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DESIGN OF DUAL STUB LOADED MONO AND BI-PLANE CENTER-FED MICROSTRIP BOW-TIE ANTENNAS FOR WIRELESS APPLICATIONS

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Abstract
Design approach of the extended model for dual-band operation of traditional frustoconical-shaped microstrip bow-tie antennas in mono and bi-plane topologies is presented and investigated numerically by simulations. Numerical investigations of the input characteristics are carried out using an electromagnetic approach based on transmission line theory in traveling-waves. Electrostatics approach solution is used to perform the calculation of the radiated electric field pattern. Some input and output performances of the designed extended model of the proposed antennas such as a dual-band, a -10dB return loss bandwidth of about 88%, a half power beam-width of about 90° and a stable gain of about 5.5dB have been achieved.

Keywords: dual stub loaded bow-tie antenna, mono/bi-plane topology, wireless applications, impedance bandwidth, radiated field pattern.

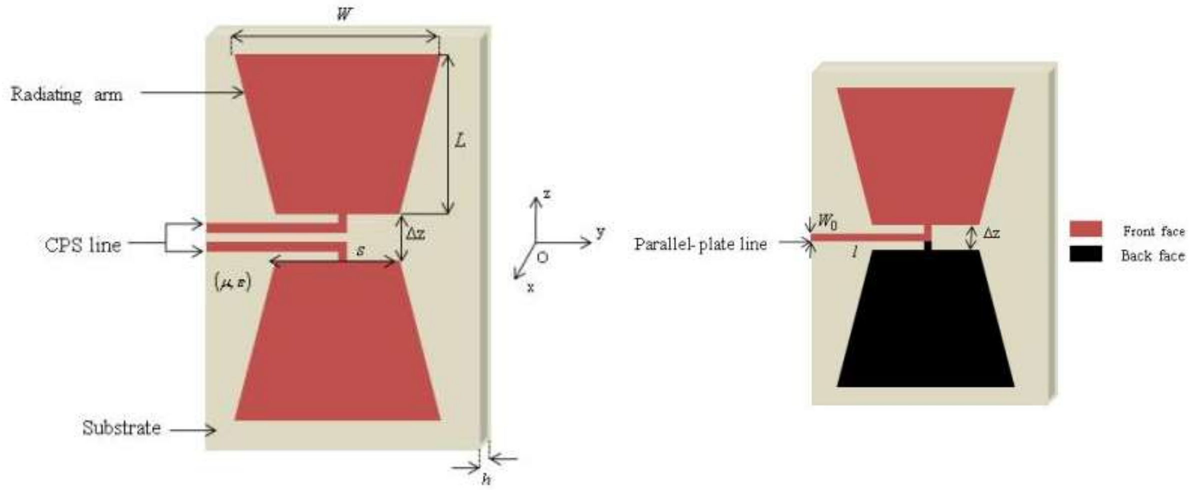
Introduction
It is known to every Amateur Radio that the free ham networks are vulnerable to the external environment because of various disturbances. The reason being that, the so co-called Industrial-Scientific-Medical (ISM) and the amateur radio bands operating in the frequency bands of 2.4 and 5GHz respectively are not subject to any rigorous regulation [1]. One of the solutions to workaround is the use of radiating elements that have certain characteristics such as a low band-width and a narrow beam-width. Microstrip bow-tie antennas have been identified as those radiating elements capable of responding at these characteristics and even more. They can also be used in wireless communication technology where multiband and ultra wideband (UWB) applications are in demand.

Several analytical and numerical approaches are proposed to design and improve the performances of the microstrip bow-tie antennas. The hybrid Bacterial Swarm Optimization (BSO) and Nelder-Mead (NM) algorithm are used to adjust the dimensions of the studied bow-tie antenna to be resonant at 2.45GHz for a matched input impedance (Z_{in}) of 50Ω [2]. Microstrip bow-tie antennas with different shapes have been designed for wireless communication technology. In [3] modified end-fire bow-tie antenna for wide band communication systems is proposed. A modified broadband bow-tie antenna using rectangular slot is reported in [4]. Several design technologies based bow-tie shaped have been proposed for dual-band operation [5-6].

In this work numerical approaches to characterize two topologies of the frustoconical-shaped microstrip bow-tie antennas made to work at 2.4GHz are proposed. The mono and the bi-plane topologies fed at their center by a 50Ω coplanar strip line and an ideal plane parallel-plate microstrip transmission line respectively are reported. Design step of the extended model for dual-band operation of the considered antennas is performed and investigated numerically by simulations using a moment method-based commercial full-wave EM simulator Momentum of Advanced Design Systems (ADS). Numerical investigations of the input characteristic based on the electromagnetic theory of transmission lines in traveling-wave were conducted. Radiated electric field calculation is carried out using electrostatics approach in the transverse electromagnetic (TEM) mode approximation. Calculation, simulation and measured results are discussed and close agreement with theoretical predictions has been established.

