Metasurface with Unequal Spacing Unit-cells based Antenna for Linear and Circular Polarizations

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***Abstract* — A metasurface based on unequal spacing between the rectangular-ring unit cells is used to propose a broadband, low profile, circularly polarized (CP) and linearly polarized (LP) antenna. This can be used for 5G New Radio and GNSS applications in navigation and telemetry on drone which uses remote sensing radar/lidar for survey mapping. The antenna structure comprises a stacked-metasurface based on unequal-spacing between the 7×7-unit cells, a radiating rectangular-patch, and a near diagonal line probe feed. A metasurface is considered using rectangular-ring 7×7-unit cells array with unequal-spacing's in *x*- and *y*-directions and it is placed above a rectangular-radiator to realize a wide CP bandwidth for GNSS applications. The antenna example reaches a 3dB axial ratio of 25.3% (1.38 GHz – 1.78 GHz) with CP (3-dB axial ratio) bandwidth of 15.8% (1.51 GHz – 1.77 GHz) and gain of greater than 8.5 dBic.**

***Keywords* — 5G NR, unequal unit cells, metasurface, stacked antenna, circularly polarized microstrip antenna, broadband, drone, UAV, remote sensing radar**

I. Introduction

Antennas with circularly polarized characteristic are suitable for advanced wireless systems owing to many advantages of the circularly polarized (CP) radiation such as stable-link, low fading/multipath, less Faraday rotation effects, low polarization loss, less alignment consequence of transmitters/receivers, etc. The antenna can create linearly polarized (LP) for 5G New Radio (NR) and CP for satellite systems. 5G NR cellular networks can operate at selected bands (n3 band at 1.8 GHz and n41 band at 2.5/2.6 GHz with multiple channelization's of 5, 10, 20 MHz [1]). A wideband CP microstrip antenna plan should retain the excitation of two modes with nearly identical magnitude with phase difference of 90 degrees across the broader spectrum using single feed for CP radiation [2]. One of the use cases for 5G and GNSS (Global Navigation Satellite System) is for an antenna system mounted on mobile platform such as drone for navigation, localisation, and telemetry, which may support the remote control and georeferencing of a remote sensing radar or lidar system for mobile surveying and mapping purposes.

The multi/dual-feed procedures are typically used to create the CP waves from the planar/microstrip antennas, then antenna geometries are typically huge with design complexity. The metasurface (symmetric) was used to plan the small CP patch antennas with narrow-band [3-8] with nearly asymmetry/disquiet in radiator structures (nearly square-patch, asymmetric-/symmetric-stub/slotted/slit) for microstrip antenna with narrow band designs.

Numerous metasurface (symmetrical) based broadband CP antennas were published since last two decades. A CP-metasurface antenna with wideband at the C-band for satellite system applications has been established in [9] and the metasurface radiator is excited by slanted-slot/aperture coupled feeding with CP-gain of 5.8dBic and strong back-lobe level/radiation. The metasurface-based antennas fed by slot/aperture coupled feeding structure with low-profile have been planned for wideband CP radiation [10] with CP-gain of 7.0 dBic with strong back-lobe level. A CP metasurface with truncated corner square-patch using a coaxial feed excitation and low profile has been studied [11] for broadband with 7.5dBic CP-gain. An array of metasurface elements with a broadband CP operation was established in [12] and 4×4-metasurface element-based array was used to realize directional radiation (high CP-gain) of 13.7dBic. A 2×2-metasurface elements sequentially rotation feeding based CP patch excitation was considered [13] with high CP-gain of 10.8dBic for broadband characteristics. Later, a probe feed broadband metasurface-array/antenna with high CP-gain is preferred with lower back-lobe level.

In this work, an innovative unequal-spacing unit cells based-metasurface is proposed with a coaxial fed rectangular-patch excitation is considered for directional radiation (high gain) with broadband. A rectangular-patch radiator fed along near diagonal line probe is used to excite the unequal spacing unit cells based-metasurface. For realizing CP radiation, in its place of using predictable slit-/slot-/truncated-patch antennas, an unequal spacing unit cells based-metasurface radiator with 7×7-unit cells are placed directly above the rectangular-patch. An irregularity is created with unequal space between the unit cells in *x*- and *y*-planes of the metasurface. Proposed metasurface/antenna configuration can be created two modes with 90° phase shift and estimated equal amplitude for a wideband CP wave.

