Design of a Novel 0.2 to 40 GHz Ultra-Wideband High-Gain Combined Antenna with and without Dielectric Lens

Ali Mehrdadian, Keyvan Forooraghi

***Abstract*—In this paper, at first, design and fabrication of an ultra wide-band combined antenna will be presented. By using the idea of combined antennas, a TEM horn antenna is combined with magnetic dipoles in order to achieve a good matching for this antenna. Proposing a suitable transition structure from Coaxial cable to the antenna, the discontinuity confronting the wave is reduced and finally, a bandwidth of 180 MHz to 30 GHz is obtained for this structure. Also, the fabrication results for this antenna verify simulation results. In the next step, another wideband element with smaller dimensions will be designed. The small dimensions of this element help its pattern not to deteriorate and not split into parts at high frequencies. Next, a dielectric lens is utilized in its aperture to increase the gain of this element. This lens increases the gain by 11 dB at high frequencies of the band. A bandwidth of 200 MHz to 40 GHz is achieved for this structure. The plots of return loss, pattern in several frequencies, and antenna's gain in terms of frequency will be presented.**

Keywords—Combined Antenna, Electric and Magnetic Energy, Lens, Microstrip Line, Reactive Energy, TEM Horn Antenna.

I. Introduction

When an antenna covering a wide frequency band is used as a standard antenna having suitable radiation characteristics in this band, the measurement can be easily handled for several devices and there is no need to change standard antenna in order to work in different frequency bands [1] [2]. An ultra-wideband (UWB) electromagnetic pulse technique is also rapidly developing [3] [4] [5]. This is due to the fact that these pulses are used widely in radar systems being used for the detection of hidden objects underground. Also, using temporal pulses with a small time width realizes high accuracy detection of objects for the radar systems. A pulse with small time width has a wide frequency spectrum whose reception and transmission needs a wideband antenna. In [6] a DR horn with the bandwidth 1 to 18 GHz with design details has been proposed. Due to the waveguide cutoff frequency, this antenna is not able radiate at low frequencies, and also its pattern becomes split at high frequencies of the band. In [7], a TEM horn with a lens at its aperture with the bandwidth 1 to 22 GHz is proposed. In [8] [9], other wideband antennas including Vivaldi, shark antenna, conical antenna and log-periodic antenna are also investigated. TEM horn antennas are suitable wideband structures which to increase their bandwidth, the idea of combined antenna is used here. In [10] [11], the fields near a symmetric electric dipole with the length 2L placed in a lossless and homogeneous medium is studied. Several structures have been presented for the combined antenna [12] [13] [14] [15] [16].

In this paper the combined antenna idea is utilized to increase the TEM horn bandwidth such that by the combination of the radiated fields of a TEM horn antenna with those of magnetic dipoles, the reactive energy around the structure is decreased and the matching bandwidth is increased. In this paper, design of a wideband combined antenna is presented which finally a bandwidth of 180 MHz to 30GHz is obtained for this element. This element is fabricated and the fabrication results are compared with simulation results. Then, the element dimensions are reduced to improve its response at high frequencies. This smaller element yields the bandwidth 200 MHz to 40 GHz. To increase the gain of this element, a wideband dielectric lens is used in its aperture which increases the antenna gain remarkably all over the bandwidth. The simulation results of this structure are presented by the means of CST.

II. Antenna Design

In order to transmit a temporal pulse with wide frequency bandwidth we need a wideband antenna which makes the least distortion in this pulse. TEM horn antenna is one of the travelling-wave antennas with TEM propagating mode and the propagation velocity is independent of frequency. Hence, several frequencies of pulse spectrum will reach to the antenna aperture simultaneously and therefore, less distortion is occurred in the pulse entered the antenna.

A. Design and Fabrication of Wideband Combined Antenna

TEM horn antenna is like a matching network between 50Ω impedance and the free-space impedance. The structure of this antenna includes two metallic plates. In order to have suitable electromagnetic wave radiation towards free-space, the characteristic impedance variations must be suitably designed along the antenna. To do this task, the distance between two metallic plated and their width must be suitably tapered. Hence, these parameters are the most important factors to achieve a wideband TEM horn antenna. The design procedure of a combined antenna has been proposed in our previous works [14] [15] [16]. To improve the matching for antenna structure and increase its bandwidth, the idea of combined antenna is used. Fig. 1 shows the fabricated combined antenna. Fig. 2 shows the VSWR resulted from simulation and fabrication. In spite of the fabrication process tolerance, a good matching exists between the simulation and fabrication results. This structure yields the bandwidth between 180 MHz and 30 GHz. Fig. 3 shows the antenna pattern resulted from simulation and fabrication in some frequencies which have good agreement.

