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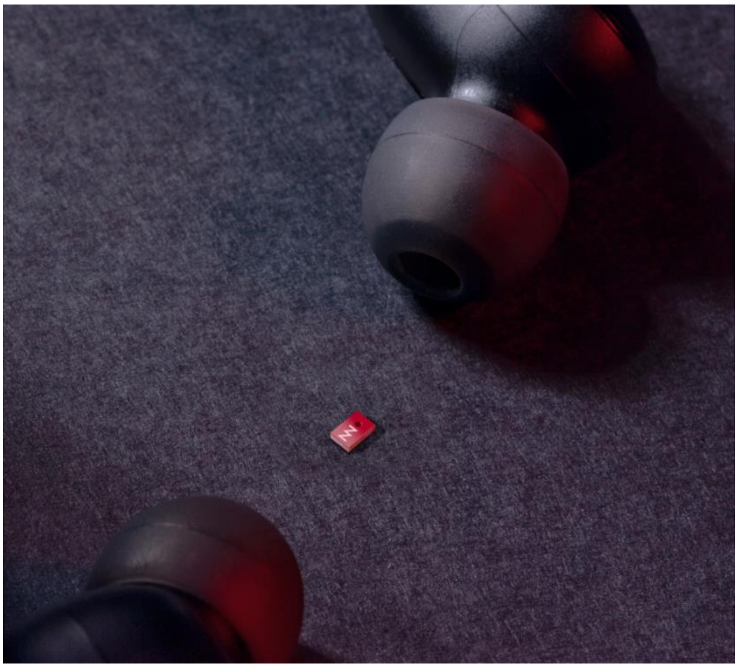
NANO mXTEND™ for wearables: A ground plane performance evaluation

APPLICATION NOTE
NANO mXTEND™ (NN02-101)

THE NANO mXTEND™, THE SMALLEST VIRTUAL ANTENNA®, EVALUATED IN DIFFERENT PCB FORM FACTORS.

- **Antenna Component**: NANO mXTEND™ (NN02-101).
- **Dimensions**: 3.0 mm x 2.0 mm x 0.8 mm.
- **Frequency regions**: 2400 - 2483 MHz.

In the rapidly evolving world of wearable technology, the importance of robust and efficient wireless communication cannot be overstated. The 2.4 GHz frequency band is widely used in wireless communication due to its global availability and compatibility with numerous communication protocols such as Bluetooth, Wi-Fi, and Zigbee.



However, designing an antenna for wearable devices operating in this frequency band presents unique challenges due to the small form factor, diverse shapes, and proximity to the human body. To address these challenges in this application note, it is shown how the NANO mXTEND™ gives **2.4 GHz connectivity to devices with many different forms, and sizes**. Including:

- Simulations in **free space**:
  - Matching network topologies and Bill of Materials.
  - VSWR & Total efficiency (%).
  - Antenna gain.
  - Radiation patterns.

- Simulations considering the **human body impact**:
  - Matching network topologies and Bill of Materials.
  - VSWR & Total efficiency (%).

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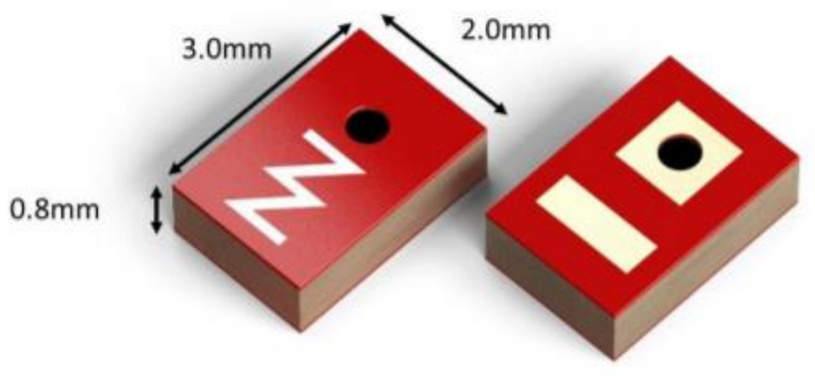
1. PRODUCT DESCRIPTION NN02-101

The NANO mXTEND™ antenna is the perfect choice for devices that are strictly limited in terms of PCB real estate and overall size. It's our product of choice when looking for a reliable and repetitive antenna solution for 2.4 GHz band. The NANO mXTEND™ is the smallest Virtual Antenna® chip to date. Featuring a size of 3 mm x 2 mm x 0.8 mm, this off-the.shelf chip antenna has been specifically designed to fit almost every IoT device from entry level to high-end products.



Material: The NANO mXTEND™ antenna booster is built on glass epoxy substrate.

