Progress In Electromagnetics Research Letters, Vol. 38, 119–125, 2013

A CONSTANT GAIN ULTRA-WIDEBAND ANTENNA WITH A MULTI-LAYER FREQUENCY SELECTIVE SURFACE

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Abstract—An ultra-wideband (UWB) antenna with a novel multi-layer frequency selective surface (FSS) reflector is presented. A significant enhancement in the gain has been achieved in a low profile design while maintaining the excellent impedance bandwidth of the UWB antenna. The average peak gain of the antenna has been increased from 4 dBi to 9.3 dBi as a consequence of the use of the FSS reflector. More importantly the gain variation within the frequency range from 3 GHz to 15 GHz is only ±0.5 dB. This is a significant improvement from ±2 dB gain variation of the UWB slot antenna without the reflector. This optimized FSS reflector provides the flexibility of mounting a planar antenna close to conducting bodies, including screens and cases.

1. INTRODUCTION

Ultra-wideband (UWB) technology shows great potential in communication systems, impulse radio, and consumer electronic products. The extended bandwidth of UWB is also used for microwave imaging and examples include biomedical imaging, non-destructive detection and ground-penetrating radar (GPR) [1]. Designing high performance UWB antennas for these systems has become one of the most exciting challenges for antenna designers. UWB printed monopole and slot [2–4] antennas designed for these systems present enormous bandwidths

Received 10 February 2013, Accepted 6 March 2013, Scheduled 13 March 2013

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and omnidirectional (OD) radiation patterns up to a certain extent, especially in the lower band of UWB. Unfortunately such antennas lose their OD advantage in some real-world scenarios, for example when mounted on the surface of electronic devices such as entertainment systems, portable hard-disks etc. due to near field interaction and reflection from nearby parallel conduction surfaces. This happens even at lower frequencies of the UWB band. The worst outcome of this is the degradation of antenna matching. On the other hand, in short distance line-of-sight (LOS) applications that only require a limited angular range, an OD pattern are not optimal since most of the power radiates in unwanted directions. In order to provide a good signal-to-noise ratio, antennas with unidirectional or semi OD (wide beam) radiation patterns with higher gains are preferred. An appropriately designed UWB reflector can bring these advantages to existing UWB antennas, as well as shielding from nearby metallic objects that would otherwise compromise matching and bandwidth. It is obvious that a planar metallic reflector does not provide these advantages over an ultra-wide bandwidth due to out-of-phase reflection. Hence appropriate solutions are needed to serve as UWB reflector. Recent developments in periodic structures have helped to solve some crucial antenna challenges. Among other characteristics, these materials offer the possibility of creating a perfect magnetic conductor (PMC) with in-phase reflection over a narrow bandwidth. Insertion of such surfaces enhances matching and hence efficiency of some antennas (e.g., printed planar antennas) when these antennas have to be installed close to conducting surfaces [5]. Frequency-selective surfaces (FSS) and partial reflecting surfaces have been integrated with printed antennas to enhance the performance of the antenna over a narrow or a broad band [6–13]. In [7], a multi-layer FSS ground plane has been incorporated into a reconfigurable printed dipole array to achieve broad band operation and to control the phase of a reflector array. An FSS has also been used as a backing reflector in order to extend the useable frequency range [8]. A dual-layer FSS as reflector has been introduced in [10], which provides a peak gain of 7.3 dBi with a large variation of 3 dB across the bandwidth. In this paper an optimized multi-layer frequency selective surface (FSS) is investigated. One objective is to achieve constant peak gain from a planar antenna over an ultra-wide frequency band. The FSS reflector consists of four different layers, each of them having its own periodicity. In particular, the first layer strongly reflects the higher frequencies and the bottom layer contributes to the reflection at lower frequencies. The intermediate layers reflect mid frequencies. These FSSs are not backed by a metal reflector hence a small amount of transmission through the FSS is allowed, which also leads to a small amount of back radiation. Although this leads to a slight reduction in the gain in the main beam direction, it helps to achieve a constant gain across an ultra-wideband. To prove the concept we have chosen a UWB slot antenna available in the literature [4] as the main radiator and the performance of the slot antenna with the FSS-based reflector is presented in this paper.

