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Wideband Omnidirectional and Sector Coverage Antenna Arrays for Base Stations

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Abstract—By using parallel strip line fed printed dipole antennas as array elements, an omnidirectional antenna array and a wide angle sector coverage array operating in octave band are designed. A maximum deviation of ± 1.25 dB from the omnidirectional pattern is achieved for the omnidirectional array, and the average gain of the antenna was measured as being 5 dB in the 1.35–2.7 GHz band. For the sector coverage array, a special reflector design is utilized to maintain a half power beam width of around 115° with a standard deviation of 14° in the aforementioned frequency band. The average gain of the sector coverage array was measured as 10 dB, thereby being almost three fold larger than the average gain of the omnidirectional array.

1. INTRODUCTION

The demand for higher data rates in modern communication systems is usually met by utilizing a wide frequency bandwidth. Those wideband communication systems require the design of broadband antennas. When the terminal antennas at mobile devices are considered, an omnidirectional radiation pattern is preferred for uniform coverage. Moreover, the small size of mobile devices restricts the size of the antenna as well. Various examples of compact antennas with omnidirectional radiation characteristics and operating in a wide frequency range can be found in literature [1–6]. The antennas on mobile devices are generally low gain antennas due to restrictions on their size and radiation characteristics. Therefore high gain antennas need to be deployed at the base station side of the link to achieve reliable communication. Fortunately, there is usually enough space at the base station to build antenna arrays in order to meet higher gain requirements. Parallel or series network configurations can be employed to feed the array. Since generally a parallel distributed feed network disturbs the symmetry of the array, the omnidirectional radiation characteristic may not be preserved for a linear array. Hence novel symmetric feeding topologies, such as back to back printed dipoles placed at either side of the center feed line [7], need to be designed. Although dual band [8, 9] and tri-band [10] versions of this design are proposed, their bandwidths are limited to almost 20%. Moreover, since the design of the feed network for this configuration is quite complex, generally 2-element array designs are studied and a 4-element array is considered only in [9]. Recently, a wider bandwidth (56.4%) is achieved with this parallel feed configuration through the use of 3D dipoles with vertical arms and parasitic dipoles [11]. In [11], first a 2-element array is designed, then higher gain values are obtained by placing 3 of these 2-element arrays on top of each other with a 120° angular shift between them to enhance omnidirectional radiation. While the gain of the 2-element array varies between 3.4 to 5 dBi, the 3×2 element array combination exhibits gain values between 5.7 to 8.0 dBi. These values imply that the approach to combine 2-element arrays is not very efficient, since a 3 dB increase in the gain would be expected by just doubling the number of array elements instead of tripling.

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Series feeding methods make it possible to design arrays with higher gain values by using larger number of elements [12, 13]. In [12], 7.75 dBi gain is achieved with a 4-element array and 10 dBi gain is obtained with an 8-element array in [13]. However due to the narrow bandwidth characteristics of series feeding technique, the bandwidths of these designs are limited to 12.5% and 5% in [12] and [13], respectively.

To increase the capacity of the wireless communication channel by exploiting polarization diversity, dual-polarized antennas operating at dual or multi bands are also proposed in literature for base stations [14, 15]. However the percentage bandwidths of each communication band considered in those applications (For example LTE band: 1710–2170 MHz) are generally at most 25%. In the communication link considered in this work, a much wider bandwidth (66.7%) is utilized to achieve higher capacity. Therefore dual polarization operation is not a requirement for this array and only vertical polarization is required. For omnidirectional antenna arrays with vertical polarization, dipole antennas are the first candidate to be considered as in this work. However when a horizontally polarized array is required, it is more difficult to achieve it in a wide frequency band. As proposed in [16], planar arrays in the azimuth plane can be used to obtain omnidirectional coverage with horizontal polarization. In [16], 4 printed arc dipoles are excited by a broadband feed network such that they form a circular loop with an in-phase current distribution.

