315 MHZ INTERNAL ANTENNA DESIGN – Considerations for EnOcean based Products

1. ABSTRACT

This guide is intended to provide a brief overview of the key considerations when selecting an antenna or looking to implement a custom antenna design. Contains additional information to STM 300C/TCM 3x0C user manuals especially for designing specific 315 MHz internal antennas; overview and specific antenna solutions are presented.

1.1. References

[1] **User Manuals:**

STM 300C http://www.enocean.com/en/enocean_modules_315mhz/stm-300c/

TCM 300C http://www.enocean.com/en/enocean_modules_315mhz/tcm-300c/

TCM 310C http://www.enocean.com/en/enocean_modules_315mhz/tcm-310c/

[2] **AN001** RANGE_PLANNING

[3] **AN007** FINAL UNIT TEST FOR RADIO PERFORMANCE

[4] **AN101** Power Supply Layout – Layout considerations for Line-Power Supplies

[5] **AN102** Basic Antenna Design Considerations for EnOcean based Products

[6] **AN103** EXTERNAL_PASSIVE_ANTENNAS

[7] **AN507** Radio Approval Of Finished Units

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1.2. Revision History

No	Major Changes
Dec. 11	Initial version

2. IMPORTANCE OF ANTENNA DESIGN

While the antenna is one of the most important aspects of RF design, it is also probably the most overlooked part of an end product. The range and performance of a wireless device are critically dependent upon its antenna. Successful antenna design is based on understanding that the entire device is part of the antenna. The primary antenna requirement must be efficiency, as the antenna acts as transducer between the radio and the environment. Unfortunately, this aspect is often neglected until the end of the design and expected that an antenna fits into whatever space is left, no matter how unfavorable to performance that location may be. As result, such designs will have to accept degraded performance or go through multiple and costly redesigns. Often such degradation is not immediately evident in a new installation, but it could appear any time in the form of "mysterious behavior" even through minor environmental changes because of insufficient link budget. Various conductive or dielectric materials in the reactive near field of the antenna (PCB, housing, wall underground of device, people and use case specifics) are unavoidable, producing a downward drift of the initial resonance frequency and impedance. Therefore optimal antenna matching must be made under typical application conditions (e.g. as use case: PCB with housing, placed on concrete respectively dry wall) in order to reach the best real compromise. The link budget is limited by allowed transmission power (e.g. by FCC or MIC regulations), receiver sensitivity, environment, noise and interferences. On the other side mostly it is required that the antenna shall be internal and small as possible. There is no ideal antenna solution for all use cases and no antenna has at the same time small dimension, high gain and large bandwidth.

Appropiate internal Antenna types, Comparison Table

Antenna	Pros	Cons
Monopole wire antenna	Standard, modular approval available, low cost, good efficiency if properly integrated, no matching needed, as PCB version reproducible and stable	Quite large at 315 MHz, not always easy to integrate.
Helical	Good efficiency, smaller, very good overall compromise for 315 MHz (size and performance)	Higher costs compared to the monopole. Narrow band, therefore easily detunable, specific matching needed. FCC device approval required with one exception, see §4.2.2.
PCB Antenna	Integrated, no additional component	Large PCB area needed at 315 MHz, environmental dependent.

3. LOCAL REQUIREMENTS

3.1. USA:

Generally, EnOcean based radio products fall under the category of RF Products for unlicensed operation. In the United States this device group is regulated under FCC (Federal Communications Commission) CFR47 Part 15:

http://edocket.access.gpo.gov/cfr_2007/octqtr/pdf/47cfr15.231.pdf.

