

DEVELOPMENT OF A BROADBAND HORIZONTALLY POLARIZED OMNIDIRECTIONAL PLANAR ANTENNA AND ITS ARRAY FOR BASE STATIONS

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Abstract—A novel broadband horizontally polarized (HP) omnidirectional planar antenna is developed for mobile communications. The proposed antenna consists of four printed arc dipoles that form a circular loop for HP omnidirectional radiation. A broadband feeding network which includes four broadband baluns and an impedance matching circuit is designed to excite the four arc dipoles. An eight-element linear antenna array is developed for 2G/3G base stations. A broadband power divider is used to feed the antenna array. Experimental results show that the HP omnidirectional antenna element has a bandwidth of 31% (1.66–2.27 GHz) while its array has a bandwidth of 34% (1.67–2.35 GHz) and an omnidirectional antenna gain of ~ 8 dBi. Both of the antenna element and its array have good omnidirectivity over the 10-dB return loss bandwidth. Simulated and measured results for the antenna element and its array are presented.

1. INTRODUCTION

Omnidirectional antennas can find wide applications in ground and airborne communications [1, 2]. It is well known that a vertically polarized (VP) omnidirectional antenna can be easily realized by a vertical dipole [3–6]. A horizontally polarized (HP) omnidirectional antenna may be obtained through a horizontal loop with a uniform current distribution [7]. However it is impossible to achieve a uniform current distribution for a resonant loop [8], thus causing difficulty in realization of broadband HP omnidirectional antennas. Over the last decade, a number of HP omnidirectional antennas have been

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developed. In [9–12], several HP omnidirectional slot array antennas were proposed. But slot antennas normally have a narrow bandwidth (e.g., $< 5\%$, see [9]). The most famous HP omnidirectional wire-structure antenna is the Alford loop [13]. A printed planar Alford loop strip antenna was patented in 1998 [14]. But this type of loop antenna also has a narrow bandwidth ($< 3\%$ for $VSWR < 2$). In recent years, some modified Alford loop antennas have been proposed with simple feeding configurations and compact antenna structures [15–19]. The maximum bandwidth for these modified Alford loop antennas is less than 10%. A combined antenna structure of an Alford loop and a slotted cylinder was proposed in [20]. The bandwidth of the combined configuration was increased to $\sim 15\%$. A broadband four magneto-electric dipole array was developed in a form of ring for HP omnidirectional radiation pattern in [21]. But the maximum gain is not in the horizontal plane and the antenna structure has a large 3-dimensional configuration (the diameter of the ring is $\sim 1.4\lambda_0$ and antenna height is $\sim 0.2\lambda_0$, where λ_0 is the free-space wavelength at the center frequency of the operating frequency band). A three-element polarization-adjustable dipole array was presented in [22]. This antenna has a bandwidth of $\sim 15\%$, but the dipole array leads to an antenna size larger than one wavelength in diameter. In [23], a planar HP omnidirectional loop antenna was realized using left-handed capacitance/inductance loading. This loop antenna has a one wavelength circumference, but a very narrow bandwidth ($\sim 2\%$). Therefore, the major problem for a HP omnidirectional antenna is to enhance its bandwidth while keeping a simple configuration.

In this paper, we propose a broadband HP omnidirectional antenna with a planar configuration. The antenna consists of four printed arc dipoles excited by a broadband feeding network. The four printed dipoles form a circular loop with an in-phase current distribution which radiates an HP omnidirectional pattern. The feeding network consists of four broadband baluns and an impedance matching circuit. The antenna element has a bandwidth of 31% (1.66–2.27 GHz) for 10-dB return loss. The gain variation in the horizontal plane is less than 0.5 dB. An eight-element linear antenna array is developed for potential applications in mobile communication base stations. The antenna array has a bandwidth of 34% (1.67–2.35 GHz) for 10-dB return loss and an omnidirectional antenna gain of ~ 8 dBi. The broadband HP omnidirectional antenna element is described in Section 2. The eight-element linear antenna array is developed in Section 3.

