3GPP RAN4 #88bis
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Agenda item: 7.6.14.2.1

R4-1812389

Technical observations of selected mmWave array simulation results

Apple Inc.

Preliminary, Subject to Change
Intended for 3GPP RAN4 submission

Background

- During the RAN4 #86 meeting a company contribution discussed UE spherical coverage performance with glass packaging [1]
- During the RAN4 #88 meeting a contribution postulated the following [2]:
  - "Our studies show EIRP gets affected along the 50%ile direction similar to peak direction. Based on a multi-module **UE implementation, which typically enjoys good margin to spherical coverage requirement**, we do not see sufficient reason to relax the EIRP requirement along the 50th %ile direction"
- In this presentation we assume that the design presented in [1] is referred to by [2] (i.e. it is representative of the UE implementation which typically enjoys good margin) and examine the technical details and underlying assumptions that were provided to RAN4

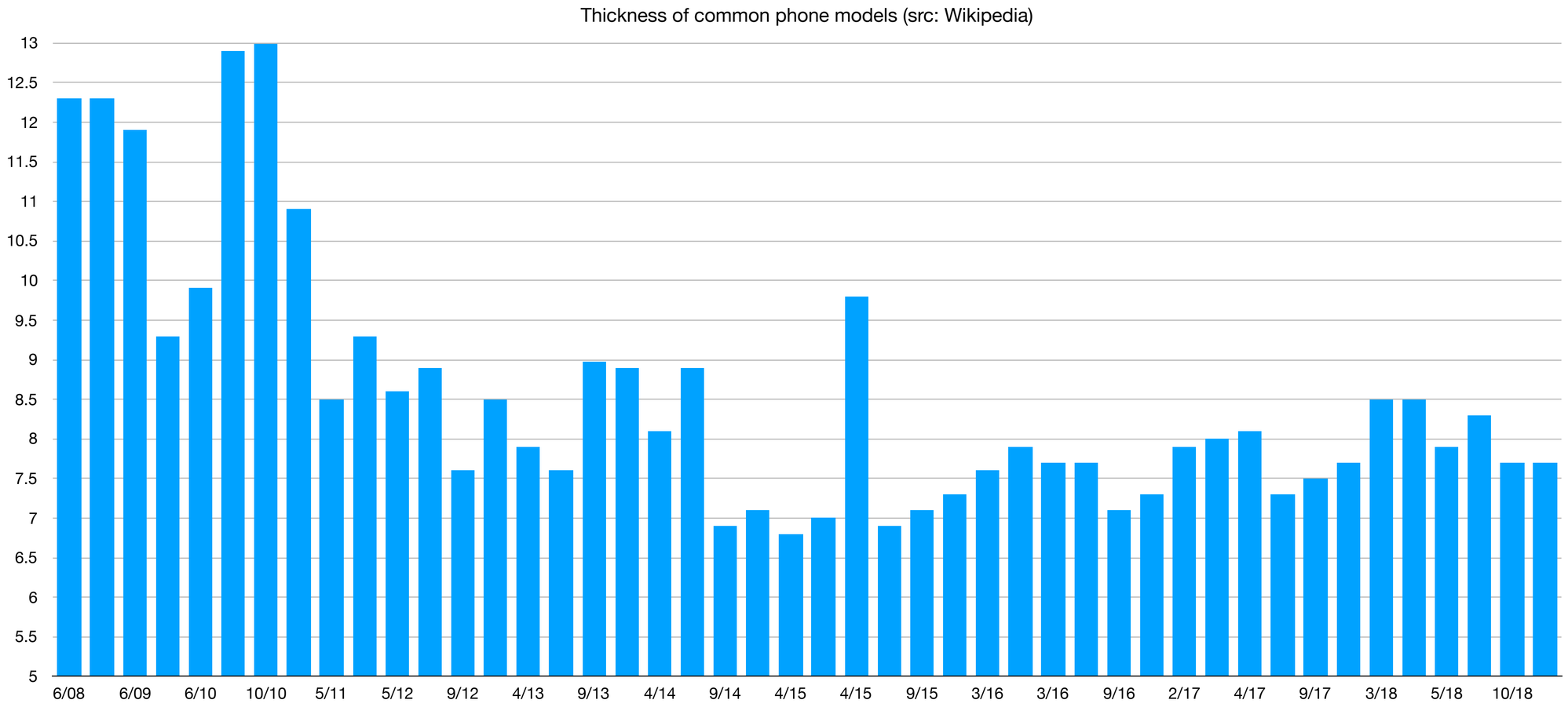
Observation 1: mmWave antenna array placement