The §15.231 regulates unlicensed transmitters in the 315 MHz band. The content of data sent defines which limits are applied to transmitters for this frequency. Two categories of intentional operation are defined:

a) Restricted to the transmission of control signals (data can be transmitted with control signal) §15.231(a). Periodic transmissions are not allowed, only with exception for security and safety applications for polling or supervision transmissions within limit of two seconds per hour.
   The field strength of fundamental wave is limited to average 6042 µV/m (75.6 dBµV/m) measured at 3 meters distance. Spurious emissions limited to average 604 µV/m (55.6 dBµV/m) §15.31(o). The limits at 315 MHz are 95.6 dBµV/m[1] for fundamental wave and 75.6 dBµV/m for unintended spurious emissions when EnOcean protocol is transmitted.

b) Any other type of operation (for example: periodic data transmission without control action) §15.231(e). Additionally the devices are limited to maximum single transmission length of one second, and the silence period should be at least 30 times the duration of the transmission, but never less than 10 seconds.
   The field strength of fundamental wave is limited to average 2417 µV/m (67.6 dBµV/m) measured at 3 meters distance. Spurious emissions limited to 241µV/m (47.6 dBµV/m). The peak limits are 87.6 dBµV/m for fundamental wave and 67.6 dBµV/m for unintended emissions.

Additionally §15.231(c) defines the bandwidth limitations. For 315 MHz transmissions, the bandwidth shall not be wider than 787 kHz (0.25% of operation frequency). Bandwidth is measured at points 20 dB down from the modulated carrier.

All EnOcean modules are within bandwidth limitations regardless to settings.

3.2. Canada:

For usage in Canada the 315 MHz EnOcean based radio modules must fulfill the requirements described in RSS-210:

http://www.ic.gc.ca/eic/site/smt-gst.nsf/vwapj/rss210-issue7.pdf/$FILE/rss210-issue7.pdf

The maximum allowed transmission power is same as for FCC regulations (95.6 dBµV/m) spurious emission limitation is the same as well. But there are some minor differences in regulations, e.g. the 99% of modulated signal bandwidth shall not exceed 0.25% of operation frequency (787 kHz). All EnOcean modules are within these bandwidth limitations regardless to settings.

[1] dBµV/m is field strength dimension, dBm power dimension. For ¼ λ wave antenna approximate conversion is 95,6 dBµV/m = -1,78 dBm

$dBm = 10\log(Watts) + 30;\ Watts = \frac{(V/m \times meters)^2}{30 \times 10^{(dBi/10)}}$; Conversion in far field $V/m = 10^{\left(((dB\mu V/m)-120)/20\right)}$;

3.3. Japan:

In the Japan 315 MHz band is governed by ARIB (Association of Radio Industries and Business) STD-T93.

http://www.arib.or.jp/english/html/overview/st_ej.html

The Transmission power is limited to 0.25 mW (-6 dBm). It is less than devices are allowed to transmit in North America. The transmission power is radiated power over antenna.

The other limitations of Japanese regulations, mostly not impacted by antenna design are:

- Spurious emissions are limited to -36 dBm below 1 GHz and to -30 dBm above 1 GHz.
- The 99% occupied bandwidth is limited to 1 MHz, but additionally upper edge shall not exceed 315.25 MHz. This limits occupied bandwidth to maximum of 500 kHz if transmitter middle frequency is exactly 315 MHz.
- transmission time control:
  - Duration of transmission and suspension for radio equipment which transmission is not periodic; duration of transmission: 5 sec or less. However, 90 sec or less for radio equipment which transmission is manually performed.
  - Periodic transmission; duration of transmission at a time: 1 sec or less duration of transmission suspension: 30 times or more of transmission duration and 10 sec or more. However in the case this radio equipment is used only to ensure a safety driving of automobiles or other vehicles.
- Additionally: the radio equipment shall be inside a case; in this case an antenna terminal is not installed and cannot be opened easily. Thus modular approval is not possible.

3.4. Other Countries:

For usage in not mentioned countries please consult local regulation authorities.

4. RECOMMENDED ANTENNA TYPES FOR 315 MHZ SHORT RANGE DEVICES

4.1. Monopole

The most simple, effective and low cost antenna is called ¼ wave monopole and is the common antenna on mobile devices (e.g. earlier generations of cell phones). Typical antenna material is a simple wire. A monopole antenna provides good overall performance and stability, has an isotropic pattern and a wide bandwidth. Antenna length is proportional to wavelength, the lower the operational frequency, the longer the antenna. At 315 MHz a ¼ wave monopole is 23.8 cm long.