987-1-5386-8274-6/18/$31.00 ©2018 IEEE

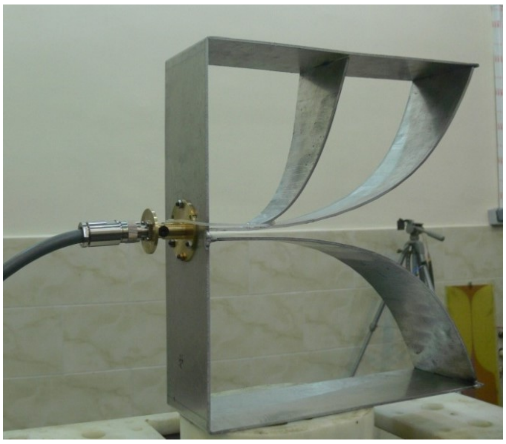


Fig. 1. Fabricated combined antenna

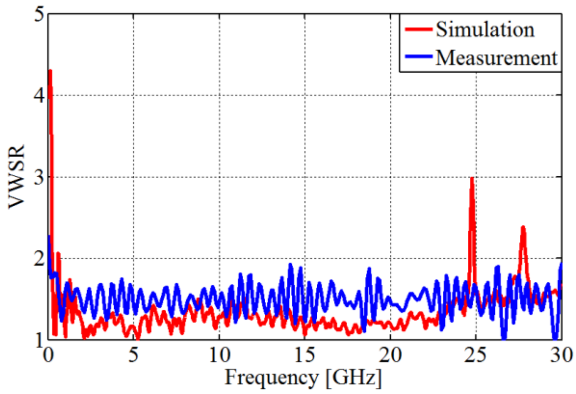
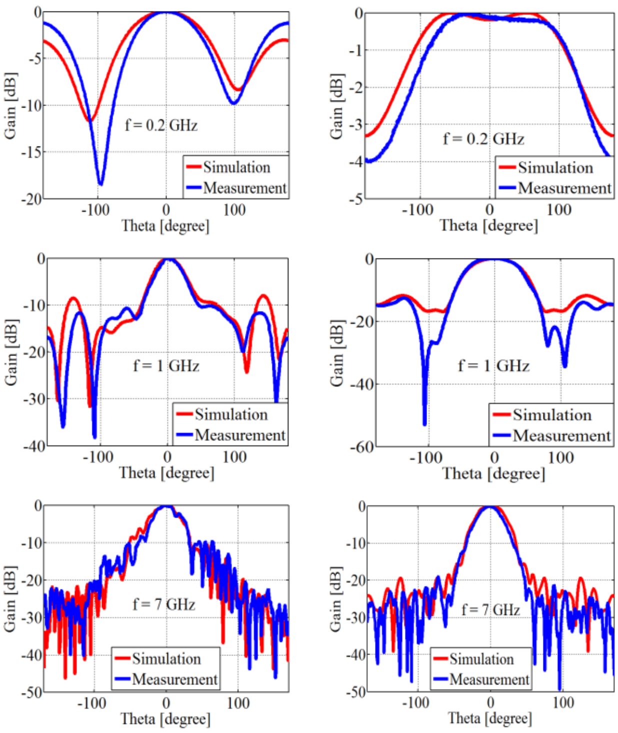


Fig. 2. VSWR resulted from simulation and fabrication



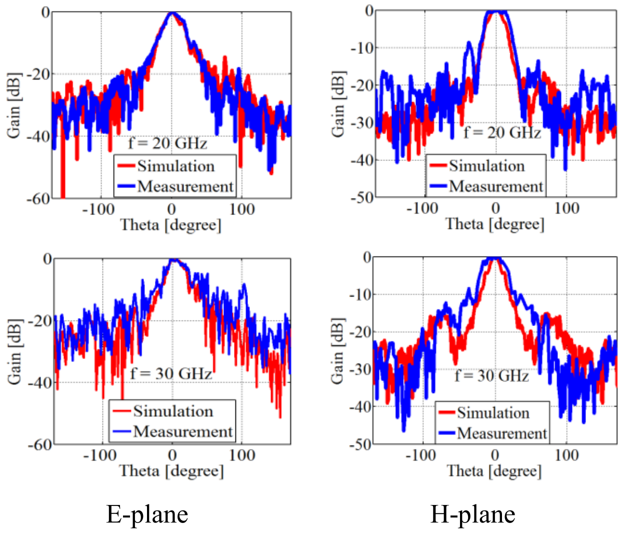


Fig. 3. Antenna pattern resulted from simulation and fabrication.