To complete the discussion about the polarization, a circularly polarized antenna with 87.3% bandwidth (1–2.55 GHz) is worth mentioning [17]. In [17], four pinwheel-shaped folded planar monopole antennas are placed at the corners of a square with consecutive 90° rotations between monopoles. Then each monopole is excited by quadruple phase delay to obtain circular polarization.

The first contribution of this paper is to propose a simple parallel fed antenna array for base stations operating in 1.35–2.7 GHz (66.7%) band with omnidirectional coverage in the azimuth plane. As proposed in [18], the array element is chosen as wide printed dipole antenna fed by parallel strip lines to achieve the required large bandwidth. A simple feed network for a 4-element array is designed by alternatingly distributing the feed network to either side of array elements in order to maintain symmetry as much as possible so that the feed network does not disturb the omnidirectional radiation characteristics.

The second aim of this work is to design an antenna array operating in the same band but with a wide (about 120°) sector shaped radiation instead of omnidirectional radiation in the azimuth plane. When such a large bandwidth and wide beam angle are considered, generally tapered slot antennas, such as Vivaldi antenna, are the first choice to be studied. Hence first a Vivaldi antenna is designed for this frequency band. However when the radiation pattern of the antenna is investigated, it is observed that the half power beam width in the H-plane varies between 75°–100° throughout the bandwidth. Therefore it is concluded that Vivaldi is not a suitable choice for this application. Microstrip antennas and their variations are generally used in applications that require lower (around 60°) angular coverage [1]. In [19], semi-circular sector horn antenna array is proposed to satisfy both wide angle coverage and wide bandwidth requirements. In this work, the motivation was to utilize the wideband printed dipole antenna as the array element of the sector antenna. Therefore as suggested in [20], a reflector is designed to shape the radiation pattern of the dipole antenna according to wide angle coverage requirement. The second contribution of this paper is to demonstrate the efficacy of a simple reflector design in limiting the omnidirectional radiation of a dipole antenna to a desired sector coverage.

In Section 2, the design of omnidirectional and sector coverage antenna arrays will be presented together with the measurement results of the designed antenna arrays. Conclusion and discussions are provided in Section 3.

2. DESIGN OF ANTENNA ARRAYS

The dielectric substrate is chosen to be 0.813 mm thick RO 4003 (dielectric constant = 3.38, loss tangent = 0.0021) from Rogers Corporation. A parallel strip line fed double-sided printed dipole antenna, as shown in Fig. 1, is designed to operate at 1.35–2.7 GHz band. The width of the antenna is quite large (26 mm) to meet the wide bandwidth requirement. This wide width results in increased cross polarization levels due to spreading of the current at the feed point and at the opposite edge. Therefore, 2 mm chamfering is implemented at the edges to minimize this effect.

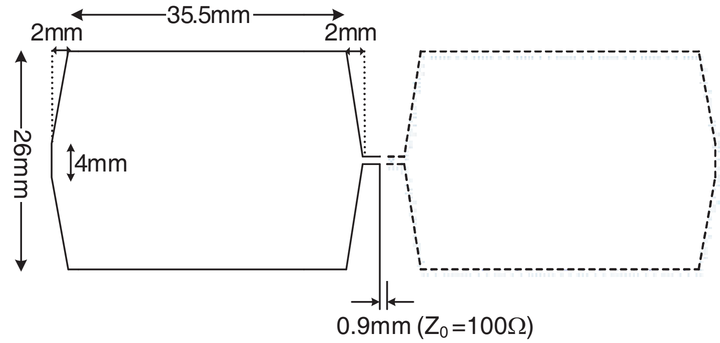

Figure 1. Parallel strip line fed double-sided printed dipole (dashed line denotes the half of the dipole on the other side of the substrate).

