Finally, One Size Fits All

THE fast pace, ever changing evolution of the wireless industry puts an enormous time-to-market pressure on the engineering of every new mobile device. Being in the heart of every mobile product, the design of the RF front-end and in particular, the antenna, becomes specially cumbersome as every product currently requires a fully customized antenna. The new Virtual Antenna™ technology has been conceived to address this particular issue, proposing a new standard antenna element, the miniature mXTEND™ Antenna Booster, to virtually replace every customized antenna in virtually every mobile product (Fig. 1).

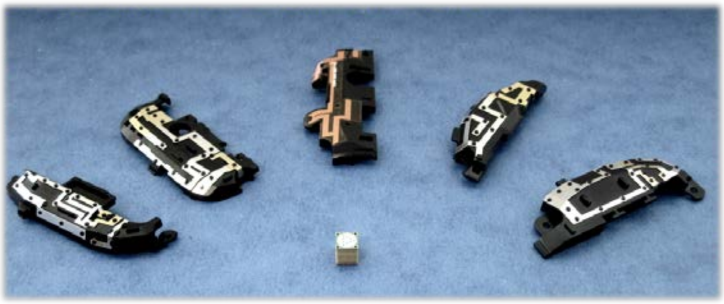


Fig. 1 The mXTEND™ Antenna Booster (center) can replace multiple customized mobile antennas (around) across multiple products.

Handset antennas have significantly evolved from the original external antennas covering one or two bands to internal antennas featuring multiple bands enabling smartphones to operate in 2G, 3G, and 4G standards in multiple regions of the world (Fig. 2).

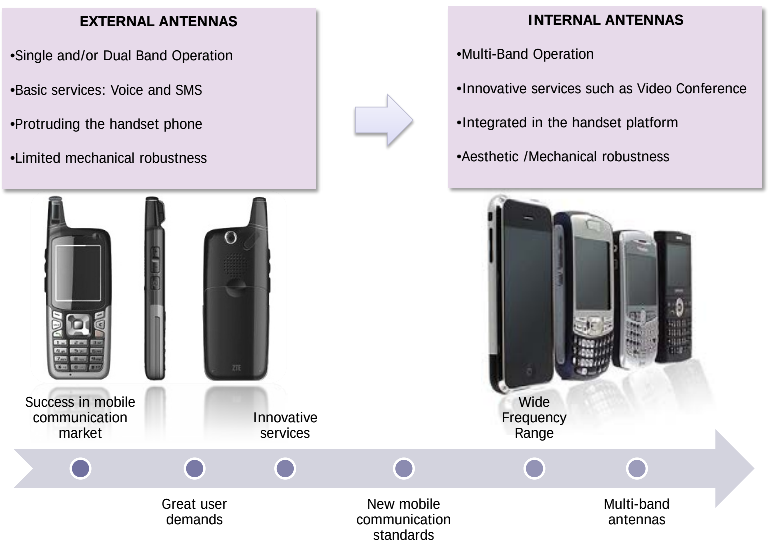


Fig. 2 Handset evolution from external antennas to internal antennas

The Challenge

The appearance of new mobile bands and smart antenna technologies, such as LTE and MIMO, adds additional challenges to the integration of conventional antenna solutions inside handset platforms:

- **Increased number of mobile antennas** inside the handset platform
- **Additional frequency bands** for new 4G standards
- **Interaction with other antennas** such as those intended for Wi-Fi and GPS
- **More discrete RF front-end components**, such as matching networks, multiplexers, power amplifiers, quad-core processors, etc.
- **Handset platforms** with **strict constraints** in terms of **size**, **weight**, **profile**, and **energy** consumption

The market pressure is currently focused on demanding handset devices capable of supporting sophisticated services requiring considerable high quality, high data rates, such as video on demand, video streaming, video conference, voice over IP, etc. The integration of all these services and functionalities inside current handset platforms featured by strict constraints in terms of size, weight, profile, and energy consumption increases the challenges for antenna engineers.

> *Current mobile platforms integrate a* ***customized antenna design*** *in* ***each handset product****. This considerably increases the complexity in all the stages that form the product design cycle. This results a* ***slow down of the time-to-market*** *while* ***increasing both design and manufacturing costs***

Following the state-of-the-art approach in handset antenna design, the complexity of the antenna solution increases together with an increase in the number of operating frequency bands. Generally, the larger the number of operating bands the greater the dimensions of the antenna and its geometrical complexity. The current technological trend has been precisely to take advantage of geometrical complexity to optimize the size and performance of every antenna in every single mobile device [1]-[2]. In general terms, the greater the number of bands, the greater antenna complexity to pack all radio wavelengths in the available space inside the mobile platform.