- One aspect of the simulation assumptions in [1] is the placement of the mmWave module into the bezel of the phone
- Although the array dimensions were not provided in the contribution, it is possible to make an approximation based on a technical literature survey (e.g. [3])
- Table 1 at right provides an approximation of the maximal dimension (patch width + ground plane extension) based on a common Rogers substrate [4]
  - Assuming a resonant frequency in the middle of NR band n257 is chosen, a possible dimension of a single patch antenna is 9.1 mm
- If 1.5 mm are allocated around the mmWave array, then the total device thickness = 1.5 + 9.1 + 1.5 = 12.1 mm
  - For arrays with a greater number of elements, the bezel may need to be increased to maintain the structural integrity of the device edge
  - This example assumes a 4-element array; with an 8-element array the bezel around the array may need to be 2.0 or 2.5 mm, resulting in up to 14.1 mm device thickness

Table 1

Band / Parameter	n257
F_high (GHz)	29.50
F_low (GHz)	26.50
Fr (GHz)	28.00
Lambda (mm)	10.71
Substrate type	RO3003
Substrate thickness (mm)	0.76
epsilon_r	3.00
W (mm)	3.79
epsilon_reff	2.54
L_eff (m)	3.36
Delta L / h	0.47
Delta L (mm)	0.35
L (mm)	2.65
Max dim (mm)	9.14

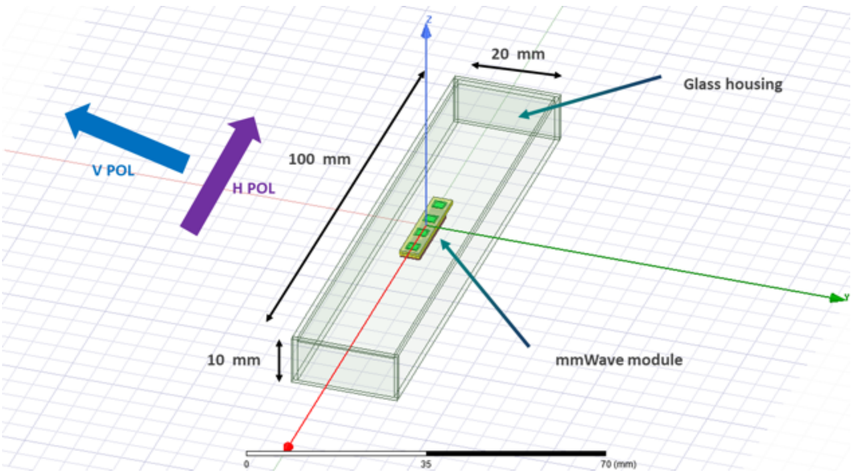
Observation 2: market trends in smartphone thickness



- A survey of Wikipedia [5] data of the thickness of common smartphone models spanning the last 10 years is shown in the figure above
  - Device thickness of models selected from 3 different manufacturers is plotted vs. month and year of introduction into the market
- A trend of device thickness can be observed in the industry: in 2018 device thickness does not exceed 8.5 mm
- Device thickness of 12.1 mm (from Observation 1) corresponds to smartphone models released in 2008-10 and may not be acceptable to the consumer market today

Observation 3: glass housing of the array

- The following aspects of the simulation assumptions in [1], as related to the scope of the model of the mmWave array and device layers, motivate a number of questions:
  - The total volume of the simulation is constrained by 100 x 20 x 10 mm
  - Glass housing dimensions are the same (100 x 20 x 10 mm)
  - Glass is not connected to a ground layer
- If, according to Observations 1 and 2, the array is not integrated into the phone side but, rather, into the device back (one possible arrangement is shown in the bottom-right figure and is taken from TR38.803 [8]), then the grounding of the glass should be taken into account
- According to our understanding, the mmWave arrangement inside the glass housing, as shown in [1], may introduce resonances or other radiation modes that may not be present in the actual design, and a simulation setup that is more representative of the device form factor is recommended



