DESIGN OF APOLLONIAN GASKET ULTRAWIDEBAND ANTENNA WITH MODIFIED GROUND PLANE

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ABSTRACT: *A printed apollonian gasket monopole antenna with CPW-feed is proposed for ultra-wideband applications. The Ultra-wide bandwidth of this antenna is achieved by modified the CPW ground plane. The experimental result of this antenna exhibits the ultra-wideband characteristics from 2.8 to 15 GHz at VSWR 2:1. The simulated results calculated from high frequency structure simulator are in good agreement with experimental results. The measured radiation patterns of this antenna are omnidirectional in H-plane and bidirectional in E-plane. The radar cross section (RCS) of this antenna is also studied for structural mode and antenna mode scattering. This type of antenna can be useful for a number of applications such as ultrawideband system, radar, ground penetrating radar, medical imaging, and other military applications.* Microwave Opt Technol Lett 54:1793–1796, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26977

Key words: *microstrip antenna; monopole antenna; coplanar waveguide feed; ultrawideband system*

1. INTRODUCTION

The Ultra-wideband (UWB) technology is in more demand in the present days because of high data rate and low power consumption [1]. The UWB system requires the UWB antenna of compact size to be operated in the frequency range 3.1–10.6 GHz. This antenna should have the feature to operate in wider bandwidth with omnidirectional radiation patterns. In open literature, several researchers have reported UWB antennas. Agrawal [2] has reported UWB antenna with direct coaxial feed. But these type of antenna required very large size vertical ground, which increase the overall size of antenna and also not suitable to integrate with MIC and MMIC devices. Some researchers have reported the UWB antennas with microstrip feed on partial microstrip ground [3], whereas many have reported the planar antenna with CPW-feed [4–6]. The CPW-feed technique is a simple and cost-effective technique. This technique provides the wide bandwidth, good radiation pattern, and suitable for integration with MIC and MMIC devices. It is noticed from published research work that ultra-wide bandwidth of antenna using circular shape is easy to achieve [7, 8]. But rectangular and square shape monopole antenna exhibit less bandwidth compare to circular and elliptical shape [9]. The research work of UWB monopole antenna with simple triangular shape has not been much reported. It required some modification either in the ground plane or in patch to achieve the Ultra-wide bandwidth. Similarly, simple apollonian gasket monopole antenna does not offer ultra-wide bandwidth [10]. To have the ultra-wide bandwidth with apollonian shape monopole antenna with CPW-feed, some modification in ground or patch is required. This article reports the apollonian gasket monopole antenna with CPW-feed for ultra-wide bandwidth.

It is known that scattering of antenna contributes the RCS in low observability platform. So, the RCS of UWB antenna is important to study. The RCS of antenna depends on the open, short, and matched load termination of antenna. It is also known fact that this termination affects the low RCS of antenna and good radiation patterns [11]. With the advent of target identification technology, UWB antennas with low RCS become important for the survivability of the antenna platforms [12].

This article discusses the UWB apollonian gasket monopole antenna with CPW-feed. The ultra-wide bandwidth of this antenna is achieved by modifying ground plane. The RCS of this UWB antenna has also been studied for open, short, and matched load termination. Antenna mode and structural mode scattering has also been calculated from simulated results of these terminations. This antenna has been discussed in terms of validation of experimental results with simulation results, measured radiation patterns, effects of various design parameters on bandwidth, and backscattering of antenna.

