Antenna Reference Design Guide for ISM Band Applications

Application Note

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I. Introduction

This document describes parameters to consider when deciding what kind of antenna to use in an ISM band device application. Antenna parameters, different antenna types and design aspects are described. Radiation pattern, gain, impedance matching, bandwidth, size and cost are some of the parameters discussed in this document. Very basic antenna theory and quick and easy measurements are also covered. A collection of different antenna types are compared to each other. The last section in this document contains reference designs for ISM band antennas.

In general, correct choice of antenna will significantly improve system performance and reduce the cost.

II. Background

A. Terms

BW	Bandwidth
CW	Carrier Wave
DUT	Device Under Test
EIRP	Effective Isotropic Radiated Power
EM	Electro Magnetic
IFA	Inverted-F Antenna
ISM	Industrial, Scientific, Medical
VLOS	Visual Line of Sight
MIFA	Meandered Inverted-F Antenna
NC	Not Connected
OTA	Over The Air
PCB	Printed Circuit Board
RF	Radio Frequency
RL	Return Loss
SRD	Short Range Device
SWR	Standing Wave Ratio
TRP	Total Radiated Power
VSWR	Voltage Standing Wave Ratio
YAGI	Directional Antenna

B. Brief Antenna Theory

An antenna is a key component for achieving the maximum range in a wireless communication system. The purpose of an antenna is to transform electrical signals into RF electromagnetic waves (transmit mode) and to transform RF electromagnetic waves into electrical signals (receive mode).

An antenna is basically an inductor of a defined wavelength. The maximum power is gathered at ¼ wavelengths as to be seen in Figure 1.

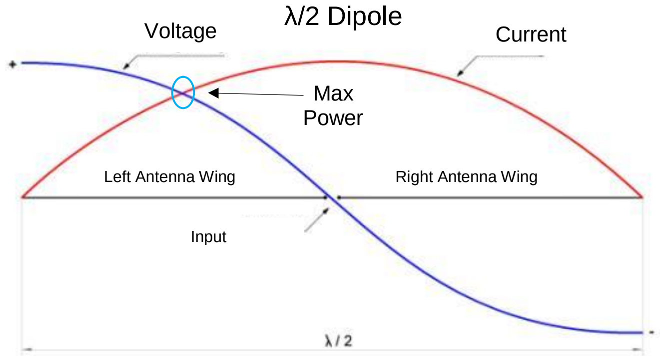

Figure 1 Voltage-Current Diagram of a dipole

Figure 1 shows that the dipole produces most power at the ends of the antenna with little power in the centre of the antenna.

C. Dipole (λ/2)

A dipole antenna most commonly refers to a half-wavelength (λ/2).

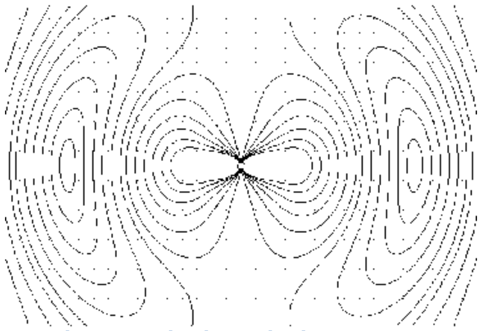

Figure 2 Dipole Emission Pattern

Figure 2 shows the typical emission pattern from a dipole antenna. The highest energy is radiated outward in the XY plane, perpendicular to the antenna in Z direction. Given this antenna pattern, one can see that a dipole antenna should be mounted in a way that it is vertically oriented with respect to the floor. This results in the maximum amount of energy radiating out into the intended coverage area. Figure 3 shows an example for a dipole.

Figure 3 Dipole Example

D. Monopole (λ/4)

A monopole antenna most commonly refers to a quarter-wavelength (λ/4). Single-ended sources, such as monopoles, may be used without balancing elements (baluns). When placed over a conducting ground plane, a λ/4 monopole antenna excited by a source at its base exhibits the same radiation pattern in the region above the ground, compared to a λ/2 dipole in free space. This is because, from image theory, the conducting plane can be replaced with the image of a second λ/4 monopole. However, the monopole can only radiate above the ground plane. Therefore, the radiated power is smaller than for the λ/2 dipole by about 50% compared to the λ/2 dipole. Figure 4 shows an example for a monopole.

Figure 4 Monopole Example

E. Wavelength Calculations for Dipole in Free Space

For the same output power, sensitivity and antenna gain; reducing the frequency by a factor of two doubles the range (visual line of sight). Lowering the operating frequency also means that the antenna increases in size (due to λ/4, λ/2 relationship). When choosing the operating frequency for a radio design, the available board space must also accommodate the antenna. So the choice of antenna, and size available should be considered at an early stage in the design.

