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A critical review of techniques in power and data transmission for implantable EMG

Eduardo F. A. Braga, Daniel P. Campos

***Abstract*—This paper presents a systematic and critical review about applications involving implantable electromyography in the last fifteen years. For the survey of these articles, several databases were investigated in order to provide a more variable consult. The more critical information was extracted and highlighted during this present study. This data have been used for the construction of a comparison table. The results of this table are used to make comparisons between the different approaches used and to identify the parameters and technologies which have demonstrated better results. These analyses and comparisons can be used to assist in the definition of new approaches to be developed.**

***Index Terms*—Electromyography, implantable medical devices, implantable EMG, wireless power transfer, inductive link.**

I. Introduction

Electromyography (EMG) is a technique to record biopotentials evoked by the depolarization of muscles and nerves. The transduter is a bipolar or monopolar electrode placed over the muscle of interest, which can be superficial (e.g. Ag/AgCl adhesive electrodes) or internal (e.g. needdles and wires) [1]. The recorded EMG signal is analyzed observing its characteristics, such as amplitude and frequency features [2], to correlate with physiological and kinesiological parameters of the individual [3].

When the goal is to look at a specific muscle fiber, it is recommended the use of internal electrodes [4]. The needle electrode is ideal to detect potentials in tissues with limited volume, however, the needle needs to be moved or removed and reinserted repeatedly in the muscles compartments to achieve a representative activity of the muscle unit [5]. For this reason, usually disposable superficial electrodes are used for its easy application [6]. Nevertheless, these type of transducer record a broader area [5], and the activity of non-related muscles is also recorded (cross-talk). This effect is particularly problematic when the muscle group is complex [3].

EMG is a technique that has many uses and applications. It can be used for clinical examinations and analysis, athlete monitoring, amputee rehabilitation training, among others [7]. However, in some application, the surface electrodes do not meet the accuracy requirements needed. Therefore, to have the precision of internal electrodes and long-term usability at the same time, implantable electrodes have been exploited in the recent literature. This paper proposes to highlight EMG applications in implantable devices, a continually expanding area that has been using different auxiliary techniques for this purpose.

Over the past fifteen years, for example, several EMG technologies with implantable devices have been developed. There is an extensive literature on subjects on the theme, from theoretical foundations and equations, coupling efficiency studies for several projects, to practical applications of the proposed technologies.

Then comes the proposal of this paper to present the approaches used in the last fifteen years in electromyography for implantable medical devices, to present comparatives of the various techniques, thus guiding the reader at the beginning of his research in this area. The present study also aims to identify which of these applications use inductive coupling wireless energy transmission techniques to power these devices, to optimize these techniques with the use of open bifilar coils.

This work presents various applications in this area of research, with the aim to compare the best technologies and methods already developed. This paper is organized as follows. Section II presents the literature review utilized for the research substantiation. Section III presents the methods used for research accomplishment. Section IV presents the results obtained for the literature review and drafts the essential pa-

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rameters for the analysis, and Section V brings the conclusion.

II. Literature Review

The papers analyzed in this research presents several parameters, approaches, technologies, and applications in electromyography for implantable devices. New approaches to this area are always being proposed and developed, as research of various technologies evolves, they can be used for this specific application, as can be seen from the work of [8], where the authors describe the design of a new resonant passive sensor for biotelemetric systems in general, and which could be easily applied to EMG.

There are several concepts to keep in mind when designing a wireless data and power transmission electromyography system, as shown in [9], where the authors present much of these concepts. They describe in a fundamental way what is electromyography and its importance, also present the fundamentals for implantable devices and protocols for wireless transmission. Still, on [9], an implantable EMG system is described, and its design presented.

A wireless power transfer (WPT) system with inductive coupling usually consists of two coils, which can be known as primary and secondary. The transmission of energy occurs when the primary source generates electric and magnetic fields, thus inducing a voltage in the receiver [10].

The WPT, it is known, was first conceived by Nikola Tesla in the early 20th century [11]. Based on Tesla's idea, several types of research have emerged over the years in this area, which is seen as promising because it has the potential to be applied in several research fields. This technique can be used for several applications, as can be seen in [12], [13], but it is worth highlighting its use for feeding implantable medical devices in recent years [14].