Since the antenna will be used as an array element, the input impedance of the antenna is designed to be $100\,\Omega$ so that when two of them are combined with $100\,\Omega$ transmission lines, the input impedance of this 2-element array becomes $50\,\Omega$. As shown in Fig. 2, these 2-element arrays are combined with tapered transmission lines to obtain 4-element arrays. At the input of the array, microstrip line to parallel strip line transition is designed for easier integration of the connector. Corporate feeding method is preferred to meet the wide bandwidth requirement. The distance between the array elements are chosen as 105 mm (0.945λ at the highest frequency) so that mutual coupling between array elements are minimized without introducing grating lobes.

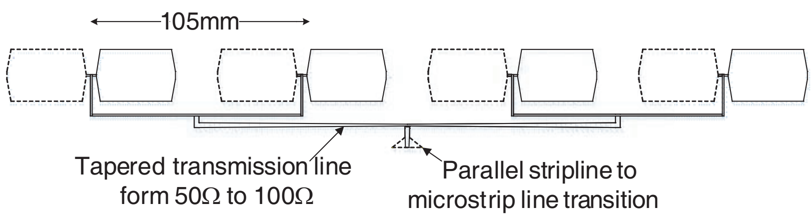

Figure 2. Feed network of wideband 4-element array.

This 4-element array is used in two different array configurations which will be explained in the following two subsections. The first one is a linear array in the elevation with omnidirectional radiation in the azimuth. The second one is again a linear array in the elevation but with a wide angle sector coverage in the azimuth.

2.1. Omnidirectional Array

It is presumable that if all the feed lines are placed at one side of the array elements, the radiation from the feed lines may disturb the omnidirectional radiation characteristics of the dipole. Hence an alternative feed network topology where the feed lines are placed symmetrically at each side of the array elements, as shown in Fig. 3, is also studied.

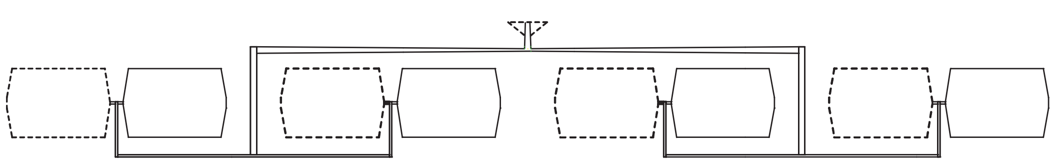

Figure 3. Symmetrical feed network topology for omnidirectional 4-element array.

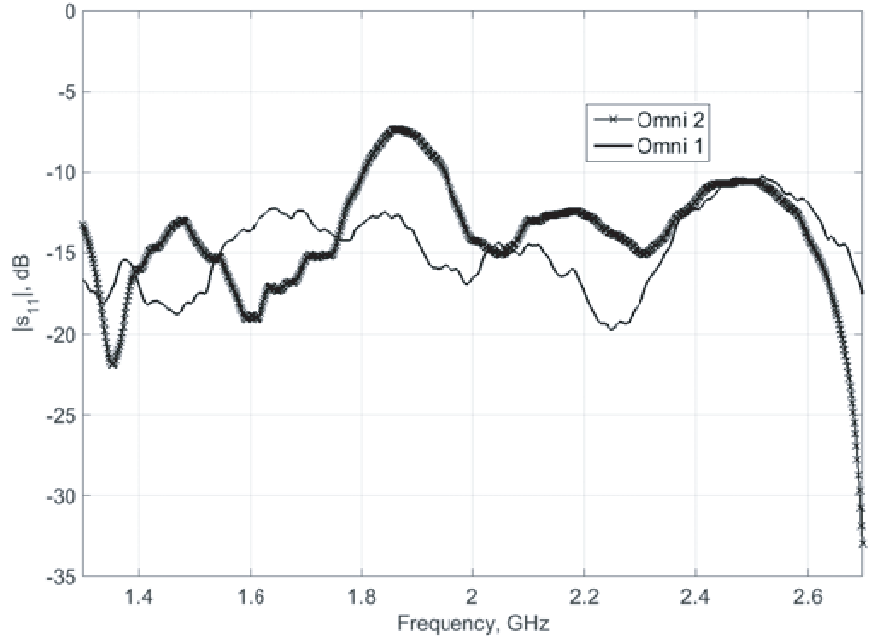

Figure 4. Measured input return loss characteristics of two arrays.