Frequency	λ/4 [cm]	λ/4 [inch]	λ [cm]	λ [inch]
2.4 GHz	3.10	1.20	12.50	4.9
955 MHz	7.80	3.1	31.4	12.4
915 MHz	8.20	3.2	32.8	12.9
868 MHz	8.60	3.4	34.5	13.6
433 MHz	17.30	6.8	69.2	27.3
169 MHz	44.30	17.5	177.4	69.8
27 MHz	277.60	109.3	1110.3	437.1

Table 1 Wavelength Calculation for different frequencies

F. Maximum Power Transfer (VSWR)

The power adoption theory states that maximum power transfer happens when the source resistance equals the load resistance, which is called power adjustment. For complex impedances, the maximum power delivered from a transmission line with impedance Z_0 to an antenna with impedance Z_a, it is important that Z_0 is properly matched to Z_a. If a signal with amplitude V_{IN} is sent in to the transmission line, only a part of the incident wave will be transmitted to the antenna if Z_0 is not properly matched to Z_a. Furthermore, the complex reflection coefficient (Γ) is defined as the ratio of the reflected waves' amplitude to the amplitude of the incident wave. The reflection coefficient is zero if the transmission line impedance is the complex conjugate of the antenna impedance. Thus if $Z_0 = Z_{a'}$ the antenna is perfectly matched to the transmission line and all the applied power is delivered to the antenna. Antenna matching typically uses both the Return Loss and the Voltage Standing Wave Ratio (VSWR) terminology.
VSWR is the ratio of the maximum output (Input + Γ) to the minimum waveform (Input – Γ),

The power ratio of the reflected to the incident wave is called Return Loss; this indicates how many dB the reflected wave power is below the incident wave.
Within antenna design, VSWR and Return Loss are a measure of how well the antenna is matched. Refer to Table 1, for the conversions between Return Loss, VSWR and percentage of power loss. When matching an antenna a VSWR of 1.5 (R_L = 14 dB) is a good match, when the VSWR is > 2.0 (R_L = 9.5 dB) then the matching network should be reviewed. VSWR of 2.0 (RL = 9.5 dB) is usually used as the acceptable match level to determine the bandwidth of the antenna. Mismatching of the antenna is one of the largest factors that reduce the total RF link budget. To avoid unnecessary mismatch losses, it is recommended to add a pi-matching network so that the antenna can always be matched. If the antenna design is adequately matched then it just takes one 0 Ohm resistor or DC block capacitor to be inserted into the matching circuit.

VSWR	Return Loss (dB)	% Power / Voltage Loss	Reflection Coefficient	Mismatch Loss (dB)
1	∞	0 / 0	0	0.000
1.15	23.1	0.49 / 7.0	0.07	.021
1.25	19.1	1.2 / 11.1	0.111	.054
1.5	14.0	4.0 / 20.0	0.200	.177
1.75	11.3	7.4 / 27.3	0.273	.336
1.9	10.0	9.6 / 31.6	0.316	.458
2.0	9.5	11.1 / 33.3	0.333	.512
2.5	7.4	18.2 / 42.9	0.429	.880
3.0	6.0	25.1 / 50.0	0.500	1.25
3.5	5.1	30.9 / 55.5	0.555	1.6
4.0	4.4	36.3 / 60.0	0.600	1.94
4.5	3.9	40.7 / 63.6	0.636	2.25
5.0	3.5	44.7 / 66.6	0.666	2.55
10	1.7	67.6 / 81.8	0.818	4.81
20	0.87	81.9 / 90.5	0.905	7.4
100	0.17	96.2 / 98.0	0.980	14.1
∞	.000	100 / 100	1.00	∞

Table 2 VSWR Chart

G. *Antenna Performance Considerations*

There are a number of things to consider when selecting the antenna:

- Antenna placement
- Ground planes for ¼ wavelength antennas
- Undesired magnetic fields on PCB
- Antenna mismatch (VSWR)
- Objects that alter or disrupt Visual Line of Sight (VLOS)
- Antenna gain characteristics
- Antenna bandwidth
- Antenna Radiation Efficiency

III. ANTENNA TYPES

There are several antenna types to choose from when deciding to develop a RF product. Size, cost and performance are the most important factors when choosing an antenna. The three most commonly used antenna types for short range devices are PCB antennas, chip antennas and wire antennas.

Antenna	Advantage	Disadvantage
PCB	• Very low cost • Good performance- at 868 MHz • Small size at high frequencies • Standard design antennas widely available	• Difficult to design small and efficient PCB antennas at < 433 MHz • Potentially large size at low frequencies
Chip	• Small size • Short development time	• Medium performance • Medium cost
Whip	• Good performance • Short development time	• High cost • Difficult to fit in many applications
Wire	• Very cheap	• Mechanical manufacturing of antenna
IP based	• Support from IP company	• High cost compared to standard free PCB antenna designs. • Similar cost to Chip

Table 3 Pros and cons of antennas

Table 3 shows the advantages and disadvantages for several antenna types. It is also common to divide antennas into single ended antennas and differential antennas. Single ended antennas are also called unbalanced antennas, while differential antennas are often called balanced antennas. Single ended antennas are fed by a signal which is referenced to ground and the characteristic input impedance for these antennas is usually 50 Ohm. Most RF measurement equipments are also referenced to 50 Ohms. Therefore, it is easy to measure the characteristic of a 50 Ohm antenna with such equipment.

