Cloaking performance of a transmission-line cloak in free space and in the near field of a horn antenna

J. Vehmas, P. Alitalo and S. A. Tretyakov

Department of Radio Science and Engineering
Aalto University
P.O. Box 13000, FI-00076, Aalto, Finland
Fax: + 358-9-47022152; email: joni.vehmas@aalto.fi

Abstract

A new design of a volumetric transmission-line-based cloaking structure is studied numerically and experimentally. It is demonstrated how the cloak can hide a set of metal cylinders from the surrounding electromagnetic waves using two different setups. Firstly, the total scattering cross section of the cloak is simulated. Secondly, the radiation pattern of a horn antenna is studied with the cloak placed in front of it in the near field of the antenna.

1. Introduction

The concept of cloaking objects using transmission line networks was previously proposed as a practical alternative for simple, cheap and broadband cloaking of mesh-like objects [1], [2]. In this paper, a new kind of transmission line cloak will be introduced - a streamlined version of the earlier designs with special emphasis on the simplicity and the manufacturability of the structure. We will demonstrate with simulations the cloaking performance of this new transmission-line cloak by calculating the scattering width of an infinite cylindrical cloak and simulating the radiation pattern of a horn antenna with a finite-sized cloak placed in front of it. In our presentation, we will also present the corresponding measurement results using an actual manufactured cloak.

2. Geometry of the cloak

The cloak introduced in this paper is similar to the ones presented earlier in [1], [2] with a few key differences in the design. Firstly, the coupling element which consisted of a set of gradually widening strips in the earlier studies has been replaced with a set of solid conical metal layers for the sake of simplicity and ease of manufacture. Secondly, the transmission line networks are printed on a substrate layer as opposed to using separate grids of metal strips. This was, again, done in order to simplify the manufacturing and assembly. The cloaking structure was optimized numerically using Ansoft's HFSS software [3] for the operational frequency of 3 GHz. The acquired dimensions are presented in Table 1 and the geometry of the cloak in Fig. 1. It should be noted that the new coupling layer design has markedly different behavior compared to the one based on widening metal strips. As the thickness of the coupling layer increases, the cloaking effect is improved with practically no shift in the operational frequency, unlike in the strip coupling layer case. That is also the reason why the radius of the coupling layer is much greater than in the earlier cloak designs utilizing gradually enlarging strips for coupling. In the numerical simulations, the metal parts are modelled as copper with realistic losses. The substrate

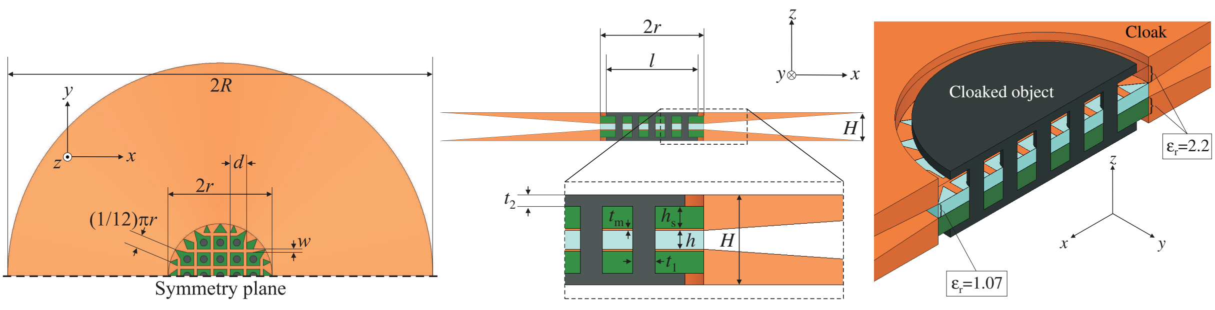
ISBN 978-952-67611-0-7

© 2011 Metamorphose-VI

material used was Rogers RT/Duroid 5880 [4] with ϵ_r = 2.2 and the loss tangent of 0.0009. The insulating layer between the transmission line strips (with height h) was Rohacell [5] with ϵ_r = 1.07 and the loss tangent of 0.0003. In [1], [2] the object to be cloaked was a set of infinitely long vertical metal rods placed inside the transmission line grid. However, in practical applications it would be beneficial if the object to be cloaked could be a fully three-dimensional mesh-like object. This idea was implemented by joining the vertical metal rods together with a periodical set of thin metal tablets as shown in Fig. 2. It was shown in [6] that such a cylinder inside the cloak does not affect the operation of the cloak because practically no fields reach the volume occupied by these tablets.

Table 1: Dimensions of the cloak

d	7 mm	H	12 mm	t_m	0.035 mm
w	1.4 mm	r	22 mm	t_1	3 mm
h	2.5 mm	R	90 mm	t_2	1.54 mm
h_s	3.175	l	39 mm		



(a) (b) (c)

Fig. 1: Cloak geometry for one half of a single cloak layer: (a) xy-plane view (b) xz-plane view (c) cut along xz-symmetry plane (upper substrate invisible).

