Tunable Electrically Small UHF PIFA-as-a-package

Lucas M. Feldner* (1), Christopher T. Rodenbeck(1) and Christos G. Christodoulou(2)
(1) Sandia National Laboratories, Albuquerque, NM
(2) The University of New Mexico

Abstract: A tunable electrically small PIFA-as-a-package antenna for miniature wireless device applications has been developed using conventional printed circuit board processing techniques and commercial-off-the-shelf surface mount switches. The design is scalable to any frequency and form factor, while enabling adaptive tuning of the characteristically narrow band resonance of electrically small antennas. Our UHF prototype measures less than 2" (.08λ) on its longest side and provides approximately -9dBi of gain from 419-472 MHz. Simulated and measured results will be discussed in the presentation.

Introduction

Many highly integrated miniature systems are required to communicate at RF wavelengths much larger than their own physical size, requiring an "electrically small antenna" (ESA). Such applications abound from HF through 5.8GHz ISM band frequencies. As the trend towards miniaturization and multifunctionality in wireless devices progresses, the need for relatively efficient and environmentally agnostic electrically small antennas in every frequency-band becomes more acute. Many next-generation wireless sensor network and RFID systems will utilize the favorable propagation characteristics available at UHF and lower frequencies. Strict physical constraints coupled with the rapid pace of battery development leave the RF antenna as the largest impediment to further miniaturization for an increasing number of applications. The well-known tradeoffs between bandwidth (Q), gain, and size of electrically small antennas must be carefully balanced to develop optimized antenna solutions for each specific application.

For a fixed frequency, antenna size reduction is accompanied by a decrease in both the obtainable bandwidth and gain. High-Q ESAs are very sensitive to the environment in their near-field which is not known *a priori* for many applications. In such cases, electrically small *reconfigurable* antennas can be implemented which have the capability to adaptively compensate for environmental de-tuning effects.

Recently, Best [1] has demonstrated that the Q of impedance matched electrically small wire radiators is primarily established by the antenna's "effective height" (when above a ground plane) in addition to its "effective volume". That is, antennas occupying greater effective volume will have a lower minimum quality factor, and greater bandwidth while maintaining reasonable gain. The specific geometry of the antenna within this volume does not seem to be a significant factor in determining the performance characteristics of small antennas [2]. However, it is in general desirable to have environmentally agnostic ESAs that are sensitive to both electric (TM_{01}) and magnetic (TE_{01}) dipole modes.

Tunable PIFA-as-a-package concept

Figure 1a illustrates the PIFA-as-a-package concept used as the basis for our tunable ESA. A capacitive feed is added to the traditional PIFA for the additional degree of impedance matching freedom [3]. The PIFA is then capacitively loaded to reduce its electrical length [4]. Commercially available surface mount switches are used to implement a "shorting-strap" tuning technique similar to the work in [5]. The non-zero insertion loss of the commercial switches is modeled using thin-film boundary conditions in commercial full-wave electromagnetic field solvers.

Fabricating the PIFA on a standard printed circuit board substrate (i.e. FR-4 epoxy) allows miniaturization of the end-loading parallel plate capacitor, while keeping the majority of the antenna dielectric material air, to avoid unnecessary dielectric loss and maximize the antenna's efficiency. Using the outer metal of the PIFA structure as the device package, the space underneath the antenna-feed pedestal and above the loading capacitor can be used to house all of the requisite transceiver circuitry and power supply batteries for many portable wireless devices. Since the antenna and the battery are typically the two biggest roadblocks to portable wireless device miniaturization, integrating them together into the device package is often the optimal solution. The battery will have an effect on antenna performance, and batteries for specific applications should be included in full wave 3D EM simulations during the design process for specific applications. Figure 1b illustrates an extremely simple-to-manufacture version of this design that can be fabricated using two copper clad printed circuit board substrates connected with shorting posts.