However many RF IC's have differential RF ports and a transformation network is required to use a single ended antenna with these IC's. Such a network is called a balun since it transforms the signal from balanced to unbalanced configuration.

A. *PCB Antennas*

As previously mentioned under III, there are many considerations when choosing the type of antenna.

Designing a PCB antenna is not straight forward and usually a simulation tool must be used to obtain an acceptable solution. In addition to deriving an optimum design, configuring such a tool to perform accurate simulations can also be difficult and time consuming.

The following sample shows PCB antennas for the 868 MHz range.

Figure 5 Antenna on same PCB as module (Monopole)

Further sample designs can be seen in Chapter VI.

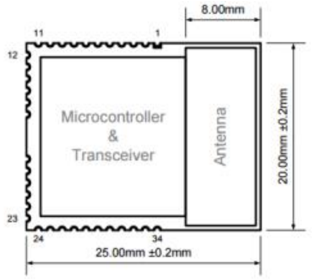

Figure 6 Integration of antenna with module

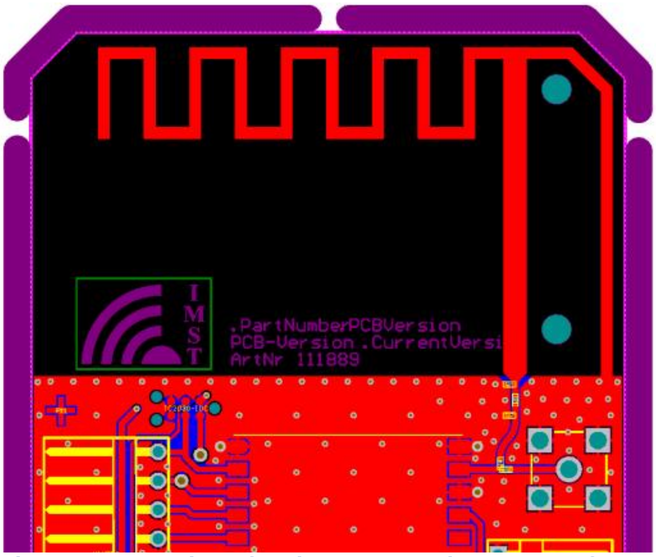

Figure 7 Integration of a Planar Inverted F-Antenna from 50 Ohms antenna foot-point of a module plus connector

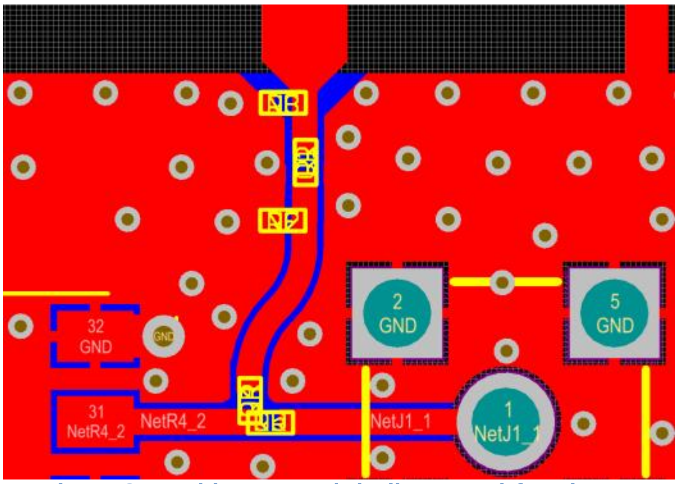

Figure 8 Matching network (yellow parts) for Planar Inverted F-Antenna from 50 Ohms antenna foot-point

If the application requires a special type of antenna (e.g. due to environmental conditions, housing or others) and none of the available designs fits the application, it could be advantageous to contact IMST for help.

B. *IP Based*

There are many IP antenna design companies that sell their antenna design competence with provided IP. Since there is no silicon or firmware involved; the only way for the antenna IP companies to protect their antenna design is through patents. Purchasing a chip antenna or purchasing an IP for the antenna design is similar since there is an external cost for the antenna design. IP based antennas are mostly designed for directional operation. An alternative to the IP solution can be a standard patch antenna or YAGI antenna, which will also give directivity but with no IP cost attached.

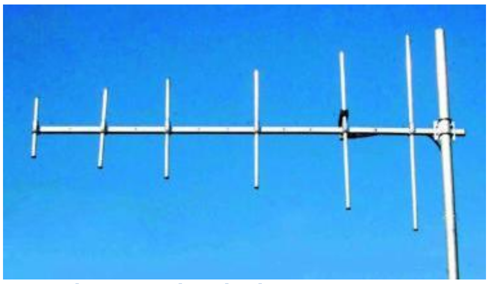

Figure 9 Classical YAGI antenna

The patch antenna mainly radiates in just one direction (one main lobe) whereas the IP Pinyon antenna has two lobes, similar to a figure eight. The YAGI antenna usually has a higher gain compared to the patch antenna and is typically larger in size, as well.