II. Metasurface Antenna: Geometry and Design

A low profile, CP stacked-metasurface antenna with unequal spacing between 7×7-unit cells is considered (L-band) for broadband characteristics. Fig. 1(a) describes the antenna structure's cross-section interpretation the antenna arrangement includes of a stacked-metasurface (unequal spacing unit cells) and near diagonal probe fed patch radiator. In planned CP antenna structure, the radiating patch (rectangular) is below the unequal spacing unit cells (metasurface) and air is used between excited patch and upper substrate with printed metasurface for high gain with broadband characteristics. For wideband CP characteristic creation from the antenna, two modes with 90° phase shift and nearly identical amplitude over the wider spectrum. By projected shared procedure of a stacked-metasurface (asymmetric) and near slanting axis probe fed patch radiator, two excited modes with 90° phase shift and nearly identical amplitude can be realized from planned antenna structure. Same dielectric Roger's (RO4003C, ε_r = 3.5, tanδ = 0.0027) substrates are used to design structure. Approximately diagonal line coaxial fed patch radiator is placed underneath the metasurface.

Fig. 1(b) defines the unequal-spacing metasurface consisting of ring (rectangular) unit cells array which is unequal space between unit cells (7×7) in *x*- and *y*-plane to a metasurface. The unit cell length is L_l = 21.18 mm with aspect ratio (U_r) of 1.17 (width = 18.1 mm). Inner unit cell length is L_s = 10.38 mm with width of 7.30 mm. Space between the along the *x*- and *y*-planes are d_{y1} = 0.95 mm, d_{y2} = 0.90 mm, d_{y3} = 0.85 mm, d_{x1} = 1.0 mm, d_{x2} = 1.025 mm, and d_{x3} = 1.05 mm.

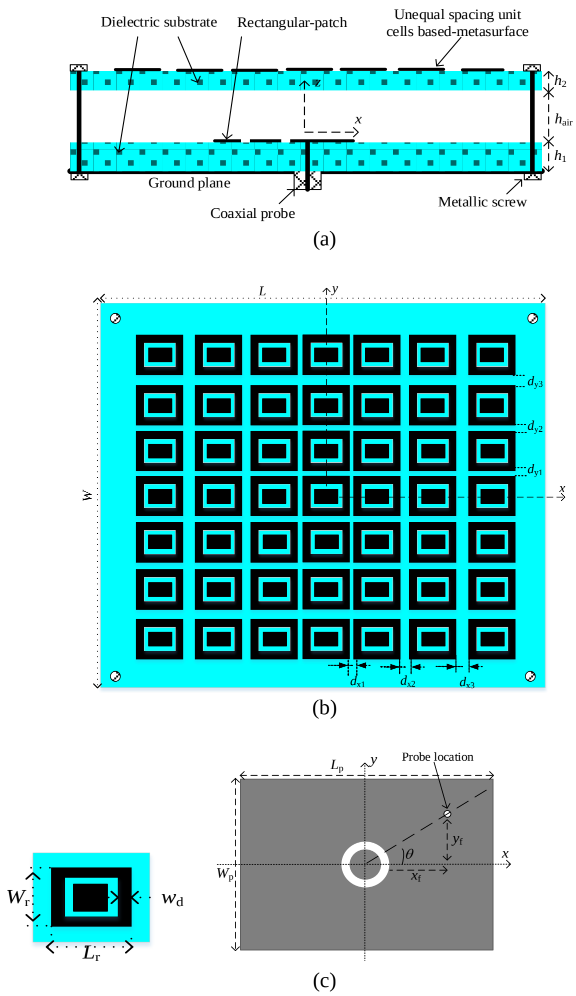


Fig. 1. Metasurface-based antenna arrangement: (a) cross-section view, (b) rectangular ring-unit cells based metasurface configuration, and (c) radiating rectangular-patch.