According to [15], the first record of WPT by inductive coupling is from the 60s. Where a system was introduced to feed an artificial heart. Since then, several applications with DMI have shown similar methods. In the 70s and 80s, it was already possible to notice an increase in the use of this technique as in [15].

Still, in the 70s and 80s, some authors used WPT by inductive coupling to transfer large levels of energy, as can be seen in [16]. This technique still has a lot of potential to be developed, mainly in biomedical applications.

New applications in this area are always being developed, especially since [17] wrote about the advantages of using inductive coupling at a defined resonance frequency, thus providing improvements in the power transmission process.

Something that made the use of WPT quite important is the issue of batteries, due to their construction limits, life span, and the fact that their replacement requires surgery for most implantable devices. On the other hand, with the use of WPT technology, they can be replaced [18], in which case they may even be on the external component of the WPT set.

In WPT systems by inductive coupling, power-transfer efficiency (PTE) is a strong function of the quality factor (Q) of the coils, as well as the coupling between them [19]. And as efficiency depends on several factors, such as size, physical space, structure and location, the coupling between the coils decreases with the increase in the distance between them [19].

The greatest efficiency can be achieved when both inductances (L_1 and L_2) and equivalent capacitances (C_1 and C_2) of the transmitter and receiver are tuned to the same operating frequency, thus adjusting the resonance frequency of each component of the set [12]. The sets at the same resonance frequency tend to have higher transmission efficiencies.

As the coupling between the coils depends on the amount of magnetic flux between the primary and secondary coils, increasing the dimensions of the external coil increases its inductance and, consequently, increases the coupling [19].

In recent years, there has been an increase in applications called multi-coils, with 3 or 4 coils [11]. However, in the case of multi-coil systems, a negative factor to take into account is the losses in the intermediate circuits [11], which can drastically reduce the efficiency of the set. But there are techniques to reduce these losses and optimize the transmission.

The capacitances between turns can even be very useful in the WPT [12], since they add to the total capacitance of the circuit, directly interfering in the self-resonance frequency of the circuit and depending on its geometry, even making it possible to eliminate the capacitor from the circuit, since it was only there to tune the frequency.

Currently, the focus of this research area can be considered as the miniaturization of implantable devices to reduce the complexity of surgical procedures and the risk of infections. Given this, the purpose of WPT is to provide the necessary power to the receiving circuit while minimizing the heating of human tissue during energy absorption. These topics are some of those responsible for moving this research to a new level, to maximize efficiency and optimize the resonance frequency, in addition to studies on different coil geometries, impedance matching, and the power delivery itself.

However, more than power transmission, this paper also assesses wireless data transmission, since both are essential for use in EMG devices. Most of the WPT concepts also apply to data transmission, so it is easy to relate one to another.

Among the most diverse techniques for implantable EMG, the work of [20] made a major contribution, where an inductive radiofrequency coupling was used to feed and transmit data between the external circuit and the implantable circuit. The energy transferred was sufficient to provide the 122 microwatts that the implantable system consumed.

Studies can also approach more fundamental questions about the subject, so that further research can leverage this information and optimize their developed techniques, as in the case of [21] where the authors describe studies on electrode placement and orientation in Implantable MyoElectric Sensors (IMES) systems.

In the literature, it is also possible to find works such as [22] and [23], where a primordial system is proposed and then over the years has been optimized and republished containing its additional results. In [24], an Implantable MyoElectric System for prosthetics for amputees was proposed and developed, and an experiment was performed and described with a volunteer. The system is powered by a magnetic field at a frequency of 121 kHz. The same work proposes the necessary

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improvements for the next version of the system. In the case of [25], an inductive radiofrequency coupling was used, where the resonance frequency used was 8 MHz. The external coil is 6 mm in diameter and the square implantable unit with sides of 2.2 mm. All of this is operating at a gap of 20 mm. For further validation, this system was tested on rats.

Some authors use separate links or technologies for power and data transmission. Other authors, however, use the same link to both, as can be seen in [26]. In [26], the authors used an inductive link for the transmission of energy and signals, where the communication and command protocol uses a frequency of 60 kHz in Band 1 and 6.8 MHz in Band 2. The power supply uses a frequency of 121 kHz. The experiments of this approach were performed on cats.

