The Design of Nerve Stimulators and Their Applications in Medical Field

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Abstract. The nerve stimulator is an important circuit component that regulates or blocks neural signals by outputting specific electrical pulses.With the continuous development of neural stimulators, they have been widely applied in various fields.Especially in the medical field, more and more diseases can be treated more effectively and safely through technologies related to neural stimulators.Through clinical treatment, it has been found that nerve stimulators can effectively alleviate symptoms of chronic pain and enable patients to resume normal life.Furthermore, the implantation surgery of the neural stimulator is minimally invasive, with quick recovery. Moreover, it can adjust the stimulation parameters according to the patient's condition, thereby reducing the surgical risks.It can be seen that it has become extremely important to design a neural stimulator with higher precision, greater stability and better safety.Implement a neural stimulator for specific indicators by using a bidirectional inverter circuit with electrical pulses as input and a symmetrical circuit with a constant current source as input. The designed neural stimulator is basically in line with the design indicators intended to be achieved. Through the above two approaches, a neural stimulator with high precision, high stability and high safety has been successfully realized.

Keywords: Neural Stimulator, Inverter Circuit, Current Mirror, Medical Care

1 Introduction

A nerve stimulator is a medical device that treats various diseases by electrically stimulating the nervous system [1].Its working principle is to regulate the functions of the nervous system by using electrical pulse signals, thereby achieving the therapeutic purpose [2].The research and application of nerve stimulators have a history of several decades and have received extensive attention both at home and abroad.In the 1940s, American scientists were the first to apply neural stimulators in clinical treatment.In 1950, French doctors developed the first transcutaneous electrical nerve stimulator.Subsequently, the application scope of the nerve stimulator gradually expanded in clinical practice, and the treatment range also continuously expanded.As of now, nerve stimulators have become an important medical tool, widely applied in neurology, pain management, rehabilitation, and other fields [3].Here are its main advantages:Personalized treatment: The neural stimulator can adjust the stimulation

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parameters, such as frequency, intensity and duration, according to the specific symptoms and responses of the patients, thus achieving personalized treatment.This flexibility enables more precise treatment and better meets the needs of patients [4].Reduce drug dependence: Neurostimulators offer new treatment options for patients who do not respond well to drug therapy or who cannot tolerate the side effects of drugs.By reducing reliance on drugs, adverse reactions related to drugs can be mitigated [5].Reduce surgical risks: Compared with traditional surgeries, implanting a nerve stimulator usually involves lower risks and fewer complications.This enables some high-risk patients to receive treatment as well [6].

To sum up, the advantages of nerve stimulators in medical applications have made them an important therapeutic tool.At present, designing a neural stimulator with better performance is a major challenge.The designs of previous neural stimulators were mostly complex and difficult to understand.To fully understand the principles of these complex neural stimulators requires a considerable amount of time and effort, as well as a solid knowledge base.This article will specifically elaborate on how to achieve high precision, high stability and high security for neural stimulators through two simple and understandable methods, thereby providing readers with ideas for designing neural stimulators.

Overall, this paper explains how to utilize the bidirectional inverter circuit with electrical pulses as input and the symmetrical circuit with constant current source as input to achieve specific indicators of neural stimulators. Moreover, it provides specific examples to illustrate the significant role of neural stimulators in the medical field.From a detailed perspective, this article elaborates on the functions of the components that constitute the neural stimulator and explains how to set the parameters of the electrical pulse signals that exert control functions.At the end of this article, the stimulating effect of the nerve stimulator in medical practice is also specifically introduced.

The first chapter of this article serves as an introduction, which provides background information on neural stimulators and explains the significance of designing such stimulators.Chapter Two elaborates in detail on how to design neural stimulators.Chapter Three elaborates on the significant role of neural stimulators in the medical field through specific examples.Chapter Four is the conclusion section, summarizing the entire text.