APPLICATIONS

- Smartwatches
- Fitness bands
- Headsets

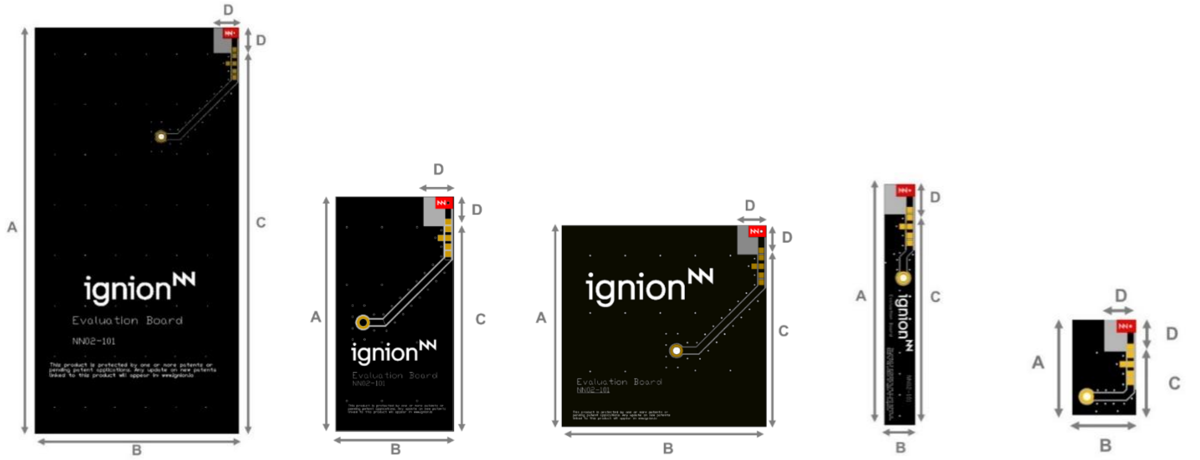
BENEFITS

- High efficiency
- Small size
- Cost-effective
- Easy-to-use (pick and place)
- Off-the-shelf standard product (no customization is required)

The NANO mXTEND™ antenna booster belongs to a new generation of antenna solutions based on the Virtual Antenna® technology developed by Ignion.

2. PERFORMANCE vs EVALUATION BOARD SIZE

2.1. EVALUATION BOARDS



80 mm x 40 mm (AxB) | **40 mm x 20 mm (AxB)** | **35 mm x 35 mm (AxB)** | **40 mm x 5 mm (AxB)** | **15 mm x 10 mm (AxB)**

D = 5 mm **C = A – D mm**

30 mm diameter (A)
7.6 mm x 4.0 mm (CxD)

15 mm diameter(A)
4.3 mm x 4.0 mm (CxD)

Figure 1 – Evaluation boards under analysis with different form factors covering 2400 MHz – 2483 MHz. Dimensions Tolerance: ±0.2 mm. The evaluation boards are built on FR4 substrate. Thickness is 1 mm.

2.2. VSWR AND EFFICIENCY

VSWR (Voltage Standing Wave Ratio) and Total Efficiency versus Frequency (GHz).

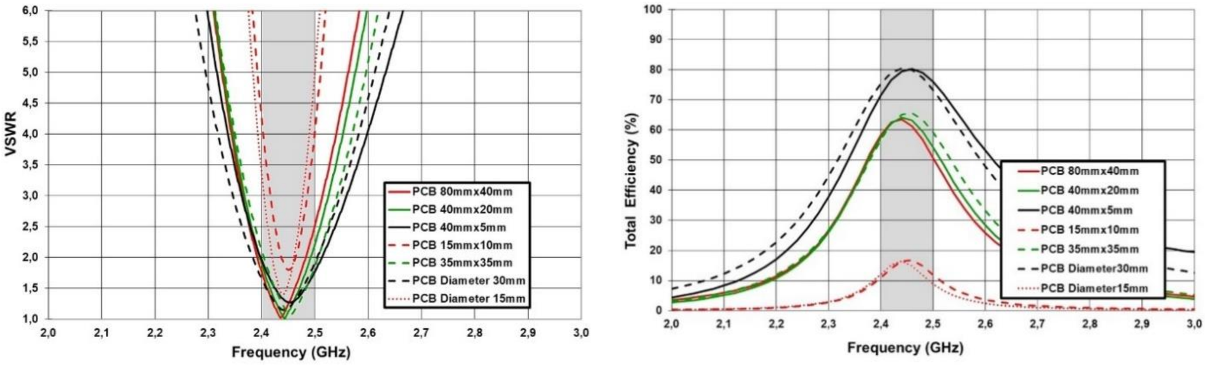


Figure 2 – VSWR and Total Efficiency for the 2400 – 2483 MHz frequency from the evaluation boards (**Figure 1**).