Other works that use inductive coupling for both transmissions are [27], but in this case, the tests were performed on monkeys. And in [28] where radio frequency coupling operating at frequencies between 6 and 7 MHz fed a system that was tested on a dog.

As an example of work with separate links for energy and information, it is vital to cite the research of [29], where an inductive link with coils for implantable circuit power was used and a radio link between two antennas designed for data transfer between the implantable and external circuits.

Other authors also performed animal tests to validate their designs, such as in [30], where experiments were performed on six dogs. This system used a 30 mm diameter telemetry coil and operated at a frequency of 6.78 MHz with a 50 mm gap. Approaches like this are of great interest in the progress of this research, which aims to take advantage of the information raised for future application design.

A more robust system is presented in [31], where an inductive coupling was used to feed the implantable circuit, where it was embedded in a silicon substrate, as it is a biocompatible material. The use of biocompatible materials in implantable systems is another matter of great importance in this area, and the authors describe this as being directly proportional to the advancement of electronic circuit technology, especially regarding the reduction of component dimensions. Still, on [31], the system was tested operating at a resonant frequency of 2 MHz and varying between distances of 30 to 50 mm. The implantable circuit consumed 140 mW, energy that was entirely provided by the wireless power. For data transmission, a loop antenna operating at a frequency of 8 MHz was used.

Some more recent work such as [32] describes an application with radiofrequency. In this case, 9-microsecond pulses and 915 MHz frequency were used to power the implantable circuit, while the data were transferred at a frequency of 457.5 MHz.

Another technology that has been widely found is the loop antenna, such as that used in [33]. A 20 X 8 mm flexible loop antenna was used in this paper, operating in the 402 to 406 MHz frequency range. The authors further argue that medical implants are widely used because of their compactness, so it is crucial to use implantable wireless devices, mainly powered by antennas.

However recent work has also used excellent transmission techniques through inductive coupling, as can be seen in [34] and [35]. In the first case, it was used to power a Multi-channel implantable EMG. In the second case, inductive couplings were used between the external and implantable circuits. Power was transferred through a resonant frequency of 13.56 MHz, and data was transferred over the 33 MHz frequency. The power coil was connected to a Class-E amplifier, and the implantable circuit was encapsulated in biocompatible silicon. The tests were performed at a distance of 5 mm.

III. Matherials and Methods

Since this review was proposed to conduct an introductory study on the topic and to survey what has been developed in recent years, there are additional details that are not presented there, such as the correct description of the techniques used in each approach. That is, this serves as the basis for facilitating and directing further consultation on approaches that interest the reader.

For the development of this review, exhaustive research was carried out in several databases, aiming at obtaining a survey of the papers related to the theme, published in journals and conference proceedings. This review was conducted using papers published over the last fifteen years, to present a more recent scenario on research in the area.

Among all the studies, only those that allow their real implementation in the biomedical area were selected, and their results were validated through experiments or simulations. Thus, the present work gains greater credibility by presenting only data already validated experimentally.

IV. Results and Discussion

The result of the critical review performed can be observed in the Table I, which reflects the essential data for analysis and comparison of the parameters related to the wireless transfer of the different techniques and approaches analyzed. It should also be noted that the most widely used technique for power transmission for implantable EMG devices in the last fifteen years has been radiofrequency, specifically in the works of [20], [25], [28], [30], [32]. For data transmission, the radiofrequency technique was also the most used.

Despite being a technique of little prominence in this specific application, the transfer of wireless energy by inductive coupling using coils deserves to be highlighted, as it has been steadily advancing in recent years. In the analyzed works, it was found in [27], [29], [31], [35], and operating in the most varied frequencies.

In [35] a frequency of 33 MHz was used for data transmission and 13.56 MHz for power transfer, the latter being a typical value for frequency in several surveys using the inductive link for wireless power transfer with coils. This technology has gained advances in different techniques for greater efficiency, such as multi-coil systems that instead of having two coils, they usually have three or four coils, as shown in Figure 1.