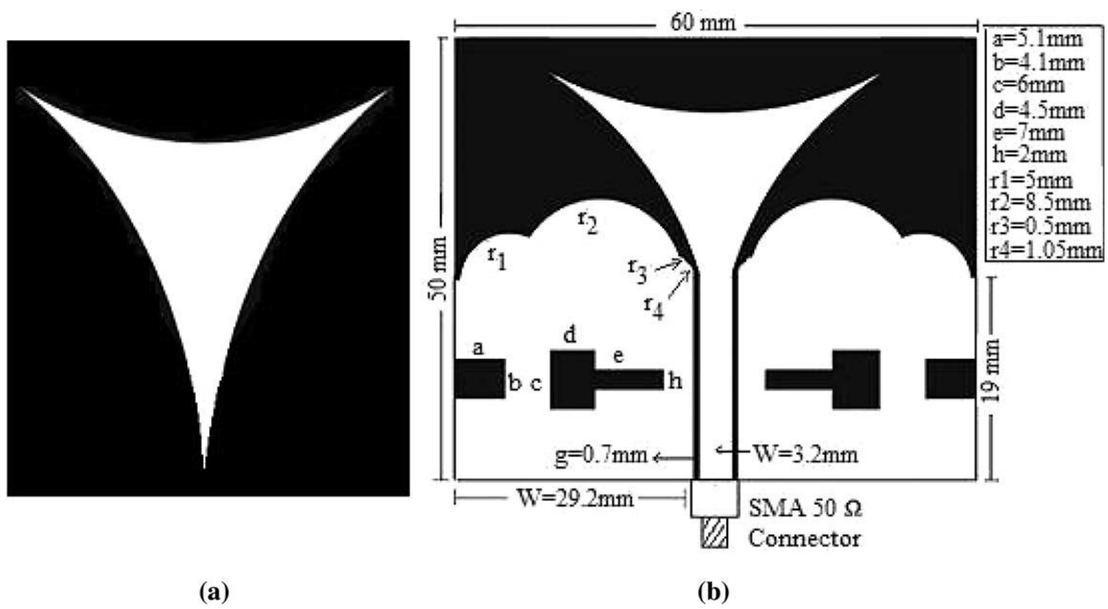

Figure 1 Apollonian monopole antenna having substrate thickness = 1.53 mm, ε_r = 4.3

2. ANTENNA GEOMETRY

The apollonian gasket monopole antenna is excited with CPW-feed as shown in Figure 1. In apollonian monopole antenna, apollonian gasket is made by having three tangential circles of diameter 75 mm. These three tangential circles are arranged in such away that all the three circles are touched each other. These tangential circles are subtracted from the metal cladded FR-4 substrate of dielectric constant $\varepsilon_r = 4.3$ and thickness $h =$ 1.53 mm as shown in Figure 1(a). The apollonian gasket is formed by intersection of three 75-mm circles and tip to tip dimension of apollonian ideally is 37.5 mm, but it is truncated with 35 mm. The care has been by keeping fabrication constraints. This structure has been fed with CPW-feed as shown in Figure 1(b). First, the apollonian gasket is fed with CPW-feed reactangular ground plane. With rectangular ground plane, it is noticed that it is not possible to achieve the Ultra-wide bandwidth of antenna. To have the UWB of apollonian gasket monopole antenna, some modification is required in the ground plane. By modifying the ground, the ultra-wide bandwidth of apollonian gasket monopole antenna is achieved. The optimized dimension of antenna and modified ground is shown in Figure 1(b). Optimized dimensions are achieved using 3D Electromagnetic simulator based on finite-element method (FEM), high frequency structure simulator (HFSS).

3. SIMULATED AND EXPERIMENTAL RESULTS

Apollonian monopole antenna has been simulated with FR-4 substrate for substrate height = 1:53 mm and dielectric constant $\varepsilon_r = 4.3$, having the substrate size 50×60 mm^2. Simulation of the antenna has been performed for various design parameters as well as with modified ground plane. First, ground width, ground length, feed width, and feed gap are optimized for best achievable result. The simulation result with these parameters is shown in Figure 2. It is observed that reflection coefficient is very poor throughout the band. To improve the reflection coefficient, semicircles r_1, r_2, r_3 and r_4 are added in ground plane and optimized. For further improvement, rectangular slot and T-shape slot in both side of ground are also optimized for their width and length. The optimized values of all semicircles are r_1 = 5 mm, r_2= 8.5 mm, r_3 = 0.5 mm, and r_4 = 1.05. The optimized dimensions of rectangular slot are in length a = 5.1 mm and width b =4.1 mm. T-type slot dimensions are c = 6.0 mm, d = 4.5mm, e = 7.0 mm, and h = 2.0 mm. The proposed antenna with optimized dimension is shown in Figure 1. The simulated reflection coefficient with and without modified ground plane are compared in Figure 2. A drastic improvement