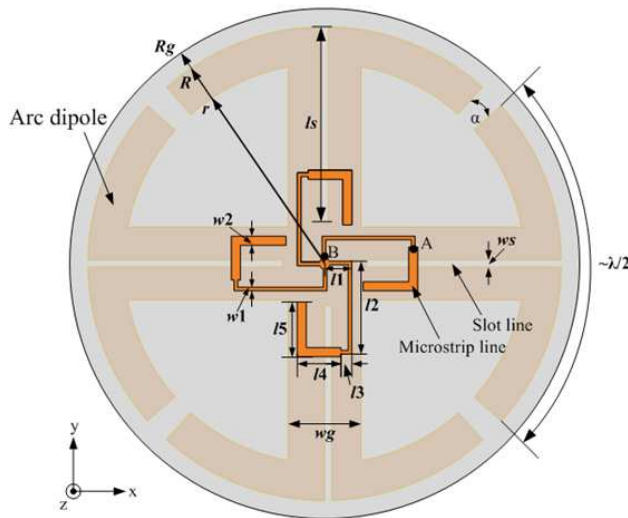


Figure 1. The configuration of the broadband HP omnidirectional antenna.

2. ANTENNA ELEMENT

2.1. Antenna Configuration

The configuration of the proposed broadband HP omnidirectional antenna element is illustrated in Figure 1. The antenna element consists of four arc dipoles which are excited by a broadband feeding network. Each arc dipole has a length of about a half wavelength ($\sim \lambda/2$). The four arc dipoles form a circular loop for HP omnidirectional radiation. The feeding network is comprised of four broadband baluns and an impedance matching circuit. This type of broadband balun has been widely used in broadband dipoles [24,25]. The matching circuit connects four broadband baluns to a 50- Ω coaxial line at the center of the antenna element. The four arc dipoles are printed on one side of a thin RO4003 substrate (thickness = 0.8 mm, $\epsilon_r = 3.55$, loss tangent = 0.0027) while the feeding network is on the other side of the same substrate. The antenna element is designed for potential applications in 2G/3G mobile communications at the 2-GHz band, which covers the frequency range of 1.7–2.2 GHz.

A simple equivalent circuit for the feeding network is depicted in Figure 2. The broadband balun for an arc dipole is simplified as a 50- Ω lumped impedance since the input impedance (looking at point “A”, see Figure 1) of the broadband balun was designed to be 50 Ω . The

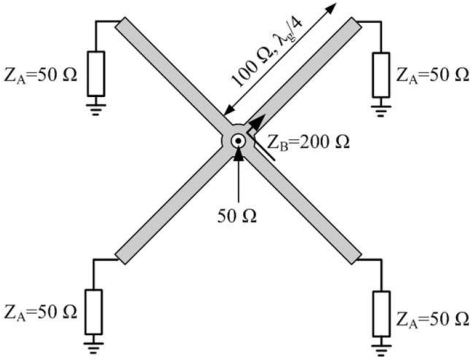


Figure 2. Equivalent circuit for the feeding network.

Table 1. Optimized geometric parameters for the broadband HP omnidirectional antenna.

| | | | |
|------|-------|----------|----------|
| Rg | 50 mm | $l2$ | 19.25 mm |
| R | 46 mm | $l3$ | 2 mm |
| r | 39 mm | $l4$ | 8 mm |
| wg | 15 mm | $l5$ | 13 mm |
| ls | 36 mm | $w1$ | 0.5 mm |
| ws | 1 mm | $w2$ | 1.8 mm |
| $l1$ | 5 mm | α | 6 deg |

theoretical analysis of the broadband balun can be found in [25]. Here we focus on the analysis of the matching circuit which connects four 50- Ω lumped impedances to a 50- Ω coaxial line. The 50- Ω impedance ($Z_A \approx 50 \Omega$) at Point “A” is transformed into a 200- Ω impedance ($Z_B \approx 200 \Omega$) at Point “B” by a 100- Ω quarter-wave ($\lambda_g/4$) transformer ($\sqrt{200 \Omega \times 50 \Omega} = 100 \Omega$). Then four 200- Ω impedances are connected in parallel, resulting in a 50- Ω impedance, and matching to the 50- Ω coaxial line at the center of the feeding network.