A similar technology but less developed is capacitive coupling wireless power transfer. That is, although it is also a technology with much potential, it is not much research, due to the interference that the electric field can cause to the human

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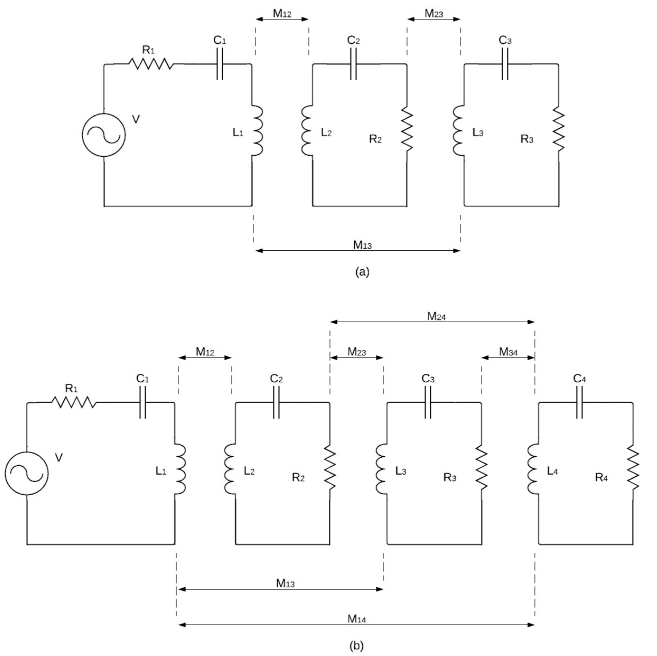

Fig. 1. Wireless power transfer system (a) with 3 coils (b) with 4 coils. The leftmost circuits are the primaries or the excitement. The rightmost circuits are connected to the load, represented by R3 or R4, respectively. The intermediate circuits are for coupling and energy transfer and must have minimum resistance values. (Modified from [36])

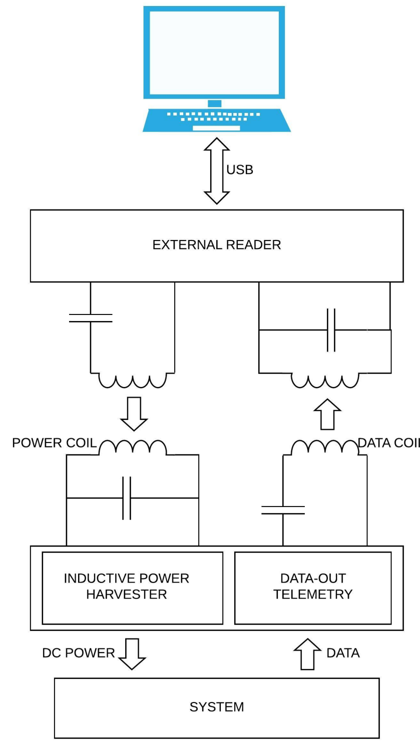

Fig. 2. Block diagram of a wireless system for an implantable medical device.

body. Even so, it is possible to find studies with it in the works of [26] and [24].

Examples of generic coil circuits can be seen in Figures 1 and 2. Where in the first one are inductively coupled power transmission circuits in 3 and 4-coil systems, and the second one is shown the circuit of the work of [35], which uses the same technology as the first image.

The results found are significant because they allow the use of the Table I to define which techniques are presenting the best results, and also present niches in techniques that can be optimized with the use of other electrical components.

The results obtained with this work shows that is extremely possible deliver power and receive data with various types of wireless links, including for applications with electromyography involved. The data obtained can be used as a basis for performing future work with various approaches. The analyzes performed should make it much easier to define essential points for new works. Besides, the literature review presents several different technologies, which, together with the results, may direct new authors to define and execute projects in ways that are more appropriate to the desired application.

V. Conclusion

In this review paper, as the objective of obtaining precise tools for comparison of parameters and results, a bibliographic survey of the works related to the theme published in the last fifteen years was presented. Several databases were used to identify potential work to be used in the review. The selected works had their data and main details extracted and presented objectively in Table I.

The results presented in the paper demonstrate not only the progress of the area in recent years but also guide further research on the approaches and technologies that have been presenting better results. These data are vital for the definition of new parameters and approaches to be implemented, enabling the readers to have a broader view of the current research landscape in this area, saving time and work of new researchers in this line of research. This way, it is possible to define some future ideas for data transfer and wireless applications for implantable EMG systems, as this is promising research that can be performed with the most varied technologies.