2 Design of the nerve stimulator

2.1 Design Specifications of the Neural Stimulator

The most important requirements for designing a neural stimulator are Current amplitude, Phase width, Interphase gap and Interstimulus delays.The nature of a neural stimulator precisely depends on the accuracy of these requirements.The higher the accuracy of the neural stimulator, the higher its stability and safety will be.The following are the specific requirements for designing the neural stimulator in this article.The current amplitude is set to 100 μA, the phase width is set to 200 μs, the interphase gap is set to 50 μs, and the interstimulus delays are set to 1 ms.

2.2 Bidirectional Inverter Circuit for Implementing Neural Stimulator

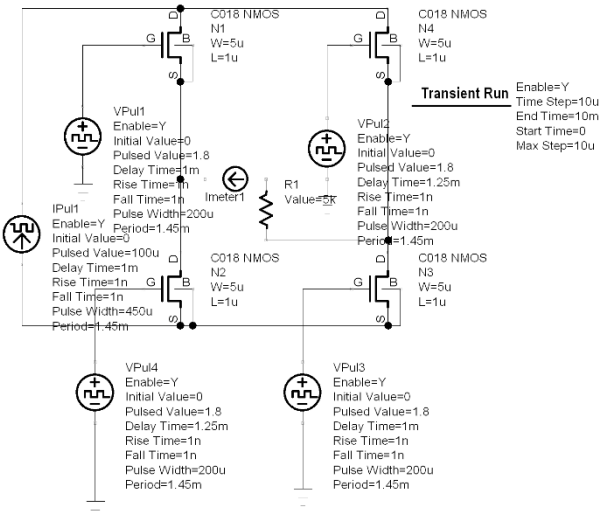

Fig. 1. Using bidirectional inverter circuit to implement neural stimulator

Figure 1 shows the design diagram of the inverter circuit for implementing the neural stimulator. From this figure, one can see the settings of each pulse parameter and the selected simulation type.The key point of realizing the neural stimulator is to achieve bidirectional current [7]. The circuit design for the first stage of the project adopts the inverter circuit structure [8].

Overall, an input current pulse signal IPul1 is applied to this circuit.These four NMOS transistors are equivalent to four switches [9]. Each NMOS transistor is controlled by a specific voltage pulse signal.The pulse signals of two NMOS transistors on the same diagonal line are consistent.The bidirectional current required by the neural stimulator is achieved by controlling the states of four NMOS transistors in the control chart.When N1 and N3 are conducting while N2 and N4 are cut off, the ammeter Imeter1 measures a negative current.When N2 and N4 are conducting while N1 and N3 are cut off, the ammeter Imeter1 measures the forward current.The current amplitude is achieved by setting the Pulused Value parameter of IPul1 to 100uA.The phase width is achieved by setting the Pulse Width parameters of the pulse signals of these four NMOS transistors to be equal to 200us.The Interphase gap is achieved by disconnecting these 4 NMOS transistors for 50us. The Interstimulus delays are realized by setting IPul1 and the Delay Time parameters of the 4 NMOS transistors to be equal to 1ms.

Next, the analysis of the circuit's working principle will be carried out.When t = 0, since the Delay Time parameters of VPul1 and VPul3 are both set to 1ms, while those of VPul2 and VPul4 are set to 1.25ms.So within 1 ms, they all output a low level.All four NMOS transistors are in the cut-off state. This meets the required Delay Time.When t = 1 m, the outputs of VPul1 and VPul3 are high level, while those of VPul2 and VPul4 are low level.N1 and N3 are conducting while N2 and N4 are cut off. The current flowing through R1 is 100uA in the opposite direction to that of the

ammeter, because the Pulse Width parameters of VPul1 and VPul3 are both set to 200us. Therefore, this state will last for 200 microseconds. It meets the required Phase Width.When t = 1.2 ms, all of VPul1, VPul2, VPul3 and VPul4 output low voltage levels. All NMOS transistors are in cut-off state. This state lasts for 50 us. The required Interphase gap is achieved.When t = 1.25 ms, the outputs of VPul2 and VPul4 are high level, while those of VPul1 and VPul3 are low level. N2 and N4 are conducting while N1 and N3 are cut off.Since the Pulse Width parameters of VPul2 and VPul4 are both set to 200us, this state will last for 200us. This duration meets the required Phase Width.At this point, the circuit has been working for a total of 1.45 ms. One cycle ends and the cycle duration is 1.45 ms.