B. Miniaturization of the Previous Combined Antenna Dimensions

In order to have a better antenna performance such as good matching and pattern at the high frequencies of the band, we reduce the previous element dimensions. To do this, we reduce the distance between two strips at the antenna input by 1 mm which causes reduction of the antenna height by 8 cm. Reduction of the distance between strips at the antenna input, reduces the discontinuities facing the wave, at high frequencies of the band and also improves the matching in these frequencies. Fig. 4 shows the miniaturized combined antenna. This structure demonstrates the bandwidth 200 MHz to 40 GHz.

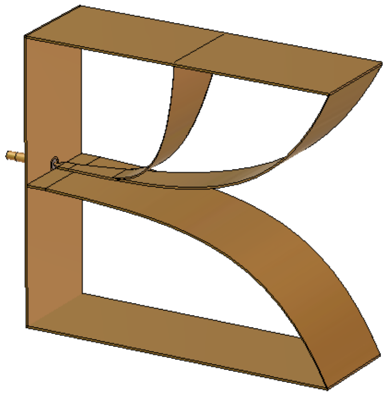


Fig. 4. Miniaturized combined antenna

C. Placing a Wideband Dielectric Lens on the Previous Antenna Aperture

Some ways exist to increase an antenna gain such as arraying the elements, using a reflector or a lens at the front of the antenna. Reflector antennas and lenses are analyzed by the means of geometrical optics. The work basic of these antenna is to generate a uniform distribution in the aperture plane of the antenna. This leads to increase the antenna efficiency and hence increase its gain. By imposing this condition, the design equation of lens surfaces or reflector is obtained. Here, to increase the gain of the element, a simple wideband dielectric lens is utilized. Different shapes such as planar, spherical, hyperbolic, and elliptic shapes are possible to be used for this lens shape. Fig. 5 shows the second wideband element with the lens at its aperture. The inner surface of this lens is circular and its outer surface is hyperbolic. The dielectric used for this surface is Teflon PTFE. The focal distance is one of the effective parameters on the lens performance. The lens focal point must coincide with the phase center of the antenna in order to have the best performance for the lens. Here, the phase center of the antenna has little changes with frequency and so by optimizing the focal distance of the lens, the best performance is achieved for it.

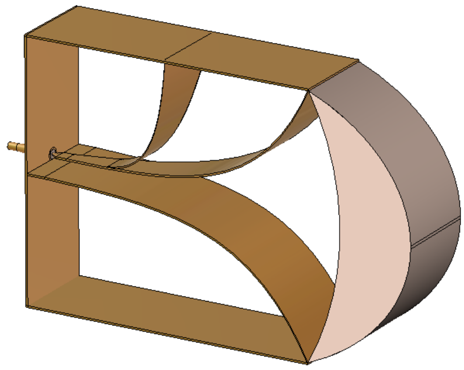


Fig. 5. Miniaturized combined antenna with lens

III. Simulation Results

In each stage of the design, the elements simulation is done by CST. To reduce the simulation time, a PMC symmetry plane is used in the E-plane of the antenna. Fig. 6 shows the return-loss for the second wideband element with- and without the lens. It is observed that adding the lens does not have any important effect on the antenna matching. Fig. 7 shows the second wideband element pattern in H-plane and E-plane with- and without the lens. It is observed that the lens causes condensation in this element pattern.

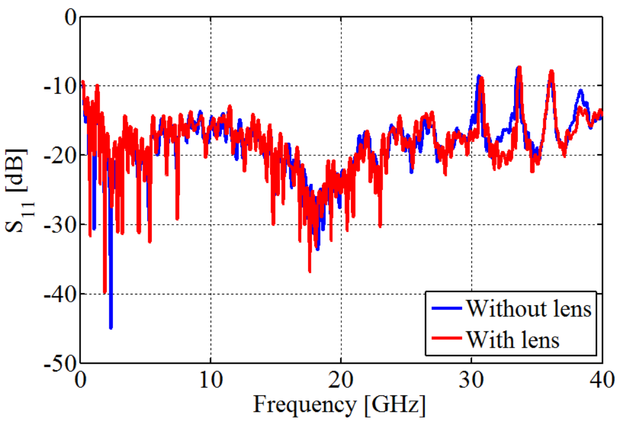


Fig. 6. Simulated return-loss of the proposed miniaturized combined antenna with and without lens