The monopole can be shortened and/or bent and/or traced above the ground plane (tilted whip). With such techniques it will be more compact, but less efficient (less power will be radiated) it means working range loss. When the antenna cannot be straight and perpendicular to the ground plane the distance from antenna to conducting structures is crucial. The antenna wire shall be at least 2.5 cm (more is better) away from conducting structures and the end of the antenna (not soldered) away from GND! The wire can be made solid or flexible, recommended with insulation.

EnOcean modules with FCC modular approval typically use a 150 mm (shortened) monopole wire antenna as a compromise for easier integration. This antenna has in best case a -5 dBi gain. This is however compensated in transmitter operation by appropriate generated Tx power settings of EnOcean module. Please consult with EnOcean Application engineers.

On receiver side antenna losses cannot be compensated, unfavorable antenna layout leads to losses of working range. Special care of antenna layout shall be taken when designing a transceiver device.

The 150 mm monopole antenna is matched internal in TCM 3x0C series modules. Thus no additional matching is required. If another length whip antenna is used please consider adding matching filter. This is not covered hereby. Also note that in this case a new FCC modular approval will be required.

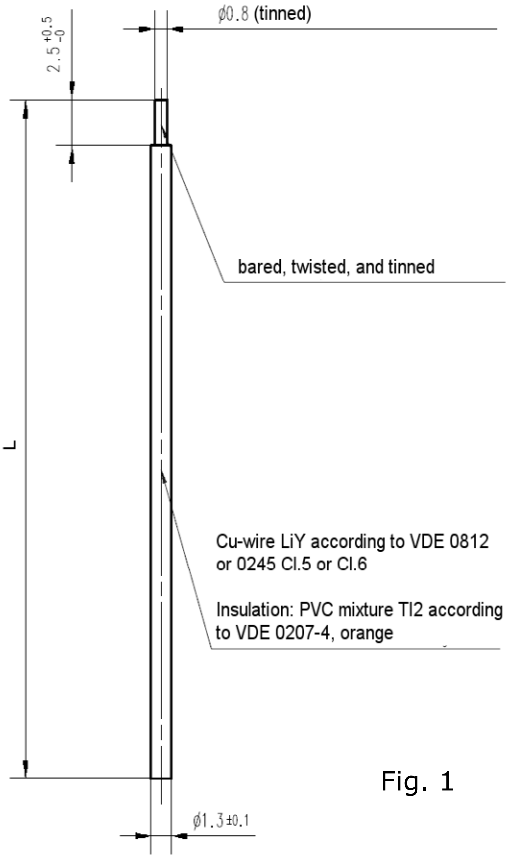

Fig. 1

EnOcean specification of used and recommended 315 MHz wire antenna (Fig. 1):

- L=150 mm @ 315 MHz
- AWG24 wire composed of 7 strands AWG32
- Material is PVC according to DIN VDE 0207
- Self-extinguishing and flame retardant according to EN 50265-2-1 / IEC 60332-1

Some adequate, more practical configurations are shown in the Fig. 2, antenna efficiency decreasing from a (better) to d (poorer), depending on the available place. The space from antenna to mounting plane (as this can be conductive) is important.