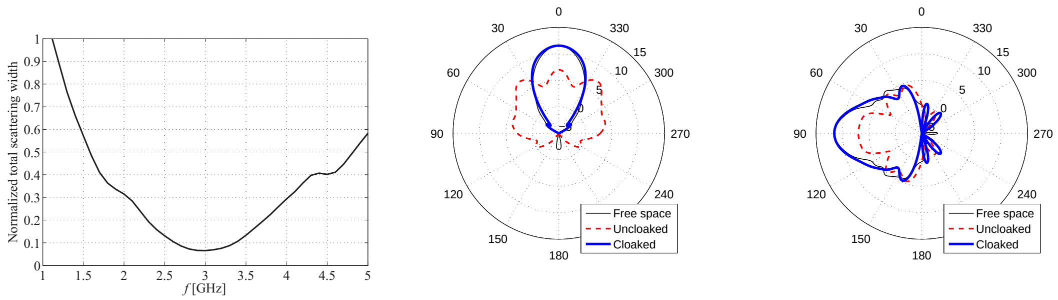
3. Numerical results

First, the total scattering from an infinitely high cloak was studied and compared to the total scattering from the bare metal object to be cloaked. This was achieved by modelling one half of the single layer shown in Fig. 1 and using appropriate symmetry boundary conditions in order to make the structure infinitely periodic in the z-direction. The structure was illuminated with a plane wave with the electric field of the plane wave parallel to the z-axis and the wave vector parallel to the x-axis. The total scattering width of the cloak normalized to the scattering width of the object to be cloaked can be seen in Fig. 2. It can be observed that the cloak works best for 3 GHz frequency with fairly wide operational bandwidth.

Next, the cloaking effect was observed by studying the effect of the cloak on the directivity pattern of a horn antenna, when the cloak is placed in the near field of the antenna. The horn antenna used in the simulations was a model of Schwarzbeck BBHA 9120-A2 [7] which is designed for frequencies 0.75 GHz – 5 GHz. A cloak with the dimensions of Table 1 and geometry of Fig. 1 and with 20 transmission-line layers (making the total height of the cloak equal to 240 mm) was placed so that the cloak was right in front of the horn and the center of the cloak structure was only 100 mm from the aperture of the horn. Corresponding simulation was also conducted for the uncloaked object as well as for the antenna alone in free space. The radiation patterns for the cloaked, uncloaked and free-space cases are shown in Fig. 2 for 3 GHz frequency. Clearly, the cloak decreases the blockage width of the metal object thus making the patterns for the free-space and cloaked cases coincide very nicely while the pattern for the uncloaked case is markedly distorted compared to the free-space radiation pattern.

ISBN 978-952-67611-0-7

© 2011 Metamorphose-VI



(a) (b) (c)

Fig. 2: Simulation results: (a) Scattering width for an infinitely high cloak; (b) Simulated directivity of the horn antenna in the xy-plane (f = 3 GHz); (c) Simulated directivity of the horn in the xz-plane (f = 3 GHz).

4. Practical realization

The manufactured cloak will have some minor differences with the one used in the simulations. Instead of copper, the conical coupling layer is made primarily of aluminium with a 2 mm thick brass ring embedded into the middle. This is done in order to make the whole structure lighter while still making it possible to attach the PCB tranmission line grids to the coupling layer by soldering. Also, the metal cylinders are made of brass and the metal rods of steel instead of copper. However, the combined dimensions of the coupling layer are the same as in the simulations and like in the horn simulations, the cloak consists of 20 transmission-line layers. In the presentation, we will present the measurement results for the radiation pattern of the aforementioned Schwarzbeck horn antenna with and without the cloak placed in front of it.

5. Conclusion

It was demonstrated with numerical simulations that the introduced volumetric cloaking structure effectively reduces the scattering width of a set of metal cylinders placed in free space and also reduces the blockage width of a set of metal cylinders placed in front of and in the near field of a horn antenna. Furthermore, this new cloak design has simpler geometry and is easier to manufacture than the earlier transmission-line cloaks. In our final presentation, its behavior will also be demonstrated for the manufactured cloak.

References

[1] P. Alitalo, F. Bongard, J.-F. Zurcher, J. Mosig and S. Tretyakov, Experimental verification of broadband cloaking using a volumetric cloak composed of periodically stacked cylindrical transmission-line networks, *Appl. Phys. Lett.*, vol. 94, p. 014103, 2009.

[2] P. Alitalo and S. Tretyakov, Broadband electromagnetic cloaking realized with transmission-line and waveguiding structures, *Proc. IEEE*,, in press.

[3] Homepage of Ansoft: www.ansoft.com

[4] Homepage of Rogers Corporation: www.rogerscorp.com.

[5] Homepage of Rohacell: www.rohacell.com.

[6] P. Alitalo, O. Luukkonen, J. R. Mosig and S. A. Tretyakov, Broadband cloaking with volumetric structures composed of two-dimensional transmission-line networks, *Microwave and Optical Technology Letters*, vol. 51, no. 7, pp. 1627-1631, 2009.

[7] Homepage of Schwarzbeck - Mess Elektronik e.K.: www.schwarzbeck.de.