A Massive MIMO Panel Array at Ka-Band with Flexible Patterns and Beam Steering Performance

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Abstract. In this paper, we are presenting a software defined based massive multiple input multiple output (MIMO) panel array antenna with flexible radiation patterns and beam steering application. This design involves a Ka-band (31.7 GHz to 33.46 GHz) 4 × 4 microstrip patch planar array with dual linear polarizations and good isolation which is required for a massive MIMO antenna system. In this case, by controlling input excitations of the selected radiating elements in the array, we generate radiation patterns with variable beamwidths or directivity at the broadside angle. Further, by applying variable amplitude and phase excitations to the partial or full array, we generate beam steering radiation patterns. Additional analysis and measured performance results will be presented during the conference.

Keywords: Software defined phased array · Massive MIMO panel · Microstrip patch · Dual linear polarization · Millimeter wave

1 Introduction

High gain directional antennas are highly desired in long range communication scenarios such as multipoint communications, airborne communication networks, airborne to ground communications, satellite to ground terminals and satellite to airborne platforms, such as shown in Fig. 1. The antenna design becomes more challenging when the separation between the transmitter and receiver system is variable such as an airborne communication system communicating with another such airborne communication system. Similarly, if the same communication system is involved with other communication platforms then we would need multiple radiating beams. These can be implemented using a software defined or digital beam forming (DBF) approach where array beams, both in transmit or receive mode, are constructed in virtual domain.

To accomplish above discussed antenna system design, we need an array antenna aperture with individual input excitations such as in a massive multiple input multiple output (MIMO) communication system. This array aperture can be reconfigured by selective excitations of the radiating elements so that we can generate radiated beams

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with flexible beamwidths or directivity for a chosen polarization and matching bandwidth. Similarly, by simultaneous excitation of a group of radiating elements with proper amplitude and phase excitations, we can generate multiple radiated beams in the digital domain. Beams can be steered by applying variable amplitude and progressive phase shifts, therefore a lot can be achieved with one array antenna aperture with the help of software defined approach contrary to an analog beam forming network (BFN) based array antenna where flexibility is limited.

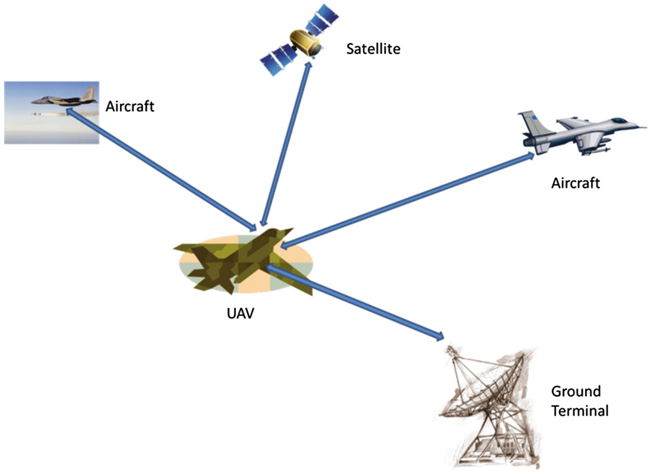


Fig. 1. Scenario showing the airborne (UAV) communication platform communicating with other communication platforms.

There are some research efforts towards the introduction of a massive MIMO antenna for beamforming which are documented in [1–3]. The design challenge involves a large size array starting from several radiating elements to a 100^{th} of radiating elements in an array. Some conventional 2 elements MIMO antennas for several handheld communication platforms are presented in [4–6]. Different phased arrays antennas and beam forming algorithms can be found in [7–10]. However, in this paper, design of a massive MIMO panel array (4 × 4 subarray) with dual linear polarization at millimeter wave frequency is presented which can be used as a building block for realizing a large size massive MIMO antenna system. Results include impedance matching, isolation and radiation patterns for different selective excitations of the array radiating elements.