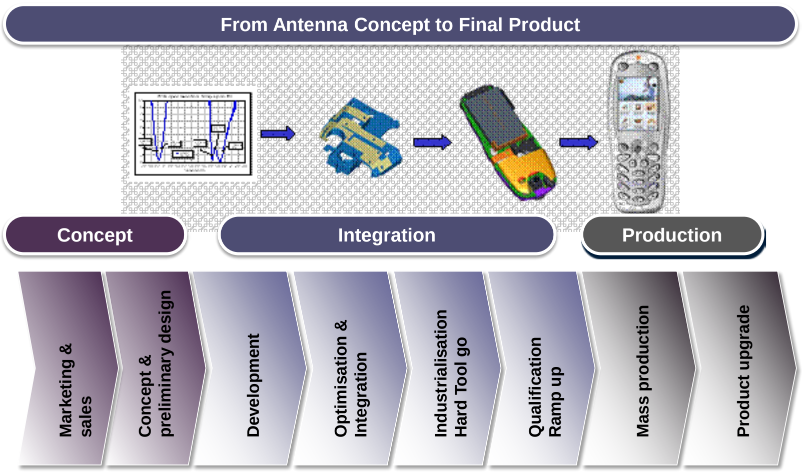


Fig. 3 Mobile product design cycle: the handset and the antenna are co-engineered in a cumbersome iterative process.

Advantages …

- **Flexible**

Modular and adaptive design since the same product can be used to cover different frequency regions

- **Versatility and scalability**

Easily adaptable to the customers' needs. The customer can elect the operating frequency bands without requiring the customization of the product

- **Passive**

Completely passive, thus preserving the duration of the battery

- **Simplicity**

Simplifies handset Front End Modules (FEMs) complexity

- **Pick and Place**

Simplifies assembly process and increase production rates

Such a design approach is subject to the well-known physical limit in the performance of small antennas [3]. A well-known fundamental principle in antenna design is that an antenna must keep a minimum size relative to the longest operating wavelength to radiate efficiently. Beyond a certain size limit, a further antenna reduction results in a rapidly decreasing bandwidth and efficiency. It is known that an antenna enters into the ‘small antenna’ regime when its overall size is smaller than λ/π. In a mobile system and considering a longest operating wavelength at a frequency of 824 MHz, such a limit is around 120mm, right about twice the top edge of a mobile phone where the antenna is usually located. Following this thought, this means that about every modern mobile phone antenna, even those integrated in current large smartphones, operates well within the small antenna regime and it is therefore understood to be subject to the bandwidth and efficiency constraints of small antennas. In other words, to further reduce the antenna size an antenna engineer needs to face overcoming a fundamental wall that has constrained antenna evolution for decades.

Besides those fundamental limits, other practical constraints introduce additional hurdles when integrating an antenna into a mobile platform. For instance, the performance of a handset antenna solution is strongly conditioned by the architecture of the handset platform and the components integrated thereof, such as battery, display, shieldings, covers, and alike. When customizing the antenna inside the phone, the antenna engineer needs to bear in mind not only the bands, bandwidth, size, and efficiency constraints inherent to the design of every antenna, but the co-existence of all those neighboring elements that might interact with antenna near fields. This results in an iterative design, integration, and optimization processes, which supposes a time-consuming and costly approach (Fig. 3).

Fig. 4 Fifteen years of handset antenna evolution. A first dual-band internal antenna (left) obtained by grouping two antennas into a conjoined antenna set (year 1999); a state-of-the-art antenna (center) taking benefit of complexity to optimize the packaging of five frequency bands (year 2011); the mXTEND™ Antenna Booster replacing both (right) (year 2013).

The Virtual Antenna™ solution aims to throw some light into this landscape by simplifying the design process while reducing the time-to-market and cost of the final mobile product. Fractus Antennas solution based on the mXTEND™ antenna booster is capable of replacing conventional handset antennas of large dimensions by miniature and off-the-shelf, standard mobile antenna components. The solution can be effectively standardized across multiple handsets sharing the same platform while featuring different form factors. The proposal has been specially thought to simplify the migration process from 3G to 4G, and it becomes a radical step forward in the evolution of handset engineering (Fig.4).

