Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications

TA: Kaushik L, Course Instructor: Dr. Hardik J. Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

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Greetings welcome to this NPTEL course on microsensors, implantable devices, and rodent surgeries for biomedical applications. In this course, you will be learning about electrodes that can be manufactured to be implanted in the brain; by the brain, I mean rodent brains, which will be later translated for humans. We will cover how we can use these electrodes via surgeries to acquire biopotentials such as ECoG signals, electrocardiography (ECG), which are signals coming from under the skull from the brain, or EEGs and ECGs. Specifically, we will focus on the brain, so EEG and ECoG. We will also explore how these electrode potentials can help us determine the activities of the local field potentials of the brain.

Once we determine how the electrodes are implanted and how they can conduct the biopotentials, we need something that can translate these values into user-friendly information, so that we, as researchers or medical professionals, can understand what is happening exactly. This is where I come in. In this lecture, you will learn about how to make an electronic system that can acquire these biopotentials, specifically brain signal acquisition, and also stimulate the brain for various applications.

I am Kaushik, a research assistant at the BEES lab at the Indian Institute of Science, and in this lecture, I will take you through the design considerations that you should take into account while designing such an electronic system. I focus on electronics, and this is where my forte lies. I will do my best to help you understand how to approach a design or electronic design for whatever applications you are looking for. Specifically, we will focus on neuro and biomedical applications. I have divided this lecture into three small chunks so that it will be easier for you as viewers to understand.

These chunks are design considerations, circuit design, and system development. By design considerations, we will look at various techniques that we can use for designing a circuit in general, whether using development boards, integrated circuits on a PCB, or a normal breadboard. We will also discuss the chips that we can use to design such a circuit. In circuit design, once we have chosen the design, we will explore how to design the peripherals for the circuit and how to control the chips that we have selected for the circuit. In system development, we will look at how to make a PCB and a schematic in an

electronic design automation tool so that we can translate it professionally onto the printed circuit board.

To give you a simple analogy, let us say we want to design an automated LED or an LED that can be controlled via sound or something like that. In design considerations, we will look at what kind of LED we need or what type of light is required, such as halogen or something else. Once we determine what kind of LED we need, we will look in circuit design at how to interface it with other components, how to power the LED, whether to connect it directly to the power supply or use a switch in between and other considerations such as how to control the current through it, using a constant current supply or constant voltage supply, etc. In system development, we will translate it into a PCB design. This is the overall flow of how we will go through this course, and I hope that you will be able to understand and apply it to your applications.

In design considerations, we will address questions such as: What is the end goal of the system or the purpose of the system? How do we go about achieving this result? What are the components that we need to select to achieve those results, and how are they involved in the system? Finally, how do we select the components, and what parameters should the components have? These are the questions we will answer in this module.

The purpose of the system, in a single sentence, is to bridge the gap between the brain and the user. As we see in this NPTEL course topic, we are focusing on rat brains or rodents in general before moving on to human brains. We have to prove the theory in rat brains, hence focusing on rodent models. The objective is to develop the system for mainly two things: one is acquiring signals from the brain, which would not be directly from the brain but from electrodes implanted in the brain, and the second objective is how to stimulate the brain. As my colleague Srinivas would have mentioned, we have developed a PCB for brain stimulation with parameters that can be varied. In simpler terms, we can divide it into two main objectives: acquiring signals from the brain and stimulating the brain.

As you can see, this is a rat's brain and the system, which is yet to be developed. Before we develop it, I have depicted it as a black box. We will have to accommodate it in a very small size so that the rat can move freely, and this has to be done in real-time. The system will bridge the electrodes and the user, providing information after the acquisition of the signal, and also bridge the other way around between the user and the brain by providing stimulation pulses according to the input. This two-way communication will be accomplished with various modules that will be attached to the system to complete the overall picture.

