Presented at the COMSOL Conference 2009 Milan

# Modeling the Behavior of Phased Arrays in Brain Tissue: Application to Deep Brain Stimulation

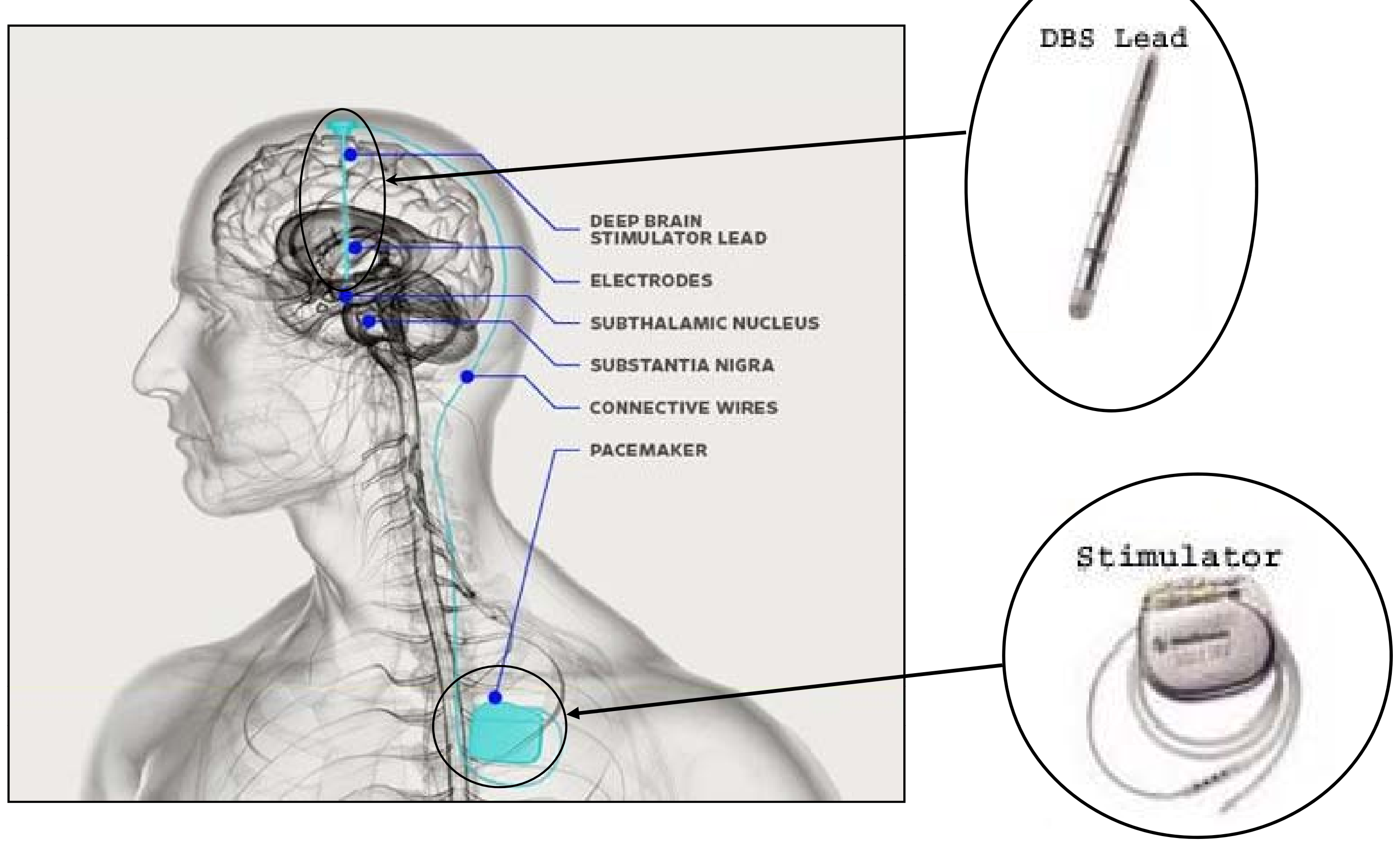
**Virgilio Valente*, Andreas Demosthenous*  and Richard Bayford****

*Department of Electronic & Electrical Engineering – Universtiy College of London – WC1E 7JE
**Department of Natural Sciences - Middlesex University - NW4 4BT - London