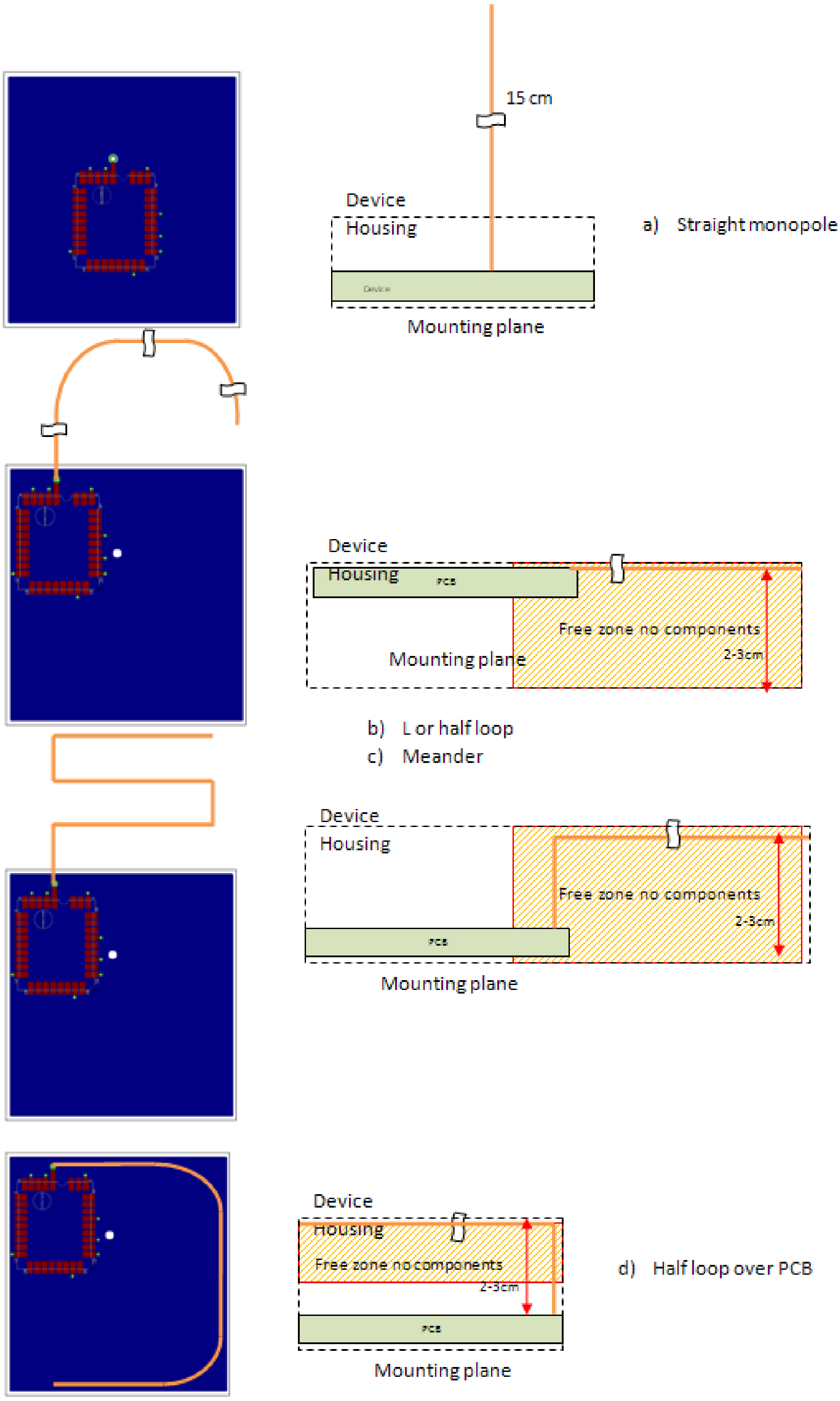
15 cm
Device
Housing
Mounting plane
a) Straight monopole
Device
Housing
PCB
Free zone no components
2-3cm
Mounting plane
b) L or half loop
c) Meander
Device
Housing
Free zone no components
2-3cm
PCB
Mounting plane
Device
Housing
Free zone no components
2-3cm
PCB
Mounting plane
d) Half loop over PCB

Fig. 2

4.2 Normal Mode Helical Antenna

A helical element is a wire coil usually wound from copper or brass. Compared to monopole, which is essentially a two-dimensional structure a helical antenna is a 3-dimensional structure but is simply a "shorter monopole". Helical antennas with physical dimensions considerably smaller than the wave length work as "normal mode helical". Their radiation pattern is similar to monopole. This provides an optimum condition for compact devices. A small helical significantly reduces the needed physical size of the antenna and that is important at longer wave; however this reduction is not without a price. Due to the helical specific higher quality factor Q, the bandwidth B is significantly narrower ($Q = F_c/B$) while the gain is as a matter of principle lower vs. a "full size" elongated ¼wave monopole.

