Quantum Antenna Theory

Said M. Mikki
University of New Haven, West Haven, CT, US

The purpose of this paper is to propose a new research area in antenna theory where radiation fields are approached through *quantum* electrodynamics/optics instead of the classical Maxwellian formalism familiar in antenna engineering. In contrast to the latter approach (here referred to as ‘c-antenna (classical antenna) theory), the fields produced by the former type of antenna’s currents are quantized; consequently, the main quantity of interest becomes the *photon*, rather than the classical **E** and **H** spacetime fields as such. This former theory will be referred to as ‘q-antenna (quantum antenna) theory.’ In both c- and q- antenna theories, the source is still a classical current, i.e., an externally-controlled conventional current distribution independent of the radiation field. Technically, we treat this current classically, while the radiated field is handled quantum mechanically. [Such approach is sometimes referred to in literature as the *hemiclassical* approach (Garrison and Chiao, 2014.)] Since q-antennas radiate quantized fields (photons), they are ideal for applications in the emerging field of *quantum communications*, where information is encoded by *quantum states* instead of fields. In fact, quantum antennas include optical antennas, but are much richer and far wider in scope since the former can deal with nonclassical information in a direct and natural way as will be shown later in detailed investigations by the author. We will also show that q- and c- antennas, while fundamentally different, share many common characteristics from the *engineering* perspective.

We start with Glauber’s theory (Glauber, 1963), where the fundamental relation between classical currents and the radiated quantum states was first derived. Next, we deploy the machinery of *coherent states* to deduce a relation between the space-distribution of point sources and the total radiated state $|\alpha\rangle$. It will be found that a “q-antenna array theory” can be created from the classical corresponding theory for the purpose of generating desired q-states with tailored properties meeting concrete digital communications systems’ needs. (The above-mentioned relation can be conveniently encoded by a *q-antenna Green’s function*.) We first recall that q-antennas are nonlinear since the quantum states $|\alpha\rangle$ do not superimpose when current sources add linearly to each other. However, a Green’s function can be found by focusing on the *complex amplitude of the radiated coherent state*, i.e., α. In fact, we show that a *photon radiation pattern* can be defined for q-antennas solely in terms of α, which approaches the radiation pattern of c-antennas in the classical limit. It turns out that for applications involving quantum communications (our main interest here), the complex amplitude of the radiation coherent quantum state α is the most relevant quantity of interest. We extend then this basic theory by describing the fundamental properties of several important q-antennas with increasing complexity. Starting with point sources, we build up the theory of array q-antennas and provide several examples of q-antenna designs intended for digital (binary and *M*-ary) communications systems. Subsequently, we study wire and patch q-antennas and discuss some of their differences and similarities with respect to their classical counterparts. The paper ends by reviewing some of the promising potentials of this new research area, q-antenna theory, in nanotechnology and information security.