## 1. Deep Brain Stimulation (DBS) - Background

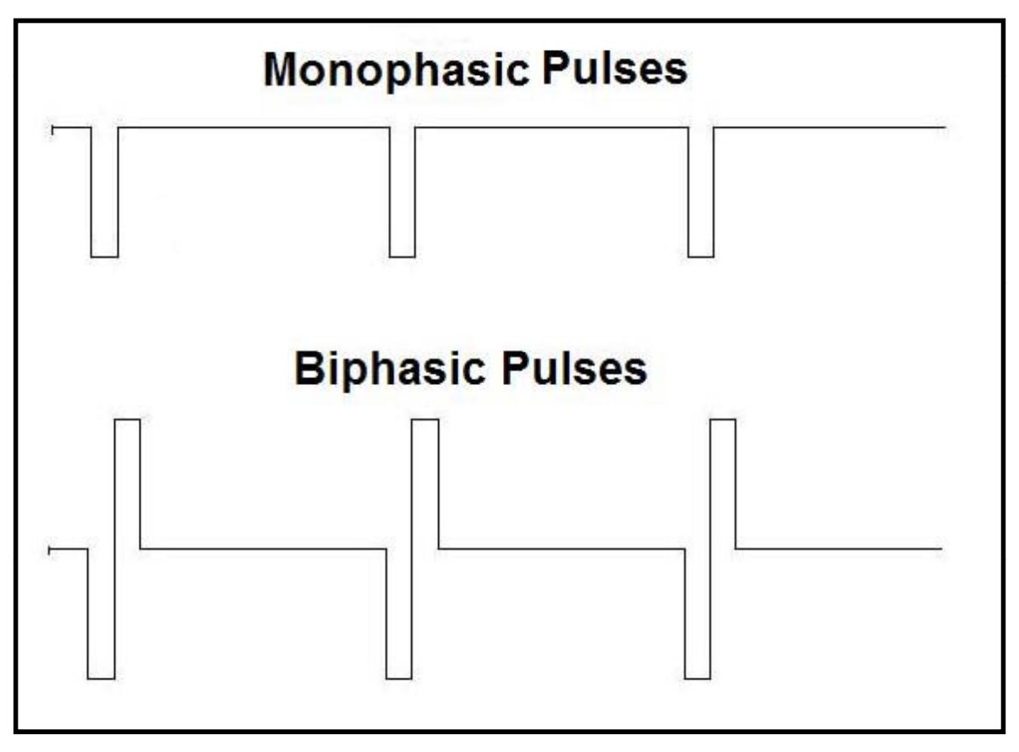
DBS is a therapeutic tool adopted to treat a number of neurological and motor disorders, including essential tremor, Parkinson's disease, dystonia and Tourette Syndrome. The clinical implant consists of a stimulator and an electrode lead terminating in four metal contacts.