Virtual Antenna™ Technology

__Fractus Virtual Antenna™ technology__ is born with the aim of replacing customized handset antenna solutions of considerable dimensions, by __miniature__ and __off-the-shelf__ elements capable of __simplifying__ the __migration__ of current __handset platforms from 3G to 4G__

The proposed Virtual Antenna™ technology breaks away from the original way of designing handset antennas. Typically, mobile antenna solutions are designed in such a way that a single antenna element is intended to provide multiband performance. It means that multiple operating wavelengths must be packed into this single element, thus leading to complex antenna geometries and considerable dimensions. The complexity of these solutions increases together with the increasing number of operating frequency bands and the decreasing size of the antenna element. **How come Fractus' antenna booster, featuring a size which is typically x10 times smaller than a customized antenna can replace current state-of-the-art technology?** A key aspect of the technology relies on optimizing the radiation commonly obtained through the ground plane and other conductive elements already inherent in any handset platform. Thanks to this optimization the size of the antenna elements can be significantly reduced while obtaining a suitable electromagnetic performance for a wide range of wireless device platforms [4]-[20].

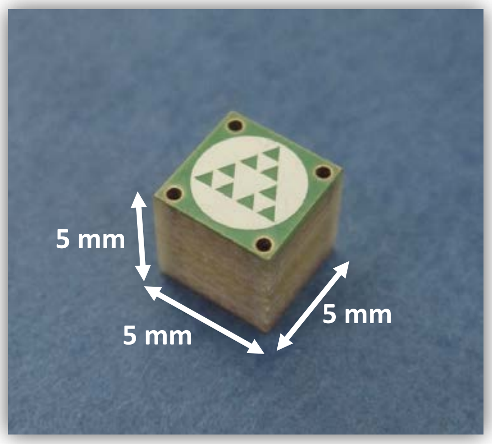


Fig. 5 Detailed view of the mXTEND™ Antenna Booster (Part Number: FR01-S4-250) emphasizing its reduced dimensions of just 125 mm^3.

Current handset antenna solutions are commonly connected to a Front End Module (FEM) through a single input/output port. This fact increases the matching network and FEM complexity. In particular, more sophisticated matching networks, filtering, and power amplifier stages are required to split and process each frequency band separately, which increases the complexity, losses, and costs of the overall system. In addition, the Printed Circuit Board (PCB) space is becoming one of the most precious and contested real state in the mobile landscape of nowadays. Therefore, any solution capable of minimizing the required PCB space while simplifying the electronics becomes attractive. The Virtual Antenna™ technology combines one or more mXTEND™ antenna boosters with one or more specifically designed matching network to provide multi-port or single port antenna front-end that seamlessly matches the RF circuitry of the mobile front-end.

mXTEND™ Antenna Booster

The mXTEND™ Antenna Booster is a miniature and standard product specially designed to provide operation in mobile bands. It is a surface-mount device (SMD) that can be directly placed onto the PCB trough pick and place machines [11]. The use of SMD technology and pick and place machines directly leads to significant advantages in terms of manufacturing and costs. The size of the mXTEND™ Antenna Booster has been reduced in an order of magnitude (x10) with respect to other current state of the art solutions (Fig. 5). The product is not only capable of operating current mobile bands (GSM850, GSM900, GSM1800, GSM1900, and UMTS…), but also to upgrade the bands to LTE and follow-up generations (LTE700, LTE2100, LTE2300, LTE2500...).

Evaluation Board

The electromagnetic performance of the solution is tested regarding an evaluation board (Part Number: EB_FR01-S4-250-UFL2[1]) having the typical dimensions to those associated to current smartphones (120 mm length and 60 mm width). The evaluation board is built on 1 mm thick FR4 substrate. In this design, two mXTEND™ Antenna Boosters are respectively placed at the corners of a transversal edge of the evaluation board. Each booster is intended to provide operation in a particular frequency region. In this sense, each booster is connected to a matching network particularly designed to cover on one hand, the low frequency region (824-960MHz) comprising the communication standards (GSM850 and GSM900), and on the other hand the high frequency region (1710-2690MHz) including the communication standards (GSM1800/DCS, GSM1900/PCS, UMTS, LTE2100, LTE2300, and LTE2500). The solution is capable of providing hepta-band operation through miniature elements occupying a volume of just 250 mm^3 (Fig. 6).

