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Development and evaluation of a silicone-based ferrite cover to optimize the transmission-characteristics of telemetric interfaces for active medical Implants

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Abstract: *A composite material composed of manganese-zinc-ferrite and medical silicone is developed. Its shaping is fitted to the geometry at the secondary side of a telemetric interface for an active medical implant. The composite material provides the suppression of unwanted eddy currents, and enables an efficient inductive power supply of the implant. It becomes apparent that the composite material exhibits excellent electromagnetic properties, even better than those of the commercially available alternatives.*

Keywords: *ferrite, silicone, eddy current, inductive power supply, implant*

Introduction

The power supply of energy-intensive, active medical implants cannot be provided reasonable by energy storages, such as batteries. Most of all inductive telemetric interfaces suit to provide the power supply of these implants efficiently. They are composed of two coils; a primary coil outside of the body and the secondary coil in close proximity to the implant inside the body. The primary coil emits an alternating magnetic field that induces current within the secondary coil [1]. Encapsulations of ferromagnetic metals have been proven as hermetic sealings for the electronics of active medical implants. The alternating magnetic field induces currents not only into the secondary coil, but also unwanted eddy currents into the ferromagnetic metal housing. These eddy currents generate other magnetic fields that oppose the original field. As a consequence; the transmission efficiency can decrease dramatically. In addition the metal housing is heated by the ohmic losses caused by the eddy currents [1].

Using manganese-zinc-ferrite (MnZn-ferrite) shall solve the problems of the inductive power supply. Due to its high magnetic permeability and its low specific resistivity, this material is suitable for influencing the extent of magnetic fields [2]. Medical silicone was functionalised with ferrite powder, forming a solid but flexible composite material in order to fit to the geometry of the secondary coil and the encapsulation. The aim was to improve the efficiency of the energy transmission for intelligent implants by influencing the electromagnetic characteristics by a ferrite-cover.
The development of the composite material of MnZn-ferrite and medical silicone, as well as the manufacturing of the ferrite-covers and the evaluation take place under use of the components of an existing telemetric interface [4].

Methods

Since the shielding ability of the silicone-based ferrite-cover increases with an increasing share of ferrite powder [3], the degree of filling (weight ratio of ferrite powder to medical silicone) should be maximised.
MnZn-ferrite powder with two different average grain sizes of 30 µm and 8 µm were applied. Also two different medical silicones are used; a 2 RTV silicone (MED6015, Nusil) and a 2 RTV silicone gel (MED6370, Nusil). Both possess a very low dynamic viscosity for medical silicones but they differ by approx. factor 10. The use of these silicones should result in a higher maximum degree of filling. In the non-cured state, the silicone components are pourable. The more ferrite powder is added to the silicone the worse is the spreadability and processability of the composite material due to a higher dynamic viscosity. For the molding a two-part negative form that works with pressure was designed and fabricated using 3D printing technology. Within the forms the coil is centered and fixed by a lug. As a result the composite material covers the coil at its edge and bottom side after the curing process.
The transmission efficiency can be quantified by means of the resonant circuit Q factor. Therefore, the inductance and the loss of resistance are determined for the silicone-based ferrite-cover as well as for commercially available reference material: ferrite foil (F 96, Keratherm), sintered ferrite plate (BFM8, Blinzinger Elektronik).
The frequency-dependent Q factor can be calculated by using Eq. 1 (*f*: frequency, *L:* inductance, *R:* resistance),

$$Q = 2 \cdot \pi \cdot f \cdot \frac{L}{R} \qquad (1)$$

A higher quality means a lower attenuation of the system and thus a more efficient power supply. Measurements were performed at five frequencies: 34 kHz, 125 kHz, 6.75 MHz, 8 MHz, and 13.5 MHz.
The energy loss, evoked by eddy currents, was evaluated by the interaction of the magnetic field of a primary coil with a ferromagnetic metal housing (1”x1” gold plated NiCo flatpack, HCC industries). In front of the housing different ferrite materials (ferrite composite and reference

material) were placed without a secondary coil. The primary coil operated at 125 kHz as a parallel resonant circuit at resonance. The indicators for energy loss were the variation of temperature at the housing and the variation of primary coil's input current (at constant input voltage) in dependency of the used ferrite material.