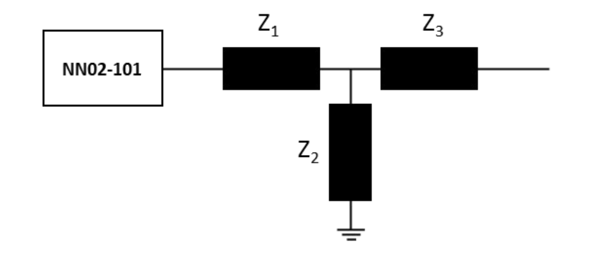
	Total Efficiency (%) 2400 – 2483 MHz				
Form Factor	**$\eta_{a\ 2400MHz}$**	**$\eta_{a\ 2483MHz}$**	**Min**	**Max**	**Av. η_a**
PCB 80 mm x 40 mm	58.4	50.9	50.9	63.5	58.9
PCB 40 mm x 20 mm	57.6	54.3	54.3	64.2	60.2
PCB 40 mm x 5 mm	71.5	76.0	71.5	80.3	77.1
PCB 15 mm x 10 mm	11.0	11.9	11.0	16.7	14.2
PCB 35 mm x 35 mm	56.8	59.3	56.8	65.6	62.0
PCB Diameter 30 mm	75.4	73.4	73.4	80.5	77.6
PCB Diameter 15 mm	12.2	8.9	8.9	16.4	13.2

Table 1 – Total efficiency (%) comparison considering the different PCB form factors (Figure 1).

2.3. MATCHING NETWORK

The NANO mXTEND™ antenna component needs a matching network to connect to your 2.4 GHz RF transceiver or module. This section presents the proposed matching networks and specifications obtained in the corresponding Evaluation Boards (**Figure 1**).

MN topology for rectangular PCB shapes	MN topology for circular PCB shapes



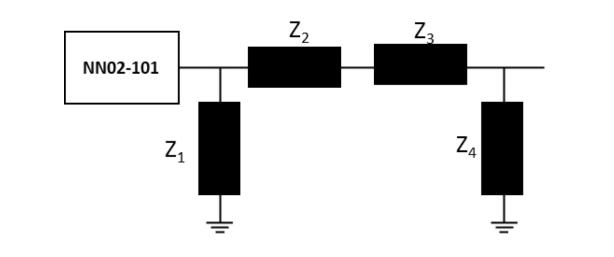


Figure 3 – Topology of matching network mounted at the solutions: PCB 80 mm x 40 mm, 40 mm x 20 mm, 40 mm x 5 mm, 15 mm x 10 mm, and 35 mm x 35 mm **on the left**. PCB Diameter 30 mm and Diameter 15 mm **on the right**.

Form Factor	Z_1	Z_2	Z_3	Z_4
PCB 80 mm x 40 mm	9.1 nH	8.7 nH	6.1 nH	-
PCB 40 mm x 20 mm	9.1 nH	8.7 nH	6.1 nH	-
PCB 40 mm x 5 mm	9.1 nH	8.7 nH	6.1 nH	-
PCB 15 mm x 10 mm	8.7 nH	8.7 nH	10 nH	-
PCB 35 mm x 35 mm	9.1 nH	8.7 nH	6.1 nH	-
PCB Diameter 30 mm	OPEN	8.7 nH	2.4 nH	1.0 pF
PCB Diameter 15 mm	OPEN	2.2 nH	18 nH	23 nH

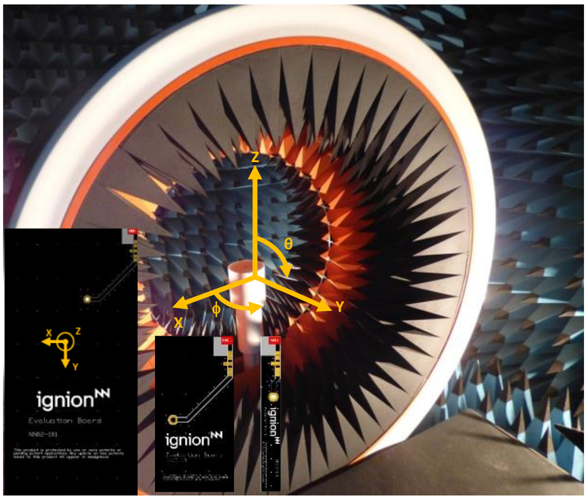
Table 2 – Values of the components for each form factor.

The antenna performance is **always conditioned by its operating environment**. Different devices with different printed circuit board sizes, components nearby the antenna, LCD's, batteries, covers, connectors, etc. may require retuning the matching network for best RF performance. Thanks to its versatility the NANO mXTEND™ antenna component **can be easily tuned for any scenario** avoiding unnecessary product redesigns each time your product specifications and operating frequencies change. Accordingly, it is highly recommended to place pads compatible with 0402 and 0603 SMD components for a matching network with high-quality factor (Q) and tight tolerance components as close as possible to the feeding point of the antenna element in the ground plane area, not in the clearance area.

