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研究課題名（和文）New metamaterial for efficient and compact WPT system for biological applications

研究課題名（英文）New metamaterial for efficient and compact WPT system for biological applications

研究代表者

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研究成果の概要（和文）：本研究の目的は、メタマテリアル支援された無線給電システムを実装する。それでは、低損失マルチリング共振器を導入し、低磁性損失メタマテリアルを提案しました。実装した設計は、受信器を鶏の胸肉の内側に9 mmの深さで取り付けた場合、伝送効率が５１%を達成しました。それに、受信機の大きさは、最新投稿された最小の受信器に比較して５０%でした。そして、受信器の裏側を付いたマッチング回路無し整流器を提案し、総合効率を４０%達成しました。さらに、実装システムは、IEEEによる定義された国際標準化された電力制限内で動作します。

研究成果の学術的意義や社会的意義
本研究では、小型の埋め込みセンサーを動作するために、高効率無線給電システムを実現できるように、低損失の新型メタマテリアルを提案する。 このメタマテリアル支援された無線給電システムは、高性能をだけでなく、悪電磁影響の国際標準制限内で鶏組織内での使用の適用可能性を証明しました。このようなシステムは、次世代の生体インプラント及びセンサーの使用しやすいに向け、社会の大きな関心となっています。将来にてこの技術は慢性疾患患者ばかりかお年寄りの生活にも役立つと思っております。

研究成果の概要（英文）：This research's objective was to implement a metamaterial-assisted wireless power transfer (WPT) system. A low magnetic loss metamaterial was proposed by introducing a multi-ring resonator that has a low magnetic loss. The implemented design achieved a measured RF-RF WPT efficiency of more than 51% when the receiver (RX) was mounted inside the chicken breast at 9 mm depth. The size of the RX was 50% smaller than the most compact design reported in the literature.
A rectifier without any additional matching circuit on the RX substrate's back side was proposed, achieving an overall RF-dc efficiency of 40%. Moreover, this system works within the international standardized power limits defined by the IEEE.
The work has been published in well-established journals as well as recognized international conferences, including the world's leading international microwave symposium.

研究分野：電気電子工学

キーワード：metamaterial　wireless power supply　low magnetic loss　rectifier　メタマテリアル　無線給電システム　低損失　整流器

１．研究開始当初の背景

The aging society and the spread of chronic diseases require new technologies to promote health care. Using sensors for health monitoring is one solution for such a purpose. However, in-body sensors require a source of power where cables cannot be imagined as the source of this power. Another solution is using batteries, which have several limitations, including the need for replacement and the danger associated with their chemical composition that poses several threats to the body in case of leakage. Instead, this work proposes wireless power transfer (WPT) technology to deliver the power wirelessly to the implanted sensor. This leads to several advantages, including the compactness of the implant and the elimination of the need for any auxiliary surgery to replace the implant. Also, this contributes to the relaxation of the economic burden on the patient by avoiding multiple surgeries and reducing governmental spending on health insurance.

Metamaterial, an electromagnetically engineered material, can alter the propagation features of the fields by designing their negative or near-zero permeability or permittivity. In the case of WPT systems, metamaterial-based ones suffer from reduced efficiency when used to charge biomedical implants due to the reduced quality (Q) factor of inductors by the human body introduced dielectric/conduction losses. In this work, we proposed a low-loss magnetic metamaterial to improve WPT system performance.

２．研究の目的

This project aims to realize a metamaterial-assisted wireless power transfer (WPT) system with a high-efficiency and compact receiver. The proposed metamaterial is stacked in a three-dimensional configuration and is attached to the WPT transmitter (TX), forming a novel meta-TX. To achieve low magnetic loss, each cell of this metamaterial is formed from a multiple-ring resonator for the first time. The implemented WPT system is also safe when used in biological tissue and is expected to eliminate the use of batteries for on-body sensor applications.

３．研究の方法

1) A new metamaterial unit cell using a multi-ring resonator (MRR) was proposed and studied to confirm its permeability (μ) performance. It has been proved that the proposed MRR-based unit cell has near zero properties (real(μz) <1 and Imaginary(μz) ≈ 0).
2) The MRR unit cell is used in a stacked configuration as the WPT transmitter, which feeds power to a receiver placed 9 mm deep into the chicken breast to emulate the body.
3) Finally, a novel rectifier was proposed without an additional matching circuit by employing the enhanced coupling characteristics resulting from the proposed metamaterial.

4．研究成果

An MRR metamaterial-based WPT system was proposed and implemented, as shown in Fig. 1. When compared with a split-ring resonator (SRR), a 50 MHz WPT system employing an MRR resonator metamaterial achieves a better efficiency performance, as shown in Fig. 2 whatever the size of the receiver.

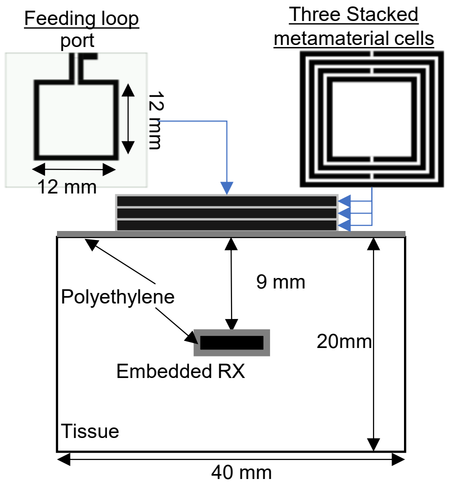

Fig. 1. Configuration of the MRR metamaterial-based WPT system with the receiver embedded into the tissue.

