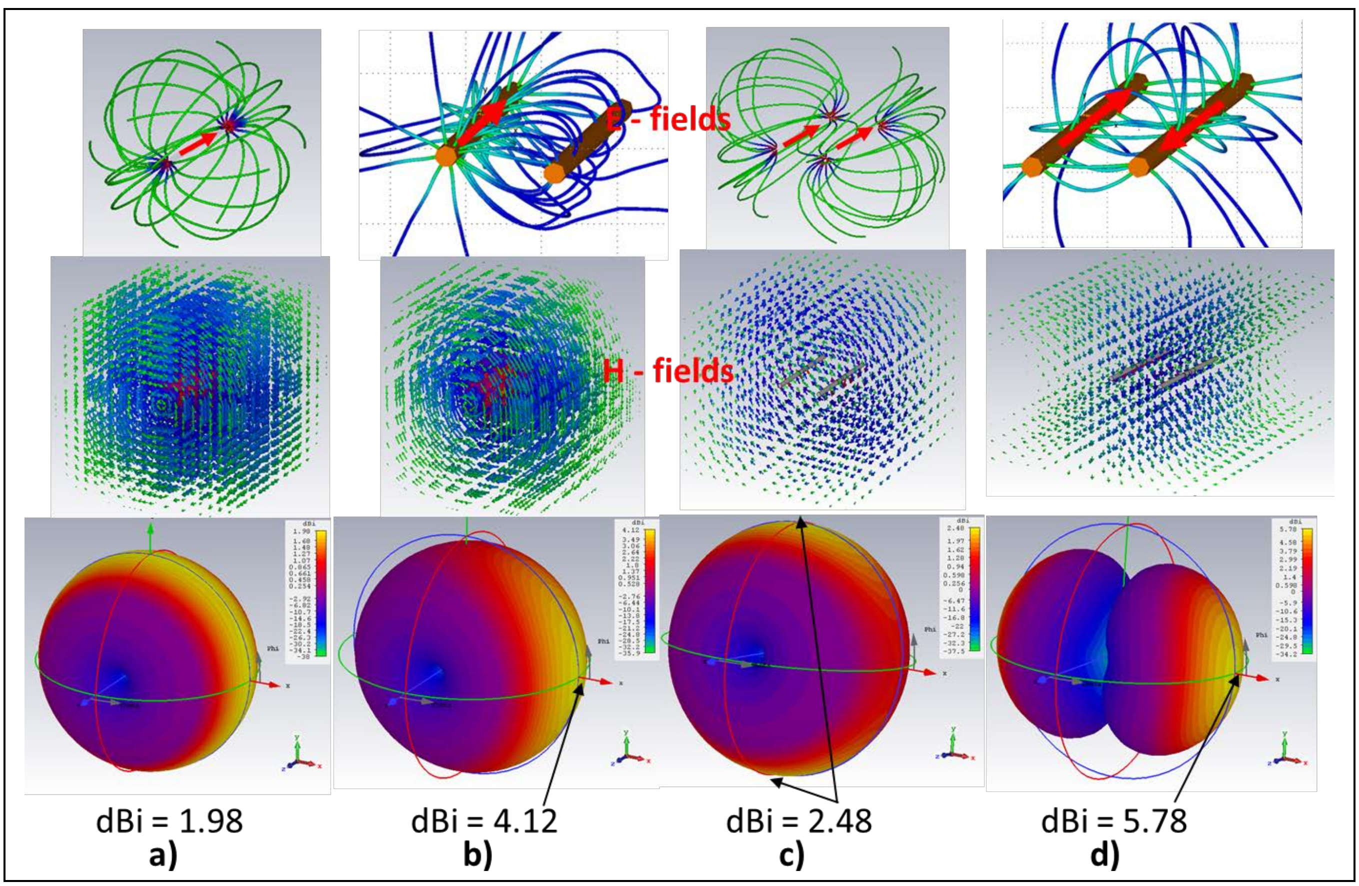
Any array element put in an array environment may be considered as a child placed in the care of large array-family where each element-child is valued and respected but his behavior as a family member changes and depends on multi-way communication aka mutual coupling with the whole array-family. The mutual coupling is a natural effect unavoidable as "death and taxes" and could be beneficial forcing each element to work as a wooden rod in a fascis, a unifying bound bundle of wooden rods and an ancient Etruscan and imperial Roman symbol of wealth and power showed on the left. Contrariwise, it might corrode the array performance like fascism (derives its name from the same word) eating away at the very fabric of democracy.