Design considerations

In many microwave applications, planar microstrip structures are widely used. Planar microstrip structures are realized by placing metallic strips, or cutting slots into metallic planes, which are generally backed by dielectric layers used both for mechanical support and to obtain a better confinement of the electromagnetic fields [13-14]. Hence, microstrip bow-tie antennas are realized by placing radiating arms on a dielectric substrate characterized by its thickness h and its constitutional parameters, permeability μ and permittivity ε. Many planar shapes of the conductors supporting wave propagation of the studied antennas are presented and studied [15]. In this work the frustoconical plane-shaped has been significantly considered. Two configurations of feed modes have been investigated namely, the mono-plane center-fed by the means of a coplanar strip (CPS) line and the bi-plane center-fed using an ideal plane parallel-plate microstrip transmission line as illustrated in Figure 1.



(a) ***(b)***

Figure 1: Frustoconical-shaped microstrip center-fed bow-tie antennas: (a) coplanar strip feed line mono-plane topology and (b) ideal finite plane parallel-plate feed line bi-plane topology

In order to design a microstrip bow-tie antenna in a mono or a bi-plane topology, certain specifications can be made. The design approach is based on the antenna sizing. Whatever topology is considered, the primary parameters are identical. Very often, some antenna parameters such as the antenna electric length $L \cong \frac{\lambda_0}{2}$ should be adjusted more precisely, to make up the resonant frequency. In a bi-plane topology, the excitation gap width Δz must be considered as an important parameter for a good impedance matching. To enhance impedance-matching, radiating arms must be meanly intertwined at the feed region (or matching zone). As it was shown, traditional frustoconical-shaped microstrip bow-tie antennas provide a single resonance with an acceptable match and a wide bandwidth.

Proposed modification

The prototype of the extended model of the conventional frustoconical-shaped microstrip bow-tie antennas that work at two frequencies f_1 and f_2 and exhibit ultra-wideband return loss bandwidth as shown in Figures 2 and 3 are discussed.

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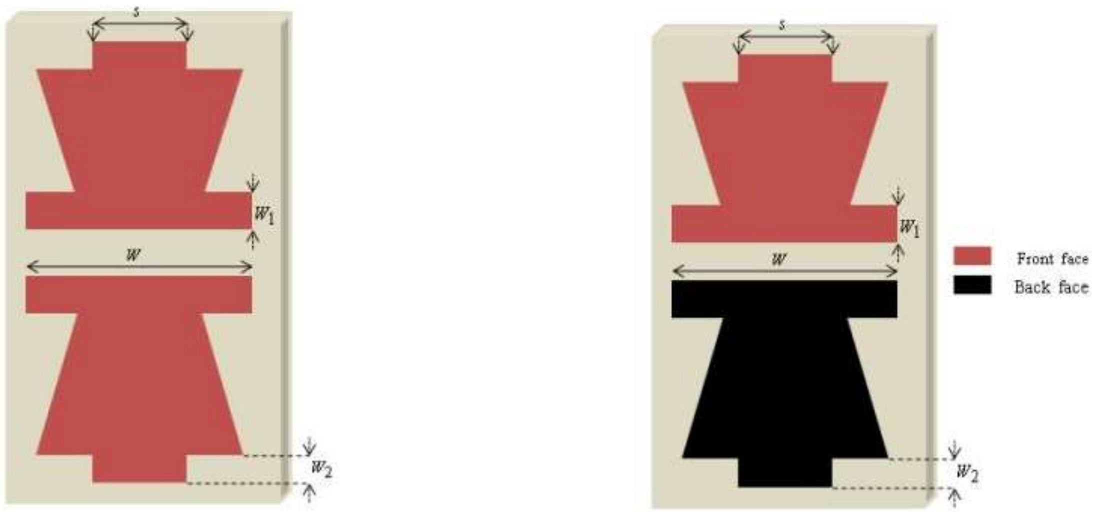
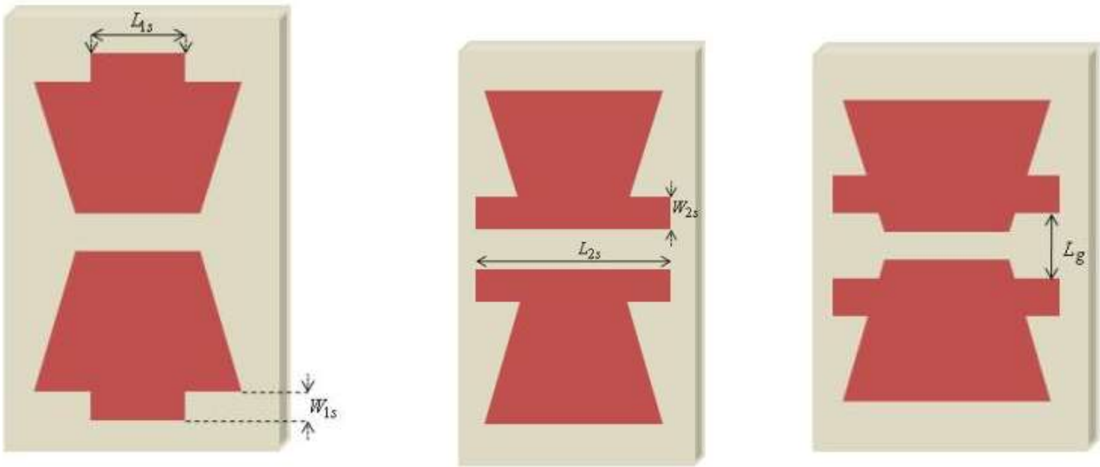


