Removable Finger Nail Antenna

Peter Njogu and Benito Sanz-Izquierdo
School of Engineering and Digital Arts, The University of Kent, Canterbury, UK, b.sanz@kent.ac.uk

***Abstract*— An antenna on a removable fingernail for on-body communication applications is proposed. The antenna consist of patch design that is shaped around the curvature of an artificial nail. Two fabrication procedures are tested. The first uses copper layers that are attached to the nail. The second is a more realistic scenario where the patch is painted by hand onto the inexpensive polymer material. The antennas operate at the 10 GHz band and are intended for future on-body wireless communications systems. Tests were conducted on the antenna, first in free space and then on human body. The tests results from the brush-painted antenna compare well with those of the design on copper and the simulations. The antennas performance in terms of reflection coefficient and radiation pattern are satisfactory. CST Microwave Studio™ was used for the simulations. This work aims to demonstrate a new concept for low-cost body-attached antennas using finger nails.**

Index Terms— Wearable antenna, on-body applications, additive manufacturing.

I. Introduction

The emergence of Body Area Network (BAN) wireless communication has ignited interest in human body mountable antenna for wearable applications such as in sports, military, health etc., [1] [2]. Coupled with this is the advancement in miniaturization of microelectronics which in conjunction with emerging technologies facilitates integration of computing devices with on-body technology. This facilitates new on-body communication applications that requires antennas [3]. On-body antennas characteristically form part of a wearable system. They can be integrated with worn piece of textile or fabrics, on-body device or worn fashion acessories. They can uniterruptedly monitor activities like body temperature, heartbeat, or disaster zone environmental parameters for rescue workers. They should be light, flexible with small surface coverage to ensure an unobstrusive integration with body environment [4].

Various body mounted antennas have been developed. Examples includes a button antenna [5, 6], belt buckle antenna [7] and a smart watch antenna [8]. In [9], an antenna on Jeans Textile is presented while a wrist worn design for wireless application is described in [10]. In [11, 12] wearable antennas for medical systems are introduced.

Most wearable electronic devices previously proposed [1] - [12] operate at frequencies below 6 GHz. However, with the arrival of the fifth generation (5G) of communication systems and beyond, there is an interest in developing antennas at higher frequencies. High frequencies would allow for wider bandwidths and higher data rates applications for future Internet of Thing (IoT) and real time video and big data communication applications.

This paper presents a patch antenna integrated into a removable fingernail for future on-body communication. An off-the shelf removable fingernail is used as substrate for the development of a conformal patch antenna. Two techniques are tested for the fabrication of the antenna. The first uses copper strips that are attached to the removable nail. In the second, the antenna is brush painted by hand using silver conductive paint. This second procedure is akin to most common manicure procedures. By using existing manicure methods, the antenna can be seamlessly fabricated at a low cost. As an initial proof of concept, the antenna has been designed to operate at 10 GHz. The 10 GHz to 10.125 GHz frequency band is currently allocated for amateur, fixed, mobile, radiolocation and earth exploration satellite communication according to [13]. For reference on the future behavior of communications at that frequency, an investigation on how a 10 GHz indoor radio channel characteristics behavior is influenced by shape of antenna pattern is presented in [14]. CST Microwave Studio™ has been employed in the design, simulation and optimization of the removable fingernail antenna.

II. ANTENNA DESIGN

A patch antenna on a small substrate is presented in Fig. 1(a). Patch design was chosen due to its hemispherical radiation pattern and possibilities in term of off-body communications. Its dimensions, Table 1, were optimized so that the antenna resonates at around 10 GHz. The substrate chosen was 1 mm thick with a relative permittivity (ε_r) of 2.4. The conductive material used for the patch was silver while the ground plane was made of copper. The antenna was fed via a coaxial probe. The designed antenna was bent along its length into a smooth 46° arc to mimic the curvature of the fake nail as shown in Fig. 1(b) and Fig. 1(c). Reflection coefficient (S_{11}), radiation pattern and the surface current distribution performance parameters were used to determine the antenna functional effectiveness.