When we talk about a system, we need to decide on certain properties of the system before we proceed with system planning. I have taken a simple example here before we

delve into the acquisition and stimulation system for rats. Consider a very simple system from a daily scenario, such as an automated irrigation system. In such a system, we need inputs like sensors to measure parameters such as temperature and humidity. These inputs have to be processed, and usually, a threshold is set. If the threshold is crossed, an output such as watering the plants or controlling motors is provided. This is a very generic system I have used for illustration, but when we come to the system we are discussing—the stimulation and acquisition of signals from a rat's brain or a rodent's brain—these are the user inputs and outputs that are required.

The overall concept model is depicted at the bottom, and you can see that the system is placed in a backpack-like manner and communicates wirelessly with the GUI. Stimulation pulses are sent from the user via the GUI to the rat, and at any given time, we also need to acquire the signals as output wirelessly to the GUI.

Here is a small video showing the rat's behaviour, done at the central animal facility in the institute, with ethical clearance for the surgery. Post-surgery, you can see an interface board above the rat. I also have the interface board in hand, and if you look here, you can see it. This interface board is what is placed post-surgery above the rat, and using this cable, we can acquire the signals using several systems. This board you see here is the stimulation setup explained by my colleague Srinivas, which I have physically here. However, we will focus on something else here because we are doing both stimulation and acquisition. Thus, the process involves several steps—not just stimulation, but also sending pulses with modifiable parameters to the electrodes implanted on the rat's brain.

It also has to wirelessly communicate and display the information in the GUI. Wireless communication is key here as it is a wireless system, and it has to be battery-powered, as wired power is not possible in our case. So, we will plan our system accordingly to facilitate all these properties of the system. Now, when it comes to a system, we have to choose the right components for the system, and as a beginner, I would suggest people use development boards that are available commercially everywhere. Development boards contain microcontrollers along with peripherals built into them, and it is just plug-and-play. You can plug it into your system, connect the required peripherals, and execute whatever operation you decide.

These development boards come with their trade-offs. For example, most of the time, we lack the resolution of the ADC. What I mean by this is that the information we get may not be accurate, and when converting analogue signals, in our case biopotentials, it may get lost due to the lower resolution. Peripheral ADC resolutions in the market are 10-bit or 12-bit ADCs, and if the board does not lack an ADC, it has a huge cost associated with it. So, it is a kind of trade-off; otherwise, they also rarely lack peripherals. This is one of

the development boards available commercially. This is provided by a platform called OpenBCI (Open Brain-Computer Interface); this board is called Cyton.

They also have previous boards associated with them, called Ganglion and others. The Cyton board is a development board, especially for biopotential measurement; by biopotential, I mean ECG or EEG, EMG, and other stuff. It contains a 32-bit PIC microcontroller; PIC is a microcontroller by Microchip Technology, and it has a dedicated Texas Instruments ADS1299. It has inbuilt processing for measuring weak signals associated with general brain signals and has a resolution of 24 bits, which is always good. The more resolution you have, the better the signal information you get. It also has a wireless BLE transmission built in; otherwise, we can also write it onto an SD card.

These are the properties associated with it, but as I mentioned, it also has a huge cost, which is generally not sustainable. But this is one of the boards that we have in hand, and we have made a system associated with it. It also includes a PSoC-based system that can stimulate. As I mentioned, this OpenBCI system has biopotential measurement, which means it can only acquire signals and can acquire up to 8 channels at a time, which means it can acquire up to 8 electrodes in the brain. This acquisition is combined with the stimulation from the PSoC-based circuit that we have developed, and together it makes a complete system of both electrical stimulation and recording. This stimulation was done for deep brain stimulation, as mentioned by my colleague.

In the PSoC-based stimulation system, we have the microcontroller, and it has the property of sourcing or sinking current. Using this property, we have placed current-mirroring blocks, which can mirror the current to the output. A current-mirroring block is a circuit usually based on a transistor or MOSFET; here it is a MOSFET. When a current flows on one branch, the same amount of current flows on the other branch. To be very generic, this is a current-mirroring circuit. The same is replicated twice; this is a kind of current-mirroring circuit that does not get affected by the load. It has both positive and negative pulse stimulation capabilities for a biphasic-based pulse stimulation system.