The broadband HP omnidirectional antenna element was simulated and optimized using HFSS v11. The optimized geometric parameters are summarized in Table 1. The simulated current distribution at 2 GHz is displayed in Figure 3. It is seen that the current flows in the same direction along the circular loop. This means that an in-phase current distribution is generated on the circular loop. It is well known that an in-phase current distribution along a circular loop can create an HP omnidirectional radiation pattern in the horizontal plane

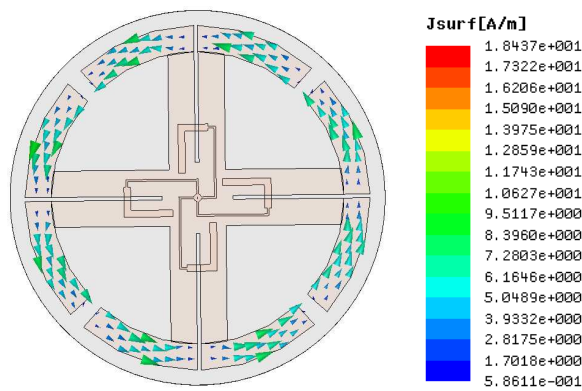


Figure 3. Simulated current distribution on the HP omnidirectional antenna at 2 GHz.

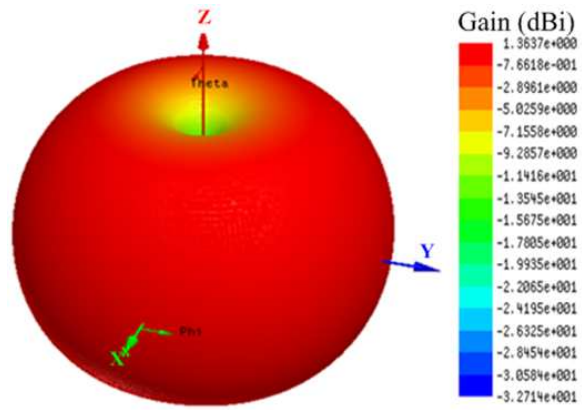


Figure 4. Three-dimensional radiation pattern of the HP omnidirectional antenna at 2 GHz.

(i.e., the xy plane) [7]. The three-dimensional radiation pattern at 2 GHz is depicted in Figure 4, showing good omnidirectional radiation pattern.

2.2. Parametric Study

One important parameter that affects the performance of the HP omnidirectional antenna element is the gap (α) between two adjacent dipoles. Figure 5(a) shows the gain variation of the antenna in the horizontal plane as the gap α changes from 2 to 10 degrees. When

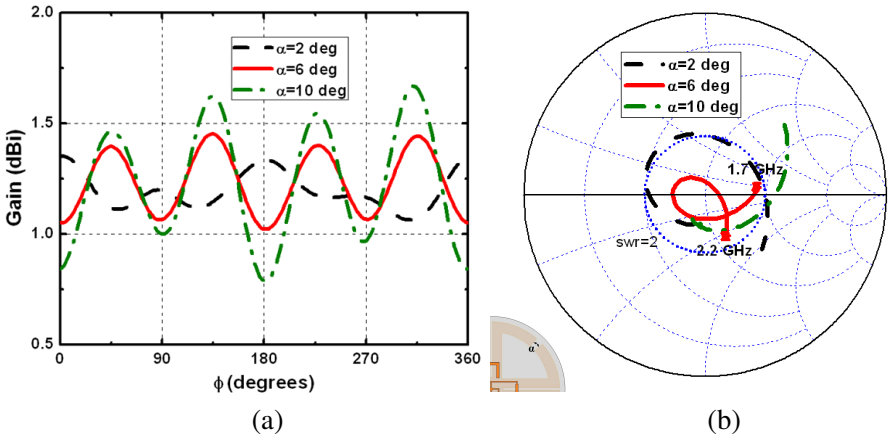


Figure 5. The effects of the gap (α) on (a) the gain and (b) the input impedance for the HP omnidirectional antenna.

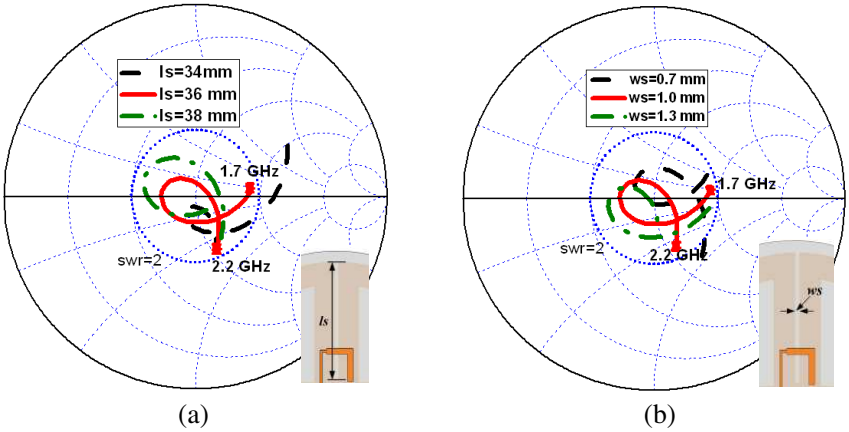


Figure 6. The effects of the slot line on the input impedance for the broadband HP omnidirectional antenna, (a) l_s and (b) w_s .