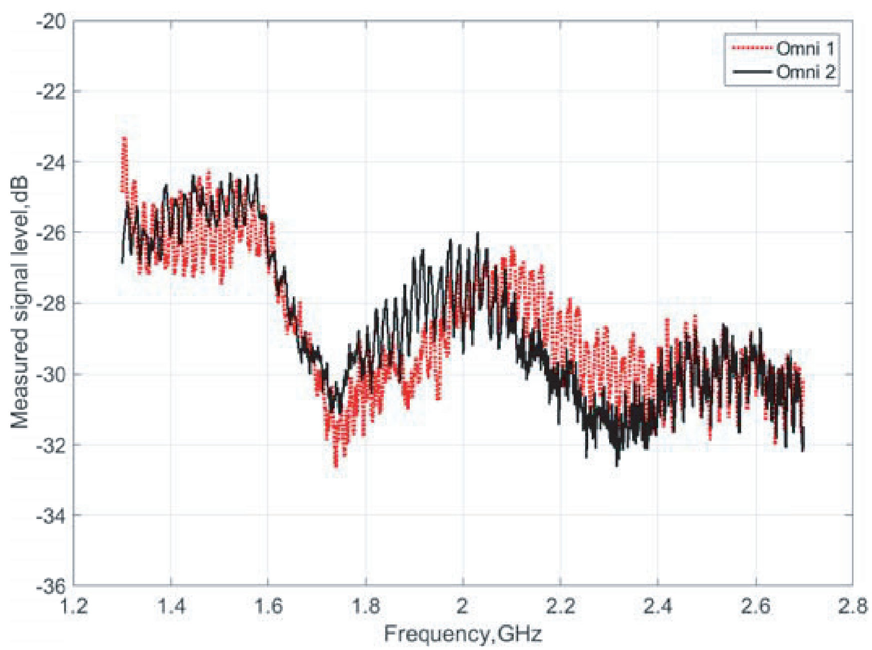

Figure 5. Variation of the measured signal level with frequency while the omnidirectional array is rotating around the array axis.

The array in Fig. 2 is denoted as Omni 1 and the array in Fig. 3 denoted as Omni 2. The measured input return loss characteristics of these two arrays are compared in Fig. 4. As can be observed from the figure, Omni 1 array provides a better matching performance whereas the input return loss of Omni 2 array increases above -10 dB for some frequencies probably due to the feed lines passing between the array elements.

A measurement setup is designed to evaluate the omnidirectional radiation performances of the two arrays within the considered wide frequency range. The array, which is oriented in the elevation direction, is rotated around the array axis, and the frequency of the signal transmitted by the array is swept between 1.35 GHz and 2.7 GHz. Then the signal received by an antenna, placed at the azimuth plane of the rotating array, is recorded. Half of the swing in the received signal, gives the maximum amount of deviation from the omnidirectional radiation. If the antenna is a perfect omnidirectional antenna, the measured signal is expected to have no ripples. The variation of the measured signal levels with frequency for both antenna arrays are presented in Fig. 5.

The maximum deviation from the omnidirectional radiation characteristics is measured to be ± 1.25 dB for both of the array configurations. Although a significant difference between the two antenna arrays is not observed in terms of the omnidirectional radiation characteristics, Omni 2 array may be considered to perform better due to its superior radiation characteristic at wider frequency bands. It can be concluded that the trade-off between better input return loss and better omnidirectional radiation should be considered during the design of the antenna array. In this application, Omni 1 array configuration is preferred due to its better matching performance and acceptable deviation from omnidirectional pattern. The measured radiation pattern of Omni 1 array in the azimuth plane is plotted for three different frequencies in Fig. 6. The degradation at 270° corresponds to the scattering caused by the connector and the cable.