A tapering space (unit cells) metasurface is designed on upper substrate thickness of h_2 = 1.524 mm and supported by the metal bolts/screws with radus of 1.25mm, a air-layer thickness is created of h_{air} = 8.0 mm. The near diagonal fed microstrip radiator is planned with aid of plan procedures published in Ref. [14]. The microstrip patch (aspect-ratio) is r_1 = 1.21 with length of *L*p= 53.0mm (width, *W*p = 43.8mm) and rmicrostrip patch is designed on a lower substrate of thickness, h_1 = 3.82 mm and a ring-slot is embedded at center of the rectangular patch with outer radius of 5.9 mm/inner radius of 4.9 mm. Fig. 1(c) shows the radiating rectangular radiator and the probe feed position is along the near slanting line with co-ordinates at $x_o = x_f \times \cos(\theta)$, $y_o = x_f \times \sin(\theta)$, where, x_f = 28.0 mm and θ = 28.5°. The area of ground plane is 180 mm × 160 mm with total antenna height of around 13.5 mm.

To recognize the CP creation of a stacked metasurface (unequal space unit cells) based antenna, the *E*-field sprinklings at various time variations were calculated and presented. Fig. 2 demonstrations the *E*-field sprinklings at 1.60 GHz and time variations (0°, 45°, 90°, and 135°). For *E*-field demonstrations with time variants, the *E*-fields alternate with time variation in rounded wave and representing antenna make CP.

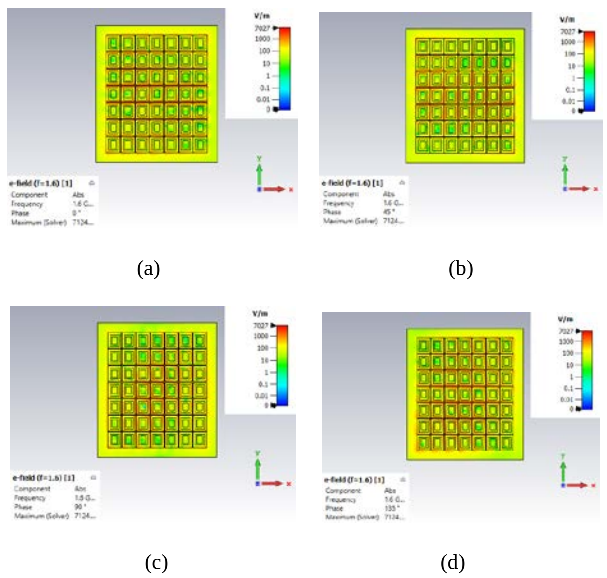


Fig. 2. Electric field intensity as a function of position along the antenna surfaceat 1.6 GHz: (a) 0º, (b) 45º, (c) 90º, and (d) 135º.

Surface-current circulations at 1.6GHz is demonstrated in Fig. 3 and mainstream of surface current is round the stacked-metasurface and patch radiator.

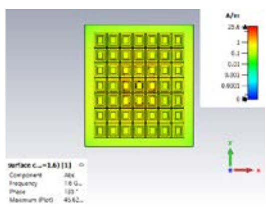
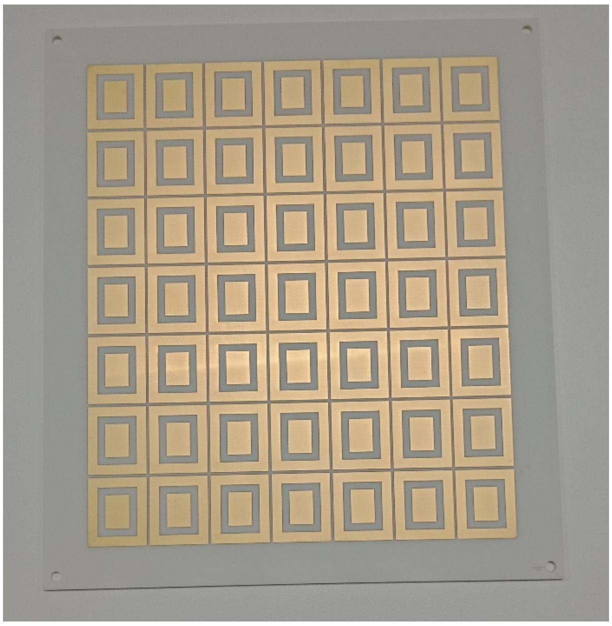