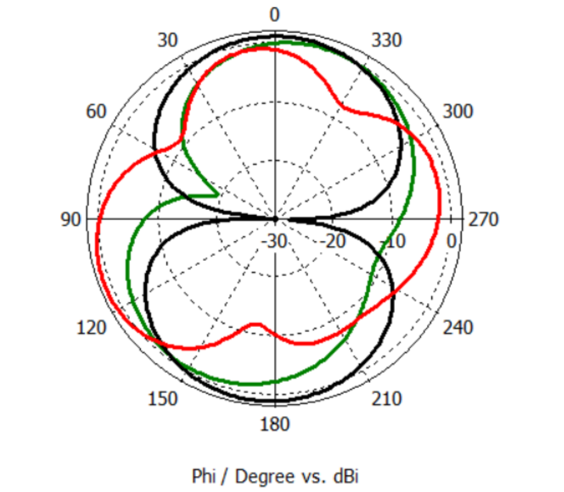
If you need assistance to design your matching network beyond this application note, please contact support@ignion.io, or if you are designing a **different device size** or a **different frequency band**, **we can assist you** in less than 24 hours. Please, try our free-of-charge[1] Antenna Intelligence Cloud™, which will get you a complete design report including a custom matching network for your device in 24h[1]. Additional information related to Ignion's range of engineering services is available at: https://ignion.io/design-center/engineering-support/.

[1] See terms and conditions for a free Antenna Intelligence Cloud™ service in 24h at: https://www.ignion.io/antenna-intelligence/

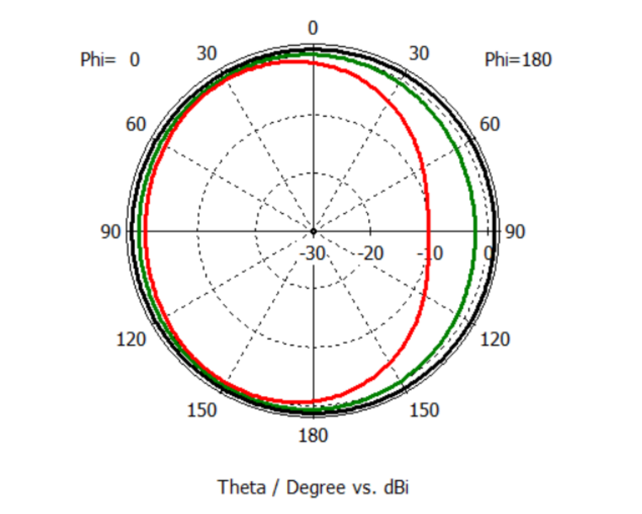
2.4. RADIATION PATTERNS (2400 - 2500 MHz), GAIN, AND EFFICIENCY



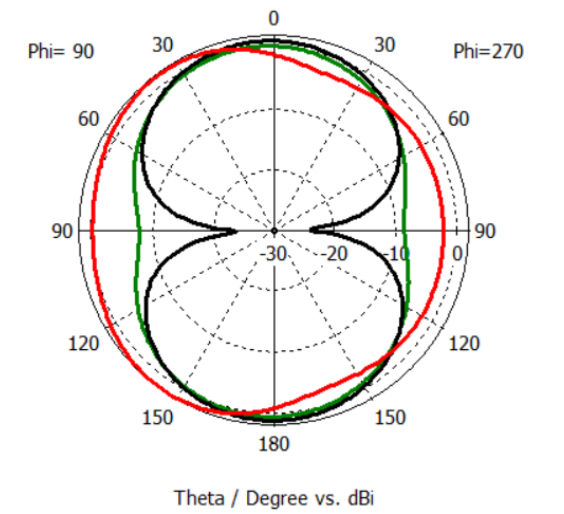
Measurement System Set-Up
Evaluation Board in Plane XY



θ = 90º Plane XY at 2.44 GHz
(80x40, 40x20, 40X5)



ϕ = 0º Plane XZ at 2.44 GHz
(80x40, 40x20, 40X5)



ϕ = 90º Plane YZ at 2.44 GHz
(80x40, 40x20, 40X5)

PCB 80x40	**Gain (dBi)**	**Peak Gain**	1.8
		Average Gain across the band	1.5
		Gain Range across the band (min, max)	0.8 – 1.8
	Efficiency (%)	**Peak Efficiency**	63.5
		Average Efficiency across the band	58.9
		Efficiency Range across the band (min, max)	50.9 – 63.5

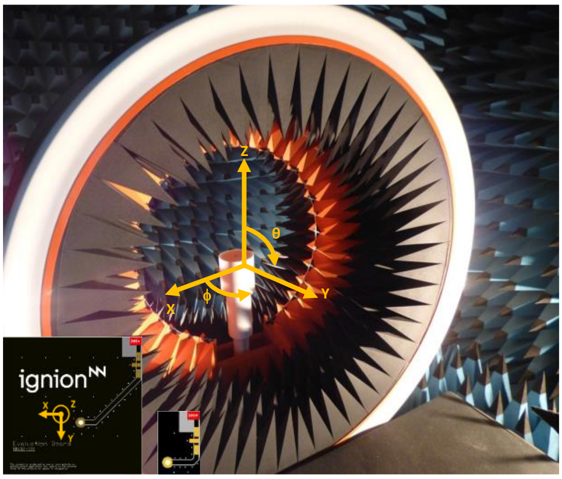
Table 3 - Antenna gain and total efficiency from the Evaluation Board of 80 mm x 40 mm. (Figure 1) for the 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.