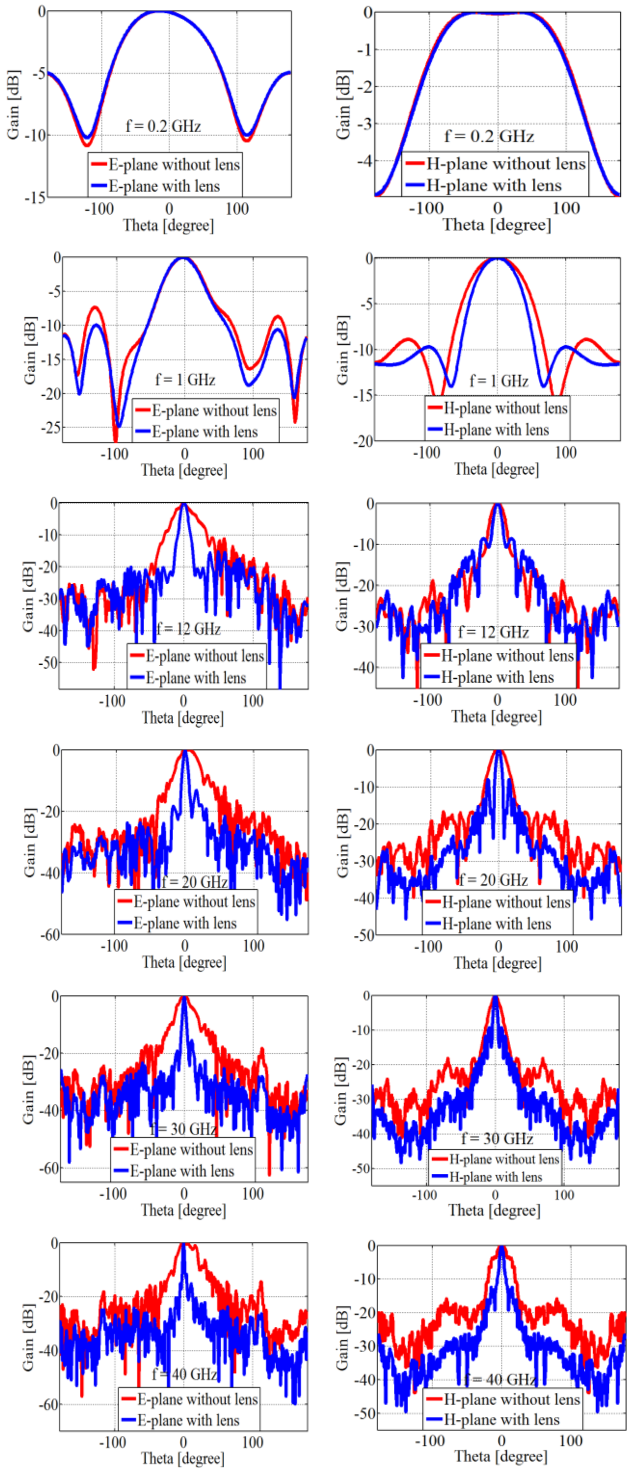


Fig. 7. Simulated radiation patterns of the proposed miniaturized antenna with and without lens at different frequencies

Fig. 8 shows this element gain in terms of frequency with- and without lens. It is observed that adding the lens causes increase in the antenna gain all over the frequency band and this increase at large frequencies of the band is 11 dB.

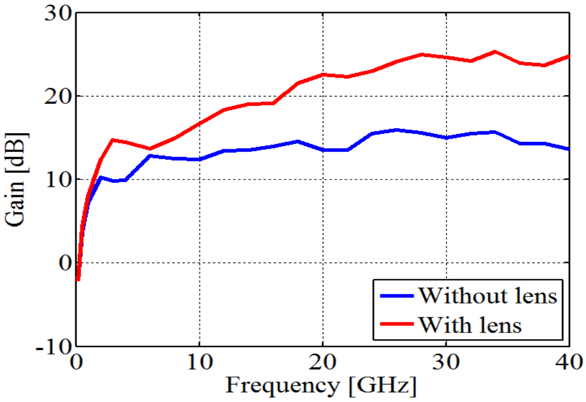


Fig. 8. Miniaturized combined antenna gain in terms of frequency with and without lens

V. Conclusions

In this paper, first, design and fabrication of a wideband combined antenna with the bandwidth 180 MHz to 30 GHz was presented. In this antenna by using the combined antenna idea, the radiated fields of a TEM horn antenna were combined by those of magnetic dipoles and hence, the reactive energy around the antenna was reduced. This caused reduction in the imaginary part of the input impedance of the antenna. The fabrication results verify the simulation results. In the next step, by decreasing the distance between two strips at the antenna input port, the antenna dimensions are reduced. This structure demonstrated the matching bandwidth 200 MHz to 40 GHz and its pattern is suitable all over this bandwidth. To increase the gain of this antenna, a dielectric lens was utilized in its aperture. This lens caused condensation in the antenna pattern and increase in the antenna gain all over the working frequency band. At large frequencies of the band, this increase is 11 dB. The CST simulation results for the element have been presented.