2 Massive MIMO Panel Array Geometry

Figure 2 shows the proposed massive MIMO panel array geometry where each of the radiating elements are dual linear polarized (Fig. 2(a)). The patch is fed using microstrip transmission lines from below the ground plane using via connections to the patch, where via refers to a wire. The 4 × 4 subarray or panel array is shown in Fig. 2(b) where patch to patch inter-element spacing is maintained around 0.585λ (free space wavelength (λ) is at the design frequency of 32.6 GHz). Overall subarray or panel size is 23.2 mm × 23.2 mm. Since feedlines are placed below the ground plane, any spurious radiation from these would be eliminated. Additionally, it would be easy to connect software defined radios from this arrangement than when feed ports are placed on the same side as the radiating elements. In the fabricated version of this array, we plan to employ stripline instead of the microstrip feedlines so that the 50Ω K-connectors can be placed.

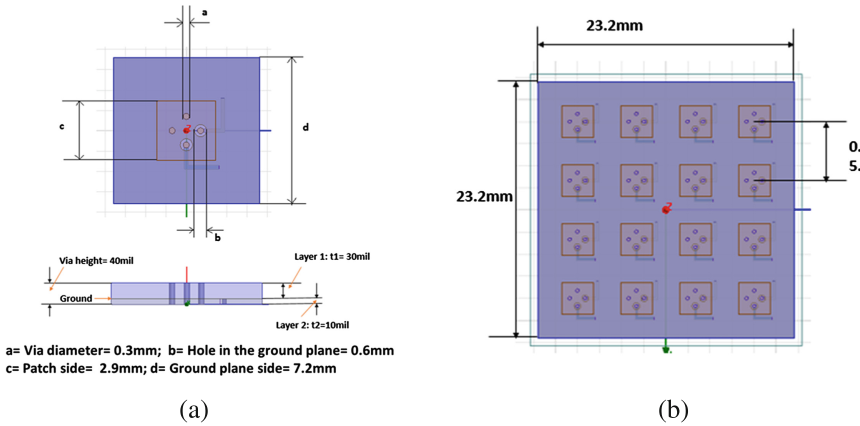
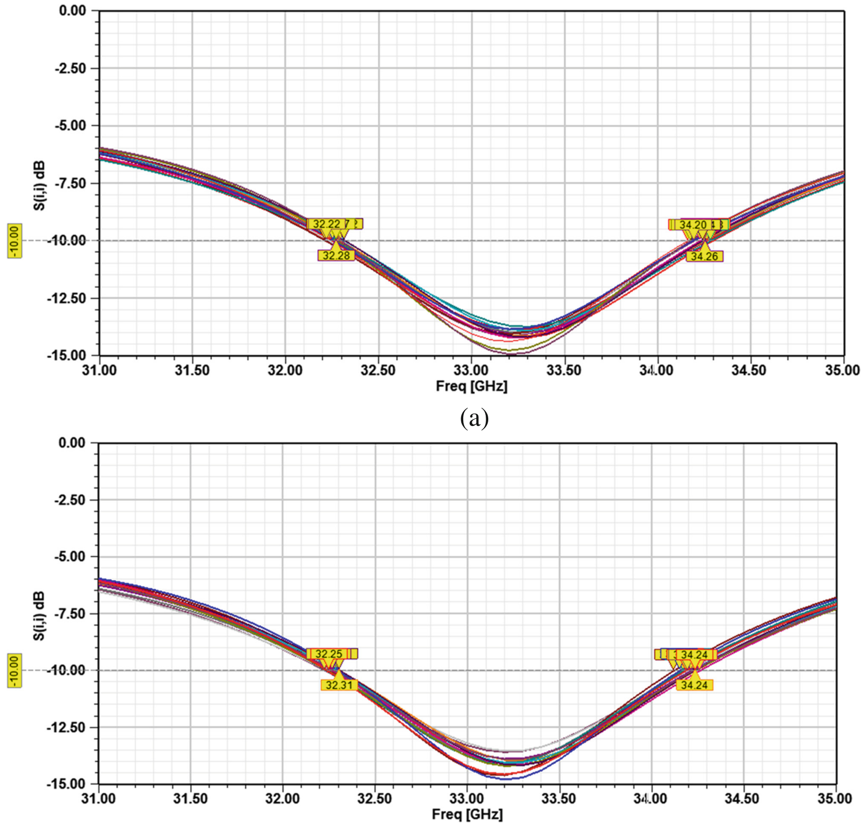


Fig. 2. Proposed millimeter wave (Ka-band) (a) Single microstrip patch antenna with dual linear polarizations and (b) a 4 × 4 massive MIMO panel array with dimensions and inter-element spacing.