4.2.1 EnOcean Helical (ANT 300C, Art. S3035-D300)

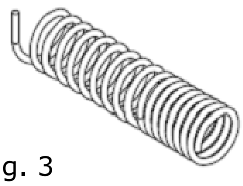

Fig. 3

The dimensions for helical antenna (Fig. 3) are 7.7 x 8.15 x 31.15 mm (WxHxL). The Helical antenna impedance depends on positioning of antenna within device. In implementation case of antenna orthogonally to TCM300C/310C antenna is matched on RF_Whip pin. In other implementation cases the modules are not directly matched with this helical antenna. Thus a matching filter has to be placed between the 50 Ω output of radio module and antenna. The impedance can be easily matched using two passive components (capacitance and inductivity, or two inductivities). Never the less it is recommended to place three components for matching filter: one in series and two parallel connected to GND. This Π filter structure is shown in Fig. 4:

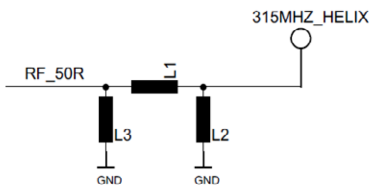

Fig. 4

Matching filter schematics

Normally L2 is not required, thus it will be positioned only in layout, but not in real assembly. L2 is needed if special antenna matching is required due to housing properties if the design rules given in following chapter cannot be fulfilled.

The matching elements for orthogonal design[2]:

Please use RF_Whip output no additional matching in this case.

The matching elements for integrated antenna design[2]:

L1 = 56 nH[3 4], L3 = 15 nH[3 4], L2 – not assembled

The given matching is in a first approximation a compromise, for best performance matching review based on measurements with network analyzer (if available) under end product use case conditions is required.

Two realization examples based on the EnOcean 315 MHz helical antenna are shown below. Blue area is one of PCB layers reserved for GND, flooded fully. Please do not place any traces in GND layer. Use four layers design, the middle layers can be used for signal traces.

[2] See next page

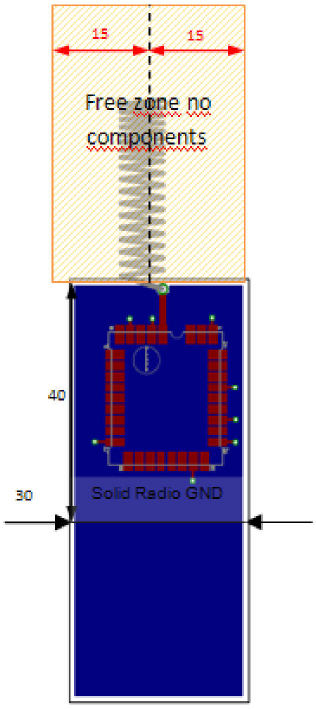

Fig. 5 Orthogonal design

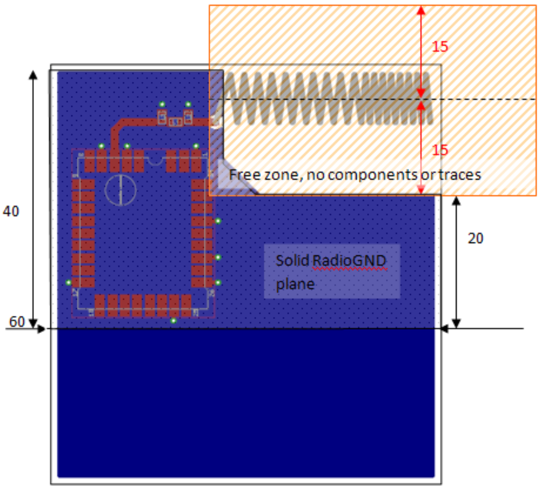

Fig. 6 Integrated design

Practically a well matched helical antenna will perform better than a bent monopole realizing best overall compromise at 315 MHz. Regarding layout recommendations please consult [4].