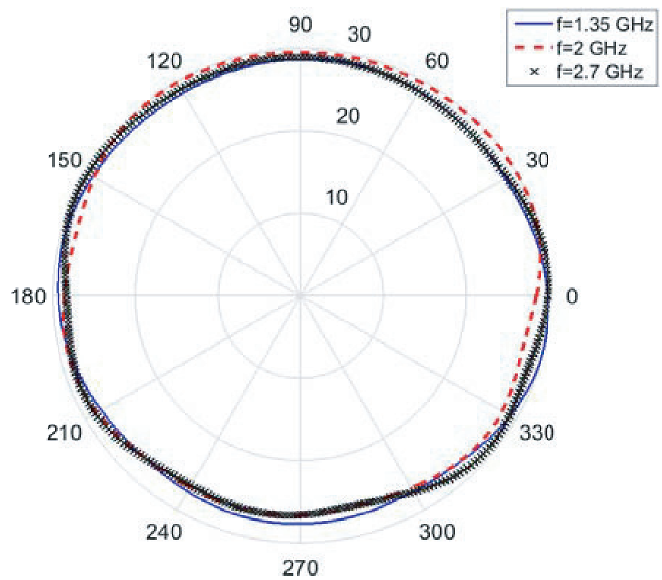

Figure 6. Measured radiation patterns of the omnidirectional array in the azimuth plane ($\theta = 90°$) at different frequencies.

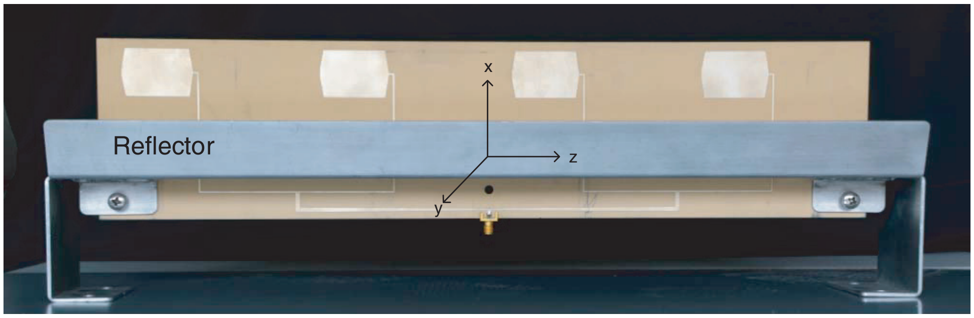

Figure 7. Top and side views of the designed wide angle sector coverage linear array of dipoles backed by a reflector.

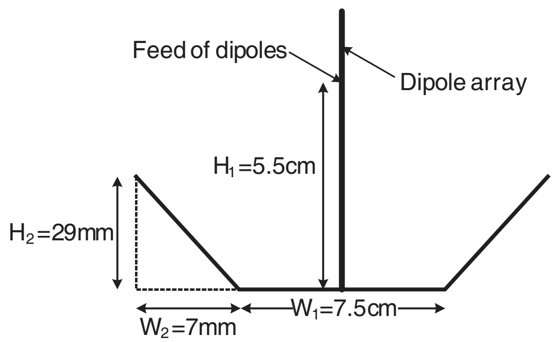

Figure 8. Design parameters of the reflector used in the sector coverage array.