α decreases, the coupling between the adjacent dipoles increases, which leads to a more uniform current distribution, thus a better omnidirectivity. However, when α decreases, the gap between two adjacent dipoles becomes narrower, which leads to a larger inductive component for the input impedance (see Figure 5(b)), thus leading in a bad impedance matching. Therefore we select α to be 6 degrees for a gain variation of less than 0.5 dB with a good impedance matching.

The slot line in the broadband balun also affects the impedance matching. Figure 6 shows the variations for the input impedance with the length (ls) and the width (ws) of the slot line. A longer slot line gives a larger inductive component for the input impedance, while a wider slot line gives a larger capacitive component. By properly adjusting the dimensions (i.e., ls and ws) of the slot line, the impedance locus moves to the center of the Smith chart, thus achieving a broadband impedance matching. The optimal values for ls and ws are found to be $ls = 36$ mm and $ws = 1$ mm for our design.

2.3. Experimental Results

The proposed broadband HP omnidirectional antenna was fabricated and measured. Figure 7 shows the front view and back view of an antenna prototype. A flexible coaxial line (Johnson/Emerson RG178) with an SMA connector is connected to the feeding network. Figure 8

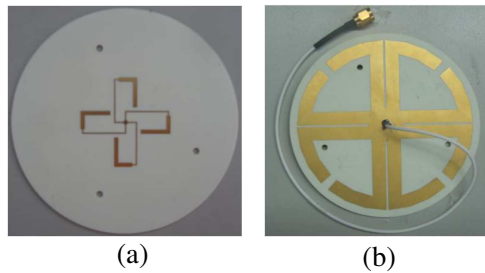


Figure 7. Front view (a) and back view (b) of a prototype of the broadband HP omnidirectional antenna.

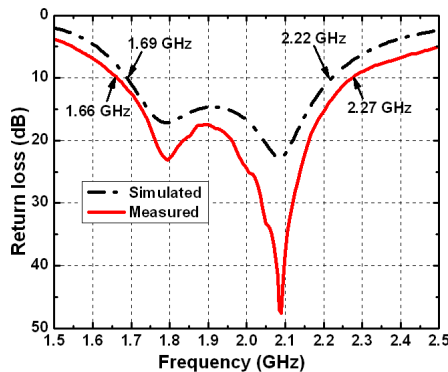


Figure 8. Measured return loss of the broadband HP omnidirectional antenna compared with simulated result.