(a) ***(b)***

Figure 2: Prototype of the proposed extended model of the studied microstrip center-fed bow-tie antennas: (a) mono-plane topology and (b) bi-plane topology

The proposed modification to achieve the extended antenna model consists of a conventional frustoconical-shaped microstrip bow-tie antenna dual-loaded at the smaller and larger bases by a rectangular stub of dimensions $W \times W_1$ and $s \times W_2$ respectively. By adjusting the load dimensions and positions as depicted in Figure 3, a desired dual-band and an ultra-wideband operation for the mono-plane topology and the bi-plane topology respectively can be achieved.

Also, the desired resonant frequencies could be obtained by adjusting the combination of the primary parameters of the basic antenna and the load dimensions. In this design, the frustoconical bow-tie section controls the first or lower operating band of the proposed antennas. The loads of the stub type are used to generate a new (higher) resonant mode. The overall size of the proposed extended prototype is the same as those of the basic structures discussed in the previous section. By choosing the optimized parameters as reported in Table 1, the proposed structures satisfied the requirements for the ISM bands.



(a) *(b)* *(c)*

Figure 3: Prototype of the proposed extended model of the studied microstrip center-fed bow-tie antennas in mono-plane topology to investigate the load dimensions and positions on the input characteristics: (a) larger base stub-loaded, (b) smaller base stub-loaded and (c) effects of smaller base stub-loaded position

Table 1. Optimized parameters of the studied microstrip bow-tie antennas in mono and bi-plane topology

Antenna parameters (mm)	L	W	s	Δz	l	W_0	W_1	W_2
Mono-plane topology	19.5	27	9	7	25	2	5	3
Bi-plane topology	17.5	27	9	4	25	2	5	3

Radiated field calculation

Experimentaly, it was demonstrated that microstrip bow-tie antenna radiates the same way as the dipole antenna but no calculation method was proposed. In this project some electrostatics approach solution is used to perform the calculation of the radiation pattern for the considered antenna. Hence, we assumed that conductive strips are uniformly loaded with a constant and positive surface density σ. An infinitesimal element of surface ds' centered at the source point P has an elementary charge $dq = \sigma ds'$. The elementary electric field radiated at the point M so far from the source point P is in the form

$$d\vec{E} = \frac{\sigma ds}{4\pi\varepsilon_0} \frac{\vec{u}_{PM}}{PM^2} e^{-\vec{k}_0 \overrightarrow{PM}} \qquad (1)$$

In theory we have $\overrightarrow{PM} = \overrightarrow{OM} - \overrightarrow{OP}$ but for the far zone radiated field we assumed that $\overrightarrow{PM} // \overrightarrow{OM}$ so that $PM = r$ in the amplitude term while $\overrightarrow{PM} = r\vec{e}_r - \overrightarrow{OP}$ in the phase term. We can clearly observe that the studied distribution has the x-y plane as unique symmetric plane as illustrated in Figure 1. Hence, the electric field created by the distribution is supported by this plane and is perpendicular to the distribution axis supposed to be parallel to the z-axis according to Curie's symmetry principle [7]. The projection of the unit vector $\vec{u}_{PM}$ in the x-y plane yields

$$dE = \frac{\sigma ds'}{4\pi\varepsilon_0 r^2} \sin\theta \, e^{-k_0 r} e^{\vec{k}_0 \overrightarrow{OP}} \qquad (2)$$

Considering uniquely the antenna factor depending on θ and φ angular coordinates, equation (2) becomes

$$dE = ds' \sin\theta \, e^{\vec{k}_0 \overrightarrow{OP}} \qquad (3)$$

In the particular direction parallel to the x-axis, $\vec{k}_0 \overrightarrow{OP} = k_z z'$ and equation (3) becomes