2.2. Wide Angle Sector Coverage Array

As discussed in the Introduction section, Vivaldi antennas do not provide radiation pattern stability in the azimuth plane where a wide sector coverage is required. Therefore, the omnidirectional array is aimed to be used in the design of the sector coverage array. To achieve sector shaped radiation pattern in the azimuth, as proposed in [20], a reflector, which will be placed at the back of the linear dipole array as shown in Fig. 7, is designed. Design parameters of the reflector and their optimized values can be seen in Fig. 8. The initial values of these parameters are chosen as the values reported in [20], since similar frequency bands are considered. Next these parameters are optimized by using the parameter sweep tool of 3D electromagnetic field solver, ANSYS HFSS. The objective of the optimization process is to minimize the variations in the half-power beamwidth (HPBW) of the array in the azimuth plane with respect to frequency.

The measured input return loss characteristic of the sector coverage antenna can be seen in Fig. 9. It can be observed that except for some narrow frequency ranges, input return loss values better than -10 dB are achieved almost for the whole frequency band.

The radiation patterns of the antenna in the azimuth ($\theta = 90°$) and elevation ($\phi = 0°$) planes are measured at different frequencies within the band. The measurement results in the azimuth and elevation planes at four sample frequencies are shown in Fig. 10 and Fig. 11, respectively. The azimuth plane results imply that the sector coverage is maintained almost within the whole bandwidth. However, at higher frequencies undulations in the radiation pattern occurs which is most probably due to the diffraction effects from the edges of the reflector.

It can be observed from the results in the elevation plane that the side lobe levels increase at low frequencies. When the cause of this effect is investigated, it is found that the mutual coupling between adjacent elements increases at lower frequencies due to the decrease in the electrical distance between them. The increased mutual coupling gives rise to unequal excitation of the array elements, and especially higher excitation is observed at the edge elements.

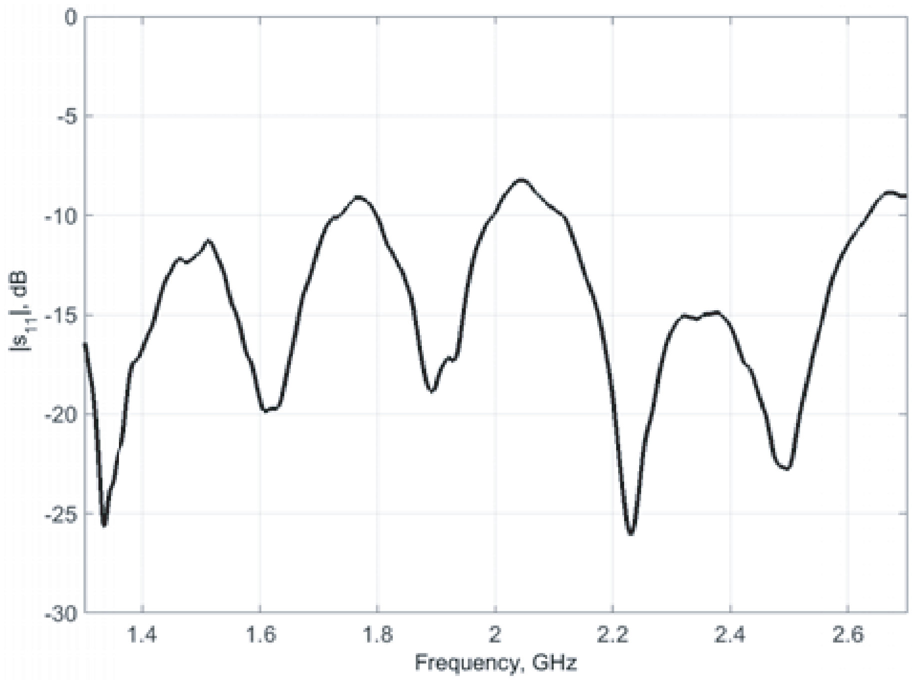

Figure 9. Measured input return loss of sector coverage antenna.

