# Design of a Combined Antenna for Ultra Wide-Band High-Power Applications

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*Abstract*— **In this paper, design and simulation of a combined antenna for wideband applications with high radiating power is presented. By using the idea of combined antennas, a TEM horn antenna is combined with magnetic dipoles in order to shift the bandwidth to lower frequencies. Furthermore, a feeding structure which is a transition between coaxial cable to the microstrip line is suggested to increase the antenna bandwidth. The obtained 10 dB impedance bandwidth is from 0.2 to 30 GHz. Radiation patterns at different frequencies, antenna gain and return loss versus frequency are presented. CST software package which is based on finite integral technique is used for the simulations.**

***Keywords-TEM horn antenna,combined antenna,electric and magnetic energy,reactive energy ,microstrip line.***

## I. INTRODUCTION

In recent years, broadband antennas have attracted the attention of many researchers since they are widely utilized in broadband communication systems, radars and electromagnetic compatibility (EMC) measurements. Short pulses which can be radiated by wideband antennas are needed to overcome some problems in radar systems [1]. High spatial accuracy can be achieved by using high-power short-time pulses which in turn provide the capability of detecting small objects [1]. Moreover, a wideband antenna can be used as a standard antenna in the antenna measurement chamber. This eliminates the need to replace the standard antenna for different frequency bandwidths.

Double ridged, TEM horn, Vivaldi, and Shark antennas are some of the well-established wide band antennas, which are extensively used for the above mentioned applications [2-8].

In [9], near-fields of a dipole are investigated and electric and magnetic energies are calculated. The difference between electric and magnetic energies near the antenna creates reactive energy around it. This energy has no role in antenna radiation and only increases radiation loss. In case of equal electric and magnetic energies near the antenna, the imaginary part of the antenna input impedance decreases, meaning better impedance matching at lower frequencies. One of the approaches to have equal electric and magnetic energies near the antenna is to combine the fields of electric and magnetic dipoles, resulting in a combined antenna. Different structures are studied for combined antenna in [10-11].

In this paper, a TEM horn antenna and magnetic dipoles are combined in order to shift the bandwidth to lower frequencies. A feeding structure is also suggested, to increase the matching bandwidth. The next section describes the design of the proposed combined antenna, and then the simulation results are presented.

## II. COMBINED ANTENNA DESIGN

We study the Vivaldi type antenna to start the design process. These antennas can be realized both by mictostrip (planar) technology and in spatial (3D) geometry. Printed antennas are not considered here because of the dielectric thickness limits the bandwidth and also the power handling capacity would not be sufficient. Therefore, we concentrate on spatial geometry design of Vivaldi antenna which is, indeed, a TEM horn antenna.

To have radiation at lower frequencies, the antenna dimensions should be large. We intend to design an antenna which is small and also covers radiation at lower frequencies as small as 0.2 GHz. Small antenna dimensions prevents the antenna pattern to be divided at higher frequencies. So, it is necessary to have a trade-off between impedance matching at lower frequencies and favorable pattern at higher frequencies.

TEM horn antenna basically works as a matching network between 50 ohm impedance and free space. It can be considered as a double strip transmission line whose impedance is given by [12]:

$$Z_c = \frac{Z_0}{\pi\sqrt{\varepsilon_{ff}}}\ln\left(\frac{4h}{w}+\frac{w}{2h}\right) \quad for \quad \frac{w}{h}<1 \qquad (1-a)$$

$$Z_c = \frac{2Z_0}{\sqrt{\varepsilon_{ff}}}\left(\frac{2w}{h}+1.393+0.667\ln\left(\frac{2w}{h}+1.44\right)\right)^{-1} \quad for \quad \frac{w}{h}>1 \qquad (1-b)$$

In which,

$$\varepsilon_{ff} = \frac{1}{2}(\varepsilon_r+1)+\frac{1}{2}(\varepsilon_r-1)\left(\left(1+\frac{6h}{w}\right)^{-1}+0.04\left(1+\frac{2w}{h}\right)^{2}\right) \qquad (1-c)$$