2. ANTENNA WITH FSS REFLECTOR DESIGN

The configuration of the FSS reflector and UWB antenna is shown in Fig. 1.

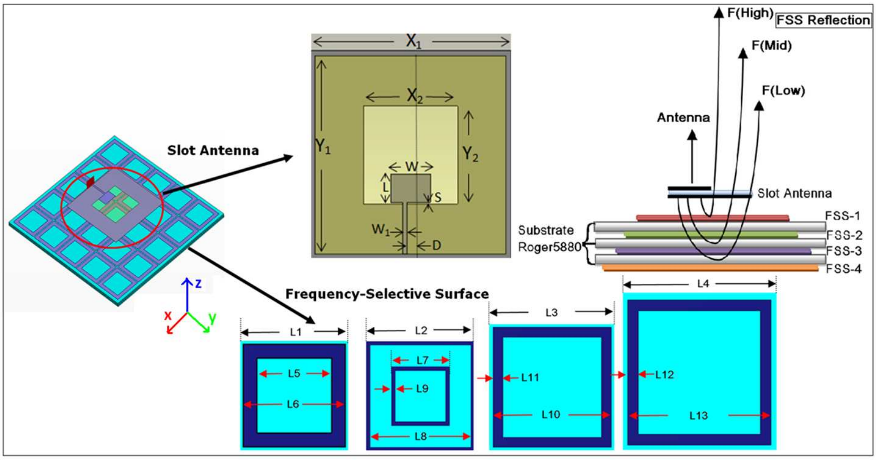

Figure 1. FSS reflector with a UWB slot antenna. (a) Reflection mechanism. (b) Prospective view. (c) Slot antenna parameters. (d) Unit cells of the four FSS layers (all dimensions are in mm).

The predicted return-loss bandwidth of the slot antenna without the reflector is 140% (2.9 GHz–18.38 GHz) [4] and its predicted average gain is 4 dBi. The gain variation is 2 dB over the impedance bandwidth. Our design process started with FSS screens labeled as FSS-1 and FSS-2, which are described in the literature [9]. Two additional layers (FSS-3 and FSS-4) have been designed, added and optimized to achieve performance over wideband. The new layers are built on substrate identical to the first layer on which FSS-1 and FSS-2 are fabricated, and the layers with FSS-3 and FSS-4 are spaced each from the other by similar dielectric with thickness 1.58 mm and having no copper on both sides. Note that FSS-1 and FSS-2 has the same periodicity but, in order to support lower frequencies, FSS-3 and FSS-4 have larger unit cells. The metal in all four layers are optimized to improve the gain flatness when combined with the UWB slot antenna. Fig. 2 shows photographs of the antenna prototype as well as the four FSS layers. The antenna is positioned in front of the FSS screen at a distance of 19 mm.