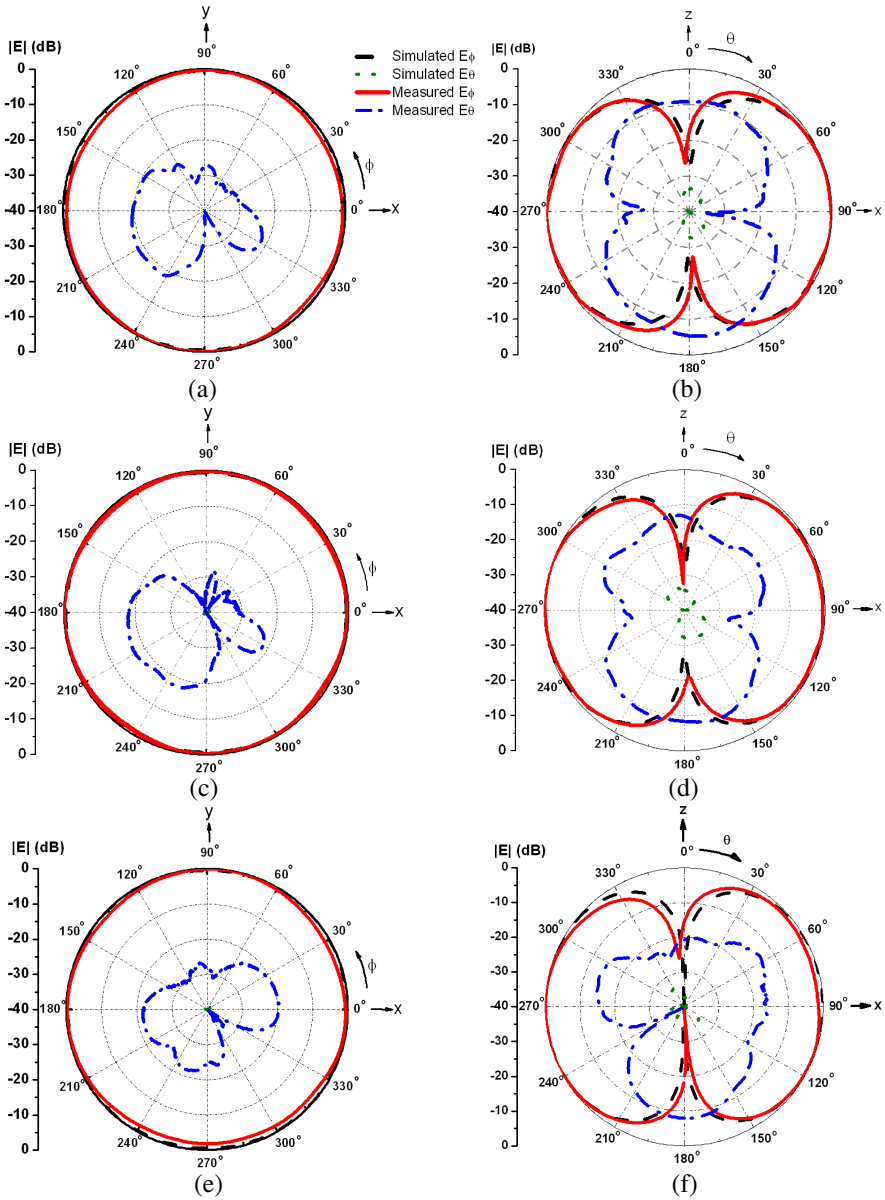


Figure 9. Simulated and measured radiation patterns for the broadband HP omnidirectional antenna, (a) 1.7 GHz (xy plane), (b) 1.7 GHz (xz plane), (c) 2.0 GHz, (xy plane), (d) 2.0 GHz (xz plane), (e) 2.2 GHz (xy plane), and (f) 2.2 GHz (xz plane).

shows agreement between the simulated and measured results for return loss (RL) of the HP omnidirectional antenna. The measured bandwidth for $RL > 10$ dB is about 31% (1.66 GHz–2.27 GHz), slightly wider than the simulation result.

The simulated and measured radiation patterns at 1.7, 2.0 and 2.2 GHz are plotted in Figure 9. Good HP omnidirectional radiation patterns are observed. Measurement shows that the gain variation in the horizontal plane is less than 1.5 dB. The cross-polarization level in the horizontal plane is about 20 dB lower than the co-polarization, higher than the simulation results due to the effect of the feeding coaxial line.

3. ANTENNA ARRAY

For base station applications, a higher gain is required for the broadband HP omnidirectional antenna. In this section, an eight-element linear array is developed for potential applications in mobile communication base stations.

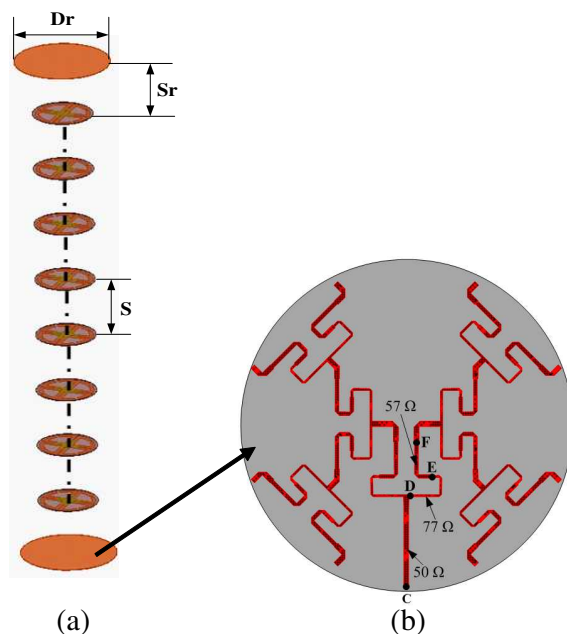


Figure 10. The geometry of the broadband HP omnidirectional eight-element linear antenna array. (a) Perspective view. (b) Feeding network.

