A Compact and Lightweight Ultra-Wideband Interferometer for Direction Finding Applications

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OUTLINE

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- **Antenna design**
- **Balun design**
- **Simulations and measurements**
- **Conclusions**

Introduction and motivation

The estimation of the direction of arrival of unknown signals from non-cooperative targets plays a key role in the detection and localization of possible hostile objects in an homeland security framework.

In particular the incoming signal may occupy any portion of the spectrum, hence the detection system must be ultra-wide band (UWB) and at the same time lightweight and economical.

Antenna size is hence a key point in design, and it must be kept as small as possible

Introduction and motivation

In this work it is proposed the design of a couple of UWB two-arm sinuous antennas:

Antenna A working in the 2-18 GHz band

Antenna B working in the 6-18 GHz band

To be assembled in a ultra-wideband array for direction finding applications.

Both antennas work with a slant 45° polarization and must provide good matching impedance and stable radiation characteristics in the considered frequency bands.

Design has been optimized in order to reduce the geometrical dimensions.

Antenna Design

The sinuous antenna is a very appealing and versatile ultra-wideband (UWB) antenna. Originally introduced and patented by Du Hamel in 1987[1], it is quite popularin its dipole and slot versions, both with two or four arms.

In particular, two-arm dipole sinuous antennas are very interesting for homeland security applications for their **UWB characteristic** and **linear polarization**.

Effective radio-goniometers can be devised by employing a limited number of sinuous antennas in slant 45° polarization.

UWB and slant polarization allows to effectively detect any incoming signal generated by the targets.

[1] R.H. DuHamel. "Dual polarized sinuous antennas," *US Patent* 4,658,262. Apr. 1987.

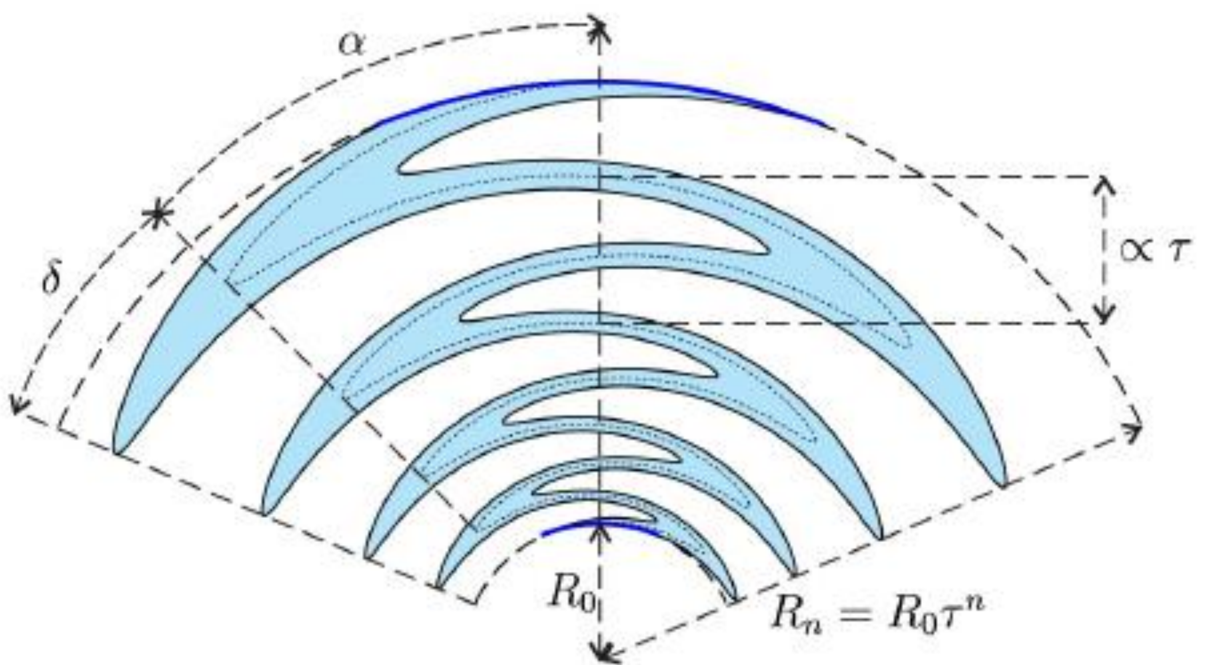
Antenna Design

The sinuous antenna profile is described by:

$$\begin{cases} \phi(r) = (-1)^P \alpha \sin\left(\frac{\pi \ln(r/R_0)}{\ln(\tau)}\right) \pm \delta \text{ per } R_0 \le r \le R_0\tau^n \\ r(\phi) = R_0 \exp\left[\frac{\ln(\tau)}{\pi} \arcsin\left(\frac{\phi \pm \delta}{(-1)^P - \alpha} + k\pi\right)\right] \end{cases}$$

$$\begin{cases} R_0(\alpha+\delta) = \frac{\lambda_H}{8} \le \frac{\lambda_H}{4} \\ R_n(\alpha+\delta) = \frac{\lambda_L}{4} \\ \frac{r_{i+1}}{r_i} = \text{cost} \end{cases}$$

$$\begin{cases} R_0 = \frac{c}{8 f_H \sqrt{\varepsilon_r}(\alpha+\delta)} \\ n = \log_\tau\left(\frac{c}{4 f_L \sqrt{\varepsilon_r}(\alpha+\delta) R_0}\right) \end{cases}$$



Antenna Design

Key points are that:

- lower working frequency is limited by the outer diameter of the antenna,
- upper frequency is limited by how close the feeding point can be manufactured.

