A Two-Port Frequency Reconfigurable Microstrip Element for Conformal Cloaking

Aftab Naqvi*, *Student Member, IEEE* and Benjamin D. Braaten, *Member, IEEE*
Department of Electrical and Computer Engineering
North Dakota State University
Fargo, ND, USA 58108-6050
Email: aftab.naqvi@my.ndsu.edu, benbraaten@ieee.org

***Abstract*—A frequency reconfigurable microstrip element for thin conformal cloaking surfaces is presented here. Initially, a reconfigurable microstrip element with a single-port is designed, simulated and tested. This element is then extended to a two-port reconfigurable design using the same simulation environment validated with measurements of the single-port element. It is shown that the two-port design is suitable for cloaking of conformal surfaces.**

***Index Terms*—Microstrip structures, cloaking.**

I. INTRODUCTION

Having a surface with the ability to direct electromagnetic (EM) waves around an object (i.e., a cloak) has promising applications in radar, phased-array antennas and wireless systems in complex EM environments. This is because a cloak could be used to reduce unwanted interaction between individual antenna elements and the surrounding area. Transformation-based cloaks (TBC) with thick substrates and strict material parameters were among the first developed electromagnetic cloaks [1]. Additionally, plasmonic cloaks [2], transmission line-based cloaks [3] and microwave networks-based cloaks [4] were developed as cloaking surfaces; however, many of these cloaking surfaces are narrowband and require complex manufacturing techniques. Therefore, the objective of this work is to develop a frequency reconfigurable cloaking element capable of operating over two frequency bands of interest and can be manufactured with simple microstrip printing techniques. More specifically, the single-band unit-cell reported in [4] will be adopted here and a new reconfigurable unit-cell will be developed.

II. THEORY AND DESIGN OF THE RECONFIGURABLE ELEMENT

The key idea behind the EM cloak in this work is illustrated in Fig. 1(a). The cloaking surface is used to channel incident EM energy around an object of interest and re-radiate in a direction different from the incident field. This is done by developing the reconfigurable elements shown in Fig. 1(b). When an EM field is incident on the surface in Fig. 1(b), a current is induced on the microstrip patch. Then, with proper matching between elements, the current will travel down the interconnecting microstrip transmission lines (TLs) and re-radiate from other elements.

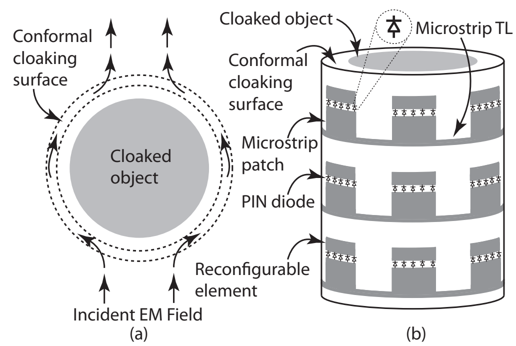

Fig. 1. (a) Top-view illustration of the conformal cloak and (b) side-view of the reconfigurable microstrip cloak.

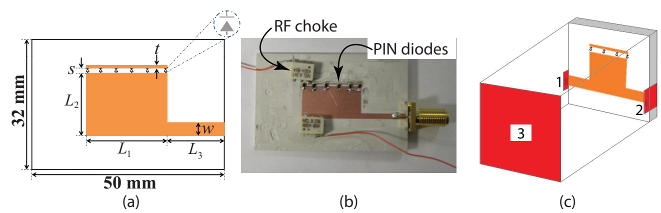

Fig. 2. (a) Single-port element geometry and (b) manufactured prototype for testing (L_1 = 20 mm, L_2 = 11 mm, L_3 = 15 mm, w = 1.92 mm, s = 0.5 mm, t = 0.5 mm and the PIN diodes were manufactured by Skyworks [8] with part number: SMP1322) and (c) two-port reconfigurable cloaking array element model in HFSS.

To design each element of the cloak, the one-port microstrip structure shown in Fig. 2(a) was modeled in ADS [5] and HFSS [6], manufactured and tested. Then, the two-port structure shown in Fig. 2(c) was considered and modeled in HFSS. In HFSS, ports 1 and 2 represent the interconnected elements and port 3 represents the incident field.

The one- and two-port networks will be considered from an S-parameters point of view. Since the third port in Fig. 2(c) represents the incident field, and a reflection is not desired at this port, the value of S_{33} should approach $-\infty$ or $S_{33} \rightarrow -\infty$. Then, to allow current to flow to other elements, $S_{31} = S_{12} = S_{23} = 0$ and $S_{11} = S_{22} \rightarrow -\infty$. Furthermore, since the element is reconfigurable, these conditions are to be met at both frequency bands.