A future work idea, which is already under development, is the design of a wireless energy transfer system via open bifilar coils for feeding implantable devices in general and for implantable electromyography systems, based on the results obtained in this study to assist in choosing the best methods to adopt. This way of winding the coil has some advantages because it has a series of self-resonance, which generates more suitable parasitic capacities for the proposed applications, to build circuits without capacitors to reduce the size of the transmitter and, especially, receiver units. [37].

In fact, these results can be used as a foundation for many other applications, thus opening up a wide variety of possibilities for applying the data found.

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TABLE I
TECHNIQUES AND SPECIFICATIONS FOR IMPLANTABLE EMG

Ref	Year	Power technique	Power frequency (MHz)	Data technique	Data frequency (MHz)	Link gap (mm)	Experiment type
[35]	2017	Inductive link with coils	13,56	Inductive link with coils	33	5	Tested in a rodent
[33]	2015	X	X	Flexible loop antenna	402 - 406	0,5	Simulation
[32]	2015	Radio frequency	915	Radio frequency	457,5	X	Tested in a human
[31]	2014	Inductive link with coils	2	Loop antenna	8	30 - 50	Simulation
[24]	2014	Magnetic link	0,121	Magnetic link	6,8	X	Tested in a human
[30]	2012	Radio frequency	6,78	Radio frequency	X	50	Tested in dogs
[28]	2011	Radio frequency	6 - 7	Radio frequency	6 - 7	X	Tested in a dog
[29]	2010	Inductive link with coils	X	Radio frequency	X	X	Simulation
[27]	2010	Inductive link with coils	X	Inductive link with coils	X	X	Tested in a monkey
[25]	2009	Radio frequency	8	Radio frequency	8	20	Tested in rats
[26]	2009	Magnetic link	0,121	Magnetic link	6,8	X	Tested in cats
[20]	2004	Radio frequency	X	Radio frequency	X	X	Simulation

REFERENCES

[1] H. J. Hermens, B. Freriks, C. Disselhorst-Klug, and G. Rau, "Development of recommendations for {SEMG} sensors and sensor placement procedures," *Journal of Electromyography and Kinesiology*, vol. 10, no. 5, pp. 361 – 374, 2000. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1050641100000274

[2] D. Stashuk, "EMG signal decomposition: How can it be accomplished and used?" *Journal of Electromyography and Kinesiology*, vol. 11, no. 3, pp. 151–173, 2001.

[3] G. Kamen and D. Gabriel, *Essentials of Electromyography*. Human Kinetics, 2010. [Online]. Available: https://books.google.com.br/books?id=9izzXnnKzJoC

[4] R. Merletti and P. Parker, *Electromyography:: Physiology, Engineering and Noninvasive Applications*. John Wiley & Sons, Inc., 2004.

[5] J. Daube, *Clinical Neurophysiology*, ser. Contemporary Neurology Series. Oxford University Press, USA, 2002. [Online]. Available: https://books.google.com.br/books?id=K5QiZzacCjgC

[6] P. Konrad, *The ABC of EMG: A Practical Introduction to Kinesiological Electromyography*. Noraxon INC. USA., 2006. [Online]. Available: http://www.noraxon.com/sdm$_downloads/abc-of-emg/$

[7] A. D. Vigotsky, I. Halperin, G. J. Lehman, G. S. Trajano, and T. M. Vieira, "Interpreting signal amplitudes in surface electromyography studies in sport and rehabilitation sciences," *Frontiers in Physiology*, vol. 8, 2018.

[8] S. F. Pichorim and P. J. Abatti, "A Novel Method to Read Remotely Resonant Passive Sensors in Biotelemetric Systems," *IEEE Sensors Journal*, vol. 8, no. 1, pp. 6–11, 2008.

[9] S. Weber and T. C. Lueth, "Concept and Realisation of an implantable EMG and motion measuring device," in *2008 Second International Conference on Pervasive Computing Technologies for Healthcare*, no. Ci, 2008.

[10] H. J. Kim, H. Hirayama, S. Kim, K. J. Han, R. Zhang, and J. W. Choi, "Review of Near-Field Wireless Power and Communication for Biomedical Applications," *IEEE Access*, vol. 5, pp. 21 264–21 285, 2017.