For good performance the distance to mounting plane should be held, especially over metallic background.

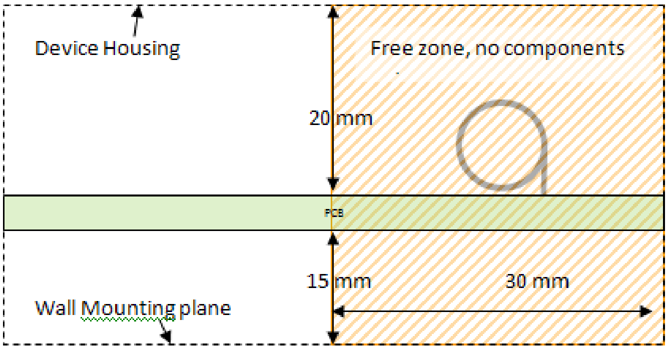

Fig. 7 Antenna positioning within housing

Important note: beside their limited bandwidth, all electrically small antennas (like e.g. helical, chip or PCB) suffer from low radiation resistance associated with a high reactance. Using correspondingly tools and experience, a matching network for a specific design can always be found to cancel the reactance and increase the input resistance to a convenient value such as 50 Ω. The antenna is then tuned at the matched frequency and specific environment. However, a matching network also has disadvantages. First, adding reactance to the whole antenna system increases the Q, thus lowering further the bandwidth and making it easier to be detuned in field. Second, loss in the matching network will also lower the efficiency.

4.2.2 Helical Antenna Module already FCC approved for STM/TCM 300C

As exception, the STM/TCM 300C modules can also be used with the antenna module **ANT_315_EO_PRO**, Fig. 8, manufacturer Vicos GmbH, A-5020 Salzburg without to need a new modular approval therefore. This is already done by Vicos.

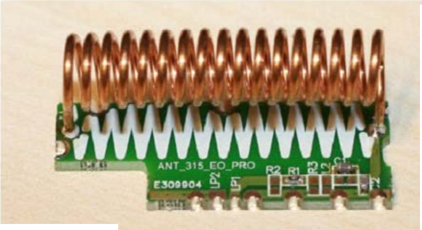

Fig. 8

- Embedded Helical (needs add. ground plane)
- Design flexibility, Drop-in solution
- Already matched for STM/TCM 300C, modular approved
- Details: **sales@vicos.at**

5. ASPECTS FOR OPTIMAL ANTENNA DESIGN

- **Antenna requires proper grounding plane.** All antennas are resonant RLC (an electrical circuit consisting of a resistor, an inductor, and a capacitor) networks and like any electronic component, have at least two connection points. IMPORTANT: Monopole, Helical, Chip or PCB antennas are in opposite with dipole, all single ended and therefore ground dependent. Therefore they must have a near and efficient ground plane to work against. Since this plane is the other half of the antenna, its size and proximity are essential for its efficiency. A compromised RF ground plane affects antenna stability, performance and resonance frequency. Please note: the required ground plane area dimension is directly proportional to the wave length; this means lower frequencies need correspondingly larger ground planes.
- **Antenna requires space** around it for optimal performance. Keep Antenna at least 25 mm from mounting plane. When the Antenna is close to device mounting surface performance degrades rapidly.
- **Antenna position**. For best performance place the antenna at the edge of device. Away from conducting materials (metal) and all the electronics on the board.
  - Please follow advice given in the antenna reference designs (Fig. 2, 5-7).
- **Antenna shape**.
  - Helical shape cannot be changed.
  - Monopole wire antenna shape can be changed.
    - The antenna bending point should be at least 25 mm from each other, please follow given advice.
    - For antenna standing over PCB keep distance between electronics at least 15 mm, recommended bigger.
- **Antenna Matching**.
  - Take special care of the RF specific layout tracking: as short as possible, and as good an approximation to a 50 Ω strip-line as you can achieve
    - 2.7 mm thick tracking on 1.6 mm FR4 board is a good start-point for microstrip 1.9 mm on 1 mm FR4 board
    - 1.1 mm thick tracking, 0.2 mm gaps on 1.6 mm FR4 board for grounded coplanar waveguide. 0.9 mm thick, 0.2 mm gaps on 1 mm FR4 board.
  - Mostly, conductive or dielectric materials in the reactive near field of the antenna are however unavoidable. In these cases, measure the antenna impedance under real application conditions and match it correspondingly. You could even realize a "defined" metallic underground in your design to reduce the later application specific environment dependency.
- **Antenna size** defines working characteristics. For antennas not discussed in this application note:
  - As a general physical rule, the antenna's efficiency is directly proportional to its volume, while the dimension of an antenna (including the ground plane) is directly related to the wavelength. The smaller the antenna volume the lower the antenna efficiency will be.