PCB 40x20	Gain (dBi)	Peak Gain	0.6
		Average Gain across the band	0.3
		Gain Range across the band (min, max)	-0.1 – 0.6
	Efficiency (%)	Peak Efficiency	64.2
		Average Efficiency across the band	60.2
		Efficiency Range across the band (min, max)	54.3 – 64.2

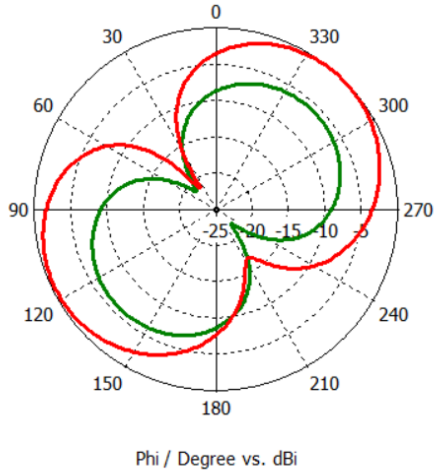
Table 4 - Antenna gain and total efficiency from the Evaluation Board of 40 mm x 20 mm. (Figure 1) for 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.

PCB 40x5	Gain (dBi)	Peak Gain	1.1
		Average Gain across the band	1.0
		Gain Range across the band (min, max)	0.6 – 1.1
	Efficiency (%)	Peak Efficiency	80.3
		Average Efficiency across the band	77.1
		Efficiency Range across the band (min, max)	71.5 – 80.3

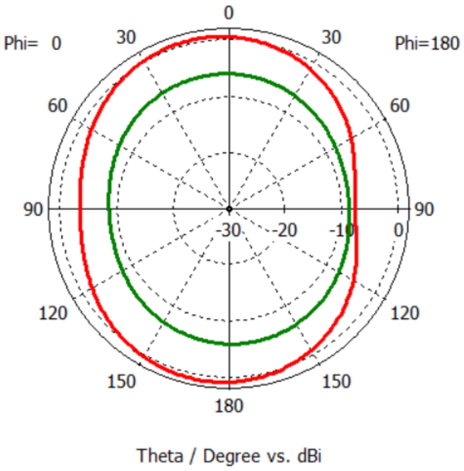
Table 5 - Antenna gain and total efficiency from the Evaluation Board of 40 mm x 5 mm (Figure 1) for the 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.



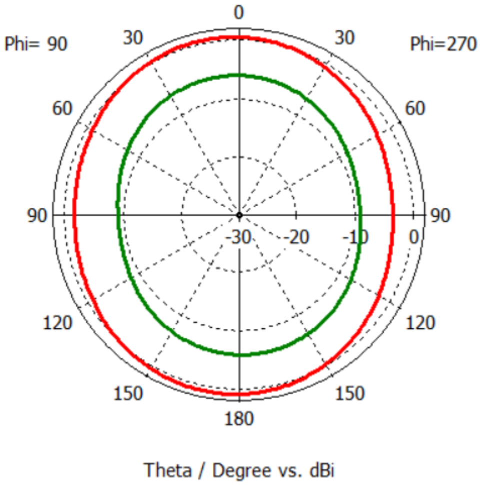
Measurement System Set-Up
Evaluation Board in Plane XY



θ = 90º Plane XY at 2.44 GHz
(35x35, 15x10)



ϕ = 0º Plane XZ at 2.44 GHz
(35x35, 15x10)



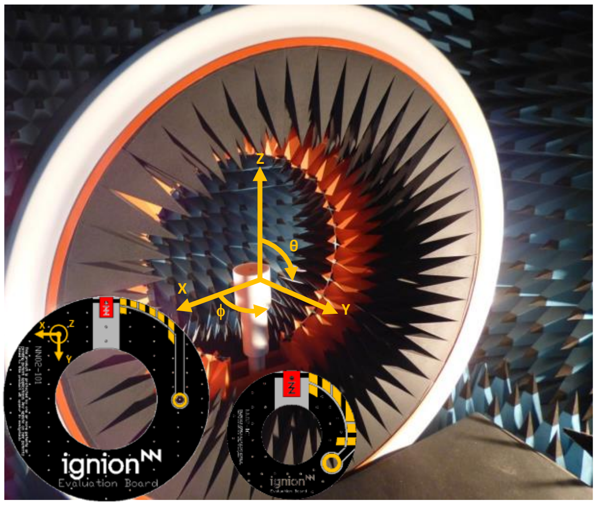
ϕ = 90º Plane YZ at 2.44 GHz
(35x35, 15x10)

PCB 35x35	Gain (dBi)	Peak Gain	0.8
		Average Gain across the band	0.6
		Gain Range across the band (min, max)	0.1– 0.8
	Efficiency (%)	Peak Efficiency	65.6
		Average Efficiency across the band	62.0
		Efficiency Range across the band (min, max)	56.8 – 65.6