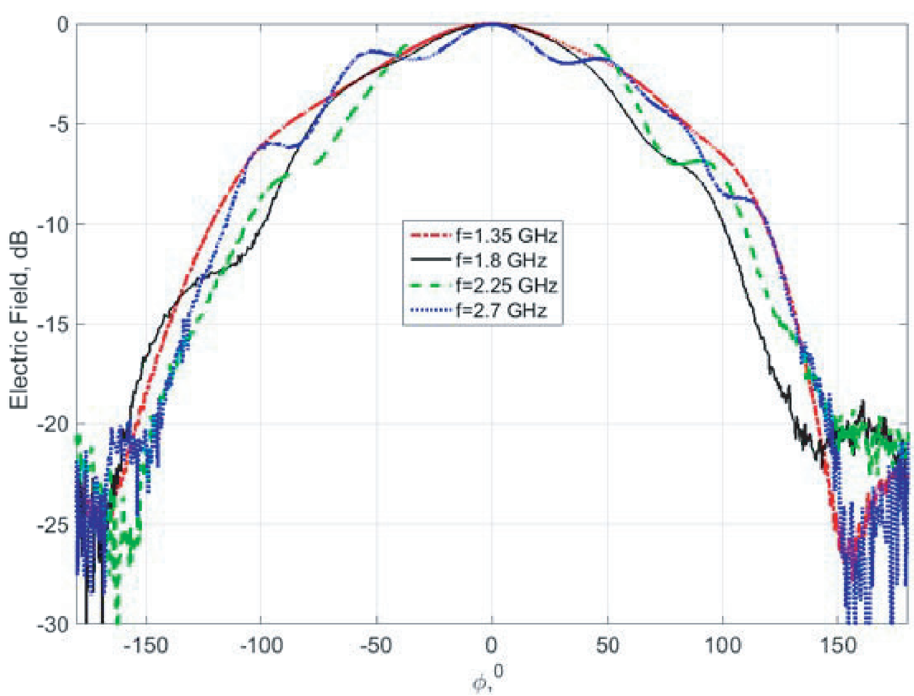

Figure 10. Measured radiation patterns of the sector coverage array in the azimuth plane ($\theta = 90°$) at different frequencies.

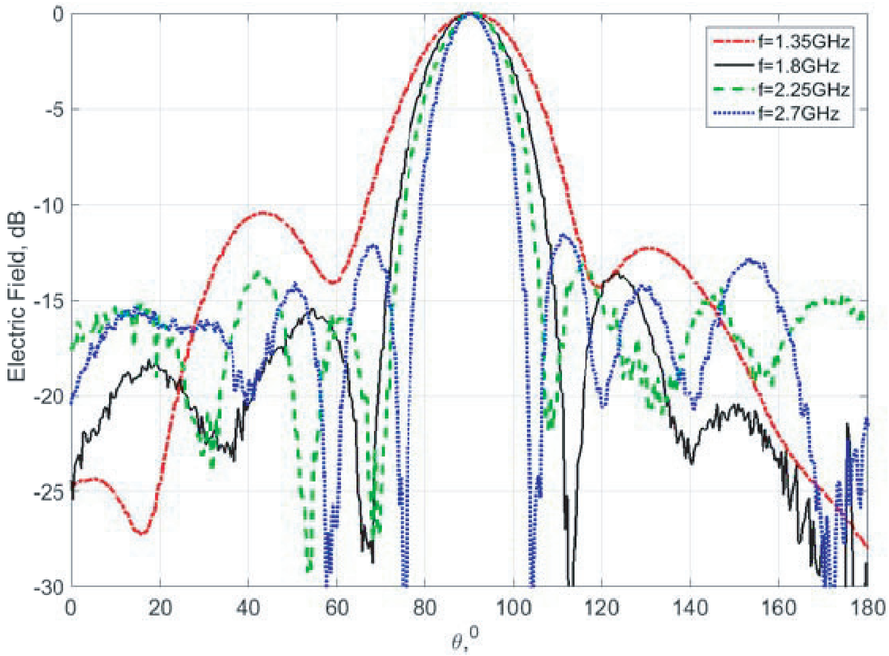

Figure 11. Measured radiation patterns of the sector coverage array in the elevation plane ($\phi = 0°$) at different frequencies.