3 Impedance Matching and Isolation Performance

The impedance matching (S_{ii}/S_{jj}) for both polarizations (X-linear and Y-linear) are shown in Fig. 3(a). From this figure, it can be seen that, impedance matching of $S_{11} \leq -10$ dB is maintained between 32.20 GHz to 34.20 GHz for all the X-polarized feed ports. The matching performance for Y-polarized feed ports is shown in Fig. 3(b) which has the same bandwidth of 32.20 GHz to 34.20 GHz.

Figure 4 shows isolation between (i) the two linear ports in each of the patches and (ii) the adjacent patches for both X-polarized and Y-polarized feed excitations. The good isolation between the two linear ports of the individual patches is a desired feature for a massive MIMO antenna system which is shown in Fig. 4(a). From Fig. 4(a), it can be seen that both polarizations in each of the patches are maintaining port isolation of better than 22 dB therefore, the two ports will not couple energy between them. From Fig. 4(b) for X-polarization case, it can be seen that isolation is better than 15 dB throughout the matching band of 32.20 GHz to 34.20 GHz, therefore two adjacent patches do not couple energy that can be of concern. Similarly, Fig. 4(c) for Y-polarization shows that isolation of better than 20 dB is maintained throughout the matching band and therefore, would offer almost no coupling between the patches. Thus, the isolation study confirms that we have good isolation between linear polarizations of the individual patches as well as between the adjacent patches for array implementations, all of which are desired feature of a massive MIMO antenna design.



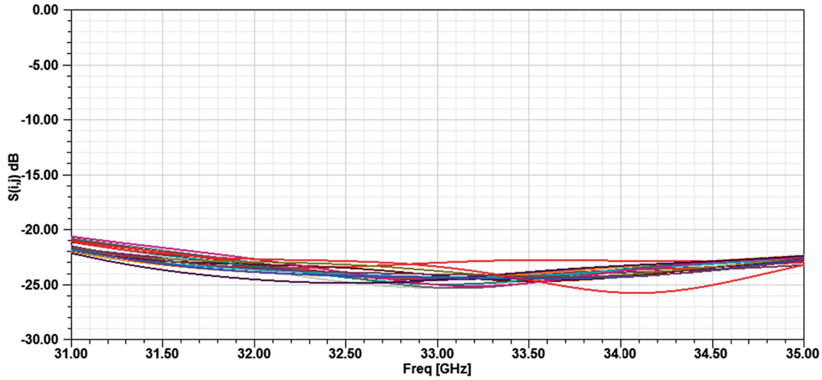
(a)

(b)

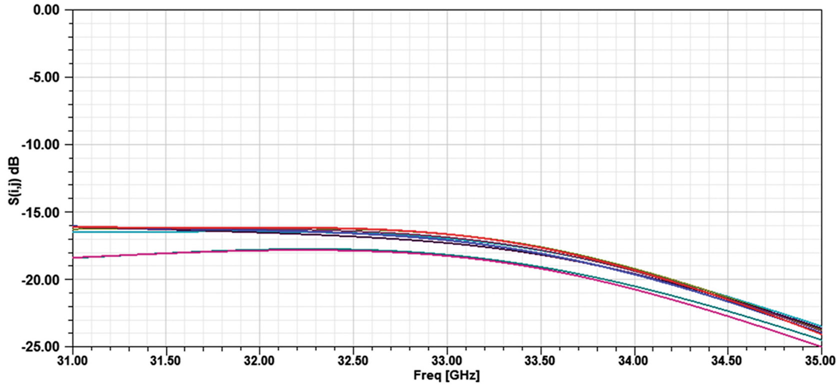
Fig. 3. Impedance matching performance for the (a) X-polarized excitations and (b) Y-polarized excitations.

4 Generation of Flexible Radiation Patterns

Since the array has individual feed port excitations for both X- and Y-polarization cases, hence by exciting the ports with proper amplitude and phase coefficients, we can generate flexible radiation patterns such as discussed in this section. We should make it clear that for simplicity, we have kept amplitude and phase values constant for all the radiating elements which are excited and chosen for the pattern generation.



