Wideband Vivaldi Antenna Array with Mechanical Support and Protection Radome for Land-mine Detection Radar

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***Abstract*—A wideband antenna array is developed for the land-mine detection in the desert with an on-board radar. The final array is very large and contains 128 Vivaldi antennas. The array is split into 16 sub-arrays of 8 elements. Each Vivaldi antenna is driven independently by electronic switches for SAR imaging purpose. In a first step, a sub-array of 8 elements has been studied, fabricated and measured in the anechoic chamber. In a second step, influences of the overall mechanical support and the protection radome are studied numerically and experimentally. This paper focuses on the second aspect with the minimization of both support and radome effects on the radiation performances of the Vivaldi elementary antenna.**

***Index Terms*—wideband antenna, Vivaldi antennas array, radome, land-mine detection radar.**

I. Introduction

The paper reports on our research activities under a FUI fund which focuses on a promoting systems using GPR (Ground Penetrating Radar) technology with SAR post-processing algorithm that can help to get rid off the mines in the desert of North-Chile. The chosen solution is to use in-flight radar which has several advantages: i) the safety of the operators is guarantued thanks to the contactless with the mined ground, ii) the scanning speed and image resolution are potentially high. The implementation of the radar on airborne enables to cover wide areas compared to existing solutions such as demining soldier or vehicles. Additionally, the radar can be adapted to different transporters without changing its properties and works under all weather conditions.

Important features of the land-mine detection with a GPR using SAR post-processing are the resolution and the expected scan area per day. Considering that the radar complexity usually increases with asking performances, a trade-off has to be considered with respect to the application and overall constraints technological and mechanical such as the transporter carriage capacity and the post-processing time of SAR measured data. Therefore the design requirements are 7*7*7 cm^3 of resolution and with a scan area of 4 km^2 per day that still remain state of the art values.

This paper focuses on the design of the mechanical support and radome in order to make them as transparent as possible to the antenna radiating performances. The paper is organized in 4 Sections. Section I states the introduction. Section II describes the design of the antenna and its support. The radome and its influence on the antennas radiation performances are studied in Section III and an optimal solution with the minimization of the radome effect is proposed. Some conclusions are drawn in Section IV.

II. Antenna and mechanical support

According to the SAR post-processing algorithm, an electrically large 2D antenna would be required to have 2D SAR images. But we have planned to take advantage of the transporter's displacement to reduce to single dimension (1D) antenna. In this case, the antenna design is simplified to 1D array [1]. Due to the overall large size of the antenna, the final array is split into 16 sub-arrays of 8 Vivaldi antennas each. In order to avoid any motorization in the antenna, one electronic switch (SP8T) is used per sub-array. Mechanical support is mandatory to solve the fixation and alignment problems for the whole complex antenna system with 128 elements.

The operating frequency band of our SAR imaging system is one octave from 2 to 4 GHz with the return loss requirements for the antenna below -12 dB. The single element antenna gain must be moderate (typically 0 - 5 dBi) over the operation bandwidth in order to maintain a wide aperture (typically around 90 - 100°@-3dB) of the radiation pattern. The last constraint is on the antenna's length which cannot exceed 60 mm in order to limit the overall antenna's size.

A. Sub-array antenna and mechanical support designing

It is well known that the acquisition of data on a large band (multi-frequencies) is an important improvement factor of the resolution in imaging with SAR post-processing. The specifications mentionned above (imaging resolution, scanning speed, operating frequency bandwidth, etc.) require an antenna array with 7 m of length containing 128 elements. In addition, for reducing as much as possible the effect of the aerodynamic force, the height of the antenna system (radiating element and mechanical support for holding antennas, switches, radome,

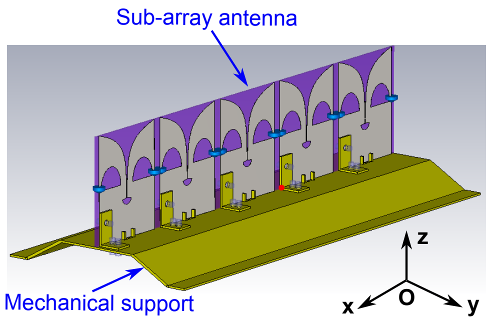


Fig. 1. Sub-array antenna model with 5 Vivaldi antennas in CST Microwave Studio.