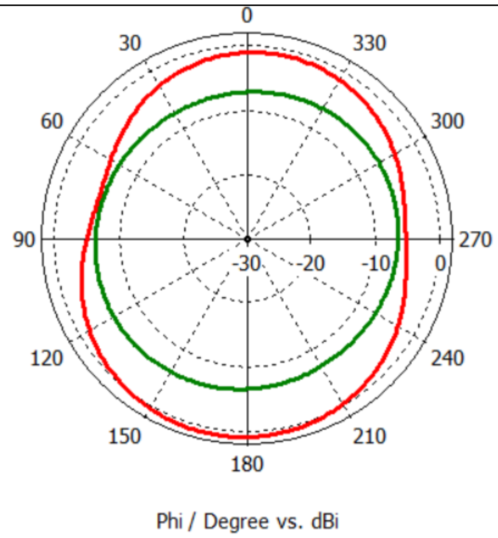
Table 6 - Antenna gain and total efficiency from the Evaluation Board of 35 mm x 35 mm (Figure 1) for the 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.

PCB 15x10	Gain (dBi)	**Peak Gain**	-6.0
		Average Gain across the band	-6.7
		Gain Range across the band (min, max)	-7.8 – -6.0
	Efficiency (%)	**Peak Efficiency**	16.7
		Average Efficiency across the band	14.2
		Efficiency Range across the band (min, max)	11.0 – 16.7

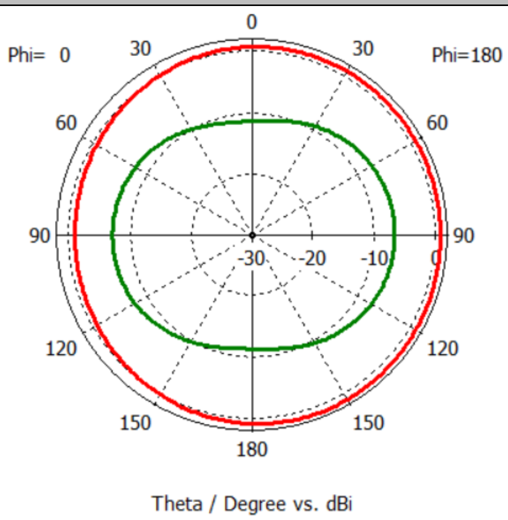
Table 7 - Antenna gain and total efficiency from the Evaluation Board of 15 mm x 10 mm. (Figure 1) for the 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.



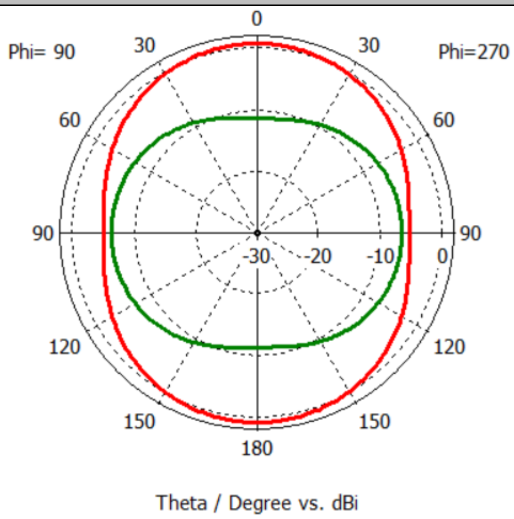
Measurement System Set-Up
Evaluation Board in Plane XY



θ = 90º Plane XY at 2.44 GHz
(Diameter30, Diameter15)



ϕ = 0º Plane XZ at 2.44 GHz
(Diameter30, Diameter15)



ϕ = 90º Plane YZ at 2.44 GHz
(Diameter30, Diameter15)

PCB Diameter 30	**Gain (dBi)**	**Peak Gain**	1.0
		Average Gain across the band	0.8
		Gain Range across the band (min, max)	0.6 – 1.0
	Efficiency (%)	**Peak Efficiency**	80.5
		Average Efficiency across the band	77.6
		Efficiency Range across the band (min, max)	73.4 – 80.5

Table 8 - Antenna gain and total efficiency from the Evaluation Board of diameter 30 mm (Figure 1) for the 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.

PCB Diameter 15	**Gain (dBi)**	**Peak Gain**	-6.0
		Average Gain across the band	-7.0
		Gain Range across the band (min, max)	-8.7 – -6.0
	Efficiency (%)	**Peak Efficiency**	16.4
		Average Efficiency across the band	13.2
		Efficiency Range across the band (min, max)	13.2 – 16.4

Table 9 - Antenna gain and total efficiency from the Evaluation Board of diameter 15 mm (Figure 1) for the 2.4 GHz band (2400 MHz – 2483 MHz). Simulated results obtained with CST.

3. INFLUENCE OF BODY ON PERFORMANCE

These form factors are found in wearable devices like earphones, tags, chest straps, and smartwatches that are very close to the human body. This section aims to analyze the human body's impact on the antenna performance and evaluate their feasibility by using body phantom models of CST (Figure 4 - Figure 7).

