Liquid Metal Based Antenna for Wearable Electronic

A. Vorobyov[1], C. Henemann[1], Ph. Dallemagne[1]
[1]CSEM (Center Suisse d'Electronique et de Microtechnique SA), Neuchâtel, Switzerland,
alexander.vorobyov@csem.ch

***Abstract*— In this paper, a liquid metal based antenna for wearable applications is presented. The proposed solution can be used as the basis for flexible and stretchable antennas. The concept has been prototyped in a loop antenna, using silicon tubing of a diameter of 1.5mm in diameter, in which Liquid Metal is injected. The antenna operational frequency has been initially tuned to 868 MHz, however the antenna can be easily tuned for 2.4GHz (ISM band), typically used by Bluetooth and WiFi.**

***Index Terms*—antenna, propagation, BAN, wearable, WiFi, flexible, stretchable.**

I. Introduction

Flexible electronics based on plastic flexible materials is a promising direction for many consumer applications from artificial skin, smart bandages and wearable electronics.

One of the most important and basic parts of any wireless communication or Body Area Network (BAN) system is the antenna. In the case of flexible wireless electronic solutions embedded in materials (e.g. sensing and communicating entities in wearables), the antenna and the channel must be viewed jointly. Flexible antenna or antenna system solutions must be closely co-designed and integrated with the devices embedded in the materials and with the materials and packaging.

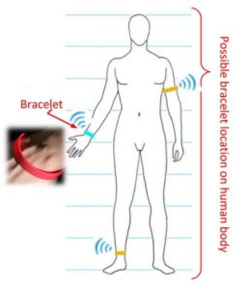
A variety of approaches have been proposed by several research groups to implement stretchable large area electronics [1]-[3], [4]-[9].

Most of them use planar or 3D meandered solid wires in combination with elastic materials to achieve a certain degree of stretchability. However, in these approaches, stretchability is restricted by the severe mechanical mismatch between the solid metals and elastic materials used to build the system.

Flexible or shape-changing antenna can be based on liquid metal (LM) (GALISTAN: Ga (68.5%), In (21.5%), Sn (10%), $\sigma=3.46\cdot10^6$ S/m). This type of antenna could lead to responsive electronic devices.

The first prototype is an unbalanced loop antenna operating at 2.4 GHz, which is demonstrated in [10]. The liquid metal is injected into the micro-structured channels via the through holes and the openings are then encapsulated with uncured polydimethylsiloxane (PDMS) mixture. A relative stretching of 40 % along two orthogonal orientations can be achieved without any damage. In [11], the Planar Inverted Cone Antenna (PICA) concept is implemented as a stretchable antenna in order to enhance the robustness of the antenna electrical performance while stretching. This antenna has a uniplanar configuration. This is makes it suitable for folding, stretching and twisting: It also simplifies the fabrication process.

In this paper we present a flexible loop antenna based on liquid metal. LM antenna is made of radiating structures created by fluidic metal alloys, which are injected into microfluidic channels built in flexible polymers. This type of antenna allows for tight physical co-design and integration with the wearable sensor devices, e.g. embedded in flexible resin based material. This is applicable to both the design of devices but also to the packaging and the sealing. The antenna fits particularly well a number of BAN applications including elastic bracelets with integrated sensors as presented in Fig.1.



LM based loop antenna +sensor solution:
- Inexpensive (easy to implement);
- Flexible (can conform many shapes);
- Stretchable (can follow deformations);
- Durable (almost unbreakable).

Fig. 1. LM based loop antenna integrated into the stretchable bracelet wearable sensor.

The proposed antenna was connected to a CSEM wireless sensor board (WiseNode) operating at 868MHz and it was tested in a realistic environment. The system was placed on an artificial, yet electromagnetically relevant human hand.

The concept of the LM based loop antenna is introduced in Section II. Then, in Section III, the antenna prototyping is discussed. The measurement setup and characterization results of the prototyped antenna are discussed in Section IV. Conclusions are drawn in Section V.