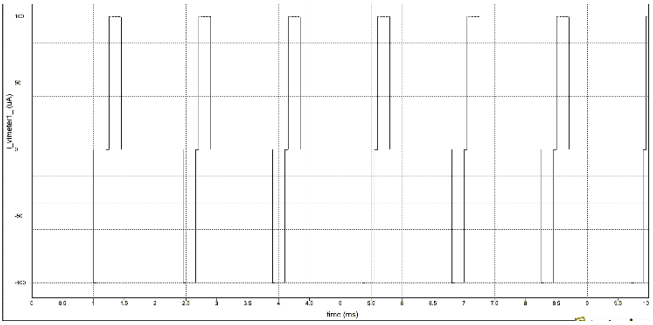

Fig. 2. Simulation result of Circuit 1

Figure 2 shows the simulation results of the neural stimulator implemented by the inverter circuit. From the figure, it can be concluded that all the indicators have been successfully achieved.The simulation analysis selects "Transient Run".Since the time variations in the circuit are all multiples of 50us, the Time Step should be less than 50us.In order to obtain a more accurate image, the Time Step is set to 10 microseconds.The setting where Start Time is 0 and End Time is 10ms ensures that sufficient number of image cycles can be observed.It can be seen from the simulation results that, except for the Current amplitude which is limited to be very close to 100uA due to the certain resistance existing when the NMOS transistor is conducting, all the other requirements are perfectly met.

2.3 Neural stimulator with constant current source as input

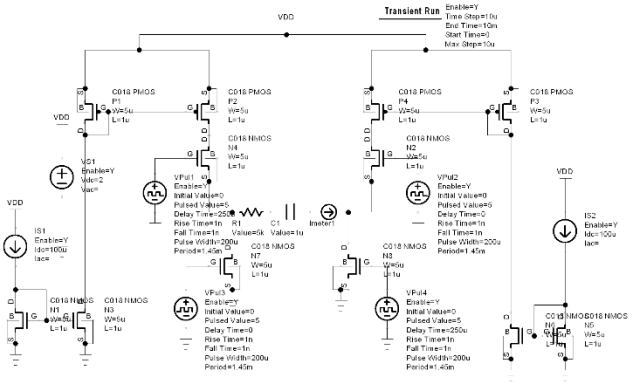

Fig. 3. A neural stimulator using a constant current source as input

Figure 3 shows the design diagram of the symmetrical circuit for implementing the neural stimulator with a constant current source as the input. From this figure, one can see the settings of each pulse parameter and the selected simulation type.It can be observed that the design circuit in the second stage is symmetrical. From an overall perspective, the left part is responsible for providing positive current, while the right part is responsible for providing negative current.Each of these two parts has a constant current source as its input.Adding a capacitor beside the resistor can effectively prevent potential safety hazards caused by rapid changes in current.Next, analyze the circuit in the left half. Current IS1 passes through the current mirror composed of N1 and N3 NMOS transistors [10]. Copy to the branch where N3 is located, in the downward direction. Then, through the current mirror composed of P1 and P2 PMOS transistors, copy to the branch where P2 is located, also in the downward direction.N4 is equivalent to a switch and is controlled by specific pulse signals. N8 is also equivalent to a switch and the pulse signal controlling N8 is the same as that controlling N4. When N4 is conducting, N8 is also conducting and the current direction is opposite to that of the ammeter.Next, analyze the circuit of the right half .Current IS2 passes through N5 and N6, which form a current mirror, and is replicated to the branch where N6 is located, flowing downward. Then, it passes through P3 and P4, another pair of current mirrors, and is replicated to the branch where P4 is located, also flowing downward.N2 and N7 are both equivalent to switches, controlled by the same specific pulse signals. The current direction is the same as that of the ammeter.In conclusion, the requirement of bidirectional current for the neural stimulator has been fulfilled.The current amplitude is achieved by setting IS1 and IS2 with Idc equal to 100uA.The phase width is achieved by setting the Pulse Width of VPul1, VPul2, VPul3 and VPul4 to 200us.The Interphase gap is achieved by disconnecting the 4 NMOS transistors N2, N4, N7, and N8 for 50us. The Interstimulus delays are realized by setting the output of VPul1, VPul2, VPul3, and VPul4 to a low level of 1ms after obtaining the required bidirectional current.