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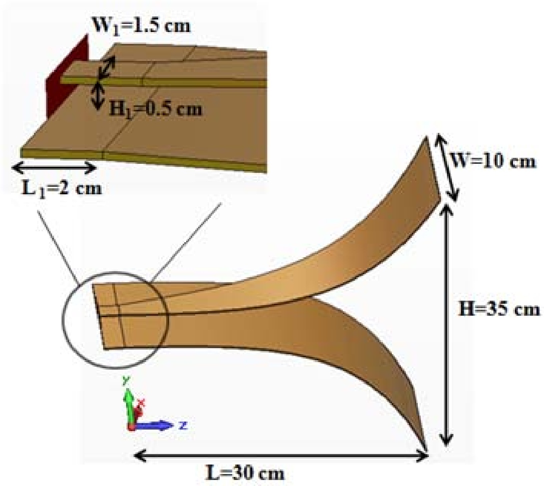


Figure 1. Configuration of the conventional TEM horn antenna

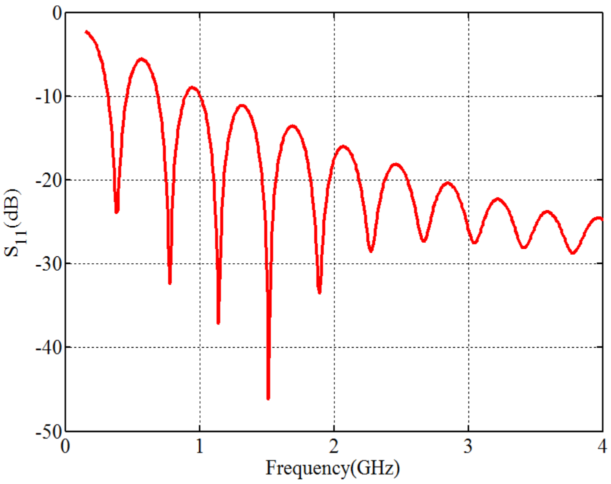


Figure 2. Simulated return loss of the conventional TEM horn at lower frequencies

where $w$ is the double strip width and $h$ is the spacing between two ribbons. $\varepsilon_r$ is the dielectric permittivity of the substrate between the two ribbons and $\varepsilon_{ff}$ is the effective dielectric permittivity.

In our case, the dielectric is air hence $\varepsilon_{ff} = 1$. In the first step, a double strip line with constant width and spacing between the ribbons with exponential tapering is designed. In the second step, the width of the ribbons also increases along the line which improves the TEM horn antenna's impedance matching. By using the image theory, the characteristic impedance of a microstrip line resulted from placing an infinite plane between the two ribbons of the double strip line is half of the above relation value. The impedance matching of coaxial cable with the microstrip line is better than its matching with a double strip line. Therefore, a large value $(W = 10cm)$is chosen for the width of the lower ribbon in the TEM horn antenna design in order to have better impedance matching. In this case, the lower ribbon acts approximately the role of ground plane in the microstrip line. The microstrip line impedance begins from 50 ohm at the antenna port and ends to free space impedance at the antenna aperture.

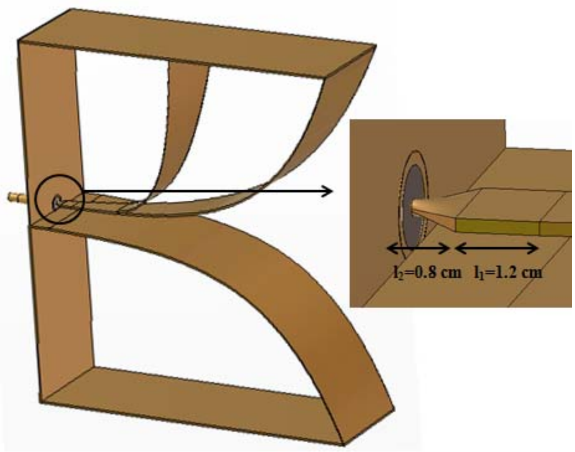


Figure 3. Configuration of the proposed combined antenna

The upper ribbon width $(w)$ and its distance $(h)$ from the lower ribbon change linearly and exponentially, respectively as follows:

$$w = 1.5 + 0.283z \qquad (0 \le z \le 30) \quad (2)$$

$$h = 0.5\mathrm{e}^{0.142\mathrm{z}} \qquad (0 \le z \le 30) \quad (3)$$

Fig. 1 shows the designed conventional TEM horn antenna. The return loss of the designed antenna at lower frequencies is shown in Fig. 2.

CST wave port is used to excite the antenna which is placed at the beginning of the double strip line. It is seen that the conventional TEM horn antenna impedance matching begins from 1GHz. In addition, practically matching deteriorates and begins from 2 GHz by adding a coaxial cable as antenna excitation. To enhance the TEM horn antenna, combined antenna is suggested.