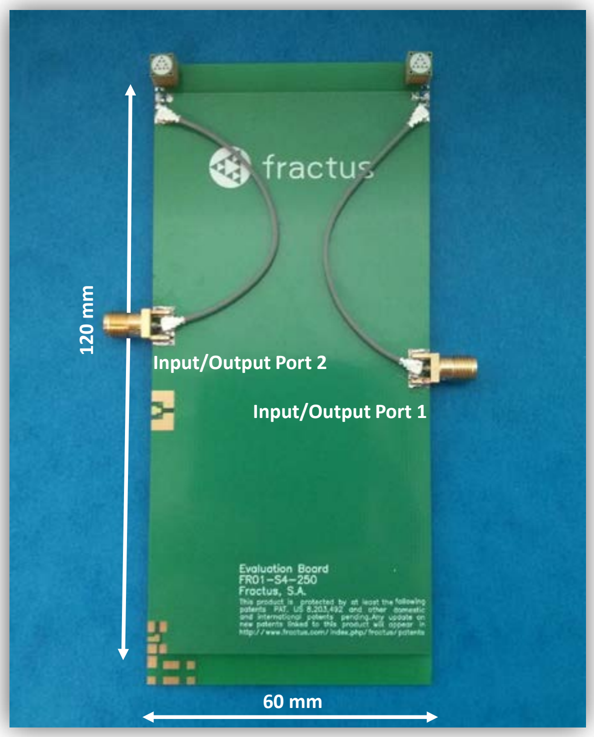


Fig. 6 Evaluation Board (Part Number: EB_FR01-S4-250-UFL2R) integrating two mXTEND™ Antenna Boosters (Part Number: FR01-S4-250).

Matching Network

Flexibility in choosing the operating frequencies: from ***single band up to hepta-band operation*** *without requiring the customization of the* ***mXTEND™ Antenna Booster****, just a matching network adjustment*

The matching network for the low frequency region comprises a series inductor, a broadband mechanism [4]-[5], [12]-[13], [21] comprising a parallel resonator, and a fine tuning stage formed by a series capacitor (Fig. 7). On the other hand, the matching network for the high frequency region consists in a "T" matching network comprising a series inductor, a shunt inductor, and a series capacitor[2] (Fig. 8). In this case, the evaluation board further includes two UFL [3] cables to connect each mXTEND™ Antenna Booster to each SMA connector. Thus, a two port solution is obtained (Fig. 6).

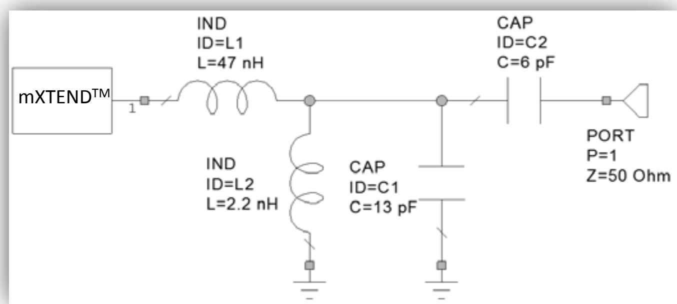


Fig. 7 Matching network designed to cover the low frequency region (824-960MHz). The components are SMD 0402 commercially available.

One of the advantages of this two port solution with respect to current single input/output port designs mainly relies on the simplification of the matching network and the Front End Module (FEM). In this solution, no additional matching network or filtering stages are required to merge a two input/output port solution into a single port solution. Accordingly, the number of reactive elements required is minimized, and with them, complexity and ohmic losses. Furthermore, since the two operating regions, low and high frequency region, are not merged into a single input/output port, there is no need to split them with multiplexers. In this way, the number of filtering stages in the FEM is also reduced and consequently, losses and complexity are again minimized. Nevertheless and with the aim of providing adaptive solutions to each customer needs, Fractus also provides a merged solution for those designs requiring a single input/output port. Further to the previous matching network components, this merged solution includes a diplexer [12]-[13].