From system-level constraints:

Antenna A diameter must be at maximum 20mm

Antenna B diameter must be at maximum 60mm

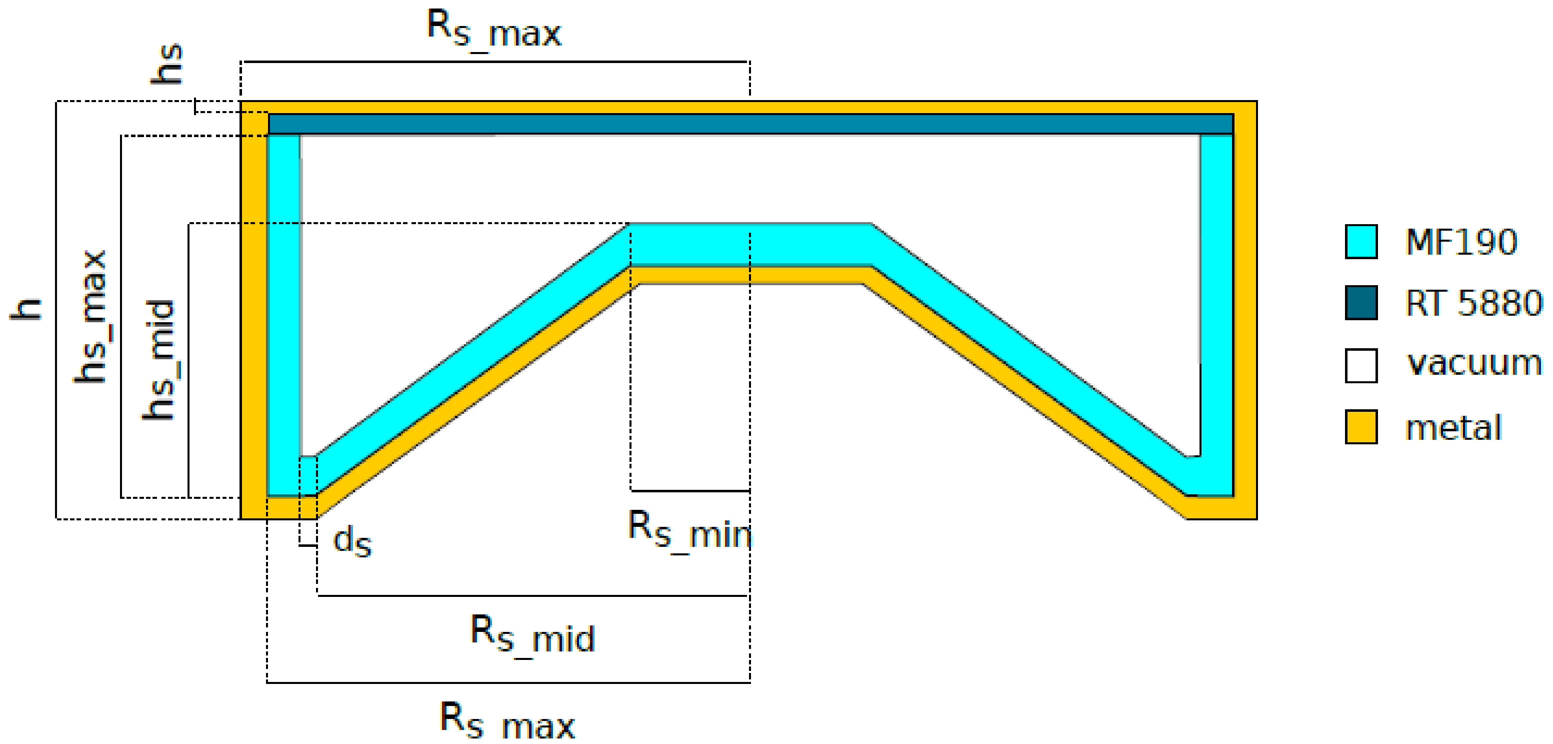
furthermore photolithographic process cannot create lines/slots thinner than about 100μm, limiting upper frequency.

These dimensional requirements are very hard to comply. In particular the theoretical analytic profile has been modified so as to never produce lines thinner than 100mm in the feeding area.

Antenna Design

These dimensional requirements were met by designing the antennas on a Rogers 5880 substrate, 0.245mm thick (ε_r = 2.2, tanδ in the range 0.0004 to 0.0009).

To obtain a single lobe pattern the antenna is backed with an ECCOSORB-MF190 absorber, with tanδ up to 4 in our frequency range.



Balun Design

Being the sinuous antenna balanced in nature, a critical design feature is the balun, necessary to allow coaxial line feeding.

The balun must have at least the same bandwidth of the antenna.

Two classes of baluns have been studied:

- A tapered Klopfenstein balun, to be mounted orthogonally to the antenna
- A slot-line based balun, to be mounted parallel to the antenna and connected via coaxial cables.