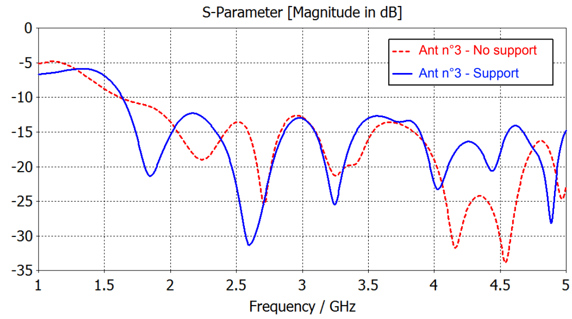


Fig. 2. Simulated reflection coefficients of the central antenna with and without mechanical support.

etc.) can not exceed 240 mm. By deeply analysing several antenna solutions (such as patches, horns, dipoles, helices, etc.), the choosen one is the reduced-size Vivaldi antenna [2], [3] excited by a wide band transition with microstrip line coupled to slot [4]. The sub-array antenna is mounted above the mechanical support as shown in Figure 1 with the modelling in CST Microwave Studio. The shape of the support is optimized in order to minimize interferences between the sub-array antenna and the mechanical support. Due to the limitation in computing resources (RAM), we can only simulate in CST the sub-array antenna with maximum 5 elements. By the way, the central antenna of the sub-array with 5 elements has the same behavior compared to the central one of the sub-array with 8 elements as shown in our previous work [5]. This confirms our choice on the 5 elements sub-array in the CST simulations.

Before going straigth to the manufacture of the sub-array antenna and its support, we must verify the matching and radiating properties of the antenna using here the CST Microwave Studio. Figure 2 presents the simulated reflection coefficients obtained with the central element (antenna n°3) of the 5 elements sub-array. Both antennas with and without the mechanical support have a good matching (lower than -12 dB) over 3.5 GHz (1.5 - 5 GHz) which respects the required specifications with 500 MHz reserved below and above the operating bandwidth. Therefore all of the results are shown between 1 - 5 GHz. More details on the simulated and mesured results on the radiating properties of the studied antenna (n°3) are shown in the next paragraphs.

B. Fabrications and measurements

The sub-array with 8 Vivaldi antennas and its support are simulated, fabricated and measured (Figure 3). In order to emulate the antenna's behavior among the radar only one antenna is emitting/receiving while the 7 other ones are loaded with 50 Ω (resistive switches will be used). All possible configurations were tested. There is a good stability of both return loss and radiation characteristics with respect to the antenna position except for the extreme-side antennas (n°1 and n°8). Their radiation pattern is slightly asymmetric. Nevertheless their influence has to be mitigated knowing that they represent only two of the 128 elements in the overall radar antenna.

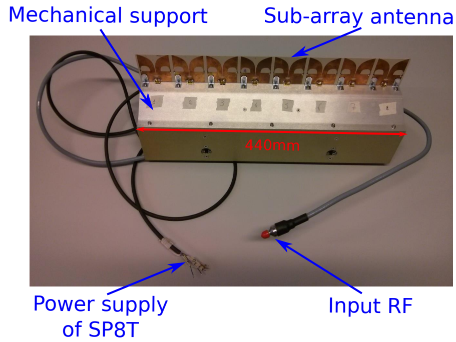
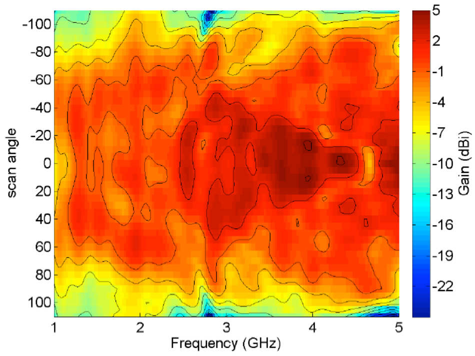


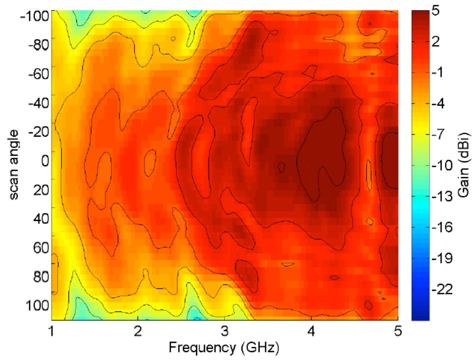
Fig. 3. Fabricated sub-array antenna with 8 Vivaldi elements named from right to left side with antenna n°1 to antenna n°8.

The measured results are presented for the central antenna (n°4) without the mechanical support in Figure 4. We notice here that only the forward radiation patterns can be mesured in anechoic chamber and they are shown within a scan angle interval varying from -100° to +100°. Both E- and H- planes show wide-angle patterns over the operating frequency bandwidth (2 - 4 GHz). The measured antenna gain is between 0 and 5 dBi. Higher gain with increasing frequency is observed, as it is usual for Vivaldi elements. Also expected is the better stability of the H-plane compared to the E-plane. It is due to the array arrangement along *Ox*-axis. Even if neighboring antennas are only coupled from the excited antenna, they could produce an array effect in the substrate plane (E-plane). The resulting array factor is frequency dependent and is subject to change rapidly because of the wide frequency band. This explains the oscillations of the gain at 0° in E-plane radiation pattern.