[11] C. M. D. Miranda, S. F. Pichorim, and P. S. Ferreira, "Analysis and development of a ressonant inductive link with four coils for biomedical purposes," in *XXV Congresso Brasileiro de Engenharia Biomedica*, 2016, pp. 2–5.

[12] S. Y. Hui, W. Zhong, and C. K. Lee, "A critical review of recent progress in mid-range wireless power transfer," *IEEE Transactions on Power Electronics*, 2014.

[13] C. K. Lee, W. X. Zhong, and S. Y. Hui, "Recent progress in mid-range wireless power transfer," in *2012 IEEE Energy Conversion Congress and Exposition, ECCE 2012*, 2012, pp. 3819–3824.

[14] R. Shadid and S. Noghanian, "A Literature Survey on Wireless Power Transfer for Biomedical Devices," *International Journal of Antennas and Propagation*, vol. 2018, pp. 1–11, apr 2018.

[15] M. Soma, D. C. Galbraith, and R. L. White, "Radio-frequency coils in implantable devices: misalignment analysis and desgin procedure," *IEEE Transactions on Biomedical Engineering*, vol. BME-34, no. 4, pp. 276–282, 1987.

[16] J. C. Schuder, J. H. Gold, and H. E. Stephenson, "An inductively coupled RF system for the transmission of 1 kW of power through the skin," *IEEE Transactions on Biomedical Engineering*, vol. BME-18, no. 4, pp. 265–273, 1971.

[17] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless power transfer via strongly coupled magnetic resonances." *Science*, vol. 317, no. 1, pp. 83–86, 2007.

[18] Y. Yi, U. Buttner, Y. Fan, and I. G. Foulds, "Design and optimization of a 3-coil resonance-based wireless power transfer system for biomedical implants," *International Journal of Circuit Theory and Applications*, vol. 43, pp. 1379–1390, oct 2015.

[19] A. K. RamRakhyani, S. Mirabbasi, and M. Chiao, "Design and optimization of resonance-based efficient wireless power delivery systems for biomedical implants," *IEEE Transactions on Biomedical Circuits and Systems*, vol. 5, no. 1, pp. 48–63, feb 2011.

[20] R. S. Ananth and E. K. Lee, "Design of a low-power, implantable electromyogram amplifier," in *2004 IEEE International Symposium on Circuits and Systems*, vol. 4. IEEE, 2004, pp. 9–12.

[21] M. M. Lowery, R. F. Weir, and T. A. Kuiken, "Simulation of Intramuscular EMG Signals Detected Using Implantable Myoelectric Sensors (IMES)," *IEEE Transactions on Biomedical Engineering*, vol. 53, no. 10, pp. 1926–1933, 2006.

[22] P. R. Troyk, G. A. Demichele, D. A. Kerns, and R. F. Weir, "IMES : An Implantable Myoelectric Sensor," in *Proceedings of the 29th Annual International Conference of the IEEE EMBS*, 2007, pp. 8–11.

[23] B. D. Farnsworth, R. J. Triolo, and D. J. Young, "Wireless Implantable EMG Sensing Microsystem," in *IEEE Sensors 2008 Conference*, 2008, pp. 1245–1248.

[24] G. A. Demichele, Z. Hu, P. R. Troyk, H. Chen, and R. F. Weir, "Low - Power Polling Mode of the Next - Generation IMES2 Implantable Wireless EMG Sensor," in *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE, 2014, pp. 3081–3084.