II. Antenna Concept

The antenna concept consists in silicon tubing and LM injected into the tubing as presented in Fig.2.

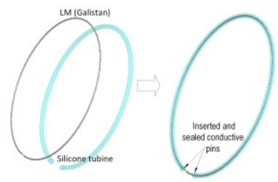
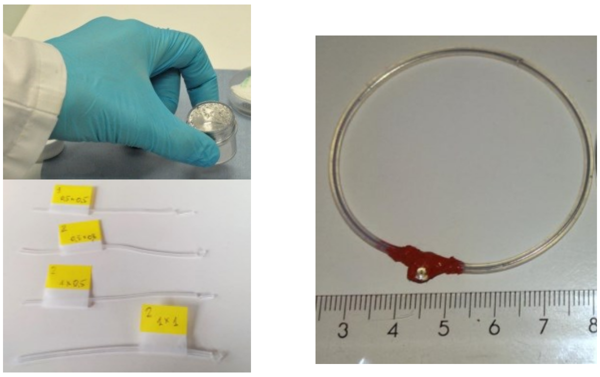


Fig. 2. LM based Loop antenna concept

The tubing ends are sealed to prevent the LM leakage. To safely seal the structure, two conductive pins of the proper diameter are inserted into the tubing ends, together with silicone based glue.

III. Antenna Prototyping

A flexible and stretchable loop antenna using the 1.5mm in diameter silicon tubing and Liquid Metal has been prototyped. It is shown in Fig.3.

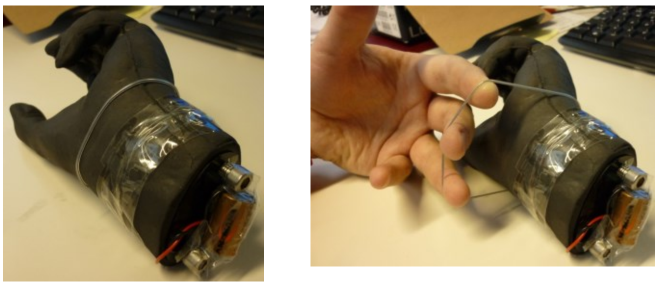


LM (Galistan) and silicone tubing — Ready and sealed LM loop antenna

Fig. 3. Realized LM based loop antenna.

After LM injection into the tubing, the tubing ends have been sealed with the incretion of conductive pins. The conductive pins were connected to a miniature µ.FL connector for the antenna testing performance. However, the antenna can be directly integrated with a device avoiding connectors.

Thanks to the physical properties of flexible polymers, the antenna exhibits excellent stretching endurance and elasticity, as shown on Fig.4, in which the antenna placed on the phantom hand wrist is widely stretched. The achieved antenna stretching during the manipulation was around 150%. The antenna stretching and its close location to the hand surface or a human body will affect the antenna resonance frequency. The resonance will be shifted to higher or lower frequencies. For the antenna resonance turning matching P-circuit or T-circuits can be used.



Tight to wrist — Stretched (150%) around the wrist

Fig. 4. LM based antenna stretching ability.

In this paper we did not apply any matching circuit for the antenna matching. The length of the antenna and hand diameter was just correct to archive desired operational frequency.

The antenna has been tuned to operate at 868 MHz. It is connected to a CSEM wireless sensor WiseNode through a short coaxial cable with two µ.FL connectors (Fig.5). The battery is located besides the WiseNode. This should prevent unwanted influence of the metallic battery casing on the antenna performance.