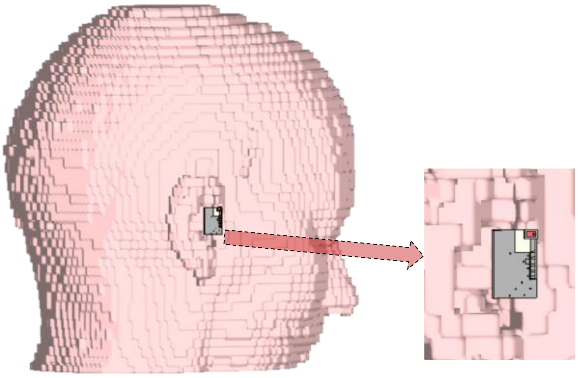


Figure 4 – PCB of 15 mm x 10 mm next to ear (earphones).

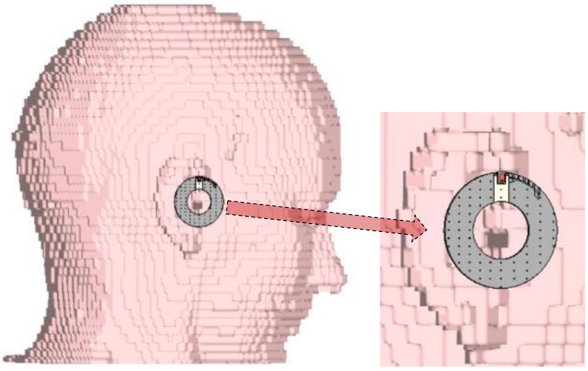


Figure 5 - PCB of 30 mm of diameter next to ear (headphones).

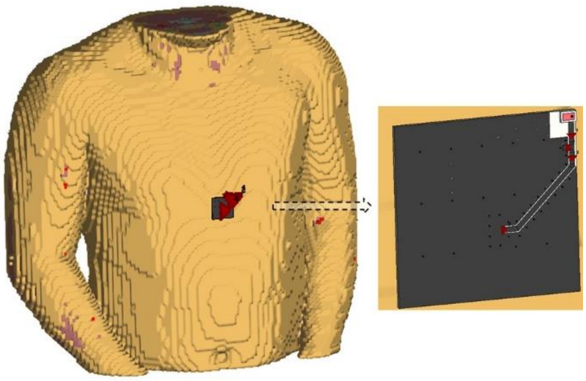


Figure 6 – PCB of 35 mm x 35 mm next to chest (chest strap Bluetooth).

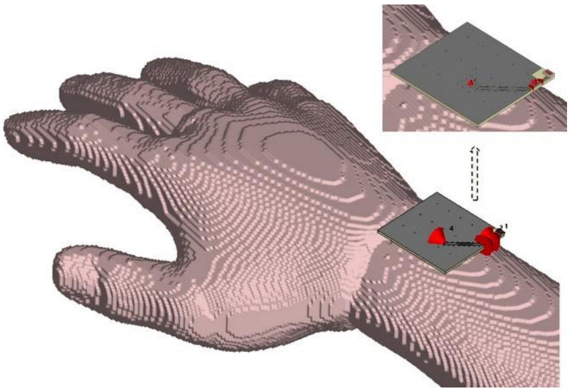


Figure 7 - PCB of 35 mm x 35 mm as a wristband (smartwatch).

3.1. MATCHING NETWORK

The body's presence may cause antenna response shifts from the free space solution. Thanks to its versatility the NANO mXTEND™ antenna component **can be easily tuned for any scenario** (2400 MHz – 2483 MHz). Nevertheless, observe that the matching network topology does not change in any case.

MN for PCB 15 mm x 10 mm (earphones), 35 mm x 35 mm (chest strap Bluetooth)

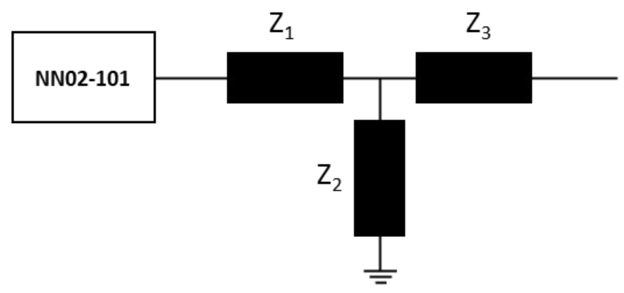


Figure 8 - Topology of matching network mounted at the solutions: PCB 15 mm x 10 mm (earphones) and 35 mm x 35 mm (chest strap).

MN for PCB Diameter 30 mm (headphones) and Diameter 15 mm (smartwatches)

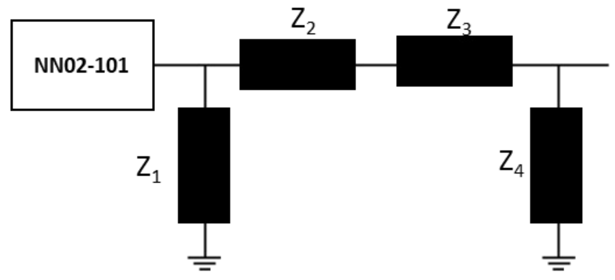


Figure 9 - Topology of matching network mounted at the solutions: PCB 30 mm of diameter (headphones) and diameter 15 mm (smartwatches).