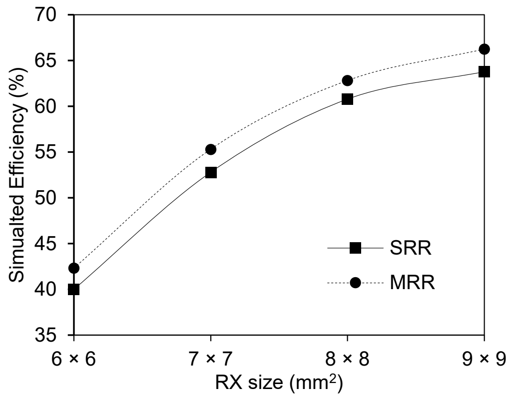

Fig. 2. Electromagnetic Simulated efficiency performance compassion of WPT systems using SRR and MRR metamaterial.

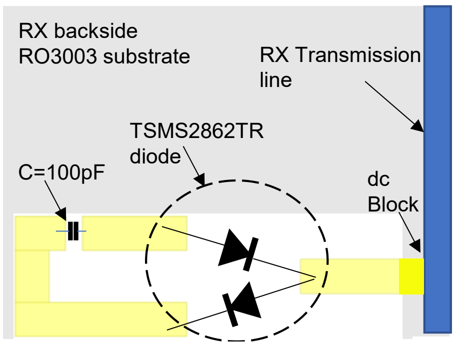

Fig. 3 The WPT receiver's backside when the rectifier is attached.

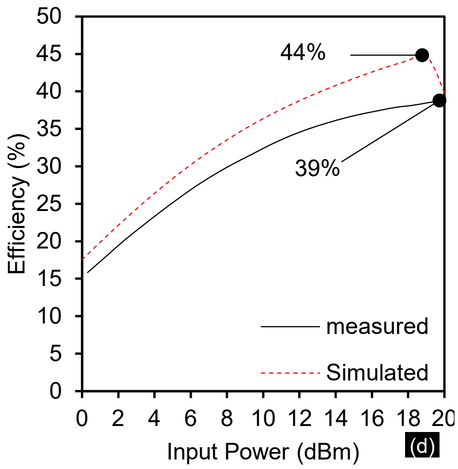

Fig. 4. Overall RF-dc efficiency of the system when the input power varies.

In addition, to regulate the RF power into a usable dc, a voltage doubler rectifier is integrated on the back side of the receiver substrate without any additional matching circuit, as shown in Fig. 3. This added to the miniaturization of the receiver as its overall size was not altered. Finally, the system is fabricated and characterized where the overall efficiency achieved up to 41% when the receiver was embedded inside a chicken breast at a 9 mm distance. This WPT system operated within the internationally standardized specific absorption rate when the input power was ≤ 21 dBm.

５．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　1件／うち国際共著　1件／うちオープンアクセス　0件）

１．著者名 Jiang Xin、Pokharel Ramesh K.、Barakat Adel、Yoshitomi Kuniaki	４．巻 71
２．論文標題 Hybrid SRR-Based Stacked Metamaterial for Miniaturized Dual-Band Wireless Power Transfer System	５．発行年 2023年
３．雑誌名 IEEE Transactions on Antennas and Propagation	６．最初と最後の頁 5014～5025
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/TAP.2023.3262977	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

〔学会発表〕　計6件（うち招待講演　2件／うち国際学会　4件）

１．発表者名 Shimaa Alshhawy, Adel Barakat, Ramesh Pokharel, Kuniaki Yoshitomi
２．発表標題 Design methodology of compact and high efficiency metamaterial-assisted WPT system through biological tissues
３．学会等名 IEICE Tech. Rep. MW2021
４．発表年 2021年

１．発表者名 Xin Jiang, Fairus Tahar, Ramesh K. Pokharel, Adel Barakat, Kuniaki Yoshitomi
２．発表標題 Six-Layers Stacked Wideband Metasurface for Compact Dual-band Wireless Power Transfer System
３．学会等名 IEICE Tech. Rep. MW2021
４．発表年 2021年

１．発表者名 Shimaa Alshhawy, Adel Barakat, Ramesh Pokharel, Kuniaki Yoshitomi
２．発表標題 Low Magnetic Loss Metamaterial Based Miniaturized WPT System for Biomedical Implants
３．学会等名 2022 International Microwave Symposium（国際学会）
４．発表年 2022年

1．発表者名 Xin Jiang, Adel Barakat, Kuniaki Yoshitomi, Ramesh Pokharel
2．発表標題 Wideband Stacked Metamaterial for a Compact and Efficient Dual-band Wireless Power Transfer
3．学会等名 2022 International Microwave Symposium（国際学会）
4．発表年 2022年

1．発表者名 Ramesh Pokharel, Adel Barakat, Costas Sarris
2．発表標題 Metamaterial Inspired Geometries for Wireless Power Transfer to Biomedical Implants
3．学会等名 The 51st European Microwave Conference（招待講演）（国際学会）
4．発表年 2022年

1．発表者名 Adel Barakat
2．発表標題 Stacked Metamaterial Based Wireless Power Transfer System for Biomedical Implant Applications
3．学会等名 International Japan-Africa Conference on Elctronics, Communications, and Computations (JAC_ECC 2022)（招待講演）（国際学会）
4．発表年 2022年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関