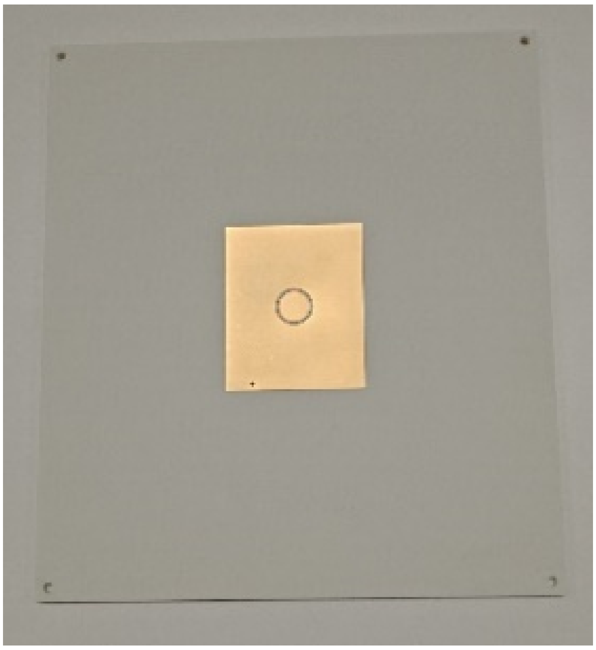
Fig. 3. Surface current as a function of position along the antenna surface at 1.6GHz.

III. Measurement Results and Discussions

The optimized antenna was fabricated as showed in Fig. 4, integrated the antenna, and measured by the Network Analyzer/Anechoic Chamber for antenna parameters. The comparison (measured/simulated) of $|S_{11}|$ (reflection coefficient) is related with frequency as displayed in Fig. 5 of the stacked-metasurface antenna.



(a) Stacked metasurface



(b) radiating slotted patch

Fig. 4. Prototype antenna structure: (a) stacked metasurface (non-uniform) and (b) radiating slotted patch

For measured reflection coefficient ($|S_{11}|$), -10dB $|S_{11}|$ matching bandwidth is realized of 25.3%, 400 MHz (1.38 GHz – 1.78 GHz) and follows the simulated matching bandwidth of 458 MHz (1.354 GHz – 1.812 GHz) which can be covered GNSS and n3/n41 bands. Fig. 6 demonstrations the measured/simulated AR at the boreside with frequency. For frequency range from 1.51 GHz to 1.77 GHz, the AR is <3dB which confirms the good CP quality with bandwidth of 15.8%. The measured gain achieved of > 8.5dBic is nearly unchanging in the band from 1.5 GHz to 1.8 GHz and simulated/measured CP-gain curves are almost identical shape with minor alteration as illustrated in Fig. 7. Figs. 8 and 9 illustration the measured/simulated radiation patterns at 1.6 GHz in both main (*xz* and *yz*) planes, respectively. A good relationship can be realized among measured/simulated radiation patterns. Waves in the tested radiation patterns characterize the AR (CP quality) performance, smaller dip in the curve at the boresight represents the lower value axial ratio or decent CP radiation.