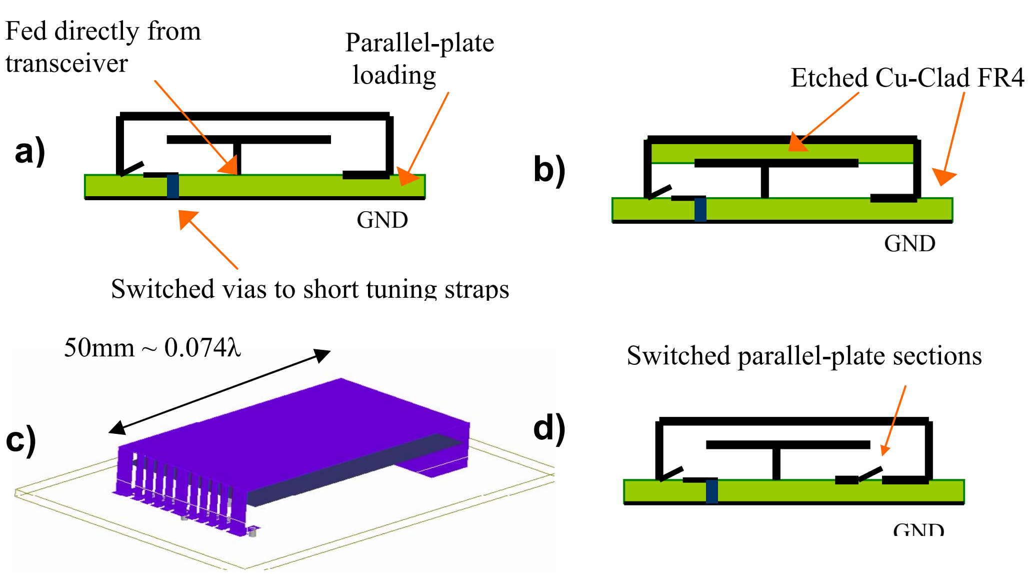

Figure 1. Tunable PIFA-as-a-package concept

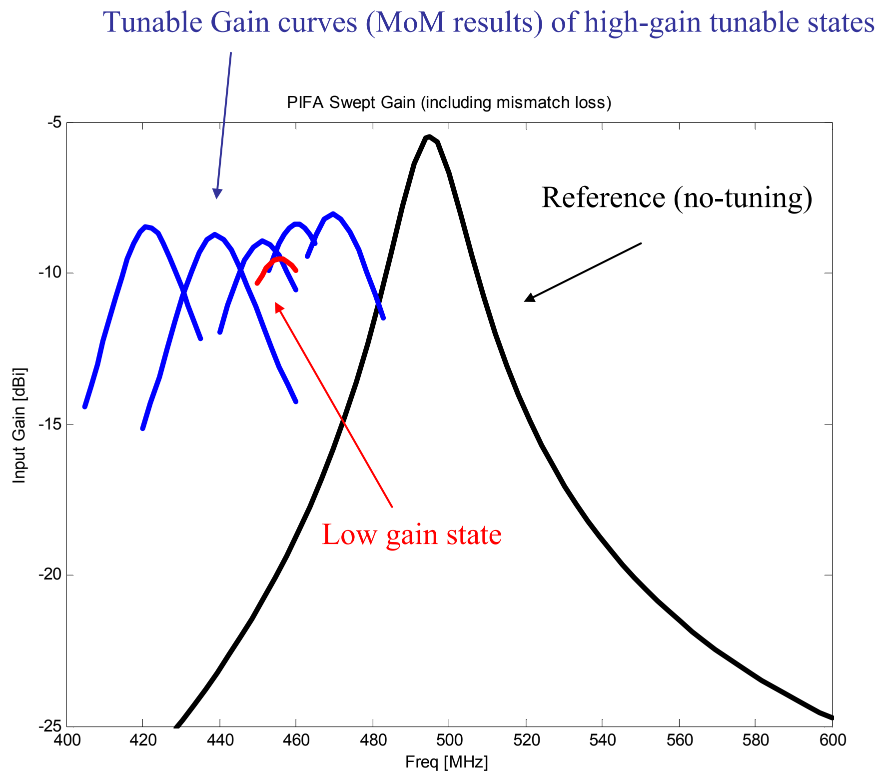

Figure 2. Tunable vs Non-tunable PIFA realized gain

Figure 1c shows a 3D rendering of the UHF-band tunable PIFA-as-a-package discussed in this work. The proposed antenna measures less than 0.08 λ on its longest side (50mm), 25mm in width and stands less than 7.5mm high. Ten surface mount low-loss switches are used to tune the ~5.5MHz instantaneous 10dB impedance bandwidth across approximately 53 MHz. Figure 2 compares the simulated swept realizable peak gain (includes mismatch losses) of our proposed tunable PIFA with a reference (non-tunable) PIFA (back curve). The blue gain curves of Figure 2 envelope the realizable gain of the proposed tunable antenna. While the non-zero switch loss degrades the peak gain of the tunable PIFA, the enhanced gain-bandwidth product using this approach is clearly evident. Simulated and measured results will be discussed in the presentation.