### IMPLANT



### CLINICAL DBS STIMULI

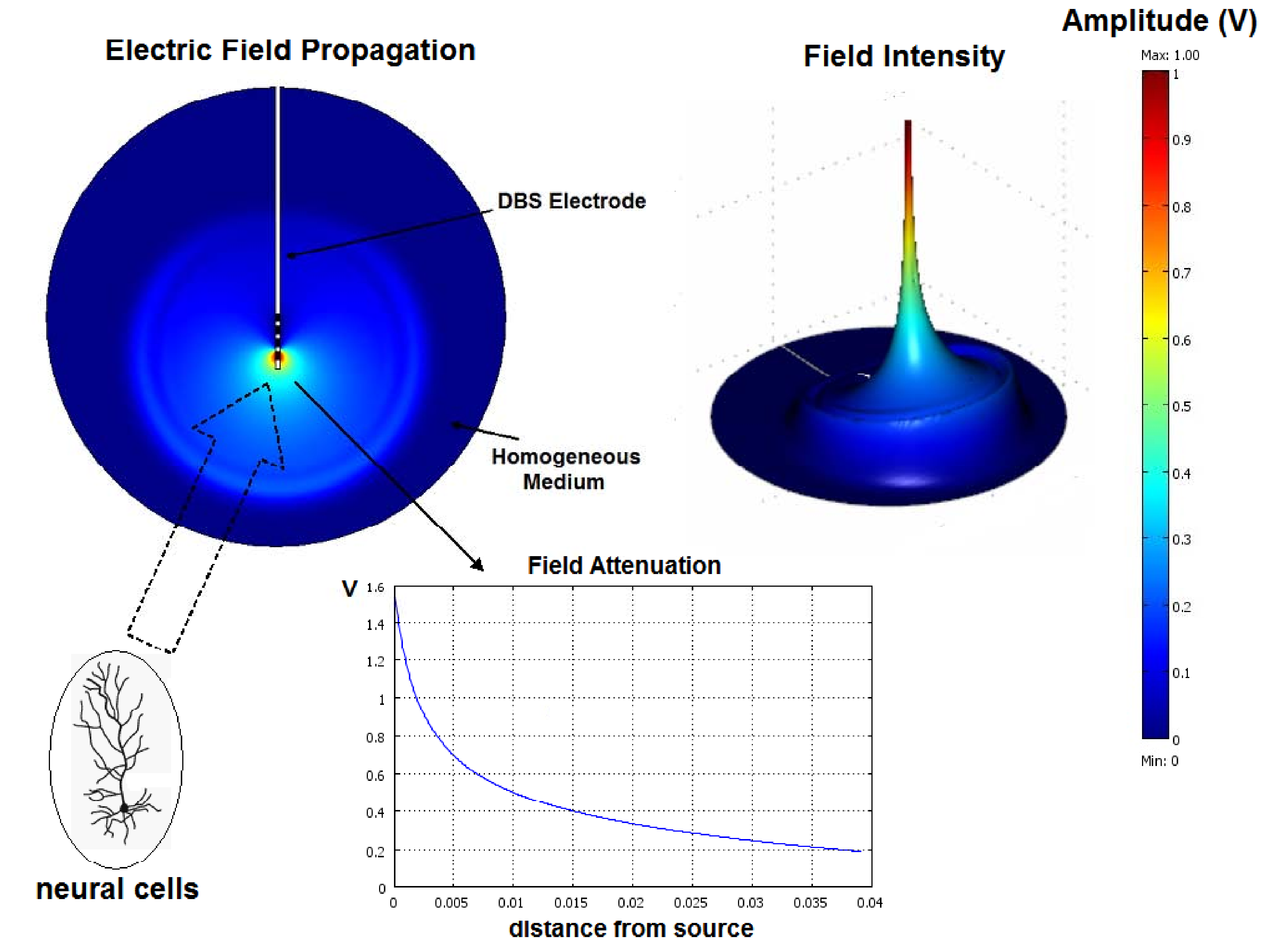
Stimulation is provided by the application of monophasic or biphasic voltage pulses, to one or more electrode contacts. A number of pulse clinical settings can be controlled via an external programmer which communicates wirelessly with the stimulator.



| Parameter | Clinical Settings |
|---|---|
| Amplitude (V) | 1-3.5 |
| Pulse Width (μs) | 60-120 |
| Pulse Rate (pps) | 100-185 |
| Electrode Polarity | Unipolar/ Bipolar |

## 2. Operation and Limitations of Clinical DBS Systems

The application of voltage stimuli generates an electric field which propagates in all directions within the brain target area surrounding the electrode. The field activates the neural cells that lie within the volume of area activated by the stimulation. The stimulating field decays exponentially due to attenuation caused by the brain fluid.



### Limitation

A major limitation of clinical DBS systems lies on the inability to control the direction propagation, which results in limited efficacy and high risk of side effects, caused by stimulation of non-target areas.