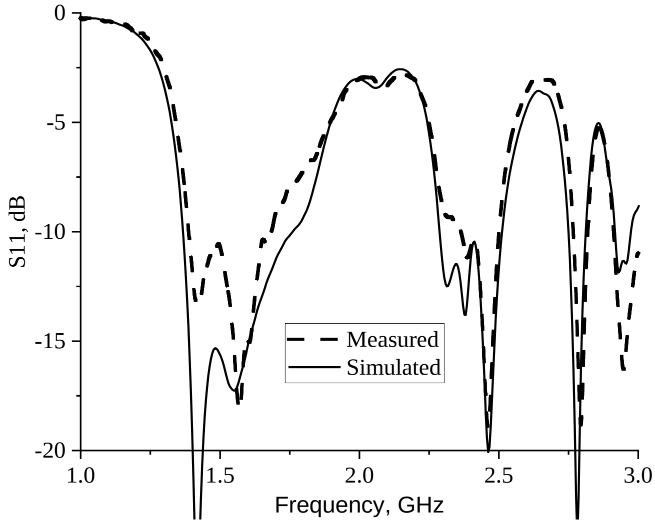


Fig. 5. Measured/simulated reflection coefficient (|S11|) with frequency.

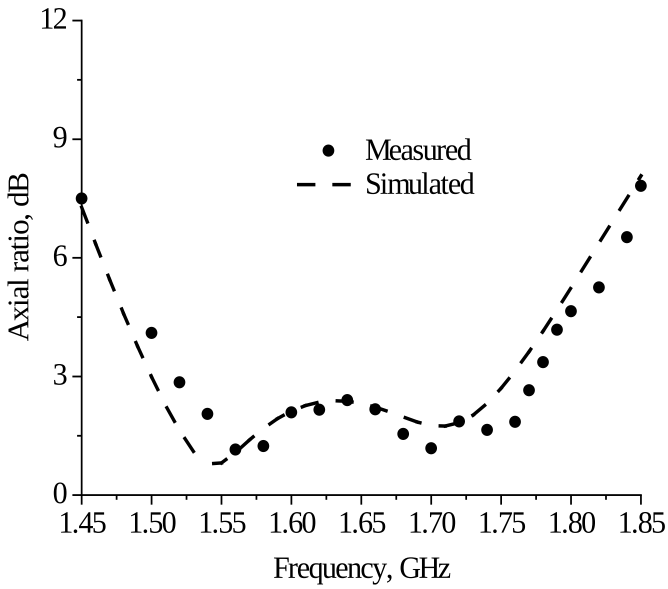


Fig. 6. Simulated/measured axial ratio at the boreside for GNSS band.

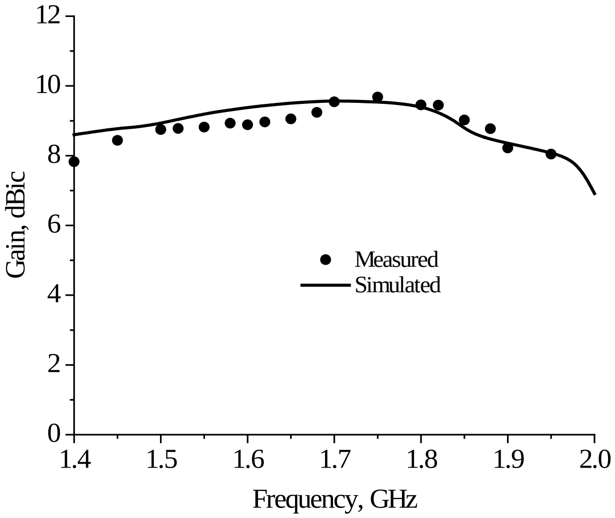


Fig. 7. Measured/simulated gain at the boreside with frequency.

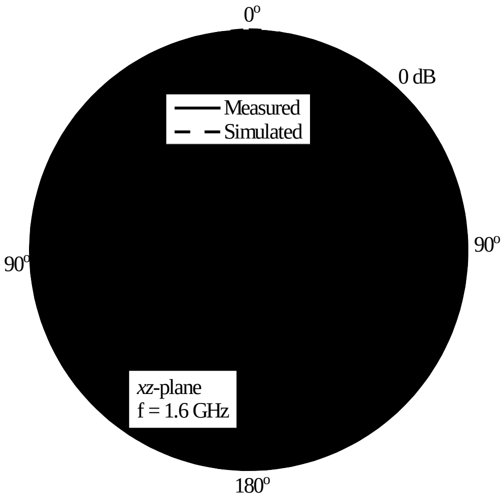


Fig. 8. Measured/simulated radiation patterns in *xz*-plane at 1.6 GHz (GNSS)