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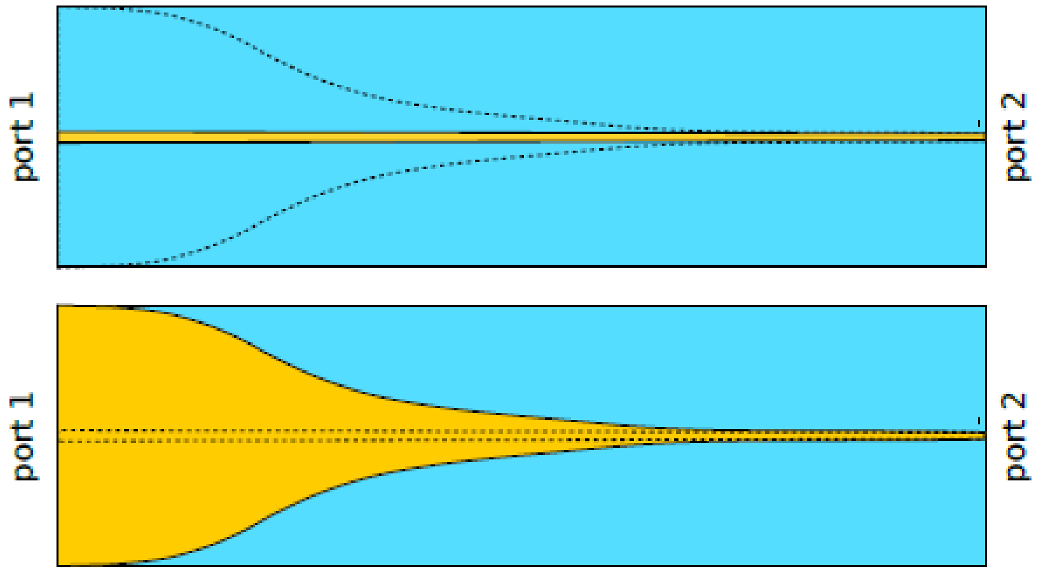
Balun Design

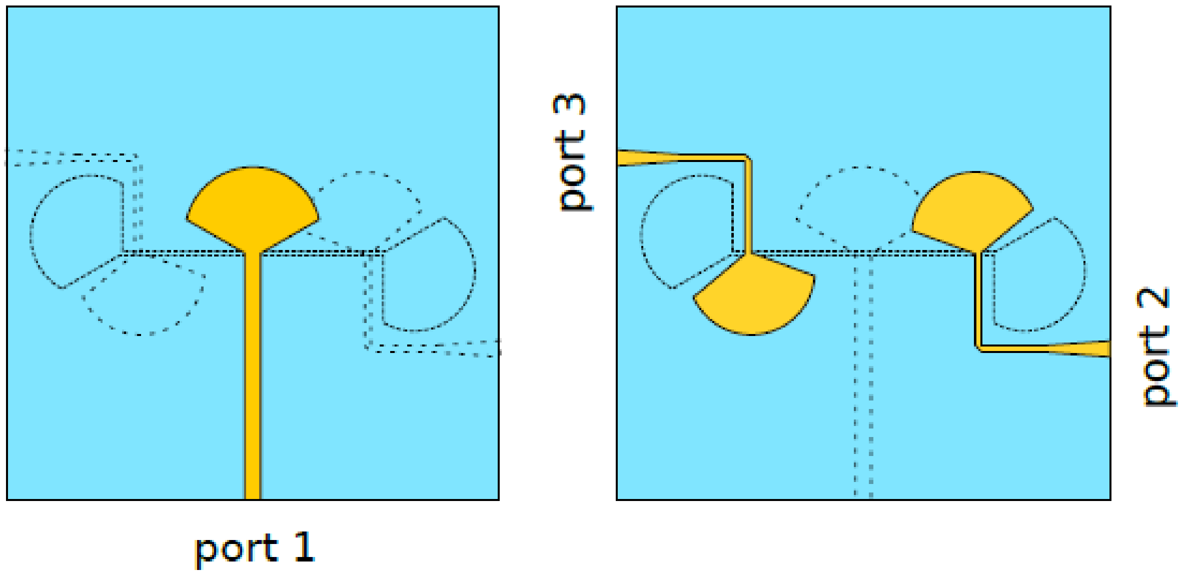
- Tapered Klopfenstein balun, to be mounted orthogonally to the antenna



- this balun is sufficiently small for the proposed application in the 6-18GHz range, but in the 2-18GHz it would be too bulky. Hence it is suitable for Antenna A but not for antenna B.

