Low-Q Antennas Miniaturized with Adaptive Tuning for Small-Platform Applications

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***Abstract*—Conventional antenna designs for small platforms have been focused on using high-*Q* antennas, resulting in narrow bandwidth easily detuned. An approach using low-*Q* antennas miniaturized by using Real-time Adaptive Tuning (RTAT) is proposed. This new approach has been applied to the development of an Adaptive Miniaturized Ultrawideband Antenna (AMUA). Preliminary results are promising.**

I. Introduction

Since early 1990s, antenna design for small platforms such as smartphones/tablets and small UAVs must struggle for ever broader bandwidths and more features, yet simultaneously for miniaturization. While this trend had been foreseen two decades ago, stemming from the wireless revolution [1], design approaches have been focused only at using high-Q (quality factor) antennas. Since high-Q antennas are subject to the fundamental Chu limit on bandwidth [2], they are narrowband and thus easily detuned during installation and operation. A fundamentally different approach is proposed in this paper.

II. A New Approach —Broadband Low-Q Antenna with Real-Time Adaptive Tuning (RTAT)

The proposed new approach is to employ low-Q antennas miniaturized by using a Real-time Adaptive Tuning (RTAT) to circumvent the Chu limit. This approach had been conceived, in a broader sense, many years ago, which employed certain low-Q antennas as "Air Interface®" (US trademark reg. No. 2,049,604, 1997) between a wireless system and its propagation environment, performing as a broadband impedance transformer. The concept is depicted in Fig. 1 for the development of a Miniaturized Ultrawideband Antenna (AMUA) for smart-phone/tablet.

Fig. 1. AMUA on a smartphone.

This approach did not immediately gain interest—due to two concerns: (1) legacy systems rarely had broadband or multi-band requirements; (2) low-Q antennas were larger, heavier, more expensive, and slightly lossier than high-performance high-Q antennas.

Consequently, even though the approach gradually gained supports with successful application to designs of smart helmet and vest antennas for U.S. Army and NASA applications during 1995-2009 [3], its practicality for the broad commercial applications was still in question. The objective of this research is to explore its viability today by taking advantage of the newly emerging low-Q antennas of even smaller size, weight, and cost, e.g. [3]-[5], the much more mature RTAT technology, and the market thirst for ever more bandwidths and features.

The present AMUA design employed an embedded multimode broadband low-Q traveling-wave (TW) antenna [3] and a RTAT mechanism developed by The Ohio State University (OSU) [6].

A. Broadband low-Q traveling-wave (TW) antenna

The TW antenna had been demonstrated a decade ago to be capable of achieving antenna gain-bandwidth beyond the Chu limit (which is applicable only to high-Q narrowband antennas) [7]. A thin small TW antenna was developed for the present application. Its measured antenna resistance and reactance are shown in Fig. 2.

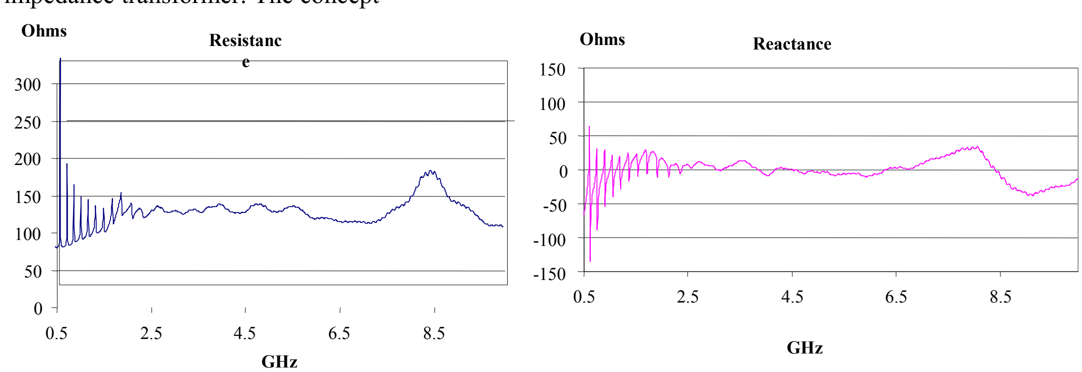

Fig. 2. Measured resistance and reactance of a TW antenna.