$$dE = \sin\theta dz' e^{k_z z'} \quad (4)$$

Integrating (4) on the entire antenna length yields

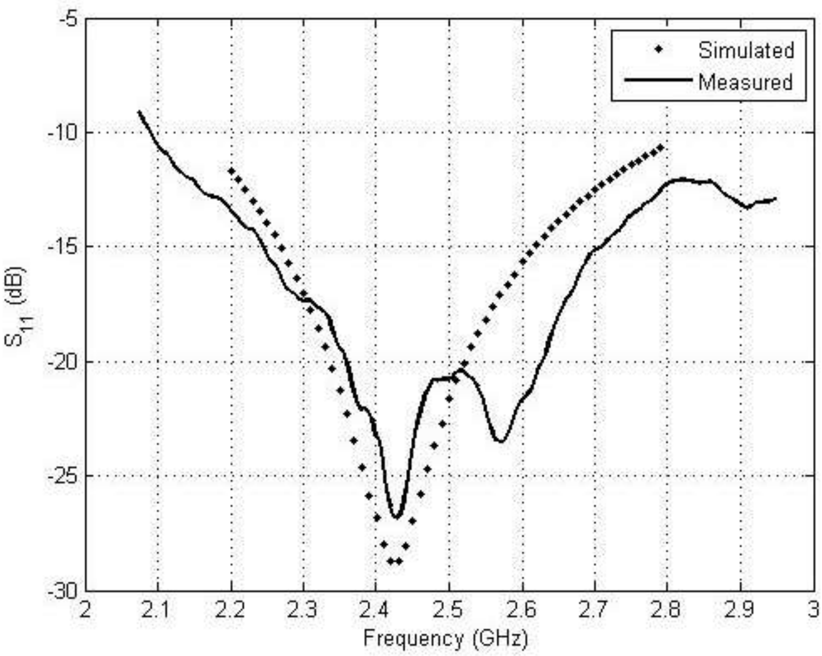
$$E = I\sin\theta \quad (5)$$

where
$$\begin{cases} I = \dfrac{1}{k_z}\left(e^{k_z L} - e^{k_z \frac{\Delta z}{2}} - e^{-k_z L} + e^{-k_z \frac{\Delta z}{2}} \right) \\ k_z = k_0 \cos\theta \end{cases}$$

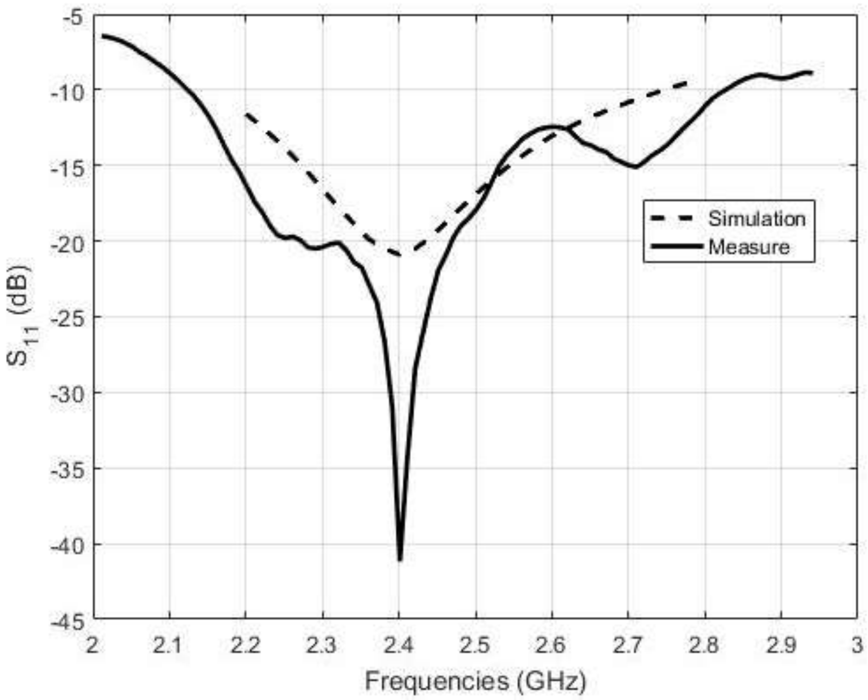
Results and discussion

As previously mentioned, the studied antennas (basic copper) are etched on a low-cost FR4 substrate of volume $48 \times 35 \times 0.8$ mm^3, relative dielectric constant $\varepsilon_r = 4.3$ and loss tangent $\tan\delta = 10^{-3}$ (neglected for lossless case assumed). The measurements of the input reflection coefficient of the conventional bow-tie antennas were carried out using a network analyzer. The extended prototypes of the considered antennas have been investigated numerically by simulations using Momentum-ADS to validate our initial design operation.

Figure 4 shows the simulated and measured input reflection coefficient of the studied conventional microstrip bow-tie antennas in mono and bi-plane topologies. In Figure 4(a) the antenna radiates at the frequency of 2.42GHz and the input bandwidth is found around 27% (2.15-2.8GHz) and 39% (2.1-2.85GHz) respectively for simulations and measurements. In Figure 4(b) the antenna radiates at the fundamental frequency of 2.4GHz and the -10dB return loss bandwidth is around 27% (2.18-2.65GHz) and 29% (2.13-2.83GHz) respectively for simulations and measurements. The experimental results show that in addition to the antenna's fundamental resonance, the additional resonances are obtained at the frequency of 2.58GHz and 2.7GHz with the input bandwidth of about 36% and 26% respectively for mono and bi-plane topologies. The difference between simulations and measurements occurred due to the imperfect situation during the measurement.



(a)



(b)

Figure 4: Return loss of the conventional bow-tie antennas: (a) mono-plane topology and (b) bi-plane topology.

