Folded Loop Antenna as a Promissing Solution for a Cochlear Implant

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***Abstract*— In this paper a promising antenna solution for a cochlear implant is presented. Proposed solution is based on folded loop antenna. The antenna and proper matching circuit is leading to increase the antenna operational bandwidth as well as radiation efficiency. The loop antenna and proper matching circuit are co-integrated with a magnet and a coupling loop for wireless powering sealed in a silicone protective shell were prototyped and characterised. Proposed antenna solution demonstrated better performance in comparison with a circular loop.**

***Index Terms*—antenna, propagation, measurement. implant, cochlear**

I. Introduction

In the past years different implantable sensors and medical devices have been receiving considerable attention. In general all these implantable sensors and medical devices can be divided by application into three groups: diagnostic, information transmission / receiving and treatment. One of these implantable devices classified for treatment is a cochlear implant (Fig.1). This medical device is electrically stimulating the auditory nerve and thus regaining hearing to deaf people [1].

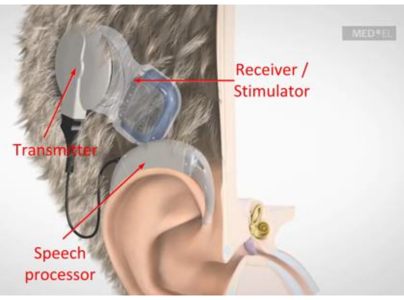


Fig. 1. Ear with cochlear implant drawing (picture is taken from MEDEL source [1])

The antenna is one of the important part of an implantable device. Fundamental limitations are restricting radiation efficiency, bandwidth and physical size of electrically small antennas. Poor bandwidth performance makes small antennas very sensitive to the environment, solved at the expense of efficiency, communication range and link budget.

For miniaturized antennas, the challenging adaptive antenna impedance matching, consisting of a reconfigurable matching network, is considered. Two separate parts can be identified in adaptive antenna systems: impedance detector block [2], [3] and tunable antenna. Tunable antenna structures are currently studied intensively and presented in the literature [4], [5], yet not as fully integrated blocks [6].

Several antenna-on-chip solutions have previously been introduced, above 5GHz [7]. Also, antenna-in-package uses LTCC [8] or plastic cover [9] and reaches as low frequencies as 2.45GHz, depending on package size.

In this paper we are going to present a promising implantable antenna solution for a cochlear implant (receiver part). Proposed antenna will be co-designed with cochlear implant parts like a magnet and a coupling loop for wireless powering and sealed in a silicone protective casing as a real implant. To increase the operational bandwidth as well as radiation efficiency, a proper matching circuit is proposed.

The concept of the cochlear implant antenna is introduced in Section II. Then, in Section III, the antenna theoretical performance and matching circuit are discussed. The measurement setup and characterization results of prototyped antennas are discussed in Section IV. Conclusions are drawn in Section V.

II. Cochlear implant antenna concept

The initial topology of the cochlear implant antenna comprises a basic circular loop antenna. The loop is made of a stranded gold wire and the whole structure is emerged in a cylindrical shape silicone casing. The loop antenna diameter corresponds to the original implantable device geometrical parameters. The main performance parameters were simulated for a loop antenna in a generic configuration are presented in Table 1.

TABLE I. Performance parameters of a loop antenna

Parameters	***Comments***	***Values***	***Units***
Dimensions	Initial loop + casing	38x38x2.2	mm
Frequency range	S_{11} at -10 dB level	2.37–2.58	GHz
Instantaneous BW	At 10dB return loss level	210	MHz
Input impedance	At 2.45 GHz, normalized to 50Ω	1.27-0.31j	
VSWR	For the freq. range 2.4–2.5 GHz	≤ 1.75	
Efficiency	Realized gain	-0.1	dBi

If a circular loop antenna is integrated in the existing cochlear implant the radiation properties will be obstructed by the inductive coupling loop and the fixation magnet (see Fig.1 left). The placement of these components decreases the intensity of the magnetic field passing through the loop. Consequently the radiation resistance is decreased. The radiation and loss resistances of an antenna determine the overall radiation efficiency. The loss resistance of a single-turn small loop is generally much larger than its radiation resistance. Thus the radiation efficiency is normally very low. To increase the radiation efficiency, a folded loop antenna is proposed (Fig.1 right).