A reactive energy is defined around every antenna as follows [9]:

$$W_r = \int_{V_a} \pi(\bar{W}_m - \bar{W}_e)dV \qquad (4)$$

Where $\bar{W}_e$ and $\bar{W}_m$ are averages of the electric and magnetic energy densities, respectively. This reactive energy has no effect on radiation and only dissipates energy as the antenna radiates. Hence, the optimum case is to have equal electric and magnetic energies near the antenna, which in this case, all energy radiates from the antenna. Magnitude of the reactive energy is determined from the antenna reactive power and also from the reactive component of the antenna input impedance.

Studying the fields around a simple electric dipole reveals that electric energy is more than magnetic energy near it [9]. Therefore, it is possible to have equal electric and magnetic energies by placing a magnetic dipole next to an electric dipole.

Fig. 3 shows the proposed combined antenna. In the structure, a number of rings are created by placing some plates around the antenna. Magnetic diploes are produced when current runs through these rings. The fields of these magnetic

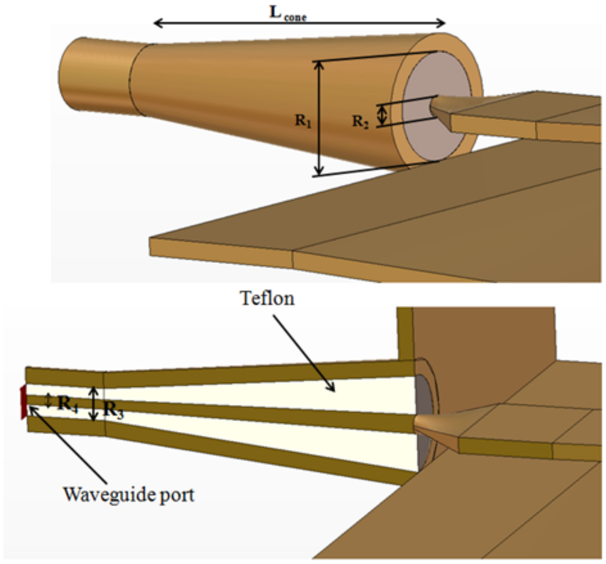


Figure 4. The connection of the coaxial cable to the antenna and the effective parameters on return loss

dipoles are combined with those of a TEM horn and reactive energy around the antenna decreases. As a result, antenna impedance matching improves at lower frequencies. A plate is placed on the upper part of the antenna to control level of the radiation fields of the magnetic dipoles, i.e., the magnetic energy around the antenna. This plate creates a second ring that can be used to find the optimized case for the impedance matching at lower frequencies, achieved by changing the ring surface. The plate is defined exponentially. By optimizing the exponential relation of the plate, the desired properties for the combined antenna are obtained.

To connect the coaxial cable to the antenna, first the back plate is pierced and the outer conductor of the coaxial cable is short-circuited to it and the inner conductor is lofted to the upper ribbon of the microstrip line. Since the impedance matching is sensitive to small discontinuities at higher frequencies, lofting the inner conductor improves the antenna impedance matching at higher frequencies remarkably.

Finally, the antenna is excited by an N-type coaxial cable. This part of antenna is very sensitive and needs proper attention. An impedance transition is utilized between the combined antenna and the standard N-type coaxial cable, since the combined antenna has a good impedance matching with a coaxial cable with large dimensions. This transition is like a transmission line with appropriate impedance function which fulfills the matching between two different impedances. This structure decreases the discontinuities along the waveguide toward the antenna and accordingly reduces the return loss at higher frequencies. Fig. 4 shows the connection of the coaxial cable to the antenna and the parameters affecting return loss. The optimized parameters for the appropriate impedance matching in the feeding part are given in Table. 1.

TABLE I. Optimized parameters for the appropriate impedance matching in feeding part

| **Variables** | $R_1$ | $R_2$ | $R_3$ | $R_4$ | $L_{cone}$ |
|---|---|---|---|---|---|
| **Values(cm)** | 1.2 | 0.4 | 0.4 | 0.12 | 4 |

## III. SIMULATION RESULTS

The proposed combined antenna was simulated by CST commercial package. In order to decrease the simulation time, the symmetry of the antenna was used and a PMC symmetry plane was defined. Fig. 5 shows the antenna return loss. The antenna gives an impedance matching from 0.2 to 30 GHz. Radiation patterns at different frequencies are shown in Fig. 6.