Human body has a high relative permittivity and electrical losses and can affect the resonance frequency and antenna efficiency. A patch antenna is a structure that can minimise such effects. To determine how it affects the antenna performance, the antenna was simulated worn on a human finger. The human finger tissues that were considered were the nail, skin and muscle all of which have different ε_r. Fig. 2(a) depicts a cross section and Fig. 2(b) the longitudinal section of the patch antenna on a non-homogenous human tissue layers of estimated dimensions: skin (0.5 mm), nail (0.5 mm), and muscle (14 mm). Their electrical characteristics at 10 GHz are given in Table II. Reflection coefficient, S_{11}, obtained for the antenna before and after it was bent as well as when worn on the finger are shown in Fig. 3. The bent in free space and on finger antennas' S_{11} results indicates a slight but progressive shift to the left of that of the unbent antenna. The shift to the left of the resonance point of the on-finger from that of the in free space finger could be due to the loss tangent, of the human finger tissues. The S_{11} results -10 dB impedance bandwidth however covers the targeted 10 GHz to 10.125 GHz in all three cases. A bandwidth of about 9.9 GHz to10.25 GHz for the unbent antenna, 9.9 GHz to 10.2 GHz for the bent off-finger antenna and 9.81 GHz to 10.2 GHz for the on-finger worn antenna were realized. Fig. 4 shows the surface current distribution indicating symmetrical pattern of surface current is generated on the symmetrical patch.

Fig. 5 depicts the simulated radiation pattern of the antenna before and after bending as well as when worn on the finger. The radiation patterns are similar in all three cases. There is a tilt in the pattern in the YZ plane. This is designed purposely in order to achieve maximum gain when the hand or whole arm of the body is slightly up. A reduction in antenna efficiency of about 0.4 dB is obtained when the antenna is placed on body antenna.

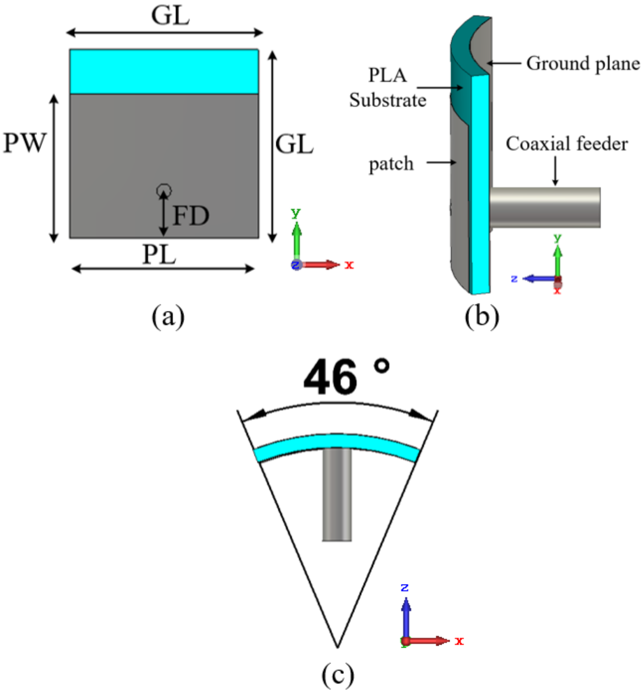

Fig. 1. The (a) designed patch (b) after bending into an arc and (c) the degree of the arc

TABLE I
THE PATCH ANTENNA DIMENSIONS

Length PL	Width PW	Ground Length GL	Feeder distance FD	Substrate thickness
12 mm	9 mm	12 mm	3 mm	1 mm

TABLE II
HUMAN TISSUE ELECTRIC CHARACTERISTICS *[15]*

Tissue	Relative Permittivity, ε_r	Conductivity, σ, (S/m)	Loss Tangent, tan (δ)
Nail	8.1197	2.1359	0.47284
Muscle	42.764	10.626	0.44666
Skin	31.29	8.0138	0.46038

