**Cortical Modem Systems Integration and Packaging**

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Description: The DoD has a critical need for breakthrough medical therapies to treat wounded warriors with multiple comorbidities of sensory organs. This topic seeks to integrate state-of-the-art electronics, packaging, and passivation technologies with the latest low-power data and power delivery semiconductor components in a single package. In other words, DARPA seeks to wirelessly bridge cortical neural activity sensing components within the skull to external computing and network systems, designing an effective “Cortical Modem” that connects human brains to computer equipment and networks in a direct analogy to early telephonic modems, which connected computers to the ARPANET.

DARPA is open to a multiplicity of system architectures that, first and foremost, demonstrate significant improvements in the scale of neural channel bandwidth from the current 100-signal demonstrations, but secondly, may span a wide spectrum of implementation strategies from high-bandwidth transmission systems with limited implantable computation capability, to implantable integrated analysis and compression systems coupled to a limited bandwidth telemetry systems.

Significant advances in the miniaturization and ever lower-power performance of electronic and photonic technologies have enabled critical developments in miniaturized communications products like cellular phones. However, the time lag between such advances and their adoption in the fields of neuroscience and neuro-engineering has, in many cases, grown to more than twenty years. With such large interface component feature sizes characteristic of the older technologies in common experimental use, the supporting interface electronics have now become one of the most significant and fundamental limits to their integration within human and animal bodies. For example, the Utah array features a 400 micrometer electrode pitch, a limitation compounded by the wet etch microfabrication technology available to the manufacturer. Note that this 400 micron feature size is representative of 1980s CMOS technologies, and is too coarse for interfacing with, for example, the visual cortex where neural pitch ranges from ten to thirty microns. As the mobile computing industry continues to push miniaturization, functionality, and power-consumption requirements to their limits, so too is the field of neuroscience pushing ever closer to full-duplex single-neuron scale interfaces. With focused technology development and integration to build a Cortical Modem, the necessary critical electronics and packaging could be leveraged across the entire academic and corporate neuroscience ecosystem to result in dramatically accelerated advances in science and commercialization of neuroscience technologies. The goal of this topic is to develop cortical modem components that substantially improve the scale of signal transduction from the current 10x10 electronic probe arrays, as well as the scale of telemetry delivery of those signals. For reference purposes, one mm^3 volume of cortical tissue encloses approximately 100,000 neurons indicating an eventual need to both transduce and deliver wireless telemetry for as many as 10^7 independent neural channels. Proposals should target the design and implementation of a COTS-based full duplex cortical interface component. Essential elements of this component include flexible direct electronic interfaces to neural activity, sensors and low power pre-processing circuitry to convert and encode neural sensor signals into formats that can be transmitted wirelessly across the skull, wireless telemetry suitable for safe use in humans, and power delivery electronics. Packaging must leverage state-of-the-art miniaturized single system-on-a-chip ceramic packaging that incorporates on-board wireless power reception and conditioning circuitry.

Critical to the design of the system is a careful power and link budget analysis to account for relevant FDA and FCC regulations. In addition, proposals should detail the intended components (i.e. make, model, and part numbers), their interface design, and the technical and mechanical specifications that will ultimately yield the lowest power, smallest form-factor, highest signal-to-noise ratio and bandwidth system possible using COTS components. Critical systems integration challenges must be addressed explicitly in the proposal. Technical challenges and considerations include system power, transmission bandwidth, frequency and data rates, transmission protocols, optical wavelengths, etc. Offerors are to first uncover and understand the critical integration challenges that may limit the translation and commercial-viability of full-duplex cortical interfaces, and second to push the standards of integration by producing a first generation of truly miniaturized and implantable interface componentry, thereby accelerating innovation across the entire field of neuro-engineering. Industrial and military collaborators should then produce products and reach their first commercialization milestones on a similarly accelerated timeline. Technical challenges may include:

• The development of a standard interface between a multiplicity of different neural sensing components and the data collection and transmission system.

• Maximizing the scalability and bandwidth-power product of both the internal neural sensing and external wireless data and power interfaces, but doing so within safe heat dissipation limits of the outer cortex and skull.

• The potential need for data translation and encoding components to minimize power requirements for transcranial data and power delivery.

• Establishing optimal trade-offs between physical, electronic, and data transmission specifications required to minimize the componentry bill of materials (BoM) and hence the size of the device that needs to be implanted.

• Sourcing state-of-the-art packaging and system-on-a-chip prototyping support

• Determining optimal bio-material passivation strategies and packaging materials limitations.

• Determining optimal power-bandwidth tradeoffs and scalability to support increasing sensory density, resolution, and sensitivity limitations.

PHASE I: Explore and determine the fundamental systems integration and packaging limitations (that are common across the entire neural interface field) in implementing a full-duplex read/write neural interface system that bridges data and power delivery across the human skull. Phase I deliverables:

1) Final Report that identifies the neural read/write signals modalities (not necessarily required to be the same); details the technical challenges relevant to the read and write signals within the deployment environment; quantifies the information limits to the system relative to the information input/output of the cortical area of interest; details component-level metrics for coping with the data and power requirements; describes integration process, system-level challenges; and a thorough business plan describing the NRE costs, minimum rate of production, units per year required to achieve sustainable production of a cortical modem, and market analysis;

2) Develop a fully-operational proof-of-concept demonstration of the key components and functional systems in a bench-top / PC-board scaled prototype along with all the design documents and complete specifications, along with documentation of committed sources and service providers for the fabrication of the ultimate integrated system-on-a-chip Cortical Modem device to be produced in Phase II; full specifications and a complete BoM are required, itemizing each component and system that comprises the final prototype system. These demonstrations should be performed in relevant in vitro environments analogous to the final deployment environment in the human skull and cortex.

PHASE II: Development, demonstration, and delivery of a working fully-integrated cortical modem at a 1:1 physical scale with the underlying neurons. The Phase II demonstration should operate within a physical simulacrum that mimics as closely as possible the electrical and mechanical properties of human cortex, skull, and scalp. The integrated system should leverage COTS silicon and electro-optical devices wherever possible, and form a data and power bridge between the internal cortex and external machines. On the cortex side, a modular neural interface architecture should support bi-directional communications through a multiplicity of neural probe modalities, including, but not limited to, optical, electronic, and bio-molecular sensing interfaces. The external interface should be comprised of a wireless interconnection through intervening brain and skull tissue to external computing systems. Proposers are encouraged to adapt modular componentry strategies that are generalizable to a wide range of neural interfaces.

The Cortical Modem system should be able to collect and transmit neural signals through the skull in a complete, implantable package. It will have a form-factor and packaging that can be implanted in the cortex with core system functionality provided by COTS semiconductor components in a single ceramic system-on-a-chip package, rather than a fully-customized chipset.

The Phase II final report shall include:

(1) full system design and specifications detailing the electronics and proof-of-concept neural interfaces to be integrated;

(2) expected performance specifications of the proposed components in vivo; and

(3) calculations of energy and link budget scalability to larger cortical regions.

PHASE III: Breakthrough medical treatments for wounded warriors with multiple comorbidities of the sensory organs. Effective restoration sight, sound, smell, and vestibular sensation after massive head trauma. Breakthrough medical treatments for upper spinal cord injuries, enabling restoration of motor and sensory capability. Breakthrough medical treatments for diseases of sensory organs, providing sight and sound to treat indications not possible through use of current retinal prostheses and cochlear implants.