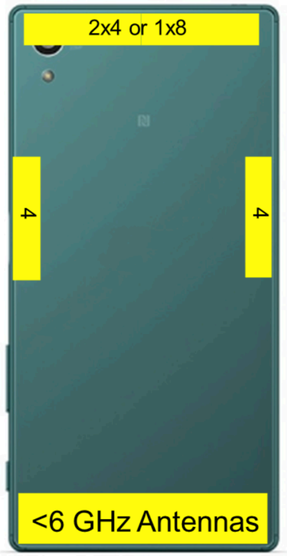
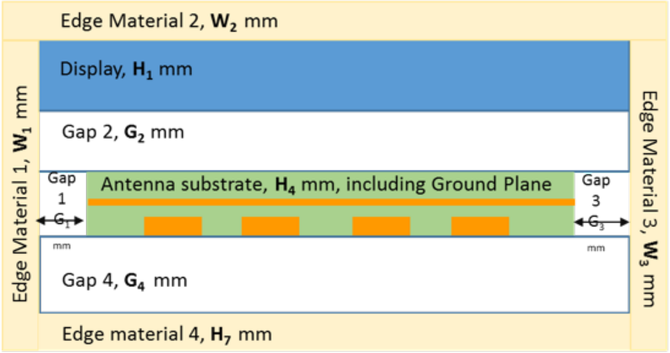


Figure 6.2.1.1.2-1: antenna arrangement on the UE with groups of mmWave antennas.

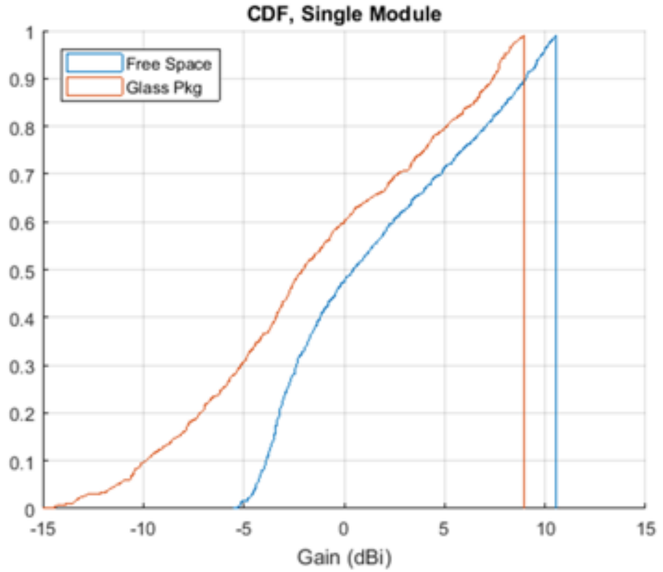
Observation 4: "optimally dimensioned" glass

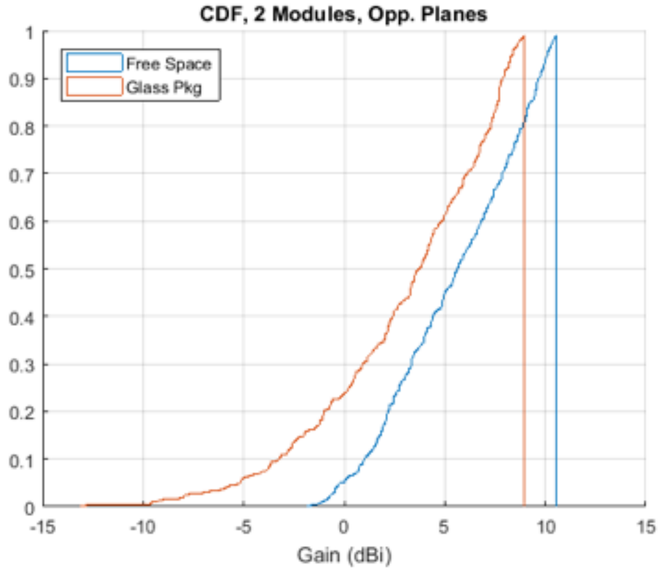
- The design presented in [1] provided an analysis of "optimal dimensioning" of the glass to array gap (G4) and glass thickness (H7)
  - Device cross-section and table of parameters shown at right
  - Analysis in the paper provided boresight gain degradation as a function of G4 and H7
  - Simulated CDF curves for a single array module and two array modules have been provided in [1] (shown at right)
- Clarification of the following is requested:
  - Were other directions of radiation simulated other than the boresight direction?
  - It appears that only narrow-band simulations at 28 GHz (i.e. optimizing band n261) were performed; was the optimality of glass dimensioning checked for band n257? n258?
  - No analysis of array performance at 39 GHz has been provided in the paper: do the authors intend to share findings of optimally dimensioned glass for band n260?
  - Assuming the UE supports both 28 GHz and 39 GHz bands (e.g. bands n261 and n260), what is the impact of G4 and H7 on performance in each band?
  - Assuming the UE supports bands n257, n258, n260, and n261, what is the impact of G4 and H7 on performance in each band?
  - The conclusions of multi-band impact on peak EIRP provided in [2] are difficult to understand without supporting analysis (such as simulation or measurement results)