C. *Chip Antennas*

*I*f the available board space for the antenna is limited a chip antenna could be a good solution. This antenna type allows for small size solutions even for frequencies below 1 GHz. The trade off compared to PCB antennas is that this solution will add a part to the BOM and mounting cost. The typical cost of a chip antenna is between 0.10 - 0.50 EUR. Even if manufacturers of chip antennas state that the antenna is matched to 50 Ohms for a certain frequency band, it is often required to use additional matching components to obtain optimum performance. The performance numbers and recommended matching given in data sheets are often based on measurements done with a test board. The dimensions of this test board are usually documented in the data sheet. It is important to be aware that the performance and required matching will change if the chip antenna is implemented on a PCB with different size, shape and material of the ground plane.

Figure 10 Chip Antenna (Future Electronics)

D. Whip Antennas

If good performance is the most important factor, size and cost are not critical; an external antenna with a connector could be a good solution. If a connector is used then to pass the RF energy, conducted emission tests must also be performed (e.g. ETSI EN 300 220-2 for 868 ISM). The whip antenna should be mounted normally on the ground plane to obtain best performance. Whip antennas are typically more expensive than chip antennas, and will also require a connector on the board that also increases the cost. Notice that in some cases special types of connectors must be used to comply with SRD regulations.

Figure 11 Whip Antenna (getfpv.com)

E. Wire Antennas

For applications that operate in the lower bands of the sub 1-GHz-band such as 315 MHz and 433 MHz; the antenna is quite large, which can be seen in Table 1. Even when the GND plane is utilized for half of the antenna design; the overall size can be large and difficult to put onto a PCB. Here a wire can be used for the antenna, while this is formed around the mechanical housing of the application. The main advantage of such a solution is the price combined with good performance. The disadvantages are the variations of the positioning of the antenna in the mechanical housing. A standard cable can be used as an antenna if cut to the right length. The performance and radiation pattern will change depending on the position of the cable.

IV. Antenna Parameters

There are several parameters that should be considered when choosing an antenna for a wireless device. Some of the most important things to consider are how the radiation varies in the different directions around the antenna, how efficient the antenna is, the bandwidth which the antenna has the desired performance and the antenna matching for maximum power transfer. The following chapters give an overview of the most important points. In general, since all antennas require some space on the PCB, the choice of antenna is often a trade-off between cost, size and performance.

A. Radiation Patterns

Antenna specs from the majority of suppliers will reference their designs to an ideal Isotropic antenna. This is a model where the antenna is in a perfect sphere and isolated from all external influences. Most of the measurements of power are done in units of dBi where "i" refers to the condition of isotropic antenna. Power measurements for a theoretical isotropic antenna are in dBi. Dipole Antenna Power is related to an isotropic antenna by the relationship 0 dBd = 2.14 dBi. The radiation pattern is the graphical representation of the radiation properties of the antenna as a function of space. I.e. the antenna's pattern describes how the antenna radiates or receives energy into or out of space. It is common, however, to describe this 3D pattern with two planar patterns, called the principal plane patterns. These principal plane patterns can be obtained by making two slices through the 3D pattern through the maximum value of the pattern or by direct measurement.

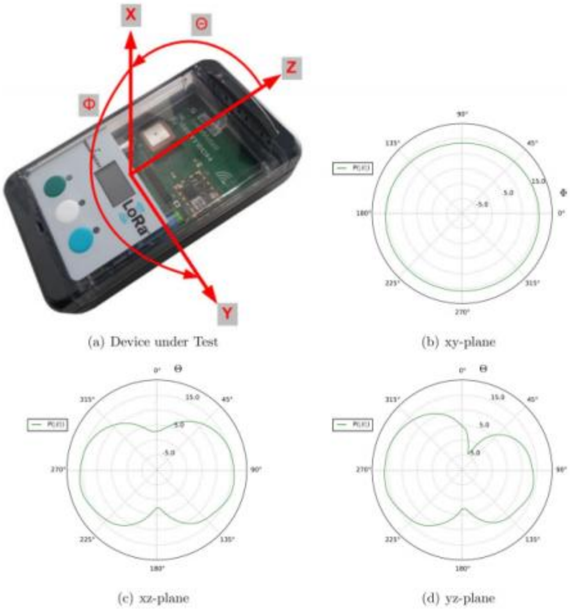

Figure 12 Antenna radiation pattern sample

It is these principal plane patterns that are commonly referred to as the antenna patterns. The antenna patterns (azimuth and elevation plane patterns) are frequently shown as plots in polar coordinates. The azimuth plane pattern is formed by slicing through the 3D pattern in the horizontal plane, the XY plane in this case. Notice that the azimuth plane pattern is directional; the antenna does not radiate its energy equally in all directions in the azimuth plane. The elevation plane pattern is formed by slicing the 3D pattern through an orthogonal plane (either the XZ plane or the YZ plane).
It is also important to be able to relate the different directions on the radiation pattern plot to the antenna. With the plots; the XYZ coordinates are usually documented with a picture of the DUT; this is required since the orientation of the DUT in the anechoic chamber usually changes depending on the physical size and the possibility to position the DUT on the turn

arm. This can be seen on top in Figure 12, showing the Mote II for LoRa from IMST.