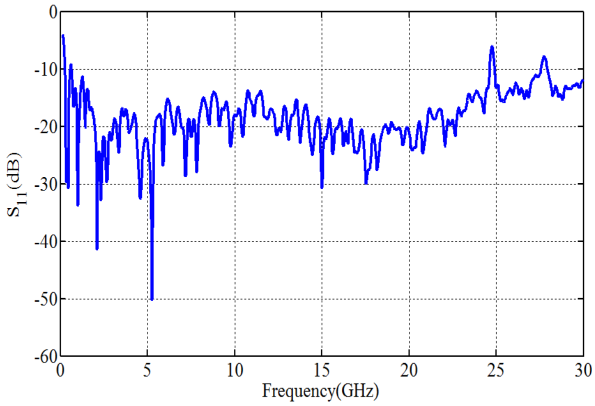
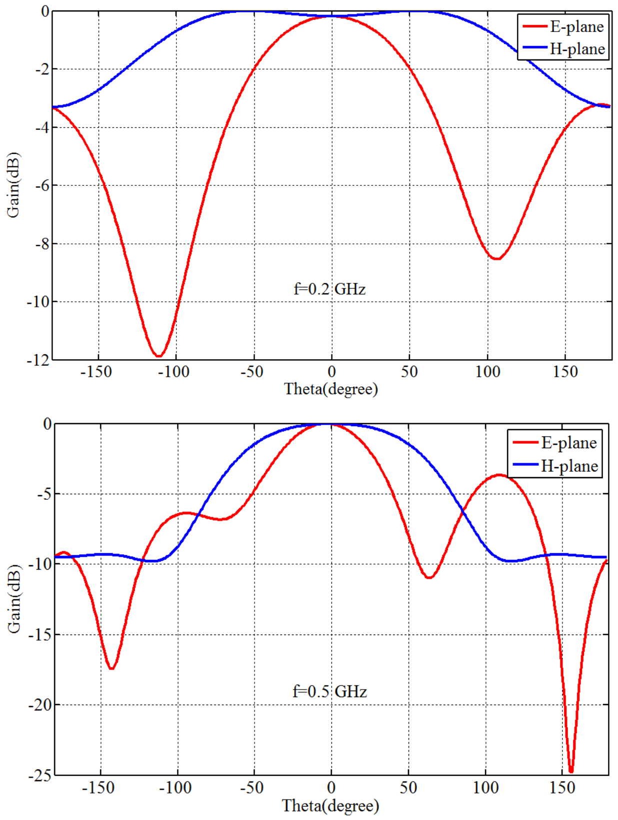