6. ADDITIONAL NOTES, SEE ALSO [5]

- Never forget, the ground plane is the other half of your antenna, more is better!
- Do not use metallic housing around antennas.
- Most problems with 315 MHz antennas usually involve its intrinsic size respectively insufficient free space around the antenna. If the available space is sufficient, use a monopole for best efficiency. Advantage: you don't need any additional FCC device approval because the STM 300C / TCM 3x0C modules already have modular approvals. If not, consider a helical alternative.
- In a small housing a well designed helical can achieve better performance than a poor shaped standard monopole while maintaining a very compact size. The helical is therefore very popular, since well designed it can provide excellent overall performance at small size.
- When using pre-manufactured antennas like e.g. helical or chip, keep in mind that their specified performance depends on the attached reference ground plane. The manufacturer's specifications are only achieved if the ground plane (including free space around!) has the same size and shape as the manufacturer's evaluation board! In all other cases, you have to measure the impedance of the pre-manufactured antenna under application conditions and to match it to the needed characteristic impedance.
- Receiver performance can be seriously degraded by interferences caused by digital circuits, switch mode power supplies, PCs or electronic ballasts. These interferences are as matter of principle stronger at lower frequencies. Always keep antennae away from such paths, e.g. try to keep digital traces short, and run them over a ground plane to help confine the electromagnetic field generated by the pulses. For more details please consult [4].
- Remark: you can never design a "too good antenna" for a receiver only, but maybe for a transmitter (transceiver)! Therefore please make sure that the final device (e.g. transmitter) still fulfils the region specific approval with respect to the radiated power
- A radio link always has <u>2 antennas</u> (transmitter and receiver). If you use any other antenna than the specified modular approval one, please consider that for best performance transmitter settings have to be optimized for each specific device (antenna) during approval procedure. The efficiency of the receiver's antenna is critical to maximize range performance. Unlike the transmitter antenna, where legal operation or energetic considerations may mandate a reduction of transmitted power, the receiver's antenna efficiency should be optimized as much as is practical possible!
  Background: for transmitters (e.g. sensors) with poor antenna efficiency a higher output transmission power could enhance the link budget, as well for a very efficient transceiver antenna (like an external antenna needed for devices unfavorably mounted behind metal shielding) a lower output transmission power would be mandatory to comply with the approval while the receiver side still fully profits from the increased antenna efficiency!
- If needed also consider using of external 50 Ω antennas if the use case or location requires/allows. TCM 300C provides 50 Ω output and TCM 320C soldering pads for an alternative SMA connector. Please note that the original whip antenna and a SMD capacitor must be removed in this case, for more details consult user manual indications and EnOcean additional appnotes [2] and [6].

7. PERFORMANCE VERIFICATION

The antenna for transmitter and receiver can be measured using the same measurement procedures due to reciprocity principle. Generally the transmission performance is easier to be measured.