(a)



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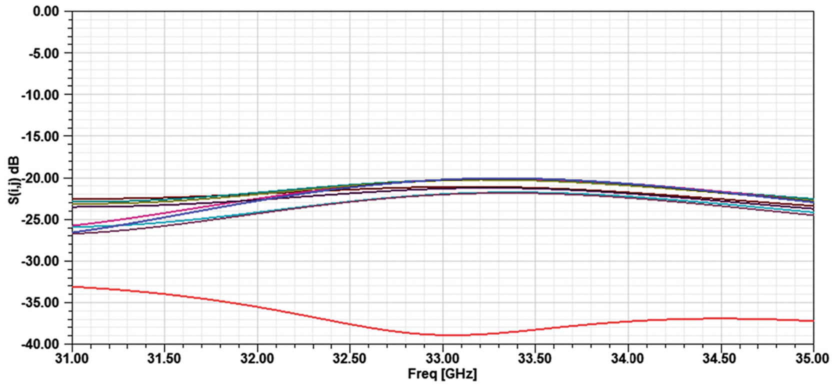
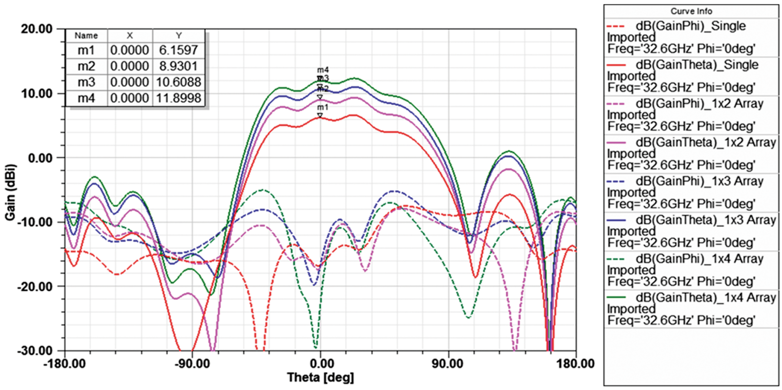


(c)

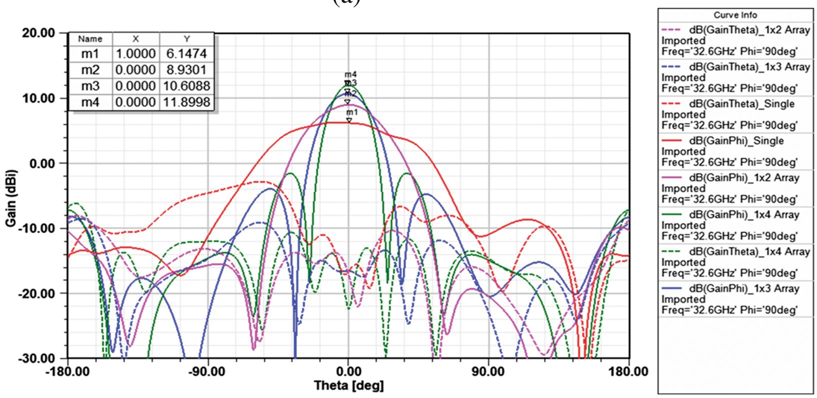
Fig. 4. Isolation between the (a) two linear polarizations in individual patches, (b) X-polarized feed excitations adjacent patches in the array, and (c) Y-polarized feed excitations between the adjacent patches in the array.

4.1 X-Polarization Based Flexible Radiation Patterns

This subsection shows flexible radiation patterns when X-polarization ports in the array are excited while Y-polarization ports are matched terminated. Figure 5 shows a case when we excite single element, and linear arrays of 1 × 2, 1 × 3 and 1 × 4 combinations for the two principal cut planes (Phi = 0 deg and 90 deg). Figure 5(a) shows Phi = 0 deg cut plane patterns where it can be seen that pattern's broadside gain is increasing as array size is increasing hence better directivity. Similarly, Fig. 5(b) shows radiation pattern performance for the Phi = 90 deg cut plane and along the array axis hence the array factor contribution is seen. The patterns show higher gain or directivity and consequently, narrow beamwidths as array size increases. We can do the similar exercise for other linear arrays as part of this planar array, however for the sake of brevity these results are not shown here. Thus, it can be seen that by selective excitation of the radiating elements, radiation patterns with variable gain or beamwidths can be generated.