3.1. Array Geometry

The geometry of the eight-element antenna array with a feeding network is shown in Figure 10. Two circular reflectors are separately placed at the top and the bottom of the array. The top reflector can serve as the cover of a radome while the bottom reflector can be considered as the ground plane of the feeding network.

The feeding network for the antenna array is an eight-way circular power divider which is placed on the bottom reflector. The detail of the power divider is shown in Figure 10(b). To match to a $50\text{-}\Omega$ input impedance, the impedance looking at the point “D” and the point “F” should be $100\text{ }\Omega$ and $50\text{ }\Omega$, respectively. A $70\text{-}\Omega$ quarter-wave transformer should be placed between the point “D” and the point “F” ($\sqrt{100\text{ }\Omega} \times 50\text{ }\Omega = 70\text{ }\Omega$). For a broadband operation, however, a two-stage transformer (DE and EF) is employed. The transformers DE and EF have the characteristic impedances of $77\text{ }\Omega$ and $57\text{ }\Omega$ with a length of $\lambda_g/8$, respectively.

3.2. Determination of Element Spacing and the Reflector

The element spacing (S) between two adjacent elements is optimized for a maximum gain without appearance of grating lobes. Figure 11 shows the gain variation at 2 GHz when S changes. As expected, a larger S leads to a higher gain. However, a larger spacing may result in appearance of grating lobes at a higher frequency. Figure 12 shows the radiation patterns at 2.2 GHz in the vertical plane at $S = 0.7\lambda_0$,

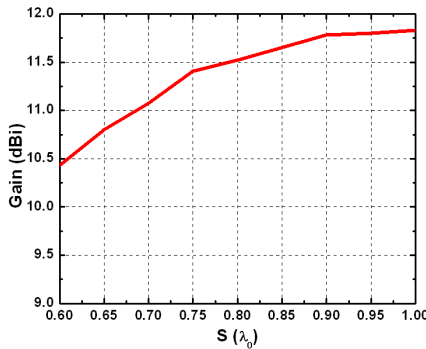


Figure 11. Simulated gain of the antenna array at 2 GHz as a function of element spacing (S).

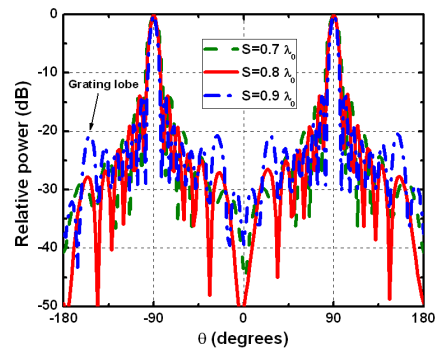


Figure 12. Simulated radiation patterns in the vertical plane for the antenna array at 2.2 GHz for different values of the element spacing (S).

$0.8\lambda_0$, and $0.9\lambda_0$ (λ_0 is the free-space wavelength at 2 GHz). It is observed that grating lobes appear at $S = 0.9\lambda_0$. Therefore, we choose $S = 0.8\lambda_0$ for the maximum gain without appearance of grating lobes.

The diameter (D_r) of the reflectors and the spacing between the reflector and the adjacent antenna element (S_r) are optimized for

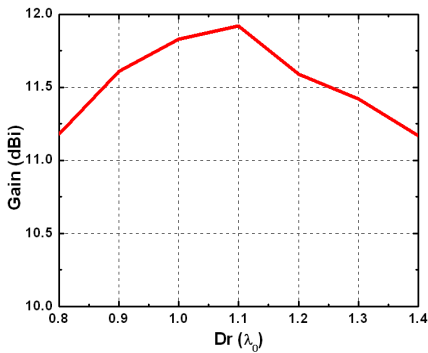


Figure 13. Simulated gain of the antenna array at 2 GHz as a function of the diameter (D_r) of the reflectors.

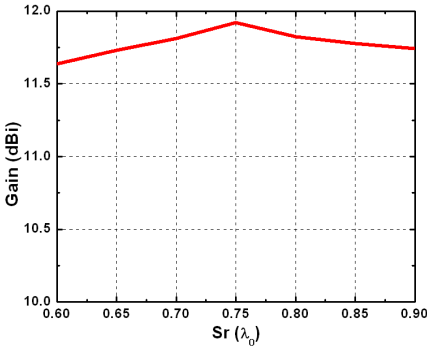


Figure 14. Simulated gain of the antenna array at 2 GHz as a function of the spacing (S_r) between the reflector and the adjacent antenna element.

