The brain gets its own broadband: Electro-quasistatic fields enable broadband communication for brain implants

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Proposed untethered BP-QBC for data communication and powering in grain-sized nodes, sprinkled throughout the brain, which communicate with a headphone-shaped wearable hub. The vision for future brain implants include a network of untethered multichannel implants/nodes, enabled by wireless communication and powering. Credit: Baibhab Chatterjee, Shreyas Sen, Purdue University.

In recent years, engineers have been working to develop increasingly sophisticated devices that can help humans to interact better with computers. These technologies, including brain-machine interfaces, electroceuticals and wearable health care devices, could potentially advance both existing medical practices and the capabilities of human users.

A research team at Purdue University recently introduced a new approach to enable communication between the human brain and computers via wireless neural implants. Their proposed approach, outlined in *Nature Electronics*, relies on a two-phase process that slowly unfolds in the brain, allows a small sensor implanted in the brain to sense and transfer information to a wearable headphone-shaped device, without disrupting the human body's physiological processes.

"Our group at Purdue University has been working in the area of electric field communication around the human body for the past eight years and pioneering technologies such as EQS-HBC, which is now being commercialized," Shreyas Sen, the principal investigator for the study, told Tech Xplore.

"Through this exercise, we learnt that similar to the communication of body-generated ECG signals through the body, we can send digital information through the tissue using various technologies, some of which we have patented."

The human body, including the brain, is innately able to support internal communications based on the generation of tiny electrical signals, the high-speed nature of which establishes a 'broadband' channel spanning across the body. So-called brain-computer interfaces are designed to enable high bandwidth interactions between these brain signals and computers.

"Once our electric-field based communication technology was mature around the body, it became an obvious choice for us to conduct this investigation, as it is also applicable inside the brain, for high bandwidth ultra-low power implant-to-computer communication," Sen explained.

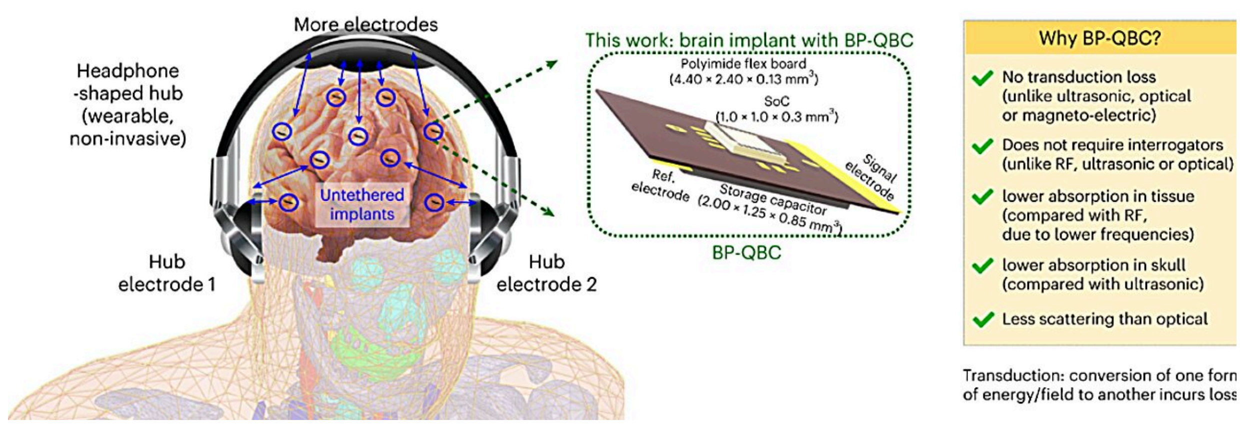
The technology developed by Sen and his colleagues is based on the idea of low-power and high-bandwidth data communication between various implanted wireless devices distributed around the brain. These distributed implants could record and stimulate various brain regions, both within the cortex (i.e., the brain's outer layer) and in the deep brain.