Balun Design

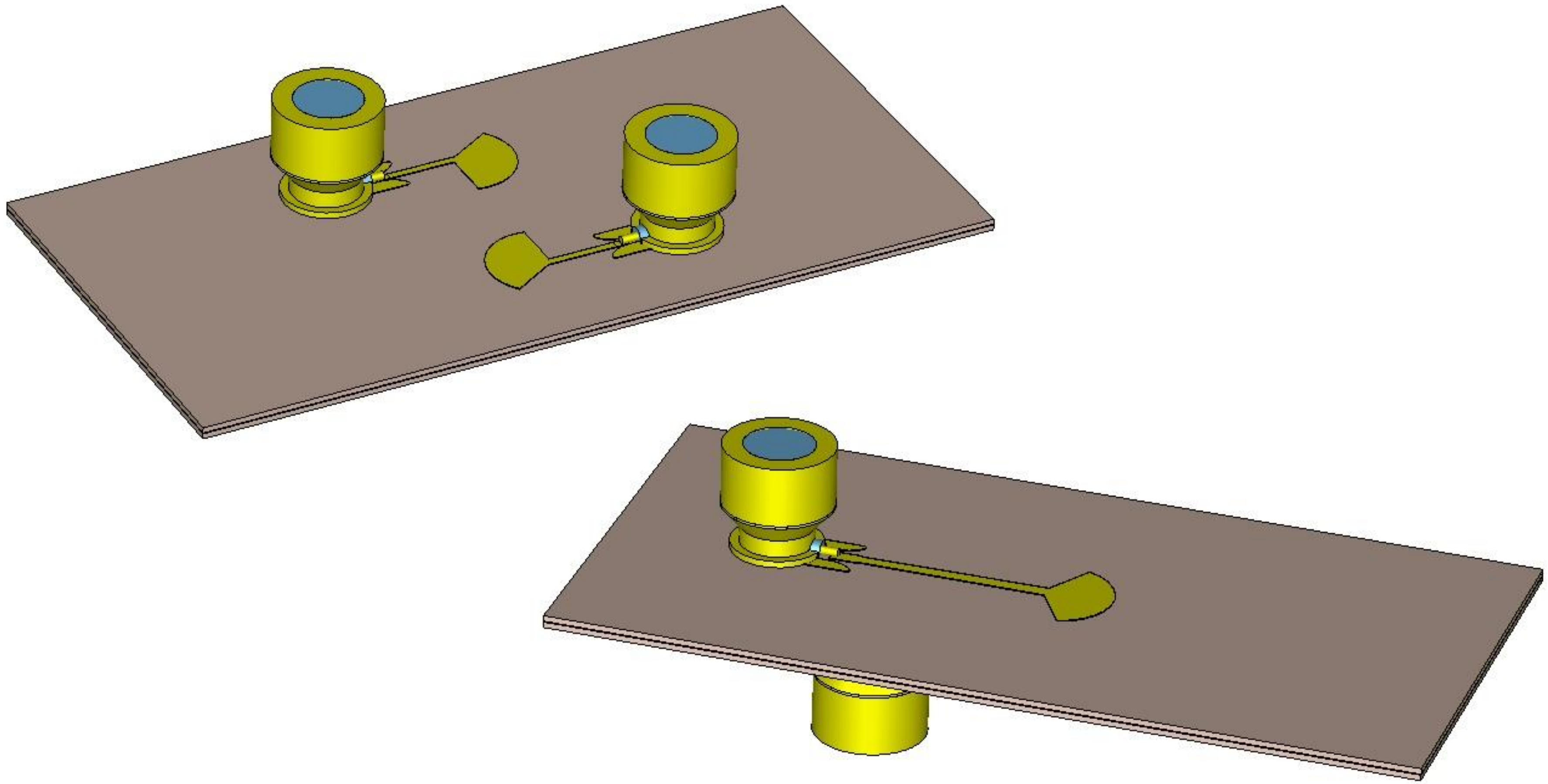
- Slot-line based balun, to be mounted parallel to the antenna and connected via coaxial cables.



- This balun is more compact than the tapered line one and allows for a lower profile for the larger antenna B, but it has the additional complexity of being multilayer and of needing coaxial cables to connect it to the antennas, with additional connectors and losses.