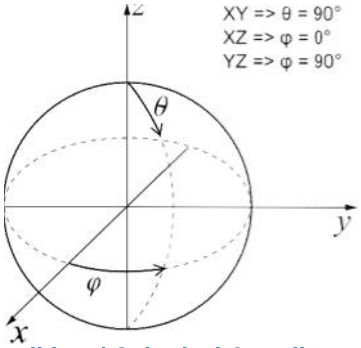

Figure 13 Traditional Spherical Coordinate System for Radiation Patterns

Figure 13 shows how to relate the spherical notation to the three planes. If no information is given on how to relate the directions on the radiation pattern plot to the positioning of the antenna, 0° is the X direction and angles increase towards Y for the XY plane. For the XZ plane, 0° is in the Z direction and angles increase towards X, and for the YZ plane, 0° is in the Z direction and angles increase towards Y.

A dipole antenna radiates its energy out toward the horizon (perpendicular to the antenna), as described in the beginning of this document. The resulting 3D pattern looks like a donut with the antenna sitting in the hole and radiating energy outward. The strongest energy is radiated outward, perpendicular to the antenna in the XY plane.

Given these antenna patterns, one can see that a dipole antenna should be mounted so that it is vertically oriented with respect to the floor or ground. This results in the maximum amount of energy radiating out into the intended coverage area. The null in the middle of the pattern will point up and down.

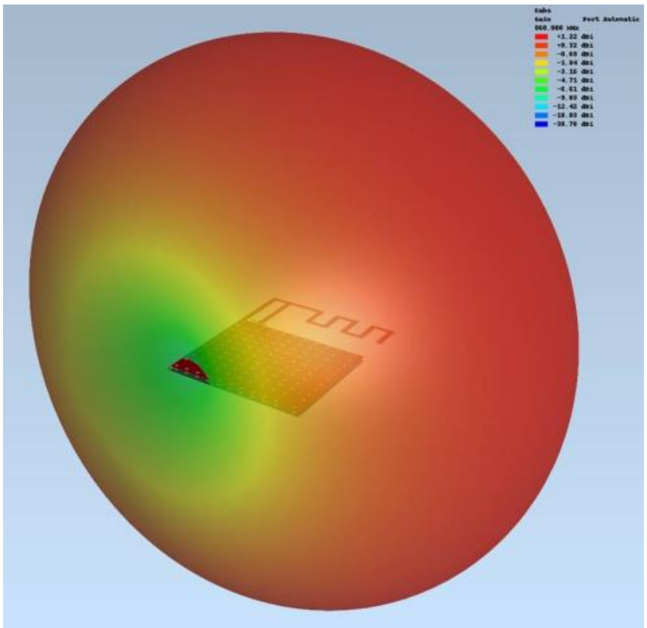

Figure 14 Simulated Antenna Radiation Pattern

Figure 14 shows the radiation from the PCB antenna, previously shown in Figure 7. It almost shows no variation in direction, but a perfect toroid. Several parameters are important to know when interpreting such a plot. With the DUT coordinate description in Figure 13 and the recorded pattern in Figure 12, the radiation pattern can be related to the DUT, which is overlaid in the given simulation. The peak signal strengths can be observed and taken into account when radiated power from a given angle. This is useful information for the positioning of the DUT when performing range tests, calculating link budgets and determining the expected range.

The gain or the reference level is usually referred to an isotropic radiating antenna which is an ideal antenna that has the same level of radiation in all directions. When such an antenna is used as a reference, the gain is given in dBi or specified as the Effective Isotropic Radiated Power (EIRP). The maximum gain is shown in Figure 14 as 1.22 dBi. The colour scale notation in the top right of Figure 14 illustrates the specific span of the gain. The lowest level is to be found at about -12 dBi.

B. Polarization

Polarization describes the direction of the electric field. All electromagnetic waves propagating in free space have electric and magnetic fields perpendicular to the direction of propagation. Usually, when considering polarization, the electric field vector is described and the magnetic field is ignored since it is perpendicular to the electric field. The receiving and transmitting antenna should have the same polarization to obtain optimum performance. Most antennas in SRD application will in practice produce a field with polarization in more than one direction. In addition reflections will change the polarization of an electric field. Polarization is therefore not as critical for indoor equipment, which experiences lots of reflections, as for equipment operating outside with VLOS. Some antennas produce an electrical field with a determined direction, it is therefore also important to know what kind of polarization was used when measuring the radiation pattern. It is also important to state at which frequency the measurement was performed. Generally, the radiation pattern does not change rapidly over frequency. Thus, it is usual to measure the radiation pattern in the middle of the frequency band in which the antenna is going to be used. For narrowband antennas the relative level could slightly change within the desired frequency band, but the shape of the radiation pattern will remain basically the same.