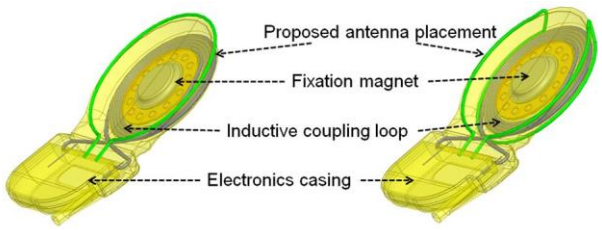


Fig. 2. Topology of the integrated loop antenna: circular loop antenna (left), folded loop antenna (right)

III. THEORETICAL ANTENNA PERFORMANCE AND MATCHING CIRCUIT

A theoretical loop antenna model immersed into a slab of silicone has been simulated with golden wires having radii of 300 um and 90 um (black and blue curves in Fig.3). The initial antenna structure with the wire diameter of 300 um is perfectly matched to 50 Ω. The loop antenna is supposed to be co-integrated with a receiver (see Fig.1), where a magnet and inductive coil are closely located to the loop antenna (Fig.2). When a metal object is inserted inside the loop, the resonance frequency is considerably detuned and shifted to a higher frequency. The red curve in Fig. 3 presents S_{11} for the loop antenna where the volume of the fixation magnet is filled with metal. The green curve presents the same loop antenna with the inductive magnet and coupling loop simulated as solid metal objects.

To get a larger bandwidth and to realize a large impedance ratio, more than two matching components are needed in the matching network. The *pi* arrangement of lumped elements, shown in Fig.4, is proposed for the loop antenna matching.

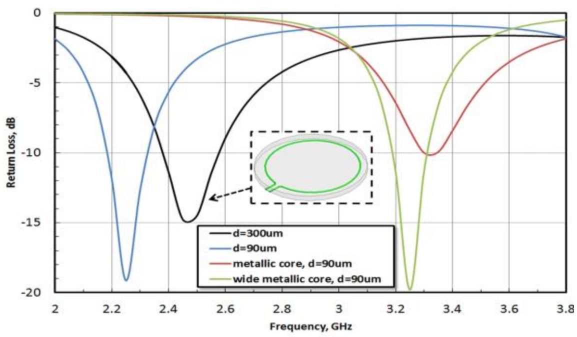


Fig. 3. Simulated performance characteristics for the integrated loop antenna

In matching a small loop antenna, it is important to remember that the series matching inductor must have a tiny series resistance. Table II summarizes the component values for the matching network depicted in Fig.4.

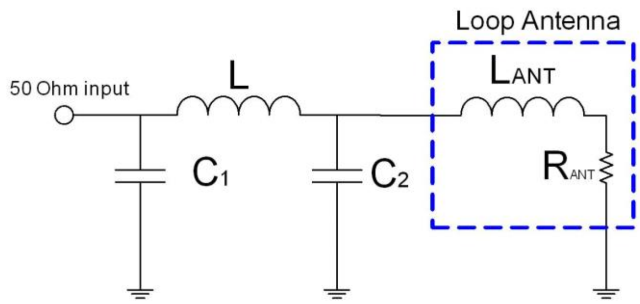


Fig. 4. Proposed lowpass PI matching network

TABLE II. MATCHING COMPONENT VALUES IN DIFFERENT LOOP ANTENNA CONFIGURATIONS

Antenna configuration (90 um wire diameter)	***L, nH***	***C1, pF***	***C2, pF***
No metal inside the loop	4.3	2.5	1.65
Magnet volume is metallic	12	4	0.23
Magnet and coupling loop are metallic	12	3.5	0.26

IV. ANTENNA CHARACTERISATION

Two loop antennas with a proper matching circuit were prototyped and characterised. These are circular loop and folded loop. Loop antenna with attached matching circuit board photos are presented in Fig.5. Prototyped loop antennas are immersed into a slab of silicone with closely located magnet and inductive coupling loop (Fig.2).

A. Antennain real environment S-parameter measurement

Reflection coefficients of the antennas (Fig.5) were measured using a vector network analyzer (Agilent 8720).