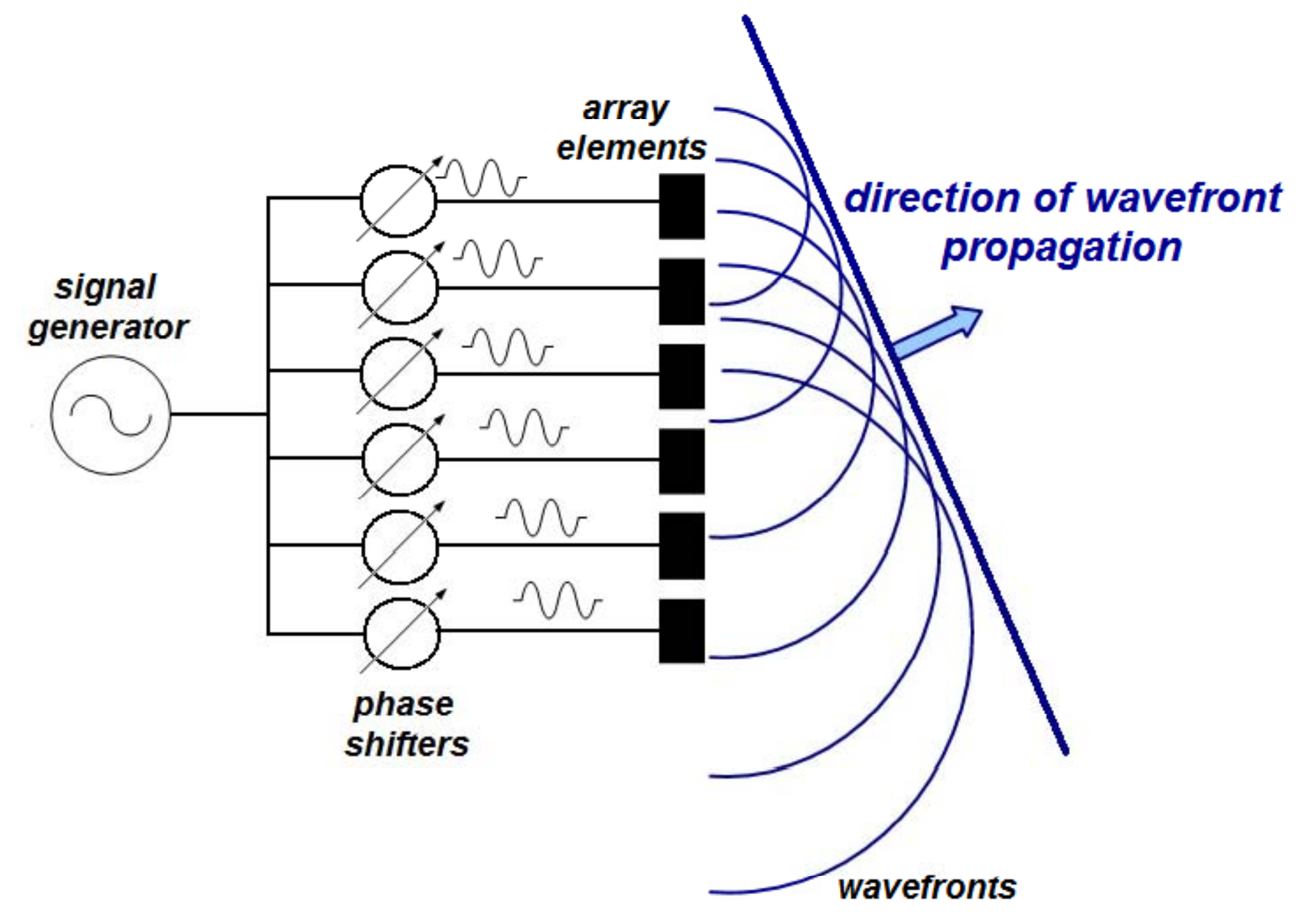
*solution*

### Field Steering

Develop methods to control the direction of propagation and focus of the electric field. The benefits would include a more efficient stimulation and reduced adverse effects