Figure 5. Simulated return loss of the proposed combined antenna



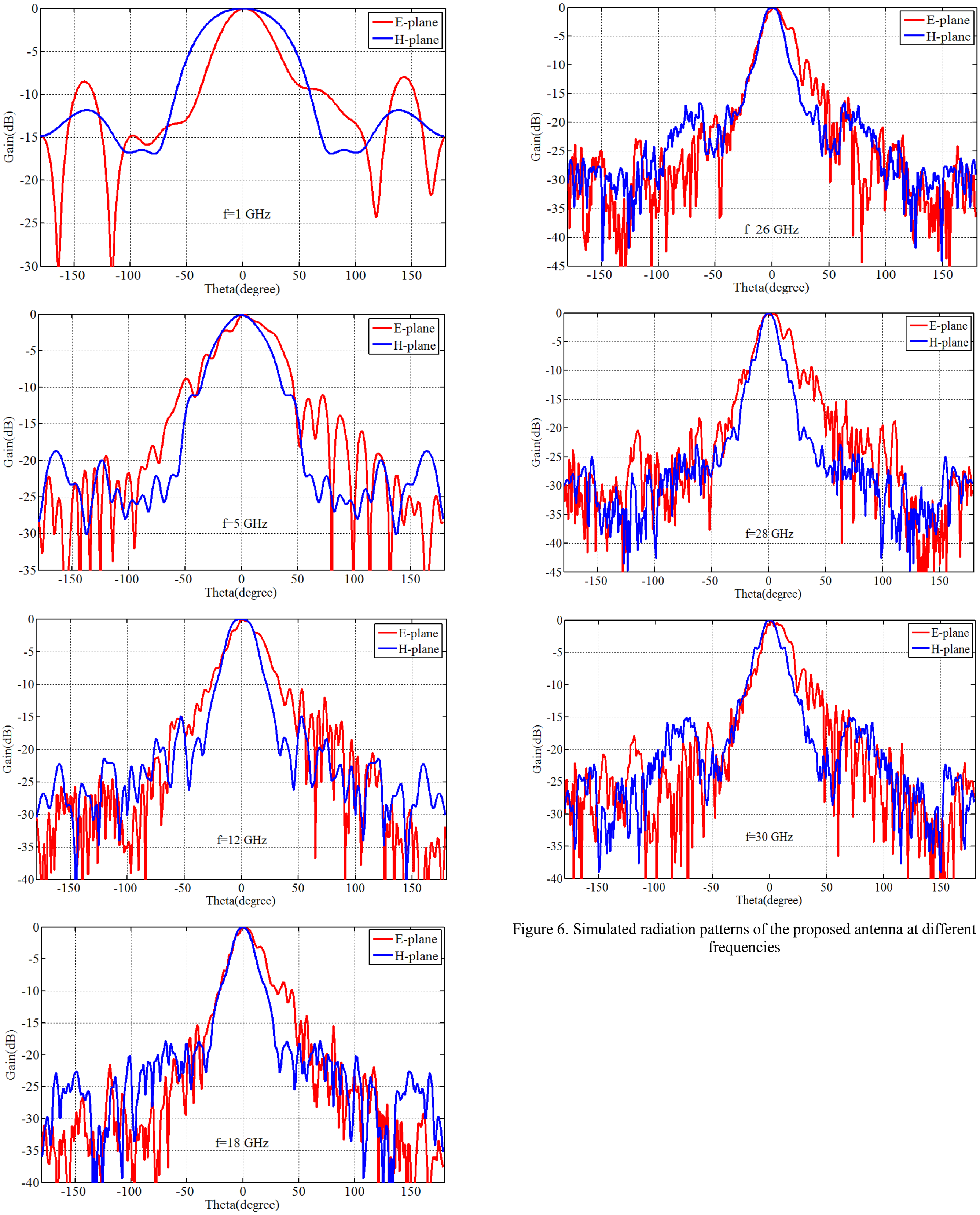


Figure 6. Simulated radiation patterns of the proposed antenna at different frequencies

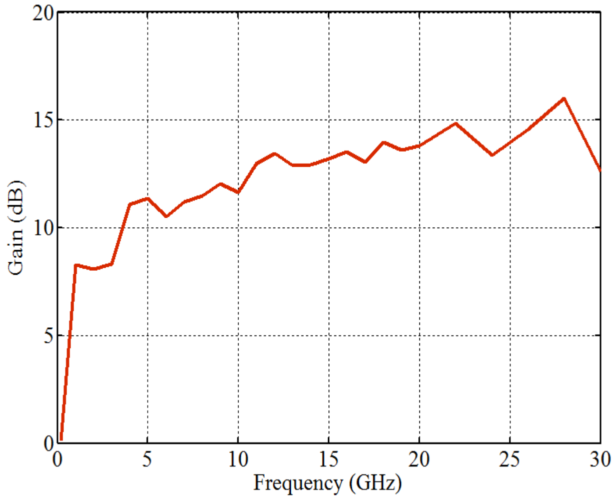


Figure 7. Simulated total gain versus frequency for the proposed antenna

It is seen that the antenna is more directive at higher frequencies. The patterns are reasonable through the whole frequency bandwidth. Fig. 7 displays the gain of the antenna with respect to the frequency.

## IV. CONCLUSION

In this paper, design and simulation of a combined antenna with a bandwidth from 0.2 GHz to 30 GHz is presented. First, a conventional TEM horn antenna was designed as a matching network between 50 ohm impedance and free space. It was seen that the combined antenna structure reduces the reactive energy around the antenna and shifts down the impedance matching to lower frequencies. In the proposed structure, impedance matching was improved at lower frequencies by creating a couple of rings as magnetic dipoles. In addition, the connection of coaxial cable to the combined antenna was modified to enhance the impedance matching through the bandwidth. Finally, return loss, radiation patterns at different frequencies and antenna gain were given to show the proper performance of the antenna.

## ACKNOWLEDGMENT

This work was supported by Iran Telecommunication Research Center (ITRC). The authors would like to thank Hojjatollah Fallahi for his cooperation.

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