Balun Design

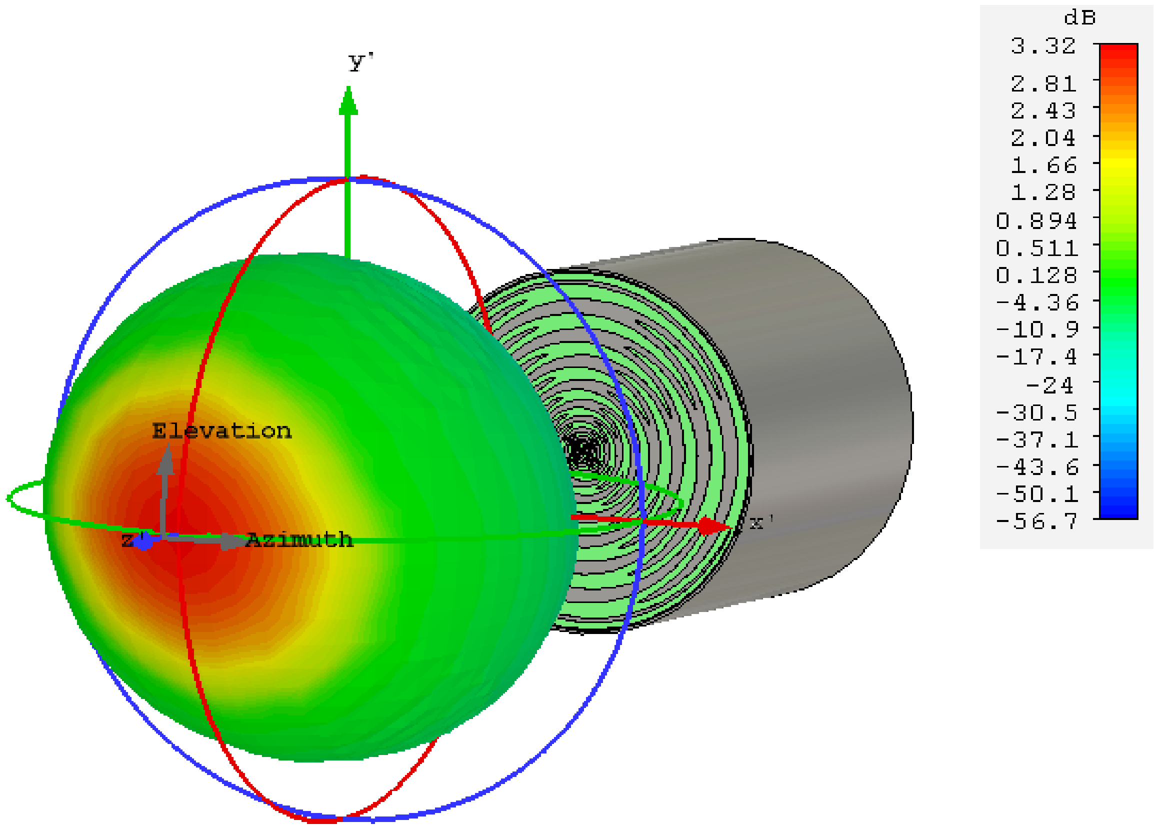
- Full numerical model comprises connectors



Simulations

Antennas A and B have been simulated with full-wave electromagnetic software CST Microwave Studio.

Obtained radiation pattern of the Slant 45 (S45) polarization shows a high symmetry on the azimuth plane for both antennas all over the working frequency bands.



Pattern for antenna A
slant 45° (S45) polarization,
frequency *f* = 6 GHz.
Boresight realized gain 3.3 dBi
half power beam width (HPBW) 80°.

