

Wearable Planar Magnetoinductive Waveguide WBANs: Bending Around Anatomical Curvatures

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Abstract—We recently reported a new class of wearable wireless body area networks (WBANs) based on planar magnetoinductive waveguides (MIWs) that offer extremely low-loss as compared to the state-of-the-art. Examining the bending effects of these WBANs around anatomical curvatures of the human body becomes crucial for their practical implementation. Previous work utilized mostly flat surfaces to evaluate performance of planar-MIW WBANs with only few quantitative data reported for bending scenarios around curved surfaces. In this paper, we provide the complete transmission performance characteristics of these WBANs over the entire frequency band (30-60 MHz) of operation pertinent to several bending scenarios that were not reported in the past. Results demonstrate excellent overlap of transmission characteristics across the operating band with minimal change in performance across various bending scenarios, including extreme bending. Overall, the study confirms the potential of planar-MIW to connect across various anatomical curvatures and to ultimately form a robust and reliable alternative for future wearable WBANs.

Keywords— *Bending; planar magnetoinductive waveguides; transmission coefficient; wearable; wireless body area networks.*

I. INTRODUCTION

We recently reported a new class of wireless body area networks (WBANs) that are based on planar magnetoinductive waveguides (planar-MIW) [1]. These WBANs offer extremely low loss and can be seamlessly integrated in garments, in addition to several other advantages as compared to the state-of-the-art [1]. Per Fig. 1, the design consists of a series of planar rectangular resonant loops that are separated by a gap. The transmitting loop (Tx) generates magnetic flux that induces voltage on neighboring loops. In turn, these loops generate their own magnetic flux, inducing voltage on other neighboring loops and leading to the formation and propagation of magnetoinductive (MI) waves. These MI waves communicate information from transmitter (Tx) to receiver (Rx).

Expectedly, MIW-based WBANs may run across different parts of the human body to interconnect various sensors. As such, there is a need to evaluate the performance of planar-MIW as they bend around different anatomical curvatures. Our previous work focused mostly on placing the MIWs on flat surfaces to study their performance [1]. Few quantitative data (e.g. maximum change in minimum loss, bandwidth, etc.) were reported for bending scenarios in [1], along with transmission

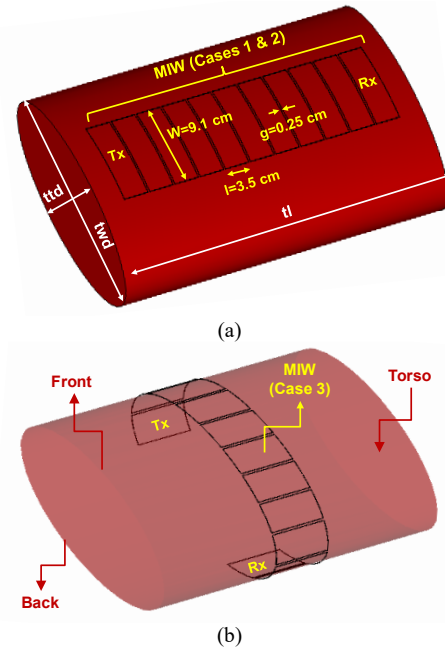


Fig. 1. Planar-MIW placed conformally on an ellipsoidal torso in two different orientations (a) Cases 1 and 2: along the length of torso, causing bending along the width of the MIW, (b) Case 3: wrapped around the width of the torso, causing bending along the length of the MIW.

characteristics presented for just one case. Here, we provide the complete transmission characteristics over the entire operating frequency band (30-60 MHz) for several bending scenarios that were not reported in the past. By exploring performance variations and their trend across the frequency range, we enable a complete picture that could not be captured via the quantitative data reported in [1].

II. SIMULATION SET-UP

The full-wave frequency domain solver of CST Microwave Studio [2] is used in our simulations. An ellipsoidal torso with 2/3 muscle representing average tissue properties [3], [4] is utilized to approximate the human anatomical torso. Referring to Fig. 1, we set the dimensions as follows: torso length= $tl=48$ cm, torso width diameter= $twd=25$ cm, and torso thickness diameter= $ttd=10$ cm [1]. An 11-loop planar-MIW WBAN with length (l)= 3.5 cm, width (w)= 9.1 cm and gap between the loops (g)= 0.25 cm, is placed conformally on the torso [1] [see Fig. 1].