C. Ground Effects

The size and shape of the ground plane will affect the radiation pattern.

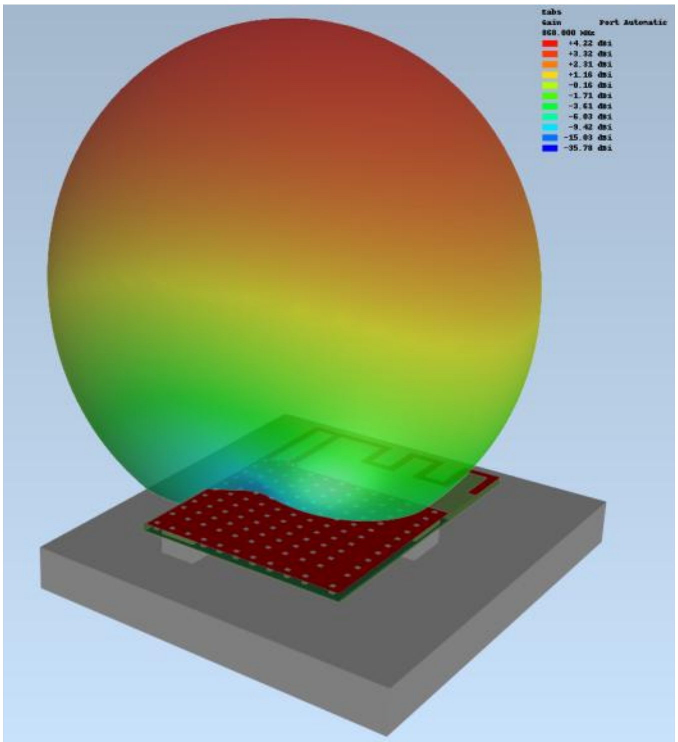

Figure 15 Simulated Antenna Radiation Pattern with GND

Figure 15 shows an example of how the ground plane affects the radiation pattern. If for example a GND plane is extended, when an antenna board is being plugged onto a base board, this has effects to the antenna match compared to using the antenna board as stand alone. The change in size and shape of the ground plane not only changes the gain but the radiation pattern. Since many SRD applications are mobile, it is not always the peak gain that is most interesting. The TRP and antenna efficiency gives a better indication on power level that is transmitted from the DUT. In Figure 15 one can see that the toroid is flattened in the bottom area, which will result in no power output in that direction.

D. Directional Antennas

High gain does not automatically mean that the antenna provides good performance. Typically for a system with mobile units it is desirable to have an omni-directional radiation pattern such that the performance will be approximately the same regardless of which direction the units are finally oriented to each other (see Figure 14 for a best-practice sample). One advantage of using a directional antenna is the reduced power-in due to the higher gain in the antenna between two devices for a given distance so that current consumption can be reduced. If that can be applied to a customer's application needs to be checked for the specific case. Another advantage is that the antenna gain can be utilized to achieve a greater range distance between two devices. However, a disadvantage of using directional antennas is that the positioning of the transmitter and receiver unit must be known in detail. If this information is not known then it is best to use a standard omni-directional antenna design.

E. Size, Cost and Performance

As an ideal antenna is hard to be found (tiny size, zero cost, excellent performance), a compromise between these parameters needs to be established. Reducing the operating frequency by a factor of two, results in doubling the effective range. Thus, one of the reasons for choosing to operate at a low frequency when designing an RF application is often the need for long range (e.g. LoRa). However, most antennas need to be larger at low frequencies in order to achieve good performance, see Table 1. In some cases where the available board space is limited, a small and efficient high frequency antenna could give the same or better range than a small and inefficient low frequency antenna. A chip antenna is a good alternative when seeking a small antenna solution. Especially for frequencies below 433 MHz, a chip antenna will give a much smaller solution compared to a traditional PCB antenna. The main draw backs with chip antennas are the increased cost and often narrow band performance.

V. Antenna Measurements

A. Measuring Characteristics with a Network analyzer

The optimum method to characterize the antenna is using a network analyzer so the parameters like Return Loss, Impedance and Bandwidth can be determined. This is done by disconnecting the antenna from the radio section and connecting (best case) a semi-rigid coax cable at the feed point of the antenna. Then the scattering parameter of an antenna can be observed. The S-parameters give an indication about the impedance or reflection for an antenna over frequency, while for the band the antenna is used in, the impedance should be lowest, resulting in power adoption. Thus, the antenna should be in resonance. To measure an antenna connected to port 1 on a network analyzer, S11 should be chosen. The measured reflection is usually displayed as S11 in dB or as VSWR See Figure 16 for an example.

Figure 16 S11 Parameter measurement with VNA

Here the optimum frequency for the measured antenna is about 760 MHz, where the minimum impedance can be seen. For 868 MHz this antenna could be designed better. This antenna was measured with housing and thus shows how the performance is affected by the plastic casing and body effects.

