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On the design of wideband and highly efficient small antennas and antenna arrays

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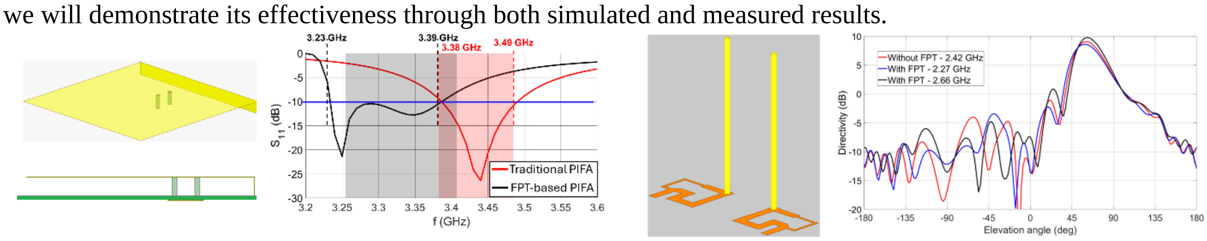
While small antennas offer advantages in compactness and integration, they suffer from low radiation efficiency and extremely narrow bandwidths. Additionally, superdirective antenna arrays that rely on such elements experience excessive high coupling, which significantly reduces both operating bandwidth and efficiency. In this work, we address these challenges, by introducing a novel method that enables (1) miniaturization of radiating structures without compromising bandwidth or radiation efficiency, and (2) antenna arrays with ultra-compact interelement spacing (as small as 0.1 λ) while maintaining wide bandwidth and high radiation efficiency.

Wideband small antennas will play a key role in future communication systems that require data transfer rates approaching 1 Tbps and reliability levels up to 99.9999%. Over the past 80 years, extensive research has been conducted on antenna miniaturization techniques, and small antenna analysis, e.g., [1-3]. Additionally, substantial efforts have focused on the design of antenna arrays capable of exceeding the directivity of conventional uniform arrays, particularly in cases where the interelement spacing is significantly smaller than $\lambda/2$, (e.g., [4]). Despite the progress in miniaturization methods, a persistent trade-off exists between size reduction and bandwidth performance. As antennas become smaller, their achievable impedance bandwidth diminishes significantly. Researchers have attempted to address that by altering the electrical or physical properties of antennas, but these modifications typically result in distorted radiation patterns, reduced efficiency, and compromised polarization purity. Similarly, while superdirective small antenna arrays have been studied for nearly a century, practical implementations remain challenging. Many existing designs are either impractical for fabrication or rely on optimization-driven approaches that lack generalizability to other configurations.

To overcome these challenges, we leverage our recently developed method called the frequency pulling echnique (FPT), [5], a novel, systematic methodology for designing antennas and arrays that achieve predetermined bandwidth or miniaturization goals while maintaining high radiation efficiency. Specifically, by utilizing our proposed methodology, we design (1) antennas that are at least 50% smaller than conventional designs while preserving broadband performance and supporting any polarization, and (2) antenna arrays with interelement spacings below λ/5, ensuring wide bandwidth and optimized impedance matching. Figure 1 shows example cases of our methodology. At the conference, we will discuss the details of our proposed method, and we will demonstrate its effectiveness through both simulated and measured results.



(a) (b)

Figure 1. (a) FPT-based PIFA element and reflection coefficient response. (b) FPT-based two-element monopole array configuration and directivity response.

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