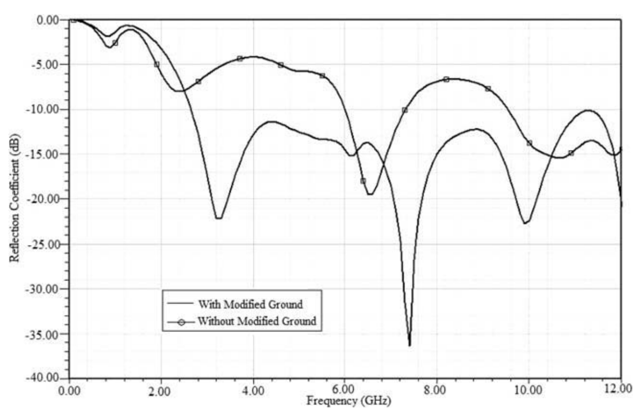

Figure 2 Simulated results with and without modified ground plane

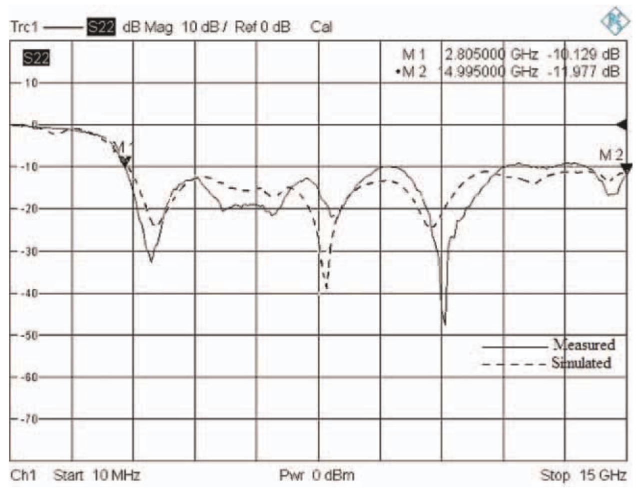

Figure 3 Experimental and simulated results of proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

in the reflection coefficient is obtained with modified ground throughout the band.

This antenna has been fabricated with optimized dimension. The performance of antenna is evaluated experimentally using ZVA40 R&S vector network analyzer. The measured reflection coefficient offers the UWB characteristics from 2.8 to 15 GHz at VSWR 2:1. This corresponds to 137.08% impedance bandwidth. The experimental reflection coefficient is compared with the simulated reflection coefficient done using HFSS. They are both in good agreement throughout the band as shown in Figure 3. It is also observed from Figure 3 that simulated and measured results are slightly varies. This may be due to the tolerance in manufacturing, uncertainty of the thickness, and/or the dielectric constant and lower quality of SMA connector (VSWR = 1.3). The differences between simulated and experimental value may also be caused by the soldering effects of an SMA connector, which have been neglected in our simulations. The SMA connector is not taken into account in all of the simulations so as to ease the computational requirements.

The simulation has also been carried out for various design parameters to observe the effect on impedance bandwidth. These design parameters are ground width, ground length, and gap between feed and ground. The effect of the ground length and ground width is simulated for various values. The antenna has been simulated for various widths of ground plane from 27.2 to