In family like manner, the current and voltage developed in the input or output of each antenna array child-element depend not only on its own terminal impedance and excitation but the current and voltage transported to and from adjacent antenna elements of array family. The mere presence of adjacent elements as metal or dielectric bodies definitely changes the structure of near- and far-field components of EM fields nearby and far away. Both effects are two faces of the same phenomenon called mutual coupling. As a consequence, such element properties as input impedance, bandwidth, radiation pattern, and radiation efficiency might be substantially different from that of the same radiator taken in isolation. Thereby generic **antenna array** characteristics are more or less altered; gain and directivity, input impedance, azimuth and elevation scan ability, sidelobe and grating lobes appearance, polarization features, bandwidth, power handling, output signal-to-noise ratio (SNR) and signal-to-interference noise ratio (SINR), radar cross section (RCS), direction-of-arrival (DOA) estimation, capacity of multiple-input-multiple-output (MIMO) wireless channels, etc.

Mutual coupling by its nature is the near-field phenomenon and primarily depends on each element near-field structure, their relative to wavelength inter-element spacing, mutual orientation, and loading. As a rule of thumb, the adjacent radiators are practically uncorrelated or at least substantially uncorrelated if the separation exceeds wavelength, or their fields' polarization is orthogonal. However, a modern tendency to develop more compact antenna arrays (like massive MIMO for 5G platforms) with a larger number of elements makes the mutual coupling more significant factor. The array child-elements start *talking* to each other and *scattering* fields in an ill-predictable way as a consequence of the complexity of near-field structure. Just look at the images of EM fields in **Chapter 4** for the most uncomplicated radiators like electrical or magnetic dipoles. The field structures become trickier under the influence of the body and



fields of nearby radiators. As an example, let us compare the nearby EH-fields and radiation pattern of a single electrical dipole of $\lambda/4$ length taken in isolation and in the presence of the second active or passive dipole of the same length.

The top row demonstrates equipotential lines of E-fields whereas the middle one is of H-fields. The bottom row illustrates the normalized to the peak 3D radiation patterns and the antenna directivity in dBi. The black arrows point out the angular location of radiation peak. The column a) corresponds to a dipole in isolation, the column b) is the parallel assembly of the same dipole and passive dipole nearby, the column d) is the same as b) but the two dipoles are excited equally in phase, while the column d) is the same as c) but the two dipoles are excited equally in opposite phase. The relatively small separation between dipoles was chosen $\lambda/8$ intentionally to facilitate visually detectable interactions.

Evidently, the presence of the second dipole clearly disturbs the EM near-field structure. First of all, the insertion of the second dipole forces the EM field around the primary dipole to adjust to new boundary conditions. The tangential component of E-fields should now be zero not only on the PEC surface of the major dipole but on the PEC surface of dipole nearby (check Section 2.3 in **Chapter 2**). Then according to Maxwell's equations, any E-fields deviation from original state initiates a new pattern of H-fields, while this new shape of H-fields generates an additional E-fields, and so on. Meanwhile, the normal to PEC components of E-fields (check Section 2.3 in **Chapter 2** again) induce the novel structure of surface electrical charges; as well the H-fields tangential components become the source of new electrical current flow on dipoles surface. Such newly formed charge and current distribution have more or less impact on voltage, and current in the connected to dipoles feed line and subsequently to the new value of input impedance (the ratio of voltage and current on dipole feed points). Well, that is not all. The transformed charges and currents generate a new set of far-fields. Just compare 3D patterns in the button row. Without a doubt, the mutual coupling and excitation cause changes in antenna beam shape, amplitude and phase (not shown) of radiated fields, angular position of peak radiation, sidelobe level and directivity. The natural and generally conceivable way to get all this information accurately is the computer simulation based on numerical solution of Maxwell's equations (look through **Chapter 9**).

The described above mechanisms of space coupling and reradiation can be formalized using **scattering matrix** approach introduced in Section 7.3 **Chapter 7**. As soon as any antenna array comprises of definitely arranged, finite sized elements, which are fed by an appropriate feed network, it can be envision as a multi-port network like shown below. For the sake of simplicity, assume that the array and its feed are an interconnection of finite number of linear components and is used in transmitting regime. Then due to Lorentz's Reciprocity Theorem (Section 3.4.3 in **Chapter 3**), the results can be correct for receiving antennas too.