Form Factor	Z_1	Z_2	Z_3	Z_4
PCB 15 mm x 10 mm (earphones)	8.7 nH	8.7 nH	9.5 nH	-
PCB 35 mm x 35 mm (chest strap)	9.5 nH	8.7 nH	5.5 nH	-
PCB 35 mm x 35 mm (smartwatch)	9.1 nH	8.7 nH	7.5 nH	-
PCB Diameter 30 mm (headphones)	Open	6.1 nH	2.6 nH	0.6 pF

Table 10 - Values of the components for each form factor.

3.2. VSWR AND EFFICIENCY

This section shows the VSWR (Voltage Standing Wave Ratio) and Total Efficiency versus Frequency (GHz) considering the presence of the human body for different form factors. The presence of the body highly affects antenna performance and is strictly related to the distance between the body and the PCB. In this case, the distance between PCBs and different body parts is around 2 - 3 mm. The closer they are the higher the drop of performance is.

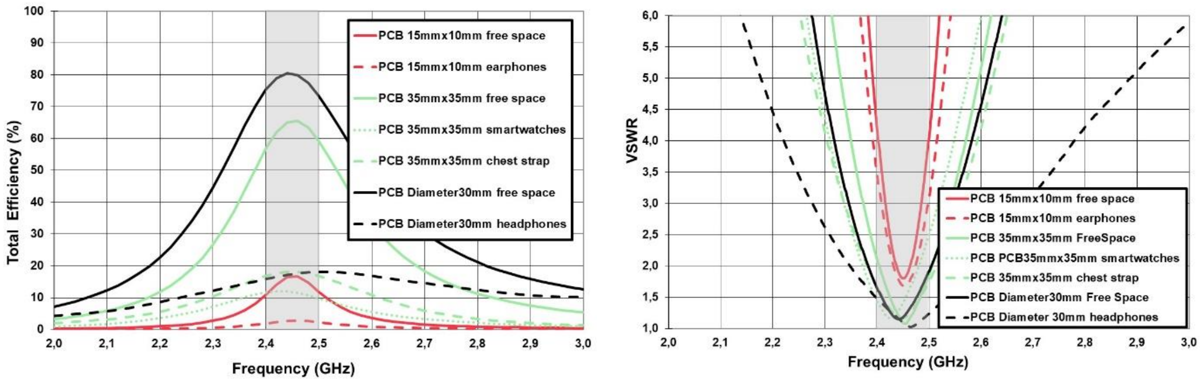


Figure 10 - VSWR and Total Efficiency for the 2400 – 2483 MHz frequency from the evaluation boards (Figure 4 - Figure 7) in FS and with presence of body.

For in-depth information on how the human body and other materials in your device's vicinity can impact its performance, please refer to our comprehensive design guide available for asset tracking: https://ignion.io/files/DG_Asset-Tracking.pdf. The PCB is positioned at distances of 20 mm and 0 mm from wood, body phantom, and metal surfaces.

4. ANNEX: BILL OF MATERIALS USED

4.1. Bill of Materials used for boards in free space.

Value		Part Number
Z1	9.1 nH	LQW18AN9N1G80
	8.7 nH	LQW18AN8N7G80
Z2	8.7 nH	LQW18AN8N7G80
	2.2 nH	LQW18AN2N2C80
Z3	6.1 nH	LQW15AN6N1G80
	10 nH	LQW18AN10NG80
	2.4 nH	LQW18AN2N4C80
	18 nH	LQW18AN18NG80
Z4	1.0 pF	GJM1555C1H1R0WB01
	23 nH	LQW18AN23NG80

Table 11 – Values and part numbers of the components used in the matching networks for the different form factors PCBs in free space (Table 2).

4.1. Bill of Materials used for boards considering human body impact.

Value		Part Number
Z1	8.7 nH	LQW18AN8N7G80
	9.5 nH	LQW18AN9N5G80
	9.1 nH	LQW18AN9N1G80
Z2	8.7 nH	LQW18AN8N7G80
	6.1 nH	LQW15AN6N1G80
Z3	9.5 nH	LQW18AN9N5G80
	5.5 nH	LQW18AN5N5G80
	7.5 nH	LQW18AN7N5G80
	2.6 nH	LQW15AN2N6G80
Z4	0.6 pF	GJM1555C1HR60WB01

Table 12 - Values and part numbers of the components used in the matching networks for the different form factors PCBs considering the human body impact (Table 10).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 674491

Ignion products are protected by Ignion patents.

Ignion is an ISO 9001:2015 certified company. All our antennas are lead-free and RoHS compliant.

ISO 9001: 2015 Certified

RoHS 2002/95/EC

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