Device Cross-Section



Name	Material	Thickness	ε_r	tan δ
Antenna substrate Dielectrics	TBD	(not relevant)		
Antenna Substrate Metals	copper	-	conductivity	
Gap 1	Air	large		
Gap 2	Air	large		
Gap 3	Air	large		
Gap 4	Air	0.5, 1.0, 1.5, 2.0mm		
Edge material 1	(not present)			
Edge material 2	(not present)			
Edge material 3	(not present)			
Edge material 4	Glass	thickness'= 0.5, 1.0, 1.5, 2.0mm	7	0.05





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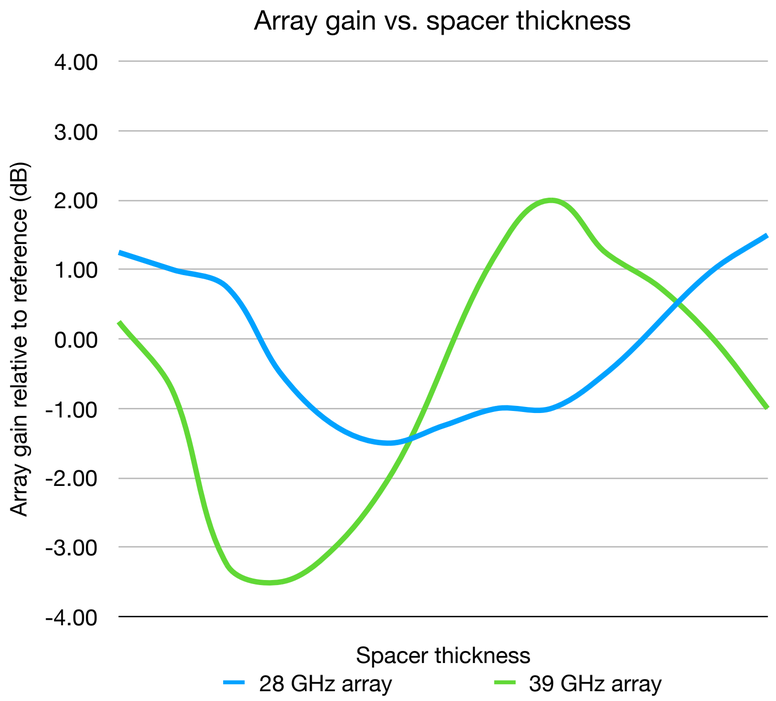
Observation 5: additional information on array - glass spacing

- In an effort to address the multi-band aspects of Observation 4, we conducted a study of array gain vs. spacer thickness, and the results are summarized in the figure at right
  - The array gain relative to a reference value is plotted as a function of spacer thickness
  - Details sensitive to the design have been removed from the plot
  - The design used in this study consists of two array designs: one design covers the frequency range from 24 to 30 GHz, and another co-located design covers the frequency range from 37 to 40 GHz; more details are provided in [9]
- We observe that the spacer thickness parameter represents a trade-off in the performance of the co-located design across the 28 GHz and 39 GHz bands
- As an example, optimizing the spacer thickness for 39 GHz leads to a 3 dB degradation at 28 GHz
- As another example, optimizing the spacer thickness for 28 GHz leads to a 2.5 dB degradation at 39 GHz



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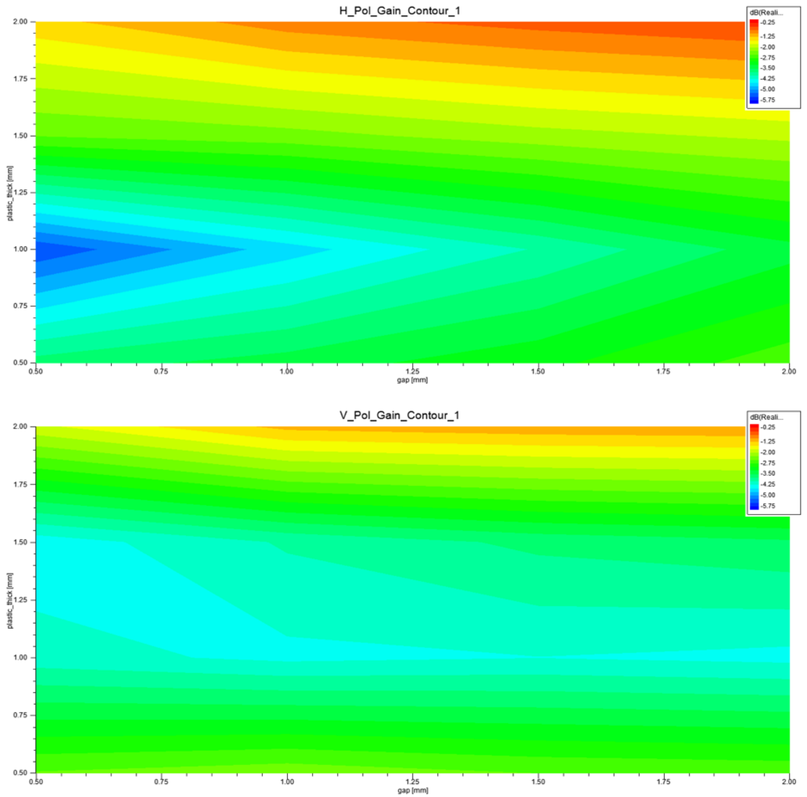
Observation 6: design tolerances

