

Joint Antenna Module Orientation and BeamCodebook Design for Dual Band 6G Tablet UE at 140 GHz and 300 GHz.

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Joint Antenna Module Orientation and Beam Codebook Design for Dual Band 6G Tablet UE at 140 GHz and 300 GHz

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Abstract—This paper outlines beam codebook design for a tablet UE with three dual band 2×5 antenna modules operating at 140 GHz and 300 GHz. Module orientations and separate codebooks for each band are optimized to improve the 10th percentile of the EIRP CDF across the sphere. Within the ideal model, coverage depends on module orientation rather than its location on the device. The proposed layout places one module on the upper front face next to the camera and two on the rear. The orientation search identifies a preferred tilt of 60° for both rear modules, with their tilt directions separated by 180° . Using 30 beams per band, the optimized layout achieves approximately 23.6 dBm at 140 GHz and 13.8 dBm at 300 GHz at the 10th percentile of the EIRP CDF.

Index Terms—6G, sub-THz, tablet UE, dual band shared aperture, beam codebook, module orientation, spherical coverage, EIRP CDF.

I. INTRODUCTION

UE operating at sub THz frequencies needed to have broad spherical coverage from a limited number of antenna modules [1]. Prior work in this modeling showed that a gap directed beam codebook can approach the lower percentile coverage of a dense uniform codebook while using far fewer beams [2]. This allows further analyzing the module orientation as an additional way to improve coverage.

This presentation considers three antenna modules on a tablet measuring approx $21\text{ cm} \times 30\text{ cm} \times 0.9\text{ cm}$. The study focuses on how the directions faced by these antenna modules (M1, M2 and M3) affect their combined spherical coverage and its respective CDFs.

Module position and orientation. The ideal model assumes far field operation and selects the best available module and beam for each observation direction. (Chassis interaction, mutual coupling, and user blockage are excluded in current modeling). Under these assumptions, moving a module without rotating it leaves the coverage distribution unchanged. Rotating the module changes the directions it serves and can therefore improve coverage slightly.

A tablet may have weak coverage in some directions when a limited number of antenna modules cannot adequately cover the surrounding sphere. Its larger form factor provides more placement options, including space for a third module. When oriented to cover directions poorly served by the existing just M1 and M2 modules, this additional module can improve spherical coverage and improve even the CDF's 10th percentile at a cost of increased bill of materials (BOM), making module

placement and orientation important design choices for the spec and carrier certifications / lab approvals.

Placement constraints. The paper examines three aspects of the design. First, it jointly optimizes the tilt angles and directions of the two rear modules and the rotation of the front module within its mounting plane. Second, it compares tilted rear modules with modules mounted flat against the tablet. In the ideal model, two modules with identical orientations and radiation patterns cover the same directions, so the second adds no coverage benefit. Tilting them apart allows each to serve different directions. Third, the study checks for grating lobes near the steering limits and evaluates how tilt changes radiation toward the tablet interior.

II. SYSTEM MODEL

Each module uses a 2×5 uniform rectangular array, with five elements along its long axis and two along its short axis. The element spacing is 0.5 mm, approximately half a wavelength at 300 GHz and 0.233 wavelengths at 140 GHz.

The element's angular attenuation follows the 3GPP TR 38.901 model [3]. Peak element gain is estimated separately from the assumed beamwidth. For the shared dual band element, we assume that beamwidth scales approximately with wavelength. A beamwidth of 65° at 300 GHz therefore corresponds to an estimated 139.3° at 140 GHz ($65^\circ \times 300/140$). Peak gain is estimated from the beamwidth using the standard directivity approximation [4], $G_{\max} = 10 \log_{10}(41253/\theta_{3\text{dB}}^2)$, where 41253 is the number of square degrees in the full sphere. This gives 9.90 dBi at 300 GHz ($41253/65^2$) and 3.28 dBi at 140 GHz ($41253/139.3^2$) [5], [6].

The input power per element is fixed at 4 dBm for 140 GHz and 0 dBm for 300 GHz. These values remain unchanged across all configurations compared within each band. For each observation direction, the UE selects the module and beam that provide the highest EIRP. Coverage is evaluated approx over 6000 directions distributed approximately uniformly across the sphere (i.e., traditionally constant density and constant step as per 3GPP OTA measurements) and summarized using CDF percentiles, following the 5G FR2 CATR measurement approach used in this modeling [7], [8].