If a broader tuning range is required, and additional gain/efficiency degradation is tolerable, the parallel plate loading capacitance can be tuned in conjunction with the strap tuning technique as illustrated in Figure 1d. Simulated full-wave Return Loss results using four parallel plate loading capacitance states are shown in Figure 3, indicating the potential utility of the proposed tunable PIFA-as-a-package where a larger tuning range is required.

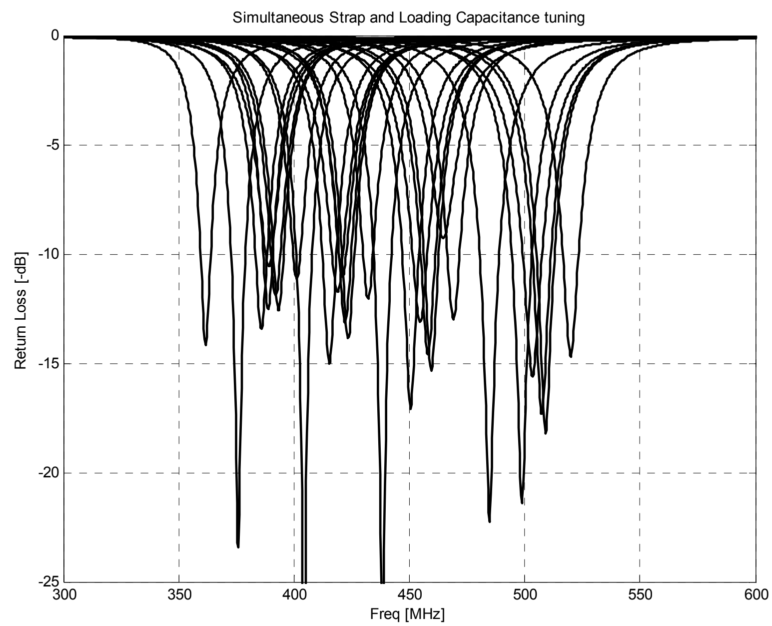

Figure 3. Strap tuned PIFA with tunable loading capacitance (ideal)

Future Work

The PIFA, like any patch-type radiator, ideally operates above an infinite ground-plane. In many miniature wireless applications a large ground plane is obviously not available. Accordingly, the tunable PIFA-as-a-package approach will be evaluated in the presence of finite ground planes and techniques to develop environmentally agnostic antennas functioning with or without a ground plane will be considered.

Acknowledgement. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

References:

[1] S. R. Best, "A Discussion on the Quality Factor of impedance matched Electrically Small Wire Antennas", *IEEE Trans. Antennas Propagat*, Vol. 53, No. 1, Jan. 2005.

[2] S. R. Best, "A Discussion on the significance of geometry in determining the resonant behavior of fractal and other non-Euclidean wire antennas", *IEEE Ant. Prop. Magazine*, Vol. 45 No. 6, pp. 1292-1300, June 2003.

[3] G. A. E. Vandenbosch and A. R. Van de Capelle, "Study of the capacitively fed microstrip antenna element", *IEEE Trans. Antennas Propagat.*, Vol. 42, pp. 1648-1652, Dec., 1994.

[4] C. R. Rowell, R. D. Murch, "A Capacitively Loaded PIFA for Compact Mobile Telephone Handsets", *IEEE Trans. Antennas Propagat.*, Vol. 45,

[5] N. C. Karmakar, "Shorting Strap Tunable Stacked Patch PIFA", *IEEE* No. 5., pp. 837-842, May, 1997. *Trans. Antennas Propagat.*, Vol 52, No. 11, pp. 2877-2884, Nov., 2004.