(a)



(b)

Fig. 5. Flexible radiation pattern generation at 32.6 GHz from the 4 × 4 subarray by selective excitation of the 1 × 4 linear radiating elements for the X-polarization case (a) along one radiating element and (b) along the array axis (single, 1 × 2, 1 × 3, 1 × 4 linear cases).

Figure 6 shows flexible radiation pattern generation for the two principal cut planes (Phi = 0 deg and 90 deg) when we selectively excite radiating elements in planar array fashion, i.e., single, 2 × 2, 3 × 3 and 4 × 4 array cases. From Fig. 6(a), it can be seen that, pattern beamwidth gets narrower as we increase the number of radiating elements. In other words, the broadside gain increases to 17.35 dBi for 4 × 4 array case compared to 6.16 dBi that of a single radiating element. Similar is the observation for Fig. 6(b) which shows the patterns for Phi = 90 deg cut plane. Finally, it should be noted that, there are several other possible linear and planar radiating element combinations which are not included here due to limited paper size.

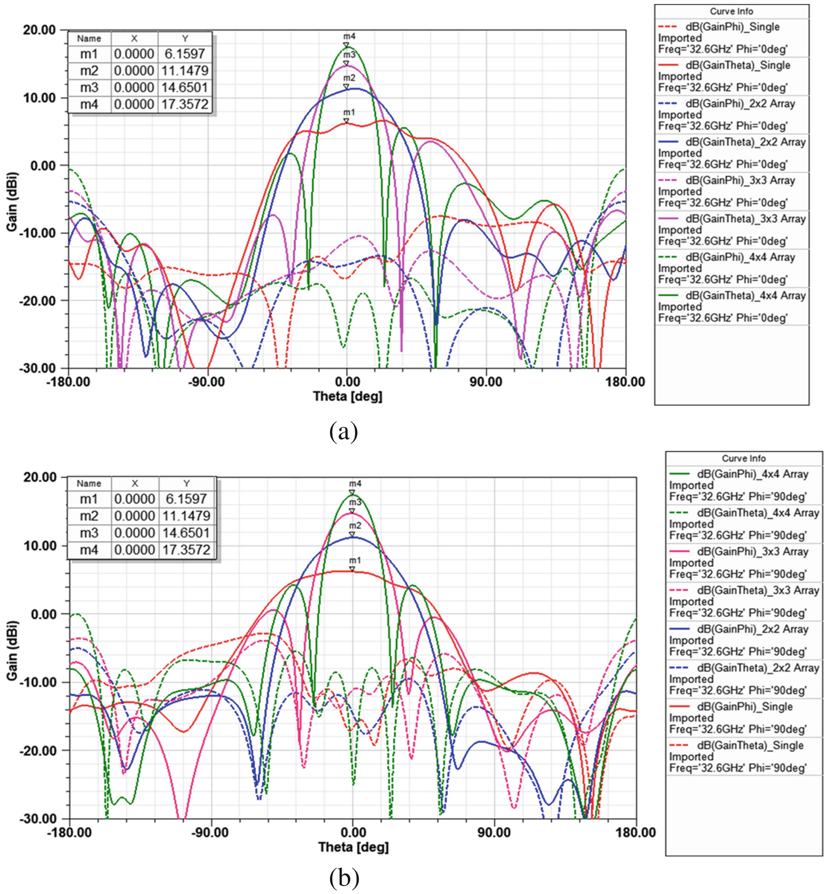
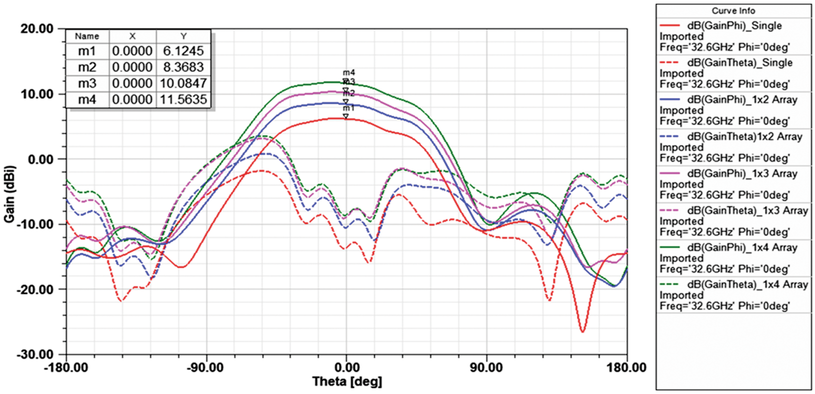