Because of the time limitation, we can not include the measured radiation pattern of the antenna mounted on its mechanical support where our measurement campaign was scheduled later in few weeks. The simulated radiation pattern obtained with CST of the central antenna mounted on the support is shown in Figure 5. For conciseness purpose only the E-plane of the central antenna is shown because the SAR post-processing is done in this plane. One remark must be noticed here that we can compute the radiation patterns of the antenna using CST in both forward and backward directions



(a) E plane



(b) H plane

Fig. 4. Measured radiation pattern of the central antenna of the sub-array.

with scan angle varying from -180° to +180°. It is shown that the E-planes are stable over scan angle and frequency. It was also well demonstrated in our previous paper [5] that they are very similar compared to the ones of the antenna alone (without the mechanical support).

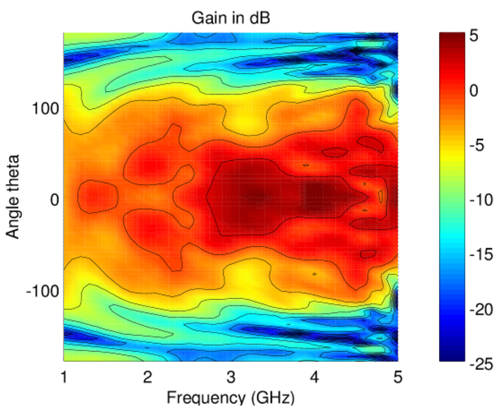


Fig. 5. E-plane simulated radiation pattern of the central antenna of sub-array with the mechanical support.

III. Radome Designing

As mentionned in the introduction, the whole antenna system with 7m of length containing 128 Vivaldi antennas of the GPR SAR radar will be mounted on an aeronautical transporter such as an helicopter or a small plane. And the radar must operate under various meteological conditions (high temperature up to 70°C, heavy rain, strong wind with dust or sand of the desert, etc.) and aerodynamic forces due to the motion of the transporter. These operating conditions require absolutly a good protection of the Vivaldi antennas and also the electronic switches by using a specific radome which is waterproof and respecting the norm IP54.

A. Radome geometry

In order to minimize the aerodynamic force acting on the radome, we must use ideally a hemispherical or cylindrical shape as shown in Figure 6. The cross-section of the radome is extended hemispherical and it contains two continious sections: i) the spherical one and ii) the extension one. The extension section is used to hang the spherical section over the top of the Vivaldi antennas (see Figure 6). The radome must be rigid enough to well protect the antenna array inside, then its thickness must be more than several milimeters (according to the advices of the radome experts). In our case, the helicopter or small aircraft transporters flights at low attitude with a moderate speed, then we can have a radome with smallest thickness which is uniform and equal to 3 mm. The radome is placed as close as possible to the Vivaldi antenna to keep the antenna's height of 240 mm. In our studies, the distance between the top of the spherical surface of the radome and the top of the Vivaldi antennas is equal to 15 mm.

It's important to notice that the mechanical support and the radome are very close to the the antenna and they are in the reactive zone (very near field zone). Then a small variation on the design (the shape of the mechanical support, the thickness of the radome and the permittivity of the material, etc.) can generate a big change in the antenna's radiating properties. By the way, we've shoosen to use CST Microwave Studio (a fullwave simulator) which is very powerfull and can take into account precisely all of the electromanetical phenomenons happening even in the reactive zone or in the farfield zone of the antenna. Then the simulated results are very reliable.

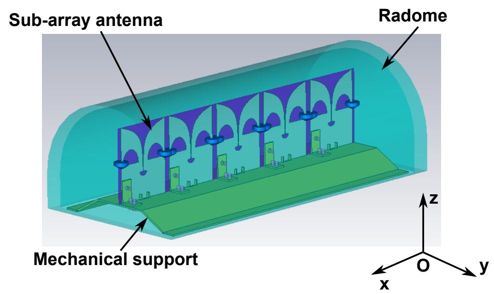


Fig. 6. CST model of the complete antenna with mechanical support and extended hemispherical radome.