## 3. Field Steering – Methods

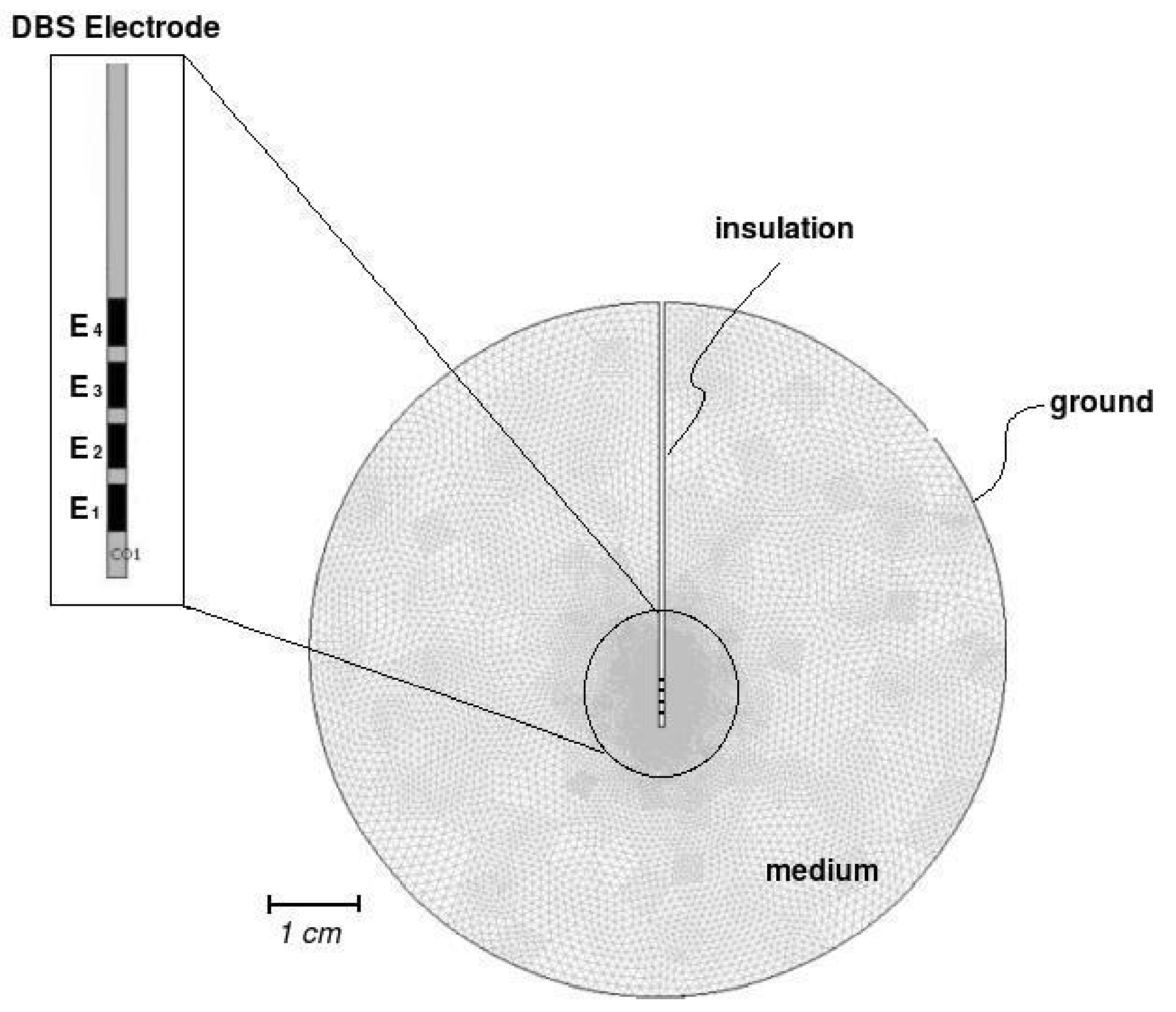
To achieve field steering we propose the development of a stimulation system based on phased arrays (PAs). PAs consist of multiple antenna elements which use variable phase shift or time delay control at each element to scan a radiation beam to a desired angle. Excitation of each element results in the generation of individual wavefronts which combine with one another to form an overall wavefront, which propagates to a desired direction specified by the angle $\theta_0$ with respect to the array axis.



$$\vartheta_0 = \cos^{-1}\frac{\varphi}{kd}$$

φ : *phase shift*
k : *wavenumber*
d : *element distance*

Field steering was modeled using finite element methods (FEM) in Comsol Multiphysics 3.5, consisting of a DBS electrode model placed at the center of a homogeneous isotropic medium. The electrode contacts were driven by a set of sinusoidal stimuli, in phasor forms. The potential distribution generated was determined by solving the partial differential wave (Helmoltz) equation .



### Stimuli

$$V_1 = A_0$$
$$V_2 = A_0 e^{\varphi_1}$$
$$V_3 = A_0 e^{\varphi_2}$$
$$V_4 = A_0 e^{\varphi_3}$$