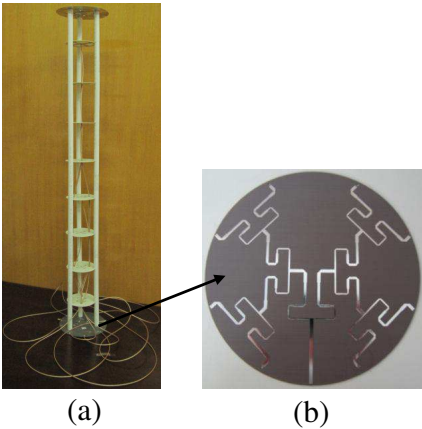


Figure 15. A prototype for the broadband HP omnidirectional antenna array. (a) Perspective view. (b) Feeding network.

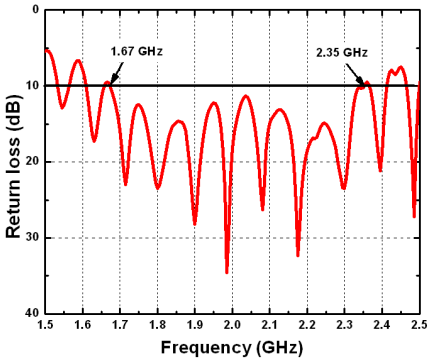


Figure 16. Measured return loss for the broadband HP omnidirectional antenna array.

the highest gain. Figures 13 and 14 demonstrate the gain variations at 2 GHz as the diameter and the position of the reflectors change. Figure 13 shows that there is a maximum gain at $Dr = 1.1\lambda_0$. The