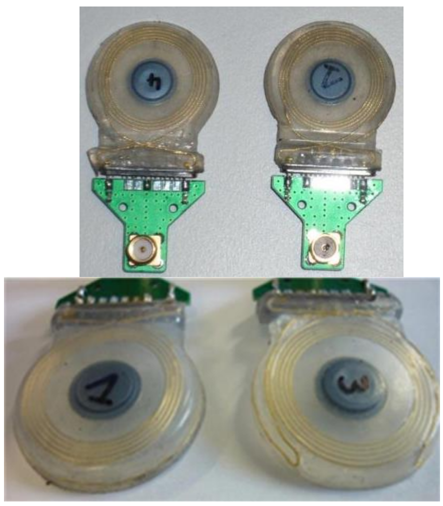
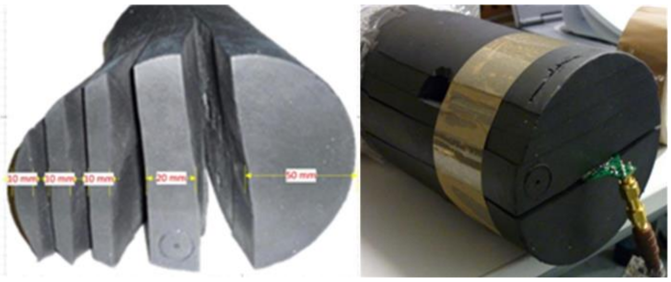


Fig. 5. Loop antennas in the silicone shell with matching circuit photos: circular loop antenna sample (left) and folded loop (right).

The tissue (Fig.6) is a special narrow band solid gel recreating environment of head (brain, bones, etc.). It is coming from SPEAG (reference number is MSL2450V2). This gel is compliant to the following standards: CELENEC EN 50361 / IEEE Std 1528-2003 / IEC 62209/CD / FCC OET Supplement C.



a b

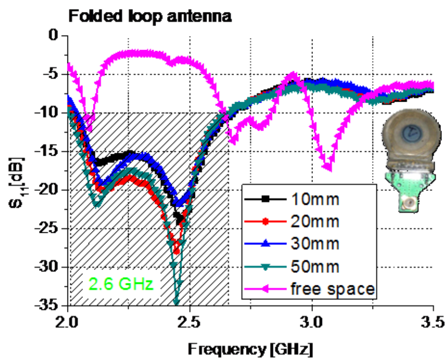
Fig. 6. Body tissue material prepared for antenna S-parameter measurements (a), antenna inside the material (b).

The form factor of the artificial tissue is cylinder with dimensions 100×200mm^2 (diameter × height). A parallel cutting along cylinder height has been made. Cut layers thickness are 10mm, 10mm, 10mm, 20mm and 50mm. Received layers imitate penetration of the antenna inside the tissue as shown in Fig.6a. Antenna under test placed inside the tissue, tightly fixed between tissue layers is presented in Fig. 6b. Four antenna positions inside the tissue have been validated from 10mm to 50mm penetration. Measurement results of antennas in free space and inserted into artificial tissue are presented in Fig.7.

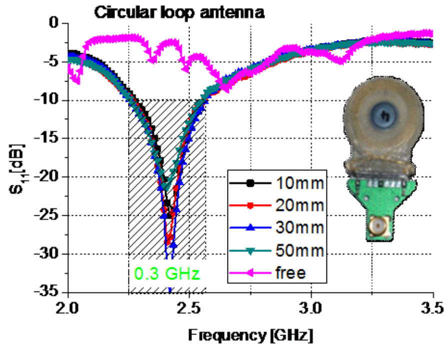
All measured antennas inserted into the tissue demonstrate a good matching at desired ISM band (2.45GHz). As expected measured antennas are not match at 2.45 GHz in free space scenario.

Despite a more complex design, the folded loop antenna is matched over a larger frequency band (2 GHz-2.6 GHz; BW=1.6GHz) in comparison with the classical shape circular loop antenna (BW=0.3GHz).