Simulations

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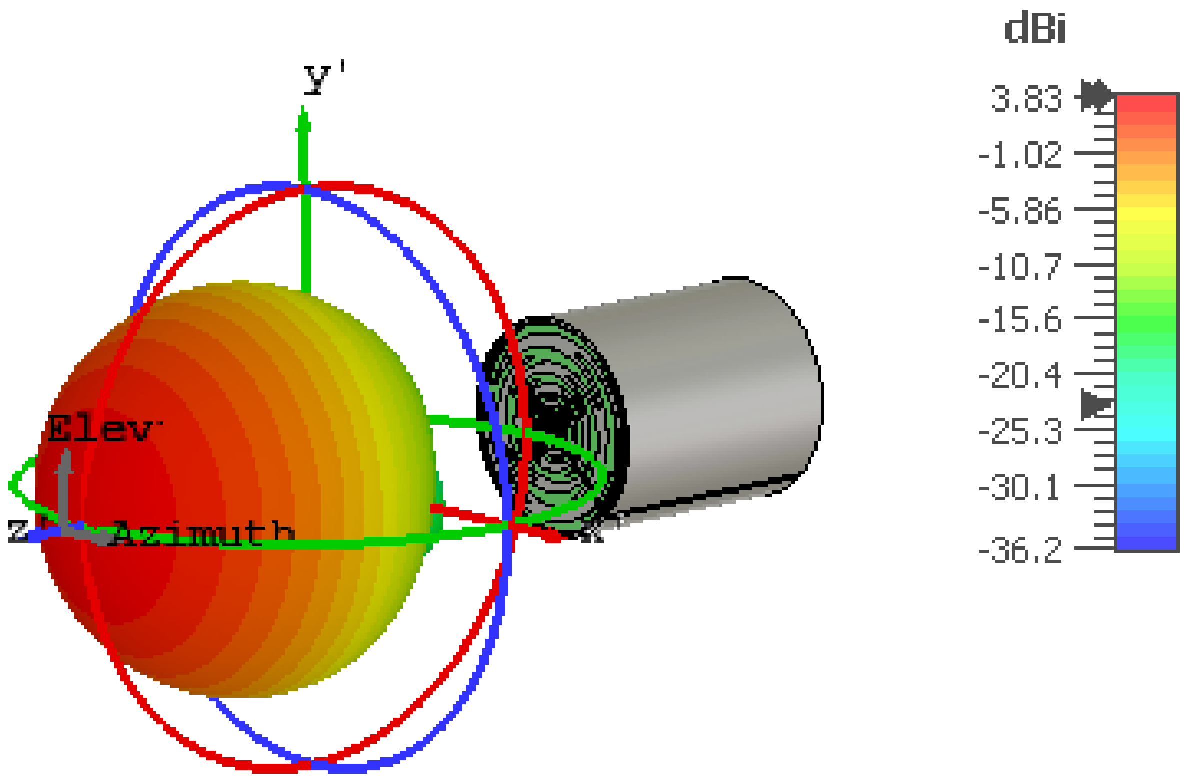
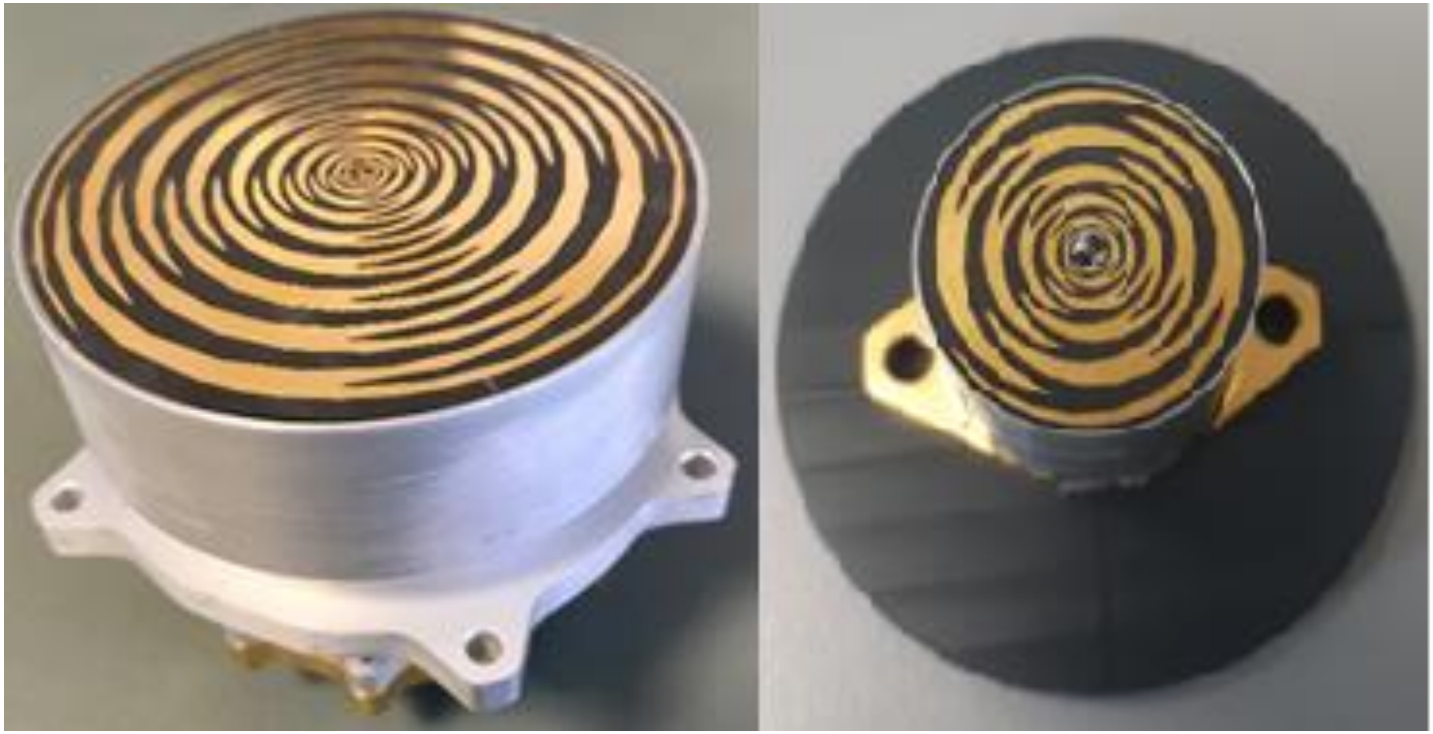


Pattern for antenna B
slant 45° (S45) polarization,
frequency *f* = 12 GHz.
Boresight realized gain 3.8 dBi
half power beam width (HPBW) 75°.

Measurements

To validate the electromagnetic properties evaluated by numerical simulation, the prototype of such antennas have been realized and measured