B. Placement of the Device under Test

How the antenna is placed during the measurement will affect the result. Therefore, the antenna should be situated in the same manner as it is going to be used in real application (see example under A), when the scattering parameters are measured. Handheld devices should also be positioned in a hand when conducting the measurement to have real life conditions. Even if the antenna is going to be used in a special environment it could also be useful to measure the antenna in free space. This will show how much body effects, plastic casing and other parameters affect the result. To get an accurate result when measuring the antenna in free space, it is important that the antenna is not placed close to other objects. Some kind of damping material could be used to support the antenna and avoid that it lies directly on a table during measurements.

C. Antenna Matching

There are several ways to tune an antenna to achieve better performance. For resonant antennas the main factor is the length. Ideally, the frequency which gives least reflection should be in the middle of the frequency band of interest. Thus, if the resonance frequency is to low, the antenna should be made shorter. If the resonance frequency is too high, the antenna length should be increased. Even if the antenna resonates at the correct frequency it might not be well matched to the correct impedance. Dependent of the antenna type there are several possibilities to obtain optimum impedance at the correct frequency.

- Size of ground plane,
- distance from antenna to ground plane,
- dimensions of antenna elements,
- feed point and
- plastic casing

are factors that mainly affect the impedance. Thus, by varying these factors it might be possible to improve the impedance match of the antenna. If varying these factors is not possible or if the performance still needs to be improved, discreet components could be used to optimize the impedance. Capacitors and inductors in series or parallel can be used to match the antenna to the desired impedance. As shown in Figure 15, the environment around the antenna has a great impact of the performance. This means that optimizing the antenna when it is not placed in the correct environment usually results in decreased performance. There are several freeware programs available for matching using Smith charts (e.g. http://www.analog.com/designtools/en/rfimpd/default.aspx)

The following picture shows, how the applied components influence the impedance.

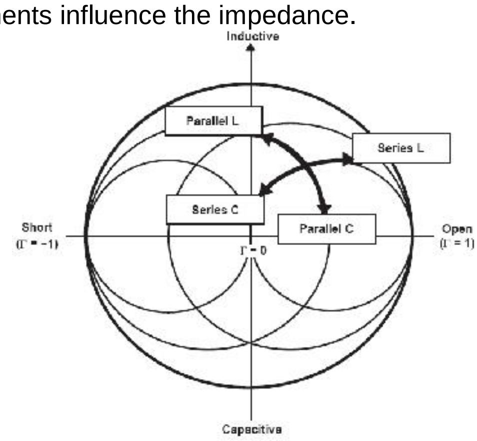

Figure 17 Smith Chart with L/C application

D. Over-The-Air (OTA) Measurements

To provide an accurate measurement of the radiation pattern, it is important to be able to measure only the direct wave from the DUT and avoid any reflecting waves affecting the result. It is therefore common to perform such measurements in an (fully-) anechoic chamber. Another requirement is that the measured signal must be a plane wave in the antenna far field.

$$R_f = \frac{2D^2}{\lambda}$$

Equation 1 Far-field equation

The far field distance (R_f) is determined by the wavelength (λ) and the largest dimension (D) of the antenna. Since the size of anechoic chambers is limited, it is common to measure large and low frequency antennas in outdoor ranges. Far Field Distance OTA testing provides a more accurate testing for wireless devices in order to be able to determine the antenna characteristics of the final product. Traditionally, the antenna radiation patterns were stated as horizontal and vertical polarizations in XY, XZ & YZ planes as shown in Figure 13. This information is still useful, but for the majority of wireless devices, the polarization and positioning is usually unknown and makes comparing antennas difficult. The testing is performed in a fully anechoic chamber and the transmitted power is recorded in a dual polarized (horizontally and vertically) antenna. The DUT is fixed onto the turn arm which is on the turn table (see Figure 18). The turn table rotates from 0 to 180 degrees and the turn arm is rotated 360 degrees so a 3D radiation diagram can illustrate the spatial distributions.

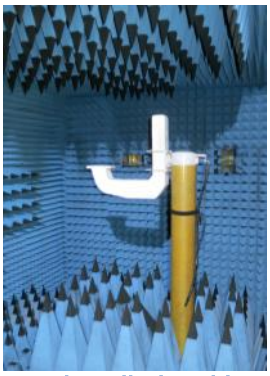

Figure 18 Test in Full Absorbing Chamber

The hardware part of this test system is based on a R&S Spectrum Analyzer, while the software is IMST developed and called DARIC (Directional Air Interface Characterization). Within the DARIC software a standard OTA report is generated from the test suite that is performed and the main results obtained are:

- Total Radiated Power, TRP (dBm)
- Peak EIRP (dBm)
- Directivity (dBi)
- Efficiency (%)
- And Gain (dBi)

The advantages of having a standard measurement suite are that two antennas can be compared and documented in an easy manner.

