A Novel Corrugated-Shank Anchor-Shaped Antenna for Wireless Power Transfer

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***Abstract*—In this paper we propose a new class of *anchor-shaped* antenna referred to as *corrugated-shank anchor-shaped* suitable for angular misalignment resilience. This new topology to operate at 360 MHz differs from previously published *anchor-shaped* antenna [1] by introducing corrugations in the shank of the anchor for stronger magnetic fields. The results suggest a 10% of power transfer efficiency (PTE) improvement with respect to that of the generic anchor. This improvement is achieved when considering misalignments in the elevational direction. This design can be used as a guideline for future misalignment-free wireless charging modalities integrated into clothing.**

I. Introduction

Wireless charging via wireless power transfer (WPT) has been of great interest in low-power applications such as Internet of Things (IoT), Internet of Health Things (IoHT) and high-power applications like charging vehicles. Such modality of powering is used to power devices like smart phones,iPad, wireless headphones, other gadgets that we use in daily life, as well as electric vehicles. Using wireless charging for such applications will be subject to misalignments. The latter will dramatically affect the RF performance of the system due to the fact that the transmitter (Tx) and (Rx) will be misaligned and the electric and magnetic fields will be affected negatively. Various attempts have been used to tackle the effects of misalignments in previous works. The most recent ones include the use of cylindrical strongly coupled magnetic resonators to achieve 40% of PTE for a full 360° angular coverage [2] and cubic transmitting coils to achieve 60% at 13.56 MHz when the separation represents 1/100 of the operating wavelength [3]. The limitations of these proposed antennas lie in the fact that not only high PTE can be achieved at all possible misalignments, but also their configurations that make them not easily clothing-integratable because of their 3D-layouts.

With that in mind, we proposed a 2D-topology of antennas referred to as *generic anchor-shaped* [see Fig.1(a)] suitable to tackle all lateral and angular misalignments [1]. This topology was later used to develop a wireless charging platform integrated into clothing [4]. This topology was inspired from the work of Hong and Lancaster [5] where the electric and magnetic modes were exploited to achieve high PTE when the Tx and Rx were subject to both lateral and angular misalignments. Using this antenna topology to operate at 360 MHz, we achieved up to 65% of PTE improvement when the Tx and Rx underwent angular misalignments and up to 25% for lateral misalignments. This PTE improvement was achieved with respect to its single-loop counter part. The results showed that the shank of the *anchor* was responsible to strengthen the magnetic field distribution and the crown [with the fringe-enabling cavities], for the strong electric fields.

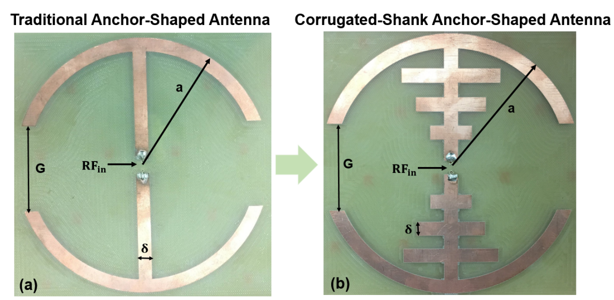

Fig. 1: Pictures of the proposed anchor-shaped antenna as well as the traditional anchor-shaped antenna previously published in [1]: (a) generic anchor-shaped antenna and (b) proposed novel anchor-shaped antenna (*a = 7.5 cm, G = 2a/3, δ = a/10*)

In this paper, we propose a new class of *anchor-shaped* antennas where the shank is comprised of corrugations to further enhance the magnetic fields; hence improve the PTE for misalignments along the shank. As per the results from [1], it is expected that its PTE, when the Tx and Rx undergo angular misalignment, will be improved when compared with that of the *generic anchor-shaped* antenna.

II. Design and Fabrication

One *corrugated-shank anchor-shaped* [see Fig. 1(b)] and one single-loop antennas were designed and fabricated to operate at 360 MHz and 680 MHz, respectively. The radius of both antennas was chosen to be 7.5 cm and the thickness of the conductive traces, 0.75 cm. Both antennas were fabricated using an LPKF milling machine on an FR4 substrate. It can be observed that the operating frequency for the *anchor* antenna is about half of that of the single loop antenna. This represents the miniaturization characteristic of the *anchor* antenna and the enhancement of its wavelength. The expression of the operating frequency of the *anchor* antenna is given by [1] and can be written as:

$$f_{theoretical-anchor} = \frac{10^{9/7} c^{8/7} \mu_o^{1/7} \rho^{1/7}}{4 \times 15^{2/7} \pi^{11/7} a^{8/7}}. \quad (1)$$