978-1-4799-3540-6/14/$31.00 ©2014 IEEE

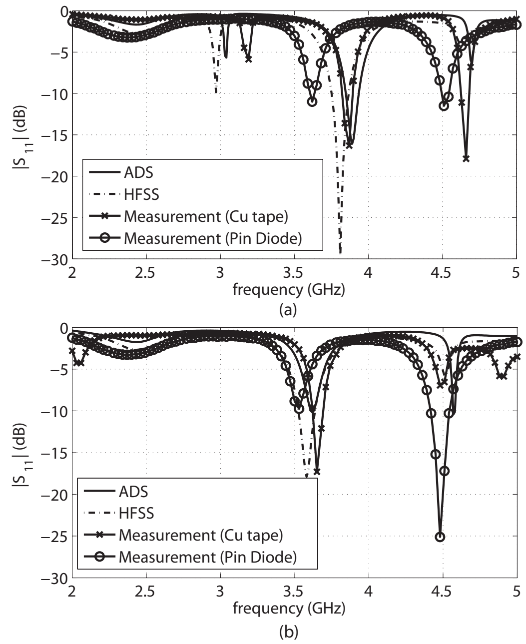

Fig. 3. S_{11} for reconfigurable single-port element when Pin Diodes are (a) OFF and (b) ON (Cu tape is modeled equivalent to pin diodes in simulations so measurements using Cu tape is necessary to agree with simulations).

III. Simulation and Measurement Results

A. The single-port element

The reconfigurable single-port element was evaluated first because it could be measured and used to validate the simulation environment. The element in Fig. 2(a) was designed on a grounded 1.901 mm thick TMM4 ($\epsilon_r = 9.9, \tan\delta = .002$) substrate [7] for switching frequencies of 3.6 GHz and 4.55 GHz in both ADS and HFSS. The dimensions of the element are shown in the caption of Fig. 2 and the PIN diodes were approximately modeled as printed conductors. To verify the simulations, the manufactured element in Fig. 2(b) was measured and the results are shown to agree in Fig. 3. Notice that in both cases, the element resonates at two frequencies. It will be shown in the next section, that the condition where $S_{33} \rightarrow -\infty$ is only satisfied in the switching bands.

B. The two-port element

Next, the two-port element in Fig. 2(c) was simulated in HFSS, expect for this design a TL was added to the opposite side of the reconfigurable patch (for symmetry) and a third-port was defined in the simulator to represent an incident EM field. The dimensions of the TLs were the same as the values in Fig. 2(b). The HFSS simulations results are shown in Fig. 4. Again, the diodes were approximated as printed conductors in HFSS. The results in Fig. 4(a) show a low reflection at port 3 at the 3.68 GHz and 3.89 GHz bands, indicating a frequency reconfigurable cloaking element. Furthermore, Fig. 4(b) shows that the coupling capability between elements of proposed design has been improved by -10 dB as compared to the super thin cloaks presented in [4]; which shows an improvement in the element for both bands.

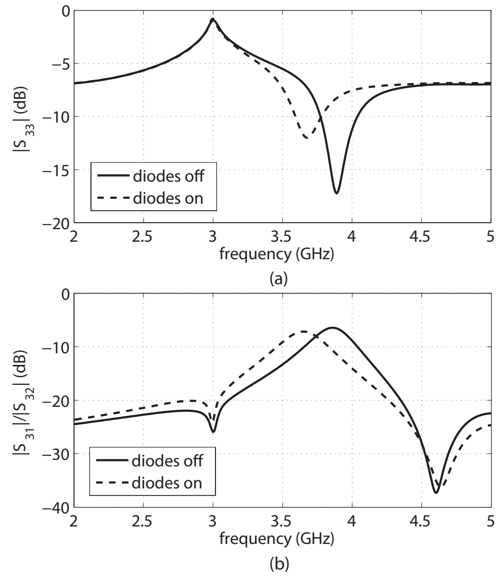

Fig. 4. (a) S_{33} and (b) S_{31}/S_{32} for the three port reconfigurable cloaking array element.

C. Discussion

The single-port results in Fig. 3 show different switching frequencies than the results in Fig. 4. This is thought to be due to the extra TL added to the other side of the reconfigurable patch in Fig. 2(c). Furthermore, a good match was achieved with the single-port structure; however, the radiation properties of the patch may not be significant enough for cloaking.

IV. Conclusion

A frequency reconfigurable element for a thin cloak was investigated in this paper. Initially, a single-port microstrip structure with PIN diodes was designed and presented. Then, this single-port element was used to develop a two-port element suitable for cloaking on conformal surfaces. Overall, simulations were validated with measurements and it was shown that a reconfigurable cloaking element could be designed.

References

[1] J. B. Pendry, D. Schurig, and D. R. Smith, "Controlling electromagnetic fields," *Science,* vol. 312, pp. 1780-1782, Jun. 2006.

[2] A. Al and N. Engheta, "Achieving transparency with plasmonic and metamaterial coatings," *Phys. Rev. E*, vol. 72, Jul. 2005, art.016623.

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

[4] J. Wang, S. Qu, Z. Xu, H. Ma, J. Zhang, Y. Li, and X. Wang, "Superthin cloaks based on microwave networks," *IEEE Trans. on Antennas and Propaga.,*, vol. 61, No. 2, Feb. 2013, pp. 748 - 754.

[5] Advanced Design System-ADS 2004A Agilent Technologies.

[6] High Frequency Structure Simulator, HFSS 2009, Version 11.2, Ansoft, LLC.

[7] Rogers Corporation [Online]. Available: www.rogerscorp.com

[8] Skyworks Inc. [Online]. Available: www.skyworksinc.com