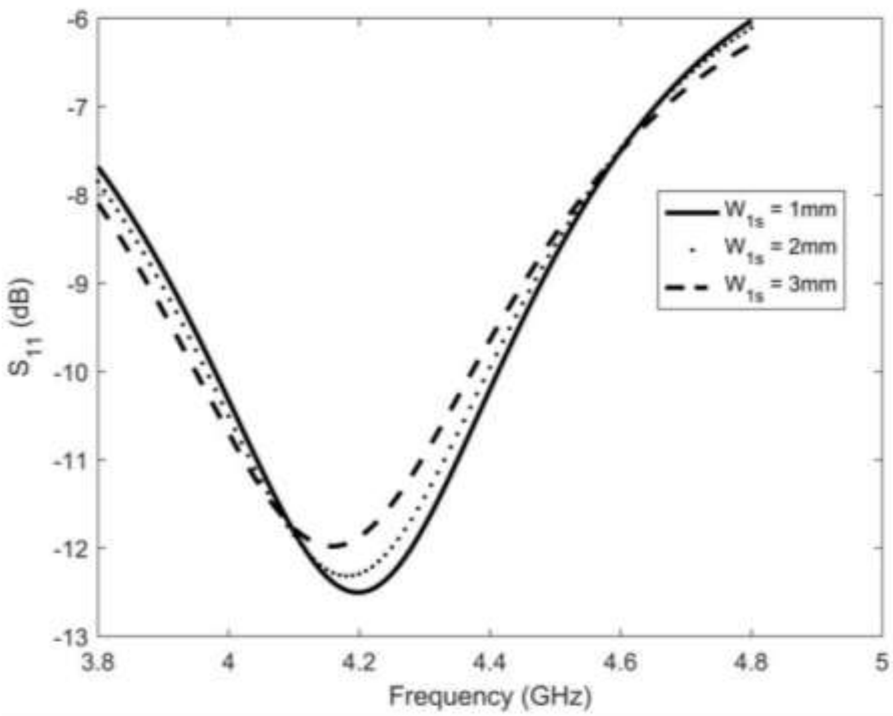


Figure 5: Effects of the load dimensions located at the larger base of the conventional structure

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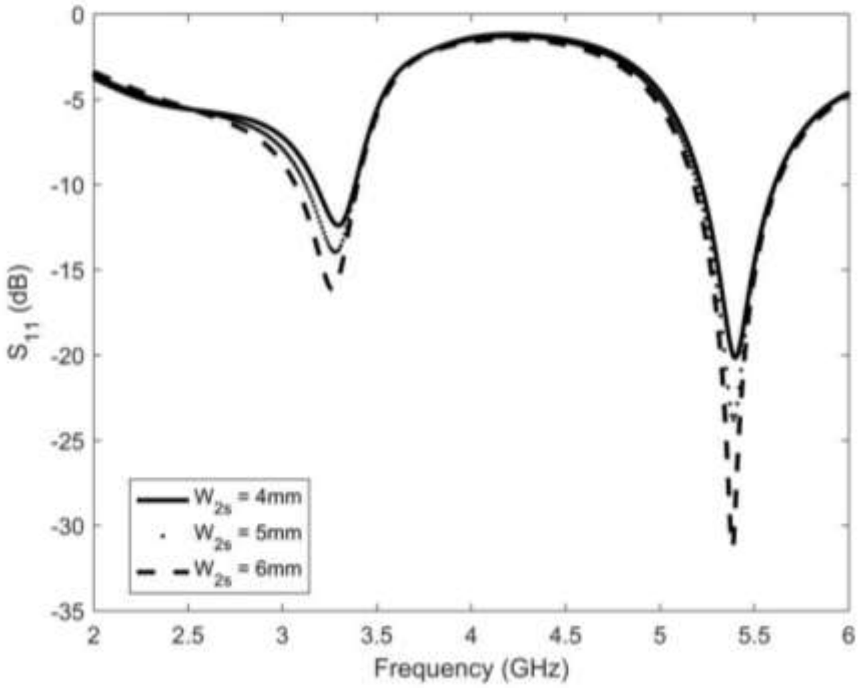

Figure 6: Effects of the load dimensions located at the smaller base of the conventional antenna in mono-plane topology