Next, a detailed analysis of the circuit's working principle within a single cycle will be conducted.When t = 0, N4 and N8 are cut off while N2 and N7 are conducting. The

left half of the circuit is not functioning while the right half is.After being duplicated twice, current IS2 passes through R1. At this moment, the direction of the current is opposite to that of the ammeter.Since the Pulse Width of VPul2 and VPul3 is 200us, this state lasts for 200us.When t equals 200 microseconds, all of VPul1, VPul2, VPul3 and VPul4 output low voltage levels, and N2, N4, N7 and N8 are all in cut-off states.Until t = 250us, the right half part is not functioning while the left half part is.After being duplicated twice, current IS1 passes through R1. The direction of the current is the same as that of the ammeter.Because N4 and N8 are conducting for 200us, the forward current lasts for 200us as well.When t equals 450 microseconds, all of VPul1, VPul2, VPul3 and VPul4 output low voltage levels, and N2, N4, N7 and N8 are all in cut-off states.No current flows through R1. This state lasts for 1 ms to achieve Interstimulus delays.At this point, the circuit has been working for a total of 1.45 ms. One cycle ends and the cycle duration is 1.45 ms.

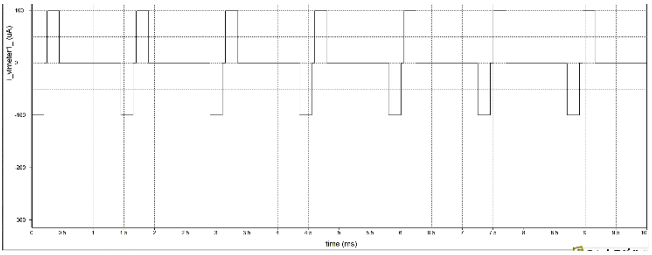

Fig. 4. Simulation result of Circuit 2

Figure 4 shows the simulation results of the neural stimulator implemented by a symmetrical circuit with a constant current source as the input. From the figure, it can be concluded that all the indicators have been successfully achieved.The simulation analysis selects "Transient Run".The time variations in the circuit are 200 microseconds, 50 microseconds, 200 microseconds and 1 millisecond respectively.The TimeStep should be at least 50 microseconds.To achieve greater precision, TimeStep is set to 10 microseconds.Set Start Time to 0 and End Time to 10 ms. Such parameters can ensure that sufficient number of image cycles can be observed.It can be seen from the simulation results that, except for the Current amplitude which is limited to be very close to 100uA due to the certain resistance existing when the NMOS transistor is conducting, all the other requirements are perfectly met.

