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Effect of Left-Handed Grip on Coverage of Quasi-Omnidirectional Millimetre Wave 5G Handset Antenna

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***Abstract*—This paper investigates the impact of a left-handed grip on the coverage of a handset featuring three antenna arrays operating in the n257 frequency band of 26.5 GHz - 29.5 GHz. Beam steering is implemented using multi-bit phase shifters while the handset is held with a left-handed grip. Results are compared to a right-handed grip, and a handset in free space. For a left-handed grip, beam steering increased the coverage region (in which gain is greater than 0 dBi) from 23.8% to 57.7% through the use of 3-bit phase shifters. Similarly, coverage increased from 24.7% to 61.0% for a right-handed grip. This paper also investigates the benefit of increasing the number of bits available to the multi-bit phase shifters and results show performance improvement begins to plateau around 3 bits. From the data collected in this paper, a right-handed grip provides better coverage than a left-handed grip for the simulated scenario.**

***Index Terms*—antenna, array, coverage, handset, blockage, 5G, mmWave, millimetre wave, millimeter wave**

I. Introduction and Motivation

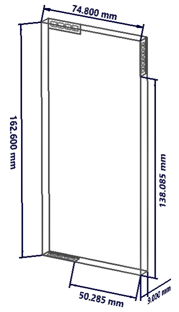
For many mobile communication devices e.g., mobile phones, an omnidirectional radiation pattern in the communication frequency bands is a desirable trait, as this enables the device to communicate with receiving equipment regardless of the spatial orientation of the device. Implementing an omnidirectional radiation pattern, however, is more challenging at millimetre wave (mmWave) frequencies such as the n257 band than at lower frequency bands, particularly sub-6 GHz bands [3]. The 3rd Generation Partnership Project (3GPP) defines constraints on the peak and 50th percentile effective isotropic radiated power (EIRP) for handheld user equipment (UE), which is described as power class 3 equipment [2]. Due to the high susceptibility of mmWave systems to shadowing [4] and resonance shift [5] from hand blockages, meeting these power constraints in the context of a handset held by a user becomes more challenging than in free space. Previous work has shown that the handset investigated in this paper was unable to meet the peak EIRP requirement while a right hand phantom held the handset, both with and without beam steering using 3-bit phase shifters [1].

This paper continues on from previous work carried out to determine the feasibility of quasi-omnidirectional handset coverage in the n257 frequency band through the use of beam steering phased antenna arrays [3]. Paper [1] carried out work to determine the ability of a handset featuring these arrays to overcome the blockage posed by a human hand when various bit sizes of multi-bit phase shifters are used to actuate beam steering. Further previous work has been carried out to study the effects of various grip-awareness models on handset coverage [6], and the effects of hand blockage on mmWave antennas and propagation [4], [6], [7]. While [1] studied the impact of a user's hand on the coverage of the handset, it only accounted for a user holding the handset with their right hand. Changing the grip to that of a left hand may alter the radiation pattern of the handset and affect its coverage [4].

This paper explores the impact of changing a user's grip on a mmWave 5G handset, from that of a right hand to that of a left hand, on the coverage area offered by the handset. This is examined with and without the implementation of multi-bit phase shifters to actuate beam steering. The effect of varying the number of bits available to the phase shifters on coverage area is also investigated. The distribution of radiated power is then investigated with respect to constraints laid out by the 3GPP in [2]. This investigation may be relevant to beyond 5G (B5G) devices as it studies the ability of a practical beamforming system to overcome shadowing caused by a human hand blockage at mmWave frequencies. Simulations carried out in [7] found that hand blockages reduced the gain of a 28GHz antenna array by a mean value of 9.5 dB, while experiments carried out in [4] found this shadowing to have a mean value of 15.26 dB. Clearly, reducing this loss should be of benefit to many handheld devices operating in this frequency band.

II. Handset

As described in [1], the handset is modelled as a hollow cuboid, with dimensions based on measurements of the Xiaomi 10, comprising perfect electric conductor (PEC) material. Three identical antenna arrays (described in [1]) are placed on the handset in positions which have been found by [3] to maximise the coverage area. Note that paper [1] compared the simulated far-field performance of these antenna arrays to the measured far-field performance of a physical antenna array in free space, and found it reasonable to assume that array simulations with the hand phantom would provide results representative of the physical antenna arrays. Holding the handset upright and looking towards the screen with the front



(a)

Fig. 1: Dimensions of simulated handset.

towards the viewer, the positions of the antenna arrays are the top-front of the right face, the front-left of the bottom face and the top-left of the back face. The dimensions of the handset are provided in Fig. 1.