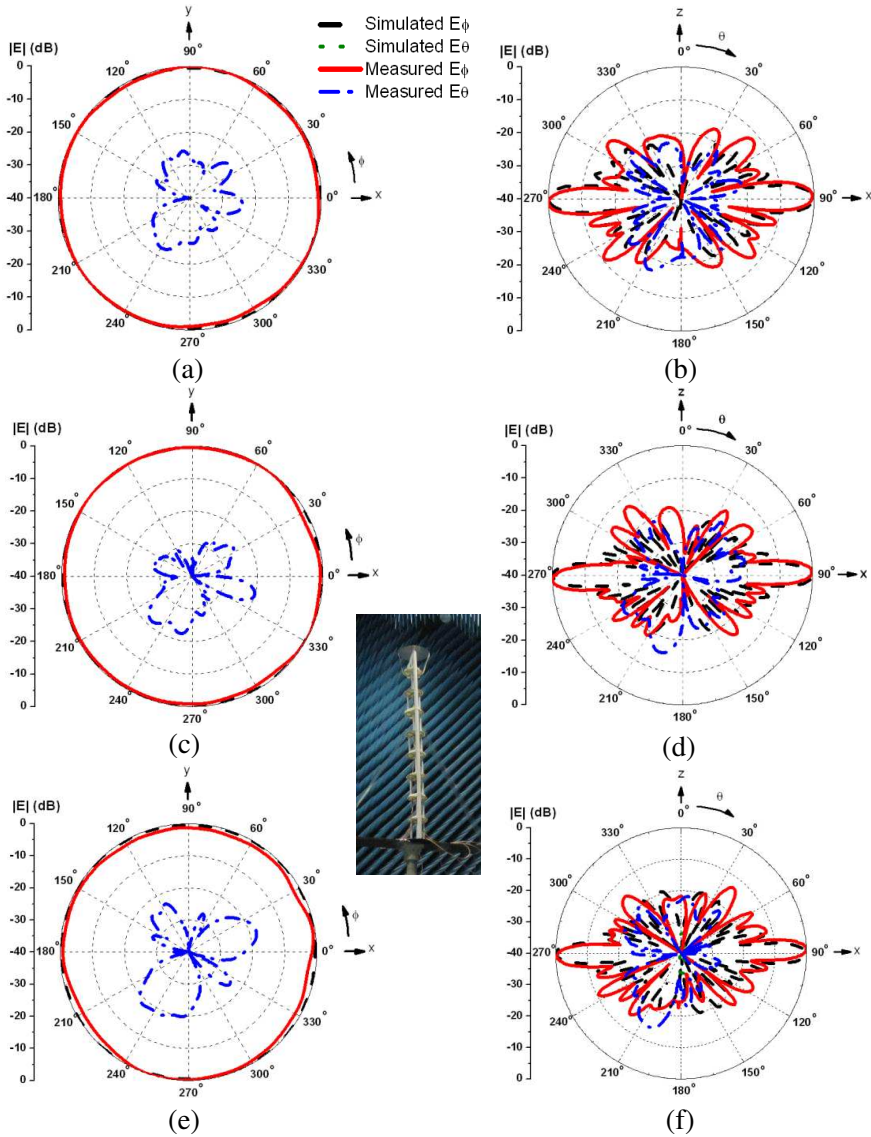


Figure 17. Measured radiation patterns for the HP omnidirectional antenna array, (a) 1.7 GHz (xy plane), (b) 1.7 GHz (xz plane), (c) 2.0 GHz, (xy plane), (d) 2.0 GHz (xz plane), (e) 2.2 GHz (xy plane), and (f) 2.2 GHz (xz plane).

optimal reflector spacing (S_r) is found to be $0.75\lambda_0$, which leads to a maximum gain of 11.8 dBi.

3.3. Experimental Results

A prototype of the eight-element antenna array with feeding network is pictured in Figure 15. The antenna elements are inserted into three hollow PVC (Polyvinyl Chloride) plastic tubes with a diameter of 16 mm. Since the dielectric constant and thickness of the PVC tubes are small ($\epsilon_r = 2.4$, thickness = 0.5 mm), their influence on the radiation pattern of the array is negligible. Eight HP omnidirectional antenna elements are connected to the feeding network by eight one-meter-long RG316 flexible coaxial lines. The feeding network for the array was fabricated on a Taconic TLY-5 dielectric substrate (thickness = 0.8 mm, $\epsilon_r = 2.2$, loss tangent = 0.0009).

Figure 16 shows the measured RL for the eight-element antenna array. The bandwidth for RL > 10 dB is about 34% (1.67–2.35 GHz). Figure 17 shows the simulated and measured radiation patterns of the eight-element array in the horizontal plane and vertical plane. Omnidirectional patterns are observed in horizontal plane. Simulation shows the gain variation in the horizontal plane is about 2 dB, slightly higher than measured results due to the effect of feeding coaxial lines. The cross-polarization in the horizontal plane is about 20 dB lower the co-polarization.

Figure 18 shows the simulated and measured gains of the eight-element antenna array. For comparison, the attenuation from the RG316 coaxial lines (~ 1.2 dB/m) and losses from the feeding network (~ 1.5 dB) and from the SMA connector (~ 0.5 dB) have been added

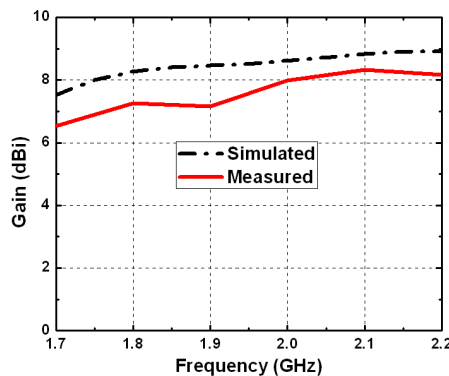


Figure 18. Measured gain for the HP omnidirectional antenna array compared with simulated result.

to the simulation result. Therefore the total loss from the feeding structures is about 3.2 dB. The measured gain is around 8 dBi, about 0.8 dB lower than the simulated result.

4. CONCLUSION

A novel broadband HP omnidirectional antenna is proposed by using four printed arc dipoles. A broadband feeding network is designed to feed the four arc dipoles. Measurement shows the HP omnidirectional antenna achieves a bandwidth of 31% (1.66–2.29 GHz) for return loss > 10 dB. The gain variation in the omnidirectional plane is less than 1.5 dB. An eight-element linear antenna array is developed for potential applications in mobile communication base stations. The 10-dB return loss bandwidth for the array is 34% (1.67–2.35 GHz) and the antenna gain is around 8 dBi with a variation of less than 2 dB in the omnidirectional plane. The HP omnidirectional antenna may find applications in base stations for ground/airborne communications.

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