Planar Ultrawideband Modular Antenna (PUMA) Arrays Scalable to mm-Waves

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Abstract—A new class of Planar Ultrawideband Modular Antenna (PUMA) arrays, the PUMAv3, is introduced. PUMAv3 is scalable to mm-wave frequencies (≈50 GHz) and improves bandwidth by 50% without the use of a matching network or external baluns. The enabling technical innovations include a new feeding mechanism that relies on capacitively loaded shorting vias and an alteration on the superstrate loading scheme. Infinite array full-wave simulations of a dual-polarized PUMAv3 suggest 10.6-47.6 GHz (4.5:1) operation with good VSWR levels out to θ=45°, high port isolation and low cross-polarization.

I. INTRODUCTION

Programmable RF front-ends that service multiple functionalities with a single adaptable unit remain in great demand. Recent research initiatives including DARPA’s RF-FPGA program and the Navy’s Advanced Multifunction RF Concept seek to spearhead such technologies. Due to frequency, pattern, and polarization flexibility, UWB electronically scanned arrays (ESA) are the radiators of choice for such systems. Despite their attractive electrical traits, UWB ESAs are typically expensive and difficult to fabricate due to complex geometries, non-modular assembly, and feeding issues. A number of proposed arrays address these issues at RF frequencies [1–4], but the more promising frontier of UWB arrays for programmable mm-wave front-ends remains virtually unexplored.

This work will discuss a new class of PUMA arrays [3, 4] that achieves frequency scalability through V-band with low-cost standard microwave fabrication technologies and improves bandwidth by 50% while maintaining direct unbalanced feeding. Designated as the PUMAv3, the array extends bandwidth at the low-end and maximally shifts the common-mode out-of-band through the use of a novel capacitively loaded shorting via, now placed at dipole arm ends. Additionally, superstrate loading is now modified using two PTFE layers and different size perforations. Altogether, these factors contribute to a low-profile (≈λhigh/3) design suggesting a 4.5:1 bandwidth with VSWR < 2 at broadside and < 2.7 out to θ=45°, high port isolation, and low cross-pol, while operating up to approximately 50 GHz. A sequel paper [5] discusses a further bandwidth improvement to 6:1 using an integrated backplane matching network.

II. DUAL-POL. PUMAV3 ARRAY

Like preceding PUMA arrays, the PUMAv3 topology employs a dual-offset dual-polarized arrangement of Munk’s implementation of the current sheet principle [2], which relies on inter-element capacitance of tightly-coupled dipoles to cancel out the reactance of an inductive ground plane over a wide bandwidth. To increase this capacitance and improve bandwidth, the shape of the PUMAv3 dipole arms now resemble diamonds to encompass a larger area and increase cross-coupling capacitance like in Fig. 1(a). Furthermore, a metallic plate is printed on the opposite side of the dielectric as seen in Fig. 1(b), saturating the available capacitance. This topology provides more capacitance at higher frequencies than the PUMAv1, where only the overlap of the dipole arms controls the capacitance. Additionally, the superstrate was divided into two unique layers with different perforation sizes and electrical constants to improve matching levels and wide-
angle scanning.

As discussed in [3, 4], PUMAs use a novel unbalanced direct feeding scheme with carefully grounded dipole arms, effectively mitigating in-band broadband common-mode resonances but also inhibiting low-band behavior with loop modes. The PUMAv3 topology manages this issue by utilizing shorting vias in a frequency-selective manner at frequencies afflicted by common-mode resonances. As depicted in Fig. 1(b), a single shorting via is positioned at the location where the four dipole arms meet and capacitively couples to them, effectively shorting them out near the common-mode frequency $f_{cm}$. This arrangement conveniently acts as a high-pass filter for the frequency-selective common-mode mitigation and, as discussed above, enhances low-frequency inter-element capacitance.

In Fig. 2, comparisons of the broadside active reflection coefficients of dual-polarized PUMA arrays using different via connections is shown. The PUMAv1 mitigates common-mode phenomena while deteriorating low-end performance, whereas removing the via has the opposite effect. However, the capacitively loaded via of PUMAv3 employs the frequency-selective common-mode methodology, acquiring both an improved low-end and common-mode suppression.

III. RESULTS

Using these principles, a PUMAv3 array was designed in an infinite array environment while utilizing only standard materials and manufacturing guidelines for multilayer PCB fabrication. The thinnest dielectric used was 5 mils (the same as the fabricated 21 GHz PUMAv1) with a grating lobe frequency, $f_g$, of 49.2 GHz and $f_{high}/f_g$ ratio of 97%. Predictions in Fig. 4(a) suggest VSWR < 2 at broadside and < 2.7 out to $\theta = 45^\circ$ over 10.6–47.6 GHz (4.5:1). As shown in Fig. 4(b), co-/cross-pol. levels remain at least 15 dB apart over the majority of the band, while the co-pol. drops by a maximum of 2 dB and cross-pol. rises to 10 dB at the low band edge. In conclusion, the PUMAv3 is a 50Ω directly fed PUMA array that more than doubles the maximum frequency and offers 50% more bandwidth than its predecessor. To our knowledge, this is the first low-cost dual-polarized UWB array manufacturable at mm-waves.

Fig. 2. Comparison of broadside active reflection coefficients between dual-polarized PUMAv1 and PUMAv3 with/without vias.

Fig. 3. Infinite array results. (a) VSWR; (b) Co-/cx-polarization.

REFERENCES