The antenna arrays operate in the n257 frequency band, which is described in [2] as utilising the frequencies 26500 MHz - 29500 MHz for both the uplink and downlink with time-division duplexing (TDD). In some regards, these antenna arrays may be compared to the commercial Qualcomm *QTM547 Antenna Module*. The specifications for this module may be found in [8]. Both modules operate in the n257 frequency band and support beam steering. A key difference between the antenna arrays simulated in this paper and the QTM547 module is that the QTM547 module supports only power classes 1 and 5 [8], while the simulated antenna arrays must support power class 3. According to 3GPP, implementation in handheld UE requires power class 3 compliance [2].

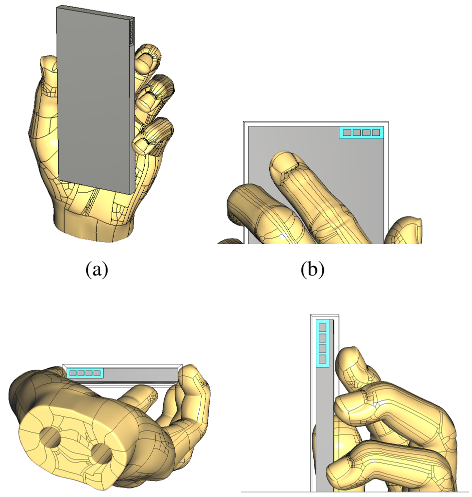
III. Left Hand Phantom

The hand phantom used in this investigation is the same numerical model, posed as if holding a handset, used in [1], with the sole distinction that it has been mirrored to convert it from a right-hand model to a left-hand model. Information on the model is available from [9]. The model used in this simulation has been arbitrarily scaled in size compared to the model available from [9]. The dielectric properties of the hand phantom were simulated as a relative permittivity of 17.6 and a loss tangent of 0.94998, which [1] found to be the average of these properties for wet and dry skin using [10].

IV. Simulation

The model of the hand phantom gripping the handset is shown in Fig. 2. This model was simulated in CST Studio Suite using the Finite-Difference Time-Domain (FDTD) method. All twelve antenna ports were excited simultaneously with no phase shift applied. A hexahedral mesh with a mesh cell count of 31,032,900 was used. This was achieved through the following mesh properties:

- Maximum cell size of 10 cells per wavelength both near to and far from the model,
- 10 cells per maximum model box edge near to the model,



(a) (b) (c) (d)

Fig. 2: (a) Perspective view of simulated model. (b) View of rear antenna array with. (c) View of bottom antenna array. (d) View of right antenna array. (b) - (d) feature the simulation bounding box.

Grip \ Scenario	No beam steering	3-bit beam steering
Left hand	23.8%	57.7%
Right hand	24.7%	61.0%
No hand [1]	26.0%	61.1%

TABLE I: Percentage coverage of spherical region with gain greater than 0 dBi for various grips and beam steering scenarios. *No hand* results taken from study [1].

- 11 cells per maximum model box edge far from the model,
- Minimum cell size of ($\frac{1}{20}$ $*$ Max. cell size near model).

Due to simulation time constraints, the bounding box of the simulation was sized such that it was close to the edges of the handset, having a minimum distance from the handset of a quarter of a wavelength at 28 GHz. This means that, of the hand, only the tips of the fingers and a portion of the palm were included in the simulation. The right-handed model examined in [1] was re-simulated with a mesh cell count of approximately 30 million in order to provide comparable data for this investigation. The mesh cell properties used for this simulation are the same as those for the left-hand simulation listed above.

