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Shaped Elevation Patterns for 5G Base Stations

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Abstract—This paper discusses the advantages and an example of using shaped elevation patterns for 5G base stations.
A simple iterative power synthesis method involving the phase of shaped patterns, and suitable for both center- and end-fed sub-arrays, is used. Numerical simulations and some experimental results for an array of linear sub-arrays with cosecant squared patterns are presented to validate the concept.

Keywords— Array antennas, 5G base stations, array antenna synthesis, power synthesis, cosecant squared pattern

I. INTRODUCTION

Many 8x8 or 16x16 element arrays are discussed for 5G base stations at millimeter waves. To increase spectrum re-use, various MIMO schemes were proposed, initially using several distributed single beam antennas, and then, as long validated for satellites [1], with analog, hybrid or digital (DBF) forming of multiple simultaneous beams, each using the full array. An excellent review of multiple beam arrays for 5G is found in [2].

At millimeter waves, with very low linear power amplifier efficiencies and high consumption of ADC's and processing, active arrays with full DBF for massive MIMO producing 2D adaptive multiple beams might not yet be competitive. Moreover, for a 200 m cell from a base station at H=10 m, about 90% of users are within 3° to 10° from the horizon (Fig. 1), and therefore with no frequency re-use benefits in elevation with 15° beams, or even the 7.5° wide beams of 16x16 element arrays.

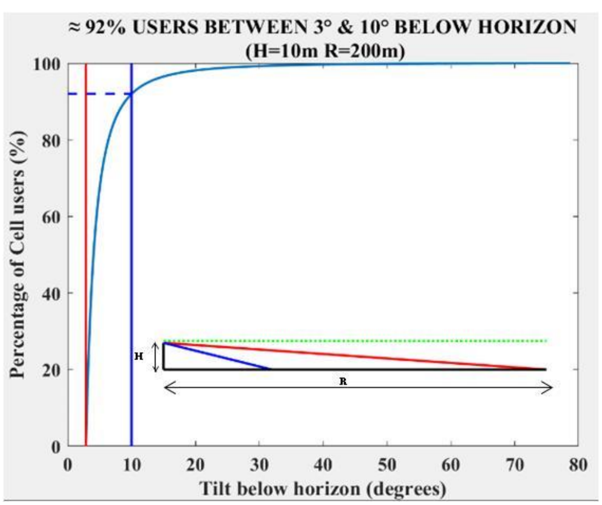

Fig. 1. Angular distribution of base station users

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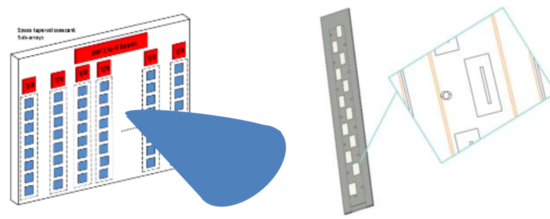

a) b)

Fig. 2. Array of vertical shaped beam sub-arrays
a) Configuration b) End-fed SIW sub-array

Instead, using sub-arrays (Fig. 2), with analog fixed or reconfigurable beam shaping in elevation and multiple agile beams in azimuth with DBF, drastically reduces the number of array chains, the complexity, processing, consumption and cost. Such an approach is discussed for a base station at 42 GHz in [3], and its system modelling for 5G at 28 GHz in [4][5][6]. The elevation beam can be a cosecant squared, better for the safety issues related to the vertical compliance distance [7], or similar. Slotted waveguides (possibly SIW) are often preferred for higher gains and frequencies. Microstrip or stripline/triplate designs are more suitable for lower gains and frequencies.
With low thickness requirements, series or travelling wave type end-feeding, despite some potential frequency scanning, is often preferred. It is easiest to design for tapered amplitude distributions, while corporate type center-feeding is easier for symmetrical ones [6]. A simple synthesis algorithm, based on iterative rephasing and projection of the wanted pattern, can generate realizable symmetrical or tapered distributions with, in both cases, an acceptable fit to the wanted template. It will be presented and validated by measurements.