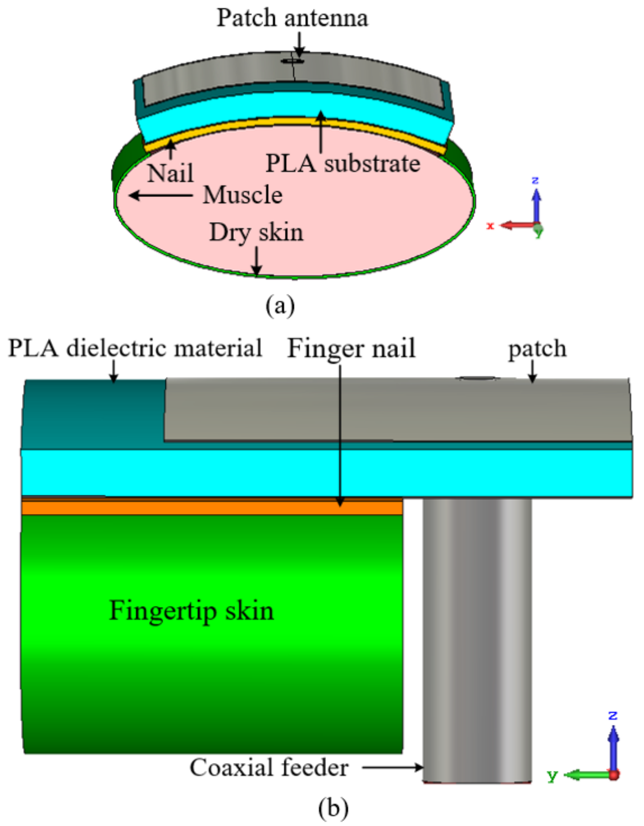

Fig. 2. (a) The cross section and (b) the longitudinal section of the human finger model with the nail antenna