3 Application of Neural Stimulators in Medicine

3.1 New Implantation Techniques for Chronic Abdominal Pain

Chronic abdominal pain is a disease with a high prevalence rate and great difficulty in treatment. Its global prevalence rate is as high as 25%.After investigation, it was found that the diagnosis status of approximately 40% of patients with chronic abdominal pain remains unknown.Although the previous treatment methods had certain effects, they would become less and less effective over time [11].Now, nerve stimulation has

brought new options to these patients.There is evidence suggesting that stimulation of the dorsal root spinal cord and dorsal root ganglion has a good effect.Peripheral nerve stimulation has achieved certain feasibility. For high-risk patients and those with potentially unsafe nerve axonal pathways or those with overly challenging technical difficulties, the effect of using a nerve stimulator to stimulate the peripheral nerves around the thoracic and abdominal nerves is better.Studies have shown that the thoraco-abdominal nerves have become an effective target for treating chronic abdominal pain. The regulation of the thoraco-abdominal nerves by using nerve stimulators is very likely to provide great assistance for the treatment of chronic abdominal pain for specific patients.

At present, through the technique of nerve block, it has been possible to achieve precise treatment for patients without damaging the nerve and vascular structures.This advancement has also enhanced the safety of wire placement.Neural stimulation technology has already provided a brand-new option for treating this chronic disease which is difficult to cure [12].

3.2 Implantation of Dual-Mode Lumbar Peripheral Nerve Stimulation Device

There have always been problems regarding the treatment techniques for lumbar axial pain and radicular pain [13].Based on previous treatment cases, lumbar radiculopathy is usually treated by epidural steroid injection. There is sufficient evidence indicating that this treatment method is indeed effective in the short term, but its safety is still controversial.Some scholars hold the view that there are certain potential risks and dangers associated with the long-term application of this treatment method.At present, the method of using temporary peripheral nerve stimulators for nerve stimulation has achieved certain success in the treatment of axial pain.

Studies have shown that for patients suffering from pain related to arthritis and radiculopathy, the use of a dual-peak temporary lead placement achieved through nerve stimulators is a feasible treatment option.Based on the statistics of the cases, it can be concluded that this treatment method has no complications.During the 7-day follow-up conducted by the researchers, the patient reported that the pain sensation had completely vanished.During the 60-day follow-up period conducted by the researchers, patients reported that they experienced minimal pain for the majority of the time.It can be seen that the use of nerve stimulators for treating this disease has obvious therapeutic effects, and the safety has been improved to a certain extent [14].

4 Conclusion

First of all, this paper introduces the background of the neural stimulator and the significance of designing a neural stimulator with high precision, high stability and high safety.Secondly, this paper elaborates on how a bidirectional inverter circuit with electrical pulses as input can be utilized to construct a neural stimulator with specific indicators.In this circuit, MOSFETs are used as switches. The four MOSFETs are equivalent to four switches. Each MOSFET is controlled by a specific voltage pulse

signal. Combined with the inverter circuit, bidirectional current can be achieved.Then, this paper introduces a symmetrical circuit with a constant current source as the input to realize a neural stimulator with specific indicators.In this circuit, the usage of MOSFETs as switches is also involved. The four MOSFETs that are used as switches are all controlled by specific voltage pulse signals.The other MOS transistors are paired two by two to form a current mirror structure, which is used to replicate the current. In this circuit, the left half provides positive current while the right half provides negative current.Finally, this paper presents two examples of the application of neural stimulators in the medical field. These two examples are respectively the new implantation technology for chronic abdominal pain and the implantation surgery of dual-mode peripheral nerve stimulator for lumbar spine.

The main contribution of this paper is to provide design ideas for beginners who are designing neural stimulators.The design principle therein is simple and easy to understand, and it is highly practical. It helps lay a solid foundation for beginners to learn how to design neural stimulators.Even for those who have certain experience in designing nerve stimulators, this can provide them with novel ideas, which can inspire them to design nerve stimulators with higher precision, greater stability and better safety.

The current research is confined to the simulation operation stage and no hardware assembly has been carried out.Therefore, during the practical application, there may be issues of deviation in accuracy. Moreover, in the simulation, factors such as temperature and humidity are not taken into account, and thus distortion may occur under extreme conditions.Future research should involve assembling the hardware and taking into account as many practical factors as possible to ensure the accuracy, stability and safety of the neural stimulator during its practical application.

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