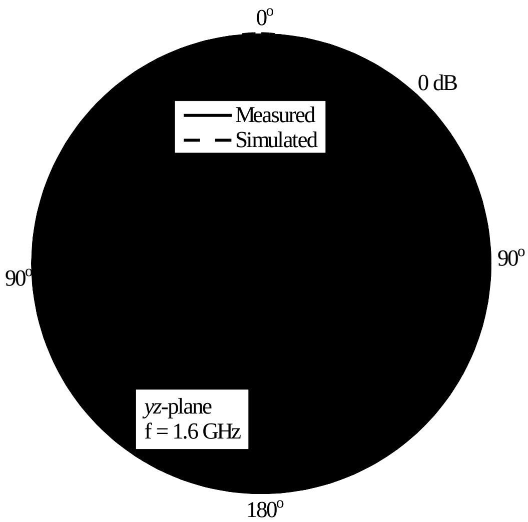


Fig. 9. Measured/simulated radiation patterns in *yz*-plane at 1.6 GHz (GNSS).

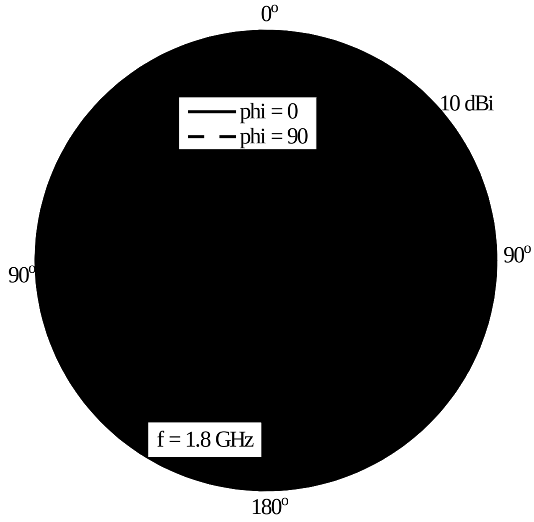


Fig. 10. Simulated radiation patterns in phi = 0° and 90° at 1.8 GHz (n3)

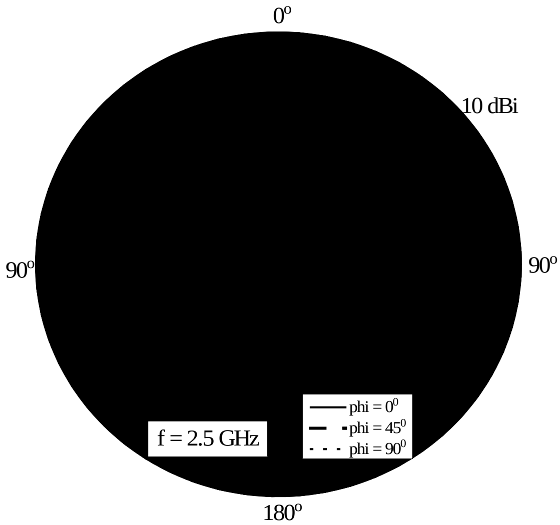


Fig. 11. Simulated radiation patterns in phi = 0°, 45°, 90° at 2.5GHz (n41).

For 5G LP band, simulated radiation patterns at 1.8 GHz (n3) and at 2.5 GHz (n41) are presented in Fig. 10 and Fig. 11 respectively with different phi cuts.

IV. Conclusion

A novel stacked metasurface antenna (unequal distance between unit cells) excited by patch radiator has been experimentally demonstrated for wider CP bandwidth and 5G NR and satellite systems. By utilization of stacked asymmetric-metasurface (unequal unit cell spacing's along the *x*- and *y*-axis) directly above a coaxial fed patch antenna, two modes with 90° phase difference and near identical magnitude across the wider spectrum can be generated for broadband 3dB AR bandwidth. The antenna structure is suitable for wideband antenna/array with CP and high gain applications in mobile platform such as drone which support remote sensing radar applications.

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