7.1 Transmitter radiation pattern measurements

The transmitter radiation pattern measurements should be done with complete device. The best approach to measure device transmission pattern is to do it in reflection loss environment, which could be anechoic chamber or 3-10 m free space open air measurement place. The setup must be calibrated to perform reliable measurements. For calibration the reference transmitter, antennas are used.

The DUT must be therefore programmed to transmit Carrier Wave (CW) signal, please consult AN507 [7].

The radiation pattern measurements are done by rotating DUT 360° in several orientations, captured data is used to plot the charts.

The transmitter power should be close below allowed FCC limits, especially in the direction away mounting side.

The lowest acceptable EnOcean transmitter power should be no more than 10 dB below the maximal approved limits. In ideal case not only completely assembled device should be measured. The measurements of devices in real application environments deliver knowledge of transmitter reliability in real world. As the walls, windows or ceilings could be very difficulty fit in a low reflection location, it is recommended to test transmitter in typical application environment.

7.2 Pragmatic test

Please consult AN507 [7].

8. REGULATION COMPLIANCE / ENOCEAN SPECIFIC RADIO SETTINGS

Usually for certification testing procedure several device samples types have to be prepared:

- Devices programmed to transmit carrier signal for field strength and spurious emissions measurements. If manufactured device does not have battery holder, it should be equipped with as small as possible temporary battery for operation needs. Please keep the battery as far away as possible from antenna, as it is not part of device and the influence to radiation pattern should be minimal. Also keep the connection wires as short as possible. See below two realisation examples.
- Best you have three identical devices with 3 different radio settings, from most powerful to the less powerful and starts with the most powerful device. In case that this exceeds the compliance limits take the next one. The goal is to keep the specific final device as close as possible under the approval requirements for transmitted power. AN507 describes how the special SW containing these individual radio settings can be compiled.
- Device programmed to transmit EnOcean sub telegrams. Refer to Table 1, AN507 [7].
- Device as for field pictures (documentation).

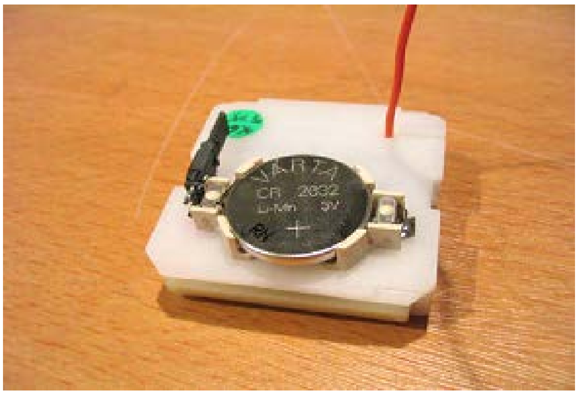

Fig. 9: DUT equipped with small battery

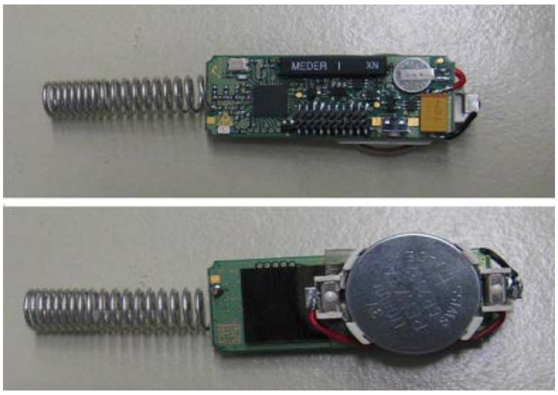

Fig. 10: DUT prepared for certification test

Disclaimer

The information provided in this document describes typical features of the EnOcean radio system and should not be misunderstood as specified operating characteristics. No liability is assumed for errors and / or omissions. We reserve the right to make changes without prior notice. For the latest documentation visit the EnOcean website at **www.enocean.com**.