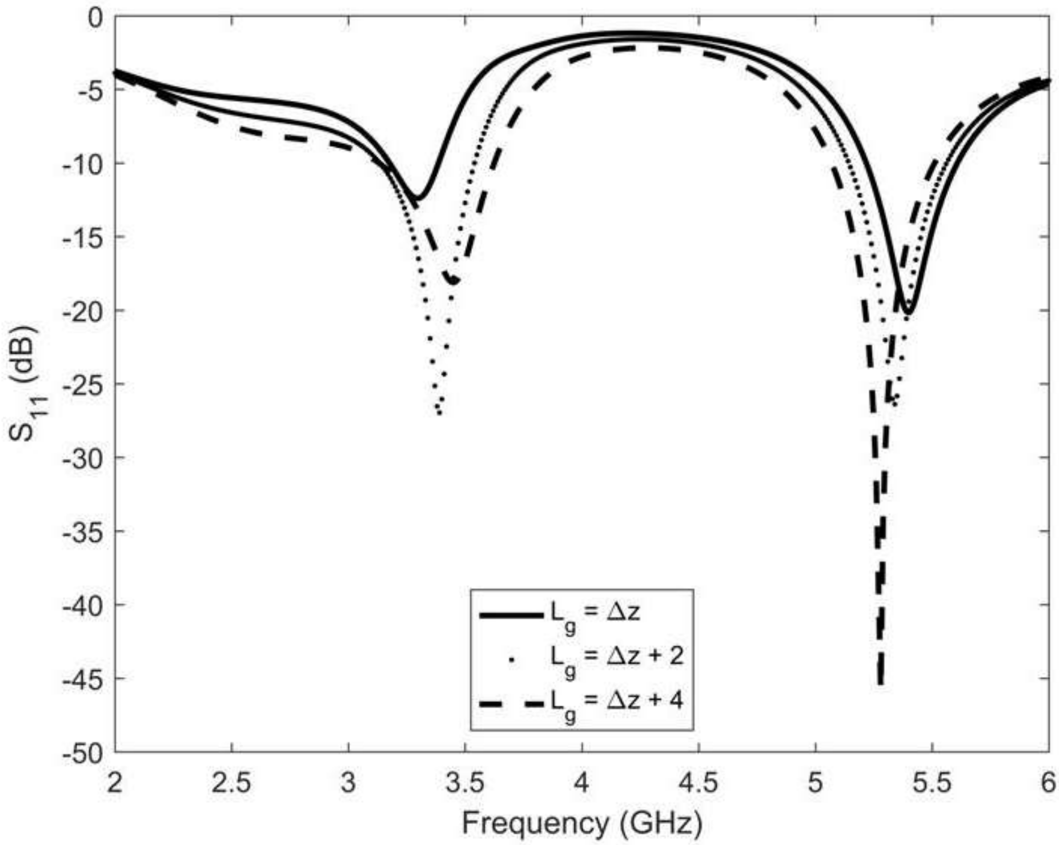

Figure 7: Effects of smaller base load position.

Figures 5 to 7 illustrate the effects of the load dimensions and positions on the input characteristics of the extended prototype of the considered antenna in mono-plane topology. It can be seen that the loads placed at the smaller bases of the excitation gap are responsible of the dual band operation and contributed significantly to enhance the impedance matching.

Figure 8 shows the simulated return loss of the extended dual-loaded model of the studied frustoconical-shaped 50Ω microstrip center-fed bow-tie antennas in the mono and the bi-plane topologies within the frequency band of 2-6GHz. From the acquired obtained results as demonstrated it can clearly be seen that a dual-band is achieved in the both cases. The first band is controlled by the conventional structure whereas the second band is controlled by the loads. For the extended radiating element in mono-plane topology, the lower resonant mode of excitation with a central frequency 3.3GHz and an input bandwidth of about 15% (2.95-3.4GHz) can be adjusted to cover the lower 3.1 GHz UWB. The higher resonant mode of excitation obtained for the frequency of 5.33GHz with a $-10\,\mathrm{dB}$ return loss bandwidth of about 6% (5.2-5.5GHz) can be used for the WLAN 5.2/5.8 GHz bands. Conversely, for the extended radiating element in bi-plane topology, the lower resonant (respectively the upper) mode of excitation with a center frequency of $2.5\,\mathrm{GHz}$ (respectively 4GHz) and a bandwidth for input $|S_{11}|$ of about 88% (2.25-4.5GHz) (respectively 58%) is sufficient to meet the requirements of the WLAN 3.6 GHz band operation. The simulated input performances of the studied antennas with other design approach are compared in Table 2. The second resonant modes for the conventional antennas are considered for real experimental results