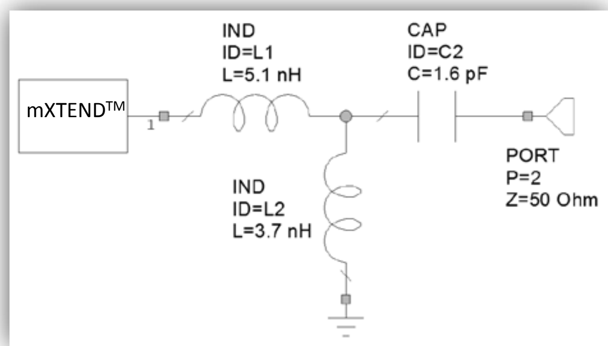


Fig. 8 Matching network for the high frequency region (1710-2690MHz). The components are SMD 0402 commercially available.

[2] High Quality Factor (Q), tight tolerance components are recommended for an optimum performance.
[3] The UFL cables can be replaced by other transmission line technology, (coplanar, microstrip, etc.) according to the customer needs.

VSWR and Total Efficiency

The Voltage Standing Wave Ratio (VSWR) and the total efficiency are obtained at each one of the input/output ports. The total efficiency is measured in the anechoic chamber Satimo Stargate-32 by 3D integration of the radiation patterns, and takes into account both ohmic and mismatch losses (1) [4].

$$\eta_{total} = \eta_{rad} \cdot \left(1 - |S_{11}|^2\right) \quad (1)$$

The mXTEND™ Antenna Boosters connected to port 1 (Fig. 6) provides operation in the low frequency region allocating the communication standards GSM850 and GSM900 (Fig. 9 and Table 1) whereas the one connected to port 2 is dedicated to cover the high frequency region, providing operation in the communication standards GSM1800/DCS, GSM1900/PCS, UMTS/LTE2100, LTE2300, and LTE2500 (Fig. 10 and Table 1).

Table 1 Technical Features (VSWR and total efficiency) of the mXTEND™ Antenna Boosters regarding the Evaluation Board EB_FR01-S4-250 (Fig. 6).

Technical Features	824-960MHz
Min. Efficiency	~46%
Max. Efficiency	~65%
Average Efficiency	>55%
VSWR	3:1

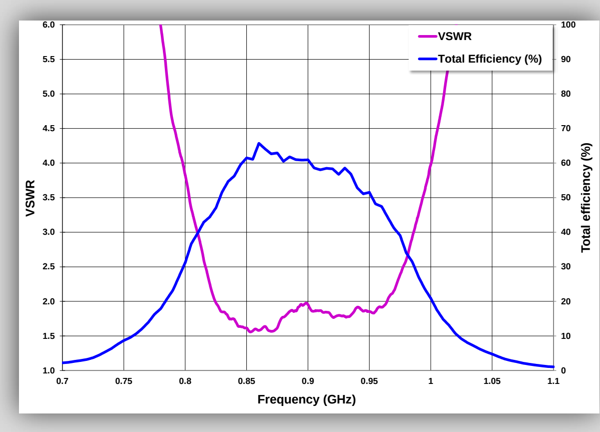


Fig. 9 Electromagnetic performance of the mXTEND™ Antenna Booster in the low frequency region (824-960MHz) measured at the input/output port 1 (Fig. 6).

Technical Features	1710-2690MHz
Min. Efficiency	~66%
Max. Efficiency	~84%
Average Efficiency	>75%
VSWR	3:1

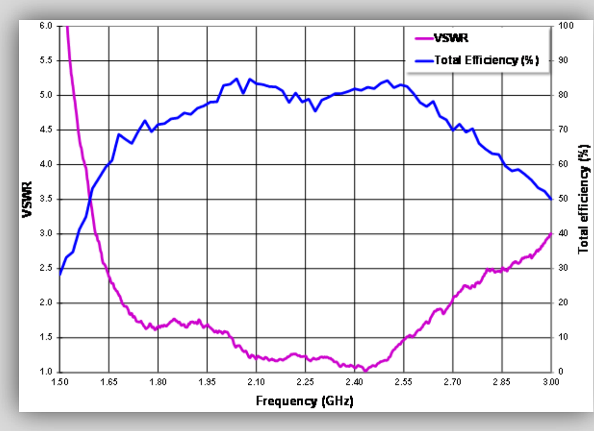


Fig. 10 Electromagnetic performance of the mXTEND™ Antenna Booster in the high frequency region (1710-2690MHz) measured at the input/output port 2 (Fig. 6).

[4] Where η_{total} is the total efficiency regarding mismatch and ohmic losses, η_{rad} is the radiation efficiency, and $|S_{11}|$ is the modulus of the input reflection coefficient.