Now, as you can see, this setup, even though it has both acquisition and stimulation capabilities, is still too large for rat-based models. As I mentioned earlier, we have to move from rats to humans step by step. We need to make this feature size very small. Even though it may look big for protein-based biopotentials, it is extremely large for a rat. We can still work with this by wiring it directly to the rat, but it restricts the movement; hence, this kind of setup becomes essential. This is where ASICs come into play. ASICs are application-specific integrated circuits. When you speak about ASICs, the OpenBCI system uses the ADS1299 chip by Texas Instruments, which you can use to

build your biopotential acquisition systems as well. The advantage of using ASICs is, of course, the feature size is extremely small, and it also has the required ADC resolution.

If you do not have the ADC resolution, this has a 24-bit ADC resolution. You can even attach external ADCs to it, and it has the necessary peripherals. It has 8 channels, and you can even add on to it serially. For example, the Free-EG 32 uses the ADS1299 in 4 chains to increase the channels to 32. So, you can even work around that. It has the same feature size as the Cyton but with multiple channels as well. The most important thing is that it has inbuilt stages. By inbuilt stages, I mean there are, even though there are an extremely large number of 24-bit ADCs available in the market, you need a certain set of stages to acquire these biopotentials as they are very weak. These stages generally include pre-amplifiers, which remove the noise, and amplifiers which amplify the amplitude of the noise-removed signal. Then they go to the ADC, and only then do you get the digital output. This is just a general overview of the stages involved in getting biopotentials, but I encourage you to look into it. These stages are generally built inside the ASICs, but there is a huge cost involved in developing ASICs; however, it is a one-time cost.

When we look at ASICs, there is a particular chip that we were interested in from Intan Technologies, based in California. This chip is similar to the ADS1299, but they have a wide range of channels. As you can see here, there are 3 H stages that they provide, and each H stage is different. These two belong to the RHD family, which is only for amplification. This belongs to the RHS family of chips, which includes both amplification (acquisition) and stimulation.

The RHS 2116 has 16 channels that can be set as acquisition electrodes or stimulation electrodes according to the user. Since this chip has this capability, we will be focusing on Intan Technologies' RHS 2116 in this module. This is the chip we will be focusing on, and in the RHS 2116, this is the circuit from the datasheet. As I mentioned, it has 16 channels which will go to the electrodes implanted in the brain. Each of the electrodes can be set as acquisition or stimulation. Some of the features of this chip, besides the 16 channels, include a wide range of stimulation current, from 10 nanoamperes to 2.5 milliamperes. The acquisition speed is fast at 60 kilo samples per second. When we design this circuit, we have to take this into account because our microcontroller needs to acquire 50 kilo samples per second, which is very crucial.

The mode of communication between the chip and our controller will be either a 32-bit SPI 4-wire or an 8-wire differential signalling SPI. Additionally, it has electrode impedance measurement built in, as I mentioned, all the stages are built inside the Intan chip. Now that we have seen the features of the RHS 2116, we will be working with this chip for our circuit design as well as system development. To conclude this lecture, I will

give you a summary of what we have covered so far. We have established the objective for our overall system.

We are making a device for the stimulation and acquisition of brain signals, ECoG signals, and other biopotentials. We have to make it a wireless system that is, of course, battery-powered since it is a standalone system and it has to be of a small footprint so that it can be used for rodent-based models. After that, we discussed the design approach, where we can either use development boards that are available on the market directly or an ASIC-based design with specific integrated chips that can measure biopotentials, like the ADS1299 or the RHS 2116. Specifically, we looked at the RHS 2116 by Intan Technologies and how its features and system are beneficial for us, especially the fact that it can acquire and stimulate at the same time with 16 electrode channels. In the next lecture, we will be going forward with the RHS 2116.

Furthermore, I will explain in detail the internal mechanisms of the RHS 2116, including how it switches between stimulation and acquisition. We will work further to develop a complete circuit. If you have any queries so far, please feel free to reach out in our forum. We will do our best to answer those questions as much as possible. Thank you for watching, and I will see you in the next one.