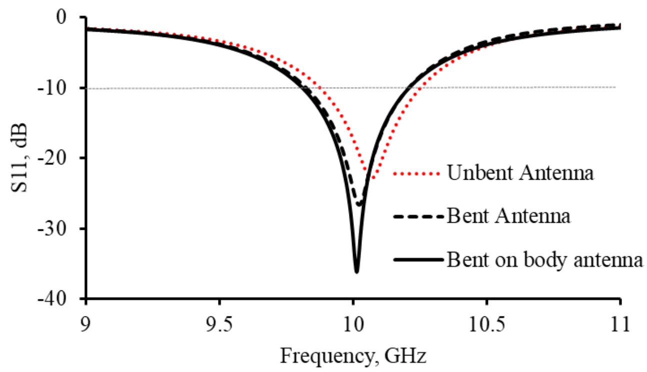

Fig. 3. Simulated unbent, bent and on-body antenna S_{11}

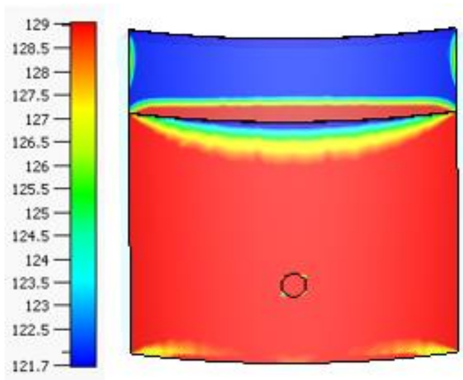

Fig. 4. Surface current distribution on the patch radiator

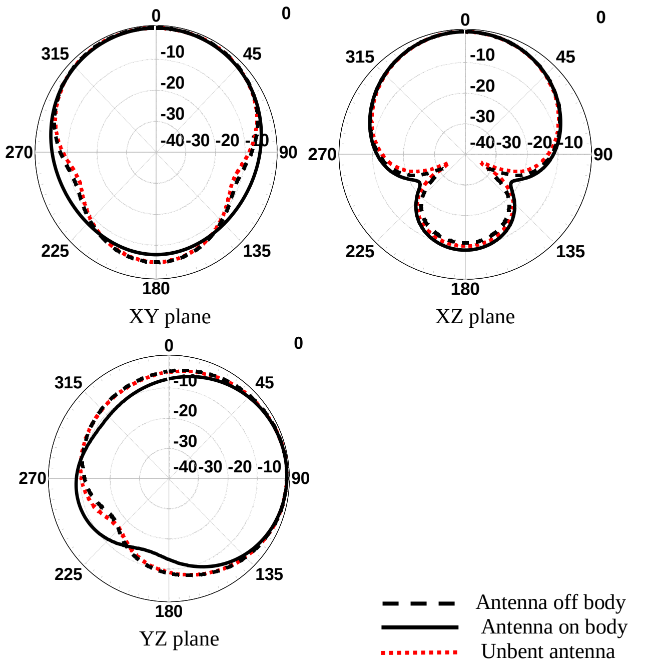

Fig. 5. Simulated radiation pattern of the in-free space unbent, bent and on finger mounted antenna

III. FABRICATION AND MEASUREMENTS

A. *The copper patch antenna*

Two prototypes were developed. The first prototype was developed using adhesive copper tape for both the patch and the ground plane as shown in Fig. 6(a) and Fig. 6(b) respectively. The antenna was feed by a rigid coaxial cable which was cut so that the inner conductor was inserted through the nail to connect to the patch while its outer conductor connects to the ground plane. The artificial nail was used as substrate for the antenna.

Using a Rohde & Schwarz ZVL vector network analyser, S_{11} of the fabricated antenna was measured for both in free space and on finger scenarios. Fig. 7 depicts the results of the simulated and measured both free space and on-body S_{11}. The results indicates that both simulated and measured on finger S_{11} is slightly shifted to the right of the in free space S_{11}. The measured -10 dB impedance bandwidth of the proposed copper antenna for both in free space and on finger were found to be about 400 MHz (9.9 GHz to 10.3 GHz). Measured bandwidth is within the targeted 10 GHz to 10.125 GHz bandwidth and slightly wider than the simulated bandwidth.

Radiation pattern of the fabricated antenna was measured in the anechoic chamber. Fig. 8 shows the XY, XZ and YZ planes of the measured and simulated radiation pattern of the antenna. There is a good agreement between measured and simulated results for all planes. They all show hemispherical directivity with the expected tilt in the YZ plane.

B. *Brush painted Silver patch antenna*

A second silver ink brush painted antenna was then fabricated. The fabrication of the simulated antenna was done