Radiation Patterns and Specific Absorption Rate (SAR)

The main cuts of the radiation patterns (phi=0º, phi=90º, and theta=90º) as well as their 3D plots, are measured at main frequencies of the low and high frequency region (Table 2). The results illustrate the omnidirectional properties of the solution. More particularly, the radiation pattern in the low frequency region presents an omnidirectional cut in the phi=0º plane and a minimum in the direction of the longitudinal axis (y axis), as typical in handsets. These omnidirectional properties make the solution suitable for mobile communications.

Table 2 Technical features, main cuts, and 3D representation of the radiation patterns (Dynamic range: 30dBs).

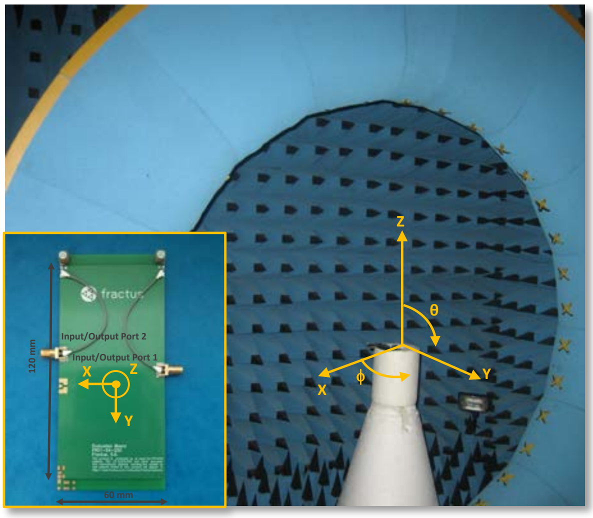
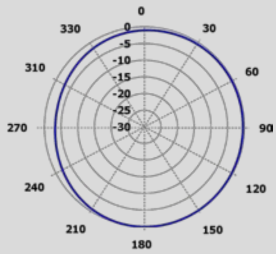
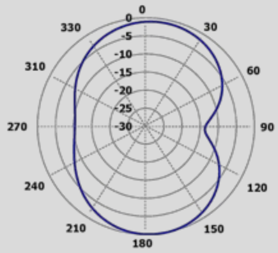


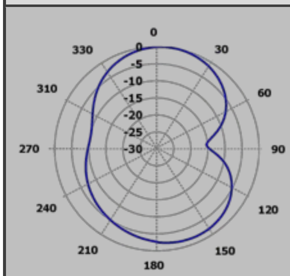
Fig. 11 Measurement set-up in the anechoic chamber Satimo Stargate-32.



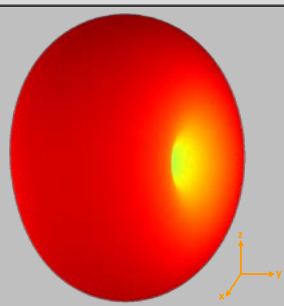
Phi=0º (890MHz)

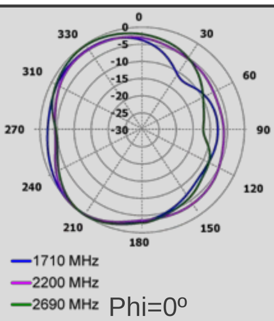


Phi=90º (890MHz)

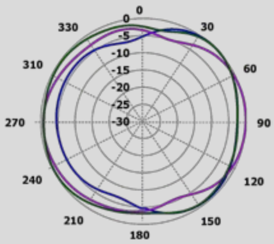


Theta=90º (890MHz)

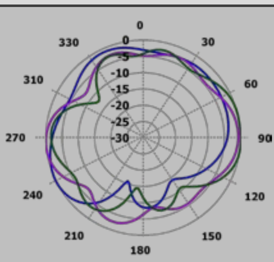




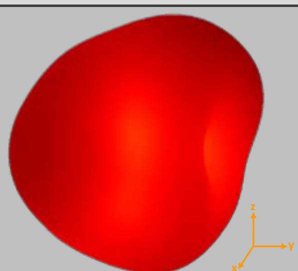
Phi=0º



Phi=90º



Theta=0º



Technical Features	824-960MHz	1710-2690MHz
Min. Gain	-0.4 dBi	1.8 dBi
Max. Gain	1.4 dBi	3.6 dBi
Average Gain	0.5 dBi	2.6 dBi
Radiation Patterns	Omnidirectional	
Polarizaton	Linear	
Weight	~0.25 g	
Temperature	-40º C to +85º C	
Impedance	50Ω	
Dimensions	5.0 mm x 5.0 mm x 5.0 mm	
Minimum isolation between port 1 and port 2	~31dBs (at aproximately 935MHz)	