B. Material selection for radome

In the normal case, the radome for aeronautical devices must be made in glass fiber thanks to the strong rigidity and the high quality in waterproofness. By the way, its permittivity is a little bit high with ϵ_r = 3.5 that can produce some secondary effects

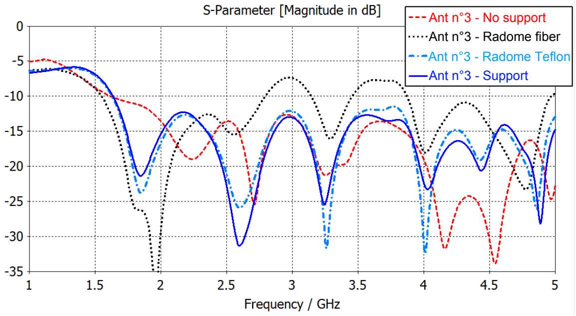


Fig. 7. Simulated reflection coefficients of the central antenna with support and radome (results obtained with CST Microwave Studio).

on the antenna radiating properties such as the distorsion in the radiation pattern, gain loss, matching problem, etc. Figure 7 presents the reflection coefficients of the central antenna (n°3) with and without the mechanical support and radome: the matching of the antenna is seriously affected with some strong perturpations around 3 GHz (larger than - 8 dB).

Based on this results, we can conclude that the radome in glass fiber produces very strong effects on the radiating properties of the antenna even with very small thickness (3mm is equal to 3/100 wavelength as 3 GHz). These effect come from the large discontinuity between the glass fiber and the air which provides a strong reflection inside the radome. As shown in Figure 6, the radome and the support connect together to form some kinds of resonant cavity inside the radome because of the strong reflection on the inner interface of the radome.

Let's take a look on the light-blue curve shown in Figure 7 with the radome made in Teflon ($\epsilon_r = 2.1$). It's almost similar to the reflection coefficient of the antenna with support and without radome. And it means that the radome made in Teflon is transparent for the Vivaldi antenna. To make the choice on the material for radome between glass fiber and Teflon, we must rise many discussions with the aerotransporters consulting and the radome experts based on the mechanical and electrical properties of these two materials. And finally, Teflon is chosen for radome's material.

C. *Influences of radome on antenna radiation pattern*

To follow the influences of the radome in glass fiber and in Teflon on the reflection coefficients of the central antenna (n°3), we'll show here its simulated radiation patterns under the presence of the radome in Figures 8 and 9. They confirm once more the strong effects of the radome made in glass fiber and the transparency of the radome made in Teflon on the radiation properties of the Vivaldi antenna.

IV. Conclusion

A sub-array antenna with 8 elements which is one part of the whole 128 Vivaldi elements array antenna for land-mine detection radar has been designed, simulated and measured. It is compliant with initial wideband, compactness and radiation requirements. A mechanical support was designed in order

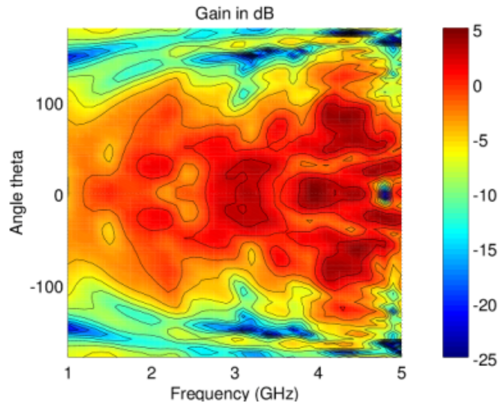


Fig. 8. E-plane simulated radiation pattern of the central antenna of sub-array with the mechanical support and radome made in glass fiber.

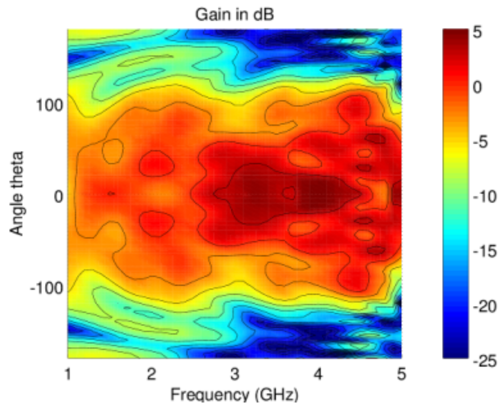


Fig. 9. E-plane simulated radiation pattern of the central antenna of sub-array with the mechanical support and radome made in Teflon.

to hold the Vivaldi antennas and to fasten RF electronics with cables. The system also requires a protection radome for operating under any metrological conditions. The radome has to be rigid enough and waterproof while keeping a good RF transparency. Electromagnetical and mechanical studies were intensively performed and the final choice is based on the extended spherical radome made with Teflon. It produces very low effects on the radiating properties of the Vivaldi antenna.

Acknowledgment

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