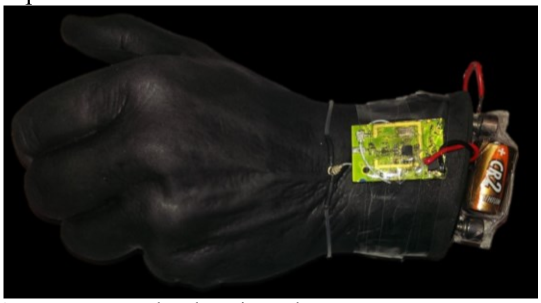


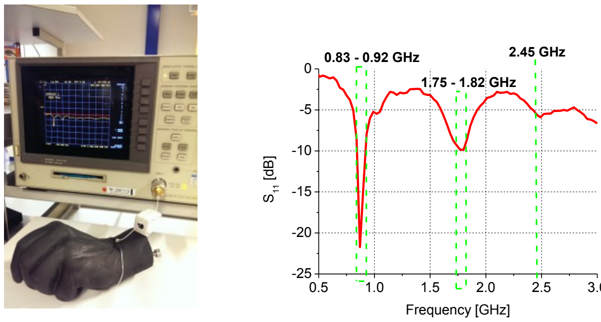
Fig. 5. Antenna connected to the WiseNode.

We should remember, that all additional metallic components and PCB placed closely to the antenna will influence on the antenna parameters (e.g. matching, radiation).

IV. Antenna Chracterisation

Two basic parameters are measured for characterising an antenna: antenna reflection coefficient and antenna radiation performance.

During the test, the antenna was connected to the VNA port, as shown in Fig.6a. All ports of the VNA were calibrated before the antenna measurements. A port is defined as the location where the antenna and the coaxial cable are connected. To prevent the influence from common mode current during the measurements, a ferrite coil has been used near the SMA connector which is attached to the Antenna Under Test (AUT).



a — b

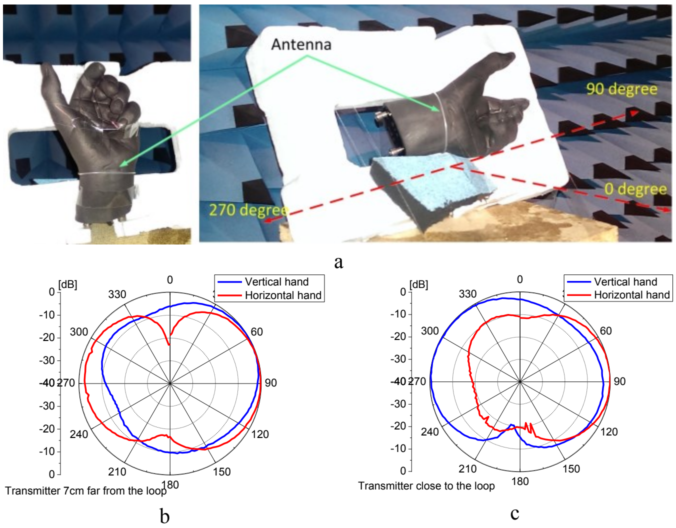
Fig. 6. Antenna S-parameter measurements

The antenna placed on the hand is well matched at the desired (868MHz) frequency (Fig.6b) and can potentially be tuned to operate at GSM (1.7GHz-1.9GHz) and ISM (2.45GHz) bands, typically used by Bluetooth and Wi-Fi.

The antenna radiation characteristics have been measured in the CSEM anechoic chamber. The antenna measurement setup is presented in Fig.7. The antenna has been measured in the vertical and horizontal positions. In addition, the antenna radiation patterns have been measured when the antenna is located close to the wireless sensor board and placed aside by

7 cm. Obviously, the sensor board placed close to the antenna (Fig.7c) affects the antenna radiation performance and changes the antenna radiation pattern. This should be taken into account during future antenna design and the sensor integration.

The antenna provides almost omnidirectional radiation (Fig.7b, c), which is an advantage for miniature wearable communication devices as shown in Fig.1.



Sensor at 7cm distance from the loop antenna (at 868MHz) | Sensor is close the loop antenna (at 868MHz)

Fig. 7. Antenna radiation pattern measurements

The measured antenna gain, when the antenna placed on the hand is around -5 dBi at maximum level. Low antenna gain can be explained by the attenuation provoked by the artificial human hand.