Shared placement and separate codebooks. The three modules form one physical placement, so their locations and orientations are shared between the two bands. Each band uses a separately optimized beam codebook since it is the same

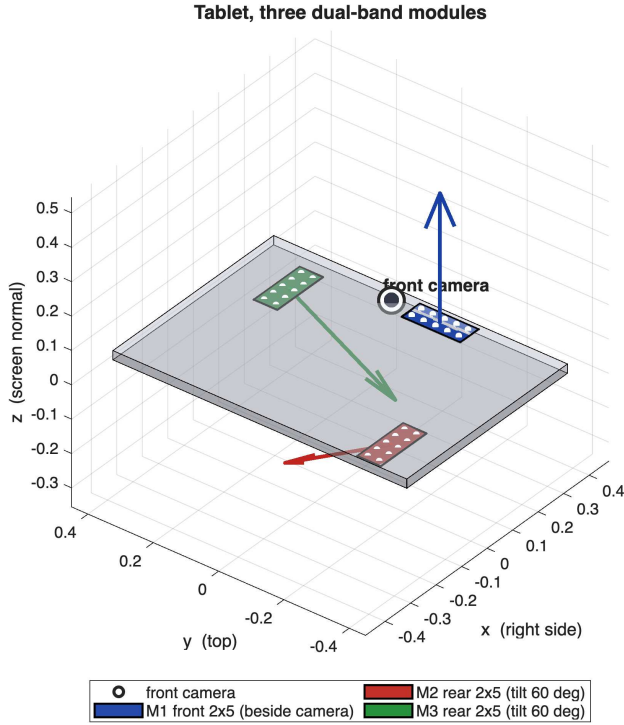


Fig. 1. Optimized tablet geometry: M1 on the front face next to the camera, M2 and M3 on the rear, tilted 60° and 50° in the rear panel. Arrows show boresight.

phase progression across fixed element positions generally produces different steering angles at the two frequencies due to difference in wavelength size. Candidate layouts (M1, M2, M3 antenna modules) are ranked using the lower of the two band's CDF 10th percentile.

III. CODEBOOK AND ORIENTATION SEARCH

Fig. 2 summarizes the search procedure. The search has two levels, an outer search over module orientations and an inner search over beam configurations. Each candidate in the outer search specifies the orientations of all three antenna modules. For each candidate (M1, M2 and M3) set of antenna module orientations, the geometry is held fixed while a separate beam codebook is constructed for each frequency band. Candidate beams are defined by the module and its steering angles along the long and short axes, sampled on a grid. Beams are added one at a time. At each step, the algorithm selects the remaining candidate that gives the highest resulting CDF 10th percentile and this continues until the beam budget is reached such that the CDF focused percentile search prioritizes improvements in weaker coverage regions / nulls or dead zones, including boundaries between regions served by different modules / intersecting regions of its radiating sphere.

The orientation search uses the rotational symmetry of the ideal continuous full sphere metric. Rotating the complete antenna arrangement about the z axis leaves its coverage distribution unchanged. M2's reference rotation angle can therefore be fixed. The search then varies M1's rotation within

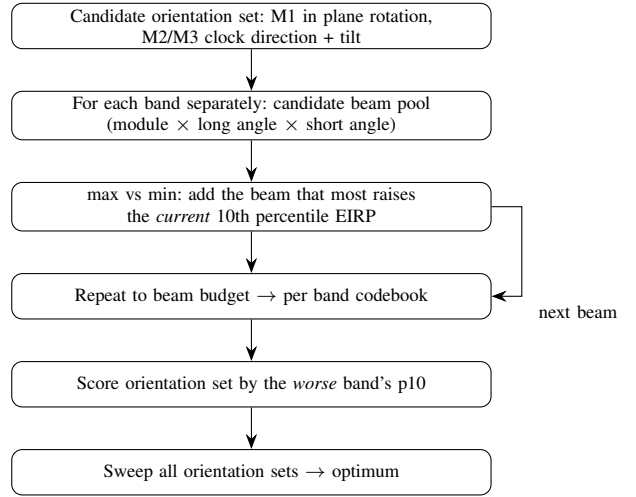


Fig. 2. Codebook and orientation search pipeline. Placement is shared across bands, codebook is Optimized per band.

TABLE I
REAR MODULE TILT SWEEP (CDF 10TH PERCENTILE EIRP)

Tilt (deg)	0	20	30	40	50	60	80
140 GHz	21.9	22.8	23.1	23.4	23.6	23.6	23.2
300 GHz	5.9	9.7	11.4	12.5	13.2	13.8	11.9

the front mounting plane, M3's rotation relative to M2, and the tilt of each rear module. Finite spherical sampling may introduce numerical differences when evaluating this symmetry. The initial search evaluates 648 ((6 × 12 × 9 six in plane rotations for M1, twelve clock offsets between the rear modules, and nine tilt angles), 0° to 80° in 10° steps) module configurations with equal tilt angles for the two rear modules. The best configuration is then refined by adjusting each rear module's tilt independently and searching a finer grid of beam directions.