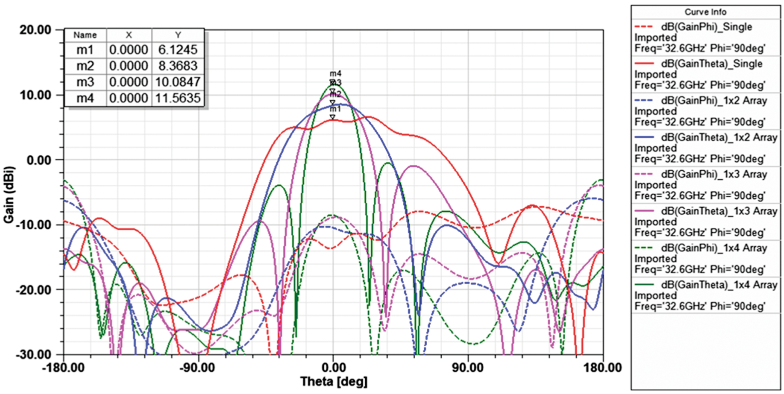
Fig. 6. Flexible radiation pattern generation at 32.6 GHz by selective excitation of a group of radiating elements in planar array configuration for the X-polarization (single, 2 × 2, 3 × 3 and 4 × 4 array) (a) Phi = 0 deg cut plane and (b) Phi = 90 deg cut plane.

4.2 Y-Polarization Based Flexible Radiation Patterns

This subsection shows flexible radiation patterns when Y-polarization ports in the array are excited while X-polarization ports are matched terminated. Figure 7 shows a case when we excite single element, and linear arrays of 1 × 2, 1 × 3 and 1 × 4 combinations for the two principal cut planes (Phi = 0 deg and 90 deg). Figure 7(a) shows Phi = 0 deg cut plane patterns from which it can be seen that the pattern broadside gain is increasing as array size is increasing hence better directivity. Similarly, Fig. 7(b) shows radiation pattern performance for the Phi = 90 deg cut plane and along the array axis hence array factor contribution is seen. The patterns show higher gain or directivity and consequently, narrow beamwidths as array size increases. We can do the similar exercise for other linear arrays as part of this planar array, however for the sake of brevity these results are not shown here. Thus, it can be seen that by selective excitation of the radiating elements, radiation patterns with variable gain or beamwidths can be generated.



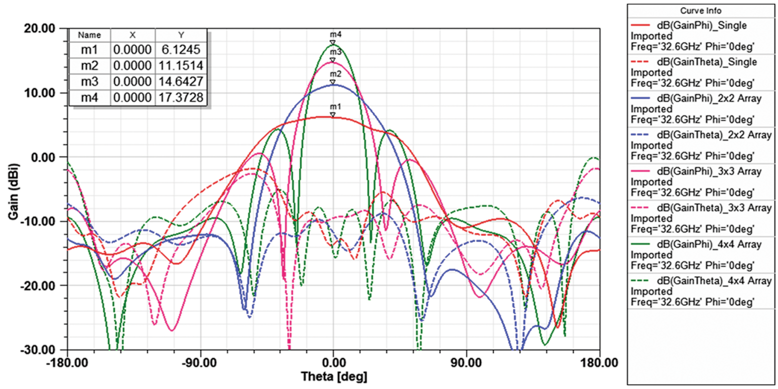
(a)