V. Conclusion

In this paper, a promising flexible loop antenna concept based on liquid metal is proposed. Simple prototyping, Easy integration, high flexibility, stretchability and reliability of the concept are key features of this antenna solution. The presented liquid metal based antenna concept can be used in many kinds of application, where physical stress and deformation on a device is high and conformance to various and changing shapes is required. For example, bending, twisting, stretching, washing, freezing (up to -19˚C) conditions are supported due to encapsulation inside flexible material. The resulting antenna is therefore a good candidate for integration into wearable wireless devices for sport or health monitoring and smart clothes solutions. The antenna is well matched at desired 868MHz and can be easily tuned to operate at some GSM and ISM bands. Combined with its almost omnidirectional antenna radiation pattern, this makes this antenna appropriate to many purposes and applications.

References

[1] D.-H. Kim, J.-H. Ahn, W. M. Choi, H.-S. Kim, T.-H. Kim, T.-H.Kim, J. Z. Song, Y. Y. Huang, Z. J. Liu, C. Lu, and J. A. Rogers, “Stretchable and foldable silicon integrated circuits”, Science, vol.320, no. 5875, pp. 507–511, Apr. 2008.

[2] D. Kim, J. Z. Song, W. M. Choi, H. Kim, R. Kim, Z. J. Liu, Y. Y.Huang, K. Hwang, Y. Zhang, and J. A. Rogers, “Materials and non-coplanar mesh designs for integrated circuits with linear elastic responses to extreme mechanical deformations,” Proceedings of the National Academy of Sciences USA , vol. 105, no. 48, pp.18675–18680, Dec. 2008.

[3] J. Baca, J.-H. Ahn, Y. G. Sun, M. A. Meitl, E. Menard, H.-S. Kim,W. M. Choi, D.-H. Kim, Y. Huang, and J. A. Rogers, “Semicon-ductor wires and ribbons for high-performance flexible electronics,”Angewandte Chemie International Edition, vol. 47, no. 30, pp.170–188, Jul. 2008

[4] S. P. Lacour, J. Jones, S. Wagner, T. Li, and Z. G. Suo, “Stretch-able interconnects for elastic electronic surfaces,” Proceedings of the IEEE, vol. 93, pp. 1459–1467, Aug. 2005.

[5] S. P. Lacour, C. Tsay, and S. Wagner, “An elastically stretchable TFT circuit,” IEEE Electron Device Letters, vol. 25, pp. 792–794, Dec. 2004.

[6] S. P. Lacour, J. Jones, Z. Suo, and S.Wagner, “Design and per-formance of thin metal film interconnects for skin-like electroniccircuits,” IEEE Electron Device Letters, vol. 25, pp. 179–181, Apr.2004.

[7] D. Brosteaux, F. Axisa, M. Gonzalez, and J. Vanfleteren, “Designand fabrication of elastic interconnections for stretchable electroniccircuits,” IEEE Electron Device Letters, vol. 28, pp. 552–554, Jul.2007.

[8] B. Huyghe, H. Rogier, J. Vanfleteren, and F. Axisa, “Design andmanufacturing of stretchable high-frequency interconnects,” IEEE Transactions on Advanced Packaging , vol. 31, no. 4, pp. 802–808, Nov. 2008.

[9] Y. N. Xia and G. M. Whitesides, “Soft lithography,” Annual Re-view of Materials Science, vol. 28, pp. 153–184, 1998.

[10] C. Shi, R. Anders, H. Klas, W. Zhigang,” Liquid metal stretchable unbalanced loop antenna,” Applied Physics Letters, Volume: 94 Issue: 14 Page(s): 144103 - 144103-3.

[11] Shi Cheng, Zhigang Wu, Anders Rydberg, „Foldable and Stretchable Liquid Metal Planar Inverted Cone Antenna“, IEEE Transactions on antennas and propagation, vol. 57, no. 12, December 2009.