IV. RESULTS

A. Tilt as a precondition check

Table I and Fig. 4 show the tilt sweep with the two rear tilt directions separated by 180°. At zero tilt both rear modules share the same outward normal and provide equivalent modeled coverage, so the second contributes nothing under switched selection: the limiting band reaches only approx 5.9 dBm at the CDF 10th percentile, below the 9.6 dBm obtained from three untilted mounting faces. The best evaluated tilt of 60° raises this to approx 13.8 dBm, a gain of approx 7.8 dB, while 140 GHz improves more modestly from approx 21.9 dBm to approx 23.6 dBm. Tilting the rear modules apart is therefore what allows the third module to contribute at all, and the weaker band is where it pays. Beyond 60° both bands decline.

B. Rear Module Orientation

The eight best configurations in the coarse search all used a 180° separation between the rear module tilt directions. This

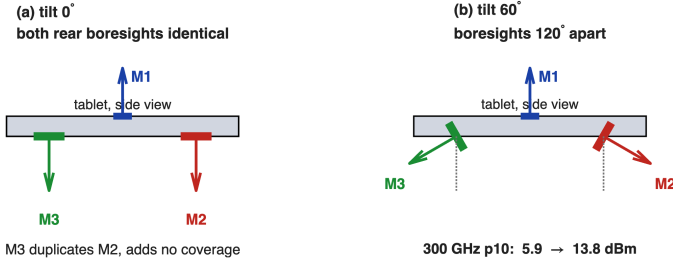


Fig. 3. Rear module tilt is a precondition. (a) Both M2, M3 rear modules share one boresight. (b) Tilted 60° in opposite directions, the two boresight separate by 120°.

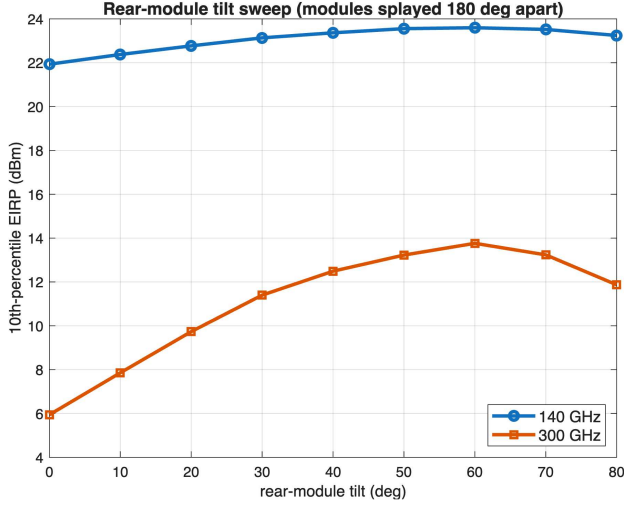


Fig. 4. Tilt sweep. Both bands improve consistently to 60° then fall away; 300 GHz.

separation emerged from the search and was not a preset requirement. The best refined configuration places M1 on the front face with an in plane rotation of 120°. The rear modules, M2 and M3, are tilted by 60°, respectively, with their tilt directions separated by 180°.

C. Coverage

Table II and Fig. 5 summarize the final EIRP percentiles. Optimizing the module orientations improves the weaker band's 10th percentile EIRP by approximately 0.6 dB compared with the fixed 4:20/10:50 clock orientations, and by approx 4.1 dB compared with the best evaluated layout using three antenna modules.

D. Antenna Performance Checks

Two checks are reported for the tilted module design, grating lobes near the steering limits, and radiation behind the module aperture, indicated in this Table III

Grating lobes. A grating lobe enters visible space when $\rho(1 + |\sin \theta_{\text{steer}}|) \geq 1$ [9]. At 140 GHz, $\rho = 0.233$, so the array is grating lobe free at every steering angle. At 300 GHz, $\rho = 0.500$ places the design exactly at the onset condition at $\pm 90^\circ$, the array is grating lobe free for all steering angles below endfire, with $\pm 90^\circ$ itself the limiting case. Tilt rotates

TABLE II
OPTIMIZED LAYOUT, 30 BEAMS PER BAND (EIRP PERCENTILES)

Band	p10	p20	p30	p50	p80	p100
140 GHz	23.62	24.19	24.64	25.35	26.14	27.20
300 GHz	13.84	15.86	17.39	19.83	22.76	27.26