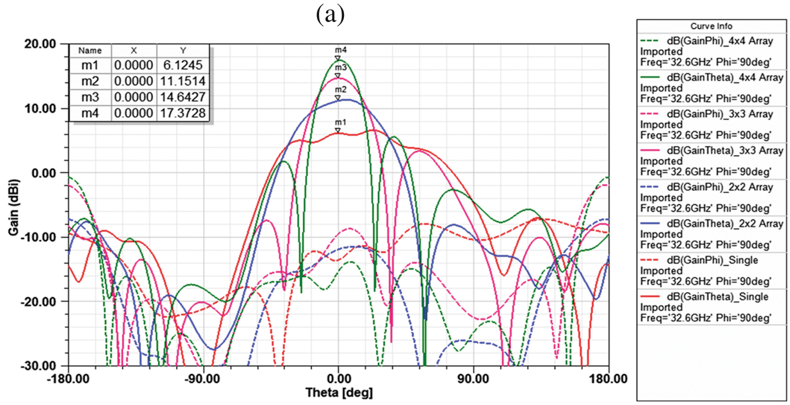
(b)

Fig. 7. Flexible radiation pattern generation at 32.6 GHz from the 4 × 4 subarray by selective excitation of the 1 × 4 linear radiating elements for the Y-polarization case (a) along one radiating element and (b) along the array axis (single, 1 × 2, 1 × 3, 1 × 4 linear cases).

Figure 8 shows flexible radiation pattern generation for the two principal cut planes (Phi = 0 deg and 90 deg) when we selectively excite radiating elements in planar fashion, i.e., single, 2 × 2, 3 × 3 and 4 × 4 array cases. From Fig. 8(a), it can be seen that, the pattern beamwidth gets narrower as we increase the number of radiating elements. In other words, the broadside gain increases to 17.37 dBi for 4 × 4 array case compared to 6.12 dBi that of a single radiating element. Similar observation can be drawn for Fig. 8(b) which shows the patterns for Phi = 90 deg cut plane. Finally, it should be noted that, there are several other such linear and planar radiating element combinations which are not included here.

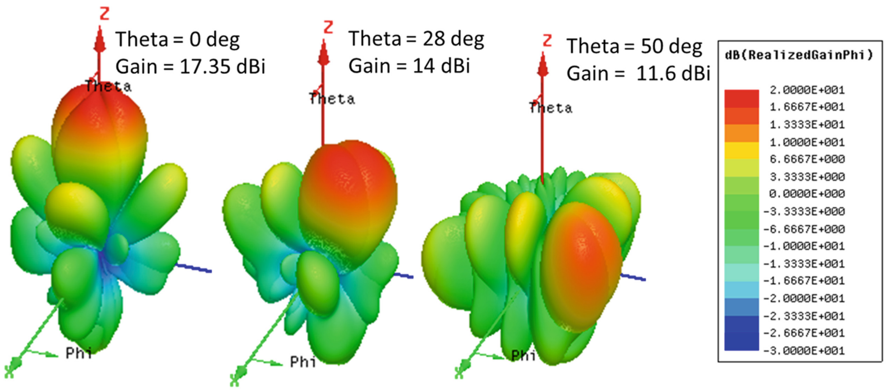


(a)

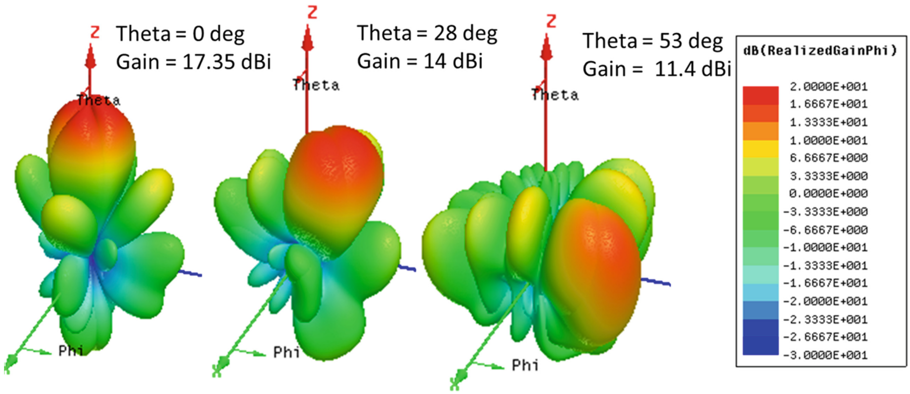


(b)

Fig. 8. Flexible radiation pattern generation at 32.6 GHz by selective excitation of a group of radiating elements in planar configuration for the Y-polarization (single, 2 × 2, 3 × 3 and 4 × 4 array) (a) Phi = 0 deg cut plane and (b) Phi = 90 deg cut plane.