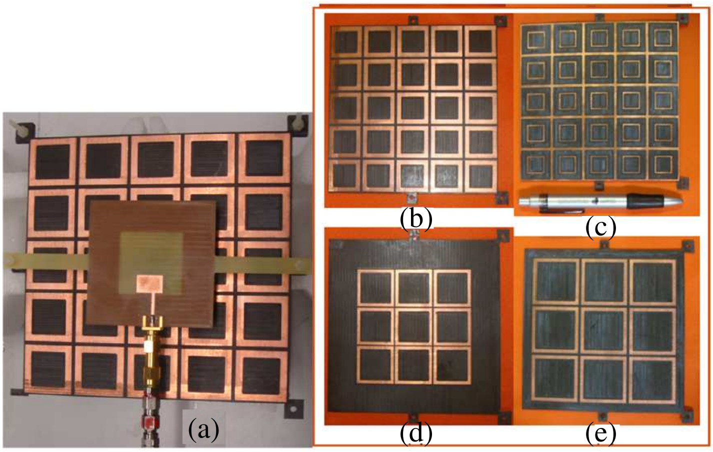

Figure 2. Photograph of prototypes. (a) UWB slot antenna with the FSS reflector. (b) FSS-Layer-1. (c) FSS-Layer-2. (d) FSS-Layer-3. (e) FSSLayer-4.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The predicted input reflection coefficient and the gain are shown in Figs. 3 and 4, respectively. It can be observed that the optimized FSS reflector has only a very small effect on the impedance bandwidth (145% with FSS and 149% without FSS). However, the gain increased significantly with the FSS reflector. A peak gain of around 9.3 dBi is achieved with the FSS, but the most significant feature of introducing the multilayer FSS reflector is the improvement in the gain flatness. The variation in the gain reduces to no more than ± 0.5 dB across the whole impedance band. Measured and computed results are presented in Fig. 4 to confirm the performance of the antenna with the new reflector. Fig. 5 shows the measured radiation patterns in the zy and the zx planes (defined in Fig. 1(b)) at 3 GHz and 6 GHz. A noticeable beam squint is observed at higher frequencies due to the unstable phase centre of the slot antenna. This reflector functionality is not limited to this particular slot antenna which in turn changes the phase error with frequency; one can integrate the reflector to a different UWB antenna with a more stable phase centre.

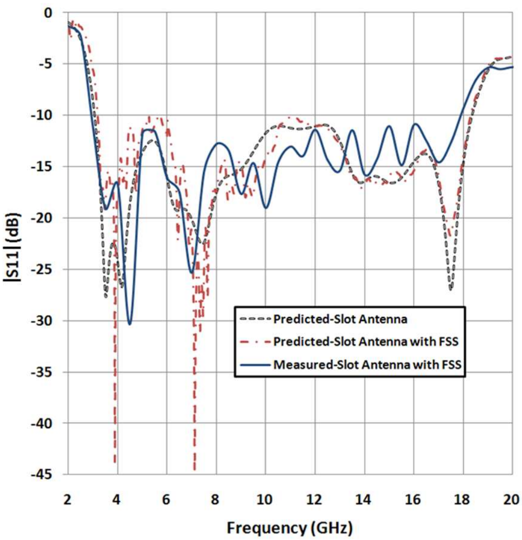

Figure 3. Theoretical and measured input reflection coefficient.

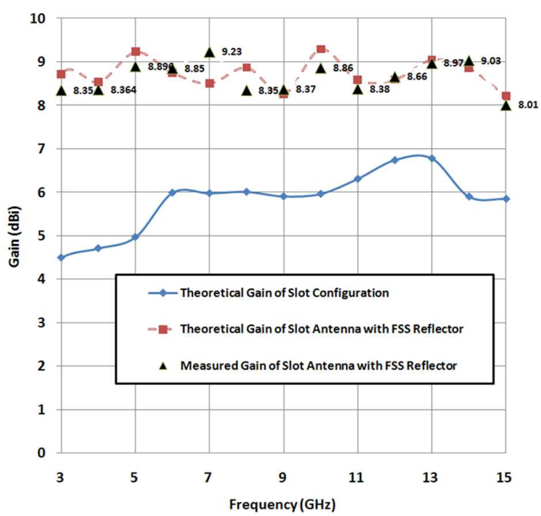

Figure 4. Theoretical and measured gain of the UWB slot antenna with and without the reflector.