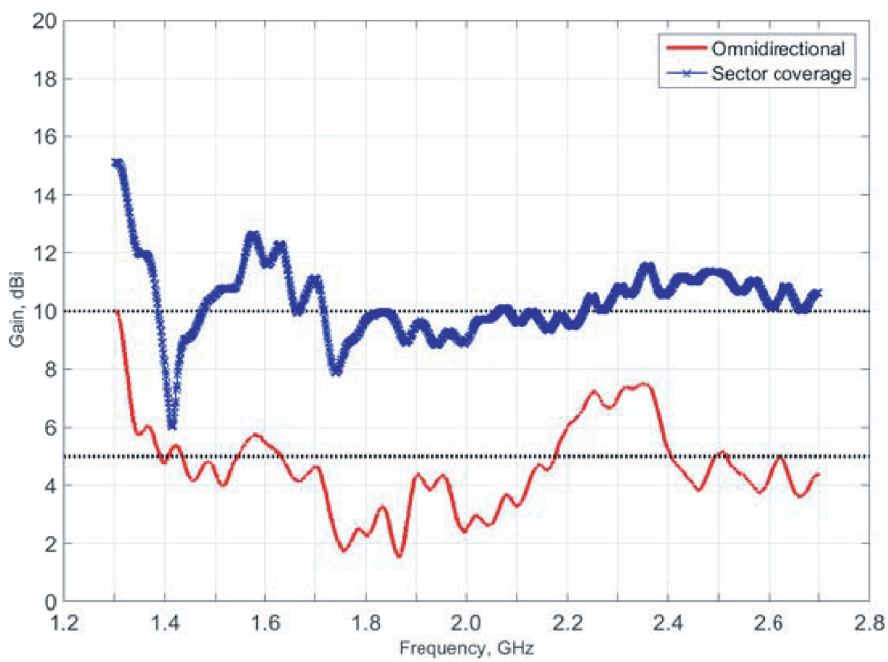

Figure 12. Measured gain of omnidirectional and sector coverage arrays.

The HPBW values measured in the azimuth and elevation planes are tabulated in Table 1. It can be observed that the HPBW in the azimuth plane is quite stable whereas the HPBW in the elevation plane decreases almost linearly with increasing frequency as expected from array theory.

Table 1. HPBW values in the azimuth and in the elevation planes of the sector coverage array.

Frequency (GHz)	HPBW (°)	
	Azimuth	Elevation
1.35	126.1	26.4
1.50	92.1	22.1
1.65	98.9	21.9
1.80	110.2	20.3
1.95	114.9	18.3
2.10	105.2	17.7
2.25	110.2	17.1
2.40	128.4	15.7
2.55	134.5	14.7
2.70	129.0	13.6

3. CONCLUSION

An omnidirectional antenna array with at most ±1.25 dB deviation from omnidirectional radiation and a sector coverage array with sector angle varying between 92° and 135° are designed to operate in 1.35–2.7 GHz band.

The gain of the omnidirectional and sector coverage arrays are measured by using a standard gain horn antenna. The measured gain results are presented in Fig. 12. The average gains of the omnidirectional and sector coverage arrays are 5 dB and 10 dB, respectively. If average HPBW of the sector coverage array in the azimuth plane is considered to be 120°, a gain of about three fold (4.77 dB) compared to omnidirectional array is expected which is consistent with the measured results. On the other hand, between 1.35 GHz and 2.7 GHz about 3 dB increase in the gain is expected due to the narrowing of the beam in the elevation plane. However, gain is observed to be almost stable within the band. This may be attributed to the increased (almost doubled) loss in the feed network at higher frequencies since the length of the feed lines will be electrically longer. As a future work, different feed lines that provide wideband operation with lower loss values may be considered.

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