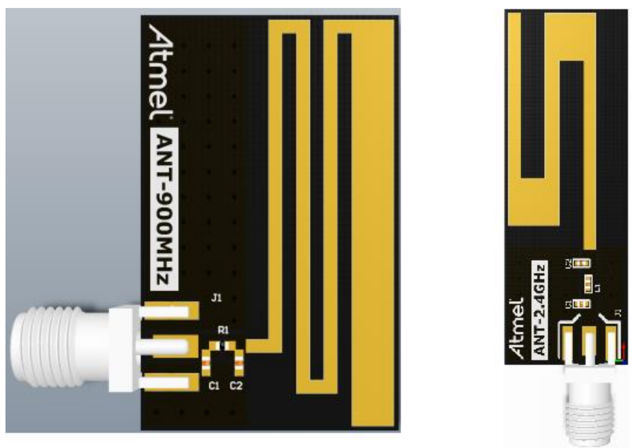
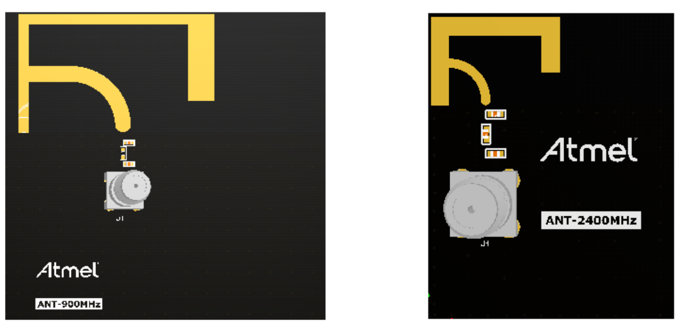


Figure 2-4. 900MHz and 2.4GHz ISM band Printed Inverted-F Antenna EVKs



3. Antenna Measurement

3.1 Return Loss Measurement

Return Loss (S11) can be directly measured in a Calibrated Vector Network Analyzer.

The antenna can be fine-tuned in the prototype to operate in the desired band by achieving better Return Loss. Increasing the length of the antenna trace reduces the resonant frequency of the antenna and decreasing the length increases the resonant frequency. Length can be increased using copper foil. Increasing the width of the line will improve the bandwidth. Another way of tuning is to use lumped elements to match the antenna impedance to characteristic impedance for the desired centre frequency [2].

3.2 Radiation Pattern, Gain, and Efficiency Measurement

Radiation Pattern, Gain, and Efficiency are measured in anechoic chamber. The 2D Radiation Pattern-cuts (Azimuth and Elevation) which describe the radiation characteristics of the antenna by measuring power density in different directions in an anechoic chamber. Test antenna is usually configured in receive mode for pattern measurement.

Peak Gain of the test antenna is measured with respect to standard transmit antenna in the main beam/maximum radiation direction. Gain varies from direction to direction in association with Radiation Pattern.

Efficiency of the PCB antennas depends on the available board space for antenna placement, antenna type, and ground plane size. The reference designs use very small ground plane and hence the efficiency might be slightly less when compared with standard antennas. If the ground plane is large enough in the final application board, the efficiency might be higher.

3.3 Guidelines for Antenna Integration with RF Transceiver

- Although, the discussed reference boards contain only two layers, these reference designs can be used for multilayer application. In multilayer application, antenna can be placed either on top layer or bottom layer based on the available space. Any change in dielectric constant or tangent loss of the PCB material or PCB thickness will shift the resonant frequency and change radiation characteristics. These factors must be considered while designing the application.
- It is a good practice to have transceiver and antenna on the same layer without having any via-hole in RF path. Via holes create discontinuity and loss of signal which will require proper impedance matching to reduce loss.
- Copper clearance must be provided in all layers beneath the antenna except patch antenna. Because, conductor will reflect RF signal and change the radiation characteristics of the antenna.
- RF trace connecting Transceiver output (Balun output for Differential output Transceivers) and antenna feed point must be 50Ω controlled impedance line. It is highly preferred to have a provision for Pi-pad matching network to improve the matching between Transceiver output and antenna input. It will avoid board re-spin during mismatched circumstances. Many combinations of lumped element matching methods are available [2].
- Mechanical enclosure of the product must not have any conductive material. Plastic enclosure is preferred; but, it might also detune the antenna from the desired band. So, tuning the antenna with lumped components must be performed by placing it within the enclosure.
- RF and antenna board can be placed seperately. If space is not a constraint, SMA cables can be used to connect RF board with antenna board. Most ISM band applications are designed on small sized boards. A small board mount RF connector such as U.FL and mating flexible RF cables can also be used to connect RF board with antenna board.

4. Abbreviations and Acronyms

BW	:	Bandwidth
CPW	:	Coplanar Waveguide
GND	:	Ground
GHz	:	Giga Hertz
ISM	:	Industrial, Scientific and Medical
MHz	:	Mega Hertz
mm	:	milli-meter
PCB	:	Printed Circuit Board
RF	:	Radio Frequency
SMA	:	SubMiniature version A
µm	:	micro-meter

5. References

[1] "Antenna Theory: Analysis and Design", Third Edition, Constantine A. Balanis

[2] "Microwave Engineering", Fourth Edition, David M.Pozar

6. Revision History

Doc. Rev.	Date	Comments
42332B	12/2014	Inverted-F antennas added.
42332A	07/2014	Initial document release.

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