[25] B. D. Farnsworth, D. M. Taylor, R. J. Triolo, and D. J. Young, "Wireless in vivo EMG sensor for intelligent prosthetic control," in *TRANSDUCERS 2009 - 2009 International Solid-State Sensors, Actuators and Microsystems Conference*. IEEE, 2009, pp. 358–361.
[26] R. F. Weir, P. R. Troyk, G. A. Demichele, D. A. Kerns, J. F. Schorsch, and H. Maas, "Implantable Myoelectric Sensors (IMESs) for Intramuscular Electromyogram Recording," *IEEE Transactions on Biomedical Engineering*, vol. 56, no. 1, pp. 159–171, 2009.
[27] J. J. Baker, E. Scheme, K. Englehart, D. T. Hutchinson, and B. Greger, "Continuous Detection and Decoding of Dexterous Finger Flexions With Implantable MyoElectric Sensors," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 18, no. 4, pp. 424–432, 2010.
[28] R. L. Hart, N. Bhadra, F. W. Montague, K. L. Kilgore, P. H. Peckham, and A. An, "Design and Testing of an Advanced Implantable Neuroprosthesis With Myoelectric Control," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 19, no. 1, pp. 45–53, 2011.
[29] P. A. Lichter, E. H. Lange, T. H. Riehle, S. M. Anderson, and D. S. Hedin, "Rechargeable wireless EMG sensor for prosthetic control," in *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology*. IEEE, 2010, pp. 5074–5076.
[30] D. Mcdonnall, S. Hiatt, C. Smith, and K. S. Guillory, "Implantable Multichannel Wireless Electromyography for Prosthesis Control," in *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE, 2012, pp. 1350–1353.
[31] Y. Zhang, "An Implanted Telemetry System for Transcutaneous Biosignal Transmission," in *2014 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)*. IEEE, 2014, pp. 491–494.
[32] H. Bhamra, Y.-j. Kim, J. Joseph, J. Lynch, O. Z. Gall, H. Mei, C. Meng, J.-w. Tsai, and P. Irazoqui, "A 24 μ W , Batteryless , Crystal-free , Multinode Synchronized SoC " Bionode " for Wireless Prosthesis Control," *IEEE Journal of Solid-State Circuits*, vol. 50, no. 11, pp. 2714–2727, 2015.
[33] C. M. Cynthia, "A Flexible Conformal Loop Antenna for Intramuscular Implantable Myoelectric Sensors," in *2015 Global Conference on Communication Technologies (GCCT)*, no. Gcct. IEEE, 2015, pp. 688–690.
[34] M. Voelker, A. NIkas, H. Zhou, J. Hauer, R. Ruff, and K.-P. Hoffmann, "Implantable EMG measuring system," in *AMA Conferences 2015 – SENSOR 2015 and IRS2 2015*, vol. 1, 2015, pp. 426–429.
[35] M. D. S. Wong, K. A. Ng, S. Nag, R. Jegadeesan, K.-w. Leong, L. J. Ong, M. Alam, G. Gerald, L. Gammad, C. W. Tsai, S.-c. Liu, K. Voges, N. V. Thakor, A. Lahiri, C. Libedinsky, Y. P. Xu, and S.-c. Yen, "A Chronic Implantable EMG Recording System with Wireless Power and Data Transfer," in *2017 IEEE Biomedical Circuits and Systems Conference (BioCAS)*, 2017.
[36] P. J. Abatti, S. F. Pichorim, and C. M. de Miranda, "Maximum Power Transfer versus Efficiency in Mid-Range Wireless Power Transfer Systems," *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, vol. 14, no. 1, pp. 97–109, 2015. [Online]. Available: http://dx.doi.org/10.1590/2179-10742015v14i1433
[37] C. M. Miranda and S. F. Pichorim, "A Self-Resonant Two-Coil Wireless Power Transfer System Using Open Bifilar Coils," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 64, no. 6, pp. 615–619, 2017.

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Uma Revisão Crítica das Técnicas de Transmissão de Energia e Dados para EMG Implantável

***Resumo:* —Este artigo apresenta uma revisão sistemática e crítica sobre as aplicações envolvendo eletromiografia implantável nos últimos quinze anos. Para o levantamento desses artigos, diversas bases de dados foram investigadas a fim de proporcionar uma consulta mais variada. As informações mais críticas foram extraídas e destacadas durante o presente estudo. Esses dados foram usados para a construção de uma tabela de comparação. Os resultados desta tabela são usados para fazer comparações entre as diferentes abordagens utilizadas e para identificar os parâmetros e tecnologias que têm demonstrado melhores resultados. Essas análises e comparações podem ser utilizadas para auxiliar na definição de novas abordagens a serem desenvolvidas.**

***Palavras-chave:* —Eletromiografia, dispositivos médicos implantáveis, EMG implantável, transferência de energia sem fio, link indutivo.**

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