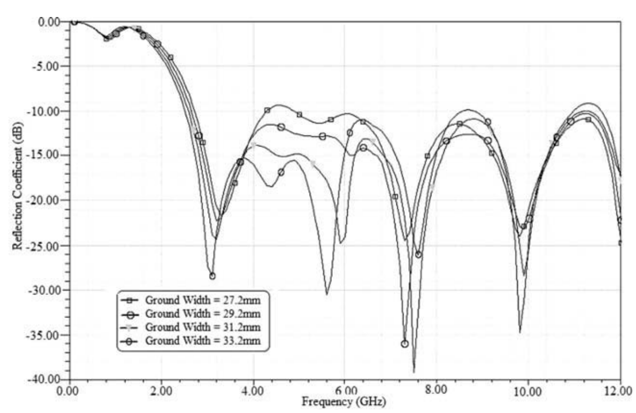

Figure 4 Simulated result of proposed antenna for various ground widths

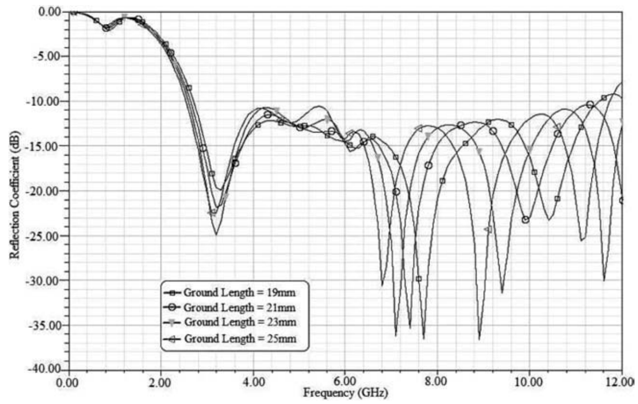

Figure 5 Simulated result of proposed antenna for various ground lengths

33.2 mm with the step of 2.0 mm keeping all design parameters fix. The simulated results of various ground width is shown in Figure 4. It is observed that as the ground width increases, the lower resonant frequency shifts slightly to the lower frequency side. But, there is an optimum width of ground that will provide the optimum bandwidth of the antenna. More or less than this width value, bandwidth is effected at higher frequency side resulted into the smaller bandwidth. This is obvious, because current distribution over the ground plane is along the width. As the width increases or decreases, in the way current over the ground plane and gives inductive effect. Here, ground plane acts as a resonant circuit which affects the higher frequency for ground width other than optimum ground. The effect of ground length is also simulated for various value of ground length. The simulated result is shown in Figure 5 for ground length from 19 to 25 mm with the step of 2 mm. It is observed from the simulated results, as the ground length increases the lower end frequency shifts toward lower frequency side. But, there is no significant change observed at higher frequency side. It can be said that ground length does not have any significant effect on the bandwidth of antenna. It is obvious, because current distribution of the antenna ground plane is along the ground width but not along the ground length. The optimum length of ground plane is obtained 19.0 mm.

4. RADIATION PATTERNS

The radiation patterns of proposed antenna are measured in in-house anechoic chamber using antenna measurement system interfaced with vector network analyzer. The radiation patterns in *E*-plane and *H*-plane have been measured at selective frequencies. The *H*-plane radiation patterns are measured at 3.04, 4.51, 7.02, and 10.2 GHz, whereas the radiation patterns in *E*-plane are measured at 3.11, 4.1, 6.04, 7.5, and 10.5 GHz. The measured radiation patterns are omnidirectional in *H*-plane and bidirectional in *E*-plane as shown in Figures 6(a) and 6(b), respectively.

5. BACKSCATTERING OF PROPOSED ANTENNA

The monostatic RCS or backscattering characteristics of apollonian gasket antenna have been studied. The study of backscattering is done in different load conditions, that is, open, short, and matched load termination. The backscattering has been calculated for antenna mode and stuructural mode from these open, short, and matched load termination simulated results [11, 12]. The simulated results of monostatic RCS versus frequency with respect to open, short, and mached load (structural mode) are shown in Figure 7. It is observed that the backscattering is small at lower frequency, because antenna size is smaller than the wavelenth of operating frequency. At higher frequency, the backscattering is increased, because antenna size becomes comparable to the operating wavelength. The antenna mode and structural mode scattering has been calculated from the tabular form simulated results of open, short, and matched load termination. From these tabular form results, the antenna mode and structural mode scattering is calculated using fomulation $\sigma = |\sqrt{(\sigma_s)} + \sqrt{(\sigma_a)}e^{j\Phi}|^2$ [11, 12] in microsoft excel and plotting the graph. The results of antenna mode and structural mode scattering are shown in Figure 7. The RCS for structural mode is