Comparisons (worse band p10):

Best 3 modules 9.62 dBm
Fixed 4:20/10:50 clocks, 60° 13.56 dBm
Free orientation 13.84 dBm

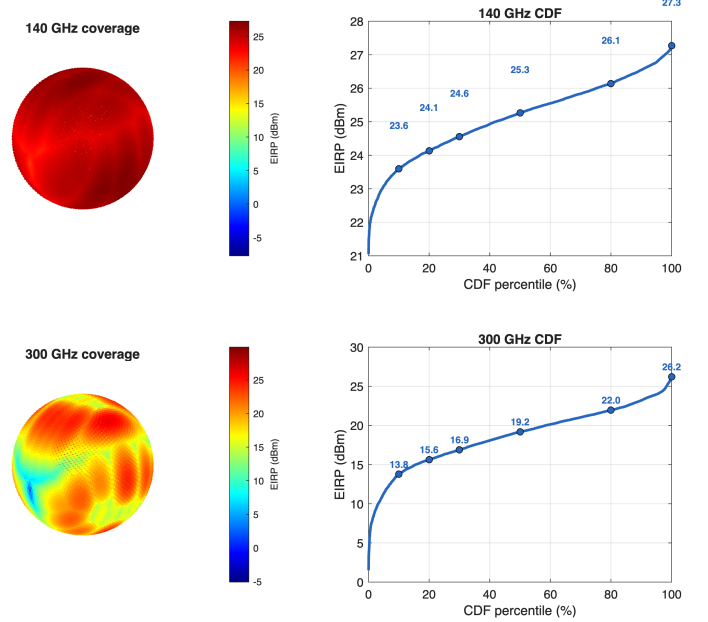


Fig. 5. Full sphere coverage and EIRP CDF at both bands for the Optimized three antenna modules.

a module but does not change its element pitch, and therefore does not affect this margin.

Radiation behind the module aperture. The modeled fraction of power radiated behind the module's own aperture plane remains approximately unchanged over tilts from 0° to 60°. This fraction is about 12 % at 140 GHz and 1 % at 300 GHz. The larger fraction at 140 GHz reflects the broader assumed individual element's radiating pattern, which retains appreciable radiation beyond 90° from boresight. Hence the difference exists even at zero tilt. However, this calculation is referenced to the module's own aperture plane, which rotates with the module.

V. DISCUSSION

For the evaluated configurations, one front module and two rear modules tilted in opposite directions provide the strongest coverage. The results indicate a tradeoff between mechanical complexity and coverage, the refined layout with rear tilts up to 60° achieves approx 13.8 dBm at the limiting band's CDF 10th percentile, compared with approx 11.4 dBm for the evaluated 30° configuration and approx 9.6 dBm for untilted edge mounting.

TABLE III
FRACTION OF POWER RADIATED BEHIND THE MODULE APERTURE
VERSUS TILT (REAR MODULES)

Tilt (deg)	0	30	60
140 GHz	13.0 %	12.1 %	12.3 %
300 GHz	1.1 %	1.0 %	0.8 %

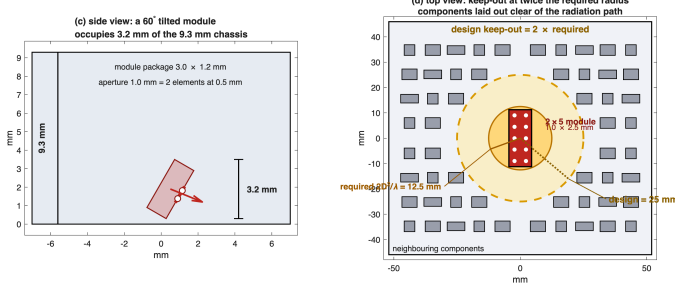


Fig. 6. (a) A 60° tilted module occupies 3.2 mm of the 9.3 mm chassis. (b) PCB layout: empty distance maintained, far field distance $2D^2/\lambda = 12.5$ mm at 300 GHz

VI. CONCLUSION

The evaluated tablet UE model shows that complementary module orientations can substantially improve spherical coverage. The best configuration uses one front module and two rear modules tilted in opposite direction by 60°, with their tilt directions separated by 180°. Using 30 beams per band, this layout achieves CDF 10th percentile EIRP values of approx 23.6 dBm at 140 GHz and approx 13.8 dBm at 300 GHz with no grating lobes being observed under the evaluated scan conditions. The fraction of power behind each module's own aperture plane remains approx unchanged with tilt (needs to be super focused on this antenna module placement and its neighboring components for the back scattering impact).

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