II. SYNTHESIS

Synthesis of shaped, sector or cosecant squared patterns started in the 1940's with the pioneering work of Woodward [8], effectively connecting the Shannon [9] sampling theory and the pattern synthesis and interpolation of antenna (array) patterns, linked to their illumination by a Fourier transform.
Most field synthesis methods imply real pattern/templates, which reduces the number of degrees of freedom used for the synthesis [10][11]. Involving the phase of the wanted pattern, helps reduce the "distance" between the wanted and the synthesized patterns belonging to the subset of complex, and not only real, patterns realizable with the array, possibly under certain excitation constraints. This has been further developed, with excellent results, by numerous authors [12][13][14].
With the huge dynamic range of signals used in 5G systems, the fit to the template is not too critical and allows to use, as a criterium, the minimization of the weighted mean-square error, rather than the equal relative error.

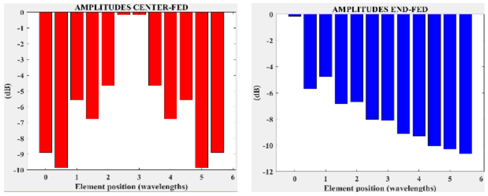

Fig. 3. Synthesized amplitudes for center and end feeding of the sub-array

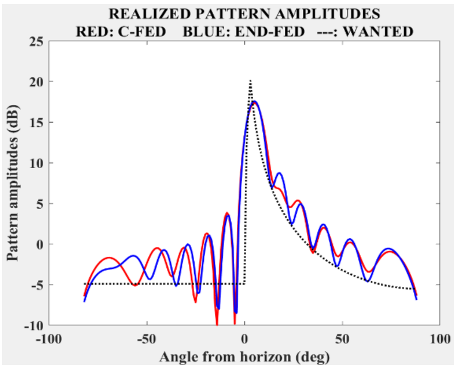

Fig. 4. Computed patterns for center- and end- feeding

While for the symmetrical center-fed amplitude excitations a real pattern might be optimum, for end-feeding asymmetrical tapered amplitudes, the pattern phase will play a key role.

If $f_w(u)$ and $f_r(u)$ are the complex wanted and realized patterns, with their respective modules and phases $F_w(u)$, $\Phi_w(u)$ and $F_r(u)$, $\Phi_r(u)$, $f_r(u)$ can be seen as a complex Hilbert space vector function, projection of $f_w(u)$ in the N dimensional sub-space R of the patterns realizable by the array. In the equation:

$$F_w(u)e^{j\Phi_w(u)} = F_r(u)e^{j\Phi_r(u)} + \delta_{wr}(u) \quad (1)$$

the “distance vector” $\delta_{wr}(u)$ must be minimized.

The iterative projection technique which used is inspired from [11], with a constraint of realizability of the excitations, here a 10 dB dynamic range for 12 element sub-arrays, as done in [14]. For the end-feeding case, to produce asymmetrically tapered amplitudes, the origin is chosen at the first element. In iteration m, the phase $\Phi_w^m(u)$ of the wanted pattern, is replaced by that of its projection on the R subspace $\Phi_r^{m-1}(u)$. The converging equalisation of the phases reduces the distance vector $\delta_{wr}(u)$.

As shown in fig. 3 and 4, the procedure can produce very different realizable center- and end-fed illuminations, with a reasonable fit to the desired pattern. Optimisation including mutual coupling has been validated at 28.5 GHz (Fig. 5) and measurements confirming predictions will be presented from arrays of 16 sub-arrays, both in microstrip and SIW [6].

III. Conclusion

Most 5G users in a (flat) cell will be seen from base stations within 10° from the horizon, leaving little scope for spectrum re-use gains from adaptive multiple beam forming in elevation. Arrays of vertical sub-arrays with cosecant squared elevation patterns and adaptive multiple beams in azimuth seem feasible. They equalize both the base station transmit power and the flux

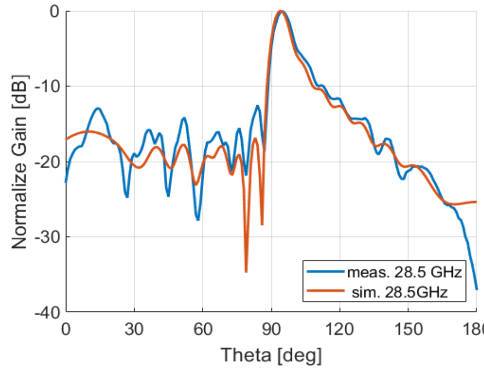

Fig. 5. Array of 16 sub-arrays: simulated v.s measured patterns

received for all line-of-sight users. Compared to large square arrays with 2D digital beamforming, their complexity, consumption and cost are potentially much reduced.

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