Table 1: Q factor at different frequencies with ferromagnetic encapsulation

Frequency	Secondary coil without ferrite	Sintered ferrite	Ferrite foil	10:1-ferrite cover	12:1-ferrite cover	14:1-ferrite cover without edging	14:1-ferrite cover
34 kHz	1,192	1,562	1,381	1,382	1,398	1,386	1,419
125 kHz	1,962	5,513	4,567	4,320	4,464	4,541	4,631
6.75 MHz	7,411	44,496	42,676	42,509	43,444	45,572	45,735
8 MHz	8,425	43,464	43,423	43,749	44,525	46,981	47,061
13.5 MHz	12,332	32,716	43,414	43,650	43,940	48,479	46,907

Results

A ferrite composite material was developed with a maximum filling degree of 14:1 (ferrite : silicone). This high ratio could be reached by mixing different silicones and by using MnZn-ferrite powder with an average grain size of 8 µm. Lower degrees of filling of 12:1 and 10:1 leads to a better processability. 30 µm ferrite powder can only be processed below a degree of filling of 10:1. Commercially available ferrite-foil and sintered ferrite, corresponding in their width and length to the silicone-based ferrite cover, were used as reference material. Since these are planar structures, the sideway surrounding of the coil was removed for the 14:1 ferrite covers to achieve a better comparability.

As is apparent from Tab. 1 the 14:1 ferrite cover without edging provides the absolute highest Q factor at a frequency of 13.5 MHz. At the three highest frequencies of 6.75 MHz, 8 MHz and 13.5 MHz the 14:1 ferrite-covers generate the highest Q factors which are greater by a maximum factor of 6.17 than in the case of the initial situation (secondary coil without ferrite). The sintered ferrite generates the highest Q factor at 34 kHz and 125 kHz.

The measurement of the temperature variations on the metal housing as an indicator of energy losses caused by eddy currents showed no significant values ($\Delta T<1$ K). The input current of the coil as another indicator is largest (most losses) while using sintered ferrite and smallest (fewest losses) while using 14:1 ferrite composite cover.

Figure 1 illustrates the ferrite cover that contains the coil in its final position on top of the encapsulation.

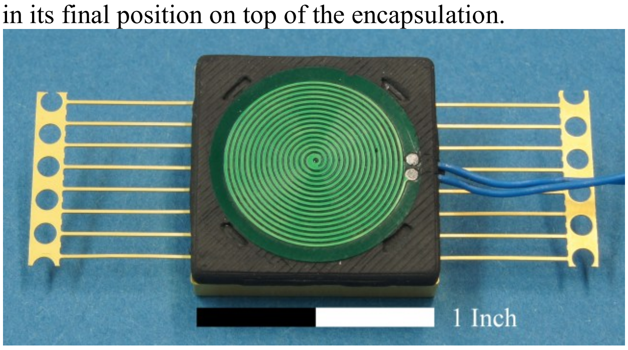

Figure 1: Ferrite cover containing coil on top of the ferromagnetic metal housing

Discussion

The measured values of the Q factor clearly show that in three of five frequencies, the power supply is most efficient in case the secondary coil is placed into a 14:1 ferrite composite. The developed material also provides the most efficient eddy current suppression in the investigated frequency range in comparison to commercially available ferrite-foil and sintered ferrite plate. Furthermore the composite material can be shaped in any geometry by the described manufacturing method. The composite material can be used not only to influence magnetic fields in telemetric interfaces, but also in every application that prohibits induced eddy currents caused by magnetic fields within the investigated frequency range.

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