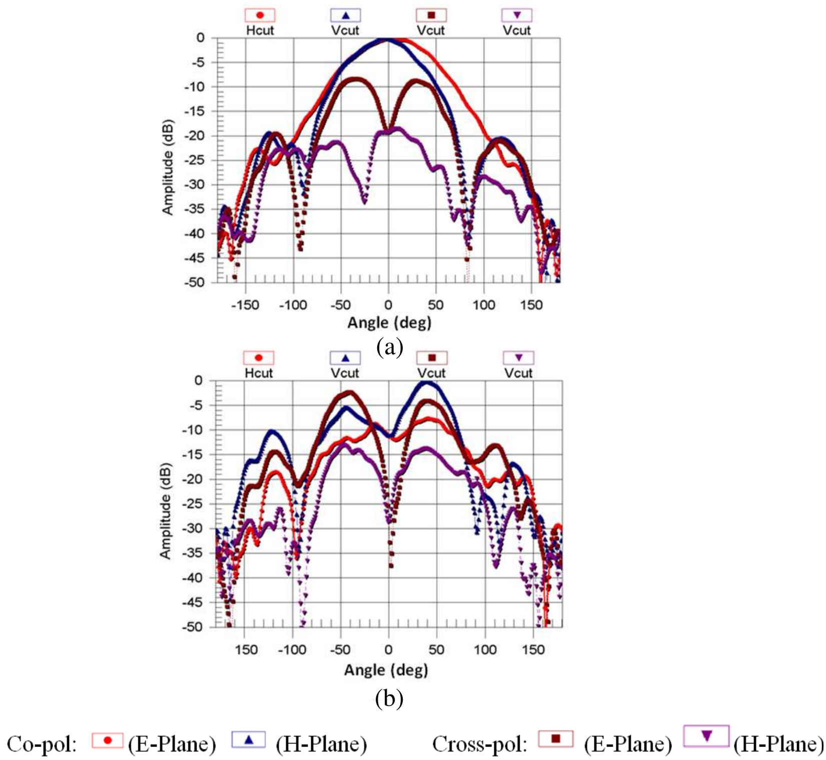

Figure 5. Measured radiation patterns at (a) 3 GHz and (b) 6 GHz.

4. CONCLUSION

The FSS reflector has a very small effect on the impedance bandwidth of the UWB slot antenna (145% with FSS and 149% without FSS). The gain increased significantly with the FSS Reflector. A peak gain of 9.3 dBi has been achieved with the reflector FSS but the most significant advantage of introducing the FSS reflector is the almost constant peak gain across the 145% impedance bandwidth. The variation in gain is only ±0.5 dB across this band. The experimental results confirm that the new four-layer FSS reflector is well suited for UWB systems where a printed antenna needs to be mounted close to a conducting body.

REFERENCES

1. Allen, B., M. Dohler, E. E. Okon, W. Q. Malik, A. K. Brown, and D. J. Edwards, *Ultra-wideband Antennas*

and Propagation for Communication, Radar and Imaging, Wiley-Interscience, 2007.

2. Ray, K. P. and Y. Ranga, "Ultrawideband printed elliptical monopole antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 4, 1189–1192, 2007.
3. Ray, K. P. and Y. Ranga, "Ultra-wideband printed modified triangular monopole antenna," *Electronic Letters*, Vol. 42, No. 19, 1081–1082, 2006.
4. Chen, H. D., J. S. Chen, and J.-N. Li, "Ultra-wideband square-slot antenna," *Microwave Optical Technology Letters*, Vol. 48, No. 3, 500–502, 2006.
5. Engheta, N. and R. W. Ziolkowski, *Electromagnetic Metamaterials: Physics and Engineering Exploration*, Wiley-IEEE Press, 2006.
6. Munk, B. A., *Frequency Selective Surfaces: Theory and Design*, 1st Edition, Wiley-Interscience, 2000.
7. Erdemli, Y. E., K. Sertel, R. A. Gilbert, D. E. Wright, and J. L. Volakis, "Frequency-selective surfaces to enhance performance of broad-band reconfigurable arrays," *IEEE Transactions on Antennas and Propagation*, Vol. 50, No. 12, 1716–1724, 2002.
8. Pasian, M., S. Monni, A. Neto, M. Ettorre, and G. Gerini, "Frequency selective surfaces for extended bandwidth backing reflector functions," *IEEE Transactions on Antennas and Propagation,* Vol. 58, No. 1, 43–50, 2010.
9. Moustafa, M. and B. Jecko, "Design and realization of a wideband EBG antenna based on FSS and operating in the Ku-band," *International Journal of Antennas and Propagation*, Article ID 139069, 2010.
10. Ranga, Y., L. Matekovits, K. P. Esselle, and A. R. Weily, "Multioctave frequency selective surface reflector for ultra-wideband antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 219–222, 2011.
11. Hosseini, M., A. Pirhadi, and M. Hakkak, "A novel AMC with little sensitivity to the angle of incidence using 2-layer Jerusalem cross FSS," *Progress In Electromagnetics Research*, Vol. 64, 43–51, 2006.
12. Zhang, J.-C., Y.-Z. Yin, and J.-P. Ma, "Design of narrow bandpass frequency selective surface for millimeter wave applications," *Progress In Electromagnetics Research*, Vol. 96, 287–298, 2009.
13. Jha, K. R., G. Singh, and R. Jyoti, "A simple synthesis technique of single-square-loop frequency selective surface," *Progress In Electromagnetics Research B*, Vol. 45, 165–185, 2012.