(a)



(b)

Fig. 9. Beam steering performance of the 4 × 4 planar array configuration for 32.6 GHz by varying progressive phase shifts for the (a) X-polarization and (b) Y-polarization.

5 Generation of Beam Steering Radiation Patterns

Since the proposed massive MIMO panel array (Fig. 2(b)) has individual feed port excitations for both X- and Y-polarization cases, hence by exciting the ports with equal amplitude and progressive phase shifts, we can also generate steered radiation patterns such as shown in this section. We have kept amplitudes constant for simplicity while phase shifts have been varied. In real implementations, we would compute proper amplitude and phase coefficients for generating an arbitrary beam scan radiation pattern by employing beam forming algorithms such as in [7–10] although it is not discussed here.

Figure 9 shows 3D radiation patterns for the beam scan cases for both X- and Y-polarizations for the positive half of the elevation angles only. The beam scan performance for the negative half of the elevation angles is almost the same as in case of the positive half of the elevation angles, hence for the sake of brevity is not shown here. From Fig. 9(a), it can be seen that as the beam scans towards elevation angle of theta = 50 deg, gain of the main beam drops to 11.6 dBi from 17.35 dBi that of the broadside beam, hence there is gain drop of almost 6 dB as beam scans. This gain drop is a feature of any beam steering array. Similarly, from Fig. 9(b) for the Y-polarization, it can be seen that as the beam scans towards elevation angle of theta = 53 deg, gain of the main beam drops to 11.4 dBi from 17.35 dBi that of the broadside beam, hence there is gain drop of almost 6 dB as well. Comparison of the two polarization cases shows that both polarizations almost perform similar which is a desired feature of a dual polarization beam steering array antenna. Once again we should note that, we can generate beam scan performance for the different linear combinations of the array also. Further, by applying variable amplitude in addition to the phase shifts, additional radiation pattern features can be generated.

6 Fabrication and Implementation Approach

The full array will be fabricated using the multilayer printed circuit board (PCB) approach with metal plated vias. The amplitude and phase excitations of the patch elements would depend on the computed amplitude and phase values based on the selected beamforming algorithms. For receive mode of the array, each of the radiating elements will be backed by low noise amplifiers (LNAs), variable gain attenuators (VGAs) and phase shifters as shown in [11]. Consequently, for the transmit mode of the array, each of the radiating elements will be backed by power amplifiers (PAs), in addition to the VGAs and phase shifters. There will be a diplexer to switch between the transmit and receive mode of the operation. Finally, to control the amplitude and phase of the array elements, we would employ microcontrollers such as done in [11].

7 Conclusions and Future Study

This paper presented simulation study results of a 4×4 microstrip planar massive MIMO panel array with dual polarization capability in Ka-band frequency range. In such an array, we have control of all the feed ports (in this case 32 ports, 16 ports each for the X-polarization and Y-polarization). By applying variable amplitude and phase coefficients to the selected feed ports in a selected polarization, we can obtain flexible radiation patterns for the fixed beam and steered beam cases. For simplicity, in this paper, we assumed amplitude to be constant while we varied phase values for a group of radiating elements. In practical realization, we will fabricate array antenna aperture in addition to RF input ports and beam forming network for the transmit and/or receive mode. The beamforming algorithm controlled through the microcontroller would be applied to the array feed ports which is a software defined based approach in reference to this array antenna. Further, the panel size can be increased and/or a large massive MIMO antenna can be implemented using the proposed massive MIMO panel array antenna of 4×4 size. During the conference, additional analysis and measured results will be presented.

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