References

[1] M. Abbas-Azimi, F. Arazm, and R. Faraji-Dana, “Design and optimisation of a high-frequency EMC wideband horn antenna,” Microwaves, Antennas & Propagation, IET, vol. 1, no. 3, pp. 580–585, 2007.

[2] A. R. Mallahzadeh and F. Karshenas, “Modified TEM horn antenna for broadband applications,” Progress In Electromagnetics Research, vol. 90, pp. 105–119, 2009.

[3] A. Mehrdadian, H. Fallahi, M. Kaboli, and S. A. Mirtaheri, “Design and implementation of 0.7 to 7 GHz broadband double-ridged horn antenna,” in 2014 7th International Symposium on Telecommunications (IST), 2014, pp. 250–255.

[4] M. Botello-Perez, H. Jardon-Aguilar, and I. G. Ruíz, “Design and simulation of a 1 to 14 GHz broadband electromagnetic compatibility DRGH antenna,” in Electrical and Electronics Engineering, 2005 2nd International Conference on, 2005, pp. 118–121.

[5] O. V. Mikheev, S. A. Podosenov, K. Y. Sakharov, A. A. Sokolov, and V. A. Turkin, “Approximate calculation methods for pulse radiation of a TEM-horn array,” Electromagnetic Compatibility, IEEE Transactions on, vol. 43, no. 1, pp. 67–74, 2001.

[6] C. Bruns, P. Leuchtmann, and R. Vahldieck, “Analysis and simulation of a 1-18-GHz broadband double-ridged horn antenna,” Electromagnetic Compatibility, IEEE Transactions on, vol. 45, no. 1, pp. 55–60, 2003.

[7] Z. Hradecky and A. Holub, “Broadband TEM horn antenna with dielectric lens for UWB measurement,” in Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on, 2009, pp. 3348–3351.

[8] E. W. Reid, L. Ortiz-Balbuena, A. Ghadiri, and K. Moez, “A 324-Element Vivaldi Antenna Array for Radio Astronomy Instrumentation,” Instrumentation and Measurement, IEEE Transactions on, vol. 61, no. 1, pp. 241–250, 2012.

[9] W. Wiesbeck, G. Adamiuk, and C. Sturm, “Basic properties and design principles of UWB antennas,” Proceedings of the IEEE, vol. 97, no. 2, pp. 372–385, 2009.

[10] V. I. Koshelev et al., “High-power ultrawideband electromagnetic pulse radiation,” presented at the Proc. SPIE, 1997, pp. 209–219.

[11] J. Andreev, V. Belichenko, J. Buyanov, V. Koshelev, V. Plisko, and K. Sukhushin, “Synthesis of ultrawideband radiators of nonharmonic signals,” in Mathematical Methods in Electromagnetic Theory, 1996., 6th International Conference on, 1996, pp. 425–428.

[12] Y. A. Andreev, Y. I. Buyanov, V. I. Koshelev, V. V. Plisko, and K. N. Sukhushin, “Multichannel antenna systems for radiation of high-power ultrawideband pulses,” Ultra-Wideband Short-Pulse Electromagnetics 4, pp. 181–186, 2002.

[13] Y. A. Andreev, V. I. Koshelev, and V. V. Plisko, “Combined antennas for radiating ultrawideband short pulses,” in Radar Conference, 2008. EuRAD 2008. European, 2008, pp. 208–211.

[14] A. Mehrdadian and K. Forooraghi, “Design and Fabrication of a Novel Ultrawideband Combined Antenna,” IEEE Antennas and Wireless Propagation Letters, vol. 13, pp. 95–98, 2014.

[15] A. Mehrdadian and K. Forooraghi, “Design of a UWB combined antenna and an array of miniaturized elements with and without lens,” Progress In Electromagnetics Research C, vol. 39, pp. 37–48, 2013.

[16] A. Mehrdadian and K. Forooraghi, “Design of a combined antenna for ultra wide-band high-power applications,” in 2012 Sixth International Symposium on Telecommunications (IST), 2012, pp. 106–110.