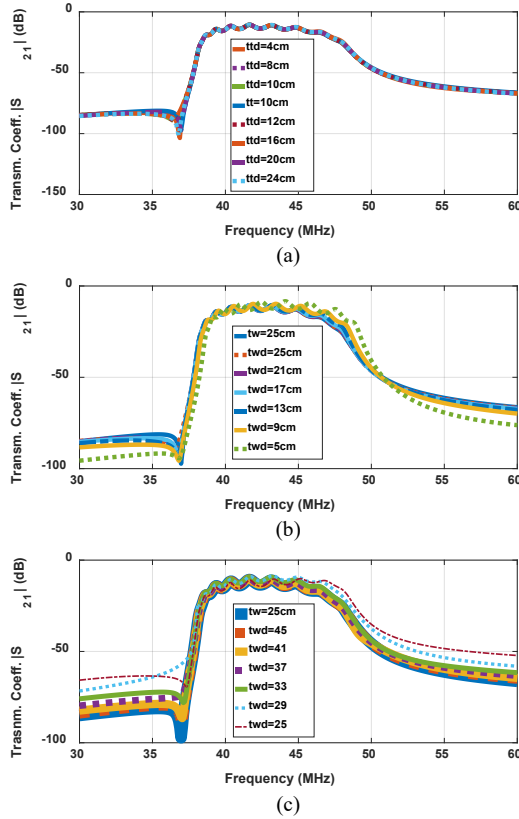


Fig. 2. Results demonstrating minimal change in performance caused due to bending, covering several different scenarios of body shape/size/parts and MIW placement through: (a) case 1, (b) case 2, and (c) case 3.

For reference, the same MIW and with similar orientation as in Fig. 1(a) is placed on a cuboidal torso with equivalent dimensions ($tl=48$ cm, torso width (tw)= $twd=25$ cm, and torso thickness (tt)= $ttd=10$ cm) such that there is no bending upon the MIW [1]. Notably, by varying twd and ttd , we can realize different body parts of different shapes and sizes and achieve different placements of the MIW WBANs. Overall, three cases are considered to study the effect of bending along anatomical curvatures. For cases 1 and 2, the MIW runs along the length of the torso such that bending happens along its width, as shown in Fig. 1(a). As discussed in Section III, these cases differ in terms of dimensions and parametric sweeps. For case 3, the MIW wraps around the torso and the bending happens along its length, as depicted in Fig. 1(b) [1]. For all cases, tl is kept fixed at 48 cm.

III. BODY PART/SHAPE/SIZE VARIATION AND RESULTS

For case 1, $twd=25$ cm (same as tw), while ttd varies from 4 cm to 24 cm with a step size of 4 cm. Additionally, $ttd=10$ cm so as to compare with the reference set up ($tt=10$ cm). Such variation allows us to emulate various shapes/sizes of torsos and limbs (e.g. thigh/leg), especially as ttd gets closer to twd [see Fig. 1(a)]. Results obtained for the transmission coefficient ($|S_{21}|$) vs. frequency with clear passband and stopband are shown in Fig. 2(a). As seen, excellent overlap is achieved with negligible change in performance as compared to the reference ($tt=10$ cm).

For case 2, $ttd=10$ cm (same as tt), and twd varies from 5 cm to 25 cm with a step size of 4 cm. The latter covers several aspects: (i) $twd (=5$ cm) $< ttd (=10$ cm) corresponds to extreme bending on the MIW [see Fig. 1(a)], representing placement on the side of a thin forearm or front of thin shank, (ii) $twd=9$ cm and 13 cm are close to $ttd=10$ cm and represents a limb (e.g. arm of different shapes/sizes), (iii) $twd=17$ cm falls in the transition region of limb to torso, and (iv) $twd=21$ cm and 25 cm represent different torso sizes. Results for $|S_{21}|$ curves are depicted in Fig. 2(b), again showing minimal deviation compared to the reference (shown as $tw=25$ cm in Fig. 2(b)). The trend depicts a slight frequency shift towards the right as extreme bending approaches. The upper frequency cut-off increases more than the lower frequency cut-off, leading to slight bandwidth improvement.

For case 3, the MIW is wrapped around the torso, as shown in Fig. 1(b). Here, $ttd=10$ cm (same as tt) and twd varies from 25 cm to 45 cm with a step size of 4 cm to emulate different torso shapes/sizes. Case 3 also covers different placement scenarios of the planar-MIW upon the torso. For example, for $twd=25$ cm, the Tx and Rx reach the backside of the torso as in Fig. 1(b), while for $twd=45$ cm, they remain on the front side of the torso (with values covering in between scenarios). Again, results overlap quite well as shown in Fig. 2(c) with minimal change in performance as compared to the reference (shown as $tw=25$ cm in Fig. 2(c)). Also, the trend depicts that the lower cut-off frequency is relatively fixed while the upper cut-off frequency increases slightly. This leads to slight improvement in bandwidth with no impact on the operating passband of the original/reference design.

Overall, only minimal change in performance is observed for all three cases of Fig. 1, as indicated in Fig. 2. This minimal change mostly improves performance (for both loss and bandwidth), with only negligible degradation.

IV. CONCLUSION

We studied the bending of planar-MIW WBANs around anatomical curvatures of the human body, exploring different shapes/sizes and body parts, as well as different placements of the MIW. Transmission coefficient results across the 30-60 MHz range demonstrated negligible change in performance. Thus, planar-MIW WBANs are robust to bending and hence have potential to provide a low-loss and reliable alternative for future wearable WBANs. In the future, we will integrate MIWs on fabric and will validate their performance on human subjects.

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