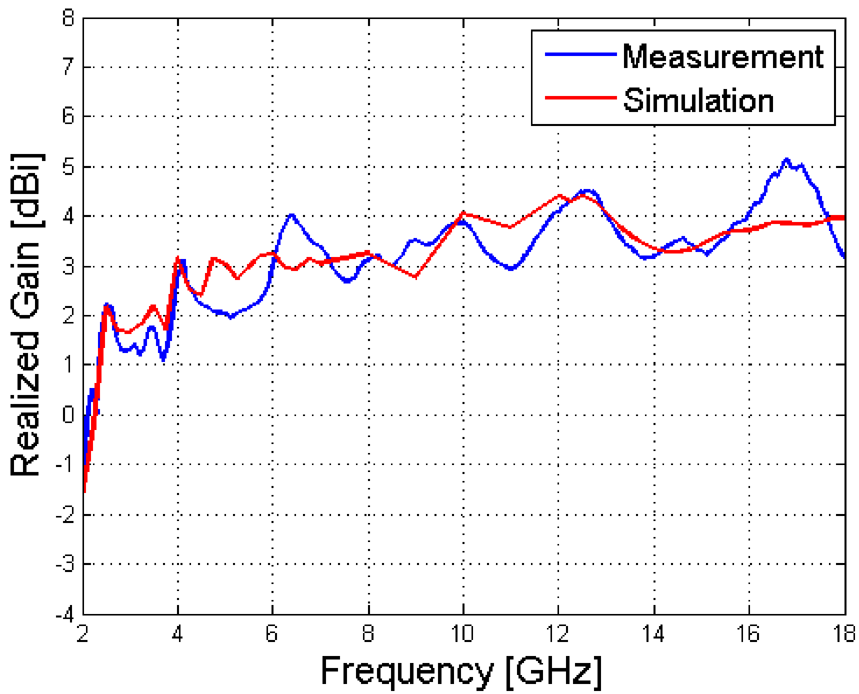
Antenna A

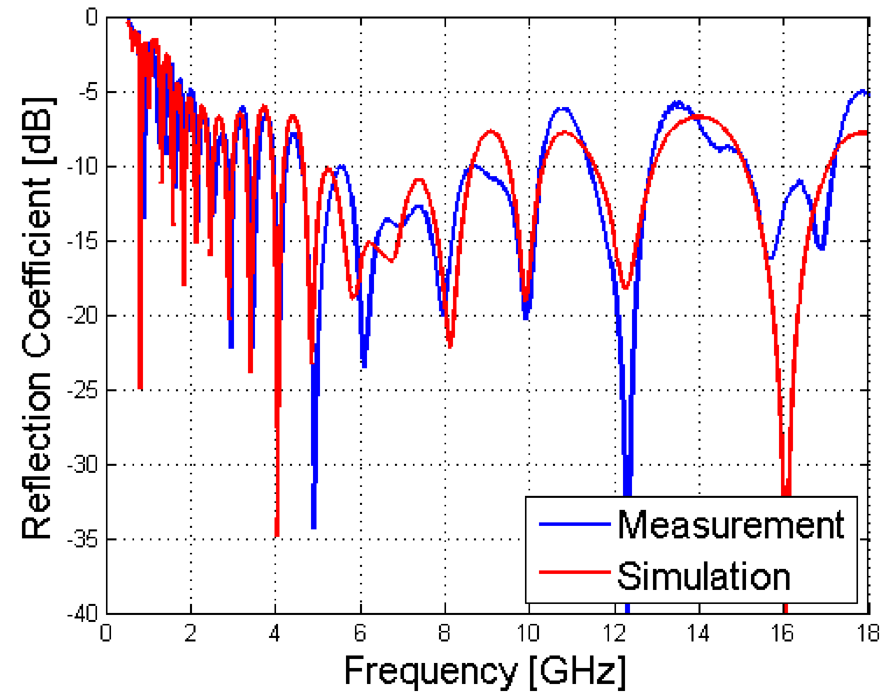
Antenna B

Measurements

Antenna A

The antenna prototypes has been characterized by using a On The Air Near Field to Far Field system (OTA NF-FF)