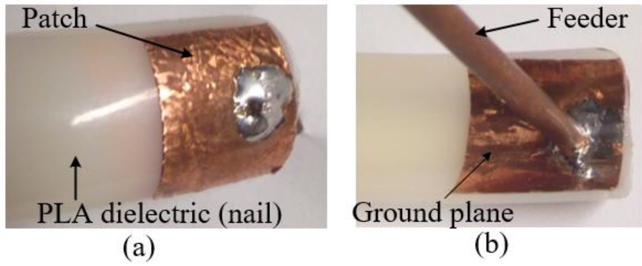

Fig. 6. (a) Finger copper tape nail antenna (b) its ground plane and feeder

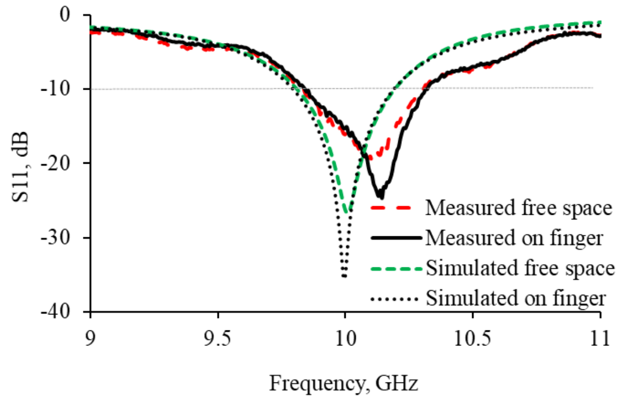

Fig. 7. Comparison of measured and simulated S_{11} of the copper antenna

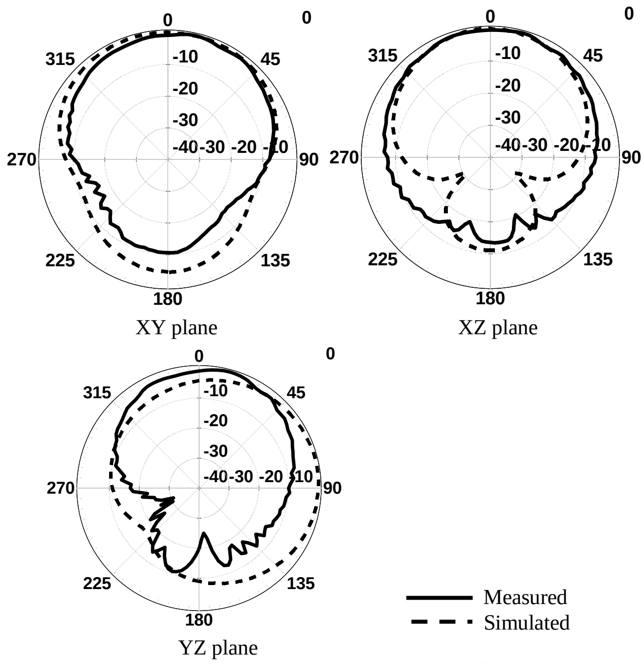

Fig. 8. Measured and CST simulated radiation pattern of the patch antenna.

on the removable fingernail substrate. Using a brush as shown in Fig. 9(a), an RS 186-3600 silver conductive paint from RS components Ltd was hand painted onto the substrate to create the patch on the nail. Fig. 9(b) shows the fabricated patch antenna while Fig. 9(c) shows its ground plane. Fig. 9(d) depicts the placement of antenna on the finger. The structure was left to cure for over 36 hours in room temperature. A multi-meter was used to test that the electrical continuity across the painted surface was continuous.

The fabricated antenna performance was tested by measuring its S_{11} and radiation pattern. Using a Rohde & Schwarz ZVL vector network analyser, S_{11} tests of the fabricated model were conducted. Fig. 10 compares the simulated and measured both free space and on-body S_{11} results of the fabricated antenna. Measured free space S_{11} is shifted to the right of the simulated S_{11}. However, the measured on-body S_{11} is shifted to the left of that of the free space. This could be due to inaccuracies due to manual fabrication. The measured −10 dB impedance bandwidth of the proposed antenna is 400 MHz (from 9.9 GHz to 10.3 GHz) and 600 MHz (from 9.7 GHz to 10.3 GHz) for the antenna in free space and on body respectively. The bandwidth in the two instances are wider than the target bandwidth (10 GHz to10.125 GHz) and thus better than the simulated results. It can also be seen that the measured results of the bandwidth of the antenna on the body is wider than in free space. Fig. 11 shows a comparison of the S_{11} of the Copper antenna and that of the copper antenna. The measured and simulated antenna have almost similar reflection coefficient indicating that the fabricated brush painted Silver ink antenna works.

IV. CONCLUSION

An antenna integrated into a removable nail has been demonstrated. The initial prototype operates at 10 GHz aimed for future body centric wireless applications. Two inexpensive procedures have been used to develop. One uses copper tape while the other conductive silver paint. The fabricated antennas have shown satisfactory performance results in free space and on body. Both the simulated and measured results demonstrated good agreement with very small changes in antenna performance when the antenna was tested on the finger.