V. Beam Steering with 3-Bit Phase Shifters

As in [1] and [3], beam steering was used to increase the overall coverage of each antenna array on the handset. This was actuated by applying a phase shift to each antenna in an array through post-processing techniques. Beam steering was only applied to one array at a time, while the antennas of the other arrays were excited with in-phase signals. The phase values applied to each antenna in the steered array are governed by Equation 1 [1].

$$s = \frac{r}{2^b} \quad (1)$$

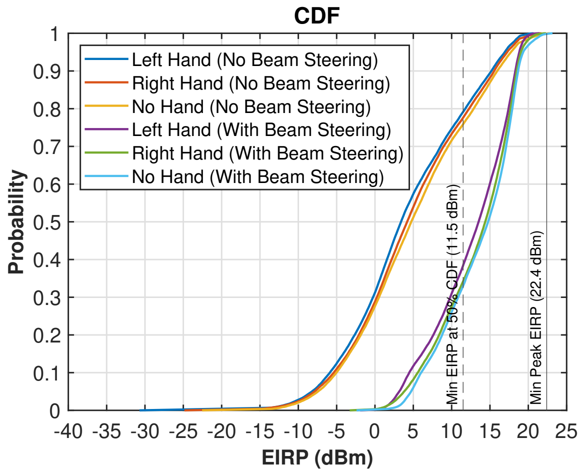


Fig. 3: CDF plot of EIRP with beam steering (all beam angles for a 3-bit phase shifter combined) and without beam steering for various grip patterns.

Where:
$s =$ Phase step difference (degrees)
$r =$ Size of desired step range (degrees)
$b =$ Number of phase shift bits used

The first antenna in the array will always have a phase shift of 0 degrees, then the phase shift at each subsequent antenna in the array is equal to the phase shift at the previous antenna plus the phase step. Each value of phase step corresponds to a beam. Phase step was varied from -180 to 180 degrees in steps equal to s degrees as found using Equation 1. For a phase step of 90 degrees, the phase shift at antennas 1-4 will be 0, 90, 180 and 270 degrees respectively. Using a 2-bit phase shifter, the values of phase step investigated would be -180, -90, 0, 90 and 180 degrees. For this investigation, the desired step range will always be 360 degrees, from -180 to 180 degrees. The coverage (for a threshold gain of 0 dBi) achieved through the use of 3-bit bit shifters is given in Table I. The *No Hand* data has been obtained from [1]. It can be observed from this data that the *No hand* simulation resulted in the greatest coverage both with and without beam steering implemented. This was followed by the *Right hand* simulation and then the *No Hand* simulation.

As described in Section I, the 3GPP define a minimum peak EIRP of 22.4 dBm and a minimum EIRP at the 50th percentile of the distribution of radiated power of 11.5 dBm for handheld devices operating only in the n257 frequency band [2]. For a left-handed grip, two cumulative distribution function (CDF) plots of EIRP were produced. One plot was produced considering only uniform excitation of each antenna, while the other plot considers the total scan pattern when all beams (achievable with a 3-bit phase shifter as described in [1]) of each array are combined. Whenever one antenna array was used for beam steering, the other arrays were uniformly excited. These plots, along with the CDFs of EIRP for a right-hand grip and a handset in free space (as found by [1]), are given in Fig. 3. The CDFs of EIRP at various values of phase step for an input power of 10 dBm were also found via the method described in [11] and are presented in Fig. 4.

Size of bit phase shifter, b	Realized Gain Threshold	% Coverage With Beam Steering		
		Left Hand	*Right Hand*	No Hand
1-bit	0 dBi	38.0	39.9	38.6
	-3 dBi	53.7	56.1	59.1
	-6 dBi	67.8	71.0	76.0
2-bit	0 dBi	54.5	57.6	58.2
	-3 dBi	67.8	70.7	74.8
	-6 dBi	79.7	83.2	88.9
3-bit	0 dBi	57.7	61.0	61.1
	-3 dBi	70.7	73.3	78.3
	-6 dBi	82.0	87.6	91.5
4-bit	0 dBi	58.8	61.9	62.5
	-3 dBi	71.5	74.1	79.8
	-6 dBi	82.7	88.2	92.4
5-bit	0 dBi	59.0	62.1	62.8
	-3 dBi	71.6	74.3	80.1
	-6 dBi	82.9	88.5	92.6
6-bit	0 dBi	59.0	62.2	62.8
	-3 dBi	71.7	74.4	80.1
	-6 dBi	82.9	88.5	92.7

TABLE II: Percentage coverage of spherical region for various grips and gain thresholds. *No hand* results taken from study [1].