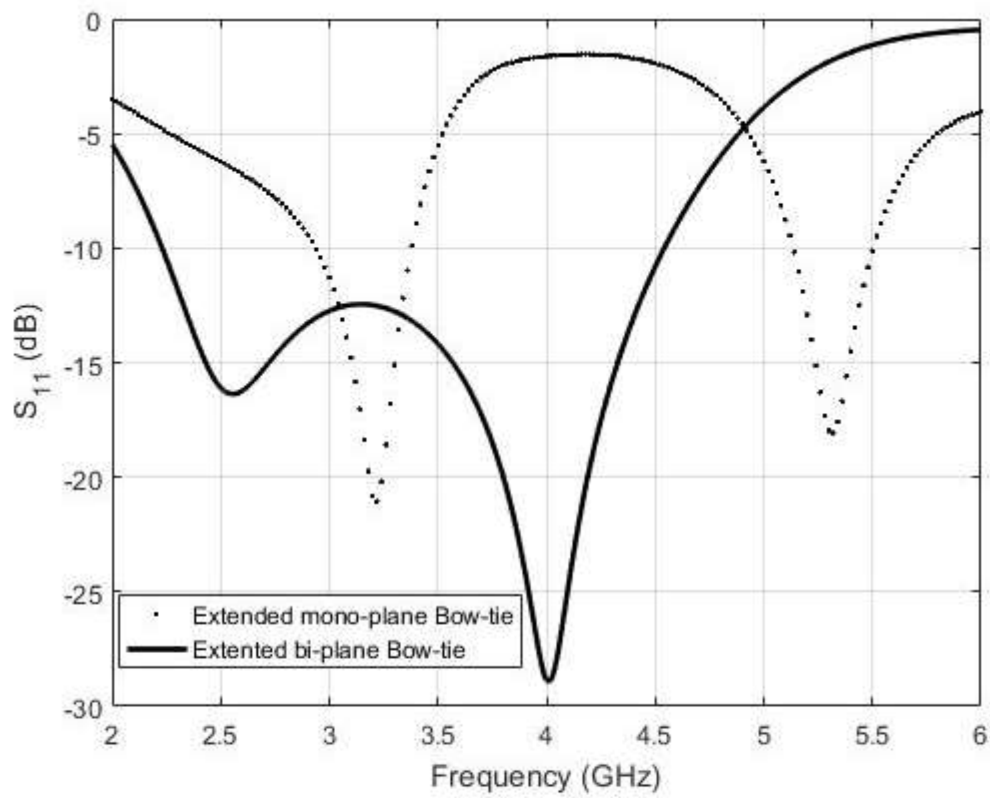

Figure 8: Simulated return loss of the extended dual-loaded model of the studied antennas.

Table 2. Comparison of the input characteristics of the proposed antennas with other published linear antennas

	First resonant mode			Second resonant mode		
Antenna topology	f_1 (GHz)	S_{11} (dB)	Bandwidth (%)	f_2 (GHz)	S_{11} (dB)	Bandwidth (%)
[8]	2.45	-19	10	5.8	-10	20
[9]	2.4	-35	20.3	3.6	-36	15.26
|10]	2.44	-15	4.1	5.60	-15	4.8
[11]	2.55	-19	11.8	3.6	-15	15.3
Studied mono-plane topolgy	2.42	-20	27	2.58	-23	36
Studied bi-plane topology	2.4	-21	27	2.7	-15	26
Extended mono-plane topolgy	3.3	-21	15	5.35	-18	6
Extended bi-plane topology	2.5	-16	88	4	-29	58