Hand brush painting as an AM technique has been proven to be a cheap solution for the fabrication of antenna integrated on a wearable device operating at 10 GHz. The advantage of the proposed fabrication technique is that no expensive equipment is required. Just a simple paintbrush is required. The antenna shape could be modified to meet new future requirements using a stencil. As a potential application, sensing and health monitoring parameters could be transferred wirelessly through the finger nail antenna. It could also be used for wireless storage and transmission of data as an alternative to current USB storage devices. Some of the electronics could be embedded in a multilayer artificial nail structure with the feeding realized through an aperture in the ground plane. With multiple fingers in one hand, antenna arrays and diversity becomes applicable. The proposed antenna could also find applications in electronics tagging and monitoring.

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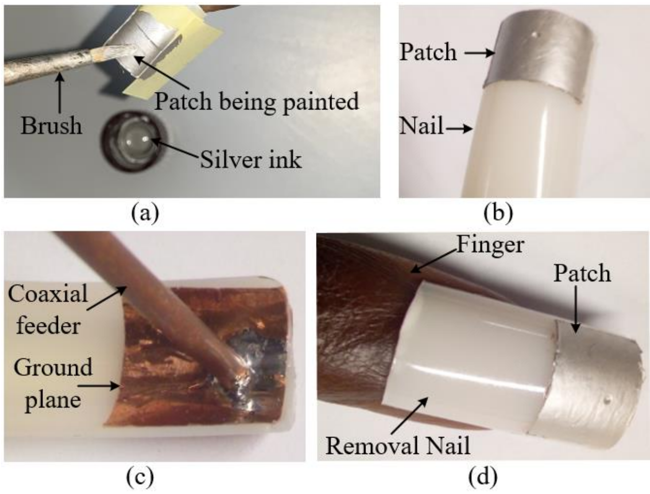

Fig. 9. The Silver ink patch fabrication process (b) the fabricated nail patch (c) its ground plane (d) antenna worn on the finger.

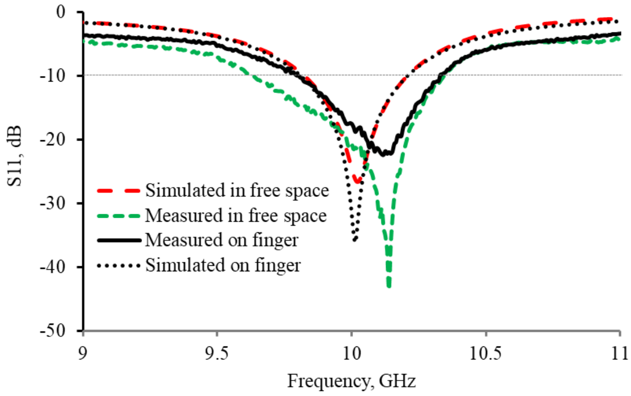

Fig. 10. Comparison of measured and simulated antenna reflection coefficient (S_{11}) of the silver ink antenna.

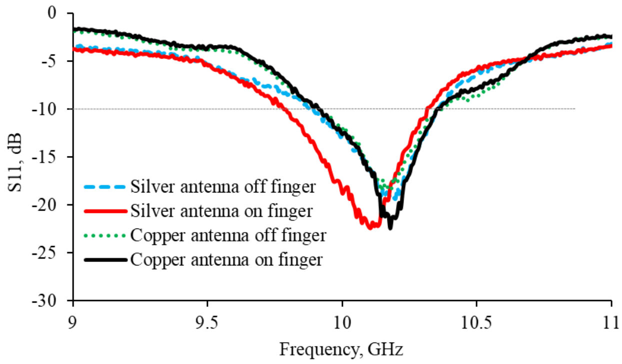

Fig. 11. Comparison of the silver vs copper patch antenna reflection coefficient (S_{11})

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