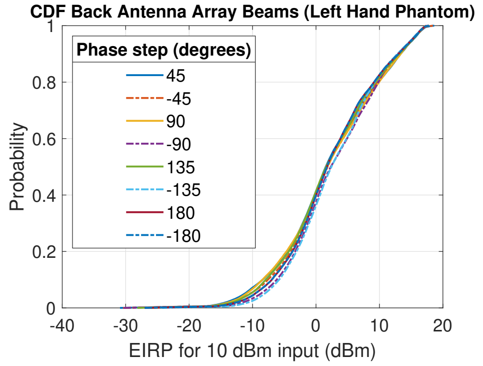
For a left-handed grip, 3-bit beam steering increased the EIRP at the 50th percentile of EIRP from 3.4 dBm to 13.4 dBm. For a right-handed grip, beam steering increased the EIRP at the 50th percentile from 4.2 dBm to 14.4 dBm. It may be observed that beam steering allowed the handset to meet the 50th percentile criterion under the effect of both grips investigated, while it did not meet this criterion for either grip without beam steering. The discrepancy between 50th percentile of EIRP with the right-handed grip between this paper and paper [1] may be due to the difference in mesh cell count between the two simulations.

VI. Varying Bits Available to Phase Shifters

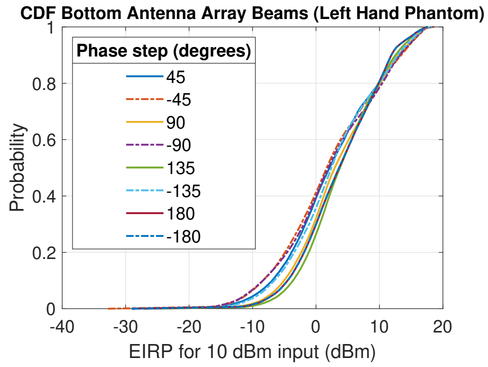
Next, the coverage which may be achieved using various sizes of multi-bit phase shifters was investigated. The coverage offered by each phase shifter bit size for different gain thresholds was found through post-processing techniques, and then combined with the *No Hand* data found in [1] to create Table II and Fig. 5. These results indicate that, for gain thresholds -6 dBi, -3 dBi and 0 dBi, the right-handed grip provided greater coverage percentage than the left-handed grip for all tested phase shifter bit sizes. It may be observed from Fig. 5 that the coverage percentage for each grip and gain threshold begins to plateau at phase shifter bit sizes of above three bits.

VII. Conclusion and Future Study

In conclusion, it has been found that increasing the number of bits available to the multi-bit phase shifters increases the percentage coverage of the handset, however this relationship begins to plateau beyond 3 bits. Additionally, the hand grip used to hold the handset has a large impact on the coverage region and the CDF of the handset's EIRP. The left-handed grip investigated in this study offered lower coverage percentages than the right-handed.



(a)



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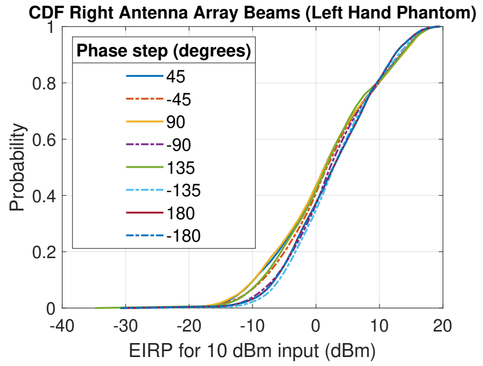

(c)

Fig. 4: CDF plots of each beam formed by each array using a 3-bit phase shifter with the left hand phantom. Back array (a), bottom array (b), right array (c).

Further work should be carried out to increase the volume of the simulation to include the entirety of the hand phantom, potentially via a ray tracing simulation method. It may be beneficial to experimentally verify the results of this paper and any future work using a physical handset and hand phantom.

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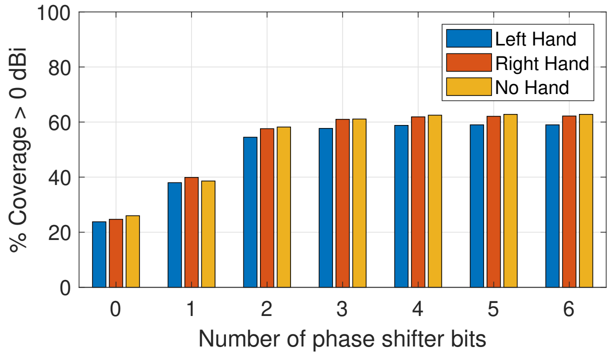

Fig. 5: Bar chart of percentage coverage against multi-bit phase shifter size. *No hand* data taken from [1].

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