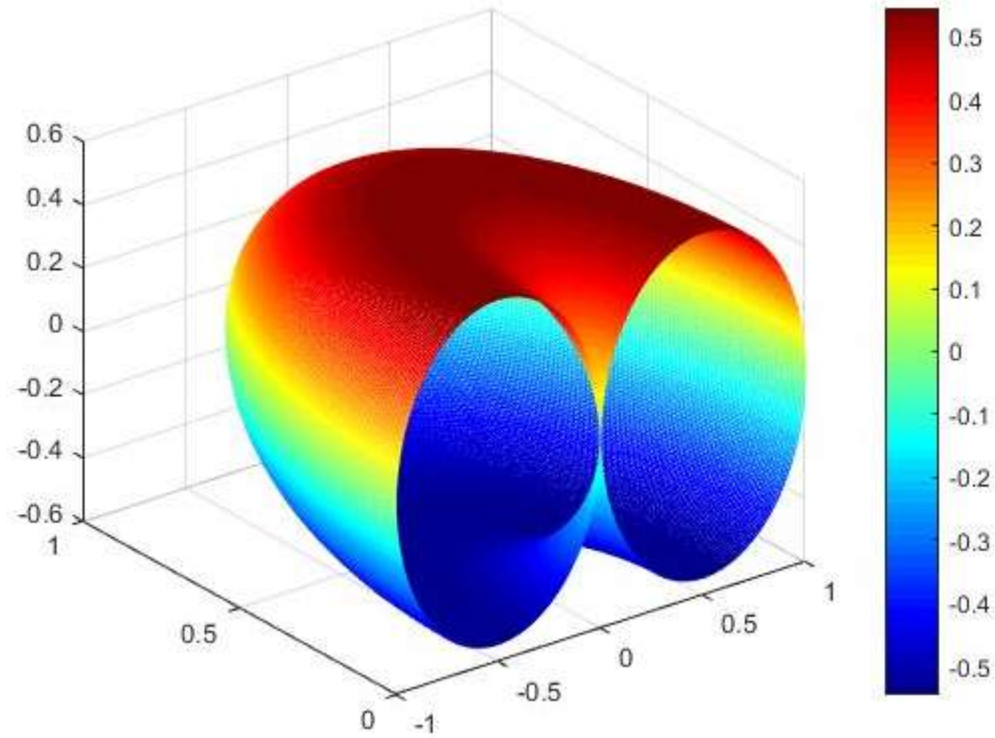

Figure 9: Calculated radiated electric field pattern

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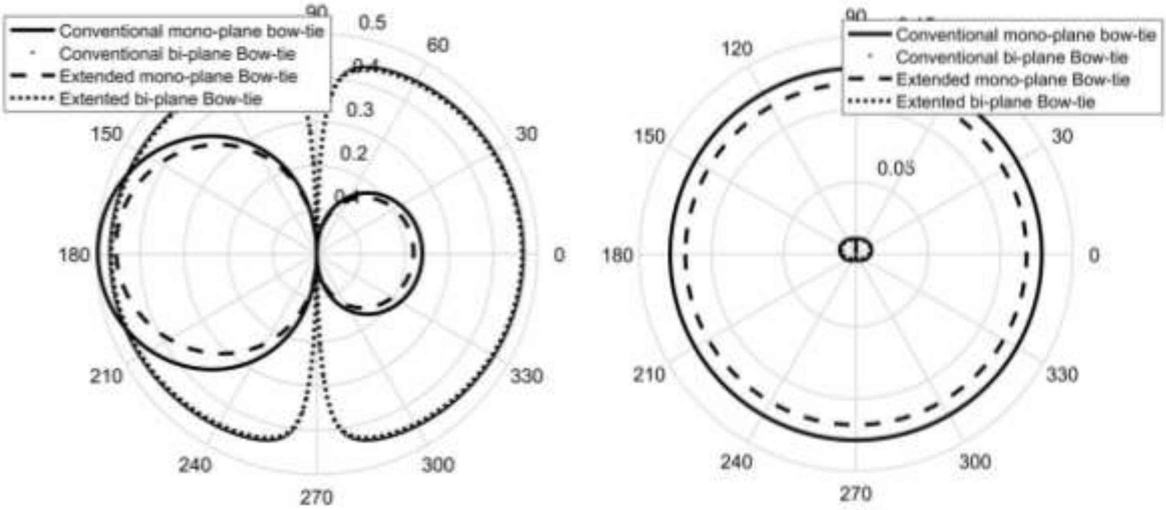

(a) ***(b)***

Figure 10: Simulated radiation pattern at 2.4GHz, (a) in E-plane and (b) in H-plane

Figures 9 and 10 indicate calculated 3D and simulated polar radiation pattern of the proposed antennas in linear scale at 2.4GHz. It is observed that based on the proposed calculation approach, the bow-tie antenna radiates effectively in the same manner like dipole antenna with an omni directional radiation pattern and the shadow regions in the antenna direction [12]. In Figure 10(a) we can see that the microstrip bow-tie antenna exhibits one main lobe oriented in a direction perpendicular to the antenna axis with a half power beam-width (HPBW) of about 90°.

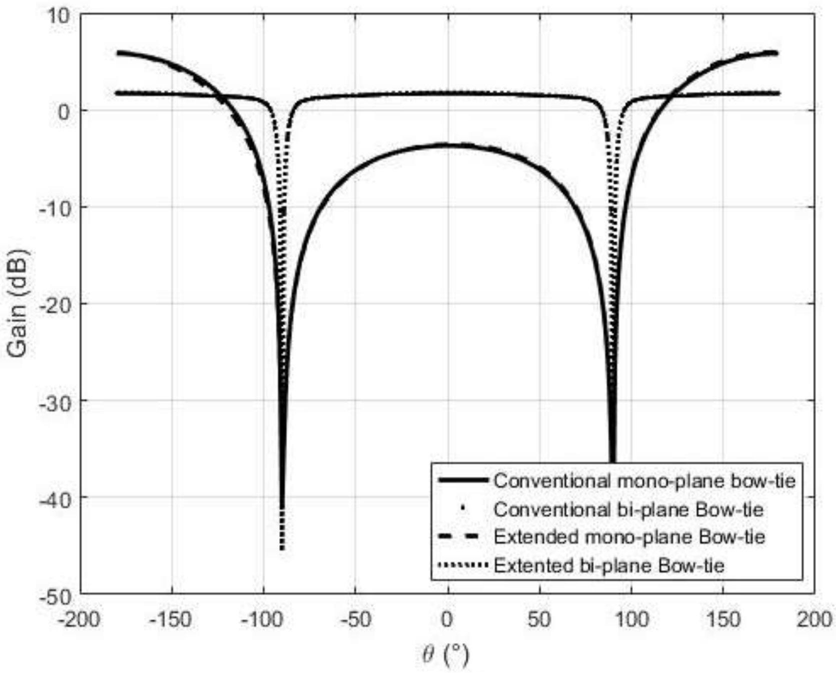

Figure 11: Simulated gain in E-plane at 2.4GHz

Figure 11 shows simulated two-dimensional radiation pattern characteristics at 2.4GHz in linear scale. It is observed that the microstrip bow-tie antenna in a bi-plane topology exhibits acceptable maximum gain of about 1.7dB as microstrip dipole antenna. However, the considered antenna in the mono-plane topology exhibits relative high gain of about 5.5dB.

Conclusion

Low profile dual-band double stub loaded based frustoconical-shaped center-fed microstrip bow-tie antennas have been designed and investigated numerically by simulations for novel personal communications network in the 2-6GHz band. Analytical method based on electrostatics approach solution has been established for the calculation of the radiation pattern and it has been shown that the studied antennas radiate bi-directionally and have a double-sided pattern as the microstrip dipole antennas. The proposed design approach of the extended model of the conventional studied antennas is flexible and provides a wide range of wireless applications choice other than the ISM band.

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