Since the *anchor* antenna performs like a dipole, we use the circuit representation of [6] and deduce that $Perimeter_{anchor} = 2\pi a + 2a - 2G = 2\pi a + 2a - 2(\frac{2}{3}a) \approx 7R = 0.7\lambda$. And the new expression of the operating frequency is:

$$f_{simplistic-anchor} = \frac{c}{10 \times a} \quad (2)$$

The theoretical and simplistic expressions of the operating frequency were verified using a full-wave simulation of the *anchor* antenna. Fig. 2(a) exhibits the comparison between the theoretical , the simplistic, and the simulated operating frequencies of the proposed antenna. The margin error between each expression with respect to the simulation results was estimated using the equation (3) and plotted in Fig. 2(b).

$$\delta = \left| \frac{Theor./Simpl. - Sim.}{Sim.} \right| \times 100\% \quad (3)$$

As a result, the simplistic expression better represents the

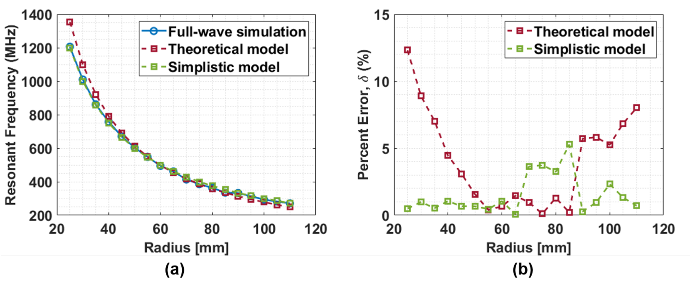

Fig. 2: Representation of the theoretical and simplistic model of the *anchor-shaped* frequency modulations compared to their simulated counterpart : (a) theoretical and simplistic models compared to simulation and (b) percent error of the aforementioned models with respect to their simulation counterpart.

antenna's characteristic. This is a justification of the dipole-like profile of the *anchor* antenna.

III. RF Wireless Power Transfer Efficiency (WPTE)

The measured WPTE was calculated using the formula from [1]. This formula combined the scattering parameters from both *corrugated-shank anchor-shaped* and single loop antennas using a 2-port vector network analyzer.

As shown in Fig. 3(a), the *corrugated-shank anchor-shaped* antenna exhibits a PTE improvement of 40% from its single-loop counterpart for azimuthal misalignment. This is approximately the same improvement exhibited by the *generic anchor-shaped* as reported in [1]. Fig. 3(b) shows that the PTE found for the *corrugated-shank anchor-shaped* antenna is an improvement of 55% from its single-loop counterpart for elevational misalignment. This is a 10%-improvement realized from the *generic anchor-shaped* as shown in [1]. This 10% of additional improvement is inherited from the presence of corrugations incorporated in the shank. This result

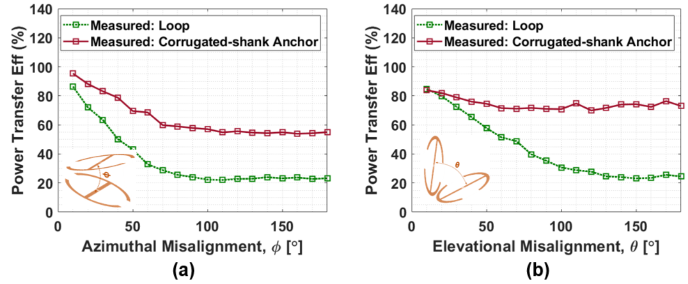

Fig. 3: WPTE of the *anchor-shaped* when the Tx and Rx underwent azimuthal and elevational misalignments : (a) azimuthal case and (b) elevational case

was anticipated from [1] suggesting resilience in angular misalignments. As can be seen on the Fig. 3, the PTE is on average constant for the whole angular coverage starting from 0 to 180 °. This is an excellent design opportunity for wireless charging where any movement affecting the elevational or azimuthal orientation will not compromise the power transfer.

IV. Conclusion

In this paper, a new class of *anchor-shaped* antenna referred to as *corrugated-shank anchor-shaped* resulted from placing some corrugations at the location of the shank of a *generic anchor-shaped* antenna to further enhance the magnetic fields for high PTE and resilience to angular misalignment in the elevational and azimuthal directions. The results suggest that using corrugations will allow the *corrugated-shank anchor-shaped* to gain 10% more in PTE when the Tx and Rx are misaligned in the elevational direction. This can be used as a design guideline for future wireless charging platforms.

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