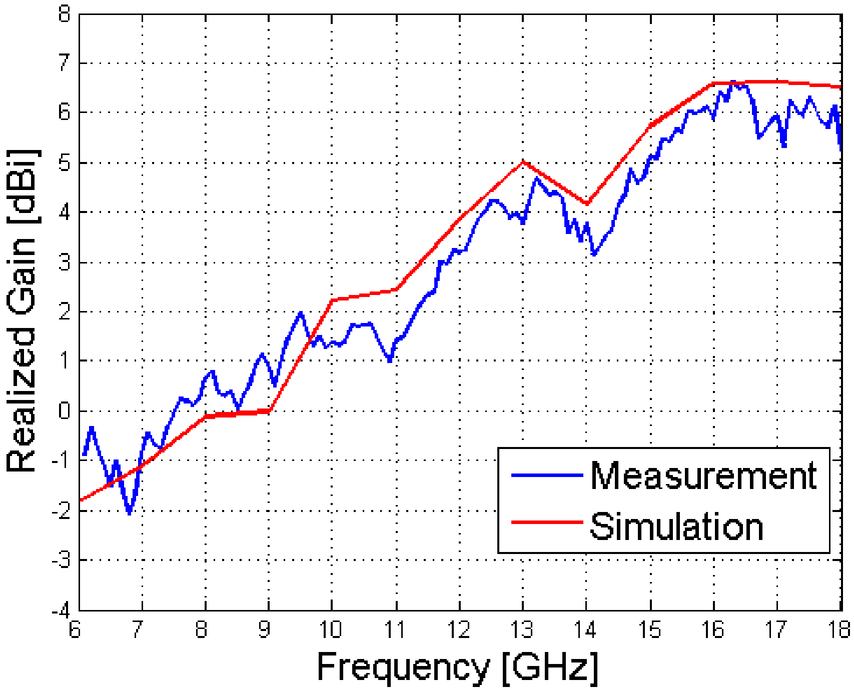


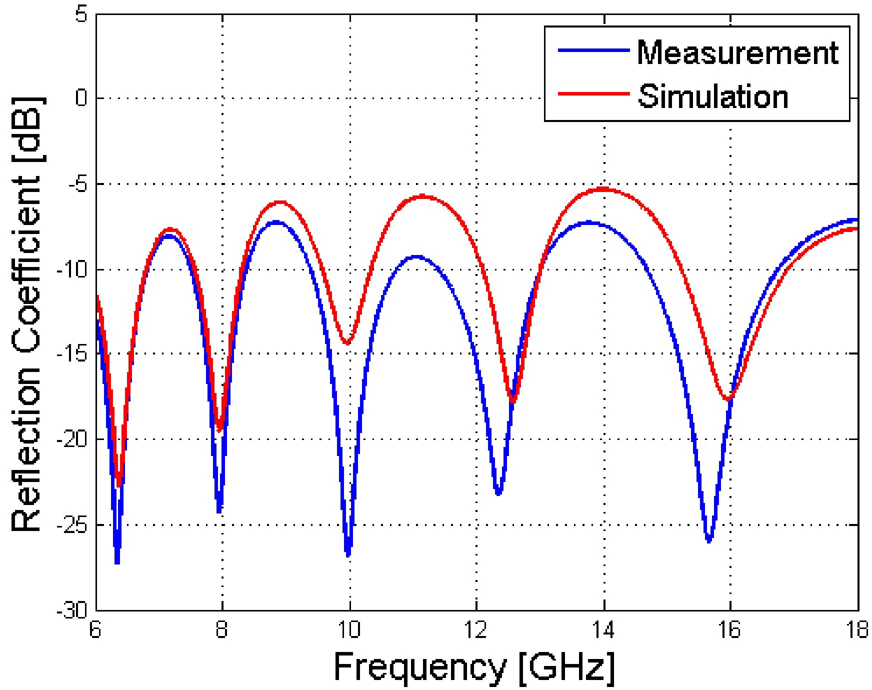


Measurements

Antenna B

The antenna prototypes has been characterized by using a On The Air Near Field to Far Field system (OTA NF-FF)





Measurements

The resulting performances in terms of accuracy of the direction of arrival estimate are here evaluated.

A three-channel receiver has been considered, switching between a set of three antennas of type A and three antennas of type B.

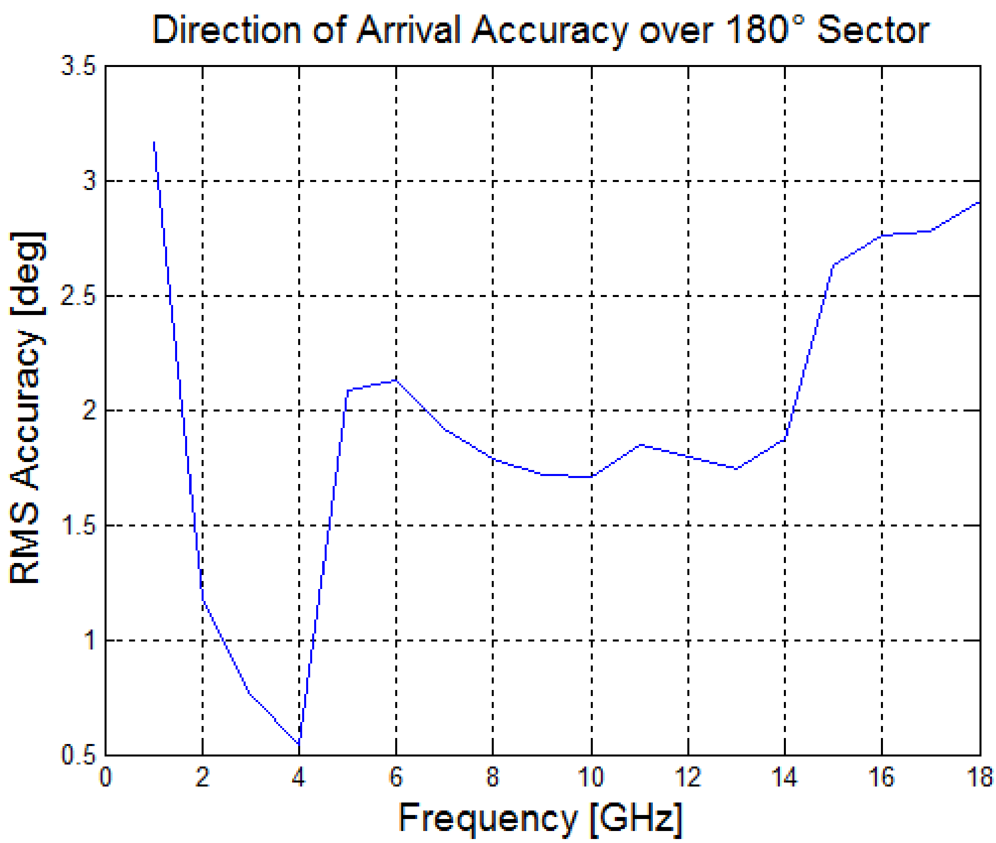
A signal-to-noise ratio equal to 20dB was considered

A correlative algorithm based on the measured results applied

. The synthetic results coming from Montecarlo simulations applied to the measured antenna patterns are shown in Fig. 12

Measurements

Synthetic results are given in terms of root-mean-square (RMS) accuracy in detecting the direction of arrival over a Montecarlo set of simulations based on the measured antenna patterns.



Conclusions

A couple of compact UWB sinuous antenna in slant 45° polarization for radiogoniometry have been designed, realized and measured.

Key issue in design was, besides band, compactness so as to be able to closely pack antennas in a DoA

Good performances are achieved in terms of gain and return loss, as verified by measurements.

Also DoA performances are good over the whole band.

Questions?

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