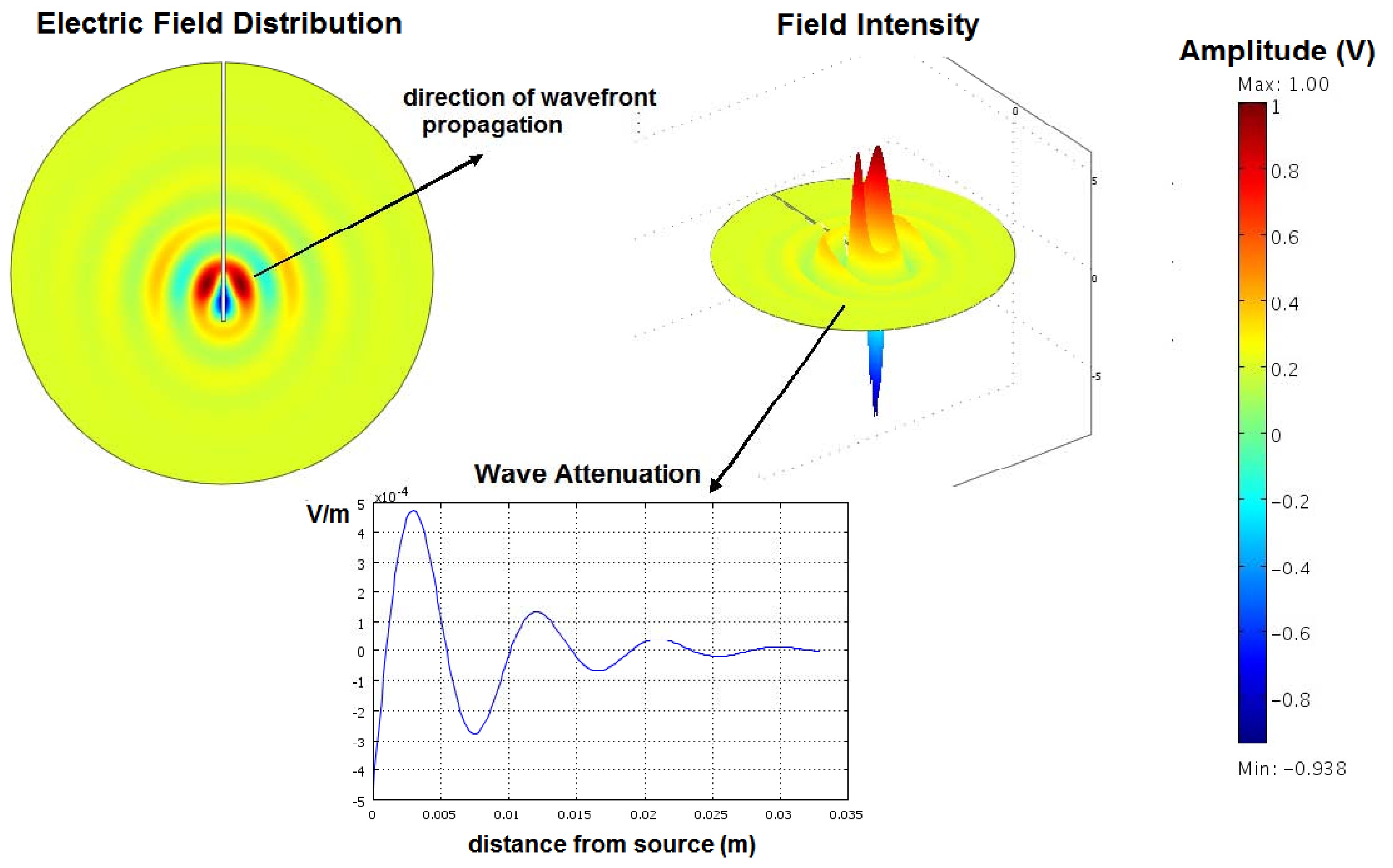
The propagation factor, γ, is derived from the Cole-Cole equation, which accounts for frequency dependent behavior of the tissue up to 100GHz.

### Wave Equation

$$\nabla^2\tilde{u} + \gamma^2\tilde{u} = 0$$
$$\gamma = a + jb$$
$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}}\left[\sqrt{1+\left[\frac{\sigma}{\omega\varepsilon}\right]^2} - 1\right]$$
$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}}\left[\sqrt{1+\left[\frac{\sigma}{\omega\varepsilon}\right]^2} + 1\right]$$

## 4. Results and Conclusion

The wave equation was solved for phased shifts ranging between -π and π. The Figure below shows one example of electric field steering to a specific direction obtained by setting the phase shifts between the stimuli to $\varphi = \pi/3$



A deep brain stimulation system based on phased arrays can provide a major improvement to today's systems, by allowing to control the direction and focus of the electric field generated by the stimulation, resulting in a more efficient and safer stimulation. Future research will include experimental validation and the design and development of an implantable application specific integrated circuit (ASIC) stimulator based on phased array systems.

Contact email: v.valente@ee.ucl.ac.uk, address: UCL , Robert's Building, room 708