As seen in Fig.7, different antenna penetration into the tissue does not change much antenna S-parameter. But different antenna location inside the tissue will influence the antenna radiation performance.



a



b

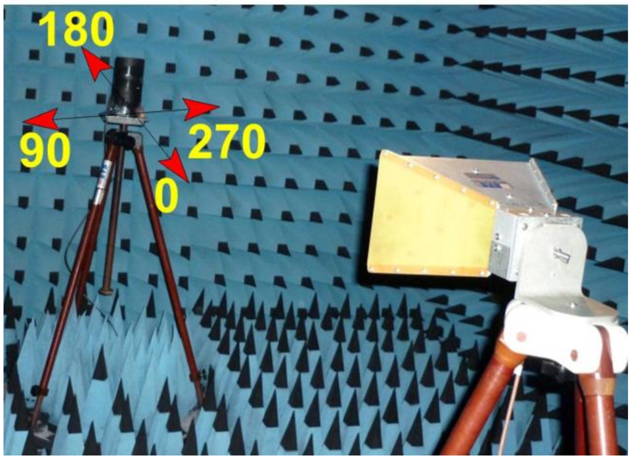
Fig. 7. Antenna S-parameter dependence from penetration into the tissue: folded loop (a) and circular shape loop (b).

B. *Inplanted antenna radiation performance*

Antennas radiation pattern were measured at CSEM anechoic chamber. We characterized two antennas:

- Folded shape loop antenna
- Classical circular shape loop antenna.

Measurement setups can be seen in Fig.8. Antenna is inserted into the body tissue material and fixed to the tripod post mount. The antenna feeding coaxial wire is passed through the cylinder tissue.



a

b c

Fig. 8. Antenna measurements in anechoic chamber (a), close up view of the antenna inserted into the tissue (b) and antenna location inside the tissue (c).

Inserted into the artificial tissue, the antenna is located in the middle of the tissue cylinder and tightly fixed as shown in Fig.8b. Antenna was placed at 10mm, 20mm, 30mm and 50mm inside the cylinder tissue (Fig.8 b). Antenna radiation pattern for 10mm antenna penetration into the tissue case is presented in Fig. 9.

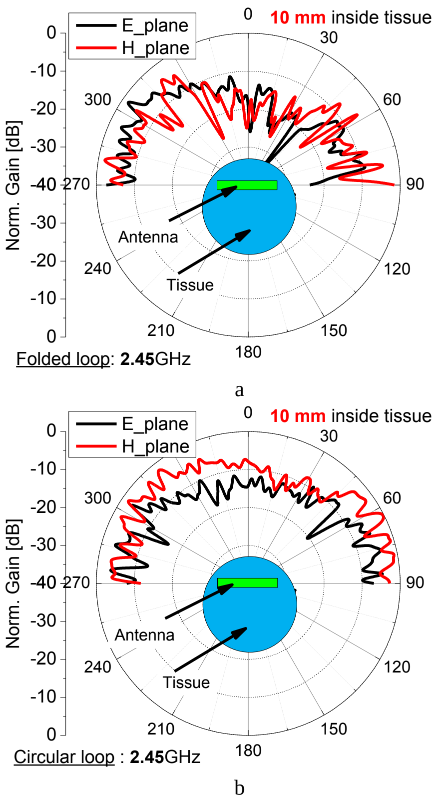


Fig. 9. Measured antenna radiation pattern at 2.45 GHz

By placing antenna deeply inside the tissue, from 10mm to 50mm the propagation loss increases (from 5dB to 20dB). This can be also explained by high attenuation inside the tissue. Measured antenna radiation pattern has multiple ripples which can be also explained by insufficient angle resolution (3 degree step used during the measurements). In case of antenna in the tissue, maximum antenna radiation is observed, when the antenna aperture is perpendicular to the reference antenna.

V. Conclusion

In this paper a folded loop antenna is proposed as a promising solution for cochlear implant devises. The loss resistance of a single-turn small circular loop is generally much larger than its radiation resistance. Thus the radiation efficiency is normally very low. To increase the radiation efficiency, a folded loop antenna is proposed. The folded loop antenna was optimised for co-integration with a magnet and a coupling loop sealed in a silicone protective shell.

To get a larger bandwidth and to realize a large impedance ratio the pi arrangement of lumped elements was proposed for impedance matching.

Two antennas with matching circuits were prototyped and characterised. Despite a more complex design, folded loop antenna is matched over lager frequency band in comparison with the classical shape circular loop antenna.

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