Total Radiated Power (TRP) is calculated by integrating the power measured for the complete rotation of the DUT.

$$TRP = \frac{1}{4\pi} \oint (EIRP_\phi(\Omega, f) + EIRP_\theta(\Omega, f))d\Omega,$$

Equation 2 TRP Equation

Effective Isotropic Radiated Power (EIRP) is the amount of power that a theoretical isotropic antenna would emit to produce the peak power density observed in the direction of maximum antenna gain and this stated in dBm. Gain is usually referred to an isotropic antenna and with the designation dBi. Directivity and Gain are angular dependent functions. Directivity is the difference from the Peak EIRP and TRP; Gain is the sum of Efficiency and Directivity, refer to Equation 3

$$Gain_{max} = \eta D_{max}$$

Equation 3 Gain

Ohmic losses in the antenna element and reflections at the feed point of the antenna determine the efficiency. It is important to state that the antenna gain is not similar to amplifier gain where there is more power generated. Antenna gain is just a measure of the antenna directivity and an antenna can only radiated the power that is delivered to the antenna. Efficiency (η) is the relation between the TRP (P_{rad}) and the input power (P_{in}) delivered to the DUT, refer to Equation 4.

$$\eta - \frac{P_{rad}}{P_{in}} * 100\%$$

Equation 4 Efficiency

This data is presented in both dB and in percentage. Efficiency can also be expressed with the relation between Gain (Gainmax) and Directivity (Dmax). Gain takes into account VSWR mismatch and energy losses.

VI. Antenna Sample Designs

The following figures show examples of typical antenna designs for the 868 MHz ISM band.

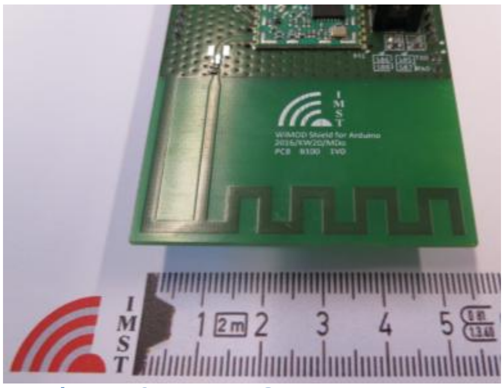

Figure 19 F-Type PCB Antenna 1

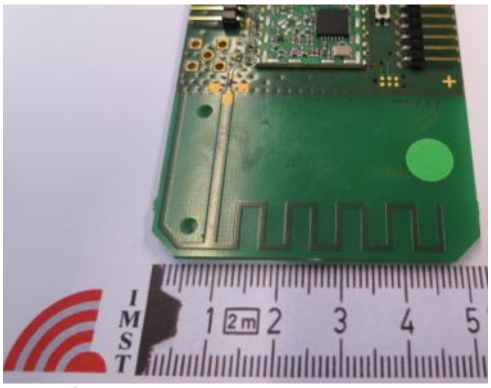

Figure 20 F-Type PCB Antenna 3

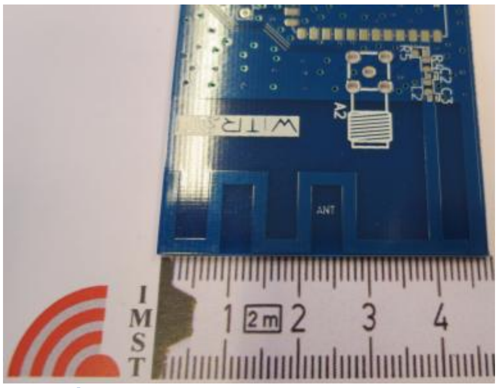

Figure 21 F-Type PCB Antenna 4

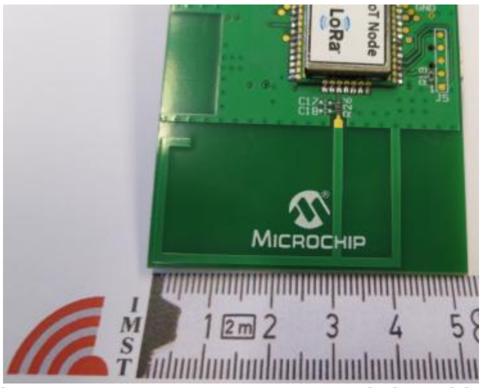

Figure 22 F-Type PCB Antenna 2 (Microchip)

If more help is needed regarding the choice of antenna and the respective integration, the reader may contact antemo@imst.de or wimod@imst.de for further help and consultant work.

VII. Acknowledgement

I would like to thank my colleagues at IMST for reading through the document and providing suggestions for what to add, for what to leave out and for what to amend to ensure a good understanding of the antenna design guideline.

VIII. References

[1] AN058 - Antenna Selection Guide (swra161b.pdf) Copyright by TI

[2] ISM Selector Guide - Semtech (www.semtech.com/images/mediacenter/collateral/ism-sg-ag.pdf).

[3] IMST Mote II for LoRa Datasheet (http://www.wireless-solutions.de/images/stories/downloads/Evaluation%20Tools/Mote_II/Mote_II_Datasheet_V1_0.pdf).

[4] LoRa End Device Radiation Performance Measurements EUV1.0 Copyright by LoRa Alliance