As can be seen, the antenna Q is low and stable over 2-7 GHz since, generally, its reactance is <10 Ω and its resistance is around 125 Ω. At frequencies 0.5-2.0 GHz, the antenna resistance oscillates in increasing amplitude to between 80 and 200 Ω, and antenna reactance oscillates increasingly to between -135 Ω and 60 Ω.

The oscillations of impedance over 0.5-2.0 GHz are due to the increasingly larger "tuning" effect of the small platform on which the antenna is mounted. We can overcome this problem by tuning it with a RTAT to achieve impedance match at designated bands. Fig. 3 shows that the VSWR is tuned to multiple resonances using a simple tuner over 0.6 to 2.6 GHz.

B. Real Time Adaptive Tuning (RTAT)

Since RTAT is still rather complex, difficult, and costly, it has only been implemented in very limited ways. For example, in some smartphones, their RTAT is limited to switching among a small set of impedance values for a specific high-Q antenna with some simple tuning algorithm set *a priori*.

In order to use low-cost MEMS switches available as Commercial-OFF-The-Shelf (COTS) parts, we took advantage of the low Q of antenna to relax the requirements on RTAT as follows: (1) adaptive mechanism is limited to impedance matching only, with no pattern diversity; (2) range of adaptation for load impedance Z_L is over $2\Omega < Re(Z_L) < 500\Omega$ and $-500\Omega < Im(Z_L) < 0\Omega$; (3) frequency range is over 800-1500 MHz where RTAT is crucially needed. (Obviously, at frequencies above 1500 MHz, the TW antenna's wide bandwidth and low Q enable it to tolerate large disruptions with small detuning.)

For this relaxed design goal, the RTAT developed by OSU using a commercial MEMS capacitor chip was able to meet the impedance tuning requirement with low insertion loss [6].

III. Integration of AMUA into Tablet

Fig. 4 is a photo showing an AMUA antenna installed in a mini-tablet 4.8"×7.5" in size with its top cover removed to reveal part of the AMUA. The copper multimode TW antenna near the left upper corner is the radiator 1" (2.54 cm) in diameter and positioned near the feed location of the tablet's antenna feed point. Underneath and connected to it is its RTAT, which can be further miniaturized, if needed, for integration into the tablet in the future.

While the integration would be best carried out in collaboration with a handset manufacturer, and ideally tailored to a specific model, this lofty goal has not yet been reached. Nevertheless, preliminary testing on this breadboard has shown its feasibility and its potential for continual improvements as higher-performance lower-cost MEMS switches become available—a likely event based on the Moore's Law projection.

IV. Miniaturization of AMUA into Smartphone

The antenna in tablet application is further miniaturized for a smartphone platform in two stages. First, the size of the TW radiator is reduced by a factor of about two by using the slow-wave technique, which has been successfully employed by this author using newly available high-ε substrates. At the second stage, a new 3-D (three-dimensional) TW antenna, [4]-[5], will be employed for further size reduction and performance enhancement. (As a side note, 3-D TW antenna's bandwidth >100:1 and size-weight reduction over the 2-D TW antenna have both been demonstrated.) These recent progresses further brighten the prospects of the proposed approach.

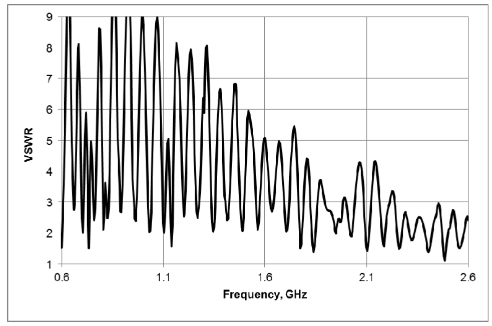

Fig. 3. Measured VSWR of the TW antenna

Fig. 4. AMUA in a mini-tablet with top cover removed.

V. Conclusion

The proposed approach employing low-Q antennas miniaturized by using Real-time Adaptive Tuning (RTAT) is shown to be a feasible solution for antennas installed in small platforms such as the smartphones and tablets.

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