The biological compatibility and user interaction of Fractus antenna boosters is described in [14]-[15]. Results show that SAR values below the standards (American standard (ANSI/IEEE): 1.6mW/g (1g) and European standard (ICNIRP) 2mW/g (10g)) can be obtained and that those become particularly low when the boosters are placed in the lower edge of the PCB. Additionally, the dual booster arrangement provides intrinsec robustness against finger detuning effect since the blocking of one of the boosters has negligible impact on the performance of the other one [10], [18].

Mobile Connectivity Made Simpler

Fractus Virtual Antenna™ technology has been conceived to make the design of mobile products simpler, faster, and cost-effective. By using a modular solution based on a first antenna booster product, the mXTEND™ product, mobile device OEMs benefit from:

- **Solving** the **size limitations of current handset technologies** while **preserving** the **electromagnetic performance** of the device.
- **Reducing the size of the antenna component by a ten times factor.** The dimensions of the **mXTEND™ Antenna Booster**, **a cube of just 5 mm on the side**, is an **order of magnitude smaller** than other current **state of the art** handset antennas, while offering the required electromagnetic performance.
- Scaling their product range to emerging technology trends such as MIMO. The considerable reduced size **of the mXTEND™ Antenna Booster** makes the solution particularly suitable for embeding **multiple antenna elements** into a single device.
- The new **Virtual Antenna™ technology** further provides **modular and adaptive** designs to the customers' needs. It offers enough flexibility as to choose between single-band up to hepta-band operation **without requiring the customization of the product**. It means that the same mXTEND™ booster can be used to provide operation at different mobile frequency bands ranging from 824-960MHz and 1710-2690MHz.
- From the commercial perspective, the solution not only **simplifies design processes** but also **manufacturing costs**, since it can **be standardized across multiple devices and platforms** as it is an **off-the-shelf solution**.

In summary, the new Virtual Antenna™ technology released by Fractus Antennas becomes an alternative to the traditional customized antenna technology and appears as standardizing solution for current and future multifunctional wireless devices.

About Fractus Antennas

Fractus Antennas is an early pioneer in developing internal antennas for cellular phones and related handheld wireless devices. In 1995, Fractus lead scientist filed the world's first patent application on Fractal antennas for mobile telecommunications. The company was founded to meet the challenge of delivering antennas small enough to fit inside a cell phone yet powerful enough to support today's multiband phones.

Fig. 12 Fractus antenna laboratory.

Fractus Antennas' patented antenna technology has been adopted by leading handset makers worldwide including LG, Motorola, Blackberry, HTC, Sanyo, Pantech, Sharp, and Kyocera. With more than 1,000 wireless OEM customers worldwide, Fractus' products and technologies are used in a broad range of wireless devices including smartphones, mobile handsets, portable navigation devices, game consoles, laptops/netbooks, tablets and e-readers.

Today, Fractus Antennas holds an Intellectual Property Rights portfolio of more than 170 patents and patent applications, including 85 patents granted in US and 41 in other regions of the world (EU, CN, JP, KR, IN, MX, RU, BR), and has shipped more than 35 million antennas worldwide. Among the numerous awards and honors the company received for its innovative work, Fractus was named in 2005 a

Fig. 13 Fractus Antennas Headquarters in Sant Cugat, Barcelona, Spain.

Technology Pioneer by the Davos World Economic Forum and listed as one of Red Herring's top innovative companies in 2006. It has also won the 2004 Frost & Sullivan award for technological innovation and the 2007 Elektra European Electronics Industry R&D Award.

From the team that pioneered fractal antennas in the 1990's and leaded the introduction of the pervasive Multilevel and Space-Filling internal antenna technologies in modern handsets, now Fractus Antennas is releasing a new antenna technology generation with its Virtual Antenna™ products. Fractus Antennas' Virtual Antenna™ solution provides a way to upgrade the bands for cellular platforms to LTE and follow-up generations by means of an ultra-compact antenna solution that can be standardized across multiple devices and platforms.

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