"This technology, when combined with further advancements in deep-brain wireless power transfer, would make it possible to gain fundamental insights into disorders like Parkinson's disease, Tourette Syndrome, Epilepsy, Depression, Anxiety, and obsessive-compulsive disorder," said Baibhab Chatterjee, who led this work as a doctoral student at Purdue and is now a faculty at the University of Florida in Gainesville.

"The low-power yet high-bandwidth data communication is made possible by using the biological tissue as a medium for signal transfer, which we have explored extensively at Purdue, for both wearables and implants, and have shown that the tissue provides a wideband channel at electro-quasistatic (EQS) frequencies (up to 10s of MHz) using capacitive termination."

This recent study partly builds on one of the team's earlier works, where they introduced a technique known as EQS-HBC, which stands for electro-quasistatic human body communication. In this previous paper, the team showed that signals can be transferred between different wearable devices by coupling the so-called capacitive return-path with the Earth's ground.

"The primary difference that makes this a unique challenge for implants is the fact that the conductive tissue completely surrounds the implant, which makes the capacitive return-path coupling to the Earth's ground almost non-existent," Chatterjee said.



Proposed untethered BP-QBC for data communication and powering in grain-sized nodes, sprinkled throughout the brain, which communicate with a headphone-shaped wearable hub. The vision for future brain implants include a network of untethered multichannel implants/nodes, enabled by wireless communication and powering. Credit: Chatterjee et al., Nature Electronics, 2023.

To overcome this challenge, the researchers previously leveraged a technique known as galvanic coupling, which is based on the theory of electrical dipole coupling. While this method was partly effective, they found that the low-impedance channel between the signal and reference electrodes of a galvanic implant resulted in an excessive amount of power consumption, if the signals are not DC-balanced.

"In this work, we demonstrate a technique called biphasic quasistatic brain communication (BP-QBC), which can reduce that power consumption by orders of magnitude (~41X reduction at 1 MHz), enabling the creation of an ultra-low-power yet broadband communication channel," Chatterjee said.

"Furthermore, owing to a fully EQS signaling, our methods do not incur any transduction loss as compared to competing technologies such as ultrasound, optical and magneto-electric data transfer, thereby reducing the system-level losses, which is another unique advantage of this technology."

The recent work by this team of researchers essentially builds on their previous work on EQS field-based communication around the body and introduces it to the brain, to enable communication between wireless neural implants and wearable computers. This technique would be implemented via ultra-low power wireless microdevices that can transfer data at a high rate, which are located in different parts of the brain, forming a unified network.

"With this invention, the human brain 'gets its own broadband,'" Sen explained. "Most notably, we found that electric field-based communication in the brain provides an extremely high bandwidth and moderate loss channel for high-speed communication between implants and wearables directly. The bandwidths achievable are significantly higher than existing optical, magnetic, ultrasound, or radio frequencybased technologies."

According to the researchers, they have merely outlined the fundamental functioning and underlying components of their proposed system so far. Further theoretical studies and in-vivo measurements could help to validate its potential, while also assessing its compatibility with existing neural implants.

"In our next works, we will explore multiple additional modalities based on the proposed fundamentals," Sen said. "We will also conduct translational research, to implement the proposed ideas as commercializable devices and hence intercept the development of future brain computer interface devices."

In the future, the new approach introduced by this team of researchers could be tested and implemented in clinical settings. If proved to be safe, reliable and effective, it could greatly advance medical research, for instance improving the present understanding of various neurological and behavioral disorders.

Sen, Chatterjee and their colleagues are now working on a new version of their proposed system that also supports multi-channel sensing. In addition, they are trying to develop new system-level approaches that could reduce the power consumption of neural implants, allowing them to transfer more data while consuming similar amounts of energy.

"Another area that we are actively working on is improving the power-transfer efficiency and reduce leakage in such implants," Chatterjee added. "At the same time, we are looking into various translatable applications of this technique for central as well as peripheral nervous systems, as part of our work in the Center for Internet of Bodies, where the goal is to establish seamless connectivity between multiple implants and wearables."

More information: Baibhab Chatterjee et al, Biphasic quasistatic brain communication for energy-efficient wireless neural implants, *Nature Electronics* (2023). DOI: 10.1038/s41928-023-01000-3