- In our further understanding, the optimal dimensioning concept optimizes the G4 and H7 parameters for the resonant frequency
  - The y axis of the gain contour plots is labeled "plastic_thick;" was Edge Material 4 glass or plastic in these simulations?
  - According to [6], typical smartphone cover glass thickness and spacing requirements are defined together with tolerance ranges
  - Glass thickness tolerance and glass cover alignment tolerance are expected to have an impact on the total variability of the optimal dimensioning concept
  - Can the authors of [1] quantify these tolerances and clarify their impact on the array gain?
  - In general, an array design's performance tends to be more sensitive to design tolerances near band edges, where meeting nominal performance metrics becomes more challenging; can the authors of [1] quantify the impact of these tolerances on band edge performance of the array design?
  - As an example, according to the boresight gain degradation plots (at right), variability of 0.5 mm in G4 or H7 parameters leads to ~3 dB variation in boresight gain
- According to a study by 9 device vendors [7], the peak EIRP analysis includes additional factors which contribute to the output power variability (i.e. form factor design tolerance of the FR2 transmitter), and the document can be a good example of quantifying the impact of design tolerance on radiated antenna performance metrics
- Even if a study of optimal dimensioning may not need to take all design tolerances into account, these tolerances should be taken into account when quantifying a design margin relative to a minimum requirement, as has been alluded to in [2]



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Conclusions

- A number of technical concerns remain with the analysis provided by the authors of [1] and [2], as explained in Observations 1 - 6 in this document; in summary:
  - Placement of the mmWave array, as proposed in [1], is not feasible for modern smartphone designs from the point of view of market expectations on the device industrial design including both thickness and mechanical stability
  - The analysis of optimal dimensioning of glass thickness and array to glass gap thickness has not considered the span of frequencies per band and has not considered the impact of supporting multiple bands
  - A related study has shown that the spacer thickness parameter represents a trade-off in the performance of co-located mmWave array designs across the 28 GHz and 39 GHz bands (Observation 5)
  - According to our understanding, the analysis in [1] and [2] has targeted nominal performance metrics and has not considered any design tolerances, such as material thickness deviations and impact of assembly tolerances on optimal dimensioning
- In our understanding, the assertion in [2] that a UE implementation considered by the authors "typically enjoys good margin to spherical coverage requirement" is based on an analysis of narrow-band simulations of the EIRP CDF quantified in the nominal sense without consideration of design and integration tolerances of a practical form factor
- It is our recommendation to the authors of [1] and [2] to take these observations into account when contributing to the derivation of minimum radiated requirements for FR2 UEs

References

[1] R4-1804587, "On UE Spherical Coverage With Glass Packaging," Qualcomm, 3GPP RAN4 #86bis, April 2018

[2] R4-1811021, "FR2 Multi-band Framework for PC3 UEs," Qualcomm, 3GPP RAN4 #88, August 2018

[3] "Design of Rectangular Patch Antenna Array for 5G Wireless Communication," Rahman, Cao, Hussain, Khalil, Zeeshan, Nazar, IEEE PIERS, May 2017

[4] Rogers RO3003 Laminates, https://www.rogerscorp.com/acs/products/42/RO3003-Laminates.aspx

[5] Wikipedia, en.wikipedia.org

[6] "Advancements in Touch Panel Modules through Atmel XSense® and 0.4 mm Corning® Gorilla® Glass," www.corning.com

[7] R4-1712319, "UE power class for FR2," Intel Corporation, Apple, OPPO, Samsung, LGE, Xiaomi, MediaTek, Motorola, Huawei, 3GPP RAN4 #85, November 2017

[8] 3GPP TR38.803, "Study on new radio access technology: Radio Frequency (RF) and co-existence aspects," 3GPP, September 2017

[9] R4-1809786, "Extending FR2 power class requirements to multi-band UEs," Apple Inc., 3GPP RAN4 #88, August 2018