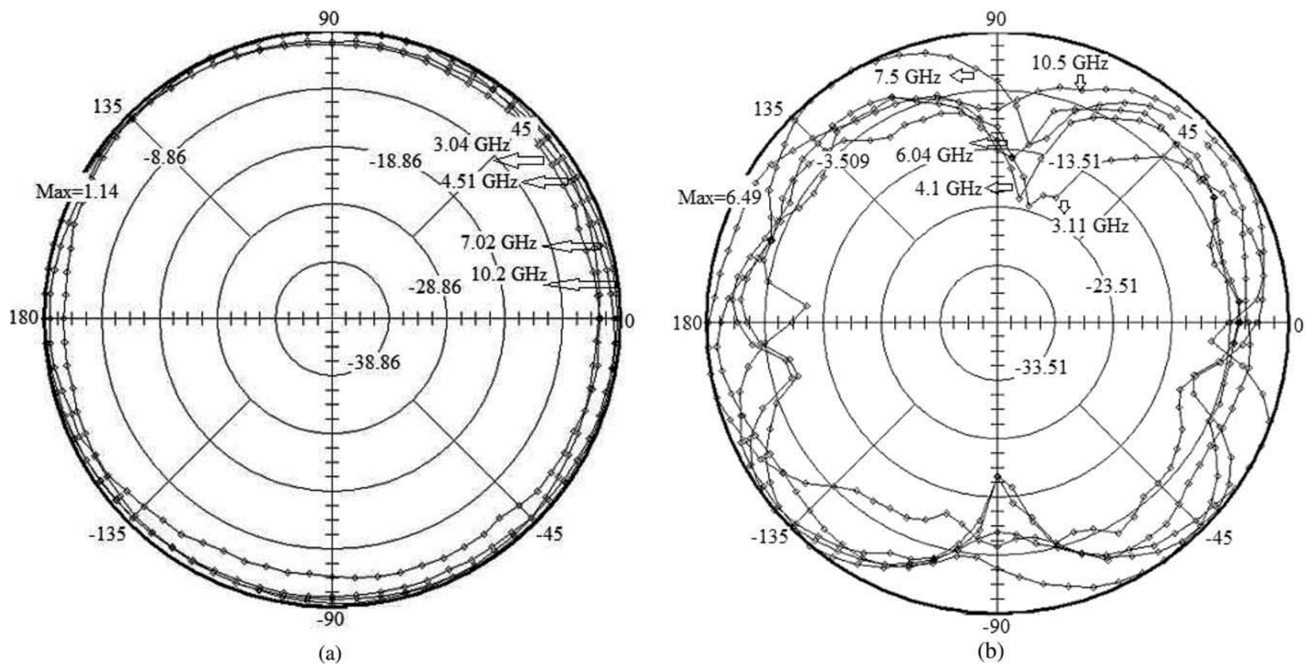

Figure 6 (a) Experimental radiation patterns in *H*-plane at 3.04, 4.41,7.02, and 10.2 GHz; (b) *E*-plane at 3.11, 4.1, 6.04, 7.5, and 10.5 GHz

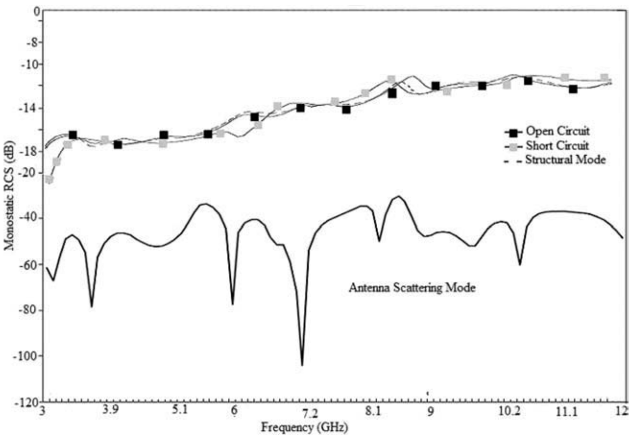

Figure 7 Simulated RCS with open circuit, short circuit, antenna mode, and structural mode scattering

equivalent to the RCS with matched load termination. It is observed that this antenna exhibits the good monostatic RCS. It makes this antenna the good potential candidate for transmitting/receive the high data rate in military environment.

6. CONCLUSIONS

The apollonian gasket monopole antenna is designed and implemented experimentally. The antenna offers the UWB characteristics from 2.8 to 15 GHz corresponds to 137.08%. The modified ground CPW-feed made it possible to achieve the bandwidth beyond FCC band. The experimental reflection coefficient is found to be very close to simulated results. The measured radiation patterns are almost omnidirectional in *H*-plane and bidirectional in *E*-plane. The backscattering characteristic of antenna is also calculated for antenna mode and structural mode scattering. The antenna mode scattering of this antenna indicates the potentiality of this antenna for military applications to transmit/receive the high date rate with high speed. This antenna is simple to fabricate and integrate with MIC/MMIC devices. This antenna can be useful for UWB system, ground penetrating radar, and medical imaging.

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DESIGN OF A FULLY INTEGRATED WIDEBAND SIX-PORT NETWORK ON A SINGLE LAYER MICROSTRIP SUBSTRATE

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ABSTRACT: *The design of a novel wideband six-port network on a single layer microstrip substrate is presented. Two different configurations of the single-layer six-port networks, one conventional and the other nonconventional, are designed, fabricated, and measured. The six-port network based on the conventional configuration is formed by one Wilkinson divider and three couplers, with one unused port terminated with a coaxial match termination. The nonconventional six-port network, proposed here, is constructed using a similar configuration except one of the couplers is replaced by a quadrature power divider eliminating the need for match termination. To obtain fully planar device with wideband operation, the six-port networks use double-stage Wilkinson dividers, disk type couplers, and a wireless via 90° phase shifter. Their performances are assessed via full-wave electromagnetic simulations and measurements. Both the simulated and the measured results show a wide bandwidth of the two six-port configurations in terms of amplitude and phase characteristics across the frequency band of 4.5–8.5 GHz.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:1796–1803, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26976

Key words: *six-port network; planar elliptical coupler; wireless via phase shifter; Wilkinson power divider; single layer technology*

1. INTRODUCTION

Six-port networks are widely used in many fields, such as reflectometers in microwave measurement systems [1–3], phase detectors in positioning systems [4–7], direct phase shift keying modulators [8–10], and correlating demodulators in a direct conversion receiver [8, 10–12]. Recently, there has been a considerable interest in designing of planar integrated six-port network with wide operational bandwidth.

Most of six-port designs presented in the open literature are moderate in terms of operational bandwidth, and their design is